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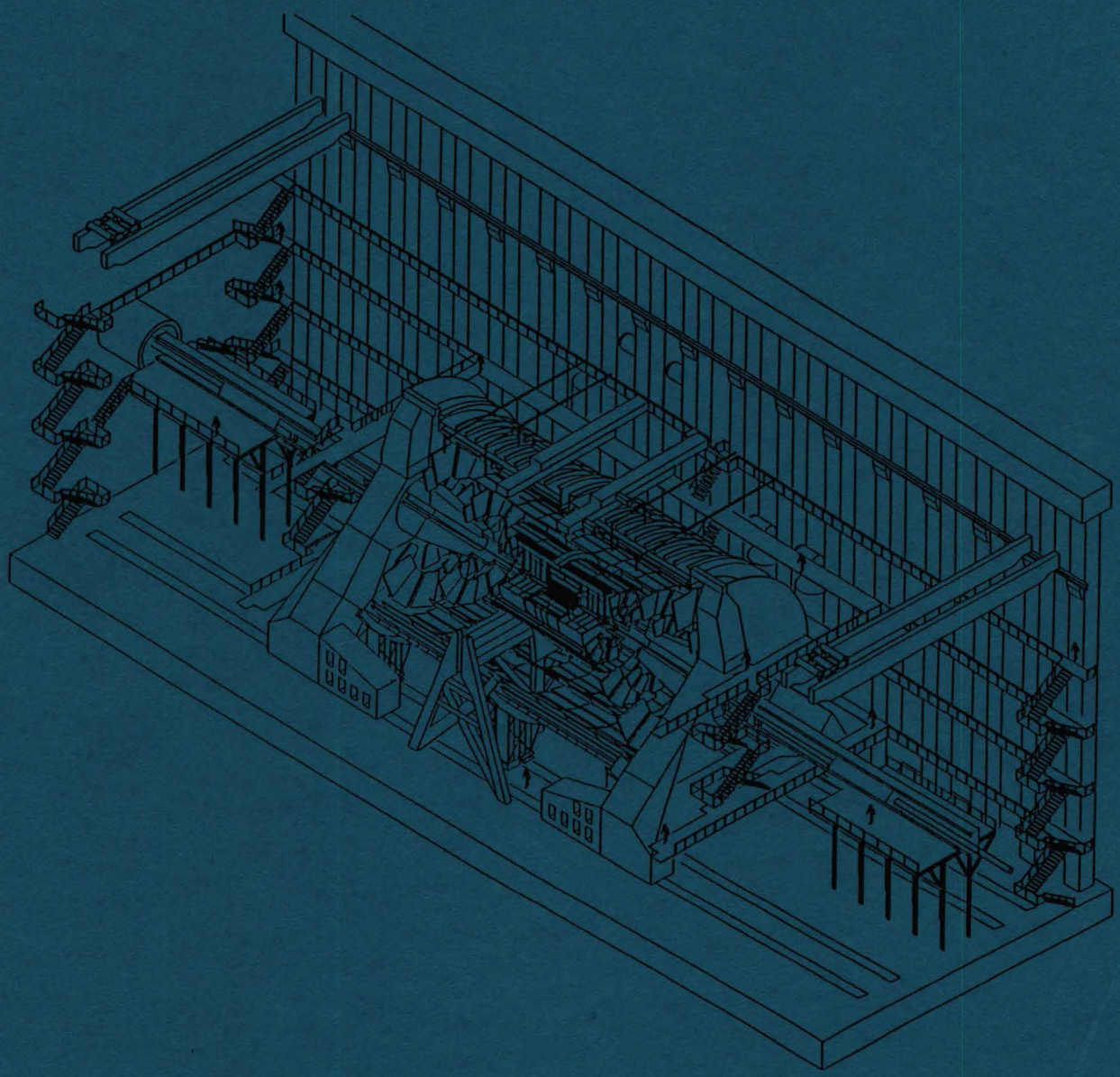
WBS Dictionary

TDR Submittal



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Acronym Glossary

522. GEM

522.5010 Tracker
- 10.01 R & D
- 10.02 Silicon Tracker
- 10.03 IPC Tracker
- 10.04 Reserved
- 10.05 Reserved
- 10.06 STS/IPC Assembly
- 10.07 Installation andFinal Test
- 10.08 Project Management
- 10.09 Conceptual/ Preliminary Design

522.5020 Calorimeter
- 20.01 R & D
- 20.02 Inner Barrel Calorimetry
- 20.03 Scintillating Barrel Hadronic Sections
- 20.04 Endcap Calorimetry
- 20.05 Forward Hadronic Calorimetry
- 20.06 Passive Absorber
- 20.07 Vacuum
- 20.08 Cryogenics
- 20.09 Instr., Power & Operational Control
- 20.10 Final Assembly
- 20.11 Hall Installation
- 20.12 Calibration and Test Beam Program
- 20.13 Subsystem Management
- 20.14 Conceptual/ Preliminary Design

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- 30.03 Endcap Region - CSC
- 30.04 Installation - CSC
- 30.05 Project Management - CSC
- 30.06 Conceptual/ Preliminary Design

522.5040 Magnet
- 40.01 R & D
- 40.02 Design Completion
- 40.03 Fabrication & Assembly
- 40.04 Installation and System Testing
- 40.05 Project Management
- 40.06 Conceptual/ Preliminary Design

522.5050 Electronics
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- 50.02 Front End
- 50.03 Data Acquisition
- 50.04 Trigger
- 50.05 Integration
- 50.06 Project Management
- 50.07 Conceptual/ Preliminary Design

522.5060 Computing
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- 60.02 Global Control System
- 60.03 On-line Computing
- 60.04 Network and Communications

522.5070 Interface
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- 70.02 Beam Pipe
- 70.03 Detector Access Equipment
- 70.04 Detector Safety Systems
- 70.05 Utility Services
- 70.06 Cranes
- 70.07 Auxiliary Equipment
- 70.08 Gas Services
- 70.09 Survey Systems
- 70.10 Magnetic Shielding
- 70.11 Test Beam/Calibration Hall
- 70.12 Cable & Plumbing Routing

522.5090 Project Management
- 90.01 Planning & Controls
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gem DETECTOR PROJECT

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522.5010 Central Tracker

This element includes all conceptual/preliminary design, research and development and construction labor (both engineering and touch) and materials required to design, fabricate, assemble, deliver and install the central tracker subsystem subassemblies and its required support systems to its downhole location at the SSCL GEM detector hall within the time constraints defined by the current schedule as understood by central tracker design team.

This element also includes the required resources to manage and administer these efforts in conjunction with GEM project management.

10.01 Central Tracker Research and Development

This element includes all efforts and resources required to define the appropriate technologies and application of those technologies to the central tracker detector. This effort will occur throughout the duration of the project but is currently budgeted in years 2 and 3 of the project.

10.01.1 Silicon Tracker Research and Development

This element includes all efforts and resources required to define the appropriate technologies and application of those technologies to the silicon tracker detector. This effort will occur throughout the duration of the project but is currently budgeted in years 2 and 3 of the project.

10.01.1.1 Overall Silicon Tracker Design Research and Development

This element includes all efforts and resources required to define the appropriate technologies and application of those technologies to the silicon tracker detector. This effort will occur throughout the duration of the project but is currently budgeted in years 2 and 3 of the project.

10.01.1.2 SI Wafer Research and Development and Prototype

This element includes all efforts and resources required to define the appropriate technologies and application of those technologies to the silicon tracker detector safer design. Tasks under this element include: Therman analysis and prototype thermal testing of the MCM heat loads and conduction paths; Ladder assembly development and performance and compatibility tests; First production prototyping and testing of the silicon detectors. This effort will occur throughout the duration of the project but is currently budgeted in years 2 and 3 of the project.

10.01.1.3 Cooling System Research and Development and Prototype

This element includes all efforts and resources required to define the appropriate technologies and application of those technologies to the silicon tracker detector wafer design. Tasks under the element include: Thermal analysis, design and prototype testing of heat pipe wicks to achieve minimal thermal gradients with the GEM specifications; Preliminary design of an enclosure test chamber for shell prototype testing. This effort will occur throughout the duration of the project but is currently budgeted in years 2 and 3 of the project.

10.01.1.4 Support System Research and Development and Prototype

This element includes all efforts and resources required to define the appropriate technologies and application of those technologies to the silicon tracker detector composite support structures. Tasks include: Design and analysis of the forward and central region cooling rings and fabrication of prototypes; Design and prototype fabrication of small low mass internal kinematic mounts; Space frame design and analysis; Inner support cylinder structural analysis and fabrication development. Design and fabrication development of the gas enclosure system. This effort will occur throughout the duration of the project but is currently budgeted in years 2 and 3 of the project.

10.01.1.5 Internal Alignment System Research and Development and Prototype

This element includes all efforts and resources required to define the appropriate technologies and application of those technologies to the silicon tracker detector internal alignment system. Tasks include: Design of the fiber optic sensor and testing of prototypes. Design and specification of the signal processing hardware and software. This effort will occur throughout the duration of the project but is currently budgeted in years 2 and 3 of the project.

10.01.1.6 Inner Shell Test Assembly Research and Development

Need input

10.01.2 IPC Tracker Research and Development

This element includes all efforts and resources required to define the appropriate technologies and application of those technologies to the IPC tracker detector. This effort will occur throughout the duration of the project but is currently budgeted in years 2 and 3 of the project.

10.01.2.1 IPC Superlayer Modules Research and Development

This element includes all efforts and resources required to define the appropriate technologies and application of those technologies to the IPC tracker barrel and endcap superlayer modules. A detailed layout and supporting analysis is required to demonstrate that the design can meet the demanding stability requirements. Tests will be performed on prototype modules at BNL to confirm analysis.

10.01.2.2 STS/IPC Support Structure Research and Development

This element includes all efforts and resources required to define the appropriate technologies and application of those technologies to the STS/IPC support structure. The support structure is the backbone of the CTS and is critical to maintaining the relative alignment between the PIC and STS. A detailed layout and supporting analysis is required to demonstrate that the design can meet the demanding stability requirements.

10.01.2.3 IPC Cooling Distribution System

This element includes all efforts and resources required to define the appropriate technologies and application of those technologies to the IPC cooling system. Detailed flow and thermal analysis are required to insure adequate heat transfer capacity and minimal disturbance to structural stability. Flow system dimensions and materials as well as system components and configurations will be specified in this element. Tests will be performed on prototype modules to confirm analysis.

10.01.2.4 IPC Gas System

This element includes all efforts and resources required to define the appropriate technologies and application of those technologies to the IPC gas system. Requirements for the gas scrubbing system will be defined and a detailed design will be established. System dimensions and materials as well as system components and configurations will be specified in this element. Tests will be performed on prototype modules to confirm analysis.

10.01.3 Reserved

10.01.4 Reserved

10.01.5 Beam Tests

This element includes all efforts and resources required to design and develop beam tests to assist in defining the appropriate technologies and application of those technologies to the central tracker detector. beam tests for prototypes are being negotiated for Brookhaven National Laboratory and Fermi National Accelerator Laboratory.

10.02 Silicon Tracker System (STS)

This element contains all facets of the STS construction. This element comprises both the mechanical and electrical constituents of the STS construction. In addition, elements for the assembly, installation, and safety issues are included.

10.02.1 STS Silicon Detector

This element contains engineering, design, construction and fabrication costs for 10836 silicon micro strip detectors which will be assembled into 1942 ladder assemblies each containing a single large multichip module. An additional 5% is included as extras, and preproduction prototypes are also included. Engineering and design, assembly, inspection and testing manpower is also included. Mechanical assembly of the ladders and required tooling is itemized, including the MCM installation.

10.02.1.1 Central Region Ladders

This element includes the central region which is composed of single sided 18 cm long ladders bonded back to back. Each detector is 3.3 mm wide x 60 mm long with 640 strips at a 50 micron pitch tilted at a 5 mrad angle. The central region will contain 2484 detectors which are bonded end to end and back to back to form 414 ladder assemblies. A large single MCM is mounted and TAB bonded to each ladder, which is stiffened with graphite epoxy rails. Each ladder is optically inspected then electrically tested. Labor estimates include engineering and designer manpower and drafting, mechanical analysis required to verify the mechanical performance, also included is the manpower to develop the final assembly specification and procedures.

10.02.1.2 Forward Region Ladders

This element includes the forward region which contains both 14 and 16 cm long ladders bonded back to back. Each detector has similar specifications as the central region, except for the shapes which will be trapezoidal. As a cost savings design, the outer most detector will be rectangular to accommodate the same MCM as the central region. Each ladder is adhesive bonded end to end and back to back, then assembled with an MCM and TAB bonded. Each Ladder is optically inspected then electrically tested. Labor estimates include engineering and designer manpower and drafting, mechanical analysis required to verify the mechanical performance and the manpower effort to develop the final assembly specification and procedures.

10.02.1.2.1 33.4 x 6 cm Forward Region Wafers

This element includes the 33.4 x 6 cm forward region wafers. The outer most detectors in the forward region will be rectangular in shape 33.4 wide x 6 cm long. 2992 are required for the forward region. See drawing GEM12-007 tab -01.

10.02.1.2.2 4 cm Tapered Forward Region Wafers

This element includes the 4 cm tapered forward region wafers. The 16 cm forward ladders will require a small tapered detector 4 cm long. 2240 of these are required. See drawing GEM12-007 tab -02.

10.02.1.2.3 6 cm Tapered Forward Region Wafers

This element includes the 6 cm tapered forward region wafers. The 16 cm forward ladders will require a tapered detector 6 cm long. 2240 of these are required. See drawing GEM12-007 tab -03.

10.02.1.2.4 8 cm Tapered Forward Region Wafers

This element includes the 8 cm tapered forward region wafers. The 14 cm forward ladders will require a long thin tapered detector 8 cm long. 752 of these are required. See drawing GEM12-007 tab -04.

10.02.1.3 Silicon Detector Prototypes

This element includes the development prototypes which will be fabricated and tested prior to establishing the final design specifications for the final fabrication runs. The development prototypes will include the vendor tasks of engineering, production development, photo mask design, and producing 2 iterations of prototypes for evaluation. Since there are 4 different configurations in the tracker 4 prototypes will be required. The first prototype will be funded in the R & D stage, the remaining 3 in the construction stage. Each prototype will be tested for conformance to the specifications, then irradiated and retested for conformance to the irradiated specifications.

10.02.1.4 Ladder Assembly

This element includes the labor and material for the ladder assembly. The 10836 silicon micro strip detectors will be mechanically assembled into 414 central region ladders and 1528 forward region ladders. The assembly steps are broken down as: end to end bonding, fiducial optical mapping, MCM assembly, MCM and strip TAB bonding, back to back bonding, rail bonding followed by ladder testing. Time and manpower estimates for each mechanical assembly operation are itemized including the overhead cost of using a high precision workcell station. Customized assembly tooling and fixturing for each step is also required.

10.02.1.4.1 Prototype Ladder Assembly

This element includes all labor and supplies required to assemble three prototype ladders.

10.02.1.4.2 Central Region Ladder Assembly

This element includes all labor and supplies required to assemble the 414 central region ladders.

10.02.1.4.3 Forward Region Ladder Assembly

This element includes all labor and supplies required to assemble the 1,528 forward region ladders.

10.02.1.4.4 Ladder Assembly Tooling

This element includes the tooling necessary for mating, alignment, and checking of the central region and forward region ladders.

10.02.2 STS Mechanical Components

This element includes all the mechanical components which make up the STS. Included in this element are all the structural components their alignment, prototype check-out and final article performance evaluation. In addition labor and hardware costs were include for any component (e.g. cooling) requiring ancillary equipment.

10.02.2.1 Central Region

This element includes the mechanical components which will form the central barrel region of the STS. This element does not include the space final assembly of these components into the space frame.

10.02.2.1.1 Central Region Cooling and Support Rings

This element includes an ultrathin graphite and cyanate-ester compression molded cooling ring which will house an internal heat pipe artery (cooling system), in addition identical rings will be used only for structural support. The silicon wafers will be bonded to the external surface of the ring parallel to the beam line. Three unique ring diameters of four each will be required for a total of twelve rings (six cooling rings and six support rings).

10.02.2.1.2 Central Region Kinematic Mounts

This element includes all the kinematic (strain free) mounts their design, and their subsequent performance evaluation.

10.02.2.1.3 Central Region and Ladder Sub-Assembly

This element includes the efforts required to take bonded ladder assemblies (WBS 10.02.1.4.2) and join them with the cooling rings to form super layers and then join two superlayer for each distinct radius to support cylinders to form a central region subassembly.

10.02.2.1.4 Central Region Assembly Tooling

This element includes the tooling necessary for mating, alignment, and checking of the central region detector components for testing, experimentation, and implementation into beam line. It also includes the procurement of the installation and instrumentation hardware necessary to mount the ladders on to the cooling ring. Reference drawing SK-GEM 058.

10.02.2.2 Forward Region

This element includes the mechanical components which will form both forward regions of the STS. It also includes all the necessary installation and alignment hardware. This element does not include the space final assembly of these components into the space frame.

10.2.2.2.1 Forward Region Cooling/Support Rings

This element includes the labor and material for the graphite and cyanate-ester laminate cooling rings. It is made up of two pieces, a type of c-channel and cover, which houses the wick and artery coding system. There will be two distinct cooling ring diameters. This element also includes the support flexure and spoke which are need to complete the mechanical components for a forward planar array. The CTE of the flexure and spoke will be tailored to match that of the cooling ring. There is one distinct diameter for this flexure. Reference drawing SK-GEM12-018

10.02.2.2.2 Forward Region Kinematic Mounts

This element includes the kinematic mounting hardware which will be used to assemble and mount the forward region silicon planar array. The mounts will be fabricated from beryllium and/or graphite/epoxy.

10.02.2.2.3 Forward Region and Ladder Sub-Assembly

This element includes the efforts required to take bonded ladder assemblies (WBS 10.02.1.4.3) and join them with the cooling rings and the flexural rings to form a forward region planar superlayer. There will be a total of 14 distinct planar array subassemblies for each forward region.

10.02.2.2.4 Forward Region Assembly Tooling

This element includes the tooling necessary for mating, alignment, and checking of the central region detector components for testing, experimentation, and implementation into beam line. It also includes the procurement of the installation and instrumentation hardware necessary to mount the ladders on to the cooling ring.

10.02.2.3 Central Region Support Cylinder Assembly

This element includes the labor and material required to construct three cylinders approximately .36 m long. Also included is the labor and material to design and install the kinematic mounts used to attach the silicon superlayer sub- assemblies. Reference drawing SK-GEM12-016.

10.02.2.3.1 Central Region Support Cylinders

This element includes three cylinders which are approximately .36 m long. Materials parts include graphite/cyanate-ester inner and outer skin laminates with graphite and cyanate-ester truss core sandwich and beryllium inserts. Stringent alignment and stability requirements for the silicon tracker demand materials with minimal coefficient of thermal expansion and minimal moisture absorption.

10.02.2.3.2 Central Region Support Cylinder Kinematic Mounts

This element includes two types of kinematic mounting hardware; the first set will be used to assemble and mount the central region superlayer assemblies to the central region support cylinders, these mounts will be fabricated from beryllium and/or graphite and epoxy. The second set of mounts will be used to mount the space frame to the central region support cylinders.

10.02.2.4 Space Frame

This element includes the labor and material to develop a lightweight stable structure constructed from aluminum / graphite metal matrix tubes and aluminum and carbide whisker joints. Assembly must support, but not obstruct, the central region and forward region silicon structures which will be kinematically mounted to it. There is also a kinematic interface with the outer gas enclosure. Resistance to physical property changes due to radiation and/or chemical attack must also be inherent to the assembly. Engineering design and development testing is included.

10.02.2.4.1 Space Frame Tubes

This element includes a collection of graphite and aluminum tubes sharing a common diameter and wall thickness, but varying in over all length. The tubes are a component of the space frame. All conditions apply regarding the space frame assembly. Prototype effort is included for testing.

10.02.2.4.2 Space Frame Joints

This element includes a collection of aluminum and carbide-whisker joints sharing a common diameter and wall thickness, but with two distinct angular orientations within the joint . The joints are a component of the space frame. All conditions apply regarding the space frame assembly. Prototype effort is included for testing.

10.02.2.4.3 Space Frame Spokes

This element includes the spokes which are a graphite and resin quasi-isotropic lay-up. These spokes are attached between the central and forward regions of the space frame. They are used to support the cylinders in the central region of the STS. Prototype effort is included for testing.

10.02.2.4.4 Space Frame Kinematic Mounts

This element includes the kinematic mounts which are attached to the space frame to stabilize and isolate the central region and forward regions from the outer gas enclosure. Prototype effort is included for testing.

10.02.2.5 Gas Enclosure

This element includes the mechanical component which will be used to form the outer, inner , and end gas enclosures around the STS. Prototype effort is included for testing. Reference drawing SK GEM12-025.

10.02.2.5.1 Outer Gas Enclosure

This element includes a cylinder that has two support rings incorporated into it and solid graphite flanges on each end. Materials include graphite and cyanate-ester inner and outer skin laminates with graphite/cyanate-ester truss core center. Stringent alignment and stability requirements for the silicon tracker demand materials with minimal coefficient of thermal and moisture expansion.

10.02.2.5.2 Inner Gas Enclosure

This element includes a beryllium tube approximately 2.2 m long x 100 mm outside diameter x .5 mm wall thickness. The final tube length may be brazed in sections. There are stiffening rings at four intervals.

10.02.2.5.3 End Gas Enclosure

This element includes a flanged dished head approximately .76 m in diameter. The material consists of graphite and cyanate-ester and outer and inner skins (honeycomb centers, with delron inserts and beryllium bushings). The end enclosure will act as our gas seal. Stringent alignment and stability requirements for the silicon tracker demand materials with minimal coefficient of thermal and moisture expansion.

10.02.3 STS Cooling Distribution System

This element includes the labor and material for the STS cooling distribution system. The STS contains over 5000 multichip module (MCM) electronics assemblies each generating 2.2 mW of heat for a total load of 11 kW. This heat is removed by an evaporative phase change cooling system that uses butane as the working fluid. Liquid butane is delivered at 0°C or slightly subcooled to the silicon modules via a wick and artery design that is contained in the structural support/cooling rings; there are 12 rings of three different diameters. MCM heat flows through the thin-walled composite cooling ring surface and isothermally produces butane vapor. This vapor migrates to a condenser in which it is liquefied and recirculated.

10.02.3.1 STS Internal Cooling Components

This element includes a coolant artery and wicking system contained in the cooling ring for both the central and forward region. The artery contains butane as the cooling medium. The thermal stability is within ±0.1°C.

10.02.3.2 STS External Cooling Components

This element includes the plumbing network external to the cooling ring. Also included is the internal piping, heat rejection system, external mechanical systems, and all cooling system instrumentation required to monitor pressure and temperature.

10.02.4 STS Nitrogen Gas System

This element includes the monitoring and sensing system for gases such as butane, oxygen and nitrogen. It is also used as a coolant buffer gas between STS and IPC (safety application).

10.02.5 STS Alignment System and Instrumentation

This element includes all the optical equipment to assemble the silicon tracker from the ladder-cooling ring level until final installation into the detector.

10.02.5.1 Assembly - Optical Alignment System

This element includes the optical system to manipulate and assemble the ladders onto the cooling rings and then assemble the modules into the space frame.

10.02.5.2 Internal Optical Monitoring System

This element includes the sensor display equipment required for optical position monitoring for alignment purposes.

10.02.06 STS Shipping

This element includes the material handling equipment for the transportation of the device, as well as the design and fabrication effort of the fixtures and shipping containers.

10.03 Interpolating Pad Chamber Tracker (IPC)

This element includes all effort off-site of SSCL required to construct and deliver the array of interpolating pad cathode chambers and its support systems. This array consists of two endcap subsystems and a barrel subsystem. Approximately 12.8 EDI&A FTEs are estimated to be required to engineer the IPC Tracker beginning in FY94 through FY98.

10.03.1 IPC Superlayer Modules

This element includes all effort off-site of SSCL required to construct this subassembly consisting of two back-to-back interpolating pad cathode chambers, a honeycomb structural core, an electronics package, gas flow manifolds, a wiring harness, endplates, and support hardware (pins, captive screws, etc.).

There are two types of interpolating pad chamber modules: those that belong to the barrel subsystem, and those of the endcap subsystems. A total of 40 doublet pair barrel module subassemblies (80 modules) and 80 endcap module subassemblies will be delivered to SSCL.

10.03.1.1 Barrel Modules

This element includes all effort off-site of SSCL required to construct the interpolating pad cathode modules for the barrel region of the tracker array. These modules are approximately two meters long and are installed as "doublets" or in tandem. A "module" includes all components as outlined in WBS 10.03.1.

10.03.1.1.1 Mechanical

This element includes effort off-site of SSCL required to construct the mechanical components within the module assembly (i.e.. anode wires, honeycomb core, cathode pad printed circuit boards, etc.)

10.03.1.1.1.1 Cathode PC Boards

This element includes all effort off-site of SSCL required to construct the finished cathode pad printed circuit board consisting of an insulating substrate with cathode pads on one side, leads on the opposite side and plated-through holes connecting them.

10.03.1.1.1.1.1 Printed Circuit Substrate

This element includes all effort off-site of SSCL required to construct insulating substrate as mentioned in WBS 10.03.1.1.1.1. The material of choice is a quartz and cyanate-ester composite 0.020 inch in thickness.

10.03.1.1.1.1.2 Finished Circuit Board

This element includes all effort off-site of SSCL required to construct the substrate with pads, leads and plated-through holes added.

10.03.1.1.1.2 Anode Wire Support Frames

This element includes all effort off-site of SSCL required to construct the insulating strips which support the anode wires used within the IPC modules. The strips are 2 cm wide by 2 mm thick and the material of choice is a quartz/cyanate-ester composite.

10.03.1.1.1.3 Cathode Wire Support Frames

This element includes all effort off-site of SSCL required to construct the Insulating strips which support the continuos cathode plane and maintain a separation between the cathode plane and the anode wires. The quartz and cyanate-ester strips have a cross-section of 1 cm wide by 2 mm thick.

10.03.1.1.1.4 Hardback Cores

This element includes effort off-site of SSCL required to construct the Nomex (aramid) honeycomb which provides lateral and longitudinal rigidity to the IPC module. The interpolating cathode printed circuit boards are bonded to this component. This subsystem element item is a leading cost driver in the IPC superlayer procurements.

10.03.1.1.1.5 Anode Wires

This element includes all effort off-site of SSCL required to construct the 20 to 40 micron gold-plated tungsten wires which are stretched at a tension of 50 grams across each chamber (or two per module) at a pitch of 2 mm. The anode wires are soldered to a high-voltage buss on the anode wire supports.

10.03.1.1.1.6 Module Gas Plenums

This element includes all effort off-site of SSCL required to construct the module gas plenums (or manifolds) provide a method for gas distribution within each module. The input/output plenum introduces the chamber gas mixture into the end of one chamber of a module and permits the gas to exit from the second chamber at the same end. The return plenum at the opposite end of the module permits the gas to flow from the first to the second chamber.

10.03.1.1.1.7 Gas Window Support Frames

This element includes all effort off-site of SSCL required to construct the gas window support frames separate the gas containment window from the continuous cathode plane. In addition, these strips provide longitudinal rigidity for the module. The proposed material is a unidirectional graphite fiber and cyanate-ester composite. The cross section is 1 cm wide by 1 mm thick.

10.03.1.1.1.8 Gas Window

This element includes all effort off-site of SSCL required to construct the gas window contains the IPC chamber gas mixture and prevents the continuous cathode plane from distorting from a pressure differential between the chamber active volume and the tracker ambient. The material of choice is polyester sheet (Mylar) between 2 and 6 mils thick. The window is stretched and bonded to the gas window frames.

10.03.1.1.1.9 Continuous Cathode Plane

This element includes all effort off-site of SSCL required to construct the continuous cathode plane which is a stretched Kapton sheet which has a thickness between 2 and 6 mils. One side is coated with a thin layer of copper or gold. The cathode plane is perforated periodically to allow the free passage of chamber gas between the active and gas containment volumes, thus eliminating a potential differential pressure. Deflection of the cathode could alter the field within the chamber.

10.03.1.1.1.10 End Plates

This element includes all effort off-site of SSCL required to construct the IPC Module endplates. The IPC module endplates are of two different types. The first ties two modules together in tandem (or "doublets") and serves as a seal at the module/support structure interface. In addition, the endplate contains all connections to the outside world (high and low voltage, chamber gas, electronics cooling, fiber-optics, etc.). The second endplate ties the opposite end of the module doublets together and provides a convenient mounting surface for the module doublet support pin.

10.03.1.1.1.11 Barrel Module Doublet Hardware

This element includes all effort off-site of SSCL required to construct the doublet support system for the barrel modules.

10.03.1.1.1.11.1 Module Doublet Strut

This element includes all effort off-site of SSCL required to construct the graphite/cyanate-ester composite structure that connects each of the modules to the support tube and that provides structural support to the electronics packages. There are three struts per doublet (1/4, 1/2, 3/4 of the doublet length).

10.03.1.1.1.11.2 Module Doublet Support Tube

This element includes all effort off-site of SSCL required to construct the filament-wound graphite and cyanate-ester composite tube approximately 2 meters long by 6.35 cm diameter (50 mil wall thickness). This tube provides additional rigidity to the module doublet assembly.

10.03.1.1.1.12 Alignment Pins, Etc.

This element includes all effort off-site of SSCL required to construct the alignment pins for the IPC module doublets which provide mechanical support for the IPC modules while allowing an axial degree of freedom at one end of the doublet assembly.

10.03.1.1.2 Electrical

This element includes all effort off-site of SSCL required to integrate the electronic systems with the mechanical systems of the barrel module. Electrical refers to wiring and on-board electronics packaging associated with the interpolating pad cathode modules.

10.03.1.1.2.1 High Voltage Distribution

This element includes all effort off-site of SSCL required to construct the buss that is part of the anode wire support strips and the cabling that is associated with it.

10.03.1.1.2.2 Low Voltage Distribution

This element includes all effort off-site of SSCL required to construct the wiring harness that provides power to the on-board electronics package.

10.03.1.1.2.3 Electrical Assembly and Interface

This element includes all effort off-site of SSCL required to install the on-board electronics package to the IPC module doublet strut. Procurements include the flexible Kapton ribbon cables between the module and the electronics package. The electronics package is included in 10.05.

10.03.1.1.3 Module Subassembly

This element includes all effort off-site of SSCL required to assemble the IPC modules which consists of many steps, including preparation of the core assemblies (cathode pad skins, honeycomb core), bonding the anode wire supports to the core assemblies, winding the anode wire, bonding the cathode supports, stretching and bonding the cathode plane, attaching the gas plenums, etc.

10.03.1.1.4 Subassembly Tooling and Fixtures

This element includes all effort off-site of SSCL required to construct the tooling required to assemble the IPC modules. This includes flat tables for lay-ups, pneumatically-operated stretching frames for the cathode and gas containment planes, anode wire winding machines, etc.

10.03.1.2 Endcap Modules

This element includes all effort off-site of SSCL required to construct the interpolating pad cathode modules for the endcap region of the tracker array. The endcap interpolating pad cathode chambers operate on the same principle as their barrel counterparts. However, the endcap chambers are trapezoidal in shape and are arranged radially instead of axially about the line of interaction. Each module is approximately 58 cm long by 53 cm maximum width by 18.6 cm minimum width. There are two chambers per endcap module with a honeycomb core between, as in the barrel modules. The major differences are in the location of the electronics and the module support scheme. The endcap electronics are arranged around the outer perimeter of the endcap region and the modules are supported individually on superlayer "disks" (see endcap gas enclosure and support structure (WBS 10.03.2.4) as opposed to a "doublet" configuration in the barrel.

10.03.1.2.1 Mechanical

See WBS 10.03.1.1.1 for a description of this element.

10.03.1.2.1.1 Cathode PC Boards

See WBS 10.03.1.1.1.1 for a description of this element.

10.03.1.2.1.1.1 Printed Circuit Substrate

See WBS 10.03.1.1.1.1.1 for a description of this element.

10.03.1.2.1.1.2 Finished Circuit Board

See WBS 10.03.1.1.1.1.2 for a description of this element.

10.03.1.2.1.2 Anode Wire Support Frames

See WBS 10.03.1.1.1.2 for a description of this element.

10.03.1.2.1.3 Cathode Wire Support Frames

See WBS 10.03.1.1.1.3 for a description of this element.

10.03.1.2.1.4 Hardback Cores

See WBS 10.03.1.1.1.4 for a description of this element.

10.03.1.2.1.5 Anode Wires

See WBS 10.03.1.1.1.5 for a description of this element.

10.03.1.2.1.6 Module Gas Plenums

See WBS 10.03.1.1.1.6 for a description of this element.

10.03.1.2.1.7 Gas Window Support Frames

See WBS 10.03.1.1.1.7 for a description of this element.

10.03.1.2.1.8 Gas Window

See WBS 10.03.1.1.1.8 for a description of this element.

10.03.1.2.1.9 Continuous Cathode Plane

See WBS 10.03.1.1.1.9 for a description of this element.

10.03.1.2.1.10 End Plates

See WBS 10.03.1.1.1.10 for a description of this element.

10.03.1.2.1.11 Alignment Pins, etc.

See WBS 10.03.1.1.1.12 for a description of this element.

10.03.1.2.2 Electrical

- See WBS 10.03.1.1.2 for a description of this element.

10.03.1.2.2.1 High Voltage Distribution

See WBS 10.03.1.1.2.1 for a description of this element.

10.03.1.2.2.2 Low Voltage Distribution

See WBS 10.03.1.1.2.2 for a description of this element.

10.03.1.2.2.3 Electrical Assembly and Interface

See WBS 10.03.1.1.2.3 for a description of this element.

10.03.1.2.3 Module Subassembly

See WBS 10.03.1.1.3 for a description of this element.

10.03.1.2.4 Assembly Tooling and Fixtures

See WBS 10.03.1.1.4 for a description of this element.

10.03.2 STS/IPC Outer Support Structure

This element includes a stable support structure used to support the STS and house the IPC barrel modules. The IPC forward modules will be mounted off of the outer support structure stringers. The modules will be supported by the two bulkheads in the structure. The structure consists of two bulkheads with twenty longitudinal stringers on the ID and the OD connecting the two. Shear panels are then bonded to the ID and OD. Every other OD shear panel is removable for access to the IPC modules. Reference drawing SK GEM12-041.

10.03.2.1 Bulkheads

This element includes the two bulkheads which are a critical part of the STS/IPC outer support structure. They support and locate the IPC modules. These will be the most critical pieces of the structure, due to the need for these pieces to be structurally sound while allowing for the IPC modules to be inserted through them into the IPC barrel region.

10.03.2.2 Inner Cylinder

This element includes the inner cylinder which is made up of shear panels bonded to longitudinal stringers that span from bulkhead to bulkhead. The cylinder has 20 facets to match the barrel IPC count. The shear panels are flat graphite honeycomb laminates.

10.03.2.3 Outer Cylinder

This element includes the outer cylinder which is similar to the inner cylinder. However, in addition to being longer, it also has some removable panels. The outer cylinder is 1 1/2 meters longer than the inner cylinder. Every other shear panel is removable form the longitudinal stringer. The removable panels are not bonded, but are screwed in place to allow access to the IPC modules in the barrel region. The removable panels only run from bulkhead to bulkhead, which leaves 10 open sectors at each end of the structure to allow for cable clearance.

10.03.2.4 End Cap Gas Enclosure

This element includes all effort off-site of SSCL required to construct the IPC endcap gas enclosure. This structure contains the inert gas which flows around the endcap IPC modules. The temperature and moisture of the gas can be more precisely controlled than that of the experimental hall ambient.

The interpolating cathode pad array endcap gas enclosure also serves as an overall mechanical support vehicle for the endcap IPC modules. The enclosure is a graphite/cyanate ester composite structure consisting of an inner cylinder at a radius of 17.7 cm and an outer cylinder of 83.7 cm radius. The depth is approximately 63 cm. Two bulkheads close out the ends of the gas enclosure. The outer bulkhead is removable to gain access to the modules *in-situ*. Axially oriented struts are arranged around the inside surface of the outer cylinder and serve two purposes: support of the four superlayer disks and connecting the bulkheads to the outer cylinder. The outer cylinder consists of ten segments which can be individually removed to access the module electronics.

10.03.2.5 Kinematic Mounts and Attachments

This element includes all effort off-site of SSCL required to construct the kinematic mounts which allow tracker subassemblies to be tied together while permitting relative growth due to temperature and pressure gradients. This is achieved by avoiding constraint of each mounting point in all six degrees freedom.

10.03.2.5.1 Mounts - IPC Endcaps to Barrel

This element includes the full structure that will be put in place with detachable roller bearing assemblies and then transferred to kinematic mounts in four places. The typical three points of support were not feasible in this case.

10.03.2.5.2 Mounts - Barrel to Calorimeter

This element includes the forward region IPC module assembly. These mounts will use a more typical three point kinematic mount. Placement will not require an external positioning mechanism.

10.03.2.5.3 Mounts - STS to IPC

This subsystem element includes all EDI&A efforts, M&S in support of EDI&A, procurement and fabrication and assembly time off-site of SSCL required to fabricate the kinematic mounts that tie the silicon tracker subassembly to the interpolating pad chamber tracker subassembly.

10.03.2.6 Polyethylene Shield

This element includes all effort off-site of SSCL required to construct the polyethylene shield which is for neutron absorption around the exterior of the support structure. It is attached to the Calorimeter inner diameter.

10.03.2.7 STS/IPC Support Structure Assembly

This element includes all EDI&A and touch labor required to construct the subassemblies that make up the STS/IPC support structure. These subassemblies will be shipped to the SSCL for later stage assembly. This later stage cost is found in 10.06

10.03.3 IPC Cooling Distribution System

This element includes the IPC cooling distribution system. The IPC electronics cooling system has been designed to fulfill IPC requirements of 25 kW total electronics heat generation, dimensional and positional stability in the range 25 mm to 100 mm, low vibration, low risk of water leakage, and low radiation length. The baseline cooling concept selected is a "leakless" chilled water cooling system. The system consists of two unconnected loops, one containing high-purity de-ionized water for cooling the electronics, and one containing house mixed chilled water. Most of the IPC electronics cooling system will be located in the mechanical room that is to be located in the GEM utilities shaft.

10.03.4 IPC Gas System

This element includes the IPC gas system. The IPC ionization gas system has been designed to be reliable and cost effective and to meet stringent performance requirements. The requirements include providing remote control and monitoring of an equimolar mixture of CF_4 and $C0_2$ with 1/4 gas change per minute in the IPC's. Less than 5 Torr pressure difference from atmospheric pressure across a Mylar window is desired to preclude damaging the windows. Gas flow will be measured and gas composition will be monitored to 1% accuracy for the major constituents and to several ppm for trace contaminants. The ionization gas system will include a gas scrubbing sub-system that will filter out water vapor, 0_2 , and total hydrocarbons to low ppm levels. The contamination levels will be continuously measured using gas analyzers. Radiation lengths for the system will be minimized by selection of low Z materials where possible. The system will account for luminosity induced heating of the ionization gas. Because of the relatively large gas flow rate and the high cost of CF_4 , a recirculating gas system has been selected. Most of the IPC ionization gas system hardware will be located at surface level in the gas mixing

10.03.5 IPC Alignment Systems

This element includes all effort off-site of SSCL required to construct the IPC tracker array alignment system which provides a method for determining the locations of each of the superlayer modules with respect to a given point. There are two general methods: passive and active. Passive alignment involves use of particles from beam collisions to locate the modules. Active alignment utilizes lasers and/or other optical systems internal to the tracker array to locate the modules. At this writing, no final decision has been made regarding the method of alignment.

10.03.6 IPC Tracker Component Shipping

This element includes all effort off-site of SSCL required to deliver the above listed subassemblies to the SSCL.

10.04 Reserved

10.05 Reserved

10.06 STS/IPC Assembly (Uphole)

This element includes all effort uphole at SSCL required to assemble the CTS. Approximately 5.2 CTS EDI&A FTEs are estimated to be required for this task for the period beginning FY96 through FY98. Approximately 9.4 CTS assembly technician FTEs are required to complete this task.

10.06.1 STS Assembly and Check

This element includes all effort required to mate, align and check the STS.

10.06.1.1 Central Region Assembly and Check

This element includes the mating, alignment, and check of the central region detector components for testing, experimentation, and implementation into beam line.

10.06.1.2 Forward Region Assembly and Check

This element includes the mating, alignment, and check-out of the forward region planar ladders. A series of ultra thin graphite and epoxy laminate cooling rings and support rings with a spoke-type interconnection and silicon wafers bonded normal to the beam axis will be used. The wafers are mounted in an alternating near side / far side pattern along the circumference of the rings.

10.06.1.3 Space Frame Assembly and Check

This element includes the space frame and its interfaces. This involves the development of assembly and disassembly concepts, as well as the procurement of alignment equipment and precision jogs to assemble the components.

10.06.1.4 Gas Enclosure Assembly and Check

This element includes the mating and assembly of the inner, outer, and end gas enclosure into a hermetic seal which provides cabling, power, and utility access.

10.06.2 IPC Assembly and Check

This element includes all effort required to mate, align and check the IPC tracker.

10.06.2.1 Barrel Pad Tracker Assembly and Check

This element includes all effort required to mate, align and check the IPC barrel tracker.

10.06.2.1.1 Barrel Module Doublet Install into Support Structure

This element includes all effort required to mate, align and check the IPC barrel support structure. This element also includes EDI&A efforts, M&S in support of EDI&A, procurement and fabrication and assembly time required to mate, align and check the IPC superlayer modules.

10.06.2.1.2 Barrel Module Gas Connection

This element includes all effort required to mate and check the gas connection to the IPC superlayer modules.

10.06.2.1.3 Barrel Module HV (anode) Connection

This element includes effort required to mate and check the high voltage (anode) connection to the IPC superlayer modules.

10.06.2.1.4 Barrel Module LV (electronics) Connection

This element includes effort required to mate and check the low voltage (electronics) connection to the IPC superlayer modules.

10.06.2.1.5 Barrel Module LV (signal) Connection

This element includes all effort required to mate and check the low voltage (signal) connection to the IPC superlayer modules.

10.06.2.2 Endcap Pad Tracker Assembly

This element includes all effort required to mate, align and check the IPC endcap pad tracker.

10.06.2.2.1 Endcap Module Can Assembly

This element includes all effort required to mate, align and check the IPC endcap support structure.

10.06.2.2.2 Endcap Modules Sub-Assembly into Endcap Can

See WBS 10.06.2.1.1 for a description of this element.

10.06.2.2.3 Endcap Module Gas Connection

See WBS 10.06.2.1.2 for a description of this element.

10.06.2.2.4 Endcap Module HV (anode) Connection

See WBS 10.06.2.1.3 for a description of this element.

10.06.2.2.5 Endcap Module LV (electronics) Connection

See WBS 10.06.2.1.4 for a description of this element.

10.06.2.2.6 Endcap Module LV (signal) Connection

See WBS 10.06.2.1.6 for a description of this element.

10.06.3 STS/IPC Integration

This element includes all effort required to integrate the STS subassembly into the IPC subassembly.

10.06.4 Calibration and Beam Tests

This element includes the labor and material for the calibration and beam tests. A high precision device like the central tracker will require careful calibration to verify locations of the detectors relative to one another. These calibrations will also be the first opportunity to operate the entire Tracker as a system and verify its performance.

10.07 Installation & Final Test (Downhole)

This element includes all necessary equipment manpower and other resources required to lower the detector and cables into the hall. It also includes all resources necessary for installation and utility hook up and performance evaluation. It is estimated that 2.6 Installation FTEs will be required to complete this task. Reference drawing SK-GEM12-062

10.07.1 Detector Installation

This element includes all necessary resources to install the central tracker into the barrel calorimeter, and connect utilities.

10.07.2 Safety System Test and Verification

This element includes the documentation of all safety procedures and standards, safety plans, and ES&H approval required.

10.07.3 Final Alignment Check

This element includes the final alignment check of the central tracker after complete installation of the device and it's supporting utilities.

10.08 Project Management

This element includes all management and administration effort required to direct the central tracker subsystem through completion. This includes engineering and management personnel and technical staff to administer and manage system engineering, resource management, and safety controls. CTS project management is divided between STS, IPC and integration functions. The FTEs are pooled from the CTS design team institutions. Travel and M&S required for the central tracker project are included in the individual subsystem elements. A composite total of 11 engineering and management FTEs are estimated over the period beginning FY94 through FY99.

10.08.1 STS Tracker Management

This element includes all STS subsystem general management and administration, resource management, environmental, safety and health controls, and quality assurance. Approximately 4 engineering and management FTEs will be dedicated to the management of the STS over the period beginning FY94 through FY99.

10.08.1.1 STS Subsystem Management and Administration

This element includes all STS general management required to support the CTS design team, including, drawing control, cost estimate planning and control, financial reporting requirements and scheduling maintenance. Approximately 1 project management FTE will be dedicated to this general management function over the period beginning FY94 through FY99.

10.08.1.2 STS Resource Management

This element includes all STS efforts required to secure and maintain the most cost efficient procurements contracts. Equipment maintenance and inventory control efforts are costed at this element item. Approximately 1 project management FTE will be dedicated to this resource management function over the period beginning FY94 through FY99.

10.08.1.3 STS ES & H Compliance Controls

This element includes all STS engineering efforts required to comply with SSCL ES&H requirements. Approximately 1 project management FTE will be dedicated to this ES&H control function over the period beginning FY94 through FY99.

10.08.1.4 STS Quality Assurance

This element includes STS engineering efforts required to develop, maintain and administer QA procedures. Approximately 1 project management FTE will be dedicated to this quality control function over the period beginning FY94 through FY99.

10.08.2 IPC Tracker Management

This element includes all IPC subsystem general management and administration, resource management, environmental, safety and health controls, and quality assurance. Approximately 4 engineering and management FTEs will be dedicated to the management of the IPC over the period beginning FY94 through FY99.

10.08.2.1 IPC Subsystem Management and Administration

This element includes all IPC I&A general management required to support the CTS design team, including, drawing control, cost estimate planning and control, financial reporting requirements and scheduling maintenance. Approximately 1 project management FTE will be dedicated to this general management function over the period beginning FY94 through FY99.

10.08.2.2 IPC Resource Management

This element includes all IPC I&A effort required to secure and maintain the most cost efficient procurements contracts. Equipment maintenance and inventory control efforts are costed at this element item. Approximately 1 project management FTE will be dedicated to this resource management function over the period beginning FY94 through FY99.

10.08.2.3 IPC ES & H Compliance Controls

This element includes all IPC I&A engineering effort required to comply with SSCL ES&H requirements. Approximately 1 project management FTE will be dedicated to this ES&H control function over the period beginning FY94 through FY99.

10.08.2.4 IPC Quality Assurance

This element includes IPC I&A engineering effort required to develop, maintain and administer QA procedures. Approximately 1 project management FTE will be dedicated to this quality control function over the period beginning FY94 through FY99.

10.08.3 Subsystem Integration

This element includes all I&A labor required to review, plan and control interfaces between the CTS mechanical systems and CTS electronics packages of the CTS subsystem and assist SSCL integration systems personnel with the integration of the CTS with the surrounding subsystem environments. Approximately 3 engineering FTEs will be dedicated to the integration function beginning FY94 through FY99.

10.09 Conceptual and Preliminary Design

This element includes all CTS E&D effort required to initiate the design of the CTS. Small M&S amounts have required in support of the engineering activities. All efforts during FY92 (our first year of R&D funding) are covered in this subsystem element. Approximately 9.4 mechanical and electronic engineering FTEs were used in this preliminary design phase.

10.09.1 STS Mechanical C/PD

This element includes all CTS FY92 E&D effort and minor M&S support directed toward the initial development of the STS Mechanical systems. Approximately 1.6 LANL engineering FTEs were directed to the effort.

10.09.1.1 Silicon Detector C/PD

This element includes minor M&S support directed toward the initial development of the Si Detector ladder assemblies at Moscow State University.

10.09.1.2-8 Other STS Mechanical C/PD

This element includes all CTS FY92 E&D effort and minor M&S support directed toward the initial development of all other STS mechanical subsystem elements, including silicon detector wafers, the composite support structure, cooling and gas systems and alignment philosophies and cabling requirements.

10.09.2 IPC Tracker C/PD

This element includes all CTS FY92 E&D effort and minor M&S support directed toward the initial development of the IPC Tracker. Approximately .7 LANL engineering FTEs were directed to this effort. Note: All Yale engineering efforts were supported by Yale's HEP base grant. Approximately 1.2 Yale engineering FTEs were supported form this base grant

10.09.2.1 IPC Mechanical

This element includes all CTS FY92 E&D effort and minor M&S support directed toward the initial development of the IPC mechanical systems, including the superlayer modules, support structures, cooling and gas systems and alignment philosophies.

10.09.3 Reserved

10.09.4 Reserved

10.09.5 Beam Tests C/PD

This element includes all CTS FY92 E&D effort directed toward the development of beam tests for STS and IPC mechanical and electronic prototype components and models at BNL and at SSCL. Approximately .6 SSCL engineering FTEs were directed to this effort.

522.5020 Calorimeter 1
20.01 Research and Development 1
20.02 Inner Barrel Calorimetry 1
20.02.1 Assembly (On-site) 1
20.02.2 EM (Electromagnetic) Module 1
20.02.2.1 Assembly 1
20.02.2.2 Absorber 1
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20.02.2.4 Motherboard 2
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522.5020 Calorimeter

This subsystem consists of all assemblies and elements required to 1) provide precise measurement of the energy of electrons and photons, 2) provide directional information for photons, 3) provide a trigger for electrons and photons, 4) provide rejection of hadronic backgrounds by shower shape or size, 5) measure hadronic energy and the tails of electromagnetic showers, 6) help in the identification of electrons and photons, 7) measure the energies of hadronic "jets" and 8) deduce the passage of energetic non interacting particles - neutrinos or new particles. It includes eight major calorimetry subassemblies (the Inner Barrel, two endcaps, the scintillating barrel, two forward hadronic sections, and two passive absorbers) as well as vacuum, cryogenics, and instrumentation, power, and control subsystems. This includes the research and development, construction, and the conceptual/preliminary design phases.

20.01 Research and Development

This element includes research and development activities associated with the GEM calorimetry subsystem. It includes the effort to develop any technology required in the calorimeter design and fabrication including component development tests and tooling development for production. This element does not include the performance of preliminary or detailed design of the calorimetry subsystems. This effort may occur throughout the early phases of the project.

20.02 Inner Barrel Calorimetry

This element includes labor and material of all calorimetry components located in the central region of the calorimeter. It includes the design, fabrication, and assembly of all tooling, handling equipment, and shipping containers required to deliver these components and complete their assembly at the Superconducting Super Collider Laboratory (SSCL).

20.02.1 Assembly (On-site)

This element includes labor and material for the assembly, integration, and testing of all components of the inner barrel calorimetry at the SSCL prior to and in preparation for installation in the experiment hall. It includes the design and fabrication of all handling and test equipment unique to the SSCL assembly operations. It also includes the fabrication of additional sets of tooling, handling equipment, or test equipment previously designed to support the fabrication and delivery of inner barrel calorimetry components to the SSCL.

20.02.2 EM (Electromagnetic) Module

This element includes labor, material, and delivery to the SSCL of all components of the electromagnetic modules including absorbers, signal electrodes, motherboards, connections, and structure. It includes the design, fabrication, and assembly of all tooling, handling equipment, and shipping containers required to deliver these modules to the SSCL.

20.02.2.1 Assembly

This element includes labor and material for the assembly design, assembly operations, testing prior to shipment, and shipment to the SSCL of completed EM modules including absorbers, signal electrodes, motherboards, connections, and structure. It includes the design, fabrication, and assembly of all tooling, handling and test equipment, and shipping containers required to assemble modules, handle and test completed modules, and ship the modules to the SSCL.

20.02.2.2 Absorber

This element includes labor and material for the design, fabrication, and assembly of the EM absorbers which are laminates of stainless steel, lead, prepreg, and G10 which are corrugated to form accordion like plates, permitting them to be stacked with signal electrodes to form the EM module.

20.02.2.3 Signal Electrode

This element includes labor and material for the design, fabrication, and assembly of the EM signal electrodes which consist of two copper coated Kapton plates with signal and high voltage pins located on two edges of the plate. After corrugation, these plates have an accordion-like structure which permits them to be stacked with absorber plates to form the EM module.

20.02.2.4 Motherboard

This element includes labor and material for the design, fabrication, and assembly of the EM motherboards which are integrated circuits boards performing functions such as signal preamplification, temperature sensing, timing, and calibration. The motherboards are hardwired to the signal electrodes and include connector pins for attachment of the signal and power cabling.

20.02.2.5 Connections

This element includes labor and material for the design, fabrication, and assembly of the cabling and connectors that are installed within the EM module and serve to connect the motherboards to the signal electrodes and distribute power form the motherboard to the signal electrodes.

20.02.2.6 Structure

This element includes labor and material for the design, fabrication, and assembly of the structural elements within the EM modules which are not part of other module elements including the inner and outer spacers and inner and outer tensioning bands.

20.02.3 Hadronic Sections

This element includes labor and material for the design, fabrication, assembly, and delivery to the SSCL of all hadronic modules in the inner barrel calorimetry. It also includes the design, fabrication, and assembly of any associated tooling, handling equipment, and test equipment.

20.02.3.1 Assembly

There is no assembly associated with completed hadronic modules except under WBS 20.02.1. Therefore, this reserved WBS element is null.

20.02.3.2 Inner Hadronic Module

This element includes labor and material for the design, fabrication, assembly, and delivery to the SSCL of all components of the fine hadronic Section 1 modules including absorber plates, ground plates, signal electrodes, motherboards, connections, and structure. It includes the design, fabrication, and assembly of all tooling, handling equipment, and shipping containers required to deliver these modules to the SSCL.

20.02.3.2.1 Assembly

This element includes labor and material for the assembly design, assembly operations, testing prior to shipment, and shipment to the SSCL of completed inner hadronic modules including absorber plates, ground plates, signal electrodes, motherboards, connections, and structure. It includes the design, fabrication, and assembly of all tooling, handling and test equipment, and shipping containers required to assemble modules, handle and test completed modules, and ship the modules to the SSCL.

20.02.3.2.2 Absorber Plates

This element includes labor and material for the design, fabrication, and assembly of the inner hadronic absorbers which are laminates of copper and prepreg plates, notched for installation keyways and to allow the striplines to run across their edges. The plates remain flat to permit them to be stacked with the signal electrodes and ground plates in forming the module. High voltage lines are connected to diagonally opposing corners of each plate. These plates are identical to the signal electrodes except that no connection is made to the striplines to obtain signal measurements.

20.02.3.2.3 Ground Plates

This element includes labor and material for the design, fabrication, and assembly of the inner hadronic ground plates which are stainless steel plates, notched for installation keyways and to allow the striplines to connect (ground only) and run across their edges. The plates remain flat to permit them to be stacked with the signal electrodes and ground plates in forming the module. High voltage lines run along a chamfer on diagonally opposing corners of each plate but are not connected.

20.02.3.2.4 Signal Electrodes

This element includes labor and material for the design, fabrication, and assembly of the hadronic signal electrodes which consist of two copper coated Kapton plates with signal and high voltage pins located on two edges of the plate. After corrugation, these plates have an accordion-like structure which permits them to be stacked with absorber plates to form the EM module.

20.02.3.2.5 Motherboard

This element includes labor and material for the design, fabrication, and assembly of the inner hadronic module motherboards which are integrated circuits boards performing functions such as signal preamplification, temperature sensing, timing, and calibration. The motherboards are hardwired to the signal electrodes and include connector pins for attachment of the signal and power cabling.

20.02.3.2.6 Connections

This element includes labor and material for the design, fabrication, and assembly of the cabling and connectors that are installed within the inner hadronic modules which serve to connect the motherboards to the signal electrodes and to provide high voltage power from the motherboards to the absorber plates and the signal electrodes.

20.02.3.2.7 Structures

This element includes labor and material for the design, fabrication, and assembly of the inner hadronic modules structure which houses and supports the plates and provides a means of attaching the module to the liquid vessel. The structure includes two end plates, two side plates, a bottom plate and a top plate.

20.02.3.3 Outer Hadronic Module

This element includes labor and material for the design, fabrication, assembly, and delivery to the SSCL of all components of the fine hadronic outer modules including absorber plates, ground plates, signal electrodes, motherboards, connections, and structure. It includes the design, fabrication, and assembly of all tooling, handling equipment, and shipping containers required to deliver these modules to the SSCL.

20.02.3.3.1 Assembly

This element includes labor and material for the assembly design, assembly operations, testing prior to shipment, and shipment to the SSCL of completed outer hadronic modules including absorber plates, ground plates, signal electrodes, motherboards, connections, and structure. It includes the design, fabrication, and assembly of all tooling, handling and test equipment, and shipping containers required to assemble modules, handle and test completed modules, and ship the modules to the SSCL.

20.02.3.3.2 Absorber Plates

This element includes labor and material for the design, fabrication, and assembly of the outer hadronic absorbers which are laminates of copper and prepreg plates, notched for installation keyways and to allow the striplines to run across their edges. The plates remain flat to permit them to be stacked with the signal electrodes and ground plates in forming the module. High voltage lines are connected to diagonally opposing corners of each plate. These plates are identical to the signal electrodes except that no connection is made to the striplines to obtain signal measurements.

20.02.3.3.3 Ground Plates

This element includes labor and material for the design, fabrication, and assembly of the outer hadronic ground plates which are stainless steel plates, notched for installation keyways and to allow the striplines to connect (ground only) and run across their edges. The plates remain flat to permit them to be stacked with the signal electrodes and ground plates in forming the module. High voltage lines run along a chamber on diagonally opposing corners of each plate but are not connected.

20.02.3.3.4 Signal Electrodes

This element includes labor and material for the design, fabrication, and assembly of the hadronic signal electrodes which consist of two copper coated Kapton plates with signal and high voltage pins located on two edges of the plate. After corrugation, these plates have an accordion-like structure which permits them to be stacked with absorber plates to form the EM module.

20.02.3.3.5 Motherboard

This element includes labor and material for the design, fabrication, and assembly of the outer hadronic module motherboards which are integrated circuits boards performing functions such as signal preamplification, temperature sensing, timing, and calibration. The motherboards are hardwired to the signal electrodes and include connector pins for attachment of the signal and power cabling.

20.02.3.3.6 Connections

This element includes labor and material for the design, fabrication, and assembly of the cabling and connectors that are installed within the outer hadronic modules which serve to connect the motherboards to the signal electrodes and to provide high voltage power from the motherboards to the absorber plates and the signal electrodes.

20.02.3.3.7 Structures

This element includes labor and material for the design, fabrication, and assembly of the outer hadronic modules structure which houses and supports the plates and provides a means of attaching the module to the liquid vessel. The structure includes two end plates, two side plates, a bottom plate and a top plate.

20.02.4 Cryostat

This element includes labor and material for the design, fabrication, assembly, and delivery to the SSCL of all cryosta components including Krypton vessel, vacuum vessel, LKr vessel cold mass support posts, rail supports, and feedthroughs and cables. Only the assembly of major components which is accomplished off-site is included. The remaining assembly of the cryostat is accomplished at the SSCL and is included under WBS 20.02.1. It includes the design, fabrication, and assembly of all tooling, handling equipment, and shipping containers required to deliver the cryostat components to the SSCL.

20.02.4.1 Engineering and Design

This element includes labor and material for the assembly design, assembly operations, testing prior to shipment, and shipment to the SSCL of completed major cryostat components including those for the Krypton and vacuum vessels, LKr vessel cold mass support posts, rail support, and cable and feedthroughs. It includes the design, fabrication, and assembly of all tooling, handling and test equipment, and shipping containers required to assemble, handle and test, and ship the major components to the SSCL. Only the assembly of major components which is accomplished off-site is included. The remaining assembly of the cryostat is accomplished at the SSCL and is included under WBS 20.02.1.

20.02.4.2 Krypton Vessel

This element includes labor and material for the design, fabrication, assembly, and delivery to the SSCL of all major components of the Krypton vessel including the EM outer cylinder structure assembly, head plate assembly, liquid vessel outer cylinder, liquid vessel feedthrough section liquid vessel support bands, cooling stays, drain tube, and multilayer insulation. It includes the design, fabrication, and assembly of all tooling, handling equipment, and shipping containers required to deliver these major components to the SSCL.

20.02.4.3 Vacuum Vessel

This element includes labor and material for the design, fabrication, assembly, and delivery to the SSCL of all major components of the vacuum vessel including the outer cylinder, vacuum vessel end plate assembly, and vacuum vessel inner cylinder assembly. It includes the design, fabrication, and assembly of all tooling, handling equipment, and shipping containers required to deliver these major components to the SSCL.

20.02.4.4 LKr Vessel Cold Mass Support Posts

This element includes labor and material for the design, fabrication, assembly, and delivery to the SSCL of the LKr vessel cold mass support post including the structural interface, heat intercept, G10 pads, and stanchion. It includes the design, fabrication, and assembly of all tooling, handling equipment, and shipping containers required to deliver these units to the SSCL.

20.02.4.5 Rail Support Beam

This element includes labor and material for the design, fabrication, assembly, and delivery to the SSCL of the rail supports including the structure, Hilman rollers, and hydraulic actuators. It includes the design, fabrication, and assembly of all tooling, handling equipment, and shipping containers required to deliver these units to the SSCL.

20.02.4.6 Feedthroughs

This element includes labor and material for the design, fabrication, assembly, and delivery to the SSCL of the cables and feedthroughs which includes cold and warm feedthrough assemblies and a cable bundle with multilayer insulation that connects the warm and cold feedthrough assemblies. It includes the design, fabrication, and assembly of all tooling, handling equipment, and shipping containers required to deliver these units to the SSCL.

20.03 Scintillating Barrel Calorimetry

This element includes labor and material for procurement and assembly of the scintillating hadron barrel calorimeter including the passive end cap and the structural components. This element shows a sum of sub WBS elements from WBS 20.03.1 through WBS 20.03.6.2.

20.03.1 Subsystem Assembly

This element includes labor and material for design, inspection, procurement and assembly of the scintillating hadron barrel calorimeter and end cap subassemblies. This element shows a sum of sub WBS elements from WBS 20.03.1.1 through WBS 20.03.1.2.5.7.

20.03.1.1 Assembly Labor

This element includes labor and material for assembling the scintillating hadron barrel and passive endcap subassemblies. This element shows a sum of sub WBS elements from WBS 20.03.1.1.1 through WBS 20.03.1.1.4.

20.03.1.1.1 Module Installation

This element includes labor and material for installation of the scintillating hadron barrel modules into the barrel geometry.

20.03.1.1.2 Readout Installation

This element includes labor and material for installation of the readout section on the scintillating hadron barrel modules.

20.03.1.1.3 Outer Barrel Passive Absorber

This element includes labor and material for installation of the passive absorber on the outside of the scintillating hadron barrel.

20.03.1.1.4 Noble Liquid Installation Rails

This element includes labor and material for installation of the Noble liquid vessel installation rail on the inside of the scintillating hadron barrel.

20.03.1.2 Assembly Equipment

This element includes labor and material for design, inspection and procurement and setup of all equipment necessary for scintillating hadron barrel and passive endcap assembly. This element shows a sum of sub WBS elements from WBS 20.03.1.2.1 through WBS 20.03.1.2.5.7.

20.03.1.2.1 Assembly Stand

This element includes labor and material for design, inspection and procurement of an assembly stand.

20.03.1.2.2 Plate Handling Fixture

This element includes labor and material for design, inspection and procurement of the plate handling fixtures.

20.03.1.2.3 Module Handling Fixture

This element includes labor and material for design, inspection and procurement of a module handling fixture.

20.03.1.2.4 Personnel Platforms

This element includes labor and material for design, inspection and procurement of personnel platforms that will be used during the assembly process.

20.03.1.2.5 General Equipment for Assembly

This element includes effort for procurement of all general equipment necessary for assembly of the scintillating hadron calorimeter such as tools, cleaning supplies, etc. This element shows a sum of sub WBS elements from WBS 20.03.1.2.5.1 through WBS 20.03.1.2.5.5.

20.03.1.2.5.1 Dimensional Inspection Equipment

This element includes labor and material for preparation of specifications, inspection and procurement of dimensional inspection equipment that will be used for inspecting the dimensions of various parts.

20.03.1.2.5.2 Transmission Fiber and Finishing Machine

This element includes labor and material for preparation of specifications, inspection and procurement of transmission fiber finishing machine that will be used for polishing the fiber ends prior to connecting to light mixers/PMT's.

20.03.1.2.5.3 Tools

This element includes effort for procurement of tools required for assembly of the scintillating hadron barrel calorimeters.

20.03.1.2.5.4 Cleaning Supplies

This element includes effort for procurement of cleaning supplies for the assembly workers and the shop.

20.03.1.2.5.5 Temporary Use Items

This element includes effort for procurement of temporary use items required for assembly of the scintillating hadron barrel calorimeter.

20.03.1.2.5.6 Fork Truck Rental

This element includes effort for procurement of rental fork truck required for assembly of the scintillating hadron barrel calorimeter.

20.03.1.2.5.7 Hand Carts (10 - 100 T)

This element includes effort for procurement of hand and lift trucks and carts required for assembly of the scintillating hadron barrel calorimeter.

20.03.2 Support Tubes

This element includes labor and material for design, inspection, procurement and assembly of support tubes for the scintillating hadron barrel calorimeter and endcap subassemblies. This element shows a sum of sub WBS elements from WBS 20.03.2.1 through WBS 20.03.2.2.4.2.

20.03.2.1 Supporting Tube Assembly

This element includes labor and material for assembling the supporting tube for the scintillating hadron barrel assembly. This element shows a sum of sub WBS elements from WBS 20.03.2.1.1 through WBS 20.03.2.1.3.

20.03.2.1.1 Center Flange and Tube

This element includes labor and material for assembly of the center flange with the support tube.

20.03.2.1.2 End Flange and Tube

This element includes labor and material for assembly of the end flange with the support tube.

20.03.2.1.3 CDS Attachment and Tube

This element includes labor and material for assembly of the CDS attachment with the support tube.

20.03.2.2 Components

This element includes labor and material for engineering, design, inspection, administration, procurement and assembly of the supporting tube components for the scintillating hadron barrel assembly. This element shows a sum of sub WBS elements from WBS 20.03.2.2.1 through WBS 20.03.2.2.4.2.

20.03.2.2.1 Outer Tube

This element includes labor and material for engineering, design, inspection, administration, procurement and assembly of the outer tube for the scintillating hadron barrel. This element shows a sum of sub WBS elements from WBS 20.03.2.2.1.1 through WBS 20.03.2.2.1.2.2.

20.03.2.2.1.1 Assembly

This element includes labor and material for assembly of the outer tube.

20.03.2.2.1.2 Outer Tube Plate

This element includes labor and material for engineering, design, inspection, administration and procurement of the outer tube plate material and the manufacturing the plates for the scintillating hadron barrel assembly. This element shows a sum of sub WBS elements from WBS 20.03.2.2.1.2.1 through WBS 20.03.2.2.1.2.2.

20.03.2.2.1.2.1 Outer Tube Plate Material

This element includes labor and material for design, inspection and procurement of the outer tube plate material.

20.03.2.2.1.2.2 Outer Tube Plate Material Manufacture

This element includes labor and material for manufacturing the outer tube plates.

20.03.2.2.2 End Flange

This element includes labor and material for engineering, design, inspection, administration and procurement for fabrication of the end flange for the scintillating hadron barrel assembly. This element shows a sum of sub WBS elements from WBS 20.03.2.2.2.1. through 20.03.2.2.2.2.

20.03.2.2.2.1 End Flange Fabrication

This element includes labor and material for fabrication of the end flanges.

20.03.2.2.2.2 End Flange Material

This element includes labor and material for design, inspection and procurement of the end flange material.

20.03.2.2.3 Center Flange

This element includes labor and material for engineering, design, inspection, administration and procurement for fabrication of the center flange for the scintillating hadron barrel assembly. This element shows a sum of sub WBS elements from WBS 20.03.2.2.3.1. through WBS 20.03.2.2.3.2.

20.03.2.2.3.1 Center Flange Fabrication

This element includes labor and material for fabrication of the center flange.

20.03.2.2.3.2 End Flange Material

This element includes labor and material for design, inspection and procurement of the center flange material.

20.03.2.2.4 CDS Attachment

This element includes labor and material for engineering, design, inspection, administration and procurement for fabrication of the CDS attachment for the scintillating hadron barrel calorimeter. This element shows a sum of sub WBS elements from WBS 20.03.2.2.4.1. through WBS 20.03.2.2.4.2.

20.03.2.2.4.1 Center Flange Fabrication

This element includes labor and material for fabrication of the center flange.

20.03.2.2.4.2 CDS Attachment Material

This element includes effort for design, inspection and procurement of the CDS attachment material.

20.03.3 Modules

This element includes labor and material for design, inspection, procurement and assembly of the scintillating hadron barrel calorimeter modules. This element shows a sum of sub WBS elements from WBS 20.03.3.1 through WBS 20.03.3.2.3.5.

20.03.3.1 Module Assembly

This element includes labor and material for assembling the scintillating hadron barrel modules. This element shows a sum of sub WBS elements from WBS 20.03.3.1.1 through WBS 20.03.3.1.2.3.

20.03.3.1.1 Assembly Labor

This element includes labor and material for assembling the scintillating hadron barrel modules.

20.03.3.1.2 Assembly Equipment

This element includes labor and material for design, inspection, procurement and setup of all equipment necessary for assembling scintillating hadron barrel modules. This element shows a sum of sub WBS elements from WBS 20.0 3.3.1.2.1 through WBS 20.03.3.1.2.3.

20.03.3.1.2.1 Module Assembly Stand

This element includes labor and material for design, inspection and procurement of an assembly stand.

20.03.3.1.2.2 Plate Handling Fixturing

This element includes labor and material for design, inspection and procurement of the plate handling fixtures.

20.03.3.1.2.3 Module Handling Fixturing

This element includes labor and material for design, inspection and procurement of a module handling fixture.

20.03.3.2 Components

This element includes labor and material for engineering, design, inspection, administration, procurement and assembly of the scintillating barrel module components. This element shows a sum of sub WBS elements from WBS 20.03.3.2.1 through WBS 20.03.3.2.3.5.

20.03.3.2.1 Absorber Plates

This element includes labor and material for engineering, design, inspection, administration and procurement for fabrication of the absorber plates for the scintillating hadron barrel assembly. This element shows a sum of sub WBS elements from WBS 20.03.3.2.1.1. through WBS 20.03.3.2.1.2.

20.03.3.2.1.1 Absorber Plate Fabrication

This element includes labor and material for fabrication of the absorber plates.

20.03.3.2.1.2 Absorber Plate Material

This element includes effort for design, inspection and procurement of the absorber plate material.

20.03.3.2.2 Scintillator

This element includes effort for engineering, design, inspection, administration and procurement of the scintillator material and fabrication of the tile for the scintillating hadron barrel calorimeter. This element shows a sum of sub WBS elements from WBS 20.03.3.2.2.1. through WBS 20.03.3.2.2.5.

20.03.3.2.2.1 Wave Length Shifting (WLS) Fibers

This element includes effort for engineering, design, inspection, administration and procurement of the WLS fibers.

20.03.3.2.2.2 Transmission Fibers

This element includes effort for design, inspection and procurement of the polystyrene transmission fibers.

20.03.3.2.2.3 Tiles

This element includes labor and material for engineering, design, inspection, administration, and procurement for fabrication of the tiles for the scintillating hadron barrel calorimeter. This element shows a sum of sub WBS elements from WBS 20.03.3.2.2.3.1 through WBS 20.03.3.2.2.3.2.

20.03.3.2.2.3.1 Tile Fabrication

This element includes labor and material for fabrication of the tile.

20.03.3.2.2.3.2. Tile Material

This element includes labor and material for design, inspection and procurement of the tile.

20.03.3.2.2.4 Aluminized Mylar

This element includes labor and material for design, inspection and procurement of the aluminized Mylar.

20.03.3.2.2.5 Joint Glue

This element includes labor and material for design, inspection and procurement of the glue for assembling tile with the fibers.

20.03.3.2.3 Module Components

This element includes labor and material for engineering, design, inspection, administration and procurement of various components required for assembling the scintillating hadron barrel calorimeter. This element shows a sum of sub WBS elements from WBS 20.03.3.2.3.1. through WBS 20.03.3.2.3.5.

20.03.3.2.3.1 Fasteners

This element includes labor and material for design, inspection and procurement of the fasteners for the absorber plates.

20.03.3.2.3.2 Banding Straps

This element includes labor and material for design, inspection and procurement of banding straps.

20.03.3.2.3.3 Side Plates

This element includes labor and material for design, inspection and procurement of the side plates.

20.03.3.2.3.4 Spacers

This element includes labor and material for design, inspection and procurement of the spacers for maintaining the space between the absorber plates.

20.03.3.2.3.5 Protective Film

This element includes labor and material for design, inspection and procurement of the protective film for the copper and brass plates

20.03.4 Readout

This element includes labor and material for design, inspection, procurement and assembly of the readout section for the scintillating hadron barrel calorimeter. This element shows a sum of sub WBS elements from WBS 20.03.4.1 through WBS 20.03.4.2.3.2.2.

20.03.4.1 Assembly

This element includes labor and material for assembling the readout section of the scintillating hadron barrel calorimeter.

20.03.4.2 Components

This element includes labor and material for engineering, design, inspection, administration, procurement and assembly of the readout section components. This element shows a sum of sub WBS elements from WBS 20.03.4.2.1 through WBS 20.03.4.2.3.2.2.

20.03.4.2.1 Photomultiplier (PMT) Assemblies

This element includes the effort for engineering, design, inspection, administration and procurement of the material and fabrication of the PMT assemblies for the scintillating hadron barrel calorimeter. This element shows a sum of sub WBS elements from WBS 20.03.4.2.1.1. through WBS 20.03.4.2.1.2.3.

20.03.4.2.1.1 Assembly

This element includes labor and material for assembling the PMT assemblies.

20.03.4.2.1.2 PMT Assembly Components

This element includes labor and material for engineering, design, inspection, administration and procurement of the PMT assembly components for the scintillating hadron barrel calorimeter. This element shows a sum of sub WBS elements from WBS 20.03.4.2.1.2.1. through WBS 20.03.4.2.1.2.3.

20.03.4.2.1.2.1 PMT Tubes

This element includes labor and material for design, inspection and procurement of the PMT's.

20.03.4.2.1.2.2 Individual PMT Structure

This element includes labor and material for design, inspection and procurement of the individual PMT structures.

20.03.4.2.1.2.3 PMT Group Framing

This element includes labor and material for design, inspection and procurement of the PMT group framing.

20.03.4.2.2 Electronics

This element includes labor and material for engineering, design, inspection, administration and procurement of the electronics for the scintillating hadron barrel calorimeter. This element shows a sum of sub WBS elements from WBS 20.03.4.2.2.1. through WBS 20.03.4.2.3.2.2.

20.03.4.2.2.1 Assembly

This element includes labor and material for assembling the electronics.

20.03.4.2.2.2 Electronics Components

This element includes labor and material for engineering, design, inspection, administration, procurement, assembly of the electronics components for the scintillating hadron barrel calorimeter. This element shows a sum of sub WBS elements from WBS 20.03.4.2.2.2.1 through WBS 20.03.4.2.3.2.2.

20.03.4.2.2.2.1 Local Electronics

This element includes labor and material for design, inspection and procurement of local electronics.

20.03.4.2.2.2.2 Base

This element includes labor and material for design, inspection and procurement of the PMT bases.

20.03.4.2.2.2.3 Cabling and Connectors

This element includes labor and material for design, inspection and procurement of the cabling and connectors.

20.03.4.2.2.2.4 Thermal Control (Reserved)

This element includes labor and material for engineering, design, inspection, administration, procurement and assembly of the electronics thermal control system. This element shows a sum of sub WBS elements from WBS 20.03.4.2.2.2.4.1. through WBS 20.03.4.2.3.2.2.

20.03.4.2.3 Calibration

This element includes labor and material for engineering, design, inspection, administration, and procurement of the calibration system for the scintillating hadron barrel calorimeter. This element shows a sum of sub WBS elements from WBS 20.03.4.2.3.1. through WBS 20.03.4.2.3.2.2.

20.03.4.2.3.1 Assembly

This element includes labor and material for assembling the calibration systems.

20.03.4.2.3.2 Calibration System Components

This element includes labor and material for engineering, design, inspection, administration, procurement, and assembly of the calibration system components for the scintillating hadron barrel calorimeter. This element shows a sum of sub WBS elements from WBS 20.03.4.2.3.2.1. through WBS 20.03.4.2.3.2.2.

20.03.4.2.3.2.1 Drive Assembly

This element includes labor and material for design, inspection and procurement of calibration system drive system.

20.03.4.2.3.2.2 Electronics

This element includes labor and material for design, inspection and procurement of calibration system electronics.

20.03.5 Outer Barrel Passive Absorber

This element includes labor and material for design, inspection, procurement and assembly of the outer barrel passive absorber for the scintillating hadron barrel calorimeter .This element shows a sum of sub WBS elements from WBS 20.03.5.1 through WBS 20.03.5.2.

20.03.5.1 Outer Barrel Passive Absorber Manufacture

This element includes labor and material for fabrication of the outer barrel passive absorber.

20.03.5.2 Outer Barrel Passive Absorber Material

This element includes labor and material for design, inspection and procurement of the outer barrel passive absorber material.

20.03.6 Noble Liquid Installation Rails

This element includes labor and material for design, inspection, procurement and assembly of the installation rails for the Noble liquid vessel. This element shows a sum of sub WBS elements from WBS 20.03.6.1 through WBS 20.03.6.2.

20.03.6.1 Noble Liquid Installation Rail Manufacture

This element includes labor and material for fabrication of the Noble liquid vessel installation rails.

20.03.6.2 Noble Liquid Installation Rail Material

This element includes labor and material for design, inspection and procurement of the Noble liquid installation rail material.

20.04 Endcap Calorimetry

This element covers the design, fabrication, and assembly of all active calorimetry components located at each end of the calorimeter except for the forward hadronic calorimetry under WBS 20.05. It includes the design, fabrication, and assembly of all tooling, handling equipment, and shipping containers required to deliver these components and complete their assembly at the SSCL.

20.04.1 Assembly (On-site)

This element covers the assembly, integration, and testing of all components of the endcap calorimetry at the SSCL prior to and in preparation for installation in the experiment hall. It includes the design and fabrication of all handling and test equipment unique to the SSCL assembly operations. It also includes the fabrication of additional sets of tooling, handling equipment, or test equipment previously designed to support the fabrication and delivery of Inner barrel calorimetry components to the SSCL.

20.04.2 EM Module

This element covers the design, fabrication, assembly, and delivery to the SSCL of all components of the electromagnetic modules including absorbers, signal electrodes, motherboards, connections, and structure. It includes the design, fabrication, and assembly of all tooling, handling equipment, and shipping containers required to deliver these modules to the SSCL.

20.04.2.1 Assembly

This element covers the assembly design, assembly operations, testing prior to shipment, and shipment to the SSCL of completed EM modules including absorbers, signal electrodes, motherboards, connections, and structure. It includes the design, fabrication, and assembly of all tooling, handling and test equipment, and shipping containers required to assemble modules, handle and test completed modules, and ship the modules to the SSCL.

20.04.2.2 Absorber

This element covers the design, fabrication, and assembly of the EM absorbers which are laminates of stainless steel, lead, prepreg, and G10 which are corrugated to form accordion like plates, permitting them to be stacked with signal electrodes to form the EM module.

20.04.2.3 Signal Electrode

This element covers the design, fabrication, and assembly of the EM signal electrodes which consist of two copper coated Kapton plates with signal and high voltage pins located on two edges of the plate. After corrugation, these plates have an accordion-like structure which permits them to be stacked with absorber plates to form the EM module.

20.04.2.4 Motherboard

This element covers the design, fabrication, and assembly of the EM motherboards which are integrated circuits boards performing functions such as signal preamplification, temperature sensing, timing, and calibration. The motherboards are hardwired to the signal electrodes and include connector pins for attachment of the signal and power cabling.

20.04.2.5 Connections

This element covers the design, fabrication, and assembly of the cabling and connectors that are installed within the EM module and serve to connect the motherboards to the signal electrodes and distribute power form the motherboard to the signal electrodes.

20.04.2.6 Structure

This element covers the design, fabrication, and assembly of the structural elements within the EM modules which are not part of other module elements.

20.04.3 Hadronic Sections

This element covers the design, fabrication, assembly, and delivery to the SSCL of all hadronic modules in the inner barrel calorimetry. It also includes the design, fabrication, and assembly of any associated tooling, handling equipment, and test equipment.

20.04.3.1 Assembly

There is no assembly associated with completed hadronic modules except under WBS 20.04.1. Therefore, this reserved WBS element is null.

20.04.3.2 Inner Hadronic A Module

This element covers the design, fabrication, assembly, and delivery to the SSCL of all components of the fine inner hadronic A modules including absorber plates, ground plates, signal electrodes, motherboards, connections, and structure. It includes the design, fabrication, and assembly of all tooling, handling equipment, and shipping containers required to deliver these modules to the SSCL.

20.04.3.2.1 Assembly

This element covers the assembly design, assembly operations, testing prior to shipment, and shipment to the SSCL of completed inner hadronic A modules including absorber plates, ground plates, signal electrodes, motherboards, connections, and structure. It includes the design, fabrication, and assembly of all tooling, handling and test equipment, and shipping containers required to assemble modules, handle and test completed modules, and ship the modules to the SSCL.

20.04.3.2.2 Absorber Plates

This element covers the design, fabrication, and assembly of the inner hadronic A absorbers which are laminates of copper and prepreg plates, notched for installation keyways and to allow the striplines to run across their edges. The plates remain flat to permit them to be stacked with the signal electrodes and ground plates in forming the module. High voltage lines are connected to diagonally opposing corners of each plate. These plates are identical to the signal electrodes except that no connection is made to the striplines to obtain signal measurements.

20.04.3.2.3 Ground Plates

This element covers the design, fabrication, and assembly of the inner hadronic A ground plates which are stainless steel plates, notched for installation keyways and to allow the striplines to connect (ground only) and run across their edges. The plates remain flat to permit them to be stacked with the signal electrodes and ground plates in forming the module. High voltage lines run along a chamfer on diagonally opposing corners of each plate but are not connected.

20.04.3.2.4 Signal Electrodes

This element covers the design, fabrication, and assembly of the hadronic signal electrodes which consist of two copper coated Kapton plates with signal and high voltage pins located on two edges of the plate. After corrugation, these plates have an accordion-like structure which permits them to be stacked with absorber plates to form the EM module.

20.04.3.2.5 Motherboard

This element covers the design, fabrication, and assembly of the inner hadronic A module motherboards which are integrated circuits boards performing functions such as signal preamplification, temperature sensing, timing, and calibration. The motherboards are hardwired to the signal electrodes and include connector pins for attachment of the signal and power cabling.

20.04.3.2.6 Connections

This element covers the design, fabrication, and assembly of the cabling and connectors that are installed within the inner hadronic A modules which serve to connect the motherboards to the signal electrodes and to provide high voltage power from the motherboards to the absorber plates and the signal electrodes.

20.04.3.2.7 Structures

This element covers the design, fabrication, and assembly of the inner hadronic A modules structure which houses and supports the plates and provides a means of attaching the module to the liquid vessel. The structure includes two end plates, two side plates, a bottom plate and a top plate.

20.04.3.3 Inner Hadronic B Module

This element covers the design, fabrication, assembly, and delivery to the SSCL of all components of the fine hadronic Section 2 modules including absorber plates, ground plates, signal electrodes, motherboards, connections, and structure. It includes the design, fabrication, and assembly of all tooling, handling equipment, and shipping containers required to deliver these modules to the SSCL.

20.04.3.3.1 Assembly

This element covers the assembly design, assembly operations, testing prior to shipment, and shipment to the SSCL of completed inner hadronic B modules including absorber plates, ground plates, signal electrodes, motherboards, connections, and structure. It includes the design, fabrication, and assembly of all tooling, handling and test equipment, and shipping containers required to assemble modules, handle and test completed modules, and ship the modules to the SSCL.

20.04.3.3.2 Absorber Plates

This element covers the design, fabrication, and assembly of the inner hadronic B absorbers which are laminates of copper and prepreg plates, notched for installation keyways and to allow the striplines to run across their edges. The plates remain flat to permit them to be stacked with the signal electrodes and ground plates in forming the module. High voltage lines are connected to diagonally opposing corners of each plate. These plates are identical to the signal electrodes except that no connection is made to the striplines to obtain signal measurements.

20.04.3.3.3 Ground Plates

This element covers the design, fabrication, and assembly of the inner hadronic B ground plates which are stainless steel plates, notched for installation keyways and to allow the striplines to connect (ground only) and run across their edges. The plates remain flat to permit them to be stacked with the signal electrodes and ground plates in forming the module. High voltage lines run along a chamfer on diagonally opposing corners of each plate but are not connected.

20.04.3.3.4 Signal Electrodes

This element covers the design, fabrication, and assembly of the hadronic signal electrodes which consist of two copper coated Kapton plates with signal and high voltage pins located on two edges of the plate. After corrugation, these plates have an accordion-like structure which permits them to be stacked with absorber plates to form the EM module.

20.04.3.3.5 Motherboard

This element covers the design, fabrication, and assembly of the inner hadronic B module motherboards which are integrated circuits boards performing functions such as signal preamplification, temperature sensing, timing, and calibration. The motherboards are hardwired to the signal electrodes and include connector pins for attachment of the signal and power cabling.

20.04.3.3.6 Connections

This element covers the design, fabrication, and assembly of the cabling and connectors that are installed within the inner hadronic B modules which serve to connect the motherboards to the signal electrodes and to provide high voltage power from the motherboards to the absorber plates and the signal electrodes.

20.04.3.3.7 Structures

This element covers the design, fabrication, and assembly of the inner hadronic B modules structure which houses and supports the plates and provides a means of attaching the module to the liquid vessel. The structure includes two end plates, two side plates, a bottom plate and a top plate.

20.04.3.4 Inner Hadronic C Module

This element covers the design, fabrication, assembly, and delivery to the SSCL of all components of the inner hadronic C modules including absorber plates, ground plates, signal electrodes, motherboards, connections, and structure. It includes the design, fabrication, and assembly of all tooling, handling equipment, and shipping containers required to deliver these modules to the SSCL.

20.04.3.4.1 Assembly

This element covers the assembly design, assembly operations, testing prior to shipment, and shipment to the SSCL of completed inner hadronic C modules including absorber plates, ground plates, signal electrodes, motherboards, connections, and structure. It includes the design, fabrication, and assembly of all tooling, handling and test equipment, and shipping containers required to assemble modules, handle and test completed modules, and ship the modules to the SSCL.

20.04.3.4.2 Absorber Plates

This element covers the design, fabrication, and assembly of the inner hadronic C absorbers which are laminates of copper and prepreg plates, notched for installation keyways and to allow the striplines to run across their edges. The plates remain flat to permit them to be stacked with the signal electrodes and ground plates in forming the module. High voltage lines are connected to diagonally opposing corners of each plate. These plates are identical to the signal electrodes except that no connection is made to the striplines to obtain signal measurements.

20.04.3.4.3 Ground Plates

This element covers the design, fabrication, and assembly of the inner hadronic C ground plates which are stainless steel plates, notched for installation keyways and to allow the striplines to connect (ground only) and run across their edges. The plates remain flat to permit them to be stacked with the signal electrodes and ground plates in forming the module. High voltage lines run along a chamfer on diagonally opposing corners of each plate but are not connected.

20.04.3.4.4 Signal Electrodes

This element covers the design, fabrication, and assembly of the hadronic signal electrodes which consist of two copper coated Kapton plates with signal and high voltage pins located on two edges of the plate. After corrugation, these plates have an accordion-like structure which permits them to be stacked with absorber plates to form the EM module.

20.04.3.4.5 Motherboard

This element covers the design, fabrication, and assembly of the inner hadronic C module motherboards which are integrated circuits boards performing functions such as signal preamplification, temperature sensing, timing, and calibration. The motherboards are hardwired to the signal electrodes and include connector pins for attachment of the signal and power cabling.

20.04.3.4.6 Connections

This element covers the design, fabrication, and assembly of the cabling and connectors that are installed within the inner hadronic C modules which serve to connect the motherboards to the signal electrodes and to provide high voltage power from the motherboards to the absorber plates and the signal electrodes.

20.04.3.4.7 Structures

This element covers the design, fabrication, and assembly of the inner hadronic C modules structure which houses and supports the plates and provides a means of attaching the module to the liquid vessel. The structure includes two end plates, two side plates, a bottom plate and a top plate.

20.04.3.5 Outer Hadronic A Module

This element covers the design, fabrication, assembly, and delivery to the SSCL of all components of the fine hadronic Section 4 modules including absorber plates, ground plates, signal electrodes, motherboards, connections, and structure. It includes the design, fabrication, and assembly of all tooling, handling equipment, and shipping containers required to deliver these modules to the SSCL.

20.04.3.5.1 Assembly

This element covers the assembly design, assembly operations, testing prior to shipment, and shipment to the SSCL of completed outer hadronic A modules including absorber plates, ground plates, signal electrodes, motherboards, connections, and structure. It includes the design, fabrication, and assembly of all tooling, handling and test equipment, and shipping containers required to assemble modules, handle and test completed modules, and ship the modules to the SSCL.

20.04.3.5.2 Absorber Plates

This element covers the design, fabrication, and assembly of the outer hadronic A absorbers which are laminates of copper and prepreg plates, notched for installation keyways and to allow the striplines to run across their edges. The plates remain flat to permit them to be stacked with the signal electrodes and ground plates in forming the module. High voltage lines are connected to diagonally opposing corners of each plate. These plates are identical to the signal electrodes except that no connection is made to the striplines to obtain signal measurements.

20.04.3.5.3 Ground Plates

This element covers the design, fabrication, and assembly of the outer hadronic A ground plates which are stainless steel plates, notched for installation keyways and to allow the striplines to connect (ground only) and run across their edges. The plates remain flat to permit them to be stacked with the signal electrodes and ground plates in forming the module. High voltage lines run along a chamfer on diagonally opposing corners of each plate but are not connected.

20.04.3.5.4 Signal Electrodes

This element covers the design, fabrication, and assembly of the hadronic signal electrodes which consist of two copper coated Kapton plates with signal and high voltage pins located on two edges of the plate. After corrugation, these plates have an accordion-like structure which permits them to be stacked with absorber plates to form the EM module.

20.04.3.5.5 Motherboard

This element covers the design, fabrication, and assembly of the outer hadronic A module motherboards which are integrated circuits boards performing functions such as signal preamplification, temperature sensing, timing, and calibration. The motherboards are hardwired to the signal electrodes and include connector pins for attachment of the signal and power cabling.

20.04.3.5.6 Connections

This element covers the design, fabrication, and assembly of the cabling and connectors that are installed within the outer hadronic A modules which serve to connect the motherboards to the signal electrodes and to provide high voltage power from the motherboards to the absorber plates and the signal electrodes.

20.04.3.5.7 Structures

This element covers the design, fabrication, and assembly of the outer hadronic A modules structure which houses and supports the plates and provides a means of attaching the module to the liquid vessel. The structure includes two end plates, two side plates, a bottom plate and a top plate.

20.04.3.6 Outer Hadronic B Module

This element covers the design, fabrication, assembly, and delivery to the SSCL of all components of the fine hadronic Section 5 modules including absorber plates, ground plates, signal electrodes, motherboards, connections, and structure. It includes the design, fabrication, and assembly of all tooling, handling equipment, and shipping containers required to deliver these modules to the SSCL.

20.04.3.6.1 Assembly

This element covers the assembly design, assembly operations, testing prior to shipment, and shipment to the SSCL of completed outer hadronic BB modules including absorber plates, ground plates, signal electrodes, motherboards, connections, and structure. It includes the design, fabrication, and assembly of all tooling, handling and test equipment, and shipping containers required to assemble modules, handle and test completed modules, and ship the modules to the SSCL.

20.04.3.6.2 Absorber Plates

This element covers the design, fabrication, and assembly of the outer hadronic B absorbers which are laminates of copper and prepreg plates, notched for installation keyways and to allow the striplines to run across their edges. The plates remain flat to permit them to be stacked with the signal electrodes and ground plates in forming the module. High voltage lines are connected to diagonally opposing corners of each plate. These plates are identical to the signal electrodes except that no connection is made to the striplines to obtain signal measurements.

20.04.3.6.3 Ground Plates

This element covers the design, fabrication, and assembly of the outer hadronic B ground plates which are stainless steel plates, notched for installation keyways and to allow the striplines to connect (ground only) and run across their edges. The plates remain flat to permit them to be stacked with the signal electrodes and ground plates in forming the module. High voltage lines run along a chamfer on diagonally opposing corners of each plate but are not connected.

20.04.3.6.4 Signal Electrodes

This element covers the design, fabrication, and assembly of the hadronic signal electrodes which consist of two copper coated Kapton plates with signal and high voltage pins located on two edges of the plate. After corrugation, these plates have an accordion-like structure which permits them to be stacked with absorber plates to form the EM module.

20.04.3.6.5 Motherboard

This element covers the design, fabrication, and assembly of the outer hadronic B module motherboards which are integrated circuits boards performing functions such as signal preamplification, temperature sensing, timing, and calibration. The motherboards are hardwired to the signal electrodes and include connector pins for attachment of the signal and power cabling.

20.04.3.6.6 Connections

This element covers the design, fabrication, and assembly of the cabling and connectors that are installed within the outer hadronic B modules which serve to connect the motherboards to the signal electrodes and to provide high voltage power from the motherboards to the absorber plates and the signal electrodes.

20.04.3.6.7 Structures

This element covers the design, fabrication, and assembly of the outer hadronic B modules structure which houses and supports the plates and provides a means of attaching the module to the liquid vessel. The structure includes two end plates, two side plates, a bottom plate and a top plate.

20.04.3.7 Outer Hadronic C Module

This element covers the design, fabrication, assembly, and delivery to the SSCL of all components of the fine hadronic Section 6 modules including absorber plates, ground plates, signal electrodes, motherboards, connections, and structure. It includes the design, fabrication, and assembly of all tooling, handling equipment, and shipping containers required to deliver these modules to the SSCL.

20.04.3.7.1 Assembly

This element covers the assembly design, assembly operations, testing prior to shipment, and shipment to the SSCL of completed outer hadronic C modules including absorber plates, ground plates, signal electrodes, motherboards, connections, and structure. It includes the design, fabrication, and assembly of all tooling, handling and test equipment, and shipping containers required to assemble modules, handle and test completed modules, and ship the modules to the SSCL.

20.04.3.7.2 Absorber Plates

This element covers the design, fabrication, and assembly of the outer hadronic C absorbers which are laminates of copper and prepreg plates, notched for installation keyways and to allow the striplines to run across their edges. The plates remain flat to permit them to be stacked with the signal electrodes and ground plates in forming the module. High voltage lines are connected to diagonally opposing corners of each plate. These plates are identical to the signal electrodes except that no connection is made to the striplines to obtain signal measurements.

20.04.3.7.3 Ground Plates

This element covers the design, fabrication, and assembly of the outer hadronic C ground plates which are stainless steel plates, notched for installation keyways and to allow the striplines to connect (ground only) and run across their edges. The plates remain flat to permit them to be stacked with the signal electrodes and ground plates in forming the module. High voltage lines run along a chamfer on diagonally opposing corners of each plate but are not connected.

20.04.3.7.4 Signal Electrodes

This element covers the design, fabrication, and assembly of the hadronic signal electrodes which consist of two copper coated Kapton plates with signal and high voltage pins located on two edges of the plate. After corrugation, these plates have an accordion-like structure which permits them to be stacked with absorber plates to form the EM module.

20.04.3.7.5 Motherboard

This element covers the design, fabrication, and assembly of the outer hadronic C module motherboards which are integrated circuits boards performing functions such as signal preamplification, temperature sensing, timing, and calibration. The motherboards are hardwired to the signal electrodes and include connector pins for attachment of the signal and power cabling.

20.04.3.7.6 Connections

This element covers the design, fabrication, and assembly of the cabling and connectors that are installed within the outer hadronic C modules which serve to connect the motherboards to the signal electrodes and to provide high voltage power from the motherboards to the absorber plates and the signal electrodes.

20.04.3.7.7 Structures

This element covers the design, fabrication, and assembly of the outer hadronic C modules structure which houses and supports the plates and provides a means of attaching the module to the liquid vessel. The structure includes two end plates, two side plates, a bottom plate and a top plate.

20.04.4 Forward Electromagnetic Section

This element includes all components and construction of EM module of FCAL prior to assembly into endcap.

20.04.4.1 Main Body Assembly

Covers fabrication and assembly of cylindrical brass absorber with holes to receive instrumented tube and rod assemblies.

20.04.4.1.1 Labor

This element includes the labor to assemble drilled plates of brass absorber into the main body assembly.

20.04.4.1.2 Material

This element includes the materials used in the main body assembly.

20.04.4.1.2.1 Brass Absorber Plates

This element includes labor and material for 70 cm diameter brass absorber plates drilled with pattern for tube and rod assemblies.

20.04.4.1.3 Assembly Equipment

This element includes the labor and material for all equipment used in the assembly of the main body assembly.

20.04.4.1.3.1 Assembly Stand

This element includes labor and material for the stand used to hold the brass absorber plates during and after assembly into the main body assembly.

20.04.4.1.3.2 Cleaning

This element includes labor and materials for the process of cleaning the main body assembly components for liquid argon service.

20.04.4.1.3.3 Tools

This element includes incidental tools required for the main body assembly process.

20.04.4.1.3.4 Temporary Use Items

This element includes the depreciation and/or rental costs of tools or stands needed for short term use.

20.04.4.2 Tube and Rod Assembly

This element includes the fundamental unit of instrumented absorber in the FCAL EM module. 14 000 assemblies are required.

20.04.4.2.1 Labor

This element includes labor and material for the process of assembling and inspecting the tube and rod components.

20.04.4.2.2 Material

This element includes labor and material for all components used in the tube and rod assemblies.

20.04.4.2.2.1 Contact Springs

This element includes labor and material for the custom formed spring for electrical contact to the rod in the tube and rod assembly.

20.04.4.2.2.2 Brass Tubes

This element includes labor and material for the outer housing for the tube and rod assemblies. Needs percision ID.

20.04.2.2.3 Quartz Fiber Spacers

This element includes labor and material for the 100 micron diameter quartz fiber (Kapton coated) used to electrically isolate rod from tube.

20.04.2.2.4 Brass Rods

This element includes labor and material for the precision ground brass rod forming the inner electrode of the tube and rod assembly.

20.04.2.2.5 Plugs

This element includes labor and material for the Injection molded PEEK plugs which hold the rod within the tube and holds the spring contact in place.

20.04.2.3 Assembly Equipment

This element includes labor and material for all equipment needed to allow assembly and inspection of tube and rod sets.

20.04.2.3.1 Assembly Stand

This element includes labor and material for all equipment needed to allow assembly and inspection of tube and rod set.

20.04.4.2.3.2 Cleaning

This element includes labor and material for the bench top equipment and for cleaning the tube and rod assembly components.

20.04.4.2.3.3 Tools

This element includes effort for the incidental hand tools needed for the tube and rod assembly.

20.04.4.2.3.4 Temporary Use Items

This element includes material and labor for the short term use of tools and stands for the tube and rod assembly.

20.04.4.3 Electrical Assembly

This element includes the process of inserting the tube and rod assemblies into the main body, mounting the interconnect board and soldering all the contact springs into the interconnect board.

20.04.4.3.1 Labor (Reserved)

20.04.4.3.2 Material

This element includes the materials and components used in the electrical assembly.

20.04.4.3.2.1 Cables

This element includes the labor and material for the ribbon cables connecting the interconnect board to the cryostat feedthroughs.

20.04.4.3.2.2 Interconnect Board

This element includes the labor and material for the printed circuit board mounted on one end of EM module. This element makes signal and high voltage connections between cables and each tube and rod assembly.

20.04.4.3.3 Assembly Equipment

This element includes the labor and material for the equipment used in electrical assembly process.

20.04.4.3.3.1 Cleaning

This element includes effort for the materials and equipment used to clean the EM module during and after electrical assembly process.

20.04.4.3.3.2 Tools

This element includes the effort for Incidental tools required to carry out the electrical assembly process.

20.04.4.3.3.3 Temporary Use Items

This element includes the effort for short term use and rental equipment for electrical assembly.

20.04.4.4 Electronics

This element includes the signal preamplifiers, calibration circuitry and exterior cabling.

20.04.4.4.1 Labor (Reserved)

20.04.4.4.2 Material

This element includes the material and components used in the electronics category.

20.04.4.4.2.1 Preamps

This element includes labor and material for the preamplifier hybrid (one signal channel) and motherboards associated with them.

20.04.4.4.2.2 Card Cages

This element includes labor and material for the VME style (6U) cages for the preamp motherboards (*ribbon cable backplane*). It replaces junction box for FCAL EM sections.

20.04.4.4.2.3 Cables

This element includes labor and material for the ribbon cables connecting the cryostat feedthroughs to the exterior card cages.

20.04.4.4.2.4 Calibration System

This element includes labor and material for separate printed circuit cards in the preamp card cages for electronic calibration of the system.

20.04.4.4.3 Assembly Equipment

This element includes effort for the equipment and materials needed for electronics assembly and testing.

20.04.4.4.3.1 Cleaning

This element includes the effort for the materials and equipment used for cleaning of electronics.

20.04.4.4.3.2 Tools

This element includes effort for the incidental hand tools required for assembly and testing of electronics.

20.04.4.4.3.3 Temporary Use Items

This element includes short term use and rental equipment and tools used in assembly and testing of electronics.

20.04.5 Cryostat

This element covers the design, fabrication, assembly, and delivery to the SSCL of all cryostat components including the argon vessel, vacuum vessel, LAr vessel cold mass support posts, rail supports, and feedthroughs & cables. Only the assembly of major components which is accomplished off-site is included. The remaining assembly of the cryostat is accomplished at the SSCL and is included under WBS 20.04.1. It includes the design, fabrication, and assembly of all tooling, handling equipment, and shipping containers required to deliver the cryostat components to the SSCL.

20.04.5.1 Engineering and Design

This element covers the assembly design, assembly operations, testing prior to shipment, and shipment to the SSCL of completed major cryostat components including those for the Argon and vacuum vessels, LAr vessel cold mass support posts, rail support, and cable and feedthroughs. It includes the design, fabrication, and assembly of all tooling, handling and test equipment, and shipping containers required to assemble, handle and test, and ship the major components to the SSCL. Only the assembly of major components which is accomplished off-site is included. The remaining cryostat assembly is accomplished at the SSCL and is included under WBS 20.04.1.

20.04.5.2 Argon Vessel

This element covers the design, fabrication, assembly, and delivery to the SSCL of all major components of the Argon vessel including the structure assembly, liquid vessel feed through section, EM monolith stay, liquid vessel inner head plate, hadronic module stay installation brackets, hadronic module stays, liquid vessel outer cylinder, liquid vessel support bands, cooling lines, drain tube, multilayer insulation, and cooling components. It includes the design, fabrication, and assembly of all tooling, handling equipment, and shipping containers required to deliver these major components to the SSCL.

20.04.5.3 Vacuum Vessel

This element covers the design, fabrication, assembly, and delivery to the SSCL of all major components of the vacuum vessel including the outer cylinder, vacuum vessel inner head plate assembly, and outer head plate. It includes the design, fabrication, and assembly of all tooling, handling equipment, and shipping containers required to deliver these major components to the SSCL.

20.04.5.4 LAr Vessel Cold Mass Support Posts

This element covers the design, fabrication, assembly, and delivery to the SSCL of the LAr vessel cold mass support post including the structural interface, heat intercept, G10 pads, and stanchion. It includes the design, fabrication, and assembly of all tooling, handling equipment, and shipping containers required to deliver these units to the SSCL.

20.04.5.5 Rail Support

This element covers the design, fabrication, assembly, and delivery to the SSCL of the rail supports including the structure, Hilman rollers, and hydraulic actuators. It includes the design, fabrication, and assembly of all tooling, handling equipment, and shipping containers required to deliver these units to the SSCL.

20.04.5.6 Feed-Throughs

This element covers the design, fabrication, assembly, and delivery to the SSCL of the cables and feedthroughs which includes cold and warm feedthrough assemblies and a cable bundle with multilayer insulation that connects the warm and cold feedthrough assemblies. It includes the design, fabrication, and assembly of all tooling, handling equipment, and shipping containers required to deliver these units to the SSCL.

20.05 Forward Hadronic Calorimetry

This element includes labor and material for engineering, design, inspection, administration, procurement and assembly of 2 forward calorimeters including the structural components. This element shows a sum of sub WBS elements from WBS 20.05.1 through WBS 20.05.3.3.2.2.2.6.

20.05.1 Hadronic FCAL Assembly

This element includes labor and material for design, inspection, procurement and assembly of FCAL modules into the structural rings. This element shows a sum of sub WBS elements from WBS 20.05.1.1 through WBS 20.05.1.2.8.4.

20.05.1.1 Assembly

This element includes labor and material for assembling FCAL modules into the structural rings and setting up assembly equipment in the shop. This element shows a sum of sub WBS elements from WBS 20.05.1.1.1 through WBS 20.05.1.1.2.

20.05.1.1.1 Module Structure Assembly

This element includes labor and material for assembling FCAL modules into the structural rings

20.05.1.1.2 Assembly Equipment

This element includes labor and material for assembling assembly equipment in the fabrication shop.

20.05.1.2 Assembly Equipment

This element includes labor and material for design, inspection and procurement and assembly of all equipment necessary for assembly of the FCAL modules into the structural ring. This element shows a sum of sub WBS elements from WBS 20.05.1.2.1 through WBS 20.05.1.2.6.

20.05.1.2.1 Assembly Stand

This element includes labor and material for design, inspection and procurement of an assembly stand.

20.05.1.2.2 Tube and End Plate Assembly Fixture

This element includes labor and material for design, inspection and procurement of an assembly fixture for tube and end plates.

20.05.1.2.3 Module Handling Fixture

This element includes labor and material for design, inspection and procurement of a module handling fixture.

20.05.1.2.4 Fiber Assembly Fixture

This element includes labor and material for design, inspection and procurement of a fiber assembly fixture.

20.05.1.2.5 Personnel Platform

This element includes labor and material for design, inspection and procurement of 2 personnel platforms that will be used during the assembly process.

20.05.1.2.6 Transmission Fiber Finishing Machine

This element includes labor and material for preparation of specifications, inspection and procurement of transmission fiber finishing machine that will be used for polishing the fiber ends prior to connecting to light mixers and PMT's.

20.05.2 Structures

This element includes labor and material for engineering, design, inspection, administration, procurement and assembly of all structural material and components. This element shows a sum of sub WBS elements from WBS 20.05.2.1 through WBS 20.05.2.2.6.2.2.

20.05.2.1 Structure Assembly

This element includes labor and material for assembling liquid piping, passive absorber, readout support, and calibration assembly

20.05.2.2 Structural Components

This element includes labor and material for design, inspection and procurement of all structural material and components. This element shows a sum for sub WBS elements from WBS 20.05.2.2.1 through WBS 20.05.2.2.6.2.2.

20.05.2.2.1 Support Ring and Flange

This element includes labor and material for design, inspection and procurement of the support ring.

20.05.2.2.2 Liquid Handling System Piping

This element includes labor and material for design, inspection and procurement of the piping for the liquid handling system.

20.05.2.2.3 Passive Absorber

This element includes labor and material for design, inspection, procurement, and assembly of the passive material between the scintillating section and the ID of the structural ring. This element shows a sum for sub WBS elements from WBS 20.05.2.2.3.1 through WBS 20.05.2.2.3.2.

20.05.2.2.3.1 Assembly

Need input

20.05.2.2.3.2 Passive Absorber Material

This element includes labor and material for design, inspection and procurement of the passive absorber material.

20.05.2.2.4 Photomultiplier Support

This element includes labor and material for design, inspection and procurement of the PMT support structure.

20.05.2.2.5 Thermal Dome

This element includes labor and material for design, inspection and procurement of the thermal dome structure for the readout section

20.05.2.2.6 Calibration System

This element includes labor and material for design, inspection, procurement, and assembly of the calibration system for the FCAL modules. This element shows a sum for sub WBS elements from WBS 20.05.2.2.6.1 through WBS 20.05.2.2.6.2.2

20.05.2.2.6.1 Calibration Assembly (Reserved)

This element includes labor and material for assembling calibration systems for both FCAL modules.

20.05.2.2.6.2 Calibration System Components

This element includes labor and material for design, inspection, procurement, and assembly of the calibration system components. This element shows a sum for sub WBS elements from WBS 20.05.2.2.6.2.1 through WBS 20.05.2.2.6.2.2.

20.05.2.2.6.2.1 Calibration Drive Assembly

This element includes labor and material for design, inspection and procurement of the calibration drive system.

20.05.2.2.6.2.2 Calibration System Electronics

This element includes labor and material for design, inspection and procurement of the calibration system electronics.

20.05.3. FCAL Module

This element includes labor and material for engineering, design, inspection, administration procurement and assembly of two FCAL modules. This element shows a sum of sub WBS elements from WBS 20.05.3.1 through WBS 20.05.3.3.2.2.2.6.

20.05.3.1 Assembly

This element includes labor and material for assembling the scintillating and readout sections together.

20.05.3.2 Scintillator Section

This element includes labor and material for engineering, design, inspection, administration, procurement and assembly of the scintillator section. This element shows a sum for sub WBS elements from WBS 20.05.3.2.1 through WBS 20.05.3.2.2.6.2.

20.05.3.2.1 Scintillator Section Assembly

This element includes labor and material for assembling the scintillator section.

20.05.3.2.2 Scintillator Section Material and Components

This element includes labor and material for design, inspection and procurement of the all material and components for the scintillator section. This element shows a sum of sub WBS elements from WBS 20.05.3.2.2.1 through WBS 20.05.3.2.2.6.2.

20.05.3.2.2.1 Tungsten Heavymet Absorber

This element includes labor and material for design, inspection and procurement of the tungsten absorber pellets.

20.05.3.2.2.2 Copper Capillary Tubing

This element includes labor and material for preparation for specification, inspection and procurement of the copper capillary tubes

20.05.3.2.2.3 Glass Capillary Tubing

This element includes labor and material for preparation for specification, inspection and procurement of the glass capillary tubes

20.05.3.2.2.4 Stainless Steel End Plates for Manifolds

This element includes labor and material for design, inspection and procurement of the four stainless steel end plates for scintillating sections.

20.05.3.2.2.5 Stainless Steel Jackets (Shell)

This element includes labor and material for design, inspection and procurement of the two stainless steel shell jackets for scintillator section.

20.05.3.2.2.6 Outlet Manifold Flange Assembly

This element includes labor and material for design, inspection and procurement of the four stainless steel head assembly for manifolds. This element shows a sum of sub WBS elements from WBS 20.05.3.2.2.6.1 through WBS 20.05.3.2.2.6.2.

20.05.3.2.2.6.1 Stainless Steel Heads for Manifolds

This element includes labor and material for design, inspection and procurement of the four stainless steel heads for manifolds.

20.05.3.2.2.6.2 Fused Quartz Window and Flange

This element includes labor and material for design, inspection and procurement of the fused quartz windows and flanges for discharge manifolds.

20.05.3.3 Readout Section

This element includes labor and material for engineering, design, inspection, administration, procurement and assembly of the readout section. This element shows a sum of sub WBS elements from WBS 20.05.3.3.1 through WBS 20.05.3.3.2.2.2.6.

20.05.3.3.1 Readout Section Assembly

This element includes labor and material for assembling the readout section.

20.05.3.3.2 Readout Section Material and Components

This element includes labor and material for design, inspection and procurement of the all material and components for the readout section. This element shows a sum of sub WBS elements from WBS 20.05.3.3.2.1 through WBS 20.05.3.3.2.2.2.2.6.

20.05.3.3.2.1 Readout Fiber Assembly

This element includes labor and material for design, inspection and procurement of the readout fiber assembly. This element shows a sum of sub WBS elements from WBS 20.05.3.3.2.1.1 through WBS 20.05.3.3.2.1.2.

20.05.3.3.2.1.1 Readout Fibers

This element includes labor and material for preparation of specification, inspection and procurement of the quartz transmission fibers.

20.05.3.3.2.1.2 Optical Fiber Collector Plate

This element includes labor and material for design, inspection and procurement of the collector plates for the optical fibers.

20.05.3.3.2.2 Photomultiplier Tube (PMT) Assemblies

This element includes labor and material for design, inspection and procurement of the PMT assembly components. This element shows a sum for sub WBS elements from WBS 20.05.3.3.2.2.1 through WBS 20.05.3.3.2.2.2.6.

20.05.3.3.2.2.1 Photomultiplier Tubes (PMT's)

This element includes labor and material for preparation of specification, inspection and procurement of the PMT's

20.05.3.3.2.2.2 PMT Accessory Components

This element includes labor and material for design, inspection and procurement of the PMT assembly accessories. This element shows a sum for sub WBS elements from WBS 20.05.3.3.2.2.2.1 through WBS 20.05.3.3.2.2.2.6.

20.05.3.3.2.2.2.1 PMT Compartments

This element includes labor and material for design, inspection and procurement of the PMT compartments.

20.05.3.3.2.2.2.2 Light Mixers

This element includes labor and material for design, inspection and procurement of the light mixers.

20.05.3.3.2.2.2.3 PMT Base

This element includes labor and material for design, inspection and procurement of the PMT bases.

20.05.3.3.2.2.2.4 High Voltage Power Supply and Cabling

This element includes labor and material for design, inspection and procurement of the high voltage power supply and cabling.

20.05.3.3.2.2.2.5 Preamplifications

This element includes labor and material for design, inspection and procurement of preamplifications.

20.05.3.3.2.2.2.6 Fasteners

This element includes labor and material for preparation of specification, inspection and procurement of fasteners.

20.06 Passive Absorber

This element includes labor and material required for the passive absorber. This element shows a sum of sub WBS elements from WBS 20.6. through WBS 20.6.2.2.2.3.

20.06.1 Assembly

This element includes effort required for EDIA, material, and assembly of the passive absorber. This element shows a sum of sub WBS elements from WBS 20.6.1.1 through WBS 20.6.1.3.3.

20.06.1.1 Assembly North Endcap

The element includes effort required for EDIA, material and assembly of north end cap.

20.06.1.2 Assembly South Endcap

The element includes effort required for EDIA, material and assembly of south end cap.

20.06.1.3 Assembly Equipment

This element includes labor and material required for EDIA and procurement of equipment for end cap assembly. This element shows a sum of sub WBS elements from WBS 20.6.1.3.1. through WBS 20.6.1.3.3.

20.06.1.3.1 Assembly Stand

This element includes labor and material required for EDIA and procurement of assembly stand to be used for assembly of the end caps.

20.06.1.3.2 Plate Fixturing

This element includes labor and material required for EDIA and procurement of plate fixturing to be used for assembly of the end caps.

20.06.1.3.3 Personnel Platforms

This element includes labor and material required for EDIA and procurement of personnel platforms to be used for assembly of the end caps.

20.06.2 Components

This element includes labor and material required for EDIA, material, and assembly of the passive absorber. This element shows a sum of sub WBS elements from WBS 20.6.2.1. through WBS 20.6.2.2.2.3.

20.06.2.1 North Endcap

This element includes effort required for EDIA, material, and assembly of the passive absorber. This element shows a sum of sub WBS elements from WBS 20.6.2.1.1. through WBS 20.6.2.1.2.3.

20.06.2.1.1 Absorber Plates

This element includes effort required for EDIA, material, and assembly of the absorber plates. This element shows a sum of sub WBS elements from WBS 20.6.2.1.1.1. through WBS 20.6.2.1.1.2.

20.06.2.1.1.1 Material

This element includes effort required for design, inspection and procurement of the endcap absorber plate material.

20.06.2.1.1.2 Absorber Plate Manufacture

This element includes labor and material required for EDIA & manufacture of north endcap absorber plates.

20.06.2.1.2 Center Tube

This element includes effort required for EDIA, material, and assembly of the center tube. This element shows a sum of sub WBS elements from WBS 20.6.2.1.2.1. through WBS 20.6.2.1.2.2.

20.06.2.1.2.1 Endcap Absorber Center Tube Material

This element includes effort required for design, inspection and procurement of the end cap absorber center tube material.

20.06.2.1.2.2 Center Tube Manufacture

This element includes labor and material required for EDIA and manufacture of the center tube.

20.06.2.1.2.3 Fasteners

This element includes labor and material required for EDIA and procurement of the fastener for assembly of north end cap.

20.06.2.2 South Endcap

This element includes effort required for EDIA, material, and assembly of the passive absorber. This element shows a sum of sub WBS elements from WBS 20.6.2.2.1. through WBS 20.6.2.2.2.3.

20.06.2.2.1 Absorber Plates

This element includes effort required for EDIA, material, and assembly of the south end cap absorber plates. This element shows a sum of sub WBS elements from WBS 20.6.2.2.1.1. through WBS 20.6.2.2.1.2.

20.06.2.2.1.1 Endcap Absorber Plate Material

This element includes effort required for design, inspection and procurement of the end cap absorber plate material.

20.06.2.2.1.2 Absorber Plate Manufacture

This element includes labor and material required for EDIA & manufacture of south end cap absorber plates.

20.06.2.2.2 Center Tube

This element includes effort required for EDIA, material, and assembly of the center tube. This element shows a sum of sub WBS elements from WBS 20.6.2.2.2.1. through WBS 20.6.2.2.2.2.

20.06.2.2.2.1 Endcap Absorber Center Tube Material

This element includes effort required for design, inspection and procurement of the end cap absorber center tube material.

20.06.2.2.2.2 Center Tube Manufacture

This element includes effort required for EDIA and manufacture of the center tube.

20.06.2.2.2.3 Fasteners

This element includes labor and material required for EDIA and procurement of the fastener for assembly of south end cap.

20.07 Vacuum

This element includes effort for design/engineering, fabrication, procurement, inspection and assembly of the vacuum system in the calorimeter. This element shows a sum of sub WBS 20.07.1 through WBS 20.07.3.4.

20.07.1 Assembly

This element includes engineering/design and inspection labor required for equipment design, fabrication and assembly of the calorimeter vacuum system. Task included in this WBS level are the design specification, inspection service, and assembly of vacuum diffusion pump with traps, gauges, valves, controllers and associated components.

20.07.2 Vacuum Equipment

This element includes effort required for vacuum equipment specification, design, procurement and inspection service. This element shows a sum of sub WBS 20.07.2.1 through WBS 20.07.2.5.2.

20.07.2.1 Assembly

This element includes engineering/design and inspection labor required for vacuum equipment design, fabrication and assembly of vacuum system for the calorimeter.

20.07.2.2 Roughing Pumps

This element includes effort required for roughing pump specification, procurement and inspection service.

20.07.2.3 Diffusion Pumps

This element includes effort for design, specification, procurement, and inspection service for diffusion pumps assembly. This element shows a sum of sub WBS 20.07.2.3.1 through WBS 20.07.2.3.6.

20.07.2.3.1 Assembly

This element includes engineering/design, and inspection labor required for the diffusion pumps assembly which will be used to the calorimeter vacuum system. Task included in this WBS level are design specification, inspection service and assembly for diffusion pump, cold trap, gauge, controller and associated components.

20.07.2.3.2 Reserved

20.07.2.3.3 Nitrogen Cold Trap and Diffusion Pumps

This element includes effort required for design, procurement and inspection service for the nitrogen cold trap and the diffusion pumps which will be used in the calorimeter vacuum system.

20.07.2.3.4 Pirari Gauge Heads

This element includes effort for pirari gauge specification, procurement and inspection service.

20.07.2.3.5 Penning Gauge Heads

This element includes effort for design specification, procurement, and inspection service for the Penning gauge heads which will be used to diffusion pumps assembly.

20.07.2.3.6 Controllers

This element includes effort for design specification, procurement and inspection service for gauge and diffusion pump controller which will be used to the diffusion pump assembly in the calorimeter vacuum system.

20.07.2.4 Vacuum Lines

This element includes effort for design/engineering, fabrication, procurement and inspection service for the calorimeter vacuum lines.

20.07.2.5 Valves

This element includes effort for design specification, fabrication, procurement and inspection service for the vacuum line valves. This element shows a sum of sub WBS 20.07.2.5.1 through WBS 20.07.2.5.2.

20.07.2.5.1 Backing and Roughing

This element includes effort for design specification, fabrication, procurement and inspection service for the backing valves and the roughing valves which will be used in the calorimeter vacuum lines.

20.07.2.5.2 Main Isolation

This element includes effort for design specification, fabrication, procurement and inspection service for the main isolation valve in the calorimeter vacuum lines.

20.07.3 Decontamination Equipment

This element includes effort for design/engineering, fabrication, procurement and inspection service for the decontamination equipment which will be used to the vacuum lines. This element shows a sum of sub WBS 20.07.3.1 through WBS 20.07.3.4.

20.07.3.1 Reserved

20.07.3.2 Vacuum Pumps

This element includes effort for design/engineering, procurement and inspection service for the vacuum pump which will be used to the decontamination equipment.

20.07.3.2.1 Controllers

This element includes effort for design specification, procurement and inspection service for the pump controller and the decontamination equipment controller.

20.07.3.3 Reserved

20.07.3.4 Valves

This element includes effort for design specification, fabrication, procurement and inspection service for the valves which will be used to the decontamination equipment.

20.08 Cryogenics System Design

This element includes engineering and design labor required for systems design of the liquid argon, liquid nitrogen, and liquid krypton cryogen systems for the calorimeter. Tasks included in this WBS level are the design, document preparation, and design reviews for bulk LAR storage, recondenser coils, cryogenic pumps, vaporizers, krypton purification system, argon and krypton purge systems, inline analytical systems, head dewars, transfer piping, valves, and other associated components. Design of the bulk LN2 storage for the detector is NOT included in this WBS, as it is covered under the magnet subsystem WBS. However a small liquid nitrogen surge vessel is included in the WBS in the LIN pumping system.

20.08.1 Assembly

This element includes engineering /design, inspection, and assembly labor required for equipment design, fabrication, and assembly/installation of the above-ground portions of the liquid argon, liquid nitrogen, and liquid krypton cryogen systems for the calorimeter. Tasks included in this WBS level are the design specifications, inspection services, and assembly of bulk LAR storage, recondenser coil, krypton purification system, argon and krypton purge systems, inline analytical systems, transfer piping, valves, and other associated components. The bulk LN2 storage for the detector is NOT included in this WBS, as it is covered under the magnet subsystem WBS.

20.08.2 Surface Storage

This element is a rollup that includes all labor and materials required for above-ground and utility shaft portions of the liquid argon, liquid nitrogen, and liquid krypton cryogen systems for the calorimeter.

20.08.2.1 Assembly

This element includes engineering/design, inspection, and assembly labor required for equipment design, fabrication, and assembly/installation of the above ground portions of the liquid argon, liquid nitrogen, and liquid krypton cryogen systems for the calorimeter. Tasks included in this WBS level are the design specifications, inspection services, and assembly of bulk LAR storage, recondenser coil, krypton purification system, argon and krypton purge systems, inline analytical systems, transfer piping, valves, and other associated components. The bulk LN2 storage for the detector is NOT included in this WBS, as it is covered under the magnet subsystem WBS.

20.08.2.2 Liquid Argon

This element includes one each, 60,000 liter horizontal vacuum-jacketed liquid argon storage tank. Standard design features of integral pressure-build, fill, vent systems, non-electropolished stainless steel inner vessel, bellows seal valves, etc. - but also special modifications including recondensor coil and vacuum-jacketed penetrations. Includes shipping, rigging, and reinforced concrete pad.

20.08.2.3 Liquid Krypton (Reserved)

Discussions with krypton vendors indicate that surface storage would be provided as a part of the purchase. Therefore, the large surface storage dewar for liquid krypton is eliminated from the scope of this estimate.

20.08.2.4 Nitrogen (Reserved)

In the interest of economy, bulk liquid nitrogen storage for all detector subsystems was consolidated into one large 600,000 liter vessel within WBS 40.02.5.1.1 of the magnet subsystem. The nitrogen storage vessel for the calorimeter was eliminated in that consolidation.

20.08.2.5 Krypton Purification Pump and Purge

This element includes one each, high temperature metal gettering type purifier to purify krypton to levels of less than 1ppm electronegative impurities. It is assumed that warm purification will be done on the surface in a non-radiation shielded structure, so gaseous purification can only be done in batches after krypton radiation levels have decayed to a safe level.

20.08.2.6 Transfer System

This element includes procured equipment and materials required for fabrication of the utility shaft transfer line sections of the liquid argon, liquid nitrogen, and liquid krypton cryogen systems for the calorimeter. Included in this WBS level are:

HP Liquid Nitrogen Supply Line, 50mm ID x 100mm OD VJ Line, 60m long
LP Argon Vapor Offload /Vent Line, 50mm ID x 100mm OD VJ Line, 75m long
Coaxial Krypton Purifier Supply/Return Line, 25/50mm ID x 125mm OD, 72m long
LP KryptonVapor Offload /Vent Line, 50mm ID x 100mm OD VJ Line, 60m long
LP Liquid Krypton Supply Line, 50mm ID x 100mm OD VJ Line, 60m long
LP Liquid Argon Supply Line, 50mm ID x 100mm OD VJ Line, 75m long
Four (4) Multipass Expansion Cans

The system subassemblies are assumed to be procured from industry and assembled onsite by a cryo installation crew. Installation materials are included in assembly section WBS 20.08.2.1.

20.08.2.7 Surface Transfer Lines

This element includes procured equipment and materials required for fabrication of the surface transfer line sections of the liquid argon, liquid nitrogen, and liquid krypton cryogen systems for the calorimeter. Equipment included in this WBS level are :

Liquid Nitrogen Supply Line to Pumps, 50mm ID x 100mm OD VJ Line, 35 m long
HP LIN Supply Line from Pumps to Shaft, 50mm ID x 100mm OD VJ Line, 20 m long
LIN Recycle Line from Pumps to Storage, 50mm ID x 100mm OD VJ Line, 35 m long
Liquid Nitrogen Supply Line to Argon Storage Condenser, 25mm ID x 75mm OD VJ Line, 15 m lg.
LP Argon Vapor Offload /Vent Line, 50mm ID x 100mm OD VJ Line, 45m long
LP Liquid Argon Supply Line, 50mm ID x 100mm OD VJ Line, 45m long
Coaxial Krypton Purifier Supply/Return Line, 25/50mm ID x 125mm OD, 20m long
LP KryptonVapor Offload /Vent Line, 50mm ID x 100mm OD VJ Line, 45m long
LP Liquid Krypton Trailer Unloading Line, 50mm ID x 100mm OD VJ Line, 45m long
LP Liquid Argon Trailer Unloading Line, 50mm ID x 100mm OD VJ Line, 5m long
Two (2) Expansion/Connection Cans

The system subassemblies will be procured from industry and assembled onsite by a cryo installation crew. Installation materials are included in assembly section WBS 20.08.2.1.

20.08.2.8 Surface Valves

This element includes 20 each, 2 inch vacuum-jacketed cryogenic valves, standard commercially available design. Includes operators; 13 each, warm valves, standard commercially available design. Includes operators; 13 each, safety relief valves, 2 inch; 1 each rupture disc

20.08.3 Hall Storage

This element is a rollup that includes all labor and materials required for detector hall portions of the liquid argon, liquid nitrogen, and liquid krypton cryogen systems for the calorimeter.

20.08.3.1 Assembly

This element includes engineering, design, and inspection labor required for equipment design, fabrication, and assembly of the below-ground portions of the liquid argon, liquid nitrogen, and liquid krypton cryogen systems for the calorimeter. Tasks included in this WBS level are the design specifications, inspection services, and assembly of hall LAR and LKr storage vessels, recondenser coils, head dewars, cryogenic pumps, LN2 buffer vessel, vaporizers, transfer piping, valves, and other associated components.

20.08.3.2 Liquid Argon

This element includes two each, 20,000 liter vertical vacuum-jacketed liquid argon storage tank with special modifications, including recondensor coil, rad hard materials and components and vacuum-jacketed penetrations.

20.08.3.3 Liquid Krypton

This element includes one each, 30,000 liter vertical vacuum-jacketed liquid krypton storage tank with special modifications, including recondensor coil, rad hard materials and components, and vacuum-jacketed penetrations.

20.08.3.4 Nitrogen (Reserved)

The coolant for the noble liquid calorimeter was changed from liquid nitrogen to liquid argon, eliminating the need for in-hall nitrogen storage.

20.08.3.5 Hall Transfer Lines

This element includes procured equipment and materials required for fabrication of the detector hall transfer line sections of the liquid argon, liquid nitrogen, and liquid krypton cryogen systems for the calorimeter. Equipment included in this WBS level are:

HP Liquid Nitrogen Distribution Line, 50mm ID x 100mm OD VJ Line, 95m long

Ntrogen Vapor Vent Header, 100mm ID x 150mm OD VJ Line, 110m long
LP Argon Vapor Offload /Vent Line, 50mm ID x 100mm OD VJ Line, 75m long
Coaxial Krypton Purifier Supply/Return Line, 25/50mm ID x 125mm OD, 20m long
LP KryptonVapor Offload /Vent Line, 50mm ID x 100mm OD VJ Line, 31m long
LP Liquid Krypton Supply Line, 50mm ID x 100mm OD VJ Line, 45m long
LP Liquid Argon Supply Line, 50mm ID x 100mm OD VJ Line, 80m long
HP Liquid Argon Intercooling Line, 50mm ID x 100mm OD VJ Line, 110m long
Emergency Cryogen Dump Line, 100mm ID x 150mm OD line, 45 m long
Five (5) distribution/expansion cans

The system subassemblies will be procured from industry and assembled onsite by a cryo installation crew. Installation materials are included in assembly section WBS 20.08.2.1.

20.08.3.6 Hall Valves

This element includes 98 each, 2 inch vacuum-jacketed cryogenic valves, standard commercially available design. Includes operators; 63 each, safety relief valves, 2 inch; 14 each, rupture disc; 8 each, three-way diverter valves. Spares 5% of total valve cost.

20.08.4 Vaporizers

This element is a rollup that includes equipment and materials required for vaporizing and warm-up equipment for the liquid argon, liquid nitrogen, and liquid krypton cryogen systems for the calorimeter.

20.08.4.1 Reserved

20.08.4.2 Nitrogen

This element covers the cost of cryogenic vaporizers/superheaters and instrumentation to warm nitrogen exiting the interstage cooling systems before venting to the hall. Includes one 125 kW electric vaporizer at the exit of the vent header. Also included are ambient vaporizers for safety vent lines of argon and krypton systems

20.08.4.3 Argon

This element covers the 56" outer and 36" inner, non-vacuum jacketed duct, 124 kW electric vaporizer, separator vessel, spray nozzles, valves, electric pressure-build vaporizers, and instrumentation. The air blower is in the conventional facilities scope. Under normal operating conditions, if the ultrapure cryogens must be unloaded from the calorimeter, they are transferred by pressurizing the fluid and transferring it in the hall storage tank as the vapor generated is condensed by the condenser coil. In emergency conditions, the liquid is quickly drained and vaporized into a large coaxial vent duct, where it is warmed to ambient by the heat capacity of high flowrate air on its' way to the surface.

20.08.5 Interstage Cooling

This element is a rollup that includes equipment and materials required for liquid nitrogen refrigeration of the storage vessel condensers and coolant systems for the calorimeter.

20.08.5.1 Reserved

20.08.5.2 Argon

This element covers the argon high pressure coolant system, including vacuum jacketed centrifugal circulating pumps, motor starters and controls, nitrogen-argon heat exchanger and vessel, temperature control heater, and instrumentation. Under the present baseline, the barrel calorimeter must be designed to use either argon or krypton as the noble liquid. To accomplish this, a separate cooling loop must be provided to accommodate the different temperature requirements between the barrel and the endcaps.

20.08.5.3 Krypton (Reserved)

The most recent design for the calorimeter calls for using liquid argon coolant for both the argon and krypton systems. Therefore, this section does not apply.

20.08.5.4 Nitrogen

This element includes three reciprocating cryogenic liquid pumps, motor starters, and associated instrumentation. Condensers and heat exchangers are covered in the vessel WBS sections. Refrigeration for the argon coolant loop and storage dewar condensers is provided by a high pressure liquid nitrogen distribution header.

20.08.6 Liquid Krypton

Covers liquid krypton to fill calorimeter and storage systems. 23,796 liters of ultrapure liquid krypton.

20.08.7 Liquid Argon

Covers argon and other utility gases consumed before detector is on-line. 126,048 liters of ultrapure liquid argon, delivered to site. 450,268 liters of standard purity nitrogen. 1,755 liquid liter equivalents of liquid helium for purging. Transfer losses will be borne by the vendor

20.09 Instrumentation, Power and Operational Control

This element includes the effort to design, specify, integrate, install and test operational control system, instrumentation and power system for the cryogenics, vacuum, and monitoring and control systems of the calorimeter. Integrate the control and interring system into the global GEM control system.

20.09.1 Power Distribution and UPS System

This element includes all effort to design, develop, install, and test the power distribution system necessary for the operation of the cryogenics system. The control room in the utility building will be provided with a standby/backup power source and a 15 kVA UPS system for critical control functions.

20.09.2 Control and Monitor System

This element includes the effort to design, specify, integrate, install and test the monitoring and control system for the calorimeter cryogenics, vacuum and monitoring subsystems. This element also includes the engineering, installation and testing effort for the control and monitoring system integrated to provide field interface panels where all sensor and control components are terminated.

20.09.2.1 Control System Hardware

This element includes the effort to procure and fabricate the hardware necessary for the monitoring and control system. This includes the hardware from pre-installed field I/O racks to and including the monitoring and control data acquisition and control system.

20.09.2.2 Control System Software

This element includes the effort to design, code and test the control software for the monitoring and control system.

20.09.2.3 Global Integration

This element includes the effort to define interfaces and integrate the controls for the vacuum, cryogenics and power systems monitoring and control with the GEM global controls. Provide the engineering, hardware, software, integration and testing required to integrate the monitoring and control system with the GEM global controls.

20.10 Final Assembly

This element includes labor and material for final assembly design, final assembly operations, and testing of two or more major components of each subsystem and two or more subsystems within the calorimeter which was not accomplished as part of the assembly of the individual components or subsystems and which is accomplished prior to installation in the experiment hall or within the surface facilities at the IR-5 site. It includes the design, fabrication, and assembly of all tooling and handling equipment required to accomplish the assembly operation.

20.10.1 Calorimeter Assembly Equipment

This element includes the labor and material for the final assembly design, assembly operations, and testing of two or more calorimeter subsystems prior to installation. This element includes the design, fabrication, and assembly of all tooling and handling equipment required to accomplish the final assembly operations.

20.10.2 Calorimetry Final Assembly

This element includes the labor and material for the final assembly design, assembly operations, and testing of two or more calorimetry subsystems prior to installation. This element includes the design, fabrication, and assembly of all tooling and handling equipment required to accomplish the final assembly operations.

20.10.2.1 Inner Barrel and Endcap Calorimeter

This element includes the labor and material for the final assembly of the inner barrel and endcaps.

20.10.2.2 Scintillating Hadron

This element includes the effort required for EDIA, material, and final assembly of the scintillating hadron barrel calorimeter.

20.10.2.2.1 Labor

This element includes the effort required for EDIA, material and final assembly of the scintillating hadron barrel calorimeter.

20.10.2.3 EM FCAL

This element includes labor and material for engineering, design, inspection, administration, and final assembly of the EM forward calorimeter. It includes cabling from the EM interconnect boards to the cryostat feedthroughs.

20.10.2.3.1 Labor

This element includes the effort required to assemble the forward EM modules into the endcap cryostat.

20.10.2.3.2 Lifting Fixture

This element includes the labor and material for the fixture required to lift the forward EM module and place it into the endcap assembly.

20.10.2.4 Hadronic FCAL

This element includes labor and material for engineering, design, inspection, administration, procurement and assembly of 2 forward calorimeters into the passive absorber endcap. This element shows a sum of sub WBS elements from WBS 20.10.2.4.1 through WBS 20.10.2.4.2.2.

20.10.2.4.1 Labor

This element includes labor and material for assembling forward calorimeters into the passive absorber endcaps.

20.10.2.4.2 Equipment

This element includes labor and material for design, inspection and procurement of equipment necessary for assembly of the scintillating forward calorimeters into the passive absorber endcaps. This element shows a sum of sub WBS elements from WBS 20.10.2.4.2.1. through WBS 20.10.2.4.2.2.

20.10.2.4.2.1 Temporary Bracing

This element includes labor and material for design, inspection and procurement of temporary bracing for assembly of the scintillating forward calorimeters into the passive absorber endcaps.

20.10.2.4.2.2 Crane Rental

This element includes labor and material for preparation of specification, inspection and procurement of a crane for assembly of the scintillating forward calorimeters into the passive absorber endcaps.

20.10.3 Reserved

20.10.4 Reserved

20.10.5 Reserved

20.10.6 Reserved

20.11 Hall Installation

This element includes labor and material for installation of major subsystems into detector support structures in underground hall.

20.11.1 Hall Installation Equipment

This element includes the equipment necessary during the installation of the calorimeter into the hall.

20.11.2 Calorimetry

This element includes labor and material for hall installation of the calorimeters.

20.11.2.1 Inner Barrel and Endcap Calorimeter

This element includes the labor and material for the hall installation of the inner barrel and endcap calorimeters.

20.11.2.2 Scintillating Hadron

This element includes labor and material for engineering, design, inspection, administration, assembly and installation of scintillating hadron barrel calorimeter. This element shows a sum of sub WBS elements from WBS 20.11.2.2.1 through WBS 20.11.2.2.2.4.

20.11.2.2.1 Labor

This element includes labor and material for engineering, design, inspection, administration, and installation of scintillating hadron barrel calorimeter in the hall.

20.11.2.2.2 Equipment

This element includes labor and material for engineering, design, inspection, administration and procurement of equipment for scintillating hadron barrel calorimeter installation in the hall. This element shows a sum of sub WBS elements from WBS 20.11.2.2.2.1 through WBS 20.11.2.2.2.4.

20.11.2.2.2.1 Temporary Bracing

This element includes the effort required for EDIA and procurement of the temporary bracing to be used for installation of the scintillating hadron barrel calorimeter in the hall.

20.11.2.2.2.2 Crane Rental

This element includes the effort required for EDIA and procurement of a rental crane to be used for installation of the scintillating hadron barrel calorimeter in the hall.

20.11.2.2.2.3 Endcap Outriggers

This element includes the effort required for EDIA and procurement of the endcap outrigger to be used for installation of the scintillating hadron barrel calorimeter in the hall.

20.11.2.2.2.4 Rollers

This element includes the effort required for EDIA and procurement of the rollers to be used for installation of the scintillating hadron barrel calorimeter in the hall.

20.11.2.3 EM Forward Calorimeter

This element includes the effort for the inspection of the EM cabling exterior to the cryostat after installation of the endcap.

20.11.2.3.1 Labor

This element includes the effort required for EM FCAL hall installation.

20.11.2.3.2 Material

This element includes the materials and components required for EM FCAL hall installation.

20.11.2.4 Scintillating Liquid FCAL

This element includes labor and material for engineering, design, inspection, administration, procurement, assembly and installation of auxiliary systems for two forward calorimeters This element shows a sum of sub WBS elements from WBS 20.11.2.4.1 through WBS 20.11.2.4.2.2.

20.11.2.4.1 Liquid Handling System

This element includes labor and material for engineering, design, inspection, administration, procurement, assembly and installation of liquid handling systems for two forward calorimeters . This element shows a sum of sub WBS elements from WBS 20.11.2.4.1.1 through WBS 20.11.2.4.1.2.5.

20.11.2.4.1.1 Liquid Handling System Assembly and Installation

This element includes labor and material for assembling and installing forward calorimeter auxiliary systems in the hall.

20.11.2.4.1.2 Liquid Handling System Components

This element includes labor and material for engineering, design, inspection, administration and procurement of liquid handling systems components for two forward calorimeters. This element shows a sum of sub WBS elements from WBS 20.11.2.4.1.2.1 through WBS 20.11.2.4.1.2.5.

20.11.2.4.1.2.1 Piping and Valves in Liquid Handling System

This element includes labor and material for engineering, design, inspection, administration and procurement of liquid handling system piping and valves for two forward calorimeters in the hall.

20.11.2.4.1.2.2 Filtration and Purification in Liquid Handling System

This element includes labor and material for engineering, design, inspection, administration and procurement of filtration and purification for two forward calorimeters in the hall.

20.11.2.4.1.2.3 Storage Tank and Monitoring Equipment in Liquid Handling System

This element includes labor and material for engineering, design, inspection, administration and procurement of storage tank and monitoring equipment in liquid handling system in the hall.

20.11.2.4.1.2.4 Liquid Circulating Pumps in Liquid Handling System

This element includes labor and material for engineering, design, inspection, administration and procurement of two liquid circulating pumps in liquid handling system in the hall.

20.11.2.4.1.2.5 Scintillating Liquid

This element includes labor and material for engineering, design, inspection, administration and procurement of scintillating liquid for the forward calorimeter systems.

20.11.2.4.2 Readout Thermal Control

This element includes labor and material for engineering, design, inspection, administration, procurement and installation of thermal system for two forward calorimeters in the hall. This element shows a sum of sub WBS elements from WBS 20.11.2.4.2.1 through WBS 20.11.2.4.2.2

20.11.2.4.2.1 Thermal Control System Assembly and Installation

This element includes labor and material for installing readout section thermal control systems in the hall.

20.11.2.4.2.2 Air Duct for Thermal Control System

This element includes labor and material for design, inspection, and procurement of air duct for readout section thermal control system.

20.11.3 Passive Endcap Installation

This element includes labor and material for engineering, design, inspection, administration, assembly and installation of the passive endcap in the hall. This element shows a sum of sub WBS elements from WBS 20.11.3.1 through WBS 20.11.3.2.4.

20.11.3.1 Labor

This element includes labor and material for engineering, design, inspection, administration, and installation of the passive end cap in the hall.

20.11.3.2 Installation Equipment

This element includes labor and material for engineering, design, inspection, administration and procurement of equipment for the passive endcap installation in the hall. This element shows a sum of sub WBS elements from WBS 20.11.3.2.1 through WBS 20.11.3.2.4.

20.11.3.2.1 Temporary Bracing

This element includes labor and material for engineering, design, inspection, administration and procurement of temporary bracing to be used for installation of the passive endcaps in the hall.

20.11.3.2.2 Crane Rental

This element includes labor and material for engineering, design, inspection, administration and procurement of a rental crane to be used for installation of the passive endcaps in the hall.

20.11.3.2.3 Endcap Outriggers

This element includes labor and material for engineering, design, inspection, administration, and procurement of endcap outriggers to be used for installation of the passive endcaps in the hall.

20.11.3.2.4 Rollers

This element includes labor and material for engineering, design, inspection, administration and procurement of rollers to be used for installation of the passive endcaps in the hall.

20.12 Calibration and Test Beam Program

This element includes labor and material for accelerator based testing of major subsystem modules for calibration purposes.

20.12.1 Inner Barrel and Endcap

This element includes the labor a material required for module calibration from initial test beam availability through beam operation.

20.12.1.1 Cryostat

This element includes the procurement costs for one barrel and one endcap cryostat used to test the modules.

20.12.1.2 Modules

This element includes procurement costs for barrel and endcap EM and Hadronic modules to be calibrated and tested. These modules are in addition to the production modules.

20.12.1.3 Electronics

This element includes the off-the-shelf electronics needed for testing the modules.

20.12.1.4 Fixtures

This element includes fixtures and 2 transporters needed for handling and holding the systems in place during testing.

20.12.1.5 Test Labor

This element is included in WBS 20.12.5.

20.12.2 Scintillating Hadron Barrel Calorimeter Test Beam

This element includes labor and material for engineering, design, inspection, administration, procurement and assembly of test beam equipment. This element shows a sum of sub WBS elements from WBS 20.12.2.1. through WBS 20.12.3.2.

20.12.2.1 Test Beam Labor

This element includes labor and material for test beam experiment coverage.

20.12.2.2 Reserved

20.12.3 EM Forward Calorimeter

This element includes the labor and material for beam testing of the EM FCAL for calibration purposes.

20.12.3.1 Reserved

20.12.3.2 Equipment

This element includes effort for the equipment required to carry out the calibration beam test.

20.12.4 Hadronic Forward Calorimeter Test Beam

This element includes labor and material for engineering, design, inspection, administration, procurement and assembly of test beam equipment. This element shows a sum of sub WBS elements from WBS 20.12.4.1. through WBS 20.12.4.2.2.

20.12.4.1 Test Beam Labor

This element includes labor and material for test beam experiment coverage.

20.12.4.2 Test Beam Equipment

This element includes labor and material for design, inspection and procurement of equipment necessary for test beam experiment of the scintillating forward calorimeters. This element shows a sum of sub WBS elements from WBS 20.12.4.2.1 through WBS 20.12.4.2.2.

20.12.4.2.1 Test Beam Test Stand

This element includes labor and material for engineering, design, inspection, procurement and assembly of test stand for hadronic forward calorimeter test beam experiment.

20.12.4.2.2 Test Beam Calibration System

This element includes labor and material for engineering, design, inspection, procurement and assembly of calibration system for hadronic forward calorimeter test beam experiment.

20.12.5 Fermilab Test Beam

This element includes the labor and material for the DAQ, data handling, the existing beam line, and testing labor to be performed at Fermilab.

20.13 Subsystem Management

This element includes the effort for management of subsystem design , construction, testing and installation.

20.13.1 Project Management and Administration

This element includes the effort for project management and administration tasks such as planning, contract administration, procurement and finance.

20.13.2 Resource Management and Travel

This element includes the effort for resource management and the travel budgets.

20.13.3 ES&H

This element includes all engineering labor to ensure current safety standards and requirements are met. ES&H effort is required both as a result of the basic engineering function and as a result of manufacturing processes.

20.13.4 Quality Assurance

This element includes the quality assurance effort necessary for the GEM calorimeter.

20.13.5 System Engineering

This element includes the following tasks: reliability, human factors, electromagnetic compatibility, mass properties, survivability requirements and systems integration. Systems engineering directly corresponds to the output generated by the design, analysis, and their supporting functions.

20.14 Conceptual and Preliminary Design

This element includes the specific design of the GEM calorimeter prior to the submittal of the TDR document.

20.14.1 Liquid Calorimetry

Need input

20.14.2 Scintillating Hadron Barrel Calorimeter Conceptual Design

This element includes labor and material for conceptual design of the scintillating hadron barrel calorimeter. This element shows a sum of sub WBS elements from WBS 20.14.2.1. through WBS 20.14.2.2.5.

20.14.2.1 Letter of Intent (LOI) Preparation

This element includes labor and material for LOI preparation for the scintillating hadron barrel calorimeter. This element shows a sum of sub WBS elements from WBS 20.14.2.1.1. through WBS 20.14.2.1.3.

20.14.2.1.1 Conceptual Design for LOI

This element includes labor and material for conceptual design of the scintillating hadron barrel calorimeter for preparation of LOI.

20.14.2.1.2 Costing Studies for LOI

This element includes labor and material for performing cost studies of the scintillating hadron barrel calorimeter for preparation of LOI.

20.14.2.1.3 Document preparation for LOI

This element includes labor and material for LOI documentation preparation for the scintillating hadron barrel calorimeter.

20.14.2.2 Preparation of Technical Proposal

This element includes labor and material for preparation of technical proposal for the hadronic forward calorimeter systems. This element shows a sum of sub WBS elements from WBS 20.14.2.2.1. through WBS 20.14.2.2.5.

20.14.2.2.1 Conceptual Design for Technical Proposal

This element includes labor and material for conceptual design of the scintillating hadron barrel calorimeters for technical proposal preparation.

20.14.2.2.2 Costing Studies for Technical Proposal

This element includes labor and material for performing cost studies of the scintillating hadron barrel calorimeter in preparation of technical proposal.

20.14.2.2.3 Manufacturing Studies for Technical Proposal

This element includes labor and material for performing manufacturing studies for the scintillating hadron barrel calorimeter for preparation of technical proposal.

20.14.2.2.4 Installation Studies for Technical Proposal

This element includes labor and material for performing installation studies for the scintillating hadron barrel calorimeter for preparation of technical proposal.

20.14.2.2.5 Document preparation for Technical Proposal

This element includes labor and material for technical proposal documentation preparation for the scintillating hadron barrel calorimeter.

20.14.3 EM Forward Calorimetry

This element includes labor and material for the EM FCAL part of the experiment conceptual design.

20.14.3.1 Preparation of Technical Proposal

This element includes the effort leading to creation of the technical design report section on the EM FCAL.

20.14.3.1.1 Conceptual Design

This element includes the effort to create fundamental components of design for the EM FCAL.

20.14.3.1.2 Costing Studies

This element includes the effort for studies to estimate costs of the EM FCAL project.

20.14.3.1.3 Manufacturing Studies

This element includes the effort for studies of manufacturing techniques and design-for-manufacture.

20.14.3.1.4 Installation Studies

This element includes the effort for studies of final assembly and hall installation procedures and feasibilities.

20.14.4 Scintillating Liquid Forward Calorimeter

This element includes labor and material for conceptual design of the forward calorimeter systems. This element shows a sum of sub WBS elements from WBS 20.14.4.1. through WBS 20.14.4.2.5.

20.14.4.1 LOI Preparation

This element includes labor and material for LOI preparation for the forward calorimeter systems. This element shows a sum of sub WBS elements from WBS 20.14.4.1.1. through WBS 20.14.4.1.3.

20.14.4.1.1 Conceptual Design for LOI

This element includes labor and material for conceptual design of the scintillating forward calorimeters in preparation of LOI.

20.14.4.1.2 Costing Studies for LOI

This element includes labor and material for performing cost studies of the scintillating forward calorimeters in preparation of LOI.

20.14.4.1.3 Document Preparation for LOI

This element includes labor and material for LOI documentation preparation for the scintillating forward calorimeters.

20.14.4.2 Preparation of Technical Proposal

This element includes labor and material for preparation of technical proposal for the hadronic forward calorimeter systems. This element shows a sum of sub WBS elements from WBS 20.14.4.2.1. through WBS 20.14.4.2.5.

20.14.4.2.1 Conceptual Design for Technical Proposal

This element includes labor and material for conceptual design of the scintillating forward calorimeters for technical proposal preparation.

20.14.4.2.2 Costing Studies for Technical Proposal

This element includes labor and material for performing cost studies of the scintillating forward calorimeters in preparation of the technical proposal.

20.14.4.2.3 Manufacturing Studies for Technical Proposal

This element includes labor and material for performing manufacturing studies for the scintillating forward calorimeters in preparation of the technical proposal.

20.14.4.2.4 Installation Studies for Technical Proposal

This element includes labor and material for performing installation studies for the scintillating forward calorimeters in preparation of the technical proposal.

20.14.4.2.5 Document Preparation for Technical Proposal

Need input

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30.01.2 Chamber Performance Evaluation 1
30.01.3 Muon Trigger 1
30.01.4 Alignment Technology 1
30.01.5 Electronics Evaluation 1
30.01.6 Simulations 1
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30.02.1.2 Off-Site 2
30.02.1.2.1 Assembly Fixturing Final Design, Machining, Assembly 2
30.02.2 Cathode Strip Chambers 2
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30.02.7.1.3 Assembly 6
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30.03 Endcap Region - CSC 6
30.03.1 Endcap Region Module Assembly 6
30.03.1.1 On-Site 6
30.03.1.1.1 Sector Storage 6
30.03.1.1.2 Test 6
30.03.1.1.3 Assembly 6
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30.03.1.2.1 Assembly Fixturing Final Design, Machining, Assembly 7
30.03.2 Cathode Strip Chambers 7
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30.03.2.1.1 Shipping 7
30.03.2.1.2 Test 7
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30.03.2.1.4 Facility Preparation 7
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30.03.2.1.6 Final Design, Drawing and Specifications Modifications 7

30.03.3 Module Support Structures 8
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30.04.1.1.1 Test 10
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30.04.1.1.3 Facility Preparation 10
30.04.1.2 Off-Site 10
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30.04.2.1.2 Mechanical Assembly 11
30.04.2.1.3 Facility Preparation 11
30.04.2.2 Off-Site 11
30.04.2.2.1 Installation Tooling Final Design, Machining, Shipping, Assembly 11

30.04.3 Global Alignment 11
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30.05.2 Resource Management 12
30.05.3 Environment, Safety and Health Assurance (ES&H) 12
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30.05.5 Subsystem Systems Integration 12
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522.5030 Muon Subsystem

This element includes effort for research and development, design, fabrication, assembly, test, and installation of the muon subsystem.

30.01 Research and Development

This element covers research and development activities associated with the GEM muon subsystem. It includes the effort to develop any technology or application of this technology required in the muon design and fabrication. This element does not include the performance of preliminary or detailed design of the muon subsystem. This effort may occur throughout the early phases of the project.

30.01.1 Develop Chamber Technologies

This element covers all activities for developing the various chamber technologies (CSC, RDT, RPC).

30.01.2 Chamber Performance Evaluation

This element covers all activities for evaluating the performance of the chambers.

30.01.3 Muon Trigger

This element covers all activities for developing the muon trigger requirements and specifications.

30.01.4 Alignment Technology

This element covers all activities for developing the local and global alignments requirements and specifications.

30.01.5 Electronics Evaluation

This element covers all activities for evaluating the electronics requirements and specifications.

30.01.6 Simulations

This element covers all activities for simulating the muon subsystem performance.

30.01.7 Individual Chamber Design and Factory Layout

Need input

30.01.8 Engineering (Structures, Costs, etc.)

This element covers all activities for determining the requirements, specifications, costs and schedules.

30.02 Barrel Region

This element includes effort for fabrication, assembly and test of the barrel chambers, support structure, gas system, cooling system and local alignment.

30.02.1 Barrel Region Module Assembly

This element includes effort for final design of modules/monolith, facility preparation, assembly, test and storage of the 24 barrel chamber modules which becomes two monoliths.

30.02.1.1 On-Site

This element includes all of the activities to be performed on site for the assembly of the barrel region modules of the muon subsystem.

30.02.1.1.1 Module Storage

This element covers the effort for storing the assembled sectors of the modules in the barrel region.

30.02.1.1.2 Test

This element covers the effort for testing the individual sectors. It includes performing sector-level checks, gas leak-check/pressure checks, chamber alignment.

30.02.1.1.3 Assembly

This element covers the effort for the assembly of the individual sectors. It includes the assembly of support structures, mounting 832 LSDT's/PDT's and RPC's to the assembled support structure, mounting sector-level gas and cooling systems hardware, mounting/harnessing sector-level electronics.

30.02.1.1.4 Facility Preparation

This element covers the activity for the preparation of the Superconducting Super Collider (SSC) facility, to support the assembly of the individual sectors.

30.02.1.2 Off-Site

This element includes the activity to be performed off-site for the barrel region modules of the muon subsystem.

30.02.1.2.1 Assembly Fixturing Final Design, Machining, Assembly

This element covers the labor and material for completing the final design of the sector assembly fixturing, modifying and generating drawings and specifications, and the machining and assembly of the fixturing.

30.02.2 Cathode Strip Chambers

This element includes labor and material for final design of the barrel chambers, facility preparation, fabrication, assembly, testing and shipping of chambers to site.

30.02.2.1 Off-Site

This element includes the activity to be performed off-site for the cathode strip chambers of the barrel region modules for the muon subsystem.

30.02.2.1.1 Shipping

This element covers the effort for packaging and shipping the assembled CSC's.

30.02.2.1.2 Test

This element covers the effort for testing the CSC's during and after assembly.

30.02.2.1.3 Assembly

This element covers the labor and material for the assembly of the CSC chambers .

30.02.2.1.4 Facility Preparation

This element covers the activity for preparing CSC chamber assembly off-site facility for assembly/test, etc., for the CSC chambers.

30.02.2.1.5 Machining and Inspection

This element covers the labor and material for the machining and inspection of CSC's and assembly fixturing. It includes the oversight and purchasing of stock and material for machining.

30.02.2.1.6 Final Design, Drawing and Specification Modifications

This element covers the activity for completing the final design of the CSC chambers and chamber assembly fixturing, and modifying and generating drawings and specifications.

30.02.3 Module Support Structures

This element includes labor and material for final design, fabrication of structure components and shipping to site.

30.02.3.1 Off-Site

This element covers the activity to be performed off-site for the module support structures of the barrel region for the muon subsystem.

30.02.3.1.1 Shipping

This element covers the effort for packaging, storage and shipping oversight of the assembled support structures.

30.02.3.1.2 Machining and Inspection

This element covers the labor and material for the machining and inspection of structure components. It includes the oversight for purchasing stock and material for machining.

30.02.3.1.3 Final Design, Drawing and Specification Modifications

This element covers the activity for finalizing the support structure design, modifying existing drawings and test/assembly specifications, and the generation of new drawings and specifications.

30.02.4 Reserved

30.02.5 Gas Systems

This element includes labor and material for final design, test, safety and maintenance procedure development, procurement of surface and hall system component, and assembly and testing of the gas system.

30.02.5.1 Off-Site

This element covers the activity to be performed off-site for the barrel region gas systems for the muon subsystem.

30.02.5.1.1 Design and Drawing Development

This element covers the activity to design the inter-connection system of the CSC chamber gas system within a module to outside interface points in the detector as well as the chamber to chamber inter-connections.

30.02.5.2 On-Site

Same as WBS 30.02.5.1, except on-site

30.02.5.2.1 Design and Drawings

This element covers the activity to design the surface and supply gas system for the CSC muon barrel chambers to interface points in the detector .

30.02.5.2.2 Test Procedure Development

This element includes the activity to develop the test procedures required for the muon barrel system gas system CSC.

30.02.5.2.3 Safety Procedure Development

This element includes the activity to develop the safety procedures required for the muon barrel system gas system CSC.

30.02.5.2.4 Maintenance Procedure Development

This element includes the activity to develop the maintenance procedures required for the muon barrel system gas system CSC.

30.02.5.2.5 Assembly and Testing

This element includes the activity for the assembly and testing of the barrel muon gas system for the CSC.

30.02.5.2.6 Surface Gas System Procurement

This element includes the activity for procurement of the surface equipment for the gas system for the CSC.

30.02.5.2.7 Hall Gas System Procurement

This element includes the activity for procurement of the hall equipment for the gas system for the CSC.

30.02.6 Cooling System

This element includes material and labor for final design, fabrication, assembly and test of components, procurement of standard components, and shipping to site.

30.02.6.1 Off-Site

This element covers the activity to be performed off-site for the barrel region cooling system in the muon subsystem.

30.02.6.1.1 Shipping

This element covers the labor and material for packaging and shipping the assembled CSC cooling system components.

30.02.6.1.2 Sub-assembly and Test

This element covers the labor and material for subassembly and test of the CSC cooling system components.

30.02.6.1.3 Machining and Inspection

This element covers the labor and material for fabrication and inspection of the CSC cooling system components.

30.02.6.1.4 Procurement

This element covers the labor and material for procurement of a portion of the CSC cooling system components.

30.02.6.1.5 Final Design, Drawing and Specifications Modifications

This element covers the activity for completing the final design of the CSC cooling system components and generating and modifying the drawings and specifications.

30.02.7 Local Alignment

This element includes labor and material for final design, facility preparation, fabrication, assembly and test of alignment system, and shipping to site.

30.02.7.1 Off-Site

This element includes the activity to be performed off-site for the barrel region local alignment of the muon subsystem.

30.02.7.1.1 Shipping

This element covers the labor and material for packaging and shipping the CSC alignment apparatus.

30.02.7.1.2 Test

This element covers the labor and material for testing the CSC alignment apparatus during and after assembly.

30.02.7.1.3 Assembly

This element covers the labor and material for the assembly of the CSC alignment apparatus and purchasing assembly equipment..

30.02.7.1.4 Facility Preparation

This element covers the labor and material for preparing CSC alignment apparatus assembly off-site facility for assembly and test, etc.

30.02.7.1.5 Machining and Inspection

This element covers the labor and material for the local alignment equipment and fixturing. It includes the oversight and purchasing of stock and material for machining.

30.02.7.1.6 Final Design, Drawing and Specifications Modifications

This element covers the labor and material required for completing the final design of the CSC local alignment assembly fixturing, and modifying and generating drawings and specifications.

30.03 Endcap Region - CSC

See WBS 30.02 for description of this element.

30.03.1 Endcap Region Module Assembly

See WBS 30.02 for description of this element.

30.03.1.1 On-Site

This element includes the activity to be performed on-site for the endcap region of the muon subsystem.

30.03.1.1.1 Sector Storage

This element covers the labor and material for storing the assembled sectors.

30.03.1.1.2 Test

This element covers the labor and material for the testing of the individual sectors. It includes performing sector-level electrical checks, gas leak-check/pressure checks, chamber alignment.

30.03.1.1.3 Assembly

This element covers the labor and material for the assembly of the individual sectors. It includes the assembly of support structures, mounting 832 LSDT's/PDT's and RPC's to the assembled support structure, mounting sector-level gas and cooling systems hardware, mounting/harnessing sector-level electronics.

30.03.1.1.4 Facility Preparation

This element covers the labor and material for the preparation of the SSC facility, to support the assembly of the individual sectors.

30.03.1.2 Off-Site

This element includes the activity to be performed off-site for the endcap region of the muon subsystem.

30.03.1.2.1 Assembly Fixturing Final Design, Machining, Assembly

This element covers the labor and material for completing the final design of the sector assembly fixturing, modifying and generating drawings and specifications, and the machining and assembly of the fixturing.

30.03.2 Cathode Strip Chambers

See WBS 30.02.2 for description of this element.

30.03.2.1 Off-Site

This element includes the activity to be performed off-site for the cathode strip chambers of the muon subsystem.

30.03.2.1.1 Shipping

This element covers the labor and material for packaging and shipping the assembled CSC's.

30.03.2.1.2 Test

This element covers the labor and material for testing the CSC's during and after assembly.

30.03.2.1.3 Assembly

This element covers the labor and material for the assembly of the CSC chambers

30.03.2.1.4 Facility Preparation

This element covers the labor and material for preparing CSC chamber assembly off-site facility for assembly and test, etc. for the CSC chambers.

30.03.2.1.5 Machining and Inspection

This element covers the labor and material for the machining and inspection of CSC's and assembly fixturing. It includes the oversight and purchasing of stock and material for machining.

30.03.2.1.6 Final Design, Drawing and Specifications Modifications

This element covers the labor and material required for completing the final design of the CSC chambers and chamber assembly fixturing, and modifying and generating drawings and specifications.

30.03.3 Module Support Structures

This element includes the labor and material for final design, fabrication of structure components, and shipping to site.

30.03.3.1 Off-Site

This element includes the activity to be performed off-site for the module support structures of the endcap region for the muon subsystem.

30.03.3.1.1 Shipping

This element covers the labor and material for packaging, storage and shipping oversight of the assembled support structures.

30.03.3.1.2 Machining and Inspection

This element covers the labor and material for the machining and inspection of structure components. It includes the oversight for purchasing stock and material for machining.

30.03.3.1.3 Final Design, Drawing, and Specification Modifications

This element covers the labor and material for finalizing the support structure design, modifying existing drawings and test and assembly specifications, and the generation of new drawings and specifications.

30.03.4 Reserved

30.03.5 Gas System

This element includes labor and material for additional components beyond those defined in WBS 30.02.5.

30.03.5.1 Off-Site

This element includes the activity to be performed off-site for the endcap region gas systems for the muon subsystem.

30.03.5.2 On-Site

Same as WBS 30.03.5.1, except on-site.

30.03.5.2.1 Assembly and Testing of Muon Gas System (Reserved)

This element includes the activity to assemble and test of the barrel muon gas system for the PDT chambers.

30.03.6 Cooling System

This element includes labor and material for additional components beyond those defined in WBS 30.02.6.

30.03.6.1 Off-Site

This element includes the activity to be performed off-site for the endcap region cooling system for the muon subsystem.

30.03.6.1.1 Shipping

This element covers the labor and material for packaging and shipping the assembled CSC cooling system components.

30.03.6.1.2 Sub-assembly and Test

This element covers the labor and material for subassembly and test of the CSC cooling system components.

30.03.6.1.3 Machining and Inspection

This element covers the labor and material for fabrication and inspection of the CSC cooling system components.

30.03.7 Local Alignment

See WBS 30.02.7 for description of this element.

30.03.7.1 Off-Site

This element includes the activity to be performed off-site for the endcap region local alignment of the muon subsystem.

30.03.7.1.1 Shipping

This element covers the labor and material for packaging and shipping the CSC alignment apparatus.

30.03.7.1.2 Test

This element covers the labor and material for testing the CSC alignment apparatus during and after assembly.

30.03.7.1.3 Assembly

This element covers the labor and material for the assembly of the CSC alignment apparatus, and purchasing assembly equipment.

30.03.7.1.4 Facility Preparation

This element covers the labor and material for preparing CSC alignment apparatus assembly off-site facility for assembly and test, etc.

30.03.7.1.5 Machining and Inspection

This element covers the labor and material for the local alignment equipment and fixturing. It includes the oversight and purchasing of stock and material for machining.

30.03.7.1.6 Final Design, Drawing and Specification Modifications

This element covers the labor and material for completing the final design of the CSC local alignment assembly fixturing, and modifying and generating drawings and specifications.

30.04 Installation

This element includes efforts in the experimental hall: mounting of the barrel and endcap monoliths, gas and cooling hookups, and global alignment.

30.04.1 Barrel Region

This element includes labor and material for final design of equipment, facility preparation, mechanical and electrical assembly, and test of the barrel monoliths.

30.04.1.1 On-Site

This element includes the activity to be performed on-site for the installation of the muon subsystem.

30.04.1.1.1 Test

This element covers the labor and material for the testing of the muon subsystem, as well as the entire muon system.

30.04.1.1.2 Mechanical Assembly

This element covers the labor and material for the central region sector installation into the magnet and sector subsystems integration of the entire central region muon system.

30.04.1.1.3 Facility Preparation

This element covers the labor and material for the preparation of the SSC facility to permit and support the installation of, and specific to, the muon subsystem.

30.04.1.2 Off-Site

This element includes the activity to be performed off-site for the installation of the barrel region of the muon subsystem.

30.04.1.2.1 Installation Tooling Final Design, Machining, Assembly

This element covers the labor and material for completing the final design of the sector assembly tooling, modifying and generating drawings and specifications, and the machining and assembly of the tooling.

30.04.2 Endcap Region

See WBS 30.04.1 for description of this element substituting endcap for barrel.

30.04.2.1 On-Site

Same as WBS 30.04.1.1 for description of this element substituting endcap for barrel.

30.04.2.1.1 Test

This element covers the labor and material for the testing of the muon subsystems, as well as the entire muon system.

30.04.2.1.2 Mechanical Assembly

This element covers the labor and material for the end cap region sector installation into the magnet, sector subsystems integration, and mechanical test of the entire end cap region muon system.

30.04.2.1.3 Facility Preparation

This element covers the labor and material for the preparation of the SSC facility, to permit and support the installation of, and specific to, the muon endcap region.

30.04.2.2 Off-Site

Same as WBS 30.04.2.1, except off-site.

30.04.2.2.1 Installation Tooling Final Design, Machining, Shipping, Assembly

This element covers the labor and material for completing the final design of the sector assembly tooling, modifying and generating drawings and specifications, machining tooling components, shipping tooling components, assembly of the tooling components, and installation into hole.

30.04.3 Global Alignment

Same as WBS 30.02.7.

30.04.3.1 Off-Site

This element includes the activity to be performed off-site for the global alignment of the installation for the muon subsystem.

30.04.3.1.1 Shipping

Same as WBS 30.02.7.1.1.

30.04.3.1.2 Test

Same as WBS 30.02.7.1.2.

30.04.3.1.3 Assembly

Same as WBS 30.02.7.1.3.

30.04.3.1.4 Final Design, Drawing and Specification Modifications

Same as WBS 30.02.7.1.6.

30.05 Project Management

This element includes the effort for the required management activities during the life of the project.

30.05.1 Program Administration and Oversight

This element covers the labor and material for system-level engineering oversight of entire final design and construction activities for the muon system. Interface primarily with other sub-management overseers (Q&A, ES&H, etc.) as well as physicists, SSCL managers and national laboratory and vendor management.

30.05.2 Resource Management

This element covers the labor and material for system-level engineering identification, allocation and oversight of available resources within the Muon System community. This function is necessary to avoid duplication of effort and cost.

30.05.3 Environment, Safety and Health Assurance (ES&H)

This element covers the labor and material for system-level engineering oversight, identification, monitoring and reporting of ES&H issues and concerns.

30.05.4 Quality Assurance (QA) Program

This element covers the labor and material for system-level engineering oversight, monitoring and reporting of component and sub-muon system QA programs.

30.05.5 Subsystem Systems Integration

This element covers the labor and material for system-level engineering oversight and monitoring of muon system integration. Oversight to ensure all integration/interface/facilities issues are identified and proper activity assigned to ensure success of installation and integration.

30.05.6 Subsystem Cost and Schedule Monitoring

This element covers the labor and material for system-level engineering oversight, monitoring and reporting of the cost and schedule status.

30.06 Conceptual and Preliminary Design

This element covers the labor and material for establishing the initial requirements, specifications, costs and schedules prior to the submittal of the TDR document.

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522.5040 Magnet Construction

This subsystem consists of all of the assemblies and elements required to provide the magnetic field in the interior of the detector. It includes the coils, coil forms, radiation shields, cold mass supports, vacuum vessels, end poles, current leads, cryogenic (LN and LHe) systems, and power and protection systems. It also includes components required to support the solenoid and end poles from the ground, the support for the central detectors, the attachment points for the muon and calorimeter subsystems, and any special tooling necessary to install any of these components. This subsystem does not include the building cranes, assembly buildings, or any concrete support features below the detector. Major interfaces are with: underground hall, above-ground facilities, muon subsystem, calorimeter subsystem, and the ring magnet system. This element also includes all research and development activities for the magnet as well as completion of the conceptual/preliminary design.

40.01 Magnet Subsystem Research and Development

This element covers research and development activities associated with the GEM magnet subsystem. This element does not include efforts to perform preliminary or detailed design of the magnet subsystem. It does include effort to develop tooling for conductor production, as well to conduct tests of proposed component concepts. This effort may occur throughout the early phases of the project.

40.01.1 Conductor Development

This element covers all activities required to verify the design of the conductor. It includes efforts to fabricate short lengths of prototype conductor, and test the performance.

40.01.2 Joint Development

This element covers all research and development activities associated with the joints between superconducting cables in the magnet. It includes subscale tests to verify the concept, as well as full-scale tests of actual joint designs.

40.01.3 Winding Development

This element covers all activities required to develop and demonstrate the winding techniques for the magnet. It includes tests of the bending performance of the conductor and initial trial winding on short lengths of dummy conductor. It also includes the acquisition of key pieces of winding tooling.

40.01.4 Component Development (Reserved)

This element covers the development of special components for the magnet subsystem. It presently includes only the development and demonstration of cryogenic insulating breaks.

40.02 Design Completion

This element consists of all design activities required for the magnet subsystem after Authorization to Proceed with construction phase. It includes preliminary and final design, analysis, trade studies, refinement of design requirements, preparation of final drawings, and preparation of presentations for the System Requirements Review (SRR), the Preliminary Design Review (PDR), and the Critical Design Review (CDR). It also includes preparation of all deliverables associated with the design, including data, drawings, reports, and presentations. Design activities are defined as complete when the procurement package for a given component is ready for solicitation of bids. This element does not include the costs for soliciting bids or placing contracts or orders for fabrication. It also does not include any effort required during fabrication to monitor progress or provide technical oversight.

40.02.1 Coil Assemblies Design

This element consists of the design of all components which are physically a part of the completed coil assemblies; these assemblies are the parts which will be assembled above-ground and delivered for installation in the underground hall. This includes the coils, the thermal radiation shields, the vacuum vessels, the cold-mass supports, and all cryogenic piping and distribution and current bussing which are within the vacuum-vessel boundary. This does not include the components required to physically support the coil assemblies, the forward field shapers, or the central detector support. It also does not include local thermosyphon supply dewars or any cryogenic piping external to the vacuum vessel boundary. Major interfaces are with the underground hall, the above-ground facilities, the poles/pole supports, the muon subsystem, and the central detector support.

40.02.1.1 Cold Mass Subassemblies Design

This element consists of the design of two (approximately) 15 m long magnet coils only, which are made up of conductor wound on coil forms, with any required diagnostics installed. It includes the design of all parts and tooling required to produce the coils, as well as assembly of multiple short coil segments, if the coil is designed in that manner. This does not include the LHe thermosyphon or LHe forced-flow cryogenic piping/distribution. Design major interfaces are with the cold-mass supports, the vacuum vessels, the radiation shields, and the internal cryogenic systems.

40.02.1.1.1 Coil Form Design

This element comprises the design of the coil form within which the coil is wound. The coil form includes ribs to accept axial conductor loads, attachment points for the cold-mass supports, and ground-plane insulation.

40.02.1.1.2 Conductor Design

This element includes all of the design required to provide the conductor which makes up the coil. The conductor includes the SC wire, the protective sheath, and the passage for the forced-flow LHe. This element includes all of these parts, even if they are designed to be physically separate. The conductor is to be delivered on large spools, ready for winding into the coil forms.

40.02.1.1.3 Diagnostics Design

This element includes the design of all hardware and activities associated with any control or diagnostic elements which are actually installed on the coil sub-assembly. This includes voltage taps, temperature sensors, etc. This element does not include the electronics necessary to read out these sensors or to effect control.

40.02.1.1.4 Winding Tooling Design

This element includes the design of all of the tooling required to remove the conductor from the storage drums and wind it into final position in the coil form. Any tooling or hardware design required for gluing or otherwise affixing the conductor in place is included in this element.

40.02.1.1.5 Winding and Testing Design

This element covers the design of all of the processes and activities required to complete 24 each 1.2 m long coil segments, starting from the basic parts identified in WBS 40.01.1.1-4. This includes the design of all processes required to prepare the coil form for winding, to actually remove the conductor from the storage drum and wind it into final position in the coil form, to install any diagnostics, sensors, or controls, to complete the electrical and fluid connections within the coil segments, and to perform tests as required to verify proper function at this level. This does not include any design required to stack or assemble the segments to form completed cold-mass halves, or to install the radiation shields, cold mass supports, or vacuum vessels. Because of the size of the completed coil subassemblies, all assembly effort take place on-site at SSCL.

40.02.1.1.6 Cold Mass Assembly Tooling Design

This element covers the design of all tooling required to accept 1.2 m long coil segments, assemble them together to form two 14.4 m long cold mass halves, test them, and prepare them for assembly with the vacuum vessels, thermal shields, cold mass supports, etc. This tooling includes hardware required to offload the coil segments from the transporter, attach them to the growing cold mass half, support the growing coil mass half, attach all manifolds for LHe, and attach all miscellaneous controls and monitors associated with the cold mass. This element does not include the design of the transporter which moves the coil segments from the winding station to the assembly area, as this is included in the facilities cost. It also does not include the design of any tooling required for coil winding, or for assembly of the completed coil halves into the vessels.

40.02.1.1.7 Cold Mass Assembly and Testing Design

This element covers the design of the assembly process which accepts 24 each, 1.2 m long coil segments and creates 2 each 14.4 m long cold mass halves. This includes completion of all electrical and fluids lines, and testing to ensure proper operation at this level of assembly. This element does not include design of any coil-winding processes, or any assembly operations which mate the cold mass halves with the vessels, thermal shields, etc.

40.02.1.2 Vacuum Vessel Subassembly Design

This element includes the design of all of the parts required to establish a vacuum boundary around the coil: the inner and outer cylindrical vessels, the end plates, any parts which are required to physically support the vessels from a concrete floor, attachment points for the central muon subsystem and magnet coil, any tooling required for fabricating the vessels and any components attached to the outer vessel to withstand operational loads. Not included is the vacuum pump and piping design.

40.02.1.2.1 Vessel Shells Design

This element includes the design of the inner and outer vacuum vessels only.

40.02.1.2.2 Vessel Stiffeners Design

This element includes the design of the vacuum vessel stiffeners, the end stiffeners (which are also the end annular closures for the vessels), as well as the longitudinal beams and ring stiffener(s).

40.02.1.2.3 Vessel Support Structures Design

This element includes the design of all hardware required to physically support the coil, vessel, and muon sector assemblies in the underground hall, including the saddles or legs to support the outer vessel as well as any jacking hardware provided to align the magnet, to compensate for ground motion, or to move the magnet assemblies. This does not include the design of any concrete structures, such as piers or support beams, which are assumed to be parts of the hall facility.

40.02.1.2.4 Assembly and Testing Design

This element includes the design of the processes and procedures to assemble the inner and outer vacuum vessels together with the stiffeners and support structure. It also covers the design of the testing procedures required to verify proper performance of the vacuum vessel subassemblies alone at this assembly level.

40.02.1.3 Cryostat Subassembly Design

This element includes all of the design of all of the elements enclosed by the vacuum vessels, except for the cold mass subassemblies. This includes the thermal radiation shields, the cold mass supports, the internal cryogenic systems, and the cryogenic current leads. Also included in this element is the design of all the tooling required for fabrication of these elements, and the hardware required for attaching or supporting them. This element does not include the design of fixtures for assembling the vessels, internal cryostat components, and cold mass together.

40.02.1.3.1 Thermal Radiation Shields Design

This element covers the design of all hardware and activities required to produce the LN-cooled thermal radiation shields and all other heat-shielding parts. Included in this element are the design of the inner, outer, and end shields, the multilayer insulation, attachment points for mechanical supports, and the supports themselves if they are different from the main cold-mass supports. This does not include the design of standard piping and manifolding for LN distribution within the vacuum vessel. Any tooling required to assemble the radiation shields (prior to combining them with the vessel and cold mass) is included.

40.02.1.3.1.1 LN Thermal Radiation Shields Design

This element covers the design of the LN radiation shields at the inner diameter, outer diameter and axial ends of the coil assemblies.

40.02.1.3.1.2 Superinsulation Design

This element covers the design of all of the super insulation within the coil assemblies, and any tooling required to prepare it for installation or to install it.

40.02.1.3.1.3 Shield Supports and Thermal Intercepts

This element covers the design of all LN shield support hardware.

40.02.1.3.2 Cold Mass Supports Design

This element includes the design of all mechanical supports for the 4K cold mass, including the thermal intercepts on the cold-mass supports and all fasteners, etc. required.

40.02.1.3.2.1 Radial Rods Design

This element includes the design of all of the cold-mass supports which support the weight of the cold mass in final position in the underground hall. It includes the design of the thermal intercepts on the radial supports. This element does not include the design of attachment points on the cold mass, LN shields, or vacuum vessels.

40.02.1.3.2.2 Axial Rods Design

This element includes the design of all of the cold-mass supports which support the axial magnetic forces on the cold mass in final position in the underground hall. It includes the design of the thermal intercepts on the axial supports. This element does not include the design of attachment points on the cold mass, LN shields, or vacuum vessels.

40.02.1.3.3 Internal Cryogenic Systems Design

This element includes the design of all cryogenic piping and distribution which is enclosed in the vacuum vessel, including all LHe and LN Bayonets, manifolding, and piping which is installed separately from the coil assembly and radiation shields. The boundary between this element and the cryogenic piping and distribution elements is at the wall of the vacuum vessel. This element includes the portion of the feedthroughs required to maintain a vacuum boundary at the vessel. This element does not include the design of any systems which are installed after the coil assembly has been installed in the underground hall.

40.02.1.3.3.1 LN Piping and Distribution Design

This element includes the design of all in-vessel LN distribution piping which is not actually mounted on the radiation shields and the LN feedthroughs through the vacuum vessel wall. It does not include any external LN piping design.

40.02.1.3.3.2 LHe Thermosyphon Piping and Distribution Design

This element includes the design of all of the in-vessel piping and manifolding required for the LHe thermosyphon system which cools the coil form; it includes the design of all LHe thermosyphon hardware which is not mounted physically on the coil form. Design of feedthroughs through the vacuum vessel is included.

40.02.1.3.3.3 LHe Forced-Flow Piping and Distribution Design

This element covers the design of all of the in-vessel piping and manifolding required for the forced-flow LHe loop, including vacuum feedthroughs. This includes the design of all the forced-flow LHe components which are not actually a part of the coil sub-assembly.

40.02.1.3.4 Cryogenics Current Leads Design

This element covers the design of the current leads which are installed after the coil is assembled into the vacuum vessels, and which are at cryogenic temperature. It includes all of the hardware required to conduct the DC current from the ends of the coils to the vapor-cooled leads, including the components required to provide structural support and cooling. It also includes the design of the vapor-cooled leads and the attachment to the external warm current bus. It does not include the design of the warm current bus which is external to the vacuum vessel.

40.02.1.4 Coil Assembly and Testing Design

This element includes all of the design associated with the assembly and testing step in which the cold masses, internal cryostat components, and the vacuum vessels are united to form coil assemblies.

40.02.1.4.1 Coil Assembly and Testing Equipment Design

This element covers the design of all of the hardware required to assemble the wound coil sub-assembly into the radiation shields and vacuum vessels, make up all internal electrical and fluids connections, verify all connections, rotate the assembly into its final orientation, and perform all checks and tests required prior to installation in the underground hall. It does not include design for testing the coil assemblies at LHe temperature, or under significant current or design for providing leak hunting equipment and LN as required for thermal-shock testing.

40.02.1.4.2 Coil Assembly Design

This element covers all design required to define all of the processes and activities necessary to assemble complete coil assemblies, ready for installation into the underground hall. It includes final assembly of the coil sub-assembly into the radiation shields and vacuum vessels, installation of the cold-mass supports, installation of all in-vessel cryogenic distribution hardware, final make-up of all diagnostic, control, and current connections within the vacuum vessel, closure of the vacuum vessel, vacuum and helium leak hunting, and rotation of the assembly into final orientation. It does not include design activities to define any testing activities under cryogenic conditions or to significant current.

40.02.1.4.3 Coil Testing Design

This element covers the design activities required to define all "acceptance" testing of the coil assemblies in the above-ground area, prior to their installation in the underground hall. This includes design of procedure for cold-leak testing prior to installation.

40.02.2 Forward Field Shapers and Support Design

This element covers all design activities required to provide the magnetic steel forward field shapers (FFSs), along with their supports and the transporter required for moving the FFSs for installation and maintenance.

40.02.2.1 Forward Field Shapers Design

This element include the design of the magnetic steel FFSs themselves, and does not include the structural design required to support their weight or move them in the underground hall.

40.02.2.2 FFS Support Structure Design

This element covers the design of the structures which support the weight of the FFSs, and move them axially to allow access inside the detector.

40.02.2.3 Assembly Design

This element covers the design activities to define the assembly operation in which the FFSs are mated to the support structure.

40.02.2.3.1 Off-site Assembly Design (Reserved)

Need input

40.02.2.3.2 On-site Assembly Design

Need input

40.02.3 Reserved

40.02.4 Power and Protection System Design

This element covers the design of all hardware required to provide current to the solenoid magnet assembly, to control and protect it in the event of unusual occurrences such as trips and quenches and to discharge it under normal and emergency conditions. This includes the design of the normally-conducting busses which connect the power supply, dump resistor, breaker, and coil. This element does not include the design of any hardware within the vacuum boundary, or any of the conventional or technical facilities required to support power and protection.

40.02.4.1 Power Supply Design

This element covers the design of the magnet power supply and all the hardware and controls between the AC power grid and the terminals of the warm bus. Only local controls on the power supply itself are included here.

40.02.4.2 Buswork Design

This element comprises the design of all of the warm (normally-conducting) busswork which connects the high-current components together. Major connections are with the power supply, the dump resistor, the breaker, and the coil. This includes the design of the hangars for the buswork and any cooling component required.

40.02.4.3 Breakers and Dump Resistors Design

This element includes only the design of the breaker and dump resistor required for emergency discharges of the magnet.

40.02.4.4 Discharge Resistor and Switch Design

This element covers the design of a separate discharge resistor and switch, used for normal discharge of the magnet. This hardware is not required in some power system designs.

40.02.5 Cryogenics Design

This element covers the design of all of the cryogenics hardware (LN and LHe) which is installed external to the coil assemblies; this includes the cryogenics plants, storage dewars, and all of the distribution and transfer lines. This interface between the cryogenics elements and the "internal cryogenics" elements is at the vacuum vessel wall. This WBS element begins with the first transfer line components which are not required for the vessel vacuum boundary.

40.02.5.1 Liquid Nitrogen System Design

This element covers the design of all of the external LN system, including all LN storage, pumping, and transfer/distribution piping up to the vacuum vessel boundary.

40.02.5.1.1 LN Storage Dewar Design

This element covers the design of the LN storage dewar itself, without piping.

40.02.5.1.2 LN Subcooler Design

This element covers the design of the LN subcooler only, without piping.

40.02.5.1.3 LN Piping and Distribution Design

This element covers the design of all of the piping required to complete the LN system, above and below ground, up to the coil vacuum vessel, all of the LN piping within the cryogenics building, and the transfer lines to the coil vessel. It also includes the design of any circulating pumps required.

40.02.5.2 Liquid Helium System Design

This element covers the design of all of the LHe hardware external to the coil vacuum vessel, including both the forced and thermosyphon systems, as well as the helium plant above ground, and all piping and distribution.

40.02.5.2.1 Liquid Helium Supply Design

This element covers the design of the main helium plant, which supplies LHe to the above-ground storage dewar. It includes all of the plumbing between the refrigerator and supply dewar. It does not include the transfer lines to any below-ground systems.

40.02.5.2.1.1 Helium Refrigeration Design

This element covers the design of the Helium refrigerator, its associated compressors and oil removal equipment and contamination monitoring only.

40.02.5.2.1.2 Liquid Helium Supply Piping and Distribution Design

This element includes the design of the piping and valving between the refrigerator cold box and supply dewar. It does not include any transfer lines to below-ground systems design.

40.02.5.2.1.3 Helium Recovery System Design

This element covers the design of all the hardware required to accommodate large rates of vapor generation, such as that which occurs at a magnet quench, and which exceed the liquefaction rate of the refrigerator.

40.02.5.2.1.3.1 Gas Bag and Associated Components

This element includes a normally deflated gas bag, gas bag pressure sensing, a blower for evacuating the gas bag, and any structure or enclosure for support or weather protection.

40.02.5.2.1.3.2 Recovery Compressor Design

This element includes the design of the compressor which feeds the contaminated gas from the gas bag through the purifiers and into clean high pressure storage or bypassing the purifiers and into contaminated high pressure storage.

40.02.5.2.1.4 Helium Purification Design

This element includes the design of the purifiers which remove air and water vapor from contaminated helium.

40.02.5.2.1.5 Gas Storage Design

This element includes the design of both the contaminated and clean high pressure gas storage.

40.02.5.2.2 Thermosyphon System Design

This element includes the design of the magnet supply dewar and cryogenic transfer lines which supply coolant to the bobbin heat exchanger. It does not include any design of the systems to actually produce LHe, or any hardware within the coil vacuum vessel boundary.

40.02.5.2.2.1 Magnet Storage and Supply Dewars Design

This element covers the design of the magnet supply dewar and associated valving.

40.02.5.2.2.2 LHe Thermosyphon Distribution Design

This element includes the design of the cryogenic transfer lines which couple the supply dewar to the bobbin heat exchanger, including the supply side check valve.

40.02.5.2.3 Forced-Flow System Design

This element includes the design of the hardware which supplies and conditions the supercritical helium flow for the magnet winding.

40.02.5.2.3.1 LHe Subcooler Design

This element includes the design of the heat exchanger which is immersed within the helium supply dewar.

40.02.5.2.3.2 Forced-Flow LHe Distribution Design

This element includes the design of all of the cryogenic transfer lines from the refrigerator to the subcooler, from the subcooler to the coil vacuum vessel and the return from the coil vacuum vessel to the supply dewar.

40.02.6 Magnet Vacuum System Design

This element covers all of the design of the vacuum system required to pump down and maintain the magnet system under vacuum. It does not include vacuum hardware associated with the main ring or any other systems.

40.02.6.1 Vacuum Pumps Design

This element covers the design of all the vacuum pumps and traps for the magnet vessels, including any foreline pumps, roughing pumps, refrigerated traps, or booster pumps.

40.02.6.2 Vacuum Piping Design

This element covers the design of all he piping, valves, flanges, etc., required for the magnet vacuum system.

40.02.7 Magnet Control Systems Design

This element covers the design of all of the local controls for the magnet subsystem. Design of any control computers and control design in the main operations center are not included in this estimate. It is assumed that safety interlocks are monitored by the main control system, and the local system is responsible only for magnet subsystem operational interlocks, such as "FFSs closed", "LCW on", etc. This control system extends as far as local programmable controllers, but does not include control computers, which are included under slow controls in the electronics subsystem.

40.02.7.1 Power Controls Design

This element includes the design of the controls, operational interlocks, and monitor readouts for the magnet power supply. This element includes all of the magnet-system interlock logic design required to permit operation of the magnet power supply; individual permissives for each part of the system are included in each element.

40.02.7.2 Protection Controls Design

This element includes the design of the controls, operational interlocks, and readouts for the magnet protection system, which includes breaker control, dump resistor status, etc.

40.02.7.3 Cryogenics Controls Design

This element includes the design of the controls, operational interlocks, and readouts for the LN and LHe systems. This includes controls for the refrigerators and all cryogenic valves.

40.02.7.4 Vacuum Controls Design

This element covers the design of all of the controls required to operate the magnet vacuum system, which includes pump controls, pressure readouts, valve controllers, etc.

40.02.7.5 Quench Detection and Diagnostic Design

This element includes the design of the hardware required for quench detection, except that which is mounted within the vacuum envelope. This element includes the design of the quench detector electronics, but not the sensors which are actually mounted within the vacuum vessel.

40.02.8 Return-Field Mitigation Design

This element covers the design of all of the hardware required to shield individual components or small volumes from the return field of the magnet, or alternatively, the additional cost of over-specifying components so they will work properly in the field, including shielding for vacuum pumps, gages, etc., as well as shielding of local counting rooms and electronic racks below ground. It does not include hardware to shield the above-ground field design.

40.02.9 Installation, Testing and Tooling Design

This element covers the design of all the processes, procedures, and tooling required to place all magnet subsystem components in their final positions and test them. It includes design of the major rigging operations, as well as the sequence of installation and testing.

40.02.9.1 Installation Tooling Design

This element covers the design of all of the hardware temporarily required for installation of magnet subsystem components into their final positions. It does not include design of any hardware which will be a permanent part of the installation.

40.02.9.1.1 Coil Assemblies Tooling Design

This element includes the design of all of the tooling required to handle the coil assemblies from the location at which they were tested above ground to their final position in the underground hall and any tooling required to anchor them and their support hardware in place and align them.

40.02.9.1.2 Reserved

40.02.9.1.3 Forward Field Shapers Tooling Design

This element includes the design of the tooling required to move the FFS assemblies from the surface to the underground hall and place them in position. If they are to be assembled in the underground hall, the tooling design required for assembly is included here as well.

40.02.9.1.4 Testing Equipment Design

This element covers the design of all of the equipment required for testing the magnet system after installation. The primary testing equipment will be a system for mapping the magnetic field inside the magnet.

40.02.9.2 Installation Design

This element covers the design of all of the actual installation of magnet subsystem hardware on-site at SSCL, including installation of the magnet assemblies in the underground hall, as well as the power and cryogenics systems above-ground. It does not include the design of any additional hardware.

40.02.9.2.1 Solenoid Magnet Installation Design

This element covers the design activities required to define the installation of the solenoid magnet assemblies. It includes design of installation of the coil assemblies, coil supports, the FFS assemblies, and the central detector support in the hall. It does not include design of the installation of the power or cryogenics systems.

40.02.9.2.2 Power and Protection System Installation Design (Reserved)

This element covers only the design activities required to define the installation of the power and protection systems. This element does not include controls or the control computer design.

40.02.9.2.3 Cryogenic System Installation Design

This element covers the installation of all of the cryogenics for the magnet subsystem. It includes installation of the major components in the cryogenics building, as well as installation of the piping and distribution lines within the building and to the underground hall.

40.02.9.2.3.1 LN System Installation Design

This element covers the activities required to define the installation of all of the LN system for the magnet subsystem, including installation of the major components in the cryogenics building, as well as installation of the piping and distribution lines within the building and to the underground hall.

40.02.9.2.3.2 LHe Systems Installation Design

This element covers the activities required to define the installation of all of the LHe system for the magnet subsystem, including installation of the major components in the cryogenics building, as well as installation of the piping and distribution lines within the building and to the underground hall.

40.02.9.2.4 Vacuum System Installation Design

This element covers the activities required to define the installation of all the pumps, valves, piping, traps, pressure sensors, etc. required for the magnet vacuum system.

40.02.9.2.5 Control System Installation Design

This element covers the activities required to define the installation of all the magnet local controls, including readouts and controls for power/protection, cryogenics, vacuum system and the installation of a local control room, but not the connection to the main operations center.

40.02.9.3 Testing Design (Reserved)

This element covers the design activities required to define all testing of the magnet subsystem after installation. This includes initial system checkout testing and extends through magnetic-field mapping. This element includes only testing performed prior to installation of the internal detector subsystems; testing of the detector as a whole is included in operations.

40.03 Fabrication and Assembly

This element consists of all fabrication and assembly activities within the magnet subsystem. It includes all activities between assembly of procurement packages and beginning of installation. The first activity within this element is solicitation of bids for fabrication. The last activity included in this element is final inspection and checkout before installation begins. This element includes all labor and materials required for fabrication and assembly, including direct touch labor, first-line supervision, engineering oversight, inspection, purchasing, expediting, and engineering effort required to respond to discrepancies.

40.03.1 Coil Assemblies Fabrication and Assembly

This element consists of fabrication and assembly of all the components which are physically a part of the completed coil assemblies; these assemblies are the parts which will be assembled above-ground and delivered for installation in the underground hall. This includes the coils, the thermal radiation shields, the vacuum vessels, the cold-mass supports, and all cryogenic piping and distribution and current bussing which are within the vacuum-vessel boundary. This does not include the components required to physically support the coil assemblies, the forward field shapers, or the central detector support. It also does not include the local thermosyphon supply dewars or any cryogenic piping external to the vacuum vessel boundary. Major interfaces are with the underground hall, the above-ground facilities, the poles/pole supports, the muon subsystem, and the central detector support.

40.03.1.1 Cold Mass Subassemblies Fabrication and Assembly

This element consists of fabrication and assembly of the two (approximately) 15m long magnet coils only, which are made up of conductor wound on coil forms, with any required diagnostics installed. It includes all activities, parts, and tooling required to produce the coils, as well as assembly of short coil segments, if the coil is designed in that manner. This does not include the LHe thermosyphon or LHe forced-flow cryogenic piping/distribution. Major interfaces are with the cold-mass supports, the vacuum vessels, the radiation shields, and the internal cryogenic systems.

40.03.1.1.1 Coil Form Fabrication and Assembly

This element comprises fabrication and assembly of the coil form within which the coil is wound. The coil form includes ribs to accept axial conductor loads, and attachment points for the cold-mass supports.

40.03.1.1.2 Conductor Fabrication and Assembly

This element includes fabrication and assembly of all activities required to provide the conductor which makes up the coil. The conductor includes the SC wire, the protective sheath, and the passage for the forced-flow LHe. This element includes all of these parts, even if they are designed to be physically separate. The conductor is to be delivered on large spools, ready for winding into the coil forms. This does not include the cost of facilities in which the work will be performed. It does include raw materials, conductor processing, storage drums, tooling, etc.

40.03.1.1.3 Diagnostics Fabrication and Assembly

This element includes fabrication and assembly of all hardware and activities associated with any controls or diagnostics elements which are actually installed on the coil sub-assembly. This includes voltage taps, temperature sensors, etc. This element does not include the electronics necessary to read out these sensor or to effect control.

40.03.1.1.4 Winding Tooling Fabrication and Assembly

This element includes fabrication and assembly of all of the tooling required to remove the conductor from the storage drums and wind it into final position in the coil form. Any tooling or hardware required for gluing or otherwise affixing the conductor in place is included in this element.

40.03.1.1.5 Winding and Testing Fabrication and Assembly

This element covers all of the activity required to complete 24 each 1.2 m long coil segments, starting from the basic parts identified in WBS 40.03.1.1.1-4. This includes all activities required to prepare the coil form for winding, to actually remove the conductor from the storage drum and wind it into final position in the coil form, to install any diagnostics, sensors, or controls, to complete the electrical and fluid connections within the coil segments, and to perform tests as required to verify proper function at this level.. This does not include any activity required to connect the 1.2 m long segments together, or to install the radiation shields, cold mass supports, or vacuum vessels. Because of the size of the completed coil subassemblies, all assembly effort take place on-site at SSCL.

40.03.1.1.6 Cold Mass Assembly and Tooling Fabrication and Assembly

This element covers the fabrication and assembly of all tooling required to accept 1.2 m long coil segments, assemble them together to form two 14.4 m long cold mass halves, test them, and prepare them for assembly with the vacuum vessels, thermal shields, cold mass supports, etc. This tooling includes hardware required to offload the coil segments from the transporter, attach them to the growing cold mass half, support the growing coil mass half, attach all manifolds for LHe, and attach all miscellaneous controls and monitors associated with the cold mass. This element does not include the transporter which moves the coil segments from the winding station to the assembly area, as this is included in the facilities cost. It also does not include any tooling required for coil winding, or for assembly of the completed coil halves into the vessels. This does include installation of the assembly tooling into the assembly area.

40.03.1.1.7 Cold Mass Assembly and Testing

This element covers the assembly process which accepts 24 each, 1.2 m long coil segments and creates 2 each 14.4 m long cold mass halves, tested and ready for assembly with vacuum vessels and thermal shields. This includes completion of all electrical and fluids lines, and testing to ensure proper operation at this level of assembly. This element does not include design of any coil-winding processes, or any assembly operations which mate the cold mass halves with the vessels, thermal shields, etc.

40.03.1.2 Vacuum Vessel Subassemblies Fabrication and Assembly

This element includes fabrication and assembly of all of the parts required to establish a vacuum boundary around the coil: the inner and outer cylindrical vessels, the end plates, and any parts which are required to physically support the vessels. This does not include vacuum pumps or vacuum piping. It does include attachment points for the central muon subsystem and magnet coil, and any tooling required for fabricating the vessels. Also included are any components attached to the outer vessel to withstand operational loads.

40.03.1.2.1 Vessel Shells Fabrication and Assembly

This element includes fabrication and assembly of the inner and outer vacuum vessels only.

40.03.1.2.2 Vessel Stiffeners Fabrication and Assembly

This element includes fabrication and assembly of the stiffeners for the vacuum vessels. It includes the end stiffeners (which are also the end annular closures for the vessels), as well as the longitudinal beams and central ring stiffener(s).

40.03.1.2.3 Vessel Support Structures Fabrication and Assembly

This element includes fabrication and assembly of all of the hardware required to physically support the coil, vessel, and muon sector assemblies in the underground hall. This will include the saddles or legs to support the outer vessel as well as any jacking hardware provided to align the magnet, to compensate for ground motion, or to move the magnet assemblies. This does not include any concrete structures, such as piers or support beams, which are assumed to be parts of the hall facility.

40.03.1.2.4 Vessel Assembly and Testing

This element includes the assembly of the inner and outer vacuum vessels together with the stiffeners and support structure. It does not include assembly of the two vessels themselves, which is included in the vessel shell element. This element also includes final testing of the vessel, to verify proper performance at this level.

40.03.1.3 Cryostat Subassembly Fabrication and Assembly

This element includes the fabrication and assembly of all of the elements enclosed by the vacuum vessels, except for the cold mass subassemblies. This includes the thermal radiation shields, the cold mass supports, the internal cryogenic systems, and the cryogenic current leads. Also included in this element is all the tooling required for fabrication of these elements, and the hardware required for attaching or supporting them. This element does not include the fixtures for assembling the vessels, internal cryostat components, and cold mass together.

40.03.1.3.1 Thermal Radiation Shields Fabrication and Assembly

This element covers fabrication and assembly of all hardware and activities required to produce the LN-cooled thermal radiation shields and all other heat-shielding parts. Included in this element are the inner, outer, and end shields, the multilayer insulation, attachment points for mechanical supports, and the supports themselves if they are different from the main cold-mass supports. This does not include standard piping and manifolding for LN distribution within the vacuum vessel. Any tooling required to assemble the radiation shields (prior to combining them with the vessel and cold mass) is included.

40.03.1.3.1.1 LN Thermal Radiation Shields Fabrication and Assembly

This element covers fabrication and assembly of the LN radiation shields at the inner diameter, outer diameter and axial ends of the coil assemblies.

40.03.1.3.1.2 Superinsulation Fabrication and Assembly

This element covers fabrication and assembly of all of the super insulation within the coil assemblies, and any tooling required to prepare it for installation or to install it.

40.03.1.3.1.3 Shield Supports and Thermal Intercepts Fabrication and Assembly

This element covers fabrication and assembly of all LN shield support hardware, not including the cold-mass supports.

40.03.1.3.2 Cold Mass Supports Fabrication and Assembly

This element includes fabrication and assembly of all of the mechanical supports for the 4K cold mass. Support for the LN radiation shields is included here, unless separate supports are found to be necessary. This element includes all of the thermal intercepts, rods, fasteners, etc. required.

40.03.1.3.2.1 Radial Rods Fabrication and Assembly

This element includes fabrication and assembly of all of the cold-mass supports which will support the weight of the cold mass in final position in the underground hall. This element does not include the attachment points on the cold mass, LN shields, or vacuum vessels; it includes thermal intercept hardware.

40.03.1.3.2.2 Axial Rods Fabrication and Assembly

This element includes fabrication and assembly of all of the cold-mass supports which will support the axial magnetic forces on the cold mass in final position in the underground hall. This element does not include the attachment points on the cold mass, LN shields, or vacuum vessels; it includes thermal intercept hardware.

40.03.1.3.3 Internal Cryogenic Systems Fabrication and Assembly

This element includes fabrication and assembly of all cryogenic piping and distribution which is enclosed in the vacuum vessel. The boundary between this element and the cryogenic piping and distribution elements is at the wall of the vacuum vessel. This element includes the portion of the feedthroughs required to maintain a vacuum boundary at the vessel. This does not include any systems which are installed after coil assembly has been installed in the underground hall.

40.03.1.3.3.1 LN Piping and Distribution Fabrication and Assembly

This element includes fabrication and assembly of all of the in-vessel LN distribution piping which is not actually mounted on the radiation shields. It also includes the LN feedthroughs through the vacuum vessel wall. It does not include any external LN piping.

40.03.1.3.3.2 LHe Thermosyphon Piping and Distribution Fabrication and Assembly

This element includes fabrication and assembly of all of the in-vessel piping and manifolding required for the LHe thermosyphon system which cools the coil form. It includes only the hardware which is not mounted physically on the coil form. Feedthroughs through the vacuum vessel are included.

40.03.1.3.3.3 LHe Forced-Flow Piping and Distribution Fabrication and Assembly

This element covers fabrication and assembly of all of the in-vessel piping and manifolding required for the forced-flow LHe loop, including vacuum feedthroughs. This includes the design of all the forced-flow LHe components which are not actually a part of the coil subassembly.

40.03.1.3.4 Cryogenic Current Leads Fabrication and Assembly

This element covers fabrication and assembly of the current leads which are installed after the coil is assembled into the vacuum vessels, and which are at cryogenic temperature. It includes all of the hardware required to conduct the DC current from the ends of the coils to the vapor-cooled leads, including the components required to provide structural support and cooling. It also includes the vapor-cooled leads and the attachment to the external warm current bus. It does not include the warm current bus which is external to the vacuum vessel.

40.03.1.4 Coil Assembly and Testing Fabrication and Assembly

This element includes all activities within the assembly and testing step in which the cold masses, internal cryostat components, and the vacuum vessels are united to form coil assemblies.

40.03.1.4.1 Coil Assembly and Testing Equipment Fabrication and Assembly

This element covers fabrication and assembly of all of the hardware required to assemble the wound coil sub-assembly into the radiation shields and vacuum vessels, make up all internal electrical and fluids connections, verify all connections, rotate the assembly into its final orientation, and perform all checks prior to installation in the underground hall. It does not include provision for testing the coil assemblies at LHe temperature, or under significant current. It does include provision of leak hunting equipment and LN as required for thermal-shock testing. It also includes any temporary supports for the assemblies (other than those to be used for permanent installation in the underground hall).

40.03.1.4.2 Coil Assembly

This element covers all of the activities necessary to assemble complete coil assemblies, ready for installation into the underground hall. It includes final assembly of the coil subassembly into the radiation shields and vacuum vessels, installation of the cold-mass supports, installation of all in-vessel cryogenic distribution hardware, final make-up of all diagnostic, control, and current connections within the vacuum vessel, closure of the vacuum vessel, vacuum and helium leak hunting, and rotation of the assembly into final orientation. It does not include any testing activities under cryogenic conditions or to significant current. Due to the sizes involved, all assembly will be on-site at SSCL.

40.03.1.4.3 Testing

This element covers all "acceptance" testing of the coil assemblies in the above-ground area, prior to their installation in the underground hall. At present, this element includes only a cool-down test to LN temperature for all cryogenics lines in the coil assemblies (including radiation shields). No testing under superconducting conditions or with LHe is planned, and no significant current will be used in these tests.

40.03.2 Forward Field Shapers and Supports Fabrication and Assembly

This element covers all activity and hardware required to provide the magnetic steel forward field shapers (FFSs), along with their supports. This includes the support structure and the transporter required for moving the FFSs for installation and maintenance.

40.03.2.1 Forward Field Shapers Fabrication and Assembly

This element includes fabrication and assembly of the magnetic steel FFSs themselves, and does not include the structure required to support their weight or move them in the underground hall.

40.03.2.2 FFS Support Structures Fabrication and Assembly

This element covers fabrication and assembly of the structures which support the weight of the FFSs, and move them axially to allow access inside the detector.

40.03.2.3 FFS Assembly Fabrication and Assembly

This element covers the assembly operation in which the FFSs are mated to the support structure.

40.03.2.3.1 Off-site Assembly (Reserved)

Need input

40.03.2.3.2 On-site Assembly

Need input

40.03.3 Reserved

40.03.4 Power and Protection System Fabrication and Assembly

This element covers fabrication and assembly of all of the hardware required to provide current to the solenoid magnet assembly, and also to control and protect it in the event of unusual occurrences such as trips and quenches. Also included in this element are the busses (normally-conducting) which connect the power supply, dump resistor, breaker, and coil. This element does not include any hardware within the vacuum boundary, or any of the conventional or technical facilities required to support power and protection.

40.03.4.1 Power Supply Fabrication and Assembly

This element covers fabrication and assembly of the magnet power supply only. It includes all the hardware and controls between the AC power grid and the terminals of the warm bus. Only local controls on the power supply itself are included here.

40.03.4.2 Buswork Fabrication and Assembly

This element comprises fabrication and assembly of all of the warm (normally-conducting) buswork which connects the high-current components together. Major connections are with the power supply, the dump resistor, the breaker, and the coil.

40.03.4.3 Breakers and Dump Resistors Fabrication and Assembly

This element includes fabrication and assembly of only the breaker and dump resistor required for discharging the magnet.

40.03.4.4. Discharge Resistor and Switch Fabrication and Assembly

This element covers fabrication and assembly of a separate discharge resistor and switch, used for norma discharge of the magnet. This hardware is not required in some power system designs.

40.03.5 Cryogenics Fabrication and Assembly

This element covers fabrication and assembly of all of the cryogenics hardware (LN and LHe) which is installed external to the coil assemblies; this includes the cryogenics plants, storage dewars, and all of the distribution and transfer lines.

40.03.5.1 Liquid Nitrogen System Fabrication and Assembly

This element covers fabrication and assembly of all of the external LN system, including all LN storage, pumping, and transfer/distribution piping up to the vacuum vessel boundary. It is assumed that LN will not be produced on-site, but rather delivered to a local storage dewar.

40.03.5.1.1 LN Storage Dewar Fabrication and Assembly

This element covers fabrication and assembly of the LN storage dewar itself, without piping.

40.03.5.1.2 Reserved

40.03.5.1.3 LN Piping and Distribution Fabrication and Assembly

This element covers fabrication and assembly of all of the piping required to complete the LN system, above and below ground, up to the coil vacuum vessel. It includes all of the LN piping within the cryogenics building, the transfer lines to the coil vessel, and the pump (if any).

40.03.5.2 Liquid Helium System Fabrication and Assembly

This element covers fabrication and assembly of all of the LHe hardware external to the coil vacuum vessel. This includes both the forced and thermosyphon systems, as well as the helium plant above ground, including all piping and distribution.

40.03.5.2.1 Liquid Helium Supply Fabrication and Assembly

This element covers fabrication and assembly of the main helium plant, which supplies LHe to the thermosyphon supply dewar. It includes all of the plumbing between the refrigerator and supply dewar. It does not include the transfer lines to any below-ground systems.

40.03.5.2.1.1 Helium Refrigerator Fabrication and Assembly

This element covers fabrication and assembly of the Helium refrigerator, its associated compressors and oil removal equipment and contamination monitoring only.

40.03.5.2.1.2 Liquid Helium Supply Piping Fabrication and Assembly

This element includes fabrication and assembly of the piping and valving between the refrigerator cold box and supply dewar. It does not include any transfer lines to below-ground systems.

40.03.5.2.1.3 Reserved

40.03.5.2.1.4 Helium Purification Fabrication and Assembly

This element includes fabrication and assembly of the purifiers which remove air and water vapor from contaminated helium.

40.03.5.2.1.5 Gas Storage Fabrication and Assembly

This element includes fabrication and assembly of both the contaminated and clean high pressure gas storage.

40.03.5.2.2 Thermosyphon System Fabrication and Assembly

This element includes fabrication and assembly of the magnet supply and storage dewar and cryogenic transfer lines which supply coolant to the bobbin heat exchanger. It does not include any of the systems to actually produce LHe, or any hardware within the coil vacuum vessel boundary.

40.03.5.2.2.1 Magnet Storage and Supply Dewars Fabrication and Assembly

This element covers fabrication and assembly of the magnet supply dewar and associated valving.

40.03.5.2.2.2 LHe Thermosyphon Distribution Fabrication and Assembly

This element includes fabrication and assembly of the cryogenic transfer lines which couple the supply dewar to the bobbin heat exchanger. The supply side check valve is included here.

40.03.5.2.3 Forced-Flow System Fabrication and Assembly

This element includes fabrication and assembly of the hardware which supplies and conditions the supercritical helium flow to the magnet winding.

40.03.5.2.3.1 LHe Subcooler Fabrication and Assembly

This element includes fabrication and assembly of the heat exchanger which is immersed within the helium supply dewar.

40.03.5.2.3.2 Forced-Flow LHe Piping and Distribution Fabrication and Assembly

This element includes fabrication and assembly of all of the cryogenic transfer lines from the refrigerator to the subcooler, from the subcooler to the coil vacuum vessel and the return from the coil vacuum vessel to the supply dewar.

40.03.6 Magnet Vacuum System Fabrication and Assembly

This element covers fabrication and assembly of all of the vacuum system required to pump down and maintain the magnet system under vacuum. It does not include vacuum hardware associated with the main ring or any other systems.

40.03.6.1 Vacuum Pumps Fabrication and Assembly

This element covers fabrication and assembly of all the vacuum pumps for the magnet vessels, including any foreline pumps, roughing pumps, traps, or booster pumps. Installation is not included here.

40.03.6.2 Vacuum Piping Fabrication and Assembly

This element covers fabrication and assembly of all of the piping, valves, flanges, etc., required for the magnet vacuum system.

40.03.7 Magnet Control Systems Fabrication and Assembly

This element covers fabrication and assembly of all of the local controls for the magnet subsystem. Any control computers or controls in the main operations center are not included in this estimate. It is assumed that safety interlocks are monitored by the main control system, and the local system is responsible only for magnet subsystem operational interlocks, such as "FFSs closed", "LCW on", etc. This control system extends as far as local programmable controllers, but does not include control computers, which are included under slow controls in the electronics subsystem.

40.03.7.1 Power Controls Fabrication and Assembly

This element includes fabrication and assembly of only the controls, operational interlocks, and monitor readouts for the magnet power supply. This element includes all of the magnet system interlock logic required to permit operation of the magnet power supply; individual permissives for each part of the system are included in each element.

40.03.7.2 Protection Controls Fabrication and Assembly

This element includes fabrication and assembly of the controls, operational interlocks, and readouts for the magnet protection system, which includes quench detection, breaker control, dump resistor status, etc.

40.03.7.3 Cryogenics Controls Fabrication and Assembly

This element includes fabrication and assembly of all of the controls, operational interlocks, and readouts for the LN and LHe systems. This includes controls for the refrigerators and all cryogenic valves.

40.03.7.4 Vacuum Controls Fabrication and Assembly

This element covers fabrication and assembly of all of the controls required to operate the magnet vacuum system, which includes pump controls, pressure readouts, valve controllers, etc.

40.03.7.5 Quench Detection and Diagnostics Fabrication and Assembly

This element includes fabrication and assembly of all hardware required for quench detection, except that which is mounted within the vacuum envelope. This includes voltage taps and other items.

40.03.8 Return Field Mitigation Fabrication and Assembly

This element covers fabrication and assembly of all of the hardware required to shield individual components or small volumes from the return field of the magnet, or alternatively, the additional cost of over-specifying components so they will work properly in the field. This includes shielding for vacuum pumps, gages, etc., as well as shielding of local counting rooms and electronic racks below ground. It does not include hardware to shield the above-ground field.

40.03.9 Installation Testing, Tooling Fabrication and Assembly

This element covers fabrication and assembly of all of the hardware temporarily required for installation of magnet subsystem components into their final positions. It does not include any hardware which will be a permanent part of the installation. It also does not include provision of the cranes in the underground hall or the heavy-lift crane for lowering major assemblies down the access shaft.

40.03.9.1 Coil Assemblies Tooling Fabrication and Assembly

This element includes fabrication and assembly of all of the tooling required to handle the coil assemblies from the location at which they were tested above ground to their final position in the underground hall. It also includes any tooling required to anchor them and their support hardware in place and align them. This includes any tooling required to move parts to the access shaft, any specially built rigging which connects the parts to the shaft crane, tooling to move the parts from below the crane to their installed position, and any tooling required for alignment measurement or alignment movement. This element includes only the specially-built tooling which is in addition to the coil and FFS transporters, and normal strongbacks which would be supplied by rigging companies.

40.03.9.2 Reserved

40.03.9.3 Forward Field Shapers Tooling Fabrication and Assembly

This element includes fabrication and assembly of all of the tooling required to move the pole assemblies from the surface to the underground hall and place them in position. If they are to be assembled in the underground hall, the tooling required for assembly is included here as well. This also covers tooling required to mount the support transporters, and align the poles.

40.03.9.4 Testing Equipment Fabrication and Assembly

This element covers fabrication and assembly of all of the equipment required for testing the magnet system after installation. The primary testing equipment will be a system for mapping the magnetic field inside the magnet.

40.04 Installation and System Testing Fabrication and Assembly

This element consists of all installation activities within the magnet subsystem. It includes all activities beginning when components are tested and ready for installation, and ending when they are in place, aligned, checked out, tested, and accepted. This element also includes preparation of all operating and maintenance documentation. This element includes all labor and materials required for these activities, including touch labor, supervision, surveying, engineering oversight, engineering/physics review of test data, preparation of test reports, and resolution of discrepancies during installation. It does not include project management activities.

40.04.1 Installation

This element covers all of the actual installation of magnet subsystem hardware on-site at SSCL. It includes installation of the magnet assemblies in the underground hall, as well as the power and cryogenics systems above-ground. It does not include the assembly of any hardware, except if it occurs during the process of installation.

40.04.1.1 Solenoid Magnet Installation

This element covers the installation of the solenoid magnet assembly in the underground hall. It includes installation of the coil assemblies, coil supports, the FFS assemblies, and the central detector support in the hall. It does not include installation of the power or cryogenics systems.

40.04.1.1.1 Coil Assemblies

This element consists of the installation of the two coil halves. It begins after the coils have been cold-tested above ground, and ends when they are in their proper, aligned position in the underground hall.

40.04.1.1.2 Reserved

40.04.1.1.3 Forward Field Shaper

This element consists of the installation of the two FFSs. It begins after they have been assembled and inspected above ground, and ends when they are in their proper, aligned position in the underground hall.

40.04.1.2 Power and Protection System Installation

This element covers only installation and testing of the power and protection systems. This element does not include controls or the control computer.

40.04.1.3 Cryogenic System Installation

This element covers the installation and testing of all of the cryogenics for the magnet subsystem. It includes installation of the major components in the cryogenics building, installation of the piping and distribution lines within the building and to the underground hall, and testing of these components.

40.04.1.3.1 LN System Installation

This element covers the installation and testing of all of the LN system for the magnet subsystem. It includes installation of the major components in the cryogenics building, installation of the piping and distribution lines within the building and to the underground hall, and testing of these components.

40.04.1.3.2 LHe Systems Installation

This element covers the installation and testing of all of the LHe system for the magnet subsystem. It includes installation of the major components in the cryogenics building, installation of the piping and distribution lines within the building and to the underground hall, and testing of these components.

40.04.1.4 Vacuum System Installation

This element covers installation and testing of all the pumps, valves, piping, traps, pressure sensors, etc. required for the magnet vacuum system. Installation and wiring of controls is not included here. Testing of the system up to the main valves on the vacuum vessel is also included.

40.04.1.5 Control System Installation

This element covers the installation and testing of all the magnet local controls, including readouts and controls for power/protection, cryogenics, and vacuum system. It also covers the installation of a local control room, but not the connection to the main operations center.

40.04.2 Testing

This element covers all subsystem-level testing of the magnet subsystem after installation. This includes initial system checkout testing and extends through magnetic-field mapping. This element includes only testing performed prior to installation of the internal detector subsystems; testing of the detector as a whole is included in operations.

40.04.3 Operation and Maintenance Procedures

This element covers preparation of manuals and procedures for operating and maintaining all magnet subsystem components. Training of operations personnel is included in this element.

40.05 Project Management

This element includes all project-management functions, including administration, cost/schedule monitoring and control, ES&H, QA, and system engineering. It also includes transfer of technology to subcontractors, and engineering oversight. It does not include supervision and engineering oversight of hands-on activities, or engineering required to respond to discrepancies.

40.05.1 Project Management and Administration

This element covers subsystem-level management, including periodic reviews and reporting upward to GEM management. It includes project management, cost/schedule tracking and reporting, and technology transfer from the National Laboratory team to the contractors.

40.05.1.1 Technology Transfer (Reserved)

This element includes the cost of transferring the technical aspects of the National Laboratory design to the contractors involved. This will include preparation of design basis documents as well as presentations to educate the contractor during the design process.

40.05.1.2 Engineering and Management Oversight

This element covers all management and oversight activities within the magnet subsystem. It includes conventional project management activities (cost/progress tracking), integration with other subsystems, safety/environmental control, and reporting to detector management. It also includes technical oversight by the SSCL of the progress of the design, fabrication, installation, and testing. It does not include any management activities for the detector as a whole.

40.05.2 Project Control

This element includes the effort required to maintain magnet subsystem cost/schedule projections, and to monitor actual progress and spending, in order to identify trends and provide information for subsystem and detector management.

40.05.3 ES&H

This element covers all activities required to ensure that magnet subsystem activities are conducted in the safest possible manner, with minimal impact on the environment and the health of the workers and public. It includes safety reviews of subsystem designs, as well as adequate tracking to ensure ES&H requirements are identified and met.

40.05.4 Quality Assurance

This element covers the effort required at the subsystem level to coordinate the magnet quality assurance program. Each individual element within the magnet project must include quality assurance as a basic requirement, but those efforts are costed to the specific elements. This element covers the subsystem-wide effort, including the development of the QA plan, and overall coordination of the effort within the subsystem and with the rest of the GEM system.

40.05.5 System Engineering

This element covers all system engineering activities within the magnet subsystem, including development of requirements, and management of the configuration and interfaces.

40.05.5.1 Requirements and Analysis

This element includes development of the system requirements review, and the accompanying documentation. It includes requirements analysis, and all system-wide analysis, such as reliability, maintainability, and manufacturability.

40.05.5.2 Configuration Management (Reserved)

This element covers the configuration control function only. It includes the maintenance at SSCL of the baseline configuration, and activities required to effect changes through the GEM and SSCL change control procedures, as appropriate.

40.05.5.3 Interface Management (Reserved)

This element covers all activities required to maintain the interfaces between the magnet subsystem and the other detector subsystems. This includes developing interface control documents for each interface, and maintaining and updating them as required.

40.06 Magnet Conceptual and Preliminary Design

This element consists of all GEM magnet design activities prior to approval as an official project; after project approval, final design will begin, under WBS 40.02. This element consists of all engineering and design required for preparation of the LOI, and all engineering and design required for preparation of the technical design report (TDR). Research and development activities associated with this engineering work is included in WBS 40.01 (above). Activities covered here include engineering analysis to define and support the design, preparation of preliminary drawings, preparation of specifications, integration with other subsystems, documenting the design, preparing the LOI and TDR documents, cost estimating, etc. This element does not include final design. Most elements in this WBS element are directly related to elements in WBS 40.0.

40.06.1 Pre-LOI Engineering and Design

This element covers all engineering activity within the magnet subsystem, starting with approval of the GEM EOI, and ending with submission and defense of the GEM LOI. This includes all design and cost-estimating work, as well as attendance at meetings, preparation of presentations, etc.

40.06.2 LOI to Technical Design Report (TDR)

This element covers all magnet engineering and design activities after the LOI preparation and defense, and through preparation and defense of the TDR. This includes analysis, preliminary design, and preparation of specifications for procurement of the major components. The technical scope of this design effort is all of the assemblies and elements required to provide the magnetic field in the interior of the detector. It includes the coils, coil forms, radiation shields, cold mass supports, vacuum vessels, end poles, current leads, cryogenic (LN and LHe) systems, and power and protection systems. It also includes components required to support the solenoid and end poles from the ground, the support for the central detectors, the attachment points for the muon and calorimeter subsystems, and any special tooling necessary to install any of these components. This subsystem does not include the building cranes, assembly buildings, or any concrete support features below the detector. Major interfaces are with: underground hall, above-ground facilities, muon subsystem, calorimeter subsystem, and the ring magnet system.

40.06.2.1 Preliminary Design

This element covers preliminary design activities for the magnet subsystem. It does not include actual preparation of the TDR, or the analysis tasks which are common to most assemblies. The technical scopes of these tasks are directly related to WBS 40.02 Magnet Subsystem (Construction). This element does include preparation of specifications for use in procurement.

40.06.2.1.1 Solenoid Magnet

This element covers preliminary design work on all the magnet subsystem components which are to be installed within the underground hall, except for parts of the cryogenic systems. This includes the coil assemblies(consisting of conductor wound on coil forms, plus the radiation shields, the cold-mass supports, and the vacuum vessels), the components which support this system from the ground, the poles and pole supports, and the support for the central detectors. This does not include the thermosyphon supply dewars, cryogenic piping external to the vessels, or current leads external to the vessel. Physical attachment points for the central region muon subsystem and calorimeter are included. Major interfaces are with the underground hall, above-ground facilities, the calorimeter subsystem, the muon subsystem, and the ring magnet system.

40.06.2.1.1.1 Coil Assemblies

This element covers preliminary design of all the components which are physically a part of the completed coil assemblies; these assemblies are the parts which will be assembled above-ground and delivered for installation in the underground hall. This includes the coils, the thermal radiation shields, the vacuum vessels, the cold-mass supports, and all cryogenic piping and distribution and current bussing which are within the vacuum-vessel boundary. This does not include the components required to physically support the coil assemblies, the end poles/pole supports, or the central detector supports. It also does not include the local thermosyphon supply dewars or any cryogenic piping external to the vacuum vessel boundary. Major interfaces are with the underground hall, the above-ground facilities, the poles/pole supports, the muon subsystem, and the central detector support.

40.06.2.1.1.1.1 Coil Subassemblies

This element consists of preliminary design of the magnet coils only, which are made up of conductor wound on coil forms, with any required diagnostics installed. It includes all activities, parts, and tooling required to produce the coils. This does not include the LHe thermosyphon or LHe forced-flow cryogenic piping/distribution. Major interfaces are with the cold-mass supports, the vacuum vessels, the radiation shields, and the internal cryogenic systems.

40.06.2.1.1.1.1.1 Coil Form

This element comprises preliminary design of, and specification preparation for, the coil form within which the coil is wound. The coil form includes ribs to accept axial conductor loads, and attachment points for the cold-mass supports.

40.06.2.1.1.1.1.2 Conductor

This element includes all activities required to perform preliminary design of the conductor which makes up the coil. The conductor includes the SC wire, the stabilizer, and the passage for the forced-flow LHe. This element includes all of these parts, even if they are designed to be physically separate. The conductor is to be delivered on large spools, ready for winding into the coil forms. This does not include development work, to verify the design or to develop tooling. The preliminary design of the tooling is included.

40.06.2.1.1.1.1.3 Reserved

40.06.2.1.1.1.1.4 Winding Tooling

This element covers design of all the winding tooling, which includes all of the tooling required to remove the conductor from the storage drums and wind it into final position in the coil form. Any tooling or hardware required for gluing or otherwise affixing the conductor in place is included in this element.

40.06.2.1.1.1.2 Thermal Radiation Shields

This element covers all preliminary design and specification preparation required to produce the LN-cooled thermal radiation shields and all other heat-shielding parts. Included in this element are the inner, outer, and end shields, the thermal-intercept hardware for the cold-mass supports, the multilayer insulation, attachment points for mechanical supports, and the supports themselves if they are different from the main cold-mass supports. This does not include standard piping and manifolding for LN distribution within the vacuum vessel. Any tooling required to assemble the radiation shields is included.

40.06.2.1.1.1.3 Vacuum Vessel Subassemblies

This element includes the preliminary design and specification of all of the parts required to establish a vacuum boundary around the coil: the inner and outer cylindrical vessels, the end plates, and any parts which are required to physically support the vessels. This does not include vacuum pumps or vacuum piping. It does include attachment points for the central muon subsystem and any tooling required for fabricating the vessels. Also included are any components attached to the outer vessel to withstand operational loads.

40.06.2.1.1.1.4 Cold Mass Supports

This element includes the preliminary design and specification all of the mechanical supports for the 4K cold mass. Support for the LN radiation shields is included here, unless separate supports are found to be necessary. This element includes all of the rods, fasteners, etc. required.

40.06.2.1.1.1.5 Internal Cryogenic Systems

This element includes the preliminary design and specification of all cryogenic piping and distribution which is enclosed in the vacuum vessel. This does not include any systems which are installed after coil assembly has been installed in the underground hall. It does include all LHe and LN bayonets, manifolding, and piping which is installed separately from the coil sub-assembly and radiation shields.

40.06.2.1.1.1.6 Cryogenic Current Leads

This element covers the preliminary design and specification of the current leads which are installed after the coil is assembled into the vacuum vessels, and which are at cryogenic temperature. It does not include the warm current busses which are external to the vacuum vessel.

40.06.2.1.1.1.7 Assembly and Testing Equipment

This element covers preliminary design and specification of all of the hardware required to assemble the wound coil subassembly into the radiation shields and vacuum vessels, make up all internal electrical and fluids connections, verify all connections, rotate the assembly into its final orientation, and perform all checks prior to installation in the underground hall. It does not include provision for testing the coil assemblies at LHe temperature, or under significant current. It does include provision of leak hunting equipment and LN as required for thermal-shock testing. It also includes any temporary supports for the assemblies (other than those to be used for permanent installation in the underground hall).

40.06.2.1.1.2 End Poles and Supports

This element covers the preliminary design and specification of the magnetic steel end poles for the solenoid, along with their supports. This includes attachment points for the muon endcap subsystem, as well as the transporter required for moving the poles for installation and maintenance. It does not include the fixtures required for installing the poles in the underground hall.

40.06.2.1.1.3 Detector Supports

This element covers the preliminary design and specification of any separate hardware required to support other subsystems within the magnet. It does not include simple attachment points on magnet components (such as those required for central-region muon sector support). This element includes the central detector support and the forward calorimeter support at this time.

40.06.2.1.2 Power and Protection System

This element covers the preliminary design and specification of all of the hardware required to provide current to the solenoid magnet assembly, and also to control and protect it in the event of unusual occurrences such as trips and quenches. Also included in this element are the busses (normally-conducting) which connect the power supply, dump resistor, breaker, and coil. This element does not include any hardware within the vacuum boundary, or any of the conventional or technical facilities required to support power and protection.

40.06.2.1.3 Cryogenics

This element covers preliminary design and specification of all of the cryogenics hardware (LN and LHe) which is installed external to the coil assemblies; this includes the cryogenics plants, storage dewars, and all of the distribution and transfer lines.

40.06.2.1.4 Vacuum System

This element covers preliminary design and specification of the vacuum system required to pump down and maintain the magnet system under vacuum. It does not include vacuum hardware associated with the main ring or any other systems.

40.06.2.1.5 Magnet Control Systems

This element covers preliminary design and specification of all of the local controls and diagnostic readouts required to operate the magnet subsystem. These controls will be brought together in a local control room, from which all magnet operations can be conducted. Controls in the main operations center are not included in this estimate. It is assumed that safety interlocks are monitored by the main control system, and the local system is responsible only for magnet subsystem operational interlocks, such as "poles closed", LCW on, etc.

40.06.2.1.6 Reserved

40.06.2.1.7 Installation Tooling

This element covers preliminary design and specification of all of the hardware temporarily required for installation of magnet subsystem components into their final positions. It does not include any hardware which will be a permanent part of the installation.

40.06.2.1.8 Conventional and Technical Facilities

This element covers all activities associated with defining requirements for conventional facilities at SSCL, including both the underground hall and the surface facilities. Also included is effort associated with defining and maintaining the magnet/technical facilities/conventional facilities interface.

40.06.2.2 Analysis

This element covers analysis effort which supports the preliminary design, but in tasks which are common to many component design efforts. These analyses will be essentially stand-alone tasks, which will interface continually with the ongoing design efforts.

40.06.2.2.1 Magnetic Field and Force Analysis

This element provides for analysis to determine the magnetic field at any interesting points in space, to predict the resulting performance, and to predict magnetic forces on any concerned components.

40.06.2.2.2 System Thermal Analysis

This element covers a comprehensive thermal analysis of the magnet subsystem, focusing on the solenoid magnet assembly. This analysis will determine heat loads to the various cryogenic systems, and operating temperatures for critical parts (such as cold-mass supports).

40.06.2.2.3 System Structural Analysis

This element includes a complete structural analysis of the solenoid magnet assembly, including cold-mass, cold-mass supports, shields, vessels, saddles, poles, etc. This analysis will support the mechanical design of most of these components.

40.06.2.2.4 Magnetic Shielding Analysis

This element covers continued analysis of fringe fields, outside the bounds of the magnet volume. This includes both fields at the surface and fields inside the underground hall but outside the detector. This analysis will support the design of any magnetic field shields.

40.06.2.2.5 Reserved

40.06.2.3 TDR Preparation

This element covers actual preparation and defense of the TDR. This includes writing the magnet subsystem chapter, preparing graphics for the report, reviewing other subsystems, contributing to the cost volume, and making oral presentations.

40.06.2.4 Magnet Subsystem Management and Integration

This element covers management of both the preliminary design and the research and development efforts through the approval of the EDR. This element includes integration activities with other subsystems and with SSCL, though it does not include facility interfaces. It includes project tracking, monitoring, and reporting, as well as attendance at collaboration meetings, engineering meetings, technical reviews, etc.

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522.5050 Electronics

This elements includes the electronics, trigger, and data acquisition subsystems that comprise the GEM readout. The electronics system starts with the preamplifiers and ends at the interface to the on-line computing system. It includes the labor and material costs associated with the design, prototyping, production fabrication, and the portion of the installation and test phase associated with connecting the electronics and verifying that they are properly operating.

The paragraphs that follow describe specific aspects of the interface between the electronics subsystems and the detector subsystems.

The Calorimeter subsystem includes the "motherboard" i.e., the printed circuit board upon which the components for the preamplifier and calibration circuits will be mounted. The active components that comprise the preamplifiers and the calibration circuitry are part of the electronics subsystem. In practice, this means that the electronics subsystem will provide hybrids that plug into the motherboards. Also included in the electronics subsystem are the cables, both inside of and outside of the cryostat, the crates used to house cable drivers (i.e., the "junction boxes"), and all associated circuitry.

The Hadronic Calorimeter includes the phototubes, their bases, and the electronics housed in those bases. The electronics subsystem includes the cables used to carry high- and low-voltage power to the bases and the signal cables used to carry the signals to the rest of the electronics chain.

The Muon subsystem includes the printed circuit boards that comprise the cathode and anode planes and any components permanently affixed (i.e., soldered, glued, or bolted) to those boards. Also included in the muon system are any mounting brackets, cooling plates, and plumbing, that are not components of assembly of the readout circuit boards. Thus the common water-cooled cold plate to which the boards are to be bolted is included as part of the muon subsystem, whereas the cold plates that are permanently attached to the individual front-end circuit boards are included as part of the electronics. The chamber-mounted front-end boards as well as all associated control, DAQ, and trigger boards are included as part of the electronics subsystem. The electronics subsystem also includes the cables and/or the printed circuit boards used to route the signals from the cathode (or anode) planes to the front-end circuit boards. Cable trays, conduits, and/or other fixturing needed to support the cables are included along with the associated design effort as part of the muon subsystem.

The DAQ portion of the electronics subsystem includes the data collection electronics, the event-building network (i.e. the "switch"), and all associated data buffers (i.e., the EDCs and the EDDs); but does not include the computers that comprise the ``Level 3" processor ranch, which are part of the on-line Computing subsystem.

The sensors and modules needed for acquisition of slow control input data from the electronics subsystem (e.g., thermocouples, voltage and current probes, and scanning ADCs) are part of the electronics subsystem. The crates, their readout controllers, and their power supplies as well as the network hardware and software required to interconnect the slow control crates and computers are part of the on-line Computing subsystem.

50.01 Research and Development

This element includes any effort necessary to define the appropriate technologies, or application of those technologies, for the GEM electronics. This effort may occur throughout the early phases of the project.

50.01.1 Silicon Tracker

This element includes all efforts associated with the silicon tracker electronics development.

50.01.1.1 Bipolar

This element covers the activities for developing the bipolar analog chip.

50.01.1.2 CMOS I

This element covers the activities for developing the CMOS-1 data driven buffer.

50.01.1.3 CMOS II

This element covers the activities for developing the CMOS-1 data driven buffer.

50.01.1.4 MCM

This element covers the activities for developing the MCM, multi-chip module.

50.01.1.5 Fiber Optics

This element covers the activities for developing the fiber optics links.

50.01.1.6 Clock Distribution

This element covers the activities associated with developing the clock distribution.

50.01.1.7 Cable

This element covers the activities associated with developing the silicon tracker cabling.

50.01.1.8 Test Station

This element covers the activities associated with developing a test station for evaluating prototype silicon tracker electronics.

50.01.2 IPC

This element includes all efforts associated with the IPC electronics development.

50.01.2.1 Preamp IC

This element covers the activities for developing the IPC preamplifier IC.

50.01.2.2 SCA IC

This element covers the activities for developing the IPC switched capacitor array IC.

50.01.2.3 SCA Test Station

This element covers the activities associated with developing a test station for evaluating the prototype IPC electronics.

50.01.3 Calorimeter Front-end

This element includes all efforts associated with the calorimeter electronics development.

50.01.3.1 Readout Electronics

This element includes all efforts associated with the calorimeter readout electronics development.

50.01.3.1.1 Preamplifier Research and Development

This element covers the activities for developing the calorimeter preamplifier circuits.

50.01.3.1.2 Calibration Circuit Research and Development

This element covers the activities for developing the calorimeter calibration circuit.

50.01.3.1.3 Shaper Amplifier Research and Development

This element covers the activities for developing the shaper amplifier circuit.

50.01.3.1.4 Cable Driver Research and Development

This element covers the activities for developing the cable driver circuit.

50.01.3.1.5 SCAIC Driver Research and Development

This element covers the activities for developing the switched capacitor array IC.

50.01.4 Muon Front-end

This element includes all efforts associated with the muon system electronics development.

50.01.4.1 CSC System Research and Development

This element covers the activities associated with developing the CSC electronics system.

50.01.4.2 CSC Preamp Research and Development

This element covers the activities for developing the CSC preamiplifier circuit.

50.01.4.3 CSC Anode Research and Development

This element covers the activities associated with developing the CSC anode readout electronics.

50.01.5 Level 1 - Trigger

This element includes all efforts associated with the Level 1 trigger development.

50.01.5.1 CAL Level 1 Research and Development ·

This element includes all efforts associated with the Level 1 calorimeter trigger development.

50.01.5.1.1 CAL Level 1 Research and Development (Analog)

This element covers the activities associated with developing the analog Level 1 calorimeter trigger.

50.01.5.1.2 CAL Level 1 Research and Development (Digital)

This element covers the activities associated with developing the digital Level 1 calorimeter trigger.

50.01.5.2 Muon Level 1 Trigger Research and Development

This element includes all efforts associated with the Level 1 muon trigger development.

50.01.5.2.1 Muon Level 1 Trigger Research and Development (Combo)

This element covers the activities associated with developing the combinational logic Level 1 muon trigger.

50.01.5.2.2 Muon Level 1 Trigger Research and Development (CAM)

This element covers the activities associated with developing the content addressable memory Level 1 muon trigger.

50.01.6 DAQ

This element includes all efforts associated with developing the GEM data acquisition system.

50.01.7 FY92 Expenditure

This element includes all electronics research and development efforts funded in FY92.

50.02 Front-End

This element includes all efforts associated with the fabrication, assembly, and testing of the front-end electronics.

50.02.1 Muon

This element includes all efforts associated with the fabrication, assembly, and testing of the muon electronics.

50.02.1.1 CSC 2nd Coordinate Readout

This element includes all efforts associated with the fabrication, assembly, and testing of the CSC 2nd coordinate readout electronics.

50.02.1.1.1 Design and Documentation

This element includes the efforts associated with design and documentation of the CSC 2nd coordinate readout.

50.02.1.1.2 Prototype CSC Anode Electronics

This element includes all efforts associated with the fabrication, assembly, and testing of the prototype CSC anode electronics.

50.02.1.1.2.1 High Voltage (HV)

This element includes the efforts associated with the procurement, assembly, and testing of the high voltage system.

50.02.1.1.2.1.1 Power Supply

This element includes the efforts associated with the procurement, assembly, and testing of the high voltage power supplies.

50.02.1.1.2.1.2 Distribution

This element includes the efforts associated with the procurement, assembly, and testing of the high voltage distribution system.

50.02.1.1.2.2 Low Voltage (LV)

This element includes the efforts associated with the procurement, assembly, and testing of the low voltage system.

50.02.1.1.2.2.1 Power Supply

This element includes the efforts associated with the procurement, assembly, and testing of the low voltage power supplies.

50.02.1.1.2.2.2 Distribution

This element includes the efforts associated with the procurement, assembly, and testing of the low voltage distribution system.

50.02.1.1.2.3 Signal Cables

This element includes the efforts associated with the procurement, assembly, and testing of the signal cable system.

50.02.1.1.2.3.1 Signal Feed (PCB1 to PCB2)

This element includes the efforts associated with the procurement, assembly, and testing of the signal cables from PCB1 to PCB2.

50.02.1.1.2.3.2 Signal Feed (PC Timing Strobe Signal Cables B1 to PCB2)

This element includes the efforts associated with the procurement, assembly, and testing of the signal cables from B1 to PCB2.

50.02.1.1.2.4 Active Components

This element includes all efforts associated with the fabrication, assembly, and testing of the active components for the muon system.

50.02.1.1.2.4.1 Integrated Preamplifier and Driver

This element includes all efforts associated with the fabrication, assembly, and testing of the integrated preamplifier and driver.

50.02.1.1.2.4.2 Integrated 24 Channel Multi-function (Shaper/Disc./AND-R/SCA/ADC)

This element includes all efforts associated with the fabrication, assembly, and testing of the 24 channel multi-function IC.

50.02.1.1.2.4.3 Control ASIC (Address List Processor and Data Collection Chip)

This element includes all efforts associated with the fabrication, assembly, and testing of the control ASIC.

50.02.1.1.2.5 Printed Circuit Boards

This element includes all efforts associated with the fabrication, assembly, and testing of the printed circuit boards.

50.02.1.1.2.5.1 6-Plane Interface Board (PCB1)

This element includes all efforts associated with the fabrication, assembly, and testing of the 6-plane interface board (PCB1).

50.02.1.1.2.5.2 Signal Processing Board (PCB2)

This element includes all efforts associated with the fabrication, assembly, and testing of the signal processing board (PCB2).

50.02.1.1.2.6 Crate and Rack

This element includes the effforts associated with the procurement, assembly, and testing of the crates and racks.

50.02.1.1.2.7 Control and Data Links

This element includes the effforts associated with the procurement, assembly, and testing of the control and data links.

50.02.1.1.2.7.1 Control Bus

This element includes the effforts associated with the procurement, assembly, and testing of the control bus.

50.02.1.1.2.7.2 Data Bus

This element includes the effforts associated with the procurement, assembly, and testing of the data bus.

50.02.1.1.3 Production System

This element includes all efforts associated with the fabrication, assembly, and testing of the production CSC.

50.02.1.1.3.1 High Voltage

This element includes the efforts associated with the procurement, assembly, and testing of the high voltage system.

50.02.1.1.3.1.1 Power Supply

This element includes the efforts associated with the procurement, assembly, and testing of the high voltage power supplies.

50.02.1.1.3.1.2 Distribution

This element includes the efforts associated with the procurement, assembly, and testing of the high voltage distribution system.

50.02.1.1.3.2 Signal Cables

This element includes the efforts associated with the procurement, assembly, and testing of the signal cable system.

50.02.1.1.3.2.1 Signal Feed (PCB1 to PCB2)

This element includes the efforts associated with the procurement, assembly, and testing of the signal cables from PCB1 to PCB2.

50.02.1.1.3.2.2 Timing Strobe Signal Cables

This element includes the efforts associated with the procurement, assembly, and testing of the signal cables from B1 to PCB2.

50.02.1.1.3.3 Active Components

This element includes all efforts associated with the fabrication, assembly, and testing of the active components for the muon system.

50.02.1.1.3.3.1 Integrated Preamp and Driver

This element includes all efforts associated with the fabrication, assembly, and testing of the integrated preamplifier and driver.

50.02.1.1.3.3.2 Integrated Function IC (Shaper/Disc./AND-OR/SCA/ADC)

This element includes all efforts associated with the fabrication, assembly, and testing of the 24 channel multi-function IC.

50.02.1.1.3.3.3 Control ASIC (ALP/DDC)

This element includes all efforts associated with the fabrication, assembly, and testing of the control ASIC.

50:02.1.1.3.4 Printed Circuit Boards

This element includes all efforts associated with the fabrication, assembly, and testing of the printed circuit boards.

50.02.1.1.3.4.1 6-Plane, 4 Layer Interface Board (PCB1)

This element includes all efforts associated with the fabrication, assembly, and testing of the 6-plane interface board (PCB1).

50.02.1.1.3.4.2 96-Channel Signal Processing Board (PCB2)

This element includes all efforts associated with the fabrication, assembly, and testing of the signal processing board (PCB2).

50.02.1.1.3.5 Control and Data Links

This element includes the effforts associated with the procurement, assembly, and testing of the control and data links.

50.02.1.1.3.5.1 Control Bus

This element includes the effforts associated with the procurement, assembly, and testing of the control bus.

50.02.1.1.3.5.2 Data Bus

This element includes the effforts associated with the procurement, assembly, and testing of the data bus.

50.02.1.1.4 Installation and Test

This element includes all efforts associated with the installation and testing of the CSC 2nd coordinate readout.

50.02.1.2 CSC Pad (925K Channels)

This element includes the design, prototyping, construction, installation , and testing of the cathode readout electronics for the cathode strip muon chambers. The system begins at the chamber and ends at the output end of the optical fiber that supplies digital data to the DAQ event data collection (EDC) modules.

50.02.1.2.1 Design and Documentation

This element includes the preliminary and conceptual design of the front CSC cathode electronics, its cost estimate, and the generation of a complete set of as-built drawings and documents.

50.02.1.2.2 Prototype

This element includes all labor and procurements needed to produce a complete pilot system suitable for validation of the design. The pilot system will comprise enough channels to instrument a set of modules suitable for a test beam. In this estimate most of the detailed design and prototyping costs have been included in this section of the WBS.

50.02.1.2.2.1 Prototype HVPS

This item includes the cost of a set of high-voltage power supply modules for prototype tests. This item does not include the cost of prototyping the HVPS system for the production readout, which is part of the CSC anode readout subsystem.

50.02.1.2.2.2 Prototype LVPS

This item reflects the costs of designing and prototyping the low-voltage power supply (LVPS) system for the CSC readout electronics. Both cathode and anode readouts are included since the two systems will use a common LVPS system.

50.02.1.2.2.3 Prototype Cath Cables

This element includes the effort for designing and prototyping three sets of cables: multi-conductor shielded flat cables running between the chambers and the front-end printed circuit boards (FEPCBs); multi-conductor flat cables carrying digital data from the FEPCBs to the readout printed circuit board (ROPCB); and multi-conductor flat cables carrying digital data between the FEPCBs the trigger section of the ROPCBs. Also included is the cost of special tooling needed to automate the production of multi-conductor shielded cathode flat cables.

50.02.1.2.2.4 Prototype Active Components

This element includes the effort for designing, prototyping and testing application specific integrated circuits (ASIC's) for the pilot system. It also includes the cost of procuring a quantity of components that is sufficient for the pilot system. In the case of commercial components there are no design and prototyping costs. When appropriate the cost of developing a suitable test fixture for the IC's is included as part of the prototype costs.

50.02.1.2.2.4.1 Prototype PASA IC

This element is a low-noise CMOS IC that amplifies and shapes the signals from the cathode pads. The PASA IC provides fast- and slow-shaped outputs. Prototype fabrication runs are assumed to be performed using a MOSIS-type multi-project service. Small-scale preproduction runs are included to validate yield assumptions, to verify manufacturability, and to provide parts for pilot system tests.

50.02.1.2.2.4.2 Prototype SCA IC

This IC accepts shaped analog signals from the PASA IC's and samples and holds these signals pending analog to digital conversion. The SCA IC also contains circuitry that discriminates the fast-shaper signals. The digital output of these discriminators is used to identify charged-track candidates.

Prototype fabrication runs are assumed to be performed using a MOSIS-type multi-project service. Small-scale preproduction runs are included to validate yield assumptions, to verify manufacturability, and to provide parts for pilot system tests.

50.02.1.2.2.4.3 Prototype ALP IC

This IC controls the read and write addresses of the SCA IC's and the sequence of analog-to-digital converter operations. It also buffers the data pending readout by the ROPCB. Prototype fabrication runs are assumed to be performed using a MOSIS-type multi-project service. Small-scale preproduction runs are included to validate yield assumptions, to verify manufacturability, and to provide parts for pilot system tests.

50.02.1.2.2.4.4 Prototype ADC

This element includes a 10-bit analog-to-digital conversion. A commercial part will be used. This IC accepts analog inputs from the SCA IC's through a system of analog multiplexers and provides

50.02.1.2.2.5 Prototype Printed Circuit Board

This element includes the effort for designing, prototyping and testing prototype printed circuit boards (PCB's) for the pilot system. It also includes the cost of assembling a quantity of boards that is sufficient for the pilot system. PCB costs include the costs of the PCB's proper as well as the cost of connectors and miscellaneous components (capacitors, resistors, and "common" IC's not explicitly accounted for in the Active Components section of this WBS). When appropriate the cost of developing a test fixture and/or burn-in facility is included as part of the prototype costs.

50.02.1.2.2.5.1 96 Prototype CH FE PCB

This element includes the effort for designing, prototyping, and evaluating the FEPCB circuit board, which houses the PASA, SCA, ALP, ADC, and analog multiplexer IC's. The FEPCB is mounted in close proximity to the chamber modules. Included as an integral part of the FEPCB is a metal backing plate, which provides thermal contact between the FEPCB and the main cooling system. This item includes the cost of a test and burn-in facility for the FEPCBs.

50.02.1.2.2.5.2 Prototype Readout PCB

This element includes the effort for designing, prototyping, and evaluating the ROPCB circuit board, which is used to collect data from the FEPCBs. The ROPCB also collects and retransmits trigger signals from the FEPCBs. This item includes the cost of a test facility for the ROPCBs.

50.02.1.2.2.6 System Test of Pilot Electronics

This element includes the effort for testing the prototype electronics in the test beam. This activity will be staffed primarily by physicists, whose costs are not included here. Salary and travel support for technicians is, however, included.

50.02.1.2.3 Production

This element includes the effort associated with mass production of the CSC cathode electronics. This includes engineering effort associated with minor design changes resulting from an evaluation of the pilot system (prototype) tests, one-time NREs and setup charges needed to initiate large scale production, procurement and assembly costs, and the costs of testing components and subassemblies prior to shipment to the SSCL.

50.02.1.2.3.1 Production LVPS

This element includes labor and material for supplying low-voltage power to the in-detector readout electronics. The low voltage system consists of a set of AC-DC converters that supply 300 VDC to a set of detector-mounted DC-DC converters that supply low voltage via copper cables to the chamber mounted electronics. The DC-DC converters typically reside in a region that has ambient fields in the few-kG range, necessitating the use of soft iron shields, which are included as part of the LVPS cost. Also included is the cost of cabling used to transmit current from the AC-DC converters to the DC-DC converters and the cost of the cabling running between the DC-DC converters and the in-detector electronics. The LVPS system powers both the cathode and the anode readout electronics.

50.02.1.2.3.2 Signal Cables

This element includes labor and material for prccuring , assembling, and testing various flat cables.

50.02.1.2.3.2.1 Production Data Cable

This element includes labor and material for procuring, assembling, and testing the digital data cables that run between the FEPCBs and the ROPCB.

50.02.1.2.3.2.2 Production Trigger Cable

This element includes labor and material for procuring, assembling, and testing the digital trigger cables that run between the FEPCBs and the ROPCB.

50.02.1.2.3.2.3 Production Cath Signal Cable

This element includes labor and material for procuring, assembling, and testing the 34-conductor flat cables that run between the chamber cathode boards and the FEPCBs. It is assumed that special tooling will be used to automate the connection of the shielding braid to the ground pins of the connectors.

50.02.1.2.3.3 Active Components

This element includes labor and material for procuring and testing integrated circuits for the production of the readout electronics. Functional descriptions of the integrated circuits can be found in the "Prototype Active Components" section above (i.e., WBS 50.02.1.2.2.4). Custom IC's will be tested via wafer probe before packaging. After packaging, each IC will be subjected to a second set of functional tests and calibration procedures.

50.02.1.2.3.3.1 Production PASA IC

This element includes labor and material for procuring and testing the production preamplifier-shaper IC's.

50.02.1.2.3.3.2 Production SCA IC

This element includes labor and material for procuring and testing the production SCA IC's.

50.02.1.2.3.3.3 Production ALP IC

This element includes labor and material for procuring and testing the production control/address list processor IC's.

50.02.1.2.3.3.4 Production ADC IC

This item includes the cost of procuring the production ADC IC's. The ADC's are a commercial product and are assumed to have been tested prior to shipment.

50.02.1.2.3.3.5 Production Analog MUX

This element includes labor and material for procuring and testing the production analog multiplexer IC's. The multiplexers are a commercial product and are assumed to have been tested prior to shipment.

50.02.1.2.3.4 Printed Circuit Board

This element includes labor and material for procuring the printed circuit boards proper, loading them with components and testing and/or burning in the completed subassemblies. Functional descriptions of the boards can be found under "Prototype Printed Circuit Boards" (WBS 50.02.1.2.2.5) above.

50.02.1.2.3.4.1 Production 96 CH FE PCB

This element includes labor and material for procuring, loading, testing and burning in the FEPCBs.

50.02.1.2.3.4.2 Production Readout PC

This element includes labor and material for procuring, loading, testing and burning in the ROPCBs.

50.02.1.2.3.5 Fiber Link

This element includes labor and material for optical fibers used to carry digital data between the ROPCBs and the DAQ. The link costs include the transmitter and the fiber, but not the receiver, which is part of the DAQ.

50.02.1.2.4 Installation and Test

This element includes labor and material for installing and testing the electronics on the chambers at the SSCL. It is assumed that all subassemblies have been tested prior to shipment to the SSCL.

50.02.1.2.4.1 Installation Boards on CSC

This element includes labor and material for physically mounting the FEPCBs and the ROPCBs on the chambers. It is assumed that this operation takes place on a supersector-by-supersector (1/12 of an azimuthal ring) basis in one of the above ground assembly buildings. This item includes the labor necessary to complete the cabling that runs between the FEPCBs, the ROPCBs and the outside world. It also includes cabling for LVPS, HVPS, and slow control. Installed cards will be tested as a subsystem using calibration pulsers and/or cosmic ray events.

50.02.1.2.4.2 Installation CSC's in Detector

This element includes the electronics portion of the effort needed to connect the pre-cabled supersector assemblies to the outside world--i.e. LVPS, HVPS, and optical fibers for data transmission in to and out of the detector.

50.02.2 Central Tracker

Need input

50.02.2.1 Silicon Tracker Front End

This element includes all the design, layout, fabrication, procurement, setup, test and prototyping activities for all the electronics and related items residing within the silicon tracker envelop such as integrated circuits, multi-chip modules, clock distributors, cables and fiber optics. It also includes the computer-based test setups for the delivery and installation of the silicon tracker at the field site as well as the cabling and fiber-optic links between the silicon tracker and the Level-1 trigger raw data buffer inside the cable shaft room. Items not included are the interfaces between the raw buffer and the GEM data acquisition installations, and the utilities to supply the space and power to the silicon tracker operation.

50.02.2.1.0 Bipolar

This element includes the design, layout fabrication, test and prototyping activities of integrated circuit chips produced in bipolar technology. The chip is to be mounted on the multi-chip module (WBS 50.02.2.1.3) and consists of multiple channels connected to the silicon strip detectors at the input end, and to the CMOS-1 (WBS 50.02.2.1.1) chip at the output end. It collects charges from the strip detectors, converts into voltage waveforms, amplifies, and shapes the waveforms before level-discrimination to determine the hit/no-hit of high energy particles for each strip per every beam crossing.

50.02.2.1.1 CMOS-1

This element includes the design, layout, fabrication, test and prototyping activities of integrated circuit chips produced in CMOS technology. The chip is to be mounted on the multi-chip module (WBS 50.02.2.1.3) and contains multiple channels connected to the bipolar chip (WBS 50.02.2.1.0) at the input end, and to the CMOS-2D (WBS 50.02.2.1.2.1) chip at the output end. It receives the logic signal from the bipolar chip, buffers the hit/no-hit information, and, at the receipt of Level-1 trigger, compresses the data and reads it out to CMOS-2D.

50.02.2.1.2 CMOS-2

Need input

50.02.2.1.2.1 CMOS-2D

This element includes the design, layout, fabrication, test and prototyping activities of integrated circuit chips produced in CMOS technology. The chip is to be mounted on the multi-chip module (WBS 50.02.2.1.3) and connects to the CMOS-1 (WBS 50.02.2.1.1) chip at the input end and to the fiber optics (WBS 50.02.2.1.2.4) at the output end. It receives the logic signal from the CMOS-1 chips on the multi-chip module, and directs it to the fiber optics multiplexer/driver.

50.02.2.1.2.2 CMOS-2A

This element includes the design, layout, fabrication, test and prototyping activities of integrated circuit chips produced in CMOS technology. The chip is to be mounted on the multi-chip module (WBS 50.02.2.1.3) and connects to the bipolar chip (WBS 50.02.2.1.0) and the CMOS-2D (WBS 50.02.2.1.2.1) at the input end, and to the slow control at the output end. It monitors various bias levels on the bipolar chips, digitizes and transmits the data to the slow control in a serial format.

50.02.2.1.3 Multi-Chip Module

This element includes the design, layout, fabrication, test and prototyping activities of modules as carriers of all the items listed above. Internal to the module, it interconnects the chips and components on the substrate. Externally, it provides connections to the silicon strip detectors and cables for all the signals and powers. It also serves as a heat transfer medium between the chips as heat generator and the cooling ring as heat sink.

50.02.2.1.4 Fiber Optics

This element includes the design, layout, fabrication, test, prototyping, assembly and installation activities of the fiber optic data link between the multi-chip module and the uphole data acquisition. It consists of MUX/driver and the LED transmitters on the MCM, optical receivers on the data acquisition, and the optical fibers in between.

50.02.2.1.5 Power Supplies

This element includes the design, procurement, installation and testing of the power supplies to operate the integrated circuit chips, LED's and strip detectors inside the silicon-tracker envelope. It does not include, however, the cabling of power lines, nor the power supplies for the data acquisitions which is external to the silicon tracker.

50.02.2.1.6 Cables

This element includes the design, layout, procurement, installation and assembly of the interconnecting cables internal to the silicon tracker envelop as well as all the connections between the silicon tracker and the power supplies/slow control in the cable shaft room. Internal to the silicon tracker, all the trunk cables for a group of multi-chip modules, cabling between the multi-chip modules and the trunk cables, and cabling between the clock distributor and the multi-chip module are included. The cabling between data acquisition and the trigger is not included.

50.02.2.1.7 Test Station

This element includes the design, layout, procurement, setup and prototyping support for the test and qualification of the fully populated multi-chip modules and the fully assembled ladder. The station is composed of computers, signal interface cards, precision clocks, pulse generators, power supplies and software for the stimulation, control and data readout as well as data display and archiving.

50.02.2.1.8 Clock Distribution

This element includes the design, layout, procurement, fabrication, prototype support and testing of the hybrid circuit for the distribution of the master clock and Level-1 trigger information. The hybrid circuit contains an optical receiver, oscillator, phase-lock loop and clock driver as well as Level-1 trigger extractor, and serves a group of multi-chip modules.

50.02.2.1.9 Command Control

This element includes the design, layout, setup and test of a computer-based monitoring and control unit. It monitors the bias voltages and currents of the bipolar and CMOS-1 through CMOS-2A, and reads out the data in a serial format for display and storage. It also sends control signals to CMOS-2D to generate stimulation signals for bipolar and CMOS-1.

50.02.2.2 IPC (400K Channels)

Need input

50.02.2.2.1 Prototype

Need input

50.02.2.2.1.1 Active Components

This element includes the primary components in the IPC readout chain include a monolithic 8 channel preamp/shaper, an analog memory, flash ADC, and readout controller.

50.02.2.2.1.1.1 Readout Controller

This element includes a gate array-based digital controller being developed using an LSI Logic rad-hard gate array. The controller generates the write addresses for 128 pad channels, and controls the readout of the system. The readout portion of the circuit includes a state machine for controlling the readout sequence, buffering for level 2 readout, zero suppression of unhit channels, and packet building for the output link. In addition, a predefined calibration sequence can be initiated through this unit. This part includes packaging and testing. The development of this part will proceed through two stages, beginning with a functional test using a Xilinx FPGA. This prototype will be used in a full scale readout system prototype on tests on an IPC chamber. After the design has been finalized, two fabrication runs yielding 50 chips apiece will be performed on the LSI gate array before full production.

50.02.2.2.1.2 Printed Circuit Boards

This element includes the packaging of the amplifier/SCA/FADC on a multi-chip module, along with the PC board on which the front end components through the readout link are mounted.

50.02.2.2.1.2.1 MCMs

This element includes the front end amplifiers, analog memory, and FADC which will be packaged on a Multi-Chip Module (MCM) that contains circuitry to service 8 IPC signals. The present design calls for the use of the Texas Instruments HDI technology, and work is progressing with TI to develop prototypes of these parts. During development, 500 MCMs will be fabricated using prototype amplifier, SCA, and FADC die. The MCMs will be mounted to the PC board using the tab bonding technique. Included in this part is testing of the finished MCM.

50.02.2.2.1.2.2 R/O Board

This element includes the amplifier/SCA/FADC MCM mounted on a flexible Kapton board. Eight MCMs are packaged per board. The cost of the board, which has an area of approximately 13 cm x 3 cm, includes any needed connectors and passive components. During development of the IPC readout system, 50 R/O boards will be fabricated and stuffed, and full system tests will be performed on chamber. Included in this element is NRE incurred during fabrication, stuffing, and testing of the board.

50.02.2.2.1.2.3 Controller Board

This element includes the controller board holding the readout controllers, voltage references for the FADC's, and the data link for 2 - 128 channel R/O board units. The cost of the board includes connectors, voltage references, and passive components. Also, included in this element is the effort of board stuffing, testing, and integration. The approximate area of this board is 13 cm x 2 cm. During development of the IPC readout system, 50 R/O boards will be fabricated and stuffed, and full system tests will be performed on chamber. Included in this element is NRE incurred during fabrication, stuffing, and testing of the board.

50.02.2.2.1.3 Control and Data Links

This element includes the data links include a 50 Mbs fiber optic link for data output. Each output link services 128 channels. The fiber is driven by an LED mounted on the controller board, and has an associated receiver located on VME cards in racks in the electronics room.

50.02.2.2.1.3.1 Receiver Board

This element includes the data output link receivers which are packaged as a 9 V x 400 mm VME module containing 32 receiver channels. A total of 3125 data links are needed in the IPC system, requiring 100 of these boards in all. These boards as assumed to provide buffering into the Level 3 processor farm. During development, 1 receiver board prototype will be constructed, as it is assumed that the development costs of this part will be shared with other GEM subsystems.

50.02.2.2.1.3.2 Data Link

This element includes the fiber optic links which are based on the use of a Honeywell LED, which has been demonstrated to have sufficient radiation tolerance for this application, driving an 80 m multimode fiber to the receiver boards. This category include the LED driver, LED, fiber termination, and fiber. The communication protocol used on these links has not yet been defined, but could be a subset of the HDDI standard. During the design and development of this link, 10 links will be fabricated. It is assumed that the development costs of this system will be shared with the inner tracker program.

50.02.2.2.2 Production

Need input

50.02.2.2.2.1 High Voltage

This element includes the high voltage which is provided to each chamber in the IPC system through separate HV cable connections to a superlayer pair. It is assumed that the chambers will be divided into regions small enough to sustain breakdown without wire damage, and that these regions are isolated on chamber by current limiting resistors.

50.02.2.2.2.1.1 Power Supply

This element includes the commercial HV supplies which are suitable for this application. The effort was based on the use of a LeCroy 1440 system. This consists of two 1449 mainframes, and twenty 1443 pods.

50.02.2.2.2.1.2 Distribution

This element includes the standard coax cables and cable connectors which are used to supply HV to each chamber pair. It is assumed that the HV mainframes will be mounted in the detector hall, and that the cable runs will be 80 meters.

50.02.2.2.2.2 Low Voltage In-detector

This element includes the 20-30 kW of power which will be consumed by the front end electronics of the IPC system. This will be supplied by regulators located in the detector hall, as close to the central tracker as possible, to minimize voltage drops in the distribution. A monitoring system using a CAMAC based scanning ADC will be used to verify proper operation of the low voltage system.

50.02.2.2.2.2.1 Power Supply

This element includes a set of 300 W regulators to be used to generate the low voltages needed by the IPC front end electronics. The outputs of these regulators will be monitored by a scanning ADC system.

50.02.2.2.2.2.2 Distribution

This element includes 12 gauge wire used to distribute the low voltages to the PIC chambers. It is assumed that a single positive and negative supply, plus returns, will be used by all electronics on the IPC chambers. A 30 meter cable run is assumed.

50.02.2.2.2.3 Signal Cables

50.02.2.2.2.4 Active Components

This element includes the primary components in the IPC readout chain which includes a monolithic 8 channel preamp/shaper, an analog memory, flash ADC, and readout controller.

50.02.2.2.2.4.1 Preamp and Shaper

This element includes an 8 channel pre-amp and shaper being developed in the Harris AVLSI-RA process. The die size of this part is 5.6 mm^2, and an 80% yield is assumed, based on an order of magnitude quote by Harris. This part does not include packaging which will be accomplished through the use of a multi-chip module, discussed separately below. Die level testing of the part is included.

50.02.2.2.2.4.2 Switched Cap Array

This element includes a 16 channel switched capacitor-based analog memory unit being developed in the Harris AVLSI-RA process. The memory has simultaneous read/write capability, and a maximum write rate of 60 MHz. An integrated 16 to 1 multiplexer on the output is used for readout to the digitization element. Memory depth is based on a 2 microsecond level 1 trigger latency. This part does not include packaging which will be accomplished through the use of a multi-chip module, discussed separately below. Die level testing of the part is included.

50.02.2.2.2.4.3 FADC

This element includes a 25 MHz, 8 bit FADC used to digitize the PIC data during the readout sequence. The Harris HA4008 has been tested for this application, and seems suitable. Center tap on the reference ladder is used to obtain a bi-linear response, allowing approximately 10 bits of dynamic range to be obtained. Die level testing of the part is included.

50.02.2.2.2.4.4 R/O Controller

Need input

50.02.2.2.2.5 Printed Circuit Boards

This element includes the packaging of the amplifier/SCA/FADC on a multi-chip module, along with the PC board on which the front end components through the readout link are mounted. Included in the PC board costs are the costs of miscellaneous passive components and voltage references.

50.02.2.2.2.5.1 R/O Board

This element includes the amplifier/SCA/FADC MCM mounted on this flexible Kapton board. Eight MCMs are packaged per board. The cost of the board, which has an area of approximately 13 cm x 3 cm, includes any needed connectors and passive components. Also, included in this element is the cost of board stuffing, testing, and integration.

50.02.2.2.2.5.2 Controller Board

This element includes the Controller board which holds the readout controllers, voltage references for the FADCs, and the data link for two 128 channel R/O board units. The cost of the board includes connectors, voltage references, and passive components. Also, included in this element is the cost of board stuffing, testing, and integration. The approximate area of this board is 13 cm x 2 cm.

50.02.2.2.2.5.3 MCMs

Need input

50.02.2.2.2.6 Control and Data Sets

This element includes the data links which have a 50 Mbs fiber optic link for data output. Each output link services 128 channels. The fiber is driven by an LED mounted on the controller board, and has an associated receiver located on VME cards in racks in the electronics room. Other links include the trigger/clock input, which is shared by a two chamber superlayer pair, and slow control.

50.02.2.2.2.6.1 Receiver Board

This element includes the data output link receivers which are packaged as a 9U x400 mm VME module containing 32 receiver channels. A total of 3125 data links are needed in the IPC system, requiring 100 of these boards in all. These boards are assumed to provide buffering into the Level 3 processor farm.

50.02.2.2.2.6.2 Fiber Data Links

This element includes the fiber optic links based on the use of a Honeywell LED, which has been demonstrated to have sufficient radiation tolerance for the application, driving an 80 m multimode fiber to the receiver boards. This element includes the LED driver, LED, fiber termination, and fiber. The communication protocol used on these links has not yet been defined, but could be a subset of the HDDI standard.

50.02.2.2.2.6.3 Receiver Crates

This element includes the crates in which the receiver cards are mounted are assumed to be 9U x 400 mm VME, mounted in racks with a capacity of three crates, and capable of supplying a total 20 kW of power to these crates. The racks will be supplied with both forced air and water cooling.

50.02.2.2.2.6.4 Clock/Trigger Links

This element includes a PC board with circuitry providing clock and trigger distribution and system calibration which is associated with each superlayer chamber pair. The clock and trigger signals for each superlayer chamber pair will be input to the system through a single multimode fiber of the same type used in the output data links. There are 160 of these units in the IPC system in all. Trigger, system reset, and calibration commands will be encoded on the clock using missing clock cycles. A phase locked loop will be used to extract the trigger and command codes from the clock, and will output a clean clock, as well as a Level 1 trigger, reset, and calibration pulses, which will be provided to the front end electronics on a bus running the length of the chamber. A tail pulse generator with associated circuitry to drive a calibration sequence is a part of this system. The output of this tail pulse generator will be provided to the front end electronics through a shielded strip line running the length of the chambers.

50.02.2.2.2.6.5 Slow Control

This element includes the slow control used in this system to load thresholds in the readout controllers used for zero suppression, and to perform system tests and diagnostics. Each superlayer chamber pair has an associated slow control link, which is input to the system on shielded twisted pair wire. Components of the slow control system external to the IPCs consist of VME based slow control cards, VME crates, and a 380n0 slow control supervisor. Readout supervisors are responsible for decoding and acknowledging addresses provided on the slow control link, and performing the appropriate function (latching the threshold value being asserted on the link, performing system tests, etc.).

50.02.3 Calorimeter

This element includes all costs involved in the design, development, prototyping, fabrication, testing, and installation of the readout electronics for the GEM calorimeter. These electronics include the preamplifiers and other components which will be mounted inside the CAL cryostat, the junction box electronics which will be mounted on the outside of the cryostat, and the shaping, buffering, digitizing, and processing electronics which will be mounted in racks on the wall of the experimental hall. Also included are the crates and racks in which the electronics will be mounted, the signal and control cables between the detector and the readout crates, the optical links which transmit the data to the Level 2 trigger system in the electronics room, and the low- and high-voltage supplies and distribution necessary for the functioning of the CAL and its electronics.

50.02.3.1 Design and Documentation

This element includes manpower and administrative costs of preparing and reproducing a set of final design documents, including updating them as the design work progresses.

50.02.3.2 Prototype

This element includes costs involved in the research and development phase of the development and design of the final electronics. Also included is the cost associated with fabrication of a pre-production series of electronics for use in beam tests and other setups. For those components which mount inside the cryostat, a total of 4000 channels will be need for test beam measurements, while 1000 channels will be sufficient for the other components.

50.02.3.2.1 High Voltage

Purchase of a commercial system for providing high voltage for CAL modules to be operated in a test beam for calibration and testing purposes.

50.02.3.2.2 Low Voltage (On-Detector)

Purchase of a commercial system for providing power for the on-detector electronics for CAL modules to be operated in a test beam for calibration and testing purposes.

50.02.3.2.3 Signal and Control Cables

Purchase of suitable cables for use in the test beam experiment.

50.02.3.2.3.1 Signal Cables to Junction Box

Need input

50.02.3.2.3.2 Signal Cables From Junction Box

- Need input

50.02.3.2.4 Active Components

This element consists of those components of the readout electronics which require the development of custom integrated circuits (ICs), as well as those commercial components which contribute significantly to the overall cost. The costs included involve the engineering manpower required for the design and development of the custom components, fabrication and testing of a series of prototype IC's while proceeding toward the final design, and production of a pre-production series of each component in sufficient quantity for the test beam experiments.

50.02.3.2.4.1 Preamplifier

This element consists of the custom preamplifier for the LKr/LAr calorimeter. Costs include engineering manpower at BNL for development of the preamp, and costs for fabrication, packaging and testing of 4000 prototype devices for use in the test beam.

50.02.3.2.4.2 Calibration Circuit

This element consists of the custom calibration circuit for the LKr/LAr calorimeter. Costs include engineering manpower at BNL for development of the circuit (which includes a custom IC as well as a custom hybrid), and costs for fabrication, packaging and testing of 4000 prototype devices for use in the test beam.

50.02.3.2.4.3 Bipolar Shaping Amplifier

This element consists of the custom bipolar shaping amplifier for the LKr/LAr calorimeter. Costs include engineering manpower at BNL for development of the custom hybrid, and costs for fabrication, packaging and testing of 1000 prototype devices for use in the test beam.

50.02.3.2.4.4 Cable Driver

This element consists of the custom cable driver for driving the LKr/LAr calorimeter signals from the junction boxes mounted on the outside of the cryostat to the off-detector readout electronics. Costs include engineering manpower for development of the custom IC, and costs for fabrication, packaging and testing of 1000 prototype devices for use in the test beam.

50.02.3.2.4.5 Switched Capacitor Analog Memory (SCA) IC

This element consists of the custom SCA IC. Costs include engineering manpower at Nevis for development of the custom IC, production costs for 6 prototype runs, and costs for fabrication, packaging and testing of 1000 prototype devices for use in the test beam.

50.02.3.2.4.6 SCA Test Station

This element consists of the custom test platform which will be used to acceptance test SCA chips. Costs include engineering manpower for design of the station, as well as fabrication costs for the station itself.

50.02.3.2.4.7 SCA Control GA

This element consists of the custom SCA Control Module, utilizing gate array technology. Costs include engineering manpower at Nevis for support during the design of the device and of the necessary test boards (most of the design effort will be performed by physicists), production costs for a series of 4 test boards, and purchase of FPGA chips for use in the development and for the test beam electronics.

50.02.3.2.4.8 Digital Signal Processor (DSP)

This element consists of the commercial 40 ns Digital Signal Processors require for the processing of the raw data on the CAL readout boards, including performing zero suppression, calculating the deposited energies and times, and formatting the data for Level 2. One DSP services 9 channels, and an additional DSP per readout board serves as the board controller.

50.02.3.2.5 Printed Circuit Boards

This element consists of those printed circuit boards required for the readout electronics. Included are the costs for design, fabrication, assembly, and testing of the boards, including the purchase of those components which are not already listed as "Active Components" (WBS 50.02.3.2.4). Also included are costs for production of boards in sufficient quantity for use in the test beam experiment.

50.02.3.2.5.1 Junction Box Driver Board

This element consists of the 5-layer, 72-channel board for housing the junction box cable drivers. Signal cables from the cryostat will terminate on this board, with the signals driven from this board differentially over twisted-pair cables to the crates of readout electronics. Costs include design of the board and production and testing of 1000 channels for use in the test beam. Not included are the costs for production of the cable drivers (which are included under active components).

50.02.3.2.5.2 Calorimeter Readout Board (CRM)

This element consists of the 8-layer, 36-channel readout board for use in the "analog memory" readout scheme. These boards receive the differential CAL signals, split the signal into HI and LO gain scales, apply the bipolar shaping function, sample the shaped signals at 60 MHz, store the samples using SCA chips, and digitize, process, and format the data for Level 1 triggered events before transferring the results to the CAL output board residing in the same crate. Costs include design of the board and production and testing of 1000 channels for use in the test beam. Not included are the costs for production of the bipolar shaping amplifier hybrids, SCA chips, SCA control modules, or DSP's (which are included under active components).

50.02.3.2.5.3 Calorimeter Output Board (COM)

This element consists of the 8-layer, 496-channel board responsible for collecting the data from the 14 CRM's resident in its crate and transmitting them optically to the Level 2 trigger system. Costs include design of the board and production and testing of 10 boards for use in the test beam.

50.02.3.2.5.4 Calibration Electronics Board

This element consists of the calibration board which resides in the readout electronics crates and which is responsible for over-seeing the control, generation, and readout of calibration triggers. Costs include design of the board and its associated electronics, and production and testing of 2 boards for use in the test beam.

50.02.3.2.5.5 Junction Box Calibration Board

This element consists of the calibration board which resides in the junction box and which is responsible for generating calibration pulses. Costs include design of the board, and production and testing of 5 boards for use in the test beam.

50.02.3.3 Production Electronics

This element includes costs involved in the production, testing, and installation of the 120 k channels of final production electronics. Also included are engineering costs involved in the final re-design of components, after taking into account experience gained through the test beam effort.

50.02.3.3.1 High Voltage

This element includes the purchase, testing, and installation of a commercial HV supply system, including allowance for NRE required to modify the existing power supply design such that it will operate in the high magnetic field environment at GEM. Also included is the HV distribution system, including the costs of buying the cable and designing and installing the cable run.

50.02.3.3.1.1 Power Supply

Need input

50.02.3.3.1.2 Distribution

Need input

50.02.3.3.2 Low Voltage In-detector

This element includes the cost of delivering low voltage power to the on-detector electronics (including the preamps and other elements inside the cryostat as well as those mounted inside the junction boxes).

50.02.3.3.2.1 Power Supply and Distribution

Need input

50.02.3.3.3 Signal and Control Cables

This element includes the cost of purchasing and installing the signal and control cables. These include the 6m single-ended cables running from inside the cryostat to the junction boxes, the 35 m twisted-pair signal cables running from the junction boxes to the readout crates mounted on the wall of the GEM experimental hall, and the control cables between the readout crates and the junction boxes.

50.02.3.3.3.1 Signal Cables to Junction Box

Need input

50.02.3.3.3.2 Signal Cables from Junction Box

Need input

50.02.3.3.3.3 Control Cables

Need input

50.02.3.3.4 Active Components

This element consists of those components of the readout electronics which require the development of custom integrated circuits (ICs), as well as those commercial components which contribute significantly to the overall cost. The costs included involve the engineering manpower required for the final redesign of the custom components, and production and testing of the final components.

50.02.3.3.4.1 Preamplifier IC

This element consists of the custom preamplifier for the LKr/LAr calorimeter. Costs include engineering manpower at BNL for the final redesign of the preamp, and costs for fabrication, packaging and testing of the final hybrids. The cost of installing the preamps on the CAL modules is not included.

50.02.3.3.4.2 Calibration Circuit

This element consists of the custom calibration circuit for the LKr/LAr calorimeter. Costs include engineering manpower at BNL for the final redesign of the circuit, and costs for fabrication, packaging and testing of the final hybrids. The cost of installing the hybrids on the CAL modules is not included.

50.02.3.3.4.3 Shaper Amplifier Hybrid

This element consists of the custom bipolar shaping amplifier for the LKr/LAr calorimeter. Costs include engineering manpower at BNL for the final redesign of the custom hybrid, and costs for fabrication, packaging and testing of the final hybrids.

50.02.3.3.4.4 Cable Driver

This element consists of the custom cable driver for driving the LKr/LAr calorimeter signals from the junction boxes mounted on the outside of the cryostat to the off-detector readout electronics. Costs include engineering manpower for the final redesign of the custom IC, and costs for fabrication, packaging and testing of the final devices.

50.02.3.3.4.5 Switched Capacitor Analog Memory (SCA) IC

This element consists of the custom 9-channel SCA IC. Costs include engineering manpower at Nevis for final redesign of the custom IC, and costs for fabrication, packaging and testing of the final devices.

50.02.3.3.4.6 SCA Control Gate Array

This element consists of the custom SCA control module, utilizing gate array technology. Costs include engineering for final redesign of the device, and purchase of FPGA chips.

50.02.3.3.4.7 DSP

This element consists of the commercial 40 ns digital signal processors require for the processing of the raw data on the CAL readout boards, including performing zero suppression, calculating the deposited energies and times, and formatting the data for Level 2. One DSP services 9 channels, and an additional DSP per readout board serves as the board controller.

50.02.3.3.5 Printed Circuit Boards

This element consists of those printed circuit boards required for the readout electronics. Included are the costs for final redesign, fabrication, assembly, and testing of the boards, including the purchase of those components which are not already listed as "active components"

50.02.3.3.5.1 Cable Driver Board

This element consists of the 5-layer, 72-channel board for housing the junction box cable drivers. Signal cables from the cryostat will terminate on this board, with the signals driven from this board differentially over twisted-pair cables to the crates of readout electronics. Costs include final redesign of the board, and production and testing of the final boards. Not included are the costs for production of the cable drivers (which are included under active components).

50.02.3.3.5.2 Calorimeter Readout Board (CRM)

This element consists of the 8-layer, 36-channel readout board for use in the "analog memory" readout scheme. These boards receive the differential CAL signals, split the signal into HI and LO gain scales, apply the bipolar shaping function, sample the shaped signals at 60 MHz, store the samples using SCA chips, and digitize, process, and format the data for Level 1 triggered events before transferring the results to the CAL output board residing in the same crate. Costs include the final redesign of the board, and production, testing, and installation of the final boards. Not included are the costs for production of the bipolar shaping amplifier hybrids, SCA chips, SCA control modules, or DSP's (which are included under active components).

50.02.3.3.5.3 Calorimeter Output Board (COM)

This element consists of the 8-layer, 496-channel board responsible for collecting the data from the 14 CRM's resident in its crate and transmitting them optically to the Level 2 trigger system. Costs include final redesign of the board and production and testing of the final boards.

50.02.3.3.5.4 Calibration Electronics Board

This element consists of the calibration board which resides in the readout electronics crates and which is responsible for over-seeing the control, generation, and readout of calibration triggers. Costs include final redesign of the board and its associated electronics, and production and testing of the final boards.

50.02.3.3.5.5 Junction Box Calibration Board

This element consists of the calibration board which resides in the junction box and which is responsible for generating calibration pulses. Costs include final redesign of the board, and production and testing of the final boards.

50.02.3.3.6 Crates

This element includes the mechanical crates used for the junction boxes, as well as the crates and racks used to house the readout boards.

50.02.3.3.6.1 Junction Box

- This element consists of the mechanical crates which mount on the outside of the cryostat and which house the cable driver boards. These crates are essentially NIM style crates, requiring only a mechanical housing and power connections, but no backplane bus. Installation costs are not included.

50.02.3.3.6.2 Readout Electronics

This element consists of the crates and racks which house the readout boards, and which are mounted on the wall of the experimental hall. Each rack contains three 9U VME crates as well as the necessary power supplies and heat exchangers, and a standard slow control crate for remote monitoring and operation.

50.02.3.3.6.3 Patch Panel

This element consists of the interface units which will map the signals as delivered by the cables from the detector onto the appropriate readout boards.

50.02.3.3.7 Control and Data Links

This element includes the 242 500 Mbit/s optic links required to interconnect the CAL readout electronics and the Level 2 Trigger and DAQ system. Included are the links running between the CAL readout crates and the ER and the encoder/decoder board needed at the CAL end of each link for converting between electrical and optical signals and back again, controlling operation of the link, etc.

50.02.3.3.7.1 Control and Data Links

This element consists of the interface units which will map the signals as delivered by the cables from the detector onto the appropriate readout boards.

50.03 Data Acquisition System

This element includes all the labor and material for the development and production of the data acquisition system. The major job of the Data Acquisition System (DAQ) is to collect digital data for each event selected by the trigger from the front-end and trigger systems. The DAQ transfers this data into an on-line array of processors (farm or ranch) for on-line filtering and further analysis. It is the function of the on-line computer system to transfer processed event data from the farm to on-line permanent storage. However, this transfer may use some of the DAQ network. A complete list of the responsibilities of the DAQ system is given below:

•Provide software and hardware to receive Level 1 and Level 2 trigger accept information, then collect event data fragments from front-end and trigger systems, to concatenate these fragments into partial or complete events ("build" events), and to transfer the events into an on-line array of processors (farm), in which the Level 3 and Level 2 algorithms are run.

•Guarantee the integrity of the collected data.

•Provide an on-line array of units to assemble and buffer collected events,

•Communicate with the on-line computer system to transfer events selected as a result of the filtering process into on-line permanent storage for later analysis.

•Provide for distribution of the clock signal, synchronized to the bunch crossings.

•Provide for distribution of all fast control signals, such as Level 1 and reset and define common standards to be used by the front-end and trigger subsystem.

•Provide the gating logic that is responsible for the proper throttling of Level 1 accept signals, in order to avoid data loss due to buffer overflows, bandwidth limitations, or processor occupation.

•Provide software and network capability for downloading, controlling and monitoring both front-end and trigger system components housed in readout crates and DAQ system components as well as other remote (on-detector) front-end and trigger system components.

•Provide powered and cooled crates and electronics to house front-end and trigger system electronics to be readout by the DAQ system into an on-line array of processors.

•Provide powered and cooled racks and electronics rack protection software and hardware for both front-end and trigger system components housed in readout crates and DAQ system components housed either in readout crates or elsewhere.

•Provide software and a network interface to the ancillary controls system.

•Provide runtime user interface software for such tasks as runtime control, control of the on-line array of processors, histogramming, calibration data bases and consumer processes.

•Provide a real-time environment in which the DAQ and front-end electronics will run.

•Provide control, monitoring and downloading software for supporting the use of memories and intelligent processors in the DAQ system, for supporting "slow" (non-event) data acquisition and for supporting the control and monitoring of adjustable devices.

•Provide software for quickly detecting system errors and recovering from these errors.

•Provide stand-alone DAQ systems for use in test beams and small tests of front-end electronics and detector systems.

The data acquisition system interfaces to the front-end systems (for receipt of event data and control/monitoring functions), to the Level 1 and Level 2 trigger systems (for receipt of event data, for control/monitoring functions and for control of event data flow), to the on-line computing system (for experiment control computers, databases and on-line storage of accepted events), and to the ancillary controls system (for overall detector control/monitoring functions).

50.03.1 Design and Document

This element contains the initial design phase which includes requirements analysis and a first full detailed design of the system. It requires extensive behavioral simulation of the overall architecture to evaluate alternative architectures. Detailed technical simulation at board and component level will be included for selected subsystems, as well as preparation and reproduction of conceptual design documents, block diagrams, schematics, layouts etc., definition of test procedures and a study of EH&S aspects of the DAQ system.

50.03.1.1 System Design and Simulation

This element includes technical management of the development, production and testing of the data acquisition system, the generation of requirements and design documentation, and the simulation needed for system optimization.

50.03.1.1.1 Project Coordination

This element includes all effort required for technical management of the development, production and testing of the data acquisition system. It also includes administrative support, all travel necessary for both project management and other data acquisition system development and production testing activities, and computer equipment, software, supplies and other miscellaneous expenditures needed for project management as well as administrative support.

50.03.1.1.2 Functional Specifications and Design Documents

This element includes the initial requirements and specifications document for the data acquisition system. It will be reviewed extensively by the collaboration. It also includes the overall design document which gives a detailed description of the architecture and defines how the elements interact. During the lifetime of the project, these documents will regularly be updated, extended and reviewed.

50.03.1.1.3 Behavioral Simulation

This element includes the studies of the overall DAQ architecture which will be supported by extensive behavioral modeling. This includes the manpower needed to set up the system models, the manpower used to run the models and to extract the data, the workstations and CASE software that is used, and the maintenance of this hardware and software.

The CASE (Computer Aided Software Engineering) tools will allow an organized hard and software design and development effort. These tools will aid the software effort in all aspects of the project life, from requirements through design, development, integration of the hardware and software efforts, and maintenance. These tools will require workstations that have powerful graphics and processor capabilities.

50.03.1.2 Event Data Collection Modules

This element contains the initial requirements and specifications documents, the procurement and testing of prototype, preproduction and production of EDCs, and final design documents for the logic. This includes receivers for the slow links from the front-end boards, large buffer memories, high speed transmitter to event builder, fast link to event builder, slow link to control network, transceivers for this link.

The EDCs receive data form multiple (16-32) front-end electronics boards via slow links. Buffers are provided to store data for a large number of events. On requests received through the control network, data for a particular event are transmitted to the event builder switching network on a fast link. The requests also specifies to which event data distribution module data is to be sent.

Switching networks are most efficient when the amount of data fed into each of their inputs is balanced over several events and when data packets of equal size are transmitted synchronously through the network. Data balancing is obtained by connecting the proper number of front-end boards to each EDC. Input queuing is performed by the EDCs. In detail, this logic:

- Receives event data fragments, varying in size from a few bytes to several hundreds of bytes, from the front-end and trigger system readout sources.

- Multiplexes data where appropriate (e.g., small event data fragments) and forms fixed-sized packets of event data for transmission through the event builder.

- Time orders and synchronizes (queues) the transmission of the packets through the switching network such that no two packets have the same switching network output as their destination during any single packet transmission time.

- Communicates with the event data flow control subsystem over industry standard high-speed fiber optic links for the control of event data flow and error checking,

- Inhibits further data flow from the front-end boards or inhibits triggers when its input buffers are becoming filled (or when there are fatal errors),

- Performs data integrity checks on incoming data,*

- Logs errors and keeps statistics

- Communicates with the DAQ control/monitoring network.

50.03.1.2.1 Functional Specifications Document

This element includes labor and material required to generate specifications for hardware and software components of the event data collector.

50.03.1.2.2 Design, Documentation and Test Procedures

This element includes labor and material required to generate a detailed design (including documentation) of hardware for the event data collector. This includes any CAE software needed in the design process.

50.03.1.2.3 Simulation and Layout

This element includes labor and material required to provide hardware simulation of the event data collector design.

50.03.1.2.4 Embedded Software

This element includes labor and material required to design embedded software for event data collector control and communication.

50.03.1.2.5 Tests and Commissioning

This element includes labor and material required for design coordination of event data collector control and communication.

50.03.1.3 Slow Links

This element includes selection of the proper link(s), design and simulation of the network topology, prototype studies. Links of moderate speed (about 62 Mbit/s) are used to transmit data from the front-end boards to the event data collectors and from the event data distributors to the farm processors. Links with similar bandwidth are used for communication between the EDCs , the control network and the EDDs. The effort for the links themselves and installation is included in the cost of the EDCs, EDDs and control network.

50.03.1.4 Fast Links

This element includes the initial requirements and specifications documents, design and simulation of the network topology, selection of the proper link(s), the procurement and testing of prototype and production event data links, and final design documents for the links.

High speed links are used to transmit data from the event data collectors, via the event builder to the event data distributors. All event data links will use high-speed one gigabit per second fiber optic links. The industrial market is driving down the cost of these links to a point where it will be a cost benefit to the to standardize on these links not only for transmission of event data but also for fast control in the DAQ system and for similar purposes in the trigger and other systems. A link includes the driver and receiver logic and optics, connectors and cable. For short distances, copper connections may be possible. The effort for the links and installation is included in the cost of the EDCs and EDDs.

50.03.1.5 Event Builder

This element includes the initial requirements and specifications documents, the procurement and testing of prototype and production switching networks, final design documents for the switching network, a switching network built from a collection of N by N switches, embedded processors - if required -, a configuration mechanism, a data flow control subsystem monitoring, control software, and hardware and software maintenance of the event builder.

The event builder system is a switching network responsible for transport of data from the EDCs to the appropriate EDDs. Both the telecommunications industry and the computing industry have been developing switching networks to increase system throughput and connectivity of systems with many nodes. Companies such as Ancor Communications, Network Systems and UltraNet have been providing switching networks of varying size. The switching network in the event builder subsystem may be a commercial switching network or a custom design using commercial components. It will be operating in a synchronous mode and can:

- Be partitioned for independent readout of detector subsystems,
- Sustain throughputs of up to 20 gigabits per second,
- Operate in non-blocking mode (an independent path from every input to every output),
- Expand in a modular way both in the number of inputs and in throughput,
- Optionally interface to commercially available large processor arrays.

50.03.1.5.1 Functional Specifications Document

This element includes manpower required to generate specifications for hardware and software components of the event builder.

50.03.1.5.2 Design, Documentation and Test Procedures

This element includes manpower required to generate a detailed design (including documentation) of hardware for the event builder. This includes any CAE software needed in the design process.

50.03.1.5.3 Simulation and Layout

This element includes manpower required to provide hardware simulation of the event builder design.

50.03.1.5.4 Embedded Software

This element includes manpower required to design embedded software for event builder control and communication.

50.03.1.5.5 Tests and Commissioning

This element includes manpower required for design coordination of event builder modules integrated with other components of the data acquisition system.

50.03.1.6 Event Data Distribution Modules

This element contains the initial requirements and specifications documents, the procurement and testing of prototype, preproduction and production EDDs, and final design documents for the logic. This item includes fast link to the event builder, high speed receiver to this link, slow link to control network, transceiver pair for this link, multiple slow links to farm processors, transceiver pair for these links, large buffer memories.

The EDDs receive event data from a number of EDCs via the event builder system. Buffers are provided to store data from a large number of events. Data belonging to the same event are assembled and sent to a specified processor in the farm. The EDDs are connected to groups of processors in the farm via multiple commercial slow links.

50.03.1.6.1 Functional Specifications Document

This element includes manpower required to generate specifications for hardware and software components of the event data distributor.

50.03.1.6.2 Design, Documentation and Test Procedures

This element includes manpower required to generate a detailed design (including documentation) of hardware for the event data distributor. This includes any CAE software needed in the design process.

50.03.1.6.3 Simulation and Layout

This element includes manpower required to provide hardware simulation of the event data distributor design.

50.03.1.6.4 Embedded Software

This element includes manpower required to design embedded software for event data distributor control and communication.

50.03.1.6.5 Tests and Commissioning

This element includes manpower required for design coordination of event data distributor modules integrated with other components of the data acquisition system.

50.03.1.7 Control Network

This element includes commercially purchased switching network or collection of switches and data concentrators. The element may also include embedded processors and infrastructure (test equipment, etc.)

The coordination of the event data flow through the DAQ system is exercised by processors distributed in the system. The control network is used to transport the messages that specify which data is to be transported from the EDCs through the event builder and EDDs to the processors. The control network includes a trigger supervisor CPU that allocates events to farm processors, and a system supervisor CPU that checks on the performance of the network. As the DAQ system must keep up with Level 1 trigger rates of up to 100 kHz, bandwidth requirement for the control network are very high. The network will be designed to use a relatively simple but secure protocol.

50.03.1.7.1 Functional Specifications Document

This element includes manpower required to generate specifications for hardware and software components of the control network.

50.03.1.7.2 Design, Documentation and Test Procedures

This element includes manpower required to generate a detailed design (including documentation) of hardware for the control network. This includes any CAE software needed in the design process.

50.03.1.7.3 Simulation and Layout

This element includes manpower required to provide hardware simulation of the control network design.

50.03.1.7.4 Embedded Software

This element includes manpower required to design embedded software for control network control and communication.

50.03.1.7.5 Tests and Commissioning

This element includes manpower required for design coordination of control network modules integrated with other components of the data acquisition system.

50.03.1.7.6 System Supervisor

This element contains the system supervisor CPU which will configure, control and monitor the control network. This item includes selection of a commercially available CPU, procurement, software and human Interface.

50.03.1.7.7 Trigger Supervisor

This element contains the trigger supervisor CPU which assigns event numbers to farm processors that have CPU capacity available for the processing of data for a new event. It also interfaces to the gating logic to know when triggers occur. This item includes selection of a commercially available CPU, procurement, software and human interface.

50.03.1.8 Clock Distribution and Fast Control

This element includes the clock signals and fast control signals are used for the synchronization of the system. Synchronization must be maintained with respect to the beam crossings and with respect to fast control signals such as reset and Level 1 accept. This includes definition of protocols, signal levels and encoding, selection and design of hardware, procurement and installation and associated software.

50.03.1.8.1 Functional Specifications Document

This element includes manpower required to generate specifications for hardware and software components of the clock/control distribution.

50.03.1.8.2 Design, Documentation and Test Procedures

This element includes manpower required to generate a detailed design (including documentation) of hardware for the clock/control distribution. This includes any CAE software needed in the design process.

50.03.1.8.3 Simulation and Layout

This element includes manpower required to provide hardware simulation of the clock/control distribution design.

50.03.1.8.4 Embedded Software

This element includes manpower required to design embedded software for clock/control distribution control and communication.

50.03.1.8.5 Tests and Commissioning

This element includes manpower required for design coordination of clock/control distribution modules integrated with other components of the data acquisition system.

50.03.1.9 Gating Logic

This element contains the gating logic which regulates the rate of Level 1 accepts to prevent data loss due to buffer overflows and bandwidth limitations. It receives information from the triggers and the various elements in the data acquisition system. This item includes definition of protocols, signal levels and encoding, selection and design of hardware, associated software.

50.03.1.9.1 Functional Specifications Document

This element includes manpower required to generate specifications for hardware and software components of the gating logic.

50.03.1.9.2 Design, Documentation and Test Procedures

This element includes manpower required to generate a detailed design (including documentation) of hardware for the gating logic. This includes any CAE software needed in the design process.

50.03.1.9.3 Simulation and Layout

This element includes manpower required to provide hardware simulation of [illegible]

50.03.1.9.4 Embedded Software

This element includes manpower required to design embedded software for gating logic control and communication.

50.03.1.9.5 Tests and Commissioning

This element includes manpower required for design coordination of gating logic modules integrated with other components of the data acquisition system.

50.03.1.10 Control and Monitoring Software

This element includes requirements analysis, selection and evaluation of commercially available products, expert systems, tailoring of the graphics user interface for optimal display and control of the system behavior.

System control software is used to guaranty proper configuration, smooth operation and graceful degradation in case of errors. Extensive diagnostic software is used for expedient fault location and, if possible, *in situ* repair. Monitoring of the system will help the optimization of the system and the prevention of catastrophic failures. Given the complexity of the data acquisition system, faults and error conditions must be detected automatically. This will require a diagnostic connection to various electronic components, a set of test procedures that exercise the system functions at start-up, and monitoring procedures that check for errors in normal data taking conditions. A comprehensive alarm and limit system is included which records alarms of varying priorities and brings those alarms requiring intervention to the immediate attention of operators. The software of this element includes this functionality.

50.03.1.10.1 Functional Specifications Document

This element includes manpower required to generate specifications for hardware and software components of the control and monitoring system.

50.03.1.10.2 Design, Documentation and Test Procedures

This element includes manpower required to generate a detailed design (including documentation) of hardware for the control and monitoring system. This includes any CAE software needed in the design process.

50.03.1.10.3 Implementation and Coding

This element includes manpower required to design embedded software for control and monitoring system control and communication.

50.03.1.11 Real-time Operating System

This element includes requirements analysis, selection and evaluation of commercially available products, design and implementation of drivers, user Interface for optimal display and control of the embedded system behavior. The data acquisition system will have a large number of embedded processors, operating under very stringent real-time conditions. Real-time operating systems with very high performance will be needed. Likely, several operating systems will be needed for the different types of processors. Proper interaction between these real-time systems must be provided.

50.03.1.12 Standard CPU's

This element includes a CPU which may be used to monitor the data and the data flow. It will use a commercial real-time operating system, DMA firmware for event data readout and downloading, a local area network port for connection to the DAQ control/monitoring network and several other features to simplify its use in the system as well as system diagnostics.It is likely each standard data acquisition system crate will contain a commercial CPU module which connects directly to the DAQ control/monitoring network and to a remote control/monitoring link.

50.03.1.13 Interface with Front-end Electronics

This element contains the detailed specification of the interface between the DAQ and the front- end electronics. This includes data formats and transfer protocols, fast signal protocols and clock specifications, physical description of items such as signal levels, cable standards, connector choices and pin allocations, and procedures used for calibration and tests.

50.03.1.14 Interface with Fast Control and Trigger

This element includes the detailed specification of the interface between the gating logic, DAQ control, first level trigger and farm. It specifies the protocols used to communicate throttling information and to perform systems resets.

50.03.1.15 Interface with On-line Computing

This element covers all aspects of the interaction with the on-line computing environment on issues such as transport of event data to and from the DAQ to the mass storage, communication of readout configurations, communication of calibration and test information, transfer of monitor and control information regarding the front-end electronics and triggers.

50.03.1.16 Ancillary Controls and Human Interface

This element includes the hard and software involved in the monitoring of the front-end systems and the first level trigger, the hard and software for the slow control of the front-end electronics, responsible for such tasks as the extraction of data for calibrations, the calculation of calibration constants, and the downloading of constants and software to the electronics. It also includes a contribution to selection and design of the human interface software for the detector, and the effort for hard and software involved of incorporation in the DAQ specific tasks in the human interface of the detector.

50.03.2 Prototype System

This element includes the effort involved in the pre-production prototype system. Prototype hard and software is procured and assembled. Hard and software tests are implemented. Prototypes are evaluated. Prototype evaluation may lead to an adjustment of requirements and to partial redesign of hard and software. Documentation is updated. Specifications for production testing are generated.

50.03.2.1 System Design and Simulation

This element includes technical management of the development, production and testing of the Data Acquisition System, the generation of requirements & design documentation, and the simulation needed for system optimization.

50.03.2.1.1 Project Coordination

This element includes:

- All travel necessary for both project management and other data acquisition System development and production testing activities, and
- Computer equipment, software, supplies and other miscellaneous expenditures needed for project management as well as administrative support.

50.03.2.1.2 Functional Specifications and Design Documents

This element includes updating of requirements and specifications document for the data acquisition system. It will be reviewed extensively by the collaboration. It also includes the overall design document which gives a detailed description of the architecture and defines how the elements interact. During the lifetime of the project, these documents will regularly be updated, extended and reviewed.

50.03.2.1.3 Behavioral Simulation

This element includes:

•The manpower needed to set up the system models,
•The manpower used to run the models and to extract the data,
•The workstations and CASE software that is used, and
•The maintenance of this hardware and software.

Studies of the overall DAQ architecture will be supported by extensive behavioral modeling. The CASE (Computer Aided Software Engineering) tools will allow an organized hard and software design and development effort. These tools will aid the software effort in all aspects of the project life, from requirements through design, development, integration of the hardware and software efforts, and maintenance. These tools will require workstations that have powerful graphics and processor capabilities.

50.03.2.2 Event Data Collection Modules

This element includes the procurement and testing of prototype, pre-production EDCs. This item includes::

•Receivers for the slow links from the front-end boards,
•Large buffer memories,
•High speed transmitter to event builder,
•Fast link to event builder,
•Slow link to control network,
•Transceivers for this link.

The EDCs receive data form multiple (16-32) front-end electronics boards via slow links. Buffers are provided to store data for a large number of events. On requests received through the control network, data for a particular event are transmitted to the event builder switching network on a fast link. The requests also specifies to which event data distribution module data is to be sent.

Switching networks are most efficient when the amount of data fed into each of their inputs is balanced over several events and when data packets of equal size are transmitted synchronously through the network. Data balancing is obtained by connecting the proper number of front-end boards to each EDC. Input queuing is performed by the EDCs. In detail, this logic:

•Receives event data fragments, varying in size from a few bytes to several hundreds of bytes, from the front-end and trigger system readout sources.
•Multiplexes data where appropriate (e.g., small event data fragments) and forms fixed-sized packets of event data for transmission through the event builder.
•Time orders and synchronizes (queues) the transmission of the packets through the switching network such that no two packets have the same switching network output as their destination during any single packet transmission time.
•Communicates with the event data flow control subsystem over industry-standard high-speed fiber optic links for the control of event data flow and error checking,
•Inhibits further data flow from the front-end boards or inhibits triggers when its input buffers are becoming filled (or when there are fatal errors),
•Performs data integrity checks on incoming data,
•Logs errors and keeps statistics
•Communicates with the DAQ control and monitoring network.

50.03.2.2.1 Functional Specifications Document

This element includes the effort required to generate specifications for hardware and software components of the event data collector.

50.03.2.2.2 Design, Documentation and Test Procedures

This element includes the effort required to generate a prototype design (including documentation) of hardware for the event data collector. This includes any CAE software needed in the design process.

50.03.2.2.3 Simulation and Layout

This element includes the effort required to provide hardware simulation and printed circuit board layout of the event data collector design.

50.03.2.2.4 Bid Package and Procurement

This element includes the effort required to generate a bid package for event data collector production. Includes procurement of components for prototype assembly.

50.03.2.2.5 Production and Assembly

This element includes the assembly of event data collector printed circuit boards. Includes pre and post assembly test of printed circuit boards. Also includes any test fixtures needed for standalone board test.

50.03.2.2.6 Embedded Software

This element includes the effort required to generate embedded software for event data collector control and communication.

50.03.2.2.7 Tests and Commissioning

This element includes the effort required for test of event data collector modules integrated with other components of the data acquisition system.

50.03.2.3 Slow Links

This element includes the effort required for the slow links. Links of moderate speed (62 Mbits/s) are used to transmit data from the front-end boards to the event data collectors. Links with similar bandwidth are used for communication between the EDCs , the control network and the EDDs. This item includes prototyping costs.

The cost of the links themselves and installation is included in the cost of the EDCs, EDDs and Control Network.

50.03.2.3.1 Functional Specifications Document

Manpower required to generate specifications for hardware and software components of the slow data links.

50.03.2.3.2 Design, Documentation and Test Procedures

This element includes the effort required to generate a prototype design (including documentation) of hardware for the slow data links. This includes any CAE software needed in the design process.

50.03.2.3.3 Simulation and Layout

This element includes the effort required to provide hardware simulation and printed circuit board layout of the slow data link design.

50.03.2.3.4 Bid Package and Procurement

This element includes the effort required to generate a bid package for slow data link production. Includes procurement of components for prototype assembly.

50.03.2.3.5 Production and Assembly

This element includes the assembly of slow data link printed circuit boards (daughterboards). Includes pre and post assembly test of printed circuit boards. Also includes any test fixtures needed for standalone board test.

50.03.2.3.6 Embedded Software

This element includes the effort required to generate embedded software for slow data link control and communication.

50.03.2.3.7 Tests and Commissioning

This element includes the effort required for test of slow data link modules integrated with other components of the data acquisition system.

50.03.2.4 Fast Links

This element includes the effort required for the fast links. High speed links are used to transmit data from the event data collectors, via the event builder to the event data distributors. All event data links will use high-speed 1 gigabit per second coaxial links. The industrial market is driving down the cost of these links to a point where it will be a cost benefit to the to standardize on these links not only for transmission of event data but also for fast control in the DAQ system and for similar purposes in the trigger and other systems. A link includes the driver and receiver logic, connectors and cable. This WBS item includes the procurement and testing of prototype event data links. The cost of the links and installation is included in the cost of the EDCs and EDDs.

50.03.2.5 Event Builder

This element includes procurement and testing of prototype switching networks for the event builder. The event builder system is a switching network responsible for transport of data from the EDCs to the appropriate EDDs. Both the telecommunications industry and the computing industry have been developing switching networks to increase system throughput and connectivity of systems with many nodes. Companies such as Ancor Communications, Network Systems and UltraNet have been providing switching networks of varying size. The switching network in the event builder subsystem may be a commercial switching network or a custom design using commercial components. It will be operating in a synchronous mode and can:

- Be partitioned for independent readout of detector subsystems,
- Sustain throughputs of up to 20 gigabits per second,
- Operate in non-blocking mode (an independent path from every input to every output),
- Expand in a modular way both in the number of inputs and in throughput,
- Optionally interface to commercially-available large processor arrays.

50.03.2.5.1 Functional Specifications Document

This element includes the effort required to update specifications for hardware and software components of the event builder.

50.03.2.5.2 Design, Documentation and Test Procedures

This element includes the effort required to generate a prototype design (including documentation) of hardware for the event builder. This includes any CAE software needed in the design process.

50.03.2.5.3 Simulation and Layout

This element includes the effort required to provide hardware simulation and printed circuit board layout of the event builder design.

50.03.2.5.4 Bid Package and Procurement

This element includes the effort required to generate a bid package for event builder production. Includes procurement of components for prototype assembly.

50.03.2.5.5 Production and Assembly

This element includes the assembly of event builder printed circuit boards. Includes pre and post assembly test of printed circuit boards. Also includes any test fixtures needed for standalone board test.

50.03.2.5.6 Embedded Software

This element includes the effort required to generate embedded software for event builder control and communication.

50.03.2.5.7 Tests and Commissioning

This element includes the effort required for test of event builder modules integrated with other components of the data acquisition system.

50.03.2.6 Event Data Distribution Modules

This element includes the procurement and testing of prototype, pre-production EDDs,. This item includes:

- Fast Link to the event builder,
- High speed receiver to this link,
- Slow link to control network,
- Transceiver pair for this link,
- Multiple slow links to farm processors,
- Transceiver pair for these links,
- Large buffer memories.

The EDDs receive event data from a number of EDCs via the event builder system. Buffers are provided to store data from a large number of events. Data belonging to the same event are assembled and sent to a specified processor in the farm. The EDDs are connected to groups of processors in the farm via multiple commercial slow links.

50.03.2.6.1 Functional Specifications Document

This element includes the effort required to update specifications for hardware and software components of the event data distributor.

50.03.2.6.2 Design, Documentation and Test Procedures

This element includes the effort required to generate a prototype design (including documentation) of hardware for the event data distributor. This includes any CAE software needed in the design process.

50.03.2.6.3 Simulation and Layout

This element includes the effort required to provide hardware simulation and printed circuit board layout of the event data distributor design.

50.03.2.6.4 Bid Package and Procurement

This element includes the effort required to generate a bid package for event data distributor production. Includes procurement of components for prototype assembly.

50.03.2.6.5 Production and Assembly

This element includes the assembly of event data distributor printed circuit boards. Includes pre and post assembly test of printed circuit boards. Also includes any test fixtures needed for standalone board test.

50.03.2.6.6 Embedded Software

This element includes the effort required to generate embedded software for event data distributor control and communication.

50.03.2.6.7 Tests and Commissioning

This element includes the effort required for test of event data distributor modules integrated with other components of the data acquisition system.

50.03.2.7 Control Network

This element includes:

- Switching network or collection of switches and data concentrators (may be commercial).
- May include embedded processors.
- Infrastructure (test equipment, etc.)

The coordination of the event data flow through the DAQ system is exercised by processors distributed in the system. The control network is used to transport the messages that specify which data is to be transported from the EDCs through the event builder and EDDs to the processors. The control network includes a trigger supervisor CPU that allocates events to farm processors, and a system supervisor CPU that checks on the performance of the network. The network will be designed to use a relatively simple but secure protocol.

50.03.2.7.1 Functional Specifications Document

This element includes the effort required to update specifications for hardware and software components of the control network.

50.03.2.7.2 Design, Documentation and Test Procedures

This element includes the effort required to generate a prototype design (including documentation) of hardware for the control network. This includes any CAE software needed in the design process.

50.03.2.7.3 Simulation and Layout

This element includes the effort required to provide hardware simulation and printed circuit board layout of the control network design.

50.03.2.7.4 Bid Package and Procurement

This element includes the effort required to generate a bid package for control network production. Includes procurement of components for prototype assembly.

50.03.2.7.5 Embedded Software

This element includes the effort required to generate embedded software for control network control and communication.

50.03.2.7.6 Tests and Commissioning

This element includes the effort required for test of control network modules integrated with other components of the data acquisition system.

50.03.2.7.7 System Supervisor

This element includes prototype implementation. The system supervisor CPU will configure, control and monitor the control network.

50.03.2.7.8 Trigger Supervisor

This element includes prototype implementation. The trigger supervisor CPU assigns event numbers to farm processors that have CPU capacity available for the processing of data for a new event. It also interfaces to the gating logic to know when triggers occur.

50.03.2.8 Clock Distribution and Fast Control

This element includes the clock signals and fast control signals which are used for the synchronization of the system. Synchronization must be maintained with respect to the beam crossings and with respect to fast control signals such as reset and Level 1 accept.

50.03.2.8.1 Functional Specifications Document

This element includes the effort required to update specifications for hardware and software components of the clock and control distribution.

50.03.2.8.2 Design, Documentation and Test Procedures

This element includes the effort required to generate a prototype design (including documentation) of hardware for the clock and control distribution. This includes any CAE software needed in the design process.

50.03.2.8.3 Simulation and Layout

This element includes the effort required to provide hardware simulation and printed circuit board layout of the clock and control distribution design.

50.03.2.8.4 Bid Package and Procurement

This element includes the effort required to generate a bid package for clock and control distribution production. Includes procurement of components for prototype assembly.

50.03.2.8.5 Production and Assembly

This element includes the assembly of clock and control distribution printed circuit boards. Includes pre and post assembly test of printed circuit boards. Also includes any test fixtures needed for standalone board test.

50.03.2.8.6 Embedded Software

This element includes the effort required to generate embedded software for clock and control distribution control and communication.

50.03.2.8.7 Tests and Commissioning

This element includes the effort required for test of clock and control distribution modules integrated with other components of the data acquisition system.

50.03.2.9 Gating Logic

This element includes the gating logic which regulates the rate of Level 1 accepts to prevent data loss due to buffer overflows and bandwidth limitations. It receives information from the triggers and the various elements in the data acquisition system.

50.03.2.9.1 Functional Specifications Document

This element includes the effort required to update specifications for hardware and software components of the gating logic.

50.03.2.9.2 Design, Documentation and Test Procedures

This element includes the effort required to generate a prototype design (including documentation) of hardware for the gating logic. This includes any CAE software needed in the design process.

50.03.2.9.3 Simulation and Layout

This element includes the effort required to provide hardware simulation and printed circuit board layout of the gating logic design.

50.30.2.9.4 Bid Package and Procurement

This element includes the effort required to generate a bid package for gating logic production. Includes procurement of components for prototype assembly.

50.03.2.9.5 Production and Assembly

This element includes the assembly of gating logic printed circuit boards. Includes pre and post assembly test of printed circuit boards. Also includes any test fixtures needed for standalone board test.

50.03.2.9.6 Embedded Software

This element includes the effort required to generate embedded software for gating logic control and communication.

50.03.2.9.7 Tests and Commissioning

This element includes the effort required for test of gating logic modules integrated with other components of the data acquisition system.

50.03.2.10 Control and Monitoring Software

This element includes the effort for the control and monitoring software. System control software is used to guaranty proper configuration, smooth operation and graceful degradation in case of errors. Extensive diagnostic software is used for expedient fault location and, if possible, in situ repair. Monitoring of the system will help the optimization of the system and the prevention of catastrophic failures. Given the complexity of the data acquisition system, faults and error conditions must be detected automatically. This will require a diagnostic connection to various electronic components, a set of test procedures that exercise the system functions at start-up, and monitoring procedures that check for errors in normal data taking conditions. A comprehensive alarm and limit system is included which records alarms of varying priorities and brings those alarms requiring intervention to the immediate attention of operators. The software of this WBS item includes this functionality.

50.03.2.10.1 Functional Specifications Document

This element includes the effort required to update specifications for software components of the control and monitoring system.

50.03.2.10.2 Design, Documentation and Test Procedures

This element includes the effort required to generate a prototype design (including documentation) of hardware for the control and monitoring system. This includes any CAE software needed in the design process.

50.03.2.10.3 Implementation and Coding

This element includes the effort required to generate embedded software for control and monitoring system control and communication.

50.03.2.10.4 Tests and Commissioning

This element includes the effort required for test of control and monitoring system modules integrated with other components of the data acquisition system.

50.03.2.11 Real-time Operating System

This element includes the real-time operating systems from which very high performance will be needed. Likely, several operating systems will be needed for the different types of processors. Proper interaction between these real-time systems must be provided. The data acquisition system will have a large number of embedded processors, operating under very stringent real-time conditions.

50.03.2.12 Standard CPUs

This element includes a standard data acquisition system crate which will contain a commercial CPU module that connects directly to the DAQ control and monitoring network and to a remote control/monitoring link. This CPU may be used to monitor the data and the data flow. It will use a commercial real-time operating system, DMA firmware for event data readout and downloading, a local area network port for connection to the DAQ control and monitoring network and several other features to simplify its use in the system as well as system diagnostics.

50.03.2.13 Interface with Front-end Electronics

This element includes the prototype implementation of the interface between the DAQ and the front-end electronics. This includes:

- Data formats and transfer protocols,
- Fast signal protocols and clock specifications,
- Physical description of items such as signal levels, cable standards, connector choices and pin allocations, and
- Procedures used for calibration and tests.

50.03.2.14 Interface with Fast Control and Trigger

This element includes the prototype implementation of the interface between the gating logic, DAQ control, first level trigger and farm. It specifies the protocols used to communicate throttling information and to perform systems resets.

50.03.2.15 Interface with On-line Computing

This element covers prototype implementation of the interface with the on-line computing environment on issues such as:

- Transport of event data to and from the DAQ to the mass storage,
- Communication of readout configurations,
- Communication of calibration and test information,
- Transfer of monitor and control information regarding the front-end electronics and triggers.

50.03.2.16 Ancillary Controls and Human Interface

This element includes prototype implementation of:

- The hard and software involved in the monitoring of the front-end systems and the first level trigger,
- The hard and software for the slow control of the front-end electronics, responsible for such tasks as the extraction of data for calibrations, the calculation of calibration constants, and the downloading of constants and software to the electronics.
- A contribution to selection and design of the human interface software for the detector,
- The effort, hard and software involved of incorporation of DAQ specific tasks in the human interface of the detector.

50.03.3 Production System

This element includes mass production of the electronics and software. Some reevaluation of requirements and redesign may be needed. Most of the electronics will be purchased commercially or produced by outside vendors. Much of the testing will be done by suppliers. Included are activities associated with subassembly testing and with verification that products meet specifications. Effort for shipping, storing and assembly of subsystems is included here.

50.03.3.1 System Design and Simulation

This element includes technical management of the development, production and testing of the data acquisition system, the generation of requirements & design documentation, and the simulation needed for system optimization.

50.03.3.1.1 Project Coordination

This element includes:

- All travel necessary for both project management and other data acquisition system development and production testing activities, and
- Computer equipment, software, supplies and other miscellaneous expenditures needed for project management as well as administrative support.

50.03.3.1.2 Functional Specifications and Design Documents

This element includes update of requirements and specifications document for the data acquisition system. It will be reviewed extensively by the collaboration. It also includes the overall design document which gives a detailed description of the architecture and defines how the elements interact. During the lifetime of the project, these documents will regularly be updated, extended and reviewed.

50.03.3.1.3 Behavioral Simulation

This element includes:

- The manpower needed to set up the system models,
- The manpower used to run the models and to extract the data,
- The workstations and CASE software that is used, and
- The maintenance of this hardware and software.

Studies of the overall DAQ architecture will be supported by extensive behavioral modeling. The CASE (Computer Aided Software Engineering) tools will allow an organized hard and software design and development effort. These tools will aid the software effort in all aspects of the project life, from requirements through design, development, integration of the hardware and software efforts, and maintenance. These tools will require workstations that have powerful graphics and processor capabilities.

50.03.3.2 Event Data Collection Modules

This element includes production and assembly of EDCs:

- Receivers for the slow links from the front-end boards,
- Large buffer memories,
- High speed transmitter to event builder,
- Fast link to event builder,
- Slow link to control network,

•Transceivers for this link.

The EDCs receive data form multiple (16-32) front-end electronics boards via slow links. Buffers are provided to store data for a large number of events. On requests received through the control network, data for a particular event are transmitted to the event builder switching network on a fast link. The requests also specifies to which event data distribution module data is to be sent. Switching networks are most efficient when the amount of data fed into each of their inputs is balanced over several events and when data packets of equal size are transmitted synchronously through the network. Data balancing is obtained by connecting the proper number of front-end boards to each EDC. Input queuing is performed by the EDCs. In detail, this logic:

•Receives event data fragments, varying in size from a few bytes to several hundreds of bytes, from the front-end and trigger system readout sources.
•Multiplexes data where appropriate (e.g., small event data fragments) and forms fixed-sized packets of event data for transmission through the event builder.
•Time orders and synchronizes (queues) the transmission of the packets through the switching network such that no two packets have the same switching network output as their destination during any single packet transmission time.
•Communicates with the event data flow control subsystem over industry-standard high-speed fiber optic links for the control of event data flow and error checking,
•Inhibits further data flow from the front-end boards or inhibits triggers when its input buffers are becoming filled (or when there are fatal errors),
•Performs data integrity checks on incoming data,
•Logs errors and keeps statistics
•Communicates with the DAQ control monitoring network.

50.03.3.2.1 Functional Specifications Document

This element includes the effort required to finalize specifications for hardware and software components of the event data collector.

50.03.3.2.2 Design, Documentation and Test Procedures

This element includes the effort required to generate a final design (including documentation) of hardware for the event data collector. This includes any CAE software needed in the design process.

50.03.3.2.3 Simulation and Layout

This element includes the effort required to provide hardware simulation and printed circuit board layout of the event data collector design.

50.03.3.2.4 Bid Package and Procurement

This element includes the effort required to generate a bid package for event data collector production. Includes procurement of components for final assembly.

50.03.3.2.5 Production and Assembly

This element includes the assembly of event data collector printed circuit boards. Includes pre and post assembly test of printed circuit boards. Also includes any test fixtures needed for standalone board test.

50.03.3.2.6 Embedded Software

This element includes the effort required to generate embedded software for event data collector control and communication.

50.03.3.2.7 Tests and Commissioning

This element includes the effort required for test of event data collector modules integrated with other components of the data acquisition system.

50.03.3.3 Slow Links

This element includes the effort required for the slow links. Links of moderate speed (62 Mbits/s) are used to transmit data from the front-end boards to the event data collectors. Links with similar bandwidth are used for communication between the EDCs , the control network and the EDDs.

The cost of the links themselves and installation is included in the cost of the EDCs, EDDs and control network.

50.03.3.4 Fast Links

This element includes the effort required for the fast links. High speed links are used to transmit data from the event data collectors, via the event builder to the event data distributors. All event data links will use high-speed 1 gigabit per second coaxial links. The industrial market is driving down the cost of these links to a point where it will be a cost benefit to the to standardize on these links not only for transmission of event data but also for fast control in the DAQ system and for similar purposes in the trigger and other systems. A link includes the driver and receiver logic, connectors and cable. This WBS item includes the procurement and testing of prototype and production event data links. The cost of the links and installation is included in the cost of the EDCs and EDDs.

50.03.3.5 Event Builder

This element includes the procurement and testing of production switching networks. The event builder system is a switching network responsible for transport of data from the EDCs to the appropriate EDDs. Both the telecommunications industry and the computing industry have been developing switching networks to increase system throughput and connectivity of systems with many nodes. Companies such as Ancor Communications, Network Systems and UltraNet have been providing switching networks of varying size. The switching network in the event builder subsystem may be a commercial switching network or a custom design using commercial components. It will be operating in a synchronous mode and can:

- Be partitioned for independent readout of detector subsystems,
- Sustain throughputs of up to 20 gigabits per second,
- Operate in non-blocking mode (an independent path from every input to every output),
- Expand in a modular way both in the number of inputs and in throughput,
- Optionally interface to commercially-available large processor arrays.

50.03.3.5.1 Functional Specifications Document

This element includes the effort required to finalize specifications for hardware and software components of the event builder.

50.03.3.5.2 Design, Documentation and Test Procedures

This element includes the effort required to generate a final design (including documentation) of hardware for the event builder. This includes any CAE software needed in the design process.

50.03.3.5.3 Simulation and Layout

This element includes the effort required to provide hardware simulation and printed circuit board layout of the event builder design.

50.03.3.5.4 Bid Package and Procurement

This element includes the effort required to generate a bid package for event builder production. Includes procurement of components for final assembly.

50.03.3.5.5 Production and Assembly

This element includes the assembly of event builder printed circuit boards. It also includes pre and post assembly test of printed circuit boards as well as any test fixtures needed for standalone board test.

50.03.3.5.6 Embedded Software

This element includes the effort required to generate embedded software for event builder control and communication.

50.03.3.5.7 Tests and Commissioning

This element includes the effort required for test of event builder modules integrated with other components of the data acquisition system.

50.03.3.6 Event Data Distribution Modules

This element includes:

- Fast Link to the event builder,
- High speed receiver to this link,
- Slow link to control network,
- Transceiver pair for this link,
- Multiple slow links to farm processors,
- Transceiver pair for these links,
- Large buffer memories.

The EDDs receive event data from a number of EDCs via the event builder system. Buffers are provided to store data from a large number of events. Data belonging to the same event are assembled and sent to a specified processor in the Farm. The EDDs are connected to groups of processors in the farm via multiple commercial slow links. This WBS item includes production EDDs.

50.03.3.6.1 Functional Specifications Document

This element includes the effort required to finalize specifications for hardware and software components of the event data distributor.

50.03.3.6.2 Design, Documentation and Test Procedures

- This element includes the effort required to generate a final design (including documentation) of hardware for the event data distributor. This includes any CAE software needed in the design process.

50.03.3.6.3 Simulation and Layout

This element includes the effort required to provide hardware simulation and printed circuit board layout of the event data distributor design.

50.03.3.6.4 Bid Package and Procurement

This element includes the effort required to generate a bid package for event data distributor production. Includes procurement of components for final assembly.

50.03.3.6.5 Production and Assembly

This element includes the assembly of event data distributor printed circuit boards. Includes pre and post assembly test of printed circuit boards. Also includes any test fixtures needed for standalone board test.

50.03.3.6.6 Embedded Software

This element includes the effort required to generate embedded software for event data distributor control and communication.

50.0.3.6.7 Tests and Commissioning

This element includes the effort required for test of event data distributor modules integrated with other components of the data acquisition system.

50.03.3.7 Control Network

This element includes:

•Switching network or collection of switches and data concentrators (may be commercial).
•May include embedded processors.
•Infrastructure (test equipment, etc.)

The coordination of the event data flow through the DAQ system is exercised by processors distributed in the system. The control network is used to transport the messages that specify which data is to be transported from the EDCs through the event builder and EDDs to the processors. The control network includes a trigger supervisor CPU that allocates events to farm processors, and a system supervisor CPU that checks on the performance of the network. The network will be designed to use a relatively simple but secure protocol.

50.03.3.7.1 Functional Specifications Document

This element includes the effort required to finalize specifications for hardware and software components of the control network.

50.03.3.7.2 Design, Documentation and Test Procedures

This element includes the effort required to generate a final design (including documentation) of hardware for the control network. This includes any CAE software needed in the design process.

50.03.3.7.3 Simulation and Layout

This element includes the effort required to provide hardware simulation and printed circuit board layout of the control network design.

50.03.3.7.4 Bid Package and Procurement

This element includes the effort required to generate a bid package for control network production. Includes procurement of components for final assembly.

50.03.3.7.5 Embedded Software

This element includes required to generate embedded software for control network control and communication.

50.03.3.7.6 Tests and Commissioning

This element includes the effort required for test of control network modules integrated with other components of the data acquisition system.

50.03.3.7.7 System Supervisor

This element includes the system supervisor CPU which will configure, control and monitor the control network. This item includes production and assembly costs.

50.03.3.7.8 Trigger Supervisor

This element includes the trigger supervisor CPU which assigns event numbers to farm processors that have CPU capacity available for the processing of data for a new event. This item includes production and assembly costs.

50.03.3.8 Clock Distribution and Fast Control

This element includes the clock signals and fast control signals which are used for the synchronization of the system. Synchronization must be maintained with respect to the beam crossings and with respect to fast control signals such as reset and Level 1 accept.

50.03.3.8.1 Functional Specifications Document

This element includes the effort required to finalize specifications for hardware and software components of the clock control distribution.

50.03.3.8.2 Design, Documentation and Test Procedures

This element includes the effort required to generate a final design (including documentation) of hardware for the clock control distribution. This includes any CAE software needed in the design process.

50.03.3.8.3 Simulation and Layout

This element includes the effort required to provide hardware simulation and printed circuit board layout of the clock control distribution design.

50.03.3.8.4 Bid Package and Procurement

This element includes the effort required to generate a bid package for clock control distribution production. Includes procurement of components for final assembly.

50.03.3.8.5 Production and Assembly

This element includes the assembly of clock control distribution printed circuit boards. Includes pre and post assembly test of printed circuit boards. Also includes any test fixtures needed for standalone board test.

50.03.3.8.6 Embedded Software

This element includes the effort required to generate embedded software for clock control distribution control and communication.

50.03.3.8.7 Tests Commissioning

This element includes the effort required for test of clock control distribution modules integrated with other components of the data acquisition system.

50.03.3.9 Gating Logic

This element includes the gating logic which regulates the rate of Level 1 accepts to prevent data loss due to buffer overflows and bandwidth limitations. It receives information from the triggers and the various elements in the data acquisition system.

50.03.3.9.1 Functional Specifications Document

This element includes the effort required to finalize specifications for hardware and software components of the gating logic.

50.03.3.9.2 Design, Documentation and Test Procedures

This element includes the effort required to generate a final design (including documentation) of hardware for the gating logic. This includes any CAE software needed in the design process.

50.03.3.9.3 Simulation and Layout

This element includes the effort required to provide hardware simulation and printed circuit board layout of the gating logic design.

50.03.3.9.4 Bid Package and Procurement

This element includes the effort required to generate a bid package for gating logic production. Includes procurement of components for final assembly.

50.03.3.9.5 Production and Assembly

This element includes the assembly of gating logic printed circuit boards. Includes pre and post assembly test of printed circuit boards. Also includes any test fixtures needed for standalone board test.

50.03.3.9.6 Embedded Software

This element includes the effort required to generate embedded software for gating logic control and communication.

50.03.3.9.7 Tests and Commissioning

This element includes the effort required for test of gating logic modules integrated with other components of the data acquisition system.

50.03.3.10 Control and Monitoring Software

This element includes the effort required for the control and monitoring software. System control software is used to guaranty proper configuration, smooth operation and graceful degradation in case of errors. Extensive diagnostic software is used for expedient fault location and, if possible, in situ repair. Monitoring of the system will help the optimization of the system and the prevention of catastrophic failures.

Given the complexity of the data acquisition system, faults and error conditions must be detected automatically. This will require a diagnostic connection to various electronic components, a set of test procedures that exercise the system functions at start-up, and monitoring procedures that check for errors in normal data taking conditions. A comprehensive alarm and limit system is included which records alarms of varying priorities and brings those alarms requiring intervention to the immediate attention of operators. The software of this WBS item includes this functionality.

50.03.3.10.1 Functional Specifications Document

This element includes the effort required to finalize specifications for software components of the control and monitoring system.

50.03.3.10.2 Design, Documentation and Test Procedures

This element includes the effort required to generate a final design (including documentation) of hardware for the control and monitoring system. This includes any CAE software needed in the design process.

50.03.3.10.3 Implementation and Coding

This element includes the effort required to generate embedded software for control and monitoring system control and communication.

50.03.3.10.4 Tests and Commissioning

This element includes the effort required for test of control and monitoring system modules integrated with other components of the data acquisition system.

50.03.3.11 Real-time Operating System

This element includes the effort for the real-time operating system. The data acquisition system will have a large number of embedded processors, operating under very stringent real-time conditions. Real-time operating systems with very high performance will be needed. Likely, several operating systems will be needed for the different types of processors. Proper interaction between these real-time systems must be provided.

50.03.3.12 Standard CPU's

Likely each standard data acquisition system crate will contain a commercial CPU module which connects directly to the DAQ control monitoring network and to a remote control and monitoring link. This CPU may be used to monitor the data and the data flow. It will use a commercial real-time operating system, DMA firmware for event data readout and downloading, a local area network port for connection to the DAQ control and monitoring network and several other features to simplify its use in the system as well as system diagnostics.

50.03.3.13 Interface with Front-end Electronics

This element includes the final implementation of the interface between the DAQ and the front-end electronics.

50.03.3.14 Interface with Fast Control and Trigger

This element includes the final implementation of the interface between the gating logic, DAQ control, first level trigger and farm. It specifies the protocols used to communicate throttling information and to perform systems resets.

50.03.3.15 Interface with On-line Computing

This element item covers final implementation of the interface with the on-line computing environment .

50.03.3.16 Ancillary Controls and Human Interface

This element includes final implementation of:

- The hard and software involved in the monitoring of the front-end systems and the first level trigger,
- The hard and software for the slow control of the front-end electronics, responsible for such tasks as the extraction of data for calibrations, the calculation of calibration constants, and the downloading of constants and software to the electronics.
- A contribution to selection and design of the human interface software for the detector,
- The effort, hard and software involved of incorporation of DAQ specific tasks in the human interface of the detector.

50.03.4 Installation and Test

This element includes the final installation of hardware and software. Careful requirements analysis and design of the final system layout is included. System test and monitoring systems are fully implemented. It is expected that serious debugging will be needed to reach optimal performance. This item includes commissioning of systems and organization of the on-site maintenance.

50.03.4.1 System Design and Simulation

This element item includes technical management of the development, production and testing of the data acquisition system, the generation of requirements and design documentation, and the simulation needed for system optimization.

50.03.4.1.1 Project Coordination

This element item includes:

- All travel necessary for both project management and other data acquisition system development and production testing activities, and
- Computer equipment, software, supplies and other miscellaneous expenditures needed for project management as well as administrative support.

50.03.4.1.2 Functional Specifications and Design Documents

This element item includes the final specifications document for the data acquisition system. It will be reviewed extensively by the collaboration. It also includes the overall design document which gives a detailed description of the architecture and defines how the elements interact. During the lifetime of the project, these documents will regularly be updated, extended and reviewed.

50.03.4.1.3 Behavioral Simulation

This element includes:

•The manpower needed to set up the system models,
•The manpower used to run the models and to extract the data,
•The workstations and CASE software that is used, and
•The maintenance of this hardware and software.

Studies of the overall DAQ architecture will be supported by extensive behavioral modeling. The CASE (Computer Aided Software Engineering) tools will allow an organized hard and software design and development effort. These tools will aid the software effort in all aspects of the project life, from requirements through design, development, integration of the hardware and software efforts, and maintenance. These tools will require workstations that have powerful graphics and processor capabilities.

50.03.4.2 Event Data Collection Modules

This element includes final design documents for the logic. This element includes:

•Receivers for the slow links from the front-end boards,
•Large buffer memories,
•High speed transmitter to event builder,
•Fast link to event builder,
•Slow link to control network,
•Transceivers for this link.

The EDCs receive data from multiple (16-32) front-end electronics boards via slow links. Buffers are provided to store data for a large number of events. On requests received through the control network, data for a particular event are transmitted to the event builder switching network on a fast link. The requests also specifies to which event data distribution module data is to be sent.

Switching networks are most efficient when the amount of data fed into each of their inputs is balanced over several events and when data packets of equal size are transmitted synchronously through the network. Data balancing is obtained by connecting the proper number of front-end boards to each EDC. Input queuing is performed by the EDCs. In detail, this logic:

•Receives event data fragments, varying in size from a few bytes to several hundreds of bytes, from the front-end and trigger system readout sources.
•Multiplexes data where appropriate (e.g., small event data fragments) and forms fixed-sized packets of event data for transmission through the event builder.
•Time orders and synchronizes (queues) the transmission of the packets through the switching network such that no two packets have the same switching network output as their destination during any single packet transmission time.
•Communicates with the event data flow control subsystem over industry-standard high-speed fiber optic links for the control of event data flow and error checking,
•Inhibits further data flow from the front-end boards or inhibits triggers when its input buffers are becoming filled (or when there are fatal errors),
•Performs data integrity checks on incoming data,
•Logs errors and keeps statistics
•Communicates with the DAQ control monitoring network.

50.03.4.2.1 Bid Package and Procurement

This element includes the effort required to generate a bid package for installation of event data collector production. Includes procurement of components for final assembly.

50.03.4.2.2 Tests and Commissioning

This element includes the effort required for test of event data collector modules integrated with other components of the data acquisition system.

50.03.4.3 Slow Links

This element includes the effort for the slow links. Links of moderate speed (62 Mbits/s) are used to transmit data from the Front-end boards to the event data collectors. Links with similar bandwidth are used for communication between the EDCs , the control network and the EDDs. This item includes final documentation and installation. The cost of the links themselves and installation is included in the cost of the EDCs, EDDs and control network.

50.03.4.4 Fast Links

This element includes the high speed links which are used to transmit data from the event data collectors, via the event builder to the event data distributors. All event data links will use high-speed 1 gigabit per second coaxial links. The industrial market is driving down the cost of these links to a point where it will be a cost benefit to the to standardize on these links not only for transmission of event data but also for fast control in the DAQ system and for similar purposes in the trigger and other systems. A link includes the driver and receiver logic, connectors and cable. This WBS item includes final installation and documentation. The cost of the links and installation is included in the cost of the EDCs and EDDs.

50.03.4.5 Event Builder

This element includes the event builder system which is a switching network responsible for transport of data from the EDCs to the appropriate EDDs. Both the telecommunications industry and the computing industry have been developing switching networks to increase system throughput and connectivity of systems with many nodes. Companies such as Ancor Communications, Network Systems and UltraNet have been providing switching networks of varying size. The switching network in the event builder subsystem may be a commercial switching network or a custom design using commercial components. It will be operating in a synchronous mode and can:

- Be partitioned for independent readout of detector subsystems,
- Sustain throughputs of up to 20 gigabits per second,
- Operate in non-blocking mode (an independent path from every input to every output),
- Expand in a modular way both in the number of inputs and in throughput,
- Optionally interface to commercially-available large processor arrays.

50.03.4.5.1 Bid Package and Procurement

This element includes the effort required to generate a bid package for installation of event builder production. Includes procurement of components for final assembly.

50.03.4.5.2 Embedded Software

This element includes the effort required to generate embedded software for event builder control and communication.

50.03.4.5.3 Tests and Commissioning

This element include the effort required for test of event builder modules integrated with other components of the data acquisition system.

50.03.4.6 Event Data Distribution (EDD) Modules

This element includes the EDDs which receive event data from a number of EDCs via the event builder system. Buffers are provided to store data from a large number of events. Data belonging to the same event are assembled and sent to a specified processor in the farm. The EDDs are connected to groups of processors in the farm via multiple commercial slow links.

This element includes the initial requirements and specifications documents, the procurement and testing of prototype, pre-production and production EDDs, and final design documents for the logic. This item includes:

•Fast link to the event builder,
•High speed receiver to this link,
•Slow link to control network,
•Transceiver pair for this link,
•Multiple slow links to farm processors,
•Transceiver pair for these links,
•Large buffer memories.

50.03.4.6.1 Bid Package and Procurement

This element includes the effort required to generate a bid package for installation of event data distributor production. Includes procurement of components for final assembly.

50.03.4.6.2 Embedded Software

This element includes the effort required to generate embedded software for event data distributor control and communication.

50.03.4.6.3 Tests and Commissioning

This element includes the effort required for test of event data distributor modules integrated with other components of the data acquisition system.

50.03.4.7 Control Network

This element includes the control network which is used to transport the messages that specify which data is to be transported from the EDCs through the event builder and EDDs to the processors. The control network includes a trigger supervisor CPU that allocates events to farm processors, and a system supervisor CPU that checks on the performance of the network. The network will be designed to use a relatively simple but secure protocol. The coordination of the event data flow through the DAQ system is exercised by processors distributed in the system.

50.03.4.7.1 Tests and Commissioning

This element includes the effort required for test of control network modules integrated with other components of the data acquisition system.

50.03.4.7.2 System Supervisor

This element includes the system supervisor CPU which will configure, control and monitor the control network. This item includes final installation and documentation.

50.03.4.7.3 Trigger Supervisor

This element includes the trigger supervisor CPU which assigns event numbers to farm processors that have CPU capacity available for the processing of data for a new event. It also interfaces to the gating logic to know when triggers occur. This item includes final installation and documentation.

50.03.4.8 Clock Distribution and Fast Control

This element includes the clock signals and fast control signals which are used for the synchronization of the system. Synchronization must be maintained with respect to the beam crossings and with respect to fast control signals such as reset and Level 1 accept.

50.03.4.8.1 Bid Package and Procurement

This element includes the effort required to generate a bid package for installation of clock control distribution.

50.03.4.8.2 Tests and Commissioning

This element includes the effort required for test of clock control distribution modules integrated with other components of the data acquisition system.

50.03.4.9 Gating Logic

This element includes the gating logic which regulates the rate of Level 1 accepts to prevent data loss due to buffer overflows and bandwidth limitations. It receives information from the triggers and the various elements in the data acquisition system. This item includes final installation and documentation.

50.03.4.9.1 Tests and Commissioning

Need input

50.03.4.10 Control and Monitoring Software

This element includes the effort for the control and monitoring software. System control software is used to guaranty proper configuration, smooth operation and graceful degradation in case of errors. Extensive diagnostic software is used for expedient fault location and, if possible, *in situ* repair. Monitoring of the system will help the optimization of the system and the prevention of catastrophic failures. Given the complexity of the data acquisition system, faults and error conditions must be detected automatically. This will require a diagnostic connection to various electronic components, a set of test procedures that exercise the system functions at start-up, and monitoring procedures that check for errors in normal data taking conditions. A comprehensive alarm and limit system is included which records alarms of varying priorities and brings those alarms requiring intervention to the immediate attention of operators. The software of this element includes this functionality.

50.03.4.10.1 Design, Documentation and Test Procedures

This element includes the effort required to generate a final design (including documentation) of hardware for the control and monitoring system.

50.03.4.10.2 Tests and Commissioning

This element includes the effort required for test of control and monitoring system modules integrated with other components of the data acquisition system.

50.03.4.11 Real-time Operating System

This element includes the effort for a real-time operating system. The data acquisition system will have a large number of embedded processors, operating under very stringent real-time conditions. Real-time operating systems with very high performance will be needed. Likely, several operating systems will be needed for the different types of processors. Proper interaction between these real-time systems must be provided.

50.03.4.12 Standard CPU's

This element includes the effort for standard CPU's. Each standard data acquisition system crate will contain a commercial CPU module which connects directly to the DAQ control monitoring network and to a remote control/monitoring link. This CPU may be used to monitor the data and the data flow. It will use a commercial real-time operating system, DMA firmware for event data readout and downloading, a local area network port for connection to the DAQ control monitoring network and several other features to simplify its use in the system as well as system diagnostics.

50.03.4.13 Interface with Front-end Electronics

This element includes the final implementation of the interface between the DAQ and the front-end electronics.

50.03.4.14 Interface with Fast Control and Trigger

This element includes the final implementation of the interface between the gating logic, DAQ control, first level trigger and farm. It specifies the protocols used to communicate throttling information and to perform systems resets.

50.03.4.15 Interface with On-line Computing

This element includes final implementation of the interface with the on-line computing environment.

50.03.4.16 Ancillary Controls and Human Interface

This element includes final implementation and documentation.

50.04 Trigger

Need input

50.04.1 Level 1 Calorimeter (Analog Option)

This element includes a system which contains 5 types of 9U VME modules, one of which, the adder module, is reconfigured for use in two different situations. The numbers of the modules for the barrel calorimeter are well defined, since the segmentation of this detector has been defined. For the endcap calorimeter, we use the simple rule that the number of modules required will be the same as in the barrel if the number is even, or one additional module if the number is odd. This gives an even number of all modules for the endcap system, which is required, since the two endcaps will have identical systems.

50.04.1.1 Design and Documentation

Need input

50.04.1.2 Prototype

Need input

50.04.1.2.1 Active components

Need input

50.04.1.2.1.1 Prototype FPGA for L1 Sum Board

This element includes the procurement of the actual field programmable gate array chips from Xilinx, for which we use catalog prices, and the development of the circuits which will be downloaded into the chip.

50.04.1.2.1.2 Prototype FPGA for the Count Logic Board

As for item 50.04.1.2.4.3, this element includes the cost for both the field programmable array part and for the design effort needed to develop the circuit which is downloaded into the chip.

50.04.1.2.1.3 IDT 7210 MAC IC for Prototype JET Sum/Filter Board

This element includes the multiply-accumulate chips used in the dual transversal filter on the JET sum module.

50.04.1.2.1.4 AD9020 FADC IC for Prototype JET Sum/Filter Board

This element includes the FADC used to sample the JET analog sum which may need to run at the machine clock speed, and therefore a 60 MSPS chip has been chosen. There is a possibility that a lower speed FADC can be used, but this is still under study.

50.04.1.2.1.5 Variable Gain Shaping Amplifier for Prototype L1 Sum Board

This element includes the amplifier on the L1 Sum board which shapes the summed signal for each of the channels. Variable gain is needed to permit the use of higher level summing and also allows uniform reference levels on the discriminators to be used. A suitable amplifier for this purpose with 20% gain variation under voltage control has been developed at BNL and was used in the liquid argon/krypton beam test run in July 1992. It is possible that some modification of this circuit is needed, and we rely on the help of the instrumentation division at BNL for this effort.

50.04.1.2.1.6 Summing Amplifier for Prototype L1 Sum Board

This element includes the amplifier that sums together the analog inputs to the L1 Sum board. We anticipate using designs of previous liquid argon systems, and expect that we will be aided in this effort by the instrumentation division at BNL.

50.04.1.2.2 Printed Circuit Board

Need input

50.04.1.2.2.1 Prototype L1 Sum Board

This element includes the effort for the prototype Level 1 sum board. This is the first board in the Level 1 trigger chain, accepting the analog summing signals from the front end electronics, discriminating them, and applying nearest neighbor logic to determine isolation. The logic on this board is carried out in a field programmable gate array, whose program is downloaded via the crate backplane. We envision building up the logic on this board through the construction of CAMAC prototype boards, which will test individual parts of the circuit. The prototype VME boards will be used in test mode to construct the entire trigger chain.

50.04.1.2.2.2 Prototype Count Logic Board

This element includes the effort for the prototype count logic board. This is the unit that receives inputs from the digital Level 1 summing board (or in the case of JET's, from the JET sum/filter board) and counts the clusters of hits in a 4x4 matrix. "Carry" signals are passed on to neighboring modules to provide for consistent cluster counting at the edges. The logic on the board will be done in a field-programmable gate array, whose data will be downloaded via the crate backplane. Each board will receive 26 4-bit input signals and produce 16 4-bit output signals.

50.04.1.2.2.3 Prototype JET Sum/Filter Board

This element includes the effort for the prototype JET sum/filter board. The function of this board is to receive the analog single particle sum signals from four Level 1 sum boards, along with one corresponding discriminator signal. The signals are added analog fashion and digitized. A dual transversal filter, which consists of eight MAC chips can produce up to 4 timing sums and 4 amplitude sums, the starting time of each being given by one of the discriminator signals. Following the transversal filter is a digital comparator which checks the amplitude of the timing signal. An acceptable sum is then transmitted to the 3 global summing trees, and a 4-bit code for each JET is sent to the count logic boards. This is a complex board, and we envision making CAMAC prototypes to test parts of the circuit before proceeding with a full prototype. The fabrication of 6 prototype boards should be sufficient for testing the global summing hardware. A 9U crate and processor for use in the testing of these prototypes and the global sum logic will probably be necessary.

50.04.1.2.2.4 Prototype Adder Board

This element includes the prototype adder board which can be used in one of two modes: it is either a set of 64 4-bit adders or 16 16-bit adders. The 4-bit adders are used to sum the outputs of the count logic system, and the 16-bit adders are used to form the global sums. It is hoped that the required configuration change can be made software selectable, but the use of jumper-installed or EPROM-based logic would also be acceptable, as the units are dedicated to one function or the other once they are installed in the system. The construction of 4 prototype boards will permit two for use in the 4-bit mode in conjunction with the count logic and two for use in the 16-bit mode in conjunction with the global sum logic.

50.04.1.2.2.5 Prototype Global Sum Board

This element includes the effort for the prototype global sum board. As currently envisioned, this is a relatively simple board, which receives the total transverse energy digital sum, converts it to an optical signal and sends it to the global Level 1 logic, located in the ER. The two moment sums are also received on this board, and they must be combined in quadrature to give the square of E_T^{miss}. This signal is also sent to the ER over optical fiber. In addition, the signals from the 4-bit adder circuits containing the final sums of hits of different types are received in this module and converted into optical signals for transmission to the global Level 1 logic. It is anticipated that the construction of a CAMAC prototype to test the quadrature addition and the optical link. High speed performance is required, since Level 1 latency is time-critical. Therefore, a 1 GB/s transmitters, of which 5 are required, has been included. The receivers are located on the global Level 1 board (WBS 50.04.3), so only one is included in our system, for test purposes.

50.04.1.2.2.6 Prototype Discriminator Surface Mount PC Board

This element includes the multilevel timing discriminator which is crucial to the level 1 trigger, since it is used to produce the digital signals for all of the EM and SP logic, as well as the timing signals used in the JET transversal filter. A single level version has been built and tested in a beam test, so we are confident of the soundness of the principles of the circuit. The main development task is to implement the multilevel feature and the priority encoding of the outputs.

50.04.1.2.3 Control and Data Links

Need input

50.04.1.2.3.1 1 G Bit/s Fiber Optics Transmitter

Need input

50.04.1.3 Production

Need input

50.04.1.3.1 Signal Cables

This element includes the effort for the signal cables. The approximate number and length of the interconnecting cables for the system is an estimate. The numbers and types of cables may change as the design progresses. However, it is believed that the highest cost items in terms of cables are accounted for here. Shielded twisted pair cables with IDC connectors are included.

50.04.1.3.2 Active Components

Need input

50.04.1.3.2.1 FPGA for L1 Sum Board

This element includes Xilinx chips needed for the L1 sum logic.

50.04.1.3.2.2 FPGA for Count Logic Boards

This element includes Xilinx chips needed for the count Logic.

50.04.1.3.2.3 IDT 7210 MAC IC for JET Sum/Filter Board

See WBS 50.04.1.2.1.3 for a description of this element. The number required scales with the number of JET sum/Filter boards (8/board).

50.04.1.3.2.4 AD9020 FADC IC for JET Sum/Filter Board

See WBS 50.04.1.2.1.4 for a description of this item. The number required is equal to the number of JET sum/filter boards.

50.04.1.3.2.5 Variable Gain Shaping Amplifier for L1 Sum Board

See WBS 50.04.1.2.1.5 for a description of this element. The number required scales with the number of L1 sum boards (7/board).

50.04.1.3.2.6 Summing Amplifier

See WBS 50.04.1.2.1.6 for a description of this element. The number required scales with the number of L1 sum boards (7/boards).

50.04.1.3.3 Printed Circuit Board

Need input

50.04.1.3.3.1 L1 Sum Boards

See WBS 50.04.1.2.2.1 for description of this element. The number of L1 sum boards will be equal to the number of calorimeter front end electronic crates, currently estimated to be 242.

50.04.1.3.3.2 Count Logic Board

See WBS 50.04.1.2.2.2 for a description of this element. The number of required boards for the barrel calorimeter is currently estimated to be 107.

50.04.1.3.3.3 JET Sum/Filter Board

See WBS 50.04.1.2.2.3 for a description of this element. In the barrel calorimeter, 40 JET sums are required. For the endcaps, 40 JET sums are also required bringing the total number of boards to 80.

50.04.1.3.3.4 Adder Board.

See WBS 50.04.1.2.2.4 for a description of this element The number of required adder boards is calculated under the assumption that the same board can be used for the 4-bit addition and the 16-bit addition. It is calculated that 24 boards are required for the EM, SP and JET signals using a one module = 4-bit configuration. Where one-half of a module = 16-bit configuration, a sum with 64 inputs (there is one input for each JET Sum/Filter board, of which there are really 80) requires 5 1/2 adder modules. For the E sum, the smaller number is probably OK, since there will be a restriction on the coverage of that sum. However, for the ETX and ETY sums, this will probably be inadequate, since coverage over all is desired, and this will perhaps include the forward calorimeter as well. To be able to sum all 80 of the signals, 7 adder boards are required for each sum. Therefore, 20 adder modules in the 16-bit configuration are needed. The total number of modules needed then is 44.

50.04.1.3.3.5 Global Sum Board

See WBS 50.04.1.2.2.5 for a description of this element. Only one such board is required. It is expected that the prototype version of the board can be used as a spare.

50.04.1.3.3.6 Timing Discriminator PC Board

See WBS 50.04.1.2.2.6 for a description of this element. The number of units scales with the number of L1 Sum boards (7/board).

50.04.1.3.4 Control and Data Links

Need input

50.04.1.3.4.1 1 G Bit/s Fiber Optics Transmitter

Need input

50.04.1.3.4.2 Rack Slot

This element includes the effort for the rack slot. In this form we indicate the total number of modules, which are all 9U single-width VME units.

50.04.1.4 Installation and Test of 489 Boards

This element includes the labor and material for the Level 1 calorimeter installation and test. Currently, only the effort associated with installing the modules in the experiment and systems tests made *in situ* have been included. Board tests, even if they are carried out at SSCL, are in principle covered in the cost of the board, according to the way they are estimated here.

50.04.2 Muon Level 1 Trigger

Need input

50.04.2.1 Design and Documentation

This element covers the design of the two major ASIC components (chamber encoder and associative memory), the FPGA components for the glue logic on the trigger boards and the trigger board control. Additionally, it covers the design of the overall system and the trigger master and the trigger DAQ link.

50.04.2.2 Barrel Production

This element covers the effort for barrel trigger component production. This includes:

1. The low voltage power for the system.
2. The cabling of the trigger from the chambers to the on-detector crates.
3. The crates for the on-detector electronics.
4. The on chamber electronics which include:
    1. The sector encoder.
    2. The cable driver.

3. Mechanical support for the cabling (SSCL-on site).

5. The trigger card (on detector) which includes:

1. CAM or associative memory.
2. Glue logic for the board.
3. PCB board.
4. Miscellaneous components.
5. Crate controller.
6. Trigger Master or supervisor boards.
7. Trigger/DAQ link (interface boards).

50.04.2.3 Endcap Production

Need input

50.04.2.4 Installation and Test

This element Includes verification of functionality, development of testing hardware and software, signal simulators, testing and auditing of tests, inspection and sign-off. Post-installation service and shipping are not included.

50.04.3 Level 1 Global Trigger

Need input

50.05 Integration

Need input

50.05.1 Rack Development

This element covers all design, engineering and documentation required to provide and support the GEM detector standard electronics racks. This includes engineering of the rack power, mechanical, cooling, control systems, design verification, test tooling , and manufacturing engineering. Hookups to facility electronics power, electronics cooling water, air supplies, control systems, and safety systems are assumed to be provided under other activities. Installation spaces and tooling are likewise not included.

50.05.1.1 Rack Systems Design and Engineering

Need input

50.05.1.2 VME Rack Parts and Materials (Prototype)

Need input

50.05.1.3 Standard Rack Assembly (Prototype)

Need input

50.05.1.4 Standard Rack Installation (Prototype)

Need input

50.05.2 Fiber Link Development

This element contains the effort for the fiber link development. This will involve collaborating with SDC, investigating commercial fiber link to meet radiation requirements, discussing with subsystem groups for common data link.

50.05.3 Facility Interface

This element contains the effort for the facility interface with different groups which provide safety, reliability, radiation, magnetic field study, EFO, CED, PB/MK, procurement, etc.

50.05.4 Facility Development

This element includes the rack design and layout, electronic room layout, cabling routing in the hall and electronics room, AC/DC power distribution and grounding for the facility development.

50.06 Project Management

Need input

50.06.1 Project Management - FY93

Need input

50.06.2 Project Management - FY94

Need input

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Need input

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Need input

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Need input

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522.5060 Computer and Controls

This element includes the global control system, the on-line computing system and the networks at the IR that support these systems. Systems include hardware and software.

60.01 Computer and Controls Research and Development

This element includes any effort necessary to define the appropriate technologies, or application of those technologies, for the GEM computer and controls. This effort may occur throughout the early phases of the project.

60.01.1 Global Control System (GCS)

This element includes the global control system which is the overall control system for GEM.

60.01.1.1 Project Plan

This element includes the production of the project plan for the GCS which is the first step in constructing the system; the plan is the basic set of documents used as a basis for further work. These documents are listed below.

60.01.1.1.1 Requirements, Specifications

This element includes the effort for the definition and documentation of user requirements and the resulting specifications of the system.

60.01.1.1.2 Standards Recommendations

This element includes the effort to make recommendations for standards for hardware and software (mechanical and electrical DAQ specifications, software standards).

60.01.1.1.3 Hardware Recommendations

This element includes the effort to provide a set of recommendations of specific hardware that satisfies the specifications, including recommendations for signal conditioning modules, sensors and actuators to be made available to the subsystems.

60.01.1.1.4 Interface to CCD (Operations Rooms)

This element includes a design for the operations rooms, and liaison with CCD.

60.01.1.1.5 Development Plan

This element includes the plan for developing the system.

60.01.1.2 Test Systems

This element includes the prototype or test systems with which requirements are refined and agreement with specifications evaluated.

60.01.1.2.1 Hardware

This element includes the hardware for the test systems.

60.01.1.2.2 Software

This element includes the software, acquired and developed, for the test systems.

60.01.1.3 Design

This element includes the prototype or test systems with which requirements are refined and agreement with specifications evaluated.

60.01.1.3.1 Data Specifications

This element includes the detailed set of specifications of the data that the system will handle.

60.01.1.3.2 Process Specifications

This element includes the detailed set of specifications of the processes in the system.

60.01.1.3.3 Hardware Specifications

This element includes the specifications of the hardware for the system.

60.01.1.3.4 Procurement Plan

This element includes the plan to procure the system, including acquired software and hardware to meet the specifications.

60.01.1.3.5 Installation Plan

This element includes the plan for installation and testing of the system, including final reviews.

60.01.1.4 Prototype Systems

This element includes the systems used for test, development, and small-scale applications (test setups, test beams).

60.01.1.4.1 Software Development

This element includes the development of prototype software, to evaluate performance, user interfaces, and completeness.

60.01.1.4.2 Acquired Software

This element includes the acquired software, including real-time operating systems, commercial analysis packages, compilers, software development tools, and CASE tools.

60.01.1.4.3 Hardware

This element includes the hardware (computers, disks, DAQ hardware, network links).

60.01.1.5 Test Beam Support

This element includes the planning, designing, and prototyping for support of control systems at test beams. It also includes costs (travel, duplication of equipment) associated with support of test beam work at FNAL and SSCL with prototype systems.

60.01.2 On-line Computing

This element includes the computing system used for Level 3 and/or Level 2 event filters.

60.01.2.1 Project Plan

This element includes the production of the project plan which is the first step in constructing the overall system; the plan is the basic set of documents used as a basis for further work. It will include documents on user requirements, preliminary analysis and design, preliminary specifications, a development plan, and a management plan.

60.01.2.2 Test Systems

This element includes the test systems which will be built for evaluating prototype solutions.

60.01.2.3 Design

This element includes the design phase, based on the project plan and test system results. Its result is the set of documents below.

60.01.2.3.1 Data Specifications

This element includes the specifications of the data to be handled by the system.

60.01.2.3.2. Process Specifications

This element includes the specifications of the processes of the system.

60.01.2.3.3 Hardware Specifications

This element includes the specifications for the hardware, to meet the data and process specifications.

60.01.2.3.4 Procurement Plan

This element includes the plan for procuring the system.

60.01.2.3.5 Installation Plan

This element includes the plan for installing and testing the system, including a final review.

60.01.2.4 Prototype Systems

This element includes the prototype systems used to evaluate concepts and to test solutions. Prototype systems may consist of a partial implementation of the final hardware configuration, and/or the final hardware with prototype software.

60.01.2.4.1 Software Development

This element includes the costs of software development, including the tools (CASE tools, compilers, workstations) to carry out the work.

60.01.2.4.2 Hardware

This element includes the hardware (processors, disks, network interfaces) to implement hardware prototype on-line computing systems.

60.01.2.5 Test Beam Support

This element includes the planning, designing and prototyping for support of test beam with on-line systems. It also includes additional costs associated with support of test beam work with prototype or test on-line systems.

60.01.3 Network and Communications

This element includes the networks and communications supporting the GCS, the on-line systems at the IR, including the interface to the off-line systems, and the operating personnel.

60.01.3.1 Digital Communications

This element includes the digital networks and data links supporting the GCS, the on-line system, and the interface to the off-line systems.

60.01.3.1.1 Project Plan

This element includes the production of the project plan is the first step in constructing the OLS; the plan is the basic set of documents used as a basis for further work. These documents are listed below.

60.01.3.1.1.1 Requirements, Specifications

This element includes the user requirements and specifications for the GCS network, for the interface between the DAQ and the ONS, for the link between the ONS and the off-line systems, for the LAN at the IR servicing general requirements, and for the links to Accelerator systems, PASS, and EMS.

60.01.3.1.1.2 Standards Recommendations

This element includes the recommendations for network/data link standards to be followed.

60.01.3.1.1.3 Hardware recommendations

This element includes the recommendations for hardware (fibers, drivers, etc.).

60.01.3.1.1.4 Interface to CCD (Ducts), ASD and IS

This element includes the liaison with CCD, ASD and IS.

60.01.3.1.1.5 Development Plan

This element includes the plan for hardware and software development.

60.01.3.1.2 Test Systems

This element includes the hardware and software systems to test crucial aspects of network and data links (such as error rates, I/O rates to workstations), and to evaluate performance of trial solutions.

60.01.3.1.3 Design

This element includes the activity of producing a design for the final system based on requirements, resulting in the documents itemized below.

60.01.3.1.3.1 Protocol Specifications

This element includes the specifications of protocols to be used, especially for DAQ to ONS and ONS to off-line systems.

60.01.3.1.3.2 Hardware Specifications

This element includes the hardware specifications for network and data link components (fibers, drivers, repeaters, etc.).

60.01.3.1.3.3 Procurement Plan

This element includes the plan to procure the hardware and software.

60.01.3.1.3.4 Installation Plan

This element includes the plan for installing the networks and data links.

60.01.3.1.4 Prototype Systems

This element includes the systems used to evaluate the designs, possibly by use in test beam work.

60.01.3.1.4.1 Software Development

This element includes the development of special software: lightweight protocol drivers, performance measurements tools, etc., for the prototype systems.

60.01.3.1.4.2 Hardware

This element includes the prototype system hardware: links, switches, workstations, etc.

60.01.3.1.5 Test Beam Support

This element includes the planning, designing, and prototyping for support of test beam work. It also includes costs associated with support of test beam activity at FNAL or SSCL with small scale or prototype systems.

60.01.3.2 Human Communications

This element includes the support of human communications at the IR and between the IR and the main campus. through videoconference and computer tools.

60.01.3.2.1 Videoconference

This element includes the GEM costs for videoconference facilities at the IR and the Main Campus. At the IR, videoconference facilities may be located in the South Assembly building and the underground hall.

60.01.3.2.1.1 Project Plan

This element includes the plan for GEM videoconference facilities.

60.01.3.2.1.2 Design

This element includes the design of GEM videoconference facilities.

60.01.3.2.2 Multimedia Computing Systems

This element includes the support of human communications through the use of multimedia computing systems, supporting desktop videoconference, voice communications, shared displays, and document access. Development of the 'electronic log book' is included here.

60.01.3.2.2.1 Project Plan

This element includes the olan for multimedia systems: user requirements, specifications, preliminary analysis and design, development plan and management plan.

60.01.3.2.2.2 Design

This element includes the design of the systems.

60.01.3.2.2.3 Test Systems

This element includes the systems to test and evaluate proposed solutions.

60.01.3.2.2.4 Prototypes

This element includes the prototype systems to evaluate and demonstrate solutions under development.

60.01.3.3 Test Beam Support

This element includes the planning, designing, and prototyping for support of test beam activity.

60.01.3.3.1 Project Plan

Need input

60.01.3.3.2 Project Design

Need input

60.02 Global Control System

This element includes the acquisition, construction, installation, and testing of the GCS.

60.02.1 Software

This element includes the software for the GCS; primarily in the EPICS framework, as currently envisaged.

60.02.1.1 User Interface

This element includes the design and implementation of the user interfaces for GEM. The specific screens and menus, etc. The software to access and display information requested by operators, and to transmit information to ASD.

60.02.1.2 Database

This element includes the software to support the databases for the logbook, and for access to other databases such as configuration, calibration and production.

60.02.1.3 Alarm Handler

This element includes the software to support alarm handling and logging.

60.02.1.4 Archive

This element includes the software to update and access the monitor archive and the software for the archive itself.

60.02.1.5 Channel Access

This element includes the software to provide channel access in the EPICS system. This will include GEM-developed drivers for specific purposes.

60.02.1.6 Monitoring Processes

This element includes the processes to read out the sensors and translate the information for logging and display.

60.02.1.7 Adaptive Control

This element includes the control functions which close the loop between monitor and control.

60.02.1.8 Commercial software

This element includes the acquired software to support the GCS.

60.02.1.8.1 RT OS

This element includes the real-time operating system licenses for GCS systems.

60.02.1.8.2 Drivers

This element includes the special drivers for RT systems.

60.02.1.8.3 Expert System

This element includes the expert systems for control, including adaptive control software.

60.02.1.8.4 Analysis

This element includes the commercial analysis tools (e.g. Mathematica, Wingz).

60.02.1.9 Interface to Other Computing Systems

This element includes the development of special drivers for network and data link interfaces.

60.02.1.10 Interface to WAN

This element includes the WAN interface will allow GCS to support operation from remote sites. The software will be constructed to support access and access control.

60.02.1.11 Electronic Logbook Support

This element includes the special equipment for electronic logbook support (frame grabbers, TV cameras, videorecorders, pen input devices, etc.).

60.02.2 Hardware

Need input

60.02.2.1 Consoles and Displays

This element includes the consoles (keyboards, other input devices), flat panel displays, large-screen displays for GCS, printers and other display devices.

60.02.2.2 Processors

This element includes the processors to support GCS, both standard workstations and rack-mounted processors for the EPICS system.

60.02.2.3 Storage System

This element includes the local storage system for GCS -- the electronic logbook and monitor archive.

60.02.2.4 Networks

This element includes the network interfaces.

60.02.2.5 I/O crates

This element includes the crates for the GCS I/O controllers, signal conditioning, archive support, alarm management, actuator control. GCS will supply the crates for subsystem signal conditioning modules.

60.02.2.6 Racks

This element includes the racks for GCS equipment, and rack space in the electronics room.

60.02.2.7 Signal Conditioning

This element includes the signal conditioning equipment specific to the GCS (subsystems will bear the cost of subdetector signal conditioning).

60.02.2.8 Interface to Accelerator

This element includes the hardware related to the accelerator interface: network interfaces, special signal processing, displays.

60.02.2.9 Interfaces to other GEM Computing Systems

This element includes the hardware related to interfaces to other computing systems.

60.02.2.10 Electronic Logbook Support

For a description of this element see WBS 60.2.1.11.

60.02.2.11 UPS

This element includes the un-interruptible power supply to maintain GCS operation for 30 minutes.

60.02.3 Documentation

This element includes the documentation for GCS.

60.02.3.1 Users Guide

This element includes the guide for users of the systems.

60.02.3.2 Manuals

This element includes the manuals covering operation of the GCS and software and hardware maintenance and enhancement.

60.02.3.3 Standards

This element includes the documentation of standards to be followed by all GEM controls and monitoring.

60.02.3.4 Specifications

This element includes the specifications for GEM control and monitoring hardware.

60.02.4 Procurement

This element includes the procurement of the GCS.

60.02.5 Installation

This element includes the installation and testing of the GCS.

60.02.5.1 Operations Room Preparation

This element includes the preparation of the operations room: special lighting, special furniture, special flooring, cable routing. HVAC and electrical is assumed to be provided by facilities, as will the raised-floor room at the IR and an optionally raised-floor room at main campus.

60.02.5.2 Hardware Installation

This element includes the installation of GCS hardware in the SAB, Electronics room, hall, utility shaft, gas mixing building.

60.02.5.3 Software Installation

This element includes the installation of GCS software.

60.02.6 Testing

This element includes the testing of the GCS system.

60.02.7 Test Beam Support

This element includes the support of test beam work at FNAL and SSCL.

60.02.7.1 Software

This element includes the test beam specific software.

60.02.7.2 Hardware

This element includes the test beam specific hardware.

60.02.7.3 Procurement

This element includes the procurement of test beam specific items.

60.02.7.4 Installation

This element includes the installation and testing of control systems at test beam areas.

60.03 On-line Computing System (ONS)

This element includes the on-line computing system to support event filters.

60.03.1 Software

This element includes the software for the on-line system. Network/data link drivers are included under the Network and communication WBS element.

60.03.1.1 Process Control

This element includes the software to control and coordinate multiple processes running in multiple CPUs.

60.03.1.2 System Management

This element includes the software for ONS management and monitoring.

60.03.1.3 Databases

This element includes the software to support local databases (configuration, calibration, production).

60.03.1.4 Commercial software

This element includes the acquired software for the ONS.

60.03.1.4.1 Operating Systems

This element includes the operating system licenses for the ONS.

60.03.1.4.2 Queuing System

This element includes the process queuing system license for the ONS.

60.03.1.5 Interface to GCS

This element includes the software (processes) to support the interface to GCS for control and monitoring.

60.03.1.6 Interface to DAQ

This element includes the software (processes) to support the interface to DAQ.

60.03.1.7 Interface to Off-line Systems

This element includes the software (processes) to support the interface to off-line systems.

60.03.2 Hardware

This element includes the hardware for the ONS.

60.03.2.1 System Management

This element includes the workstations and peripherals to support ONS system management.

60.03.2.2 Processors

This element includes the processors and associate memory for the ONS compute server.

60.03.2.3 Networks

This element includes the network/data link interfaces and network/data link hardware internal to the ONS.

60.03.2.4 Racks

This element includes the racks to mount ONS processors.

60.03.2.5 Interface to GCS

This element includes the hardware for the interface to GCS (e.g., network interfaces, special processors).

60.03.2.6 Interface to DAQ

This element includes the hardware for the interface to DAQ (e.g., special processors).

60.03.2.7 Interface to Off-line system

This element includes the hardware for the interface to the off-line system (e.g., special processors, buffers, network interfaces).

60.03.2.8 UPS

This element includes the uninterruptible power supply for the ONS, to maintain operation of the system management function for 10 minutes and the compute server for five minutes.

60.03.2.9 HVAC

This element includes the HVAC for the compute server. This is only the heat exchangers; chilled water is to be provided by CCD.

60.03.3 Documentation

This element includes the documentation for the ONS.

60.03.3.1 Users guide

This element includes the user's guide for the ONS.

60.03.3.2 Manuals (operations, maintenance)

This element includes the operations manuals for the ONS software and hardware, and a maintenance manuals.

60.03.3.3 Standards

This element includes the documentation of ONS standards for software and hardware.

60.03.3.4 Specifications

This element includes the ONS specifications.

60.03.4 Procurement

This element includes the procurement of the ONS acquired software and the hardware.

60.03.5 Installation

This element includes the installation of the ONS.

60.03.5.1 Compute Server Room Preparation

This element includes the preparation of the computer server room: special lighting, cable routing, HVAC (heat exchanger) installation.

60.03.5.2 Hardware Installation

This element includes the installation of the computing hardware (system management, compute servers, disk arrays).

60.03.5.3 Software Installation

This element includes the installation of software.

60.03.6 Testing

This element includes the testing of hardware and software.

60.03.7 Test Beam Support

This element includes the support of test beam work with on-line systems.

60.03.7.1 Software

This element includes the specific test beam software.

60.03.7.2 Hardware

This element includes the specific test beam hardware.

60.03.7.3 Procurement

This element includes the procurement of test beam equipment and software.

60.03.7.4 Installation

This element includes the installation and testing of test beam on-line systems.

60.04 Network and Communications

Need input

60.04.1 Digital Communications

This element includes the network and data link systems for support of GCS, ONS and off-line interface.

60.04.1.1 Software

This element includes the software to support digital communications.

60.04.1.1.1 Protocol Development

This element includes the development of special-purpose protocols for data links and networks.

60.04.1.1.2 Driver Development

This element includes the network management tools.

60.04.1.2 Hardware

Need input

60.04.1.2.1 Data Links

This element includes the data link hardware between DAQ and ONS, ONS and off-line system (e.g., routers, bridges.)

60.04.1.2.2 LAN at IR

This element includes the LAN at the IR to support GCS, including bridges, routers.

60.04.1.2.3 UPS

This element includes the uninterruptible power supplies to maintain network functionality for one hour, or as needed for safety.

60.04.1.3 Documentation

Need input

60.04.1.3.1 Users Guide

This element includes the guide for network users, including programmers.

60.04.1.3.2 Manuals (Operations, Maintenance)

This element includes the operations and maintenance manuals for network hardware and software.

60.04.1.3.3 Standards

This element includes the network standards documentation.

60.04.1.3.4 Specifications

This element includes the network specifications.

60.04.1.4 Procurement

This element includes the procurement of network hardware and acquired software.

60.04.1.5 Installation

This element includes the network installation.

60.04.1.6 Testing

This element includes the network testing.

60.04.2 Human Communications

This element includes the network/data link and CCTV hardware in support of human communications.

60.04.2.1 Videoconference Facilities

This element includes the procurement, installation, testing and documentation of network facilities, in support of GEM videoconference facilities, for which the GEM project is responsible.

60.04.2.2 Multimedia Systems

This element includes the procurement, installation, testing and documentation of network facilities, in support of GEM multimedia systems, for which the GEM project is responsible.

60.04.3 Test Beam Support

This element includes the network and communications support of test beam activities.

60.04.3.1 Software

This element includes the software specific to test beam support.

60.04.3.2 Hardware

This element includes the hardware specific to test beam support.

60.04.3.3 Procurement

This element includes the procurement of hardware and acquired software.

60.04.3.4 Installation

This element includes the installation and testing of test beam networking and communications specific to GEM.

60.05 Project Management

This element includes the management of the above projects: project leaders, project administration support personnel, travel, review costs, computers, project management software, quality assurance, ES & H compliance.

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522.5070 Interface Systems

This element includes structures, utilities, support equipment, access, and gas and cryogenic support systems required to support assembly, installation and operation of the GEM detector, but not forming an integral part of one of the detector subsystems. Also included under this WBS section are all labor, supervision, transportation and other related activity necessary to design, document, procure, assemble, and maintain the items of interface hardware during the detector assembly, installation and commissioning periods. Maintenance of support hardware and systems defined under this WBS during detector operations are excluded.

70.01 Central Detector Support (CDS)

This element includes the Central Detector Support (CDS) structure as well as all assembly and installation support fixtures, rigging, transporting fixtures, positioning mechanisms and anchoring hardware necessary to assemble the CDS on the surface, transport it to the installation shaft, lower it down the shaft, position it at its nominal location on the hall floor, jack it to its operational height and position, and permanently anchor it to the hall floor.

70.01.1 Central Detector Support Design

This element includes all labor and material to design, develop, manufacture and assemble the central detector support and to install it in the underground hall.

70.01.2 Central Detector Support Tooling Design

This element includes all effort to design, develop, manufacture, assemble and align all jigs and fixtures for positioning and aligning CDS components during the assembly process. Also included are all ladders and scaffolding needed for personnel and equipment access to the CDS during assembly operations.

70.01.3 Central Detector Support Fabrication Assembly

This element includes all effort associated with the design, purchase and fabrication of special-purpose cradles, supporting fixtures or other hardware needed to support and maintain the alignment and structural integrity of the CDS during lifting and transporting operations.

70.01.4 Central Detector Support Tooling Fabrication Assembly

This element includes all effort associated with the design, purchase and fabrication of cables, slings, load spreaders, hooks, shackles, clevises or other hardware needed to properly accommodate the load of the CDS during lifting and transporting operations.

70.01.5 Central Detector Support Installation

This element includes all effort associated with the specification, procurement and transportation of heavy duty rollers or other load-bearing mechanisms needed to translate the CDS from a position at the bottom of the installation shaft, along a set of embedded bearing rails, to the final position at the center of the underground hall.

70.02 Beam Pipe

This element includes all effort to design, develop, manufacture, assemble, test and install the beam pipe elements that connect the GEM detector components with the accelerator system in the underground hall. The beam pipe is expected to be fully assembled and tested in a surface assembly area and then partially disassembled and transported to the underground hall for final installation and testing.

70.02.1 Beam Pipe Design

This element includes all effort necessary to determine beam pipe design requirements, translate requirements into preliminary design options, perform simulations and analyses to verify design conformance to requirements, and produce a final detailed design.

70.02.2 Beam Pipe Documentation

This element includes all specifications, drawings, parts lists and assembly and installation instruction packages necessary to detail the beam pipe design and to document assembly and installation requirements.

70.02.3 Beam Pipe Procurement

This element includes all effort to identify and qualify potential vendors for beam pipe components, prepare procurement documentation, carry out the bid and award process, and monitor and control vendor performance under the ensuing contract.

70.02.4 Beam Pipe Manufacture

This element includes the effort associated with manufacture and off-site assembly of the hardware components of the beam pipe and shipment of the components to the assembly site at IR5. Manufacturing may be accomplished off-site.

70.02.4.1 Beryllium Section

This element includes all effort associated with manufacture, assembly and testing of the beryllium pipe section which is situated inside the Central Tracker system. This section is expected to be mated with the Central Tracker above ground and installed in the underground hall with the Tracker.

70.02.4.2 Aluminum and Stainless Steel Section

This element includes all effort associated with manufacture, assembly and testing of the beam pipe subsystems which link the beryllium section with the main accelerator beam line and maintain vacuum integrity.

70.02.4.3 Vacuum Pumps, Valves and Bellow Assemblies

This element includes all effort to procure, assemble and functionally test vacuum pumping and valving hardware for evacuating the beam pipe and for isolating the beam pipe assembly into vacuum sectors for maintenance purposes.

70.02.5 Vacuum Pumping and Monitoring Control System

This element includes all effort to design, procure, assemble, test and install all electronics, hardware and display systems needed to monitor and control the detector beam pipe vacuum condition and to interlock the detector vacuum system with the accelerator system.

70.02.6 Beam Pipe Assembly (Surface)

This element includes the supervision and labor necessary to assemble on-site the beam pipe components into a complete system. Components will be assembled initially in a surface facility and tested functionally before installation in the underground hall.

70.02.7 Beam Pipe Installation (Tunnel)

This element includes the supervision and labor necessary to transport the beam pipe components from the assembly site to the installation shaft, lower the components down the installation shaft to the hall floor, and install the (aluminum)(stainless steel) sections, vacuum pumping systems and monitoring systems into the detector. Also included are all supervision and labor to connect the beam pipe and vacuum system to the collider quadrupole/collimator system and perform final testing of the vacuum system, including controls and interlocks. The beryllium section of the beam pipe will be installed into the central tracker on the surface and lowered into the underground hall as part of the tracker subsystem.

70.02.8 Detector In-hall Pump and Pipe Support Structures

This element includes all effort to design, procure, fabricate and install mounting brackets, trusses, webbing, support rollers and "spiders" needed for support of the beam pipe and pumping apparatus in or on the GEM detector.

70.02.9 Beam Pipe Special Handling and Support Fixtures

This element includes all effort to design, procure, fabricate and install all temporary and permanent scaffolds, stanchions, ladders and special handling tools and fixtures needed to transport assembled beam pipe and pumping components and to support and access components during assembly, installation and maintenance.

70.03 Detector Access Equipment

This element includes all effort to design, procure, assemble, and install all scaffolding, gangways, catwalks, ladders and other hardware needed for personnel and equipment access to the GEM detector and technical utility systems during installation and maintenance operations. Also included are all scaffolds, ladders and other structures needed to support and access electronics equipment mounted on the detector.

70.03.1 Access Equipment Design

This element includes all effort necessary to determine detector access design requirements, translate requirements into preliminary design options, perform simulations and analyses to verify design conformance to requirements, and produce a final detailed design.

70.03.2 Access Equipment Documentation

This element includes all specifications, drawings, parts lists and assembly and installation instruction packages necessary to detail the access equipment design and to document assembly and installation requirements.

70.03.3 Access Equipment Procurement

This element includes all effort to identify and qualify potential vendors for the access equipment, prepare procurement documentation, carry out the bid and award process, and monitor and control vendor performance under the ensuing contract.

70.03.4 Access Equipment Installation and Dismantle

This element includes the effort associated with manufacture assembly and shipment of the hardware components of the access equipment for installation and dismantling to the IR5 site.

70.04 Detector Safety Systems

This element includes the design, manufacturing, installation and integration/test and validation tasks including labor, material, travel and incidental costs to provide technical and unique safety systems for the GEM experiment. This scope is defined to provide those unique elements required by the experiment which are not logically able to be provided by either EFD or CCD. Where an external system interface (from a facility system) is required with the GEM safety system, the GEM task is specified to start at the junction supplied by EFD or CCD.

70.04.1 Safety System Design

This element includes analysis of the proposed GEM safety system designs, determination of specific and related design requirements, simulation of design for conformance and validation. Specific investigations include four elements 1) fire protection/suppression, 2) oxygen deficiency monitoring, 3) fire/smoke detection and 4) consulting on critical safety issues. The task consists of labor costs.

70.04.2 Safety Systems Documentation

This element consists of the labor to document the safety systems drawing package for those technical systems used on or by the GEM experiment.

70.04.2.1 Detector and Support Equipment Safety Systems

This element includes preparing specifications, drawings, part lists (the engineering drawing package), and manufacturing, assembly and installation work order documents (the installation/test package). Safety system areas included in the packages are as follows: 1) detector based or housed safety systems, 2) support equipment located in the hall or shafts, 3) operations center safety equipment and center (not specified in subsystems designs), and 4) GEM specified technical support safety items located in surface facilities. Documentation may be either system safety unique work packages or included as elements of other (subsystem) work packages.

70.04.2.2 Safety Control Center

This element includes the control center which is a dedicated safety workstation or console which encompasses a computer, enunciators, communications and monitoring equipment items. The task includes specification development, design, and preparation of manufacturing and test procedures, drawing package preparation, and end item documentation.

70.04.3 Safety Systems Procurement Management

The element includes the effort to identify and qualify potential vendors for the safety systems identified through the drawing package (specified), to prepare procurement documentation, to carry out the bid and award process, and to manage vendor activities after award. Task includes labor and travel.

70.04.4 Safety Systems Manufacture, Assembly and Test

This element includes the manufacture, assembly and acceptance of hardware items for safety systems for work performed at the SSCL. The task includes material and labor associated with the task.

70.04.4.1 Safety Control Center Console.

This element includes materials, components and incidental process items to construct the safety center console equipment. Labor is to manufacture, assemble and test prior to installation.

70.04.4.2 Other Interface Items

This element predominantly includes fixtures, cables and incidental items to provide interface with other EFD supplied items. Such equipment encompasses picking-up a junction of EFD equipment that will interface back to GEM warning and controls.

70.04.4.3 Safety Systems Software

This element consists of the development of safety specific hardware for the GEM experiment which will be associated with the PASS, GCS and the safety control center computer. Task includes labor and incidental materials (Computer or control hardware is in WBS 70.04.4 or 70.04.5.)

Element 1. PASS

This element includes software modifications or module additions to current (SSCL provided system) software to augment, enhance and meet GEM experiment/detector specific requirements.

Element 2. GCS

The element includes software modules and interfaces which are related to safety systems for enunciation, alarm, monitoring, communication and controls, and are specifically identified as safety critical which will interface to the safety workstation.

Element 3. Safety Control Center

The element includes software development, coding, code/module level test and simulations for critical safety systems. Final installation and verification is in task WBS 70.04.5.

70.04.5 Safety Systems Installation, Integration and Test

This element (and each subtask and element) includes labor, material and incidental expense to install and integrate GEM technical safety systems and related devices in above ground facilities. Material is for equipment items which are installed directly into systems or subsystems and racks/crates or shafts (not EFD supplied), i.e., items that do not require manufacturing or subassembly.

70.04.5.1 Above Ground Safety System Installation

This element includes the installation and integration of technical safety systems in NAB, SAB other support facilities and in particular the GEM Operations Center located in the SAB.

Element 1. Operations Center Safety Systems

This element encompasses final assembly, installation and test of safety system hardware - primarily the safety control center in the operations center.

Element 2. PASS/GCS Safety Interfaces

This element includes the installation of safety specified interfaces to GCS and PASS. Items include communication interfaces, enunciator interfaces and miscellaneous hardware.

Element 3. Other Above Ground Installations

This element provides the interface of GEM technical safety equipment with other facility equipment. Included are technical safety systems and the integration of EFD provided safety devices which are required to interface with GEM alarms and other such safety systems (such as butane gas leaks in utility building or static magnetic field monitors). The GEM task is defined at the junction where an output is provided by EFD/CCD.

70.04.5.2 Underground Safety System Installation

This element includes the installation, integration and test of GEM safety systems. Safety equipment will be installed and integrated on the detector, in the hall contained equipment racks, carts and gas or other GEM specified systems, in the counting/power rooms in the electronics shaft, and magnet electrical, gas and cryogen supply in the utilities shaft. Task elements are based on particular functional safety systems.

Element 1. PASS

This element includes material purchases and installation of required detector entry protection and various safety systems which interfaces with PASS in order to provide personnel protection. Integration and checkout will be done under this element.

Element 2. ODH Monitoring and Control

This element includes oxygen deficiency monitors throughout the detector's subsystems using detectors, BIT and annunciation/alarm.. It includes interfaces to the PASS and GCS.

Element 3. Gas and Cryogen Leak

This element includes detector subsystem monitors for flammable gas and cryogen leaks using detectors and circuitry that interfaces to the GCS. Redundancy will be provided for critical areas.

Element 4. Smoke Detection

This element includes smoke detection equipment and installation for specific areas within the detector, in cable runs or trays to/from the detector, in hall racks/crates, in racks in the counting/power rooms, and for GEM equipment in the utility shaft.

Element 5. Fire Detection and Suppression

This element includes the detection and suppression hardware and installation. Also, stand-alone alarms plus integration with hardware into GCS and other SSCL safety systems at the GEM detector interface with facilities are included. Depending on the subsystem or support equipment item, suppression encompasses nitrogen, water, mist and other non-halon gases depending on the location within the detector, hall, and shafts. This task does not include facility (EFD/CCD) supplied systems.

Element 6. Inerting Systems.

- This element includes gas inerting capabilities for the tracker and muon subsystems. Inerting will be performed in the event of a butane or mixed gas leak in either subsystem. Hardware and installation are included.

Element 7. Miscellaneous Devices

This element includes the material purchase and installation, as applicable, of other devices such as limited radiation monitoring equipment, dosimeters, local fire suppression, e.g., extinguishers, detector mounted power-OFF emergency switches, specialized portable monitoring equipment and portable communications items which will be used during installation or maintenance of the detector prior to operational status. Task does not include PRD or EFD/CCD supplied items.

70.04.5.3 Safety Computer Systems

This element includes the PASS, GCS and Safety control center which will interface and provide coherent monitoring, alarms and other communication functions. The effort includes software integration and test. Interface equipment and the safety computer are included in this task. Integration of external detectors and other devices to the safety console is included. Final test and checkout are included herein.

70.04.6 Safety Systems Verification and Readiness Review

This element includes the labor for the ORR and on-site safety review. It is anticipated that during the detector operations readiness review (ORR) that safety systems and the communication, enunciation, alarm systems will be similarly reviewed.

70.05 Utility Services

This element includes all effort to design, develop, manufacture, procure, assemble, test and install the utility service elements needed to provide power and cooling for the GEM detector. Power and cooling requirements necessary to maintain a safe, comfortable operating environment for personnel in the underground hall are excluded from this element.

70.05.1 Heating, Ventilating, and Air Conditioning (HVAC)

This element includes all effort to design, develop, manufacture, procure, assemble, test and install the heating, cooling and air conditioning services needed for the proper operation of the GEM detector.

70.05.2 Cooling Water

This element includes all effort to design, develop, manufacture, procure, assemble, test and install the cooling water services needed for the proper operation of the GEM detector. This includes chillers, pumps, heat exchangers and other hardware elements on the surface as well as plumbing, piping, mounting hardware and other items needed to deliver cooling water to the detector subsystems and return the heated water to the surface equipment.

70.05.3 Compressed Air

This element includes all effort to design, develop, manufacture, procure, assemble, test, and install the compressed air services needed for the assembly of the GEM detector and instrumentation.

70.05.4 Electrical Power System

This element includes all effort to design, develop, manufacture, procure, assemble, test and install the electrical power services needed for the proper operation of the GEM detector and its instrumentation.

70.05.4.1 Hall and Electronics Shaft

This element includes all effort necessary to determine detector electrical system design requirements, translate requirements into preliminary design options, perform simulations and analyses to verify design conformance to requirements, and produce a final detailed design.

70.05.4.1.1 60 Hz Power Distribution and Grounding

This element includes all effort to design, develop, install, and test the power distribution system necessary for the operation of electronics in the cable electronics shaft and in the detector hall. These systems will be served from the "clean power distribution system" and include K rated isolation transformers, branch circuit panelboards, and branch circuit wiring.

For grounding, this element includes all effort to design, develop, install, and test the grounding system necessary for the operation of electronics in the cable electronics shaft. The grounding system for the cable electronics shaft will be derived from the facility grounding access points.

70.05.4.1.2 IR Region Communication

This element includes all effort to design, develop, install, and test emergency communications systems that include emergency telephone, paging, and radio communications systems.

70.05.4.1.3 Cable Trays

This element includes all effort to design, develop, install, and test cable tray raceways in the cable electronics shaft that are necessary for operation of the electronics in the cable electronics shaft and in the detector hall.

70.05.4.2 Utility Building

This element includes all effort to design, develop, install, and test the power distribution system necessary for the operation support systems for the GEM detector.

70.05.4.2.1 50 Hz Power Distribution

This element includes all effort to design, develop, install, and test the power distribution system necessary for DC power system and the cryogenics system. These distribution systems include 5 KV and 480 V feeders, 5 KV and 480 V motor control systems, branch wiring and power wiring for the control room.

70.05.4.2.2 Communication

This element includes all effort to design, develop, install, and test emergency communications systems that include emergency telephone, paging, and radio communications systems.

70.05.5 Mechanical Controls

This element includes the effort to design, specify, integrate, install and test the instrumentation and control system for the technical mechanical systems to include HVAC, MCHW, LCW, and compressed air. This element also includes the engineering, hardware, software and installation effort for the mechanical control system integrated to provided field interface panels where all sensor and control components are terminated.

70.06 Cranes

This element includes all effort to design, develop, manufacture, procure, assemble, test and install the crane services needed to transport heavy components during on-site manufacture, assembly, test and installation of GEM detector subsystems, both on the surface and in the underground hall.

70.06.1 Surface Cranes

This element includes all effort to design, develop, manufacture, procure, assemble, test and install the cranes needed for processing GEM subsystems during detector assembly operations on the surface. This includes the heavy lift crane needed for lowering very large detector subsystem components down the installation shaft to the underground hall floor.

70.06.1.1 Surface Crane System Design

This element includes all effort necessary to determine detector surface crane system design requirements, translate requirements into preliminary design options, perform simulations and analyses to verify design conformance to requirements, and produce a final detailed design.

70.06.1.2 Surface Crane System Documentation

This element includes all specifications, drawings, parts lists and assembly and installation instruction packages necessary to detail the surface crane system design and to document assembly and installation requirements.

70.06.1.3 Surface Crane System Procurement

This element includes all effort to identify and qualify potential vendors for the surface crane system, prepare procurement documentation, carry out the bid and award process, and monitor and control vendor performance under the ensuing contract.

70.06.1.4 Surface Crane System Manufacture, Assembly and Test

This element includes the effort associated with manufacture, assembly and acceptance testing of the hardware components of the surface crane system and shipment of the components to the assembly site at IR5.

70.06.1.5 Surface Crane System Installation

This element includes the supervision and labor necessary to transport the detector surface crane system components to the assembly site and install the components and monitoring systems at the appropriate location at the IR5 site.

70.06.2 Underground Hall Cranes

This element includes all effort to design, develop, manufacture, procure, assemble, test and install the dual bridge cranes needed for processing GEM subsystems during detector installation operations in the underground hall.

70.06.2.1 Underground Hall Crane System Design

This element includes all effort necessary to determine detector underground hall crane system design requirements, translate requirements into preliminary design options, perform simulations and analyses to verify design conformance to requirements, and produce a final detailed design.

70.06.2.2 Underground Hall Crane Documentation

This element includes all specifications, drawings, parts lists and assembly and installation instruction packages necessary to detail the underground hall crane system design and to document assembly and installation requirements.

70.06.2.3 Underground Hall Crane System Procurement

This element includes all effort to identify and qualify potential vendors for the underground hall crane system, prepare procurement documentation, carry out the bid and award process, and monitor and control vendor performance under the ensuing contract.

70.06.2.4 Underground Hall Crane System Manufacture, Assembly and Test

This element includes the effort associated with manufacture, assembly and acceptance testing of the hardware components of the underground hall crane system and shipment of the components to the assembly site at IR5.

70.06.2.5 Underground Hall Crane System Installation

This element includes the supervision and labor necessary to transport the detector underground hall crane system components to the assembly site and install the components and monitoring systems at the appropriate location at the IR5 site.

70.07 Auxiliary Equipment

This element includes all effort associated with temporary equipment and structures needed to install muon, calorimeter and tracker subsystems in the underground hall. Examples of auxiliary equipment include special rail structures required to support and guide subsystems while translating from initial positions at the bottom of the installation shaft to their final position in the detector, traction systems needed to move the subsystems along the rails, and temporary support structures required to balance asymmetrical loading of the central detector support during installation. Miscellaneous items include unique rigging, tooling and consumables used during installation. Permanent mounting rails and brackets for the subsystems are included with the individual subsystem and are not included in this element.

70.07.1 Experimental Hall System

This element includes all effort necessary to determine detector auxiliary equipment design requirements, translate requirements into preliminary design options, perform simulations and analyses to verify design conformance to requirements, and produce a final detailed design.

70.08 Gas Services

This element includes the gas services which provide materials, components, and assembly labor for gas support to the muon and tracker detector systems during assembly, checkout, and hall integration.

70.08.1 Assembly Building

This element includes gas system piping and components, installation, gas consumables, and system support for chamber testing and checkout.

70.08.1.1 Gas System Assembly Equipment

This element includes gas system equipment including components, piping, and storage tanks to support chamber assembly, testing, and system checkout.

70.08.1.2 Consumables Assembly Building

This element includes the gas supply for the tracker and muon chamber testing and system checkout.

70.08.1.3 Gas Services Manufacture, Assembly, Test - Assembly Building

This element includes the muon and tracker gas system hall integration labor for system component assembly and installation.

70.08.2 Detector Hall

This element includes the tracker gas systems hall integration and gas system gas supplies.

70.08.2.1 Gas System Hall Equipment

This element includes the tracker gas system integration components consisting of the piping and exhaust system.

70.08.2.2 Consumables - Hall

This element includes the gas supply for the muon and tracker chamber testing, chamber protection, and system checkout prior to detector operations.

70.08.2.3 Gas Services Manufacture, Assembly, Test - Hall

This element includes the tracker gas system hall labor for gas system integration and installation.

70.08.3 Gas Control and Monitor System

This element includes the effort to design, specify, integrate, install and test the instrumentation and control system for the calorimeter gas controls. This element also includes the engineering, hardware, software and installation effort for the gas control system integrated to provide field interface panels where all sensor and control components are terminated.

70.09 Survey Alignment Systems

This element includes all effort associated with design, documentation, procurement, assembly and installation of hardware and software systems necessary to accurately measure the location and alignment of detector subsystems relative to each other and to the collider interaction point. Included are technical advice to subsystem designers during subsystem design, definition of survey alignment requirements as part of subsystem design, supervision of survey alignment activities and operation of the survey alignment system during detector installation and testing.

70.09.1 Survey Alignment System Design

This element includes all effort necessary to determine detector survey alignment system design requirements, translate requirements into preliminary design options, perform simulations and analyses to verify design conformance to requirements, and produce a final detailed design.

70.09.2 Survey Alignment System Documentation

This element includes all specifications, drawings, parts lists and assembly and installation instruction packages necessary to detail the survey alignment system design and to document assembly and installation procedures and requirements.

70.09.3 Survey Alignment System Procurement

This element Includes all effort to identify and qualify potential vendors for the survey alignment system components, prepare procurement documentation, carry out the bid and award process, and monitor and control vendor performance under the ensuing contracts.

70.09.4 Survey Alignment System Manufacture, Assembly and Test

This element includes the labor, supervision and procurement associated with manufacture, assembly and acceptance testing of the hardware and software components of the survey system, shipment of the components to the assembly site at IR5, and inspection and testing of components on-site.

70.09.5 Survey Alignment System Installation and Monitor

This element Includes the supervision, labor, material and data processing effort necessary to transport the detector survey system components from the assembly site to the installation shaft, lower the components down the installation shaft to the hall floor, and install, calibrate and align the components and monitoring systems in the underground hall and detector. Also, included are labor and material to monitor, support and operate the survey alignment system during detector installation and testing.

70.10 Magnetic Shielding Systems

This element includes the specification, design, procurement, fabrication and installation of all iron shielding material and support structures required to mitigate the effects of the GEM detector magnetic field on personnel, machinery, equipment and electronics subsystems located in the cable/electronics shaft.

70.10.1 Magnetic Shielding System Procurement

This element includes all effort to identify and qualify potential vendors for the magnetic shielding hardware, including assembly bolts, tools, and handling fixtures, prepare procurement documentation, carry out the bid and award process, and monitor and control vendor performance under the ensuing contract.

70.11 Test Beam and Calibration Hall

Need input

70.11.1 Calibration Hall

Need input

70.11.1.1 Mechanical Systems

Need input

70.11.1.2 DAQ

Need input

70.11.1.3 Equipment and Supplies

This element includes the labor necessary to support software engineering and design required to set up a DAQ/data handling and storage system for GEM in the calibration hall. Labor, materials, and hardware required to collect and store data; labor and materials required to assemble and install DAQ devices for the GEM test beam; and labor and materials required to install the hardware for controls and diagnostic interfaces to the GEM transporters and modules under test in the calibration hall.

70.11.1.3.1 Shielding Blocks and Platforms

This element includes the effort for engineering, design, inspection, administration, and labor costs necessary to fabricate and erect elevated platforms required to position GEM technical equipment to a beam height of 16 feet within the calibration hall. Materials necessary to install the GEM tracker, the GEM cryostat and transporter, and GEM muon test devices to a beam height of 16 feet. Handrails and stairways as necessary for personnel safety on elevated platforms for GEM technical devices.

70.11.1.3.2 Rigging

This element includes the effort for engineering, inspection, administration, and labor costs necessary to provide rigging support for the installation and set-up of the GEM tracker, the GEM cryostat and transporter, and GEM muon test devices in the calibration hall.

70.11.1.3.3 Tools and Fixtures

This element includes the effort for engineering, design, inspection, administration, materials, and equipment required to furnish GEM with tools and fixtures necessary to install the GEM tracker, the GEM cryostat and transporter, and GEM muon test devices in the test beam of the calibration hall.

70.11.1.3.4 Access Equipment

This element includes the effort for engineering, design, inspection, administration, materials, and equipment to provide GEM with access equipment required to install the GEM tracker, the GEM cryostat and transporter, and GEM muon test devices at an elevation of 16 feet in the calibration hall.

70.11.1.3.5 Electronics Support

This element includes the effort for engineering, materials, and equipment required to provide GEM test beam operations with necessary electronics support.

70.11.1.3.6 Technical Labor Support

This element includes the effort for engineering, inspection, administration, and labor to hire and maintain technical labor force to support the installation and set-up of GEM test beam devices within the calibration hall.

70.11.1.3.7 Consumables

This element includes the effort to cover consumables during the installation of GEM technical devices in the test beam of the calibration hall.

70.12 Detector Cable and Plumbing Routing, Design and Verification

This element includes the design and engineering of cable and plumbing services for the GEM detector. This includes cabling (including fiber optics), cable installation, and installation labor from detector subsystems to underground hall racks if used and to Tunnels 5 and 6 if not. This also includes design, engineering, and installation of water, butane, and other plumbing services needed between the detector subsystems and the underground hall. To verify that clearances are adequate and to verify that associated requirements have been correctly identified, a mockup will be built and fitted with detector cabling and plumbing if needed.

70.12.1 Detector Cable and Plumbing Installation

This element includes all effort necessary to design cable and plumbing services for the central detector region, and the transition links connecting the detector to the underground hall, excluding magnet services. Also includes design of installation and support hardware and installation of detector cabling and plumbing components.

70.12.1.1 Detector Cable and Plumbing Design

This element includes all effort necessary to specify cable and plumbing installation design requirements, translate requirements into preliminary design options, produce a final detailed design, and document that design for fabrication. Design activities include design of personnel access and support structures to assure a stable work place for personnel during cable and plumbing installation. Includes effort required to design mechanical supports for cables and plumbing.

70.12.1.2 Detector Cable and Plumbing Design Documentation

This element includes all specifications, drawings, outline dimensions and other parameters necessary to enable competent vendors to proceed with fabrication of the support hardware and installation hardware suitable for GEM detector cabling and plumbing.

70.12.1.3 Detector Cable and Plumbing Procurement and Fabrication

This element includes all effort to identify and qualify potential vendors for provided cabling and plumbing, cable tray hardware and other supports, installation equipment, and any subcontracts or contract labor required, carry out the bid and award process, and monitor and control vendor performance under the ensuing contract or contracts.

70.12.1.4 Detector Cable and Plumbing Installation

This element includes the supervision and labor costs necessary to transport detector cabling and plumbing to the final installation site, to install them in the final configuration with appropriate support and access structures, and to test installed components.

70.12.2 Cable and Plumbing Routing and Installation Design Verification

In order to verify that complex interfaces are correctly designed, determine potential bundle build-up and interference problem areas, and enable early start on final cable and plumbing fabrication and assembly, a full scale or modified full scale mockup of the central detector area will be built. The mock-up fixture will emulate the exact configuration of the CDS, barrel calorimeter, scintillating calorimeter, endcap calorimeter, beam pipe, forward calorimeter, IPC tracker, silicon tracker, and interfacing muon system equipment for the purpose of determining desired and optimum cable and plumbing routing. Includes the specification, design, procurement, and fabrication of the mock-up fixture and support structures to enable personnel to access the mock-up fixture. Due to its size, it may be necessary to fabricate the fixture and its support structure on-site in one of the GEM Assembly buildings.

70.12.2.1 Cable and Plumbing Routing and Fit Test Fixture Design

This element includes all effort necessary to specify mock-up design requirements, translate requirements into preliminary design options, and produce a final detailed design. Design activities include design of integral personnel access and support structures to assure a stable work place for personnel during cable and plumbing routing and fit tests.

70.12.2.2 Cable and Plumbing Routing and Fit Test Fixture Documentation

This element includes all specifications, drawings, outline dimensions and other parameters necessary to enable a competent cabinet maker to proceed with fabrication of the mock-up fixture.

70.12.2.3 Cable and Plumbing Routing and Fit Test Fixture Procurement

This element includes all effort to identify and qualify potential vendors for the mock-up fixture, carry out the bid and award process, and monitor and control vendor performance under the ensuing contract.

70.12.2.4 Cable and Plumbing Routing and Fit Test Fixture Manufacture, Assembly and Test

This element includes the costs associated with fabrication of the mock-up fixture components, shipment of the components to the appropriate location, assembly in the test location, and installation of test cables and plumbing.

522.5090 Project Management 1
90.01 Planning and Controls 1
90.02 Engineering and Integration 1
90.03 Environmental Safety and Health/Quality Assurance ES&H/QA 1
90.04 Administration 1

522.5090 Project Management

This element includes all centralized detector project management effort from research and development to commissioning. Individual subsystem management effort is not included in this element.

90.01 Planning and Controls

This element includes all the effort to collect, organize, analyze and report cost and schedule information for the subsystems and the total detector project. It also includes all necessary contracting effort for the GEM project including requisition, acquisition planning, RFP's, MOU's, and foreign laboratory agreements.

90.02 Engineering and Integration

This element includes all the engineering effort to integrate the subsystems together into a total GEM detector system. This includes systems engineering and configuration control, as well as engineering support to the subsystems necessary to ensure detector wide compatibility of all engineering systems.

90.03 Environmental Safety and Health/Quality Assurance ES&H/QA

This element includes only the management portion of safety effort. The design, development, manufacturing, assembly and test of safety systems is included in WBS 70.04. Top level QA management for the detector is included. Specific QA inspection of manufacturing and hardware is included in the cost of the hardware component.

90.04 Administration

This element includes the clerical, secretarial and administrative effort for the detector project office.

Acronym Glossary

ADC IC ..... analog to digital converter integrated circuit

ALP IC ..... address list processor integrated circuit

ASIC ..... application specific integrated circuits

BNL ..... Brookhaven National Laboratory

CAE ..... computer aided engineering

CAL ..... calorimeter

CAMAC ..... physics electronic standard

CASE ..... computer aided software engineering

CDR ..... critical design review

CDS ..... central detector support

COM ..... calorimeter output board

C/PD ..... conceptual/preliminary design

CRM ..... calorimeter readout board

CSC ..... cathode strip chamber

CTE ..... coefficient of thermal expansion

CTS ..... central tracker system

DAQ ..... data acquisition

DSP ..... digital signal processors

ECL ..... emitter coupled logic

EDC ..... event data collector

EDD ..... event data distributor

EDIA ..... engineering, design, inspection and administration

EM ..... electromagnetic

ES&H ..... environmental safety ad health

FADC ..... fast analog to digital converter

FCAL ..... forward calorimeter

FEPCB ..... front end printed circuit boards

FFS ..... forward field shaper

FNAL ..... Fermi National Accelerator Laboratory

FPGA ..... field programmable gate array

FTE ..... full time equivalent

HV ..... high voltage

HVAC ..... heating, ventilation and air conditioning

HVPS ..... high voltage power supply

I&A ..... inspection and administration

IC ..... integrated circuit

ID ..... inner diameter

IPC ..... interpolating pad chambers

LCW ..... low conductivity water

LAr ..... liquid argon

LED ..... light emitting diode

LHe ..... liquid helium

LKr ..... liquid krypton

LN ..... liquid nitrogen

LOI ..... letter of intent

LSDT ..... limited streamer drift tubes

LSI ..... large scale integration

LV ..... low voltage

LVPS ..... low voltage power supply

M&S ..... material and supplies

MCM ..... multichip module

MOU ..... memorandum of understanding

NAB ..... north assembly building

NRE ..... non-recurring engineering

OD ..... outside diameter

PASA IC ..... preamplifier/shaper IC

PASS ..... personnel access safety system

PCB ..... printed circuit boards

PDR ..... preliminary design review

PDT ..... pressurized drift tubes

PMT ..... photomultiplier tube

RDT ..... round drift tube

RFP ..... request for proposal

ROPCB ..... readout printed circuit board

RPC ..... resistive plate counters

SAB ..... south assembly building

SCA IC ..... switched capacitor array integrated circuit

SSC ..... superconducting super collider

SSCL ..... superconducting super collider laboratory

SSR ..... system requirements review

ST ..... silicon tracker

STS ..... silicon tracker system

TDR ..... technical design report

UG ..... underground hall

VLSI ..... very large scale integration

VME ..... VMEbus specifications

WLS ..... wave length shifting