GEM TN-92-231
Draft

Progress Report on the GEM Detector Baseline Design

GEM Collaboration

December 1, 1992

Abstract:

This document details parameters of the current GEM detector baseline design. This design will be used for an in-depth analysis of cost, schedule and physics performance.

Draft Copy

GEM BASELINE 2

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1. OVERVIEW

OVERVIEW

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OVERVIEW

The GEM (Gammas, Electrons, and Muons) detector emphasizes the precise measurement of gammas, electrons, and muons. Improving the detector performance for these offers the best chance of increasing the discovery reach of the SSC. The measurement of hadronic energy is less precise but sufficiently good that studies of jets and missing transverse energy are limited primarily by irreducible standard model backgrounds. Charged particle momenta are measured with only moderate resolution but in a system with very low occupancy. The overall design of the detector, shown in Fig. 1.1-1.6, and the choices of the various technologies imply that it can operate at luminosities well in excess of the nominal $10^{33}\,cm^{-2}\,s^{-1}$. Thus GEM can probe the whole range of SSC physics while offering particular advantages for some of the most important channels.

The GEM detector consists of a central tracker, an electromagnetic calorimeter, a hadron calorimeter, and a muon tracker, all contained in a large 8 KG magnet. There is also a forward field shaper to bend the solenoidal field and so improve the muon momentum resolution in the forward region and a central detector support.

The central tracking system has six double layers of silicon microstrips followed by four double layers of interpolating pad chambers (IPC's). The main goals of the tracker are to identify the primary vertex, to aid in identifying γ's, e's and μ's, to determine e signs up to about $pT = 600$ GeV, and generally to add redundancy. Full event reconstruction and identification of secondary vertices are regarded as less important goals. Since Baseline I, the radius has been increased to 95 cm to improve the momentum resolution. Also, it has been shown that the IPC's have quite good resolution for two nearby tracks. Since both the silicon and the IPC's have high segmentation, the occupancy is expected to be less than 1% at $10^{33}\,cm^{-2}\,s^{-1}$, contributing to the robustness of GEM at high luminosity. Critical remaining issues involve reducing the amount of material in the tracker, achieving the requisite alignment, and dealing with radiation damage from charged particles, photons, and especially neutrons.

The electromagnetic (EM) calorimeter in GEM consists of a barrel and two endcap sections. The barrel is a liquid krypton sampling calorimeter with the lead absorber in a projective accordion geometry to achieve fast readout. The energy resolution calculated with a very detailed EGS simulation of the proposed design is $5.5\%/\sqrt{E}$. Beam tests of slightly different accordion designs at BNL essentially achieved

their calculated resolutions and furthermore showed a constant term much less than 0.5% using only the built-in electronic calibration. The endcaps use liquid argon and an absorber with a modified accordion geometry which achieves projectivity in both dimensions with no dead spaces. Liquid krypton is not needed in the endcaps because the energies are higher so the sampling term in the resolution is less important. The GEM design provides excellent energy resolution, segmentation, background rejection, and directional information for photon showers, and it is intrinsically radiation hard. It is in the judgment of the Collaboration the best possible EM calorimeter for SSC physics.

The hadron calorimeter must help to identify leptons and single photons through isolation cuts and measure jets and missing transverse energy $\not{E}_T$ from neutrinos or other new, weakly interacting particles. Part of the hadron calorimeter is combined with the EM one in the same cryostats. The absorber has a parallel plate geometry with electrostatic transformers to increase the speed. The absorber is copper in the endcap for greater compactness and lead in the barrel to provide a better *e/h* ratio with krypton. A total of 12λ of absorber is required to protect the muon system at high luminosity, much more than is needed for the calorimeter. To simplify the mechanical design and fabrication of the cryostat and to avoid having an excessively large volume of krypton, the back portion of the barrel calorimeter will use scintillator with a copper absorber. The boundary will be at approximately 6λ at $\eta = 0$, so most of the energy is contained in the front part.

The forward calorimeter is intended mainly to measure missing energy ($\not{E}_T$)and to tag forward jets. It is currently integrated with the endcap and uses tungsten as the absorber to produce smaller hadron showers and hence better angular resolution. The design of the forward calorimeter interacts heavily with that of the beam pipe and with other integration issues, so it remains subject to evolution and optimization.

Muons are measured outside the calorimeter using the classical three-point sagitta method in the large air core magnet. Cathode strip chambers (CSC's) have been selected for both the barrel and the endcap. They both measure the bend coordinate with very good precision and measure the second coordinate, identify the correct bunch, and provide the trigger. Several prototypes have been constructed and are currently being tested. Round drift tubes (RDT's) combined with resistive plate chambers (RPC's) are a backup. The RDT test met its

resolution goal. and considerable progress has been made on highrate RPC's. The expected resolution for p_T = 500 GeV is 5% at η = O and 12% at η = 2.5, the limit of the coverage. A conceptual design has been worked out to use optical straightness monitors to maintain the 25μ alignment tolerance needed to achieve this resolution, although alignment remains a challenging area. Other issues now being studied are the neutron background and the pattern recognition problem for muons which create EM showers or which are accompanied by hadronic punchthrough. Since the muon measurement in GEM is purely external, it should be robust at the highest attainable luminosity.

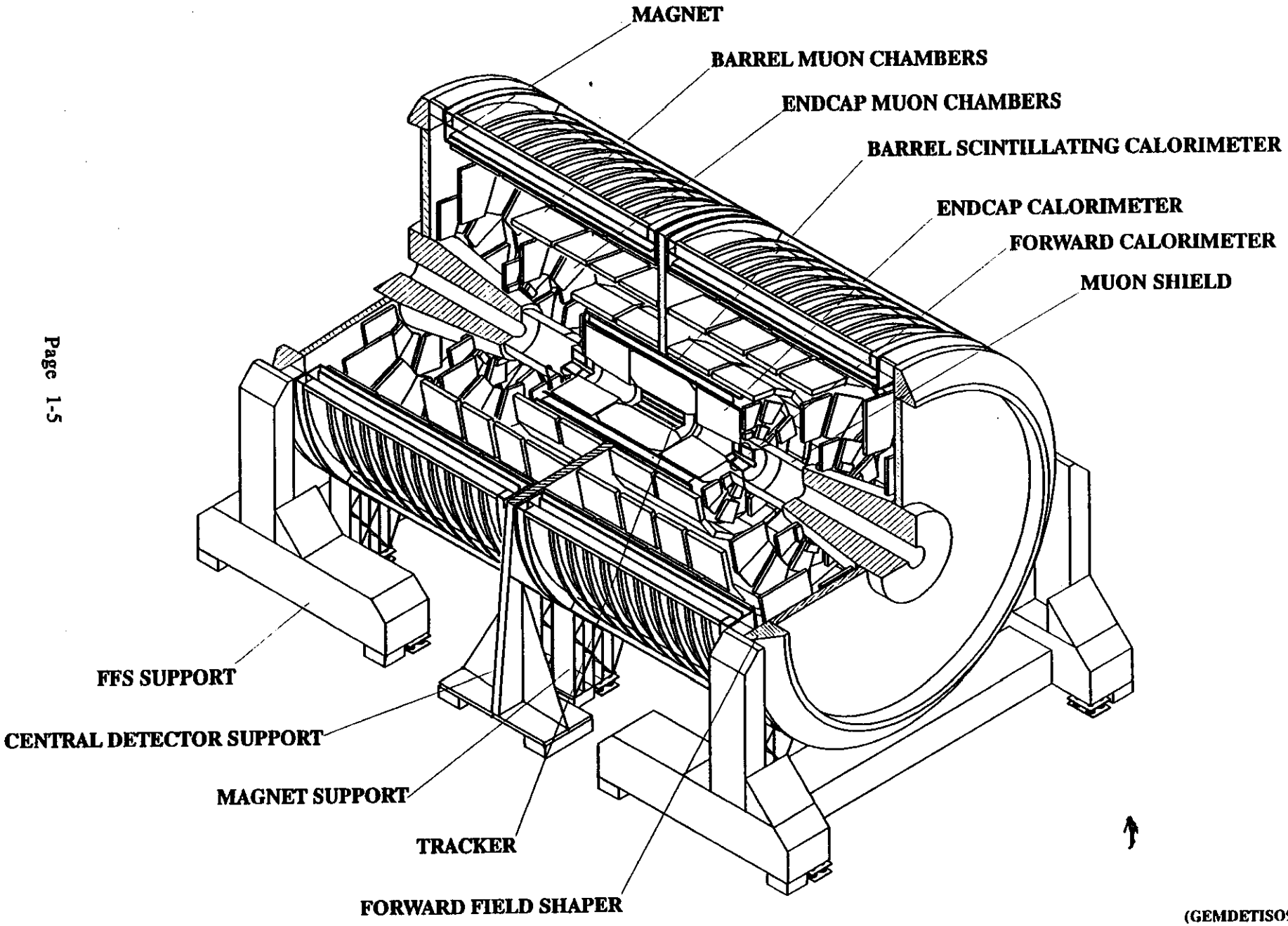
The entire GEM detector is contained in a large superconducting solenoid with diameter of 18 m, a combined length of 31 m, and a field of 8 KG. For reasons of cost and schedule there is no flux return, so the magnetic field fills the experimental area, dropping to about 50 G at the surface. The safety and environmental issues from such a field have been reviewed and resolved by the Collaboration, SSCL and DOE. The coil is split in the middle by a central detector support which supports the calorimeters and central tracker and also provides a path for signal cables and other services. The central detector support causes only a small loss of muon acceptance. At each end of the magnet there is a forward field shaper, a large cone of permeable steel which bends the magnetic field and so greatly improves the momentum resolution in the forward calorimeter. The forward field shapers and the coils can be moved to provide access for assembly and for maintenance during long shutdowns.

The trigger system has the usual three levels. Level 1 is synchronous and pipelined and is implemented entirely in hardware. Level 2 is asynchronous. We have tentatively adopted a new baseline, called a "virtual Level 2," wherein the Level 2 trigger is run on the same processor array that is to be used for the Level 3. For Level 2, however, only relevant portions of the event--e.g., calorimeter signals from the region surrounding photon or electron candidates identified by level 1--are transmitted to the array. The Level 2 design will incorporate provisions for the eventual addition of special purpose hardware, if that should prove necessary for running at high luminosity. Level 3 is a processor ranch with approximately 10^5 SSCUPs of computing power. The design output of each level is a factor of ten less than the design capacity of the next level. The most demanding trigger is the two-photon trigger used for the H - $\gamma\gamma$ search at low masses. The rates for this trigger in particular have been simulated in detail and can be accommodated by the design.

OVERVIEW

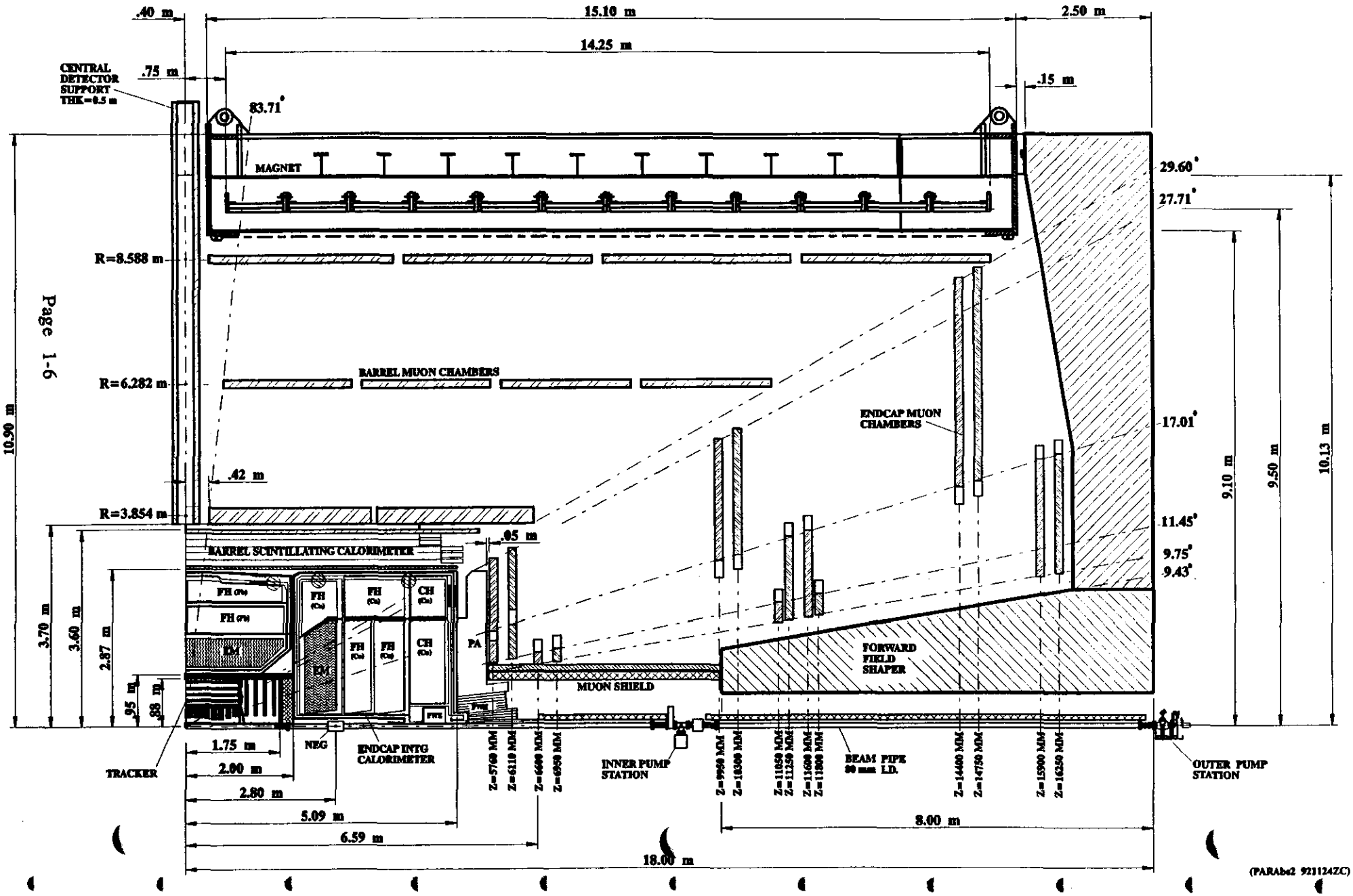
GEM is designed to measure all of the quanta of the standard model—γ's, e's and μ's, jets, and ν's or other missing particles. As its name suggests, it has particular strengths in the identification and very precise measurement of γ's and e's and in the precise and robust measurement of μ's. Its design and technology choices allow it to operate well at luminosities well above $10^{33}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$. GEM will be a superb instrument for discovery and study of new physics at the SSC.

GEM DETECTOR

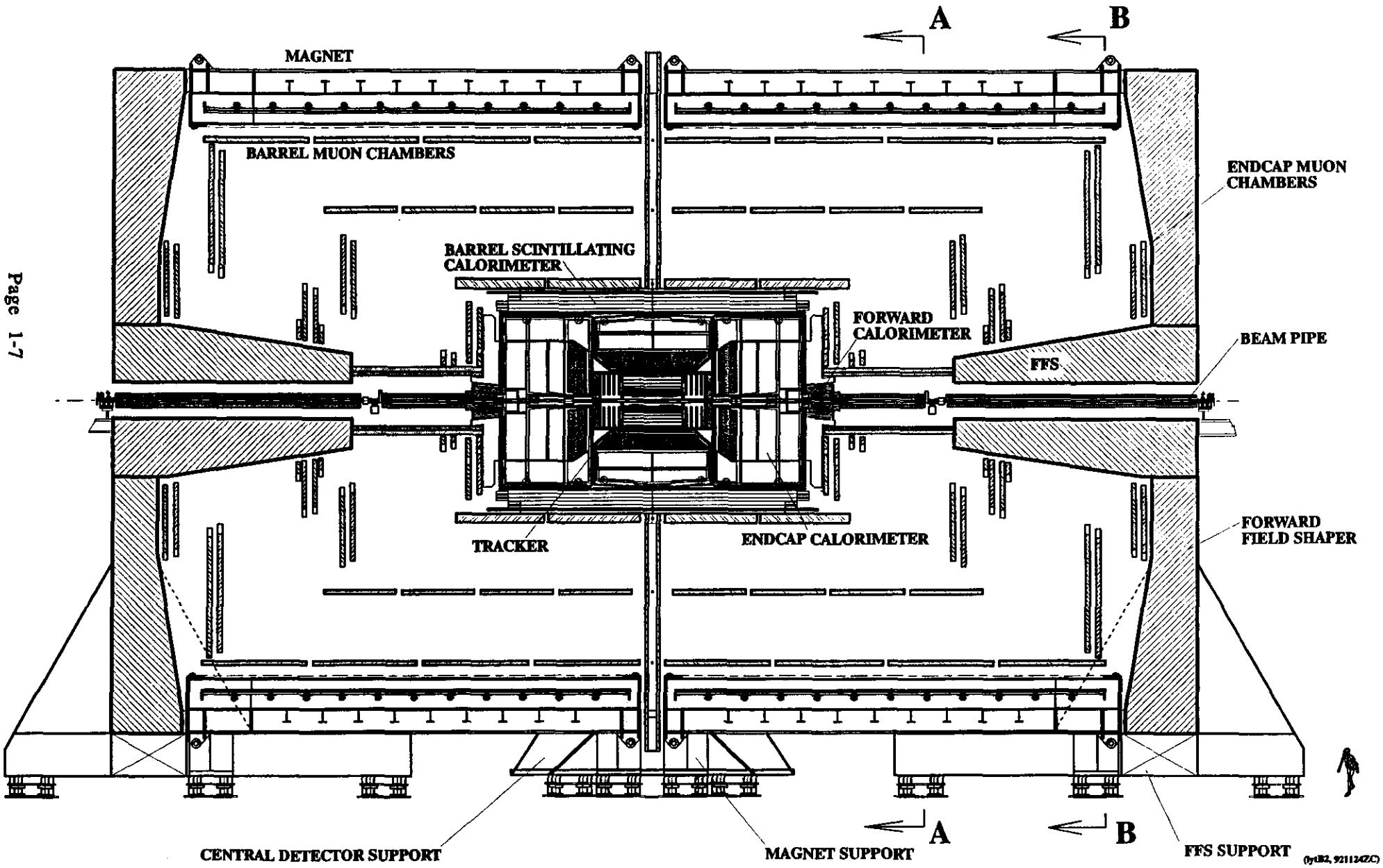


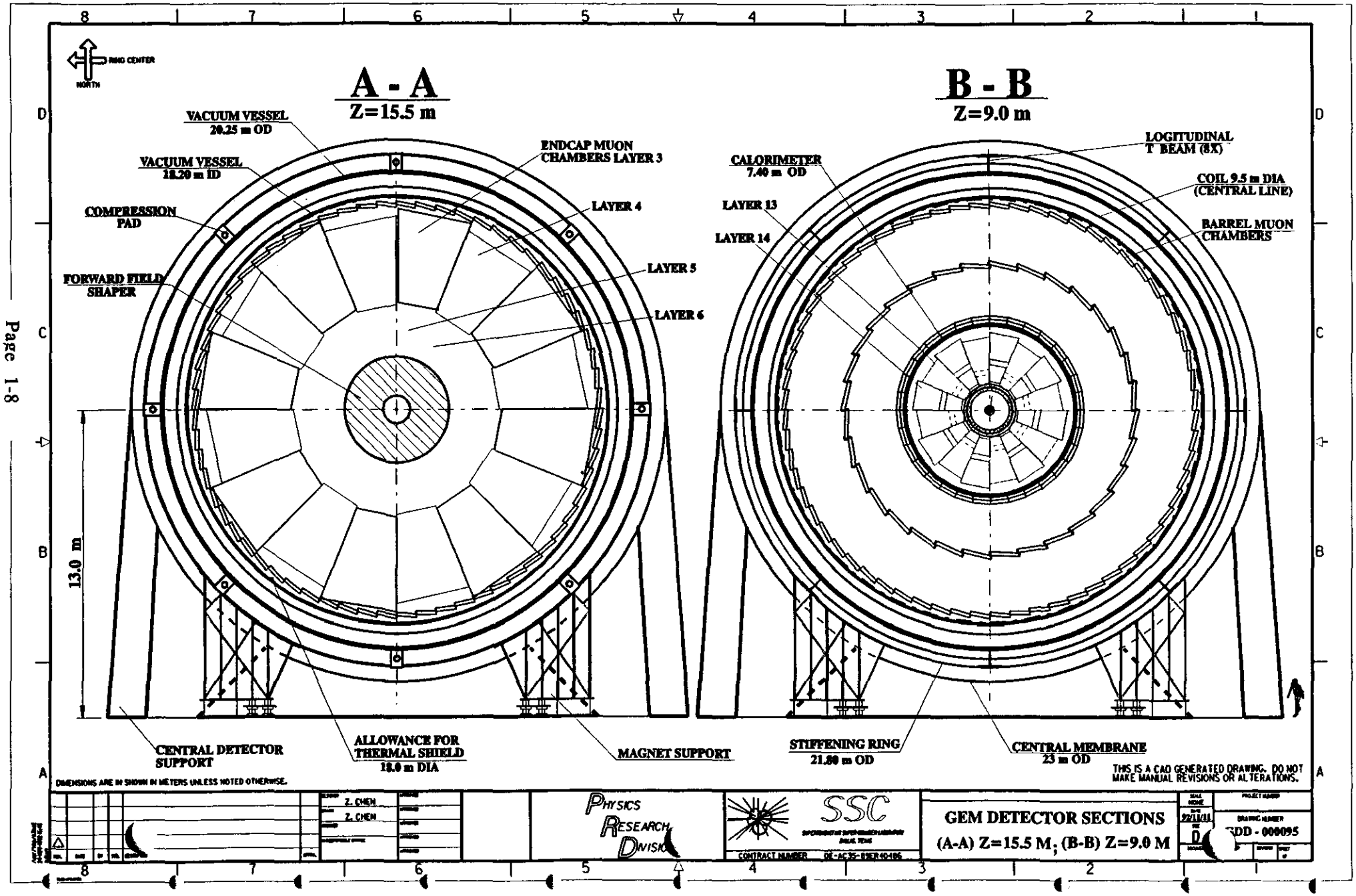
(GEMDETISO921118CHEN)

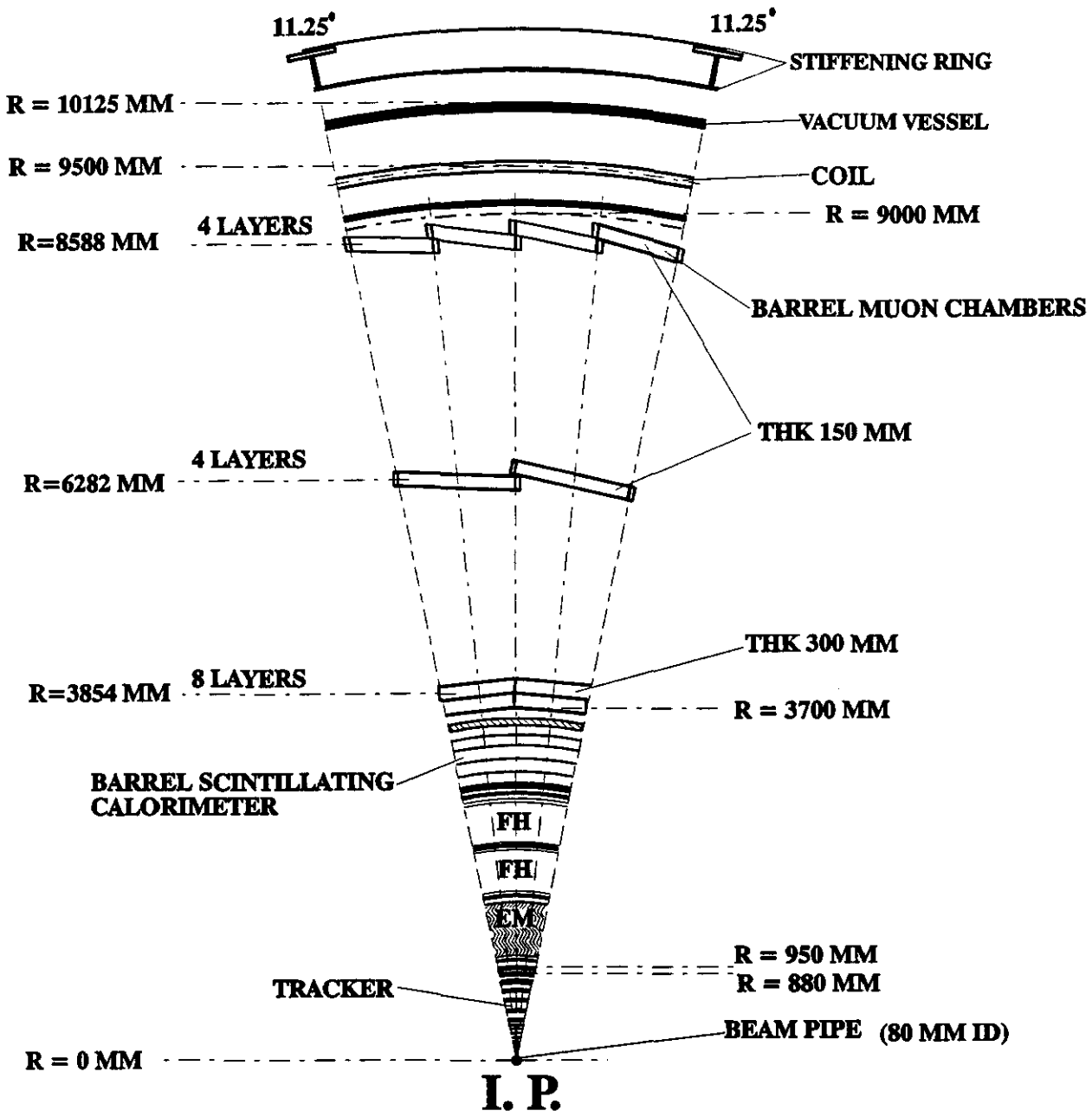
GEM DETECTOR PARAMETERS
BASELINE 2



GEM DETECTOR LAYOUT

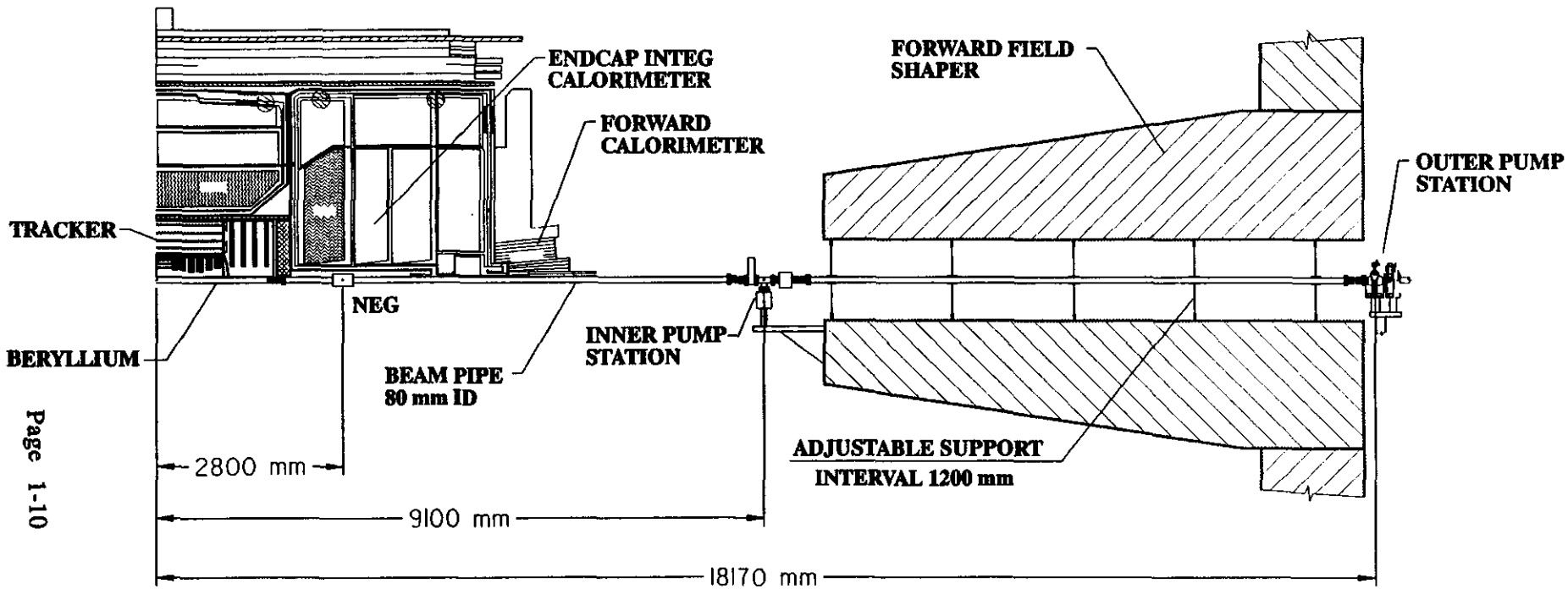



A - A
Z=15.5 m
B - B
Z=9.0 m
RING CENTER
NORTH
VACUUM VESSEL
20.25 m OD
VACUUM VESSEL
18.20 m ID
COMPRESSION
PAD
FORWARD FIELD
SHAPER
ENDCAP MUON
CHAMBERS LAYER 3
LAYER 4
LAYER 5
LAYER 6
13.0 m
CENTRAL DETECTOR
SUPPORT
ALLOWANCE FOR
THERMAL SHIELD
18.0 m DIA
MAGNET SUPPORT
CALORIMETER
7.40 m OD
LAYER 13
LAYER 14
LOGITUDINAL
T BEAM (8X)
COIL 9.5 m DIA
(CENTRAL LINE)
BARREL MUON
CHAMBERS
STIFFENING RING
21.80 m OD
CENTRAL MEMBRANE
23 m OD
DIMENSIONS ARE IN SHOWN IN METERS UNLESS NOTED OTHERWISE.
THIS IS A CAD GENERATED DRAWING. DO NOT
MAKE MANUAL REVISIONS OR ALTERATIONS.
Z. CHEN
Z. CHEN
PHYSICS
RESEARCH
DIVISION
SSC
CONTRACT NUMBER DE-AC35-89ER40486
GEM DETECTOR SECTIONS
(A-A) Z=15.5 M; (B-B) Z=9.0 M
92/11/11
D
DDD - 000095



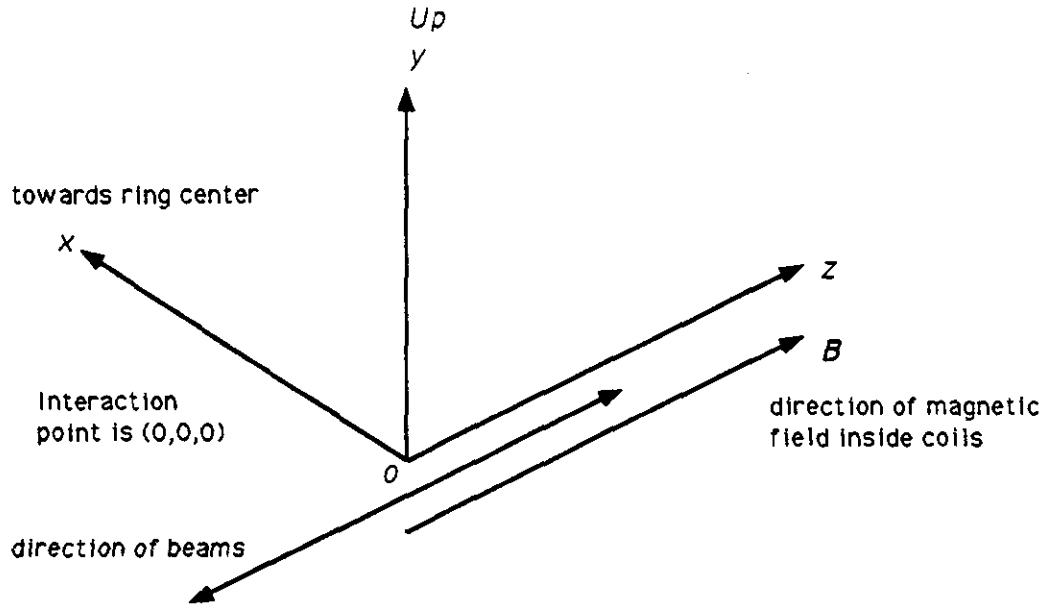
TYPICAL AZIMUTHAL CUT IN BARREL REGION

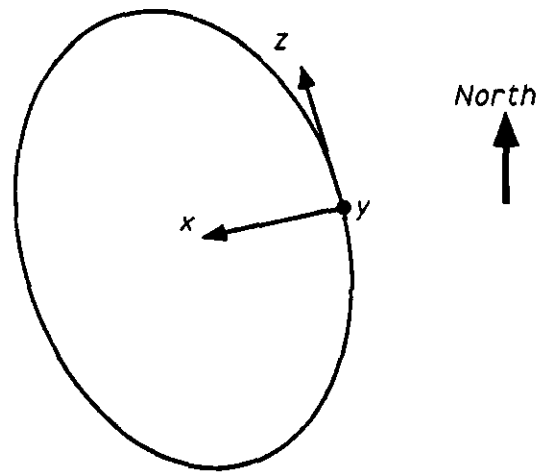
BEAM PIPE SUPPORT IN FFS



INTRODUCTION

GEM Coordinate System and Field Direction





The GEM coordinate system is right-handed with its origin at the nominal interaction point, the *z* direction is along the beam direction and *positive z is North*. The positive *x* direction is towards the machine center and *y* is up.
The magnetic field is parallel to the *z* axis, roughly in the same direction as the Earth's field.

2. SCHEDULE/MILESTONES

SCHEDULES/MILESTONES

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OVERVIEW

All milestones shown in this section have been extracted from a preliminary master schedule for the GEM detector. The master schedule was constructed based on previous experience on other detectors, discussions with the principle physicists and engineers from the various subsystems, and on certain assumptions regarding funding of the project as well as construction progress. For these reasons, the dates for many of the activities shown may be subject to revisions as the project becomes better defined. In particular, the availability of the various surface and underground facilities may be affected by funding profile restrictions. Perturbations in the availability of facilities will have serious repercussions on assembly of subsystem components into completed subsystems on-site. Although some contingency planning has been built into the schedule, substantial slips in availability of key facilities could result in serious schedule delays.

This section is organized to present top-level events and activities for the overall GEM detector first, followed by the activity sequence for installation of the detector into the underground hall. The site availability dates (Beneficial Occupancy Dates, BOD) for the various facilities are presented next. Finally, lists of significant events during the development, fabrication, assembly and installation of the different detector subsystems are presented.

Source: M Harris
Update: 6/26/92

SCHEDULE/MILESTONES

GEM MILESTONES

1.	PAC Review	December, 1992
2.	Magnet RFP	December, 1992
3.	Muon Option Choice	January, 1993
4.	Technical Design Report	March, 1993
5.	Magnet Prime Contract	March, 1993
6.	PAC Review	July, 1993
7.	DOE Review	September, 1993
8.	JOD South Assembly Building	April, 1994
9.	BOD South Assembly Building	July, 1994
10.	BOD North Assembly Building	October, 1994
11.	BOD Underground Experimental Hall	April, 1996
12.	Start Detector Installation	April, 1996
13.	Complete Detector Installation	July, 1999
14.	Detector Ready for Physics	October, 1999

Glossary:

PAC Program Advisory Committee
RFP Request for Proposals
DOE Department of Energy
JOD Joint Occupancy Date
BOD Beneficial Occupancy Date

SCHEDULE/MILESTONES

INSTALLATION SEQUENCE REQUIREMENTS

1.	Underground Hall Ready	April, 1996
2.	Install South Forward Field Shaper	May, 1996
3.	Install South Magnet Half	July, 1996
4.	Install Central Detector Support	August, 1996
5.	Install North Magnet Half	September, 1996
6.	Install North Forward Field Shaper	October, 1996
7.	Close & Test Magnet & Map Field	November, 1996
8.	Install Scintillating Barrel Calorimeter	May, 1997
9.	Install Noble Liquid Barrel & Endcaps	July, 1997
10.	Install & Align South Muon Barrel	December, 1997
11.	Install & Align North Muon Barrel	March, 1998
12.	Install & Align South Muon Endcap	June, 1998
13.	Install & Align North Muon Endcap	August, 1998
14.	Globally Align Muon System	January, 1999
15.	Install Tracker	February, 1999
16.	Install Detector Beampipe	July, 1999
17.	Close Magnet & Test Systems	September, 1999
18.	Detector Ready for Physics	October, 1999

3. FACILITIES

FACILITIES

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FACILITIES

OVERVIEW

1. Introduction

The GEM detector will be assembled, installed and operated at the interaction region #5 (IR-5), located on the east side of the main collider ring in Ellis County near the town of Palmer.

2. Surface Facilities

The IR-5 site layout has undergone a design evolution in which the number of assembly halls has been reduced from five to two. Drawings of the collider and the east experimental areas are shown in this section. The proposed layout of GEM surface facilities is displayed in the IR-5 Site Plan. The IR-5 site is in close proximity to major transportation routes, municipal services, and utilities.

Work will soon begin on the required road improvements leading to the site, ensuring that the wide and heavy components can be transported in a reasonable way. A rail head is available at Palmer for off-loading detector components or materials which may be brought by rail to the site.

The site layout will mainly be determined by the assembly requirements of the large components that may require difficult maneuvers during the assembly process. Attention must be paid to assure that these components can be lowered with the minimum of effort into the underground hall. The alignment of the load paths to the shafts plays a vital role in this consideration.

There will be two large surface buildings dedicated to assembly of the various detector subsystems, known as the North Assembly Building (NAB) and South Assembly Building (SAB). Magnet coils will be wound in the SAB and then moved to the NAB for further assembly and eventual installation in the vacuum vessel. Muon modules will be constructed in the SAB and stored in both the SAB and NAB. The south wing of the SAB will contain a two level office area for detector computer operations, general offices, and other personnel facilities. The north wing of the NAB will be used for Tracker, Beamline and Calorimeter assembly. Shaft headhouses are also desirable if economically feasible.

3. Underground Facilities

The GEM detector will be housed in an underground hall whose foundation rests on Austin Chalk. The dominant factors driving the general configuration and size of the underground facilities are the configuration, installation, and maintenance requirements of the detector and accelerator systems in addition to their radiation shielding requirements.

The hall will be situated to allow for the positioning of the long axis of the detector parallel to the beam line, so that it is centered around the interaction region. The hall floor is level but not parallel with the beam pipe which drops almost 0.2 meters between the north and south ends of the hall. The length and the width of the hall are determined by the detector installation and maintenance access requirements.

Two large shafts are required for the installation of the detector within the time span allowed by the present collider start up schedule. Each assembly shaft will be closed with a 6 meter thick removable radiation shield after detector installation is complete.

The detector cable and fiber readout services will exit the underground hall via the cable/electronics room access shaft situated on the west side of the hall. This will also contain several levels of shielded modules equipped with racks of electronics equipment. The electronics rooms are positioned underground to minimize delay between detector electronics and trigger electronics. A utility shaft on the opposite side of the hall will permit the routing of the technical and conventional utility systems to the hall and detector.

Each wall of the experimental hall will have gangways for access to the survey monuments and around the detector. This complex will be connected to the various elevator and stair systems contained in the utility and electronics shafts for access and egress.

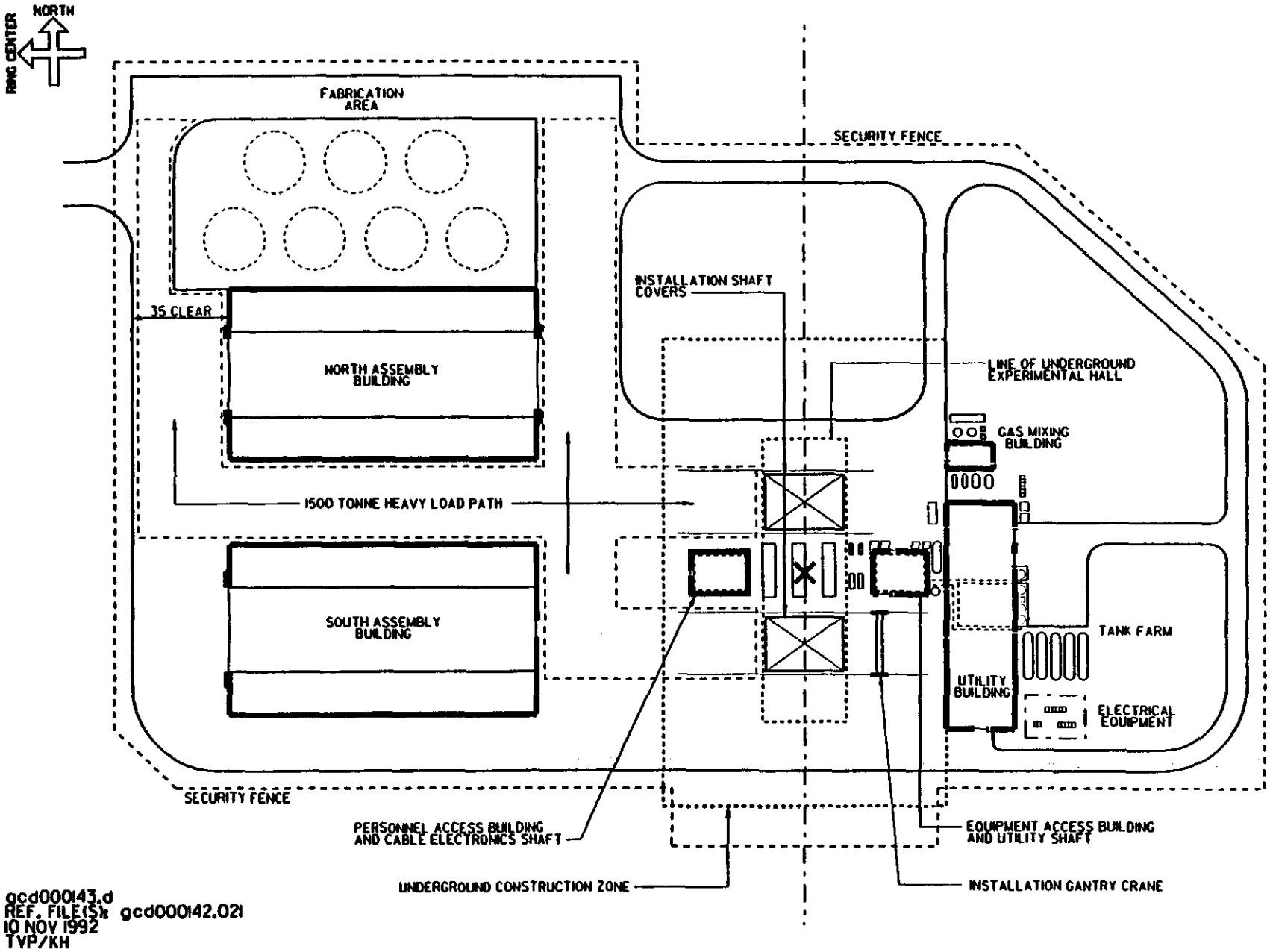
Two identical 75/20 ton bridge cranes are required in the experimental hall to install the detector. The cranes must be capable of being operated simultaneously, but independently, from separate portable control stations. They must also be capable of tandem operation from a single control. In addition, the surface will be equipped with the necessary heavy lift cranes that will lower the detector components down the proper assembly shaft.

FACILITIES

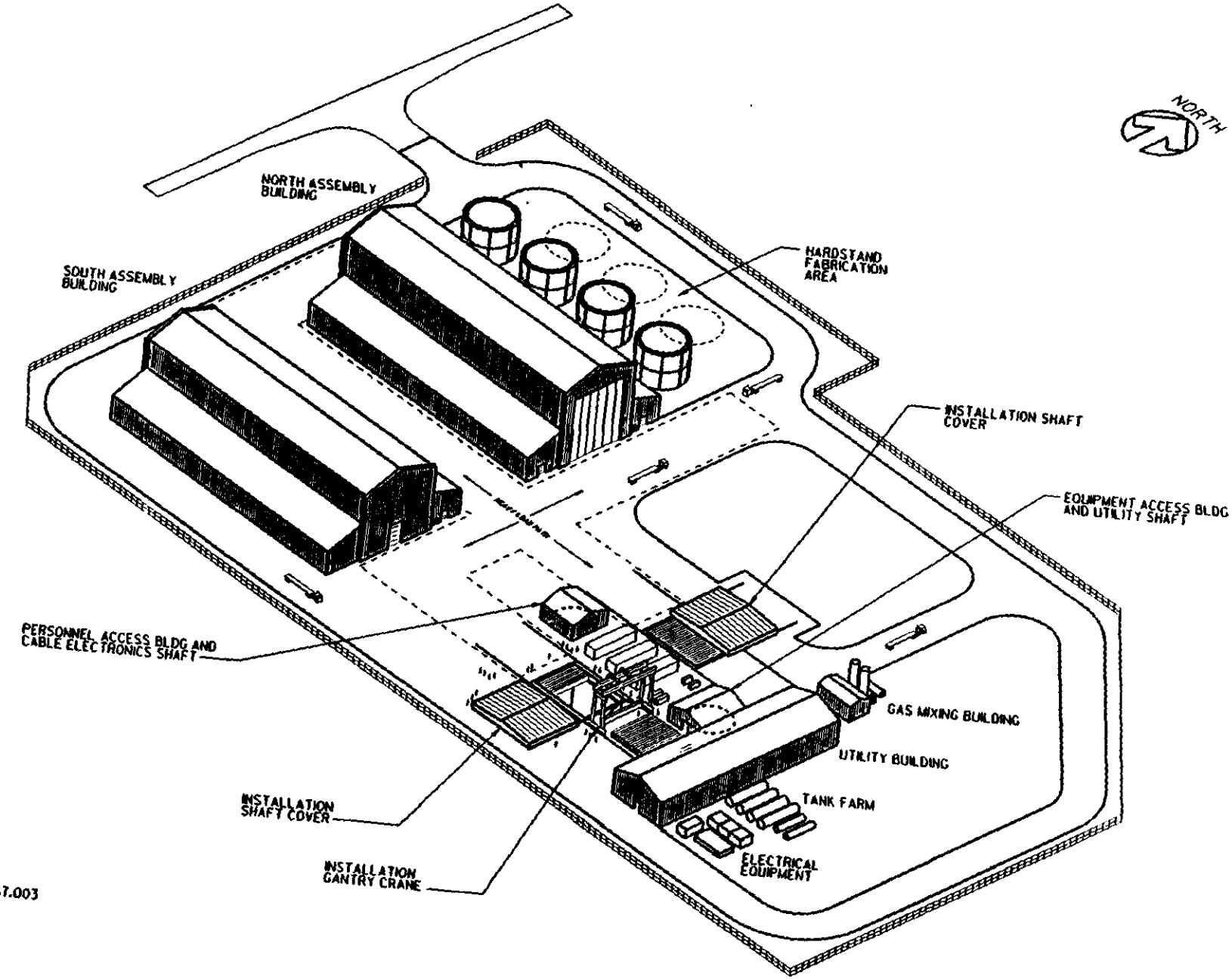
East Complex Buildings

Building Identification	Dim (meters) L	W	H	Area m 2	Area ft2	Req'd Occ.
South Assembly Building						
High Bay Assembly	110	30	19	3,300	35,503	Feb-94
Gantry Crane -35/10t						
Gantry Crane -35/10t						
North Low Bay	110	15	8	1,650	17,751	Apr-94
South Low Bay Assembly	58	15	4	870	9,360	
South Low Bay Office (dn)	52	15	4	780	8,392	
South Low Bay Office (up)	110	15	4	1,650	17,752	
North Assembly Building						Aug-94
High Bay Assembly	110	30	26	3,300	35,503	
Low Bay Assembly - north	110	16	10	1,760	18,935	
Low Bay Assembly - south	110	16	10	1,760	18,935	
Utility Building	80	24	7/12	1,920	20,656	May-94
Installation Gantry Crane - 75/20 tons						Mar-96
Installation Shaft Cover (north)	25	18	n/a	450	4,841	Jan-96
Installation Shaft Cover (south)	25	18	n/a	450	4,841	Jan-96
Personnel Access Building	18.6	13.1	4	244	2,622	Mar-96
Equipment Access Bldg.	17.1	13.1	4	224	2,414	Mar-96
Gas Mixing Building	16.5	9	4	149	1,598	Jan-96

Source: WE/JNG
Updated: 11/16/92



IR-5 Site Plan



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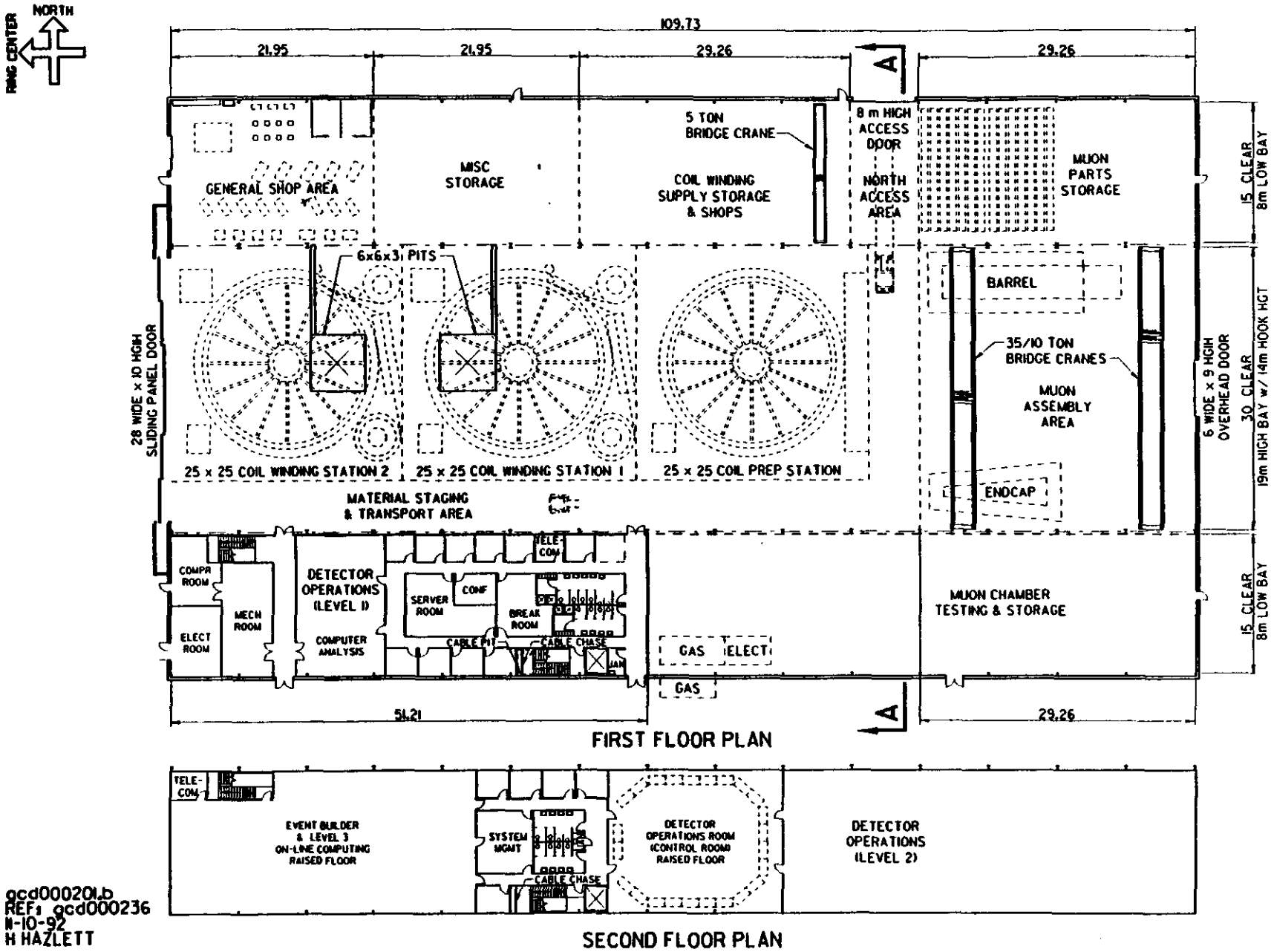
IR-5 Site Isometric



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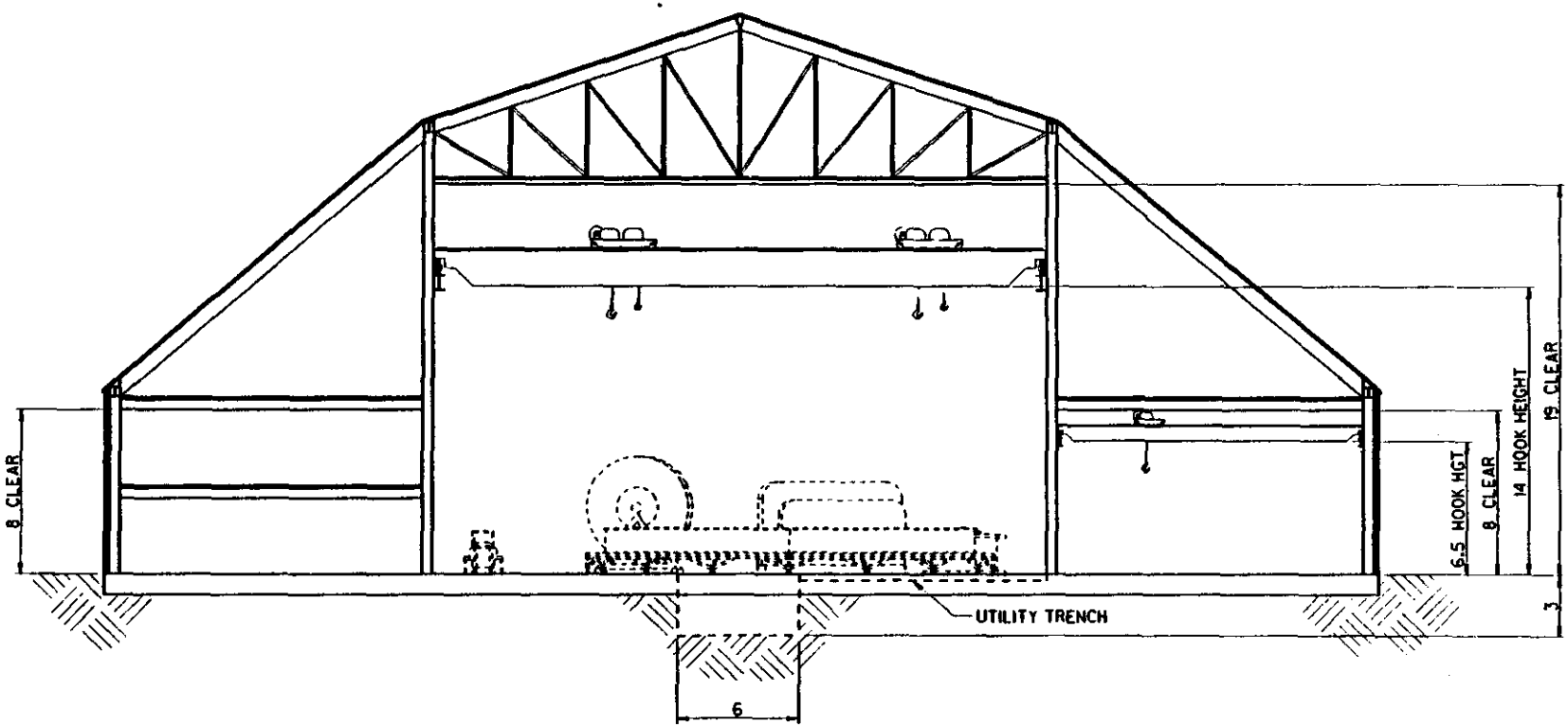
South Assembly Building Floor Plan



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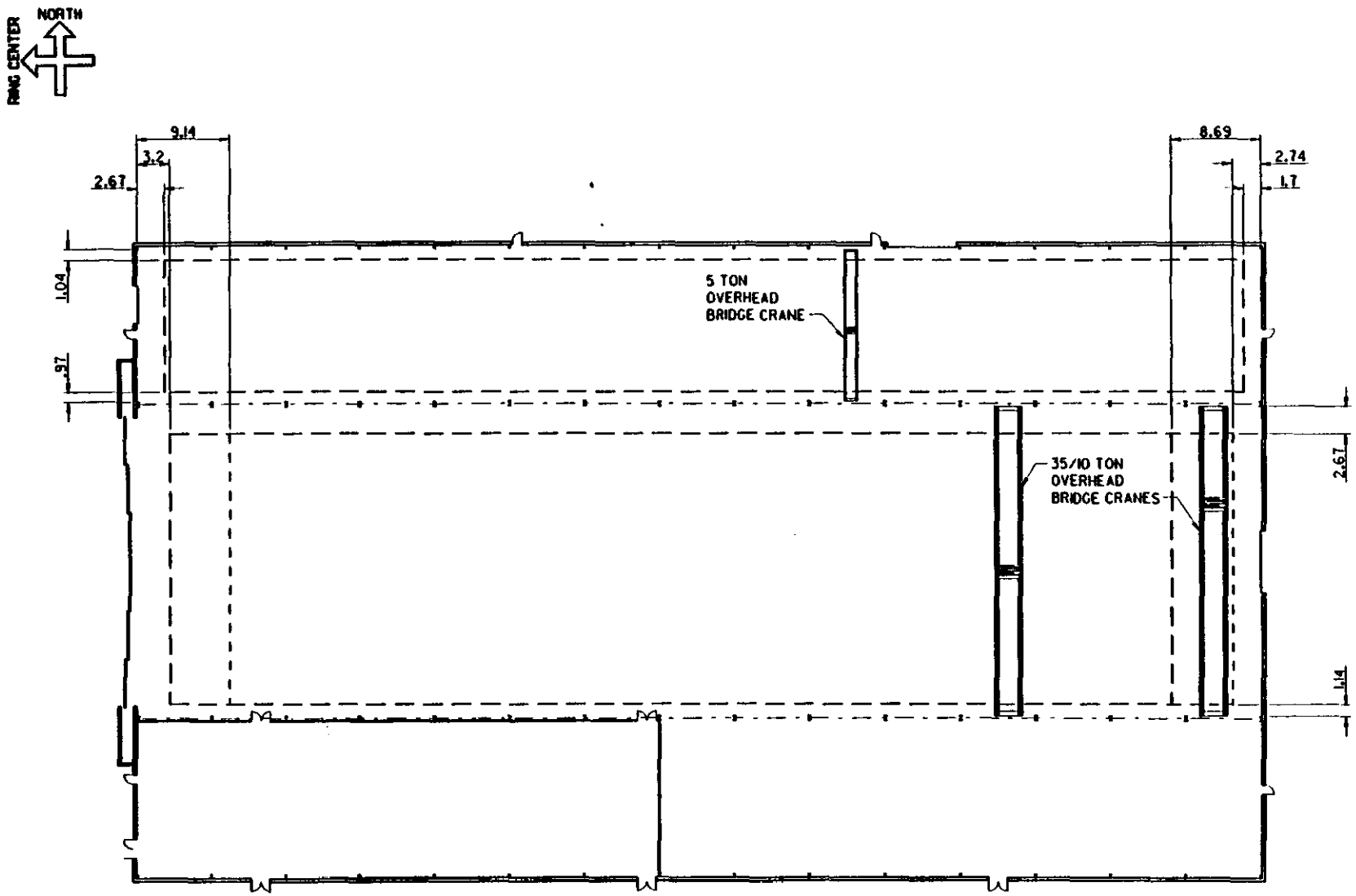
SECTION A-A

South Assembly Building Section



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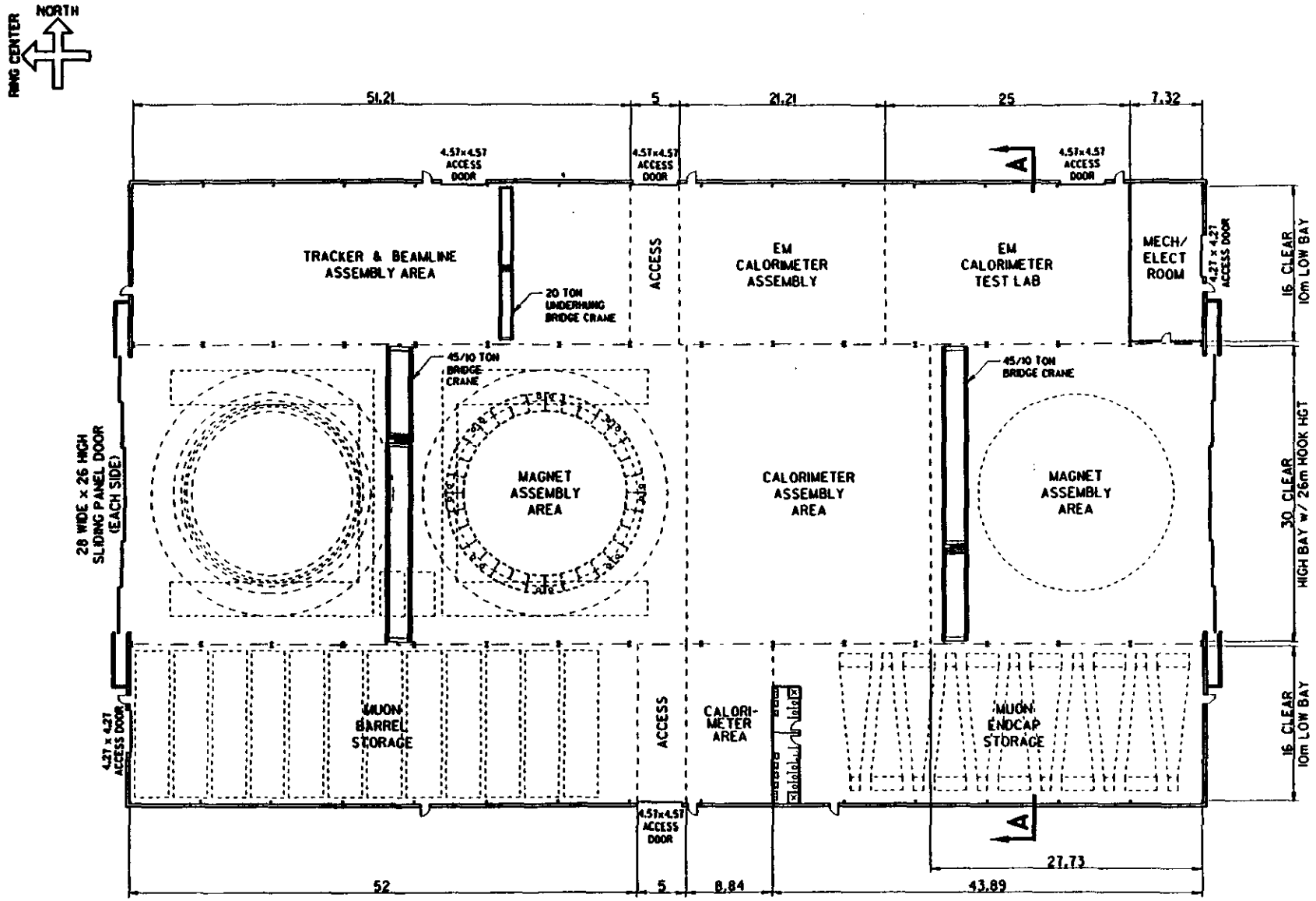
South Assembly Building Crane Coverage Plan



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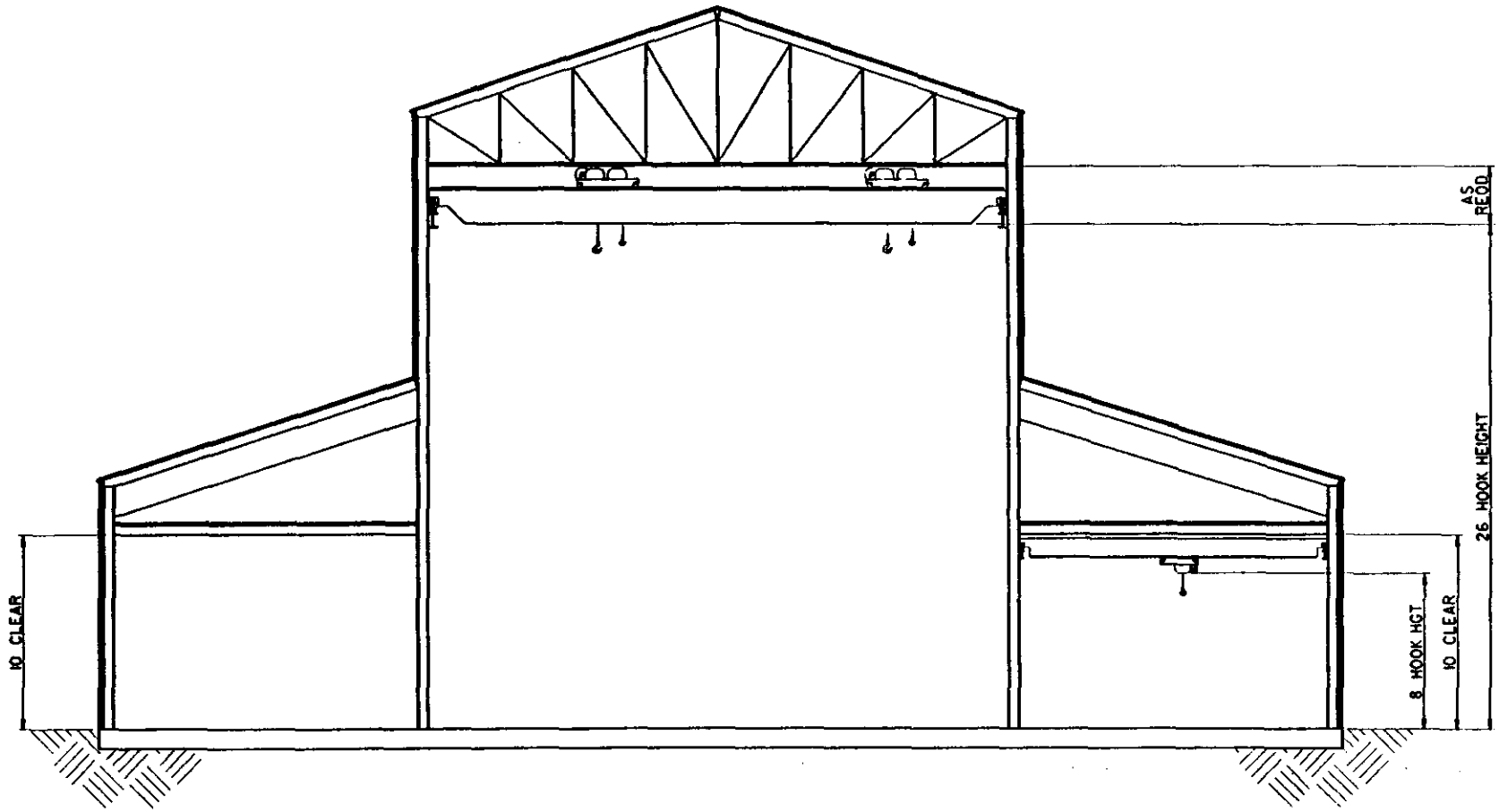
North Assembly Building Floor Plan



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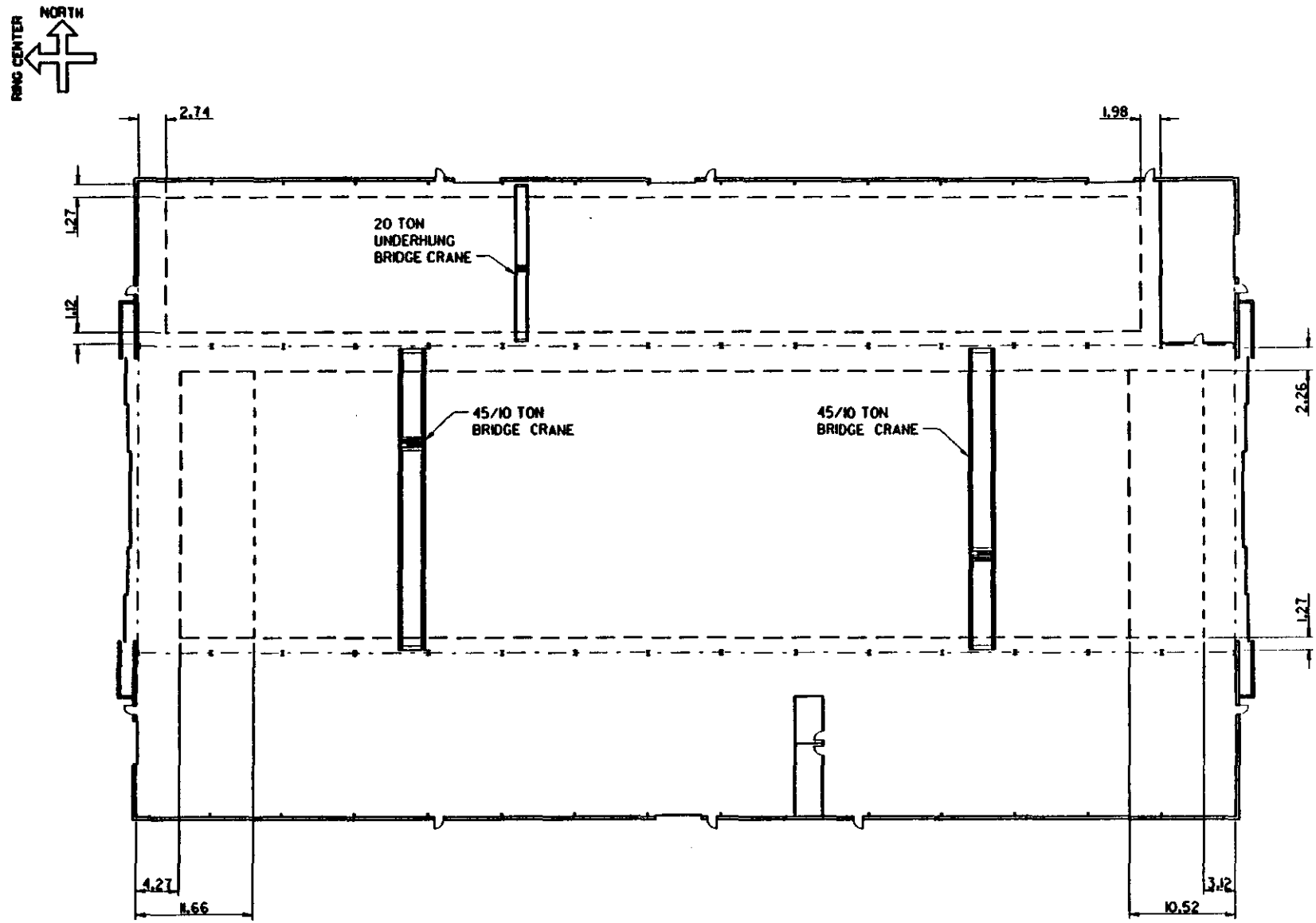
North Assembly Building Section



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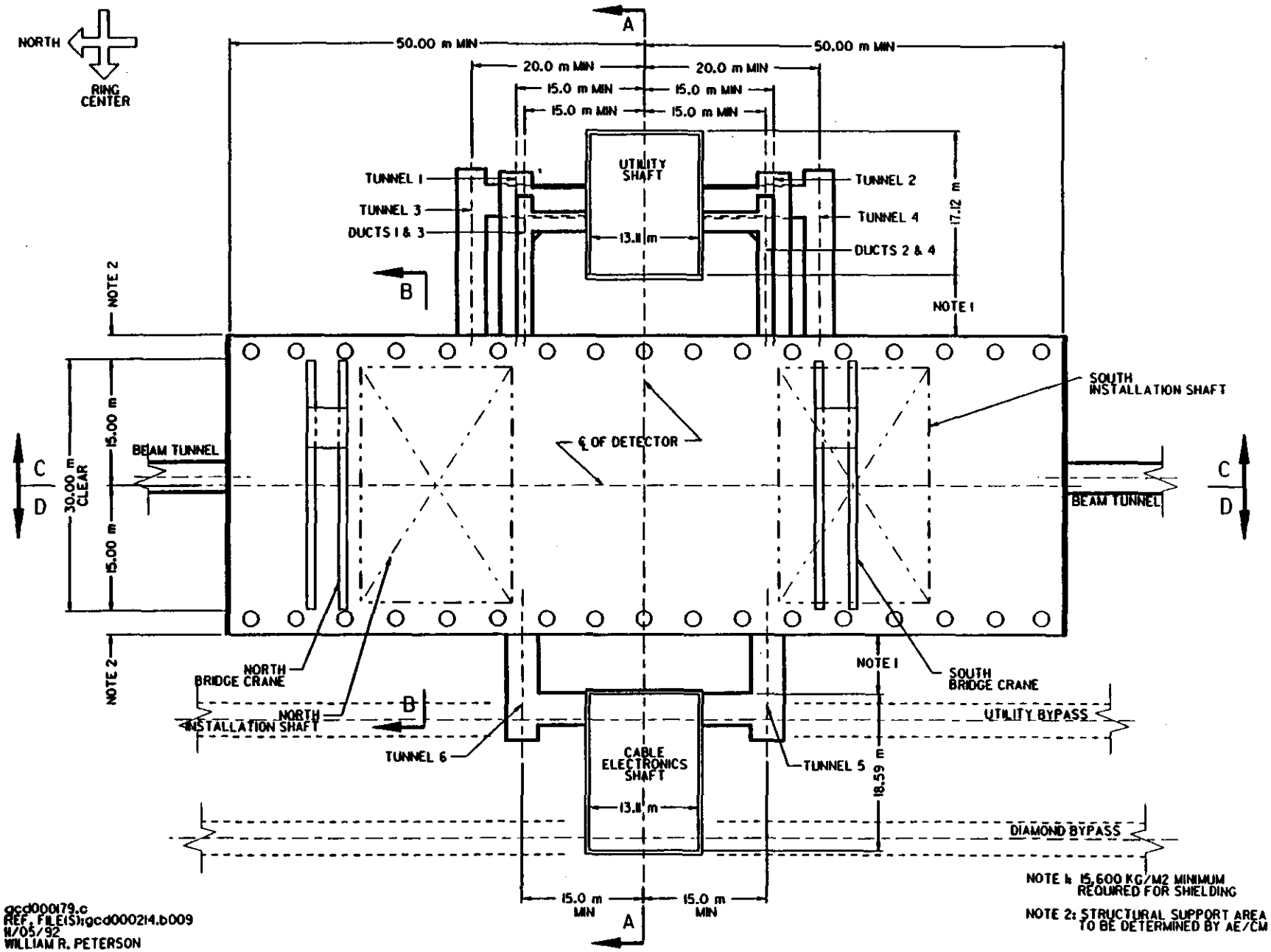
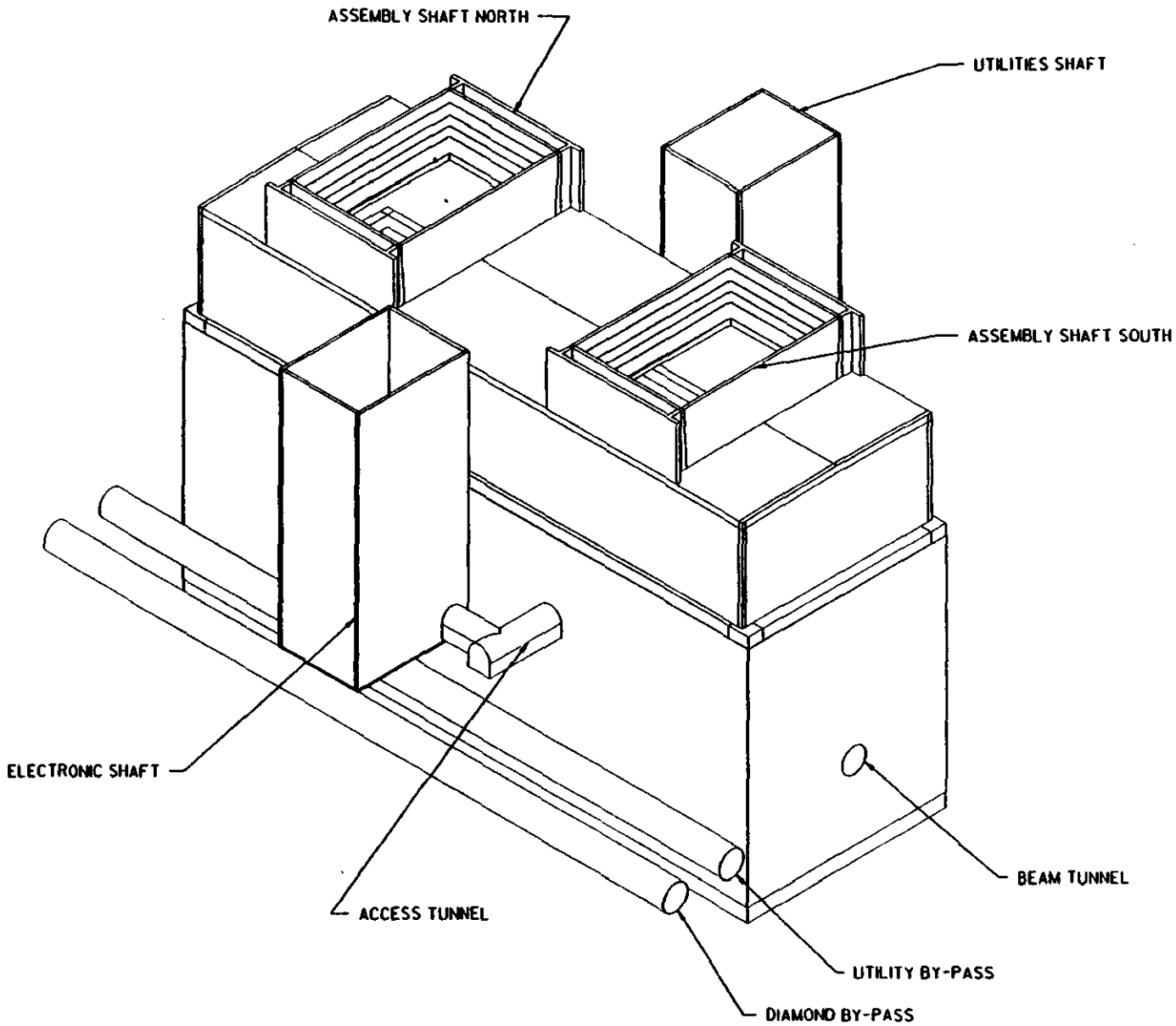
North Assembly Building Crane Coverage Plan



Experimental Hall Floor Plan



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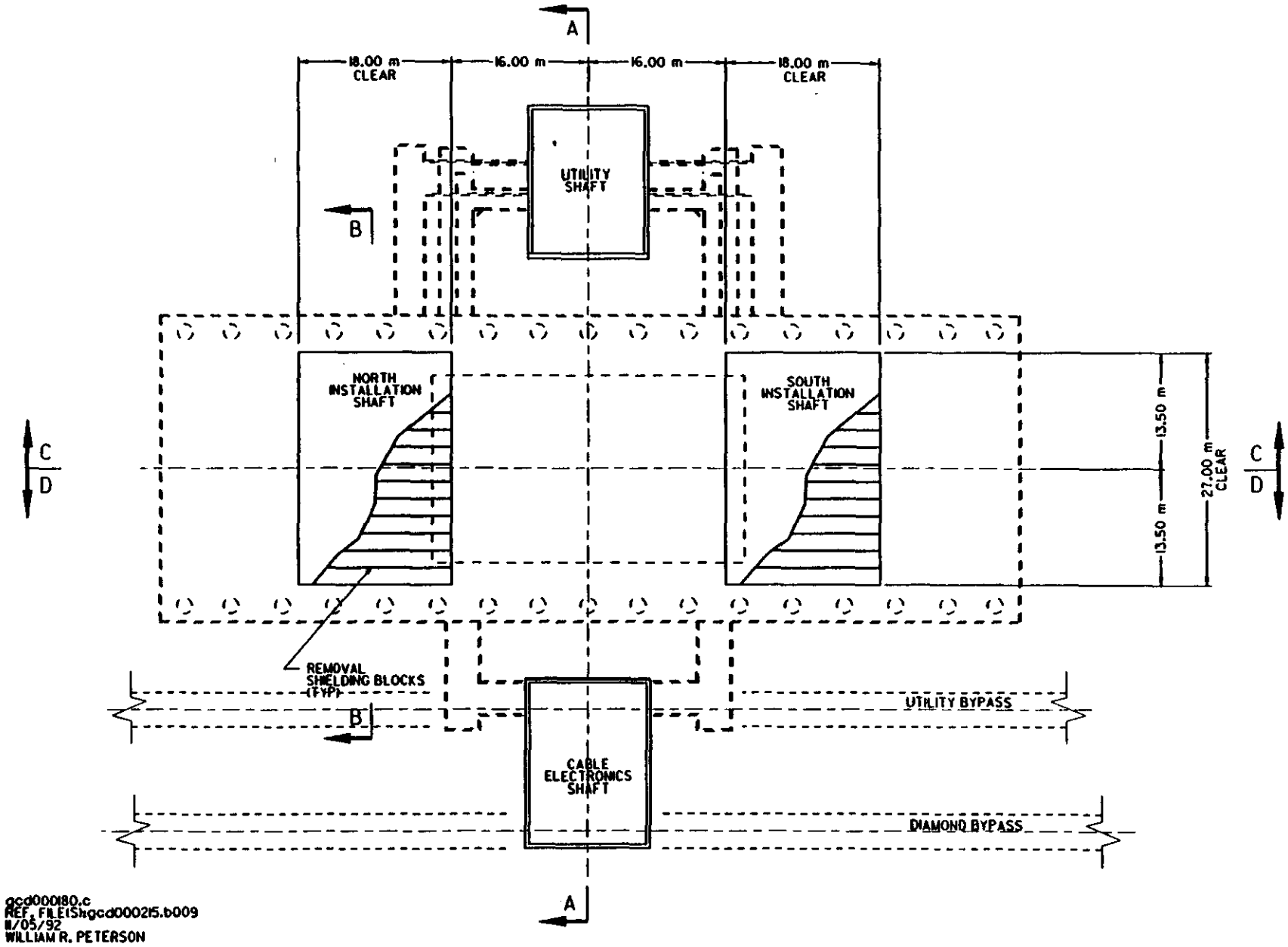
K. R. NELSON

Experimental Hall Isometric



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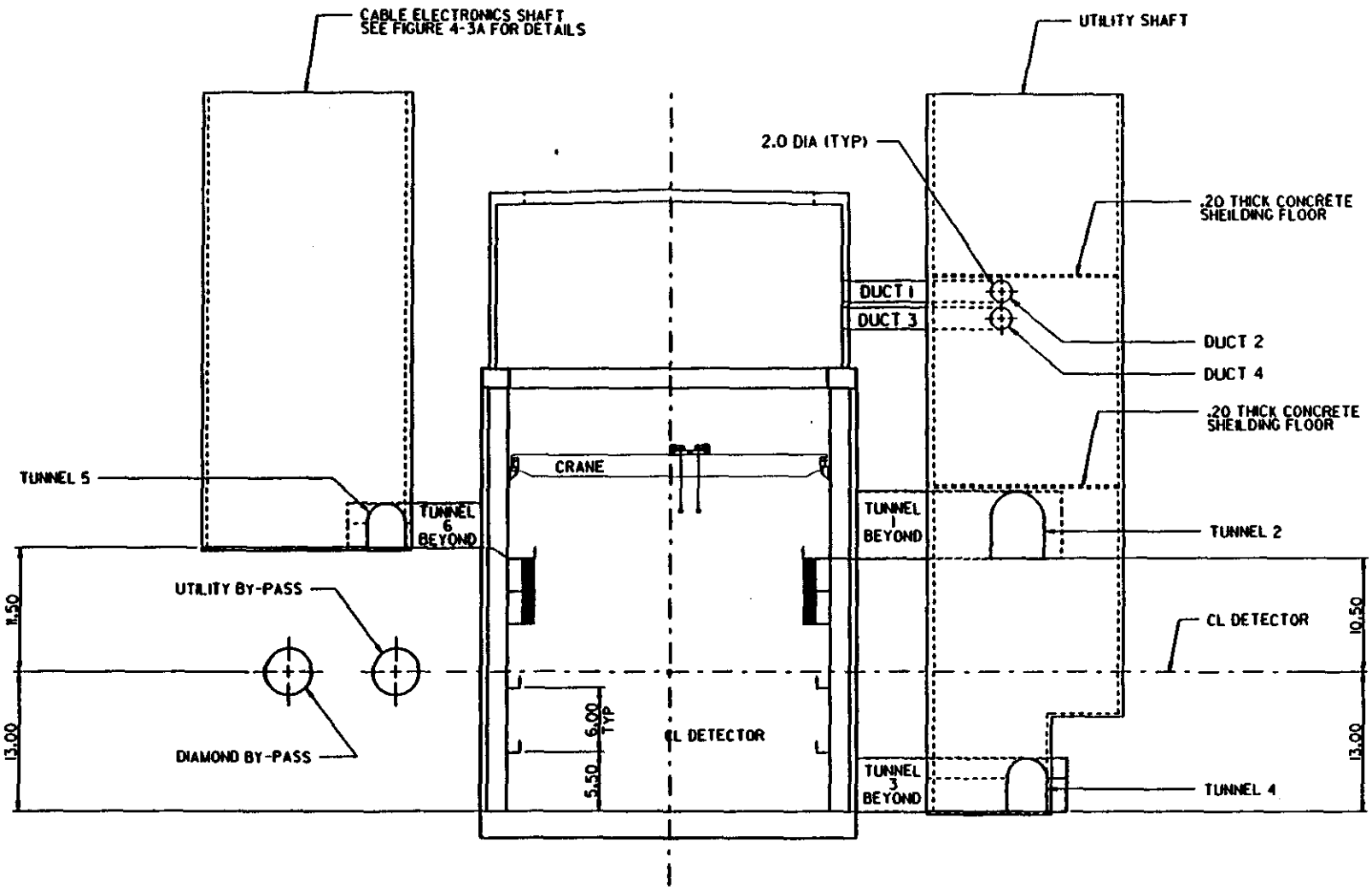
WILLIAM R. PETERSON

Experimental Hall Roof Plan



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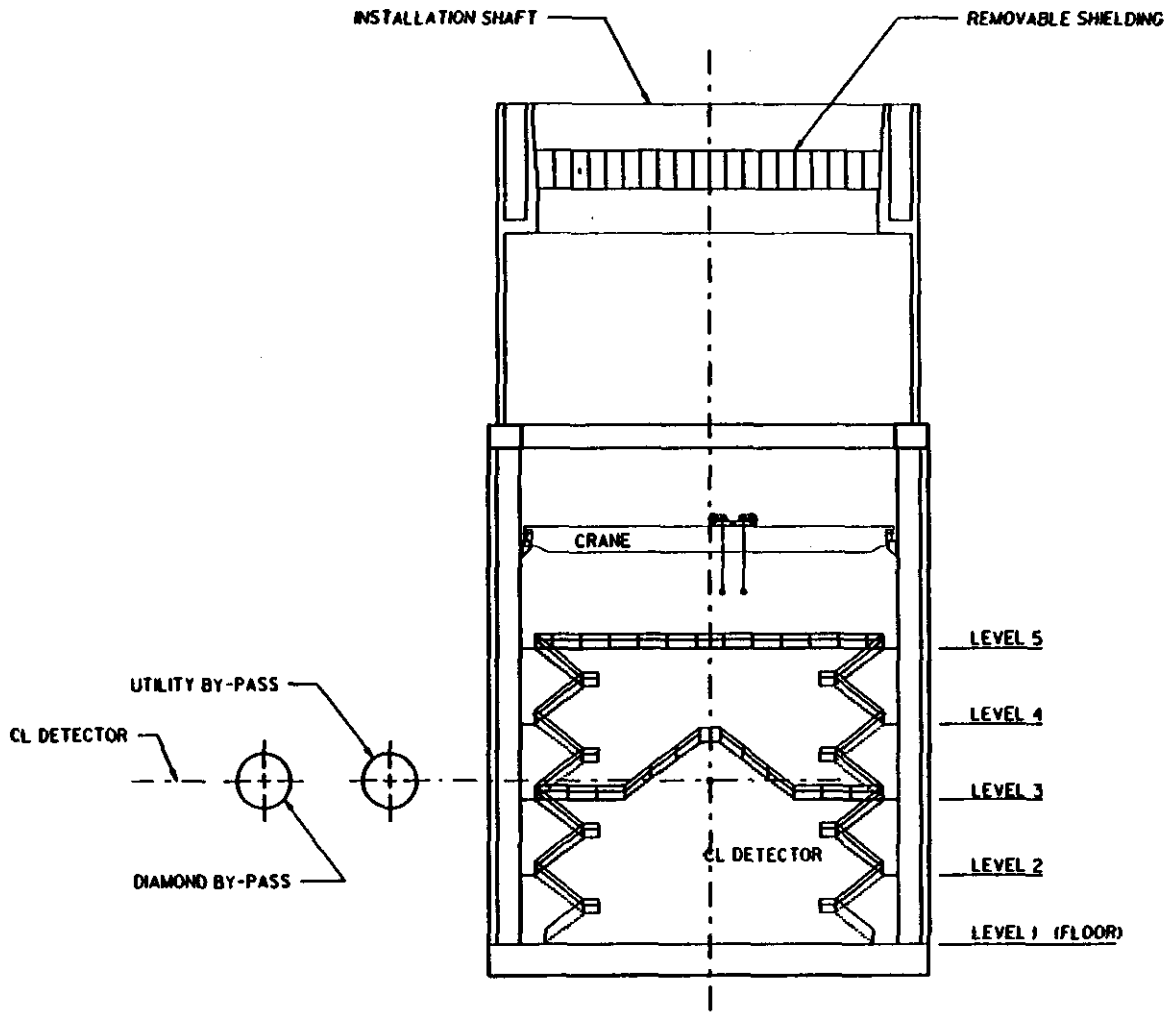
HAWKES

Experimental Hall Section A-A



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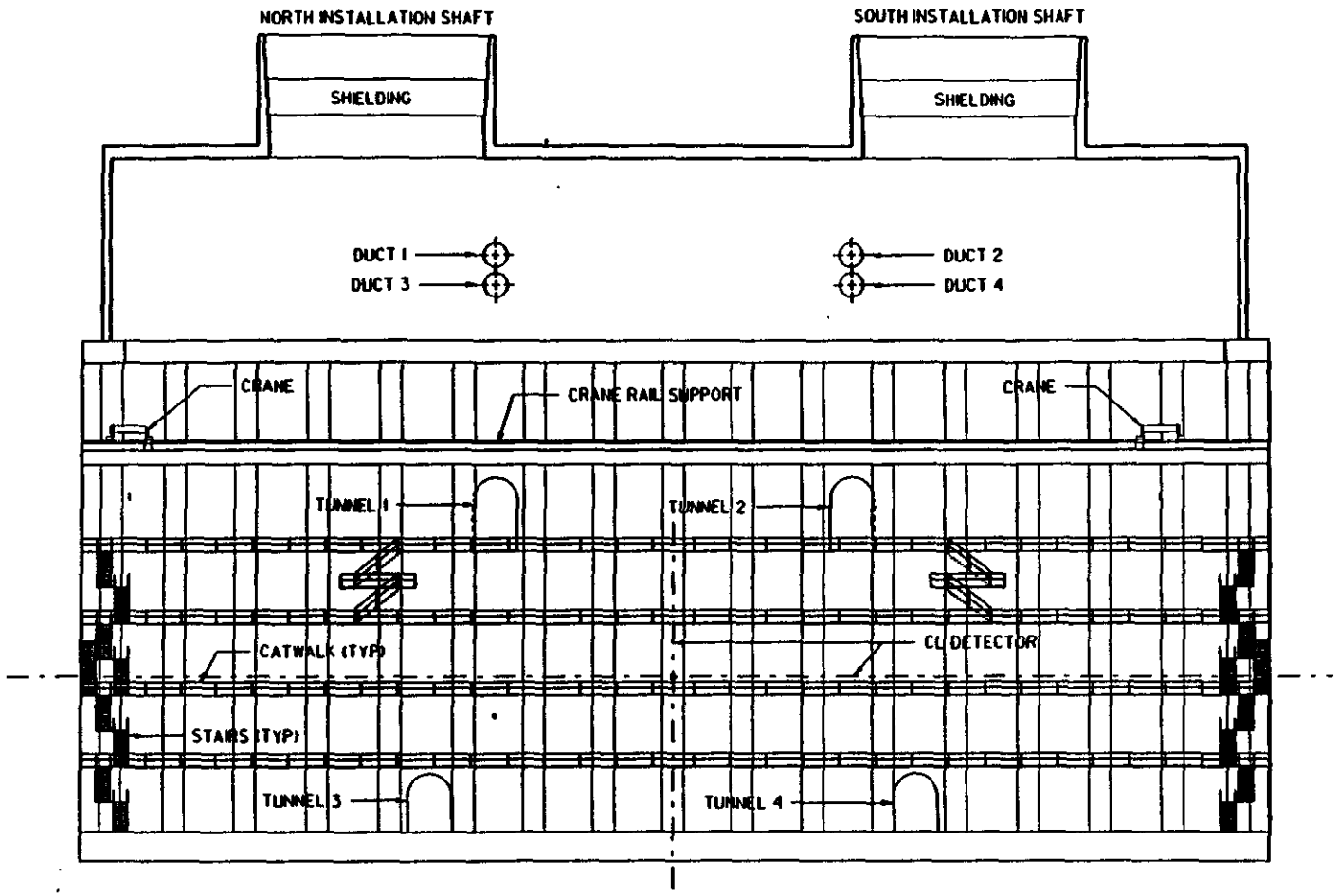
5 NOV 1992
HAWKES

Experimental Hall Section B-B



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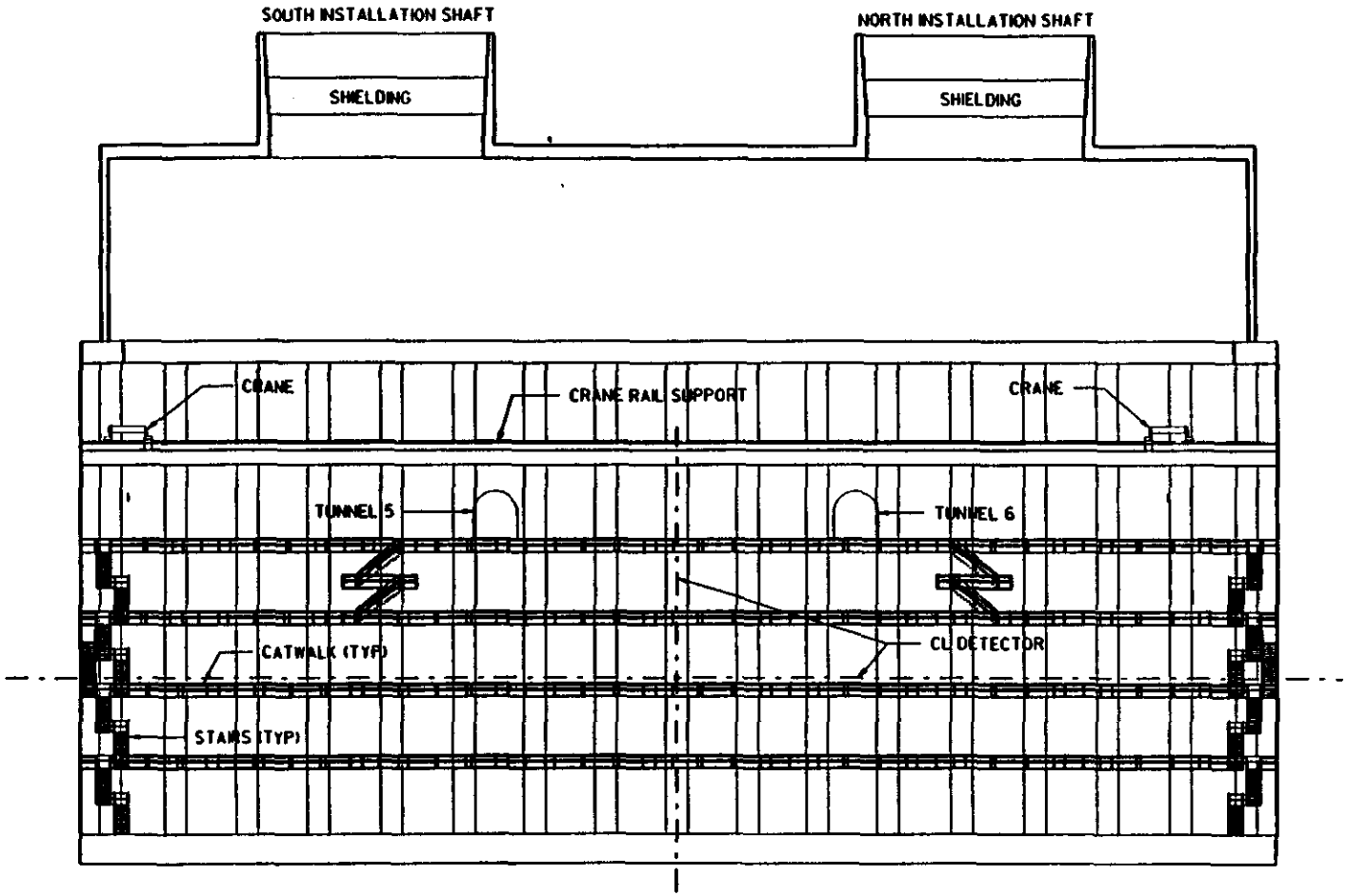
HAWKES

Experimental Hall Section C-C



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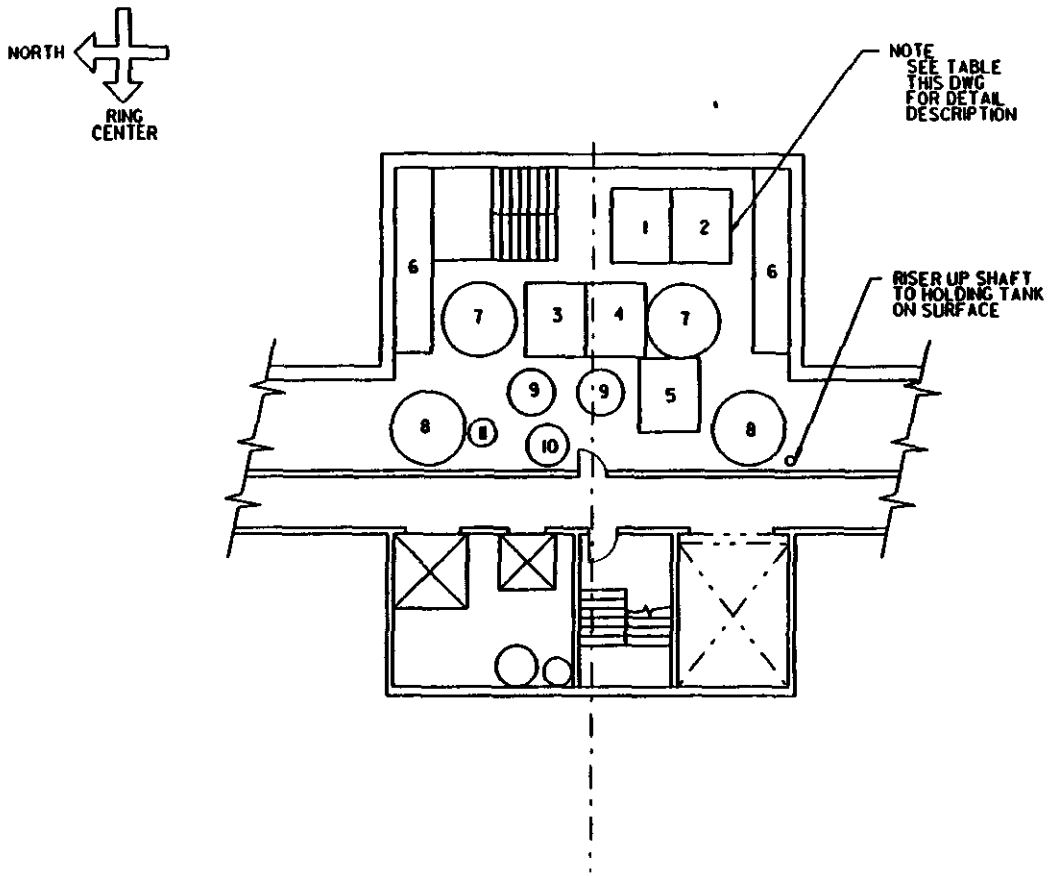
5 NOV 1992
HAWKES

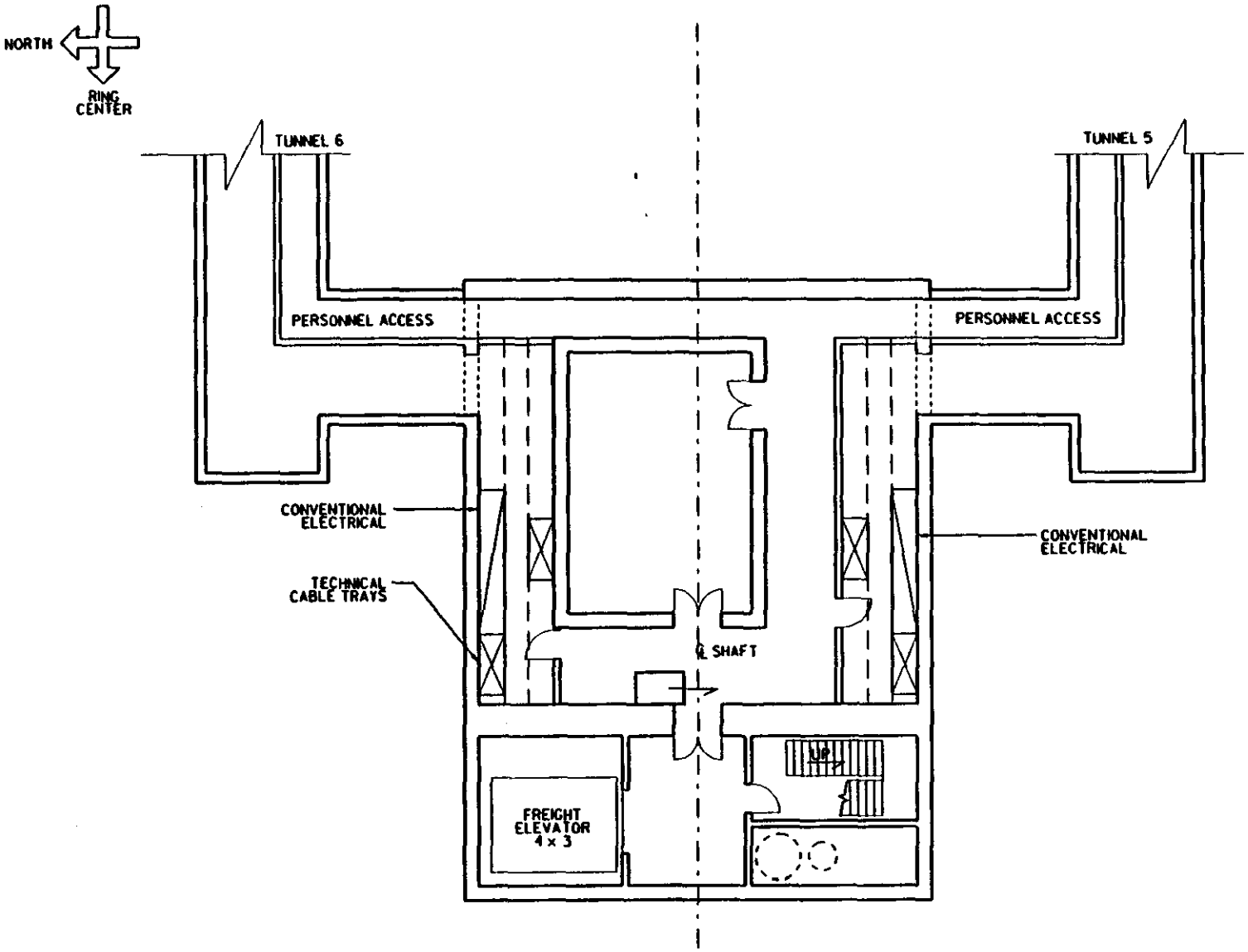
Experimental Hall Section D-D



UTILITY SHAFT SPACE REQUIREMENTS		
ITEM	DESCRIPTION	SIZE
1	TECH WATER PIPING	6'-6" x 8'-0"
2	TECH GAS PIPING	6'-6" x 8'-0"
3	TECH ELEC/BUS BARS	6'-6" x 8'-0"
4	TECH UTILITIES	6'-6" x 8'-0"
5	TECH CYRO PIPING	6'-6" x 8'-0"
6	CONVENTIONAL ELEC	80 SF (BA)
7	HALL AIR SUPPLY DUCTS	8'-0" DIA
8	HALL AIR RETURN DUCTS	8'-0" DIA
9	DETECTOR SUPPLY/RETURN	5'-0" DIA
10	ARGON SUMP EXHAUST	4'-6" DIA
11	COMMON EXHAUST	3'-0" DIA

gcd000186.c
REF. FILE(S):gcd000221
05-NOV-92
K. R. Nelson

Experimental Hall Utility Shaft Plan at Tunnels 1 & 2



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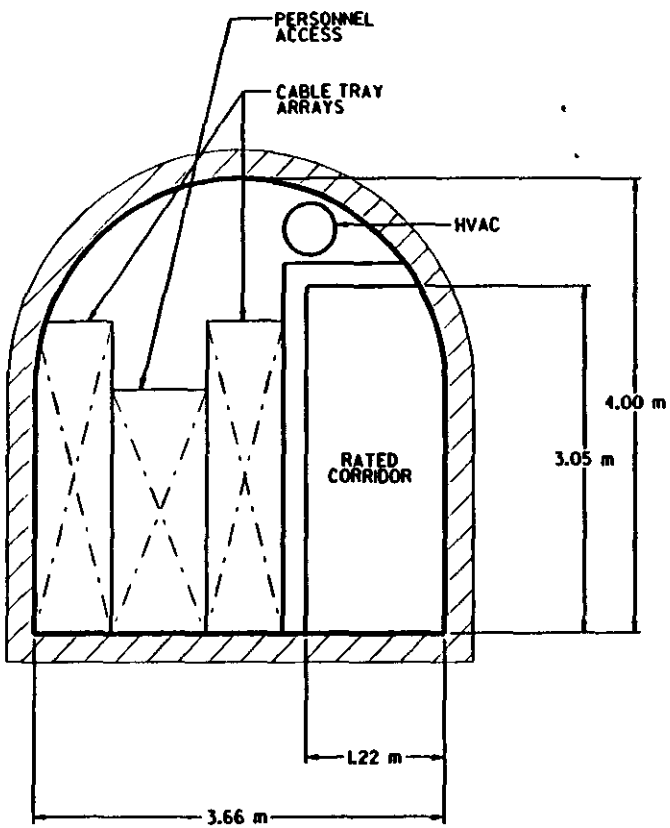
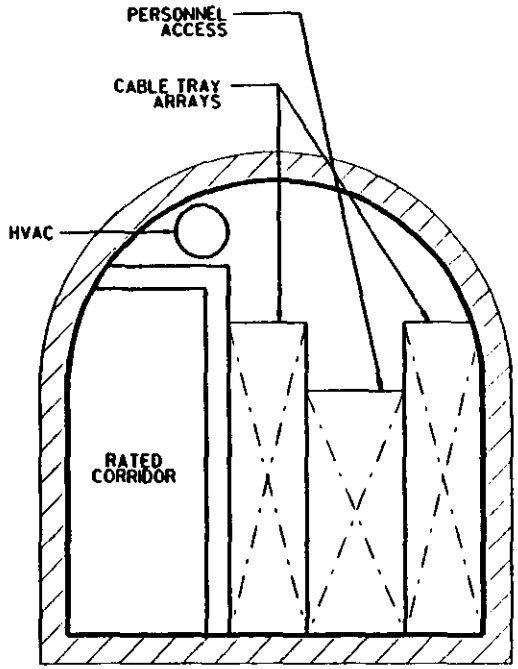
8/06/92
WILLIAM R. PETERSON

Experimental Hall Cable Electronics Shaft Plan At Tunnels 5 & 6



TUNNEL 6



TUNNEL 5

gcd000190.c
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11/06/92
WILLIAM R. PETERSON

Experimental Hall Cable Electronics Shaft Tunnels 5 & 6 Sections

UNDERGROUND FACILITIES REQUIREMENTS

HALL

Length	100 m
Width	30 m
Distance Between Floor and Beam	13 m
Lift Clearance Above the IP	19 m

ASSEMBLY SHAFTS

Length	18 m
Width	27 m

CABLE ELECTRONICS SHAFT

Length	13.11 m
Width	18.59 m

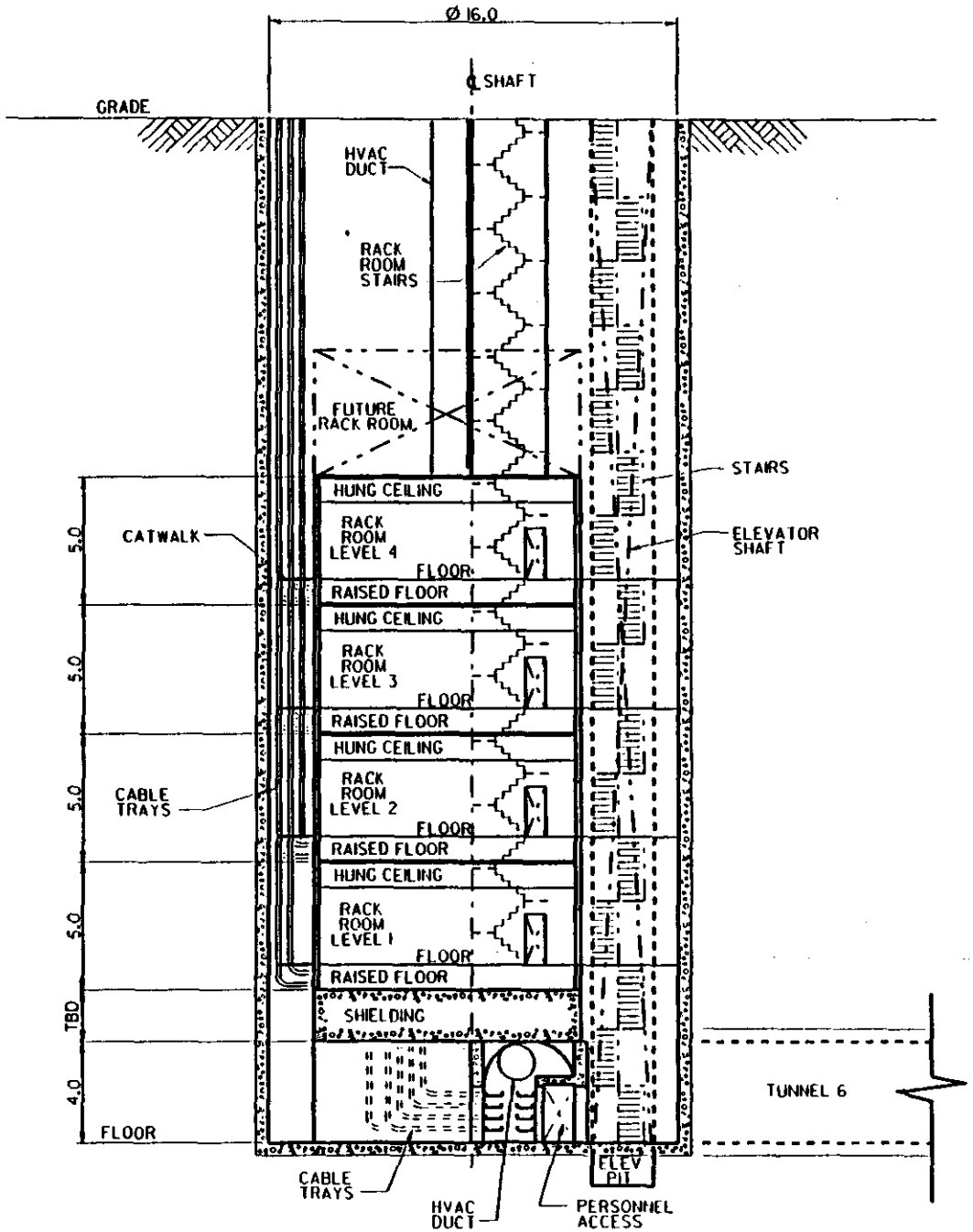
UTILITIES SHAFT

Length	13.11 m
Width	17.12 m

BRIDGE CRANES (2)

Load Capacity -	Main Hoist	75 tons
	Auxiliary Hoist	20 tons

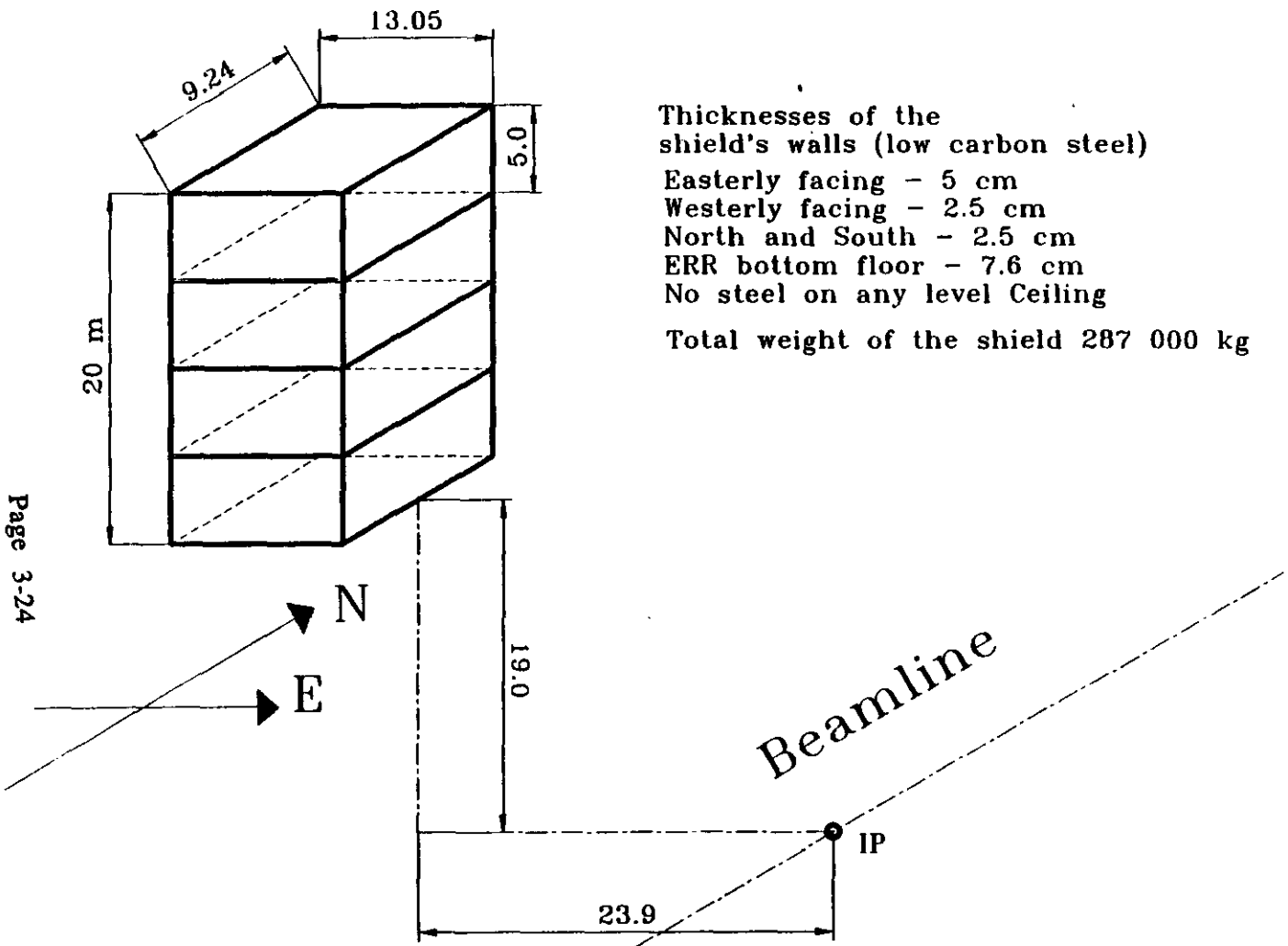
csect1
jun-25-92



SECTION A-A
CABLE ELECTRONICS SHAFT

em

Electronic Rack Room Iron Shield (for max B < 50 G)



Thicknesses of the shield's walls (low carbon steel)

Easterly facing - 5 cm
Westerly facing - 2.5 cm
North and South - 2.5 cm
ERR bottom floor - 7.6 cm
No steel on any level Ceiling

Total weight of the shield 287 000 kg

4. DETECTOR INSTALLATION

DETECTOR INSTALLATION

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OVERVIEW

FIGURES:

Group of related drawings showing baseline GEM installation sequence (14 drawings total)

DETECTOR INSTALLATION

OVERVIEW

The GEM detector schedule must conform to the Collider start up milestone date since the Collider cannot be completed without having the detector in position. The critical path in the installation schedule is largely determined by the logic of the detector component installation sequence which is driven by the timeliness of design approval, the efficiency of procurement actions, the manufacturing process, the availability of facilities, and surface assembly operations (not necessarily in that order).

The overall installation period in the underground hall is estimated as approximately 3.5 years. The large superconducting magnet is planned as the first subsystem to be lowered during 1996. Assuming that a first contract could be placed in the beginning of 1993, this would leave a period of three years to build one of the world's largest superconducting magnets, containing 24 coil sections, each almost 18 m in inner diameter and 1.3 m high. The time to wind, insulate and test each section is estimated to take an average of one month. The magnet surface assembly process is expected to take at least six months and the subsequent tests another three. This would indicate that the magnet could be ready for installation if the procurement strategy is pursued as a top priority critical action item and that key contracts are placed no later than the beginning of next year.

The detector installation schedule is based on a series of sequential operations except in the case of the muon barrel chambers which could be installed at the same time as the calorimeter. The installation sequence begins with the south forward field shaper being lowered down the north construction shaft. The remaining magnet components are each lowered and installed, followed by a magnet system test and a field mapping process. This is expected to take approximately 13 months.

During the next six month period the magnet is then reopened and the calorimeter is installed with the use of rail structures partly situated at a convenient point under the north construction shaft. The calorimeter is then closed up, tested and reopened to permit the central tracker to be installed. During this time the barrel muon chamber assemblies are being lowered through the south construction shaft and placed inside the completed magnet half sections.

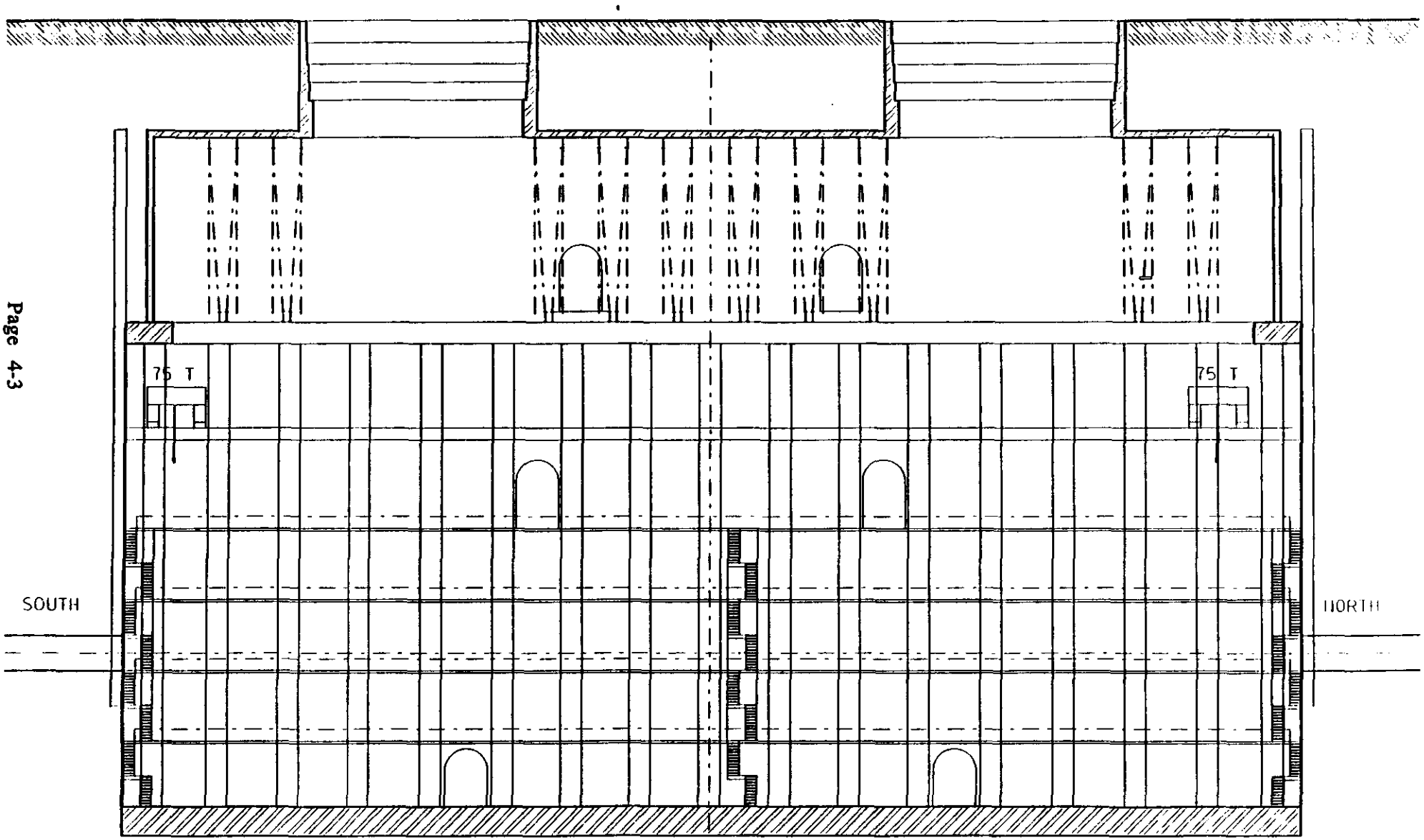
Source: M. Harris/A. Gober
Updated: 6/26/92

The tracker installation and checking is expected to require seven months. After tracker installation the calorimeter is again closed up and the muon barrel installation is completed. This permits the magnet half sections to be brought together so that, during the following five month period, the muon endcaps can be installed using both construction shafts. The magnet forward field shapers are then closed and final connections and tests are carried out. Throughout the period of installation there will be a continuous laying and connecting of services, power busses, cables and fibers.

The two large construction shafts permit flexibility in the case of schedule changes and provides the option of first lowering the calorimeter, followed by the magnet, through both shafts. Surface facility heavy-load transport paths will be laid out to accommodate use of both shafts.

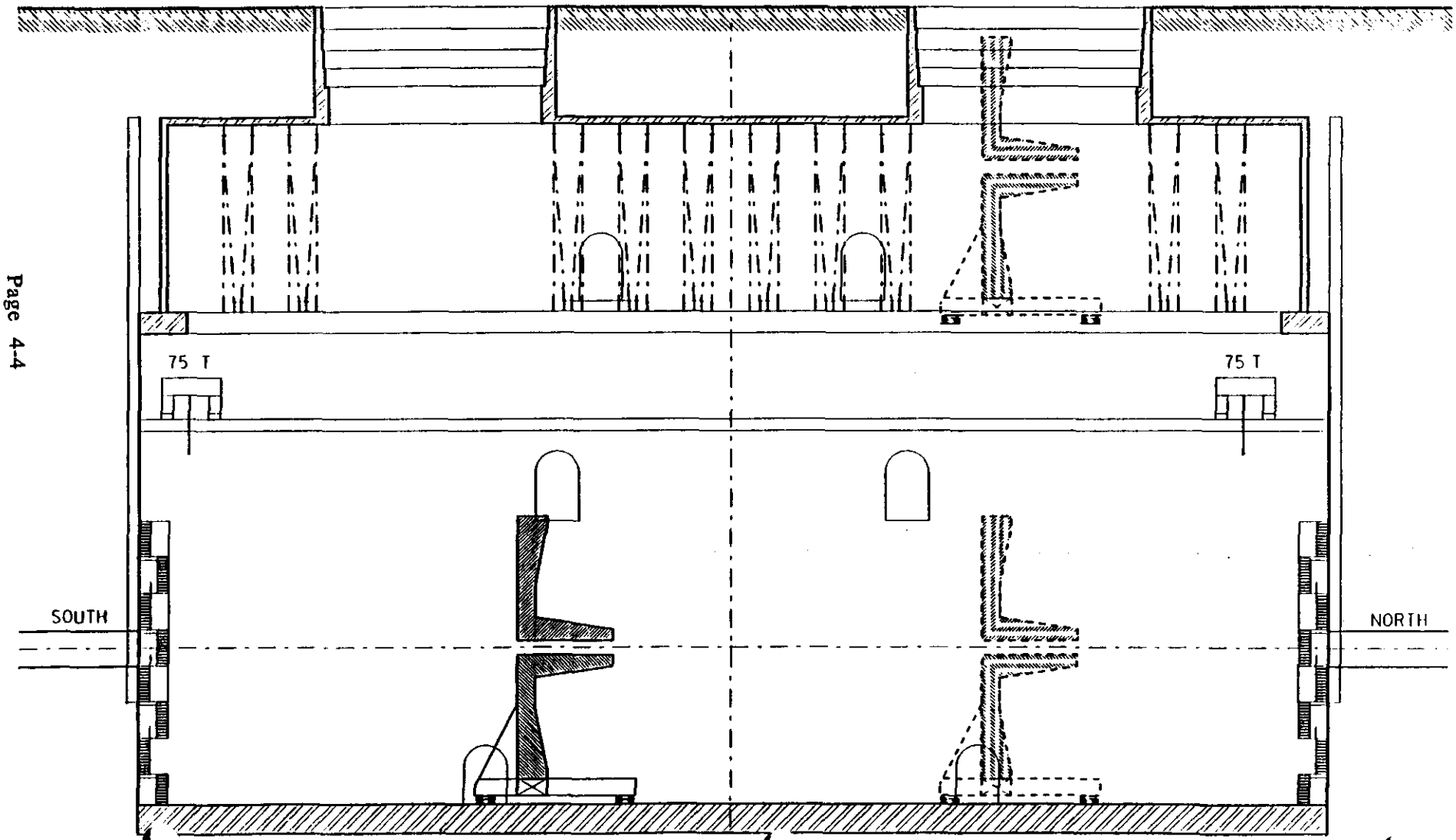
Source: M. Harris/A. Gober
Updated: 6/26/92

PHASE I



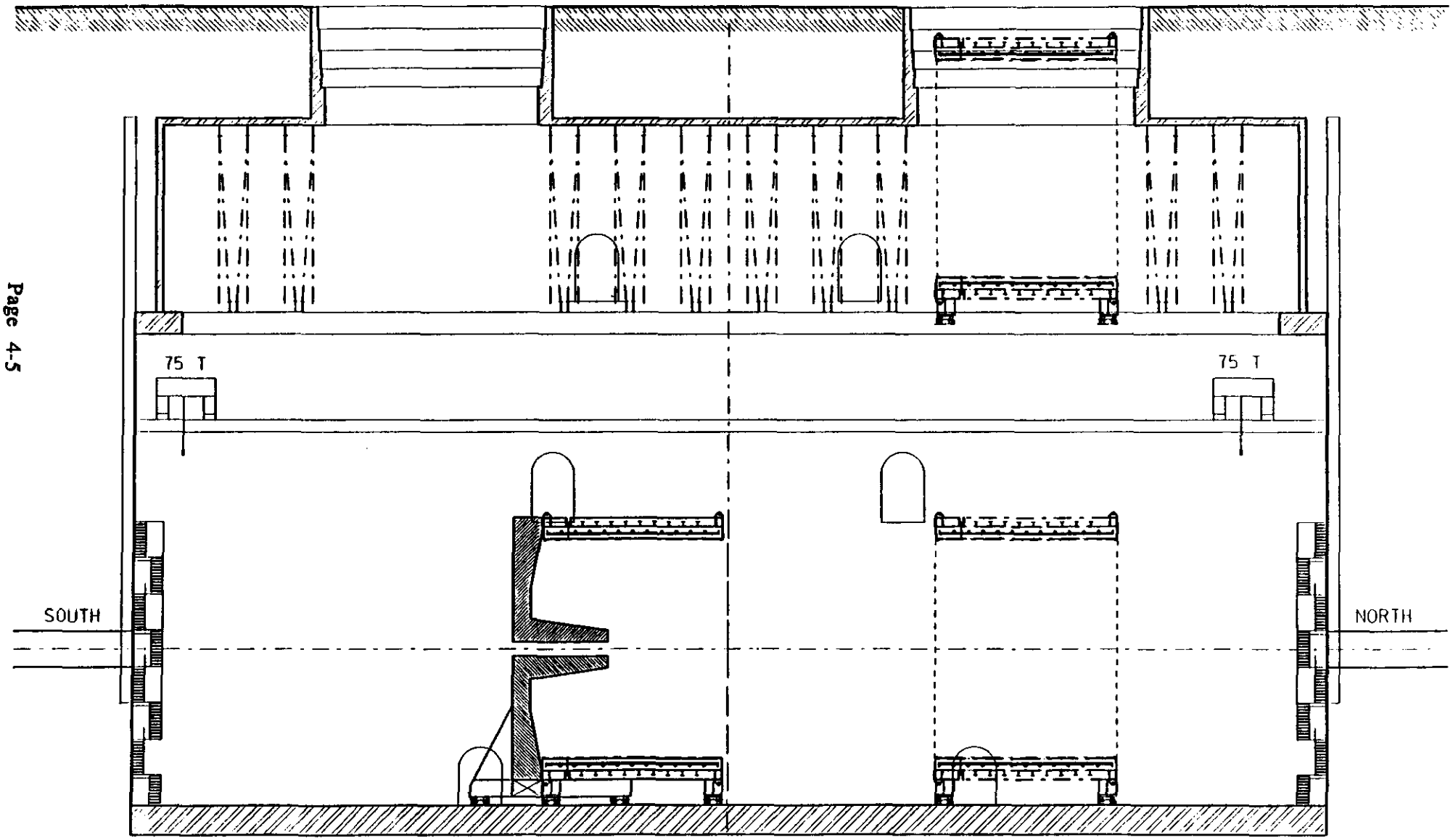
UNDERGROUND HALL COMPLETED

PHASE 2



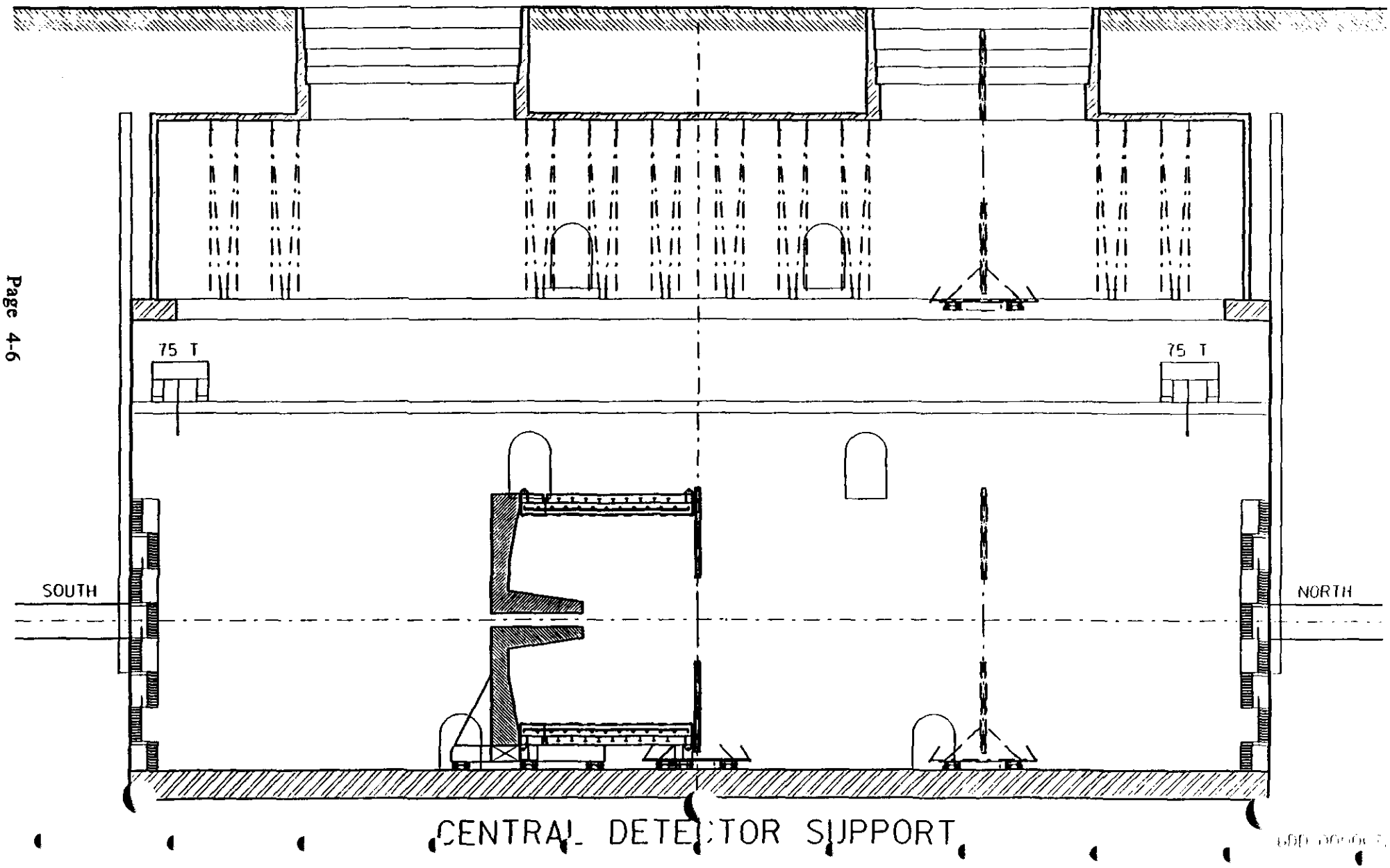
FORWARD FIELD SHAPER SOUTH

PHASE 3

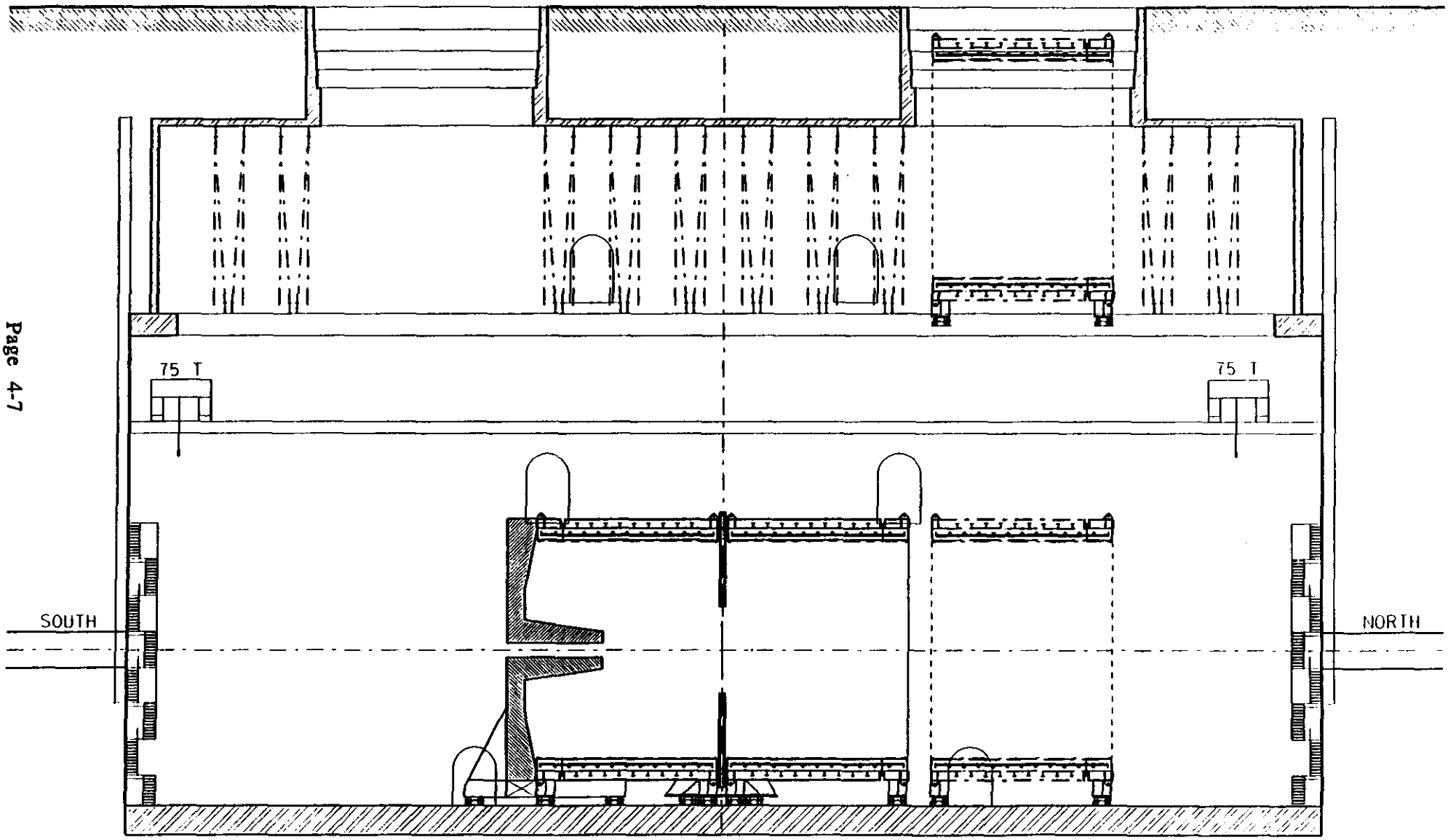


MAGNET HALF COIL SOUTH

PHASE 4



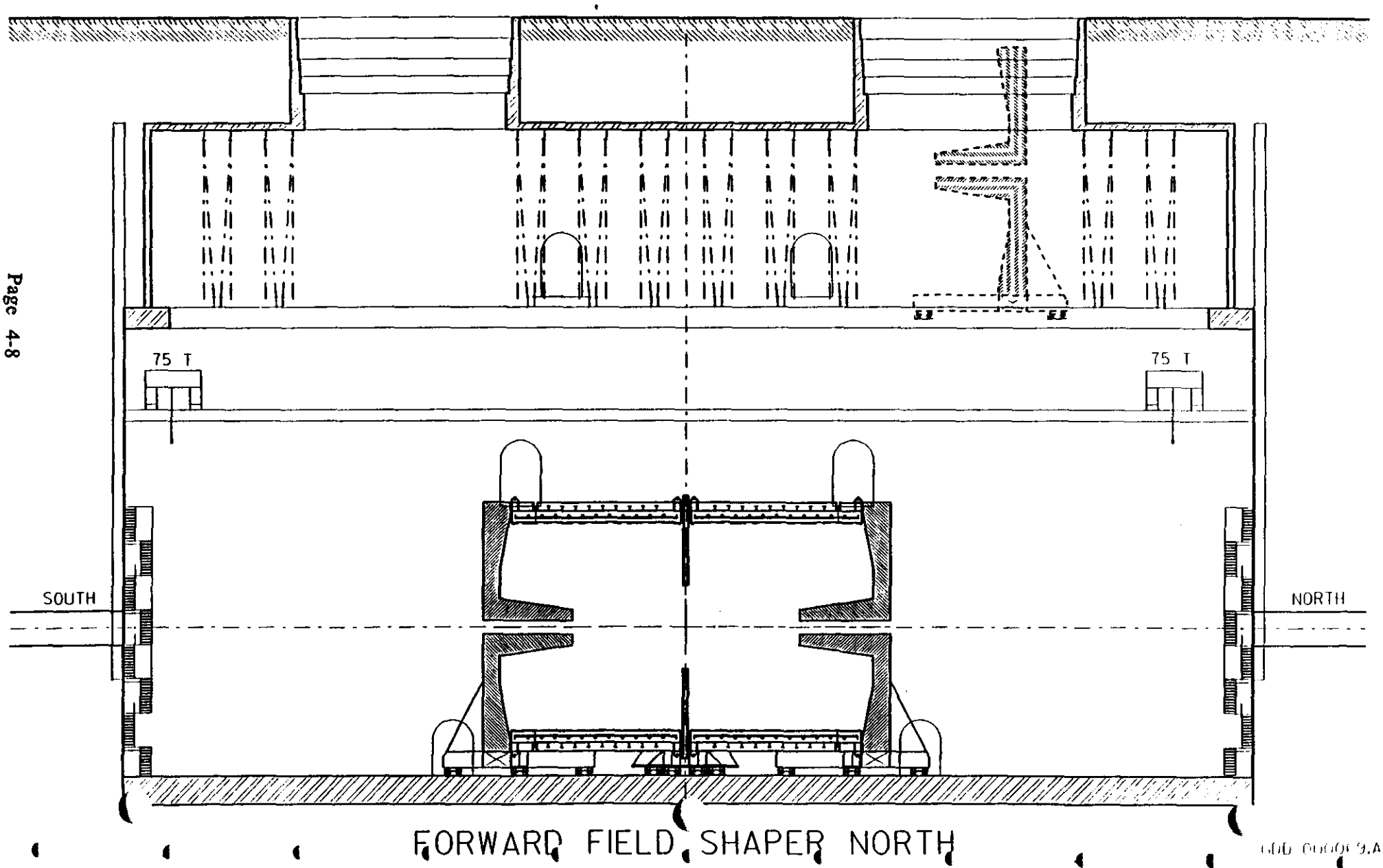
PHASE 5



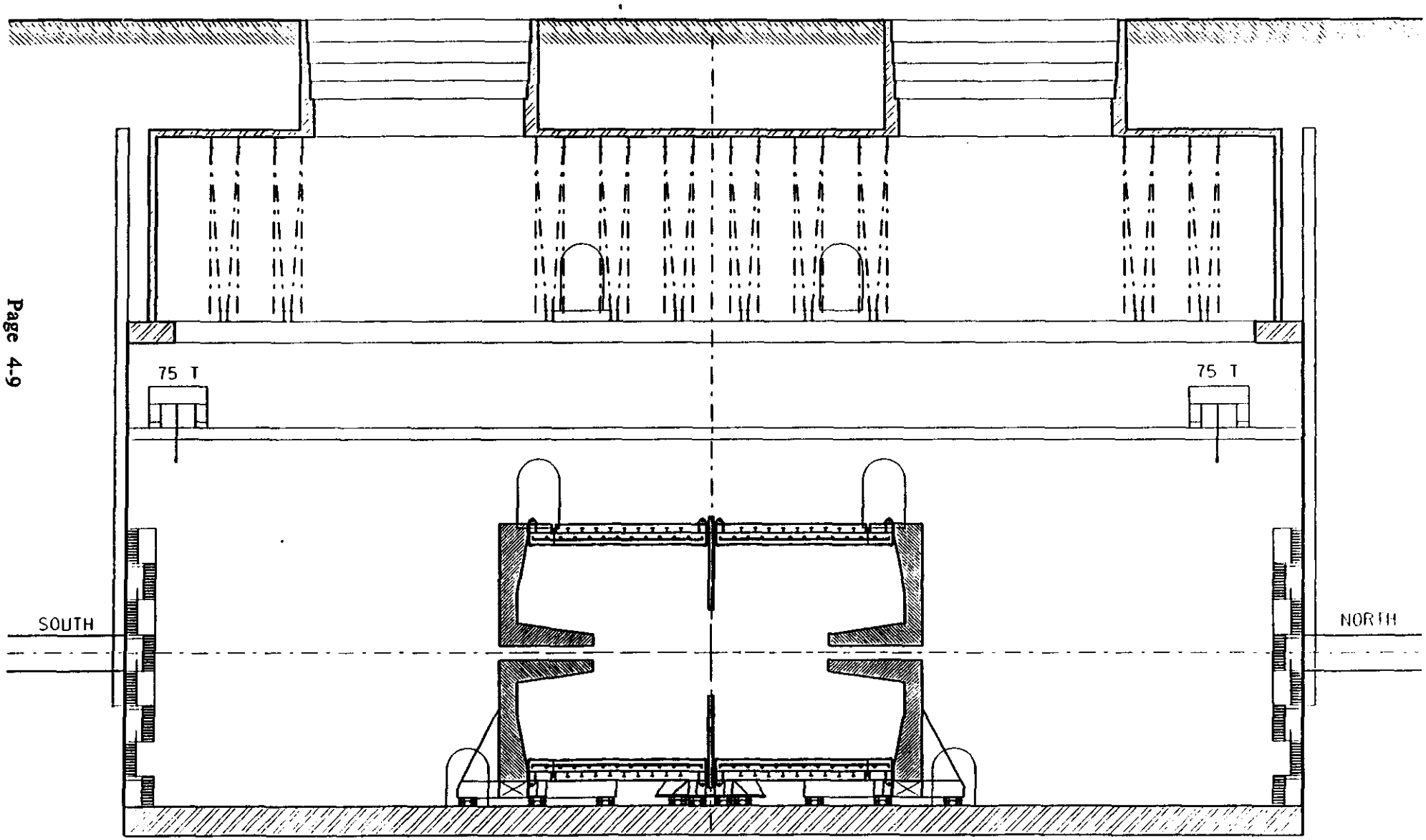
MAGNET HALF COIL NORTH

GDD-000062A

PHASE 6

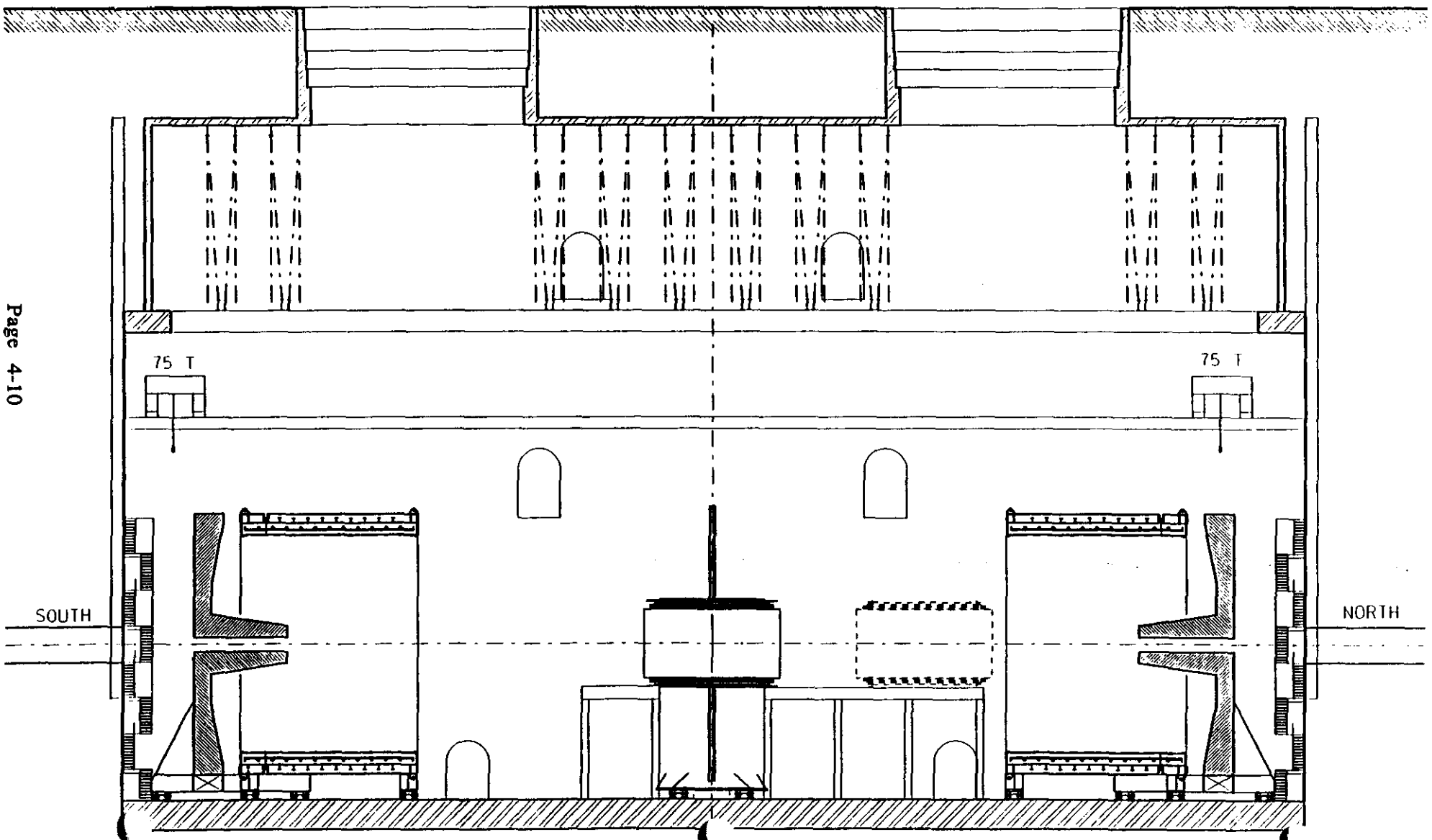


PHASE 7 - 8



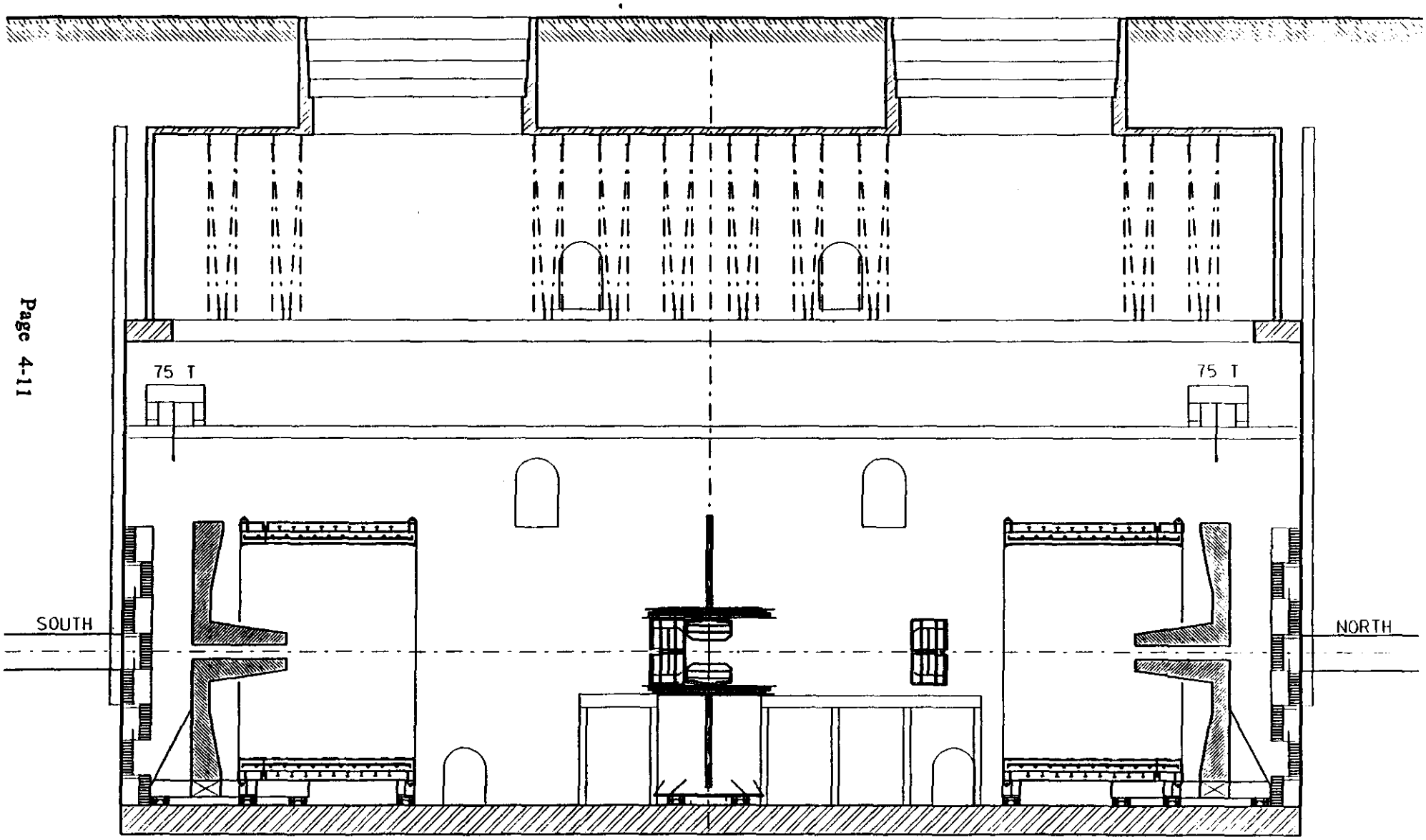
TEST MAGNET SYSTEMS - MAP MAGNET FIELD

PHASE 9



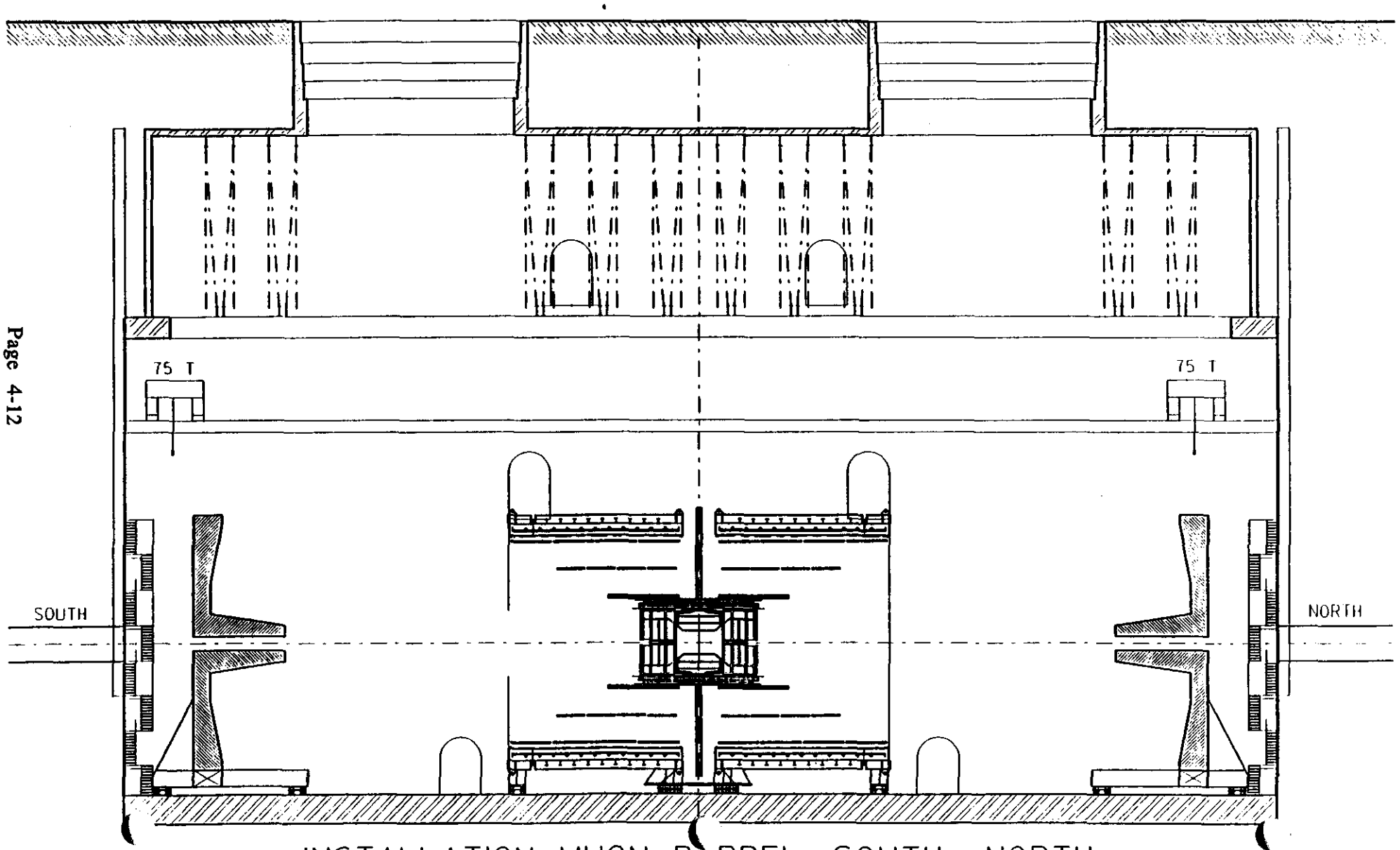
OPEN MAGNET - INSTALLATION BARREL SCINTILLATING CALORIMETER

PHASE 10



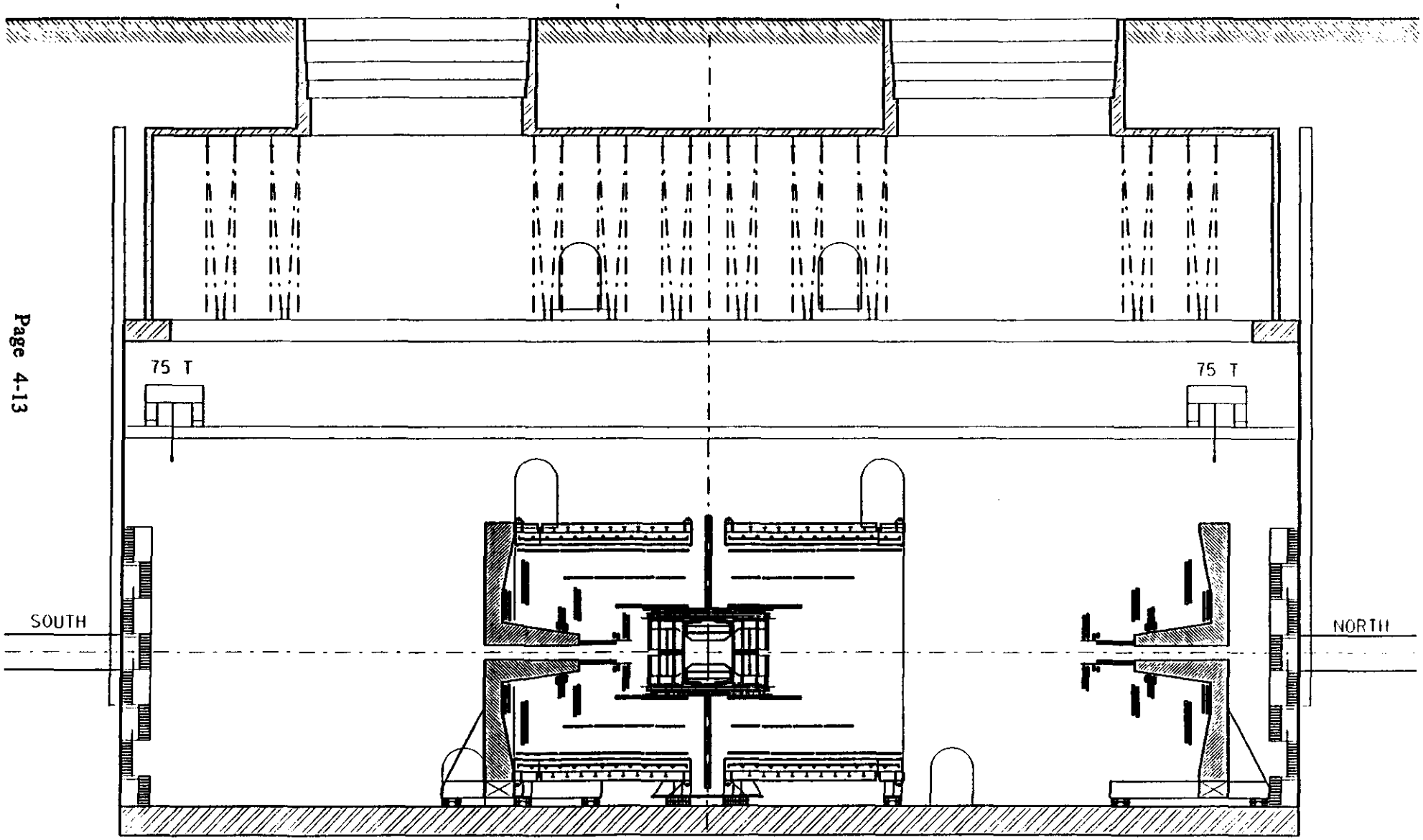
BARREL AND END - CAP INTEGRATED CALORIMETER INSTALLATION

PHASE II



INSTALLATION MUON BARREL - SOUTH - NORTH

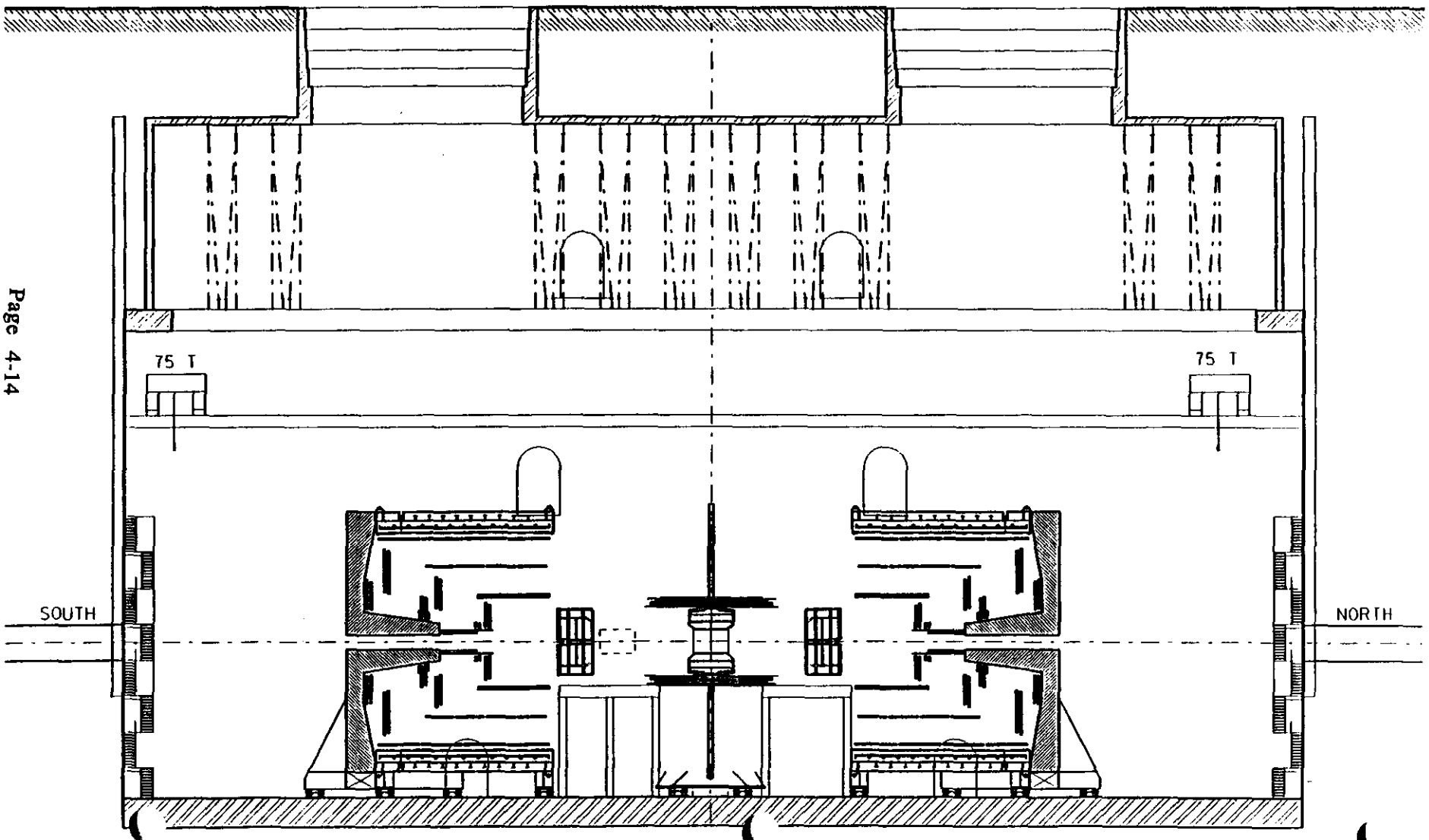
PHASE 12



END _ CAP MUON INSTALLATION

GDD-000074.A

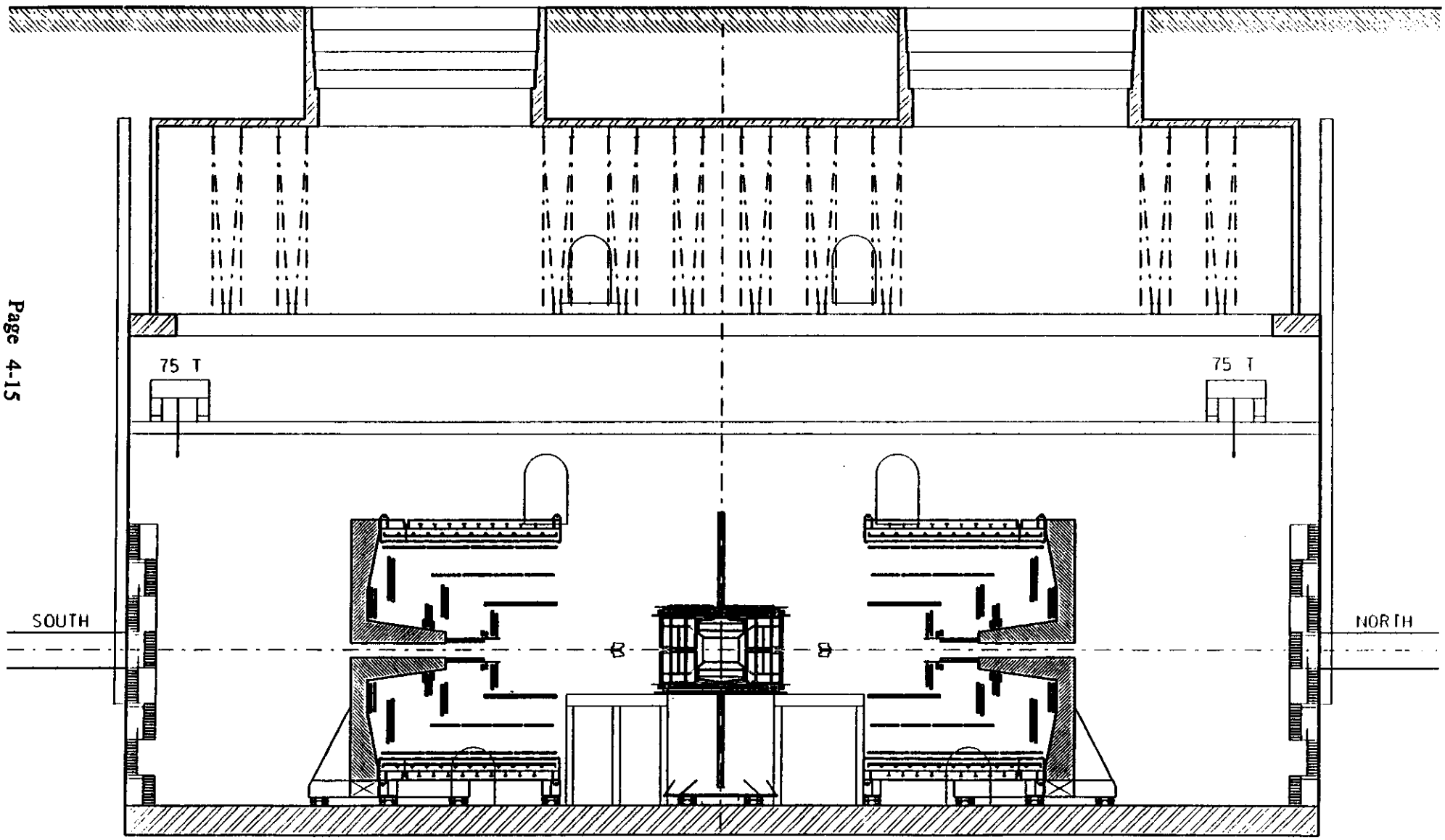
PHASE 13



TRACKER INSTALLATION

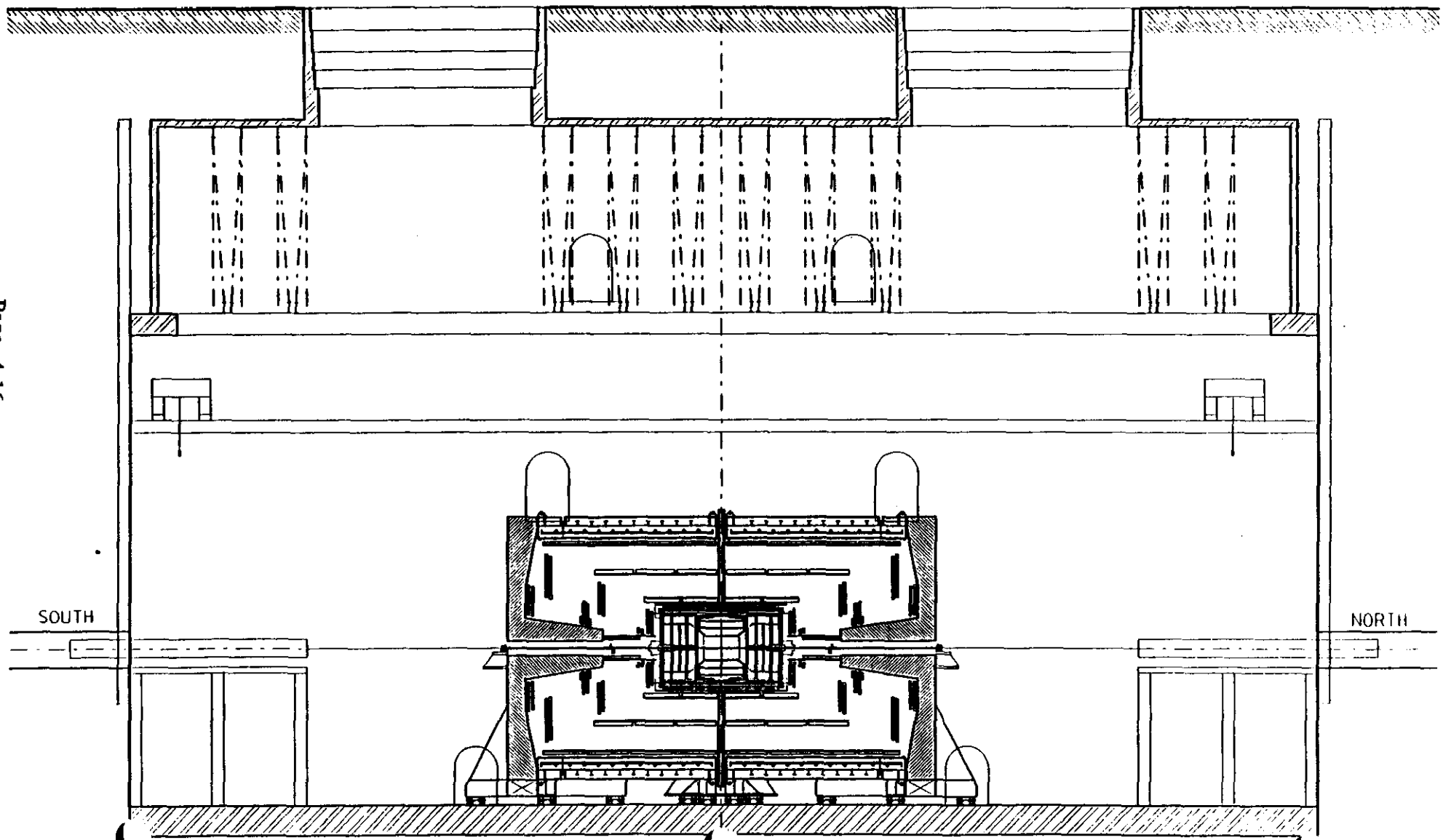
GDD-000-75.2

PHASE 14



VACUUM SYSTEM AND FORWARD CALORIMETER INSTALLATION

PHASE 15 - 16



COMPLETE SUBSYSTEM CONNECTIONS-LAST PART VACUUM PIPE

5. DETECTOR ACCESS

DETECTOR ACCESS

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Operation and Maintenance
Terminology

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GEM Beam Pipe Subsystem Utilities Layout
GEM Calorimeter Subsystem Utilities Layout
GEM Muon Subsystem Utilities Layout
GEM Magnet Subsystem Utilities Layout
GEM Tracker Subsystem Utilities Layout
Inner Detector Access
Detector Maintenance Option

TABLES:

GEM Detector Maintenance Access (2 pages)

DETECTOR ACCESS

OVERVIEW

The maintenance access philosophy for the GEM detector was originally predicated on a planned three-month annual scheduled maintenance shut-down of the SSC collider. This provided sufficient time to remove the collider quadrupole magnets, open the detector by splitting the magnet halves, and accessing the central tracker region. The SSCL is currently proposing to change the collider operating profile by reducing the annual three-month scheduled maintenance shut-down period to a number of shorter periods with a maximum duration of one month.

The maintenance access philosophy to comply with this new shut-down duration is currently being developed. An important factor being considered is placement of the SSC quadrupoles at 35 m from the IP at each end of the detector instead of the current position at 20 m. This approach permits the magnet half units to be split and moved the required 10 m without disturbing the major collider components. This would reduce the time required to access the central tracker by approximately one month.

An engineering feasibility analysis is also being conducted on a scheme that may result in reducing access to the central detector region by another month. This involves displacing the endcap muon chambers on the forward field shapers as they are withdrawn and placing a structure inside the magnet that bridges the space between the calorimeter and the end of the magnet. If the concept proves feasible, central detector components would then be withdrawn on this bridge support structure without splitting the magnet halves or disturbing the barrel muon system.

Movement of the quadrupoles to 35 meters will require improvement in the design of the quadrupoles to enlarge the aperture in order to minimize loss of luminosity or, alternatively, development of a mini-quadrupole magnet inside the detector. This latter approach could be implemented after the detector is commissioned.

Operation and Maintenance

During beam runs, there will be no access to the below ground experimental hall, although there may be limited access to the shielded electronic rooms adjacent to the experimental hall. When short shut-down periods occur and the magnet is de-energized, the access conditions are similar to the commissioning stage.

The current SSC Level 2 Specifications for Experimental Systems (11/25/91) describes an operations scenario with scheduled down

times of 940 hours at one day per week, and a maximum of 2190 hours for long term repairs. The current GEM access philosophy, which impinges strongly on the design, assumes that short accesses will only allow maintenance to components outside the magnet. This will permit access to much of the calorimeter electronics located at the periphery of the support membrane. In addition there is limited access to the muon volume through the ends of the magnet through the support structure for the FFS, or by opening the detector slightly as discussed above. This will allow access in the plane of the beam along a walkway, and more limited access to modules out of the plane. This route provides access also to the periphery of the calorimetry where some electronics can also be located. The vacuum pumps located downstream of the forward calorimetry are also accessible here.

All access to other components in the interior of the detector requires a once-per-year down time of 3 months (2160 hrs) which allows for detector disassembly, including rolling apart the magnet halves, and permits access and removal of the inner tracker. This can be accomplished in various stages which are illustrated in this section. First, the IR quads and collimators, which are currently located directly behind the FFS, must be removed. (There is serious consideration of moving these quads further upstream to avoid this problem and the attendant issues of activation and magnetic shielding). The FFS can then be moved for better access to the barrel muon chambers, one or both magnet halves, with the muon chambers and FFS attached, can be moved. - This provides access to the calorimetry and also the muon chambers. With the magnet halves open, the end calorimeters can be moved to provide access to the inner tracker. This operation of opening and closing the magnet halves is estimated to require approximately two months.

Further study is in progress to understand the impact of limited access on the performance of GEM. The location of critical elements, the redundancy of systems for greater reliability, and the reliability studies of components all must be validated. The use of movable carriers for the service cables will allow the services to remain connected to the detector subsystems, thus eliminating the time normally needed to disconnect the detector components. Temporary platforms, scaffolding and hydraulic elevators may then be transported to the maintenance area over the top of the magnet using the hall crane.

The following tables lists for each GEM subsystem hardware which can be repaired at a specified access level. Access levels are listed in order

of increasing difficulty, e.g., equipment located on the surface will be continually accessible, but equipment located in the detector hall will be accessible only when the beam and field are off, with perhaps other restrictions as well. Much hardware, e.g., cabling, is listed at almost every access level; clearly the access level required to repair such hardware depends on the location of the failure. Generally hardware is listed only at the least difficult access level unless the next level of access exposes additional surface.

Terminology

Electronics includes racks, crates, cards and chips but excludes cables and power supplies.

Process cooling includes both water and air cooling.

Slow control instrumentation includes such items as thermocouples, pressure sensors, etc and associated equipment.

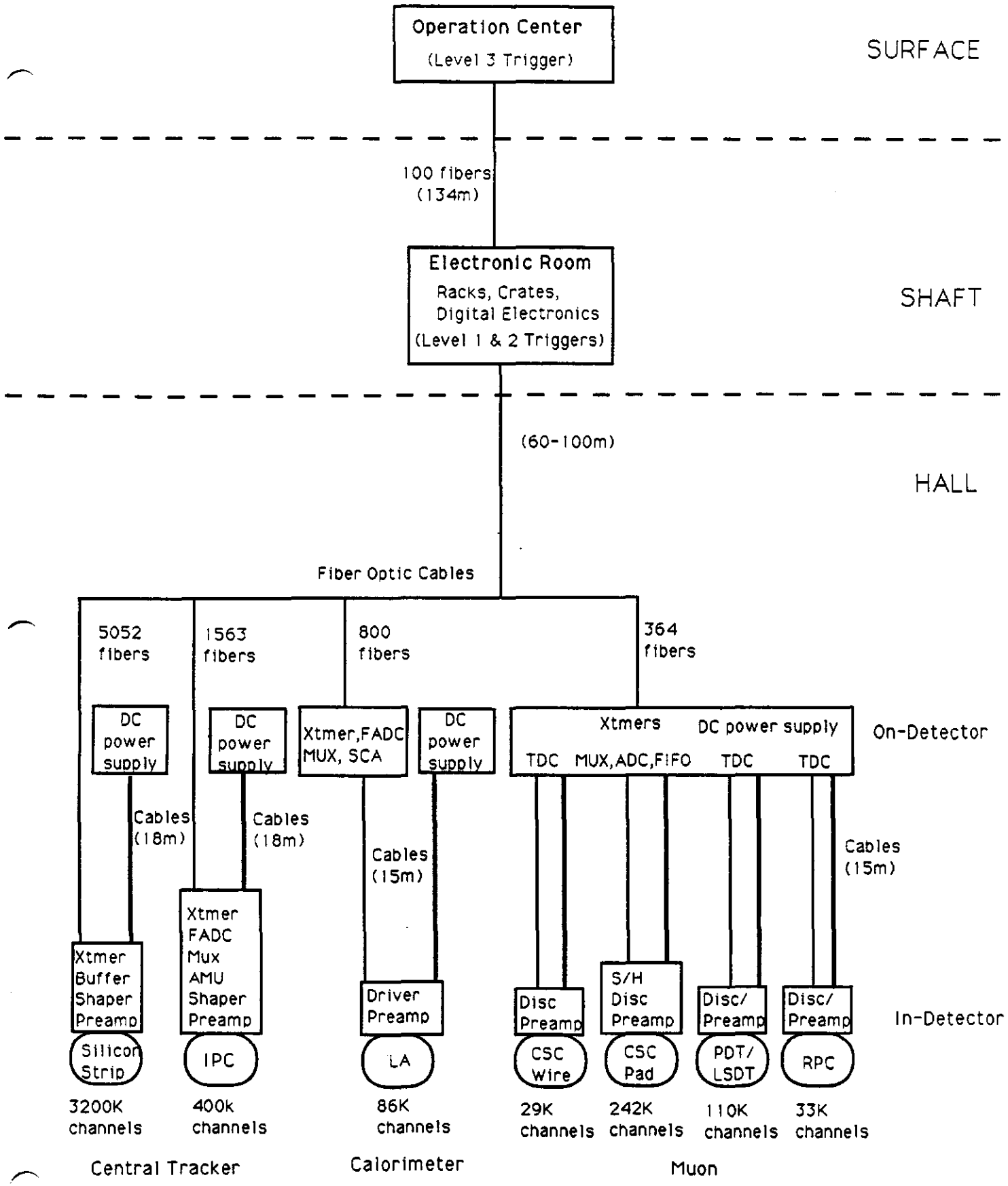
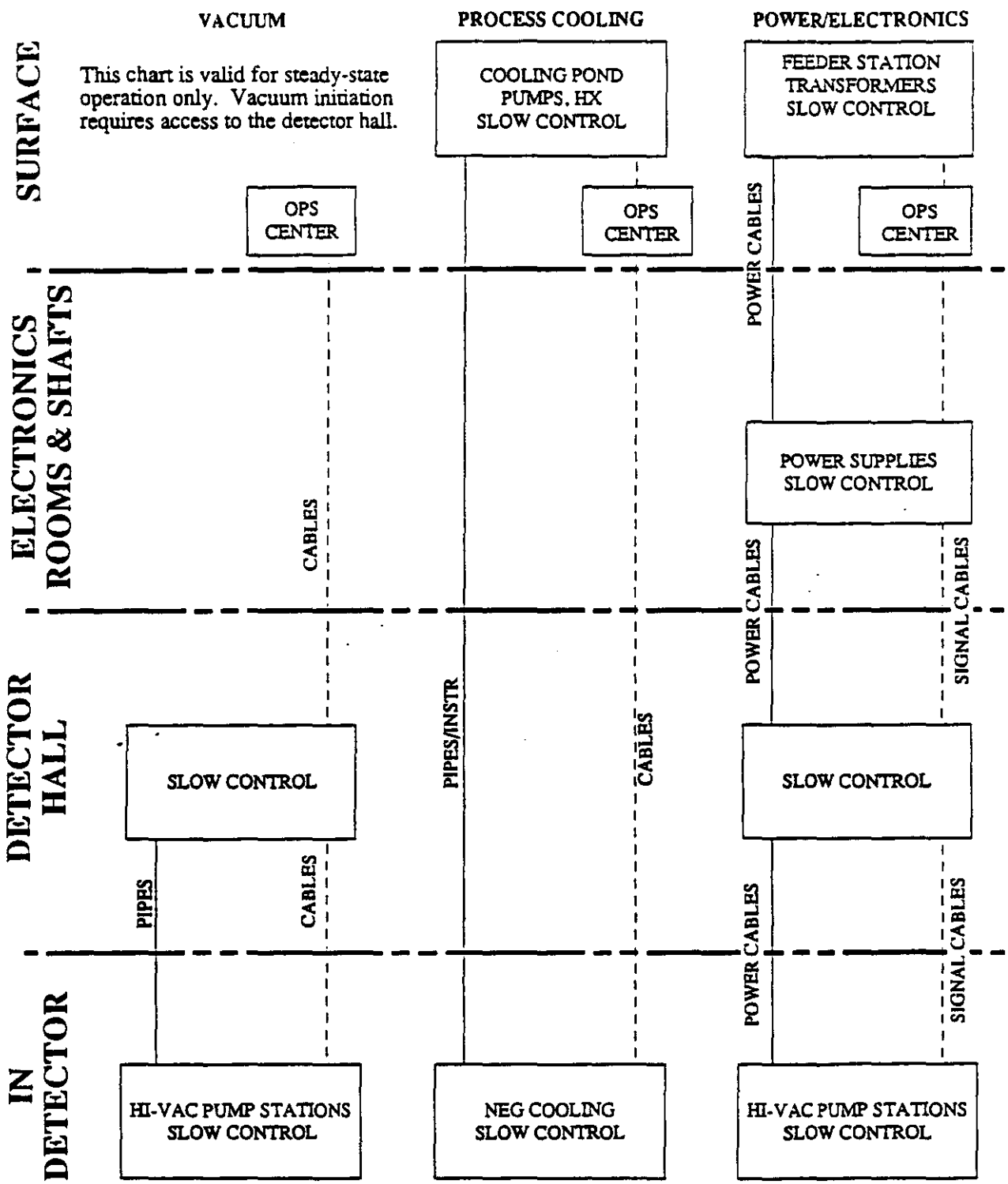


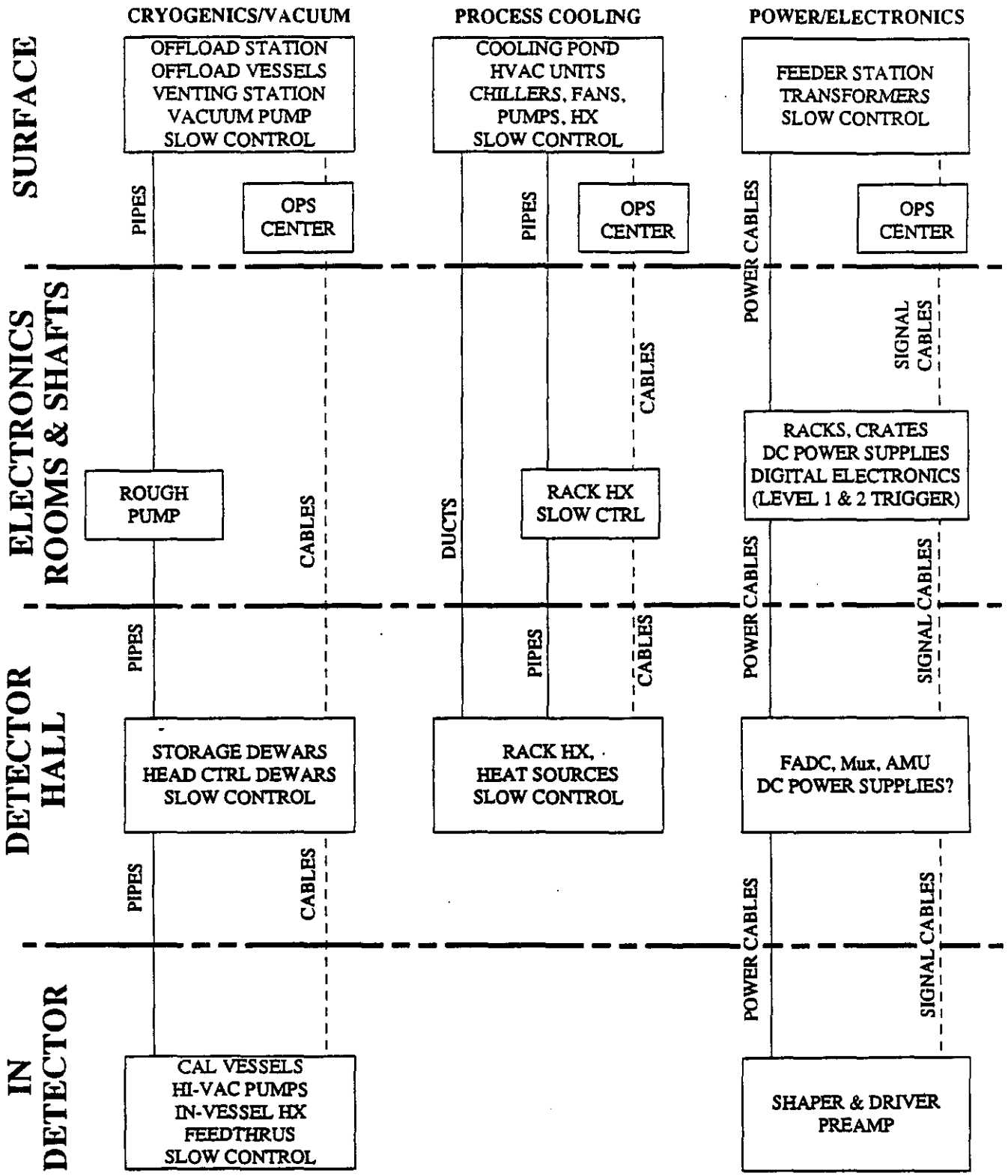
Figure 5-1. Electronics System Layout



GEM BEAM PIPE SUBSYSTEM UTILITIES LAYOUT

EBERLE 07/01/92

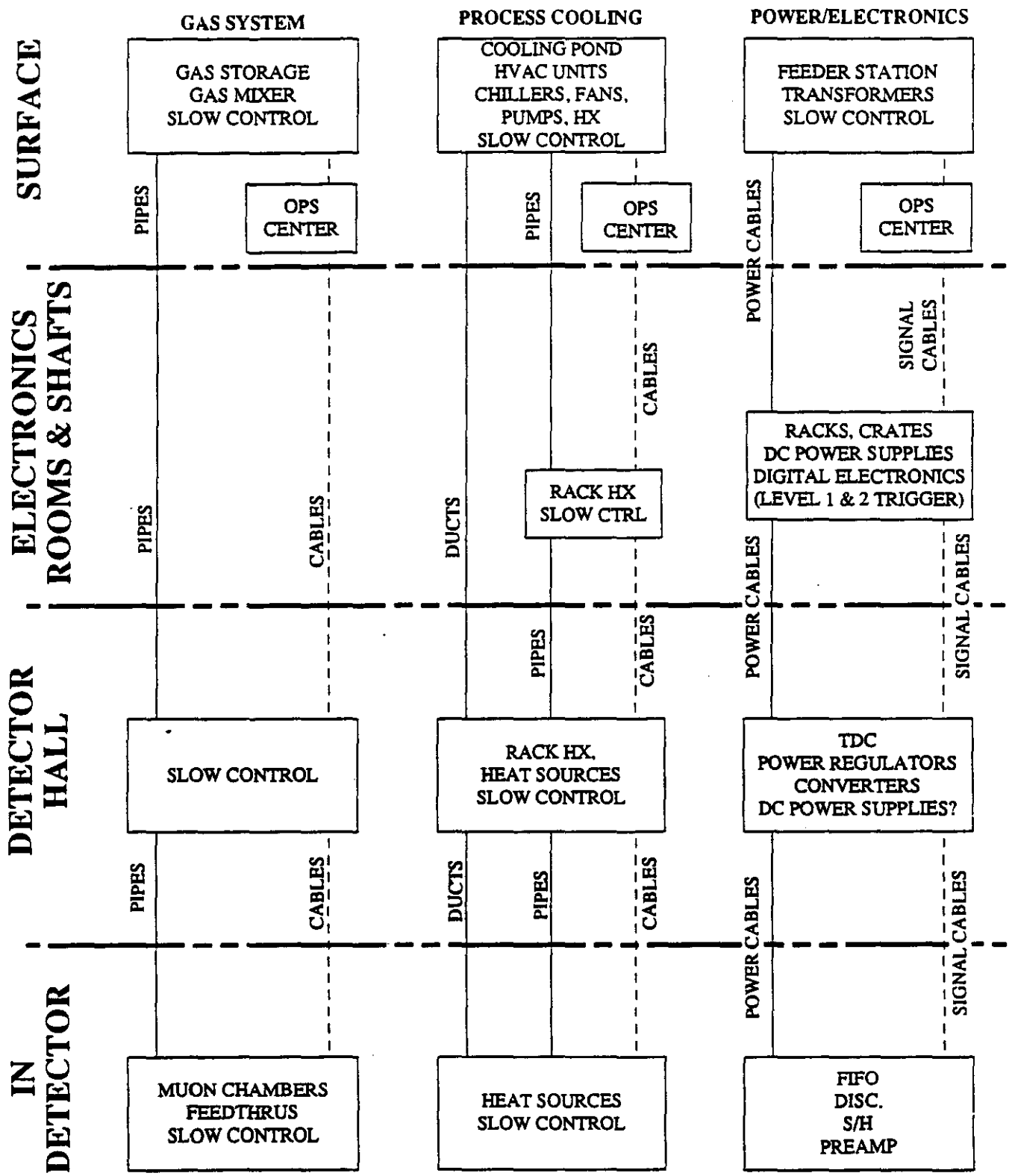
KEY: HV = HIGH VOLTAGE
HX = HEAT EXCHANGER
NEG = NONEVAPORABLE GETTER PUMP
OPS = OPERATIONS



CALORIMETER SUBSYSTEM UTILITIES LAYOUT

EBERLE 07/01/92

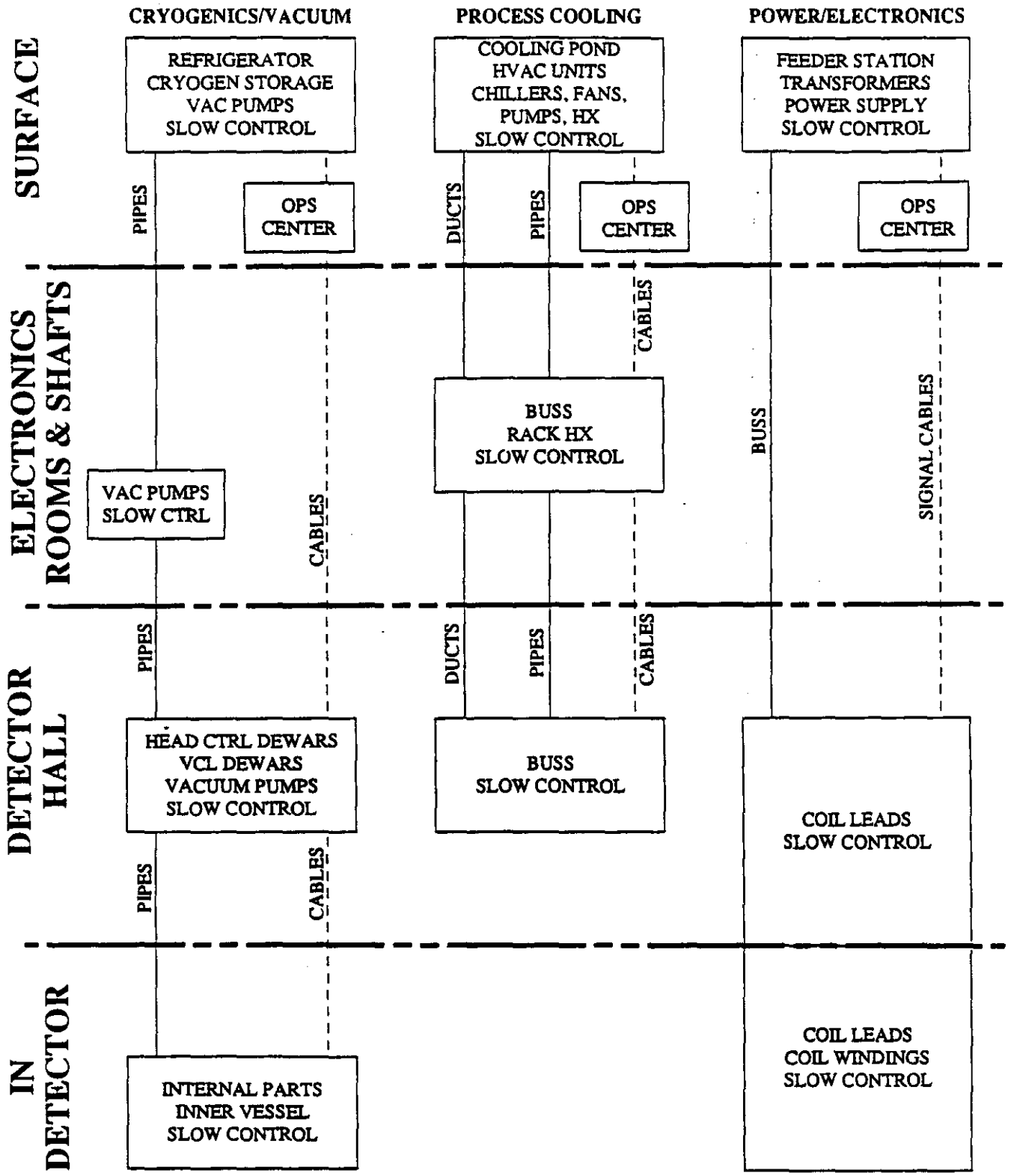
KEY: HV = HIGH VOLTAGE
HX = HEAT EXCHANGER
OPS = OPERATIONS



***GEM* MUON SUBSYSTEM UTILITIES LAYOUT**

EBERLE 07/01/92

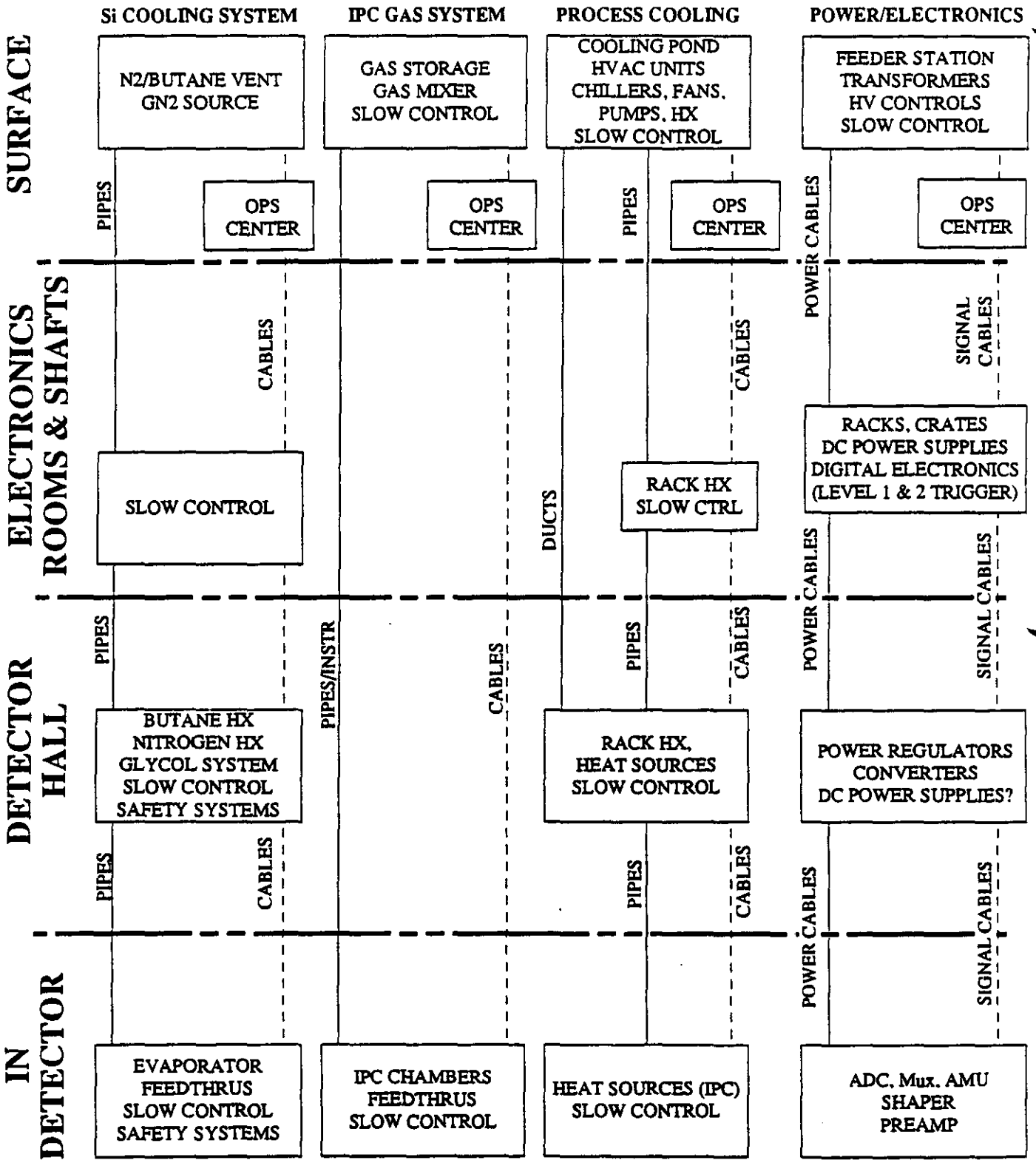
KEY: HV = HIGH VOLTAGE
HX = HEAT EXCHANGER
OPS = OPERATIONS



GEM MAGNET SUBSYSTEM UTILITIES LAYOUT

EBERLE 07/01/92

KEY: HV = HIGH VOLTAGE
HX = HEAT EXCHANGER
OPS = OPERATIONS
VCL = VAPOR-COOLED LEAD

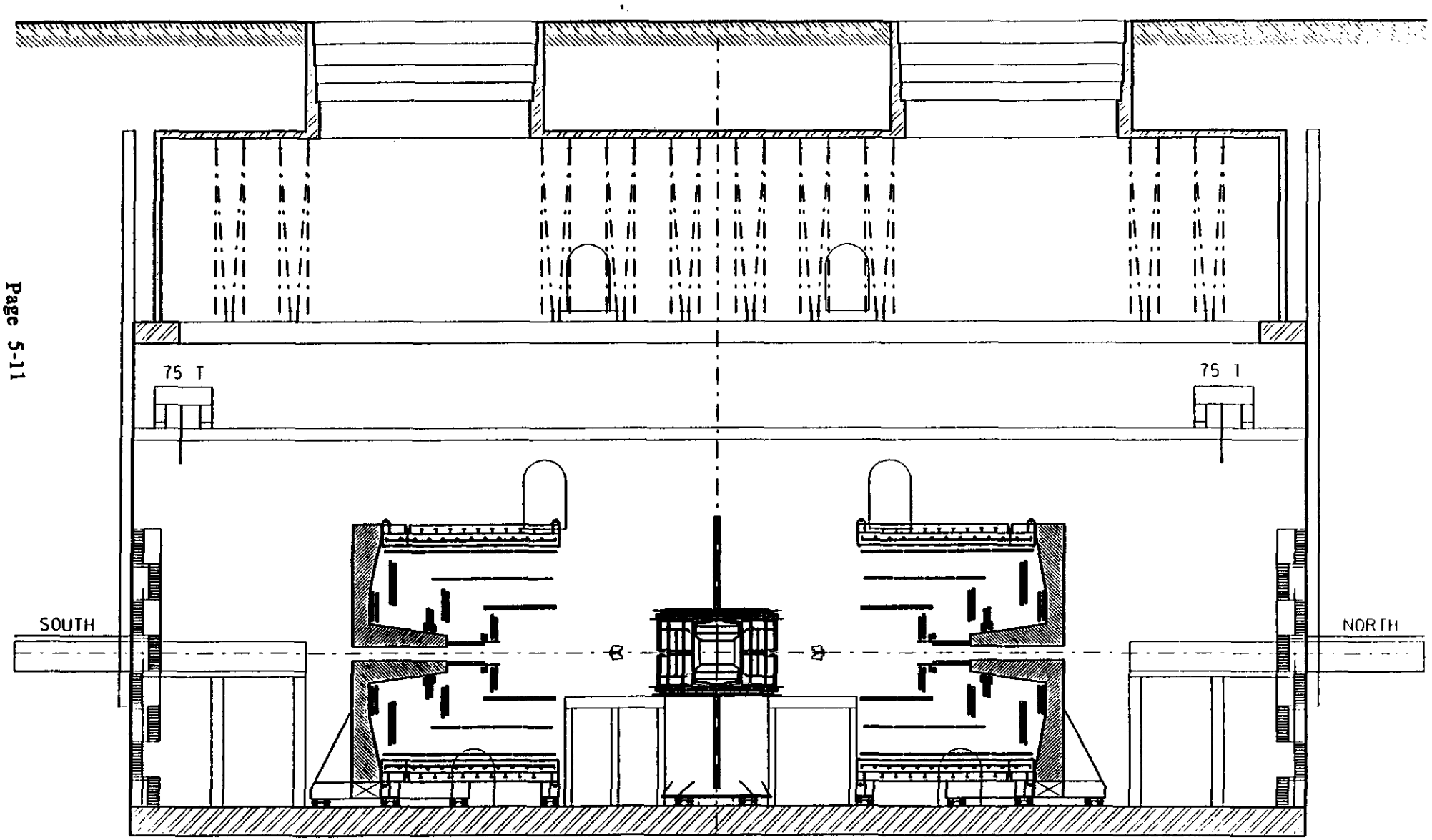


GEM TRACKER SUBSYSTEM UTILITIES LAYOUT

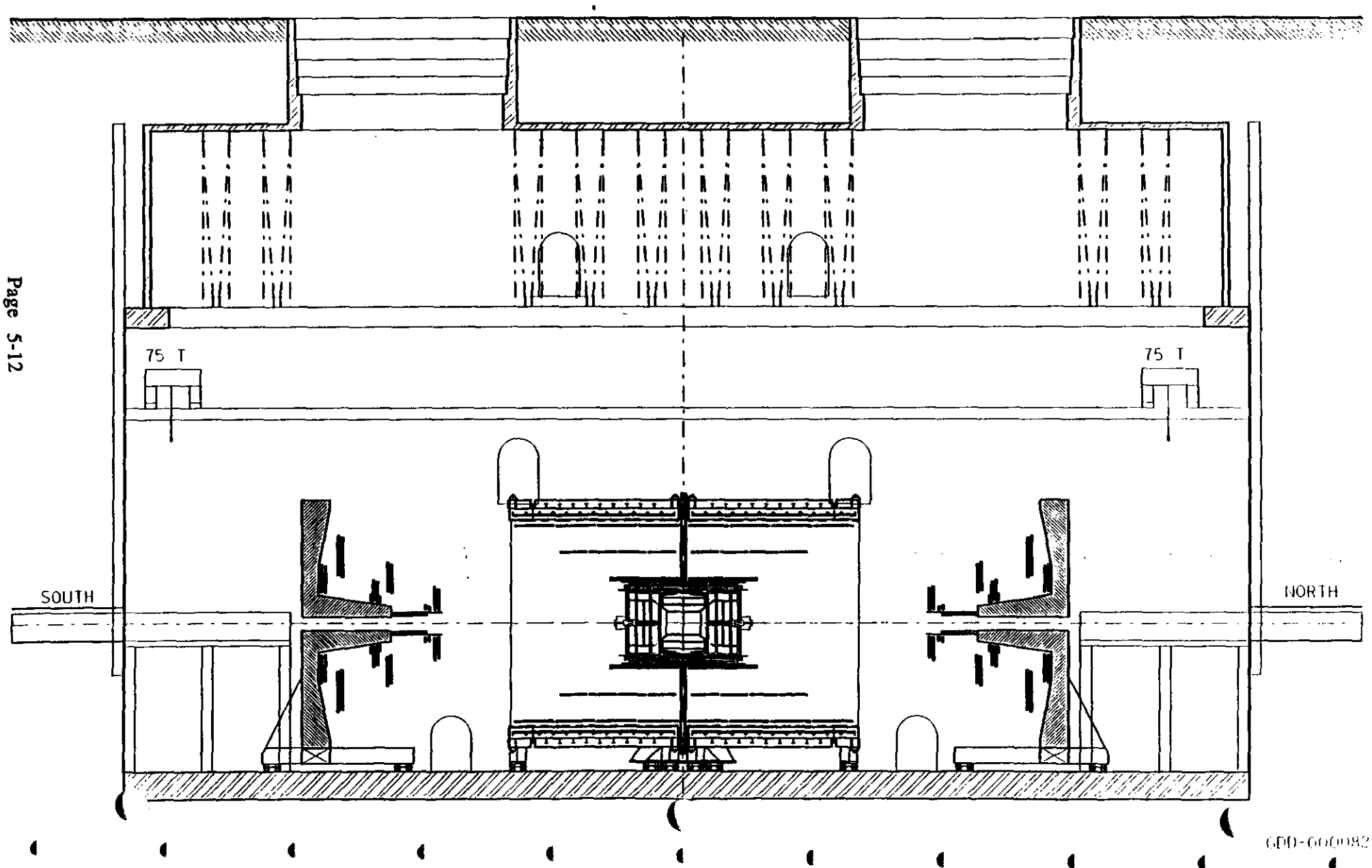
EBERLE 07/01/92

KEY: GN2 = GASEOUS NITROGEN
HV = HIGH VOLTAGE
HX = HEAT EXCHANGER
OPS = OPERATIONS

INNER DETECTOR ACCESS



DETECTOR MAINTENANCE OPTION



GEM DETECTOR MAINTENANCE ACCESS

ACCESS LEVEL	Hardware Description *At the specified access level, the listed types of hardware can be accessed for repair*				
	Magnet	**Muons**	**Calorimeters**	**Tracker**	**Beam Pipe**
Surface **Unrestricted Access**	Ops center	Ops center	Ops center	Ops center	Ops center
	Power supply	Gas storage	Pipes	Gas storage	UHV controls
	Buss	Gas mixer	Slow control	Gas mixer	Cables
	Slow control	Slow control		Slow control	
	Process cooling	Process cooling	Process cooling	Process cooling	
	Refrigerator	Pipes		Pipes	
	Helium storage		Cryogen storage	N2 & Butane vents	
	Pipes			HV controls	
Electronics Rooms, Cable Shaft & Utilities Shaft **Restricted Access**	Buss	Electronics	Electronics	Electronics	N2 pipes
	Slow control	Cables	Cables	Cables	Vac interlocks
	Pipes	Slow control	Slow control	Slow control	Vac terminals
	Process cooling	Process cooling	Process cooling	Process cooling	(State of vac system)
	Cables	Pipes	Pipes	Gas storage	Cables
	Vac pumps		Valves	HV supplies	
			Rough pump	Pipes	
			ODH monitor		
Detector Hall **Beam & Field Off for Access**	Buss	Electronics	Electronics	Electronics	Sector valves
	Leads	Power supply	Power supply	Power supply	
	Cables	Cables	Cables	Cables	Cables
	External vac vessel	Process cooling	Process cooling	Process cooling	External ion pump station
	Head control dewars	Slow control	Cryogen storage	Slow control	Sublimation pump
	Slow control	Pipes	Pipes	HV	
	VCL dewars		Valves	Gas storage	
	Pipes		Slow control	Pipes	
	Vac pumps		ODH monitor		
In-Detector, Closed **Beam & Field Off, Access between Coils & FFS**		Electronics	Electronics	Minimal Accessible Hardware	Nitrogen Pipes
		Cables	ODH monitor		Valves
		Process cooling	Vac vessel (endcap head)		Internal ion pump station
		Slow control			
		Small gas leak			
		Alignment			
		Pipes			

GEM DETECTOR MAINTENANCE ACCESS

ACCESS LEVEL	Hardware Description *At the specified access level, the listed types of hardware can be accessed for repair*				
	Magnet	**Muons**	**Calorimeters**	**Tracker**	**Beam Pipe**
In-Detector, Coils Retracted **Beam & Field Off, Coils Moved for Access**		Electronics	Electronics	Minimal Accessible Hardware	Pipe thru FFS
		Cables	Cables		
		Process cooling	Vac vessel minor repair		
		Small gas leak	Hi vac pump		
		Alignment	Feedthrus		
		Pipes			
		Slow control			
In-Detector, End Cals Retracted **Beam & Field Off, Coils & End Cals Moved for Access**		Same as Coils Retracted	Same as Coils Retracted, with more vac vessel surface areal exposed	IPC Detectors	NEG
				Electronics	Cables
				Cables	Pipe thru calorimeters
				Process	Bakeout equip
				Pipes	Nitrogen pipes
				Slow control	
				HV	
				Gas leaks	
				Gas enclosure	
				Feedthrus	
Subsystem Removal **Beam & Field Off, Coils (& End Cals) Moved, Subsystem Disassembled for Access**	Major vessel repair	Structural repair	Pressure vessel repair	Internal components	Pipe thru tracker
	Coil windings	Broken wires	Module repair	Electronics	Supports
		Major gas leak	Pre-amps	Cables	
	Internal components		Vac vessel major repair	Process cooling	
			Internal cables	Slow control	
			N2 HX repair	HV	
			Feedthrus	Pipes	

6. BEAM LINE

BEAM LINE

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BEAM LINE

OVERVIEW

The design of the beam line within the GEM experimental area has begun. The following describes our current thinking.

Diameter: The section of the beam pipe running through the Central Tracker is fixed at 80 mm in diameter. In all other areas the pipe is nominally 80 mm, although shape and diameter may grow to increase our pumping efficiency if needed.

Material: The beam pipe in the Central Tracker consists of Beryllium nominally 1 mm thick. Both Stainless Steel and Aluminum are being considered for the subsequent sections of pipe. Vacuum quality and bake-out temperatures argue for stainless steel while activation results and total material in the beam line indicate the advantages of aluminum. Thicknesses will depend on the choice of material. Simulations must be done to study the effect of the material in the pipe, pumps, and flanges.

Vacuum: We are currently designing the system to a goal of 10^{-9} torr with the expectation that real operating conditions will degrade that figure at least to 10^{-8} torr. To achieve this value under perfect conditions requires ion pumps located immediately outside the Forward Calorimeters and again immediately after the Forward Field Shapers. In addition, a heat activated gettering pump is considered to be necessary at either end of the Central Tracker to complement the ion pumping.

An *in situ* bake-out of the vacuum line appears to be difficult to effect in certain areas of the experiment. However it may be required. A more detailed set of vacuum calculations assuming less perfect conditions will be done in the near future to address this issue as well as pipe shape, pipe diameter and pumping locations.

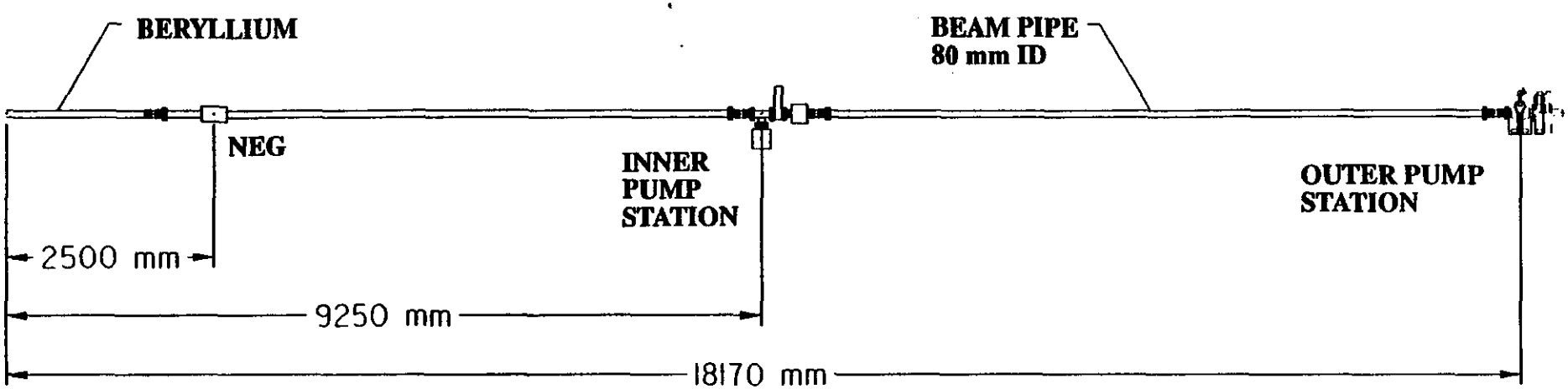
We require ion pumps which can operate in our magnetic field. Design studies for the gettering pump are in progress. Two different methods of heat activation are under consideration; direct current and convection. Prototypes will be constructed and tested to determine the optimum design.

IR Quadrupoles/Machine Interface: The Final Focusing Quadrupoles are nominally located at ± 20 m from the IP with a 2 m long Iron or Tungsten collimator located directly in front of the quads beginning at ± 18 m. The design of the lattice in the Interaction Regions is not

complete. There are indications that these quads may be moved further away from the IP with limited effect on the maximum luminosity of the machine. Moving the quads has numerous benefits for the experiments as well as for the machine; and the GEM collaboration is requesting that the accelerator group seriously consider the possibility of moving the quads further from the IP. Previous studies on activation levels at the quadrupoles indicate that after one year of operation, the innermost portions of the quads will be activated to more than 100 Rads/h. This result argues in the favor of placing the quads further from the experiment for access and shielding purposes.

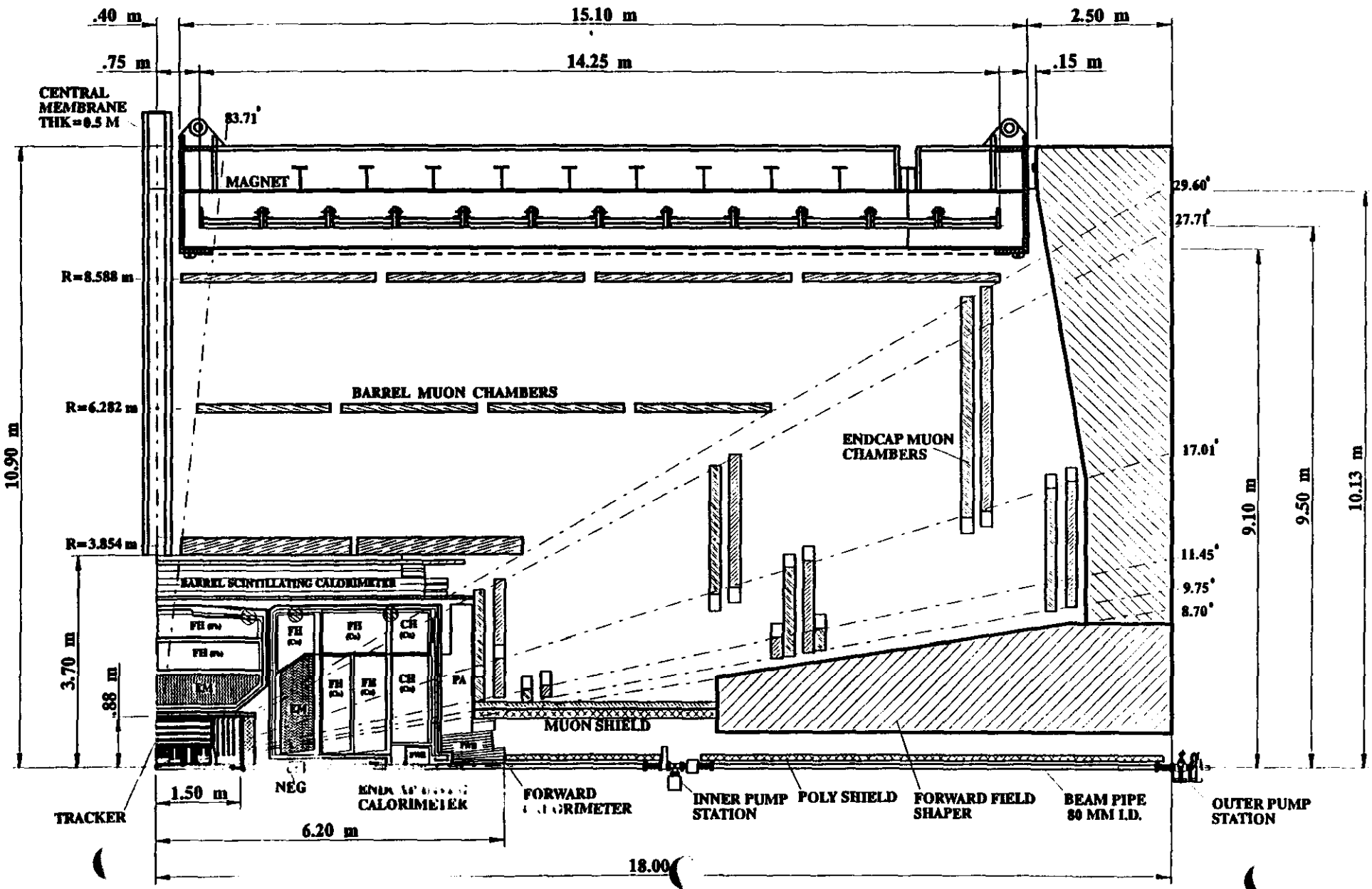
Installation/Access: The installation of the beam line will proceed in sections beginning at the Central Tracker and adding each successive section of pipe and the associated pumping stations as the detectors are installed. Each section will be aligned to the theoretical beam line and then vacuum tested before the next section is installed. The couplings are presently considered to be a combination of welded joints and/or traditional bolted flanges, depending on the assembly scenario for a given section. Permanent access to the ion pumps must be maintained even with the detector closed. However, access to the gettering pumps will require disassembly of the entire detector and beam line.

BEAMLINE LAYOUT



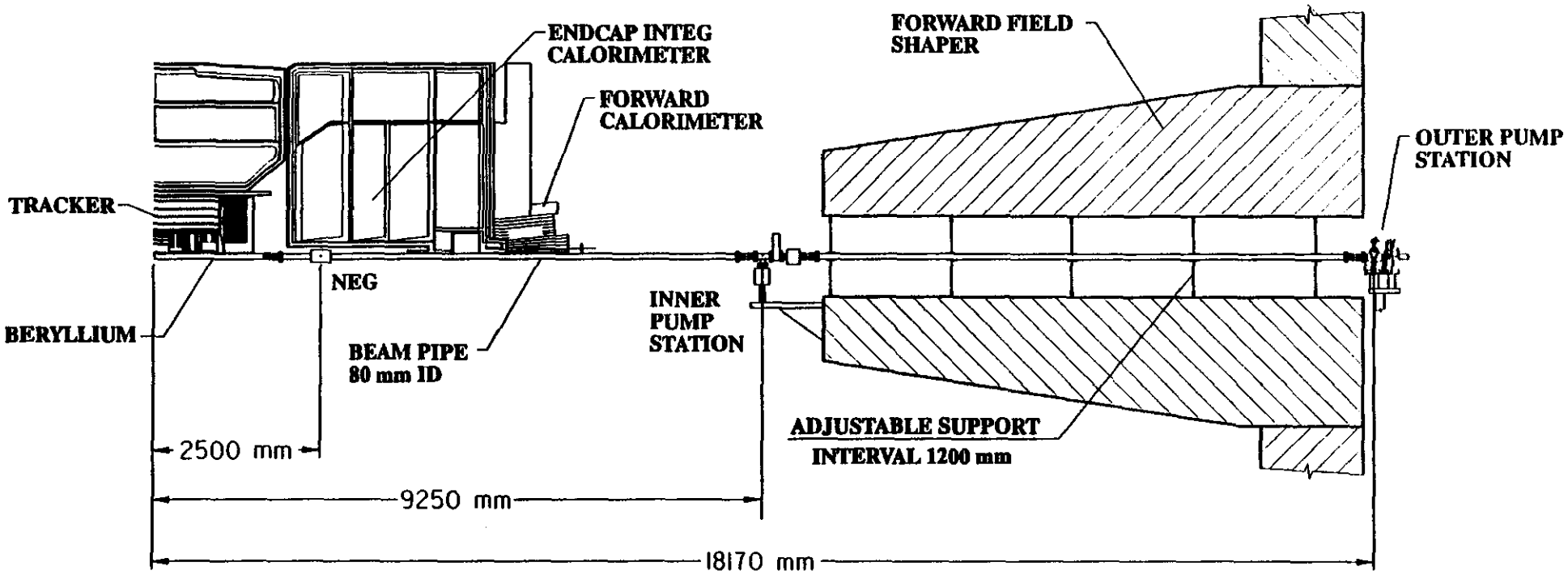
beamline.2
11/19/92

GEM DETECTOR PARAMETERS
BASELINE 2

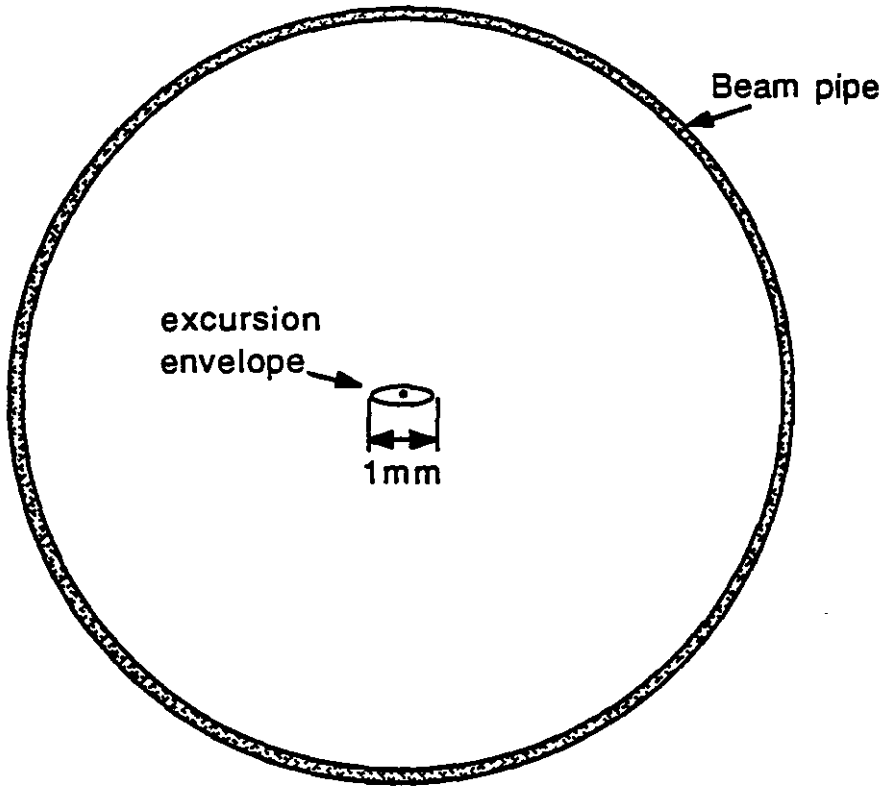


(PAGADS2 18-NOV-1992)

BEAM PIPE SUPPORT IN FFS



Transverse Excursion of the Beam in the Experiments*



The beam can be moved transversly about 1mm in the experiments. The two experiments are coupled, so displacement of the beam in one experiment will cause displacement in the other. More than 1mm motion is possible, but will result in loss of luminosity.

The beam can be positioned in the 1mm envelope to less than 100μm precision and this position is expected to be reproducible to less than 100μm even from fill to fill.

*Information from the Accelerator/Experiment Interface Meetings K. Morgan 6.9.92

7. MAGNET, FIELD SHAPER & CENTRAL DETECTOR SUPPORT

MAGNET, FIELD SHAPER & CENTRAL DETECTOR SUPPORT

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Vacuum Vessel [Parameters]
Forward Field Shaper (FFS) [Parameters]

Baseline 2 Status

Differences between the present Baseline 2 and the previous Baseline 1 designs for the Magnet Subsystem are extremely minor. Significant details exist in the magnet preliminary design, but are not included in this document, which focusses on information required for interfacing with other subsystem and for physics simulation. The principle changes since the previous version are a 10-cm lengthening of the vacuum vessels, and a minor change in the shape of the Forward Field Shaper

OVERVIEW

The GEM magnet is a large superconducting solenoid assembly with field shaping in the forward region. The solenoid assembly is physically 31 m long with 18 m diameter inner bore and produces a central field of 0.8 T. It consists of two half-length coil assemblies, each 15.1 m long, separated by a distance of 0.8 m at the midplane. Magnetically, the solenoid is composed of two cylindrical current sheets, each of 9.5 m radius, separated by 1.6 m at the midplane, and extending axially to a total combined length of 29.9m. In the forward direction (η = 1.5 to 2.5), the magnetic field is shaped to improve the muon resolution. This shaping is accomplished by large ferromagnetic structures, called Forward Field Shapers, which are roughly projective to the IP, coaxial with the beam axis, and occupy the volume from 10-18 m from the IP in both directions. The magnet does not have a return yoke and has a substantial fringe field outside of the volume of the solenoid.

The detector subsystems are completely enclosed in the magnet, with the possible exception of a future upgrade to the muon system which adds chambers outside. The central tracker and both the electromagnetic and hadronic calorimeters are supported by a free-standing fixed central detector support situated between the two coil halves. Muon system modules for the central barrel are mounted on the magnet vacuum vessel.

The two coil halves are designed to be mobile along the beam axis, allowing for their separation from the central detector support for the initial installation of the detector subsystems and for the access to the calorimeters and central tracker after the detector is put together. The iron field shapers are also designed to be mobile with an independent

support system. Coupling the support of the coil halves to that of the Field Shapers is still being explored.

Each coil half is constructed in 12 identical segments of conductor wound on the inside of 1.2 m long aluminum bobbin segments. Each segment has 19 turns of "cable-in-conduit" conductor consisting of 450 braided strands of NbTi superconducting alloy enclosed in a 2.0 cm ID stainless steel tube filled with liquid helium. The stainless steel tube is surrounded by an aluminum sheath, which provides hot-spot protection in the unlikely event of a quench. The cooling is provided by a natural convection flow of liquid helium provided by a thermo-syphon system using tubes on the outside of the bobbin. The baseline design of the conductor joints between individual segments has resistive coupling with separate cooling for each joint. The design of the procedure of winding and assembly of the coil is still preliminary. Several options are being considered. The choice of the winding process will depend on the feasibility study to be conducted by industry.

The magnet coils will be constructed above ground in the North and South Assembly Buildings and the outside fabrication area nearby. They will be completely assembled and tested above ground for electrical continuity and for gas leaks of the cryogenic systems. They will be then lowered to the experimental hall and assembled together with the central detector support and Forward Field Shapers. A full cold test of the magnet and a measurement of the field map will follow the underground installation.

The magnet is designed for a normal charge and discharge time of about 8 hours with an emergency discharge time of 5 minutes.

General Physical

Central induction	0.80	T
Inner radius, magnet subsystem	9.00	m
Overall outer radius (outside ribs)	10.9	m
Number of coil/cryostat assemblies	2	
Central membrane maximum Z	300	mm
Cryostat inner end minimum Z	400	mm
Cryostat outer end maximum Z	15.5	m
Magnet axis height above hall floor	13.0	m
Operating current	50.2	kA
Maximum Allowed Operating Current	51.0	kA
Stored energy	2.5	GJ
Inductance	1.98	H
Number of turns	456	

Magnet Component Masses

Total mass of magnet assy (each half)	1,378	Mg
Cold mass, total	1,052	Mg
Cold mass (total, each half)	560	Mg

Coil component masses	per module	total	
Bobbin	14,882	357,159	kg
Compression flanges	13,875	333,012	kg
Conductor aluminum sheath	7,986	191,671	kg
Conductor conduit	1,607	38,576	kg
Conductor cable	1,814	43528	kg
Turn insulation	1,846	44,300	kg
Ground wrap	1,819	43,650	kg
Number turns per module	19	456	
Total coil module mass	43,829		kg
Number coil modules per magnet half	12		

Total mass of coil windings (per half)	159	Mg
Total mass of cryostat vessel (each half)	818	Mg
Total mass of FFS + support (each half)	1,884	Mg

Cold Mass

Mean radius of windings	9.50	m
Length, end-to-end (per half)	14.25	m
Axial force on conductor (each half)	52	MN
Inner radius of inner ground wrap	9.456	m
Inner radius of conductor	9.466	m
Mean radius of conductor	9.5	m
Outer radius of conductor	9.534	m
Bobbin inner radius	9.544	m
Bobbin outer radius	9.620	m
Bobbin minimum Z	750	mm
Winding minimum Z	804	mm
Winding maximum Z	14.946	m
Bobbin maximum Z	15.000	m
Conductor length (total)	27,219	m
Total mass of coil windings (per half)	159	Mg
Total mass cold 4.5° K structure (per half)	526	Mg

Vacuum Vessel and Internal Components

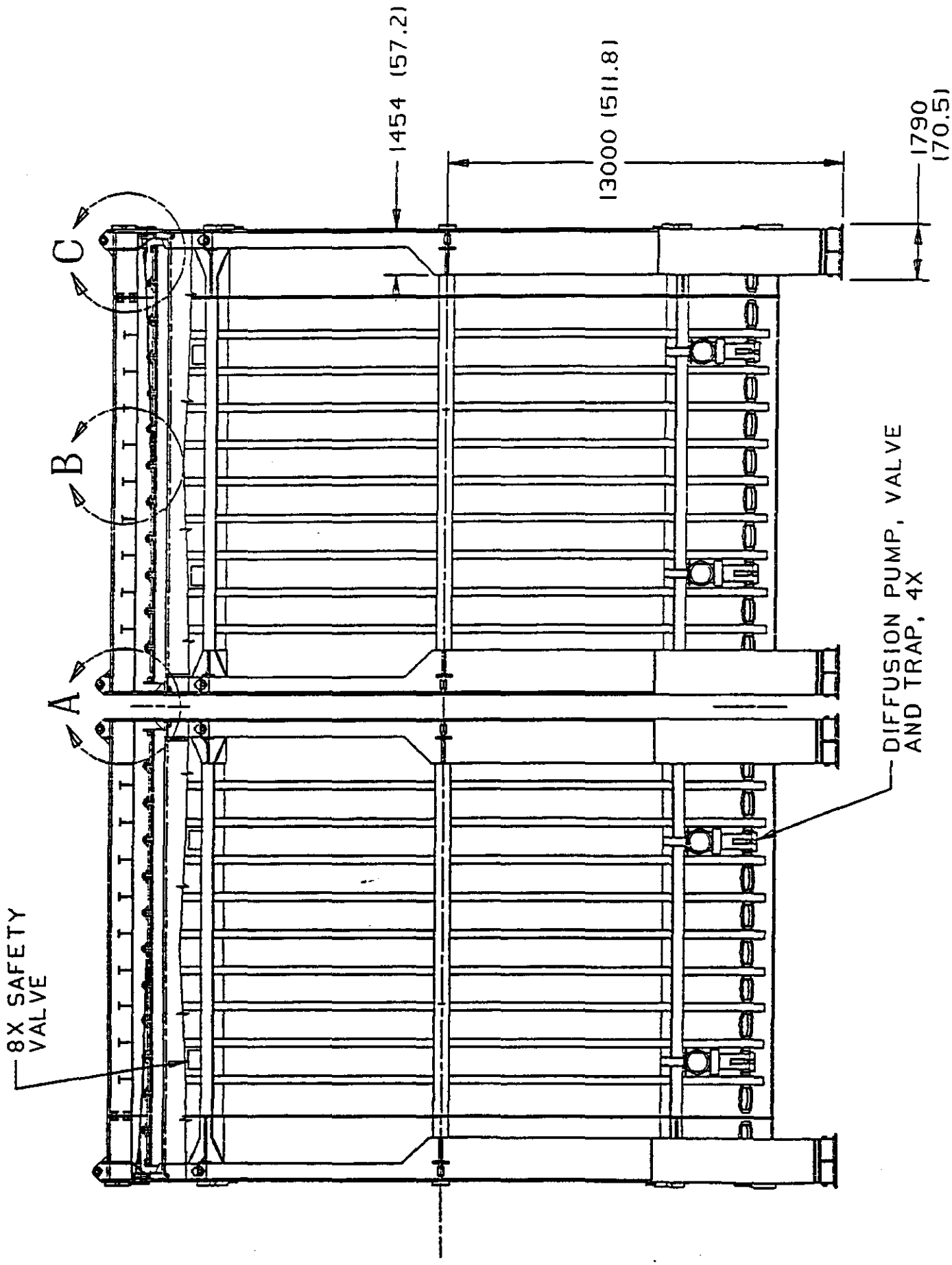
Cryostat vessel length (each half)	15.1	m
Inner radius, magnet subsystem (excluding muon attachments)	9.00	m
Overall outer radius (outside longerons) (excluding lift eyes and utility connections)	10.9	m
Inner radius of inner cryostat vessel	9.10	m
Outer radius of inner cryostat vessel	9.1255	m
Inner radius of inner LN shield (avg)	9.230	m
Outer radius of inner LN shield (avg)	9.993	m
Inner radius of outer LN shield (avg)	9.998	m
Outer radius of outer LN shield (avg)	9.803	m
Inner radius of outer cryostat vessel	10.1	m
Outer radius of outer cryostat vessel	10.125	m
Overall outer radius (outside longerons)	10.9	m
Thickness of inner vessel (Δr)	25.5	mm
Thickness of outer vessel (Δr)	25.5	mm
Thickness of inner thermal shield (Δr)	3.2	mm
Thickness of outer thermal shield (Δr)	3.2	mm
Height of outer circumferential ribs (Δr)	406.2	mm
Number of circumf. ribs per coil assembly	10	
Width of flange on cirmf ribs (Δz)	254	mm
Thickness of web on circumf ribs (Δz)	9.5	mm
Height of longerons (Δr)	825.2	mm
Number of longerons	8	
Thickness of longeron web ($\Delta\theta$)	76.2	mm
Width of longeron flanges ($\Delta\theta$)	254	mm
Thickness of longeron flanges (Δr)	25.4	mm
Thickness of vessel ends (Δz)	76.2	mm
Cryostat inner end minimum Z	400	mm
Cryostat inner end maximum Z	476.2	mm
LN shield minimum Z	527	mm
LN shield maximum Z	15.343	m
Cryostat outer end minimum Z	15.424	m
Cryostat outer end maximum Z	15.5	m
Total mass of cryostat vessel (each half)	818	Mg

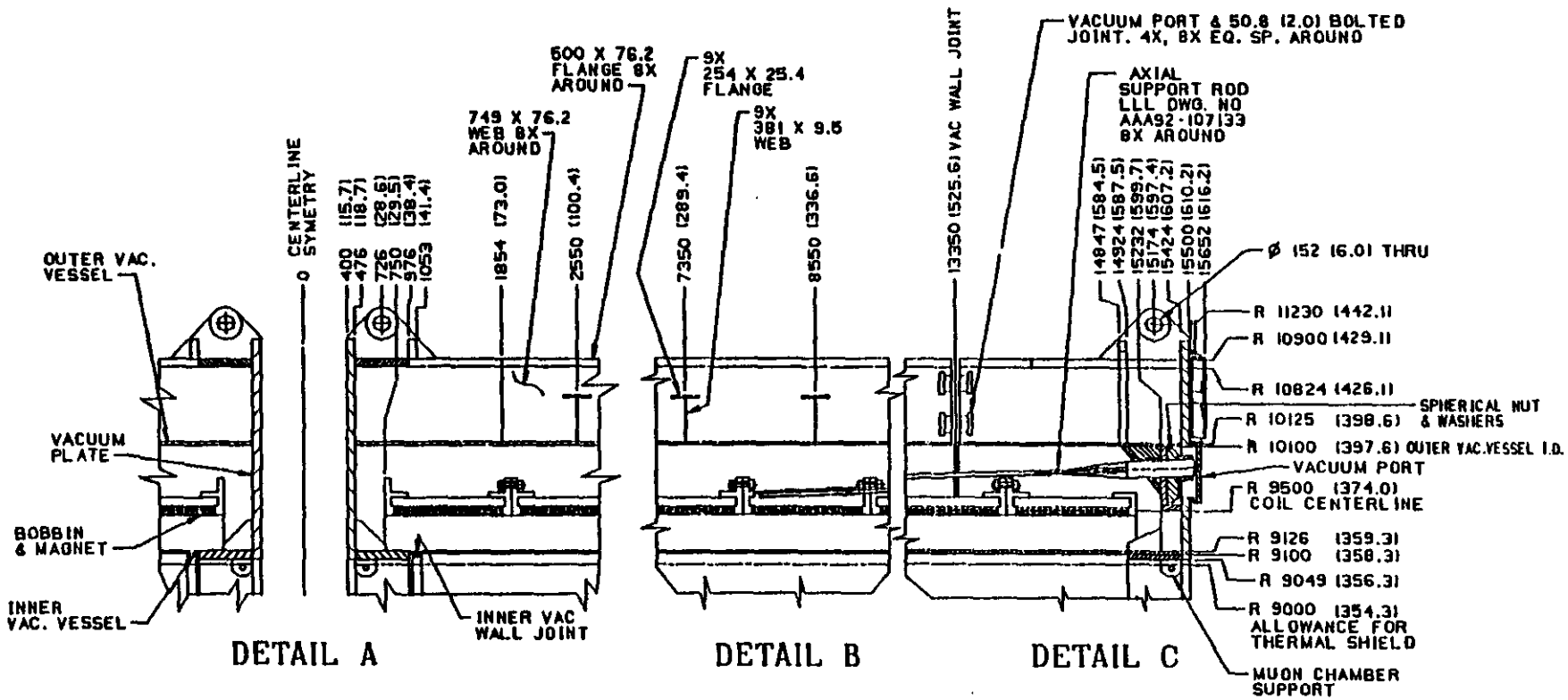
Forward Field Shaper (FFS)

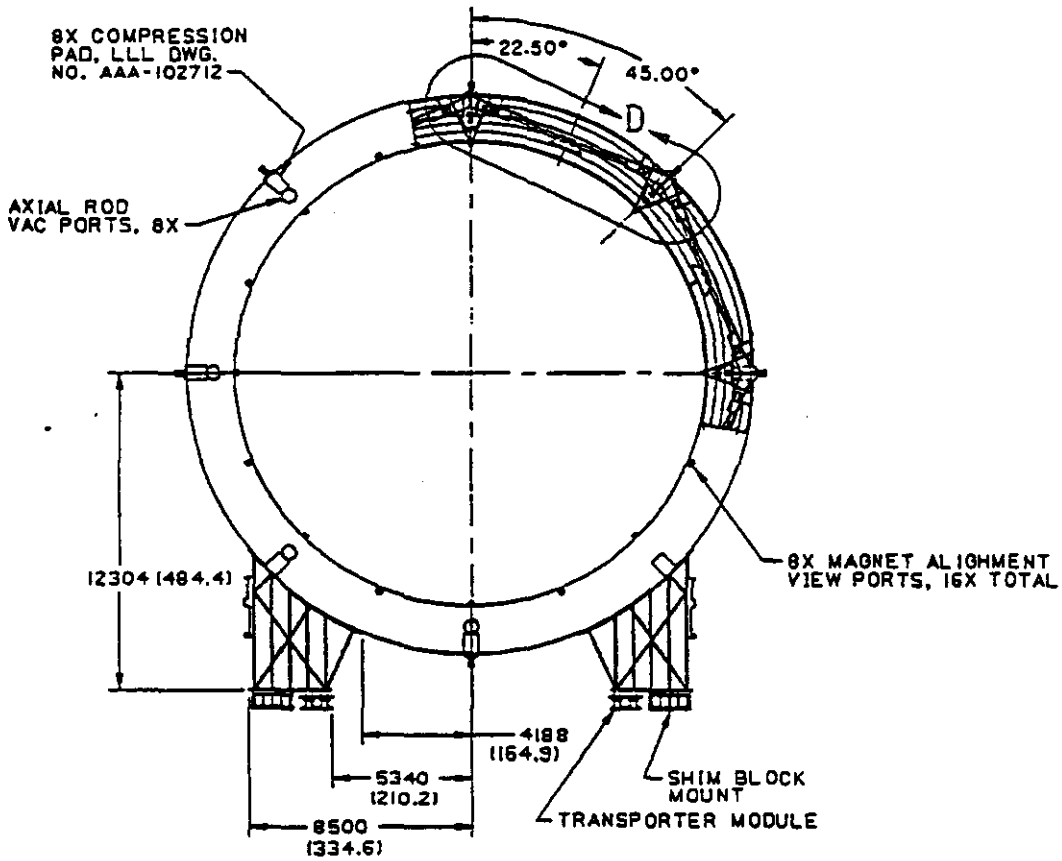
Minimum Z	10	m
Maximum Z, overall	18	m
Outer radius @ minimum z	1402	mm
Included angle (tapered section)	18.8	deg
Tapered section maximum z	16.5	m
Outer radius, cylindrical section	2478	mm
Axial (z) location to which cone is projective	1531	mm
Inner radius (clear bore)	0.6	m
Axial force on forward field shaper	12.2	MN
Forward field shaper mass	899	Mg
Forward field shaper support mass	985	Mg
Total mass of FFS + support (each half)	1884	Mg

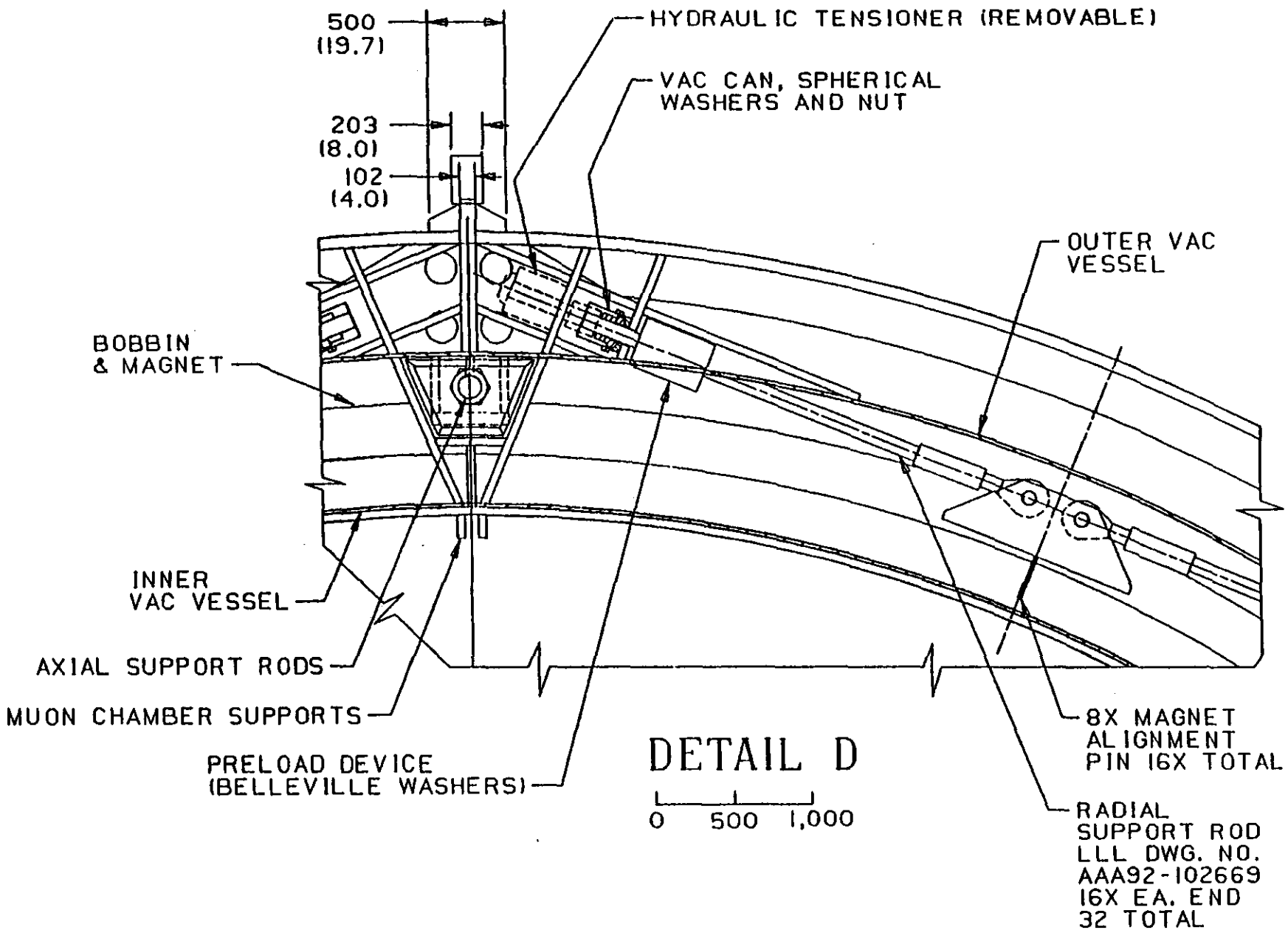
Interface Information

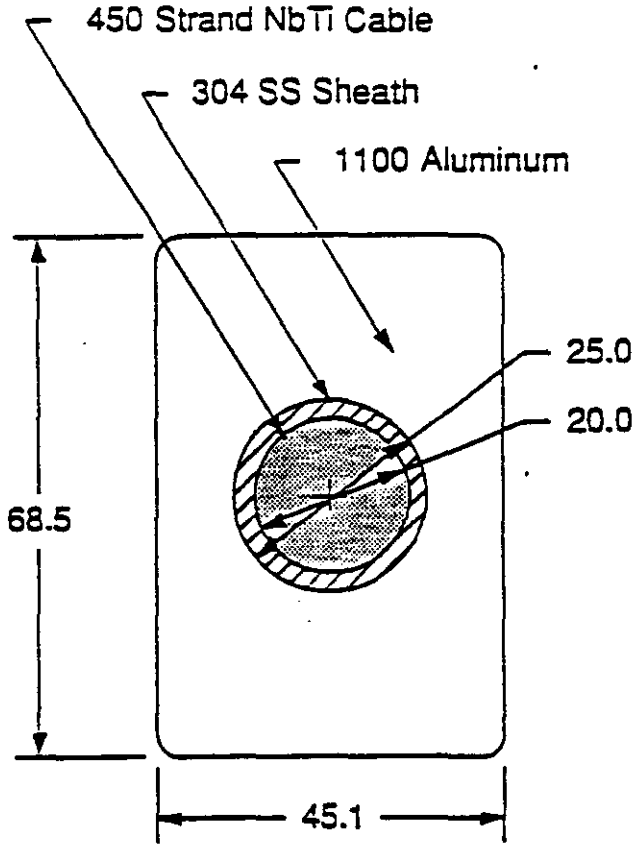
Mass of one muon sector	11,400	kg
Number of barrel muon sectors (per half)	16	
Radius of CG of barrel muon sectors	6.22	m
Location of barrel muon sectors CG in Z	3.89	m


1454 (57.2)
13000 (511.8)
1790 (70.5)
C
B
A
DIFFUSION PUMP, VALVE AND TRAP, 4X
8X SAFETY VALVE


OUTER VAC. VESSEL
VACUUM PLATE
BOBBIN & MAGNET
INNER VAC. VESSEL
0 CENTERLINE SYMETRY
400 (15.7)
476 (18.7)
726 (28.6)
750 (29.5)
976 (38.4)
1053 (41.4)
1854 (73.0)
2550 (100.4)
749 X 76.2 WEB 8X AROUND
500 X 76.2 FLANGE 8X AROUND
INNER VAC WALL JOINT
DETAIL A
7350 (289.4)
9X 254 X 25.4 FLANGE
9X 381 X 9.5 WEB
8550 (336.6)
DETAIL B
13350 (525.6) VAC WALL JOINT
VACUUM PORT & 50.8 (2.0) BOLTED JOINT. 4X, 8X EQ. SP. AROUND
AXIAL SUPPORT ROD LLL DWG. NO AAA92-107133 8X AROUND
14847 (584.5)
14924 (587.5)
15232 (599.7)
15174 (597.4)
15424 (607.2)
15500 (610.2)
15652 (616.2)
Ø 152 (6.0) THRU
R 11230 (442.1)
R 10900 (429.1)
R 10824 (426.1)
SPHERICAL NUT & WASHERS
R 10125 (398.6)
R 10100 (397.6) OUTER VAC.VESSEL I.D.
VACUUM PORT
R 9500 (374.0) COIL CENTERLINE
R 9126 (359.3)
R 9100 (358.3)
R 9049 (356.3)
R 9000 (354.3) ALLOWANCE FOR THERMAL SHIELD
MUON CHAMBER SUPPORT
DETAIL C

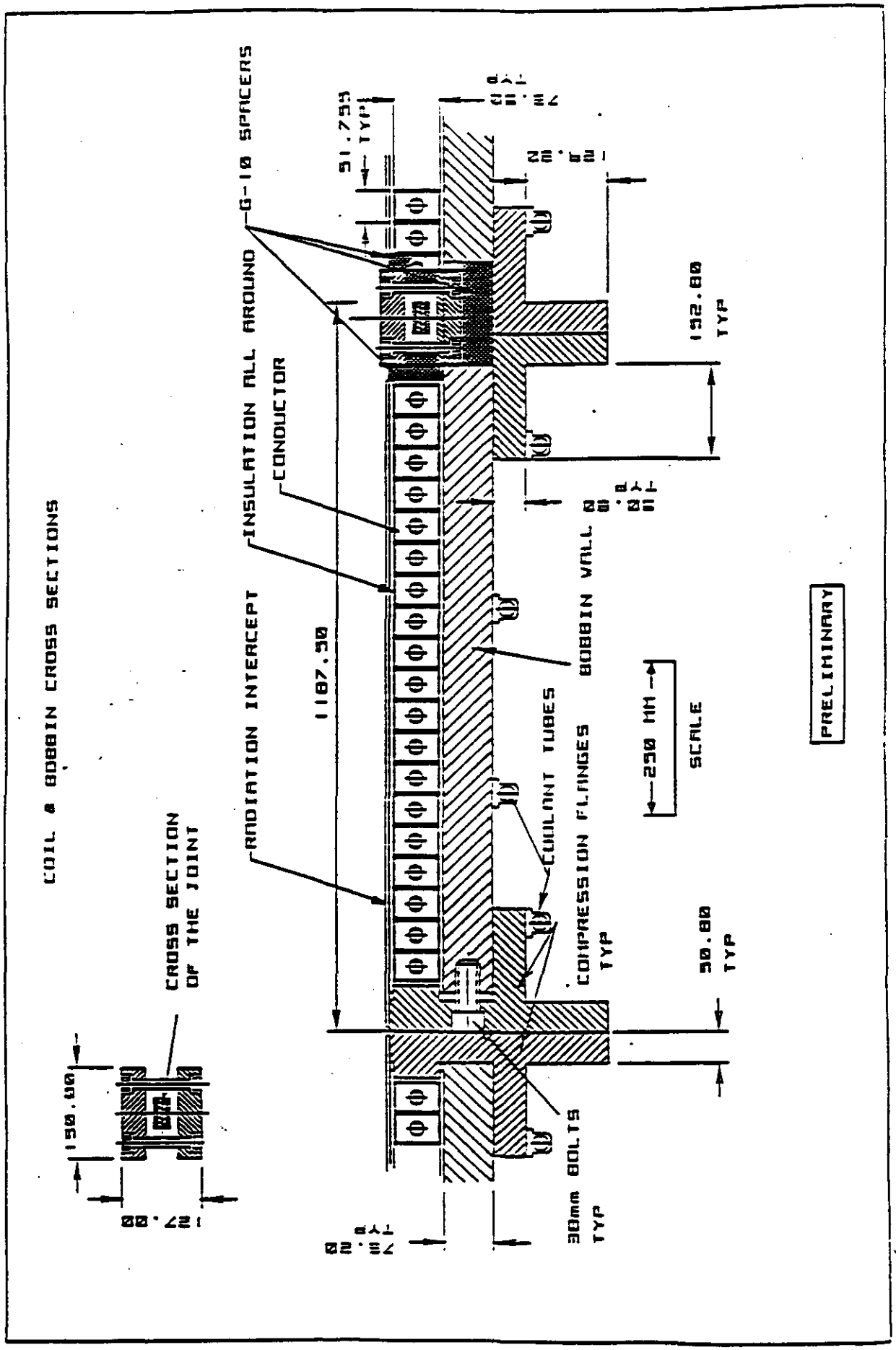

8X COMPRESSION PAD, LLL DWG. NO. AAA-102712
22.50°
45.00°
D
AXIAL ROD VAC PORTS, 8X
12304 (484.4)
8X MAGNET ALIGHMENT VIEW PORTS, 16X TOTAL
4188 (164.9)
5340 (210.2)
8500 (334.6)
SHIM BLOCK MOUNT
TRANSPORTER MODULE


500
(19.7)
203
(8.0)
102
(4.0)
HYDRAULIC TENSIONER (REMOVABLE)
VAC CAN, SPHERICAL
WASHERS AND NUT
OUTER VAC
VESSEL
BOBBIN
& MAGNET
INNER
VAC VESSEL
AXIAL SUPPORT RODS
MUON CHAMBER SUPPORTS
PRELOAD DEVICE
(BELLEVILLE WASHERS)
DETAIL D
0 500 1,000
8X MAGNET
ALIGNMENT
PIN 16X TOTAL
RADIAL
SUPPORT ROD
LLL DWG. NO.
AAA92-102669
16X EA. END
32 TOTAL

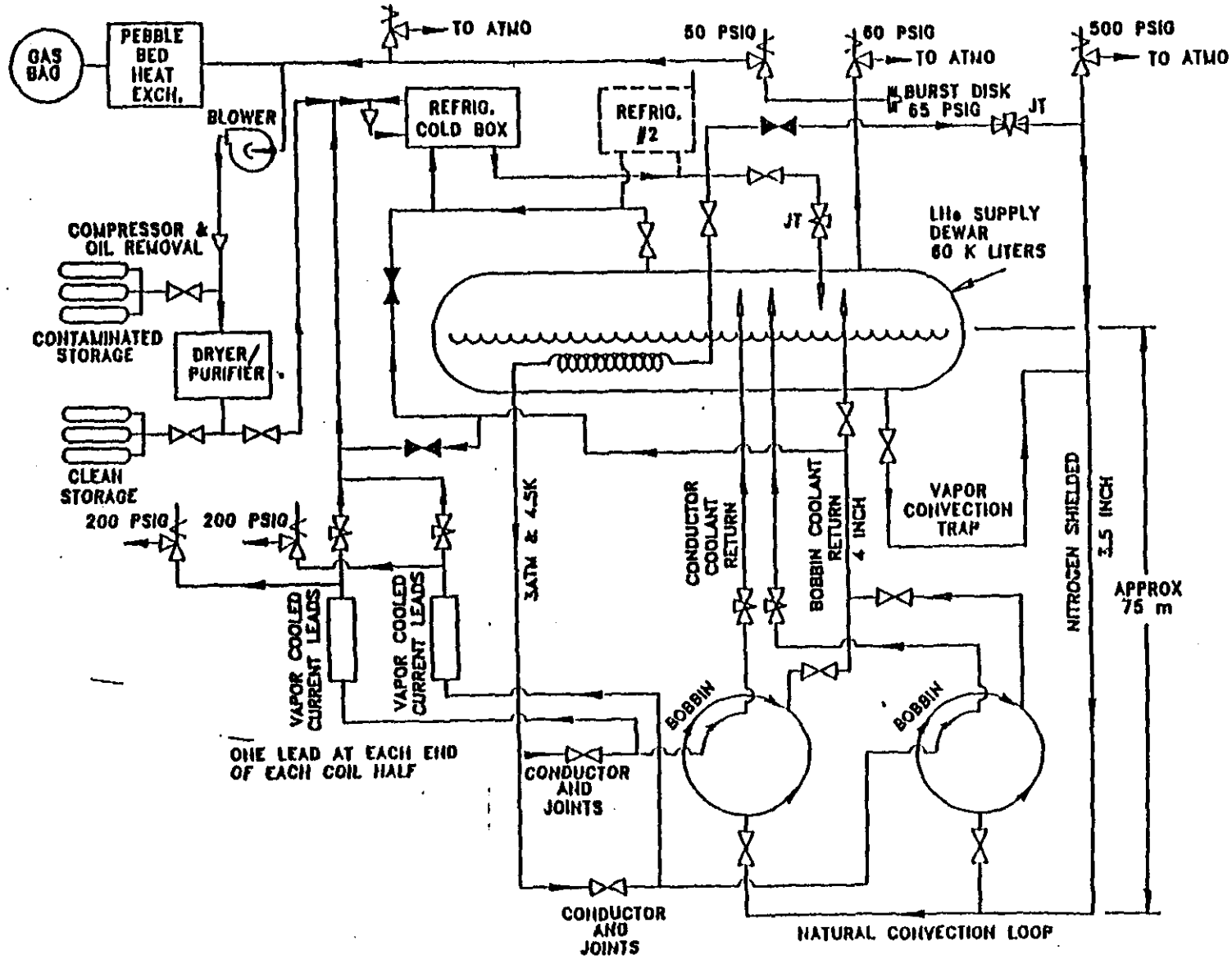


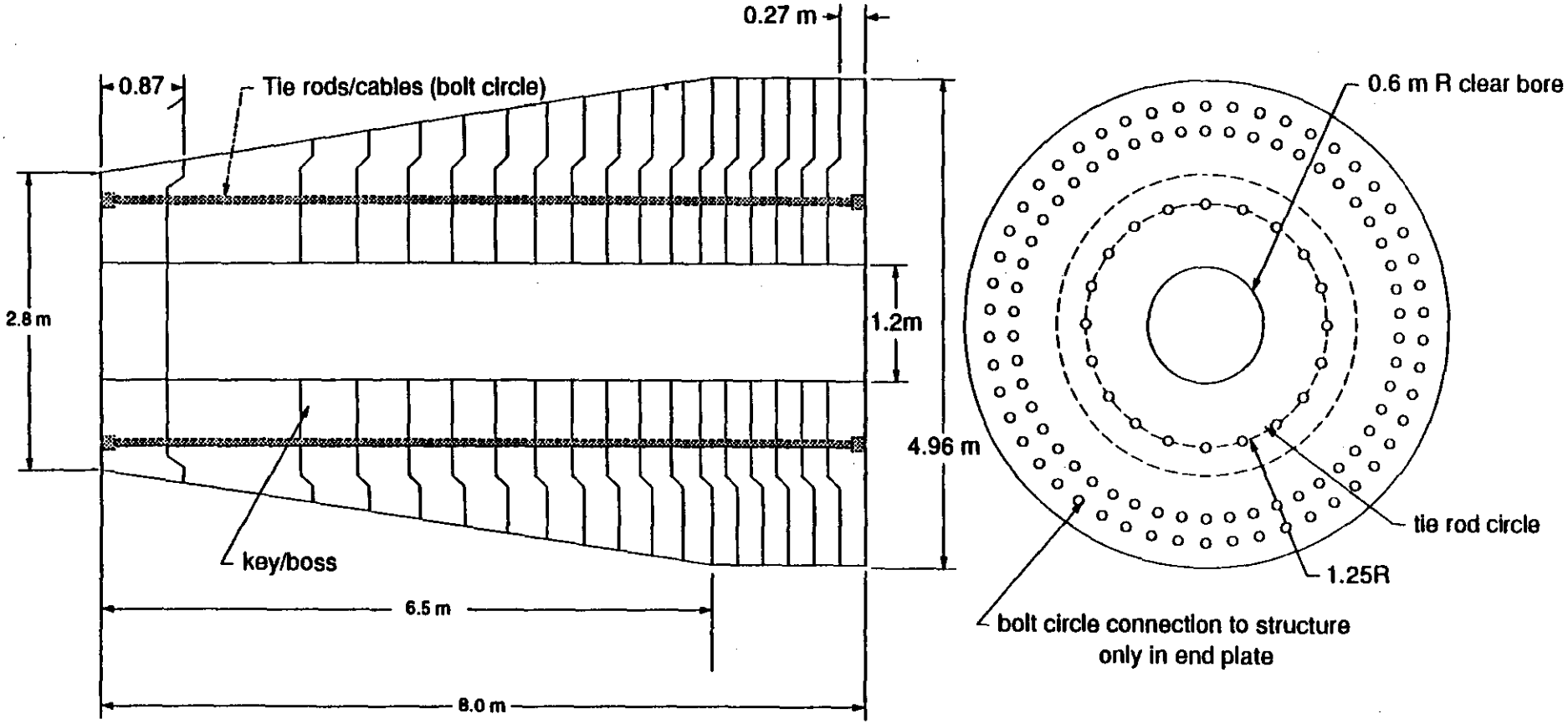
GEM Magnet Conductor

Sheath Material	Aluminum Alloy 1100
RRR	14
Hole Diameter (mm)	25.0
Width (mm)	45.1
Height (mm)	68.5
Corner Radii (mm)	3.0
Conduit Material	Type 304 SS
Outer Diameter (mm)	25.0
Inner Diameter (mm)	20.0
Cable	
Cable Pattern	3x5x5x6
Strand Diamter (mm)	0.73
Cu:Non-Cu	3
Number of Strands	450
Operating Current (A)	50,000


COIL & BOBBIN CROSS SECTIONS
CROSS SECTION OF THE JOINT
150.00
127.00
RADIATION INTERCEPT
INSULATION ALL AROUND
CONDUCTOR
G-10 SPACERS
1187.50
51.759 TYP
73.20 TYP
22.86
192.80 TYP
73.20 TYP
BOBBIN WALL
COOLANT TUBES
COMPRESSION FLANGES TYP
250 MM
SCALE
50.80 TYP
30mm BOLTS TYP
73.20 TYP
PRELIMINARY

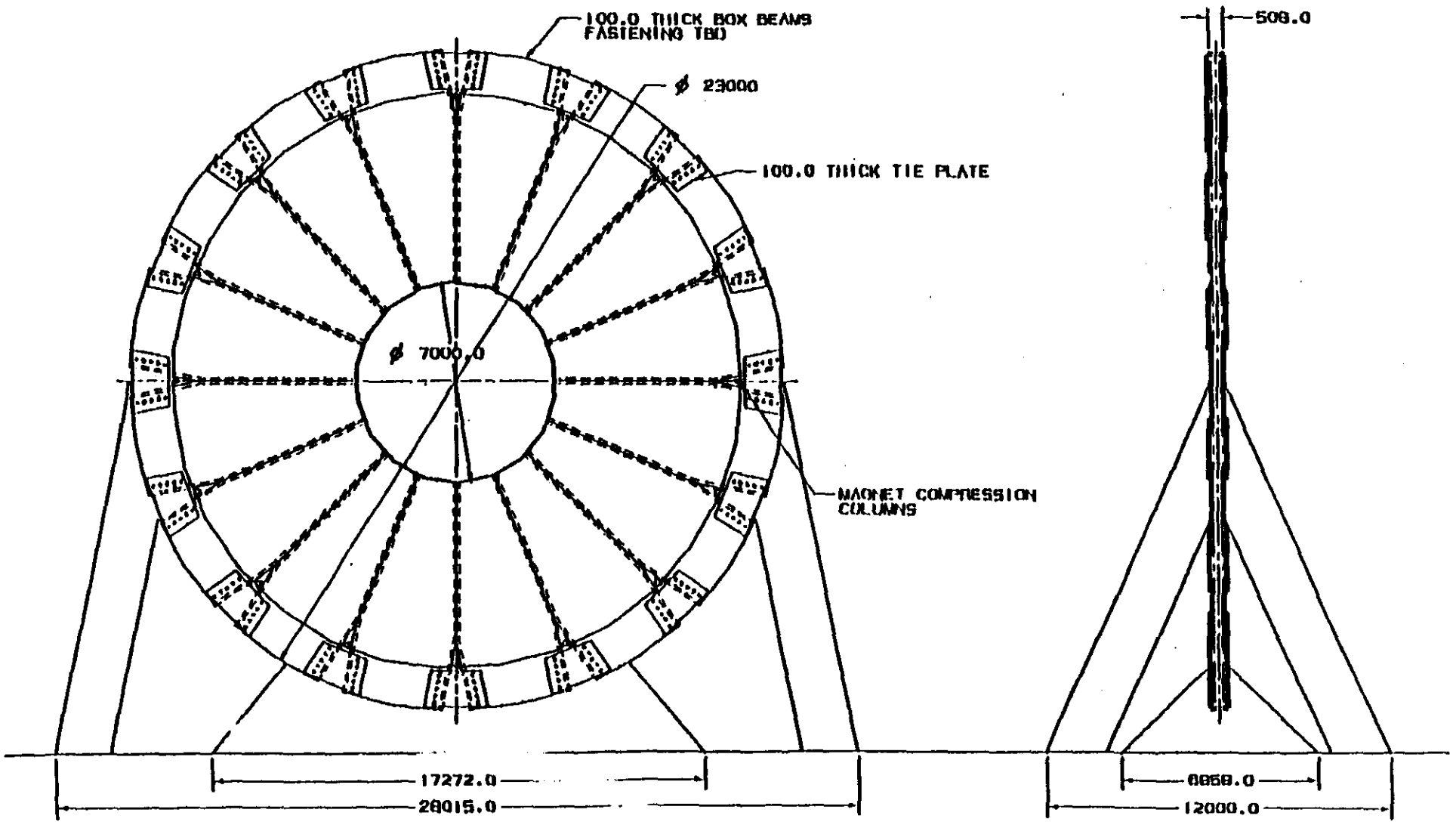
Helium Flow Schematic





Forward Field Shaper (detail)
Baseline 2 - 11/18/92

CENTRAL DETECTOR SUPPORT



8. MAGNETIC FIELD

MAGNETIC FIELD

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OVERVIEW

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Muon resolution vs. eta, for various muon momenta
Assumed geometry for muon resultion calculations
Magnetic geometry
Representative flux lines
Contours of constant B, 50m x 50m
Contours of constant B, 20m x 20m
Contours of constant B, 8m x 8m
Representative flux lines (distorted scale) 5m R x 40m axial
Contours of constant B, (distorted scale) 5m R x 40m axial
Contours of constant B_Z, (distorted scale) 5m R x 40m axial
Contours of constant B_r, (distorted scale) 5m R x 40m axial
Representative flux lines (distorted scale) 6m R x 20m axial
Contours of constant B, (distorted scale) 6m R x 20m axial
Contours of constant B, (distorted scale) 3m R x 23m axial
IR-5 Magnetic field pattern at surface, plan view
IR-5 Magnetic field pattern at IP, section view

MAGNETIC FIELD

OVERVIEW

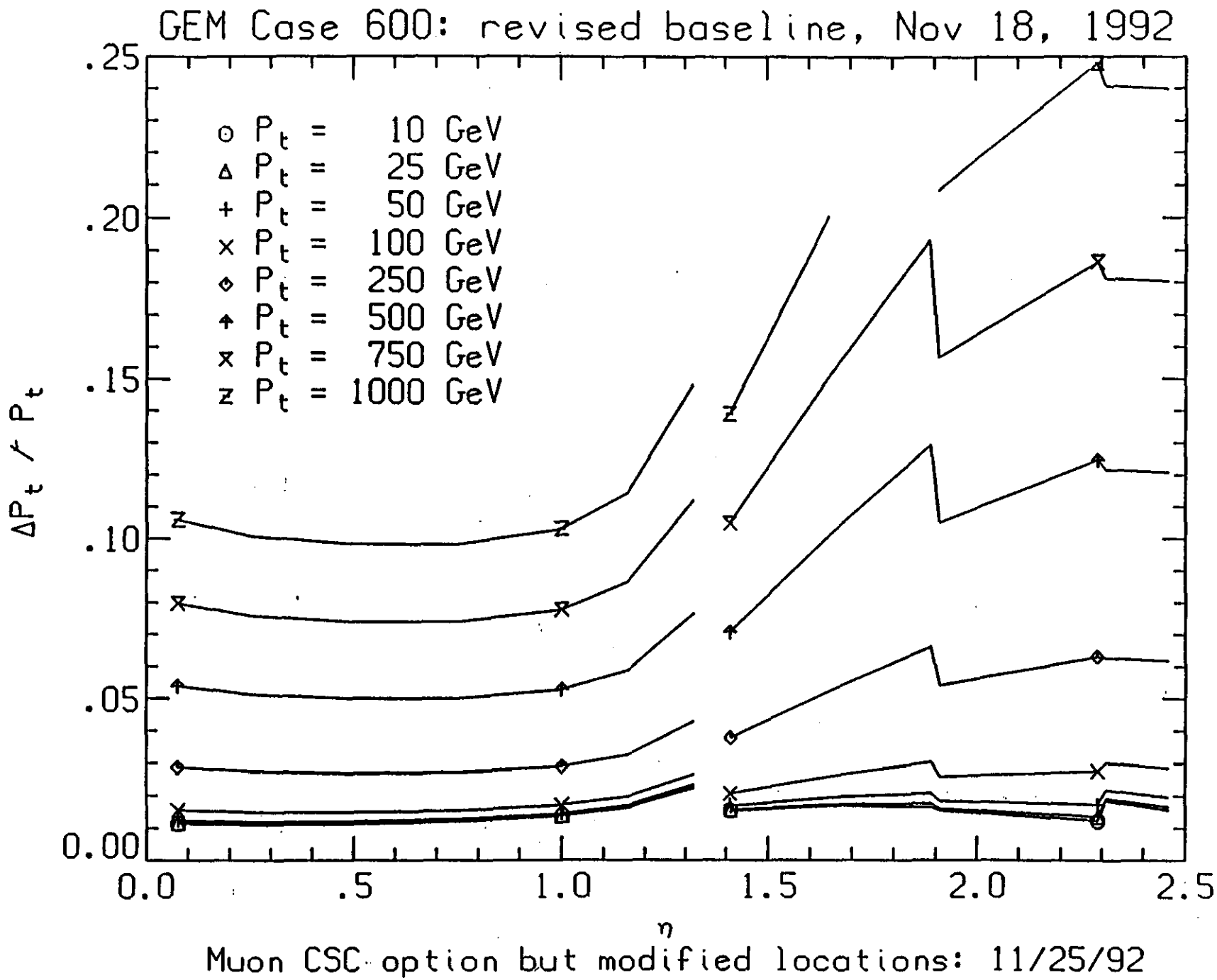
The size of the GEM magnet and the value of its central field result from a cost optimization procedure required to satisfy physics goals of the experiment. A baseline design with a 9 m radius of the inner bore and 0.8 T central field satisfy the requirements of 5% momentum resolution for 500 GeV/c transverse momentum muons in the rapidity range of η = 0 - 1.5. In the forward direction requirements necessitate addition of field shaping iron, which provides flux concentration and a rapid field gradient in the forward region.

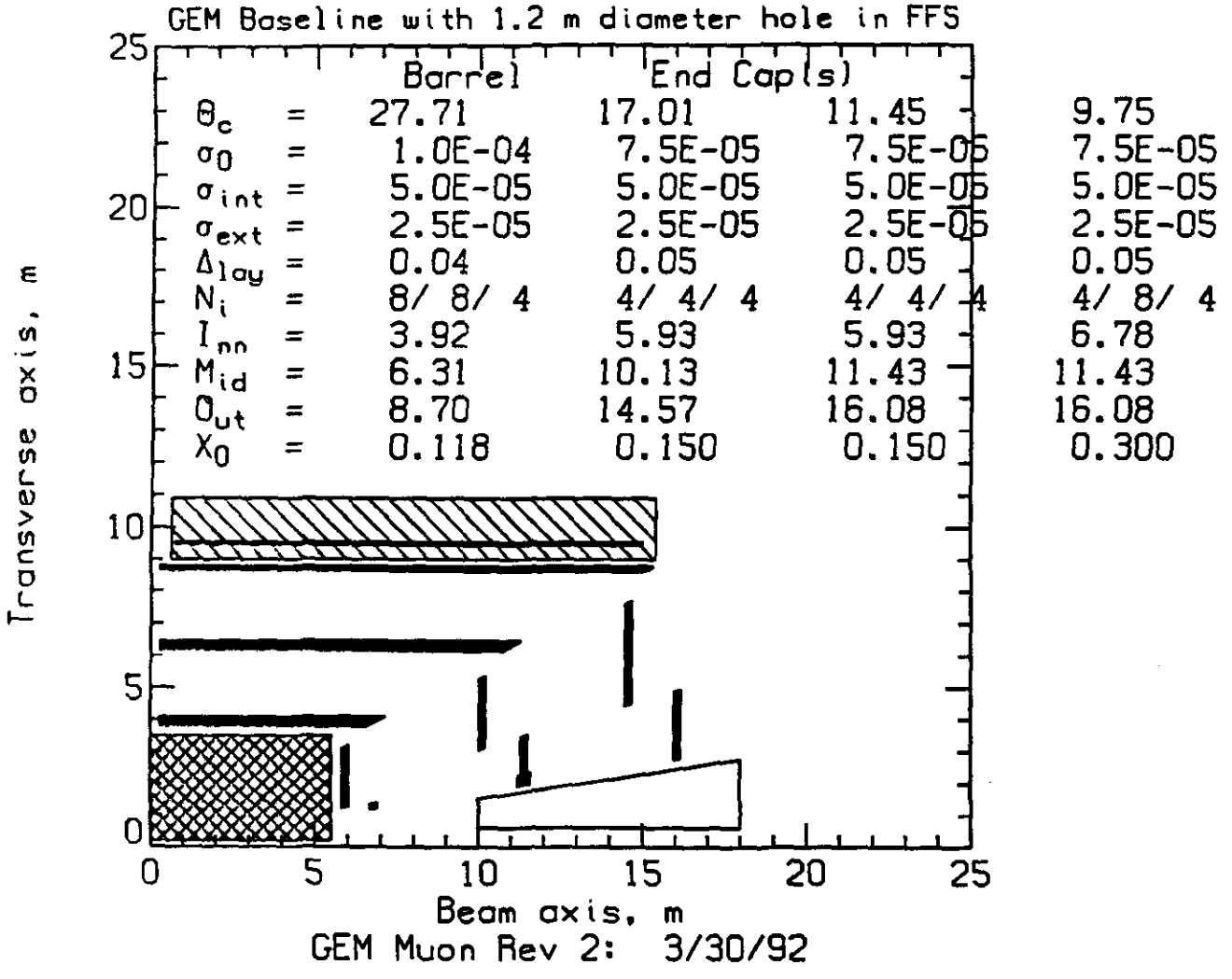
The magnitude and direction of the magnetic field must be known in order to measure muon and electron momenta. In addition to inducing a curvature of charged particle trajectories, the field also influences the drift of ionization electrons towards the sense wires of tracking chambers affecting position measurement resolution. Furthermore, the field and its direction affect placement and performance of photo-sensitive devices considered for the signal readout of the calorimetric devices.

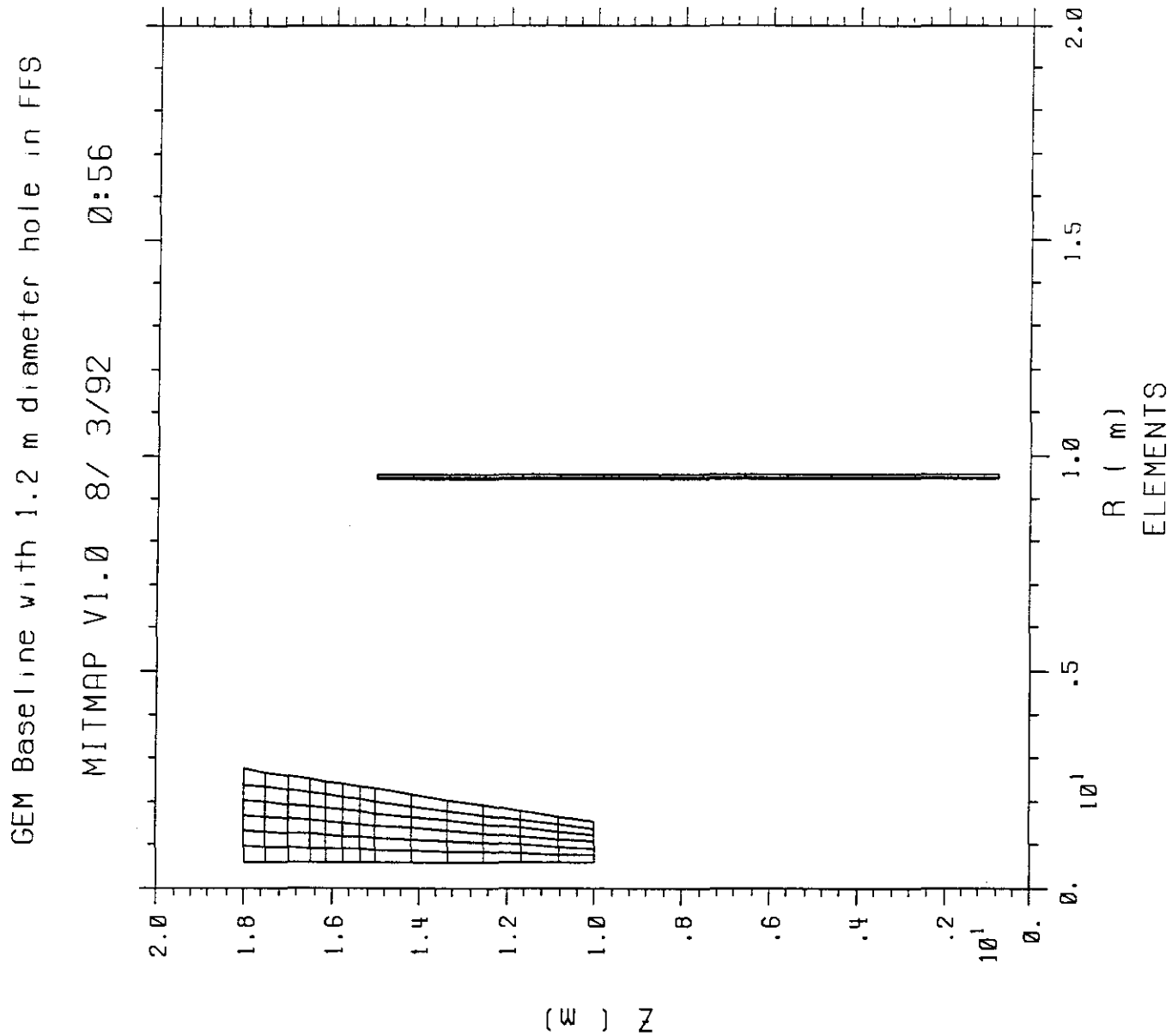
As a result of cost and construction schedule considerations, the GEM magnet does not have a return yoke. The substantial fringe field is present at all points of the experimental hall and a residual field remains at the surface. Precise knowledge of the field is needed to estimate and correct its influence on the beam, the IR quadrupoles and to mitigate its effects on any mechanical or electronic component in the hall, the electronic counting house or in the operations center.

Procedures and requirements for field mapping and monitoring during GEM operations are under development. These will include a full field map measurement, directional placement of sensitive equipment and local shielding.

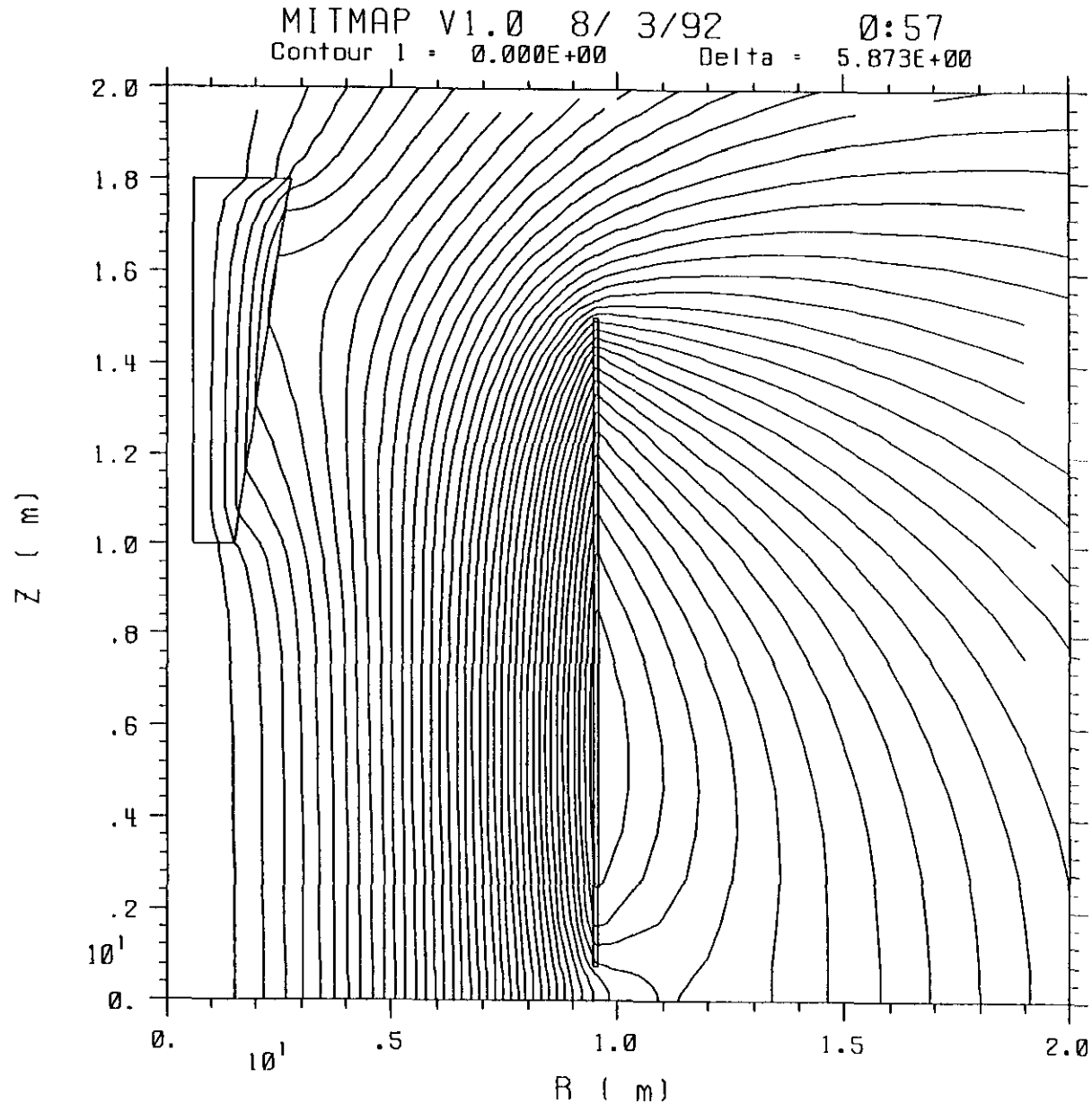
Source:
Updated:


GEM Case 600: revised baseline, Nov 18, 1992
⊙ P_t = 10 GeV
△ P_t = 25 GeV
+ P_t = 50 GeV
× P_t = 100 GeV
◇ P_t = 250 GeV
↑ P_t = 500 GeV
⧖ P_t = 750 GeV
z P_t = 1000 GeV
$\Delta P_t / P_t$
.25
.20
.15
.10
.05
0.00
0.0
.5
1.0
1.5
2.0
2.5
η
Muon CSC option but modified locations: 11/25/92


GEM Baseline with 1.2 m diameter hole in FFS
Barrel
End Cap(s)
θ_c = 27.71 17.01 11.45 9.75
σ_0 = 1.0E-04 7.5E-05 7.5E-05 7.5E-05
σ_{int} = 5.0E-05 5.0E-05 5.0E-05 5.0E-05
σ_{ext} = 2.5E-05 2.5E-05 2.5E-05 2.5E-05
Δ_{lay} = 0.04 0.05 0.05 0.05
N_i = 8/ 8/ 4 4/ 4/ 4 4/ 4/ 4 4/ 8/ 4
I_{nn} = 3.92 5.93 5.93 6.78
M_{id} = 6.31 10.13 11.43 11.43
O_{ut} = 8.70 14.57 16.08 16.08
X_0 = 0.118 0.150 0.150 0.300
Transverse axis, m
Beam axis, m
0
5
10
15
20
25
GEM Muon Rev 2: 3/30/92

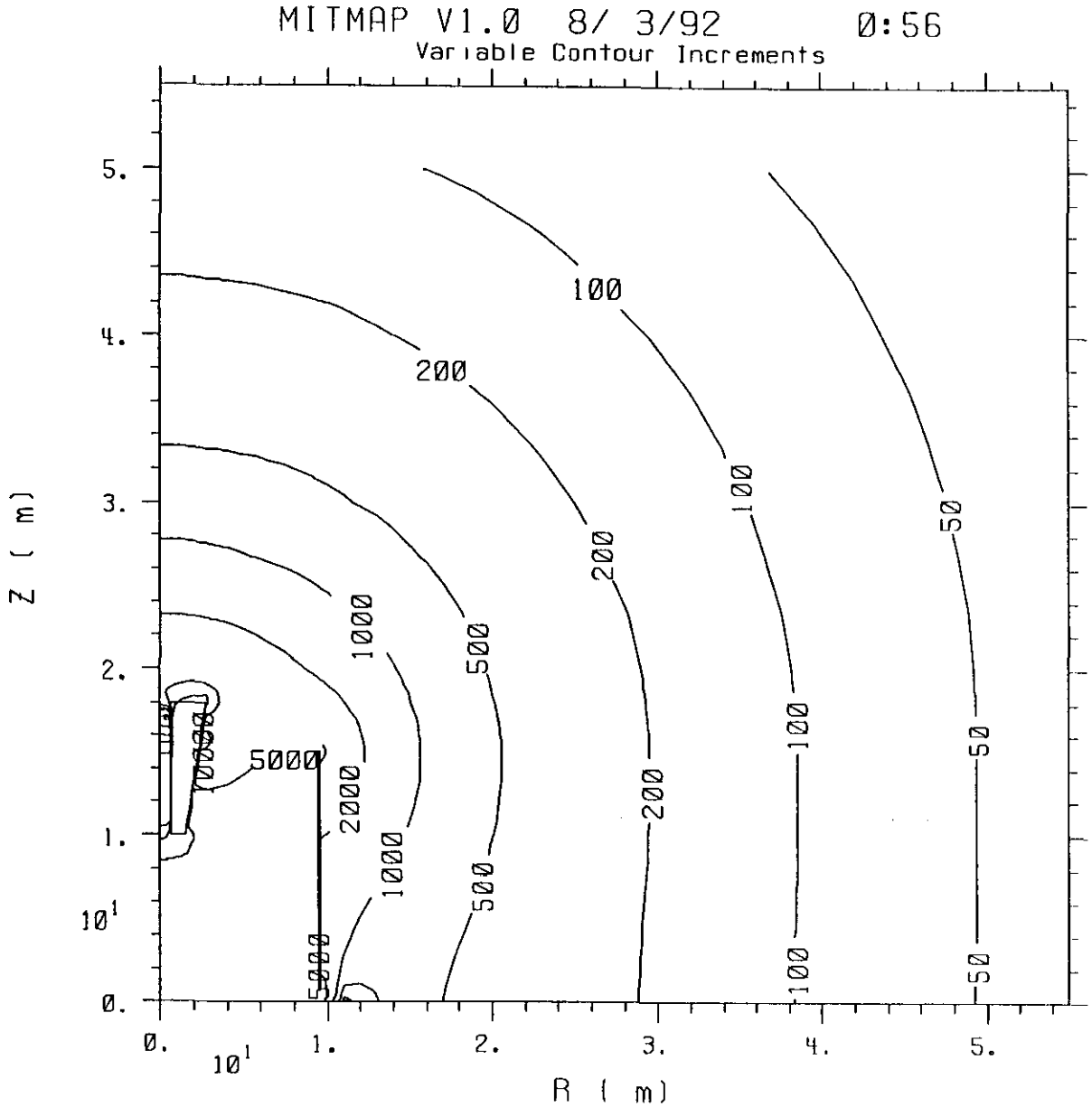

GEM Baseline with 1.2 m diameter hole in FFS
MITMAP V1.0 8/ 3/92 0:56
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
10¹
0.
Z (m)
0.
10¹
.5
1.0
1.5
2.0
R (m)
ELEMENTS

GEM Baseline with 1.2 m diameter hole in FFS



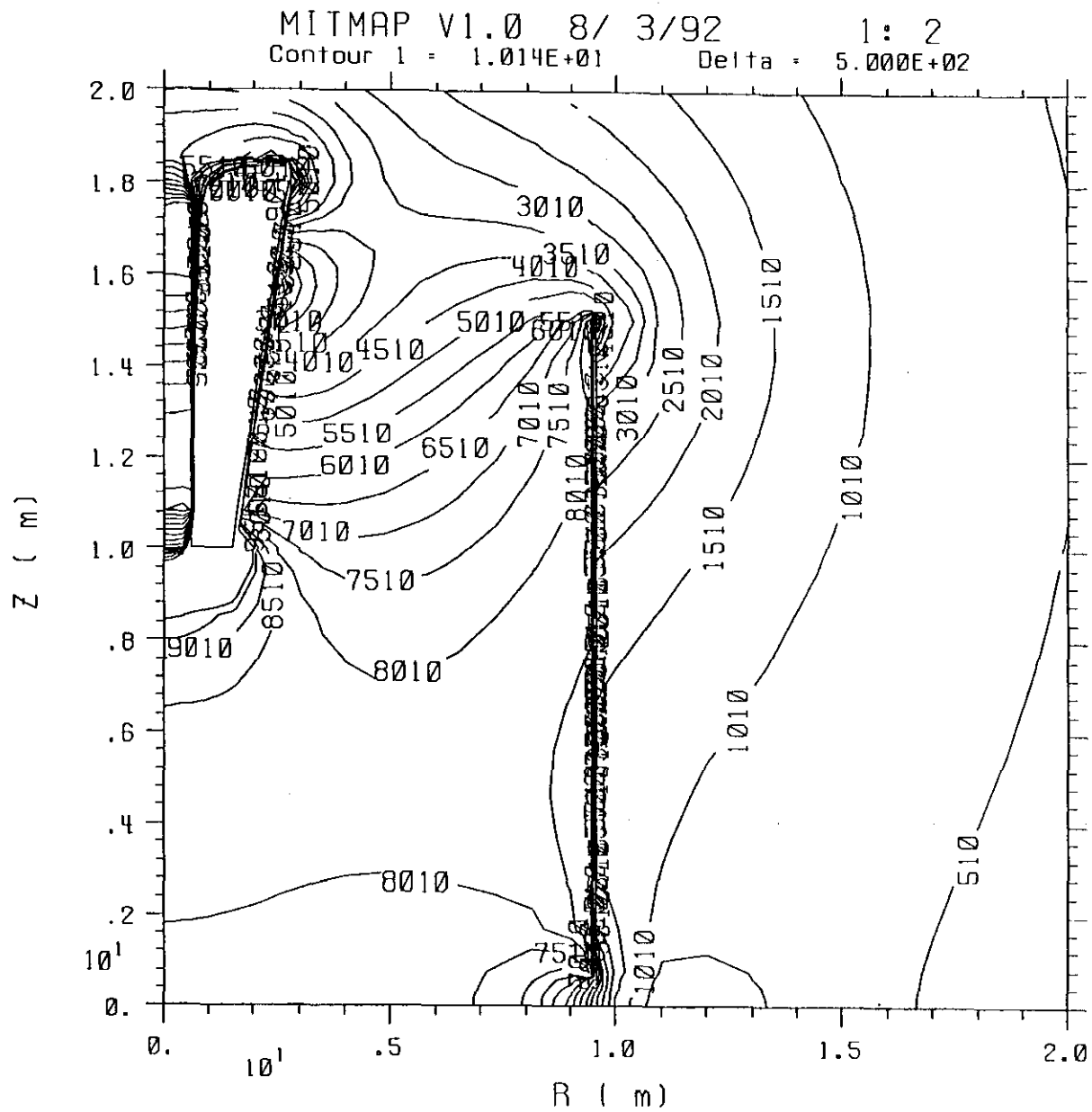
CONTOURS OF CONSTANT FLUX

GEM Baseline with 1.2 m diameter hole in FFS



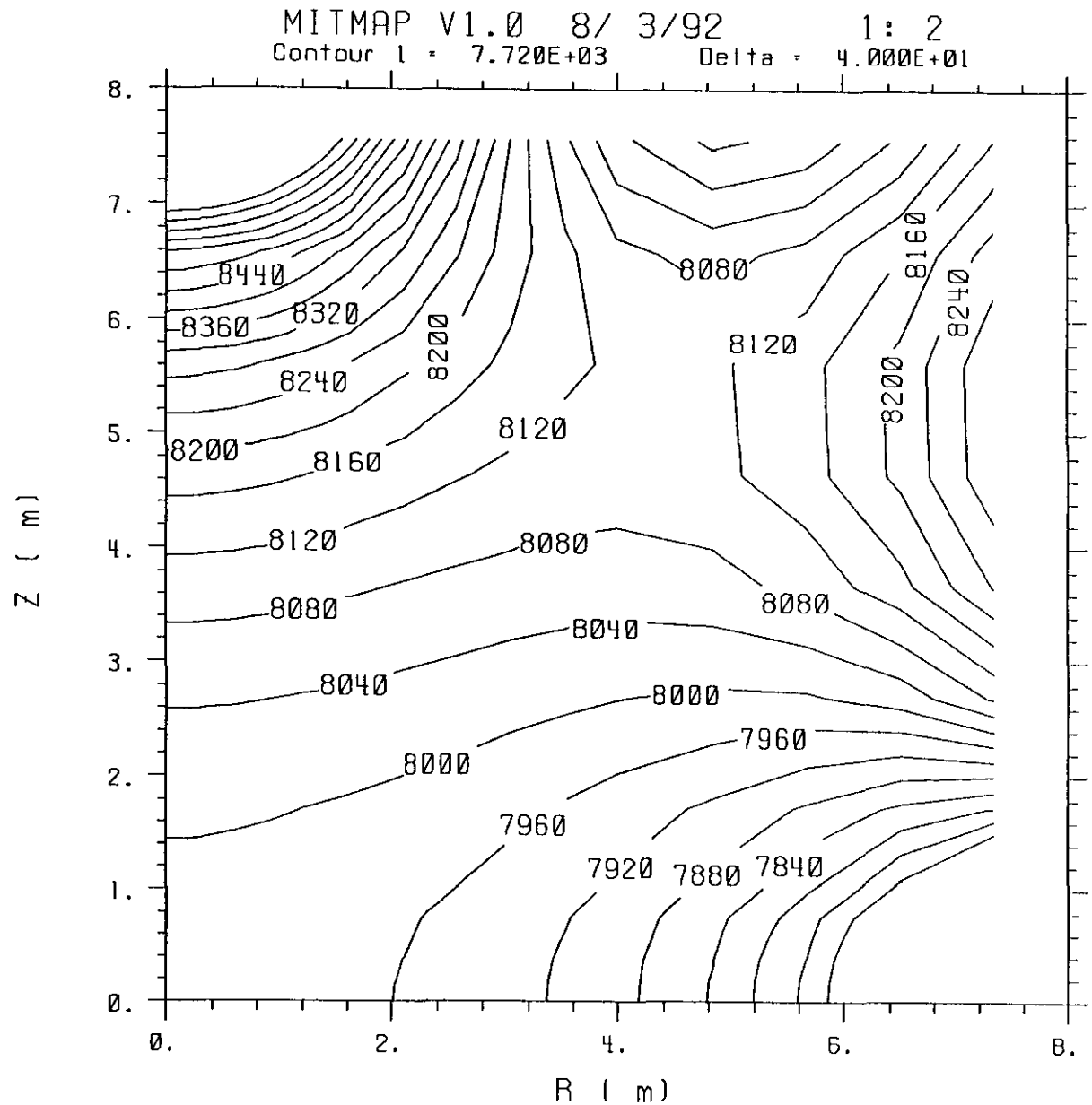
CONTOURS OF CONSTANT B

GEM Baseline with 1.2 m diameter hole in FFS



CONTOURS OF CONSTANT B

GEM Baseline with 1.2 m diameter hole in FFS



CONTOURS OF CONSTANT B

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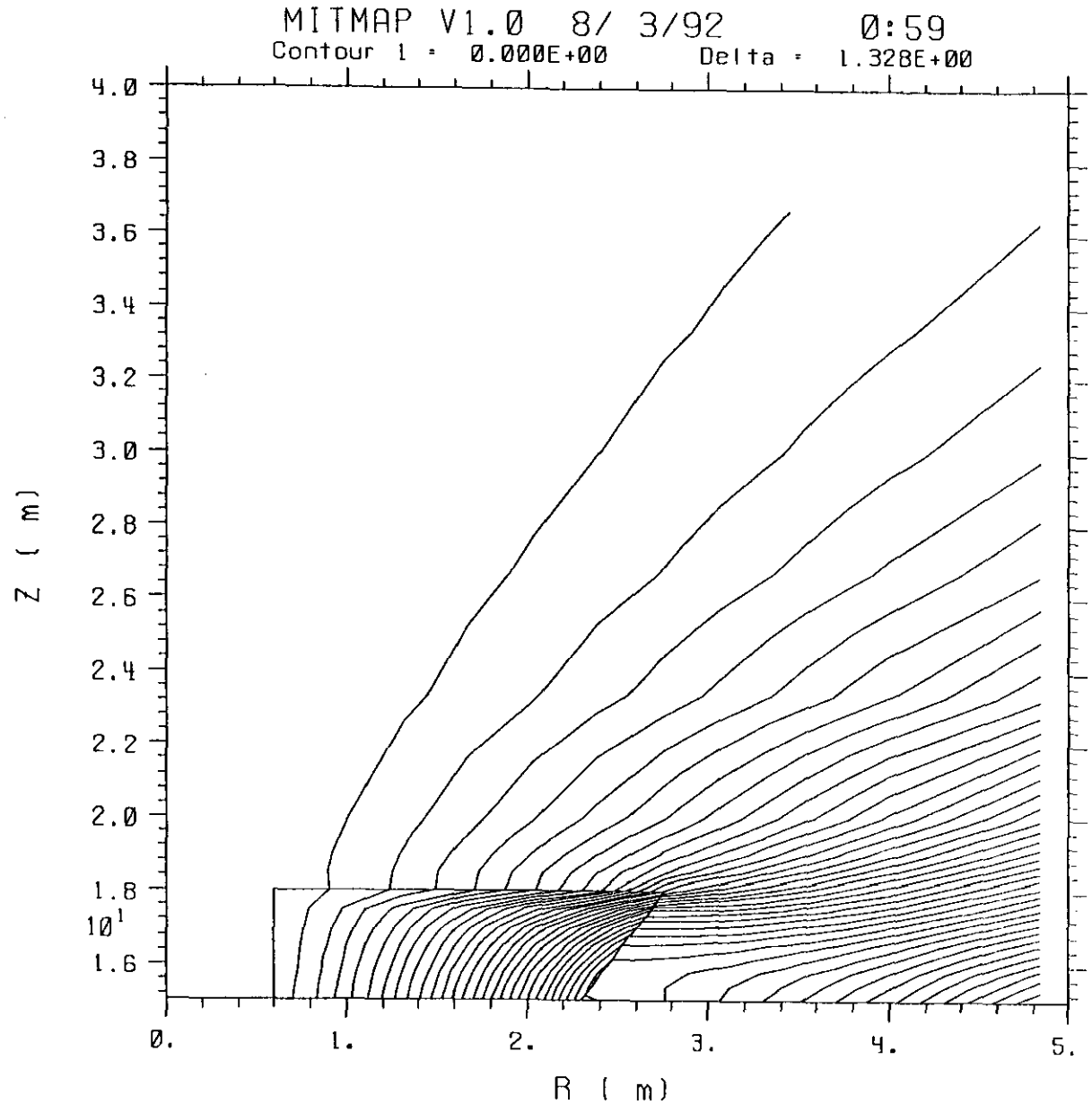
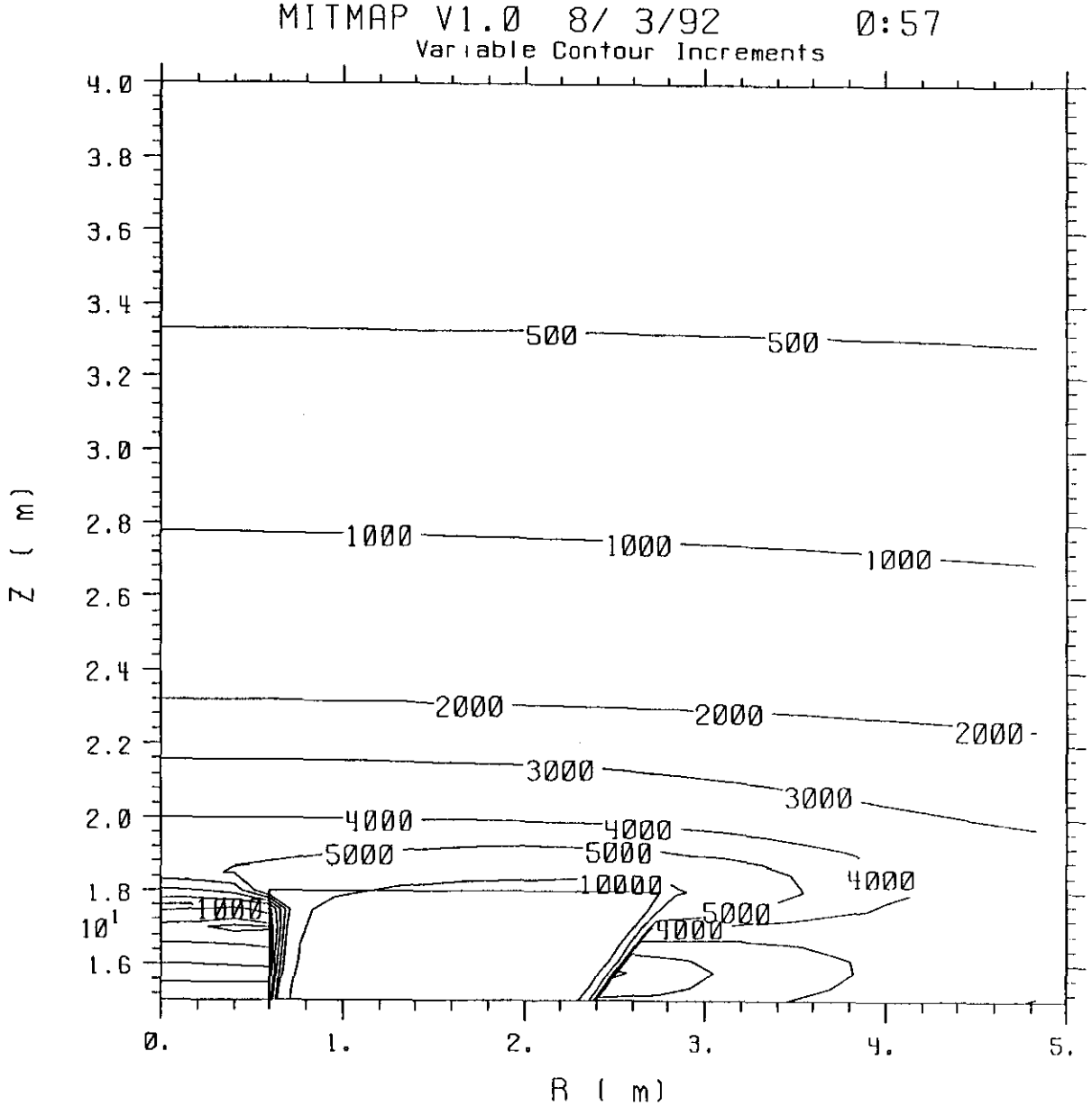


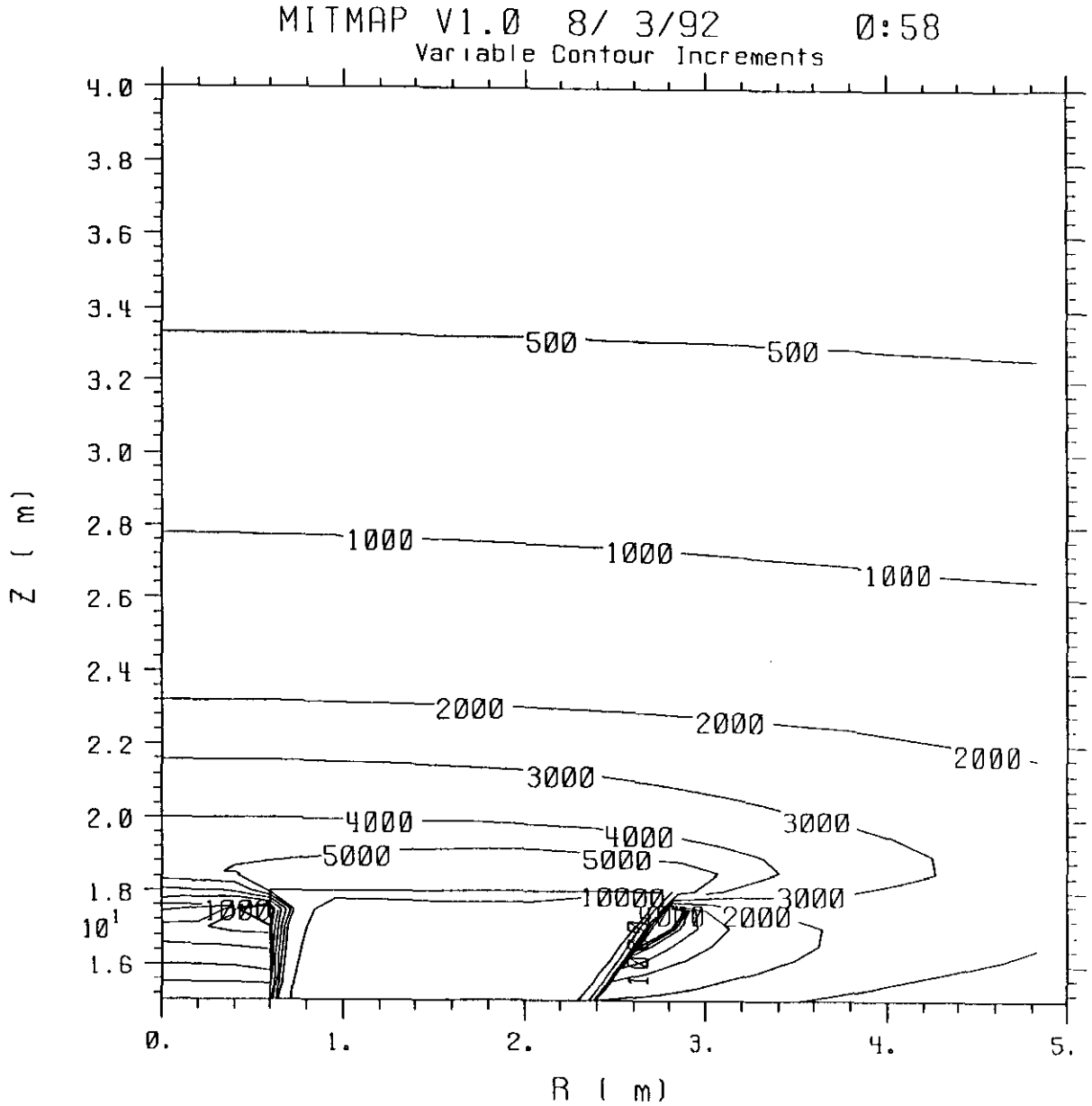
CONTOURS OF CONSTANT FLUX

GEM Baseline with 1.2 m diameter hole in FFS



CONTOURS OF CONSTANT B

GEM Baseline with 1.2 m diameter hole in FFS

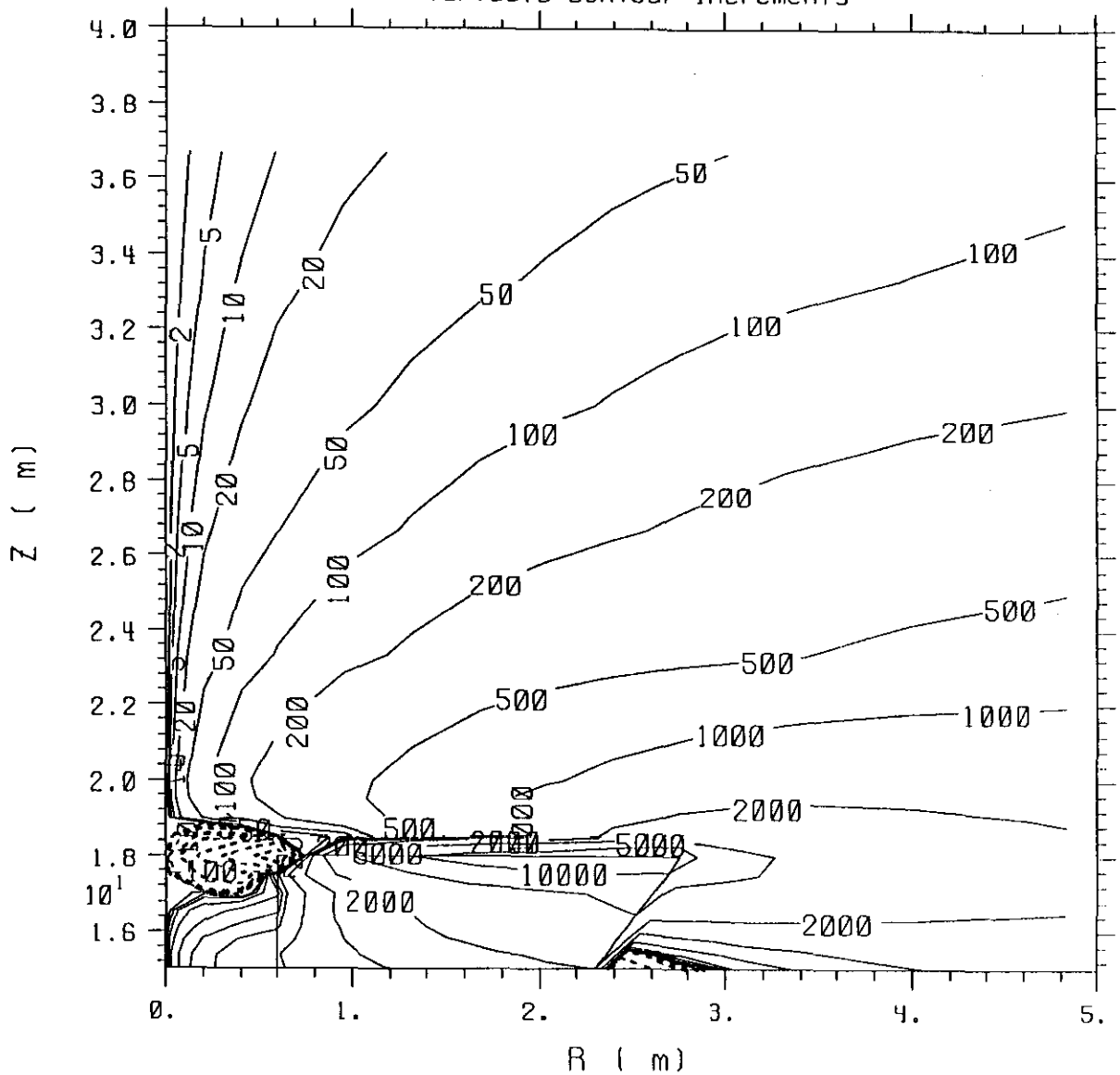


CONTOURS OF CONSTANT Bz

GEM Baseline with 1.2 m diameter hole in FFS

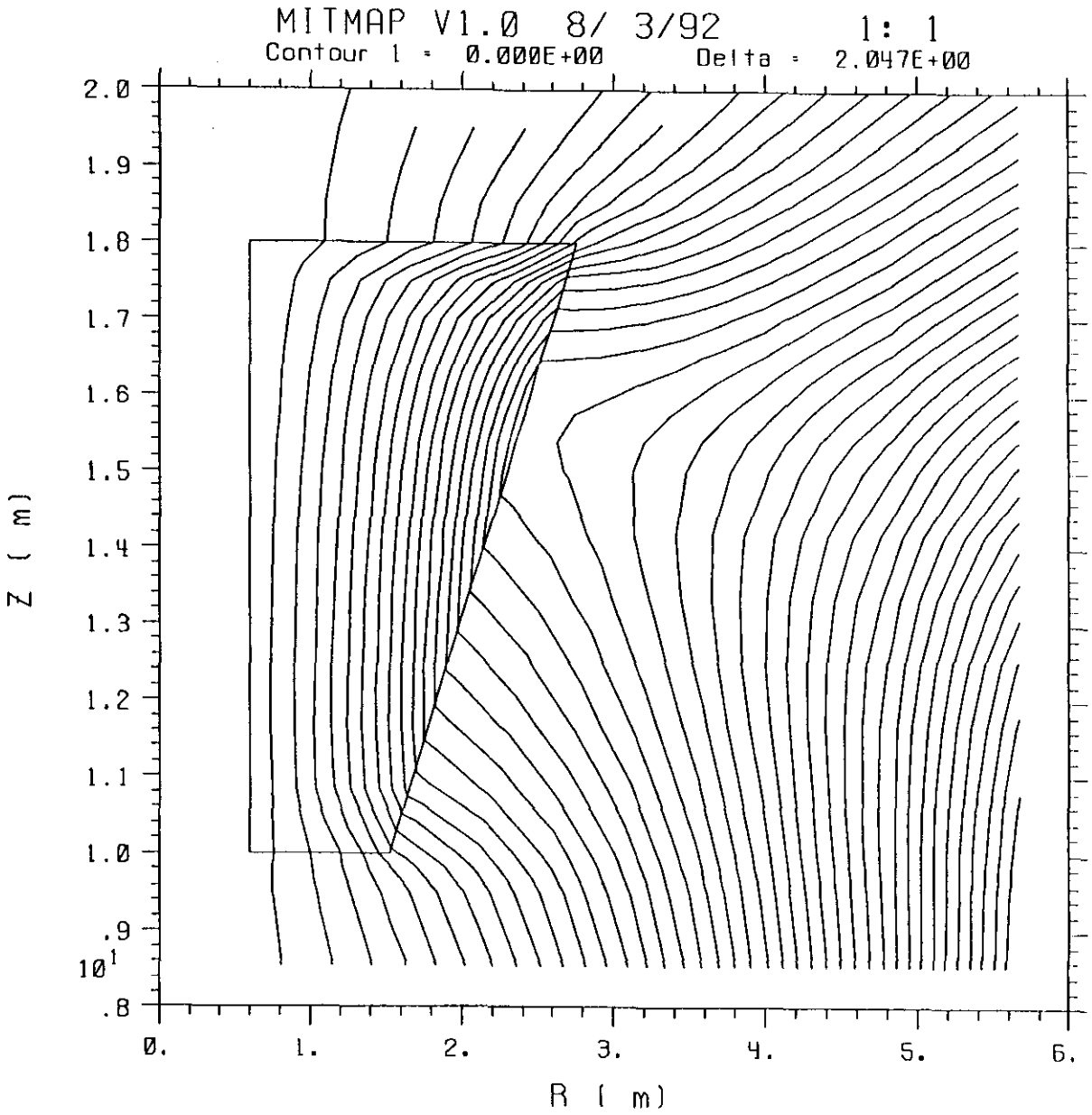
MITMAP V1.0 8/ 3/92 0:58

Variable Contour Increments



CONTOURS OF CONSTANT Br

GEM Baseline with 1.2 m diameter hole in FFS

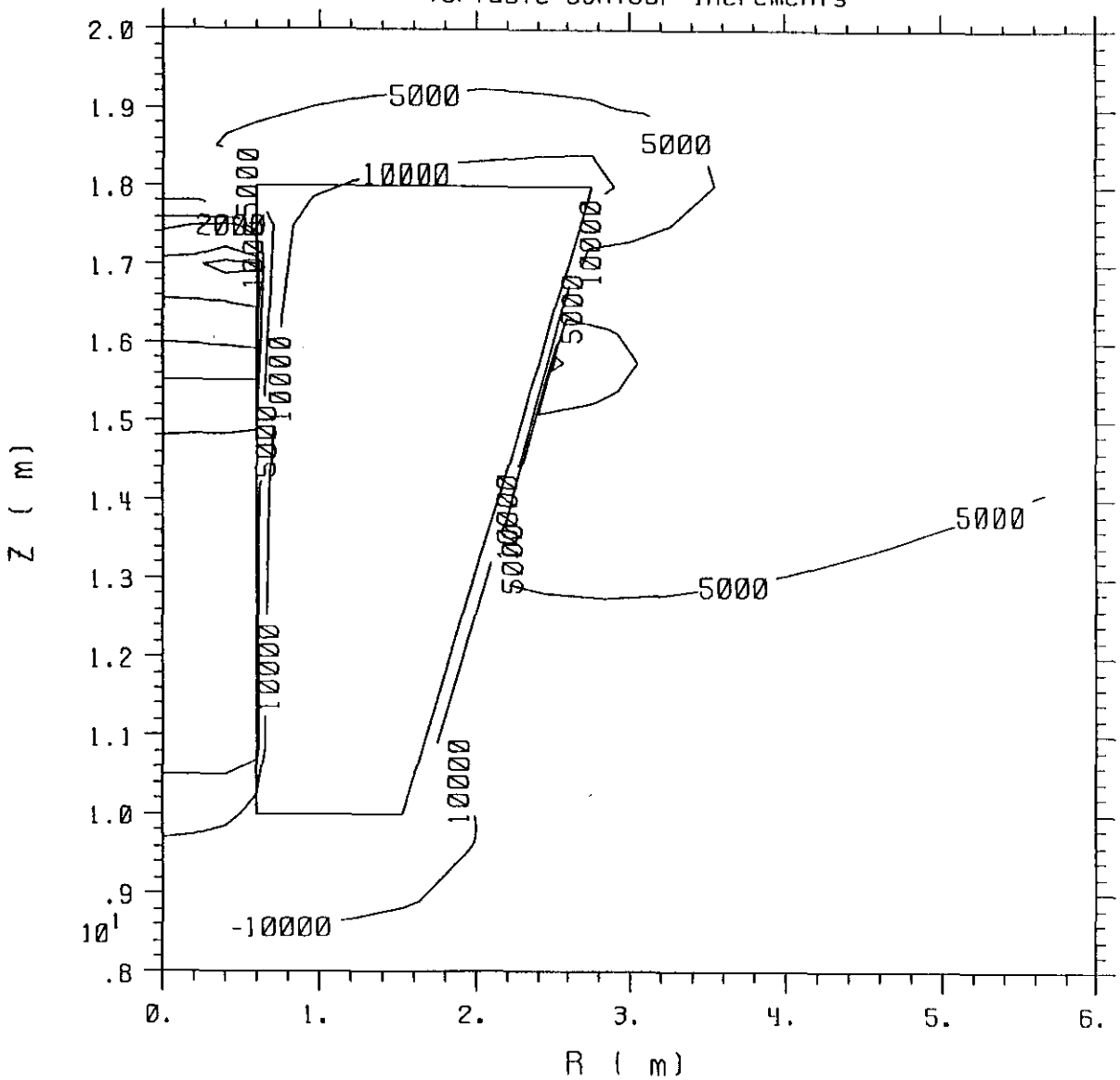


CONTOURS OF CONSTANT FLUX

GEM Baseline with 1.2 m diameter hole in FFS

MITMAP V1.0 8/ 3/92 1: 1

Variable Contour Increments

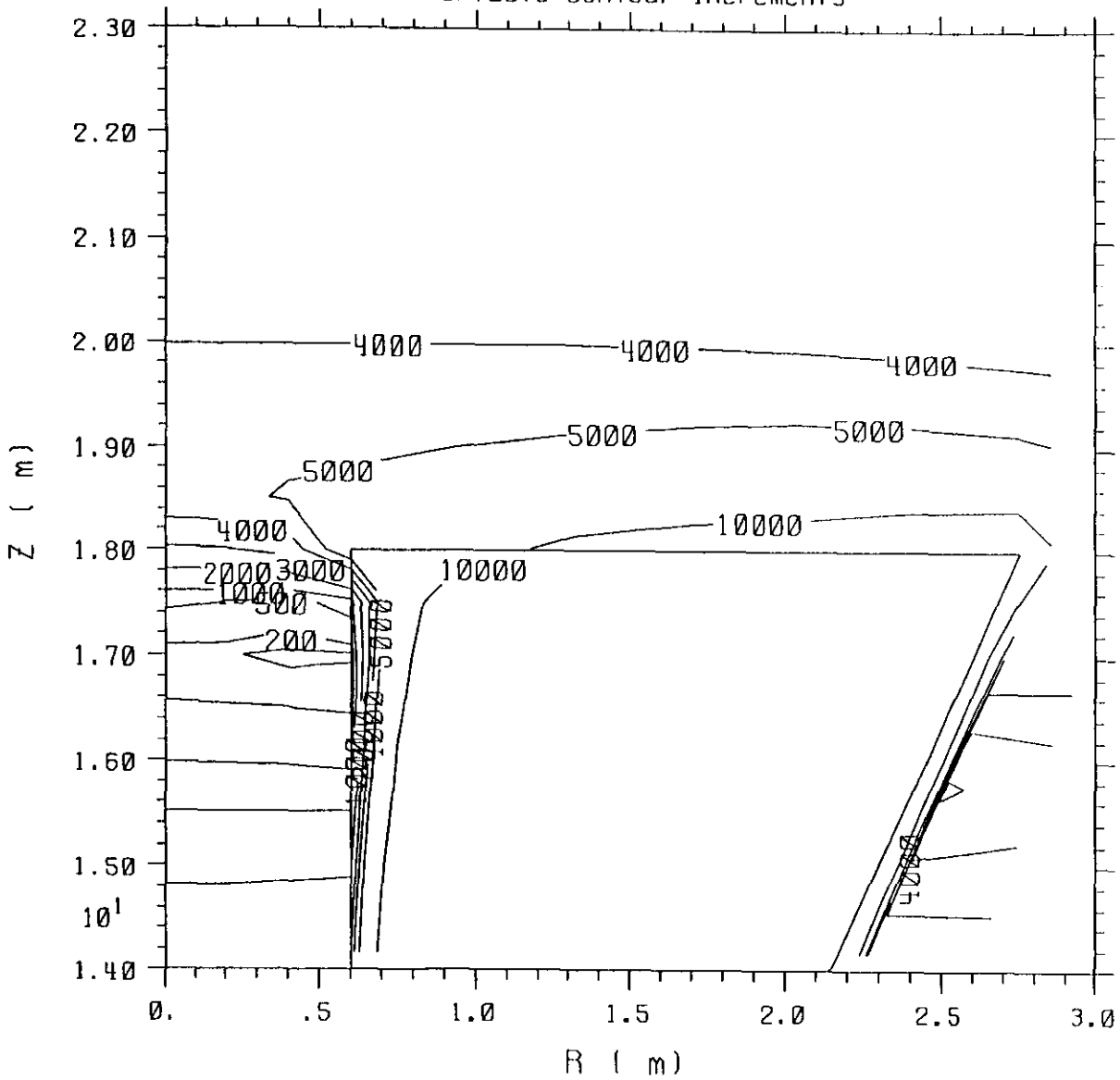


CONTOURS OF CONSTANT B

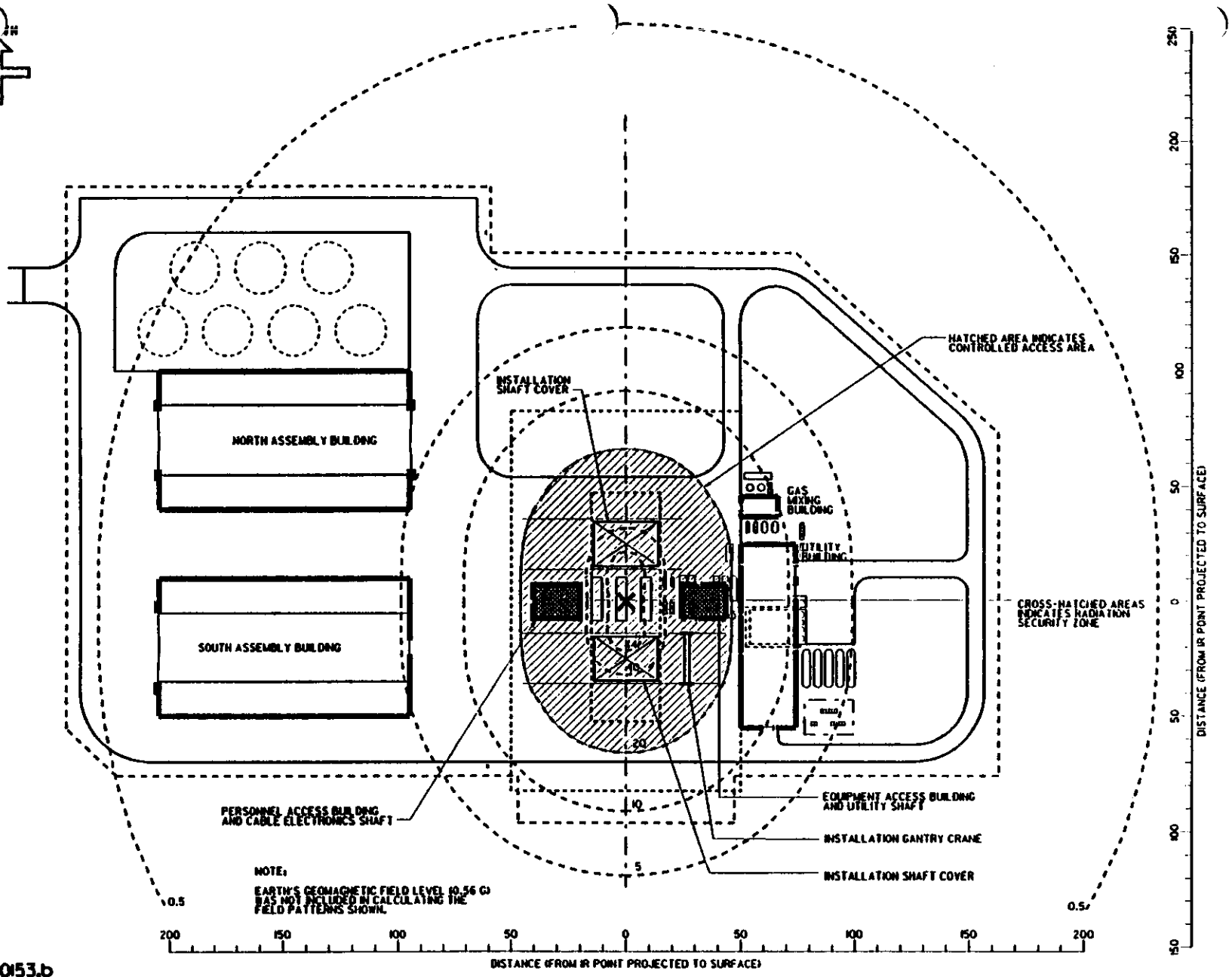
GEM Baseline with 1.2 m diameter hole in FFS

MITMAP V1.0 8/ 3/92 0:59

Variable Contour Increments

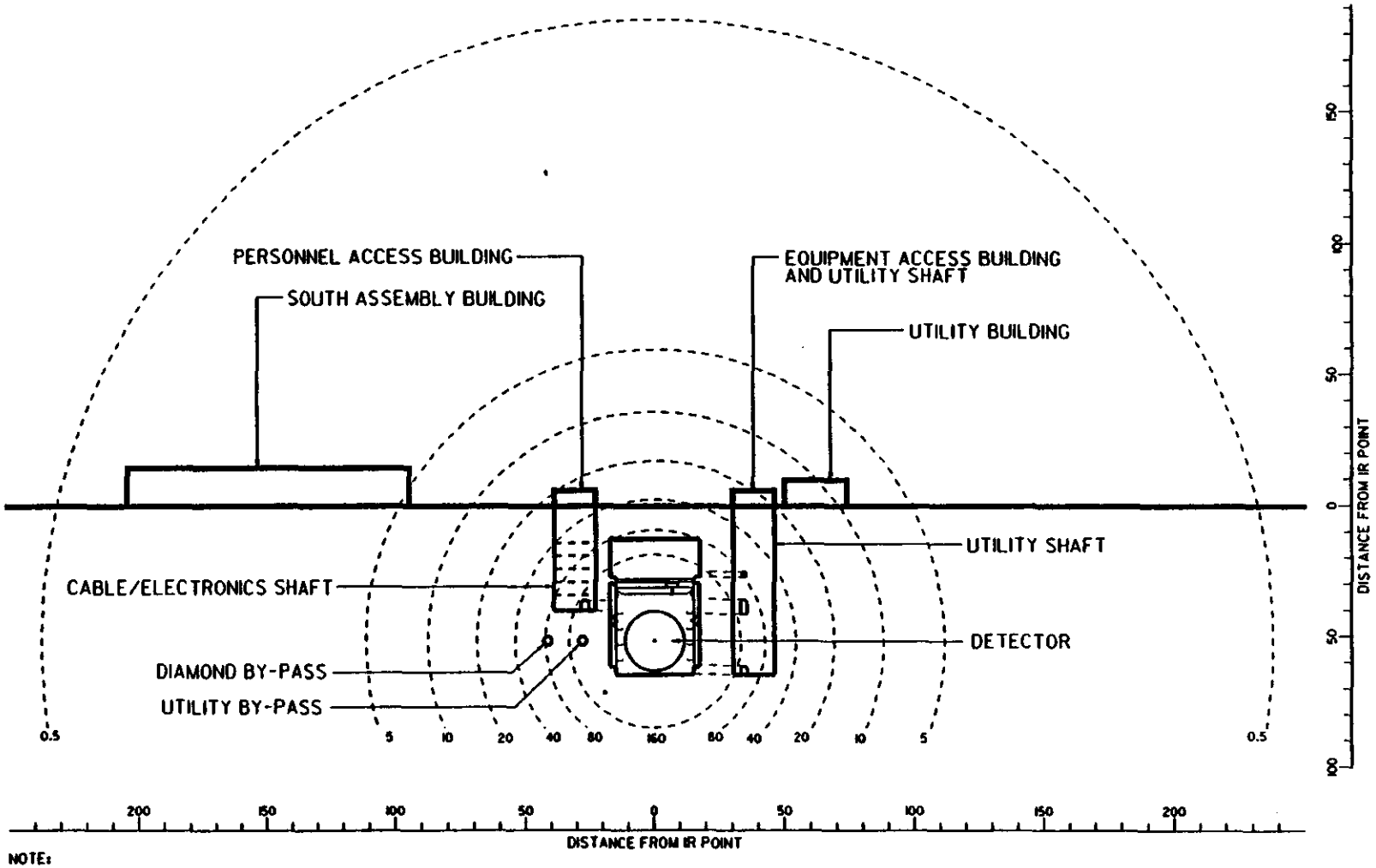


CONTOURS OF CONSTANT B



gcd000153.b
REF. FILE: gcd000142.021
10 NOV 1992
RW/KH

IR-5 Magnetic Field Pattern Plan at Surface



NOTE:

EARTH'S GEOMAGNETIC FIELD LEVEL (0.56 G) WAS NOT INCLUDED IN CALCULATING THE FIELD PATTERNS SHOWN.

gcd000156.b
REF. FILE(S): gcd000155
10 NOV 1992
RW/KH

IR-5 Magnetic Field Pattern Section at IP

9. TRACKER

TRACKING SYSTEM

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Silicon Tracker Space Frame Assembly
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OVERVIEW

The Central Tracker of the GEM detector is designed to operate in the 0.8 Tesla magnetic field of the large GEM superconducting solenoid. The tracker is compact, with a 88 cm outer radius and a total length of 350 cm. It covers a pseudorapidity range of ±2.5 units. The present baseline design consists of a Silicon Microstrip (SM) inner tracker and an Interpolating Pad Chamber (IPC) outer tracker. The geometry of the Central Tracker in this design is shown in Figure 9.1(a).

Since the submission of the GEM Expression of Interest, a variety of technologies were considered for use in the GEM Central Tracker. For the inner tracker silicon microstrips, silicon pixels and long drift length silicon detectors were discussed. Silicon pixel and long drift silicon detectors were considered to be too immature, with large uncertainties of performance, radiation resistance, and costs, to be a sensible choice at this time. Silicon microstrip detectors were chosen as the baseline design for the following reasons:

1. The very fine segmentation possible combined with proven high radiation resistance make this detector ideal as the element closest (~10 cm) to the interaction point.

2. Very high spatial resolution allows very precise vertex position and track impact parameter measurement.

3. It is a mature technology, which is presently in use in a number of fixed target and collider experiments with relatively well understood performance, radiation resistance and cost properties.

Silicon detectors were considered to be too expensive for the outer tracker. Technologies under serious discussion for outer tracker were Straw Tubes, Scintillating Fibers and Interpolating Cathode Pad Chambers. The Interpolating Pad Chambers were chosen for the baseline design for the following reasons:

1. Pad sizes of the order of a few cm^2 in area are quite natural. This allows for a low occupancy even at a luminosity of $10^{34} cm^{-2} sec^{-1}$. Thus, this technology is suitable even at the highest luminosities of the SSC. The other technologies would result in considerably higher occupancies.

2. The pads, in some approximation, approach 3 dimensional points,which is quite important for good tracking in the high rate and multiplicity environment of the SSC. The two other technologies produce stereo images i.e. all tracks projected onto a plane, which make pattern recognition more difficult in this environment.

3. Interpolating Pad Chambers are not a new technology; they have been demonstrated to have the resolution needed with chamber sizes similar to those required for the GEM tracker design.

The Silicon Microstrip inner tracker consists of six layers of silicon strip ladders. The geometrical layout of the silicon is shown in Figure 1.2. Each ladder is composed of two back-to-back single sided silicon sensors with a ±5 mrad stereo angle between the two sensors. Each sensor is 300 μm thick with a strip pitch of 50 μm. Each pair of sensors provides a space point with a resolution of 10 μm in the r-ϕ plane and 1.5 mm in the r-z projection. The six layers of ladders are organized into three superlayers, each of which provides a track stub to a track finding algorithm. In the forward region, the silicon sensors are mounted into disks with the strips projecting radially inward toward the beam axis. The Silicon Tracker is ~200 cm long and extends in a radius from 10 to 37 cm. The total area of silicon ladders in the detector is about 7 m^2 with about 3.5×10^6 strips to be read out. The read-out will be highly multiplexed, with 1028 strips to one fiber optic readout channel, for a total readout channel count of 3500.

The outer tracker consists of 8 layers of pad chambers, both in the barrel region at radii between 37 and 80 cm, and in the forward region which extends from 20 to 80 cm in radius. The 8 layers are arranged in 4 superlayers with 2 layers each. Each barrel layer will consist of 20 chambers, each covering 18° in azimuth, with the largest chamber being 30 cm wide × 200 cm long. The forward layers will be disks divided into ten trapezoidal chambers about 50 cm × 50 cm each.

The IPC's in this system will be very similar in concept and performance to chambers which have been constructed and are now taking data in experiment E-814 at Brookhaven AGS [2]. These chambers have various sizes up to 50 cm × 200 cm and have obtained a resolution of ~50 μm, or ~1% of the pad size, which is what the GEM design calls for.

Each of the chambers will be tilted in azimuth by the Lorentz angle of the gas (~10°) so that the $\overline{E}\times\overline{B}$ effect in the 0.8 T field does not degrade the resolution. This tilt also allows the chambers to be overlapped, eliminating dead regions due to electronics and structural elements (see Figure 9.1b).

The direction of good resolution in these pad chambers is along the anode wire. Thus, the wires in the barrel chambers will run across the chambers, in the "ϕ direction", keeping the wire length between 15 and 30 cm. In the forward chambers the wires will also run in the "ϕ direction", with wire length between 10 and 40 cm. The wire spacing will be 2 mm in both the barrel and the forward chambers.

In the present design pad sizes are a uniform $\Delta\eta\times\Delta\phi = 0.0007$ in all parts of the tracker. This results in a total of just under 400,000 pads for the entire device. (See Fig. 9.3.)

The pads are 2.5 mm wide (in the ϕ direction) and a few centimeters long (in the z direction, which is the direction along the beams). With an analog readout we expect to interpolate to obtain a precision in the ϕ direction of ~50 μm. To obtain better precision than the pad length in the z direction, the pads will be tilted by ±50 mrad in the two layers of each superlayer, respectively. This stereo angle will provide a z resolution of ~700 μm, which is good enough to provide a vertex z resolution of ~1 mm from the IPC's alone, so that this vertex z resolution will be available at the highest luminosities at the SSC.

The IPC readout electronics for each pad include a fast front end amplifier and shaper feeding an analog pipeline which is multiplexed at the output by a factor of 256, giving a total of 1600 channels. The present design calls for on board digitization using an 8 bit flash ADC system, multiplexed to optical drivers.

Physics Goals of the Central Tracker

The physics goals for the central tracking in GEM can be divided into two categories. The first are those features that are required to support the primary objectives of GEM, namely the detection of gammas, electrons and muons at high p_t. Some examples of these are:

- Identify the primary vertex of an event of interest, so that it can be separated from other pileup events in the memory time of the detector.
- Separate electrons and gammas using the presence or absence of a charged track pointing to an electromagnetic shower in the calorimeter.
- Provide track information for e, μ or γ isolation cuts, and to help with rejection of conversions and Dalitz pairs.
- Help with electron-hadron separation by providing a momentum measurement that can be compared with the energy deposition in the calorimeter.
- Help with rejection of background by matching the muon momentum measured in the central tracker with the momentum measured in the muon chambers.
- Determine the electron sign up to 600 GeV/c.

The tracker should be able to fulfill these goals well at the design luminosity of $10^{33}cm^{-2}s^{-1}$. These capabilities should also survive to luminosities up to $10^{34}cm^{-2}s^{-1}$. These minimum goals do not require full pattern recognition, but can be met by looking for hits in the tracker in a specific road extrapolated from the calorimeter or the muon system.

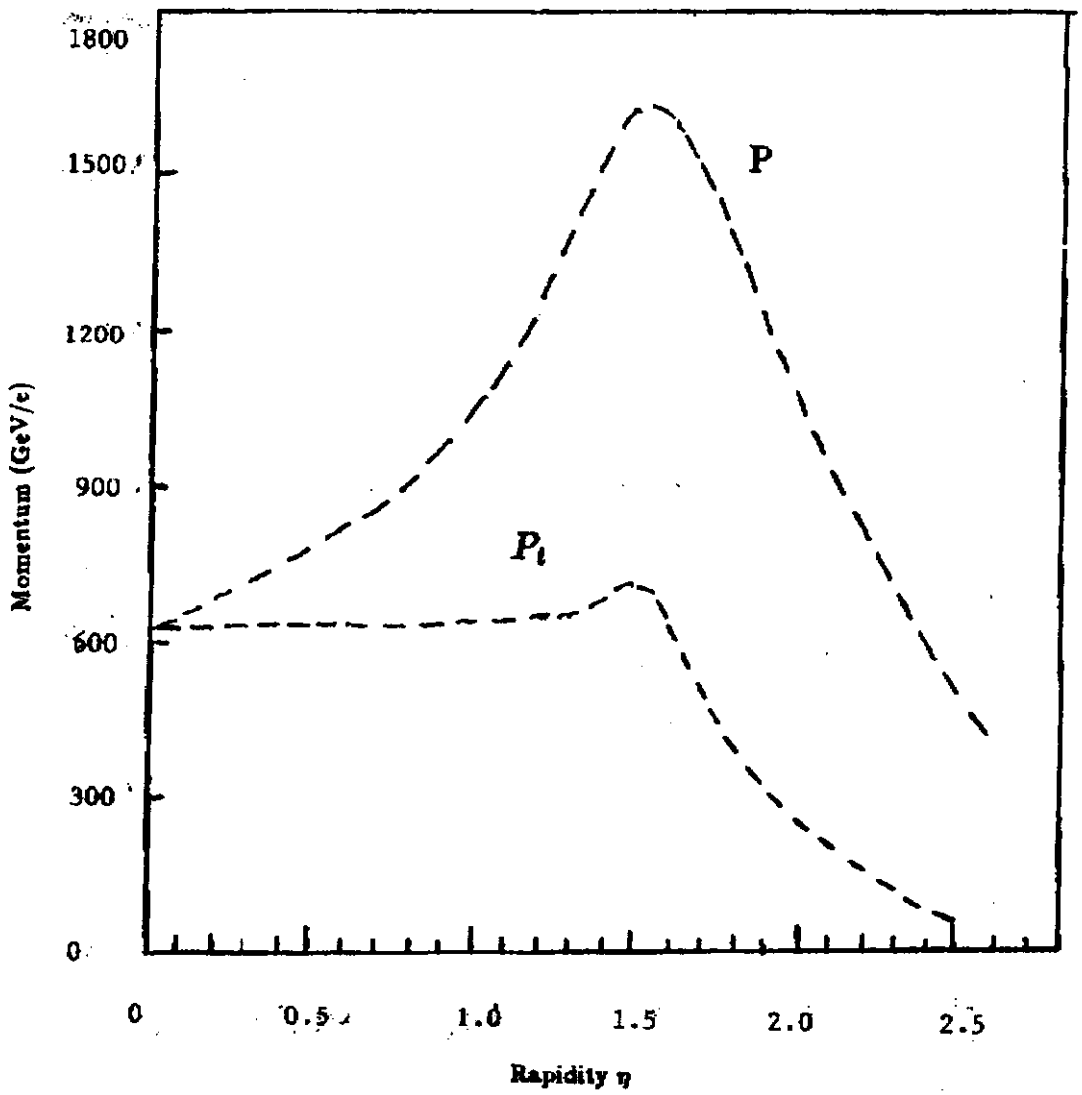
Design Parameters for the Central Tracker	
Outer Radius	88 cm
Length	±175 cm
Rapidity Coverage	$\lvert\eta\rvert \leq 2.5$
Magnetic Field	0.8 T
Occupancy at $L = 10^{33}cm^{-2}sec^{-1}$ at $L = 10^{34}cm^{-2}sec^{-1}$	 $\leq 1\%$ $\leq 10\%$
Charge separation at 95% c.l.	$p \leq 600 GeV/c$

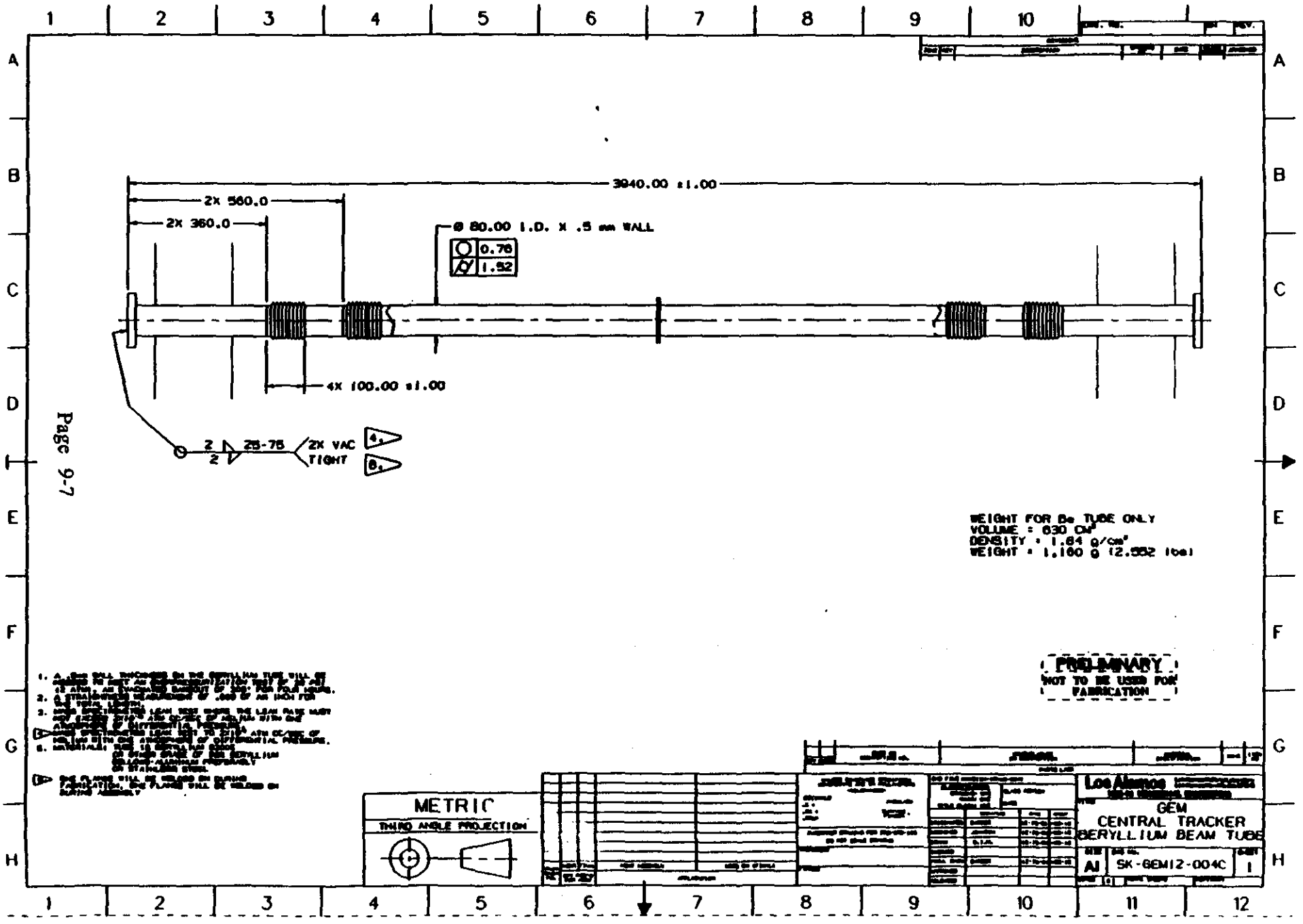
Design Parameters for the Central Tracker (cont'd)	
Momentum Resolution at high momenta (measurement limited)	$\Delta p / p^2 \sim (1 \text{ to } 3) \times 10^{-3}$ (GeV / c)$^{-1}$
at low momenta (multiple scattering limited)	$\Delta p / p \sim 2$ to 4%
Vertex Resolution along beam direction impact parameter	$\delta z \sim 1$ mm $\delta b \sim 30\ \mu$m above 10 GeV/c

Physics Processes	Id. Primary Vertex	e/γ Separation	e, μ, γ Isolation Cuts	e/h Separation	Muon Momentum Check	e± Sign Separation	Secondary Vertex	Low Momentum Track	Full Event Reconstr.
$H^0 \to \gamma + \gamma$	X	X	X						
$H^0 \to e^+e^-l^+l^-, e^+e^-\nu\bar{\nu}, e^+e^-$ jetjet	X	X	X	X		X			
$H^0 \to \mu^+\mu^-l^+l^-, \mu^+\mu^-\nu\bar{\nu}, \mu^+\mu^-$ jetjet	X		X		X				
Gluino Pair Prod $\tilde{g}\tilde{g} \to e^\pm e^\pm, \mu^\pm e^\pm$	X	X	X	X	X	X			
Techni eta $\eta_T \to b + \bar{b}$ or $t + \bar{t}$	X		X				X		
WW Scattering $W^\pm W^\pm \to e^\pm e^\pm, \mu^\pm e^\pm$	X	X	X	X	X	X			
$Z^1 \to e^+e^-$ Asymmetry	X	X	X	X		X			
B Physics, e.g. $B \to \Psi$, etc.	X						X	X	X
Top Physics $t \to W + b$, etc.	X		X				X	X	X

CENTRAL TRACKER PHYSICS STUDIES

95% CONFIDENCE LEVEL CHARGE SEPARATION




3940.00 ±1.00
2X 560.0
2X 360.0
Ø 80.00 I.D. X .5 mm WALL
0.76
1.52
4X 100.00 ±1.00
2 25-75 2X VAC TIGHT
WEIGHT FOR Be TUBE ONLY
VOLUME = 630 CM³
DENSITY = 1.84 g/cm³
WEIGHT = 1.160 g (2.552 lbs)
PRELIMINARY
NOT TO BE USED FOR FABRICATION
METRIC
THIRD ANGLE PROJECTION
Los Alamos
GEM
CENTRAL TRACKER
BERYLLIUM BEAM TUBE
AJ
SK-GEM12-004C
1

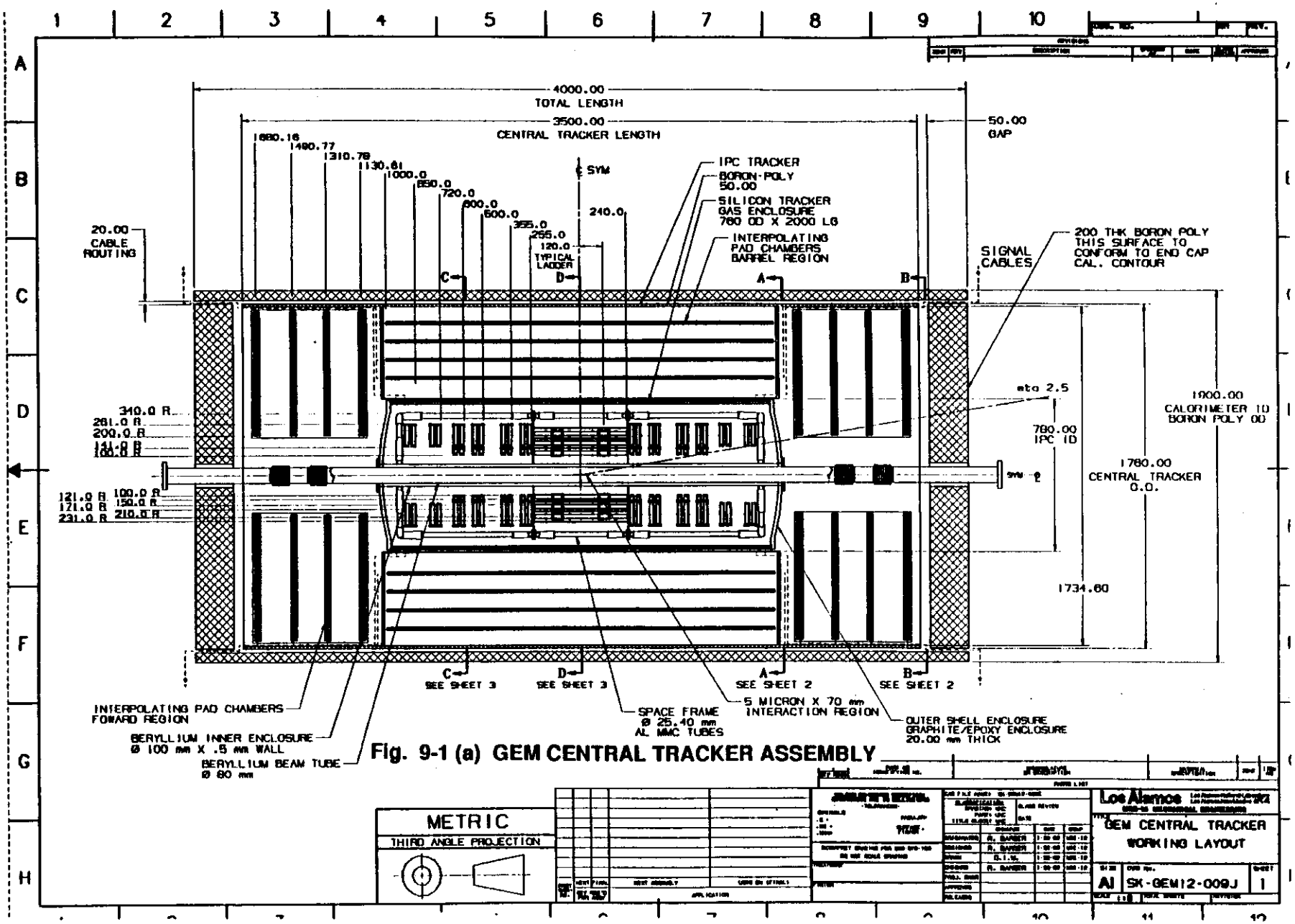


Fig. 9-1 (a) GEM CENTRAL TRACKER ASSEMBLY

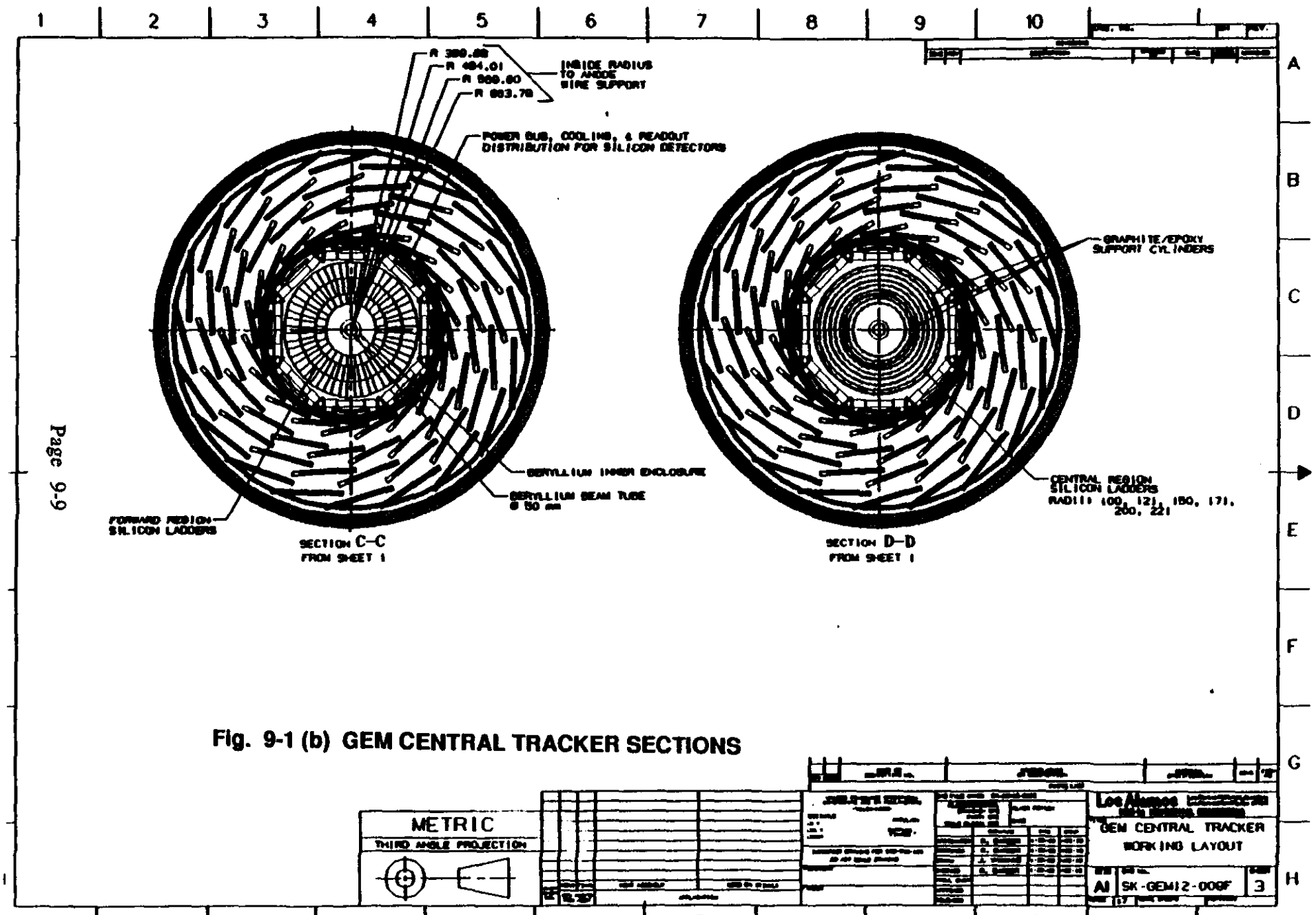


Fig. 9-1 (b) GEM CENTRAL TRACKER SECTIONS

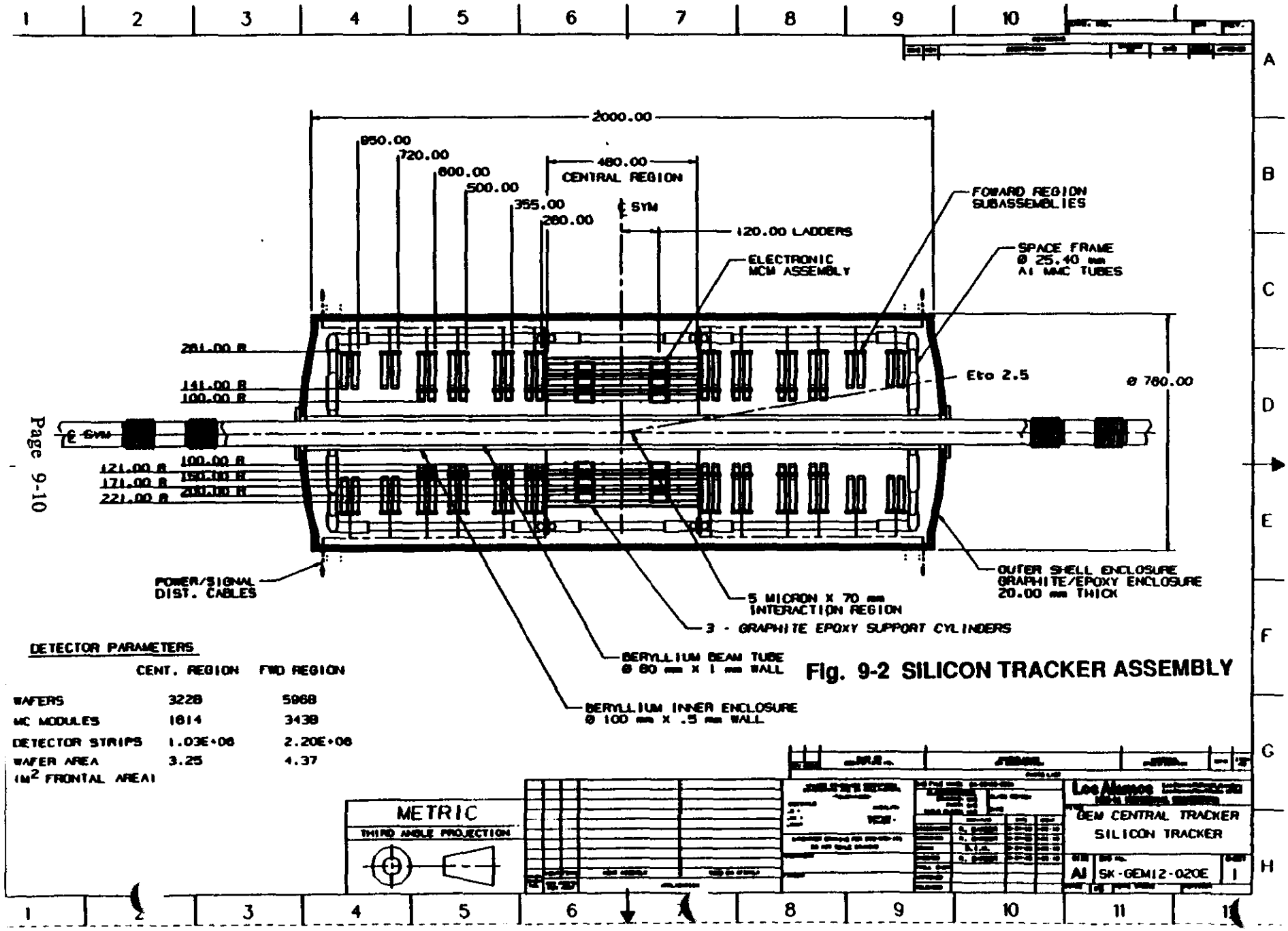


Fig. 9-2 SILICON TRACKER ASSEMBLY

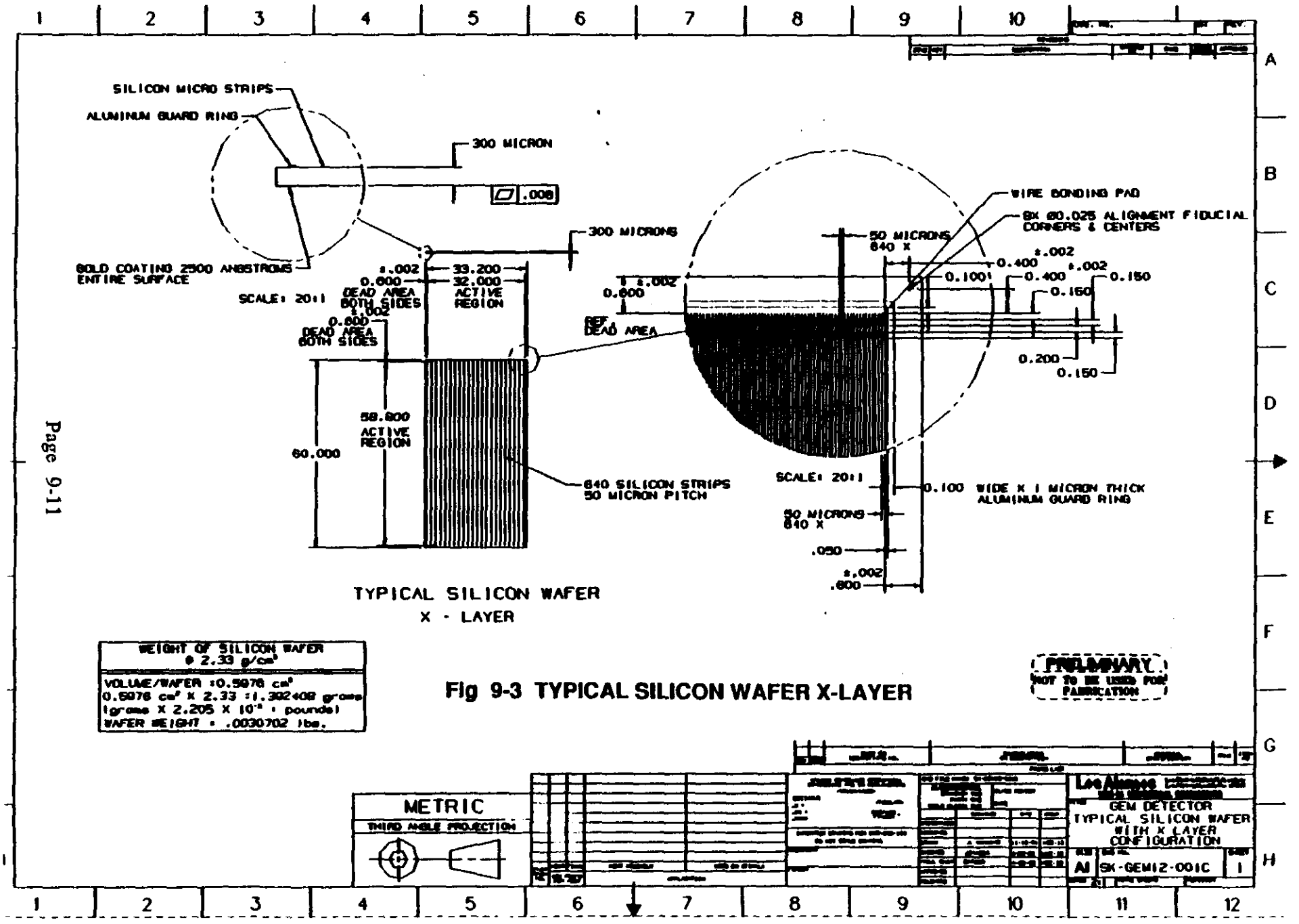
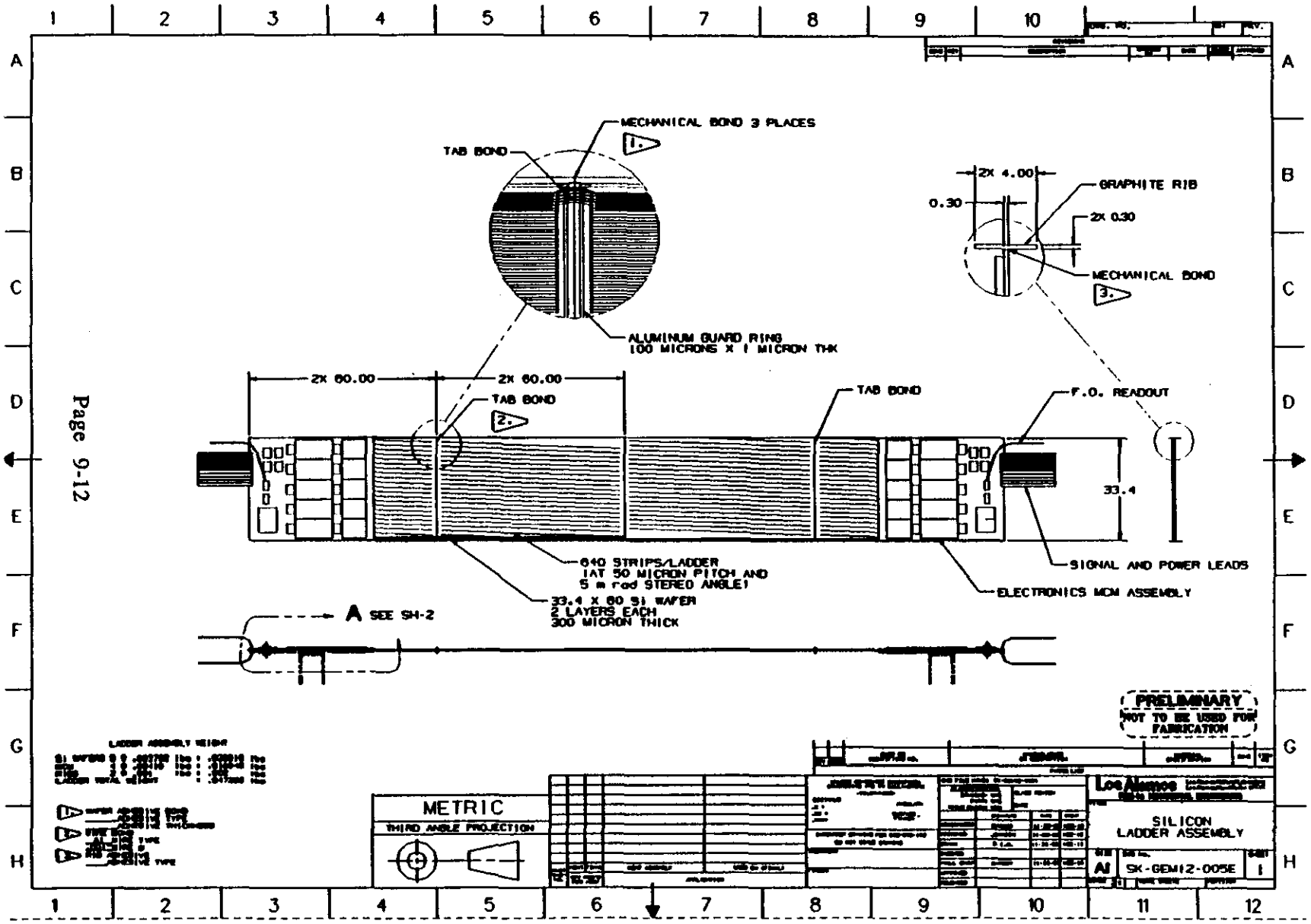


Fig 9-3 TYPICAL SILICON WAFER X-LAYER


MECHANICAL BOND 3 PLACES
1.
TAB BOND
ALUMINUM GUARD RING
100 MICRONS X 1 MICRON THK
2X 4.00
0.30
GRAPHITE RIB
2X 0.30
MECHANICAL BOND
3.
2X 60.00
2X 60.00
TAB BOND
2.
TAB BOND
F.O. READOUT
33.4
640 STRIPS/LADDER
(AT 50 MICRON PITCH AND
5 m rad STEREO ANGLE)
33.4 X 60 Si WAFER
2 LAYERS EACH
300 MICRON THICK
SIGNAL AND POWER LEADS
ELECTRONICS MCM ASSEMBLY
A SEE SH-2
PRELIMINARY
NOT TO BE USED FOR
FABRICATION
METRIC
THIRD ANGLE PROJECTION
Los Alamos
SILICON
LADDER ASSEMBLY
A1
SK-GEM12-005E
1

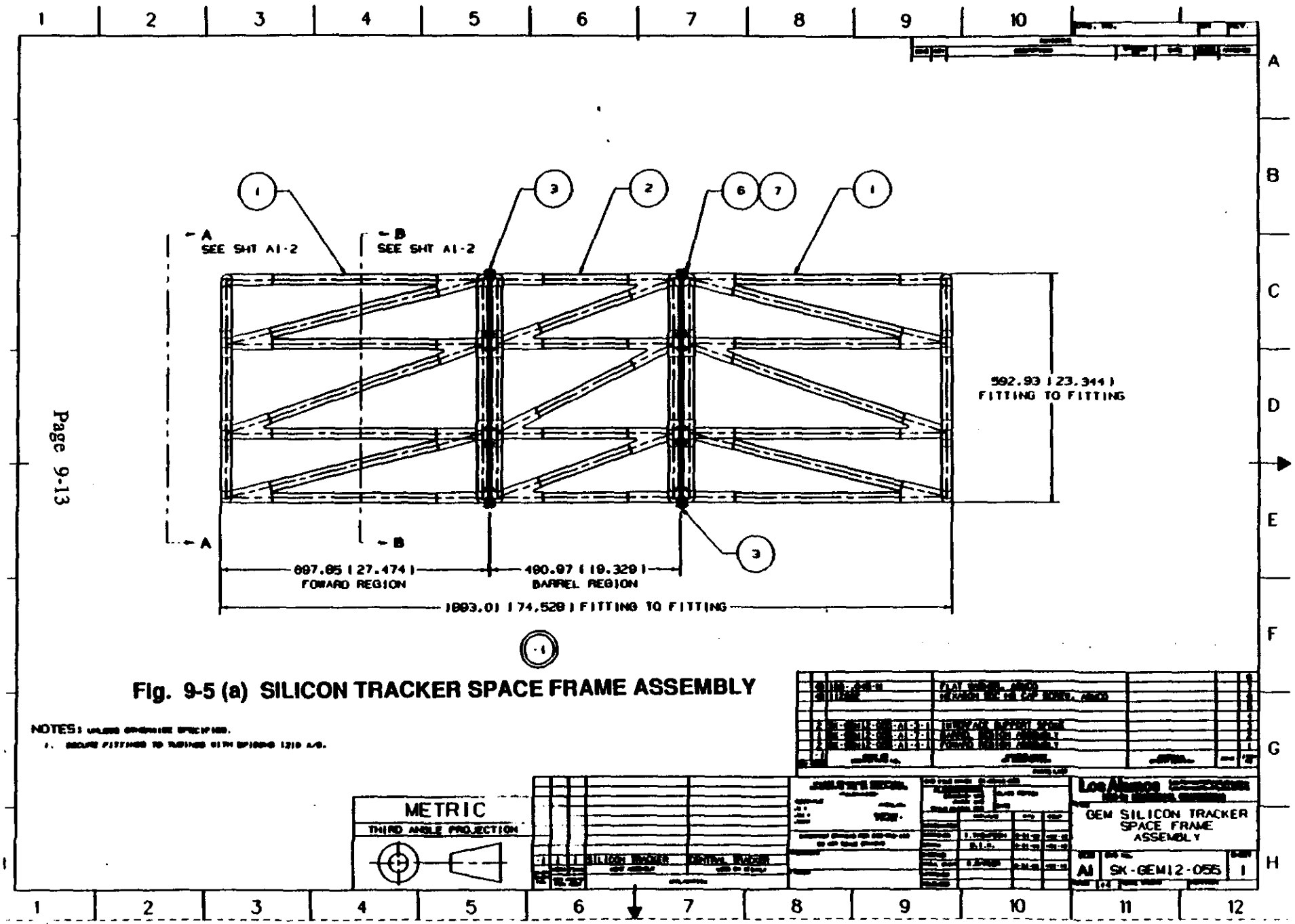


Fig. 9-5 (a) SILICON TRACKER SPACE FRAME ASSEMBLY

NOTES: UNLESS OTHERWISE SPECIFIED.
1. SECURE FITTINGS TO TUBINGS WITH SPIGNO 1210 A/B.

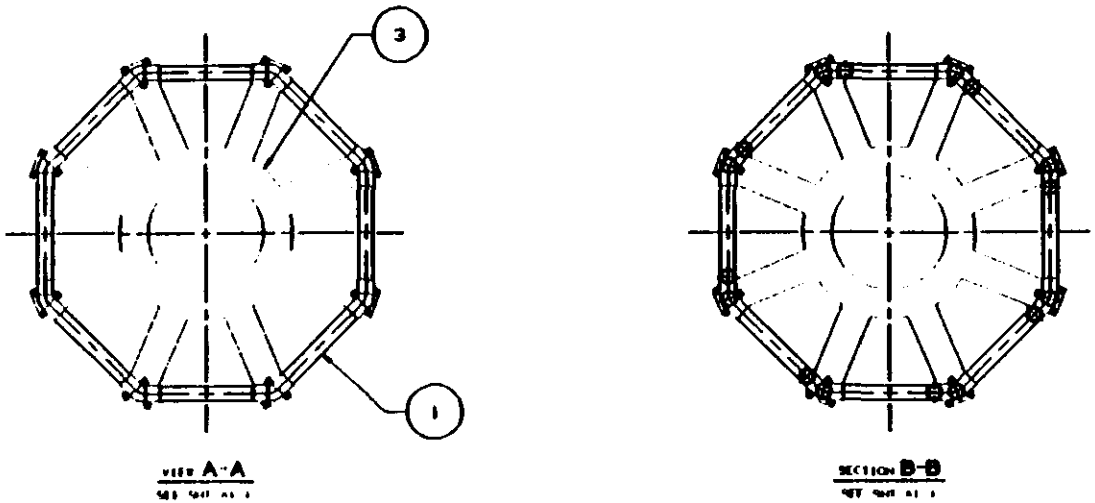
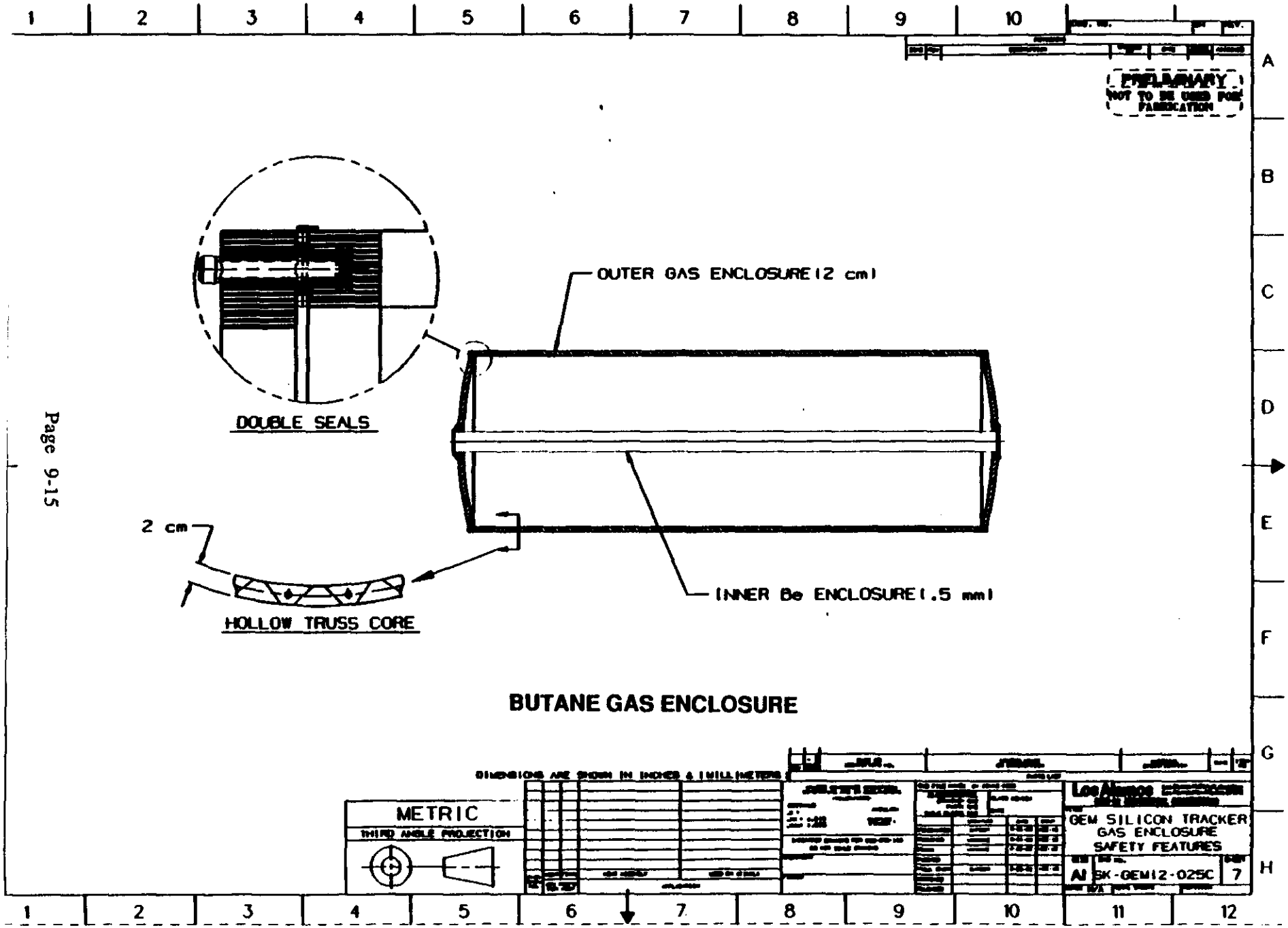


Fig. 9-5 (b) SILICON TRACKER SPACE FRAME SECTIONS

METRIC
THIRD ANGLE PROJECTION

GEM SILICON TRACKER
SPACE FRAME
ASSEMBLY VIEW & SETION

A1 SK-GEM12-055 2


PRELIMINARY
NOT TO BE USED FOR FABRICATION
OUTER GAS ENCLOSURE (2 cm)
DOUBLE SEALS
2 cm
HOLLOW TRUSS CORE
INNER Be ENCLOSURE (.5 mm)
BUTANE GAS ENCLOSURE
DIMENSIONS ARE SHOWN IN INCHES & [MILLIMETERS]
METRIC
THIRD ANGLE PROJECTION
Los Alamos
GEM SILICON TRACKER
GAS ENCLOSURE
SAFETY FEATURES
A1
SK-GEM12-025C
7

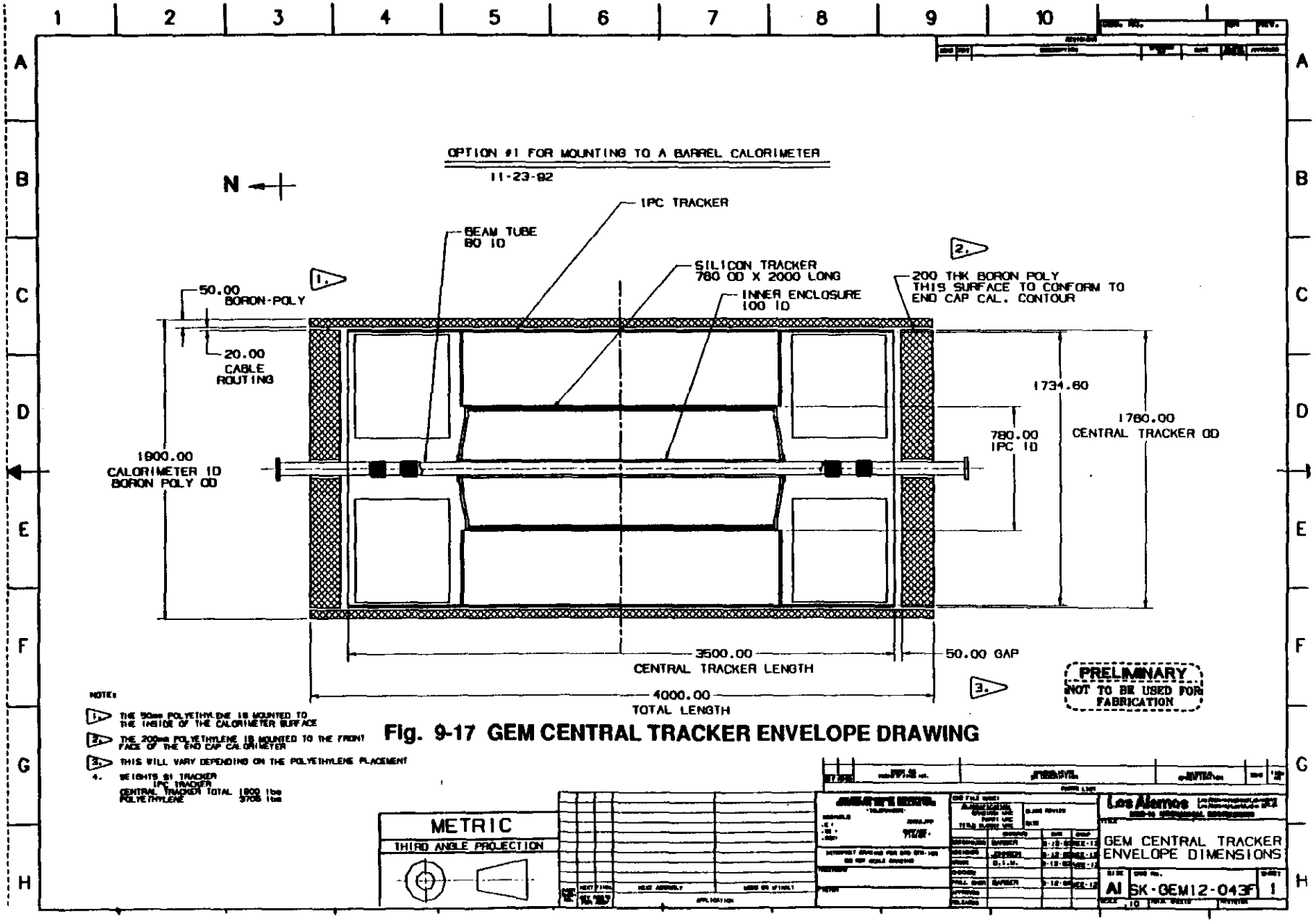


Fig. 9-17 GEM CENTRAL TRACKER ENVELOPE DRAWING

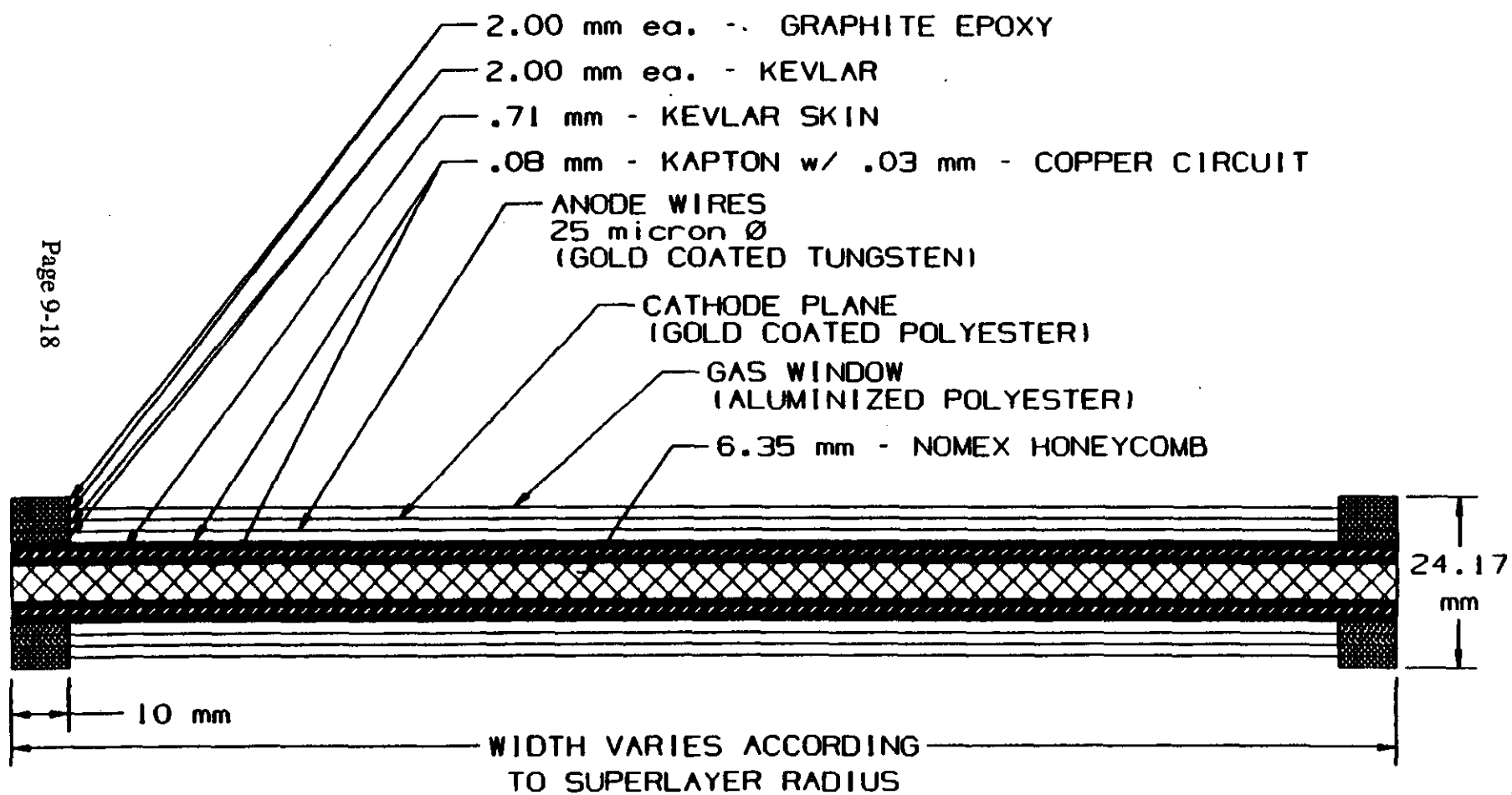
IPC Design Parameters	
Parameter	Quantity
Beam crossing rate	60 Mhz
Charged track density/min bias event	$dN/d\eta d\phi = 1.2$
Number min bias events/crossing@ 10^{34} Lum	16
Tracks/sec-mm wire @ 10^{34}	$1 \times 10^4\ s^{-1}mm^{-1}$
Integrated charge/yr-cm wire @ 10^{34}	1.4 C/cm-yr
Position resolution (pads)	50 μm
Position resolution (Wires)	600 μm
Occupancy @ 10^{34}	< 10 %
Wire spacing	2 mm
Anode-Cathode spacing	2 mm
Wire diameter	40 μm
Voltage	3000 volts
Gas	50-50 CO_2-CF_4
Barrel channel count	16000

IPC Array Design Parameters	
Parameter	Quantity
Lorenz angle	12 degrees
Number of sectors - barrel superlayer	20
Number of sectors - endcap superlayer	10
Number of superlayers - barrel and endcap	4
Number of chambers per superlayer	2
Chamber depth (cathode to cathode)	4 mm
Anode wire pitch - barrel and endcap	2 mm
Anode wire diameter	$25 \leq d \leq 40$ μm
Anode wire potential	3 Kv
Barrel IPC superlayer length	200 cm
Barrel IPC array inner radius boundary	35 cm
Barrel IPC array outer radius boundary	70 cm
Endcap IPC minimum axial boundary	110 cm
Endcap IPC maximum axial boundary	140 cm
Chevron pad width in ϕ	0.5 cm
Number of barrel pads	222360
Number of pads (each endcap)	87280
Electronics power dissipation - barrel	13.6 Kw
Electronics power dissipation - each endcap	5.2 Kw

IPC Array Stability Requirements	
Parameter	Quantity
Between superlayer modules in ϕ	25 μm
Between superlayers modules in z	100 μm
Between endcaps and barrel in ϕ	25 μm
Between endcaps and barren in z	100 μm
Maximum superlayer module deflection	1000 μm
Module transverse flatness	160 μm
-or-	20 μm over adjacent pads

Source: K. Morgan/R. Barber
Updated: 6/25/92

GEM IPC SUPERLAYER

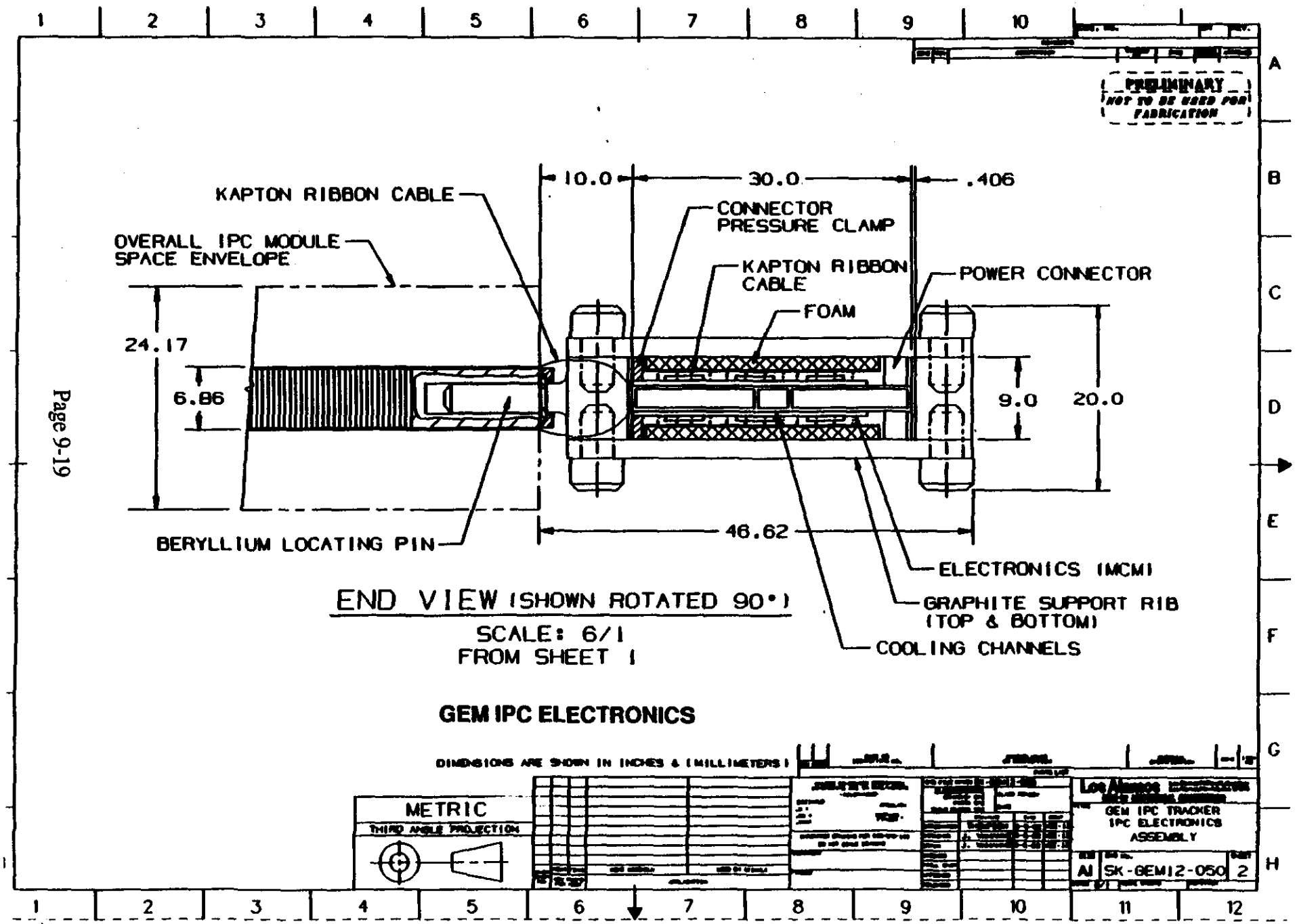


ALL DIMENSIONS ARE IN mm

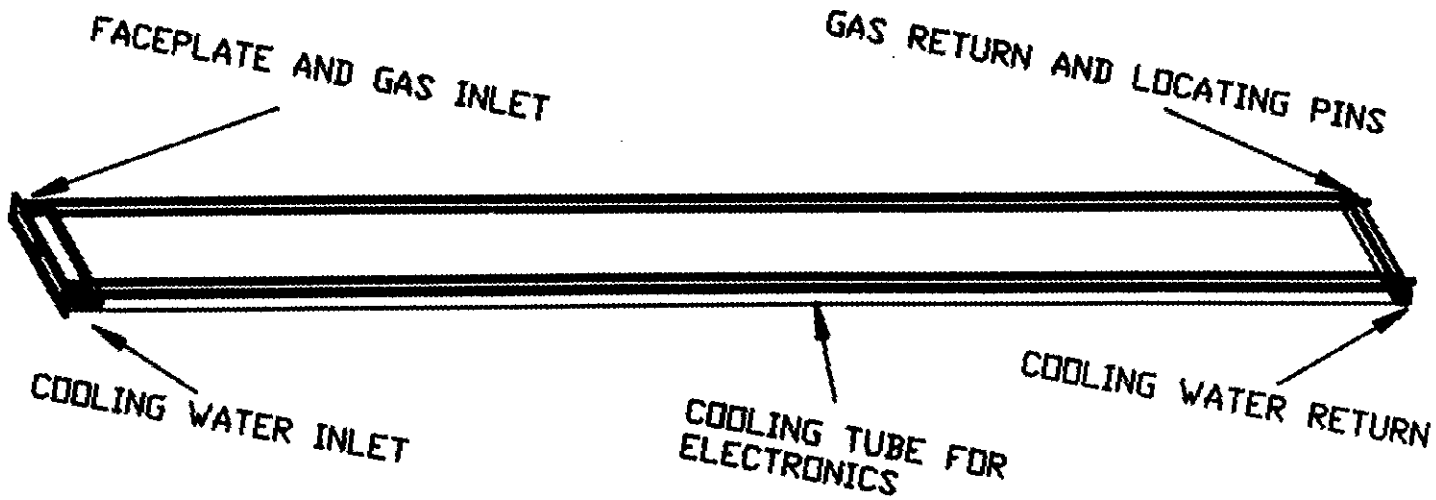
GEMVG-IPC-SUPERLAYER

gem

LANL


PRELIMINARY
NOT TO BE USED FOR FABRICATION
KAPTON RIBBON CABLE
OVERALL IPC MODULE SPACE ENVELOPE
10.0
30.0
.406
CONNECTOR PRESSURE CLAMP
KAPTON RIBBON CABLE
POWER CONNECTOR
FOAM
24.17
6.86
9.0
20.0
46.62
BERYLLIUM LOCATING PIN
ELECTRONICS (MCM)
GRAPHITE SUPPORT RIB (TOP & BOTTOM)
COOLING CHANNELS
END VIEW (SHOWN ROTATED 90°)
SCALE: 6/1
FROM SHEET 1
GEM IPC ELECTRONICS
DIMENSIONS ARE SHOWN IN INCHES & (MILLIMETERS)
METRIC
THIRD ANGLE PROJECTION
Los Alamos
GEM IPC TRACKER
IPC ELECTRONICS
ASSEMBLY
A1
SK-GEM12-050
2

IPC SUPERLAYER



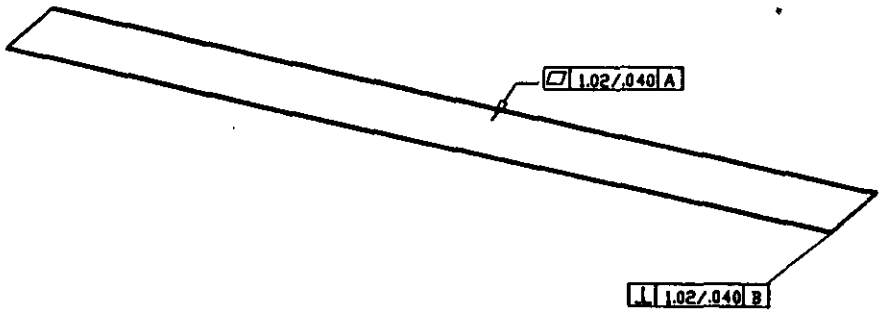
Through panel only	Layer Th. (cm)	Rad. Lngth (cm)	%
Graphite version			
Copper circuit	0.00254	1.44	0.18%
Kapton H film	0.00762	28.40	0.03%
Rohacel foam	0.0508	900.00	0.01%
Kapton H film	0.00762	28.40	0.03%
Copper circuit	0.00254	1.44	0.18%
Rohacel foam	0.0508	900.00	0.01%
Gr/E skin	0.02032	25.00	0.08%
Gr/P core	0.635	879.00	0.07%
Gr/E skin	0.02032	25.00	0.08%
Rohacel foam	0.0508	900.00	0.01%
Copper circuit	0.00254	1.44	0.18%
Kapton H film	0.00762	28.40	0.03%
Rohacel foam	0.0508	900.00	0.01%
Kapton H film	0.00762	28.40	0.03%
Copper circuit	0.00254	1.44	0.18%
TOTAL %			1.07%

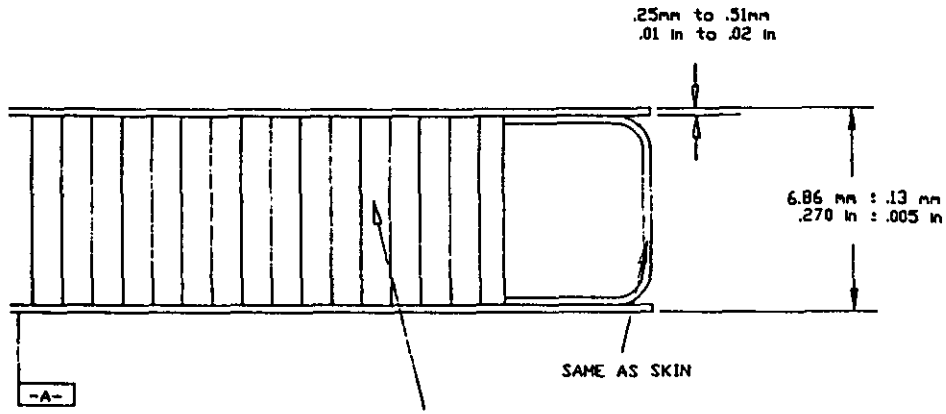
Kevlar version			
Copper circuit	0.00254	1.44	0.18%
Kapton H film	0.00762	28.40	0.03%
Kevlar skin	0.07112	30.00	0.24%
Kapton H film	0.00762	28.40	0.03%
Copper circuit	0.00254	1.44	0.18%
Nomex	0.635	900.00	0.07%
Copper circuit	0.00254	1.44	0.18%
Kapton H film	0.00762	28.40	0.03%
Kevlar skin	0.07112	30.00	0.24%
Kapton H film	0.00762	28.40	0.03%
Copper circuit	0.00254	1.44	0.18%
TOTAL %			1.36%

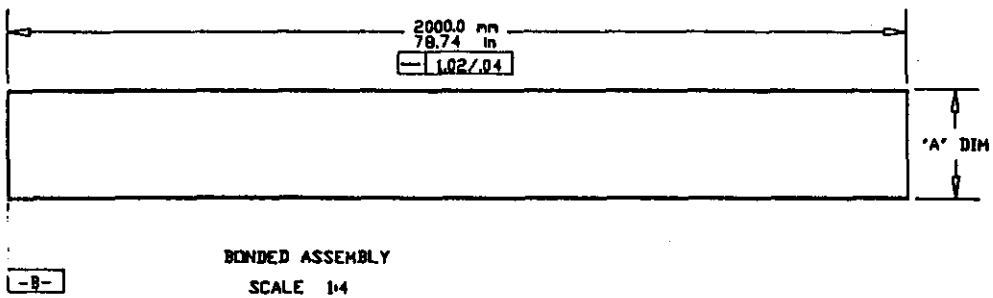
Electronics assembly			
Through center section	Layer Th. (cm)	Rad. Lngth (cm)	%
Graphite Epoxy	0.0201	25.00	0.08%
Foam (open cell)	0.0175	1200.00	0.00%
Kapton H film	0.05	28.40	0.18%
Copper circuit	0.00254	1.44	0.18%
Aluminum Nitride	0.0508	8.30	0.61%
Graphite Epoxy	0.041	25.00	0.16%
cooling medium (H2O)	0.201	36.10	0.56%
Graphite Epoxy	0.041	25.00	0.16%
Aluminum Nitride	0.0508	8.30	0.61%
Copper circuit	0.00254	1.44	0.18%
Kapton H film	0.05	28.40	0.18%
Foam (open cell)	0.0175	1200.00	0.00%
Graphite Epoxy	0.0201	25.00	0.08%
TOTAL %	[redacted]		2.98%

Through panel & frame	Layer Th. (cm)	Rad. Lngth (cm)	%
Graphite version			
Graphite skin	0.2	25.00	0.80%
Kevlar skin	0.2	30.00	0.67%
Kevlar skin	0.2	30.00	0.67%
Copper circuit	0.00254	1.44	0.18%
Kapton H film	0.00762	28.40	0.03%
Rohacel foam	0.0508	900.00	0.01%
Kapton H film	0.00762	28.40	0.03%
Copper circuit	0.00254	1.44	0.18%
Rohacel foam	0.0508	900.00	0.01%
Gr/E skin	0.02032	25.00	0.08%
Gr/P core	0.635	879.00	0.07%
Gr/E skin	0.02032	25.00	0.08%
Rohacel foam	0.0508	900.00	0.01%
Copper circuit	0.00254	1.44	0.18%
Kapton H film	0.00762	28.40	0.03%
Rohacel foam	0.0508	900.00	0.01%
Kapton H film	0.00762	28.40	0.03%
Copper circuit	0.00254	1.44	0.18%
Kevlar skin	0.2	30.00	0.67%
Kevlar skin	0.2	30.00	0.67%
Graphite skin	0.2	25.00	0.80%
TOTAL %			5.34%

Kevlar version			
Graphite skin	0.2	25.00	0.80%
Kevlar skin	0.2	30.00	0.67%
Kevlar skin	0.2	30.00	0.67%
Copper circuit	0.00254	1.44	0.18%
Kapton H film	0.00762	28.40	0.03%
Kevlar skin	0.07112	30.00	0.24%
Kapton H film	0.00762	28.40	0.03%
Copper circuit	0.00254	1.44	0.18%
Nomex	0.635	900.00	0.07%
Copper circuit	0.00254	1.44	0.18%
Kapton H film	0.00762	28.40	0.03%
Kevlar skin	0.07112	30.00	0.24%
Kapton H film	0.00762	28.40	0.03%
Copper circuit	0.00254	1.44	0.18%
Kevlar skin	0.2	30.00	0.67%
Kevlar skin	0.2	30.00	0.67%
Graphite skin	0.2	25.00	0.80%
TOTAL %			5.62%

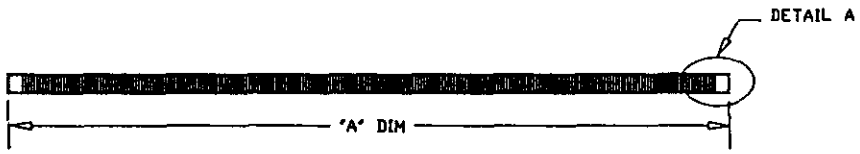






BONDED ASSEMBLY

SCALE 1:4



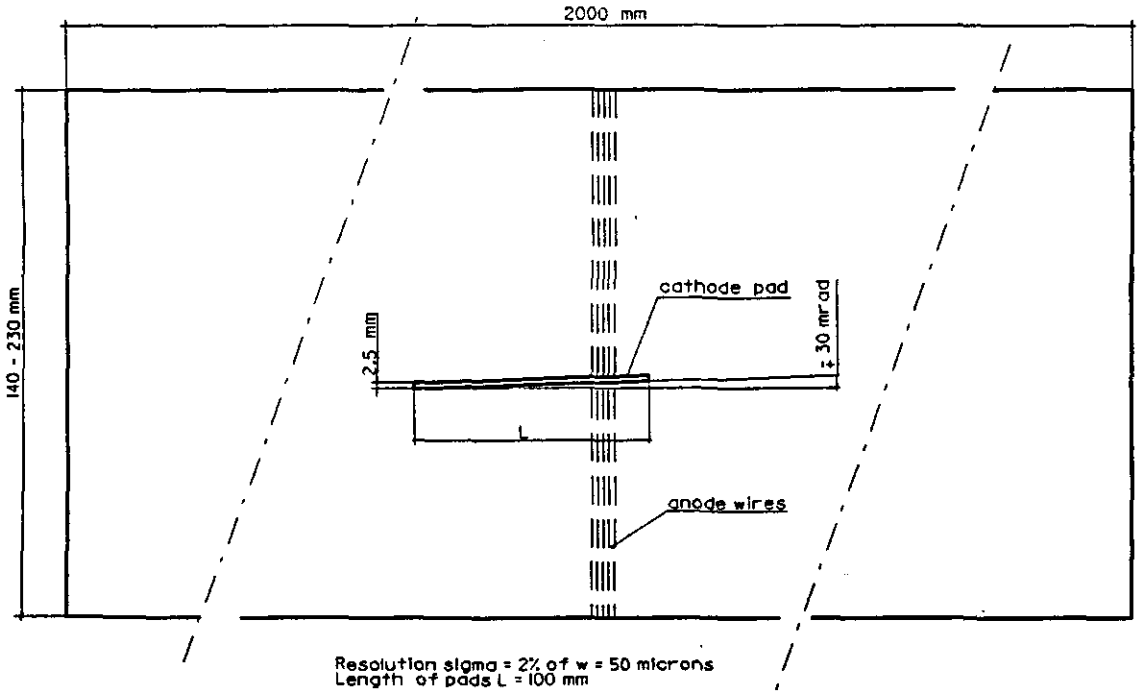
BONDED PANEL END VIEW

SCALE 2:1

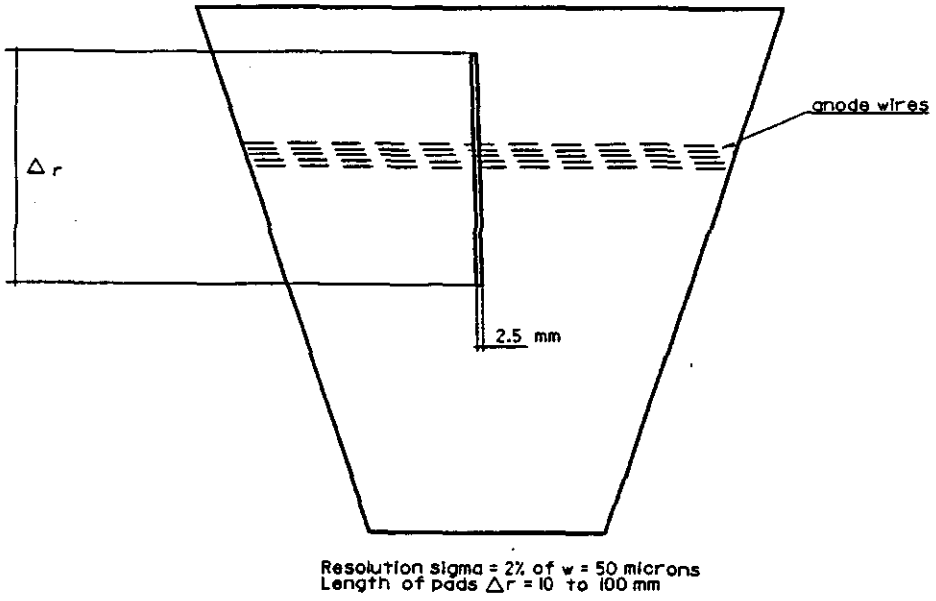
ITEM	'A' DIM		
1	243.8 mm - 9.60 in	—	.13/.005
2	214.4 mm - 8.44 in	—	.13/.005
3	187.8 mm - 7.39 in	—	.13/.005
4	150.9 mm - 5.94 in	—	.13/.005

ALL DIMENTIONS ARE IN MILLIMETERS/INCHES	YALE UNIVERSITY		
	TITLE GEM IPC TRACKER BARREL MODULE		
CHECKED W.EMMET	NAME J.SINNOTT		SECTION P.P.G
APPROVED W.EMMET	SCALE SHOWN	INST	SHEET 1

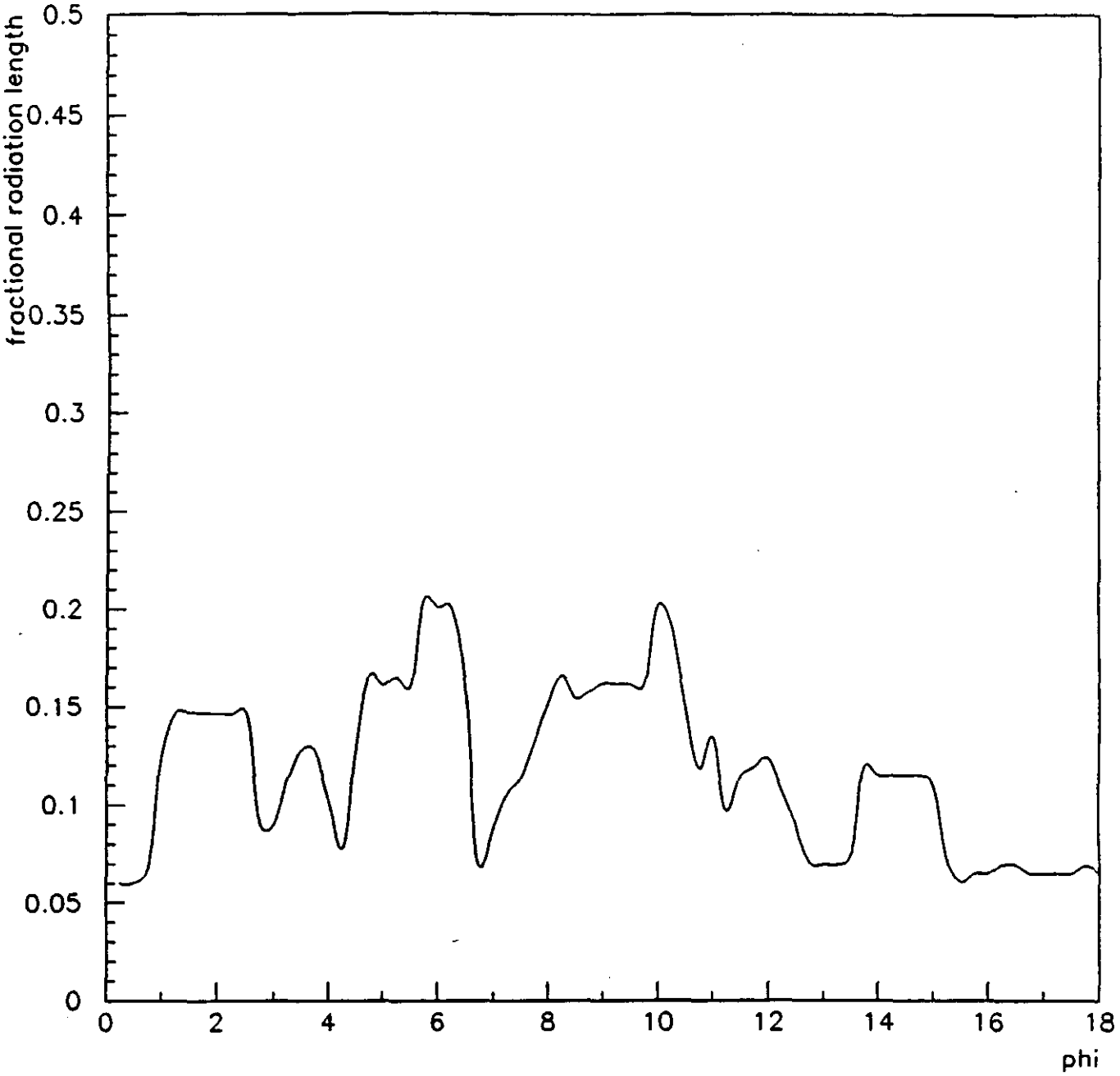
a) Cell geometry viewed along the wire



b) Pad arrangement in the Barrel Chambers



c) Pad arrangement in the End Cap Chambers



Phi Across One Module (in degrees)

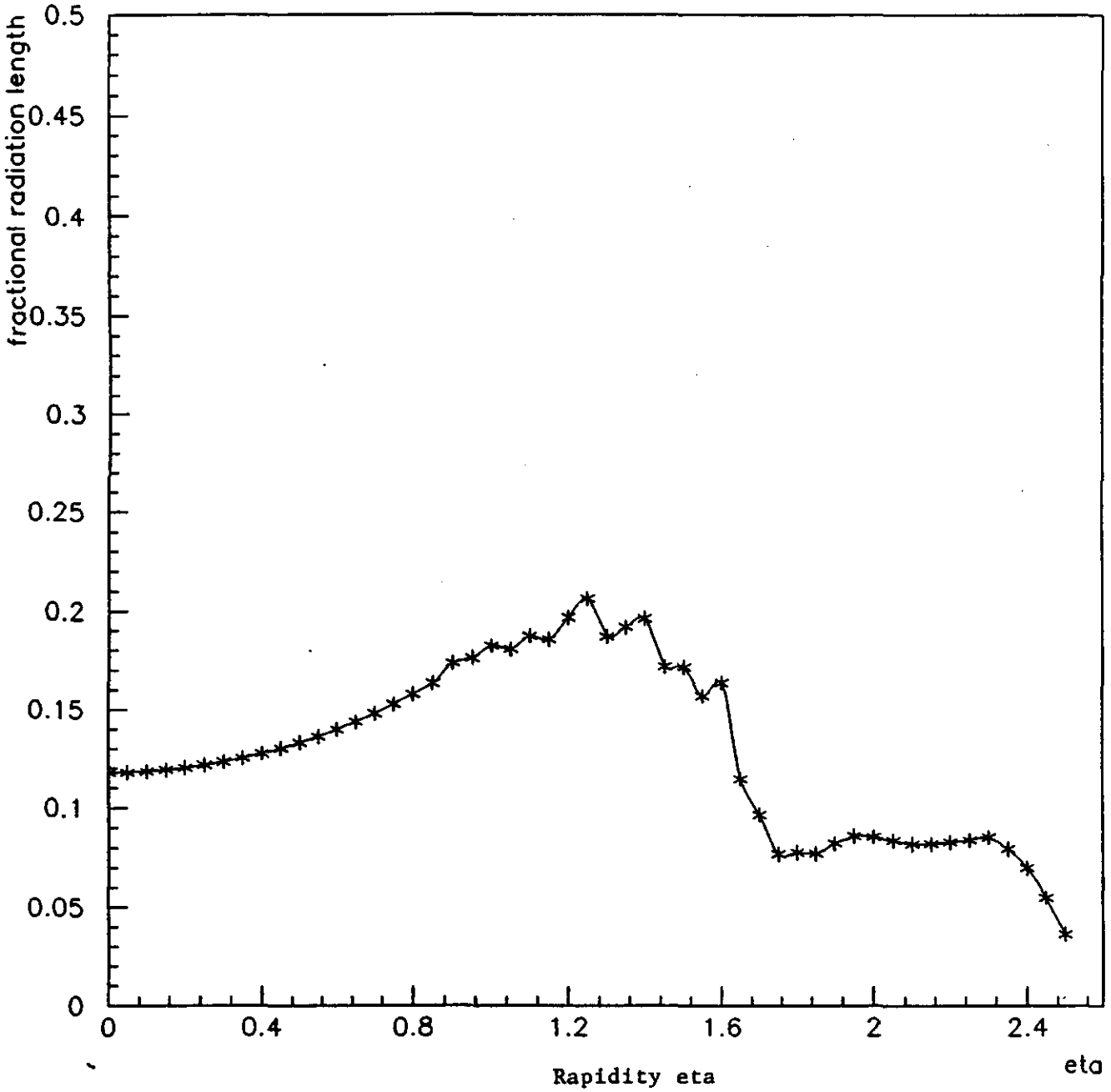


Fig 9-12 MATERIAL IN CENTRAL TRACKER EXCLUDING OUTERMOST PAD CHAMBERS AND FORWARD OUTERMOST ELECTRONICS

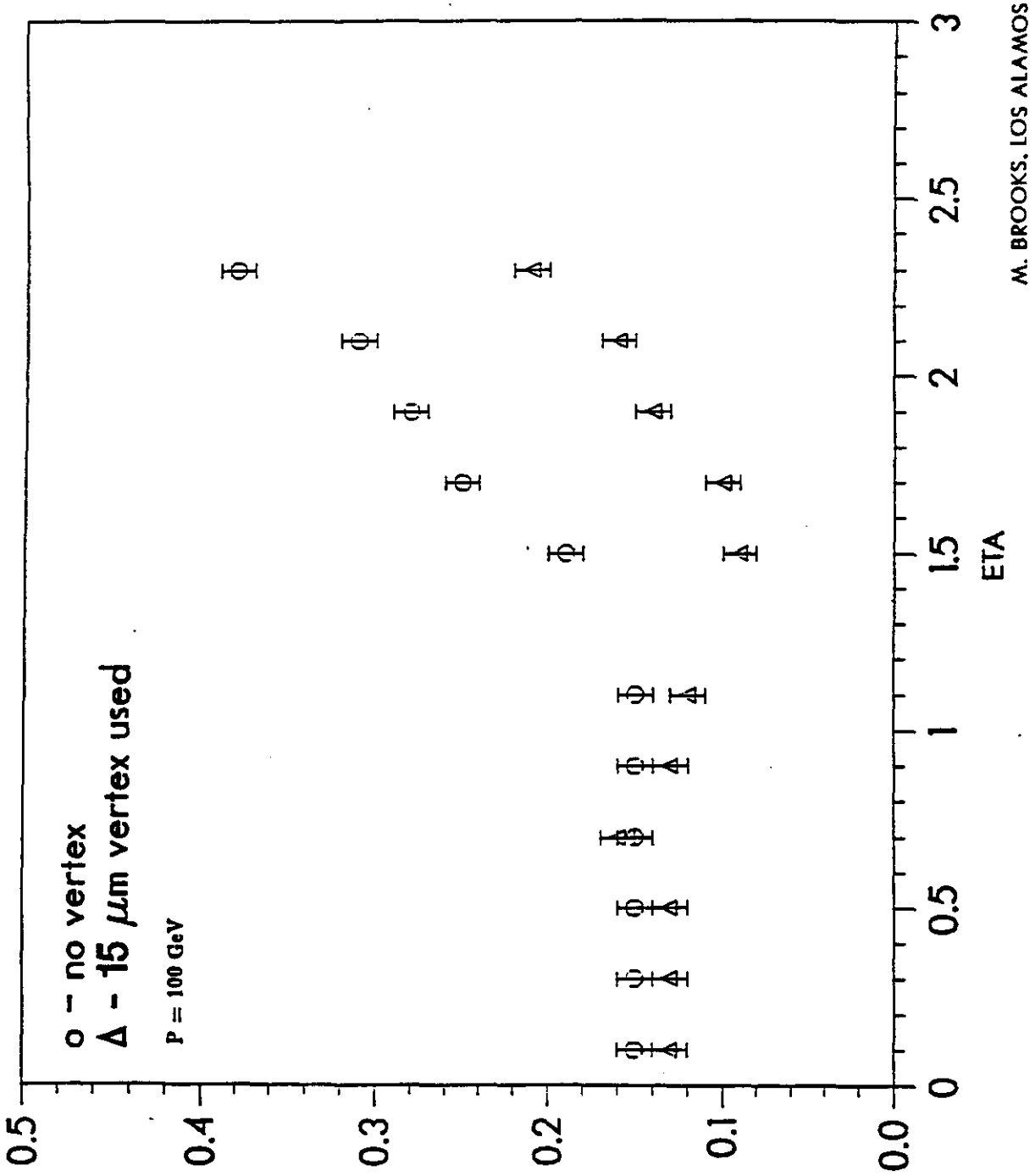
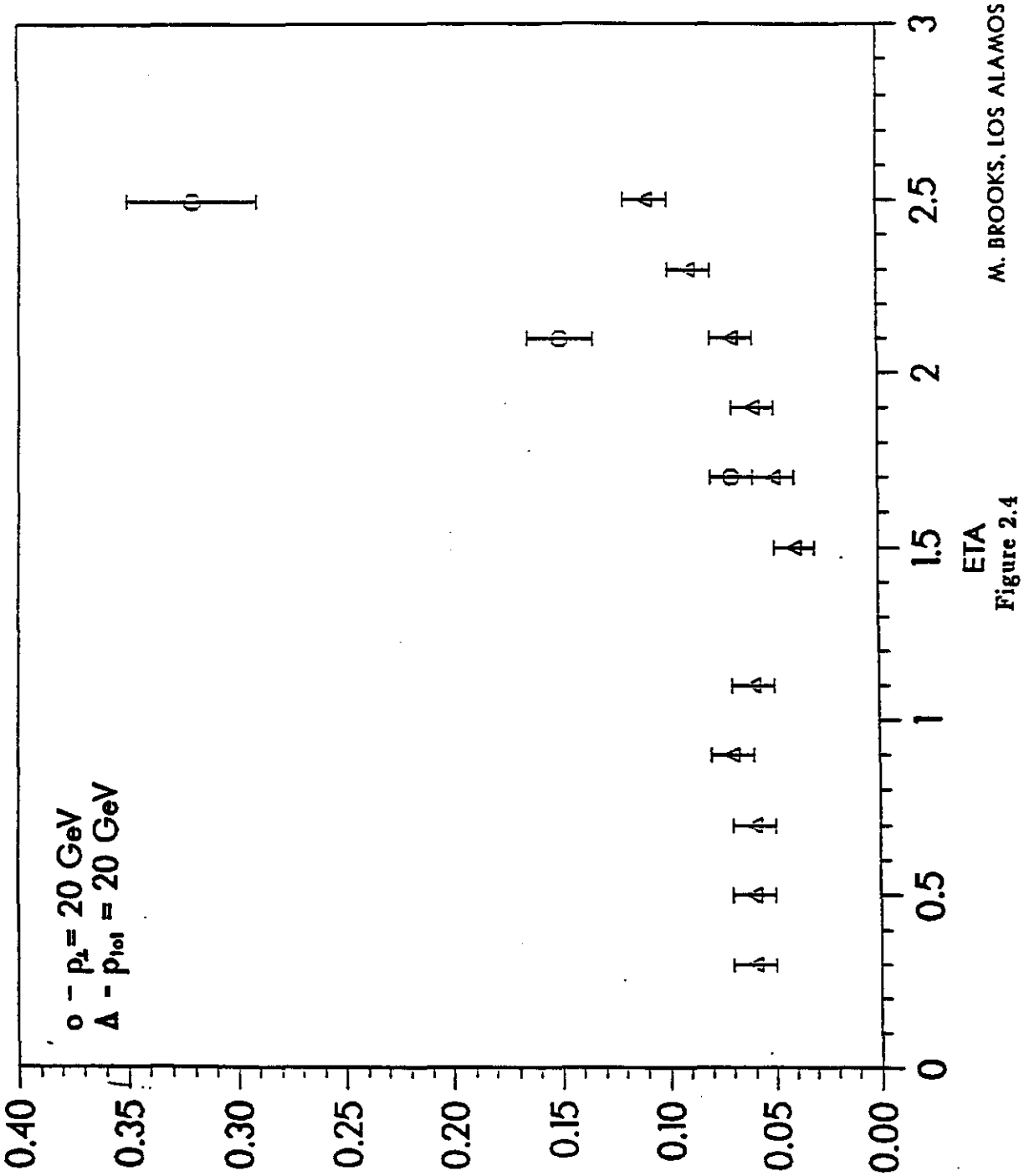


Figure 2.3b

MOMENTUM RESOLUTION VERSUS ETA
FOR 100 GeV PARTICLES (measurement limited case)



TRANSVERSE MOMENTUM RESOLUTION VERSUS ETA FOR 20 GeV PARTICLES (multiple scattering limited)

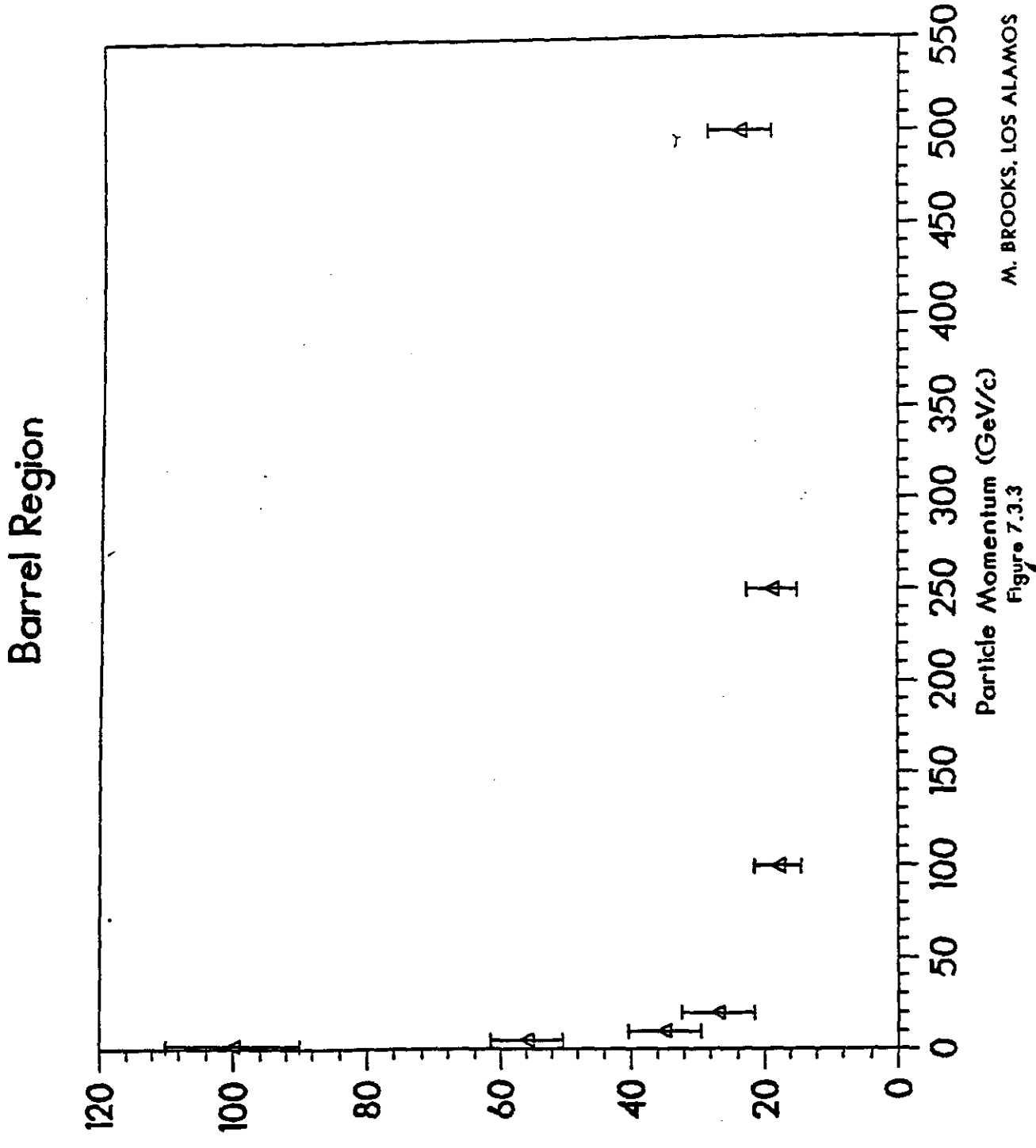
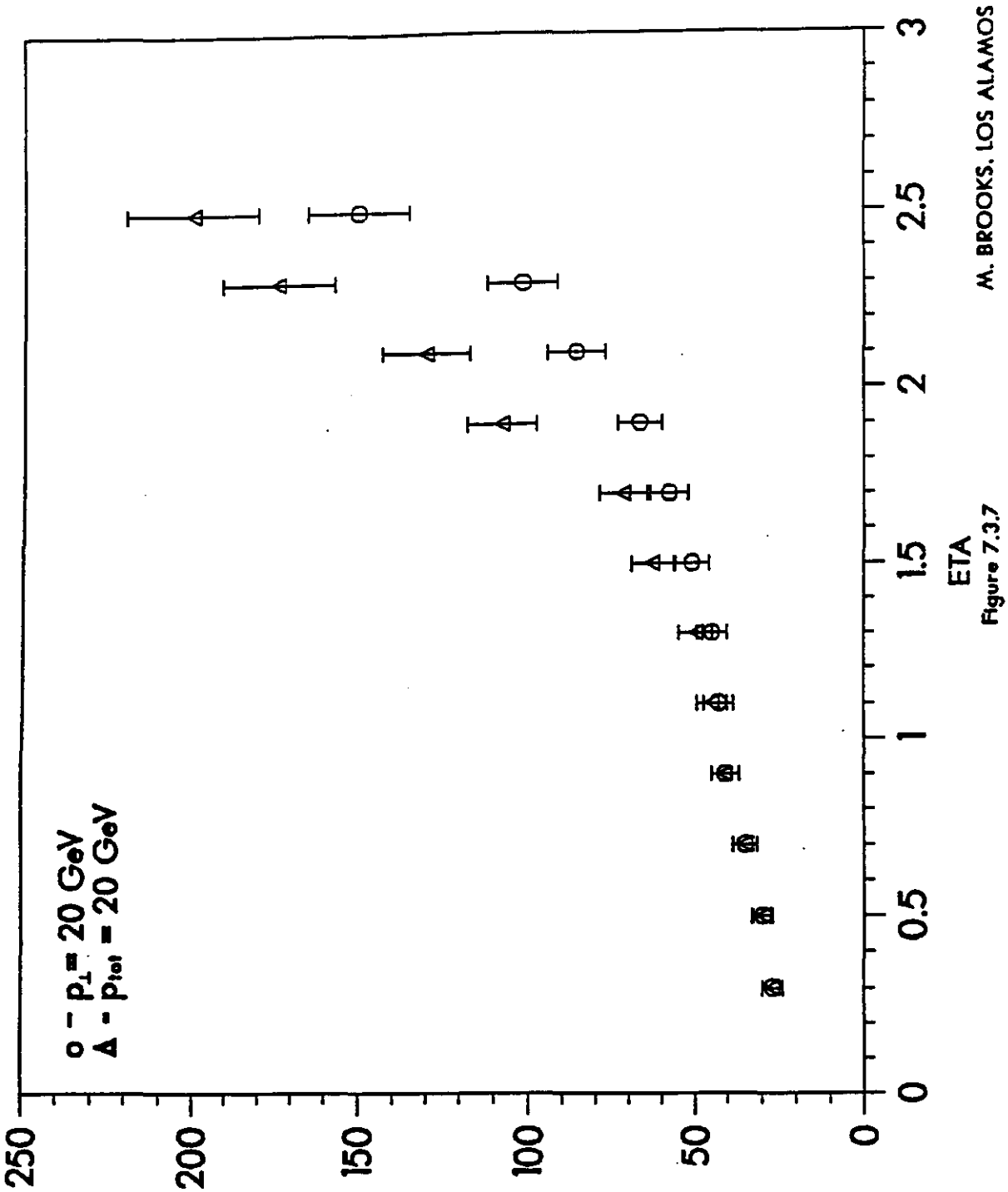


Figure 7.3.3

IMPACT PARAMETER RESOLUTION VERSUS MOMENTUM



IMPACT PARAMETER VERSUS ETA

10. CALORIMETER

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Endcap Accordion EM
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Barrel Hadronic Module
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OVERVIEW

The GEM collaboration has selected a hybrid calorimeter which is composed of a barrel liquid krypton (endcap liquid argon) inner calorimeter followed by a scintillator/copper outer calorimeter. This choice reflects the goal of developing a major detector for the SSC which emphasizes the discovery potential of gamma, electron and muon final states with important abilities for $\not{E}_t$ and high luminosity. We intend to optimize the use of this dual technology calorimeter. The liquid krypton technique will allow precise energy resolution while maintaining robustness against backgrounds.

This section describes the present baseline parameters for the calorimeter system. The noble liquid section of the calorimeter allows GEM to achieve its design goal of energy resolution better than $7.5\%/\sqrt{E} \oplus 0.5\%$. It has inherent system stability and uniformity over time as well as linearity enabling calibration of the system to 0.2%-0.3%. Using fast shaping, time resolution of the order of nanoseconds can be obtained with signal to noise many times larger than that of minimum ionizing particles. The scintillating outer calorimeter, which is about 5 λ in depth, measures jet hadronic energy and provides information on muon energy deposition and ensures a quiet environment for the muon spectrometer.

The noble liquid portion of the calorimeter is divided into three vessels: a barrel annulus and two endcap calorimeters. These are fully contained in the barrel scintillating calorimeter. This system is supplemented by a forward calorimeter.

Electromagnetic Calorimeter

The goal for the electromagnetic calorimeter (EM) is to achieve an energy resolution of better than $7.5\%/\sqrt{E} \oplus 0.5\%$. There are 25 X_0 in the barrel and 28 X_0 in the endcap since the mean energy is higher there. The absorber plates are a composite of lead, prepreg and stainless steel skins. The plate thickness is kept constant in η, but the fraction of lead is decreased at higher η to maintain resolution. The EM calorimeter covers the region $-3 < \eta < 3$.

Electrode Structure. The EM calorimeter will utilize the accordion design with signals collected on electrodes (which are transmission lines) and sums the signal longitudinally. In the GEM design there are 4

cells per tower and the granularity in the η, ϕ directions is 0.026 × 0.026. Each tower will be segmented into three sections longitudinally, of 4, 8, and 13 radiation lengths. The transverse and longitudinal segmentation allows one to get a position resolution at the face of the calorimeter of better than $5mm/\sqrt{E}$ and to be able to point back to the vertex with an angular resolution of better than 6 mrad at 120 GeV. The small transverse segmentation will also be beneficial in improving the π^0 to γ separation using shower shape analysis. There will be ~ 104,000 EM channels.

Readout. The readout chain for the calorimeter will consist of a JFET pre-amp that will be placed inside the LAr calorimeter, and able to survive more than 200 Mrad. The shaping amplifiers will be located in standard crates on the central detector support outside the magnet coil. For the electromagnetic section we are planning to use shaping time of 40 ns. This shaping time minimizes the total contribution to the noise from both beam related pileup and thermal noise. For a typical tower at $\eta = 0$ we will get thermal noise of 20 MeV and pileup noise of 25 MeV at $10^{33}cm^{-2}s^{-1}$. The noise in the EM section does not significantly affect energy resolution and/or isolation criteria using cluster algorithms to reconstruct the energy. The output of the shaper is sampled every 16 ns and stored in dual range AMU. Each AMU should have a dynamic range of 12 bits. The AMU output is multiplexed into a 12 bit ADC.

To achieve the required dynamic range of 10^5 with the accuracy required, we are planning to use a nonlinear pre-amp that will have a linear response up to an energy of about 200 GeV and then condense the upper end of the dynamic range. Thirty-six towers (6 × 6) are added together for an EM trigger tower (0.16 × 0.16).

Noble Liquid Hadronic Calorimeter

The requirements on the hadronic calorimeter are less stringent than the electromagnetic calorimeter but it is still a formidable challenge to achieve the needed requirements. The physics objectives are to achieve an energy resolution of $60\%/\sqrt{E} \oplus 2\%$.

EST electrode structure. In order to match the detector capacitance to that of the pre-amp, we are planning to use the "electrostatic transformer" configuration in the hadronic section, by adding layers in

series. The absorber material will be lead tiles in the barrel and copper tiles in the endcap. The transformer ratio is 4.

Segmentation. The hadronic segmentation is determined by the size of the hadronic shower and the need to match up with the EM granularity. We have thus selected a granularity of 0.08×0.08 in η and ϕ. There are three readouts in depth in the barrel, and four in the endcaps. Sixteen non-overlapping towers (4×4) will be added together for a hadron veto for each EM trigger tower. Four of these veto towers will be added together for a jet trigger tower. There will be ~ 20,000 channels in this hadronic section.

Cryostat. The cryostat will be an aluminum alloy with a thickness 0.3 X_0 at the entrance at $\eta = 0$. For the endcap, the total thickness will be 0.7 X_0. The interface between the barrel and the endcap, from $1 \leq \eta \leq 1.15$, will have degraded EM resolution but will have useful comparable hadronic resolution.

Installation and Assembly. The hadronic granularity leads naturally to 40 hadronic modules. In the EM section, we envision building mini-modules consisting of about 6 towers or 9°in ϕ.. The full barrel will have 240 towers in ϕ. In the endcap there would be 20 modules in ϕ for the hadronic modules, while the EM in the endcap would be a monolith. The 40 EM mini-modules and hadronic modules will be assembled at the SSC Lab inside the cryostat. The cryostat itself will then be welded shut. The calorimeter will be fully assembled above ground and tested before being installed in the experimental hall.

Scintillating Hadron Calorimeter

The properties of a scintillating hadron calorimeter are inherent speed (allowing a 32 ns gate width), compactness, adjustable compensation via the selection of an appropriate scintillator/absorber ratio, hermeticity, and simplicity of construction. The scintillating calorimeter section will have five longitudinal segments. The segmentation in ϕ is .04. Segmentation in η, which will be achieved via time division, is expected to be about 15 cm. The scintillator will be read out by photo tubes at each end.

Forward Calorimeter

Electromagnetic Section. This section will be immersed in liquid argon. It will be built out of tungsten rods and tubes creating a small drift distance which is needed to minimize the positive charge buildup. The forward calorimeter will cover the region of $3 < \eta < 5.5$. The E_t resolution is expected to be 10% independent of the energy since the error will be dominated by the angular resolution.

Hadronic Section. This section will provide coverage out to $\eta = 5.5$ while also backing the electromagnetic section. It is designed for location as close to the beam pipe as is possible. It uses tungsten absorbers to maximize transverse containment of hadronic showers and may be read out with scintillating material.

Revision 3.0; Nov. 17, 1992

10.1.0 Calorimeter Baseline

10.1.1.0 Primary Physics Goals

10.1.1.1 Lead/Liquid Krypton/Argon EM Calorimeter (EM)

- Precision energy measurement of isolated photons or electrons.
- Precision impact coordinate measurement at the front surface of the calorimeter for isolated photons and electrons; momentum vector determination, using two longitudinal segments of the EM calorimeter.
- e/π separation using longitudinal and transverse segmentation.
- Search for narrow resonances by reconstructing the invariant mass of multi-photons or electrons.

10.1.1.2 Liquid Krypton/Lead (Argon/Copper) Hadron Calorimeter (HAD)

- Electron and photon identification (hadron veto).
- Muon identification, isolation, and pattern recognition.
- Muon energy loss measurement.
- Jet energy measurement.
- Missing energy measurement (using also EM and Forward calorimeters).

10.1.1.3 Barrel Scintillator Calorimeter

- Muon energy loss measurement.
- Jet energy measurement.
- Missing energy measurement (using also EM and Forward calorimeters).

10.1.1.4 Forward Liquid Argon/Tungsten Calorimeter (FWEM)/Scintillating Forward Hadron(FWD)

- Missing energy measurement (using also EM and HAD calorimeters).
- Jet tagging.

Source: W. Willis
Updated: 11/92

10.1.2.0 Secondary Physics Capabilities

- Provide a fast trigger for tagging the beam crossing.
- Rejection of backgrounds with isolation cuts at the trigger level.

10.1.3.0 Unique Physics Capabilities

- Higgs searches: $H^\circ \rightarrow \gamma\gamma$
  $t\bar{t}\ H^\circ/WH^\circ \rightarrow \gamma\gamma$
  $H^\circ \rightarrow e^+e^-e^+e^-$ (including ZZ*).
- Toponium searches: $\theta \rightarrow \gamma\gamma$.
- $Z^{\circ\prime}$ searches: $Z^{\circ\prime} \rightarrow e^+e^-$.
- Search for unknown narrow resonances which decay to multi-photons and/or electrons.
- Jet energy measurements up to the highest energies.
- Missing energy at the 100 GeV level.

10.1.4.0 Physics Performance

Time resolution

$E_{EM} \geq 20$ GeV	$\Delta t \leq 1$ ns
$E_{jet} \geq 50$ GeV	$\Delta t \leq 3$ ns

Speed shaping time

EM	20-40 ns
HAD(Liquid)	50-200 ns
Scintillating Barrel Calorimeter	Waveform Recording, 4 ns sampling
FWD	16 ns

Noise (thermal/pileup at $L=10^{33}$ cm^{-2} s^{-1})

EM	20/25 MeV/tower (0.026×0.026)
HAD	1st Hadronic(1λ): 75/50 MeV (0.08×0.08)
	2nd & 3rd Hadronic(3.5λ) 135/60 MeV
Scintillating Barrel Calorimeter	1/5 MIPS

Source: W. Willis
Updated: 11/92

Hermeticity (E_t Measured)	$0 < \eta < 5.5$
EM energy resolution - Barrel	$6\% / \sqrt{E} \oplus 0.4\%$
- Endcap	$7.5\% / \sqrt{E} \oplus 0.4\%$
EM position resolution	4.4 mm $/\sqrt{E}$
EM Pointing resolution	40 mrad$/\sqrt{E}$
EM dynamic range	-10^5(up to ~10 TeV)
Hadron energy resolution (Jets)	$60\% / \sqrt{E} \oplus 2.5\%$
Hadron dynamic range	10^5 - 50 MeV to 5 TeV
Number of absorption lengths	
at $\eta = 0$	>11
at $\eta = 3.0$	11 active, 16.5 total
Barrel Dimensions	
inner radius	0.95 m
outer radius	3.70 m
Lateral segmentation	
EM	0.026×0.026
HAD	0.08×0.08
Longitudinal segmentation	3 EM, 3 HAD(in liquid)barrel; 4 Endcap 5 Layers in Scintillator

10.1.5.0 Physical Parameters

10.1.5.1 Lead Liquid Krypton/Argon EM Calorimeter

Absorber material	0.2 mm SS/0.1 mm prepreg/1 mm Pb 0.1mm prepreg/0.2mm SS
Readout Board	0.4mm (Kapton/Cu)
Sense Material	2 x 2 mm argon
Lateral segmentation (η, ϕ)	0.026×0.026
Longitudinal segmentation	3(4 X_0, 8 X_0, 13 X_0)
Inner Radius (cryostat/accordion)	950/1077 mm
Outer Radius (accordion)	1597 mm

Source: W. Willis
Updated: 11/92

Radiation Lengths	25 X_0 at $\eta = 0$; 28 X_0 at $\eta = 3$	
Absorption Lengths	1.3	λ
Number of Channels-Total	18,720×3=56,160 Barrel 7,938×3=23,814 /Endcap 103,788 Total	
Readout Device	JFET preamplifier (75 mW / channel)	
Weight of Barrel	57	Mg
Weight of Each End Cap	24	Mg

10.1.5.2 Liquid Krypton/Lead(Argon/Copper) Hadron Calorimeter

Lateral segmentation (η, ϕ)	0.08 × 0.08	
Longitudinal segmentation	3-Barrel 4-Endcap	
Dimensions		
Inner Radius (active)	1,710	mm
Outer Radius (active)	2,649	mm
Length (including passive absorber)	11,280	mm
Absorber Thickness(Pb in Barrel, Cu in Endcap)	9	mm
Sense Material: (Kr in Barrel, Ar in Endcap)	2	mm
G10 Thickness	2 ×0.5	mm
Readout Channels - total hadron	20,000	
Assemblies (including EM and vessel)	3	each
Barrel Weight	433	Mg
End Cap Weight (each)	380	Mg
Total	1,192	Mg
Liquid Volume		
Barrel(krypton)	24,135	liters
End cap (each)(argon)	19,238	liters
Reserve in head vessel	3×1,200	liters
Reserve	3×2,000	liters
Total(krypton/argon)	27,334/44,880	liters

10.1.5.3 Barrel Scintillating Calorimeter

Lateral Segmentation	
η segmentation(effective - from time division)	15 cm
ϕ segmentation	0.04
Longitudinal segmentation	5

Source: W. Willis
Updated: 11/92

Dimensions		
Inner Radius	2873	mm
Outer Radius	3700	mm
Length	9900	mm
Sense Material: Scintillator	6%	
Absorber: Copper	83%	
Neutron Absorber	8%	
Gaps	3%	
Weight	881	Mg
Readout		
Photomultipliers(1 at each end)	2000	

10.1.5.4 Forward Calorimeter

10.1.5.4.1 Forward EM Liquid Argon Calorimeter

Segmentation	0.2×0.2	
Distance from IP to near face	4,482	mm
Total Weight (per side)	3	Mg
Channels (per side)	400	
Active Absorption Length	4	λ
Dimensions		
Inner Radius	75	mm
Outer Radius	310	mm
Depth in Z	402	mm
Integration Time		
EM Module	20	ns

10.1.5.4.2 Forward Scintillating Calorimeter

Segmentation	0.2×0.2	
Distance from IP to near face	5,089	mm
Total Weight (per side)	15	Mg
Channels (per side)	200	
Active Absorption Length	9	λ

Source: W. Willis
Updated: 11/92

Dimensions		
Inner Radius	45	mm
Outer Radius	628	mm
Depth in Z	1000	mm
Integration Time		
Hadron Tower	20	ns

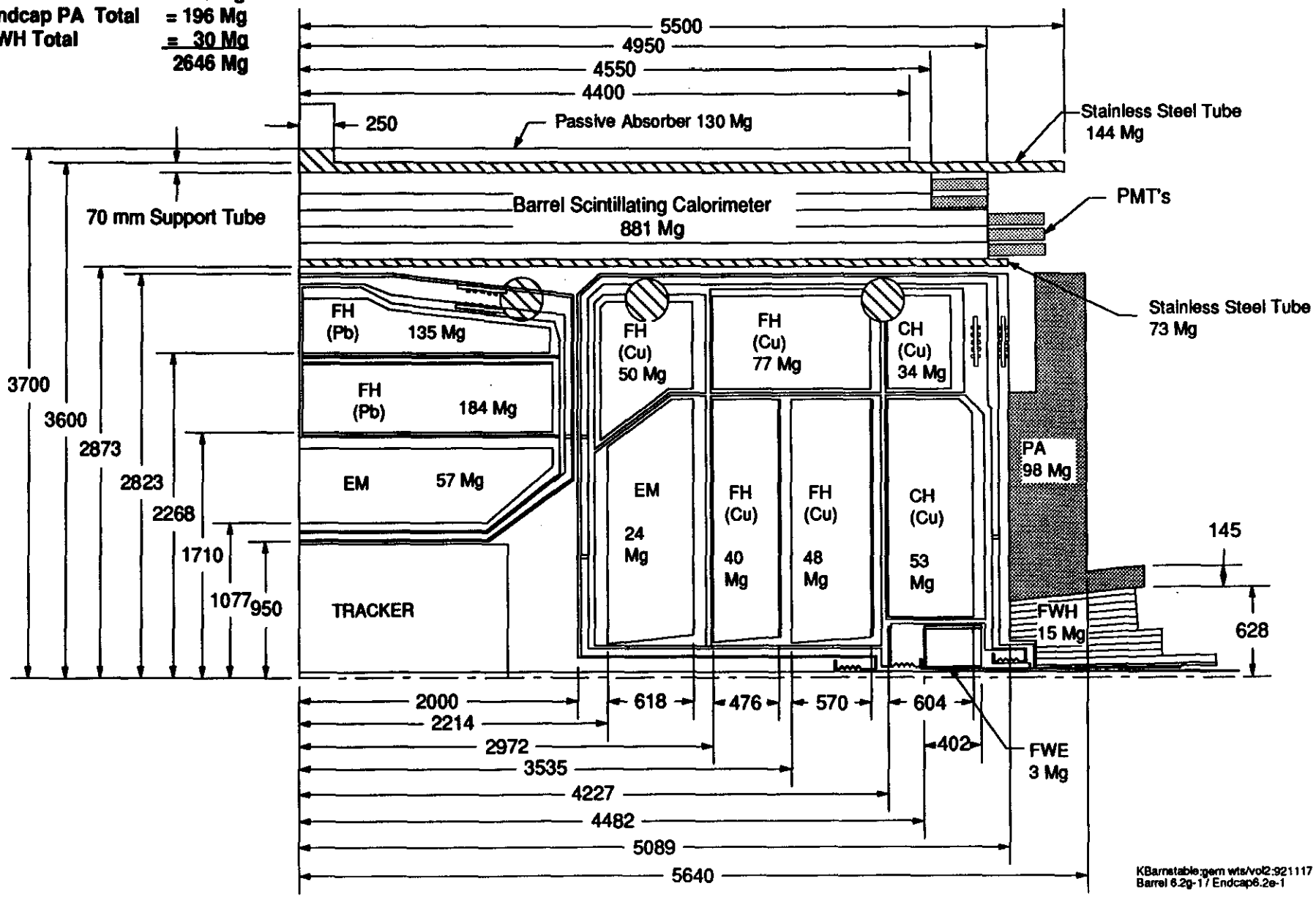
10.1.5.5 Total Weigh of Calorimeter System

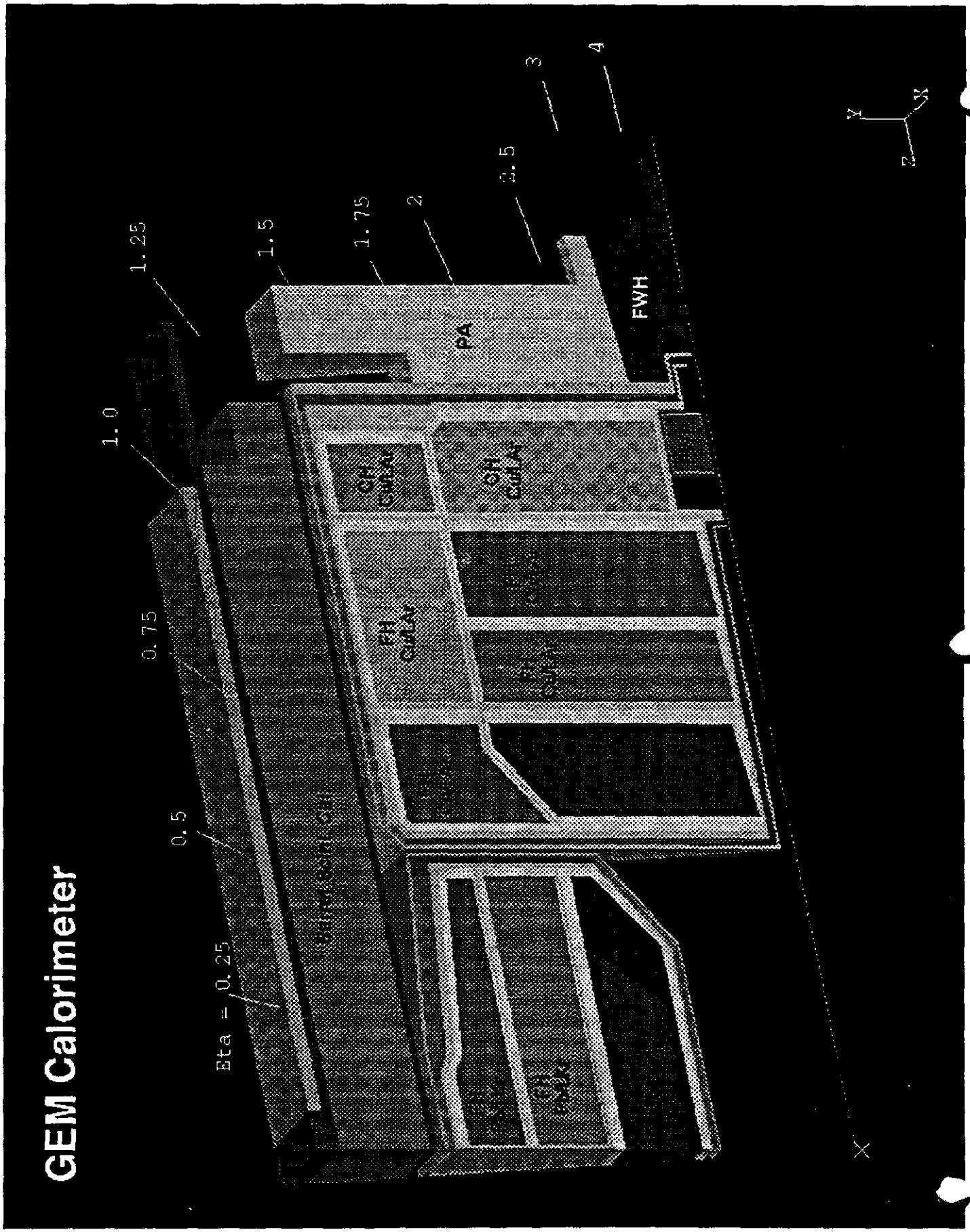
Liquid - Barrel	433	Mg
Liquid - Endcaps	759	Mg
Barrel Scintillating Calorimeter	881	Mg
Forward Hadron Calorimeters	30	Mg
Barrel Passive Absorber(Cu)	130	Mg
Endcap Passive Absorber(Cu)	196	Mg
Stainless Steel	217	Mg
Total	2,646	Mg

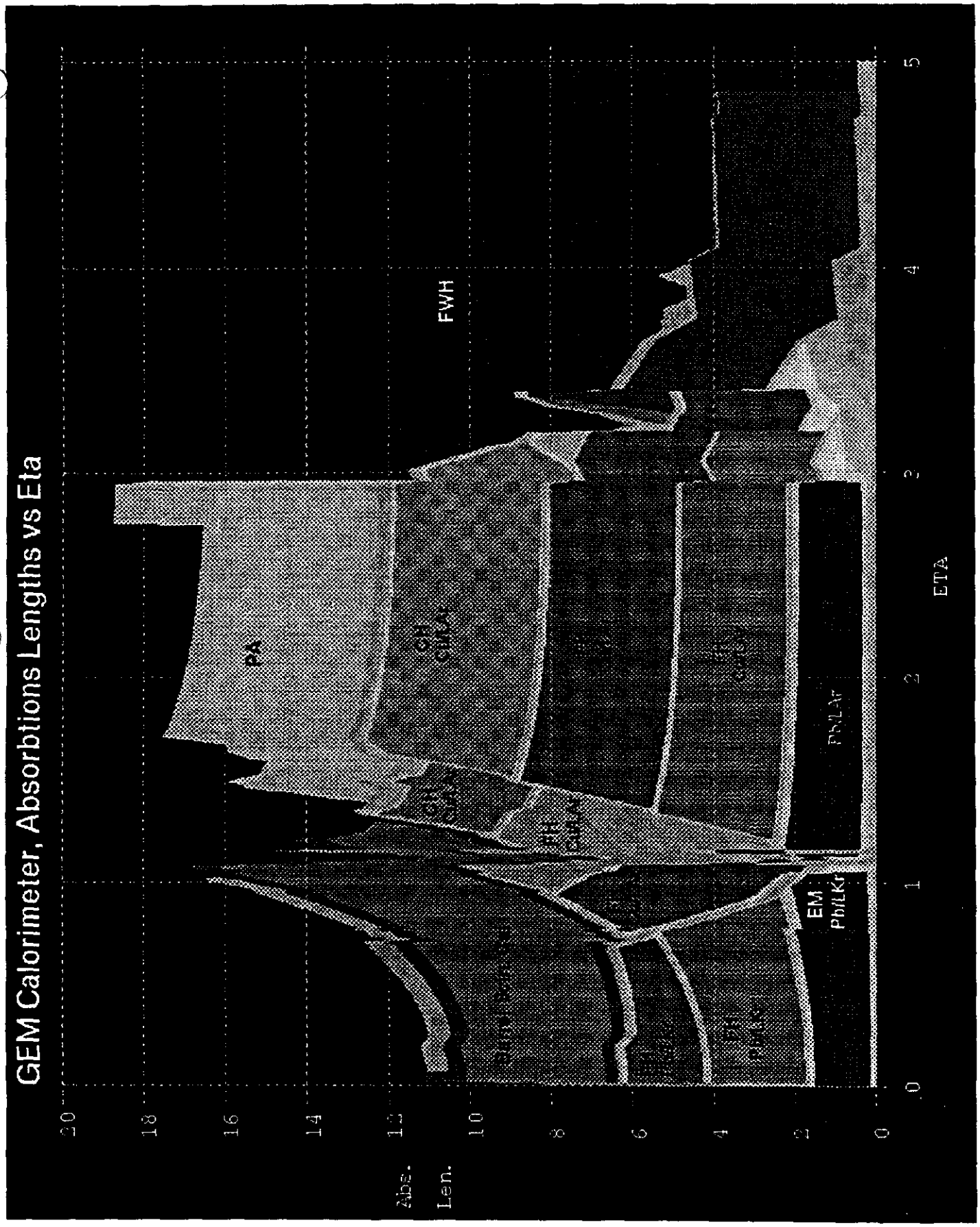
Source: W. Willis
Updated: 11/92

GEM Calorimeter

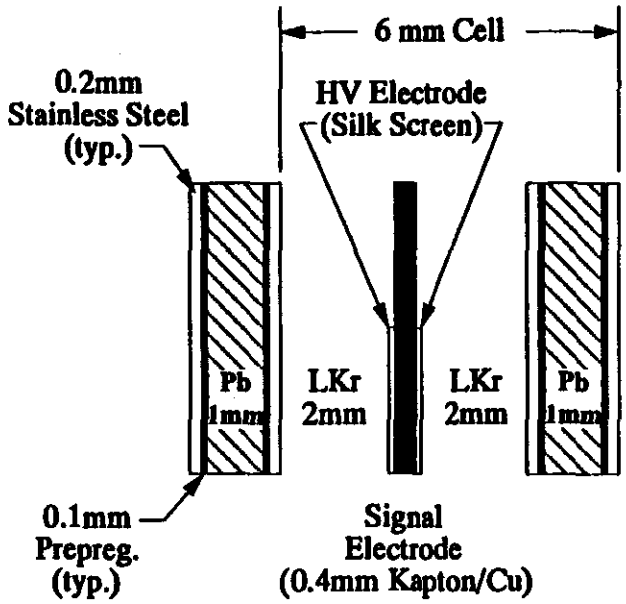
	Weight	Volume
Barrel Calorimeter	= 433 Mg	24135 L. LKr
2 Endcap Total	= 759 Mg	38475 L. LAr
Scint. Cal. & St. St.	= 1228 Mg	
2 Endcap PA Total	= 196 Mg	
2 FWH Total	= 30 Mg	
	2646 Mg	



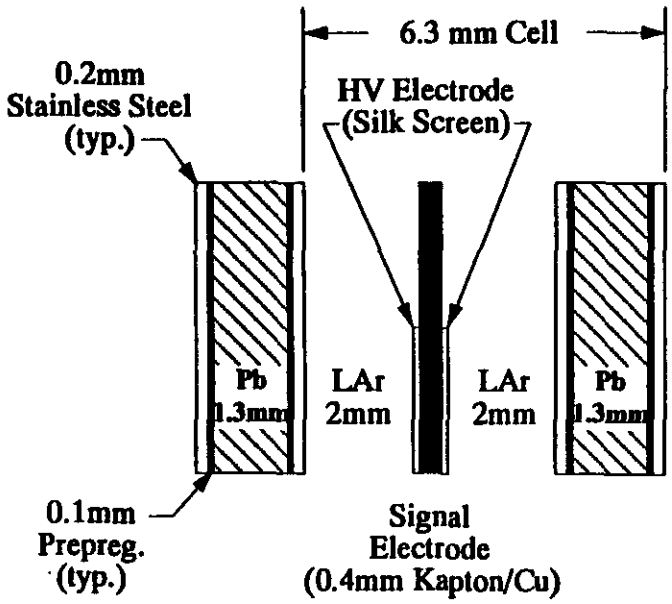

GEM Calorimeter
Eta = 0.25
0.5
0.75
1.0
1.25
1.5
1.75
2
2.5
3
4
PA
FWH
CH
CuLAr
CH
CuLAr
FH
CuLAr
CH
EMLAr
Y
X
Z


GEM Calorimeter, Absorbtions Lengths vs Eta
Abs.
Len.
ETA
FWH
PA
CH
CH/Cu
CH/Cu
EM
Pb/LKr
Pb/LAr
Pb/LAr
Pb/LAr
Pb/LAr
Pb/LAr
0
2
4
6
8
10
12
14
16
18
20
0
1
2
3
4
5

EM Electrode Structures

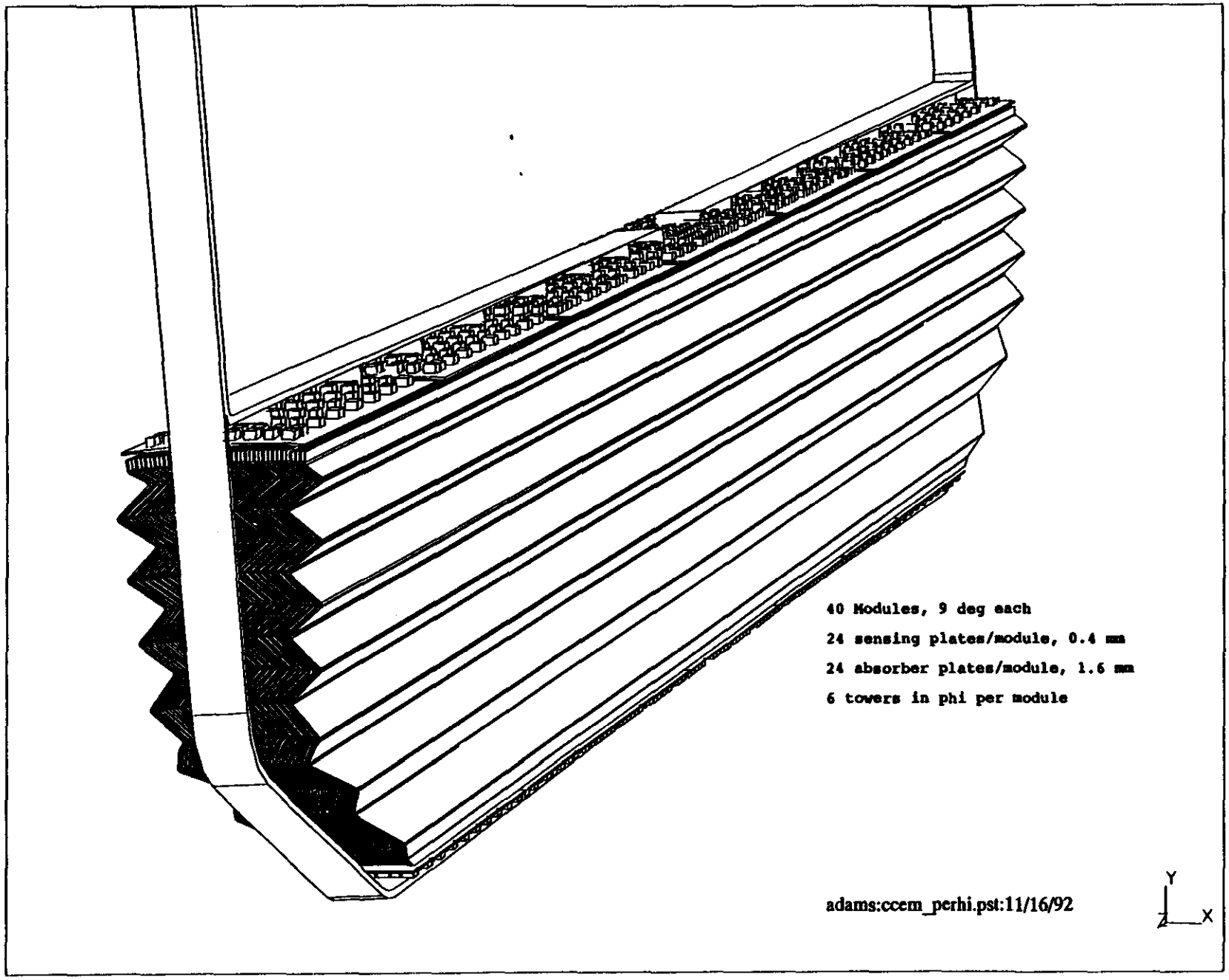


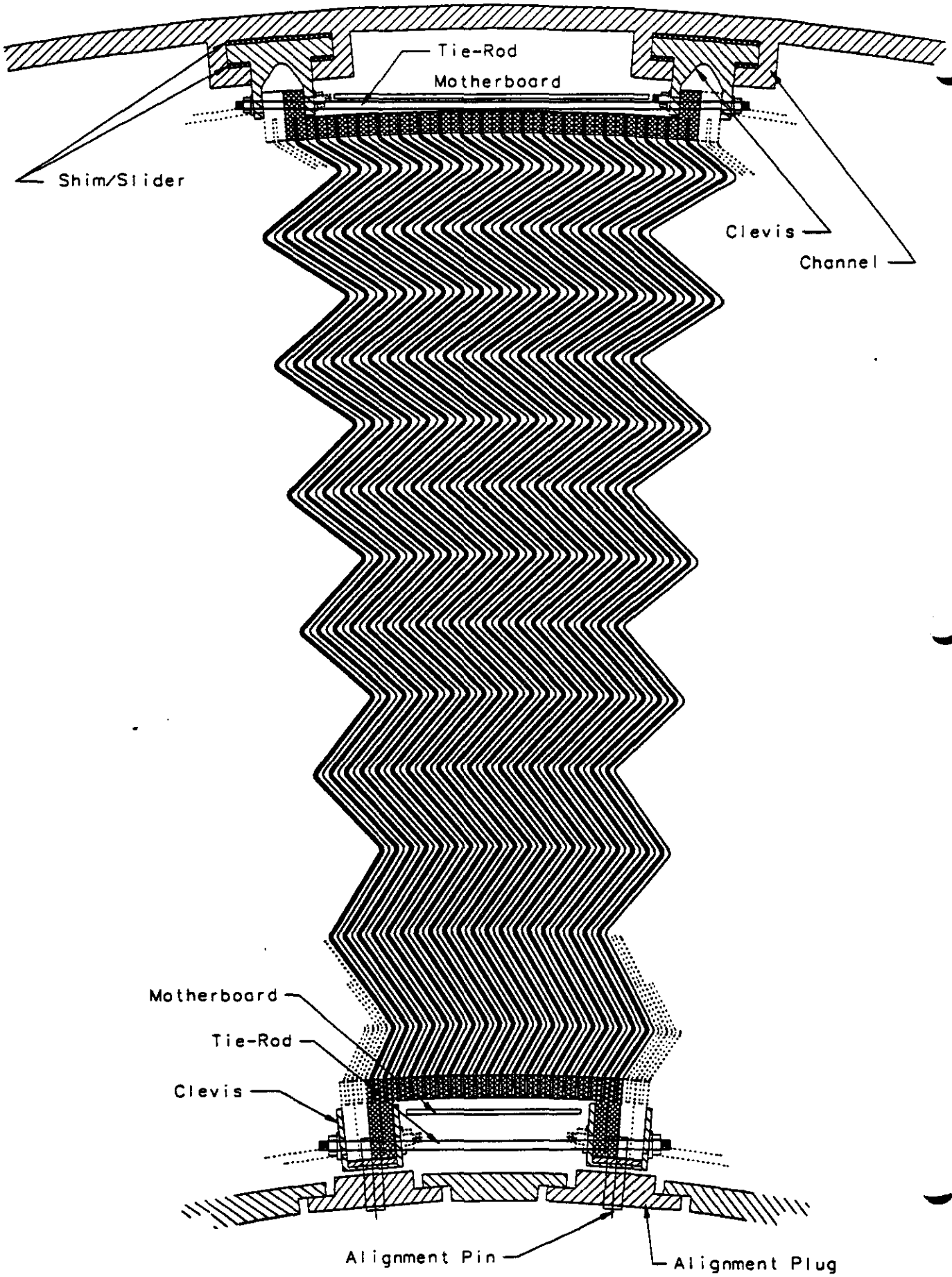
Barrel



Endcap

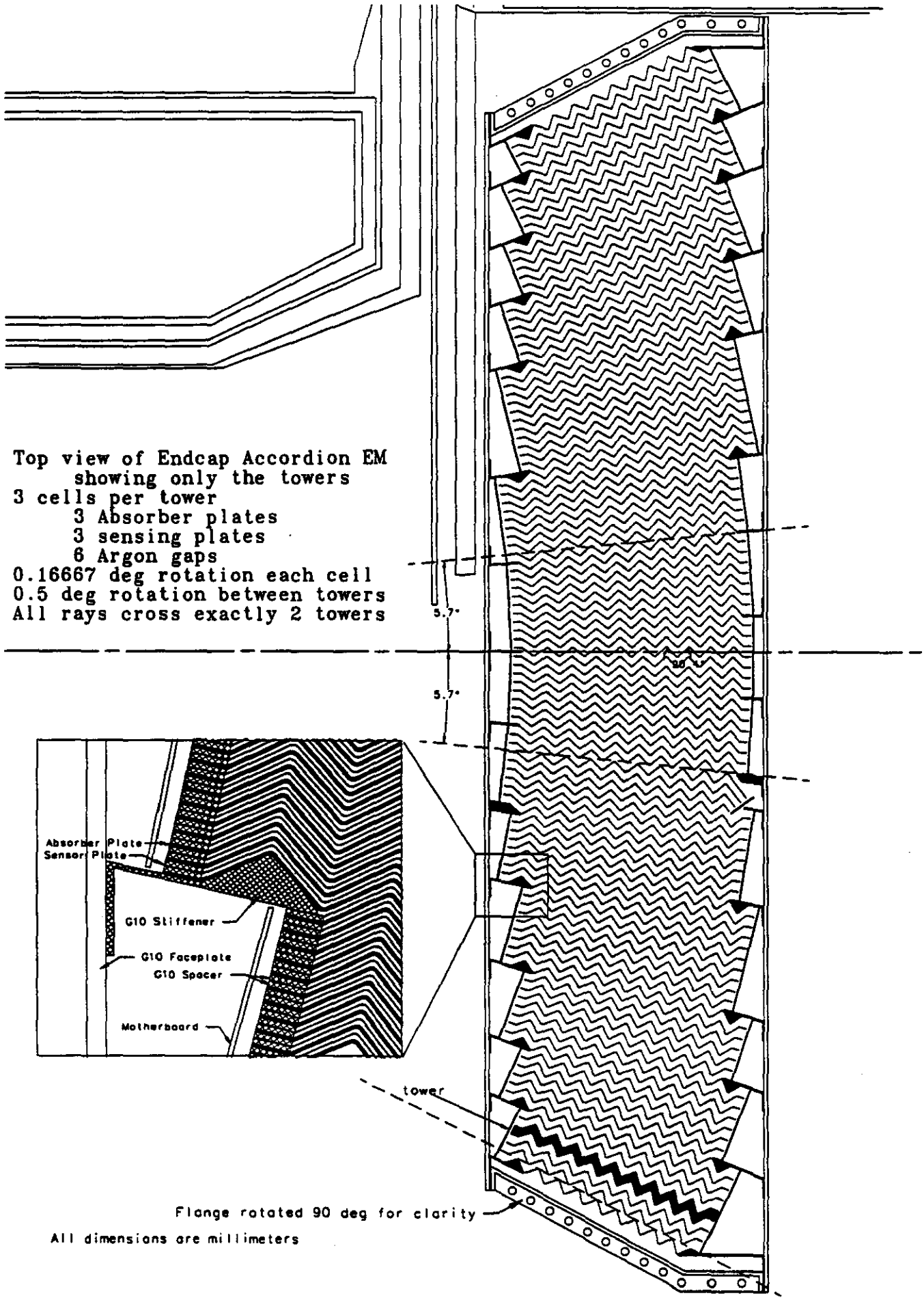
EM BARREL MODULE with Electronics and Cables



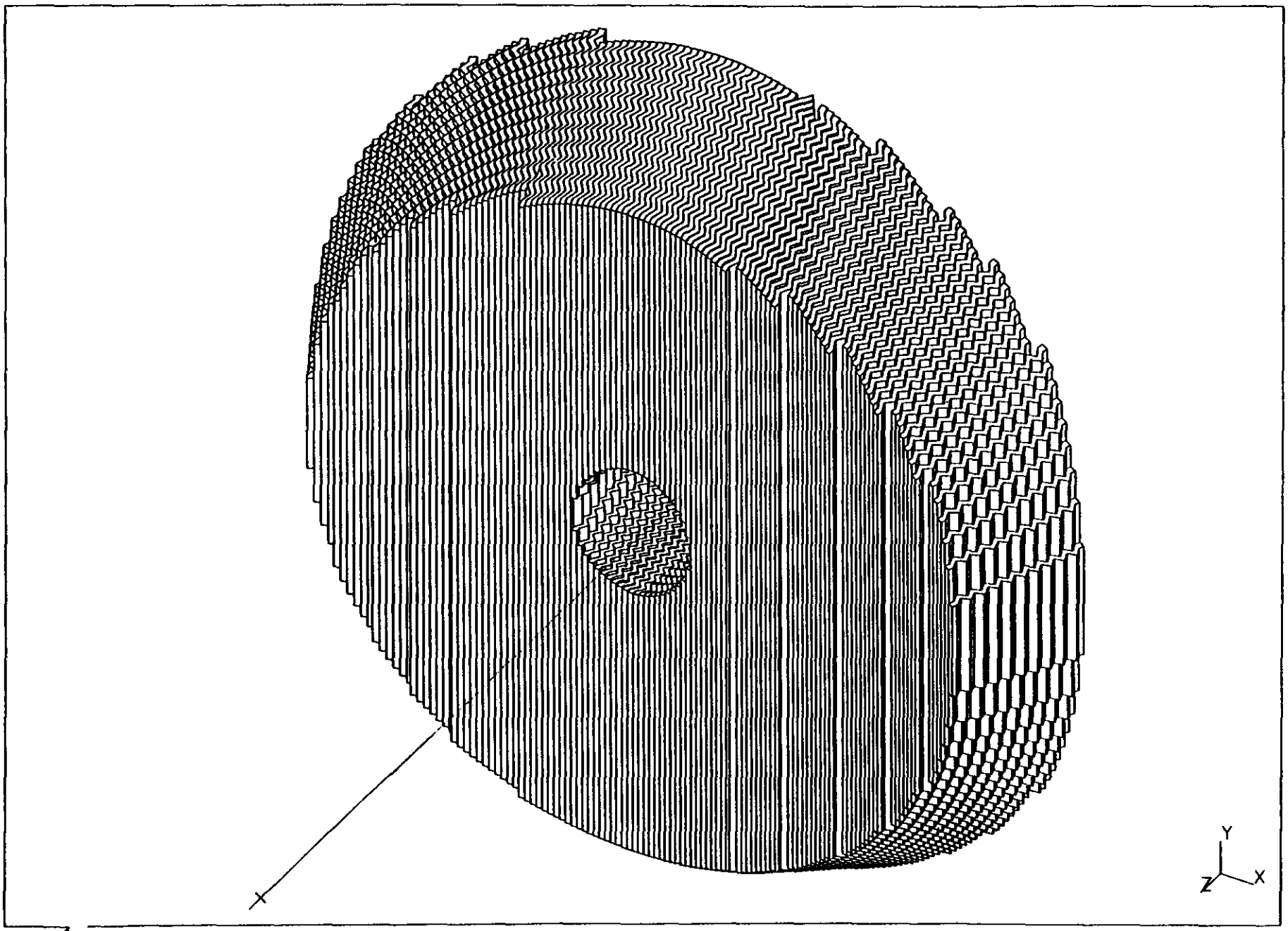


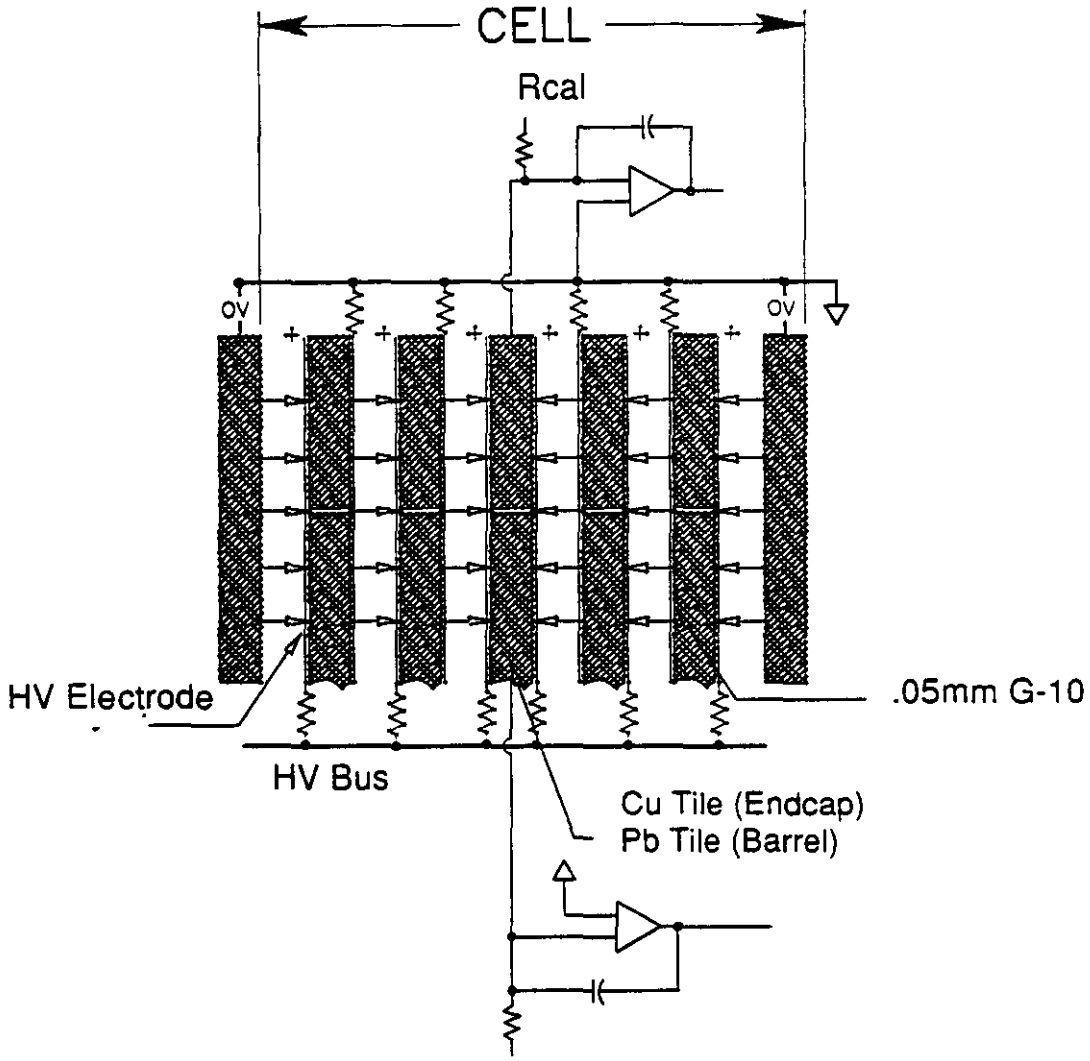
BARREL EM MODULE CROSS SECTION

EASOM: bc_em_xc.pst: 11/16/92


Top view of Endcap Accordion EM
showing only the towers
3 cells per tower
3 Absorber plates
3 sensing plates
6 Argon gaps
0.16667 deg rotation each cell
0.5 deg rotation between towers
All rays cross exactly 2 towers
5.7°
5.7°
Absorber Plate
Sensor Plate
G10 Stiffener
G10 Faceplate
G10 Spacer
Motherboard
tower
Flange rotated 90 deg for clarity
All dimensions are millimeters

Endcap Accordion EM



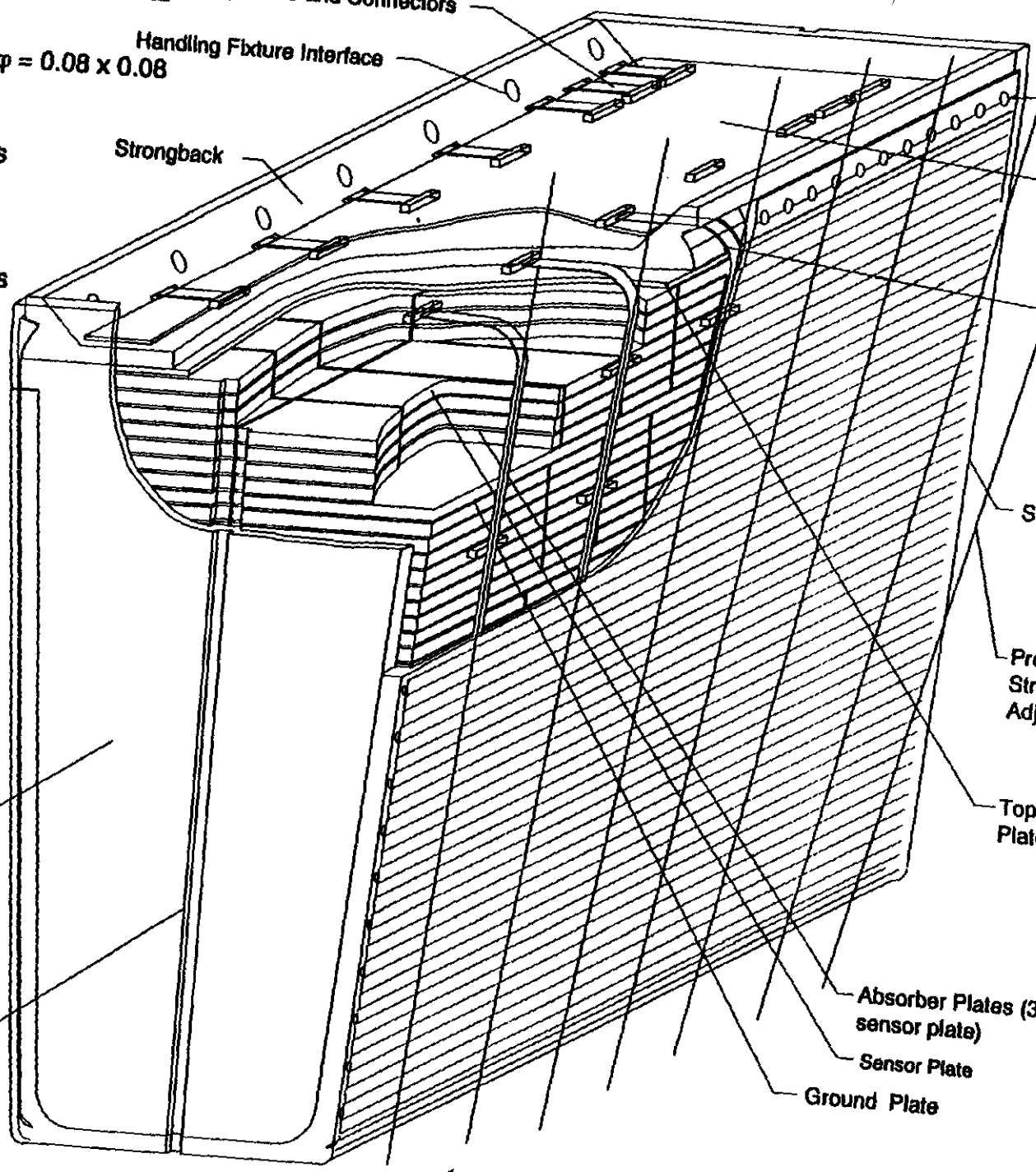


Hadronic Configuration with Electrostatic Transformer

DSM

Barrel Inner Hadronic

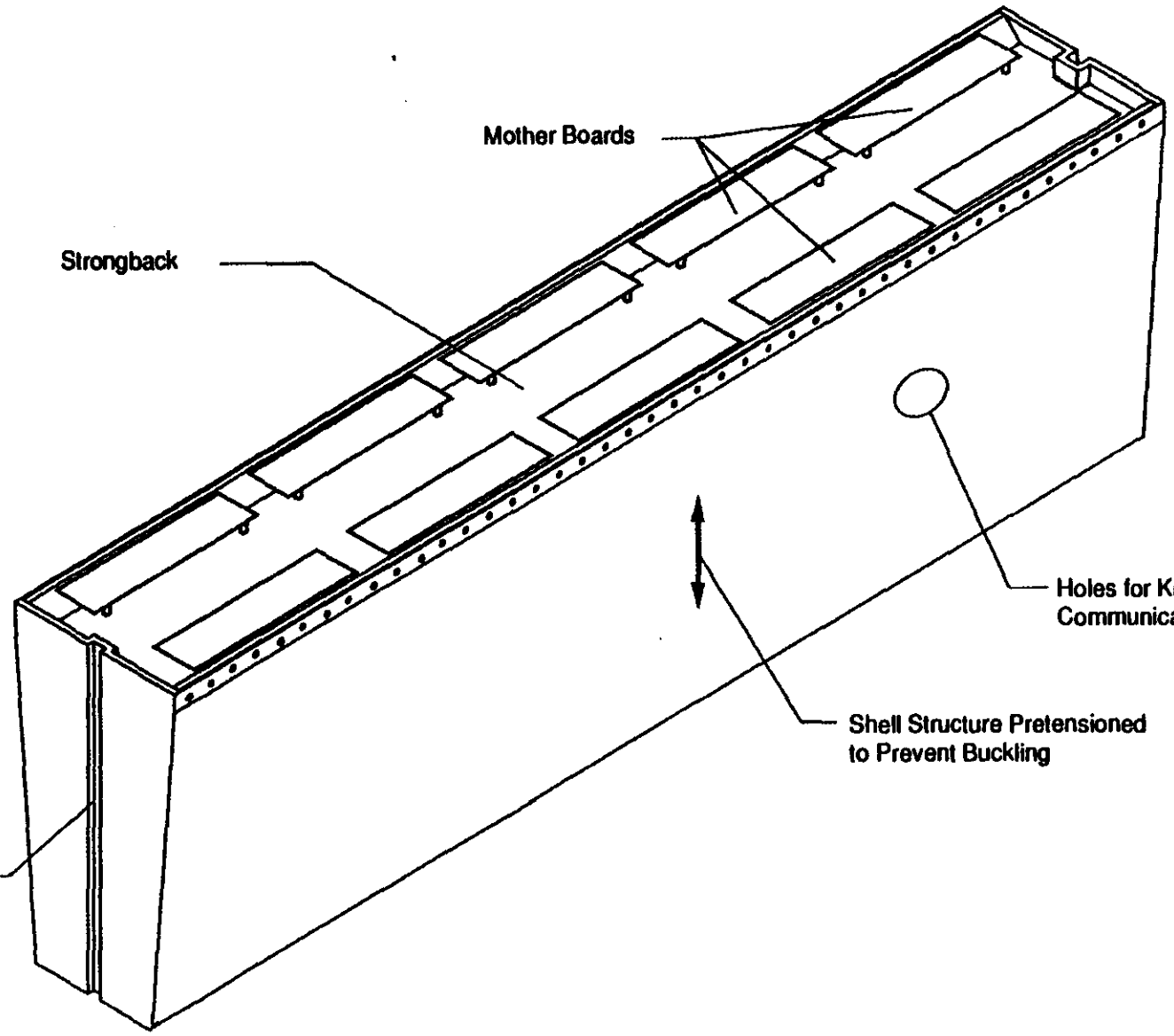
5 Cells Depth
Segmentation $\Delta\eta \times \Delta\varphi = 0.08 \times 0.08$
80 Modules Required
Wt. = 2.38 MT each
Each Module Contains the Following:
1 - Top Ground Plate
1 - Bottom Gnd Plate
4 - Included Gnd Plates
30 - Absorber Plates
5 - Sensing Plates
1 - Strongback
1 - Structural Shell
2 - End Plates
Lines and Electronics



LLMason HadMod.iso 11/16/92

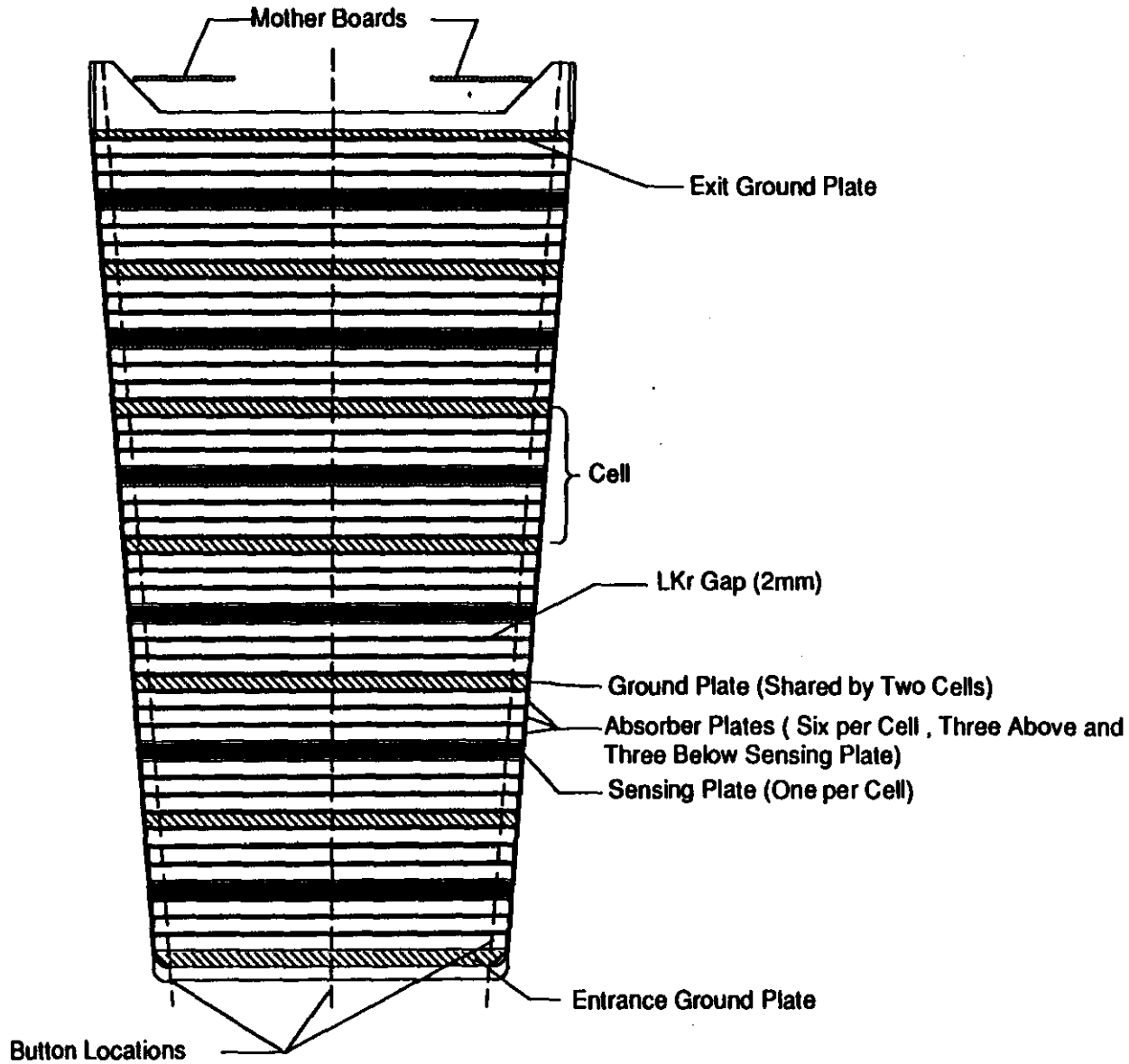
SHELL MODULE CONCEPT (Barrel Inner Hadronic)

9 degree Included Angle
1797 mm Length
489 mm Depth
80 required



ADAMS:HAD MOD DETAILS2:11/16/92

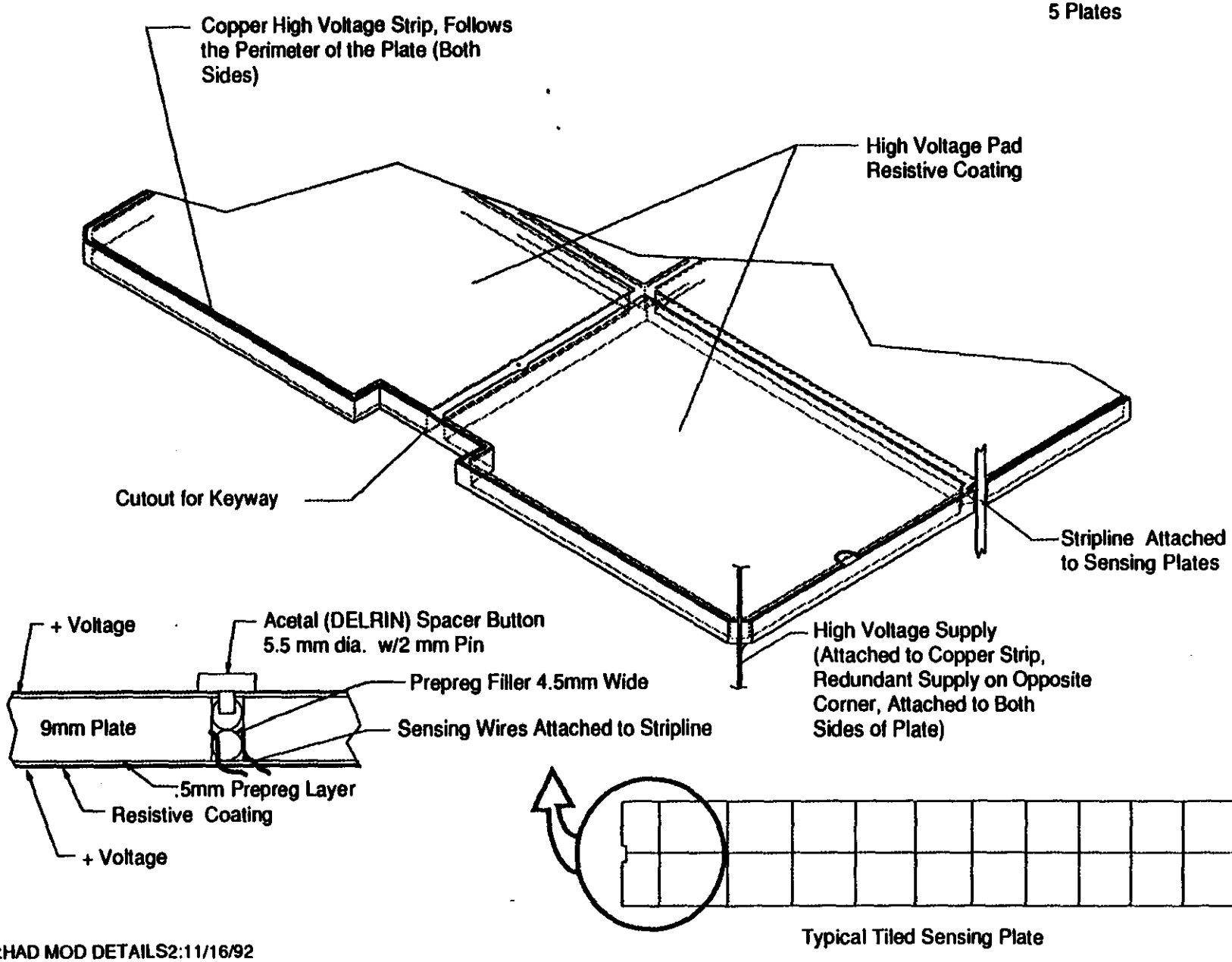
MODULE STACKUP CROSS SECTION (Barrel Inner Hadronic)



ADAMS:HAD MOD DETAILS2:11/16/92

SENSING PLATE (Barrel Inner Hadronic)

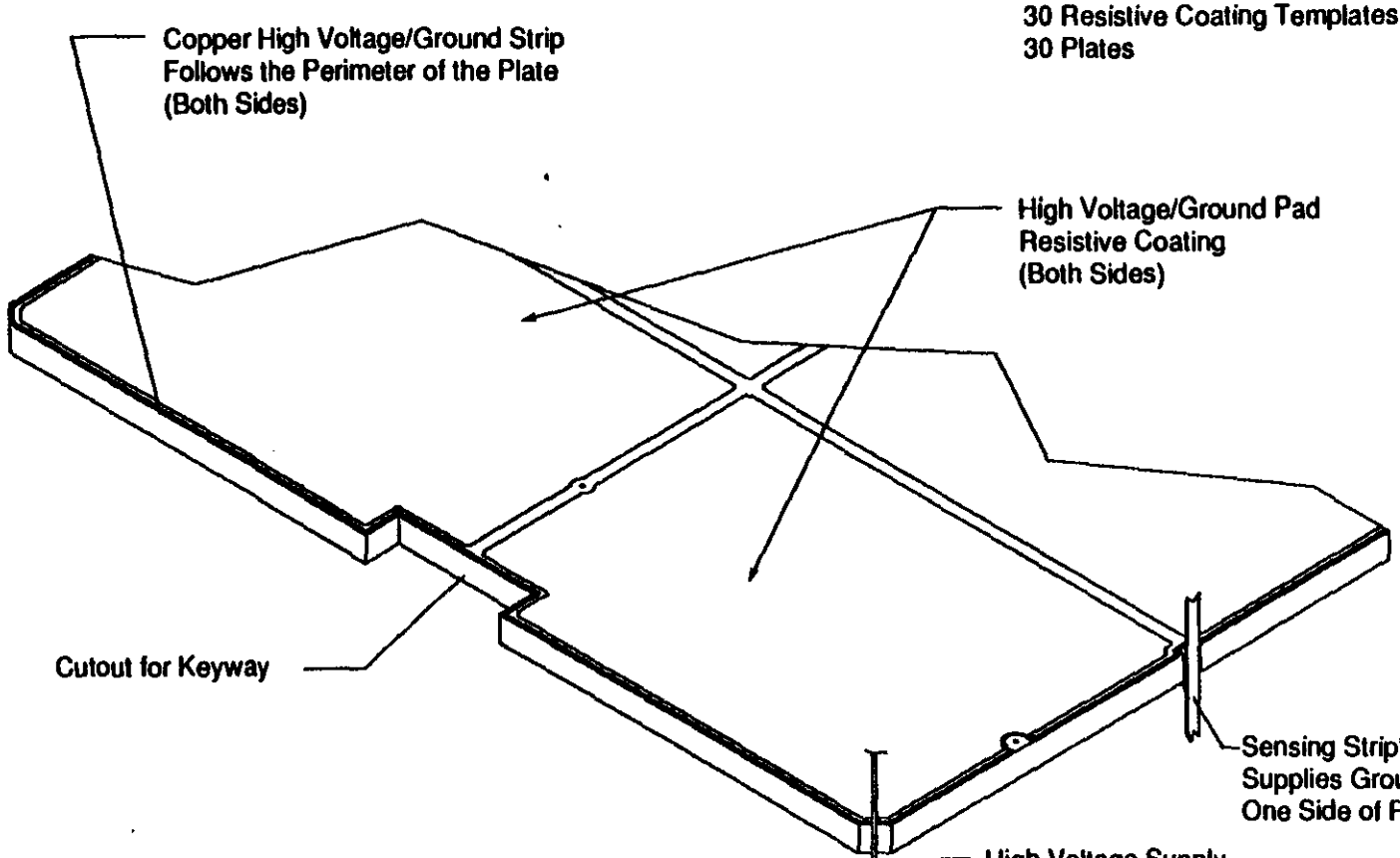
5 Cell Depths
5 Resistive Coating Templates
5 Plates

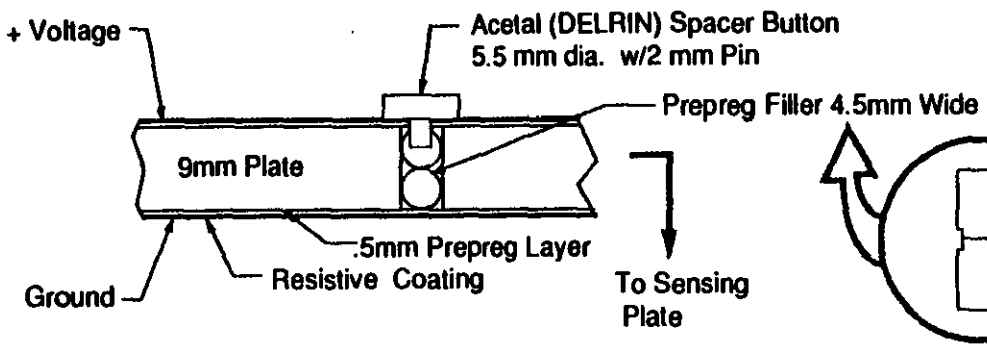


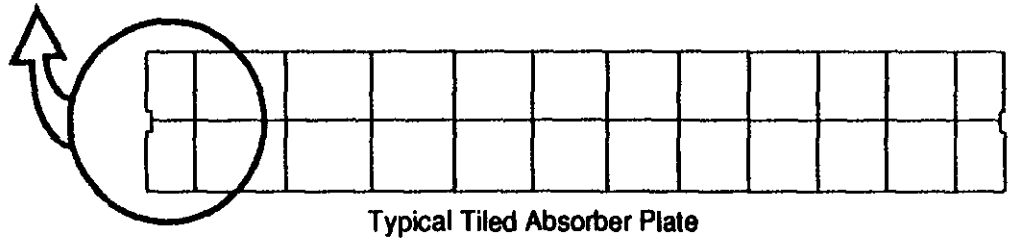
ADAMS:HAD MOD DETAILS2:11/16/92

ABSORBER PLATE (Barrel Inner Hadronic)

5 Cell Depths
30 Resistive Coating Templates
30 Plates



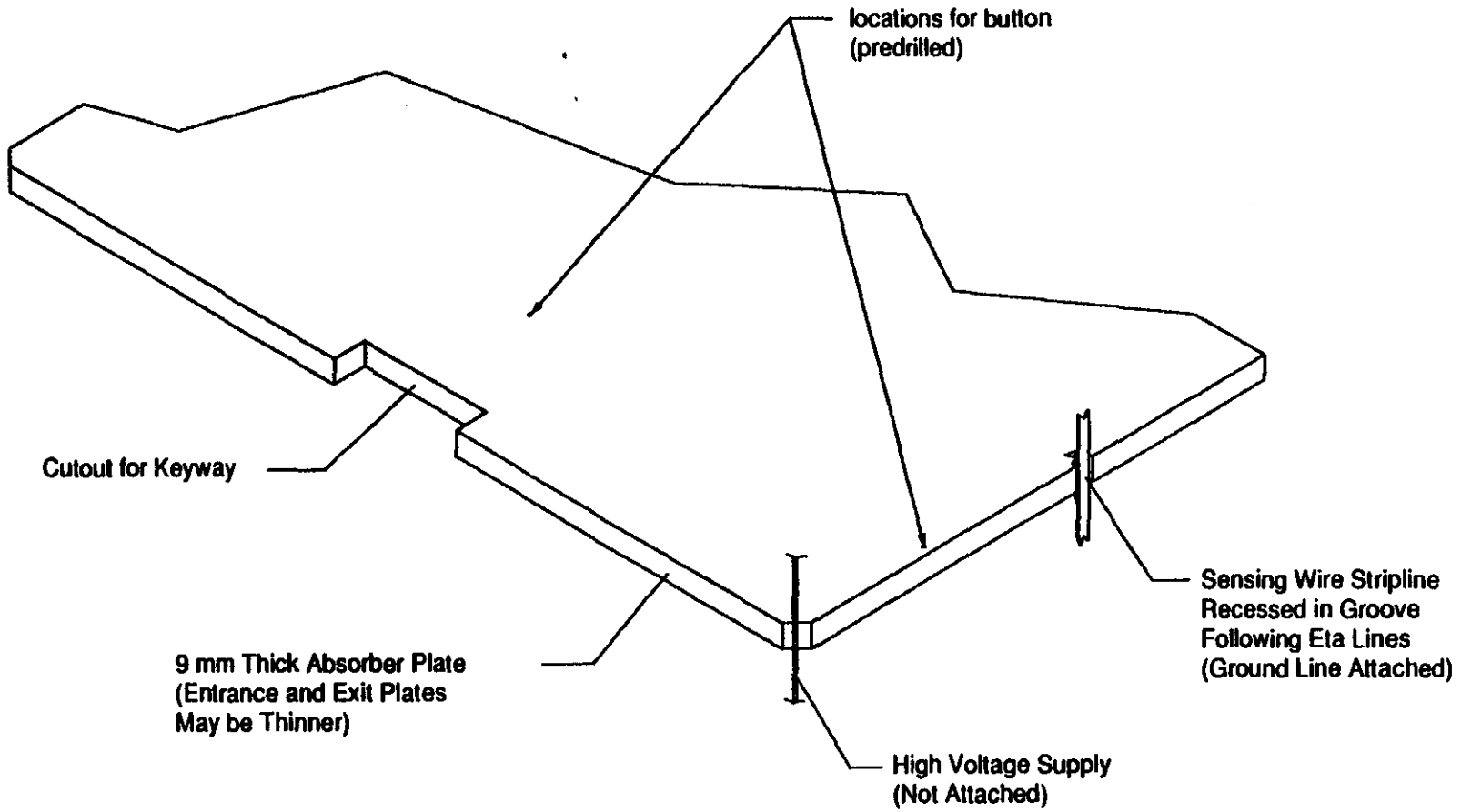


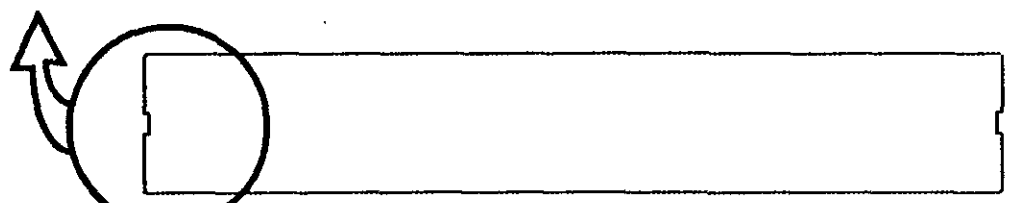


ADAMS:H MOD DETAILS2:11/16/92

GROUND PLATE (Barrel Inner Hadronic)

4 Plates
1 Entrance Plate
1 Exit Plate

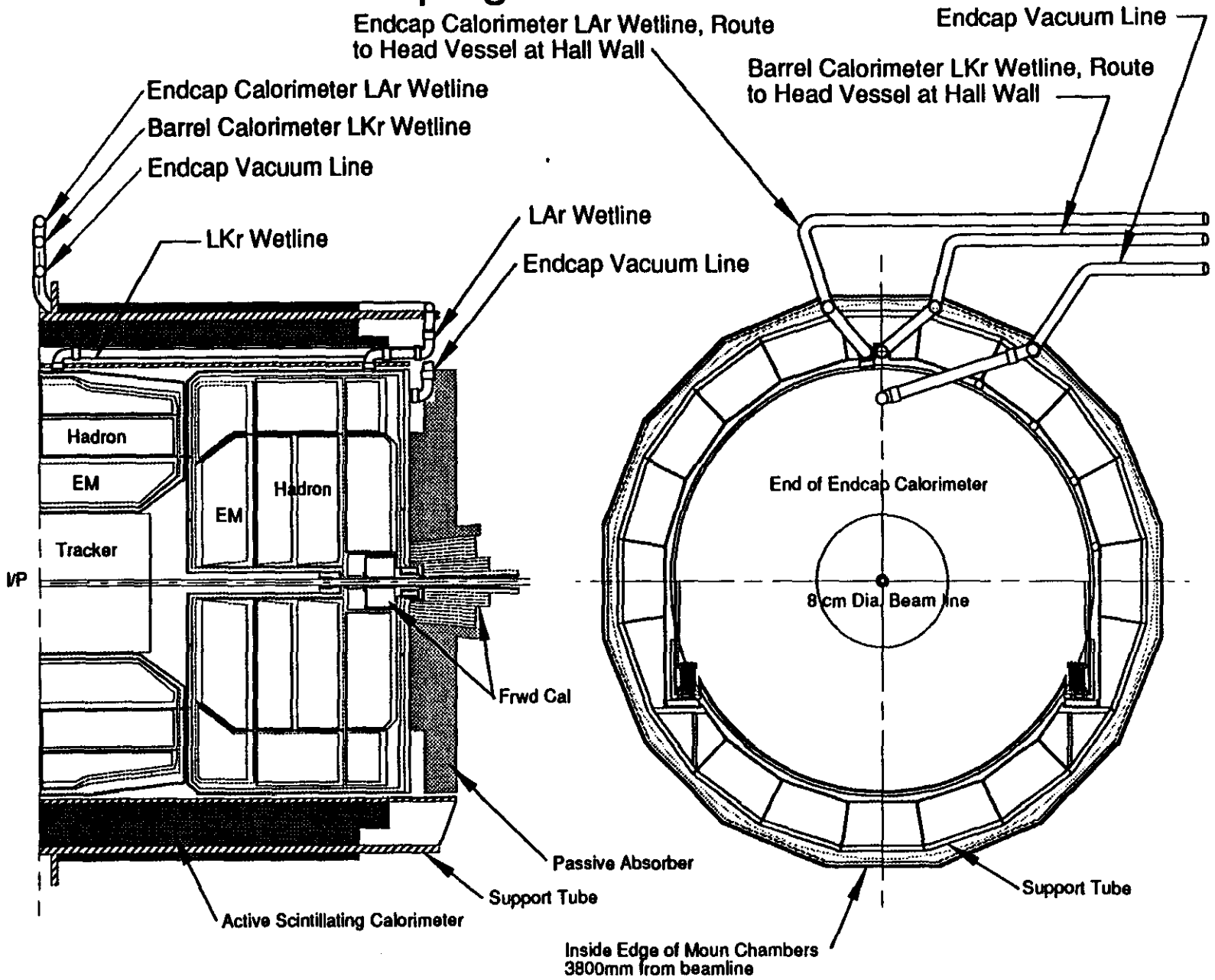




Typical Absorber Ground Plate

ADAMS:HAD MOD DETAILS2:11/16/92

GEM Calorimeter Piping Plan

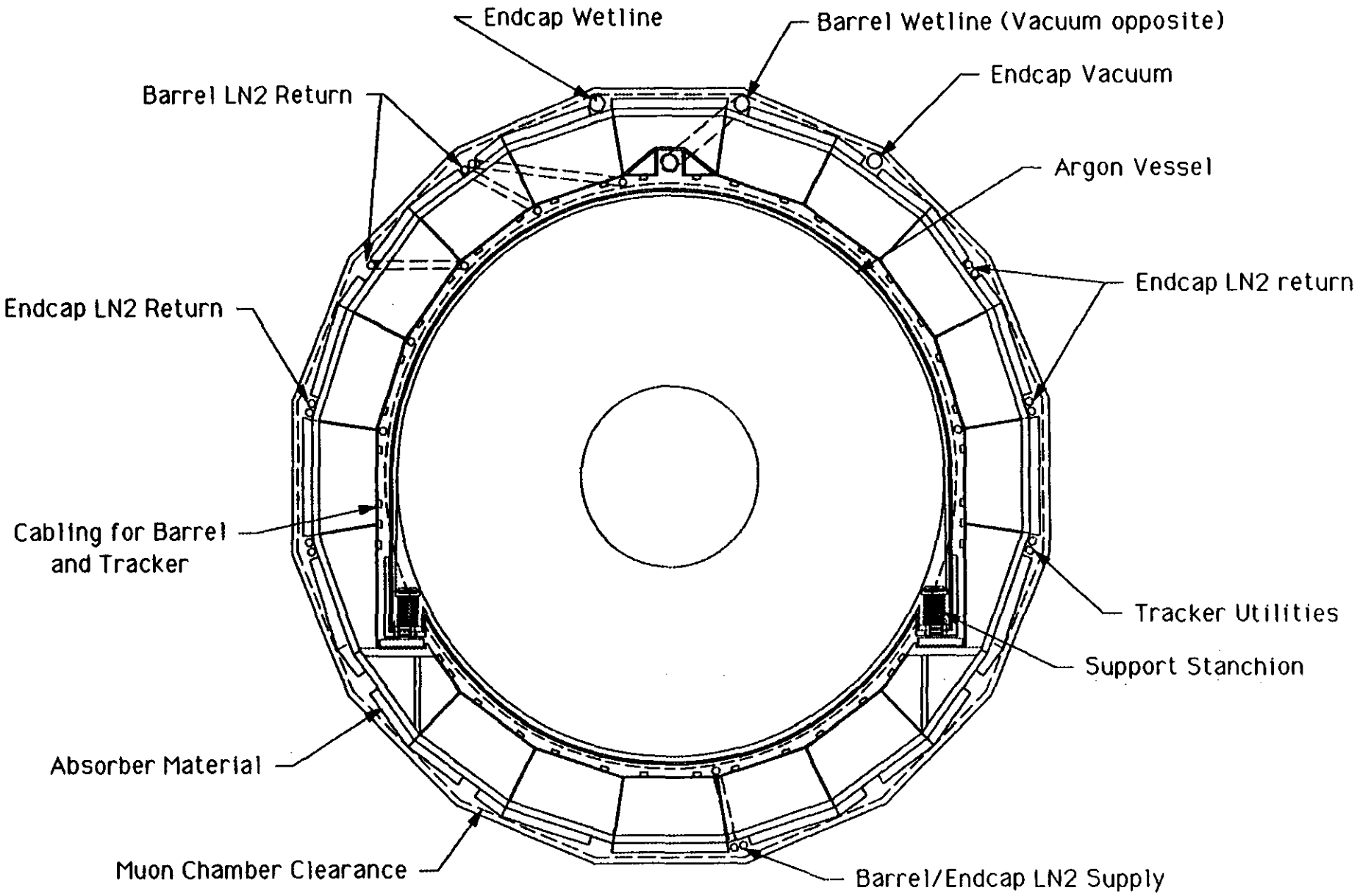


Half Section - GEM Calorimeter

End View - Gem Calorimeter

LLMason:Calorimeter Piping:11/16/9

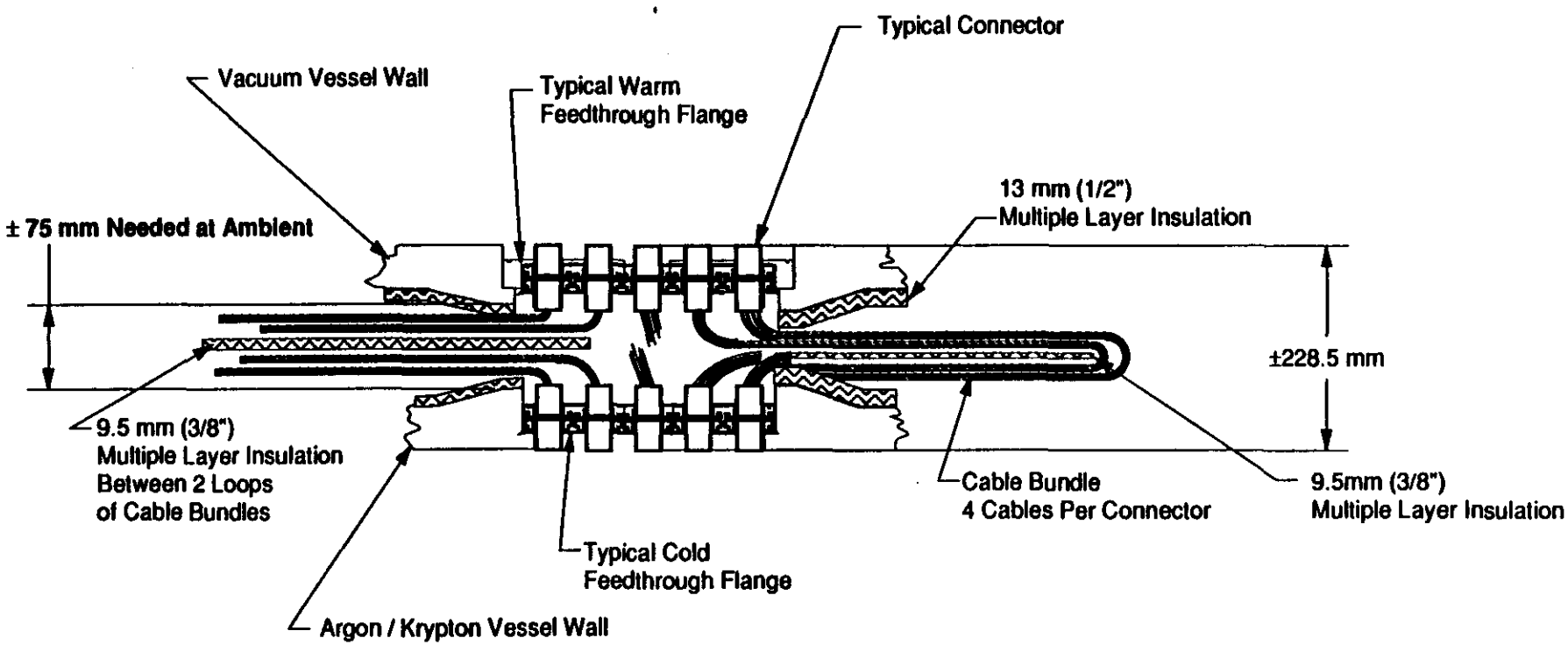
Calorimeter Cross Section



G.A.Velasquez.Crossection.ccad.111692

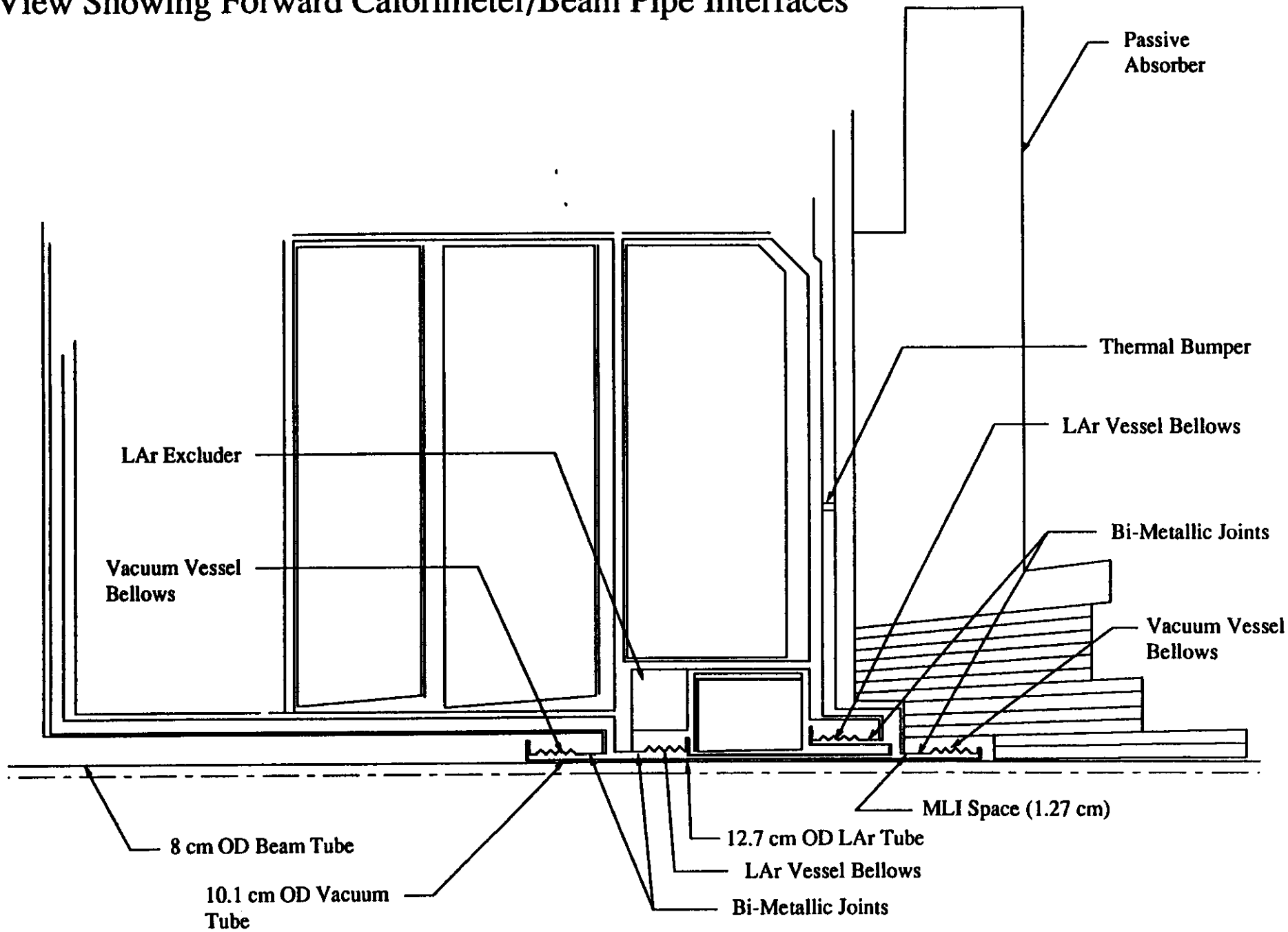
NOBLE LIQUID CALORIMETER

Electronic Feedthrough Cross Section



KBarnstable:GEMCAL FT's:111692

View Showing Forward Calorimeter/Beam Pipe Interfaces



Adams:Fwd Cal:11/16/92

11. MUON SYSTEM

MUON SYSTEM

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MUON SYSTEM

OVERVIEW

The GEM Muon System is based on a large, open solenoidal magnet with an air flux return. Three superlayers of muon tracking chambers will be deployed between the calorimeter and magnet cryostat to reconstruct the sagitta in the magnetic field. Iron flux concentrators will be placed along the central axis of the magnet to create a radial component of the B-field, thereby increasing the bend power at small angles. Muon trajectories will be reconstructed from $|\eta| \approx 0$ to 2.5 over most of the azimuth. The design goals for the momentum resolution of the system are for Pt = 500 GeV/c, $\delta Pt/Pt \approx 5\%$ at $\eta \approx 0$ and $\approx 12\%$ for $|\eta| \approx 2.5$. A Pt dependent trigger will be provided, allowing selective access to processes involving high transverse momentum muons.

The magnet will furnish a field at the IP of 0.8 T. It will consist of a superconducting coil of 9.5 m radius, constructed in two parts, each with a coil length of approximately 14.25 m. The coil halves will be separated by 1.5 m. The inner cryostat radius is 9.0 m and constrains the outer radius of the barrel muon chambers. The steel of the field shaper will be located in a cone of half-angle 9.4° (maintaining a constant "stay clear" distance from the MUON chambers), extending from 10 m to 18 m from the IP. There will be no pole pieces.

The resolution of the reconstructed muon momentum will be determined by the chamber resolution, alignment precision within a superlayer and between superlayers, bending power of the magnet (BL^2) and "unreconstructable" fluctuations of the energy loss in the calorimeter. For the barrel region the lever arm, L, at 90° will be $\approx$ 4.8 m, and in the endcaps, equal to, or larger than, 8.6 m (plus angle factors). Multiple layers of chambers will be required with exacting spatial resolutions (of order 75 μm per detector element) and systematic alignment (of order 25 μm) to reach the desired momentum resolution.

(1) Physics Goals:

(1) Provide muon identification-track penetrating 12 to 14 λ of calorimeter
(2) Charge assignment of muons
(3) P_t trigger - both levels 1 and 2
(4) Beam crossing time marker
(5) Muon momentum determination from a few GeV/c to a few TeV/c. Design goal: $\delta P_t/P_t \approx 5\%$ (12%) at $\eta = 0$ (2.5), for $P_t = 500$ GeV/c.

(2) System Parameters

Barrel Region:

Geometry:

Rmagnet (inner radius of cryostat)	9.0 m
B-field at the IP	0.8 T
Rcalorimeter (outer radius of calorimeter)	3.60 m
Calorimeter thickness at $\eta = 0$	12 λ
Assumed calorimeter material (hadronic section)	Cu
Number of sectors in Φ	16
Location of neutron shield	3.60 m < R < 3.70 m
Chamber stay-clear (from neutron shield or magnet cryostat)	6 cm

Chamber Parameters:

Cathode Strip Chambers (CSC for both tracking and triggering)
Spatial resolutions:

Chamber single-layer resolution	75 μm (σ)
Chamber internal alignment	50 μm
Superlayer-to-superlayer alignment	25 μm
Radiation length/chamber layer	3.75%
Chamber thickness	5 cm / layer
Timing resolution (for trigger)	< 10 ns for "OR" of 4

Channel segmentation and count:

For all θ-segments

Bend plane segment width	5 mm
Bend plane channel count	754,000
Nonbend plane segment width	10 cm
Nonbend plane channel count	124,000

MUON SYSTEM

Spatial resolutions:	
Chamber single-layer resolution	75 μm (σ)
Internal chamber alignment	50 μm
Superlayer-to-superlayer alignment	25 μm
Radiation length/chamber layer	3.75 %
Chamber thickness	5 cm/layer
Chamber configuration	8:4:4
Radii of superlayer midplanes	SL 1 = 3.854 m
	SL 2 = 6.282 m
	SL 3 = 8.588 m
Barrel lever arm	4.74 m
Half-lengths of superlayers along axis of magnet (Z)	SL 1 = 6.319 m
	SL 2 = 10.426 m
	SL 3 = 14.750 m
Φ Widths of sectors	SL 1 = 1.485 m
	SL 2 = 2.390 m
	SL 3 = 3.296 m
Coverage:	
Polar angle	$29.6° < \theta < 85.8°$
Pseudorapidity	$0.074 < \eta < 1.33$
Azimuthal angle	95.3%

Endcap region:

Geometry:

B-field at IP	0.8 T
Length of magnet cryostat	15 m
Z-separation of coils	1.5 m
Forward Field Shaper (FFS):	
Z_{front}	10.0 m
Z_{rear}	18.0 m
OD-half angle of steel	9.4°
ID	1.2 m
$Z_{calorimeter}$ (half-length of calorimeter along beam axis)	5.50 m
Calorimeter thickness at $\eta \approx 2.5$	14 λ
Z_{max}	16.5 m
Number of sectors in Φ	16
Location of neutron shield 10 cm behind calorimeter	5.50 m < Z < 5.60 m
Chamber stayclear	6 cm

Chamber Parameters:

Cathode Strip Chambers (CSC for both tracking and triggering)

Spatial resolutions:	
Chamber single-layer resolution	75 μm (σ)
Chamber internal alignment	50 μm
Superlayer-to-superlayer alignment	25 μm
Radiation length/chamber layer	3.75%
Chamber thickness	5 cm / layer
Timing resolution (for trigger)	< 10 ns for "OR" of 4

Channel segmentation and count:

For all θ-segments	
Bend plane segment width	5 mm (at middle)
Bend plane channel count	294,000
Nonbend plane segment width	5 cm
Nonbend plane channel count	35,000
Single channel rate at L = $10^{33}/cm^2sec$	< 100 Hz
Occupancy for "OR" of 7 strips at L = $10^{34}/cm^2sec$	< 3 %

Coverage:

Polar angle	$9.75° < \theta < 27.71°$
Pseudorapidity	$1.40 < \eta < 2.46$
Azimuthal angle	100%

Endcaps - Tracking and Triggering:

(a) <u>Forward angle region:</u>	$9.75° < \theta < 11.45°$	$(2.30 < \eta < 2.46)$
Chamber configuration		8:8:4
Average Z location of chambers		SL 1 = 6.78 m
		SL 2 = 11.43 m
		SL 3 = 16.08 m
Average lever arm		9.3 m
(b) <u>Intermediate angle region:</u>	$1.45° < \theta < 17.01°$	$(1.90 < \eta < 2.30)$
Chamber configuration		8:4:4
Average Z location of chambers		SL 1 = 5.94 m
		SL 2 = 11.43 m
		SL 3 = 16.08 m
Average Lever arm		10.14 m
(c) <u>Outer angle region:</u>	$17.01° < \theta < 27.71°$	$(1.40 < \eta < 1.90)$
Chamber configuration		8:4:4
Average Z location of chambers		SL 1 = 5.94 m
		SL 2 = 10.13 m
		SL 3 = 14.58 m
Average lever arm		8.64 m

(3) Momentum Resolution

The muon momentum is reconstructed by the 3-point sagitta method (neglecting various angle factors), where the sagitta is given in terms of measured quantities as:

$$S = (y_1 + y_3)/2 - y_2 = qBL^2/8P.$$

y_1, y_2, and y_3 are the bend-plane locations of the muon trajectory in the three super-layers, B is the magnetic induction, L is the path length between super-layers 1 and 3, q is the muon charge, and P is the momentum. Hence good resolution is achieved for a large L even at a modest B.

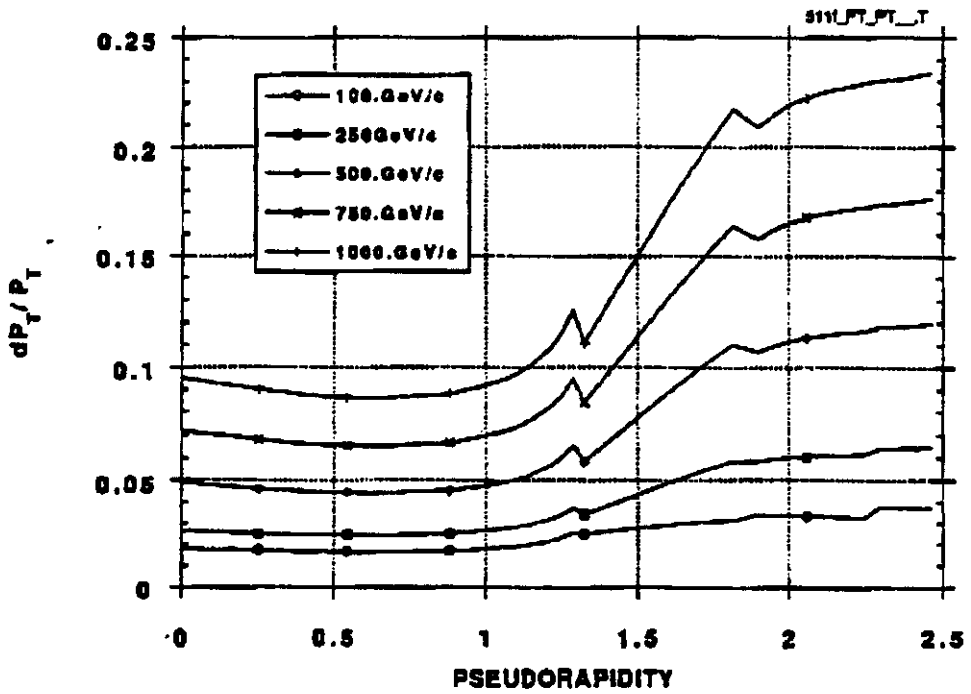


Fig. 3-1.1: The resolution for constant transverse momentum, P_t is shown as a function of pseudo-rapidity, $|\eta|$.

(4) Hadron Punchthrough

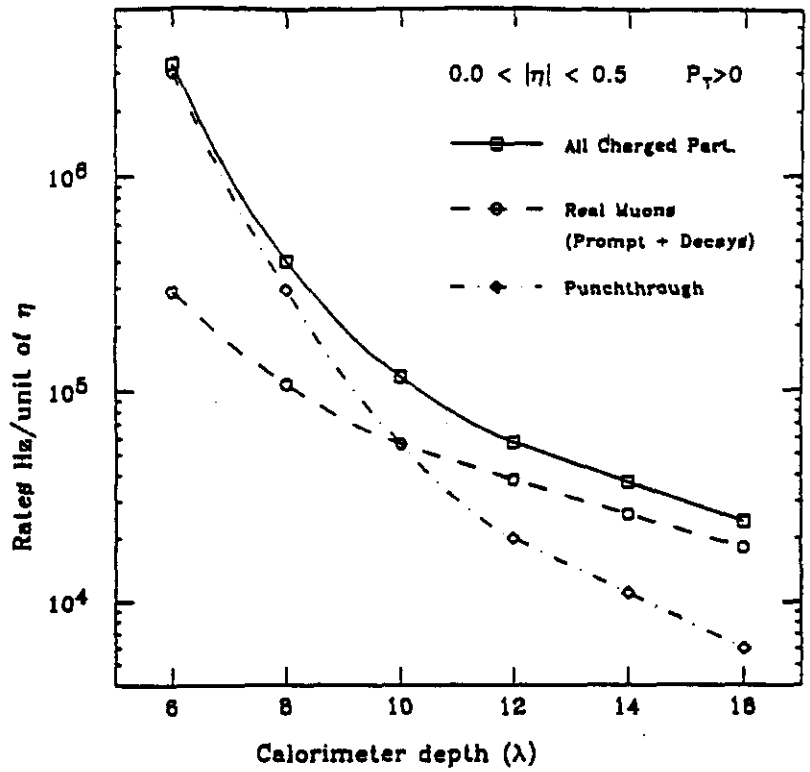
Extensive Monte Carlo studies have been performed which indicate that for a calorimeter thickness of greater than 12 λ in the barrel region the charged particle rate in the first super-layer of the muon system is dominated by prompt leptons from the primary vertex, and hadron decay in the central tracker and calorimeter. The hadron punch-through is smaller by a factor of 2.

In the endcap region the particle rate increases quite rapidly as the polar angle decreases. Owing to the energy spectrum of the punch-throughs and the prompt muons, and the geometry of the calorimeter and inner tracker, we find that the charged particle rate is decreased with some efficiency up to 14 λ, but thereafter with diminishing returns. Hence in the forward direction a calorimeter of 14 λ will keep the occupancy low and the trigger operational.

References:

[1] Hadronic Calorimeter resolution vs. λ.
[2] GEM Baseline 1, GEM TN92-76, April 23, 1992.
[3] See for example transparencies talk given by R. McNeil at the GEM Collabor meeting July 17, 1991.
[4] R. McNeil, " How Thick should the GEM Barrel Calorimeter Be," GEM TN92-68 March 10,1992.
[5] RD5 Collaboration, Status Report, CERN/DRDC/91-53 1992.
[6] M. Mohammadi, to be submitted as a GEM Note.
[7] GEM Letter of Intent, SSCL-SR-1184, GEM TN-92-49, Nov. 30, 1992.
[8] "Study of Hadron Punchthrough and Muon Rates at the SSC", Y. Chang and B. Zhou, GEM-TN-92-101

See the figs. following.



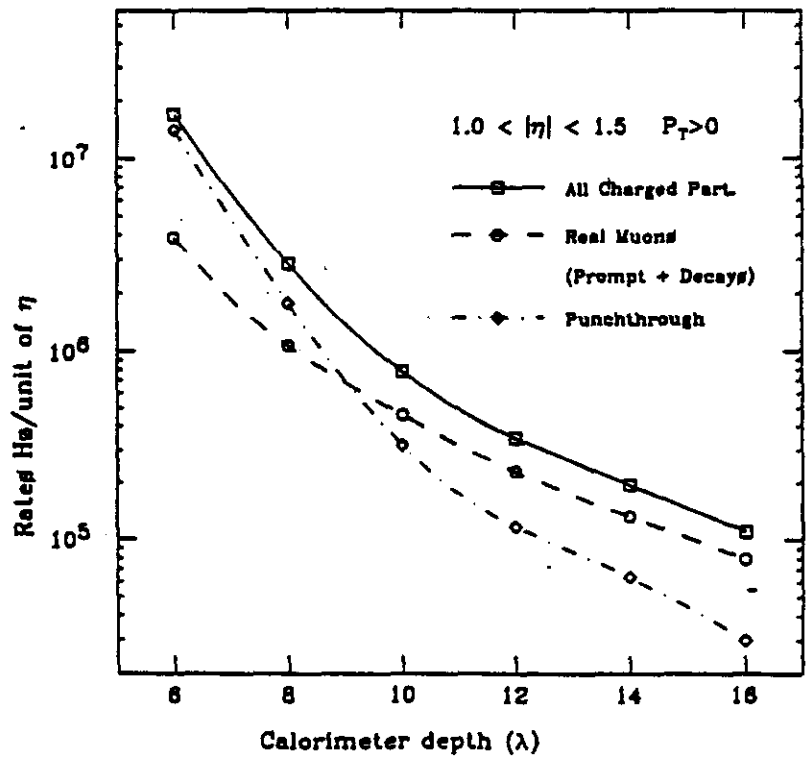
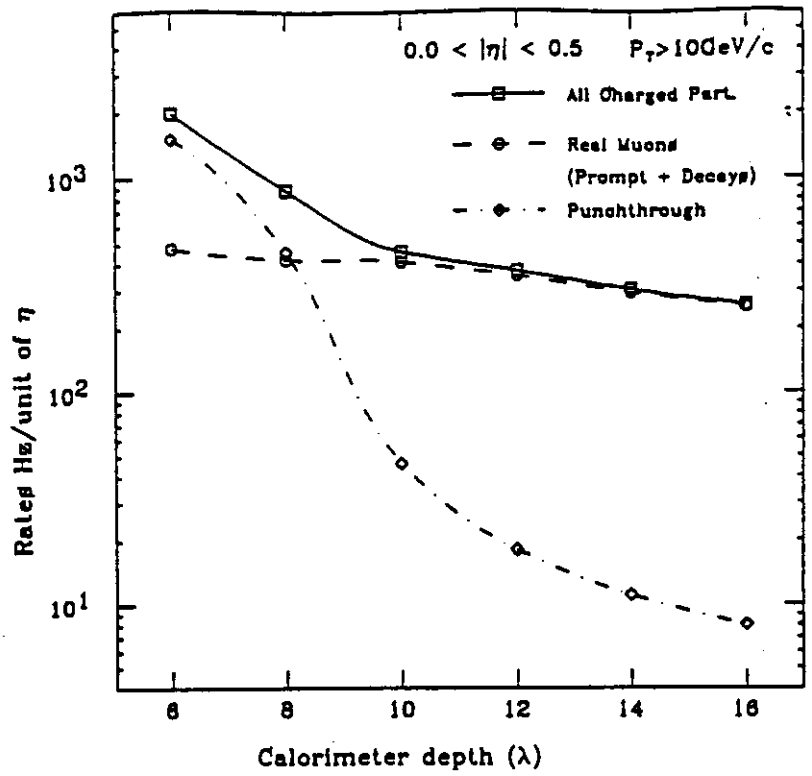


Figure 1. The rate of all Charged particles rates at 10^33 cm^-2/s SSC luminosity exiting the barrel calorimeter for a) |eta|<0.5 and b) 1.0<|eta|<1.5 rapidity intervals. The solid curve is the total rate, the dashed curve is the rate from prompt muons and pi/K decays in the inner tracking region, and the dot-dashed curve is the rate from hadron punchthrough.



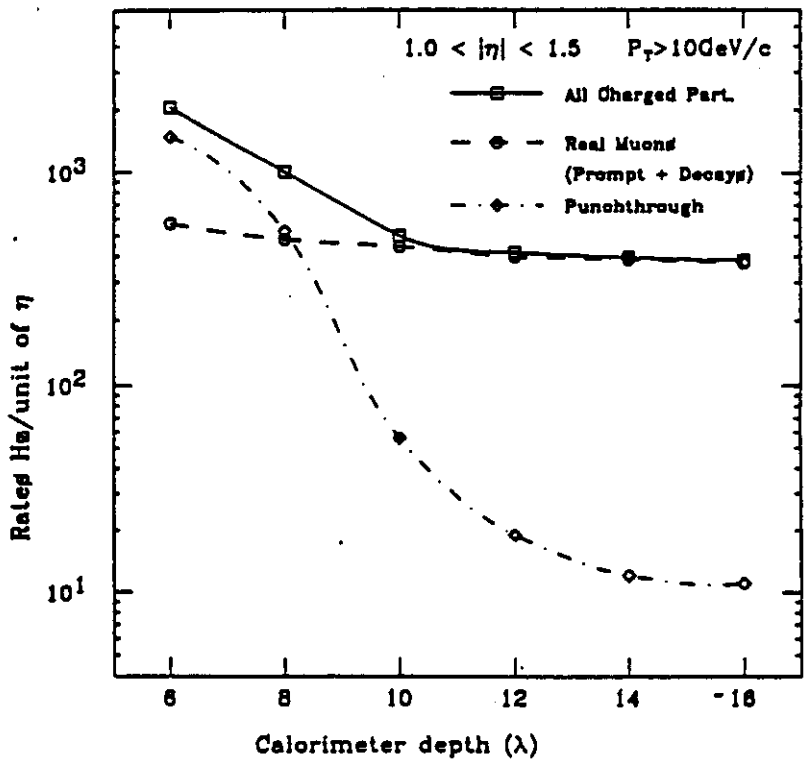


Figure 2. The rate of Charged particles with transverse momentum above 10GeV/c at 10^33 cm^-2/s SSC Luminosity exiting the barrel calorimeter for a) |eta|<0.5 and b) 1.0<|eta|<1.5 rapidity intervals. The solid curve is the total rate, the dashed curve is the rate from prompt muons and pi/K decays in the inner tracking region, and the dot-dashed curve is the rate from hadron punchthrough.

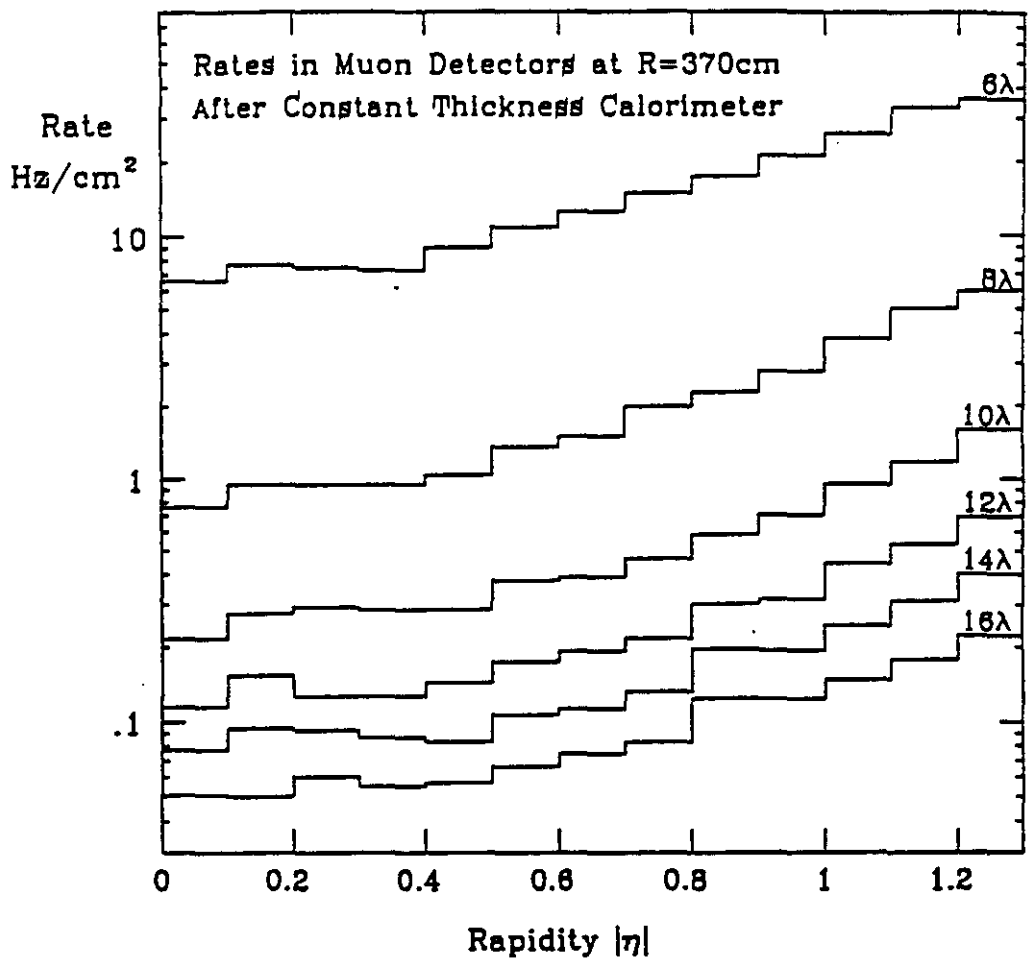


Figure 3. The hit occupancy in the first layer of the GEM barrel muon system at R-370cm at 10^33 cm^-2/s SSC luminosity as a function of rapidity for various constant calorimeter thicknesses.

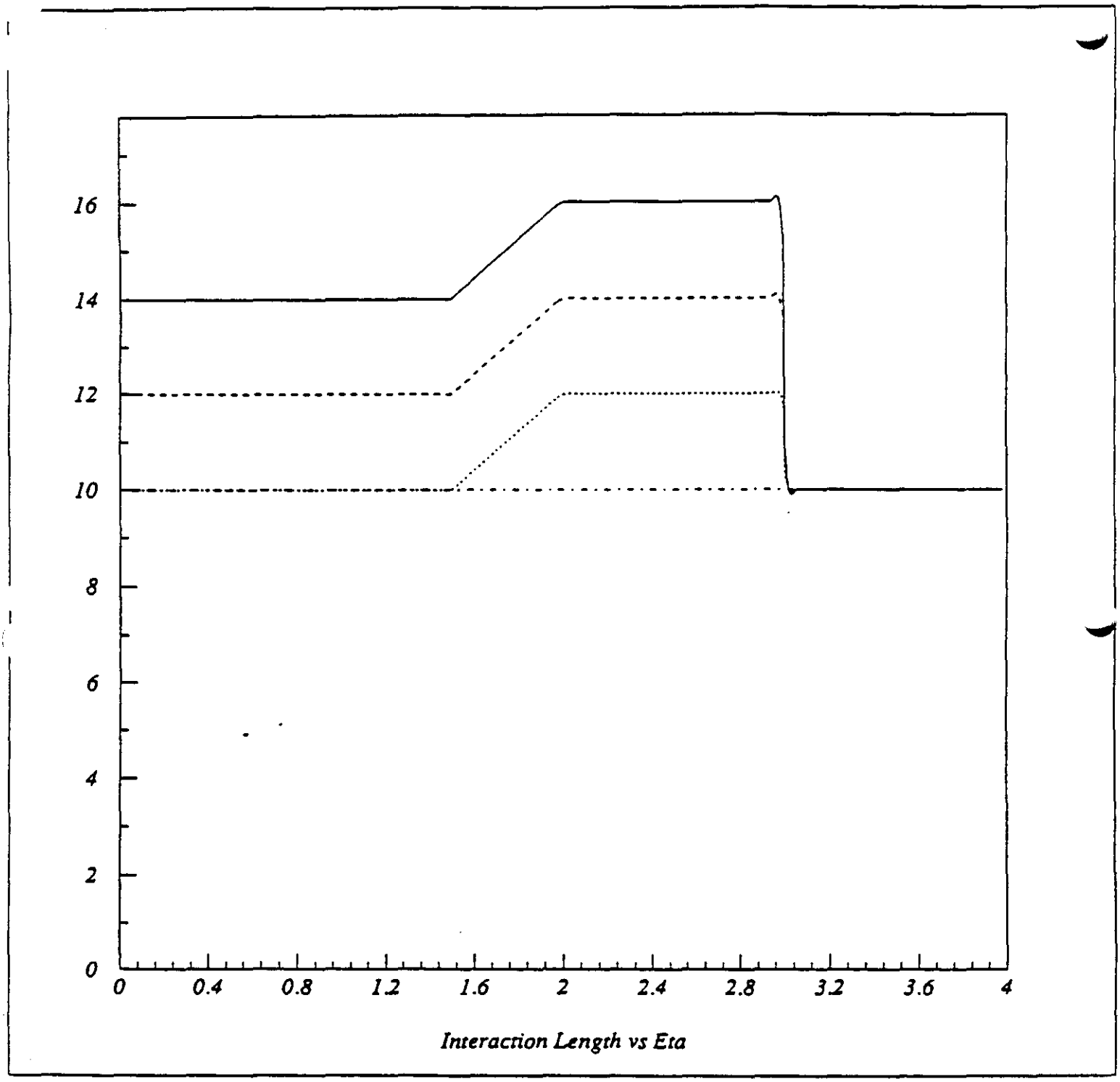


Fig. 4 - Interaction length versus rapidity representing the calorimeter depth model used in the Hit-level Monte Carlo.

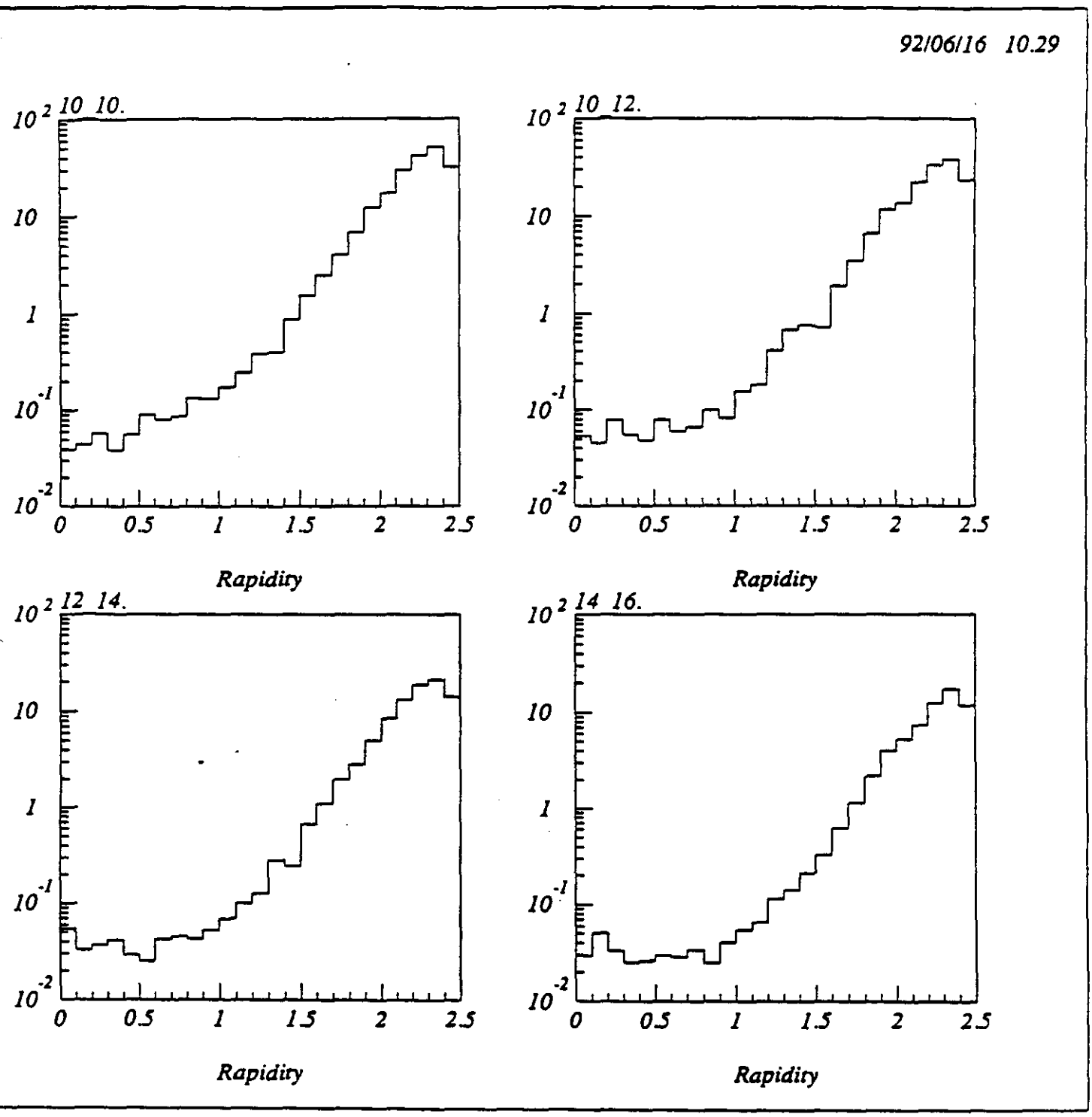


Fig. 5 - Charged particle flux (Hz/cm^2) versus rapidity for four calorimeter depths 10-10, 10-12, 12-14, and 14-16 lambda in the barrel-endcap. (L=10^33 cm^-2 s^-1)

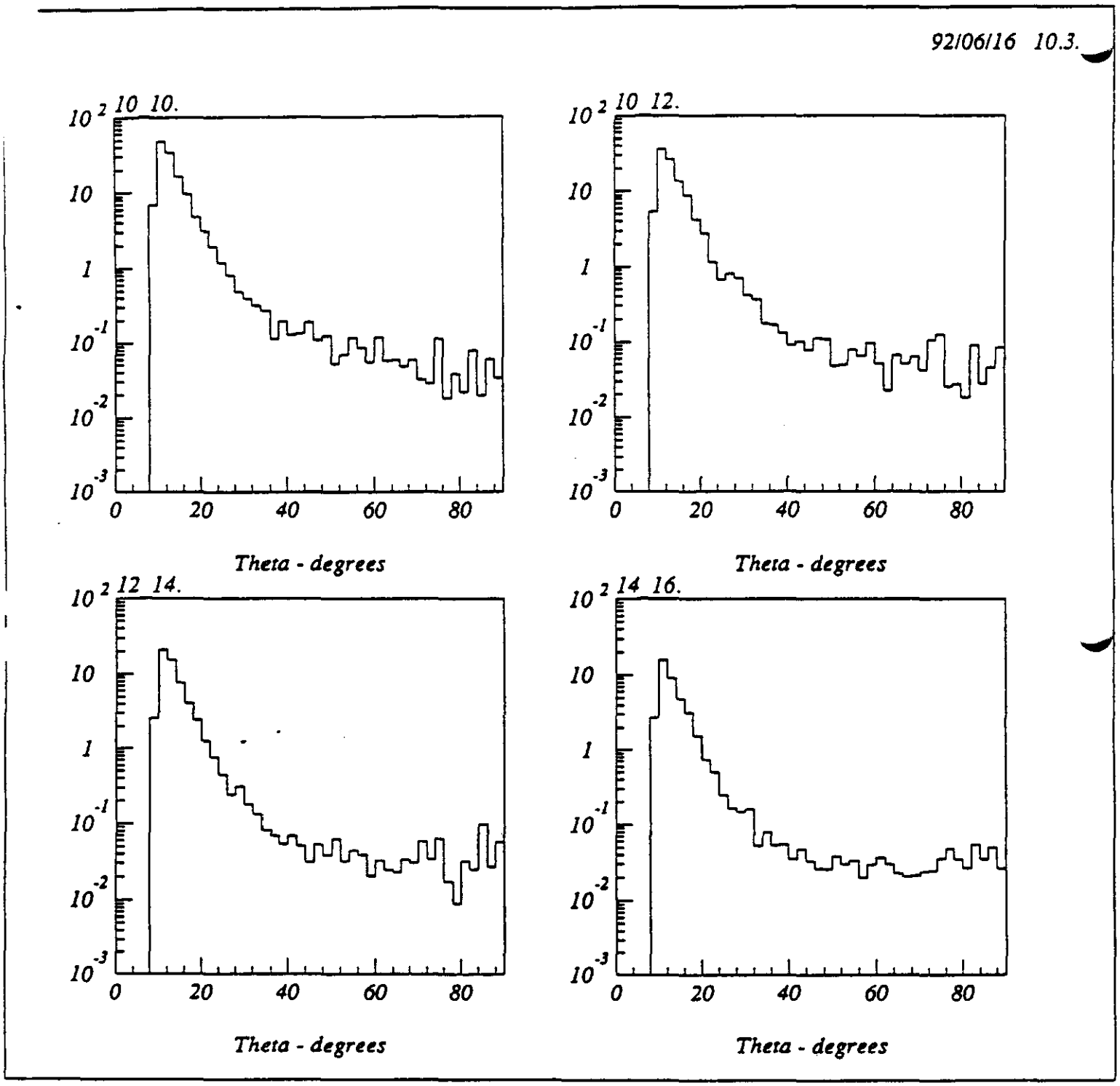


Fig. 6 - Charged particle flux (Hz/cm^2) versus polar angle theta (degrees) for four calorimeter depths. (L=10^33 cm^-2 s^-1)

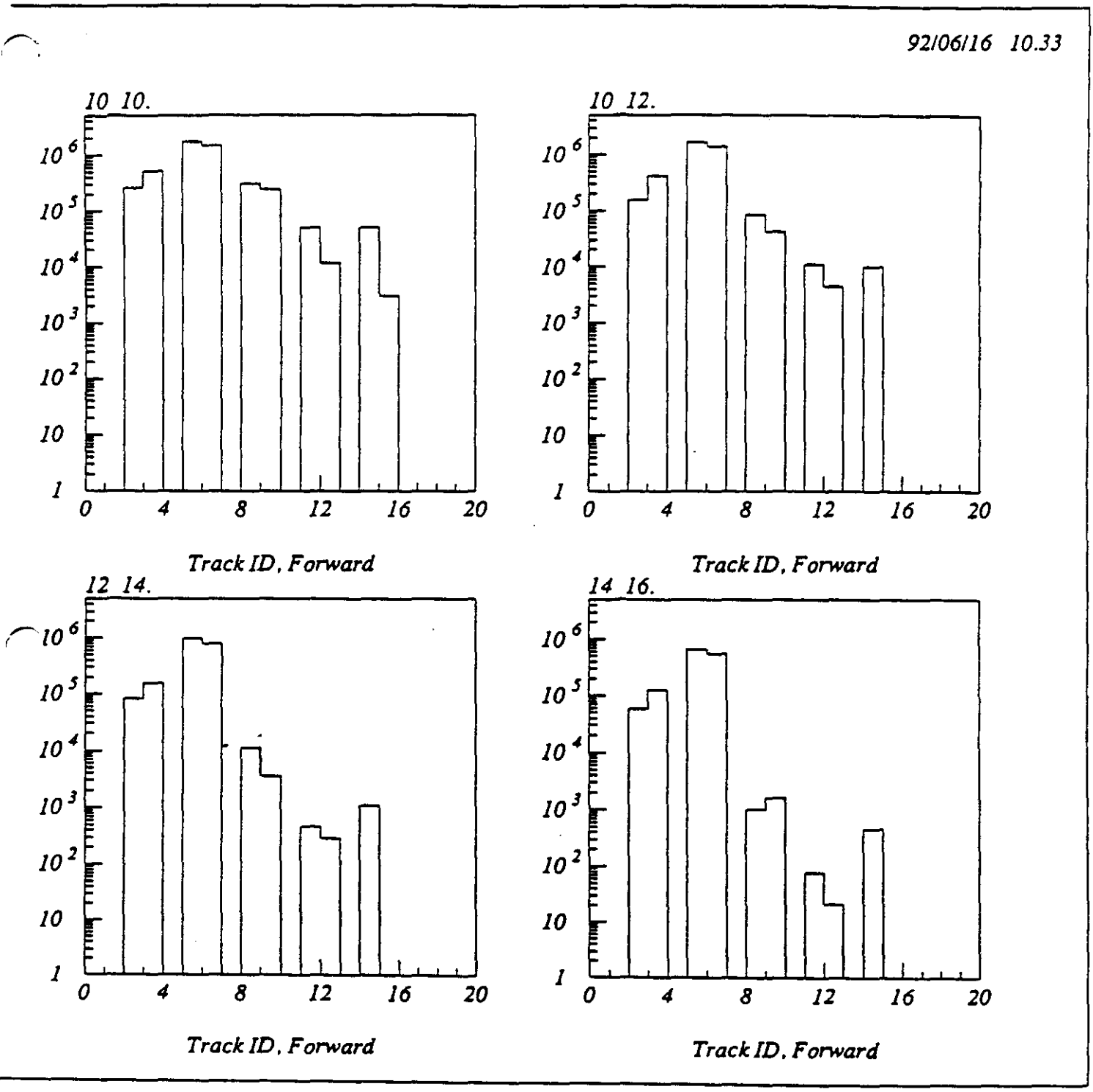


Fig. 7 - Charged particle rate (Hz) in the forward endcap versus track ID for four calorimeter depths. The ID's are: 2 or 3 electrons, 5 or 6 muons, 8 or 9 pions, 11 or 12 kaons, and 15 or 16 protons. (L=10^33 cm^-2 s^-1)

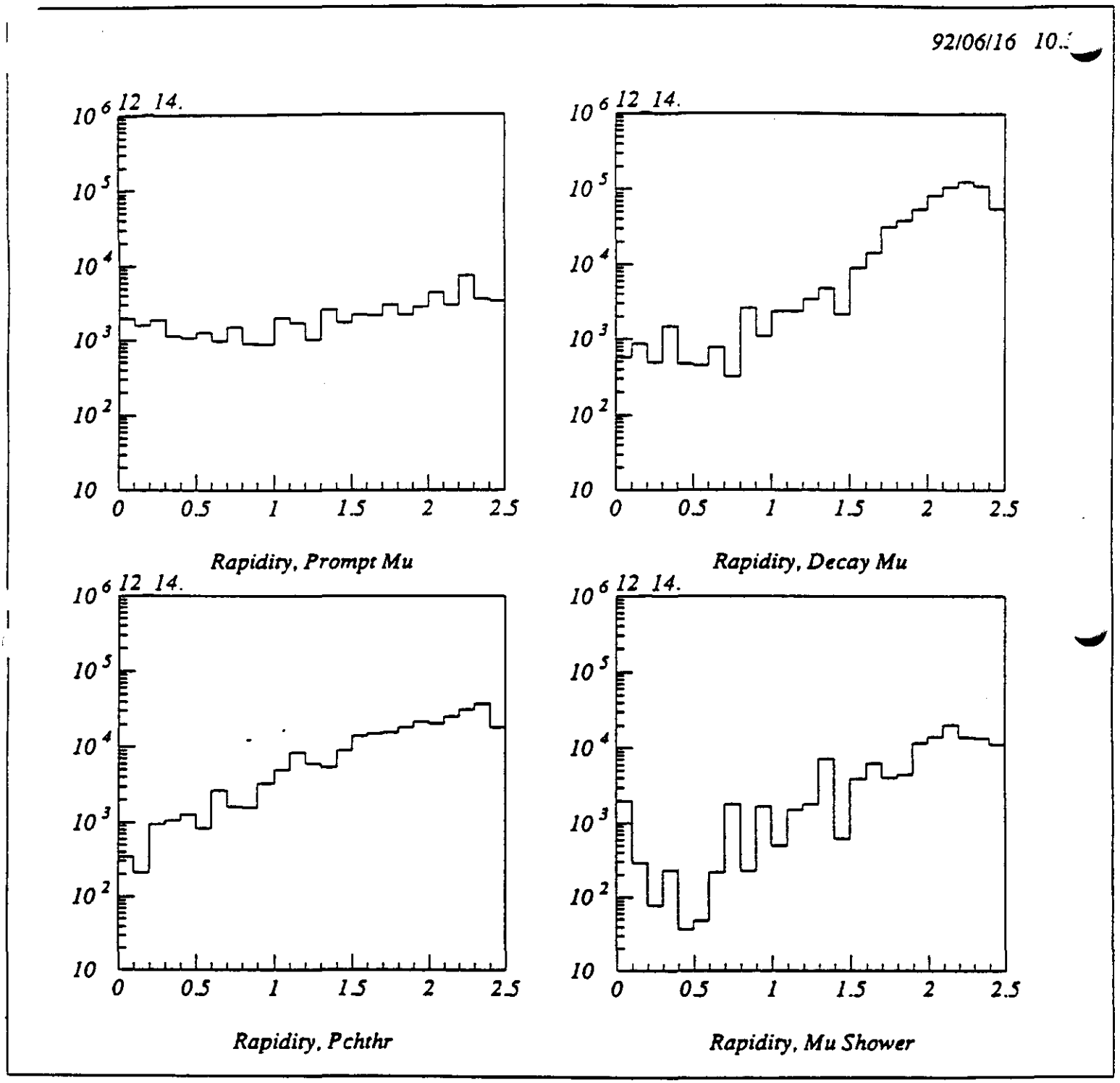
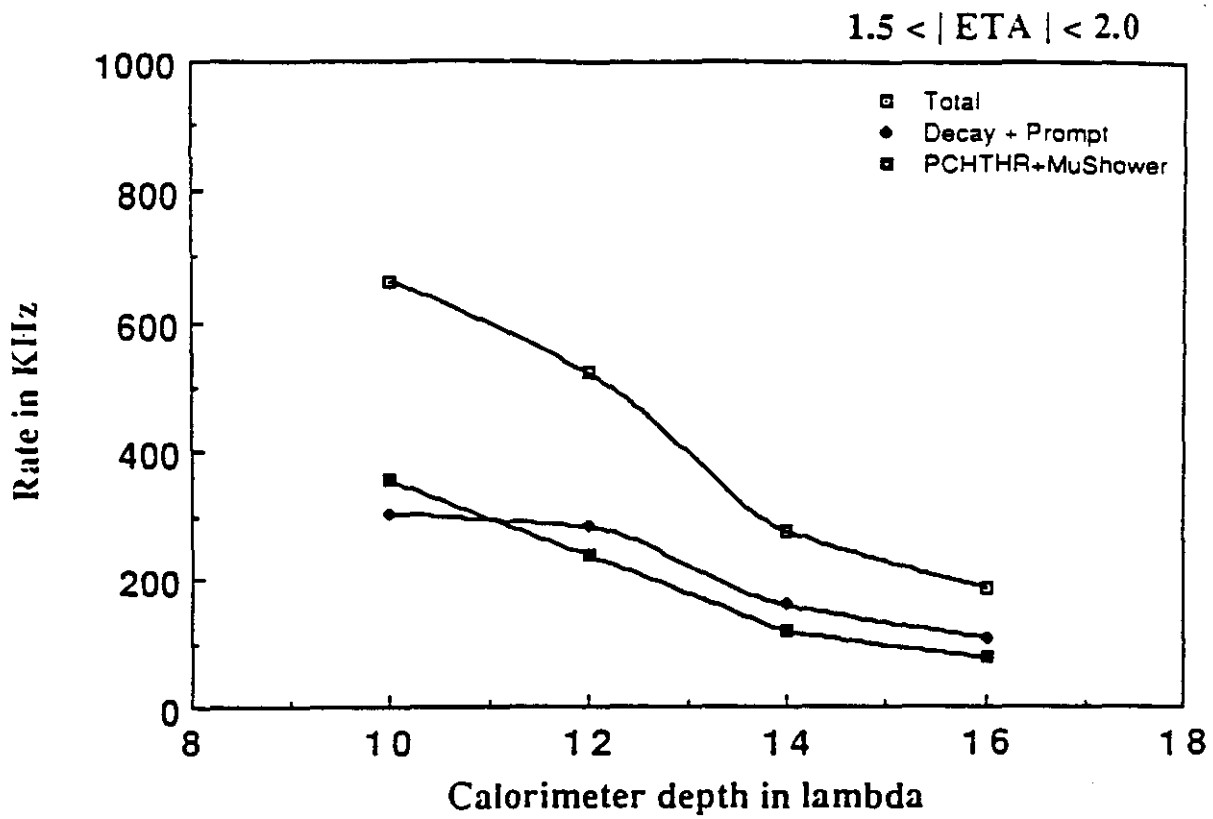


Fig. 8 - Charged particle rate (Hz) versus rapidity for prompt muons, decay muons, punchthrough particles and muon induced showers for a calorimeter depth of 12-14 lambda in the barrel-endcap. (L=10^33 cm^-2 s^-1)



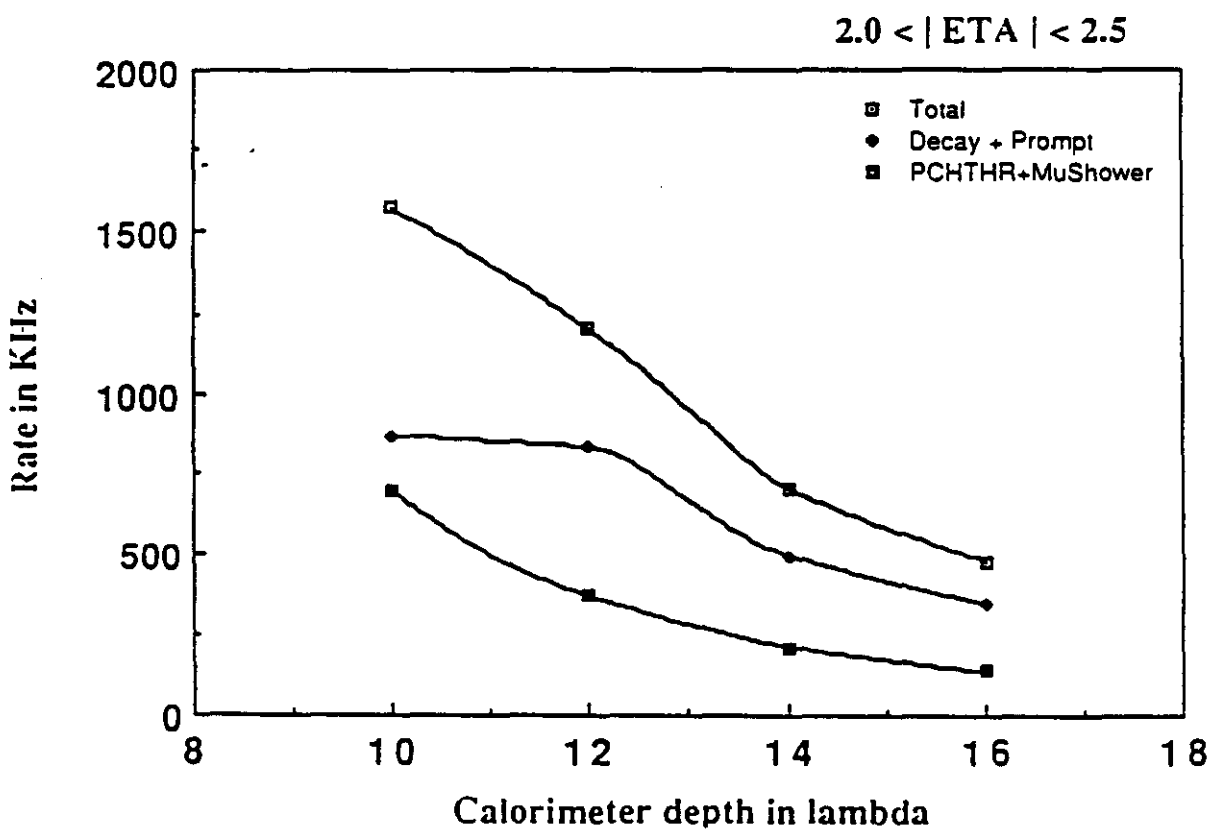


Fig. 9 - Charged particle rate (kHz) versus calorimeter depth (lambda) for two rapidity intervals 1.5<|eta|<2.0 and 2.0<|eta|<2.5. (L=10^33 cm^-2 s^-1)

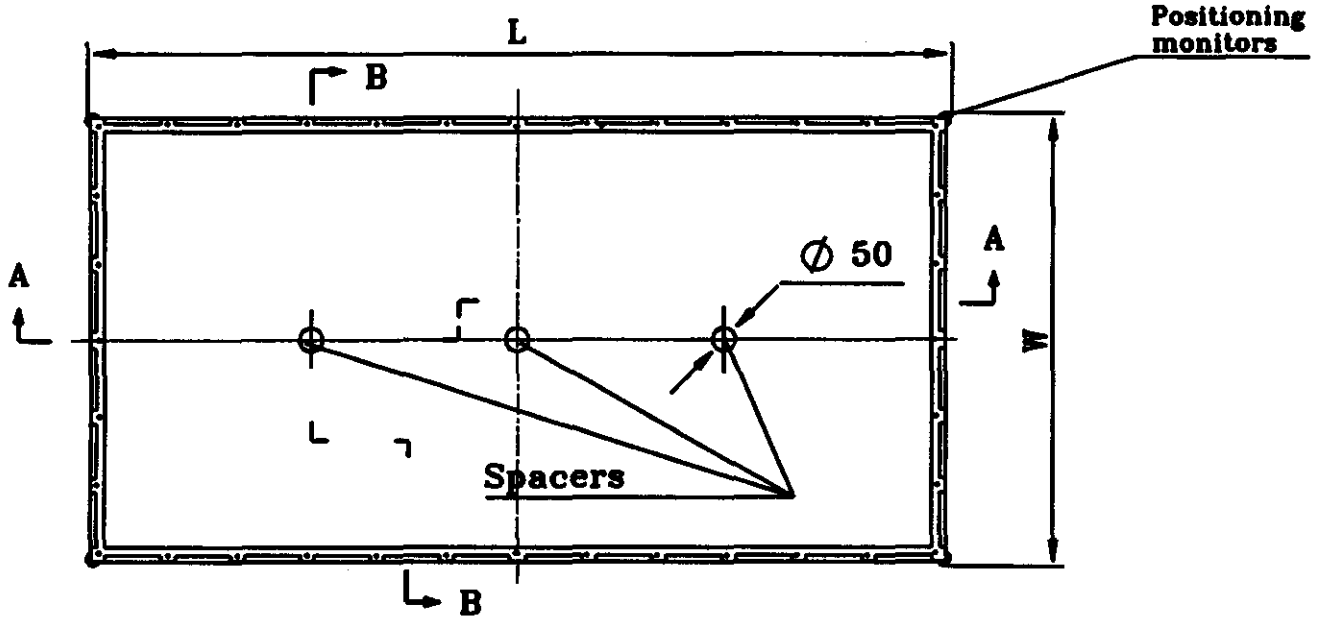
(5) Overview of CSC Module Construction

The position and timing resolution requirements are met by constructing modules with multiple chambers in a common package. Internal, relative alignment of the individual chambers is mechanically stable and precision of each chamber is controlled and monitored so that the position resolution of N chambers is $1/\sqrt{N}$ times the single chambers resolution. Timing resolution is approximately 1/N times that of a single chamber. Modules will combine four chambers. Each module has common utilities, control, and DAQ connections. The module is the fundamental unit for further alignment, relative to other modules in the muon system and relative to the detector coordinate system.

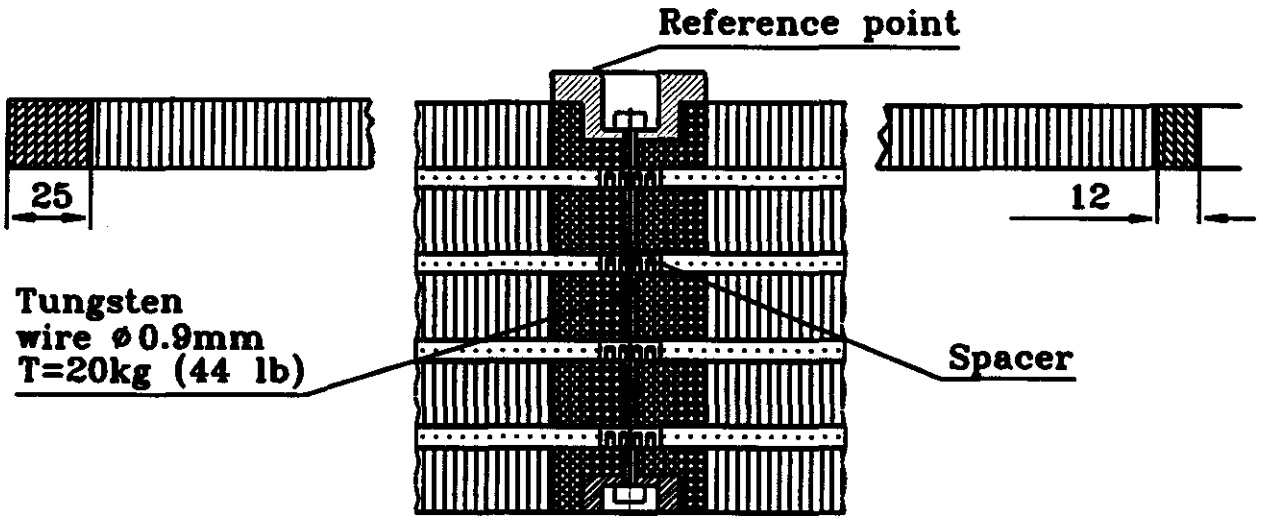
Modules in the barrel are rectangular. In the endcaps, the modules are trapezoidal, reflecting the requirement for the momentum trigger that the cathode strips be radial. The width (anode direction) of the module is limited by several factors. Electrostatic instability of the 30 μm diameter tungsten wires limits the unsupported anode wire length to roughly 1.2 to 1.5 meters, depending on operating voltage and gas gap. The availability of cathode materials and the limitations of technologies for applying the strip pattern provide a practical limit on the width also in the range of 1.2 to 1.5 meters. The length (strip direction) of the CSC's in the barrel is 3 to 4 meters, set by noise due to strip capacitance and by material and process limitations. In the endcaps, the charged particle flux below $\theta \sim 17°$ further limits the strip length.

A plausible module design is shown in various sections in Figures 5.1 to 5.3. These designs have been developed from several generations of prototype chambers that have been constructed and are now under test. The central idea in the design is to meet requirements of flatness and rigidity of the chambers by using panels made by laminating the cathodes onto a lightweight cellular core (e.g. Nomex at 1.8 lb/ft^3). With a core thickness of order 1" the laminated panels will have acceptable sag in any orientation. In the endcaps, gravity-induced sag is not an issue and core thickness could be reduced.

BARREL CSC



A–A (B–B)



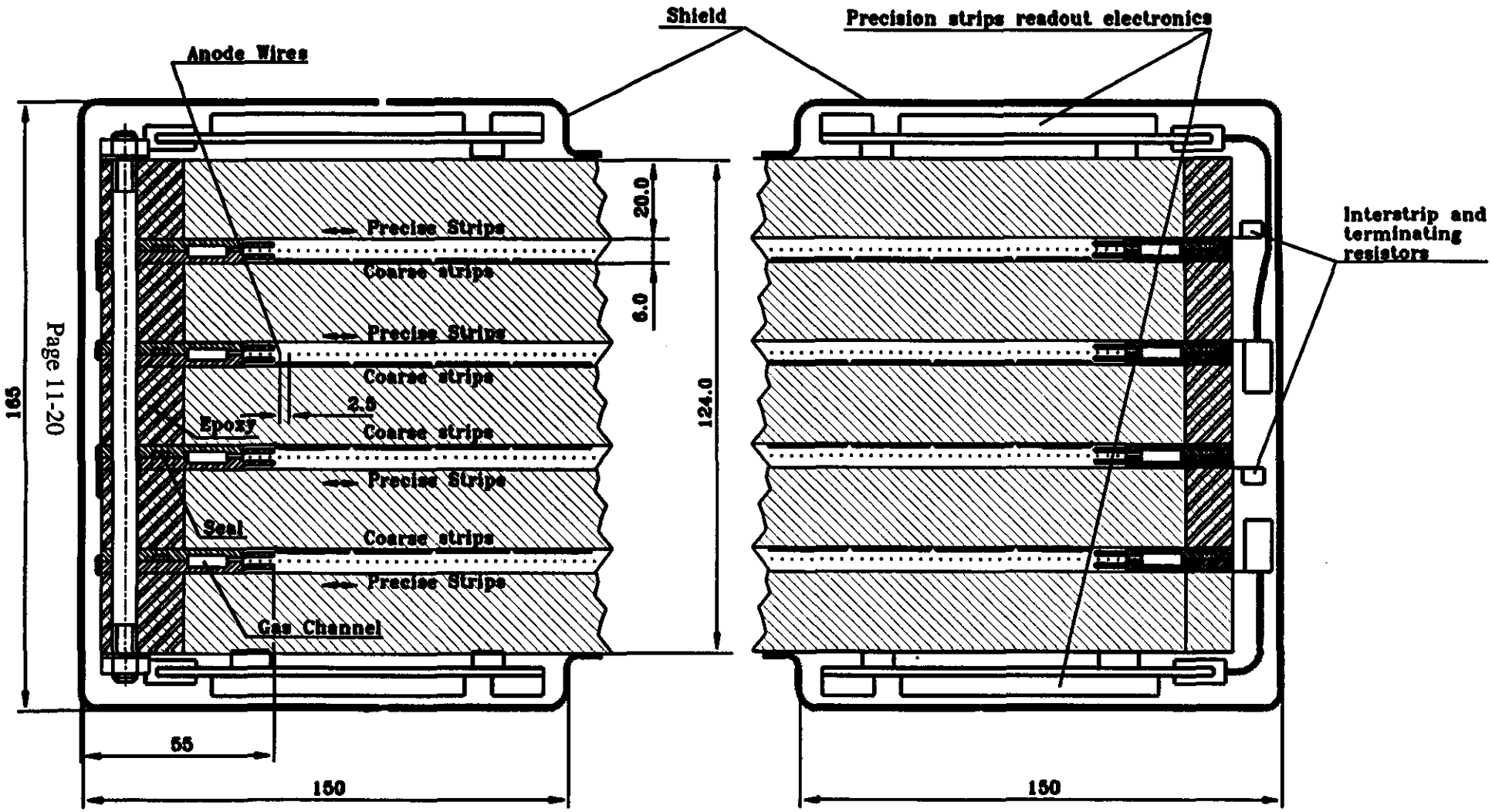
	Outer Layer	Middle Layer	Inner Layer
L	3.506m	2.515m	3.152/3.028m
W	0.960m	1.320m	0.740m

Fig. 2.8

Y.Ershov
I.Golutvin
V.Lysiacov
S.Movchan

BARREL CSC

CROSS SECTION ALONG THE STRIPS (A–A)



Y.Ershov
I.Golutvin
V.Lysi-kov
S.Mc an

Fig.2.9

BARREL CSC

CROSS SECTION
ALONG THE WIRES
(B–B)

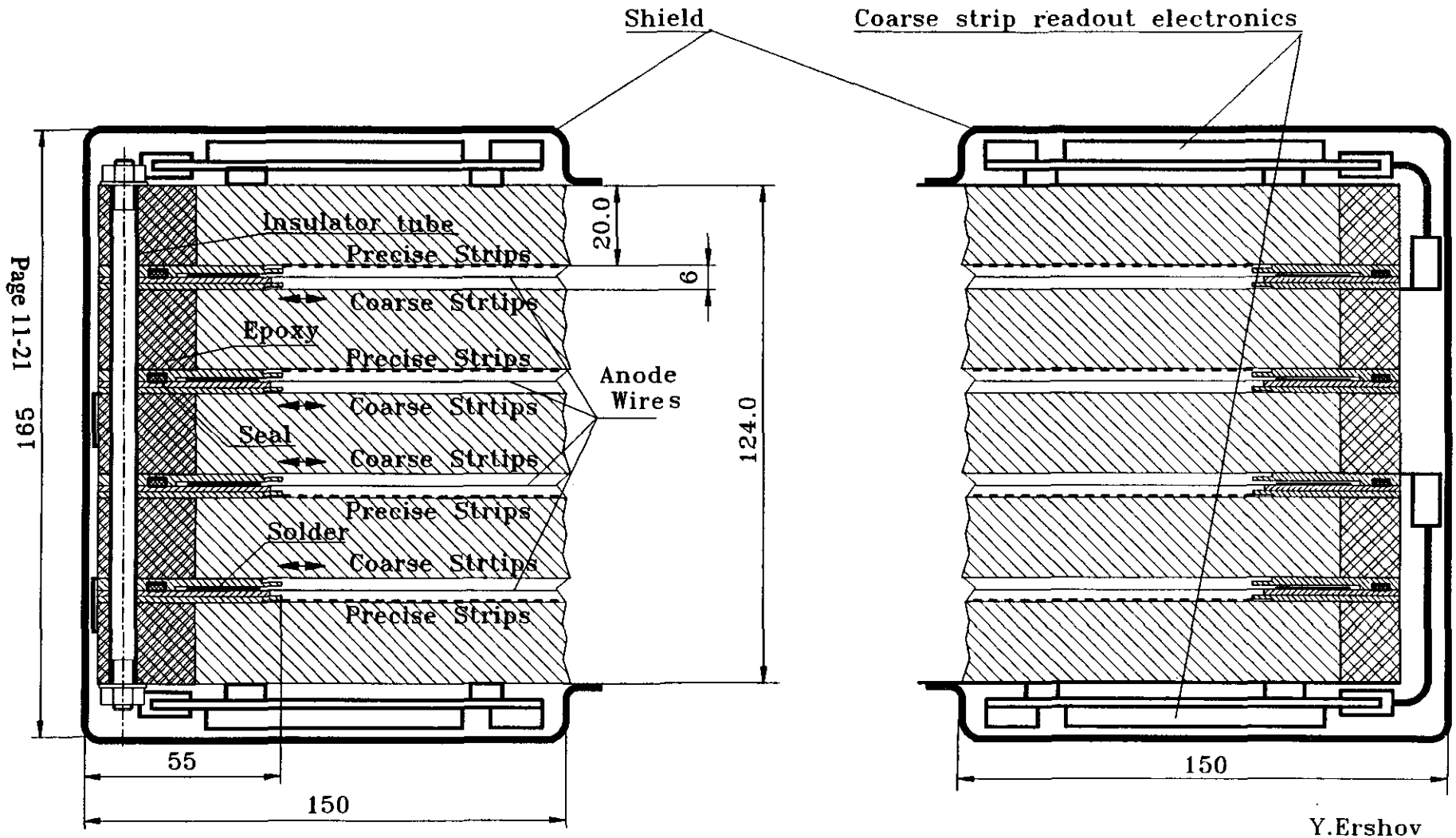


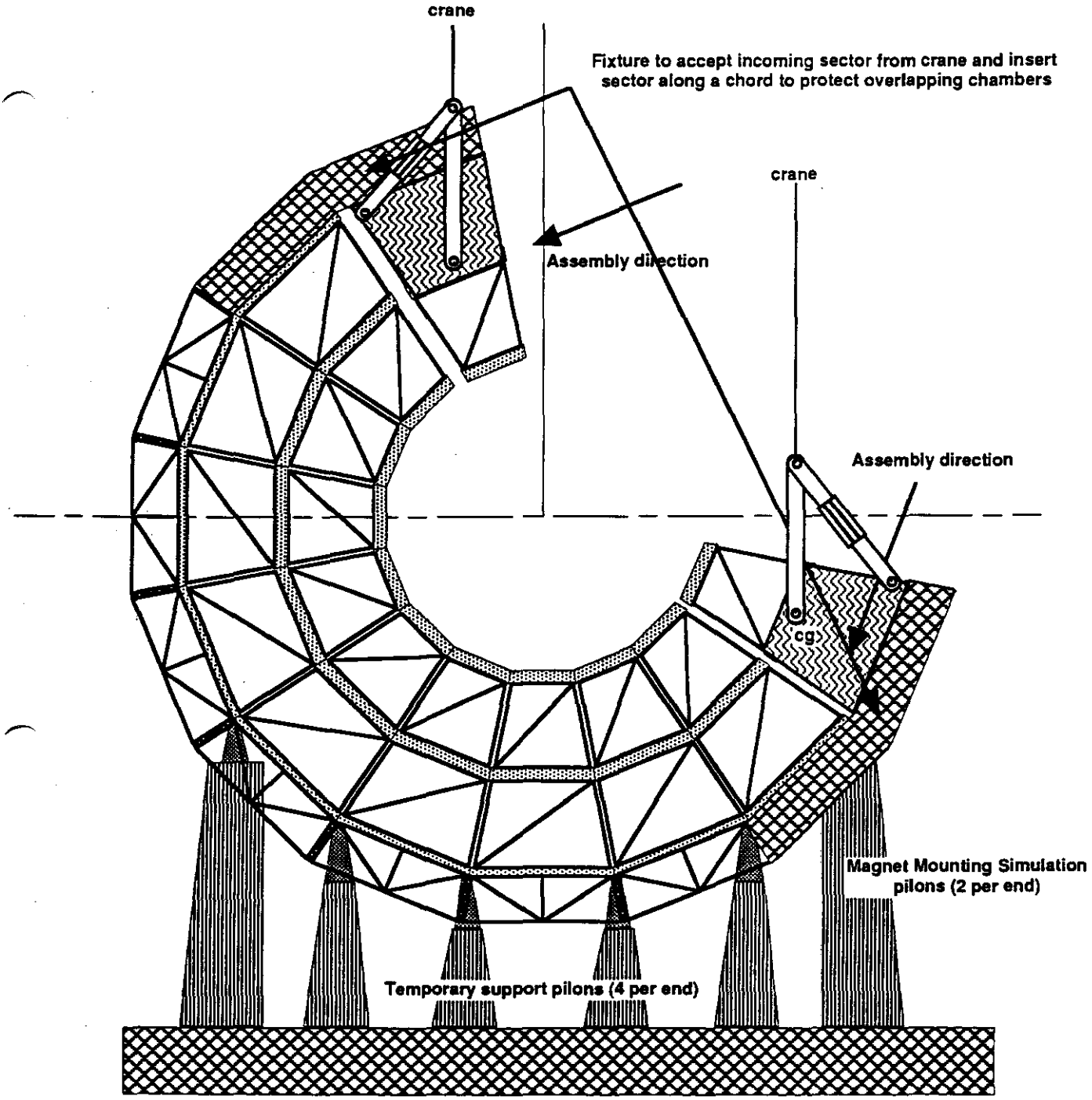
Fig.2.10

Y.Ershov
I.Golutvin
V.Lysiakov
S.Movchan

(6) Support Structure

The GEM muon support structure will be composed of four monolithic structures. There will be two monolithic structures for the barrel section, and two for the end cap section. The monolithic structures will each be assembled from sixteen sector-like sections that will have their muon chambers installed and roughly aligned. Figure 6-1 illustrates a way that the sectors could be joined to form the monolithic structure for one of the barrel halves.

The monolithic structures will be assembled above ground and moved to the experimental hall for installation into the magnet. The chambers in the monolith will be preliminarily aligned to each other and to the approximate IP above ground, and they will be finally aligned when they are installed into the magnet.



GEM MUON SYSTEM BARREL ASSY
(Sectors With Integral Structural Ring

END VIEW OF BARREL

Cooper Laboratory		
GEM Muon System Assy (end view, barrel)		
Drawn By:	F. Nimblett	Rev (-)
Dwg. No:	GMU0023	11/18/92
Approved by:		

12. ALIGNMENT

ALIGNMENT SYSTEM

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ALIGNMENT SYSTEM

OVERVIEW

The GEM alignment effort is developing the design for the precision alignment of all of the GEM subsystems relative to each other and to the beamline. The requirements which are controlling this process span the spectrum of placement, measurement and stability tolerances which range from 5 microns to many millimeters. In order to meet these requirements a philosophy has been crafted which emphasizes precision measurement rather than precision placement. This strategy has resulted in an alignment solution that is achievable with conventional alignment equipment and demands placement accuracies consistent with the realities of moving, and maintaining the position of large, complex structures.

Because of its size and precision requirements the muon system poses the greatest alignment challenge in GEM. Details of the alignment strategy for this system are discussed below followed by a top level discussion of the global alignment requirements and the installation alignment strategies for all of the major GEM subsystems.

MUON SYSTEM

Local alignment

The barrel region local alignment system for the muon detector is conceptually defined in Figure 12-1. The chambers are arranged in projective towers. At the four corners of each tower are located straightness monitors which measure misalignment in the phi and z direction only. In addition, two more alignment paths are located at the mid-sides of each tower end. These paths are required to distinguish z-axis rotational modes from phi direction translation. In order to meet the 75 micron total muon sagitta measurement precision, the accuracy of each alignment monitor is required to be less than 25 micron. When the alignment paths are arranged projectively as shown several significant benefits are obtained. Most importantly the precision which the chambers must be placed relative to each other is greatly reduced. Calculations indicate that chamber misplacements up to 5 mm in translation and 3 mrad in rotation are acceptable. Figure 12-2 shows a result of a Monte Carlo analysis which simulates the performance of a 6 point projective alignment system due to randomly applied misplacement and thermal expansion of the muon chambers. Assuming the aforementioned maximum misplacements and adding additional

errors due to 3 mrad of chamber torque and 5 C of uniform thermal expansion the rms error is shown to be less than the 25 micron requirement.

The realization of the projective alignment scheme in a complete muon barrel sector for both the CSC and RDT options is shown in Figure 12-3. The CSC technology requires 8 towers in each muon sector because of the size limitations of the chambers. This results in 48 alignment paths per barrel module and 1536 for both barrel halves. This is reduced to 630 if the RDT technology is deployed. Multipoint alignment monitoring previously envisioned in Baseline 1 is no longer required but may be added for redundancy or to improve total acceptance. Further detailed engineering evaluation is required to demonstrate its cost/performance benefit.

The local alignment system of the the endcap muon towers is expected to be similar in concept to the barrel region. Figure 12-4 again shows projective alignment paths at the corners of each endcap tower. As with the barrel region, two additional paths will probably be required to distinguish rotational modes. Additional analysis is required to justify this requirement. Precision bubble levels may also be employed to identify z axis rotation and tower torquing.

The baseline alignment monitor system is the LED/lens system (Figure 12-5) proven at L3 and further developed at Draper Laboratory. These are simple devices composed of an LED, lens and quadrant photodiode. An image of a smooth-aperture, collimated source (LED) is projected onto a planar detector (quadrant photodiode) through a focusing lens. Displacements of the lens from the line between the source and detector are detected by a shift in the illumination of the centroid at the photodiode. The straightness monitor components will be fixed to the drift chambers such that they precisely reference the cathode strips or sense wires positions. The mounts containing the optical devices and the gain balance between detector quadrants will be precisely adjusted as these components are fabricated. During construction of each muon sector, the straightness monitors will be cross-checked using cosmic ray data and external measurements. The accuracy of this straightness monitor system has been experimentally verified to be much better than the 25 micron requirement over distances up to 9 meters. Dynamic range limitations are presently about 1 mm (Figure 12-6). Development efforts are underway to extend this range by using either

optical enhancement techniques for the baseline LED/lens system or CCD arrays in place of the photodiode. Present projections are that ± 5 mm range is achievable.

Alignment of muon towers

The alignment of the muon chambers relative to a common vertex will first be achieved during initial assembly in the surface facility. Each muon sector will be assembled independently on a simple assembly fixture that supports the sector truss structure and permits rotation of the structure to validate alignment at all orientations. After installation, the chambers will be aligned to achieve local alignment requirements and to simultaneously achieve proper registration of the chambers relative to the support structure. After all sectors have been completed they will then be assembled and coupled together into a monolithic structure. This structure will contain all of the components of the barrel muon system. After integration, both local and global alignment of the sectors (relative to an imaginary vertex) will be verified using both local straightness monitors and external precision surveying equipment. Deviations from specifications will be corrected by adjustment of the chamber kinematic mounts. This adjustment capability is required on only two of the three layers and may be done remotely.

The alignment sequence for the endcap muon system will be performed in a similar way. Individual sectors will be constructed, and aligned then coupled together and aligned to a common vertex. Upon completion of this task the end cap assembly will be transported to, and installed into the barrel while it is still located in the surface facility. An adjustable support mechanism will be design to provide for accurate, relative positioning between the two large assemblies. It is anticipated that some re-adjustment of individual chambers will have to be performed after this installation but structural calculations indicate that these disturbances will be localized and will affect only a small fraction of the total chamber population.

Upon completion of the the alignment in the surface facility the coupled barrel/endcap assembly will be transported to the experiment hall. After installation into the magnet the four support points of the monolithic muon system assembly will be adjusted to locate the imaginary vertex established during surface facility assembly at the same point as the expected IP which is defined by the experiment hall monuments. During transportation some alignment disruption will be inevitable. However, careful fixture and transport designs will be implemented to assure that support conditions established in the

surface facility are duplicated in the final resting position inside the magnet. In this way the alignment disturbance and installation time in the experiment hall will be minimized.

The precision alignment requirements that will drive the detailed design of the muon system have been examined in critical detail. Tables 1-4 identify initial requirements that have been established. They take into account physics and engineering requirements regarding bend plane muon resolution, z-axis vertex distribution, multiple scattering in the calorimeter, alignment of trigger roads, dynamic local range of straightness monitor sensors, pattern recognition and line-of-sight deviation from the IP. The overriding requirement for global alignment is trigger road alignment which demands placement accuracy of the barrel muon towers relative to the IP to be less than 5, 10 and 5 mm in the phi, r and z directions respectively and 5, 4, and 10 mm in the same directions for the endcap towers. These placement requirements can be achieved with standard adjustable support designs and can be verified during assembly with conventional precision surveying equipment. It is conceivable that these requirements can be relieved even further if the trigger roads can be reprogrammed in situ. This possibility is being evaluated and will be reported at a later date.

A GEM goal (not requirement) is to be able to measure (not place) the muon tower position relative to the IP to better than 200 microns. This will permit vertex inclusion as a fourth point in the momentum calculation and result in a further improvement in resolution capability. Preliminary calculations indicate that single event background muons may provide sufficient resolution to satisfy this requirement. Additional more detailed calculations are being performed to confirm the initial finding. Should this technique prove feasible other real time global placement measuring systems may not have to be developed. However, several conceptual designs are being evaluated to develop a contingency plan that could be implemented. Two examples of candidate systems are shown in Figure 12-7. In one case the pointing position of each tower is translated to the calorimeter outer diameter using a laser reference beam. Transfer from that point to the vertex is accomplished through installation knowledge of the tracker's position inside the calorimeter and using the tracker as a beam position monitor. The other technique projects tower position axially to a position outside of the magnet and then down to a beam position monitor using precision optical techniques.

GLOBAL ALIGNMENT

Requirements

Successful global alignment implementation will require that four different tolerance categories be addressed: placement accuracy, stability, drift and real time measurement. These must be related not only to the position of each major assembly relative to the beamline but also relative to each other. Tables 5 through 8 compile all of these alignment requirements for the GEM detector. Tolerances are tabulated in a cylindrical coordinate system (radial, azimuthal (phi) and z) for each relationship. Constraint parameters are also identified which identify relationships between tolerances which are physically constrained For example the stability requirement of the tracker can not be more stringent than the RSS of the stability requirements of the calorimeter and CDS structure because these three systems are serially connected one to another. All of these requirements are fluid and will evolve as the GEM design matures. This requirement database provides the mechanism for tracking and controlling this information.

Central detector assembly alignment strategy

The first subsystem requiring alignment in the experiment hall will be the central detector support structure. Initially it will be positioned without great accuracy since it is the placement of the subsystems which are mounted on it that require the more precise alignment. The barrel calorimeter will then be installed on the CDS. Precision fiducials located around the perimeter of either end flange will be used to accurately locate the calorimeter relative to the CDS. Then the CDS support legs will be adjusted to accurately center the calorimeter/CDS assembly relative to the IP. It is expected that standard precision survey equipment will be more than capable of measuring the placement of this assembly to less than the millimeter level accuracies that are required. The tracker will then be placed inside the barrel calorimeter and precisely adjusted, using its own precision kinematic mounts, to accurately be centered on the IP as defined by the Hall monuments.

It is important that tracker placement relative to the IP be obtained with the greatest accuracy that is reasonable and achievable. Lack of concentricity will reduce the lifetime of the components which are closest to the IP because of the increased radiation exposure. The accuracy of the final relative position between the tracker and the IP must be no greater than 5 mm in order to maintain component lifetime

requirements. This requirement drives many of the related tolerances defined in Tables 12-5 through 12-8.

After tracker installation the endcap and forward calorimeters are installed and accurately placed relative the barrel calorimeter. Placement accuracy on the order of a few millimeters is acceptable although the measurement of the relative position between tracker and calorimeter is desired to be known to within a few hundred microns. During this process the beampipe will also be installed. Concentricity of the beampipe with the beamline is presently not driving installation alignment requirements. However, in order to accommodate installation clearances and the misalignment between detectors, flexibility in the beampipe bellows is required and is believed to be on the order of a few millimeters.

Muon/magnet assembly alignment strategy

The magnet will have numerous alignment fiducials located internally on the coil and externally on the end flanges. During assembly in the surface facility the coil will be accurately placed relative to the end flanges using these fiducials. Cryogenic testing of the magnet will occur in the surface facility and will provide the opportunity to measure the motion of the fiducials and thus quantify the thermal deformations of magnet. Upon completion of magnet testing and characterization, the magnet is then transported and installed into the experiment hall. Using end flange fiducials only, the magnet will be positioned relative to the IP defined by the experiment hall monuments. Placement accuracy is expected to be limited by the precision of the magnet shimming process which is expected to be better than ± 10 mm.

The prealigned muon monolithic structure is installed into the magnet on its four support points. Adjustment mechanisms at those points will be used to locate the vertex of the structure at the IP with millimeter precision. Confirmation of the global placement of each muon tower will be confirmed using either conventional precision surveying equipment or specialized alignment techniques adapted to the complex muon system geometry. Local chamber adjustments may be required to compensate for any residual distortion caused by the transportation process or misalignment of the structure in the magnet. Misalignment between the muon system and the magnet structure is acceptable as long as assembly clearances are not violated. Magnetic field measurements will be made using numerous sensors located throughout the muon truss structure to precisely determine the magnetic field strength at any muon chamber location.

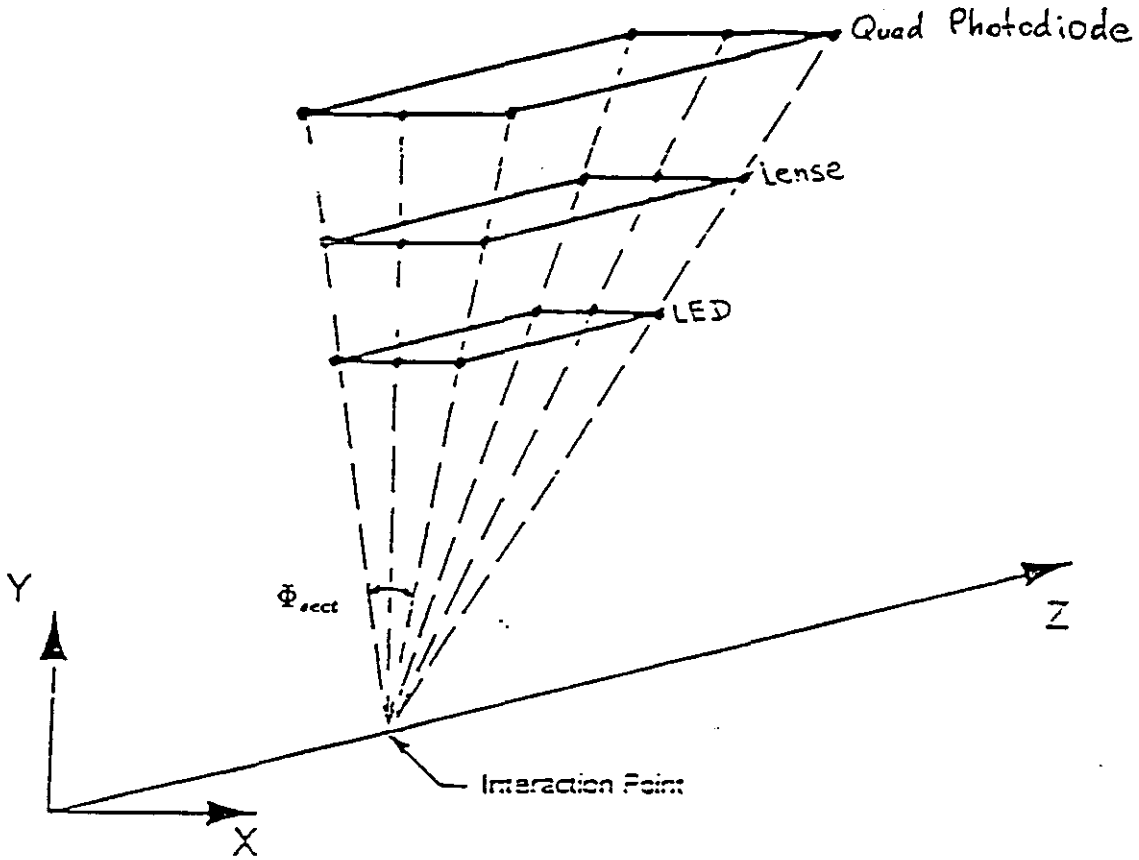
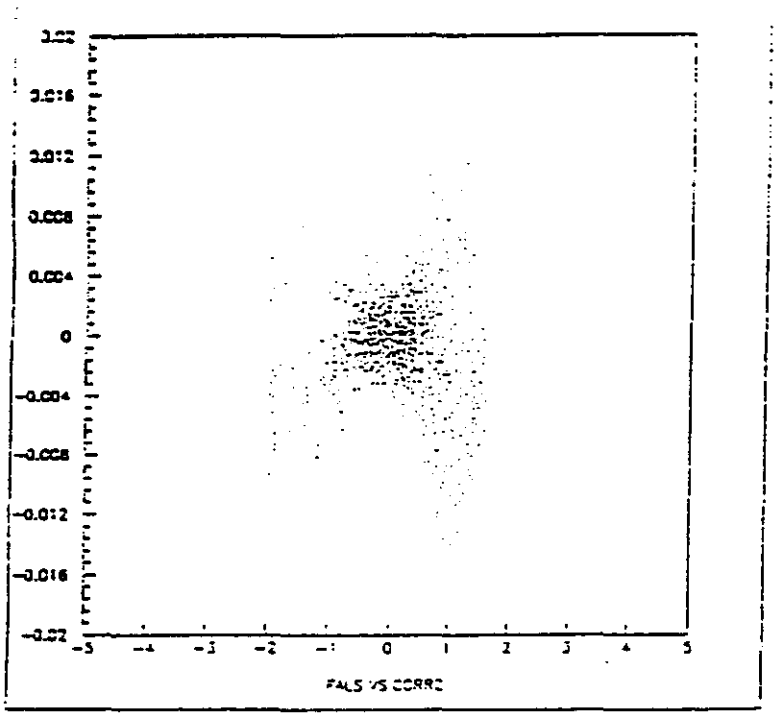
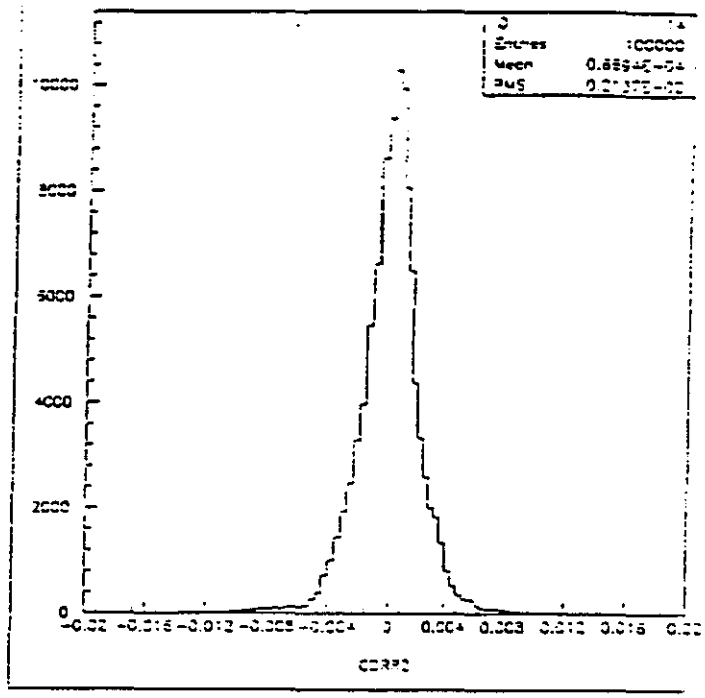


Figure 1. Muon alignment tower



Corrected Sagitta(cm) vs False Sagitta(cm)



Corrected Sagitta(cm)

Shifts and Rotations of Muon Chambers: $Dx, Dy, Dz \leq \pm 5mm$; $Sx, Sy, Sz \leq \pm 3mrad$

Deformations of Muon Chambers: $\Psi_{torqe} \leq \pm 3mrad$, $\Delta t^0 \leq \pm 5^0$

Figure 2. Muon sagitta errors caused by chamber misalignment

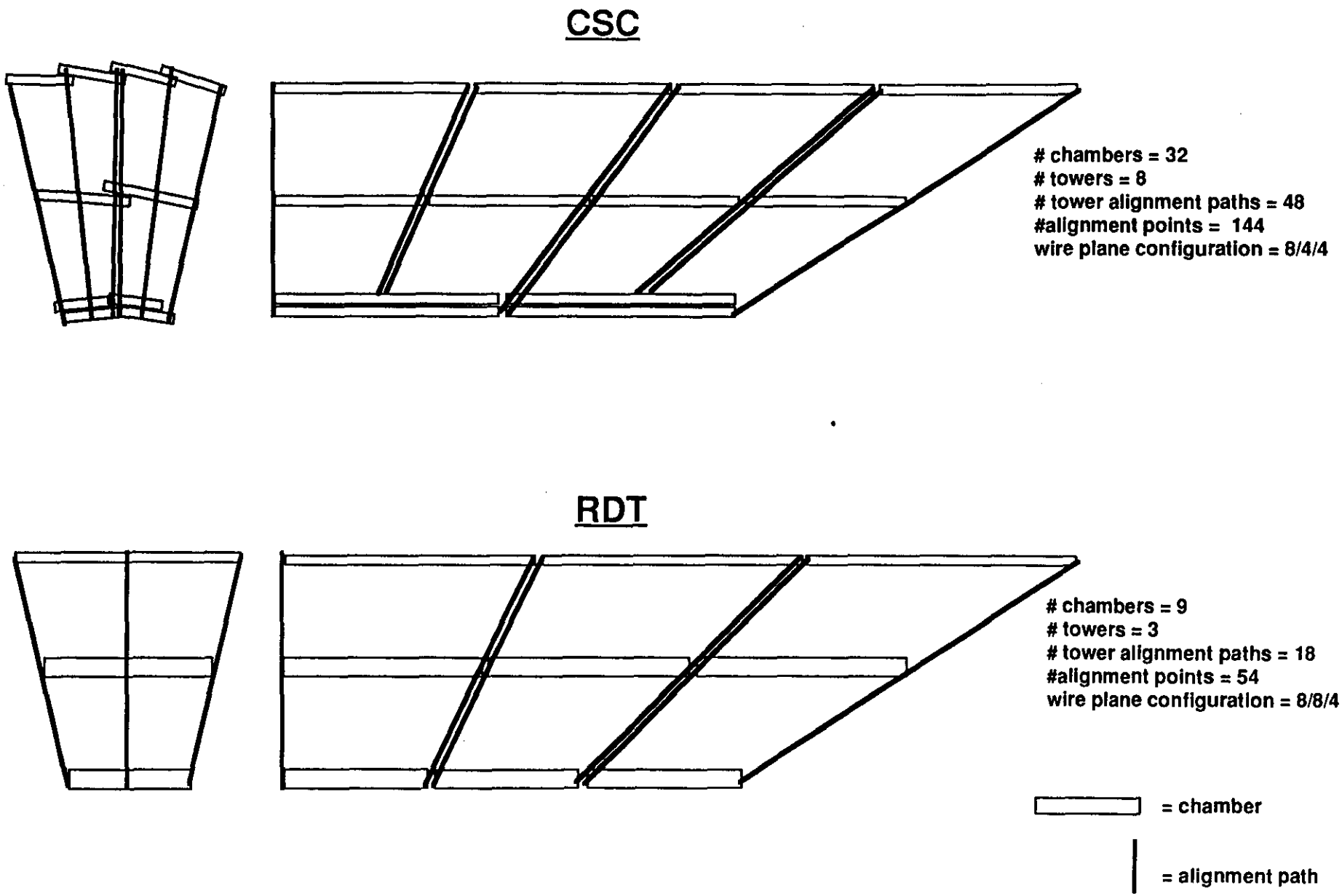


Figure 3. Local alignment schemes for muon barrel

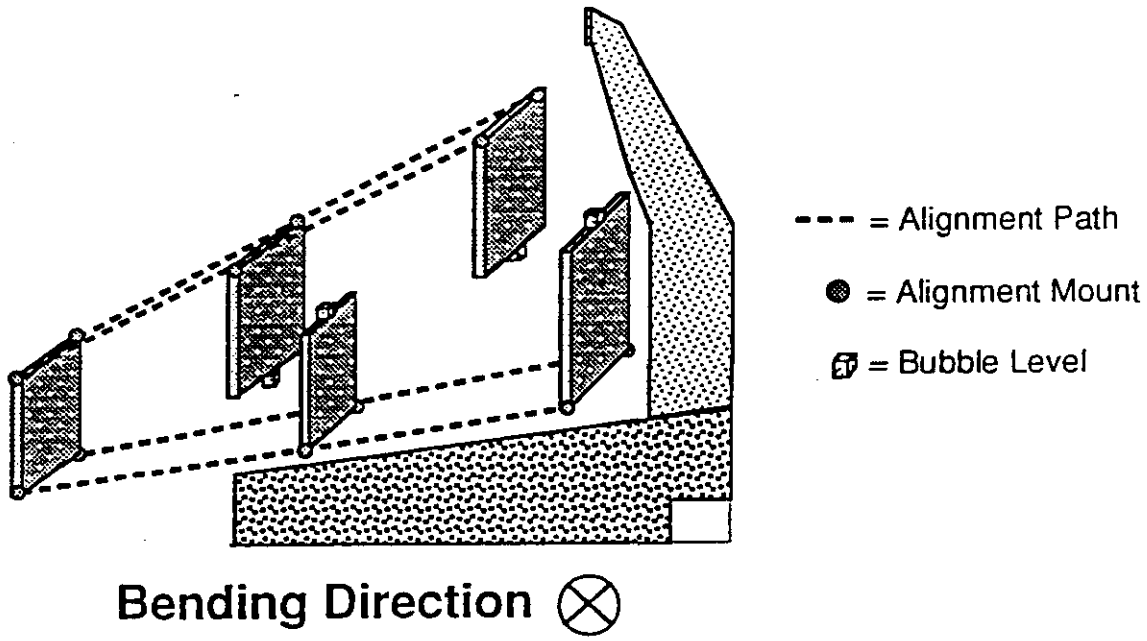
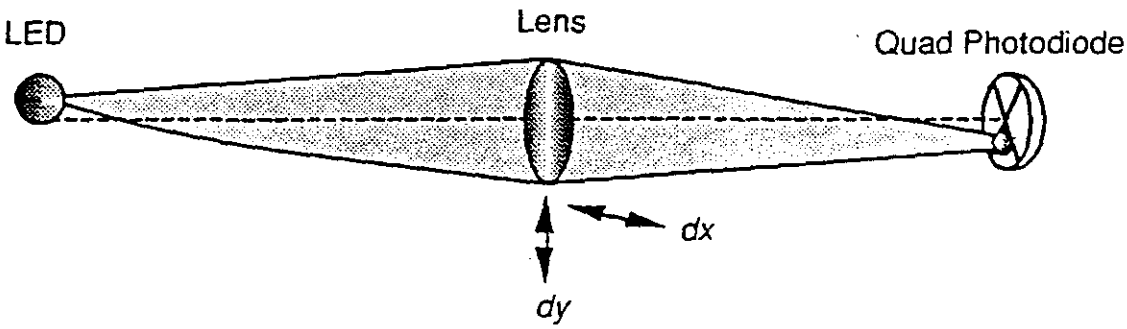
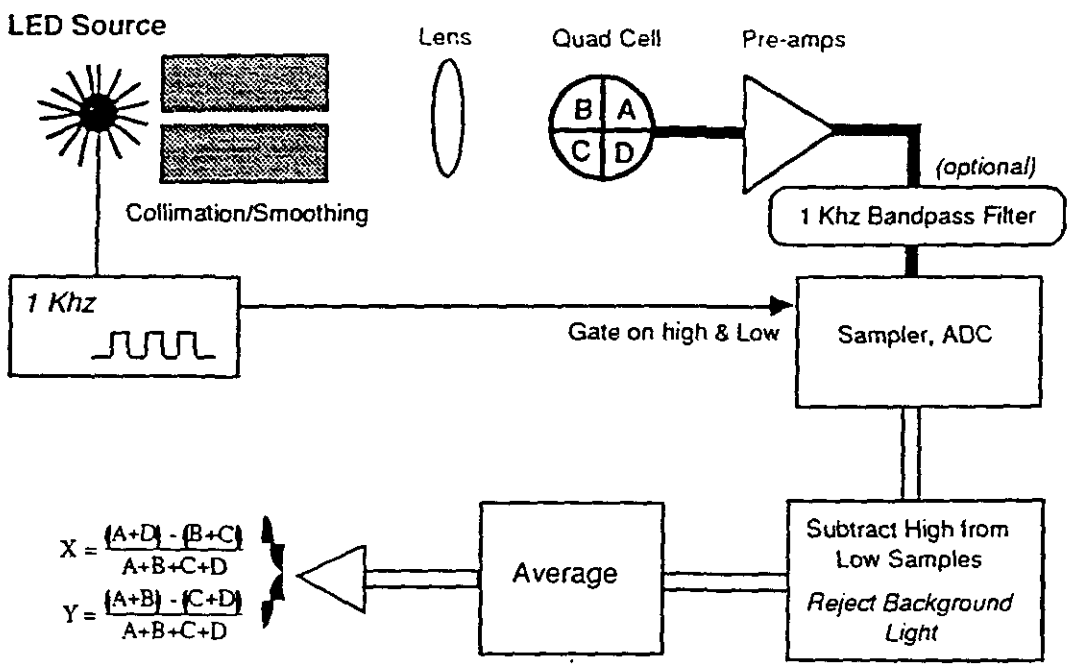


Figure 4. Possible scheme for aligning muon endcap



The Basic Straightness Monitor



Straightness Monitor Electronics

Figure 5. LED/lens straightness monitor

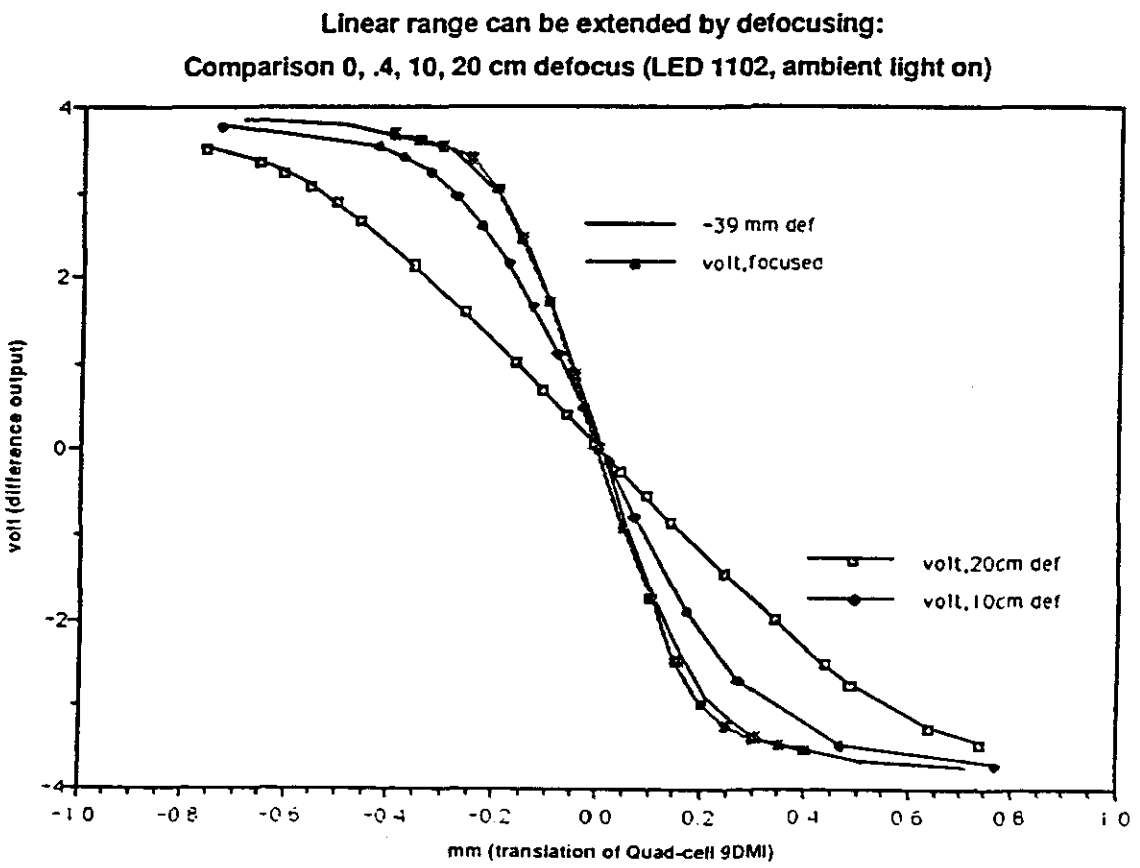


Figure 6. Straightness monitor transfer function

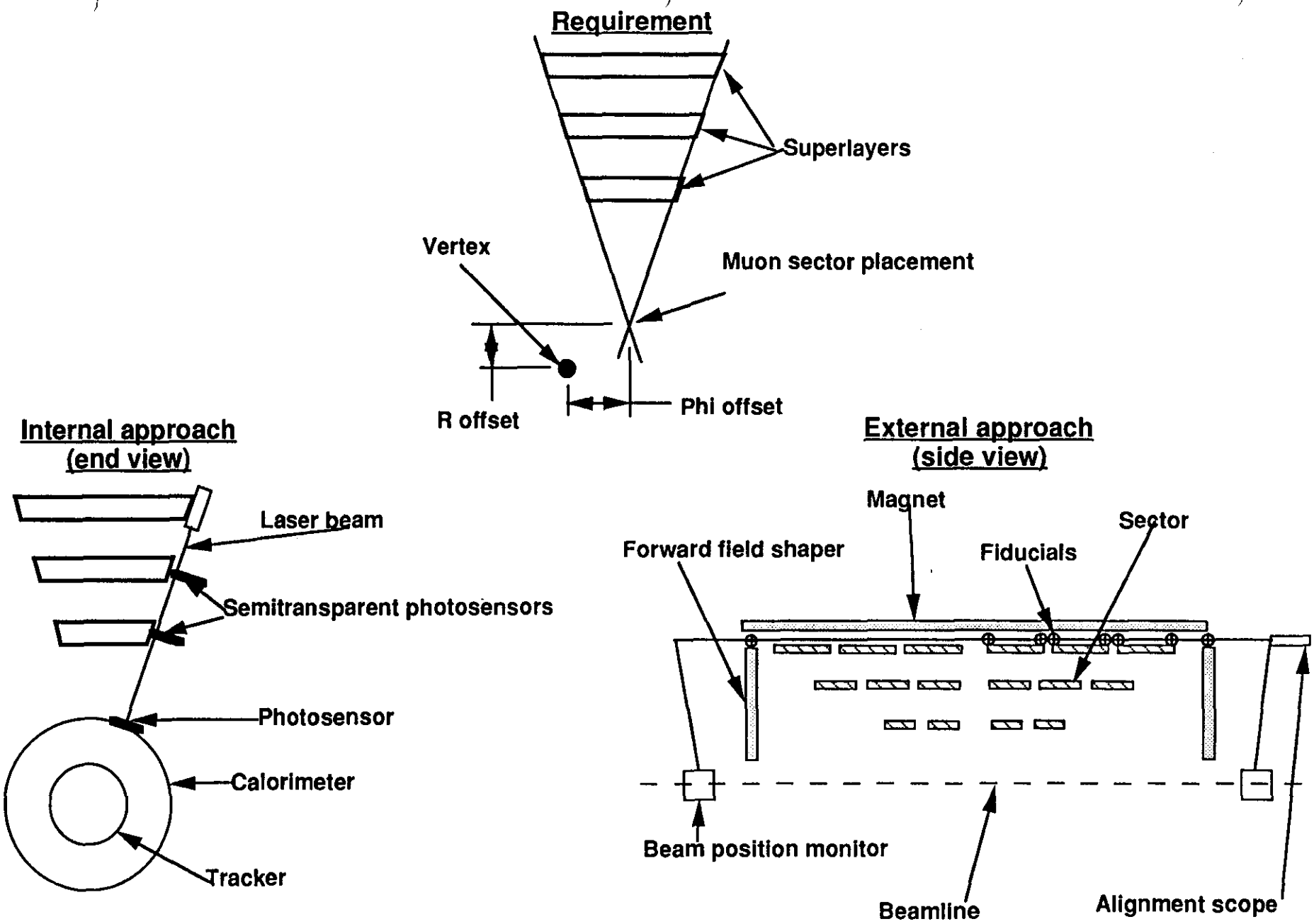


Figure 7. Global measurement concept

	Intrinsic Smears (+4)		Structural Accuracy		
All ±mm and ±mr	Interaction Diamond (7 cm)	Scattering in Calorimeter (50 GeV)	Dynamic Range of Local Alignment	Trigger Roads (10% Loss)	*Summary*
90° / 30°	+4	+4			
Barrel					
Δx(b)			1 | 1	2 | 2	1 | 1
Δx(c)			1 | 1	3.25 | 3.25	1 | 1
Δz(b)			1 | 1	3.25 | 3.25	1 | 1
Δz(c)			2 | 2	4.5 | 4.5	2 | 2
Δy(b)			1 | 0.9	∞ | 1.9	1 | 0.9
Δy(c)			1 | 1	∞ | 2.6	1 | 1
ΔX(g)		2 | 2		6.3 | 6.3	6.3 | 6.3
ΔY(g)	x | 6.8	2 | 2		15 | 2.5	15 | 6.8
ΔZ(g)	12 | 12	x | 4		4.5 | 4.5	12 | 12
Δθ	x | 0.35	0.5 | 0.5			
Δφ		0.5 | 0.5			
30° / 10°					
Endcap					
Δx(b)			1 | 1	2 | 2	1 | 1
Δx(c)			2 | 2	3.25 | 3.25	2 | 2
Δy(b)			1 | 1	1.75 | 1.75	1 | 1
Δy(c)			2 | 2	3.5 | 3.5	2 | 2
Δz(b)			1.7 | 5.7	3 | 10	1.7 | 5.7
Δz(c)			3.4 | 10.4	6 | 20	3.4 | 10.4
ΔX(g)		3.3 | 3.3		5.6 | 5.6	5.6 | 5.6
ΔY(g)	6.8 | 2.1	3.8 | 3.3		4.8 | 4.8	6.8 | 4.8
ΔZ(g)	12 | 12	1.8 | 6.3		4.1 | 14	12 | 12
Δθ	0.35 | 0.13	0.5 | 0.5			
Δφ		0.5 | 0.5			

Table 1: Alignment factors impacting structural accuracy

			Precision Requirements			
All ±mm and ±mr	Scattering in Calorimeter (500 GeV)	Ultimate Detector Resolution	Precision Momentum	Momentum Vector	Mass Resolution	*Summary*
90° / 30°	+4					
Barrel						
Δx(b)			0.025 / 0.025			0.025 / 0.025
Δx(c)			0.05 / 0.05			0.05 / 0.05
Δz(b)						(1 / 1)
Δz(c)						(2 / 2)
Δy(b)			0.063 / 0.063			0.063 / 0.063
Δy(c)			0.125 / 0.125			0.125 / 0.125
ΔX(g)	0.2 / 0.2	0.33 / 0.33	0.2 / 0.2 (Goal!)		4.7 / 9.4	4.7 / 9.4
ΔY(g)	0.2 / 0.2	x / 1.6		∞ / 60	∞ / 11	∞ / 11
ΔZ(g)	x / 0.4	13 / 13		∞ / 100	4.7 / 19	4.7 / 19
Δθ	0.05 / 0.05	2.7 / 0.67		∞ / 6.7	1.2 / 1.2	1.2 / 1.2
Δφ	0.05 / 0.05	0.13 / 0.13			1.2 / 1.2	1.2 / 1.2
30° / 10°						
Endcap						
Δx(b)			0.025 / 0.025			0.025 / 0.025
Δx(c)			0.05 / 0.05			0.05 / 0.05
Δy(b)						(1 / 1)
Δy(c)						(2 / 2)
Δz(b)			0.125 / 0.360			0.125 / 0.360
Δz(c)			0.25 / 0.72			0.25 / 0.72
ΔX(g)	0.33 / 0.33	0.33 / 0.13	0.2 / 0.2 (Goal!)		9.4 / 7.2	9.4 / 7.2
ΔY(g)	0.38 / 0.33	9 / 9		60 / 20	11 / 8.4	11 / 8.4
ΔZ(g)	0.18 / 0.63	15 / 53		100 / 100	19 / 48	19 / 48
Δθ	0.05 / 0.05	2.7 / 2.7		6.7 / 2.9	1.2 / 1.2	1.2 / 1.2
Δφ	0.05 / 0.05	1.3 / 1.3			1.2 / 1.2	1.2 / 1.2

Table 2: Alignment factors impacting Precision Measurements

	Intrinsic Smears (+4)		Structural Accuracy		
All ±mm and ±mr	Interaction Diamond (7 cm)	Scattering in Calorimeter (50 GeV)	Dynamic Range of Local Alignment	Trigger Roads (10% Loss)	*Summary*
	+4	+4			
Barrel					
Δx(b)			1	2	1
Δx(c)			1	3.25	1
Δz(b)			1	3.25	1
Δz(c)			2	4.5	2
Δy(b)			1	1.9	1
Δy(c)			1	2.6	1
ΔX(g)		2		6.3	6.3
ΔY(g)	6.8	2		2.5	6.8
ΔZ(g)	12	4		4.5	12
Δθ	0.35	0.5			
Δφ		0.5			
Endcap					
Δx(b)			1	2	1
Δx(c)			2	3.25	2
Δy(b)			1	1.75	1
Δy(c)			2	3.5	2
Δz(b)			1.7	3	1.7
Δz(c)			3.4	6	3.4
ΔX(g)		3.3		5.6	5.6
ΔY(g)	2.1	3.3		4.1	4.1
ΔZ(g)	12	6.3		4.4	12
Δθ	0.13	0.5			
Δφ		0.5			

Table 3: Most Restrictive Alignment Factors (Structural Accuracy)

			Precision Requirements			
All ±mm and ±mr	Scattering in Calorimeter (500 GeV)	Ultimate Detector Resolution	Precision Momentum	Momentum Vector	Mass Resolution	*Summary*
	←4					
Barrel						
Δx(b)			0.025			0.025
Δx(c)			0.05			0.05
Δz(b)						1
Δz(c)						2
Δy(b)			0.063			0.063
Δy(c)			0.125			0.125
ΔX(g)	0.2	0.33	0.2 (Goal!)		4.7	4.7
ΔY(g)	0.2	1.6		60	11	11
ΔZ(g)	0.4	13		100	4.7	4.7
Δθ	0.05	2.7		6.7	1.2	1.2
Δφ	0.05	0.13			1.2	1.2
Endcap						
Δx(b)			0.025			0.025
Δx(c)			0.05			0.05
Δy(b)						1
Δy(c)						2
Δz(b)			0.125			0.125
Δz(c)			0.25			0.25
ΔX(g)	0.33	0.13	0.2 (Goal!)		7.2	7.2
ΔY(g)	0.33	9		20	8.4	8.4
ΔZ(g)	0.63	15		100	19	19
Δθ	0.05	2.7		2.9	1.2	1.2
Δφ	0.05	1.3			1.2	1.2

Table 4: Most Restrictive Alignment Factors (Precision Measurement)

Table 5. Placement Tolerance Matrix

		1 Tracker		2 Calorimeter		3a Muon chamber Barrel		3b Muon chamber Endcap		4 Magnet		5 Flux shaper		6 Membrane		7 Beamline		8 Hall	
		Requirement	Constraint	Requirement	Constraint	Requirement	Constraint	Requirement	Constraint	Requirement	Constraint	Requirement	Constraint	Requirement	Constraint	Requirement	Constraint	Requirement	Constraint
1	Tracker	0.050 0.050 1.000		0.200 0.200 0.400		10.000 10.000 10.000		10.000 10.000 10.000		10.000 10.000 10.000		10.000 10.000 10.000		10.000 10.000 10.000	1.020 1.020 1.077	4.000 4.000 10.000	3.323 3.323 5.212	1.500 1.500 10.000	1.428 1.428 1.470
2	Calorimeter			0.800 0.800 0.800		10.000 10.000 10.000		10.000 10.000 10.000		10.000 10.000 10.000		10.000 10.000 10.000		1.000 1.000 1.000		3.500 3.500 10.000	3.317 3.317 5.196	1.000 1.000 1.000	
3a	Muon chamber (barrel)					0.063 0.025 1.000		10.000 10.000 10.000		3.000 3.000 10.000		10.000 10.000 10.000		10.000 10.000 10.000		10.000 5.000 5.000	3.317 3.317 5.196	1.000 1.000 1.000	
3b	Muon chamber (endcap)							1.000 0.025 0.063		10.000 10.000 10.000		3.000 3.000 10.000		10.000 10.000 10.000		4.000 5.000 10.000	3.317 3.317 5.196	1.000 1.000 1.000	
4	Magnet									10.000 10.000 10.000		10.000 10.000 10.000		10.000 10.000 10.000		15.000 15.000 10.000	10.488 10.488 11.225	10.000 10.000 10.000	
5	Flux shaper											none none none		10.000 10.000 10.000		15.000 15.000 10.000	10.488 10.488 11.225	10.000 10.000 10.000	
6	Membrane													none none none		5.000 5.000 10.000	3.317 3.317 5.196	1.000 1.000 1.000	
7	Beamline															none none none		3.000 3.000 5.000 ○	
8	Hall																	1.000 1.000 1.000	

9 Intracalorimeter		10a Intramuon Barrel		10b Intramuon Endcap	
Requirement	Constraint	Requirement	Constraint	Requirement	Constraint
0.250 0.250 0.250		0.900 0.900 0.900		0.900 0.900 0.900	

All units = millimeters
Diagonal elements represent fiducialization requirements
○ = Mean position of interaction diamond

Format: X (radial) placement
Y (circumferential) placement
Z (axial) placement

Constraint equations :

(1,6)>((1,2)^2+(2,6)^2)^0.5
(1,8)>((1,2)^2+(2,8)^2+(6,8)^2))^0.5
(1,7)>((1,2)^2+(2,8)^2+(6,8)^2+(7,8)^2)^0.5
(2,7)>((2,8)^2+(8,8)^2+(7,8)^2))^0.5

(3a,7)>((3a,8)^2+(8,8)^2+(7,8)^2)^0.5
(3b,7)>((3b,8)^2+(8,8)^2+(7,8)^2)^0.5
(4,7)>((4,8)^2+(8,8)^2+(7,8)^2)^0.5
(5,7)>((5,8)^2+(8,8)^2+(7,8)^2)^0.5
(6,7)>((6,8)^2+(8,8)^2+(7,8)^2)^0.5

Table 6. Stability Tolerance Matrix

		1 Tracker		2 Calorimeter		3a Muon chamber Barrel		3b Muon chamber Endcap		4 Magnet		5 Flux shaper		6 Membrane		7 Beamline		8 Hall	
		Requirement	Constraint	Requirement	Constraint	Requirement	Constraint	Requirement	Constraint	Requirement	Constraint	Requirement	Constraint	Requirement	Constraint	Requirement	Constraint	Requirement	Constraint
1	Tracker	0.005 0.005 0.005		0.010 0.010 0.000		0.050 0.050 0.100		0.050 0.050 0.100		0.100 0.100 0.100		0.100 0.100 0.100		0.015 0.015 0.015	0.014 0.014 0.010	0.020 0.020 0.020	0.018 0.018 0.015	0.020 0.020 0.020	0.018 0.018 0.015
2	Calorimeter			0.250 0.250 0.100		0.100 0.100 0.100		0.100 0.100 0.100		0.100 0.100 0.100		0.100 0.100 0.100		0.010 0.010 0.010		0.020 0.020 0.020	0.015 0.016 0.015	0.015 0.015 0.015	0.015 0.015 0.015
3a	Muon chamber (barrel)					0.010 0.005 0.025		0.100 0.100 0.100		0.010 0.010 0.020		0.100 0.100 0.100		0.100 0.100 0.100		0.025 0.015 0.025	0.023 0.015 0.029	0.025 0.015 0.025	0.023 0.015 0.029
3b	Muon chamber (endcap)							0.025 0.005 0.025		0.100 0.100 0.100		0.020 0.010 0.010		0.100 0.100 0.100		0.025 0.015 0.025	0.029 0.016 0.023	0.025 0.015 0.025	0.102 0.101 0.102
4	Magnet									0.100 0.100 0.100		0.100 0.100 0.100		0.100 0.100 0.100		0.020 0.010 0.020	0.021 0.011 0.021	0.020 0.010 0.020	
5	Flux shaper											none none none		0.100 0.100 0.100		0.020 0.010 0.020	0.021 0.011 0.021	0.020 0.010 0.020	
6	Membrane													none none none		0.010 0.010 0.010	0.011 0.011 0.011	0.010 0.010 0.010	
7	Beamline															none none none		0.001 0.001 0.001	
8	Hall																	0.005 0.005 0.005	

	9 Intracalorimeter		10a Intramuon Barrel		10b Intramuon Endcap	
	Requirement	Constraint	Requirement	Constraint	Requirement	Constraint
	0.100 0.100 0.100		0.030 0.010 0.100		0.100 0.010 0.060	

All units = millimeters
Diagonal elements represent fiducialization requirements

Format: X (radial) stability
Y (circumferential) stability
Z (axial stability)

Constraint equations:

(1,6)>((1,2)^2+(2,6)^2)^0.5
(1,8)>((1,2)^2+(2,6)^2+(6,8)^2+(8,8)^2)^0.5
(1,7)>((1,2)^2+(2,6)^2+(6,8)^2+(8,8)^2+(7,8)^2)^0.5
(2,8)>((2,6)^2+(6,8)^2+(8,8)^2)^0.5
(2,7)>((2,6)^2+(6,8)^2+(8,8)^2+(7,8)^2)^0.5

(3a,7)>((3a,4)^2+(4,8)^2+(8,8)^2+(7,8)^2)^0.5
(3a,8)>((3a,4)^2+(4,8)^2+(8,8)^2)^0.5
(3b,7)>((3b,5)^2+(5,8)^2+(8,8)^2+(7,8)^2)^0.5
(3b,8)>((3b,5)^2+(5,8)^2+(8,8)^2)^0.5
(4,7)>((4,8)^2+(8,8)^2+(7,8)^2)^0.5
(5,7)>((5,8)^2+(8,8)^2+(7,8)^2)^0.5
(6,7)>((6,8)^2+(8,8)^2+(7,8)^2)^0.5

Table 7. Drift Tolerance Matrix

		1 Tracker		2 Calorimeter		3a Muon chamber Barrel		3b Muon chamber Endcap		4 Magnet		5 Flux shaper		6 Membrane		7 Beamline		8 Hall	
		Requirement	Constraint	Requirement	Constraint	Requirement	Constraint	Requirement	Constraint	Requirement	Constraint	Requirement	Constraint	Requirement	Constraint	Requirement	Constraint	Requirement	Constraint
1	Tracker	0.002 0.002 0.500		0.050 0.050 0.500		5.000 5.000 10.000		5.000 5.000 10.000		5.000 5.000 10.000		5.000 5.000 10.000		0.300 0.300 10.000	0.206 0.206 5.025	1.200 1.200 10.000	1.242 1.242 7.124	1.200 1.200 10.000	1.137 1.137 7.106
2	Calorimeter			0.100 0.100 10.000		5.000 5.000 10.000		5.000 5.000 10.000		5.000 5.000 10.000		5.000 5.000 10.000		0.200 0.200 5.000		1.200 1.200 10.000	1.241 1.241 7.106	1.200 1.200 10.000	1.136 1.136 7.089
3a	Muon chamber (barrel)					0.005 0.005 1.000		5.000 5.000 10.000		0.500 0.500 1.000		5.000 5.000 10.000		5.000 5.000 10.000		1.200 1.200 1.200	1.323 1.323 1.581	1.200 1.200 1.200	1.225 1.225 1.500
3b	Muon chamber (endcap)							0.005 0.005 1.000		5.000 5.000 10.000		0.500 0.500 1.000		5.000 5.000 10.000		1.200 1.200 1.200	1.323 1.323 1.581	1.200 1.200 1.200	1.225 1.225 1.500
4	Magnet									5.000 5.000 10.000		5.000 5.000 10.000		5.000 5.000 10.000		1.200 1.200 1.200	1.225 1.225 1.225	1.000 1.000 1.000	
5	Flux shaper											none none none		5.000 5.000 10.000		1.200 1.200 1.200	1.225 1.225 1.225	1.000 1.000 1.000	
6	Membrane													none none none		1.200 1.200 10.000	1.225 1.225 5.050	1.000 1.000 5.000	
7	Beamline															none none none		0.500 0.500 0.500	
8	Hall																	0.500 0.500 0.500	

9 Intracalorimeter		10a Intramuon Barrel		10b Intramuon Endcap	
Requirement	Constraint	Requirement	Constraint	Requirement	Constraint
0.200 0.200 0.500		0.200 0.200 0.200		0.200 0.200 0.200	

All units = millimeters
Diagonal elements represent fiducialization requirements

Format: X (radial) drift / Y (circumferential) drift / Z (axial) drift

Constraint equations:

(1,6)>((1,2)^2+(2,6)^2)^0.5
(1,8)>((1,2)^2+(2,6)^2+(6,8)^2+(8,8)^2)^0.5
(1,7)>((1,2)^2+(2,6)^2+(6,8)^2+(8,8)^2+(7,8)^2)^0.5
(2,8)>((2,6)^2+(6,8)^2+(8,8)^2)^0.5
(2,7)>((2,6)^2+(6,8)^2+(8,8)^2+(7,8)^2)^0.5

(3a,7)>((3a,4)^2+(4,8)^2+(8,8)^2+(7,8)^2)^0.5
(3b,7)>((3b,5)^2+(5,8)^2+(8,8)^2+(7,8)^2)^0.5
(3a,8)>((3a,4)^2+(4,8)^2+(8,8)^2)^0.5
(3b,8)>((3b,5)^2+(5,8)^2+(8,8)^2)^0.5
(4,7)>((4,8)^2+(8,8)^2+(7,8)^2)^0.5
(5,7)>((5,8)^2+(8,8)^2+(7,8)^2)^0.5
(6,7)>((6,8)^2+(8,8)^2+(7,8)^2)^0.5

Table 8. Real Time Measurement Tolerance Matrix

		1 Tracker	2 Calorimeter	3a Muon chamber Barrel	3b Muon chamber Endcap	4 Magnet	5 Flux shaper	6 Membrane	7 Beamline	8 Hall
1	Tracker	none none none	none none none	none none none	none none none	none none none	none none none	none none none	0.050 0.010 none	none none none
2	Calorimeter		none none none	none none none	none none none	none none none	none none none	none none none	1.000 1.000 10.000	none none none
3a	Muon chamber (barrel)			none none none	none none none	none none none	none none none	none none none	4.000 9.700 O 50.000	none none none
3b	Muon chamber (endcap)				none none none	none none none	none none none	none none none	7.000 1.000 O 2.000	none none none
4	Magnet					none none none	none none none	none none none	none none none	0.500 0.500 0.500
5	Flux shaper						none none none	none none none	none none none	0.500 0.500 0.500
6	Membrane							none none none	none none none	0.500 0.500 0.500
7	Beamline								none none none	0.050 0.050 none
8	Hall									0.500 0.500 0.500

9 Intracalor.	10a Intramuon Barrel	10b Intramuon Endcap
none none none	0.020 0.020 1.000	1.000 0.020 0.020

All units = millimeters
O goal is .200 mm

Format: X (radial) measurement
Y (circumferential) measurement
Z (axial) measurement

13. ELECTRONICS

ELECTRONICS

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OVERVIEW

Architecture

The trigger system has the usual three levels. Level 1 is synchronous and pipe-lined and is implemented entirely in hardware. Level 2 is asynchronous. We have tentatively adopted a new baseline, called "virtual Level 2," wherein the Level 2 trigger is run on the same processor array as that used for the Level 3. For Level 2, however, only relevant portions of the event are transmitted to the array.

- **Level 1**

  -- Synchronous: the Level 1 trigger decision is delivered to the front end elements, a fixed number of bunch crossings (~ 120 crossings – 2 ms) after the event. The trigger elements must tag the bunch crossing.

  -- Pipelined: a trigger decision is delivered every bunch crossing--i.e. every 16.7 ns.

  -- Front end data are stored in digital or analog pipelines for the 2 ms delay.

- **Level 2**

  -- Asynchronous: the time elapsed between Level 1 and the corresponding Level 2 varies from event to event.

  -- Virtual Level 2: The Level 2 trigger will be run on the same processor array that is to be used for the Level 3. Only relevant portions of the event--e.g., calorimeter signals from the region surrounding photon or electron candidates identified by Level 1--are transmitted to the array.

  -- Upgrade Path: The Level 2 design will incorporate provisions for the eventual addition of special-purpose hardware to pre-process the data being passed to the CPU array. This will allow us to defer certain specific Level 2 design decisions until we have had an opportunity to study actual detector data.

-- Level 1 Front End Data: Front en' data from Level-1-accept events are stored in derandomizing buffers (either analog or digital). This permits dead-time-less operation, provided the average time between Level 1 accepts is less than or equal to the average Level 2 trigger decision time.

-- Latency: The Level 2 latency time is under study, but is expected to be in the range 10 μs to 100 μs.

- Level 3

-- CPU ranch; ~ 10^3 CPU's of ~ 10^2 VUP's (VAX 11/780 equivalents) each.

Design goals call for a factor-of-ten margin between the input rate capacity of a given readout stage and the output rate of the preceding trigger level at $\mathcal{L} = 10^{33}$ cm^{-2} s^{-1}. Thus a Level 1 accept rate of 10 kHz requires a Level 2 input capacity of 100 kHz.

Electronics Placement

Locate electronics in most readily accessible place consistent with uncompromised performance and acceptable cable plants. Significant portions of the Level 1 trigger, the Level 2 trigger, and the data acquisition (DAQ) electronics are located in the electronics room (ER), which is accessible with the beam on.

- Front-end Electronics

-- Silicon Vertex Tracker: preamps, discriminators, and delay pipelines are mounted on the detector elements. Hit data from detector are transmitted by optical fiber after Level 1. This electronics must be rad hard.

-- IPC Central Tracker: preamps, switched-capacitor analog (SCA) pipeline delays, analog multiplexers, and ADC's are mounted on IPC. Digitized data from detector are transmitted by optical fiber after Level 1. This electronics must be rad hard.

- -- Calorimeter: preamps are mounted in the LAr and coupled by copper transmission lines to front-end boards mounted in crates on the membrane. The front end crates house shaping amps, SCA pipeline delays, ADC's, and elements of the Level 1 and Level 2 triggers. Only the preamps need be rad hard.

- -- Drift-Wire Muon Electronics: preamplifiers and discriminators are mounted on-chamber and connected to TDC crates mounted on the magnet via twisted pair transmission lines.

- -- Cathode-strip Electronics: Low-noise preamps, shaping circuits, storage capacitors, multiplexers, and ADC's are chamber mounted. Digitized data are transmitted off detector over optical links.

- Level 1: After the first level of analog summing or logical OR'ing, which is done in close physical proximity to the front ends, the signals are transmitted to the ER by optical fiber for further processing.

- Level 2 & DAQ: After first level of data collection at the front ends, digital data are transmitted to the ER for further processing.

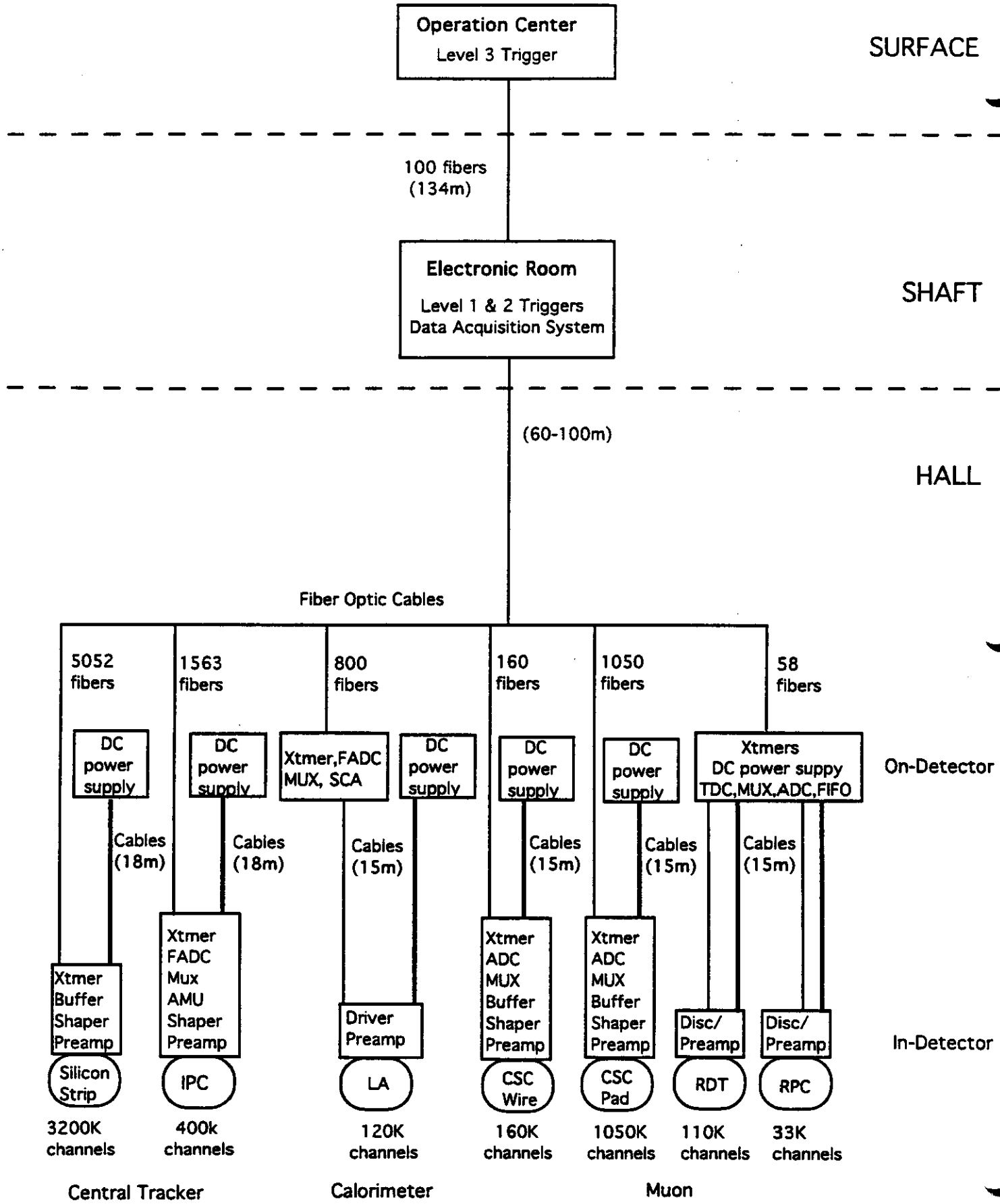
- Level 3 CPU Ranch: Reduced data from the ER are transmitted by optical fiber to the operations center at the surface, where the Level 3 CPU ranch is located.

GEM Trigger/DAQ Design Goals				
Level	Rate In	Rate Out	Latency	Comments
1	60 MHz	10 kHz	2μs	Synchronous, Pipelined
2	100 kHz	300 Hz	100μs	Asynchronous, Monotonic
3	3 kHz	10 Hz	–	CPU Ranch

Table 13.1 TRIGGER RATE TABLE

CHANNEL INFORMATION TABLE
(November 18, 1992)

	Central Tracker		Calori-meter	Muon			
	Silicon Strip	IPC	Liquid Argon	RPC	RDT	CSC Wire	CSC PAD
No. of Channels	3200K	400K	120K	33K	110K	160K	1050K
Power dissipation/channel (In-detector)	3mW	60mW	100mW	100mw	100mW	100mW	100mW
Power dissipation/channel (On-detector)	0	0	5W	1W	1W	0	0
Resolution	1-bit	8-bit	8-bit	1ns	1ns	<16ns	8-bit
Dynamic range	1-bit	9-bit	16-bit	4us	4us(TDC)	4us	10-bit
Occupancy/channel (%)	.06-.22	1.8	5	<1	<1	<10	<10
Number of sample	1	3	5	1	1	1	3-5
Number of bytes/hit	2	2	2	4	4	2	4
Channel/link	640	128	32	2500	2500	1000	1000
Link bandwidth - 0 suppression (Kbyte/s)	23	48000	40	5.3	5.3	5.3	10
Link type (wire/optic)	fiber	fiber	yes	yes	yes	yes	yes
Radiation (rads/yr at 1E33)	0.44M	20K	OD <1K ID high	<1K	<1K	<1K	<1K
Low-voltage power supply	1.5V,3.3V	yes	yes	yes	yes	yes	yes
High-voltage power supply	100V	2-3KV	2-3KV	yes	yes	yes	yes
Cost (y=mx+b)	$2.85/ch	$16+2.3M	$141+3.1M	tbd	tbd	tbd	tbd
Persons contact	G. Mills S.K. Hahn (LASL)	J. Musser (Indiana)	J. Parsons (Columbia)	M. Atiya (BNL)		V. Polychronahos P. O'Connor (BNL)	



Electronics System Layout (November 18, 1992)

GEM/ELB1

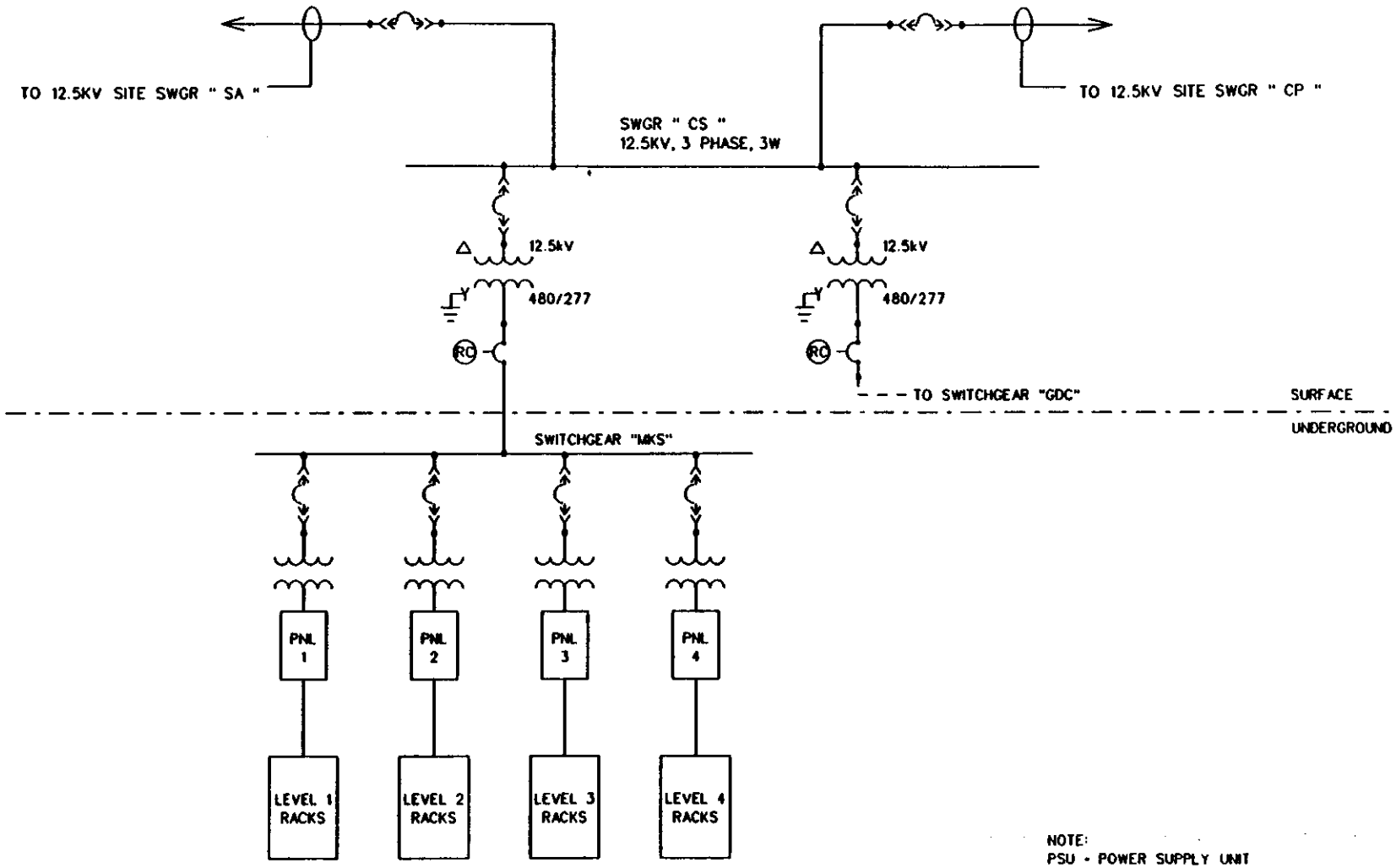
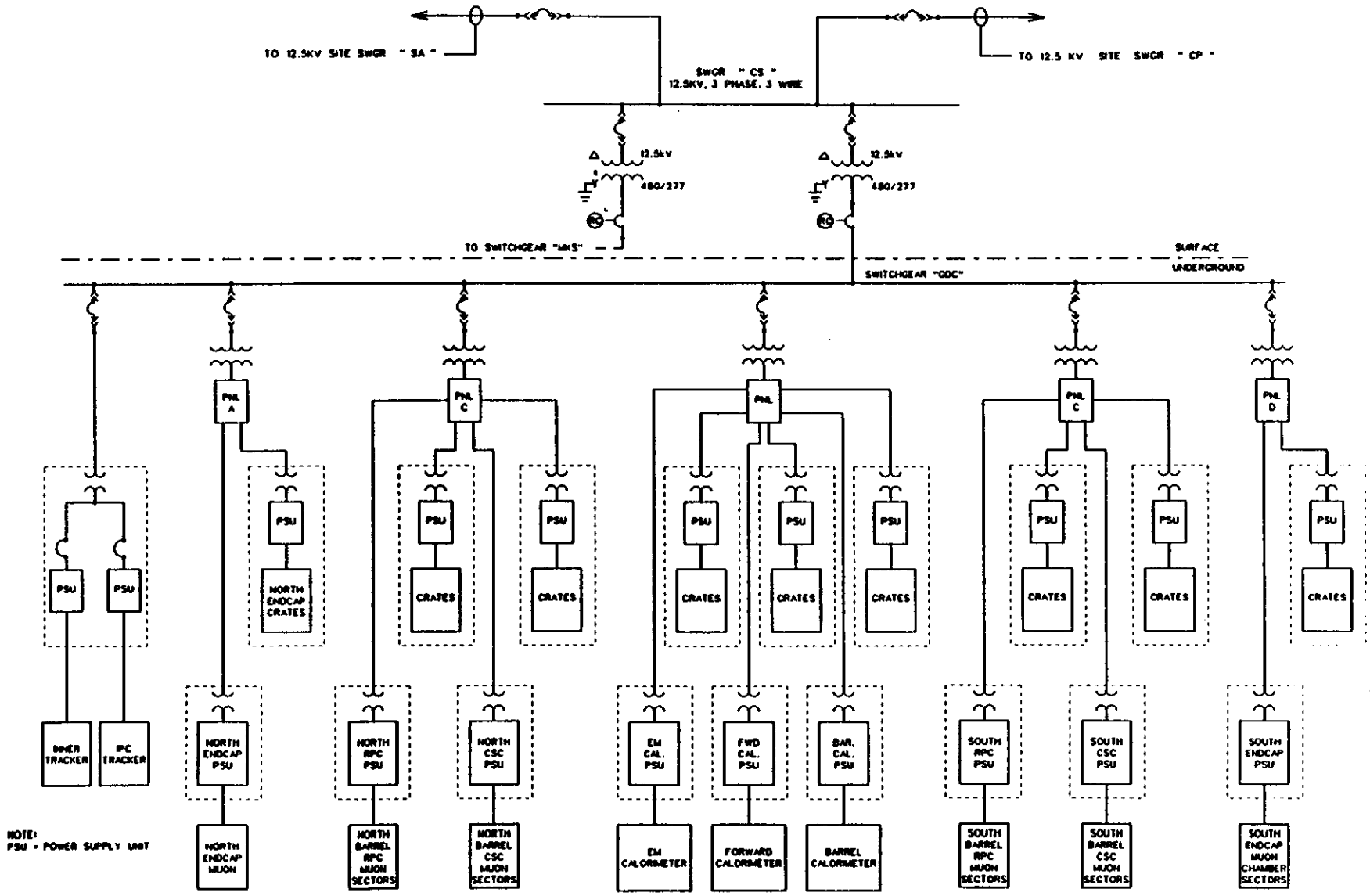


FIGURE 13.3 CABLE ELECTRONICS SHAFT
POWER DISTRIBUTION



14 OCTOBER 1992

FIGURE 13.4 DETECTOR HALL ELECTRICAL DISTRIBUTION DIAGRAM

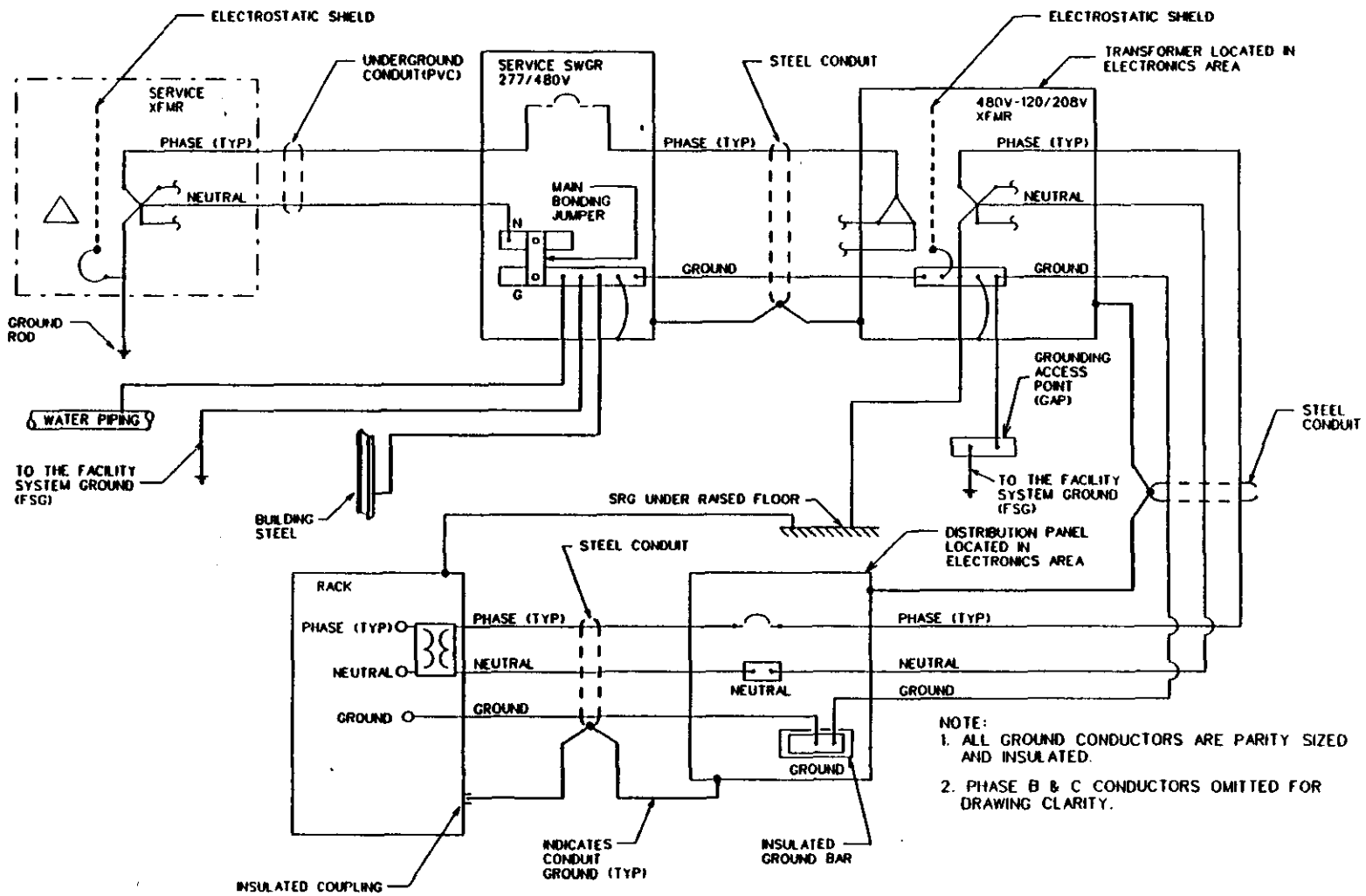
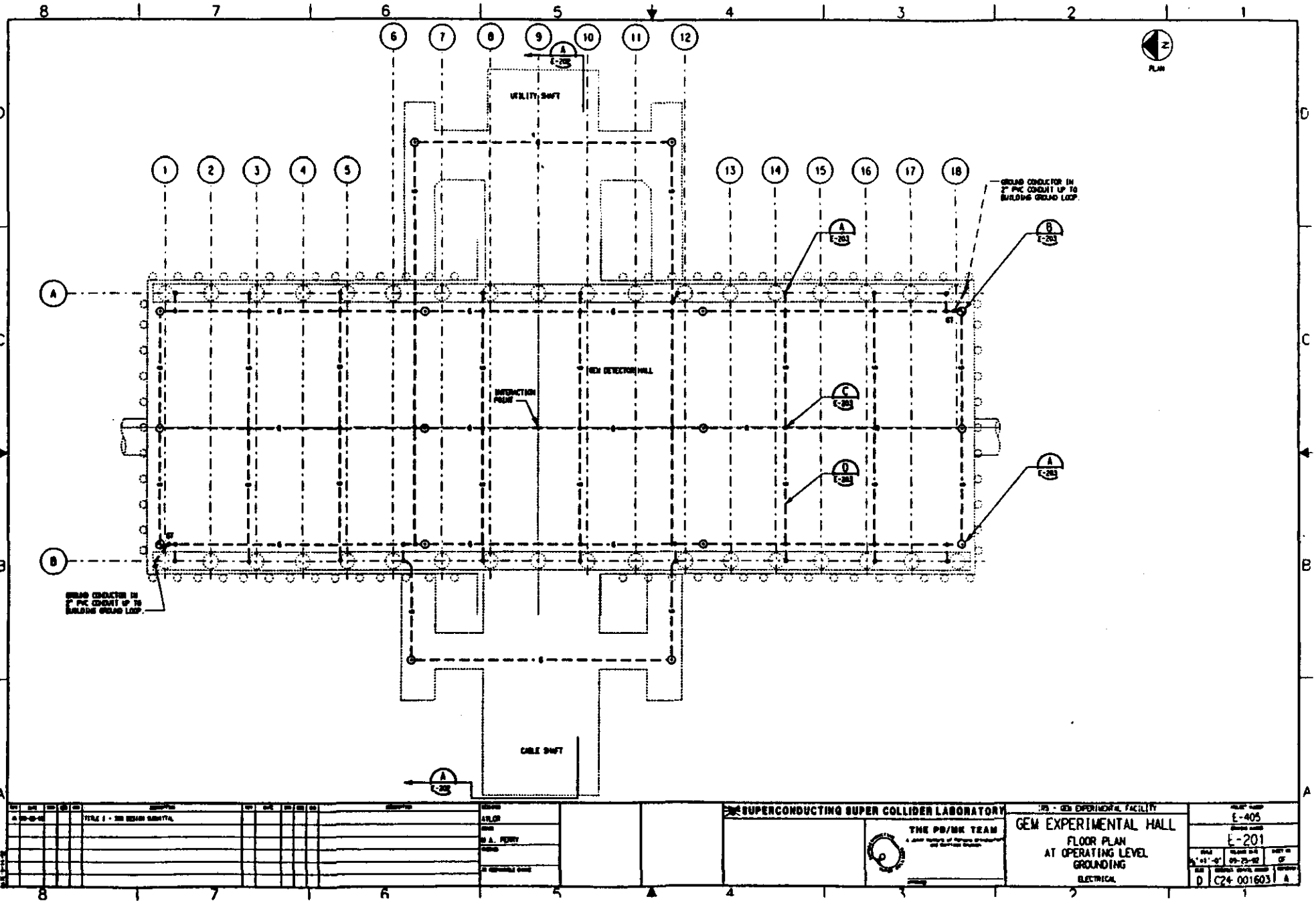


FIGURE 13.5 ELECTRONICS ROOM GROUNDING DIAGRAM


UTILITY SHAFT
GEM DETECTOR HALL
INTERACTION POINT
CABLE SHAFT
GROUND CONDUCTOR IN 2" PVC CONDUIT UP TO BUILDING GROUND LOOP.
GROUND CONDUCTOR IN 2" PVC CONDUIT UP TO BUILDING GROUND LOOP.
SUPERCONDUCTING SUPER COLLIDER LABORATORY
THE PB/MK TEAM
GEM EXPERIMENTAL HALL
FLOOR PLAN
AT OPERATING LEVEL
GROUNDING
ELECTRICAL
E-405
E-201
D
C24 001603

14. COMPUTING

COMPUTING

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COMPUTING

OVERVIEW

The following functions are included under computing: slow control (detector operations), on-line computing (Level 3), off-line computing (PASS1, analysis, simulation), storage, databases and communications. Overall planning is focussed at the SSCL. Figure 14-1 shows the general hardware architecture; the following sections give a brief description of the features of this figure. Main features are:

1) Integrated on-line/off-line computing facility

2) PASS1 completed in `real time'

3) Integrated storage system

This section deals mostly with requirements such as computing power, data link capacity, and space needs at the IR, but also touches on other aspects.

Open systems

GEM will use an open systems approach. In practice this means, among other things, using operating systems which are variants of Unix, or compatible with Unix at the system level. We plan to fully exploit the capabilities of Unix systems as they evolve while being open to new developments. There is a transitional period during which the installed base of VAX/VMS systems will be catered to.

Integration of functions

There are two aspects to integration: software and hardware.

The overall goal for GEM software is to integrate the computing system so that so that the same environment is used for all tasks from slow control through analysis. This will reduce software development effort and allow the creation of common tools and user interfaces.

A major determinant of costs is the overall required CPU power and the data link capacity. For example, GEM projects requirements for 200,000 SSCUPs for on-line and 600,000 for off-line. These estimates are very tentative, and it is wise to plan for large departures. Rather than partition on-line (Level 3) and off-line into separate systems, GEM is studying the possibility of integrating these functions, allowing great flexibility and full use of what will be a limiting resource. If these studies continue to support the basic idea, this will impact on budget

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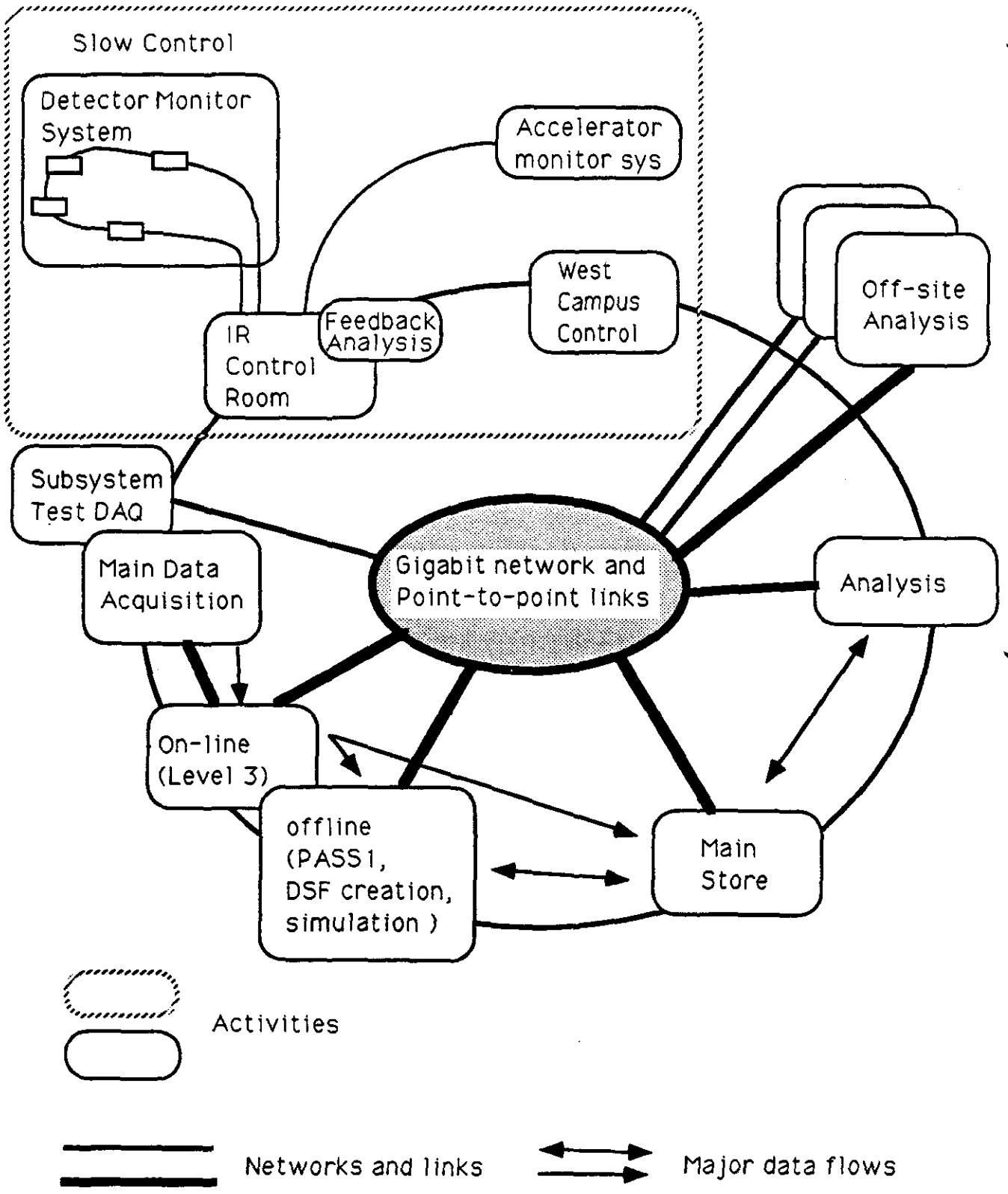

Figure 1 - Gem Computing System schematic

baseline_comp_fig1_2

and facilities. Figure 14-2 shows the outline of one model being evaluated for this integrated facility, while figure 14-3 shows results from a simple model of its performance in terms of CPU utilization as a function of Level 3 input rate and PASS1bis input rate (this model has 1600 CPU's in 400 boxes, and assumes a single data link capacity of 100 MB/s). Note the high utilization of the CPU's and the ability to catch up PASS1bis when the detector is off.

Relation to Industry

We are highly dependent on industry to provide basic hardware and software. We should use commercial or public-domain solutions rather than develop HEP solutions with their attendant maintenance responsibilities and limitations. We are beginning this process in establishing an environment for the development of GEM software.

There will be areas where we (GEM or SSCL) can work with industry to bring techniques to fruition through joint projects, techniques which might otherwise be delayed for lack of motivation. An example may be gigabit rate input directly to workstations. Also, we can help transfer developments like the `ranches' to industry at the same time as advancing that art. An example is the GEM computing architecture study on combining the on-line (Level 3) and off-line systems, in consultation with industry.

Coordination with SSCL

A group at the SSCL will support and coordinate GEM computing. In addition, the Physics Research Division Computing Support group will support GEM.

Coordination with SDC

There is much in common between the requirements of GEM and those of SDC. Therefore we plan to work with SDC on the development of software and hardware. However, some of our requirements do differ, and some of our approaches may also differ. It is useful to have complementary approaches in computing as well as for detectors.

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SUPERCONDUCTING SUPER COLLIDER LABORATORY
GEM DETECTOR COMPUTING STUDY

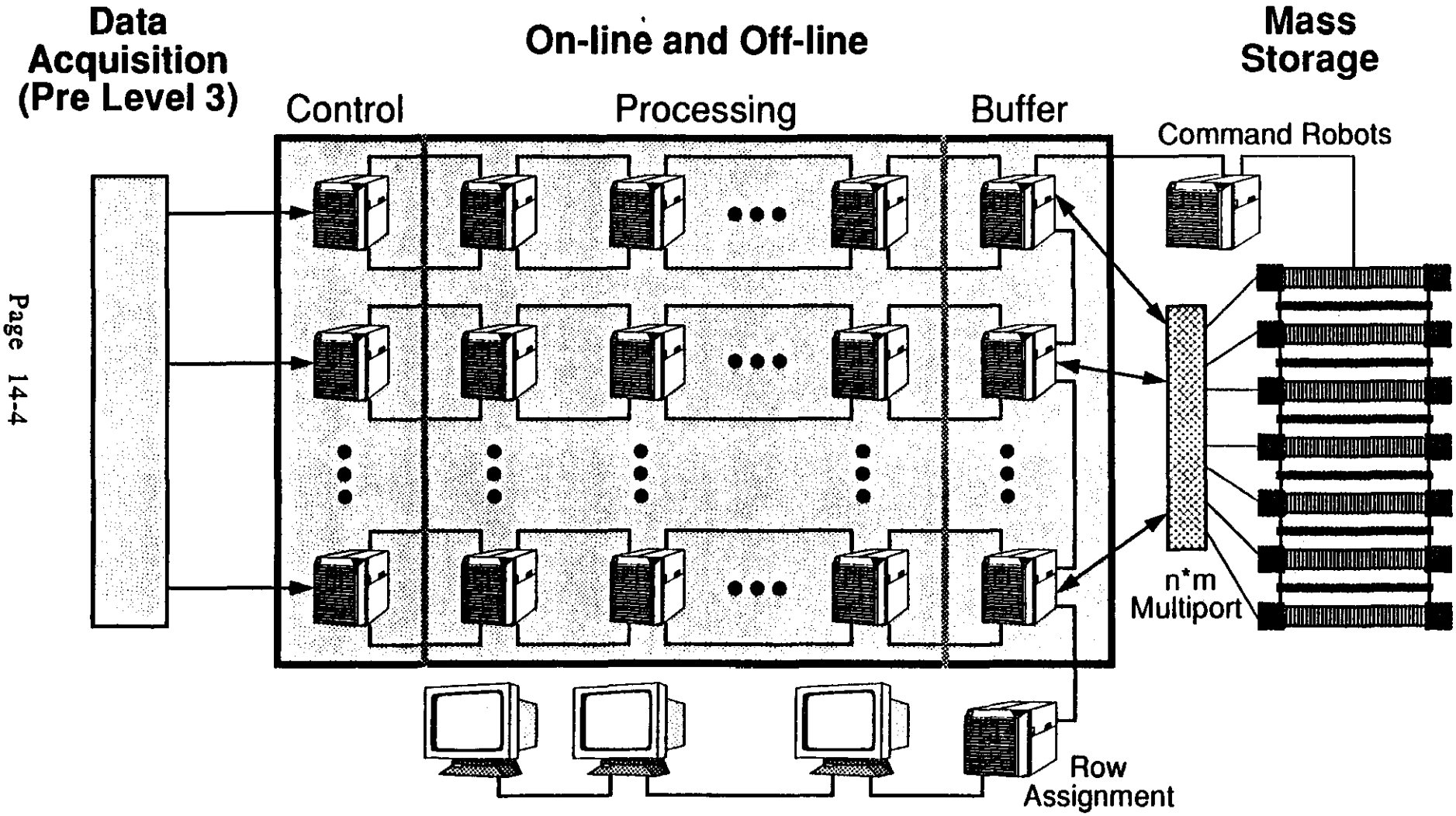
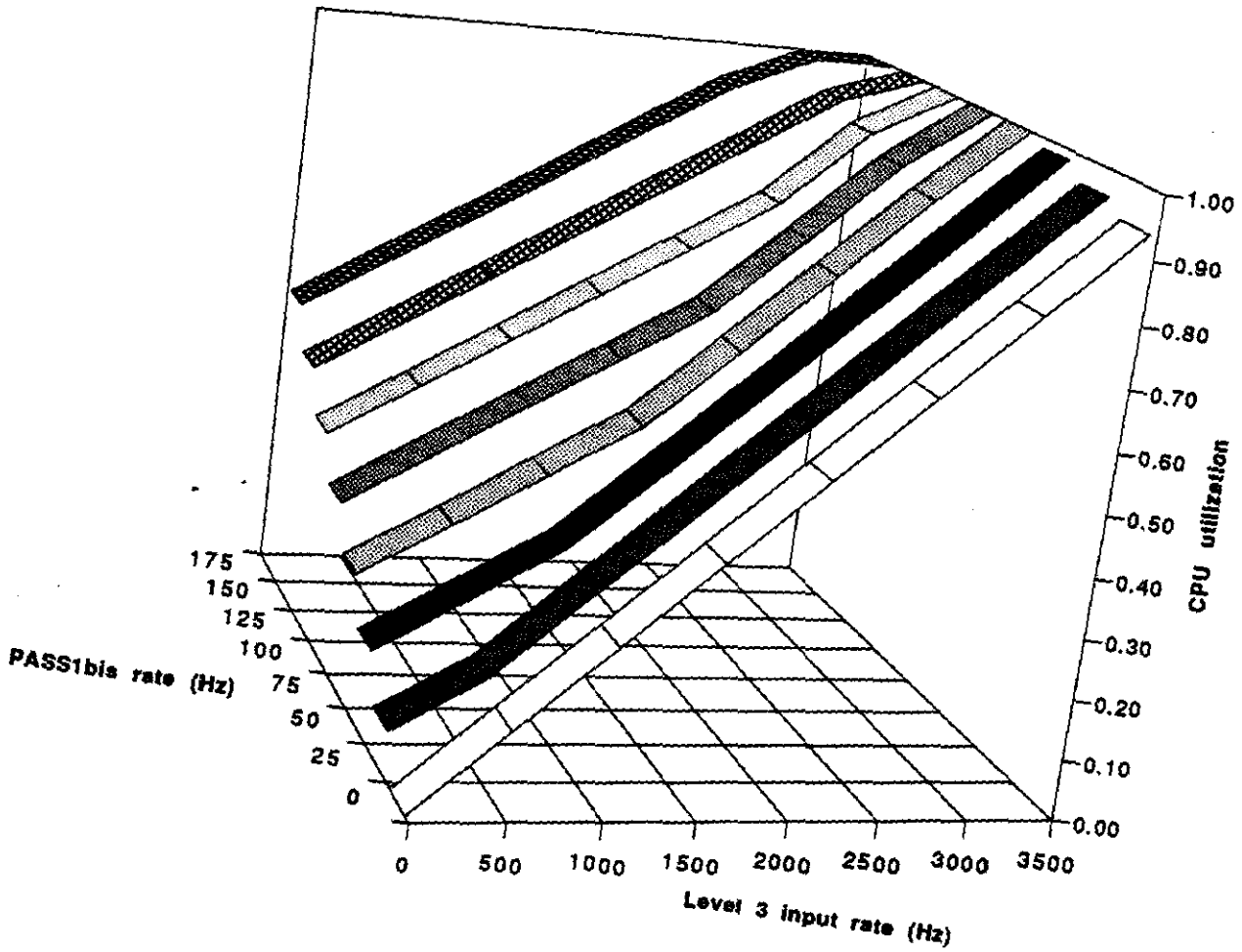


Figure 3 -- CPU utilization with Level 3, PASS1 at 1/30 and PASS1bis



Requirements Summary

Note that we have adopted the convention of Section 13, that the input capacity of a trigger level should be 10 times the desired output rate from the previous level. This permits variations in the rejection ratio of a given level. However, we desire to have the full capacity available at detector turn on, to allow the use of loose triggers. The expected rates are shown in Table 14-1. It is assumed that the input to PASS1bis is the output of PASS1, not Level 3.

Table 14-1 -- Trigger rates, event sizes and rate to storage

Stage	Input rate	Rejection factor	Output rate	Event size	Rate to store
Level 1	60 MHz	600 - 6,000	10-100 kHz	0.35 - 1 MB	NA
Level 2	10-100 kHz	30 - 300	0.3 - 3 kHz	0.35 - 1 MB	NA
Level 3	0.3 - 3 kHz	30	10 - 100 Hz	0.4 - 1.05 MB	4 - 105 MB/s
PASS1	10 - 100 Hz	1 - 2	5 - 100 Hz	1.4 - 2 MB	7 - 200 MB/s
PASS1bis	0 - 200 Hz	1	0 - 200 Hz	1.4 - 2 MB	0 - 400 MB/s

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COMPUTING

The compute time for Level 3 is taken as 67 SSCUP-seconds, while that for PASS1 is 2,100 SSCUP-seconds/MB; these numbers are based loosely on CDF experience. These lead to the requirements of table 14-2.

Table 14-2 -- Computing and Data Rate Requirements

System	Input Rate Goal	Input Design requirement	Output rate goal
On-line (Level 3)	300 Hz @ 1 MB from Level 2	3 kHz @ 1 MB from Lvl 2 200kSSCUPS @ 67 SSCUP-s/event	10 Hz
Storage	10 Hz @ 1 MB from Level 3 10 Hz @ 2 MB from PASS1 10 Hz @ 2 MB from PASS1bis 10 Hz @ 2 MB from simulation 10 MB/s from analysis	600 MB/s: 100 MB/s from Level 3, 400 MB/s from Off-line, 100 MB/s from analysis, simulation	400 MB/s
Off-line	10 Hz @ 1 MB from Level 3 10 Hz @ 1 MB for PASS1bis from storage simulation, analysis, DSF creation @ 200,000 SSCUPs	100 Hz @ 1 MB from Lvl 3 for PASS1 @ 2100 SSCUP-s/event 100 Hz @ 1 MB for PASS1bis simulations Total: 600,000 SSCUPs	

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Slow Control

The slow control system will monitor and control detector operations, including verifying readiness of the on-line/off-line and storage facilities; a schematic is shown in figure 14-4. The functions of the system are:

a) Safe operation of the detector and related systems, that is also easy and fast

b) Assurance of data quality through monitoring of all relevant parameters

c) Recording of all relevant data

d) Setup and monitoring of Level 3, PASS1 and storage

e) Remote capability, e.g for satellite control room at West Campus

It will include data-acquisition equipment (temperature gauges, voltage monitors..) and control equipment (magnet current, detector high voltages, detector ON/OFF) coupled to workstations and possibly high-reliability computers. There will be links to other parts of the computer system (on-line - Level 3, storage, off-line, analysis) to ensure readiness of these systems (possible controlling them) and obtain feedback.

The physicists/staff will use eight to ten workstations in a control room with many additional displays, and a space of at least 25 by 40 feet. Control and monitoring tasks will not be bound to any particular workstation (with the possible exception of safety-related tasks). There will be a set of displays which have a standard layout. Besides this control room there will be auxiliary control points where technical staff will monitor and control subsystems such as refrigerators, etc. The space for these must be specified by the systems concerned. For the control room only, an estimate of 1,500 sq.ft. net is reasonable. Support space (kitchen, emergency shower) must be added. The control room must be at the IR during construction and setup, though some functions can be duplicated in an auxilliary control room at the West Campus as shown in figure 14-1..

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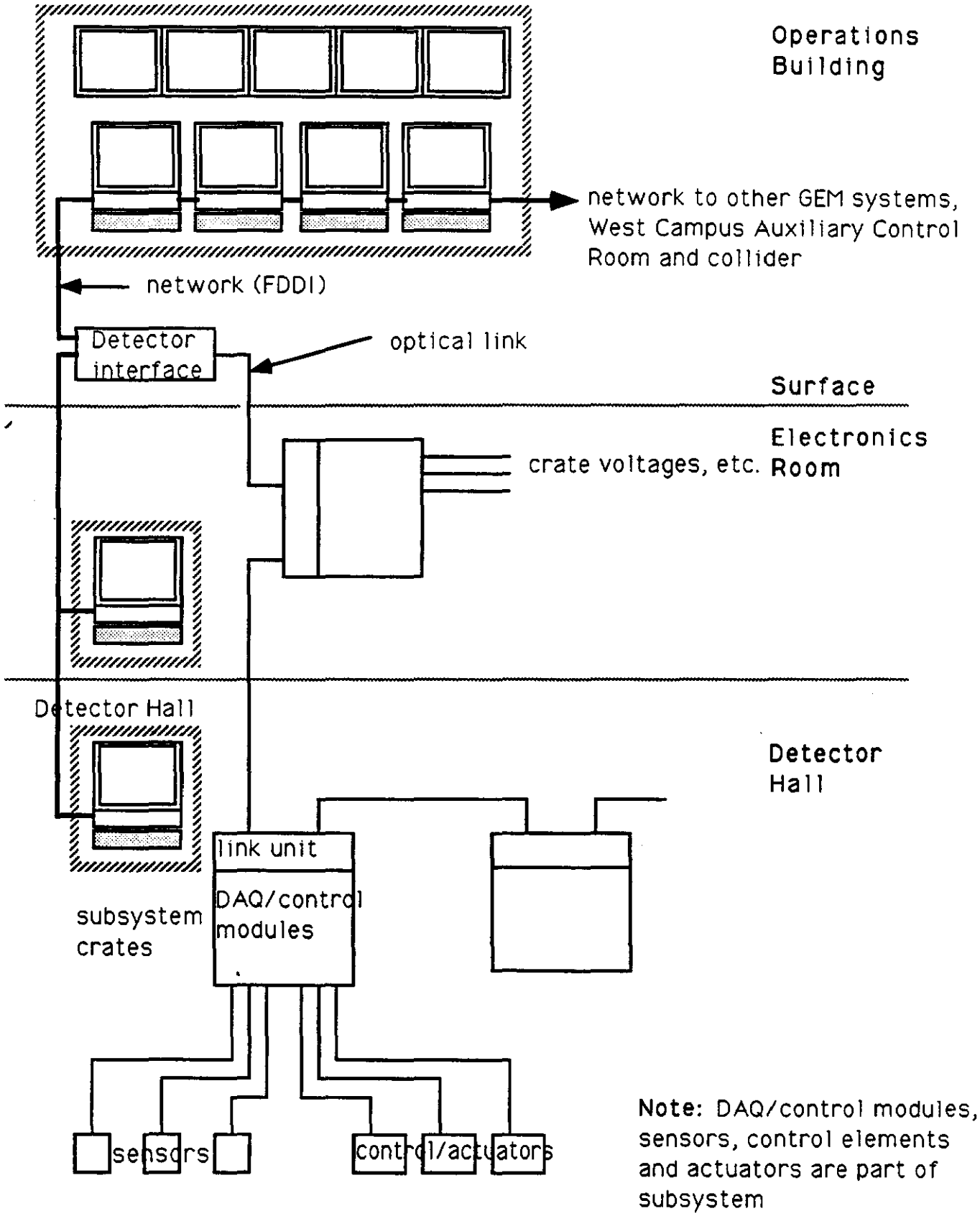

Figure 4 -- GEM Slow Control Hardware

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The slow-control data-acquisition equipment will be located near the appropriate systems, and data will be sent to the surface on redundant fiber-optic links; control messages will use the same links. There will be less than 100 such links, which will use a standard communications protocol. Sensors and control equipment are the responsibility of the subsystems.

On-line

This takes data from the Level 2 trigger and reduces it to a flow which can be permanently recorded. The input requirement is to handle up to 3,000 events per second, with events of 1 MB, for an input rate of 3 GB/s, or 24 Gb/s (see Table 14-1). The system is to reduce the output rate to 100 Hz of 1 MB events. Since algorithms are not yet developed, a dependable estimate of the needed computing power is not available. Our baseline estimate is 200,000 SSCUPs (a unit of computing power defined by an SSC benchmark suite, roughly equal to a VAX 11/780, or 1.5 MIPS). The networking and support requirements remain the same, so we can estimate a space of 60 by 60 feet, or about 3,500 sq.ft. Again, this should be at the IR.

As noted above, our preferred option is to combine the on- and off-line processing in one facility.

Subdetector DAQ system

The individual subsystems (tracker, calorimeter, muon system) will need the ability to monitor data acquisition independently of the primary DAQ system. This will require an independent data path, likely one or more gigabit networks or links.

Off-line

This serves our off-line needs, and a capacity of 600,000 SSCUPs is needed, based on a mix of activities: 100 Hz for PASS1, the same for a second PASS1 after recalibration (each at 2100 SSCUP-s /MB, from CDF) and a load equal to PASS1 from analysis, simulation, etc. This mix will be detector operation dependent. We estimate 5,500 sq.ft. including some support space.

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Main Store

This is a single logical store, where all our data will be stored: raw data, processed data, calibrations, Data Summary files (DSFs), etc. Our baseline model for this is to store 5 years of data, resulting in a possible requirement for 15 Petabytes (PB) of storage. This system would be hierarchical, consisting of bulk store ('tape') with slow access (one second - one minute), rapid access store ('disk') with access times of milliseconds, and fast access ('mass memory') with access times of microseconds.

Database

A database will be needed for a variety of purposes: calibration data, monitor information, catalogs of data files at a minimum.

Analysis

Analysis will consist of the creation of Data Summary Files (DSFs), ntuple files, special reconstruction and fitting tasks, event selection and visualization. The CPU power needed will be small compared with the off-line system. An important demand will be for fast file access. This aspect is illustrated by the possibility of examining a sample of 10^7 Z^0's from one year's running (1 pb sample). If a DSF of these events consists of 1 kB per event, then we have 10 GB of data. To transmit this to a single workstation in 100 seconds requires 0.8 Gb/s. If we assume that there are 30 physicists analyzing data, each looking at 1 pb samples with varying amounts of data per sample (average 10 kB), and spending one hour on each sample, we have a total data rate of 1 GB/s, or 8 Gb/s. Clearly, development is needed both for networks and for workstation interfaces, where current data rates are more in the 10 MB/s range.

Space is needed for up to 40 non-SSCL people working at workstations. At least 10 of these should be at the IR, using at least 1,200 sq.ft. there, and a total of 4,800 sq.ft. overall (this assumes that 10 workstations can be fit in a space of 1,200 sq.ft.)

Simulation

We expect to use up to 200,000 SSCUPs for simulation

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Communications

Machine

We also need space and facilities for networking -- some is included with each subsystem above, but about 500 sq.ft. ought to be allocated at the IR for general networking. Our computing strategy depends heavily on reliable and wide-band networking, in most cases using dedicated lines, possibly with special protocols. With that, we may have some flexibility in location of the parts of our system; however it is clear that the most likely system to be reliable from this point of view would be one entirely at the IR. Table 14-3 lists some requirements. We expect that gigabit links will be standard items. Note that the use of dedicated link is not meant to preclude use of a network. However, high performance from 'commodity' components may be best achieved by point-to-point dedicated links with light-weight protocols.

Table 14-3 -- Network or dedicated data link requirements

Connection	Rate, Gigabits/second
Slow control to all systems	0.1 Gb/s (network)
DAQ to Level 3	24 Gb/s (multiple streams, links)
Level 3 to Storage (detector on)	0.8 Gb/s (link)
Level 3 to Storage (detector off)	1.6 Gb/s (link)
Storage to Level 3 (detector off)	0.8 Gb/s (link)
Level 3 to PASS1 (detector on)	0.8 Gb/s (link)
Storage to Off-line (PASS1bis+analysis inp)	1.6 Gb/s (link)
Storage and off-line to analysis	0.8 Gb/s (network)
Analysis to storage and off-line	0.8 Gb/s (network)

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Human

Teleconferencing space at the IR and at the West Campus. The space needed is about 1,000 sq.ft.

Options

Among options that are being considered are not storing the Level 3 output, but only the PASS1 output. This would reduce storage requirements.

Work Underway

Work underway includes development of a fast simulation package, a full GEANT simulation, architecture studies of an integrated system and gaining of experience with database techniques with the TTR project.

Definitions

Here we clarify some terms as used in GEM:

L1, L2: These are the trigger systems that reduce the trigger rate to a level at which it can both be computed in general-purpose computer and needs to be, since the task is to correlate information from the entire detector. L1 is generally synchronous, while L2 can be asynchronous.

L3: The trigger system, based on general-purpose computing, that accepts the L2 output rate and filters events to a rate at which the data can be permanently stored.

PASS1: An initial reconstruction pass over events, which applies calibrations and does a further filtering. Events passing the PASS1 filters are written to storage with the data generated in PASS1.

PASS1bis: A re-application of the PASS1 stage, with final calibration constants. (Also called PASS2 in some places.)

Slow Control: The system which monitors and/or controls the various parts of the detector. It includes run control and, in our model, control of the on-line, off-line and storage systems.

Subdetector test systems: It will be necessary to permit parallel DAQ from subdetector systems for test and monitoring, independent of the

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main data flow. This data flow will be routed around the normal trigger system and into the online-offline system.

On-line: Level 3 and its support systems

Off-line: the software and hardware that supports PASS1, analysis, simulation, making of DSF's (Data Summary Files), etc.

SSCUP: SSC Unit of Processing power for typical HEP code, approximately 0.9 VAX-11/780, and about 1.2-1.8 MIPS.

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15. TEST BEAM

TEST BEAMS

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Floor Plan - Test Beam Hall
Floor Plan - Test Beam Area
Elevation Section - Test Beam Hall

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SSCL Test and Calibration Beam Requirements

TEST BEAMS

OVERVIEW

SSCL test beams will initially be restricted to those available from the MEB. The HEB is scheduled to be operational in 1998. 2 TeV test beams from the HEB are in the conceptual design stage; however, no funding has actually been allocated for such beams and therefore it is premature to plan for them.

The primary beam from the MEB, with a maximum energy of 200 GeV, will impact a target to produce secondary beams at an angle of approximately 5 mr (for radiation safety reasons, it will not be possible to transport the primary beam to the calibration hall). The secondary beam will have a maximum energy of 170 GeV. It will have a collimated momentum bite of up to 6%; the actual particle momentum will be tagged by a spectrometer with resolution better than that of the GEM electromagnetic calorimeter. Beam composition can be selected to be electrons, hadrons, or muons, with contaminations (after tagging) low enough to satisfy GEM needs.

It is important to realize that not only are the test beams at the SSCL necessary for long-term and short-term testing and calibration of GEM components, but they are the first operational exposure GEM will have. Almost all of the safety issues, electronics issues, DAQ issues, etc., which GEM will face in the detector will have to be faced for the test beams first. Therefore, it is worth concentrating an adequate effort on this because it provides experience for the final direction.

The turn-on date for SSCL test beams is discussed below; it will be no earlier than 1996. To fill the gap, and to extend the energy reach, we plan to run at other laboratories. This will be described next.

Test and Calibration Running at Other Labs

Beams at Fermilab may be available in late 1994 or early 1995. They have a maximum attainable energy of about 800 GeV. Therefore, they fill a need for running earlier than SSCL beams are available, and they also fill a need for the calorimeter to investigate the "constant" term at very high energies, and a need to investigate muon Bremsstrahlung and hadron punch-through into the muon chambers.

The subsystem which drives the beam requirements (and much of the space requirements) is the calorimeter. Detailed study of "cracks" caused by cable runs, cryostat walls, and so on, is crucial to understanding the performance of the calorimeter. This is complicated

by the complex hybrid designs being considered by GEM. The greatest possible energy range must be covered in order to study the response, in the presence of such imperfections, over the full range of physics. Muon chamber tests also require the highest attainable energies, as will be discussed. The calorimeter resolution is expected to approach

$$\frac{\Delta p}{p} \sim 5\%/\sqrt{E} \oplus 0.2\%$$

for electromagnetic calorimetry. Tagged electron beams and hadron beams at low energy (down to ~ 2 GeV) can calibrate the response to particles in jets. The same at high energies will give us the constant term. Although it is, at least in principal, possible to infer the constant term by extrapolation in $1/\sqrt{E}$ from low energies, in practice such extrapolations are unreliable and subject to large errors. For reliable operation in the SSCL high energy environment a thorough understanding of the high energy behavior of the apparatus is required. Production prototypes, and actual production modules, will be tested.

Therefore, we have submitted to Fermilab a proposal to run at the earliest possible dates on a beam capable of delivering electrons and hadrons from 2 GeV up to 175 GeV for electrons and up to 800 GeV for hadrons.

In addition to the calorimeter, we must test the muon chambers. This requires beams above about 10 GeV for the direct tests of the chambers in the beam. In addition, we must understand hadron punch-through and muon Bremsstrahlung, both of which require high energy hadron and muon beams. A small-scale prototype chamber (0.6 × 0.6 × 0.4 m^3) will be placed in a 0.8 T magnetic field for tests of its performance. Tests of hadron punch-through will also be conducted in this field. Large-scale prototypes will also be tested, but not in a magnetic field.

Fermilab test beams serve also as test beds for data acquisition and electronics designs. Prototypes of these systems will be brought there and tested also with the detector modules.

Tracker testing must begin in 1993. The tracker will need beams of a few GeV to test the resolution of a full-size prototype of the barrel pad chambers. For this test, Brookhaven beams are well-suited, and negotiations are currently underway. In 1994, the rate capabilities of full-sized barrel and endcap prototypes will be studied. This is very

challenging because it will require an instantaneous flux of up to 10^9 Hz (which can be spread over 30 cm^2). This can be done, for example, using a "pinged" beam of 10 ms duration. Negotiations with Brookhaven and Fermilab are underway for this high flux running. Radiation safety is the primary hurdle to be surmounted here. In 1995, similar rate studies of the full tracker system, including gas, cooling, mechanics, etc. of the final design, with the final electronics will be conducted. This may be done at the same lab as the 1994 tests.

SSCL Test and Calibration Beam Characteristics

The requirements for the SSCL beams are given in Table I. A total of three beams is being designed (expandable to six plus three 2 TeV beams, if and when HEB test beams become available). The three beams will be directed into three pits in a single calibration hall. One pit will be dedicated to GEM; the other two are for SDC and as yet unspecified smaller experiments. This means that all GEM test and calibration activities will have to be scheduled carefully. Any module which blocks the beam to other modules will have to be mounted on a retractable transporter.

A possible layout of GEM test modules in the GEM beam line is shown in Fig. 1. The tracker is shown first, with a 1 m length in front and behind it for silicon positioning telescopes (not shown). The tracker will be rotated as shown, and retracted when not in the beam. Behind the tracker location is a cryogenic liquid cryostat. This cryostat can be rotated as shown, and also retracted. In the scintillating fiber hybrid calorimeter design, the actual cryostat will be smaller than depicted, and fiber calorimeter modules will be mounted at the back when joint testing is to be performed. The last system shown is a full barrel tower of muon chambers.

The MEB operates with a maximum 8 second cycle. The maximum spill duration will be about 1 second. The current secondary beam design calls for the full MEB load to be sent to the target for a single secondary beam, rather than all three at once in a split mode. This means that the effective cycle time is about 24 seconds if all three beams are in operation at full energy. If less than full primary energy is used on any line, the 8 second cycle time for that line can be reduced, since it will not then require as much time to achieve the desired energy in the MEB. Such a situation will obtain for low energy secondary beams, since the flux of, for example, low energy pions is not maximized at 200 GeV primary energy. In addition, a lower energy primary beam generates

less radiation in the target hall, with consequent reduction in induced radioactivity, heatload, etc.

Table I. SSCL Test and Calibration Beam Requirements

Energy resolution:	$\frac{\Delta p}{p} < 5\%/\sqrt{E} + 0.2\%$
Maximum Energy	170 GeV
Minimum Energy	2 GeV
Background Muon Rate in Calibration Hall	150 kHz/m^2
Maximum Momentum Acceptance	6%
Electron Beams:	
particle ID (π/e)	10^3:1
flux range*	100-1000 Hz
spot size (diameter)	1 cm
Hadron Beams (> 20 GeV):	
particle ID (e/π)	10^4:1
flux range*	10-10^7 Hz
spot size (diameter)	1 cm
Hadron Beams (≤ 20 GeV):	
particle ID (e/π)	10^2:1
flux range*	10-100 Hz

* flux is instantaneous rate; maximum duration will be 1 second

Tertiary beams are being considered for low energy hadrons, but may not be necessary. The distance from the target hall to the calibration hall is about 450 meters. Consequently, a 2 GeV pion beam will have decayed to about 2% of its original intensity, with consequent creation of muon contamination. However, most of these muons will be created near the upstream end of the beam, and, at 2 GeV, will have a maximum angle with respect to the beam of order of 10 mr. Therefore, they will not be transported with the pions. At worst, a broad halo of muons will accompany the pions to the calibration hall, and these can mostly be vetoed by their position off axis. Therefore, the muon contamination at low energies may not be a serious problem. Furthermore, since the required pion fluxes listed in Table I are not large, they are easily obtained even with the decay losses (protons will

also be present; the percentage is not known at the present time). Therefore, it may not be necessary to construct tertiary beams.

Particle identification will be accomplished with equipment which is being specified. Candidate technologies include synchrotron radiation counters, transition radiation detectors, and Cerenkovs.

The Calibration Hall

An overview of the Calibration Hall is shown in Figures 2-5. The beams are incident into the pits from the north (Figs. 2, 3). The east pit will be dedicated to SDC, the middle pit to the smaller experiments, and the west pit to GEM (Fig. 4). Counting rooms are south of the pit. Shielding walls surround the pit. Each pit is separated from the next by a six-foot thick wall (Fig. 4). A truck access is placed as shown (Figs. 2, 3). A staging and test area and other facilities are placed as shown (Fig. 3). A 50 ton crane, with a 10 ton auxiliary hook, covers the entire staging area and the three pits. A utility building contains gas handling equipment and other utilities (Fig. 2). Stairways access the pits at each end; an elevator access is south of the counting house.

Office space and other lab space is not shown. This will either be in trailers or in permanent west campus buildings not far away.

A vertical section of the Calibration Hall through the pits is shown in Figure 5. Shown is the elevation of the beamline and the cable and other duct banks from the utility area and the counting house down to the pit. An electronics mezzanine is also shown along the south wall of the pit, under the counting house.

Thanks to the walls between the pits, any of the lines may be in use while the others are occupied by people working. The walls stop at the height of the mezzanine, which can therefore not be occupied while any of the beams are running. The stairway and elevator behind the counting house provide the normal access to the pits. This access contains a separate personnel interlock to each area (Fig. 4).

SSCL Test and Calibration Program

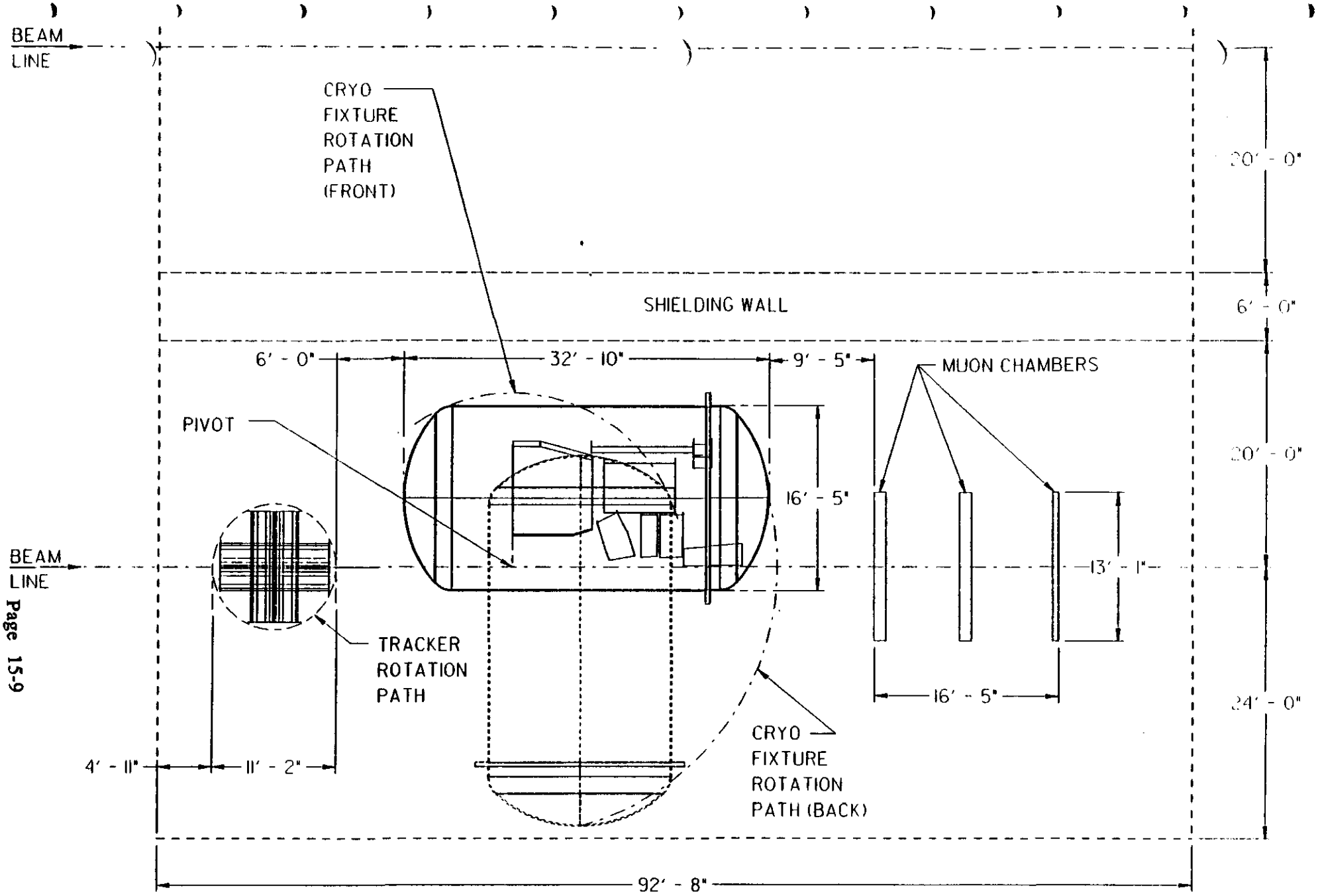
Beneficial occupancy of the calibration pits is currently scheduled for January, 1995. Under the most optimistic scenario, beams would be delivered one year later. However, the MEB completion date may be later than this, perhaps by a year or more. This situation should be clarified in the coming months. In the event that beams are available in

early 1996, it is imperative that GEM be in a position to use them. Therefore, design work on the transporters, the longest lead-time items, has to begin soon.

Tracker tests at SSCL will be performed after construction of the actual tracker has been completed. These tests will locate the positions of the tracker components relative to each other. They will also permit full operation of the tracker under controlled conditions before installation into the detector itself, where it will be inaccessible once running has commenced. These tests must commence, with stable beam, by mid 1997 at the latest. The tracker will actually be assembled elsewhere, transported to the Calibration Hall, and then transferred to the IR after calibration. Transport will be at 5 mph in order to avoid subjecting the fully-aligned tracker to shock.

Calorimeter tests will complement those run at Fermilab. A full test plan is still under construction, but these will require the full range of energies available and the full spectrum of particle types. This will most likely be the first time at which the final calorimeter data acquisition and other electronics systems will be under test with actual calorimeter modules.

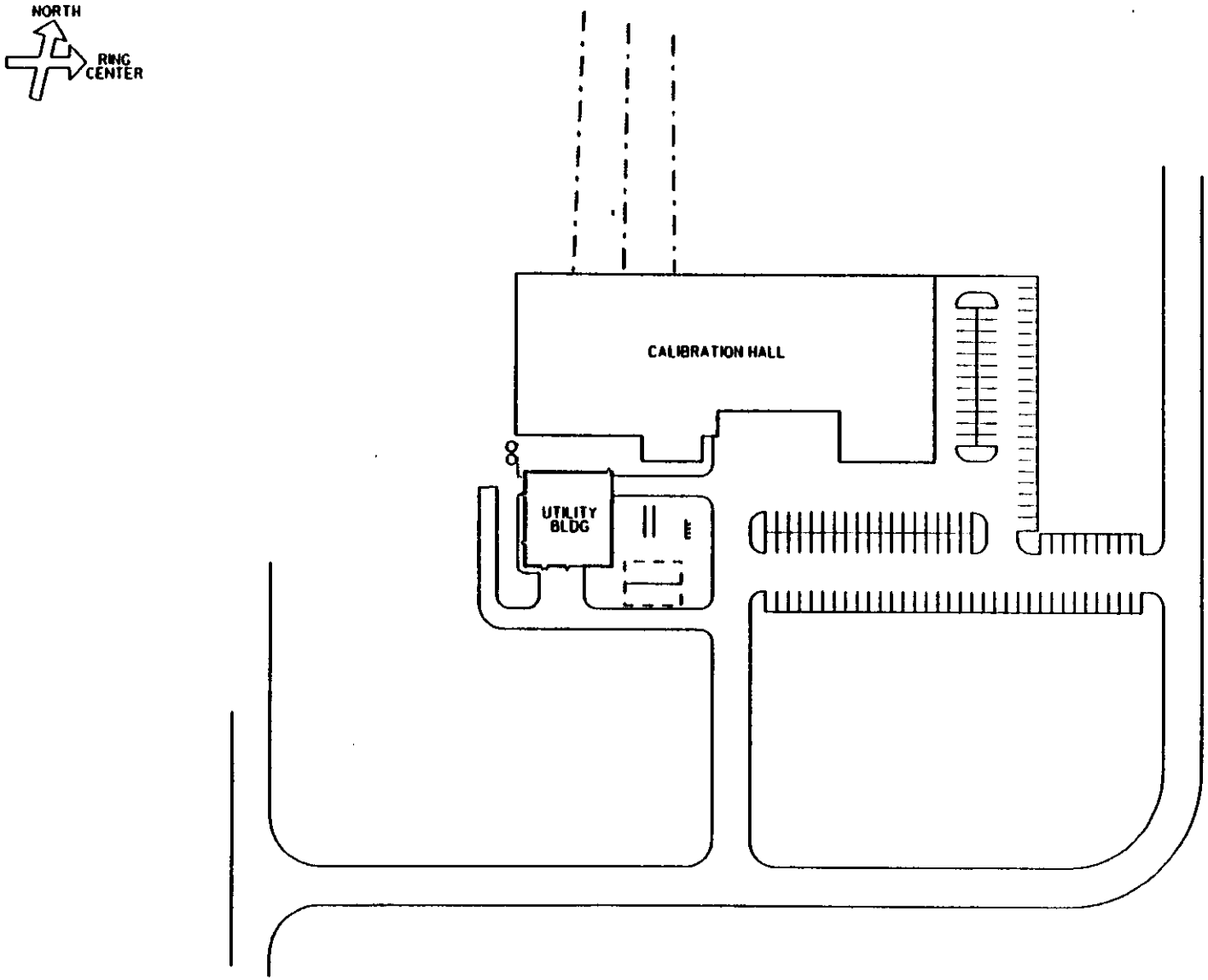
Finally, the muon chambers will also be tested with their final DAQ and electronics. Punch-through and pattern recognition problems will be addressed. A magnet (not shown in the drawings) will be installed to enable these questions to be studied in small prototype chambers in a field. High energy tests will be performed on full-scale modules in order to understand their performance and to understand their alignment which, for GEM, is very demanding.



PLAN VIEW

DIMENSIONS ARE IN FT/IN

GEM DETECTOR TEST BEAM CALIBRATION LAY OUT



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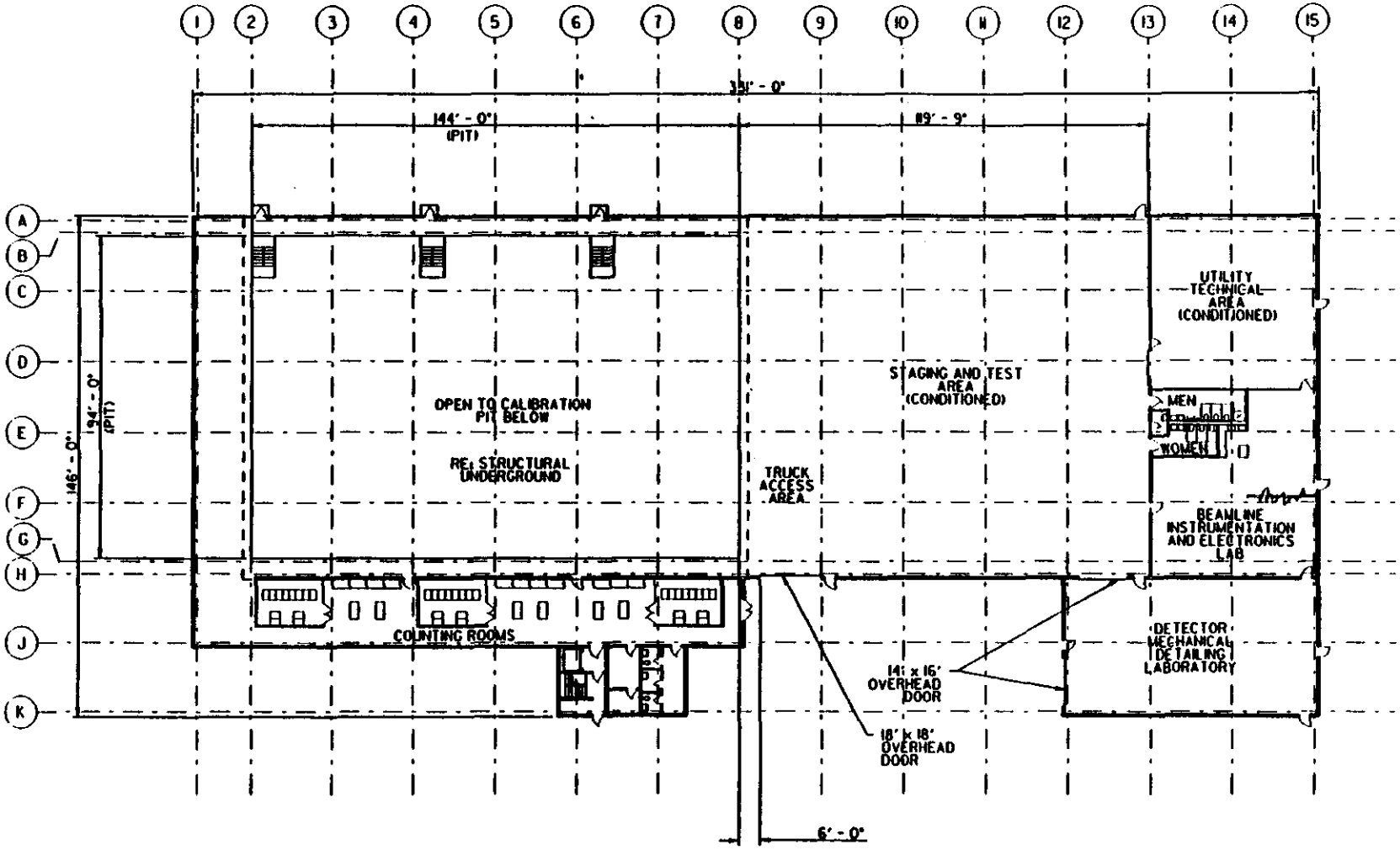

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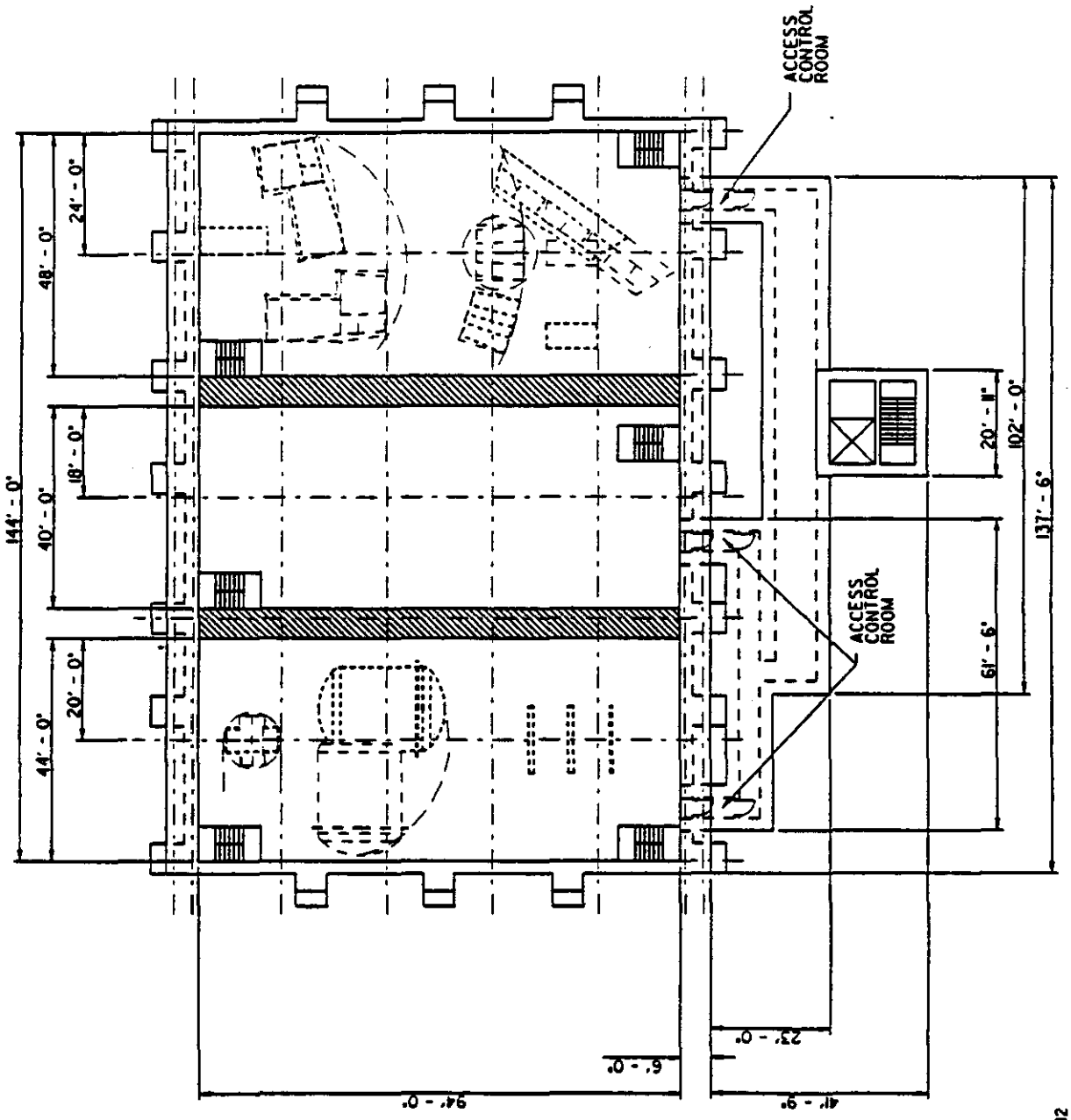

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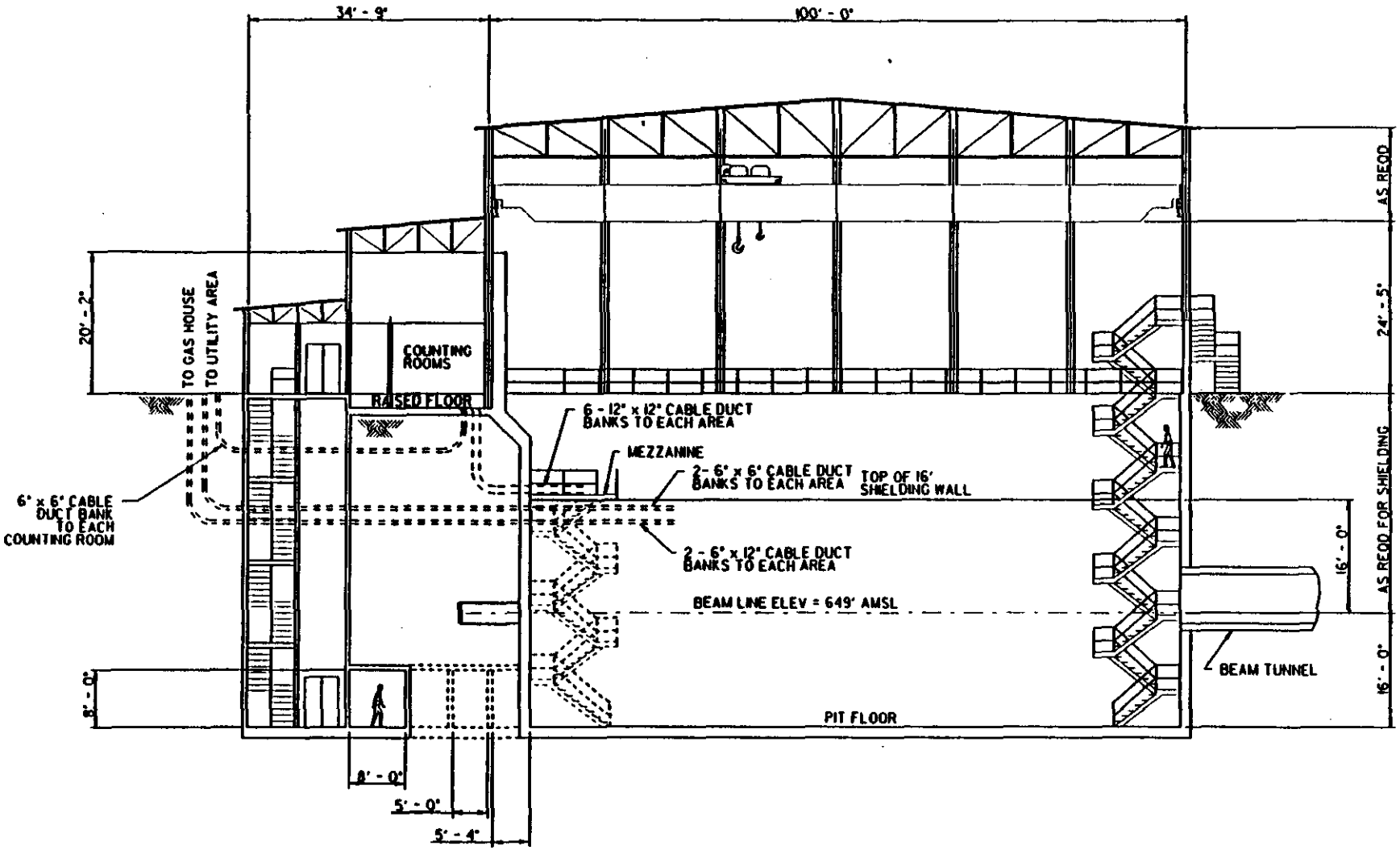

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K. R. Nelson

16. RADIATION ENVIRONMENT

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RADIATION ENVIRONMENT

OVERVIEW

The Los Alamos High Energy Transport (LAHET) simulation package and other codes are now being used to model various aspects of the GEM radiation environment. Several detector geometry alternatives are under investigation, with results periodically issued in the form of GEM Notes (TN-92-91). One design under current study is the Baseline 1 detector geometry shown in figures 16-1 and 16-2, and table 16-1. Results from this design and a summary of the implication of past studies are reviewed in this report. To date emphasis has focused on neutron calculations, and similar results for photons are forthcoming. All results given here are for a luminosity of 10^{33}.

Neutron Fluence: Potential Radiation Damage and Background Effects

The flux of neutrons at sensitive sites such as the silicon vertex detector and the drift chambers is an active area of investigation. Table 16-2 shows the calculated neutron fluence through the silicon vertex barrel. Studies indicate deterioration of silicon detectors at fluences of around 10^{12}, and the numbers calculated for this area indicate a need for a moderator such as borated polyethylene. Table 16-2 also gives the vertex neutron fluence with a B-poly lining of 5 cm along the barrel and 10 cm in the forward direction. Studies of a previous detector design (TN-92-91) indicate little additional reduction can be gained by further increasing the forward B-poly layer thickness. Figure 16-3 shows the neutron energy spectrum along the tracker cylinder. Such information can provide guidance in choosing appropriate neutron sources for radiation damage tests. Table 16-3 and figure 16-4 give neutron fluence calculations for the first muon chamber at the edge of the endcap calorimeter. Similar spectra provided by this code have been used by the muon system designers to investigate the background these particles will cause.

Material/Component Studies

Studies outlined in table 16-4 illustrate the results of neutron flux studies under varying options of the calorimeter geometry and makeup. The detector shown in figure 16-5 (the study was done for the geometry design of TN-92-91) was examined with both copper and uranium as the absorber material. For the copper case, the effect of removing the FCAL and field shaper was studied. In the endcap, the neutron fluence is larger for the uranium option, but only in the first few hadronic sections. The primary showers have ended by the time

Source: L Waters
Update: 6/24/92

the end of the calorimeter is reached. Here, the flux is dominated by leakage from the FCAL. Removal of the FCAL results in a spray of particles backward from the field shaper. This has the effect of doubling the neutron flux into the first endcap muon chamber, indicating the effectiveness of the FCAL as a shield for more forward regions.

Activation Studies

Studies of detector activation will have implications for background from decay particle spectra, the useful life and subsequent long term storage of elements, and for worker health and safety issues. The most immediate concern is for elements at large h; the beamline and getter pumps, FCAL, field shaper and quads. Preliminary calculations for the FCAL have been carried out with the CINDER90 code for a previous FCAL design shown in figure 16-5. The decay of the residual nuclei from the LAHET reactions and from the MCNP neutron flux are followed for 30 time bins. The beam is considered to run continuously for 6 months, then shut off and the subsequent activation history tracked for another 6 months. As a function of time, figure 16-6 shows the activity density in curies/cm^3 for sections 1 and 16. Integration over the entire FCAL gives a total of 18.7 ci after 6 months of beam. After cooling off for one day a total of 9.7 ci is estimated. Corresponding figures for decay power are 52.7 and 18.3 mWatts. A point kernal shielding method calculation of the dose equivalent rate was made with the major radionuclide sources at the one day cool-down time. Results are shown in figure 16-7.

Source: L Waters
Update: 6/24/92

	EM	HAD	FCAL	B-Poly
density (gm/cm^3)	4.369	6.2165	17.022	1.39
elements (%)				
hydrogen	4.95	8.08	.14	11.6
boron				5.0
carbon	4.44	4.82	.32	61.2
nitrogen		.39	.03	22.2
oxygen	2.62	4.45	.06	
silicon	.64	1.89		
argon	43.13	6.15	2.14	
chromium	3.58	1.91		
iron	11.69	6.26	2.14	
nickel	1.98	1.07	9.65	
copper		64.98	4.08	
tungsten			83.58	
lead	26.97			

Table 16-1: Material specifications for detector components. Numbers are given in atomic percent, except for borated polyethylene, which is given by weight. Elements are further broken down into their naturally occurring isotopes. Cryostats are A15083, the beampipe is beryllium out to ±227 cm, and the getter pumps and remaining beamline are stainless steel 442. All magnet elements are natural iron.

SETUP	Fluence < 100 keV	Fluence > 100 keV	Total Fluence
no shield	30.2	21.3	51.5
5+10 cm B-poly	1.83	2.98	4.81

Table 16-2: Central tracker neutron fluence. As long as the composition of the nearby electromagnetic calorimeter sections does not change, these numbers are insensitive to changes in the material of the hadronic sections. Another study shows that if the endcap calorimeter are moved inward by 10%, the fluence numbers shown increase by 8-9%. The neutrons have a long time distribution, and form a 'dc' background. Numbers are in units of 10^{12} per SSC year, per cm^2.

Source: L Waters
Update: 6/24/92

Bin (cm)	Fluence < 100 keV	Fluence > 100 keV	Total Fluence
116-178	12.1	5.1	17.2
178-240	3.35	1.44	4.79
240-302	2.11	.89	3.01

Table 16-3: Neutron fluence through the first endcap muon chamber, for three radial bins. Studies indicate lower energy neutrons come primarily from the calorimeter, while the higher energies are dominated by leakage from more forward elements. If the FCAL is removed, these figures increase by factors of 2-3. There is no B-poly shielding in this study. Numbers are in units of 10^{12} per SSC year, per cm^2.

Z distance (cm)	^{238}U	^{64}Cu	^{64}Cu no FCAL	^{64}Cu no fwd
z=263.3	45.1	47.7	43.51	45.83
	26.5	27.1	24.91	26.22
z=318.6	45.3	33.3	30.28	30.39
	25.3	20.2	18.18	18.59
z=372.6	22.7	11.4	10.85	10.79
	12.2	6.2	5.99	5.87
z=427.6	18.1	9.9	8.45	9.24
	9.7	5.3	4.45	4.97
z=482.6	87.5	85.6	17.11	8.32
	39.4	39.0	9.76	4.15

Table 16-4: Endcap neutron fluence at various Z values between a radius from 5.7 degrees to 180 cm. Numbers are in units of 10^{12} per SSC year, per cm^2. Two lines are given for each interval; the first represents total neutron fluence, the second is the neutron fluence less than 100 keV. The cases studied represent Uranium as primary absorber, a copper option, the copper option with FCAL removed, and copper with FCAL and forward field shaper and shield removed.

Source: L Waters
Update: 6/24/92

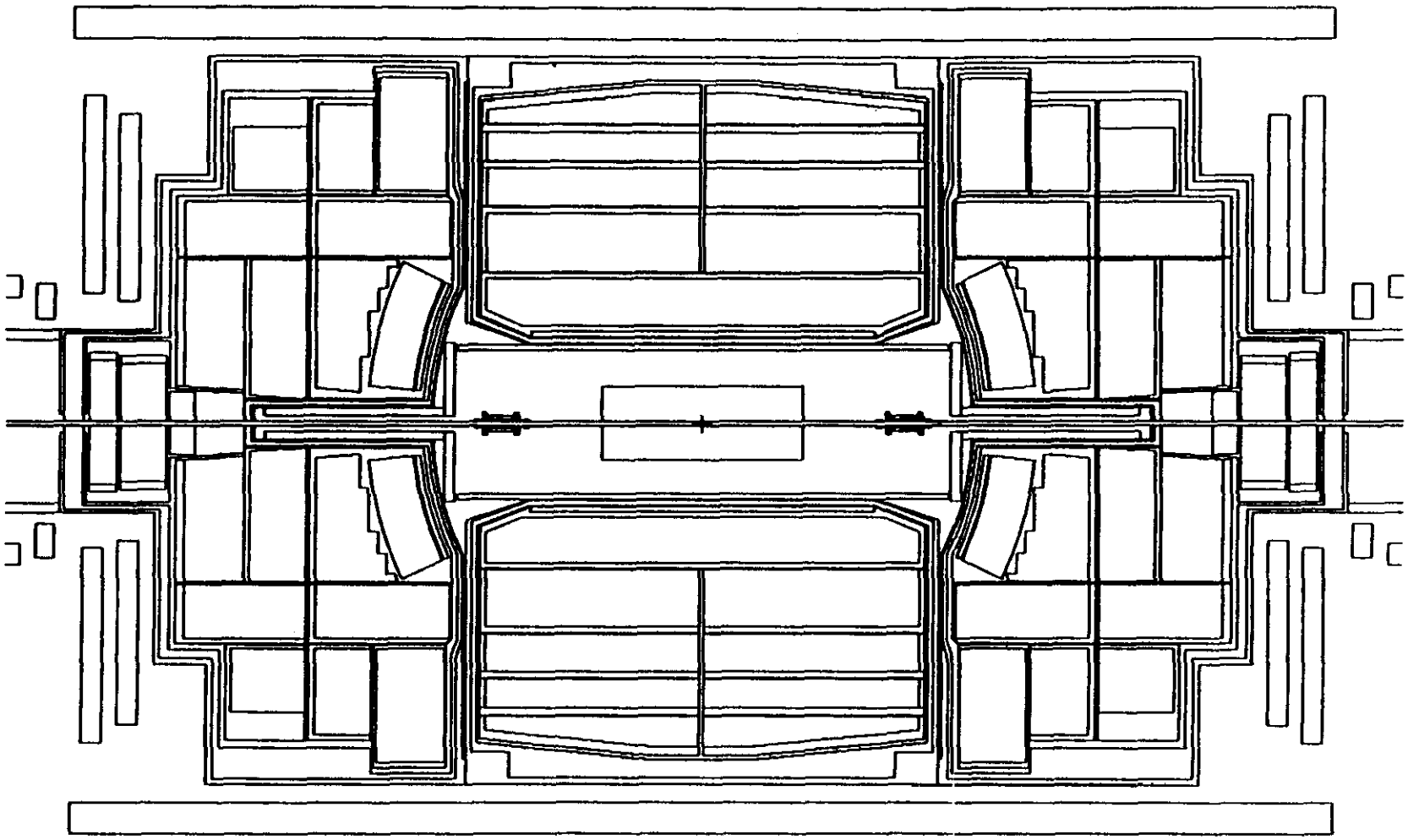

Figure 1 LAHET/MCNP geometry simulation for calorimeters

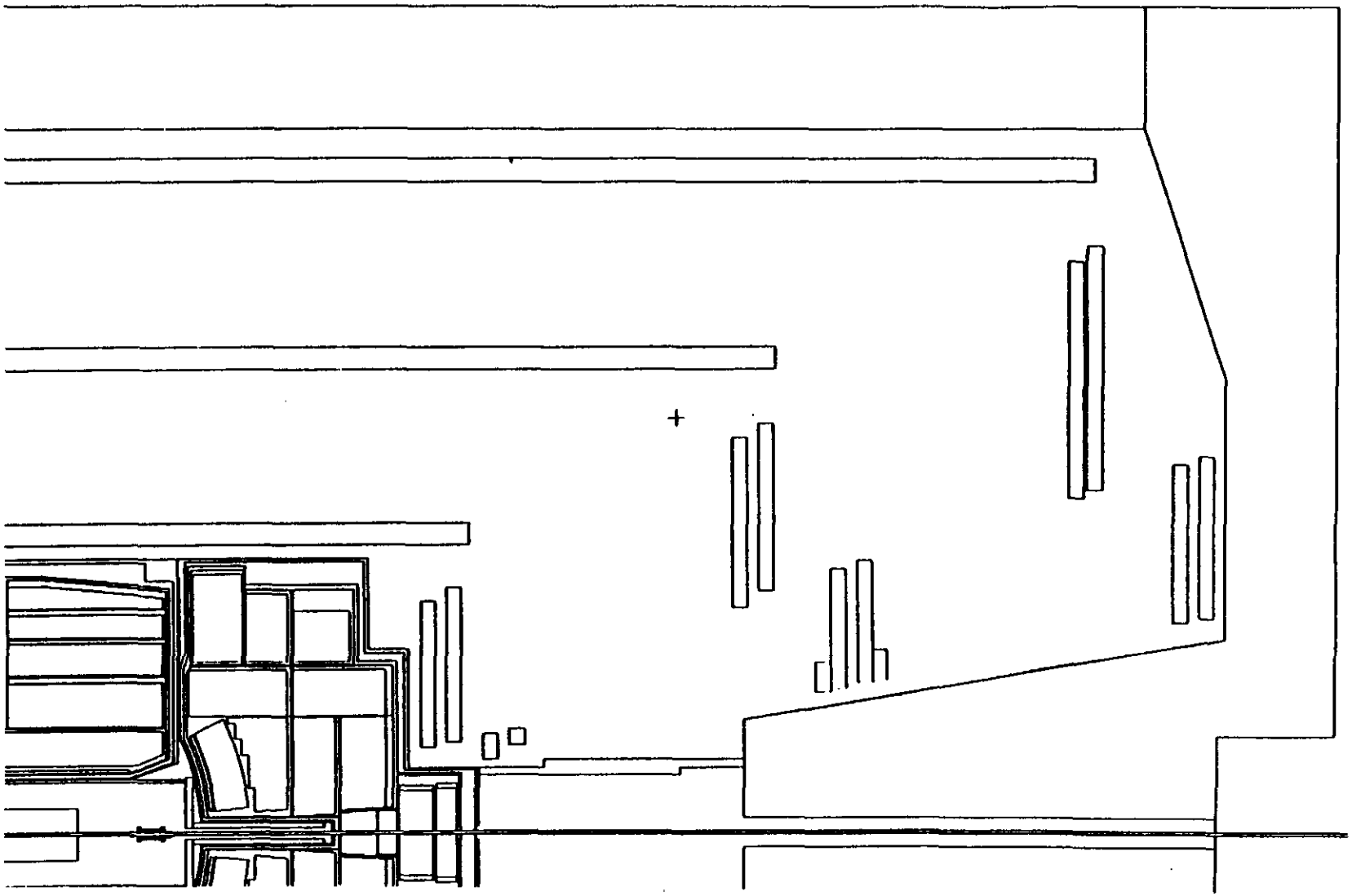

Figure 2 LAHET/MCNP geometry simulation for drift chamber and magnet

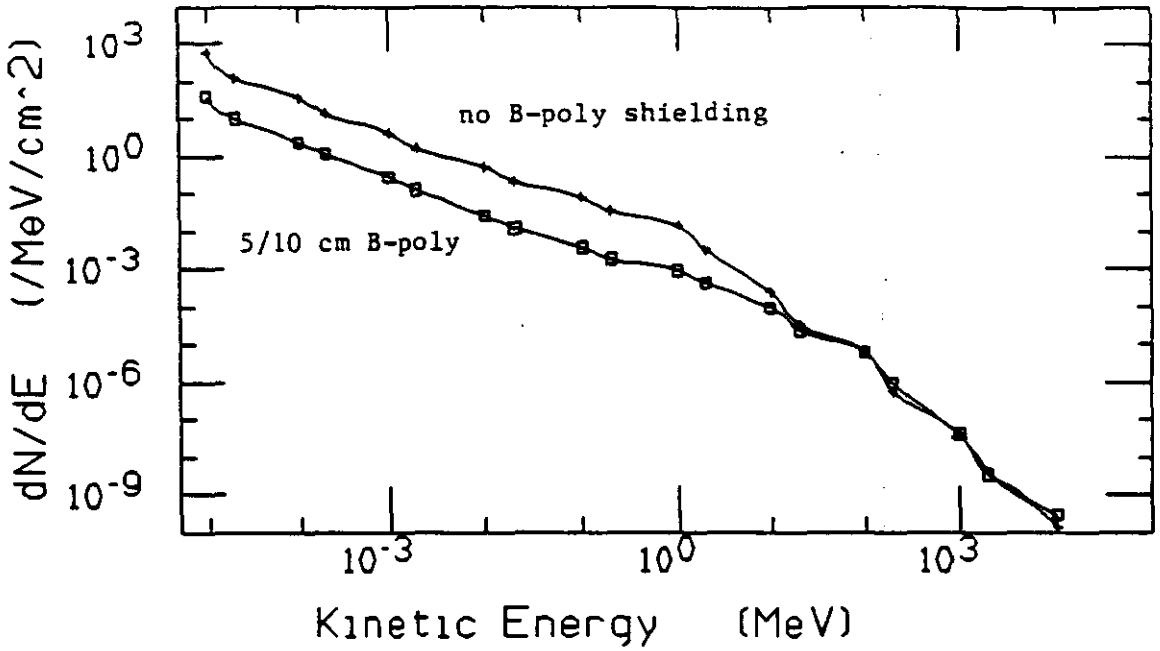

Figure 3 Energy Spectra of neutrons through the silicon vertex detector

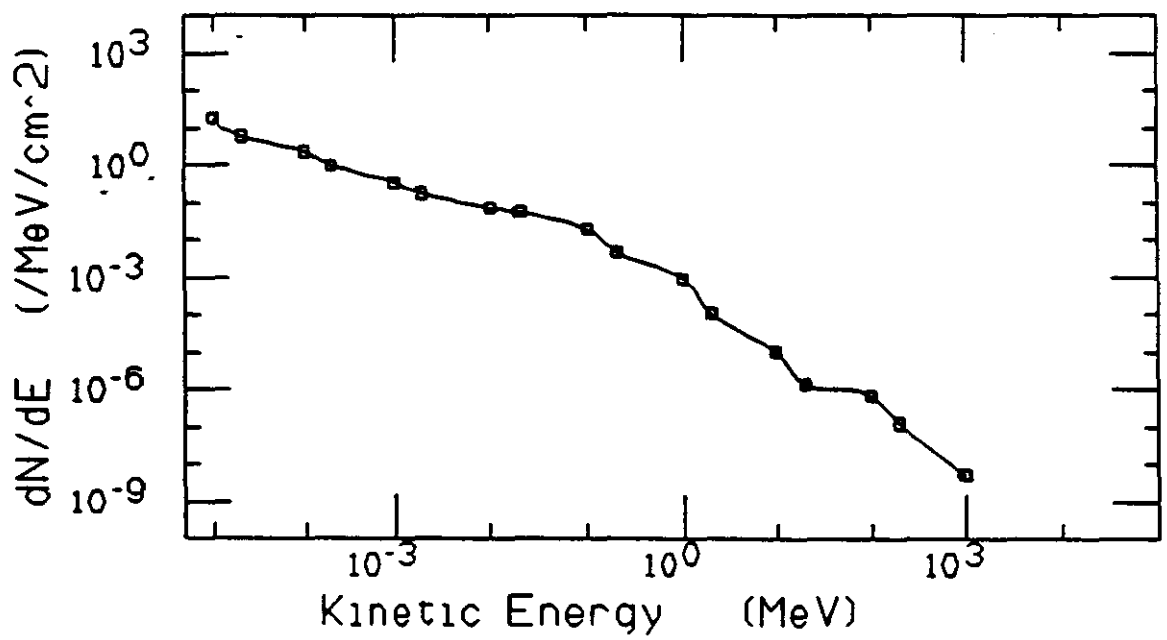

Figure 4 Energy spectra of neutrons through the first Endcap muon chamber

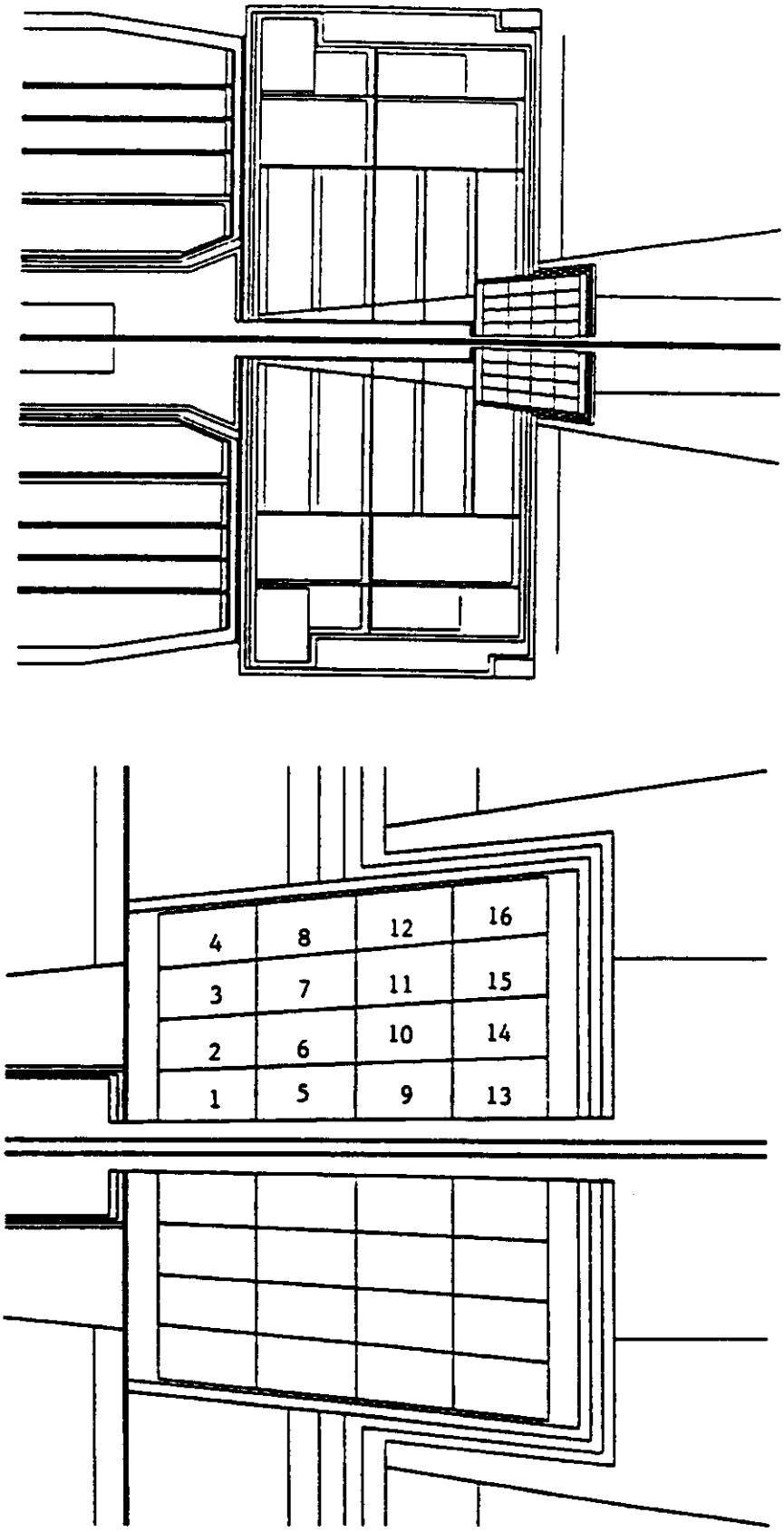

Figure 5 Endcap and FCAL geometry simulations form TN-92-91. This differs from the Baseline 1 configuration. For the activation FCAL calculations, the detector was divided into 16 segments.

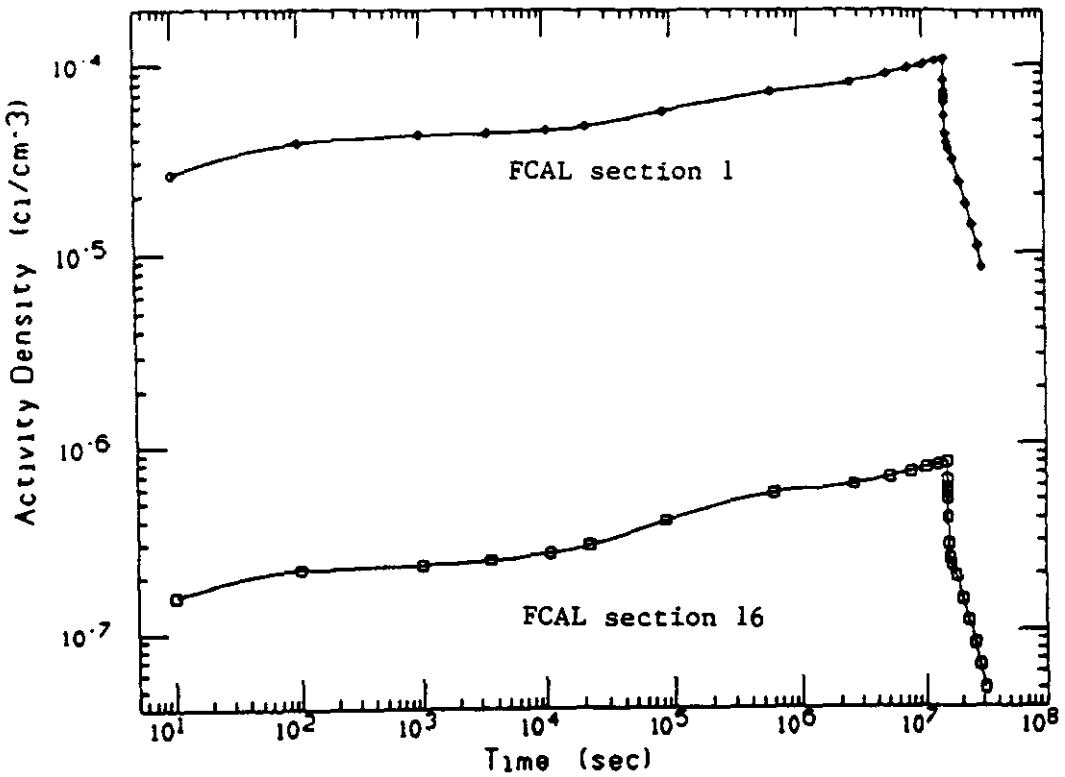

Figure 6 Activity density in the FCAL: preliminary results

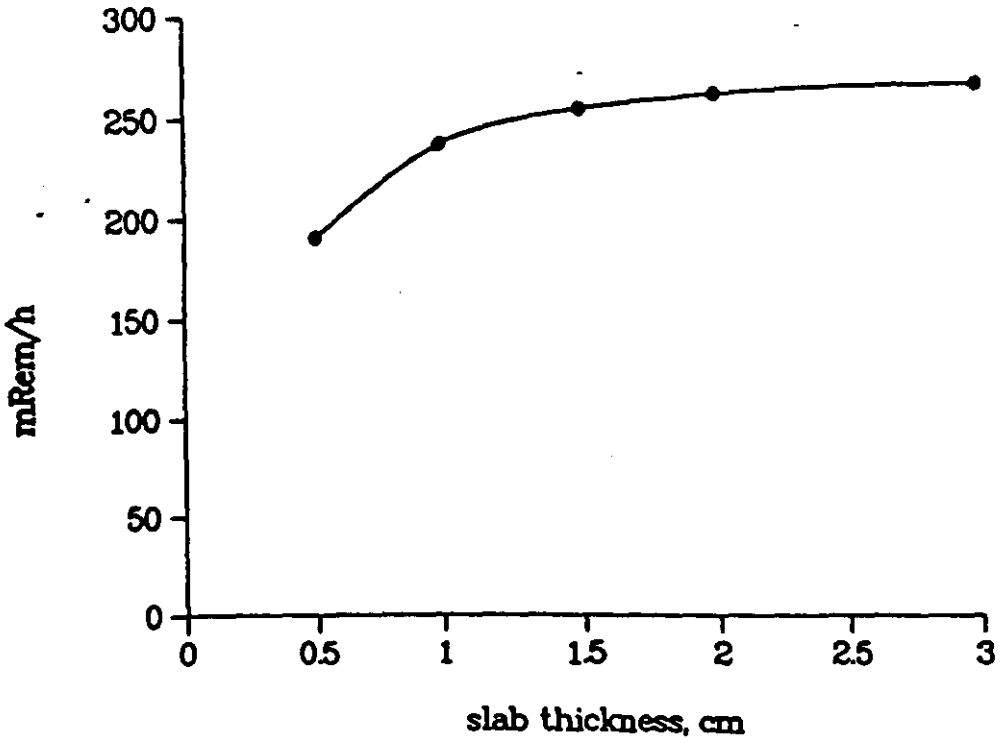

Figure 7 FCAL dose equivalence. The major reaction products were assummed to form an infinite slab of material of varying thickness. The measurement of dose was taken 10 cm away after one day of cooldown. Note the self-shielding properties of the detector.

17. ENVIRONMENTAL SAFETY & HEALTH

ENVIRONMENTAL SAFETY & HEALTH

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INTRODUCTION

This chapter provides a description of the basic and relevant hazards along with their proposed mitigating action. Safety aspects have been developed concurrently and at the same level of specificity as the technical designs. The safety approach follows the same evolution path as the designs and is sensitive to and directly affects costs. System engineers will coordinate with and include system safety within their design process. Before the TDR is finalized, the draft PSAR will be completed which will take all proposed design modifications into consideration. In keeping with the SSCL's ES&H goal of effective excellence, the GEM ES&H design philosophy is to provide a realistically-appropriate and reasonable level of hazard mitigation action to successfully resolve all credible and probable catastrophic and serious-outcome events. Worst-case non-credible or improbable events will not require design-modifying mitigating action.

OVERVIEW

This Chapter specifies the ES&H parameters of the GEM Detector at the current stage of development and provides definition of the detector's safety design. It is intended as a resource document for all critical ES&H functions:

- Design of the several safety systems and their integration into the detector;
- Costing of these safety systems; and
- Performance optimization (effectiveness and efficiency) and interference minimization (normal-operational transparency) of these safety systems upon the detector.

Safety systems' impact upon the detector performance, design and/or cost will be evaluated prior to their implementation. This section will be expanded in the GEM Technical Design Report.

Control and management of ES&H documents will be the responsibility of the GEM ES&H Coordinator, implemented through the GEM Document Control Center and conforming to the requirements of SSCL's Configuration Management Plan. Document changes will be handled as described within the Overview (chapter 1, section 1.2).

SCHEDULE/MILESTONES

ES&H documentation will be separated into three stages of development for each system, the overall detector, and all facilities. First, a draft Preliminary Safety Analysis Report (dPSAR) will be initiated during the conceptual-to-preliminary design phase period and completed prior to the start of the detailed design phase. Second, the PSAR will be completed and approved prior to start of construction, and finally the SAR will be completed and approved six months prior to commissioning. Safety hazard analyses will be performed upon the Construction, Installation and Test activities for the detector, as well. These will be completed and approved by the PRD AD and GEM Collaboration Project Manager, prior to initiating the activity.

Listed below are the proposed critical milestones for GEM ES&H documents:

1.	Draft Preliminary Safety Analysis Report (Appendix to the draft TDR)	December 1992
2.	Draft ES&H Chapter for Technical Design Report	December 1992
3.	GEM Magnet dPSAR and TDR ES&H chapter	December 1992
4.	Completion of 2 & 3 above for TDR	January 1993
5.	GEM ES&H Implementation Plan	February 1993
6.	GEM U/G Hall dPSAR (from EFD)	March 1993
7.	GEM Tracker dPSAR	June 1993
8.	GEM Magnet PSAR	August 1993
9.	GEM Calorimeter dPSAR	September1993
10.	Central Detector Support dPSAR	March 1994
11.	GEM Tracker PSAR	April 1994
12.	GEM Calorimeter PSAR	May 1994
13.	Detector Construction/ Assembly Hazard Analysis	May 1994
14.	GEM Beam Line PSAR	November 1994
15.	GEM Muon dPSAR	June 1995
16.	Central Detector Support PSAR	June 1995
17.	U/G Hall PSAR	August 1995
18.	GEM Muon PSAR	January 1996
19.	Detector Installation Hazard Analysis	April 1996
20.	Detector Test Hazard Analysis	July 1996
21.	GEM Detector SAR	January 1999

FACILITIES

Conventional and technical safety systems will be installed and equipped in conformity with US Codes, Standards, and Regulations, particularly those concerning life safety and fire protection. Underground facilities require special attention to safety hazards due to the type and location of occupancy with it's special risks. Following are areas where specialized safety systems will be employed:

- Emergency lighting with low-visibility floor directional lights.
- Ventilation, normal and emergency for smoke/gas extraction.
- Special fire protection system in the vertical shafts' cables and optical fibers ducting.
- Special fire protection system inside the GEM detector, with VESDA smoke and gas detection and non-sprinkler-type suppression. Possible N_2 blanketing of the Calorimeter and Tracker.
- Special fire protection system in the electronic room and electronic racks - Non-halon-type suppression.
- Emergency power generator and distribution.
- During operation, the U/G Hall's ventilation will be recirculated, preventing release of activated air/gas.
- Use of laser/infra-red scanning for incipient fire/smoke detection.
- Ability of electromechanical components to function within the facilities' static magnetic field.
- The U/G Hall and several surface facilities will have the Personnel Access Safety System (PASS) protection installed to control and monitor access, ingress and egress to/from the areas.

Where volatile hydrocarbons and epoxies are applied surface facilities will contain special ventilation filtration systems to effectively remove them from the recirculated air. Several areas in the Operations and Gas-Mixing buildings may be have their sprinkler systems supplemented or replaced by high-expansion foam to minimize equipment damage from sprinkler discharge. If building thermal insulation is to be used, it will be of a fire-retardant material.

DETECTOR INSTALLATION

All crane, hoist, and lifting equipment will be constructed, tested, and used in accordance with applicable US Regulations. For each installation step, special mobile access devices such as mobile platforms and

adapted scaffoldings will be present. From the beam line installation step (phase 1) access devices such as ladders and platforms will be installed. A Safety Analysis which outlines all hazards and their remedies will be completed for this critical installation activity. Each step of detector installation will require a Job Safety Analysis prior to initiation. The crane and hoist equipment will have load tests performed prior to critical lifts being initiated. The crane will have a lock-out system installed which will interface with the PASS, to prevent unauthorized access and operation.

DETECTOR ACCESS

The Code-required emergency egress travel distances will be adhered to and achieved by design within the U/G Hall (See Figures 1&2).
The following conditions and requirements will be applied:

- Access to the equipment outside the fully-energized magnet, for short-duration shut downs (± 1 day depending of the collider program) will be allowed. Access within the U/G Hall and external to the detector will be allowed at a the normal level of energization, while access internal to the detector will be allowed at a reduced level of energization (1/2 the energy) for a specified duration. Special consideration will be applied to strategic locations of equipment requiring frequent access and/or maintenance as in the case of a future upgrading of muon chambers around the magnet.
- Access to the Tracker, Calorimeter, and Neg Pumps may be required through the FFS. This time-consuming operation requires the removal of some shielding inside the central cavity. The access to some equipment inside the detector will be facilitated by either integrated access pathways, permanent access structures or personnel transport devices. The access capabilities are governed by the ANSI and OSHA Standards for Confined spaces. Under specific circumstances (Charged with cryogens, presence of energized sources, magnet energized, flammable gases are used, or the detector flow-through ventilation is off), inside the closed detector will be a **Permit-required Confined Space,** due to the potential life safety hazards. In addition to the normal safe-working rules which apply in such conditions, the following requirements will apply inside the detector:
  - ⇒ Ventilation of the entire volume at the rate of 5 volume changes/hour.

- ⇒ Permanent lighting at min. 50 ft/candles, for precise work.
- ⇒ Emergency lighting UPS operated.
- ⇒ Communication system.
- ⇒ Emergency supply.

- Access through the side of the FFS when it is withdrawn ~2 meters would be allowed with the same conditions as above.
- The two FFS are withdrawn for a long shut down, the access space becomes a **Non-permit required Confined Space.** In this case the gas systems are without any pressure, and the liquid calorimeters are the only charged chambers.
- The two half portions of the magnet are withdrawn to give access to the calorimeters and to the tracker. This area then becomes a **Non-restricted space** and the systems require no specific safe conditioning.
- The Electronics rooms will be classified as **Non-restricted space (employees, restricted for public access).**

BEAM LINE

Each part of the experiment vacuum tube will be chosen after tests on prototype tubes to find practical safety factors. These factors will be confirmed relative to external pressure using the prototype(s). The collapse safety factor may be determined by destructive tests on samples of the same shape. Another way consists of assigning a safety factor (to be defined) which will be applied on a backup tube. The beryllium tube will be separated from the collider vacuum tube with protective means for separation of volumes in case of vacuum problems.

MAGNET, FIELD SHAPER & CENTRAL DETECTOR SUPPORT

The GEM Magnet Group has adopted a single-coil solenoid configuration, without iron flux return. The proposed safety-design methodology, will maintain compliance with DOE Orders 5481.1B and 5480.ACC, the SSC Final and Supplemental SSC Environmental Impact Statements (FEIS, SEIS), and applicable regulatory codes and standards. DOE Order 5480.5 *Safety of Nuclear Facilities,* does not apply. This proposed design action is described in *GEM Magnet Safety Evaluation, GEM TN-92-222, Considerations Leading to the Choice of Open Field Magnet, GEM TN-91-30, and SSC GEM Magnetic Field Safety & Health Effects, GEM TN-91-19.*

Among the safety hazards which will be considered and analyzed within the Magnet PSAR are:

1) Quench protection (from sources such as: 'Hot Spot' occurrence, Vacuum Loss, etc.)
2) Practical testing of the magnet performance
3) Helium cooling
4) High pressure within the conductor, from Quench (340 bar)
5) Magnetic Field Effects characterization (including Health impacts)
6) Open Circuit within the Dump Resistor
7) Magnet shutdown process-Detector access in 'B' Field
8) Stress Effects
9) Helium & Nitrogen Overpressurization protection and venting
10) Use of the vessel vacuum line as overpressure vent line, with rupture disc (no PRV)
11) Vacuum pump 'small-leak' handling capacity
12) Gross cryogenic liquid leak effects - embrittlement, electronics, personnel exposure
13) Radioactive hazardous waste handling

The use of Magnet structural materials having very similar coefficients-of-expansion/contraction prevents coil static instability from axial and radial thermal expansions/contractions during warming/cooling between ambient and cold mass (4.5°K) temperatures, from being a safety issue. Static instability of the internal vessel of the cryostat may result in case of overpressure due to helium leaks inside the cryostat. Liquid helium leaks could give cryogenic burns to workers and an eventual ODH problem. Compared to other thin superconducting magnets, the E/M value of 3.6 kJ/kg for the GEM magnet provides a margin of safety, in case of quench (note: SDC's E/M is ~7).

Quench can be expected to be a rare but potentially catastrophic event when the superconducting coil transitions to a normal state. This energy will be discharged in a 0.02 ohm Dump Resistor (DR) where GEM's quench detection system 'triggers' the fast dump switches, discharging in a time constant of ~100 seconds. This energy will actually be dissipated within the coil and the DR, in ratio to their resistance. The voltage across the DR will be 1kV or buss-to-ground voltage will be 0.5 kV, therefore stringent safety protection must employed. Quench results in heat generation and rapidly increases the pressure inside the magnet conductor channel to ~6,300 psig at a T=100° K. The helium system will be designed to safely handle this event. 'Hot spots' can occur inside the conductor where the (relatively) low quench velocity does not allow the heat generated to dissipate uniformly throughout the entire coil. If the quench detection system does not properly 'trigger' the DR

switches, the hot spot(s) can heat-damage the conductor. The GEM magnet hot spots will mainly be within the aluminum conductor.

The most probable system disturbance is that of a quench. An opening of the electrical circuit between the coil and the DR, in which an overvoltage would be generated between the coil and the mass, is very unlikely to occur from development of resistance points inside the buss bar system, loose connections, etc.

The construction of the GEM Magnet superconductor is different in comparison to other existing superconductors. An advantage for the GEM conductor is that the conductor is directly cooled by the supercritical helium, an important factor for stability against quench. Superconducting wires are designed to be stable against all credible disturbances. A practical test should be performed upon several loops of the conductor to verify it's integrity.

Buckling and Load stress analyses have been performed upon the CDS. Refer to GEM TN-92-224 "Structural Analysis of the GEM Central Detector Support." Embrittlement and resulting fatigue cracking, from prolonged contact with accidentally spilled cryogenic liquid (from within the detector), do not present a collapse hazard.

The FFS may be designed to allow for access to the Tracker with resulting personnel access requirements. Minimum personnel entry dimensions and safeguards against accidental beampipe contact will be applied.

MAGNETIC FIELD

The GEM Detector's single-coil solenoidal magnet produces a static magnetic field of ~0.8 Tesla strength within the coil. Immediately external to the superconducting coil the field is ~0.2 Tesla at the coil end corners and ~0.1 Tesla along the z-axis coil surface. The fringe field dissipates rapidly as a function of distance ($1/r^3$), and radially at an approximate distance of several meters the field strength is ~0.05 Tesla and at the bottom of the Cable Shaft within the lower Electronics room floor the field is ~0.02 Tesla while most of the remaining rooms are ~0.006 Tesla (see Figures 4&5). The Electronics Room will be shielded at all floors to ~0.005 Tesla, to ensure proper electronics operation. Various safety actions have been agreed to regarding protection of workers and public from exposure to the magnetic field. The GEM TN-91-19 report on GEM Magnetic Field ES&H Effects, and the DOE

Environmental Assessment provide information about the safety aspects of this problem.

Equipment required to operate within the Hall's static field will be so designed (ex: Neg. Pumps; subsystem electronics; relays; pre-amplifiers, motors; and safety systems)

TRACKER

The GEM Tracker safety will be similar to that of SDC with the double-wall enclosure for butane cooling and N_2 blanketing protection. Water cooling of the electronics provides potential leak problems and will require Ground Fault Circuit Interrupters on the power supplies, to prevent shock or significant damage. Use of a low-pressure water cooling system which increases the pipes' diameter, reduces the problem in case of water leaks.

CALORIMETERS

EM Calorimeter: As the liquid krypton has a density of 2.89, provisions are to be taken to contain any leaks which will be safely evacuated to the surface. The construction of the calorimeter vessel will adhere to the ASME code and be stamped. Feed-through connection will be Mil Std. and have documented reliability testing.

Hadron Calorimeter: Where Scintillating Fibers are used, access to the photo multipliers will be design-integrated. Handling of the lead plates (toxic/waste) for the fine hadronic calorimeter, will be an construction and decommissioning safety hazard. The coarse and fine hadronic calorimeters containing liquid argon and copper must be further analyzed.

Liquid krypton and liquid argon end cap calorimeters are treated as applicable above. The forward hadronic calorimeter must be further analyzed. Effective secondary cryogenic liquid spill containment will be designed into the detector.

MUON SYSTEMS

Muon chambers are not reliably gas tight therefore flammable gas mixtures will be avoided and the flammable gas component inside the mixture will be regulated with automatic shut off in case of excess flow

and pressure delivery conditions. Cathode Strip Chambers (CSC) have been physics-performance proven with gas mixture concentrations below the Lower Flammable Limit (LFL). If flammable gas mixtures are required, Pressurized Drift Tubes should be avoided. This would require the installation of complex gas detection systems, heavy reliance upon computer automated event control actions, and N_2 inerting of all the electronics around the chambers.

ALIGNMENT

Guarding will be utilized around the un-installed and installed beam pipe to prevent physical contact and damage to the beampipe wall. During installation, manual handling of the pipe will be minimized to prevent damage and contamination of the wall surface (skin contaminants). When access to the U/G Hall is allowed, the beampipe will be provided with guarding to prevent accidental contact and alignment alteration. The possibility exists whereby bolts could be sheered if proper system alignment is not achieved. The recommended method may be to complete system alignment during assembly. Several alignment tools presently being studied have some possible safety issues associated with their active alignment use. The LLNL Lasers w/ Lens system will probably be a low wattage Class II or III laser, which has personnel exposure ramifications. The X-ray (~60 KeV) system option has ionizing radiation implications, and not enough is known of the High-Range Sensor system to comment here. Other alignment issues regarding beam contact with the inner wall surface are addressed within the Alignment Chapter of this Baseline 2 document.

ELECTRONICS

Safety considerations focus upon the read-out electronics and high-voltage equipment. The main safety criteria follow:

- Accessibility, maintenance: due to the number of channels, crates in and around GEM and crates and racks in the electronics rooms, the number of interventions has to be considered as important and as the access periods during operation will be short, the access to each electronic must be easy for quick intervention. The crates should be divided into three main parts: cooling; crate electronics, and their supply. Capability for separation should be by quick disconnects. With the power in 60Hz, one goal will be to decrease the weight of each supply. Single-person manual lifting of the crates is limited to 30 lbs.

- Power connections low-voltage: The experience shows that the high current at low-voltage trough the same plug in for the data gives problems during connection and disconnection (short circuits). It is proposed that the power plug is separated physically from the data plug. This is specially valid for cards connected to the back plate.
- Current protection: Each card/board circuit (where safety regulation-required) must be protected by fuses or other overcurrent devices.
- High Voltage: The high voltage >1 kV dc is required for muons, tracker, photo multipliers and calorimetry systems. Experience in High Energy Physics and IEC 479-1 (International Electrical Commission) has shown that the safe limit of direct effects on human body is fixed at:
  - ⇒ Safe current limit= 10 milliamp.
  - ⇒ Safe duration limit if current > 10 mA= 20 msec.
  - ⇒ Safe stored energy= 10 joules.

  The high-voltage installations under these limits do not need special measures except inaccessibility to live parts and high-voltage signs. Secondary accidents can occur with this type of installation. Installations having voltages higher than the safe limits (120 V AC/DC RMS) must be treated as high-voltage installations, with actuated discharge systems in addition to the use of interlocking systems, log out and tag out procedures. It is recommended that high-voltage distribution systems not be used for such components as the photo multipliers, opting instead for low voltage distribution. The high-voltage is developed directly inside the photo multiplier base.

- Electronics cooling: The pressurized water cooling causes problems and damage in case of leaks. GEM will provide low-pressure water cooling instead; L3 type.

- Electronics protection: The following criteria must be monitored and must trigger necessary actions:
  - ⇒ Early smoke detection system in racks.
  - ⇒ Temperature at the top level of the rack.
  - ⇒ Temperature above and under each crate.
  - ⇒ Temperature of power supply.
  - ⇒ Cooling water temperature and flow at the heat exchangers level.
  - ⇒ Cooling water leaks.

⇒ Overcurrent , overvoltage and phases conditions in the power supplies.

COMPUTING

The Slow Control System will consist of four status levels of notification.

- **Level A** is simply a **'System status'** indication.
- **Level B** is an **'Operational Fault'** type condition which does not warrant initiation of any response action other than maintenance or repair of the faulty component or subsystem.
- **Level C** is a **'Caution'** type condition which indicates that an event has occurred but at a level or degree below that which is designated as an emergency condition by Code or Standard (ex: Caution alarm at 10% of Lower Explosive Limit (LEL) for a gas leak, requires that the gas system flow be idled and the source of leak be located and fixed).
- **Level D** is the standard **'Warning'** level condition which requires evacuation of the area, and Emergency Response Team action. Hard-wired safety systems must be employed to control this severe condition (ex: Emergency Power-Off button). This is the safety limit that is addressed within SSCL's ES&H Manual and the US Regulations, as an emergency condition.

For the detector electronics Slow Control System safety application entails monitoring and controlling:

- The temperature within the crates and racks (resulting in local corrective action);
- The VESDA gas sampling and ODH monitoring indication pre-alarms (ODH: Level C @ 20% & Level D @ 19.5% O2 conc.);
- The pressure within the detector chambers;
- The Iso-butane temperature and pressure within the Tracker (Level B, C & D @ 2%, 5% & 10% of normal operating pressure, respectively);
- The liquid level in the butane supply vessel.

Other areas where slow control safety will be applied are TBD.

TEST BEAM

The same safety measures described within the Tracker, Calorimeter and Muon Chambers sections will apply to the test beam experiment within the Calibration Hall, especially if the Tracker will require Iso-butane cooling. Safety measures will be provided to prohibit the test beam from misaligning to it's target or dump. Accidental dumping of the primary beam into the Hall will be redundantly prevented, by the 5 mr delivery angle from the secondary target and one other safeguard means. The radiation shielding of ~2 meter thick walls will be provided to separate the three beam areas. For safety requirements, refer to the Calibration Hall draft PSAR document GEM TN-92-230.

RADIATION

Shielding will be applied to attenuate radiation levels at or above the surface in accordance with the SSCL Environmental Impact Statement. Direct radiation interference with the 'physics' and damage to materials of construction will be studied. Radioactivation of air, groundwater, and system components, and health impact during detector access and repair will be addressed. Provision will be made to use those safety system components which are the most radiation resistant or even radiation-hard, from the manufacturer. Radiation shielding of proper attenuating material and sufficient thickness will be integrated within the U/G Hall design at the areas where surface radiation levels or equipment damage require. In the U/G Hall the following areas will be shielded:

- Utility and Cable shafts
- Accelerator tunnel / Hall interface
- Low-beta quadrapoles
- All Non-Rad Hard subsystems
- Electronics Rooms

GENERAL SAFETY

A general control system, similar to CERN's SDN system for oxygen-intrusion into inerted spaces (Tracker & Calorimeter), smoke, and ODH conditions, will be used. The safety system approach between SSCL, SDC, CCD and GEM will be consistent for alarms systems, slow control, cable choice (standard to be used), and electronics. Continuous access capability must be provided for the physics-related cabling. The various cables will be segregated in accordance with the NEC requirements. The use of wide-angle fiber-optic cameras for closed circuit personnel surveillance will be studied.

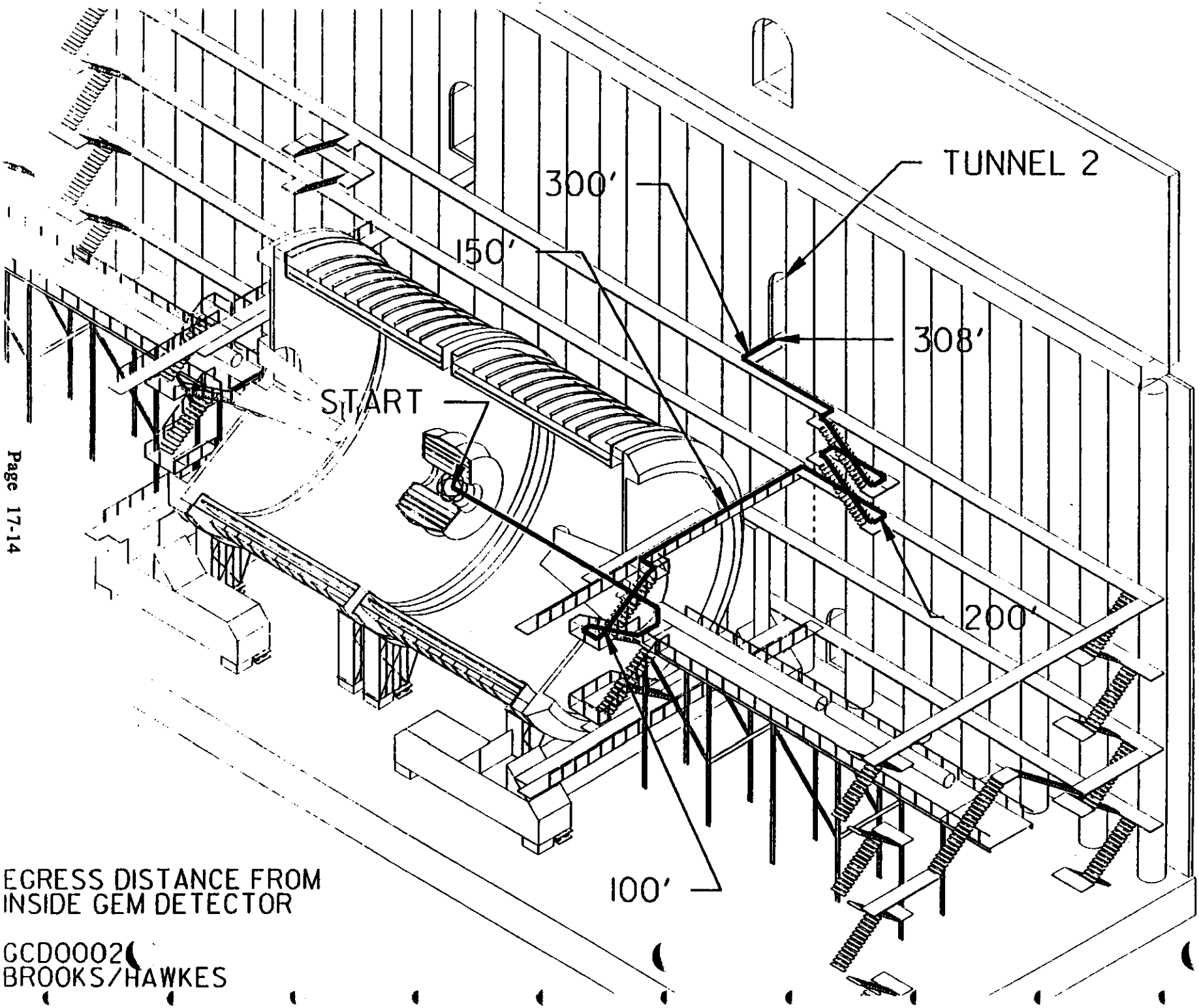
FIRE CONTROL

The strategy will be to minimize the use of flammable gas mixtures within the detector (must justify, if physics-required) and the need for manual Emergency Response Team(ERT) fire suppression activity within the U/G Hall. Due to the inaccessibility of the different components inside GEM some fire control is to be developed and it is proposed:

- In the tracker region to have a permanent inerting with N_2 in the space between the calorimeter and the tracker. Also tthe powered electronics situated on the tracker end caps should be permanently inerted when in operation.
- The muon electronics space, around each chamber, should be controlled by early smoke detection systems and action on the supplies.
- Sprinklers will be replaced by proven, approved state-of-the-art type fire suppression systems, such as high-expansion foam or dynamic nitrogen inertion, or EPA approved halon substitute. Use of dry chemical, hand-held fire extinguishers will be avoided, due to particulate residue.
- Local fire suppression systems will be utilized in lieu of total suppression systems, within the U/G Hall. The high-voltage cable trays and detector interior will be equipped with either N_2 blanket inerting or high-expansion foam ducts, which will be manually activated.

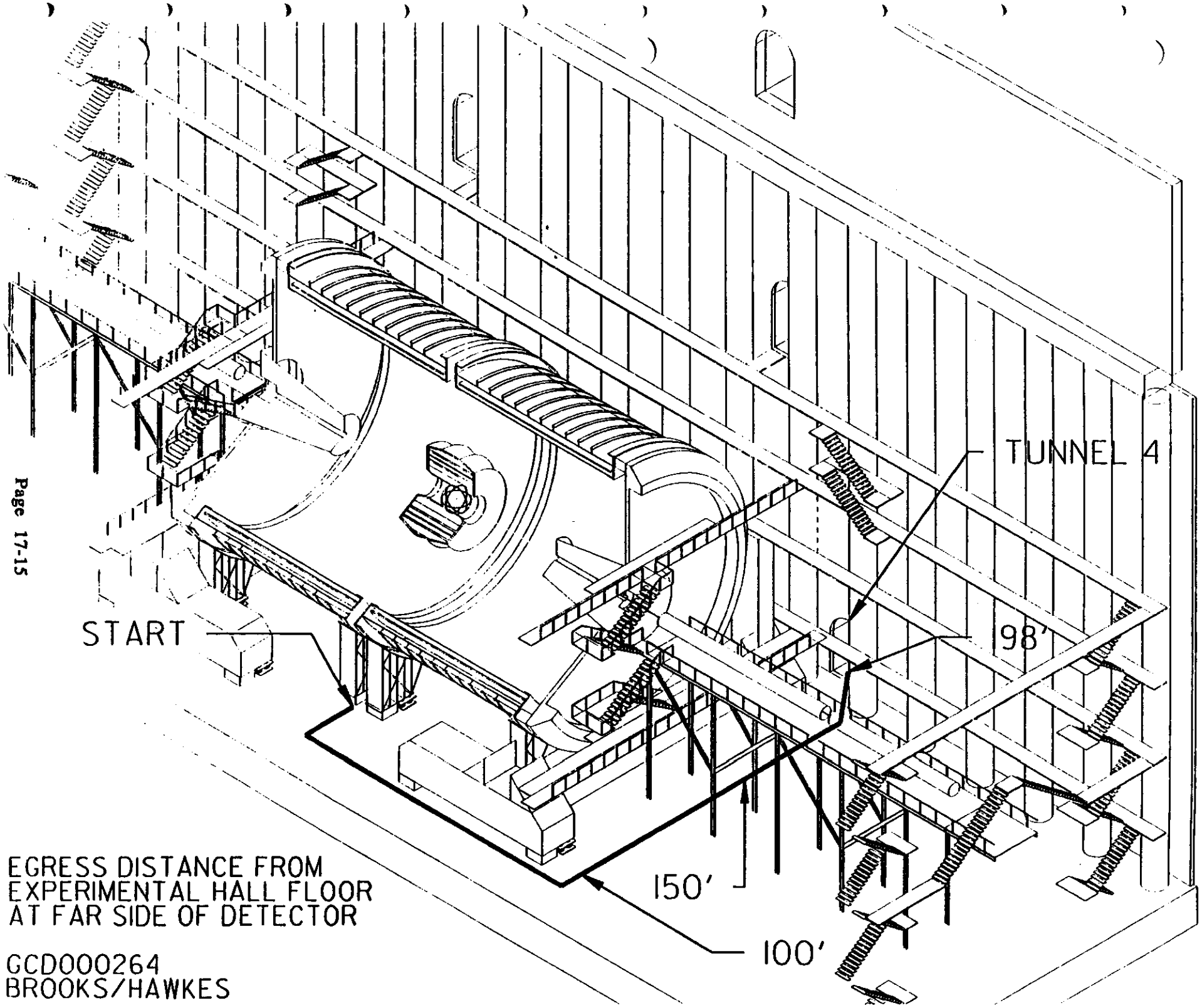
HAZARDOUS WASTE

Generation of mixed hazardous waste within the IR-5 site will be strictly limited. This requires that the use of lead within the fine hadronic calorimeter be scrutinized and minimized. Process gases which are released from the detector or U/G Hall must be quantively monitored for reporting to the Texas Dept. of Air Quality and the EPA. Radioactivated gases and air from within the detector can be vented to the U/G Hall and then recirculated in a closed ventilation system until the Argon, Krypton, Nitrogen, or Oxygen radioactive half-life limits are achieved. Calibration Hall dumps and targets must be carefully handled and disposed of as mixed waste. The boron-doped polyethylene neutron absorbing material within the detector must be treated as mixed waste, requiring strict disposal methods. If doped scintillating liquid is used within the hadronic barrel calorimeter, it would be treated as mixed waste also.



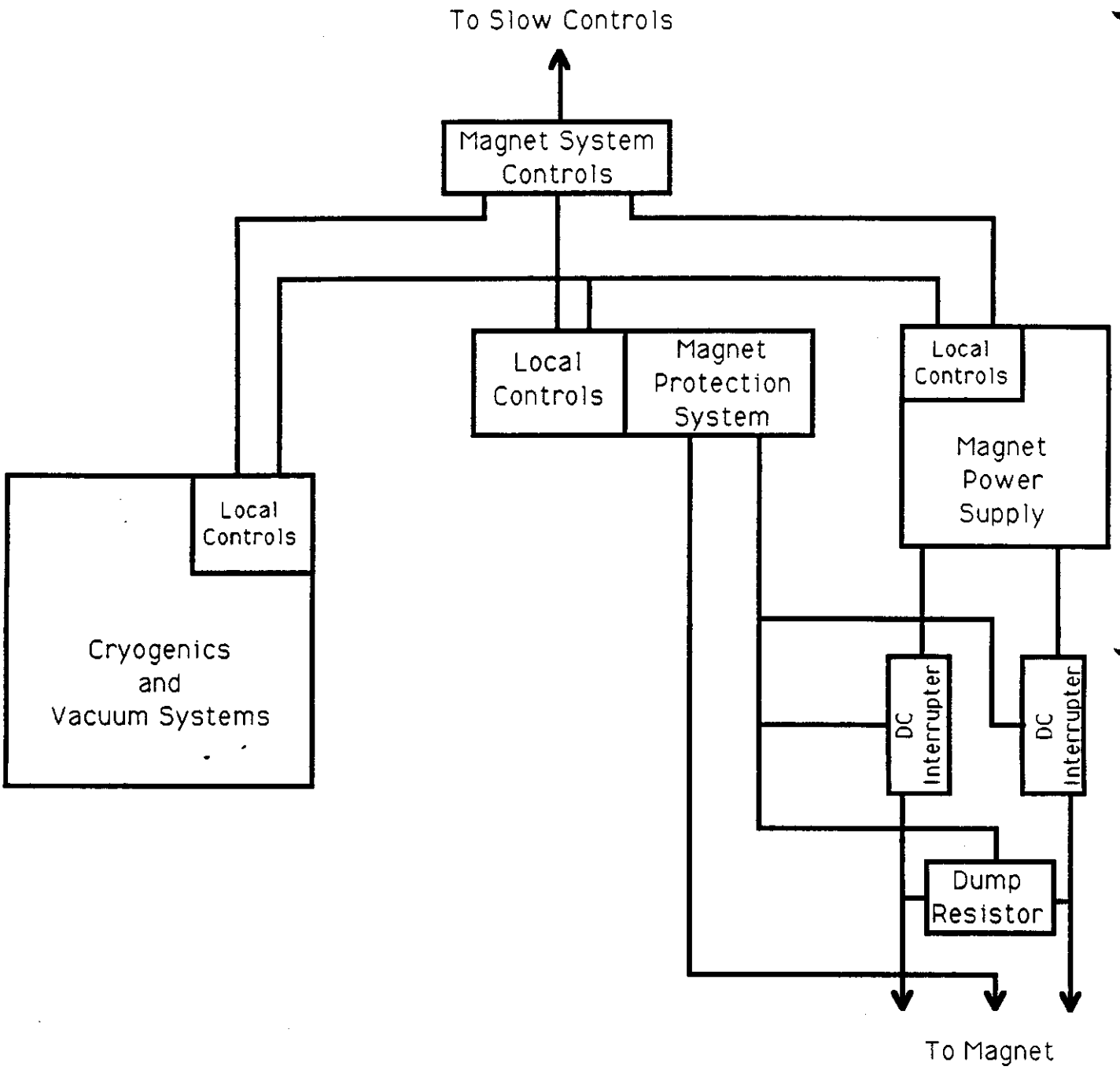
EGRESS DISTANCE FROM
INSIDE GEM DETECTOR

GCD0002
BROOKS/HAWKES

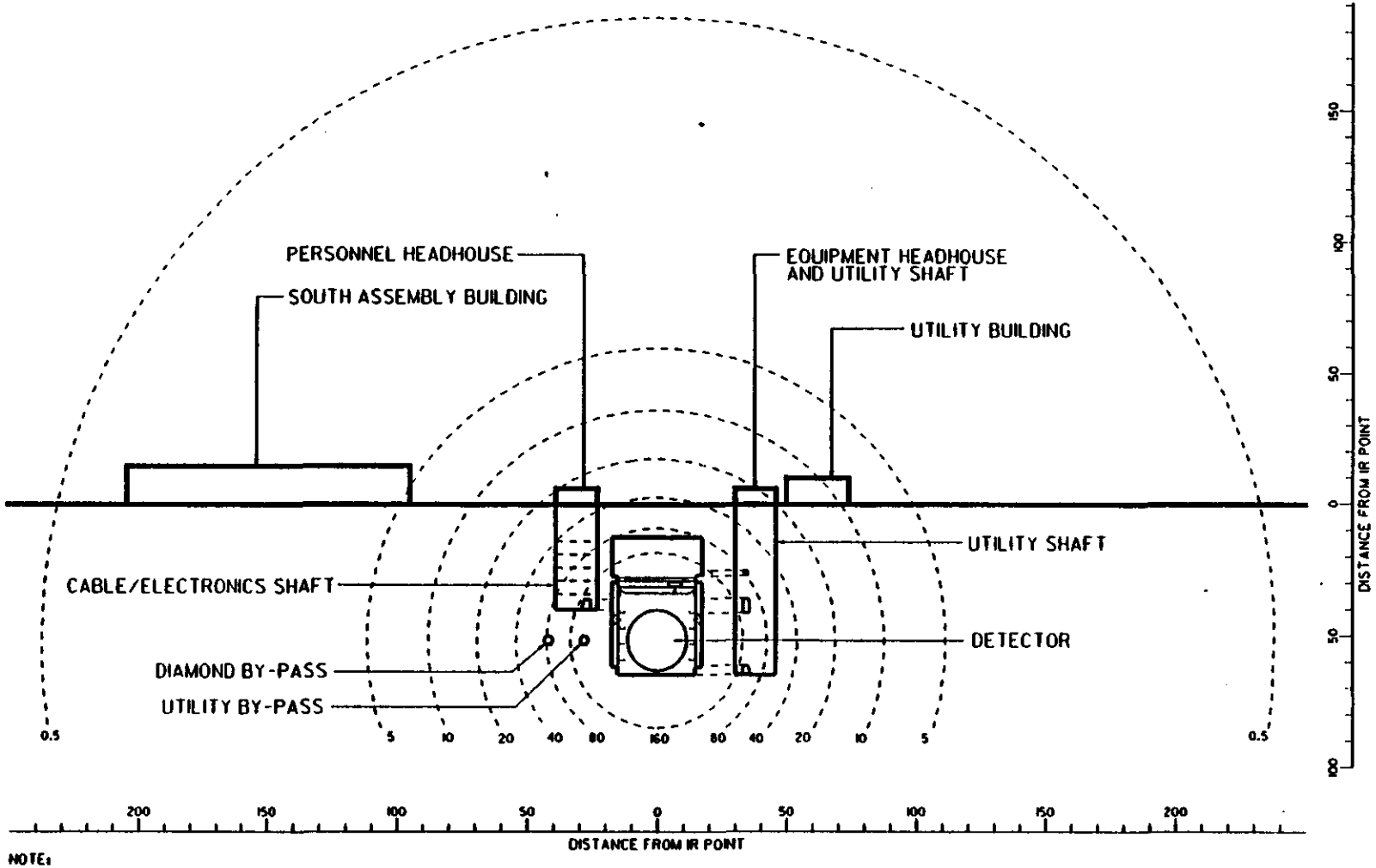


EGRESS DISTANCE FROM
EXPERIMENTAL HALL FLOOR
AT FAR SIDE OF DETECTOR

GCD000264
BROOKS/HAWKES



MAGNET CONTROL SYSTEM

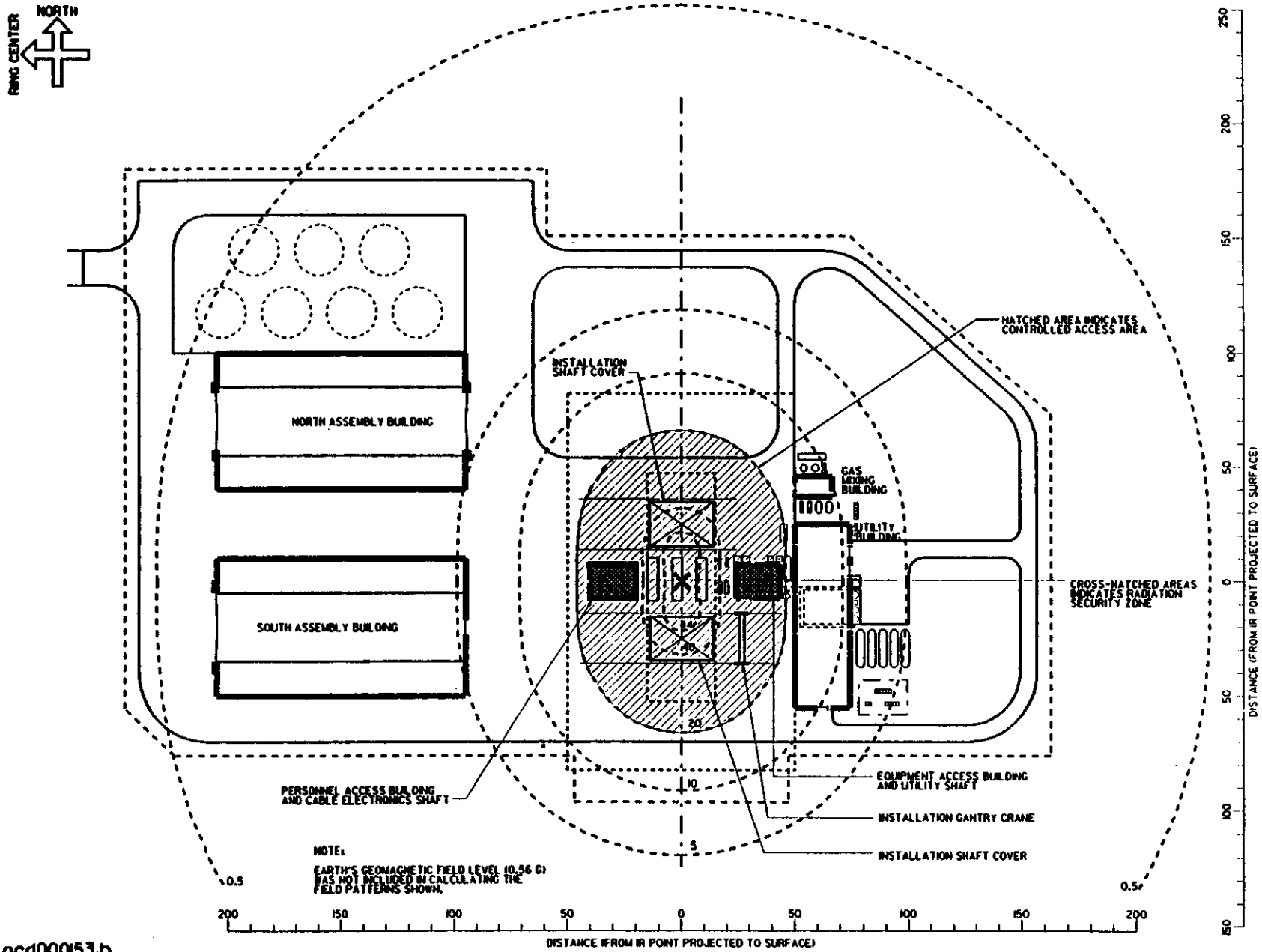


NOTE:

EARTH'S GEOMAGNETIC FIELD LEVEL (0.56 G) WAS NOT INCLUDED IN CALCULATING THE FIELD PATTERNS SHOWN.

GEM FRINGE MAGNETIC FIELD

GCD-000156.A
REF. FILE(S): GCD-000155
17 AUGUST 1992
RW/KH



gcd000153.b
REF. FILE: gcd000142.021
10 NOV 1992
RW/KH

IR-5 Magnetic Field Pattern Plan at Surface

18. SPECIFICATIONS

Working Draft

GEM Detector System Specification

DRAFT

1.0 SCOPE

This specification establishes the subsystem specifications and requirements for the Magnet, Tracker, Calorimeter and the Muon system per the following sections.

SPECIFICATIONS

Working Draft

GEM Detector
Magnet Subsystem Specification

GEM DETECTOR MAGNET SUBSYSTEMSPECIFICATION

1 SCOPE

This specification establishes the technical requirements for the Super Conducting Super Collider GEM Detector Magnet Subsystem. Included in the specification are a summary of the magnet interfaces with other detector subsystems, magnet performance requirements and physical characteristics.

The GEM Detector, Figure 1, will observe gammas (photons) and electrons with a highly accurate electromagnetic calorimeter. The GEM design for muon measurement relies on tracking in a magnetic field outside of the calorimeter. High precision on the muon momentum is attained by measuring the curvature over a 5 m track length in a magnetic volume. This design philosophy leads to the need for a very large electromagnet.

The GEM Magnet subsystem must provide a stable, well-characterized, large-volume magnetic field to support the operation of the other detector subsystems. The central magnetic field strength, 0.8T, is modest in comparison with other large superconducting magnet systems. Because of its unusually large size, the magnet has a relatively high stored energy - 2.5GJ at full charge. Since this energy could cause significant damage if deposited in any component in an uncontrolled manner, excellent magnet stability and protection are required. In addition, the large size of the magnet necessitates field-fabrication and field-assembly of many large and heavy components, some of which need to be clean, well-aligned, and mobile.

The Magnet subsystem is an intrigal part of the GEM detector as shown in figure 1.

Figure 1. GEM Detector

2 APPLICABLE DOCUMENTS

2.1 GENERAL

The following documents form a part of this specification to the extent specified herein. If conflict between the documents referenced herein and the contents of this specification, the contents of this specification shall be considered a superseding requirement. In those instances where a document is referenced for use as a guide, the Contractor must provide his own interpretation and verify proper applicability before use.

2.2 SSC LABORATORY DOCUMENTS

a.	TBD	GEM Detector Magnet Interface Control Document
b.	SSC-SR-1043	Field Measurements and Analysis of Underground Vibrations at the SSC Site
c.	P40-000003	SSCL Standard, Part Numbering System
d.	P40-000004	SSCL Standard, Engineering Drawing Format
e.	P40-000013	SSCL Guideline 4.4, Engineering Drawings
f.	P40-000017	SSCL Standard, Engineering Drawing Preparation
g.	P40-000030	SSCL Practice, Parts List Preparation
h.	P40-000001	SSCL Document Numbering Procedure
i.	P40-000070	Draft SSCL Guideline 3.21.1, Mechanical Engineering
j.	P40-000137	Identification marking of Parts & Assembly

2.3 NON-SSC LABORATORY DOCUMENTS

a.	American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code	
b.	ASME B31.3	Chemical Plant and Petroleum Refinery Piping
c.	American Institute of Steel Construction (AISC); Codes of	
d.	MIL-STD-454	Standard General Requirements for Electronic Equipment
e.	ANSI C84.1	Electrical Power Systems and Equipment
f.	ANSI/IEEE 241-1983	Standard Specifications of Testing Concrete
g.	NFPA-70	National Electric Code
h.	DOE Order 5481.1B	Safety Analysis & Review System

i.	ANSI B30	Hoisting & Rigging of Critical Components
j.	IEEE	Large Rotating Electrical Apparatus Test
k.	ASME B31.1	Power Piping
l.	Section 3.7B Seismic Criteria,	Comanche Peak Steam Electric Station, Final Safety Analysis Report
m.	FED-STD-595	Colors
n.	MIL-Q-9858A	Quality Assurance
o.	LLNL-MEL-92-001810	SSCL GEM Vacuum Vessel

3 REQUIREMENTS

3.1 SYSTEM DEFINITION

3.1.1 General Description

The coil assemblies (magnet halves) consist of the cold mass subassemblies, the vacuum vessels and the internal cryostat components which include, the thermal radiation shields, the cold-mass supports, the cryogenic current leads, and the internal cryogenic systems. The two coil assemblies are stand-alone objects, capable of supporting themselves against gravity and seismic loads, holding vacuum, and moving in limited ways. With the addition of auxiliary systems (vacuum, cryogenics, and power), the coil assemblies can be operated a magnet.

Since the magnet subsystem itself does not perform a physics measurement, as do most other subsystems, the overall physics performance requirement on it is to properly support the operation of the other subsystems. The primary physics requirement placed on the magnet subsystem is to provide the magnetic field for appropriate operation of the muon subsystem. It must also provide the field required by the central tracker, but this requirement does not drive the design in any significant way.

The general configuration of the GEM magnet will be a large solenoid, with magnetic-field shaping in the forward regions. All other GEM detector subsystems present at startup will be placed inside the magnet. The return field of the magnet is free in the sense that it does not have a local flux return, such as an iron barrel. Overall, the working inner volume of the magnet will be 10.0 m inner diameter, by 30.8 m length (measured between the ends of the magnet vacuum vessels).

The coil assembly, which includes the cold mass subassemblies, internal cryostat components, and vacuum vessels, will be split at the axial midplane, and the two halves will have the capability to be moved apart axially, to provide access to the internal detector hardware. The central detectors (calorimeters and tracker) will be supported by a structure which is physically independent of the coil assemblies and is capable of remaining in place and stable even when both coil assemblies are moved away axially for internal access. When the coil assemblies are in operating position, the (compressive) axial magnetic loads between the two assemblies will be reacted on separate structures, which penetrate through the central detector support. The compressive loads will not be transferred to the central detector support itself.

The magnet subsystem shall provide structural support for the muon subsystem. The muon subsystem will provide the space-frame structures necessary to support and align the detectors to the required accuracy, and the magnet subsystem shall provide discreet mounting points for these structures. The mounting points shall be structurally stable, and able to accept the loads applied by the muon subsystem.

As a design goal, the overall magnet configuration should allow for possible future upgrade of the muon subsystem. Specifically, an annular space around the outside of the magnet vessels shall be reserved for the addition of an external superlayer of muon detectors.

To facilitate maintenance and repair on the other detector subsystems, the magnet shall be charged or discharged (under normal circumstances) in a maximum of 8 hours; at the end of such a normal discharge cycle, the magnet will be ready for immediate re-charging. This allows field-free access to components outside the working volume of the magnet with two-day turnaround. In an emergency situation, the magnet shall be capable of a 5 minute discharge without sustaining any damage. Following an emergency discharge, the magnet is not required to be capable of immediate recharge, and may require a longer period to cool down before charging.

3.1.2 Subsystem Diagrams

A functional schematic of the magnet subsystem is shown in Figure 2. The entire magnet system is designed around the superconducting coil, which operates at a temperature of approximately 4.5°K. When the design current is flowing in the coil, the required magnetic field is produced inside the central field region defined herein. All of the magnet subsystems are involved in establishing and maintaining this condition or in protecting the coil against damage in the event of a fault condition.

The coil is suspended inside an evacuated vessel, with heat shields and insulation designed to minimize heat flow to the coil and liquid helium. The GEM Detector layout, Figure 3, shows the major dimensions and the relationship between the magnet and other detector subsystems.

3.1.3 Magnet Interfaces

The magnet interfaces with various systems/components as summarized in the following paragraphs. The magnet interfaces are defined in the Magnet Technical Design Report (TDR).

3.1.3.1 Magnet/Central Tracker Interface

The main requirements imposed on the magnet by the interface with the central tracker involve magnetic field, physical support, and access for installation and maintenance. The tracker has modest magnetic-field requirements for proper operation; the field is required to be high as possible, and uniform throughout the tracker volume to 0.5%. The central membrane support subsystem must physically support the tracker's weight, but it does this through the calorimeter subsystem. The central detector support must provide the necessary stability for proper long-term operation of the tracker, and this requirement will drive the design of the support. The tracker will be the last detector subsystem to be available for

Figure 2. Magnet System Functional Schematic

Figure 3. GEM Detector Layout

installation, and the magnet subsystem design shall accommodate this installation. Furthermore, the magnet must allow some access for possible repair of the tracker, on a long, (3 month) turn-around basis. These requirements were key in developing the requirement for the split/mobile magnet halves.

3.1.3.2 Magnet/Calorimeter Interface

The calorimeter interface provides requirements which primarily affect the design of the central detector support. The weight of the calorimeter and the required stability are the key factors in this area. A potential fault mode for the LiAr calorimeter is a cryogenic spill, and this fault mode will affect the magnet inner vessel. The magnet shall withstand this calorimeter fault without significant damage.

3.1.3.3 Magnet/Muon Interface

This interface provides requirements on the magnetic field, most of which result from consideration of muon performance. The structural stability of the muon mounting points is required to meet the alignment requirements of the muon detector.

3.1.3.4 Magnet/Forward Field Shaper Interface

The magnetic force exerted on the Forward Field Shaper (FFS) is transferred to the vacuum vessel through the FFS support structure. There are eight points of load transfer from the support structure to the vacuum vessel. These interfaces at the vessel are landing pads located at each of the eight longeron stiffeners.

3.1.3.5 Magnet/Facility Interface

The magnet interfaces extensively with the above-ground and underground facilities at SSCL. Since design of the facilities is in progress, the magnet subsystem must accept most of the requirements as imposed on it by the facilities design. This is the case particularly for the above ground assembly buildings. The magnet subsystem provided rough requirements to the facilities design. However, the overall requirement on the magnet subsystem is to fit into the facilities available to it.

3.1.3.6 Magnet/GEM Control System Interface

3.1.4 Major Components

The GEM Magnet System consists of two identical magnet halves or coil assemblies. Each magnet half is composed the Coil Subassembly, the Vacuum Vessel, and the Forward Field Shaper (FFS). The Central Detector Support (CDS), the Cryogenic System and the Power/Protection System are common to the two magnet halves. Major elements of each component are defined in the following paragraphs.

3.1.4.1 Coil Subassembly

The superconducting coils of the GEM Coil Subassembly provide the magnetic field necessary for the high precision measurement of muon momentum. The GEM Coil Subassembly is composed of twelve identical coil modules that are joined together to become a monolithic structure. Each 19 m diameter coil module consists of the coil form , a approximately 1140 meters of cable-in-conduit (CIC) conductor. The coil modules will be mated electrically and

mechanically with resistive, helium cooled joints. The coil form consists of an outer wall, end flanges, ground plain insulation, and liquid helium cooling tubes. Two identical Coil Subassemblies are required for the GEM magnet.

3.1.4.2 Vacuum Vessel

The vacuum vessels contains the following principal elements:

a Internal Cryogenic Piping (includes 4.35 K LHe, and 80 K LN)

b. 80 K Thermal Shields

c. Thermal Insulation

d. Coil Subassembly Suspension System

e. Annular Vacuum Shell

f. External Support/Transportation

It serves to support the coil subassembly accurately and reliably within the vacuum vessel, provides all required internal cryogenic piping, and insulates the cold mass from heat radiated and conducted from the environment. It must function reliably during magnet movement and handling, normal magnet operation, quenches, and other upset conditions. The external support saddles shall provide the transportation to separate the installed coil assemblies and to move them axially to their respective ends of the experimental hall to allow access to the internal detector components. The GEM Magnet System requires two identical vacuum vessels.

3.1.4.3 Cryogenic System

The GEM Magnet is cooled by liquid helium (LHe) which flows by natural convection in a thermosyphon loop which couples a large storage dewar located at the ground surface with the magnet about 50 m below. A second flow circuit supplies a small flow of supercritical helium, cooled to the temperature of the thermosyphon loop, to the conductor conduit for the purpose of enhancing the conductor stability, cooling the conductor splices and cooling the current leads. The interface between the cryogenic system and the rest of the magnet subsystem is defined to be the outer surface of the vacuum vessel.

3.1.4.4 Magnet Power Supply and Protection Systems

The Magnet Power Supply and Protection Systems supply a controlled DC current to the magnet, detect magnet quenches and dissipate the energy stored in the magnet during emergency dump situations. The Power Supply System consists of a 20 VDC, 55 KA power supply , high current buswork and local controls. The Protection System consists of 55 KA current interrupters, dump resistor, magnet quench detection and diagnostic monitors (sensors), and local controls. The interface between the power/protection system is defined to be at the connection of the warm current busses to the vapor-cooled leads at the vacuum vessel outer surface.

3.1.4.5 Forward Field Shaper/Support

The Forward Field Shapers (FFS's) are large steel cones used to shape the magnetic field inside the GEM detector. Field calculations determine the size and form of the forward field shaper, as well as its location relative to the vacuum vessel. The GEM detector has two identical Forward Field Shapers (FFS). Each FFS is held in space by a support structure which butts to the end of the vacuum vessel. Each FFS weighs approximately 900 mg tons. Each support structure weighs an additional 900 mg tons. The FFS is an approximately 8 meters long truncated solid cone varying in diameter from 3.1 to 5 meters. Each FFS assembly, including the support structure, is independently mounted to the experimental hall floor, at specially reinforced mounting locations. For initial installation, and ongoing maintenance and repair, each assembly can be lifted and translated to the ends of the experimental hall.

3.1.4.6 Central Detector Support

The Central Detector Support (CDS) provides dead load support and seismic stability for the central detectors. It is a free standing structure with a coil assembly (magnet half) on either side. The magnet axial loads are reacted via columns through holes in the CDS or on bearing pads between the coil assemblies. In the present design, the CDS is composed of two annular membranes, separated by radial gussets which connect them. Each membrane weighs about 360 mg tons, is 0.1 m thick, and 21.8 m in diameter. The total structure weighs approximately 1800 mg tons. The Central Detector Support with the detectors installed weighs approximately 4500 mg tons.

3.1.4.7 Magnet System Control

3.2 CHARACTERISTICS

3.2.1 Performance

3.2.1.1 Magnetic Field

Overall, the field shall be roughly solenoidal, with some shaping in the forward direction. The magnetic field shall be 0.8T and uniform to 0.5% in the Tracker volume (an area .7m in dia. and 2.8 m long centered on the interaction point). Since the field is provided by two axially-separated coil halves, some non-uniformity will occur at large radii near the z=0 midplane; this non-uniformity shall be less than that produced by a 1.5 m gap between the two coil subassemblies.

In the forward region, the required field shape is presently defined by the shape and location of the Forward Field Shaper iron which results in acceptable muon subsystem resolution. The required field shape is produced by a frustum of a cone extending from z=10 m to z=18 m, with an included angle of 17.4 degrees;

The magnetic field and its distribution shall be known at all times during operation to high accuracy to facilitate data reduction. The field magnitude and distribution shall be known at all times during operation to an accuracy of 0.1%. T accuracy may be attained by a combination of detailed field-mapping before interior detectors are installed and continuous monitoring at numerous locations within the working volume.

3.2.1.2 Superconducting Coil Stability

The cable-in-conduit (CIC) conductor is stable against sudden disturbances. Coils made with CIC conductors are distinguished by the lack of training often found in coils made with other conductor types. This high stability is due to a) the high heat capacity of the helium which is in intimate contact with the superconducting wires, and b) the very large heat transfer surface area from the wire to the helium. The most likely source of disturbance in the GEM Magnet is due to some mechanical event occurring external to the CIC. In this case, the superconducting strands are buffered from this disturbance energy by the helium in the conduit. The energy margin then is given by the enthalpy of the helium and the wire between the operating temperature of 4.5K and the current sharing temperature. This is dominated by the helium enthalpy which is 1-2 orders of magnitude greater than all the other conductor components. For such an external perturbation event, the time scale is practically irrelevant since all the helium must be brought up to the current sharing temperature before a quench will occur.

Other types of disturbances internal to the cable can also occur, although these are very much less likely in the GEM operation. One of these could be AC loss, but only during coil charge or discharge. Since the nominal charge time is 8 hours, the loss energy will be removed on a quasi-steady state basis by the thermal-siphon loop. Another possible disturbance source could be sudden wire motion within the cable. Measurements of the mechanical hysteresis have been performed at 4.2K on a large, similar cable. Those results indicate that, even if all this energy was deposited suddenly in the cable, the energy margin is at least one order of magnitude greater.

For internal disturbances the stability margin is defined as the largest sudden energy deposition to the conductor from which it can still recover the superconducting state. The stability margin is not necessarily equal to the enthalpy margin of the helium because the helium is only effective if the energy dissipated directly in the cable can be transferred effectively to the fluid. This depends on the power balance between heat generation, due primarily to Joule heating in the strand, ? the convective heat flux to the supercritical helium. The GEM conductor is designed to insure that this energy balance always satisfied, i.e. at normal operating conditions the helium enthalpy is used to maximum advantage. This is

accomplished by insuring that the limiting current between being well-cooled or ill-cooled is above the operating current. The limiting current is defined as I_{lim} where,

$$I_{lim} = \frac{hpA_{cu}(T_c - T_b)}{\rho_{cu}}$$

where,

h = heat transfer coefficient (W/m^2-K)

p = cooled perimeter (m)

A_{cu} = area of copper stabilizer in cable

ρ_{cu} = copper stabilizer resistivity (Ω-m)

T_c = critical temperature (K)

T_b = initial helium temperature (K).

The stability results for the main coil modules are summarized as follows:

Energy margin for external disturbances 315 J/m

Energy margin for internal disturbances 250 J/m

By comparison the energy margins of indirectly cooled, high purity aluminum conductors typical of those used for other large solenoidal detector magnets (e.g.., CDF, ALEPH, DELPHI) is between one and two orders of magnitude lower than that of the CIC. This implies that conductor motion of ~1 mm would quench the magnet.

The joints between the coil modules have been designed to be cryostable. This is done primarily by using large copper blocks with integral cooling channels to lower the Joule heating below the steady state heat flux. With a cryostable joint design, this normally resistive portion of the coil circuit is not a weak link, but actually more stable than the bulk of the coil. This can be achieved with a moderate flow of 0.5 g/s of supercritical helium at 4.5 K to independently remove the 1.25 W generated at each joint.

3.2.1.3 Coil Protection

The Magnet Assembly shall be protected against conductor overheating, voltage breakdown and structural damage during quenches, cryogenic system failures or other off-normal conditions.

3.2.1.4 Charging Time

The time required to charge the magnet central field from 0 to 0.8 Tesla shall be kept to a minimum and shall be no greater than 8 hours. This shall include the effects of eddy current heating during charging.

3.2.1.5 Discharge Time

The time required for normal (not emergency) discharge of the magnetic field from 0.8 to 0 Tesla shall be kept to a minimum and shall be no greater than 8 hours. The effects of eddy current heating during discharging shall be considered and included in the design. Following a normal discharge, the magnet shall be ready for immediate charging.

In an emergency situation, the time required to discharge the magnet from 0.8 to 0.04T shall be no more than 300 sec (implying a time constant, τ, of less than or equal to 100 sec for an exponential discharge). For this discharge, the

maximum lead-to-lead voltage in the magnet DC circuit shall be ≤ 1kV. Following an emergency discharge, the magnet is not required to be capable of immediately initiating a charge.

3.2.1.6 System Shut Down

The magnet system shall be capable of controlled shutdown in the following modes:

a. Normal discharge of the coil, as defined in Paragraph 3.2.1.5.

b. The magnet system shall be capable of operating normally for 12 hours without an external supply of liquid helium, other than the storage dewar, to allow for shutdown of the Helium Refrigerator for maintenance or repair.

c. Automatic emergency discharge of the magnet, initiated by the Magnet Protection System, to protect the coil from damage (ref. Paragraph 3.2.1.3) or in response to some other critical system failure.

d. Operator initiated emergency discharge of the magnet. Procedures shall be defined and the necessary controls provided for rapid, safe system shutdown in response to emergency situations. Their procedures shall be developed considering all SSCL requirements in addition to the magnet requirements.

3.2.1.7 Duty Cycle

Under normal circumstances, the magnet shall operate at 100% capacity continuously, 24 hours per day, for 9 months, with 99% availability.

3.2.1.8 Lifetime

The design lifetime of the magnet subsystem shall be 20 years. During this time period, the magnet shall be capable of 100 thermal cycles and 200 vacuum cycles. It shall also be capable of 200 normal charge/discharge cycles, including emergency discharge cycles. These requirements shall be incorporated into the component designs for fatigue and fracture-toughness. The operating cycles are defined as follows.

a. A vacuum cycle begins with the vacuum vessel at ambient pressure, and ends when the vessel is returned to ambient pressure after evacuation.

b. A thermal cycle begins with the magnet evacuated and at ambient temperature, and ends when the magnet is warmed from operating temperature to ambient. This may be in preparation for maintenance or repair of the accelerator system (not necessarily the magnet itself). The magnet may remain at 293 K for an extended time depending upon the nature of the maintenance.

c. A magnetic charge/discharge cycle occurs when the magnet is excited from a low field level (typically 0 Tesla) to the operating level (typically 0.8 Tesla). A magnetic cycle is completed when the excitation of the magnet is reduced to a low field level.

d. An emergency discharge cycle occurs when the magnet is discharged from the operating field level (approximately 0.8T) to zero field.

3.2.1.9 Alignment

The magnetic field must be aligned to the collider, and its position must be well-known and stable. Because magnet components also serve as mounting bases for the other detector subsystems, the physical positions of the vacuum vessels, FFS's, and CDS must also be well-known and stable. Separate requirements are specified for the placement accuracy, the stability, and the drift. These requirements will be frequently updated, and will be controlled through Interface Control Documents. The current specifications are listed below.

Magnet components shall be positioned in the underground hall by measuring the position of alignment fiducials on the magnet components with respect to the position of alignment fiducials mounted in the hall. Misalignment of the actual

positions of alignment fiducials on coil halves, FFS's, and CDS shall be less than 10 mm (radially or axially) with respect to the ideal position as measured from the hall monuments. It shall be assumed that the actual position of any component can be measured with an accuracy of 1.0mm at best, and this measurement inaccuracy is not a part of the 10 mm misalignment allowance. The position of alignment fiducials on magnet components shall be known, with respect to the sensitive elements (coils) with a total error of less than 20mm radially or axially.

Coil halves and FFS's shall exhibit uncontrolled short-term motion relative to the beamline of less than 0.02mm radially, 0.01mm azimuthally, and 0.02mm axially. The CDS shall exhibit uncontrolled short-term motion relative to the beamline of less than 0.01mm radially, 0.01mm azimuthally, and 0.01mm axially. This requirement relates primarily to vibration and thermal motions which vary on a time scale of less than a minute..

Long-term motion (drift) of the coil halves and the FFS with respect to the hall fiducials shall be less than 1mm radially, azimuthally, and axially between realignments. Long-term motion (drift) of the CDS with respect to the hall fiducials shall be less than 1mm radially, 1mm azimuthally, and 5mm axially between realignments.

3.2.1.10 Eddy Current Effects

The Coil Assembly shall not be damaged electrically or structurally by a magnetic field collapse occurring during an emergency discharge. Internal heating due to a normal charge or discharge shall not cause the magnet to quench spontaneously.

3.2.1.11 Grounding Requirements

All metallic surfaces (excluding multilayer insulation) not requiring electrical isolation, shall be attached with low resistance techniques and be at the ground potential of the shell. The connections shall not create any undesired ground loops that may impact operation, testing or safety.

3.2.1.12 Cryogenic Piping

The coil assembly design shall be such that the heat load to the cold mass is less than 1200 W (total for both cold mass assemblies, not including VCL's). The design of the thermal radiation shields shall be such that the heat load to the thermal radiation shield shall be less than 4 w/m^2.

Design Pressure

All cryogenic piping will be designed to withstand a leak checking pressure of at least 2.0 MPa while at room temperature. Working pressures for magnet operation are tabulated in Table 1.

TABLE 1

CRYOGEN WORKING PRESSURE AT EXPERIMENTAL HALL FLOOR

	P, Atm., abs.
Liquid nitrogen	6.2[1]
Liquid helium thermosyphon	2.1[2]
Helium forced flow system	3.8 - 4.8
Quench pressure (all cryogenic piping)	15
Quench pressure (conductor)	340

Test Pressure

Test pressure will be 1.5 times the maximum operating pressure.

Flow Capacity

The flow capacity of the liquid helium thermosyphon system shall be such as to accommodate a heat load to the cold mass of 1600 W while maintaining the cold mass temperature within 0.3 K of the liquid helium storage temperature.

The flow capacity of the forced flow system shall be such as to accommodate a flow of 13 g/s current lead flow with warm return plus 24 g/s total flow for conductor stabilization and splice cooling, with cold return to the storage dewar.

The mass flow rate of the liquid nitrogen system shall be sufficient to accept the design heat loads, and maintain the shields between 77 k and 89 k.

Shielding and Insulation

The helium supply and cold returns for the thermosyphon and forced flow systems shall be shielded with liquid nitrogen temperature shields. Multilayer insulation will be used between the outer vacuum jacket and LN shield and between the LN shield and inner line. These lines shall not require continuous pumping to maintain insulating vacuum.

3.2.1.13 Changes in Parameters

The magnet shall be designed so that during its useful life for the operating cycles defined in 3.2.1.7, 3.2.1.8 and the expected transportation environments:

a. The magnet shall exhibit no damage or net shifting of component positions as the result of a thermal cycle.

b. The leakage current from coil to ground shall not exceed twice the original value while subjected to the specified environmental conditions.

---

[1] Hydrostatic head plus 1.2 atm storage pressure. Increase for higher storage pressure and/or pump head

[2] Hydrostatic head plus 1.3 atm storage pressure

3.2.2 Physical Characteristics

3.2.2.1 Size

The size/envelope of the magnet system major components described in paragraph 3.1.4 are to be determined by the subcontractor and defined in his design. Approximate sizes are shown in the drawing package provided..

3.2.2.2 Weight

The approximate weight of the components described in paragraph 3.1.4 are shown below. The final weight of the magnet system major components shall be refined by the subcontractor and defined in the design.

COMPONENT	ESTIMATED WEIGHT (mg)
Coil Form Wall	15
Compression Flanges	14
Conductor	11
Turn Insulation	2
Ground Insulation	2
Subtotal Coil Subassy Module(1)	44
Subtotal Coil Subassembly (12)	528
Vacuum Vessel - Outer (per half)	544
Vacuum Vessel - Inner (per half)	363
Radiation Shields (per half)	23
Coil Subassembly Supports (per half)	9
Subtotal Magnet Half	1467
Total Magnet	2934

3.2.2.3 Helium Inventory

Liquid Helium	60,000 L
Gaseous Helium	2500 m^3 @ 18 Atmospheres

3.2.2.4 Power

Conventional power and technical power will conform to, ANSI C84.1 and ANSI/IEEE 241-1983.

?0 volt power will be 1 phase, separate ground wire, 120VAC, 60 Hz.

208 volt power will be 3 phase,4 wire, 208VAC, 60 Hz.

277 volt power will be 1 phase, separate ground wire, 277VAC, 60 Hz.

480 volt power will be 3 phase,4 wire, 480VAC, 60 Hz.

4160 volt power will be 3 phase,3 or 4 wire, 4160VAC, 60 Hz.

3.2.3 Reliability

The magnet system shall have adequate design margins to ensure the capability to operate continuously or intermittently without failure or degradation of performance over the magnet useful life. The magnet shall exhibit no wear or fatigue type failures when exposed to the moving, storage, installation or maintenance, misalignments, pre-operating and operating environments and the specified number and types of cycles (paragraph 3.2.1.8). A total of 1130 hours of unscheduled maintenance and 3130 hours of scheduled maintenance and upgrades are planned per year for the SSC collider and accelerator systems. However, routine maintenance of the GEM magnet subsystem shall not require the magnet to be discharged for a period exceeding 14 hours at any one time, not including the charge and discharge time.

3.2.3.1 Electrical Connections and Cabling

All electrical connections and cabling shall be joined in a reliable and inspectable manner and secured and adequately protected from degradation due to radiation exposure, thermal, magnetic or quench hydraulic induced movements, and assembly or maintenance procedures. Cabling shall be routed to avoid the contact with rough surfaces and adequately protected against chafing. Termination of wires shall be in a manner to prevent loosening or degradation. Wires to be connected during magnet installation shall be provided with a permanent unique identification.

3.2.4 Maintainability

The magnet system shall provide for:

a. Roll back of each of the two coil assemblies (magnet halves) in 144 hours (after the collider quadrupoles and beam pipes have been removed) to allow access to the internal detector components.

b. Reinstallation of each of the two coil assemblies (magnet halves) in 264 hours (this includes floor settling and leveling but does not include external systems reconnection).

c. External systems reconnection in 72 hours.

d. Interchangeability of assemblies and equipment elements (if any) that are designed for removal and replacement as the normal corrective maintenance action .

e. Standardization and simplicity of test equipment and its use.

f. Accessibility for in-place maintenance and inspection consistent with the design constraints, and tools and test equipment.

g. Capability of being repaired by skilled/semi-skilled technicians possessing magnet specific training, working under an experienced supervisor.

h. Minor periodic realignment in 48 hours while cold and installed in the experimental hall.

3.2.5 Environmental Conditions

3.2.5.1 Natural Environments

The magnet shall meet the performance requirements of 3.2.1 during and after exposure to the following operating and pre-operating (moving/handling, storage and installation) environments. Some of these steps will be environmentally controlled, others will not.

3.2.5.1.1 Temperature

Operating Ambient Temperature: 23 ° ± 1 °C

Pre-Operating Temperatures: 12 ° C

3.2.5.1.2 Humidity

The relative humidity environments shall be as follows:

a. Operating: 45% ± 5%

b. Pre-Operating:10% to 98%

The superconducting coil subassemblies shall be protected during manufacturing, installation, pre-operating and operating conditions to prevent degradation due to humidity. Other oxidizing components shall be protected from rusting.

3.2.5.1.3 Foreign Debris

During all phases of assembly, test, and installation the magnet components shall be protected from contamination or damage from foreign debris.

3.2.5.1.4 Corrosive Atmosphere

The magnet shall not degrade when exposed to the expected operating and pre-operating environments.

3.2.5.2 Induced Environments

The magnet shall meet the operational requirements of 3.2.1 during or after exposure to the following induced environments.

3.2.5.2.1 Radiation

The magnet shall be designed to withstand a radiation dose of 10 Mrad at the coil minimum radius.

3.2.5.2.2 Operating Magnetic Environment

The magnet and external components and subsystems shall be able to withstand and function nominally without permanent or transient structural, mechanical, or electrical detrimental degradation during exposure to the operationally induced magnetic environments resulting from compliance with all operating conditions specified herein.

3.2.5.2.3 Operating Thermal Environment

The magnet shall be able to withstand and function nominally without permanent or transient structural, mechanical, or electrical detrimental degradation during exposure to the operationally induced thermal environments resulting from all conditions specified herein.

3.2.5.2.4 Transportability/Handling

For movement of components to the receiving site at SSCL and for movement/handling of the magnet and assemblies or lowering into the experimental hall, the items shall be transportable without detrimental degradation in alignment or performance. During movement and handling for assembly or installation of the magnet into the experimental hall, mechanical restraints may be used to prevent misalignment or damage. Provisions shall be made for measuring environmental conditions (temperature, moisture and vibration) during transport and handling to verify that the magnet has not exceeded the vibration environment shown in 3.2.9, the shock loads of 3.2.9, the temperature limits of 3.2.5.1.1, or the humidity levels of 3.2.5.1.2.

3.2.5.2.5 Installation

The magnet shall be installed in the experimental hall and acceptance tests satisfactorily accomplished by the Subcontractor. The coil subassemblies shall then be separated and moved axially to the ends of the experimental hall to allow access for installation of internal detector components. The coil assemblies shall then be moved to their operating positions, re-connected to the auxiliary subsystems, and functionally tested, including field mapping.

3.2.5.2.6 Storage Protection and Airborne Pollutant

The magnet, and its components during assembly and installation, shall be protected from the temperature and humidity environments specified herein that may cause loss of prestress, creep, water absorption or other detrimental efforts.

3.2.5.2.7 Vibration Environment

The response of the magnet to vibrations present in the tunnel and experimental hall, as described in SSC-SR-1043, "Field Measurements and Analysis of Underground Vibrations at the SSC Site", shall not cause the alignment tolerances to be exceeded as specified herein. The suspension system shall be dampened where possible and shall not degrade or suffer fatigue that will reduce the capability of meeting the magnet life expectancy when subject to the tunnel vibrations over operating and non-operating temperature ranges, the vibrations during transportation, the vibrations due to cryogenic equipment operation and flow.

3.2.5.2.8 Shock Loads

Magnet assemblies and subassemblies shall be designed to handle static loads and seismic loads defined in section 3.2.11. Additional loads imposed by transportation and rigging shall be addressed by additional design enhancements and analysis to meet the factors of safety defined in section 3.3.6. Shock loads imposed by transportation and rigging shall be minimized and thoroughly analyzed in the design documentation.

3.2.5.2.9 Earthquake Loads

The magnet system shall be designed to earthquake criteria defined in section 3.7B, Seismic Criteria, of the Comanche Peak Steam Electric Station Final Safety Analysis Report. Comanche Peak is a power plant operated by Texas Utilities near the SSCL. This report defines design response spectra for both horizontal and vertical motion. Maximum ground accelerations are defined to be 0.08 vertical and 0.12 horizontal. Factors of safety under dynamic load for all systems shall be those defined in section 3.3.6.

3.3 DESIGN AND CONSTRUCTION

Level three drawings and associated lists shall be provided. P40-000001, P40-000004, P40-000013, P40-000017, P40-000030, and P40-000034 shall be used in the preparation of these documents.

3.3.1 Materials, Processes and Parts

The magnet shall be designed and fabricated to the intent of the ASME Boiler and Pressure Vessel Code (B&PVC) section VIII and ANSI/ASME B31.1 (Power Piping) and B31.3 (Chemical Plant and Refinery Piping Code) as applicable. Full compliance with material and fabrication requirements are required for all components of the magnet

assembly. Full material and manufacturing process documentation as required by the B&PVC and B31.3 shall be provided by the manufacturer. Non pressure subsystems shall be designed in accordance with the AISC Structural Design Code. Design of vacuum components shall conform to (B&PVC) design requirements unless otherwise approved by SSCL.

3.3.1.1 Corrosion Prevention and Control

All materials subject to corrosion will be protected by paint or grease. Direct externally exposed surface-to-surface contact between dissimilar metals shall be controlled according to the best available practices for corrosion prevention and control, and leak tightness. Preventive maintenance may be used on external magnet components to control corrosion.

3.3.1.2 Colors

External magnet assembly surfaces requiring protection shall be painted **TBD blue with 27769 white** lettering per FED-STD-595, Colors.

3.3.1.3 Materials to be Avoided

Only materials consistent with the radiation environment shall be used in magnet design and construction. Radiation sensitive materials such as PTFE shall not be used in the coil subassembly.

3.3.1.4 Weldments

All manufacturing and field weldments of pressure components shall be performed by a qualified welder and conform to the requirements of ASME B&PVC, section VIII and ANSI/ASME B31.3 as applicable. In addition all other manufacturing and field weldments shall be in according to the SSCL Mechanical Engineering Guideline, section 4.3.5 and LLNL-MEL-92-001810. The design shall accommodate the use of standard welding machines to allow for conformance to this requirement. Welding, and weld test and acceptance, shall be accomplished according to Process Control Procedures that have been reviewed and accepted by the SSC Laboratory. Flanges provided for repair/maintenance activities shall not be degraded by up to 6 such activities.

3.3.1.5 Soldering and Brazing

All soldered connections shall be designed and constructed as part of the joint contractor/SSCL development effort. Any soldering flux used shall be approved by the SSCL before use.

3.3.1.6 Coating, Potting, and Molding

Coating, potting and molding shall conform to the subcontractor's specifications, standards and drawings. These shall be submitted to SSCL for review prior to use.

3.3.1.7 Selection of Parts

Maximum use shall be made of standard or commercial parts.

3.3.2 Nameplates and Product Markings

Nameplates, product marking, serial and lot number markings, and all other identifying informational and certifying marking shall be according to the SSC Laboratory's direction.

3.3.3 Workmanship

The magnets shall be fabricated with repeatable field quality and quench characteristics and finished in a thoroughly workmanlike manner. Particular attention shall be given to freedom from blemishes, defects, burrs, sharp edges and foreign materials; saturation induction of magnetic materials; accuracy of dimensions; application of insulating material; care during assembly; radii of fillets; marking of parts; thoroughness of cleaning; quality of brazing, welding, riveting,

painting and wiring; alignment of parts; and specification tightness, prestress and torquing of fasteners. MIL-STD-454, Requirement 9, shall be used as a guide in applying workmanship standards.

3.3.4 Safety

Performance under this contract shall be consistent with the DOE policy of providing employment and a place of employment free from recognized occupational safety and health hazards by complying with the DOE Order 5481.1B and DOE prescribed OSHA standards. The magnet system shall be designed to comply with the National Electric Code (NFPA-70). Specific personnel hazards and/or special instructional markings of hardware shall be identified by the subcontractor and noted on applicable drawings or procedures. The subcontractor shall also identify and advise SSCL of personnel safety considerations, e.g., helium gas venting duct size, liquid air runoff hazard, high voltage hazard, etc., which should be incorporated into the facility which will house the magnet system. A failure modes and effects analysis identifying all potential safety hazards is required.

3.3.5 Human Performance/Human Engineering

The magnet design shall be consistent and compatible with the human capabilities required to build, test, install and repair the magnet in a repeatable, consistent, effective and safe manner. This includes tasks, tools, equipment, environment, personnel-equipment interfaces and other items required of this design. Mature, performance proven, standard, commercially available equipment shall not be modified without due consideration of safety to personnel or equipment.

3.3.6 Structural Integrity

3.3.6.1 Handling Attach Points

Rings, shackles and lugs shall be designed for a minimum yield factor of safety of 3.0 based on dead load (weights).

3.3.6.2 Allowable Stresses

Stresses in piping shall comply with ASME B31.1, Power Piping, or ASME B31.3, Chemical Plant and Refinery Piping, as applicable. Design of vacuum vessel and pressure vessel components shall conform to ASME Boiler and Pressure Vessel Code Section VIII, Division 1. In cases of combined loads or geometries not explicitly covered in these codes, adequate supporting calculations shall be performed to insure that allowable Code stresses are not exceeded. Stresses in non-pressure boundary components, such as auxiliary equipment support structure and brackets, shall conform to the AISC Specification for the Design, Fabrication, and Erection of Structure Steel for Buildings.

Load conditions on magnet subsystem components shall include, but shall not necessarily be limited to gravity, static preload, steady-state and transient magnetic, steady-state and transient thermal, steady-state and transient cryogenic fluid pressure, magnet quench, transportation and handling, and environmental loadings.

3.4 MAINTENANCE

The design shall be such that scheduled maintenance and repair shall not be required. Minimal preventive and corrective maintenance shall be required.

Working Draft

GEM Detector
Muon Subsystem Specification

DRAFT

GEM DETECTOR MUON SUBSYSTEM SPECIFICATION *

1 SCOPE *

This specification establishes the technical requirements for the Super Conducting Super Collider GEM Muon Subsystem. Included in the specification are a summary of the muon interfaces with other detector subsystems, performance requirements and physical characteristics.

The GEM Muon subsystem must provide an accurate, robust measurement system capable of measuring Sagitta in muon trajectories of up to 2mm, with an accuracy of 100 microns over an area of aprox. 10^3 M^2 within each event period of 1.4 microsecond. The subsystem will detect muons with 98% solid angle coverage and high precision measurements of the momenta by measuring the curvature over a 5 m track length in a magnetic volume. Muon trajectories will be reconstructed from $|\eta| \approx 0$ (90 degrees to the beam line) to 2.5 over most of the azimuth. The design goals for the momentum resolution of the system are for Pt = 500 Gev/c, $\delta Pt/pt \approx 5\%$ at $\eta \approx 0$ and $\approx 12\%$ for $\eta| \approx 2.5$.

The muon subsystem is and intigeral part of the GEM Detector as shown in figure 1-1.

Figure 1. GEM Detector

APPLICABLE DOCUMENTS *

2.1 GENERAL *

The following documents form a part of this specification to the extent specified herein. If conflict between the documents referenced herein and the contents of this specification, the contents of this specification shall be considered a superseding requirement. In those instances where a document is referenced for use as a guide, the Contractor must provide his own interpretation and verify proper applicability before use.

2.2 SSC LABORATORY DOCUMENTS

a.	TBD	GEM Detector Muon Interface Control Document
b.	SSC-SR-1043	Field Measurements and Analysis of Underground Vibrations at the SSC Site
c.	SSC 3.21.1	Mechanical Engineering Guideline
d.	SSC-MAG-M-7380	SSC Dipole Electrical Interconnect Assembly
e.	P40-000001 thru P40-0000034	SSCL Document Numbering Procedure
f.	P40-000137	Identification marking of Parts & Assembly

2.3 NON-SSC LABORATORY DOCUMENTS

a.	American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code	
b.	ASME B31.3	Chemical Plant and Petroleum Refinery Piping
c.	American Institute of Steel Construction (AISC); Codes of	
d.	MIL-STD-454	Standard General Requirements for Electronic Equipment
e.	ANSI C84.1	Electrical Power Systems and Equipment
f.	ANSI/IEEE 241-1983	Standard Specifications of Testing Concrete
g.	NFPA-70	National Electric Code
h.	DOE Order 5481.1B	Safety Analysis & Review System
i.	ANSI B30	Hoisting & Rigging of Critical Components
j.	IEEE	Large Rotating Electrical Apparatus Test
k.	ASME B31.1	Power Piping
l.		Section 3.7B Seismic Criteria, Commanche Peak Steam Electric Station, Final Safety Analysis Report
m.	FED-STD-595	Colors
n.	MIL-Q-9858A	Quality Assurance

3 REQUIREMENTS *

3.1 SYSTEM DEFINITION *

3.1.1 GENERAL DESCRIPTION *

To access this important physics, the GEM Muon System will furnish muon charge assignment, Levels 1 and 2 p_T trigger, beam crossing time marker, and muon momentum determination from a few GeV/c to a few TeV/c.

The muon system is arranged into two regions, the barrel region and the endcap region. The barrel region lies between a large, open solenoidal magnet with an air flux return and a calorimeter that surrounds the IP (Interaction Point). The endcap region covers an area between the field shaper and intersects with the barrel region. Field shapers will be placed along the central axis of the magnet to create a radial component of the B-field, thereby increasing the bend power at small angles. Multiple layers of chambers will be required with exacting spatial resolutions and systematic alignment to reach the desired momentum resolution. A Pt dependent trigger will be provided, allowing selective access to processes involving high transverse momentum muons.

The resolution of the reconstructed muon momentum will be determined by the chamber resolution, alignment precision within a superlayer and between superlayers, bending power of the magnet (BL^2) and "unreconstructable" fluctuations of the energy loss in the calorimeter.

3.1.2 SUBSYSTEM DIAGRAMS *

A functional schematic of the Muon subsystem is shown in Figure 3.1.2-1

3.1.3 MUON SYSTEM INTERFACES *

The Muon System interfaces with various GEM subsystems/components as summarized in the following paragraphs.

3.1.3.1 MUON/CALORIMETER INTERFACE *

Proper correction of muon energy loss in the calorimeter is very important for high energy muon measurements. The energy loss spectrum has a significant high energy tail due to radiation processes. The calorimeter is required to accurately measure muon energy loss and provide adequate shielding for the muon system. A potential fault mode for the liquod noble gas calorimeter is a cryogenic spill, and this fault mode will affect the muon chambers. The muon must chambers withstand this calorimeter fault without significant damage.

3.1.3.2 MUON/MAGNET INTERFACE *

3.1.3.2.1 MAGNETIC INTERFACE *

The physics goals of the GEM experiment are high resolution measurements of the muons emitted at large transverse momentum in proton - proton collisions. The aim of the design concept is to have 5% momentum resolution for 500 GeV muons at 90 degrees ($|\eta|=0$) assuming 100 micron measurement errors, no vertex constraint, and 12% at 500 GeV at 9.75°. A large Superconducting solenoidal magnet with field shaping iron end poles and a field of 0.8 T is required.

3.1.3.2.2 MAGNET STRUCTURAL INTERFACE *

Structure for the barrel region is arranged into 16 nominally identical measurement modules per end for a total of 32 barrel region modules. These modules utilize an aluminum bolted and pinned truss structure to support the weight of the muon chambers. Each of these modules is attached to the Superconducting magnet cryostat endplates; the attachment hardware will be kinematic.

The endcap regions has physical overlap requirements about the θ and ϕ. This limits the placement of structures in the inner and outer ϕ limits of the region as well as in the active space between the chambers. However the structural requirements are identical to the barrel region and the modules will be attached to the magnet cryostat endplates.

3.1.3.3 MUON/POWER INTERFACE *

The muon subsystem consist of many components having different voltage requirements. All muon power subsystem components will be supplied by the muon front end system, the power supplies will be design and procured as part of the muon system and the AC power supplying the power supplies will be a part of the facility system. The interface will be at the power supply AC electrical connection to the power supply.

3.1.34 MUON/COMPUTER INTERFACE

(TBD)

3.1.3.5 MUON/FACILITY INTERFACE *

The muon subsystem interfaces extensively with the above-ground and underground facilities at SSCL. Since design of the facilities is in progress, the muon subsystem must accept most of the requirements as imposed on it by the facilities design. This is the case particularly for the above ground assembly buildings. The muon subsystem provided rough requirements to the facilities design. However, the overall requirement on the subsystem is to fit into the facilities available to it.

3.1.3.6 MUON/ CENTRAL DETECTOR INTERFACE *

The central detector will have gussets or struts at the tube to membrane interface. This will cause a critical installation and alignment problem for the inner muon chambers. Final design and fabrication will allow for at least 10cm clearance between the muon chambers and any structural member.

3.1.3.7. MUON/ALIGNMENT INTERFACE

TBD

Figure 2. Muon System Functional Schematic

Figure 3. GEM Detector Layout

3.1.4 MAJOR COMPONENT DESCRIPTIONS *

The Muon system consist of 2ea barrel muon subassemblies in the central area, 2 ea. end cap muon subassemblies (1 on each end), power and protective systems, muon barrel subassembly support and handling equipment, muon end cap subassembly support and handling equipment, a data acquisition system, and gas system.

3.1.4.1 BARREL MUON SUBASSEMBLY *

The Barrel Region, covers polar angles in the range of 29° to 90°. Three layers of muon tracking chambers fill the volume, bounded on the inside by the dimensions of the neutron shield surrounding the calorimeter, and the solenoid magnet inner dimensions.

3.1.4.2 END CAP MUON SUBASSEMBLY *

The Endcap Region, covers angles in the ranges of 29° to 9.5^o. Three layers of muon tracking chambers fill the volume, bounded by the end the endcap calorimeter, the forward field shaper and the end of the solenoidal magnet.

3.1.4.3 TRIGGER *

The trigger will provide selective access to processes involving high transverse momentum muons.

3.1.4.4 MUON POWER AND PROTECTION SYSTEMS

(TBD)

3.1.4.7 DATA ACQUISITION

(TBD)

3.1.4.8 GAS SYSTEM

(TBD)

3.2 CHARACTERISTICS *

3.2.1 PERFORMANCE *

3.2.1.1 MOMENTUM RESOLUTION *

The muon momentum is reconstructed by the 3-point sagitta method (neglecting various angle factors), where the sagitta is given in terms of measured quantities as: $S = (y_1 + y_3)/2 - y_2 = qBL^2/8P$. y_1, y_2, and y_3 are the bend-plane locations of the muon trajectory in the three super-layers, B is the magnetic induction, L is the path length between super-layers 1 and 3, q is the muon electrical charge, and P is the momentum. Hence good resolution is achieved for a large L even at a modest B. To set the scale for the momentum reconstruction, S = 1.5 mm for Pt = 500 GeV/c. If we are to achieve a 5% measure of this momentum our total error budget should be no larger than 75μm. Hence the chambers should have good resolution and the should be aligned superlayer-to-superlayer to of order 25μm.

3.2.1.2 RAPIDITY COVERAGE. *

To obtain good statistics for the Higgs to 4 muon channel (either through ZZ* or ZZ) a large

solid angle (i.e., pseudorapidity) coverage for the muon chambers is required. For detection of the Higgs the goal is to maximize $N(s) = N(\text{Signal})/\sqrt{N(\text{Background})}$. From the studies of Higgs production and detection, it has been found that $N(s)$ is roughly constant, having a value of about 6, for muons out to a rapidity of about 2.5. And a rapidity coverage of $-2.5 < \eta < 2.5$ provides about 90% acceptance for a 4 TeV/c^2 $Z\phi$ and even greater acceptance for a heavier $Z\phi$.

3.2.1.3 CHAMBER OCCUPANCY *

The design goal limits the occupancy at $L = 10^{34}$ cm^{-2} s^{-1} below a few percent in order to guarantee an muon track-finding efficiency of nearly 100%. The muon rate as a function of pseudorapidity, η for the inner, middle and outer modules, assuming 12 λ in the barrel calorimeter, and 14 λ in the endcap calorimeter. In the endcap region, the rate increases to about 150 Hz/cm^2 in the inner modules at $\eta = 2.5$. For a 1 m long and 5 mm wide cathode strip chamber, and a Level 1 delay time of 3 *m*s, the occupancy would be less than 3%.

3.2.1.4 TRIGGER *

Both the trigger and beam crossing tag will be provided by the CSCs. The bend plane strip segments which are used to form the trigger are the 0.5 cm wide strips readout digitally at trigger time. The non-bend plane measurement is provided by means of the anode wires which will be segmented in 5 cm wide electronic channels. Since the maximum drift time of the CSC is < 24 ns per plane, several planes in a superlayer must be "ORed" together to achieve sufficient resolution for the beam crossing tag.

The Level 1 muon trigger is based on hits in super-layers 2 and 3 (SL2 and SL3, respectively) which uses the change of the phi angle, to measure the curvature (momentum) of the track originating from the interaction point. $\Delta\phi$ is given in terms of the, or the number of CSC pickup strips (0.5 cm wide) for an endcap muon subsystem. The line formed by the hit in SL2 and the interaction point extrapolated to SL3 gives the position of the muon track for infinite momentum. The difference measured in strips, ΔN_{strip}, between the hit in SL3 and the extrapolated point is a measure of the muon momentum.

3.2.1.5 HADRON PUNCHTHROUGH *

For the calorimeter thickness of greater than 12 λ in the barrel region, charged particle rate in the first super-layer of the muon system is dominated by prompt leptons from the primary vertex, and hadron decay in the central tracker and calorimeter. The hadron punch-through is smaller by a factor of 2.

In the endcap region the particle rate increases quite rapidly as the polar angle decreases. Owing to the energy spectrum of the punch-throughs and the prompt muons, and the geometry of the calorimeter and inner tracker, we find that the charged particle rate is decreased with some efficiency up to 14 λ, but thereafter with diminishing returns. Hence in the forward direction a calorimeter of 14 λ will keep the occupancy low and the trigger operational.

3.2.1.6 STABILITY *

Barrel Region

Maximum deflections for the barrel region structures, for the independent modules, will be less than (4) mm in any orientation and Von-Mises stresses less than (3) ksi for 10 ton barrel module weights. Specifically, for modules inserted in the top or bottom locations, the maximum deflections are (2) mm whereas they are (4) mm for the side mounted modules. The respective

maximum Von-Mises stresses for these mounting locations are (2) ksi and (3)ksi.

Buckling factors for the mounting configuration (side-mounted modules)will be a factor of 4 to 5 Structural frequencies will be above **TBD** hz for the barrel region

Endcap Region

The endcap region modules are supported by four points at the outer radii of these modules. These should be a good indicators of expected deformations for the space-frame assembly. Maximum deformations and stresses in these structures are slightly less than those for the endcap region modules. One matter for concern however, is that similar deformations for less mass in these modules indicates the lower natural frequencies than those observed for the barrel region.

Maximum deflections for the endcap region structures, for the independent modules, will be less than **(TBD)** mm in any orientation and Von-Mises stresses less than **(TBD)** ksi for 1.0 ton endcap module weights. Specifically, for modules inserted in the top or bottom locations, the maximum deflections are **(TBD)** mm whereas they are **(TBD)** mm for the side mounted modules. The respective maximum Von-Mises stresses for these mounting locations are **(TBD)** ksi and **(TBD)**ksi.

Buckling factors for the worst-case mounting configuration (side-mounted modules during installation attached to the inner radius of the module) will be **TBD** g's. Structural frequencies will be above **TBD** hz for the end cap region

The effects of uniform temperature changes as well as thermal gradients across the detector will have **TBD** effect on the alignment of the chambers. Temperature sensitivity is **(TBD/°C)** and gradient sensitivity is (**TBD**/(°C/m)).

3.2.1.7 DUTY CYCLE *
Under normal circumstances, the muon subsystem is required to operate at 100% capacity continuously, 24 hours per day, for 6 months, with 80% availability.

3.2.1.8 LIFETIME *
The design lifetime of the muon subsystem shall be 20 years and 20 magnet emergency discharge cycles..

3.2.1.9 ALIGNMENT

(TBD)

3.2.1.10 GROUNDING REQUIREMENTS *
All metallic surfaces not requiring electrical isolation, shall be attached with low resistance techniques and be at the ground potential of the shell. The connections shall not create any undesired ground loops that may impact operation, testing or safety.

3.2.2 PHYSICAL CHARACTERISTICS *

3.2.2.1 SIZE *
The size/envelope of the muon subsystem shall be defined by the space allocation plan being maintained at SSCL.

3.2.2.2 WEIGHT
The approximate weight of the components described in paragraph 3.4 are shown below.

COMPONENT	ESTIMATED WEIGHT (kg)
Barrel segment	TBD
Barrel Assembly	TBD
End Cap Assembly	TBD

3.2.2.4 POWER *
Conventional power and technical power will conform to, ANSI C84.1 and ANSI/IEEE 241-1983.
120 volt power will be 1 phase, separate ground wire, 120 VAC, 60 Hz.
208 volt power will be 3 phase, 4 wire, 208 VAC, 60 Hz.
277 volt power will be 1 phase, separate ground wire, 277 VAC, 60 Hz.
480 volt power will be 3 phase, 4 wire, 480 VAC, 60 Hz.

3.2.3 RELIABILITY *
The muon subsystem shall have adequate design margins to ensure the capability to operate continuously or intermittently without failure or degradation of performance over its useful life of 20 years. The subsystem shall exhibit no wear out or fatigue type failures when exposed to the moving, storage, installation or maintenance, misalignments, pre-operating and operating environments. A total of (TBD) days per month down time is allowed for routine maintenance of the SSCL.

3.2.3.1 ELECTRICAL CONNECTIONS AND CABLING *
All electrical connections and cabling shall be joined in a reliable and inspect able manner and secured and adequately protected from degradation due to radiation exposure, thermal, magnetic and assembly or maintenance procedures. Cabling shall be routed to avoid the contact with rough surfaces and adequately protected against chafing. Termination of wires shall be in a manner to prevent loosening or degradation. All wiring shall be provided with a permanent unique identification.

3.4.3.2 MISSION RELIABILITY
The design of the muon system shall, as a minimum, achieve an Mission Reliability of TBD over the service life requirement list in the service life paragraph. The design shall incorporated features of active redundancy, parts selected utilizing Environmental Stress Screening (ESS), Thermal Derating. This goal shall be verified by utilizing the Failure Modes and Effects (FMECA) and Reliability allocations and predication process.

3.2.3.3. OPERATING CYCLES
For design purposes, the muon system shall survive the capability of 200 normal operating cycles, and 20 emergency discharge cycles.

3.2.3.4 AVAILABILITY
The muon system shall be designed to achieve an overall Availability rate of (TBD) for an average operating year of (TBD) hours.

3.2.3.5 FAILURE TRACKING
The failures experienced during operation of the calorimeter shall be recorded and tracked for the identification and mitigation of failure trends.

3.2.3.6 SERVICE LIFE
The muon system shall be designed for a minimum service life of twenty (20) years of operation while achieving the mission reliability goal defined in mission reliability. Aging sensitive

materials shall be designed for al minimum service life of one (1) year after integration into the SSC complex with a twenty (20) year average life, with utilization of the existing maintenance concept, as the design goal. During the minimum life the muon system will be capable of withstanding multiple cycles of installation with and removal from the SSC without degradation of its inherent performance capabilities.

3.2.3.7 FAILURE DEFINITION
Any performance degradation beyond the limits defined herein will be considered a failure. Failures include loss of electrical integrity, loss of mechanical integrity and inability to record SSC output parameters to design specifications.

3.2.4 MAINTAINABILITY *
The muon subsystem shall provide for:

a. Interchangeability of assemblies and equipment elements (primarily surface support equipment) that are designed for removal and replacement as the normal corrective maintenance action .
b. Major repair and assembly replacement within the **TBD** mo. period required to open and close the magnet.
Standardization and simplicity of test equipment and its use.
c. Accessibility for in-place maintenance and inspection consistent with the design constraints, and tools and test equipment.
d. Capability of being repaired by skilled/semi-skilled technicians possessing muon specific training, working under an experienced supervisor.
e. Minor periodic realignment in 6 shifts while installed in the experimental hall.

3.2.5 ENVIRONMENTAL CONDITIONS*

3.2.5.1 NATURAL ENVIRONMENTS *
The muon system shall meet the performance requirements of 3.2.1 during and after exposure to the following operating and pre-operating (moving/handling, storage and installation) environments. Some of these steps will enclosed, others exposed to the weather.

3.2.5.1.1 TEMPERATURE *

Operating Ambient Temperature: $23^{o} \pm 1^{o}C$

Detector Hall Pre-Operating Temperatures: $12^{o}\ C \pm 5^{o}\ C$

3.2.5.1.2 HUMIDITY *
The relative humidity environments shall be as follows:

a. Operating: 0% to 98%
b. Detector Hall Pre-Operating: 10% to 98%

The muon subassemblies shall be protected during manufacturing, installation, pre-operating and operating conditions to prevent degradation due to humidity.

3.2.5.1.3 FOREIGN DEBRIS *
During all phases of assembly, test, and installation the magnet components shall be protected from contamination or damage from foreign debris.

3.2.5.1.4 CORROSIVE ATMOSPHERE *
The muon subsystem shall not degrade when exposed to the expected operating and pre-operating environments.

3.2.5.2 INDUCED ENVIRONMENTS *
The muon system shall meet the operational requirements of 3.2.1 during or after exposure to the following induced environments.

3.2.5.2.1 RADIATION. *
The muon subsystem shall be designed to withstand a radiation dose of **TBR Mrad** continuously over its 20 year useful life.

3.2.5.2.2 OPERATING MAGNETIC ENVIRONMENT *

Operating	.8T
Nonoperating	Residual

3.2.5.2.3 OPERATING THERMAL ENVIRONMENT *
The muon subsystem shall be able to withstand and function nominally without permanent or transient structural, mechanical, or electrical detrimental degradation during exposure to the operationally induced thermal environments resulting from all conditions specified herein.

3.2.5.2.4 TRANSPORTABILITY/HANDLING *
For movement of components to the receiving site at SSCL and for movement/handling of the muon subassemblies at SSCL, the items shall be transportable without detrimental degradation in alignment or performance. During movement and handling for assembly or installation, mechanical restraints may be used to prevent misalignment or damage. Provisions shall be made for measuring environmental conditions (temperature, moisture and vibration) during transport and handling to verify that the magnet has not exceeded the vibration environment shown in 3.2.9, the shock loads of 3.2.9, the temperature limits of 3.2.5.1.1, or the humidity levels of 3.2.5.1.2.

3.2.5.2.5 INSTALLATION *
The muon subsystem shall be lowered to the experimental hall installed into the magnet volume, while the magnet is in the open position. The magnet will be moved to the operational position where the final acceptance test will be performed.

3.2.5.2.6 STORAGE PROTECTION *
The muon subsystem, and its components during assembly and installation, shall be protected from the temperature and humidity environments specified herein that may cause loss of prestress, creep, water absorption or other detrimental efforts.

3.2.5.2.7 VIBRATION ENVIRONMENT *
The response of the muon subsystem to vibrations present in the tunnel and experimental hall, as described in SSC -SR-1043, "Field Measurements and Analysis of Underground Vibrations at the SSC Site", shall not exceed field alignment tolerances specified herein. The suspension system shall not degrade or suffer fatigue that will reduce the capability of meeting the life expectancy when subject to the tunnel vibrations over operating and non-operating temperature ranges, the vibrations during transportation (per the attached PSD curves), the vibrations due to cryogenic equipment operation and flow.

3.2.5.2.8 SHOCK LOADS *
The muon subassemblies shall be designed to handle static loads and seismic loads defined in section 3.2.11. Additional loads imposed by transportation and rigging shall be addressed by

additional design enhancements and analysis to meet the factors of safety defined in section 3.3.6. Shock loads imposed by transportation and rigging shall be minimized and thoroughly analyzed in the design documentation.

3.2.5.2.9 EARTHQUAKE LOADS *
The muon subsystem shall meet the intent of the earthquake criteria defined in section 3.7B, Seismic Criteria, of the Commanche Peak Steam Electric Station Final Safety Analysis Report. Commanche Peak is a power plant operated by Texas Utilities near the SSCL. This report defines design response spectra for both horizontal and vertical motion. Maximum ground accelerations are defined to be 0.08 vertical and 0.12 horizontal. Factors of safety under dynamic load for all systems shall be those defined in section 3.3.6.

Static Loads	
Direction	Gs
Vertical	1.2
Lateral	0.25
Axial	0.25

3.3 DESIGN AND CONSTRUCTION *
Level three drawings and associated lists shall be provided. P40-000001, P40-000004, P40-000013, P40-000017, P40-000030, and P40-000034 shall be used in the preparation of these documents.

3.3.1 MATERIALS, PROCESSES AND PARTS *
Where applicable the muon subsystem shall be designed and fabricated in accordance with the AISC Structural Design Code, full compliance with material and fabrication requirements are required for all components of the assembly. Pressure subsystems shall be designed to the intent of the ASME Boiler and Pressure Vessel Code (B&PVC), section VIII and ANSI/ASME B31.1 (Power Piping) and B31.3 (Chemical Plant and Refinery Piping Code). Design of vacuum components shall conform to (B&PVC) design requirements unless otherwise approved by SSCL.

3.3.1.1 CORROSION PREVENTION AND CONTROL *
Direct externally exposed surface-to-surface contact between dissimilar metals shall be controlled according to the best available practices for corrosion prevention and control, and leak tightness. Preventive maintenance may be used on external magnet components to control corrosion.

3.3.1.2 COLORS *
External muon assembly surfaces requiring protection shall be painted **TBD** and lettered per FED-STD-595, Colors.

3.3.1.3 MATERIALS TO BE AVOIDED *
Only materials consistent with the radiation environment shall be used in design and construction. Radiation sensitive materials such as PTFE shall not be used be used.

3.3.1.4 WELDMENTS *
All manufacturing and field Weldments of pressure components shall conform to the requirements of ASME B&PVC, section VIII and ANSI/ASME B31.3 as applicable. In addition all other manufacturing and field Weldments shall be in according to the SSCL Mechanical Engineering Guideline, section 4.3.5. The design shall accommodate the use of standard welding machines to allow for conformance to this requirement. Welding, and weld test and acceptance, shall be accomplished according to Process Control Procedures that have been reviewed and

accepted by the SSC Laboratory. Flanges provided for repair/maintenance activities shall not be degraded by up to 6 such activities.

3.3.1.5 SOLDERING AND BRAZING

All soldered connections shall be designed and constructed as part of the joint contractor/SSCL development effort. Any soldering flux used shall be approved by the SSCL before use.

3.3.1.6 COATING, POTTING, AND MOLDING *

Coating, potting and molding shall conform to TBD standards and drawings.

3.3.1.7 MATERIALS TO BE AVOIDED

The muon system shall not include ozone depleting chemicals and shall minimize the use of hazardous materials including those used in the hardware and those required to maintain or service hardware. Only materials consistent with the radiation environment shall be used in the calorimeter design and construction. Radiation sensitive materials such as PTFE shall not be used.

3.3.1.8 FUNGUS RESISTANCE

Materials which are nutrients for fungi shall be avoided. Where nutrient materials must be used outside of hermetically sealed containers, such materials shall be treated with a fungicidal agent.

3.3.2 NAMEPLATES AND PRODUCT MARKINGS *

Nameplates, product marking, serial and lot number markings, and all other identifying informational and certifying marking shall be according to the SSC Laboratory's direction.

3.3.3 WORKMANSHIP *

The muon subsystem shall be fabricated with repeatable field quality and finished in a thoroughly workmanlike manner. Particular attention shall be given to freedom from blemishes, defects, burrs, sharp edges and foreign materials; saturation inductance of magnetic materials; accuracy of dimensions; application of insulating material; care during assembly; radii of fillets; marking of parts; thoroughness of cleaning; quality of brazing, welding, riveting, painting and wiring; alignment of parts; and specification tightness, prestress and torquing of fasteners. MIL-STD-454, Requirement 9, shall be used as a guide in applying workmanship standards.

3.3.4 SAFETY *

Safety shall be consistent with the DOE policy of providing employment and a place of employment free from recognized occupational safety and health hazards by complying with the DOE Order 5481.1B and DOE prescribed OSHA standards. The muon subsystem shall be designed to comply with the National Electric Code (NFPA-70). Specific personnel hazards and/or special instructional markings of hardware shall be identified and noted on applicable drawings or procedures.

The GEM Preliminary Safety Assessment Report, PSAR, shall identify the hazards and mitigating actions associated with the design and operation of the Central Trakcer. This will also include a hazard list for the Central Tracker.

3.3.5 HUMAN PERFORMANCE/HUMAN ENGINEERING *

The muon subsystem design shall be consistent and compatible with the human capabilities required to build, test, install and repair, in a repeatable, consistent, effective and safe manner. This includes tasks, tools, equipment, environment, personnel-equipment interfaces and other items required of this design. Mature, performance proven, standard, commercially available equipment shall not be modified unless safety to personnel or equipment is a factor. MIL-STD-

1472 shall be used as a guide.

3.3.6 STRUCTURAL INTEGRITY *

3.3.6.1 HANDLING ATTACH POINTS *

Rings, shackles and lugs shall be designed for a minimum yield factor of safety of **3.0** based on dead load.

3.3.6.2 ALLOWABLE STRESSES

Piping shall comply with ANSI/ASME B31.3 (Chemical Plant and Refinery Piping) Code. The design of all other pressure vessel components shall comply with the ASME Boiler and Pressure Vessel Code, Section VIII. In addition, the design of non-pressure vessel ferrous components shall be based on the material allowable stresses for the materials used at the temperature at which the applied or internal loads are expected for all applicable combinations of loads.

Any composite or non-metallic material used in a critical application may be used up to 40% of ultimate strength and then only when sufficient statistical data are available to a 50% level of confidence. Materials with insufficient strength data shall be accompanied with a test program to determine physical properties before usage.

Loading conditions include, but shall not necessarily be limited to: gravity, static shell preload, steady-state and transient magnetic, steady state and transient thermal, steady state and transient cryogenic fluid pressure, earth motion, transportation/handling, ambient environmental, and the loads listed herein.

For allowable stresses not specified above, the intent of the following industrial codes shall apply as appropriate:

a. Code(s) of American Society of Mechanical Engineers (ASME)
b. Code(s) of American Society for Testing and Materials (ASTM)
techniques.

3.5 MAINTENANCE *

The design shall be such that minimal scheduled maintenance and repair shall not be required. Some minor preventive and corrective maintenance shall be required.

Working Draft

GEM Detector
Calorimeter Subsystem Specification

DRAFT

1.0 SCOPE

This specification establishes the performance, design, development, and test requirements for the Superconducting Super Collider Laboratory (SSCL) Gammas, Electrons, Muons (GEM) Calorimeter which is an integral part of the GEM Detectory as illustrtated in Figure 1-1.

Figure 1-1 GEM Detector

2.0 APPLICABLE DOCUMENTS

2.1 GENERAL

The following documents, of the exact issue shown, form a part of this specification to the extent specified herein. In the event of conflict between the documents referenced herein and the contents of this specification, the contents of this specification shall be considered a superseding requirement. In those instances where a document is referenced for use as a guide, the design agency must provide its own interpretation and verify proper applicability prior to its use.

2.2 SSC LABORATORY DOCUMENTS

TBD	GEM Detector Magnet Interface Control Document
P40-000001	SSCL Document Numbering Procedure
P40-000003	SSCL Standard, Part Numbering System
P40-000004	SSCL Standard, Engineering Drawing Format
P40-000013	SSCL Guideline 4.4, Engineering Drawings
P40-000017	SSCL Standard, Engineering Drawing Preparation
P40-000030	SSCL Practice, Parts List Preparation
P40-000070	Draft SSCL Guideline 3.2.1.1, Mechanical Engineering
P40-0000137	Identification Marking of Parts and Assembly
P40-000140	Drafting Practices Handbook
SSC-SR-1043	Field Measurements and Analyses of Underground Vibrations at the SSC Site

2.3 NON-SSC LABORATORY DOCUMENTS

SPECIFICATIONS

Unless agreement is specifically made between the design agency and the SSCL to use another issue, the latest edition and addenda of each of the following documents issued prior to the date of this specification will be the governing document until completion of all work and testing.

American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code

ANSI/ASME B31.3 Chemical Plant and Petroleum Refinery Piping

26 Oct 90	
MIL-STD-785B	Reliability Prediction of Electronic Equipment
15 Sep 80	
DOD-HDBK-344	Environmental Stress Screening of Electronic Equipment
20 Oct 86	
MIL-STD-454	Standard General Requirements for Electronic Equipment
AWS D1.1-90	Standard for Structural Welding Code – Steel
Notice 1, 12 Sep 90	
AWS D1.2-90	Standard for Structural Welding Code – Aluminum
Notice 1, 12 Sep 90	
MIL-STD-882B	System Safety Program Requirements
1 Jul 87	
MIL-STD-965	Parts Control Program
Notice 3, 24 Jul 89	
MIL-STD-1472D	Human Engineering Design Criteria for Military Systems,
20 Mar 91	Equipment, and Facilities
DOD-D-1000B	Drawings, Engineering and Associated Lists
1 Jul 90	
MIL-STD-100E	Engineering Drawing Practices
30 Mar 92	

3.0 REQUIREMENTS

3.1 SYSTEM DEFINITION

3.1.1 General Description

The Calorimeter is one of seven subsystems in the GEM detector. Its primary functions are 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 noninteracting particles - neutrinos or new particles.

3.1.2 Subsystem Diagrams

To accomplish the functions identified in 3.1.1, the calorimeter shall include both electromagnetic and hadronic calorimetry, packaged to fit within the central region of the GEM detector immediately outside the central tracker. The Calorimeter shall include the major

components (subsystems) illustrated schematically in Figure 3.1.2-1. The calorimetry components are illustrated in Figure 3.1.2-2.

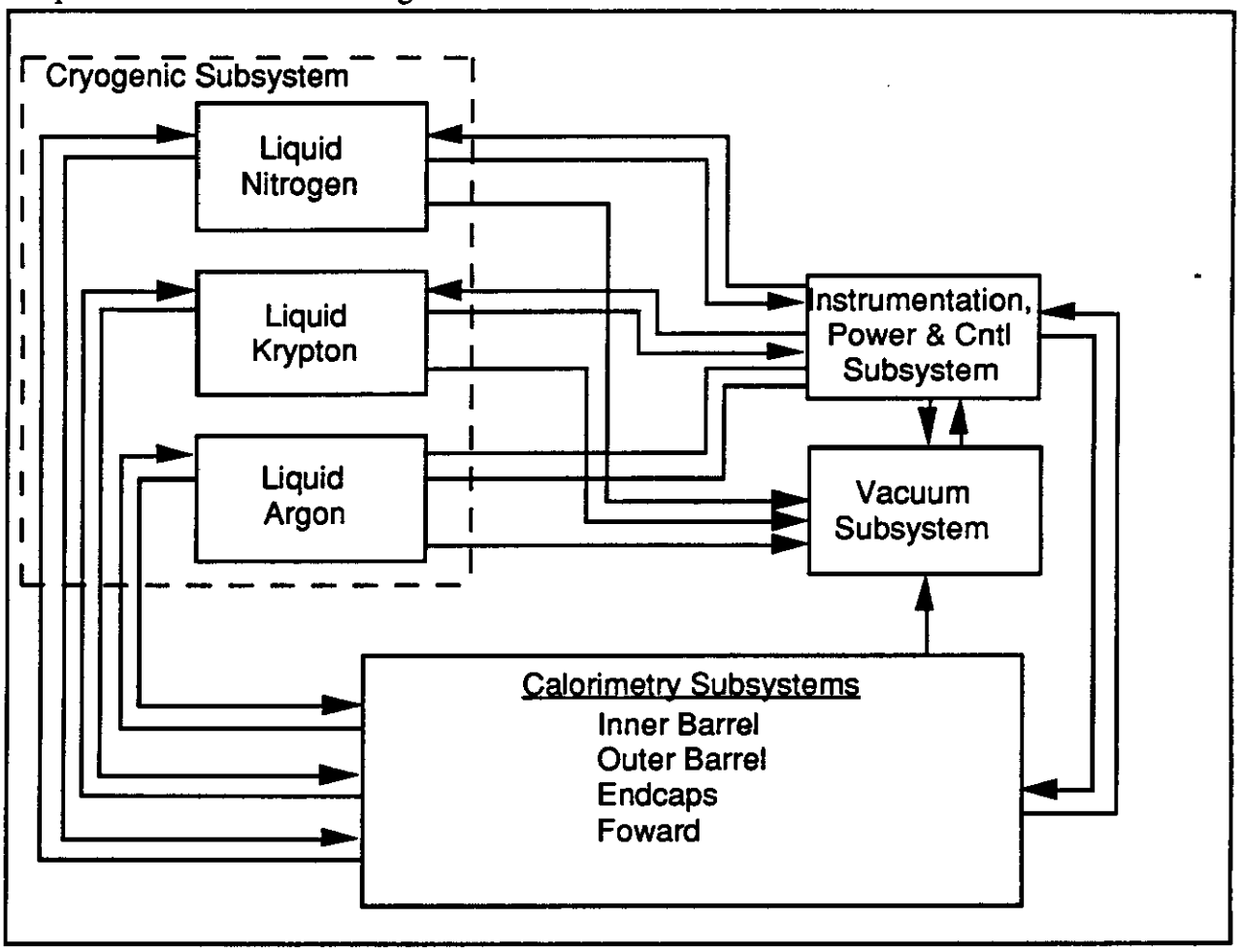


Figure 3.1.2-1 Calorimeter Functional Schematic

3.1.3 Calorimeter Interfaces

An interface is the functional and physical characteristics required to exist at a common boundary between two or more items of equipment/computer programs. The interfaces between the calorimeter and other GEM subsystems (external interfaces) are controlled by the interface control documents (ICD) process. Interfaces between subsystems or components within the calorimeter with separate design agencies will also be controlled with ICDs. These interfaces are briefly described in the following paragraphs.

3.1.3.1 External Interfaces

3.1.3.1.1 Central Detector Support

This mechanical interface provides for the mounting, support, and alignment of the calorimetry subsystems within the detector. The entire weight of the calorimeter is transferred through the scintillating barrel subsystem of the calorimeter to the Central Support. The position of the

calorimeter with respect to the central support is fixed through this interface, permitting alignment of the calorimeter with respect to the beamline by using fiducials on the calorimeter and the position adjustment capability of the central membrane. The details of this interface are documented in GDT – 000024.

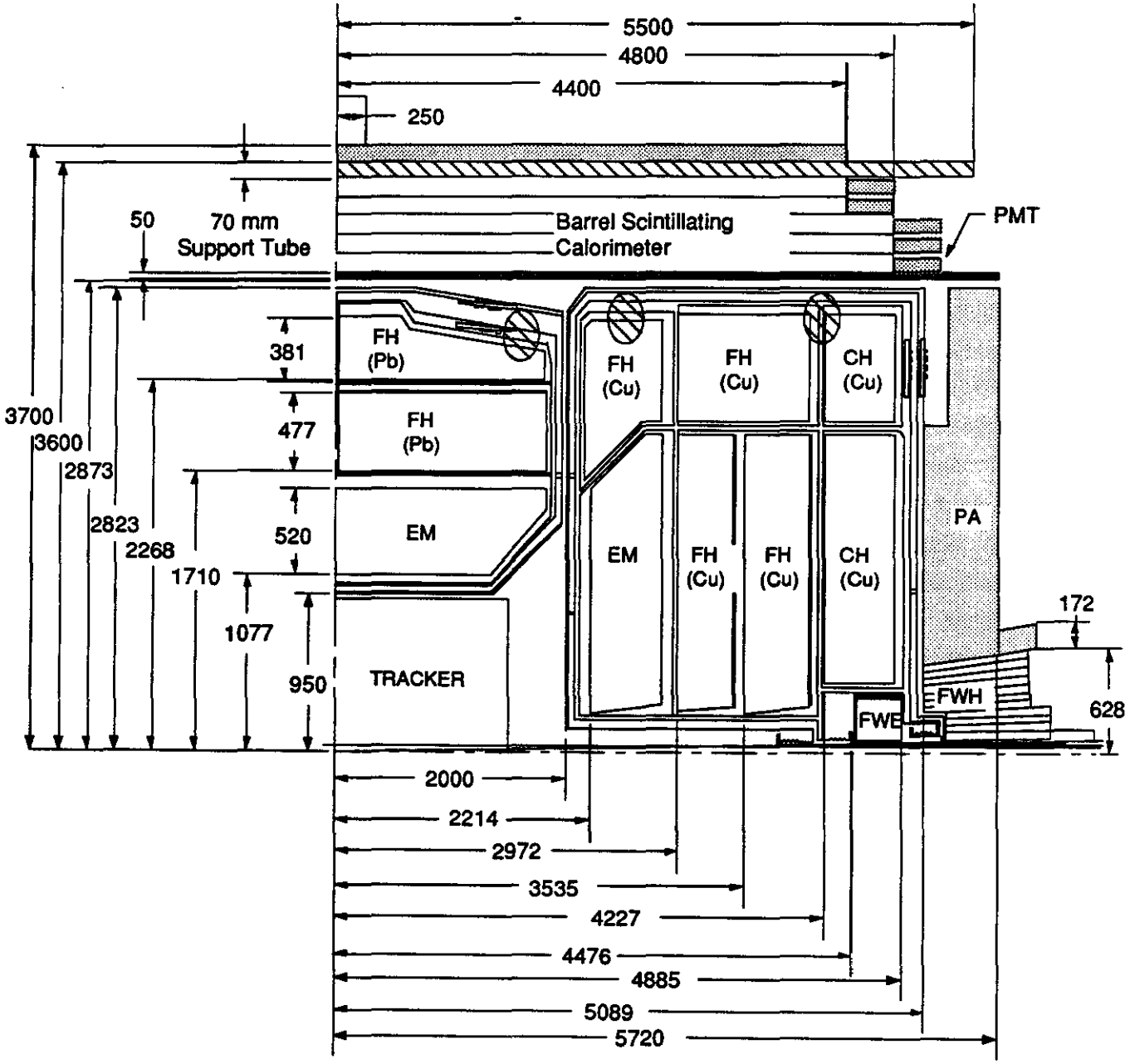


Figure 3.1.2-2 Calorimetry Subsystems Conceptual Design

3.1.3.1.2 Central Tracker

This mechanical interface provides for the mounting, support, and alignment of the central tracker within the detector. The central tracker attaches to the inner barrel of the calorimeter using kinematic mounts which transfer the weight of the tracker into the inner barrel subsystem. These mounts provide the adjustments necessary for alignment of the tracker to the beamline. The details of this interface are documented in GDT – 000025.

3.1.3.1.3 Beam Tube.

This volumetric interface provides a 1 cm annular space around the beam tube and assures that the requirement for a warm beam tube is not violated. The details of this interface are documented in GDT – 000026.

3.1.3.1.4 Muon

This envelope interface assures adequate space for the calorimeter and muon system utilities. The calorimeter is limited to a cylindrical space on each side of the central membrane having a radius of 3600 mm and length of 5500 mm. An additional space with a radius of 890 mm and a length of 1123 mm is provided for the foward section of the calorimeter. This interface is documented in GDT – 000027

3.1.3.1.5 Facilities

Several calorimeter subsystems require space and attachment points to the GEM facilities. These interfaces are identified in GDT – 000028..

3.1.3.1.6 Electronics

The calorimeter interfaces electrically with the detector electronics system which reduces the data flow from the sensors to the data recording system. This interface is documented in GDT – 000029.

3..1.3.2 Internal Interfaces

3.1.3.2.1 Inner-to-Scintillating Barrel Calorimetry

This mechanical interface provides for the mounting and support of the inner barrel calorimetry subsystem within the outer barrel calorimetry subsystem. This interface is documented in GDT – 000030..

3.1.3.2.2 Scintillating Barrel-to-Endcap Calorimetry

This mechanical interface provides for the mounting and support of the endcap calorimetry subsystem within the outer barrel calorimetry subsystem. The details of this interface are given in GDT – 000031..

3.1.3.2.3 Endcap-to-Foward Hadronic Calorimetry

The Foward Hadronic Calorimetry subsystem is attached to the Endcap Calorimetry Subsystem, providing the necessary structural support These interfaces are documented in GDT - 000031.

3.1.4 Major Components

The major components (subsystems) of the Calorimeter illustrated in Figure2 3.1.2-1and -1 are described in the following paragraphs.

3.1.4.1 Inner Barrel Calorimetry Subsystem

This cylindrical subsystem contains a portion of the active elements of the calorimeter, providing axisymmetric electromagnetic and hadronic coverage along the z-axis of the detector (Fig. 3.1.1-2).

3.1.4.2 Scintillating Barrel Calorimetry Subsystem

This subsystem is a cylindrical scintillator sourrounding the inner barrel. It provides additional active lengths outside the inner barrel region, improving the overall resolution of the calorimeter.

3.1.4.3 Endcap Calorimetry Subsystem

This subsystem also contains active elements of the calorimeter. It is divided into two sections, both including electromagnetic and hadronic calorimetry, for coverage at each end of the inner barrel subsystem. A foward section is also included to provide electromagnetic coverage in the regions $3 < |\eta| < 5.5$.

3.1.4.4 Foward Calorimetry Subsystem

This subsystem provides near-axis hadronic coverage in the regions $3 < |\eta| < 5.5$.

3.1.4.5 Passive AbsorberSubsytem

This uninstrumented subsystem provides added protection to the Muon system.

3.1.4.6 Vacuum Subsytem

The vacuum subsystem includes the vacuum pumps and lines necessary to create and maintain vacuum conditions within the vacuum vessels associated with the barrel and endcap calorimetry subsystems and to aid in cleaning of these systems.

3.1.4.7 Cryogenic Subsystem

The cryogenic subsystem includes the dewars, vents, valves, pumps, and piping necessary to supply liquid argon, liquid krypton, and thermal conditioning liquid nitrogen to the calorimetry subsystems.

3.1.4.8 Instrumentation, Power, and Operational Control Subsystem

The instrumentation and control subsystem consists of sensors, wires, terminal boards, and connectors which provide electrical power to the other subsystems and calorimeter operational monitoring and control.

3.1.5 Calorimeter Modes and Cycles.

3.1.5.1 Normal Operational Mode

The normal operating mode for the calorimeter occurs when the detector magnet is operating, cryostats are filled with cryogenic fluid, all electrical components are powered up, and the collider is operating at flat top energy.

3.1.5.2 Installation Mode.

This mode is initiated immediately after surface assembly and checkout is completed. It includes installation, alignment, checkout, and initial calibration of the caloimeter in the Experiment Hall.

3.1.5.3 Commissioning Mode

The commissioning mode is the first opertational mode following initial installation or a maintenance action requiring magnet half rollback.

3.1.5.4 Maintenance Modes

3.1.5.4.1 Scheduled Maintenance Mode

The Calorimeter scheduled maintenance mode is defined as the scheduled down time each month in which preventive and minor corrective maintence can be performed without access to the interior of the detector or removal of the cryogenic fluids from the calorimety subsystems.

3.1.5.4.2 Unscheduled Maintenance Mode

The unscheduled maintenance mode is defined as any unscheduled downtime required for corrective maintenance. The length and nature of this mode depends on the required maintenance. However, the calorimeter must meet specific availability requirements which minimizes the unscheduled maintenance mode.

3.1.6 Calorimeter Coordinate System

The calorimeter coordinate system is consistent with the GEM detector coordinate system (Fig. 3.1.4-1). It is a right-handed system with the origin at the interaction point. The positive x-axis is towards the center of the ring and the positive y-direction is vertically upward.

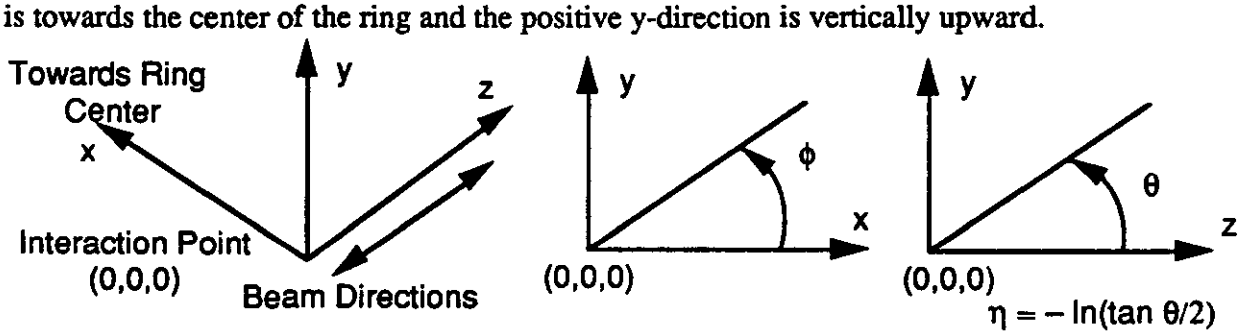


Figure 3.1.4-1 Detector Coordinate System.

3.2 CHARACTERISTICS

3.2.1 Performance

The calorimeter shall meet the performance requirements identified in Table 3.2.1-1.

Table 3.2.1-1 Calorimeter Performance Requirements

Performance Parameter	Electromagnetic	Hadron
Fractional Energy Resolution	$(7.5/\sqrt{E})\% + 0.5\%$	$(60/\sqrt{E})\% + 2.0\%$
Time Resolution	$\Delta t = 1$ ns ($E_{EM} \geq 20$ GeV)	$\Delta t = 3$ ns ($E_{jet} \geq 50$ GeV)
Noise (thermal/pileup)	20/30 MeV/Channel	130/118 MeV/Channel
Dynamic Range	10^5 (up to 10 TeV/tower)	10^5 (50 MeV to 5 TeV)
Depth	25 X_O at $\eta = 0$ 28 X_O at $\eta = 3$ $\lambda_I \geq 1.3$ for $0 < \eta < 3$	$\lambda_I \geq 10.7$ at $\eta = 0$ $\lambda_I \geq 12.7$ at $\eta = 3$
Coverage	$0 < \eta < 3$	$0 < \eta < 5.5$
Lateral Segmentation (η x ϕ)	0.032 x 0.032	0.08 x 0.08
Longitudinal Segmentation	2 Electromagnetic Segments	4 Hadronic Segments
Speed Shaping Time	40 ns	50-200 ns
Position Resolution	4.4 mm/$\sqrt{E}$	

3.2.2 Physical Characteristics

The calorimeter shall meet the following physical requirements:

3.2.2.1 Orientation and Size

Except for the Forward Calorimetry Subsystem, the calorimeter shall fit within the volume defined by a cylinder with its axis along the z-axis of the detector, radius of 3.6 m, length of 11 m, and centered with respect to the central detector support. The Foward Calorimetry Subsystem shall extend no more than 1.123 m along the z-axis and out to a radius of 0.89 m at each end of the calorimeter.

3.2.2.2 Assembly/Disassembly Design Features.

The endcap calorimetry subsystem shall be supported by and aligned with the barrel calorimetry subsystem through attachment points at each end of the barrel subsystem. These attachment points shall facilitate the assembly/disassembly process. The endcap subsystem shall include those features which provide the mobility necessary for access to and/or removal of the central tracking subsystem.

3.2.2.3 Utility Accomodations

The calorimeter design shall include all necessary provisions for mounting of electronic boards; power and instrumentation cable routing; and cryogenic piping.

3.2.2.4 External Fiducials

The cryostat outer vacuum shell shall be provided with four main external fiducial points, each having a unique set of coordinates with respect to the z-axis geometric centerline of the calorimeter.

3.2.3 Reliability.

3.2.3.1 Mission Reliability

The design of the calorimeter shall achieve, as a minimum, an Mission Reliability of TBD over the service life requirement listed in 3.2.3.5. The design shall incorporate the features of active redundancy, parts selection utilizing Environmental Stress Screening Thermal Derating. This goal shall be verified utilizing the Failure Modes and Effects and Reliability allocation and prediction processes.

3.2.3.2 Operating Cycles

For design purposes, the calorimeter shall survive 10,000 normal operating cycles, 150 emergency shutdown cycles, and 30 cycles from operating to hall room temperature.

3.2.3.3 Availabililty

The calorimeter shall achieve an overall availability rate of .98 (TBR) for an average operating year of 5631 hours where avaliability is defined as

$$A_0 = \frac{\text{Annual Operating Time - Mean Down Time}}{\text{Annual Operating Time}}$$

3.2.3.4 Failure Tracking

The failures experienced during operation of the calorimeter shall be recorded and tracked for the identification and mitigation of failure trends.

3.2.3.5 Service Life

The calorimeter shall be dessigned for a minimum service life of twenty (20) years of operation while achieving the mission reliability goal defined in 3.2.3.1. Age sensitive materials shall be designed for a minimum service life of one (1) year after integration into the detector with an average life of twenty (20) years, utilizing the planned maintenance concept, as a design goal. During the minimum life, the calorimeter shall be capable of withstanding multiple cycles of installation and removal from the experiment hall without degradation of inherent performance capabilities.

3.2.3.6 Failure Definition

A failure shall be considered to have occurred when the capability to acquire useful calorimetric data falls below 95% of the planned coverage. No more than 0.5% of the 5% loss shall be in any one contiguous area.

3.2.4 Maintainability

3.2.4.1 Maintenance Concept

The calorimeter shall be designed for ease of operation, calibration, and repair and shall operate for the service life defined in 3.2.3.5 with weekly shutdowns of approximately 1 day per week and annual shutdowns of 3 months (2190 hours) during which scheduled scheduled maintence will be performed. Upon failure identification, all maintenaance, calibration, and repair shall be performed by SSC personnel utilizing approved procedures, test/support equipment, and spares.

3.2.4.2 Repair Time

The calorimeter shall be designed to meet an average Mean Time to Repair (MTTR) of 8 hours and a maximum MTTR goal of 24 hours for the performance of major maintenance by the 95th percentile support personnel. This activity includes failure identification, isolation, removal, and replacement of faulty components, and validation. This requirement does not include cool down time and spares logistics down time and will be verified using an MTTR allocation and prediction process.

3.2.4.3 Preventive Maintenance

The calorimeter shall be designed to require minor preventive maintenance. When required, preventive maintenance will be scheduled for periods of SSC non-operation. When major preventive scheduled maintenance (requiring access to the interior of the calorimeter or detector) is required, it will be accomplished during the normal annual shutdown period.

3.2.4.4 Design Guidelines

The MTTR goal shall be consistent with the availability goal. The calorimeter shall be designed to provide the following inherent design features:

- Ease of testability and calibration
- Ease of access for performance of maintenance tasks
- Minimum shill level/training requirements
- Standardization of components and test equipment
- Minimal requirement for scheduled and preventive maintenance
- Rapid failuire identification and warning
- Minimum need for on-site spares inventory
- Design consideration given to ease of handling, transportation, and maintenance
- Ease of access to high failure components

3.2.5 Environmental Conditions

The calorimeter shall meet the performance requirements of 3.2.1 after exposure to the non-operating environments and during exposure to the operating environments (except shock) defined in the following paragraphs. The calorimeter and its components shall be protected as necessary to prevent degradation due to exposure to these envirnonments which may occur separately or in combination during shipping, handling, assembly, installation, and operation.

3.2.5.1 Temperature

a. Operating: 23°C ± 1 °C

b. Non-Operating: –35 °C to +52 °C

3.2.5.2 Humidity

a. Operating: 45% ± 5%

b. Non-Operating 10% to 98% with conditions that may produce condensation in the form of water or frost.

3.2.5.3 Vibration

a. Operating Defined in SSC-SR-1043, Field Measurements and Analysis of Underground Vibrations at the SSC Site.

b. Non-Operating When packaged for shipment, system equipment shall withstand or be protected from vibration levels defined by the PSD curves in Figures 3.2.6.3-1. The breakpoints for these curves are presented in Table 3.2.6.3-1.

3.2.5.4 Mechanical Shock

a. Operating: Meet the intent of seismic criteria in the Comanche Peak Stem Electric Station Final Safety Analysis Report

b. Non-Operating Packaged equipment weighing less than 45 kg shall be protected from drops of 61 cm.

3.2.5.5 Radiation

a. Operating. 2×10^6 Gray over the useful life.

b. Non-Operating None

3.2.5.6 Magnetic

a. Operating 0.8 Tesla

b. Non-operating Residual

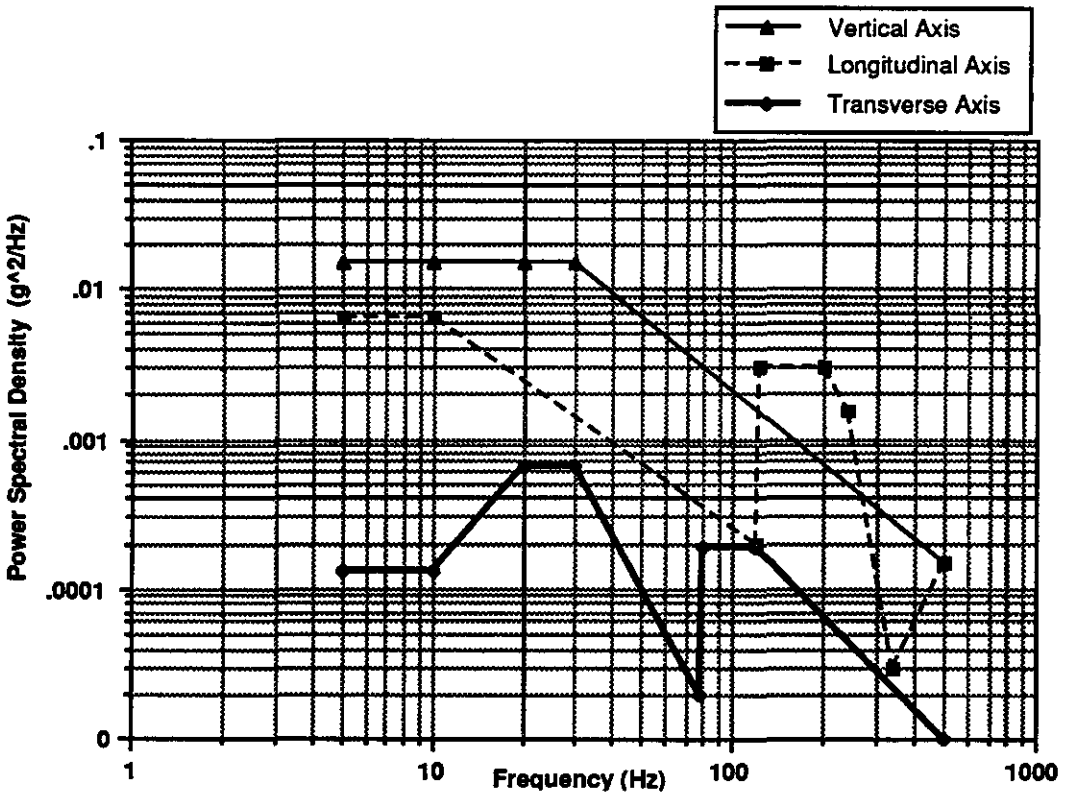


Figure 3.2.6.3-1 Common Carrier Transportation Environment

Table 3.2.6.3-1 Common Carrier Transportation PSD Breakpoints

Frequency (Hz)	Vertical Axis PSD Value	Transverse Axis PSD Value	Longitudinal Axis PSD Value
5	0.015	0.00013	0.00650
10	0.015	0.00013	0.00650
20	0.015	0.00065	
30	0.015		
40		0.00002	
78		0.00019	
79			
100			
120		0.00019	0.00020
121			0.00300
200			0.00300
240			0.00150
340			0.00003
500	0.00015	0.00001	0.00015

3.3 DESIGN AND CONSTRUCTION

Engineering drawings shall be in accordance with P40-000001, P40-000004, P40-000013, P40-000017, P40-000030, and P40-000034.

3.3.1 Parts, Materials, and Processes

3.3.1.1 Specifications and Standards

The calorimeter shall be assembled in accordance with the cleanliness requirements in the SSCL Quality Assurance Requirements. The cold mass pressure vessel shall comply with the requirements of ASME Boiler and Pressure Vessel Code (B&PVC), Section VIII and ANSI/ASME B31.3 (Chemical Plant and Refinery Piping Code as applicable.

3.3.1.2 Parts Selection

The design agency shall establish and maintain a parts control program using Task 207 of MIL-STD-785 and Procedure 1 of MIL-STD-965 as guides. The materials selected for use in the calorimeter shall not degrade when subject to thermal cycling, cryogenic temperatures, radiation environments, vacuum or other conditions consistent with design and application.

3.3.1.3 Environmental Stress Screening

Components within the calorimetry subsystems and other components whose location and reliability could preclude meeting the intent of 3.2.4 shall be subjected to environmental stress screening using Task 301 of MIL-STD-785 and DOD-HDBK-344 as guides.

3.3.1.4 Corrosion Prevention and Control

Material shall either be of a corrosion resistant type or suitably treated to resist corrosion. Protective methods and materials for cleaning, surface treatment, and application of finishes and protective coatings shall be implemented. Whenever dissimilar metals are in direct contact, suitable methods for controlling electrolytic corrosion shall be used. Suitable materials and processes for corrosion control shall be selected.

3.3.1.5 Workmanship

The calorimeter and its components shall be fabricated and finished in such a manner that the criteria of appearance, fit, and adherence to specific tolerances are met. Particular attention shall be given to thoroughness of soldering, wiring, plating, painting, welding, brazing, and freedom of parts from burrs. All electrical connections and cabling shall be joined in a reliable and inspectable manner. Cabling shall be routed to avoid contact with rough surfaces and protected against chafing. Termination of wires shall be done to prevent loosening or degradation. MIL-STD-454, Requirement 9, shall be used as a guide in applying workmanship standards.

3.3.1.6 Weldments

All weldments are to be in accordance with AWS D1.1-83 and AWS D1.2-83. The design shall accommodate the use of standard welding machines to allow for compliance with this requirement. Welding and weld test and acceptance shall be accomplished in accordance with process control procedures that have been reviewed and accepted by the SSCL. All weldments

of pressure vessels and piping shall conform to the intent of ASME B&PVC, section VIII and ANSI/ASME B31.3 as applicable.

3.3.1.7 Soldering and Brazing

All soldering connections shall be designed and constructed as part of the joint contractor/SSCL development effort. Any soldering flux used shall be approved by the SSCL before use.

3.3.1.8 Materials To Be Avoided

The calorimeter shall not include ozone depleting chemicals and shall minimize the use of hazardous materials including those used in the hardware and those required to maintain or service hardware. Only materials consistent with the radiation environment shall be used in the calorimeter design and construction. Radiation sensitive materials such as PTFE shall not be used.

3.3.1.9 Fungus Resistance

Materials which are nutrients for fungi shall be avoided. Where nutrient materials must be used outside of hermetically sealed containers, such materials shall be treated with a fungicidal agent.

3.3.2 Nameplates and Product Markings

Nameplates, product marking, serial and lot number markings, and all other identifying informational and certifying markings shall be according to SSCL direction.

3.3.3 Interchangeability

The calorimeter subsystems and components shall be capable of being removed and replaced with an equivalent unit possessing identical form, fit, and function.

3.3.4 Safety

The calorimeter shall present no safety hazards during delivery and operation by complying with DOE Order 5481.1B and and DOE prescribed OSHA standards plus applicable state, local, and SSCL safety requirements. MIL-STD-882 shall be used as a guide in establishing the system safety program. The GEM Preliminary Safety Assessment Report shall identify the hazards and mitigating actions associated with the design and operation of the Calorimeter. This report shall also include a hazard list for the Calorimeter.

3.3.5 Human Performance/Human Engineering

The calorimeter shall be consistent and compatible with the human capabilities required to build, test, install, and repair the calorimeter in a repeatable, consistent, effective, and safe manner. This includes tasks, tools, equipment, environment, personnel-equipment interfaces and other items required of the calorimeter in meeting the requirements of this specification. MIL-STD-1472 shall be used as a guide.

3.3.6 Structural Integrity.

3.3.6.1 Allowable Stresses

SPECIFICATIONS

The calorimeter piping shall comply with ANSI/ASME B 31.3 (Chemical Plant and Refinery Piping) Code. All other pressure vessel components shall comply with the ASME Boiler and Pressure Vessel Code, Section VIII.

Working Draft

GEM Detector
Central Tracker Subsystem Specification

DRAFT

1.0 SCOPE

This specification establishes the technical requirements for the Super Conducting Super Collider GEM Central Tracker Subsystem. Included in the specification are a summary of the central tracker interfaces with other detector subsystems, performance requirements and physical characteristics.

The GEM Central Tracker Subsystem must operate in a .8 Tesla magnetic field and cover a pseudorapidity range of $\pm$ 2.5 units. The Central Tracker must identify the primary vertex of the event of interest, be able to separate electrons and gammas, provide track information for e, μ or γ isolation cuts, and determine the electron sign up to 400 GeV/c. The Central Tracker must also help with electron-hadron separation and rejection of background.

The Central Tracker is an integral part of the GEM Detector as shown in Figure 1-1.

SPECIFICATIONS

Figure 1-1 GEM Detector

2.0 APPLICABLE DOCUMENTS

2.1 GENERAL

The following documents form a part of this specification to the extent specified herein. If conflict between the documents referenced herein and the contents of this specification, the contents of this specification shall be considered a superseding requirement. In those instances where a document is referenced for use as a guide, the Contractor must provide his own interpretation and verify proper applicability before use.

2.2 SSC LABORATORY DOCUMENTS

a.	TBD	GEM Detector Central Tracker Interface Control Document
b.	SSC-SR-1043	Field Measurements and Analysis of Underground Vibrations at the SSC Site
c.	SSC 3.21.1	Mechanical Engineering Guideline
d.	SSC-MAG-M-7380	SSC Dipole Electrical Interconnect Assembly
e.	P40-000001	SSCL Document Numbering Procedure
f.	P40-000003	SSCL Standard, Part Numbering System
g.	P40-000004	SSCL Standard, Engineering Drawing Format
h.	P40-000013	SSCL Guideline 4.4, Engineering Drawings
i.	P40-000017	SSCL Standard, Engineering Drawing Preparation
j.	P40-000030	SSCL Practice, Parts List Preparation
k.	P40-000070	Draft SSCL Guideline 3.21.1, Mechanical Engineering
l.	P40-000137	Identification marking of Parts & Assembly
m.	GEM TN-92-63	Central Tracker Technical Design Report, Volume V

2.3 NON-SSC LABORATORY DOCUMENTS

a.	American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code	
b.	ASME B31.3	Chemical Plant and Petroleum Refinery Piping
c.	American Institute of Steel Construction (AISC); Codes of	
d.	MIL-STD-454	Standard General Requirements for Electronic Equipment
e.	ANSI C84.1	Electrical Power Systems and Equipment
f.	ANSI/IEEE 241-1983	Standard Specifications of Testing Concrete
g.	NFPA-70	National Electric Code
h.	DOE Order 5481.1B	Safety Analysis & Review System
i.	ANSI B30	Hoisting & Rigging of Critical Components
j.	IEEE	Large Rotating Electrical Apparatus Test
k.	ASME B31.1	Power Piping
l.	Section 3.7B	Seismic Criteria, Commanche Peak Steam Electric Station, Final Safety Analysis Report
m.	FED-STD-595	Colors
n.	MIL-Q-9858A	Quality Assurance
o.	MIL-STD-785B	Reliability Prediction of Electronic Equipment
p.	DOD-HNBK-344	Environmental Stress Screening of Electronic Equipment
q.	MIL-STD-965	Parts Control Program

3.0 REQUIREMENTS

3.1 SYSTEM DEFINITION

3.1.1 General Description

The Central Tracker of the GEM Detector is designed to operate in 0.8 Tesla magnetic field of the large GEM superconducting solenoid. The tracker is compact, with a 75 cm outer radius and a total length of 300 cm. It covers a pseudorapidity range of $\pm$ 2.5 units. The present baseline consists of the Silicon Microstrip (SM) Inner Tracker and the Interpolating Pad chamber (IPC).

The Silicon Microstrip Inner Tracker is broken into several subsystems: Silicon Ladder Assembly, Central Region Subassembly, Forward Region Planar Subassembly, Truss Space Frame, SM Cooling System, SM Alignment System, and Silicon Tracker Electronics.

The Interpolating Pad chamber consists of: Barrel IPC, Endcap IPC, IPC Cooling System, IPC Support Structures, Outer Tracker Gas System, IPC Alignment System, and IPC Front End Electronics.

3.1.2 Subsystem Diagrams

A functional schematic of the Central Tracker Subsystem is shown in Figure 3.1.2-1.

3.1.3 Central Tracker System Interfaces

The Central Tracker System interfaces with various GEM subsystems/components as summarized in the following paragraphs. These interfaces are defined in the Central Tracker Technical Design Report, GEM-TN-92-63.

3.1.3.1 Central Tracker / Magnet Interface

3.1.3.1.1 Magnetic Interface

The primary requirements imposed on the magnet interface with the Central Tracker involve the magnetic field, physical support, and access for installation and maintenance.

The tracker has modest magnetic field requirements for proper operation. The field is required to be as high as possible and uniform throughout the length of the tracker volume to 0.5%. A large superconducting solenoidal magnet with field shaping iron end poles and a field of 0.8 T will meet these requirements.

3.1.3.1.2 Magnet Structural Interface

The magnet subsystem must physically support the tracker's weight. This is accomplished through the EM Calorimeter Subsystem. The support must also allow the tracker to meet its goal for alignment stability and alignment per sections 3.2.1.7.

The magnet subsystem must also allow for routing of the Central Tracker utilities.

3.1.3.2 Central Tracker / Em Calorimeter Interface

The Calorimeter provides the mechanical support for the mounting, support, and alignment of the Central Tracker. The Central Tracker attaches to the inner barrel of the calorimeter using

kinematic mounts which transfer the weight of the tracker into the barrel subsystem of the calorimeter.

The Calorimeter must maintain and allow for adjustments necessary for alignment of the Central Tracker per Section 3.2.1.7.2.

The Calorimeter may provide electrical bonding for the Central Tracker. (This may also be accomplished through the GEM Central Support.)

3.1.3.3 Central Tracker / Muon Interface

The Calorimeter provides the mechanical support for the mounting, support, and alignment of the Central Tracker. The Central Tracker attaches to the inner barrel of the calorimeter using kinematic mounts which transfer the weight of the tracker into the barrel subsystem of the calorimeter.

The Calorimeter must maintain and allow for adjustments necessary for alignment of the Central Tracker per Section 3.2.1.7.3.

The Calorimeter must also provide routing for the Central Tracker front end electronics and cooling gases.

3.1.3.4 Central Tracker / Beam Pipe Interface

The inner diameter of the Central Tracker must allow passage of the Beam Pipe which has a radius of 8 cm.

The Central Tracker must not apply any stress to the Beam Pipe.

3.1.3.5 Central Tracker / Power Interface

The Central Tracker Subsystem consist of many components having different voltage requirements. All Central Tracker power subsystem components will be supplied by the central tracker front end system, the power supplies will be design and procured as part of the central tracker system and the AC power supplying the power supplies will be a part of the facility system. The interface will be at the power supply AC electrical connection to the power supply.

3.1.3.6 Central Tracker / Computer Interfaced

(TBD)

3.1.3.7 Central Tracker / Facility Interface

The Central Tracker System will require a dedicated facilities on site to complete the initial assembly, disassemble, and conduct maintenance operations throughout its ten year life time. The facility will contain two 10 X 10 m Class 10,000 Clean Rooms for parallel assembly operations of the Silicon Tracker and the Interpolating Pad Chamber System. A highbay, 20 X 20 m, with a 20 ton crane, with a 5 ton auxiliary, covering the entire floor area will be used to combine the two subsystems and to perform systems tests and calibration.

The Central Tracker System interfaces extensively with the above-ground and underground facilities at SSCL. The Central Tracker System must accept most of the requirements as imposed on it by the facilities design. This is the case particularly for the above ground assembly buildings.

3.1.3.8 Central Tracker / Central Detector Interface

The central detector may have gussets or struts at the tube interface. This may cause a critical installation and alignment problem for the inner central tracker chambers.

3.1.3.9 Central Tracker / Alignment Interface

The Central Tracker must maintain alignment criteria with the other systems per section 3.2.1.7.

Figure 3.1.2-1 Central tracker System Functional Schematic (TBD)

Figure 3. GEM Detector Layout

3.1.4 Central Tracker Major Components

The Central Tracker System consists of a Silicon Microstrip Inner Tracker and an Interpolating Pad Chamber Outer Tracker.

3.1.4.1 Silicon Microstrip Inner Tracker Assembly

The Silicon Microstrip Inner Tracker is broken into several subsystems: Silicon Ladder Assembly, Central Region Subassembly, Forward Region Planar Subassembly, Truss Space Frame, SM Cooling System, SM Alignment System, and Silicon Tracker Electronics.

3.1.4.1.1 Silicon Ladder Subassembly

The Silicon Microstrip Inner Tracker consists of six layers of silicon strip ladders. Each ladder is composed of two back-to-back single sided silicon sensors with a 5 mrad stereo angle between the two sensors.

In the central region, the two ladders are bonded end to end and back to back to form a 24 cm long ladder assembly. In the forward region, some of the ladder lengths may be only 4 cm. The edges of the silicon ladder are structurally reinforced with thin graphite epoxy rails to increase transverse stiffness of the assembly.

The six layers of ladders are organized into three superlayers, each of which provides a track stub to a track finding algorithm.

3.1.4.1.2 Central Region Subassembly

The Silicon Ladder assemblies are grouped into superlayers consisting of two ladder layers. There are 3 superlayers radially in the Central Region which are separated by Graphite/Epoxy support cylinders. Each superlayer is segmented into either 24 or 12 cm long Shell Assemblies, which are multiples of ladder lengths. There are a total of 12 Shell Assemblies: 3 forming the inner superlayer, 4 forming the middle superlayer, 5 forming the outer superlayer.

The ends of the 24 cm long ladder assemblies are mechanically bonded to the inside and outside diameter of the Graphite/Epoxy Cooling rings. In addition to providing the mechanical support for the superlayers, the hollow cooling ring provides the passage for the wick coolant distribution. The external surface will contain the signal readout and power distribution bus.

3.1.4.1.3 Forward Region Planar Subassembly

Design specifications and details for the Forward Region Planar Subassemblies are similar to those of the Central Region. The wafers will be tapered from a maximum of 33 mm wide toward the centerline, with ladder lengths 4, 6 or 10 cm. Identical electronics are mounted at the readout end of the wafers.

Structural support for the ladders will come from an inner and outer ring constructed of low mass graphite/epoxy with 3 interconnected spokes at 120° intervals.

3.1.4.1.4 Truss Space Frame Subassembly

The Central and Forward Planar subassemblies will be installed into a low mass, highly stable truss space frame. The Truss Space Frame must be able to maintain relative alignments for long

periods of time.

The Frame must also meet the following requirements: Butane vapor compatibility, radiation compatibility, thermal stability, low creep, ease of assembly and installation.

Aluminum Metal Matrix Composite material meets these requirements. The material has a high elastic modulus with an acceptable radiation length, it has no moisture sensitivity, and can be modified to a near zero modulus of thermal expansion.

3.1.4.1.5 Silicon Microstrip Gas Enclosure Subassembly

A gas enclosure will be required to contain the Butane vapor and prevent external gasses from contaminating the butane coolant. The enclosure design must meet the radiation length requirements and the withstand the external and internal pressure.

The outer shell enclosure will be constructed of a double wall truss core made of graphite/epoxy materials. The inner enclosure will be constructed of Beryllium to minimize the radiation. Removable end are required to allow access to the ends of the Tracker where utilities and signals pass through the gas enclosure.

A secondary enclosure of double wall truss core design will be used to contain any potential butane leak. This layer will flow Nitrogen gas and will contain a Hydrocarbon Sensor.

3.1.4.1.6 Silicon Microstrip Cooling Subassembly

Heat generated in the Central Region Subassembly is extracted through 12 cooling rings of 3 different diameters. The Forward Region contains 40 cooling rings.

The cooling rings uses an evaporative phase change system that is a closed loop thermo-siphon system with liquid priming and temperature stability self regulating.

3.1.4.1.7 Silicon Microstrip Alignment Subassembly

A monitoring system for the silicon tracking system is required to achieve a high resolution system. Resolution of detector alignment will be sufficient to determine when another calibration is required.

Central Tracker alignment system and methodology is currently under development.

3.1.4.1.8 Silicon Microstrip Electronics Subassembly

The detector electronics subsystem is divided into four functional blocks: the front-end electronics, fiber-optic data link, power and slow control, and data acquisition.

3.1.4.1.8.1 Silicon Microstrip Front End Electronics

The silicon microstrip front end electronics provides the following:

- bias and ground connection to the strip detectors
- collects charges from each strip detector and shapes the signal discrimination
- produces a logic pulse when signal exceeds threshold level for each channel per beam crossing

- buffers and process (compresses) the logic bit pattern of multiple strips for read out
- sends the bit pattern for a specific beam crossing event to the fiber optics after receiving triggers
- performs housekeeping functions such as monitoring voltages, currents and temperatures

3.1.4.1.8.2 Silicon Microstrip Fiber Optics

Fiber Optics link the front end electronics with the rest of the electronics. It provides two separate links: one for data read out and the other for clock and trigger inputs.

The Fiber optics have to penetrate the hermetic enclosure of the Silicon Tracker through special connectors.

3.1.4.1.8.3 Power Distribution And Slow Control

The Power Distribution Subsystem consists of the power supplies with the necessary controls, interfaces and safety features and the cabling from the power supplies to the Multichip Modules.

The Slow Control section will monitor the health status of the system and be responsible for system initialization. It will also update the on-line database with regard to system status.

3.1.4.1.8.4 Data Acquisition

Data Acquisition Subsystem is the origin and destination of the fiber optic link signals interfacing the Multi-Chip Modules with the external systems. It receives the Front-End beam crossing data from each Multi-Chip Module and send it to the central data processing unit. It also sends the clock and trigger signals from the detector house to the Multi-Chip Modules.

3.1.4.2 Interpolating Pad Chamber Assembly

The Interpolating Pad Chamber consists of: Barrel IPC, Endcap IPC, IPC Cooling System, IPC Support Structures, Outer Tracker Gas System, IPC Alignment System, and IPC Front End Electronics.

3.1.4.2.1 Barrel IPC Subassembly

The barrel IPC modules consist of 4 modules per sector with a total of 20 sectors. The Barrel IPC modules are supported by two honeycomb core composite annular disks at $Z = \pm 100$ cm. The disks are tied together by honeycomb core cylinders at the outer and inner radii. All of these components are made out of graphite/epoxy materials.

The modules are installed alternately at each end to allow sector overlap and leave enough material on each support disk for structural continuity.

3.1.4.2.2 Endcap IPC Subassembly

The Endcap IPC modules are arranged radially about the beam line. The modules are less than 50 cm in length. The "S" cross-section allows for module overlap.

The endcaps will be enclosed in gas volumes similar to the barrel section.

3.1.4.2.3 IPC Cooling System

The Interpolating Pad Chamber Cooling System cools the electronics mounting boards of the outer tracker. The system uses water flow through an aluminum conduit which is bonded to the side of each board opposite the electronic components.

3.1.4.2.4 Outer Tracker Gas System Subassembly

The Outer Tracker Gas System provides ionization gas for the Interpolating Pad Chambers of the outer tracker of the GEM Detector. The Outer Tracker Gas System is a recirculating type using an equimolar mixture of CO_2 and CF_4.

3.1.4.2.5 IPC Alignment Subassembly

Methods of alignment of the GEM IPC tracking array and between the IPC tracker and other GEM subsystems have not been defined.

3.1.4.2.6 IPC Front End Electronics Subassembly

The front end electronics for the GEM Outer Tracker consist of CMOS integrated circuits. The front end electronics for the outer tracker can be broken down into four main components: the IPC Preamp and shaper, the IPC Switched Capacitor Array, the IPC Flash ADC, and the IPC Readout Controller.

3.1.4.2.6.1 IPC Preamp And Shaper

The front end preamp and shaper IC is packaged as a separate chip in order to minimize the noise coupling of the digital signals in the analog readout.

The preamp design uses an n-channel input device in a folded cascade configuration.

The shaper is a low-pass stage that has a second order transfer function. A passive differentiator and two stages of this type form a shaper whose peaking time can be controlled (for all channels on a chip) by a single bias without distorting the shape of the resulting pulses.

3.1.4.2.6.2 IPC Switched Capacitor Array

The switched Capacitor array is a 16 channel, approximately 128 deep array, fabricated in the rad-hard Harris AVLSI process. The SCA will be fabricated on the same wafer as the preamp/shaper. It currently is based on a voltage write-charge read topology (VWCR).

3.1.4.2.6.3 IPC Flash ADC

A 6-8 bit video Flash ADC (FADC) has been designed in the Harris AVLSI process. The FADC operation is based on the action of a large number of voltage comparators.

3.1.4.2.6.4 IPC Readout Controller

The IPC readout controller is a state machine that drives the readout sequence, addresses drivers for the analog pipelines, a 128x8 static RAM buffer holding the threshold values used in zero suppression function, an 8 bit comparator, an output buffer, and test and calibration circuits. The

readout controllers on an IPC chamber are serviced by a single low bandwidth input link. This allows the threshold values to be set, and allows it to trigger test and calibration functions.

The readout controller is responsible for driving the switched capacitor array write address lines, which are common to all arrays serviced by a single readout controller.

3.2 CHARACTERISTICS

3.2.1 Performance

3.2.1.1 Resolution

3.2.1.1.1 Momentum Resolution

Assisting in electron-hadron separation is one of the primary physics goals for the Central Tracker. This is accomplished by providing momentum measurements that can be compared with the energy deposition in the calorimeter.

A secondary physics goal for the Central Tracker is to provide tracking at low momenta with good resolution.

Specific momentum requirements for momentum resolution for the Central Tracker are:

a. High Momenta (measurement limited) - The central tracker shall have a momentum resolution at high momenta of $\Delta p / p^2 \sim 1$ to $3\ 10^{-3}$ GeV/c.

b. Low Momenta (multiple scattering limited) - The central tracker shall have a momentum resolution at low momenta of $\Delta p / p \sim 2$ to 4%.

3.2.1.1 Vertex Resolution

The Vertex resolution of the Central Tracker along the beam direction impact parameter shall be:

$\delta z \sim 1$ mm

$\delta b \sim 30$ mm above 10 GeV/c

3.2.1.2 Rapidity Coverage

The Central Tracker shall have a pseudorapidity coverage of $-2.5 < \eta < 2.5$.

3.2.1.3 Chamber Occupancy

The occupancy design goal for the Central Tracker at $L = 10^{33}\ cm^{-2}\ s^{-1}$ is $\leq 1\%$.
At $L = 10^{34}\ cm^{-2}\ s^{-1}$, the Central Tracker shall have an occupancy $\leq 10\%$.

3.2.1.4 Charge Separation

The Central Tracker must be able to determine the electron sign up to 600 GeV/c at 95% c.l.

3.2.1.5 Stability

3.2.1.5.1 Silicon Microstrip Inner Tracker Region

Silicon alignment stability shall be within 10 mm.

3.2.1.5.1 Interpolating Pad Chamber Region

Pad chamber alignment stability shall be within 25 mm.

3.2.1.6 Lifetime

The design lifetime of the Central Tracker Subsystem shall be a minimum of 5 years and a maximum of 10 years.

3.2.1.7 Alignment

The Central Tracker System must match a shower centroid in the calorimeter to approximately 1 millimeter. This means that the allowable rotation of the beam axis with the Central Tracker System axis is 5 mrad if the CTS and the calorimeter are fixed together and 0.5 mrad if they are not.

3.2.1.7.1 Central Tracker / Beam Interaction Alignment

Placement requirements between the Central Tracker and the Beam Pipe are ϕ = none, $r \leq 250$ mm, and Z = none. Measurement requirements are $\phi \leq 250$ mm, $r \leq 250$ mm, and $Z \leq 500$ mm. Stability requirements are $\phi \leq 100$ mm, $r \leq 100$ mm, and Z about 500 mm.

3.2.1.7.2 Central Tracker / Em Calorimeter Alignment

Placement requirements between the Central Tracker and the Electromagnetic Calorimeter are $\phi \leq 250$ mm, $r \leq 250$ mm, and $Z \leq 500$ mm. Measurement requirements are $\phi \leq 250$ mm, $r \leq 250$ mm, and $Z \leq 500$ mm. Stability requirements are $\phi \leq 200$ mm, $r \leq 200$ mm, and $Z \leq 500$ mm.

3.2.1.7.3 Central Tracker / Muon Chamber Alignment

Placement requirements between the Central Tracker and the Muon Chambers is within centimeters for ϕ, r, and Z. Measurement requirements between the two units are $\phi \leq 100$ mm, $r \leq 100$ mm, and Z within millimeters. Stability requirements are $\phi \leq 200$ mm, $r \leq 200$ mm, and Z within millimeters.

3.2.1.8 Grounding Requirements

All metallic surfaces not requiring electrical isolation, shall be attached with low resistance techniques and be at the ground potential of the shell. The connections shall not create any undesired ground loops that may impact operation, testing or safety.

Grounding for the Central Tracker shall be accomplished either through the GEM Calorimeter or through the GEM Central Support.

3.2.2 Physical Characteristics

3.2.2.1 Size

The outer radius of the Central Tracker shall not exceed 95 cm. The length shall not exceed 300 cm.

3.2.2.1 Silicon Microstrip Size

The inner radius of the Silicon Microstrip shall not be less than 10 cm. The outer radius of the Silicon Microstrip shall not exceed 35 cm. The length shall be ~ 200 cm.

3.2.2.1 IPC Size

The inner radius of the Interpolating Pad Chamber shall not be less than 35 cm. The outer radius of the IPC shall not exceed 95 cm. The length shall not exceed 300 cm.

3.2.2.2 Weight

The Central Tracker shall minimize its total mass. The approximate weight of the components described in paragraph 3.1.4 are shown below.

COMPONENT	ESTIMATED WEIGHT (kg)
Silicon Microstrip Inner Chamber	**TBD**
Interpolating Pad Chamber	**TBD**

3.2.2.3 Radiation Length

The Central Tracker shall minimize the radiation length of materials used.

3.2.2.4 Power

Conventional power and technical power will conform to, ANSI C84.1 and ANSI/IEEE 241-1983.

120 volt power will be 1 phase, separate ground wire, 120 VAC, 60 Hz.
208 volt power will be 3 phase, 4 wire, 208 VAC, 60 Hz.
277 volt power will be 1 phase, separate ground wire, 277 VAC, 60 Hz.
480 volt power will be 3 phase, 4 wire, 480 VAC, 60 Hz.

3.2.3 Reliability

The central tracker subsystem shall have adequate design margins to ensure the capability to operate continuously or intermittently without failure or degradation of performance over its useful life of 10 years.

3.2.3.1 Operational Reliability

The Central Tracker shall achieve a mean-time-between-critical-failure (MTBCF) of **TBD** hours. MTBCF is defined as the total uptime divided by the number of failures that degrade full operational capability (FOC). FOC is that level of performance which allows the Central Tracker to perform the functions listed in Section 3.1 without degrading below minimum levels stated in 3.2.3.2.

3.2.3.2 Reliability Performance Criteria

The minimum performance criteria shall be met for full operational capability of the Central Tracker is defined as the capability to acquire useful tracker data over 95% (TBR) of the planned coverage. No more than 0.5% (TBR) of the 5% loss shall be in any one contiguous area.

3.2.3.3 Availability

The Central Tracker shall have an operational availability of 98% (TBR) over the standard operational year of 5631 hours where operational availability is defined as

$$A_O = \frac{\text{Annual Operating Time - Mean Down Time}}{\text{Annual Operating Time}}$$

3.2.3.4 Service Life

The Central Tracker shall be designed for a minimum service life of ten (10) years of operation while achieving the operational reliability defined in 3.2.3.1.

3.2.4 Maintainability

The Central Tracker Subsystem shall provide for:

a. Interchangeability of assemblies and equipment elements (primarily surface support equipment) that are designed for removal and replacement as the normal corrective maintenance action .
b. Major repair and assembly replacement within the 3 mo. period required to open and close the magnet.
Standardization and simplicity of test equipment and its use.
c. Accessibility for in-place maintenance and inspection consistent with the design constraints, and tools and test equipment.
d. Capability of being repaired by skilled/semi-skilled technicians possessing central tracker specific training, working under an experienced supervisor.
e. Minor periodic realignment in 6 shifts while installed in the experimental hall.

3.2.5 Environmental Conditions

The Central Tracker shall meet the performance requirements of 3.2.1 after exposure to the non-operating environments and during exposure to the operating environments (except shock) defined in the following paragraphs. The Central Tracker and its components shall be protected as necessary to prevent degradation due to exposure to these environments which may occur separately or in combination during shipping, handling, assembly, installation, and operation.

3.2.5.1 Temperature

a. Operating Ambient Temperature: +23 °C ± 1 °C
b. Detector Hall Pre-Operating Temperatures: +12 °C ± 5 °C

3.2.5.2 Humidity

a. Operating: 45 % ± 5 %
b. Non-Operating: 10 % to 98 %

The central tracker subassemblies shall be protected during manufacturing, installation, pre-operating and operating conditions to prevent degradation due to humidity.

3.2.5.3 Foreign Debris

During all phases of assembly, test, and installation the magnet components shall be protected from contamination or damage from foreign debris.

3.2.5.4 Corrosive Atmosphere

The central tracker subsystem shall not degrade when exposed to the expected operating and pre-operating environments.

3.2.5.5 Radiation

a. Operating: 10 Mrad
b. Non-Operating: None

3.2.5.6 Magnetic Environment

a. Operating: 0.8 Tesla
b. Non-Operating: Residual

3.2.6 Transportability / Handling

For movement of components to the receiving site at SSCL and for movement/handling of the central tracker subassemblies at SSCL, the items shall be transportable without detrimental degradation in alignment or performance. During movement and handling for assembly or installation, mechanical restraints may be used to prevent misalignment or damage. Provisions shall be made for measuring environmental conditions (temperature, moisture and vibration) during transport and handling to verify that the magnet has not exceeded the vibration environment shown in 3.2.9, the shock loads of 3.2.9, the temperature limits of 3.2.5.1, or the humidity levels of 3.2.5.2.

3.2.7 Installation

The central tracker subsystem shall be lowered to the experimental hall installed into the magnet volume, while the magnet is in the open position. The magnet will be moved to the operational position where the final acceptance test will be performed.

3.2.8 Storage Protection

The central tracker subsystem, and its components during assembly and installation, shall be protected from the temperature and humidity environments specified herein that may cause loss of prestress, creep, water absorption or other detrimental efforts.

3.2.9 Vibration Environment

The response of the central tracker subsystem to vibrations present in the tunnel and experimental hall, as described in SSC -SR-1043, "Field Measurements and Analysis of Underground Vibrations at the SSC Site", shall not exceed field alignment tolerances specified herein. The suspension system shall not degrade or suffer fatigue that will reduce the capability of meeting the life expectancy when subject to the tunnel vibrations over operating and non-

operating temperature ranges, the vibrations during transportation (per attached (**TBD**) PSD curves), the vibrations due to cryogenic equipment operation and flow.

3.2.10 Shock Loads

The central tracker subassemblies shall be designed to handle static loads and seismic loads defined in section 3.2.11. Additional loads imposed by transportation and rigging shall be addressed by additional design enhancements and analysis to meet the factors of safety defined in section 3.3.6. Shock loads imposed by transportation and rigging shall be minimized and thoroughly analyzed in the design documentation.

3.2.11 Earthquake Loads

The central tracker subsystem shall meet the intent of the earthquake criteria defined in section 3.7B, Seismic Criteria, of the Commanche Peak Steam Electric Station Final Safety Analysis Report. Commanche Peak is a power plant operated by Texas Utilities near the SSCL. This report defines design response spectra for both horizontal and vertical motion. Maximum ground accelerations are defined to be 0.08 vertical and 0.12 horizontal. Factors of safety under dynamic load for all systems shall be those defined in section 3.3.6.

3.3 DESIGN AND CONSTRUCTION

Level three drawings and associated lists shall be provided. P40-000001, P40-000004, P40-000013, P40-000017, P40-000030, and P40-000034 shall be used in preparation of these documents.

3.3.1 Materials, Processes, And Parts

Where applicable the central tracker subsystem shall be designed and fabricated in accordance with the AISC Structural Design Code, full compliance with material and fabrication requirements are required for all components of the assembly. Pressure subsystems shall be designed to the intent of the ASME Boiler and Pressure Vessel Code (B&PVC), section VIII and ANSI/ASME B31.1 (Power Piping) and B31.3 (Chemical Plant and Refinery Piping Code). Design of vacuum components shall conform to (B&PVC) design requirements unless otherwise approved by SSCL.

3.3.1.1 Corrosion Prevention And Control

Materials used shall be either of a corrosion resistant type or suitably treated to resist corrosion. Protective methods and materials for cleaning, surface treatment, and application of finishes and protective coatings shall be implemented.

Direct externally exposed surface-to-surface contact between dissimilar metals shall be controlled according to the best available practices for corrosion prevention and control, and leak tightness. Preventive maintenance may be used on external tracker components to control corrosion.

3.3.1.2 Materials To Be Avoided

Only materials consistent with the radiation environment shall be used in design and construction. Radiation sensitive materials such as PTFE shall not be used be used.

The Central Tracker shall not include ozone depleting chemicals and shall minimize the use of hazardous materials including those used in the hardware and those required to maintain or

service hardware.

3.3.1.3 Weldments

All manufacturing and field Weldments of pressure components shall conform to the requirements of ASME B&PVC, section VIII and ANSI/ASME B31.3 as applicable. The design shall accommodate the use of standard welding machines to allow for conformance to this requirement. Welding, and weld test and acceptance, shall be accomplished according to Process Control Procedures that have been reviewed and accepted by the SSC Laboratory. Flanges provided for repair/maintenance activities shall not be degraded by up to **6 (TBR)** such activities.

3.3.1.4 Coating, Potting, And Molding

Coating, potting and molding shall conform to the subcontractor's specifications, standards and drawings. These shall be submitted to SSCL for review prior to use.

3.3.1.5 Selection Of Parts

The design agency shall establish and maintain a parts control program using Task 207 of MIL-STD-785 and Procedure 1 of MIL-STD 965 as a guideline. The materials selected for use in the Central Tracker shall not degrade when subject to thermal cycling, cryogenic temperatures, radiation environments, vacuum or other conditions consistent with design and application.

3.3.1.6 Soldering And Brazing

Coating, potting and molding shall conform to **TBD** standards and drawings.

3.3.1.7 Environmental Stress Screening

Components within the Central Tracker subsystem and other components whose location and reliability could preclude meeting the intent of 3.2.4 shall be subjected to environmental stress screening using Task 301 of MIL-STD-785 and Procedure 1 of MIL-STD 965 as a guideline.

3.3.2 Nameplates And Product Markings

Nameplates, product marking, serial and lot number markings, and all other identifying informational and certifying marking shall be according to the SSC Laboratory's direction.

3.3.3 Workmanship

The central tracker subsystem shall be fabricated with repeatable field quality and finished in a thoroughly workmanlike manner. Particular attention shall be given to freedom from blemishes, defects, burrs, sharp edges and foreign materials; saturation inductance of magnetic materials; accuracy of dimensions; application of insulating material; care during assembly; radii of fillets; marking of parts; thoroughness of cleaning; quality of brazing, welding, riveting, painting and wiring; alignment of parts; and specification tightness, prestress and torquing of fasteners. MIL-STD-454, Requirement 9, shall be used as a guide in applying workmanship standards.

3.3.4 Safety

Safety shall be consistent with the DOE policy of providing employment and a place of employment free from recognized occupational safety and health hazards by complying with the DOE Order 5481.1B and DOE prescribed OSHA standards. The central tracker subsystem shall be designed to comply with the National Electric Code (NFPA-70). Specific personnel hazards

and/or special instructional markings of hardware shall be identified and noted on applicable drawings or procedures.

The GEM Preliminary Safety Assessment Report, PSAR, shall identify the hazards and mitigating actions associated with the design and operation of the Central Tracker. This will also include a hazard list for the Central Tracker.

3.3.5 Human Performance / Human Engineering

The central tracker subsystem design shall be consistent and compatible with the human capabilities required to build, test, install and repair, in a repeatable, consistent, effective and safe manner. This includes tasks, tools, equipment, environment, personnel-equipment interfaces and other items required of this design. Mature, performance proven, standard, commercially available equipment shall not be modified unless safety to personnel or equipment is a factor. MIL-STD-1472 shall used as a guideline.

3.3.6 Allowable Stresses

Piping shall comply with ANSI/ASME B31.3 (Chemical Plant and Refinery Piping) Code. The design of all other pressure vessel components shall comply with the ASME Boiler and Pressure Vessel Code, Section VIII. In addition, the design of non-pressure vessel ferrous components shall be based on the material allowable stresses for the materials used at the temperature at which the applied or internal loads are expected for all applicable combinations of loads.

Any composite or non-metallic material used in a critical application may be used up to 40% of ultimate strength and then only when sufficient statistical data are available to a 50% level of confidence. Materials with insufficient strength data shall be accompanied with a test program to determine physical properties before usage.

Loading conditions include, but shall not necessarily be limited to: gravity, static shell preload, steady-state and transient magnetic, steady state and transient thermal, steady state and transient cryogenic fluid pressure, earth motion, transportation/handling, ambient environmental, and the loads listed herein.

For allowable stresses not specified above, the intent of the following industrial codes shall apply as appropriate:

a. Code(s) of American Society of Mechanical Engineers (ASME)
b. Code(s) of American Society for Testing and Materials (ASTM)

3.4 MAINTENANCE

3.4.1 Scheduled Maintenance

The design shall minimize the requirement for scheduled maintenance and repair.

3.4.2 Preventive Maintenance

Minimal preventive maintenance shall be required during operational use or extended periods of non-use. Preventive maintenance shall be limited to visual inspection, cleaning surfaces, cryogenic and vacuum pump servicing, and similar tasks to ensure that the Central Tracker does not deteriorate with age or use. Redundancy shall be considered for those components requiring preventive maintenance.

3.4.3 Corrective Maintenance

Minor corrective maintenance (i.e. not requiring access to the interior of the detector) shall be accomplished during a scheduled downtime of one day per week (940 total hours).

Major corrective maintenance (i.e. requiring access to the interior of the detector) shall be accomplished during a once-per-year downtime of three months (2190 total hours).