Fermilab

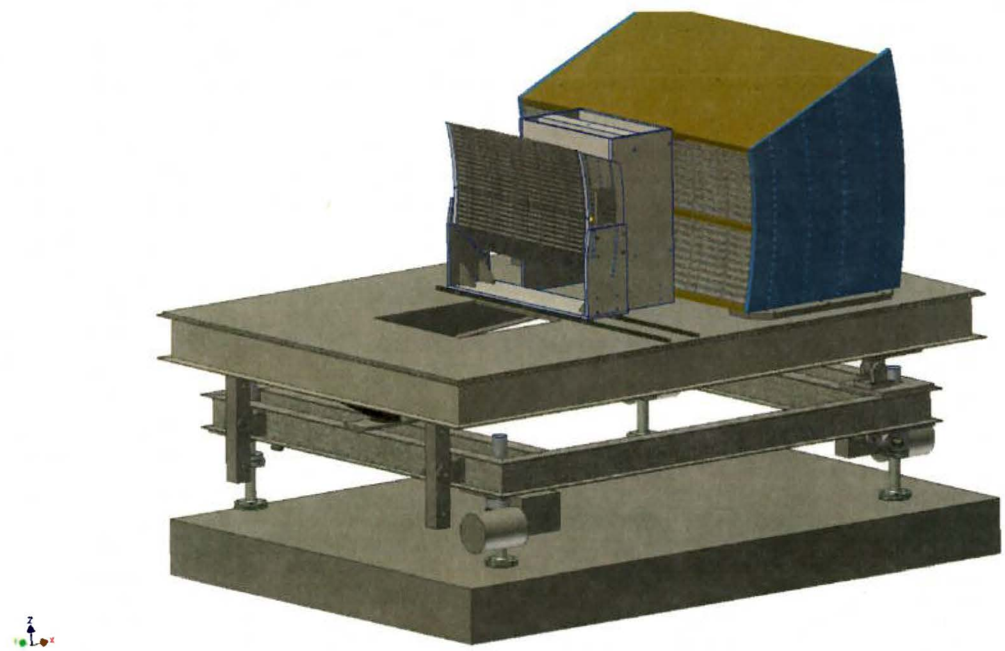
Directorate

TECHNICAL SCOPE OF WORK
FOR THE 2016 FERMILAB TEST BEAM FACILITY PROGRAM

T-1044

sPHENIX Calorimetry Test Update

January 20, 2016



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INTRODUCTION

This is a technical scope of work (TSW) between the Fermi National Accelerator Laboratory (Fermilab) and the experimenters of the sPHENIX collaboration who have committed to participate in beam tests to be carried out during the FY2016 Fermilab Test Beam Facility program.

The TSW is intended primarily for the purpose of recording expectations for budget estimates and work allocations for Fermilab, the funding agencies and the participating institutions. It reflects an arrangement that currently is satisfactory to the parties; however, it is recognized and anticipated that changing circumstances of the evolving research program will necessitate revisions. The parties agree to modify this scope of work to reflect such required adjustments. Actual contractual obligations will be set forth in separate documents.

This TSW fulfills Article 1 (facilities and scope of work) of the User Agreements signed (or still to be signed) by an authorized representative of each institution collaborating on this experiment.

Description of Detector and Tests:

The sPHENIX upgrade to the PHENIX detector is designed to study jets in heavy ion collisions at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory and address questions about the nature of the perfect fluid, the quark-gluon plasma. The upgrade consists of the 1.5 Tesla BaBar superconducting solenoid, central tracking, electromagnetic and hadronic calorimeters with uniform coverage over a rapidity range of $|\eta| < 1.1$ and 2π in azimuth. The sPHENIX detector concept takes advantage of technological developments to enable a compact design with excellent performance. A tungsten-scintillator electromagnetic calorimeter read out with silicon photomultipliers (SiPMs) allows for a physically thin device, which can operate in a magnetic field, without the bulk of photomultiplier tubes and the need for high voltage distribution. The smaller electromagnetic calorimeter also allows the hadron calorimeter to be less massive, and the use of silicon photomultipliers for the hadron calorimeter allow for nearly identical electronic readout for the calorimeter systems.

The requirements for the sPHENIX electromagnetic calorimeter (EMCal) leads to a design that is compact (i.e. has a small Molie`re radius and short radiation length), has a high degree of segmentation (0.024×0.024 in η and ϕ), and can be built at a reasonable cost. The reference design calls for the EMCal to be located inside the solenoid with an inner radius 90 cm of and outer radius of 116 cm. The electromagnetic calorimeter will be a SPACAL design using scintillating fibers embedded in a tungsten powder infused epoxy. Light mixing blocks on the inner radius will be coupled to SiPMs to provide the optical readout and define the tower geometry of the EMCal. The physics goals of sPHENIX require that the EMCal have a modest energy resolution of $\leq 15\%/\sqrt{E}$.

The hadronic calorimeter (HCal) performance requirements are directly tied to the physics goals of sPHENIX. The focus of sPHENIX on measuring jets and dijets in heavy ion and proton collisions leads to a requirement of good energy resolution, $\sigma_E/E = 100\%/\sqrt{E}$, and transverse segmentation of the HCal, $\Delta\eta \times \Delta\phi \approx 0.1 \times 0.1$ over a rapidity range of $|\eta| < 1.1$ with minimal dead area. The combination of the EMCal and HCal needs to be at least 6 λ_{int} lengths deep in order to absorb 97% of impinging hadrons with momenta below 50GeV/c. The electromagnetic calorimeter is ~ $1\lambda_{int}$ thick, so an iron-scintillator hadronic calorimeter should be ~ $5\lambda_{int}$ deep. The HCal also serves as the flux return for the solenoid in the sPHENIX design.

These performance requirements lead to an HCal design that consists of 2 sections, inner and outer, 1.5 and 3.5 interactions lengths deep respectively. Both in the inner and outer sections segments are constructed of tapered absorber plates, tilted with respect to a radius vector perpendicular to the beam axis. The plates for the inner and outer sections are tilted in opposite directions and staggered by half the thickness of the plates. The gaps between the iron gaps are 8mm wide and contain individually wrapped 7 mm thick scintillating tiles with a diffuse reflective coating and embedded wavelength shifting fibers following a serpentine path. Both ends of the fibers are coupled to an SiPM mounted on the detector for readout.

The acquisition of the BaBar solenoid by the PHENIX collaboration has resulted in a change in the reference design of the sPHENIX detector since the initial T-1044 run. At the time of the original proposal, the reference design called for the electromagnetic and hadronic calorimeters being outside the cryostat. With the larger BaBar solenoid, the electromagnetic and inner hadronic calorimeter have been moved inside the cryostat and the outer hardronic calorimeter has been positioned against the outer radius of the cryostat and serves as the flux return for the solenoid as shown in Figure 1. With the inner hadronic calorimeter now inside the solenoid, the inner absorber plates are now constructed from non-magnetic stainless steel while the outer plates continue to be steel to provide the magnetic flux return.

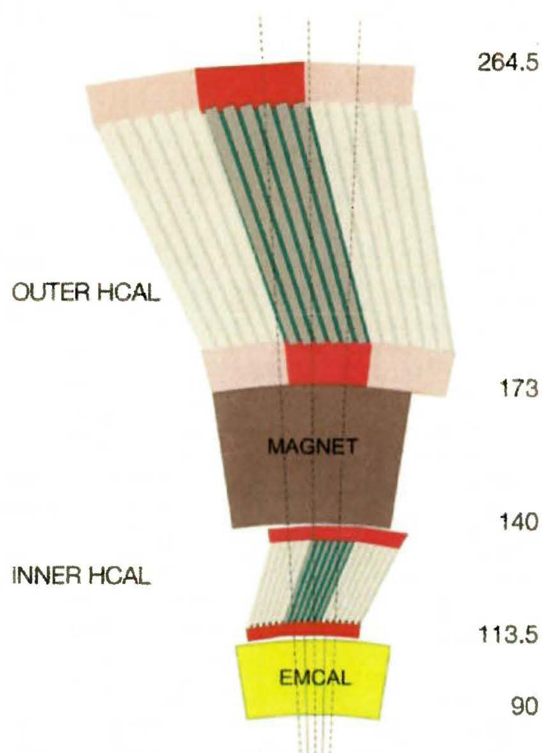


Figure 1: Cross section view of the sPHENIX detector showing the location of the EMCal, Inner HCal, Cryostat and Outer HCal. The steel absorber plates for the Outer HCal serve as the flux return for the magnet.

The February 2014 running of T-1044 was very successful. Construction of the EMCal prototype allowed for a better understanding of the challenges of constructing a wavy plate, scintillating fiber device. Although the device did not ultimately meet the energy resolution goals, an energy resolution of $30\%/\sqrt{E}$ was achieved. The poor performance has been attributed in part to poor light collection, non-uniformity of the wavy plate design and deficiencies in the front-end analog signal processing.

The HCal prototype construction also highlighted a number of challenges associated with building a large tilted plated calorimeter with wave shifting fiber readout. The HCal data has also been analyzed and the results have been summarized in a PHENIX technical note. The data was compared to a GEANT4 based simulation of the prototype detector. The *e/h* ratio varies from 1.2 to 1.9 for beam energies up to 20 GeV and the shape of the energy spectrum is consistent with the simulation results.

Since the first run of T-1044 in 2014, the prototype calorimeters have been modified to reflect the new reference detector design and implement changes based on what was learned in the first run of T-1044. The design for the EMCal detector is a 1-D SPACAL design similar to the EMCal being designed at UCLA and tested in T-1018. The HCal detector has been modified to consist of 2 sections, inner and outer, with 1 λ_0 of material separating the two sections to simulate the cryostat. The optical sensors used in the initial test beam run have been replaced with 40K $15\mu m^2$ micro-pixel devices. The increase in the number of pixels increases the dynamic range of the device, while the smaller feature sizes reduces the sensitivity of the devices to the effects of neutron radiation. While neutron radiation is not an issue for test beam operations it will be an issue for sPHENIX running at RHIC. The frontend amplifiers have been upgraded to improve the signal-to-noise and a switchable gain setting allows the detector to be calibrated on MIP signals from cosmic muons. The next generation digitizer boards based on 14-bit ADCs are also expected to be available for the next test beam run in the spring of 2016.

The goals for this test beam experiment are to verify the performance of the electromagnetic and hadronic calorimeters for hadrons with energies ranging from a few GeV to 50 GeV and a variety of geometrical orientations of the detectors to the impinging particles, In addition, the tests will allow testing of the electronics that are being designed for the calorimeter readout. In order to accomplish these goals, the experimenters anticipate an initial 5 weeks effort at the M-Test facility. The first week will be devoted to detector assembly and testing, followed by 4 weeks of beam tests. A second run planned for FY17 will test the performance of the high rapidity region of the detector. Details of the proposed schedule can be found in Section 2.4.

PERSONNEL AND INSTITUTIONS:

Spokesperson: Eric Mannel

Lead Experimenter in charge of beam tests: John Haggerty

Fermilab Experiment Liaison Officer: Mandy Rominsky

The group members at present are:

	Institution	Country	Collaborator	Rank/Position	Other Commitments
1.1	Brookhaven National Laboratory	USA	Mickey Chiu	Scientist	PHENIX
			Achim Franz	Scientist	PHENIX
			John Haggerty	Scientist	PHENIX
			Edouard Kistenev	Scientist	PHENIX
			Eric Mannel	Scientist	PHENIX
			Martin Purschke	Scientist	PHENIX
			Chris Pinkenburg	Scientist	PHENIX
			Craig Woody	Scientist	PHENIX
			Craig Woody	Scientist	PHENIX
			Bob Azmoun	Physics Associate	PHENIX
			Sean Stoll	Physics Associate	PHENIX
			Steve Boose	Elect. Engineer	PHENIX
			Rich Ruggerio	Design Engineer	PHENIX
			Carter Biggs	Technician	PHENIX
			Michael Lenz	Technician	PHENIX
			Frank Toldo	Technician	PHENIX
1.2	Georgia State University	USA	Xiaochun He	Professor	PHENIX
			Megan Conners	Professor	PHENIX
1.3	University of Illinois	USA	Anne Sickles	Professor	PHENIX
			Vera Loggins	Post-Doc	PHENIX
					PHENIX
					PHENIX
1.4	University of Michigan	USA	Christine Aidala	Professor	PHENIX
1.5	University of Colorado	USA	Jamie Nagle	Professor	PHENIX
			Ron Belmont	Post-Doc	PHENIX
					PHENIX
					PHENIX
					PHENIX

I. EXPERIMENTAL AREA, BEAMS AND SCHEDULE CONSIDERATIONS:

2.1 LOCATION

2.1.1 The beam test(s) will take place in the MT6.2-B and MT6.2-D areas. Initial testing of the EMCal in standalone mode will be done in the MT6.2-B area on the small motion table. The HCal will be installed on the support table and located on the floor of the MT6.2-D floor. For combined detector testing, EMCal will be located on front section of the support table.

2.1.2 The experimenters request additional space, 3 x 4 m^2 outside the beam line enclosure for initial setup and debugging of the readout system. The space should have access to electrical power for electronics including a 220-3phase AC outlet for low voltage bulk power supplies, 2 tables to serve as work surfaces, and 1 standard height rack. In addition a cabinet for storage will be needed.

2.2 BEAM

2.2.1 BEAM TYPES AND INTENSITIES

Energy of beam: 1 GeV – 60 GeV
Particles: pions/muons/electrons
Intensity: 10k – 100k in units of particles/ 4 sec spill
Beam spot size: about 1cm^2

2.2.2 BEAM SHARING

During dedicated running, limited running of parasitic upstream experiments will be considered provided they do not insert a significant amount of material in the beam, and can be readily moved out of the beam for cross calibration to understand the effects of the material present. Given the type of detectors, electromagnetic and hadronic calorimetry, and being located in the downstream portion of the MT6.2 test area, downstream parasitic operations are not possible. In the beam direction, the EMCal is ~18X_0 and 1 λ_{int}, and the HCal is ~35 X_0 and 5 λ_{int} in length.

2.2.3 RUNNING TIME

The experimenters request a total of 4 weeks beam time during the month of April 2016. The first week will be devoted to characterizing the MTest Beam, understanding the MTest infrastructure (e.g MPWCs, PbGlass, Cerenkov counter) and commissioning the sPHENIX calorimeters. The last three weeks of running will be devoted to detailed studies of the sPHENIX calorimeter performance for different beam energies, species and detector configurations.

The experimenters anticipate running during the standard operational hours of the M-Test beam line. During the initial startup phase, frequent accesses of varying length are anticipated to commission the system. Once commissioned, the experimenters anticipate several accesses per day to re-position the detector to study geometrical properties of the detector and changes in the beam tune to understand the energy response of the detectors. See section 2.4 for total run time and long-term schedule.

2.3 Experimental Conditions

2.3.1 Area Infrastructure

The sPHENIX prototype calorimeter consists of a 64 tower EMCal module, 16 tower Inner HCal detector, dummy cryostat, and 16 tower Outer HCal detector, along with trigger and veto counters mounted on a support structure that can be tilted $\pm 5^{o}$ in the vertical plan. For the April running the detector will be configured to match the central rapidity region of the sPHENX detector (~ ± 0.1 in η). The over all dimensions of the detectors on the support structure measure 10 x 9 x 7 ft^3 and weighs ~21,000lbs. Drawings of the 3 detectors and dummy cryostat on the table are shown in Figure 2.

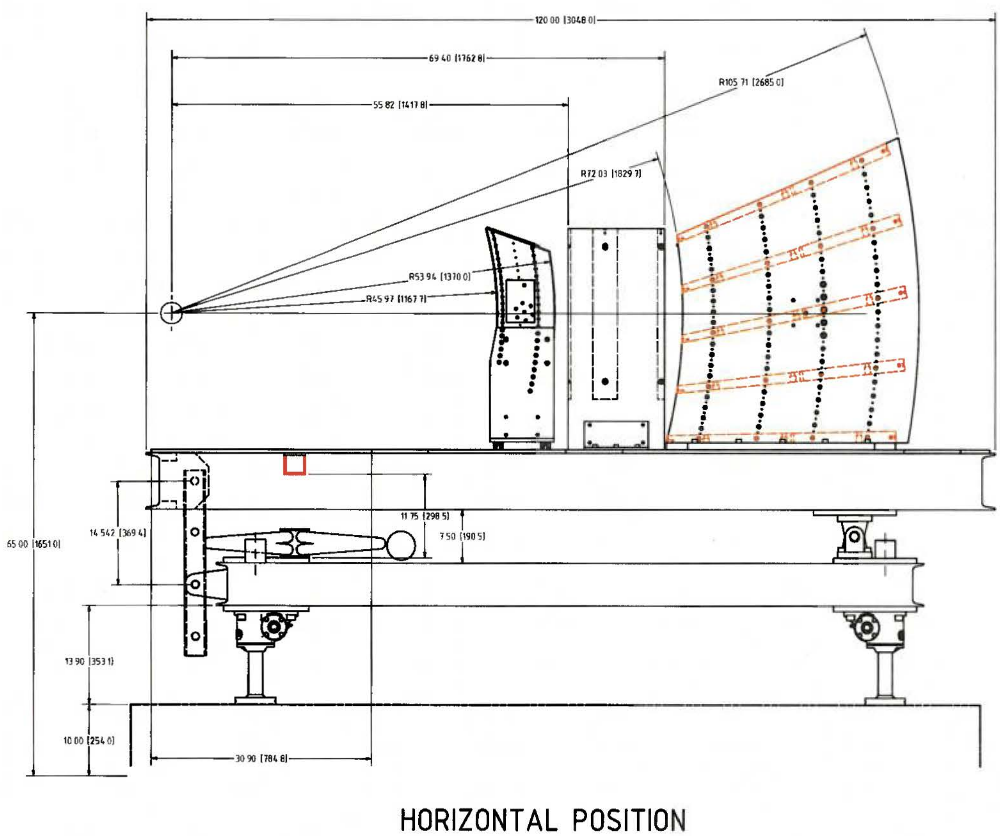


Figure 2: The EMCal, Inner HCal, dummy cryostat, and Outer HCal mounted on support table.

The EMCal is a tungsten-scintillating fiber (SPACAL) detector consisting of 64 towers in an 8x8 array. The towers are 1-D projective in the ϕ direction constructed of scintillating fibers embedded in a tungsten powered-epoxy mixture. Each tower covers 0.024 x 0.024 in $\eta-\phi$, measuring ~1x1x7 in^3 with an approximate density of 10 gm/cm^3, and is readout using 4 silicon photomultipliers (SiPMs). Eight towers are glued together in a 1x8 array to define a ϕ slice. Light mixing blocks are mounted to the front surface of the towers. Eight ϕ slices are assembled together in a support frame to form the 8x8 detector. A 1x8 preamp board has 32 SiPMs arranged in 8 2x2 arrays that match the spacing of the light mixing blocks and are coupled directly to the mixing blocks. The signals from the 4 SiPMs for a tower are passively summed, amplified, shaped and driven off detector for processing. Located in the center of the 2x2 SiPM arrays are thermistors used to monitor the SiPM temperatures to allow for gain corrections due to temperature variations. Also located on the preamp board are LEDs for calibration and monitoring. The entire EMCal is mounted on a stand that allows it to be positioned to the beam line independent of the HCal detectors. The EMCal and support frame measure ~1.5 x 1.5 x 1.5 ft^3 and weighs ~75 lbs and is mounted in a aluminum frame that allows it to be moved independent of the HCal. For initial testing, the experimenters plan to place the EMCal on the motion table in the MT6.2-B area.

The Inner HCal is a steel-scintillating tile with wave shifting fiber readout detector consisting of 16 towers in a 4x4 array. Each tower covers 0.1x0.1 in $\eta-\phi$, and is 1.5 λ_{int} in depth, ~21 cm. A tower consists of 5 tiles, 8mm thick, mounted between tapered steel plates approximately 10mm thick at the front edge and 15mm at the back edge. The steel plates are arranged horizontally with a 32° angle with respect to the beam line. At the outer (back) edge of a tile a SiPM is mounted in a holder viewing both ends of the wave length shifting fiber in the tile. Also located on the SiPM holder is an LED that can be used to illuminate the tile for calibration and monitoring. Signals from 5 SiPMs, which form a tower, are passively summed on a preamplifier-shaper-driver circuit board mounted on the backside of the detector. The preamplifier board also distributes bias to the 5 SiPMs and drives the LEDs associated with the tower. The inner HCal is mounted on rails that allows the inner HCal to be translated in the horizontal direction perpendicular to the beam line to allow for access to the electronics. A locking mechanism is used to prevent movement of the detector when access to the electronics is not required.

The dummy cryostat is designed to model the average material thickness of the BaBar solenoid. It consists of 4 aluminum plates, 2x2 ft^2 and 4 in thick. The dummy cryostat is fixed to the support table

The outer HCal is similar in construction to the Inner HCal. The steel plates are 3.5 λ_{int}, ~ 70 cm, in the beam direction with an inner thickness of 26 mm and outer thickness of 42 mm and tilted 12° with respect to the beam line and in the opposite direction of the inner HCal plates.

Trigger and veto counters will be mounted in front of the detector. The trigger counters are an X-Y array of 0.5 mm wide scintillator counters readout with PMTs. The signals from the counters will be used to form a trigger for the calorimeter readout. Several large scintillator paddles surrounding the trigger counters will be used to veto events where there might have been a shower upstream of the detectors.

Several large scintillator paddles instrumented with PMTs will be located downstream of the outer HCal and used to identify events with a large energy leakage out the back of the HCal.

The support table is a steel I-beam structure capable of supporting the full weight of the EMCal, HCal and cryostat. Four jack screws located at the corners of the structure allow the elevation of the table to be adjusted to ± 3" to position the detectors on the nominal beam line vertically. A scissor jack at the front allows the upper layer of the table to be tilted ± 5^0 about a pivot point at the center of gravity of the table with detectors mounted on it. A locking mechanism secures the table at the desired angle.

A common electronics design, as described in section 2.3.2 reads out both the HCal and EMCal. All triggered digitized signals will be readout by a PHENIX DAQ system located in the control room, and capable of 7 kHz operations.

Additional instrumentation needs include the use of a pb-glass block and phototube for cross calibration of EMCal energy response, use of the differential Cerenkov counter for electron ID up to 8 GeV, and the MWPC system for tracking charged particles into the calorimeters, and several scintillator counters with PMTs for veto counters and identifying leakage pacticles out the back of the detector.

2.3.2 Electronics and Computing Needs

The HCal and EMCal readout is based on Silicon Photomultipliers (SiPMs) from Hamamatsu. A local temperature compensation circuit monitors the local temperature of the SiPM and adjusts the SiPM bias voltage to provide constant gain. SiPMs gains have a linear dependency of the gain on both the bias voltage and temperature. By adjusting the bias voltage over the operational range of the device, it is possible to adjust to the gain of the SiPM to compensate for temperature variations. A functional diagram of the temperature compensation and amplification circuit is shown in Figure 4. Local logic uses the output of a thermistor mounted next to the SiPM to provide a DC offset to the bias that corrects the gain of the SiPM for temperature.

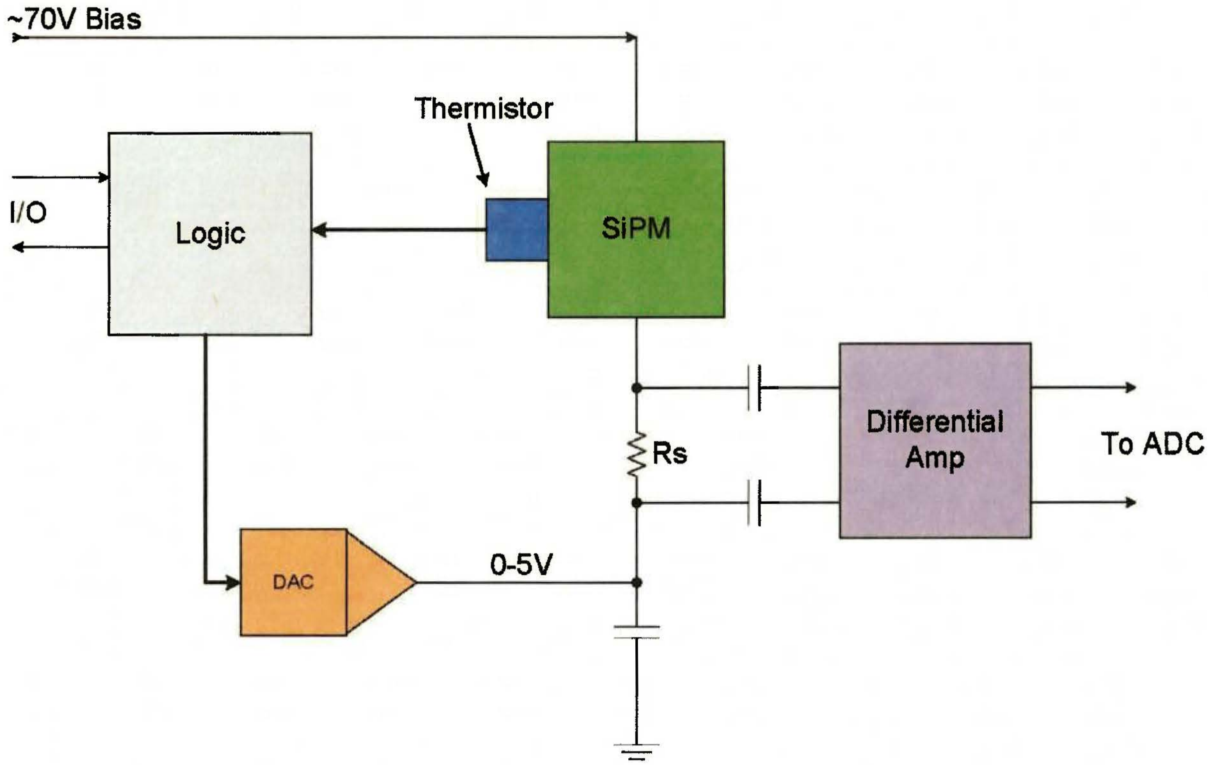


Figure 4: Block diagram of the SiPM temperature compensation circuit for the sPHENIX EMCal and HCal detectors.

The Front End Electronics (FEE) consists of 3 modules, the sensor/preamp board, the preamp interface board, and the controller board, and shown in figure 5. Signals from 4 (EMCal) or 5 (HCal) SiPMs are passively summed and then amplified with a preamplifier. A shaper-driver circuit with a peaking time of 30nSec drives the analog signals differentially to the digitizer boards located several meters from the detector. The EMCal preamplifier circuit has a high gain mode which can be switched on and allows for the detectors to be calibrated on cosmic muons, while the HCal amplifiers have both dual gain output. The preamp interface board multiplexes the analog signals from 8 preamplifiers onto a common data cable, and provides low voltage, bias and control signals to the sensor/preamp board. A processor mounted on the controller board provides the temperature compensation for the SiPMs based on the temperature measurements from the local thermistors mounted near the SiPMS. The parameters required for thermal compensation are downloaded from a local PC via a RS-485 serial interface. The circuit design for both the EMCal and the HCal is the similar however, differences in light yield for the EMCal and HCal will require different gains in the preamplifier stage.

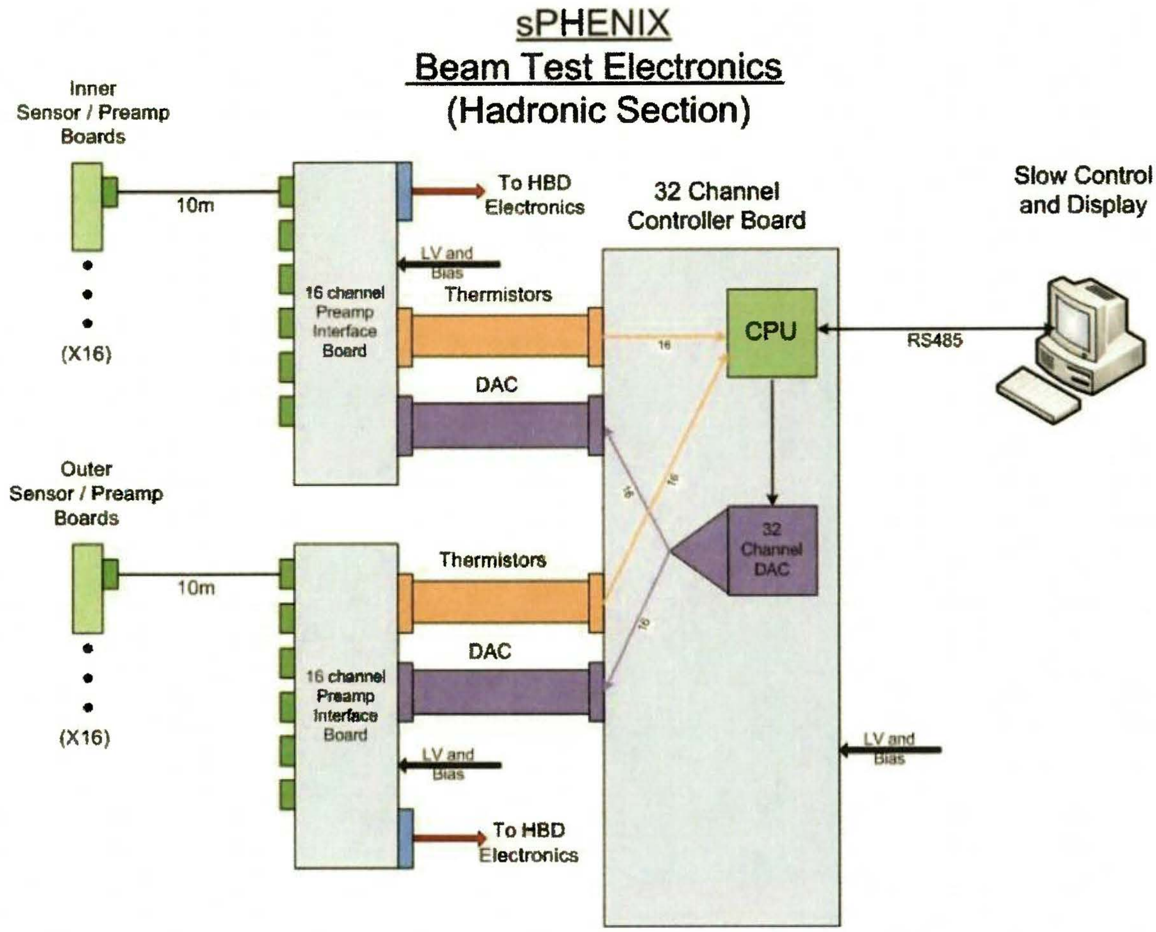


Figure 5: Front End Electronics (FEE) for the HCal. The EMCal electronics circuit design is the same, however, the layout topology is different to accommodate the difference in the topology of the fibers for the detector.

The analog signals are digitized and buffered by a front-end digitization module (FEM) that was originally designed and used by the PHENIX HBD detector. The digitized events are readout using a PHENIX style DAQ system consisting of a timing module, trigger module, data collection modules (DCMs) and Linux based data computer. A block diagram of the HBD readout system is shown in Figure 6. Readout of the detectors will require 3 ADC boards, crate controller and clock master located in a custom crate located in a short rack near the detector in the MT6 area. Digital data from the FEMs is transmitted to the DCMs via fiber optical cables located in the rack room. The readout system will require a total of 2 crates of PHENIX electronics in the control room, along with Linux based computers for control and data logging. The experimenters will provide the required racks and power supplies for the FEMS and DAQ. The bulk supplies for the readout system requires 220V AC.

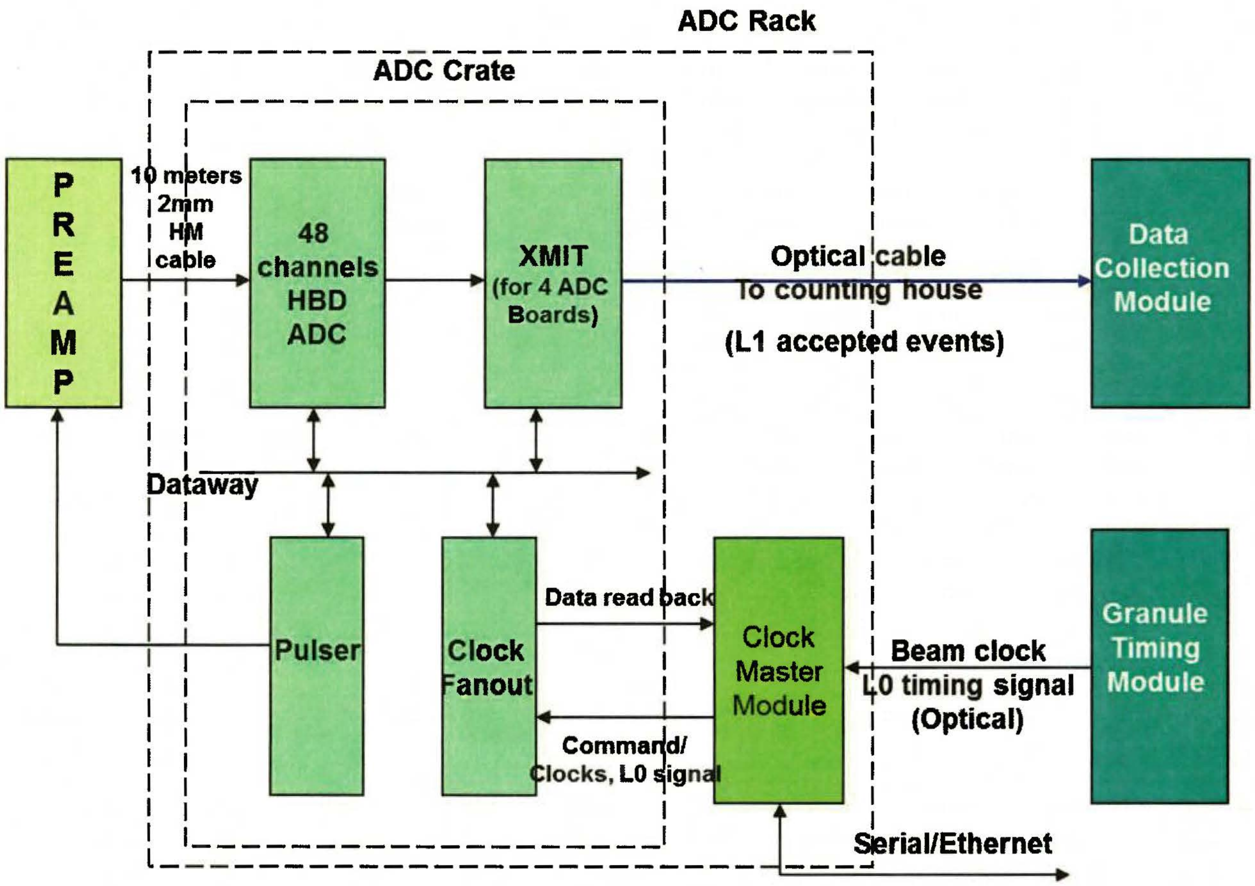


Figure 6: Block diagram of the HBD electronics that will be used for the HCal and EMCal readout.

If running time permits, the experimenters plan to test the second-generation digitizers being designed for sPHENIX. The second-generation design uses a 14-Bit ADC with 64 channels per board. The digitized events are readout using a PHENIX style DAQ system consisting of a timing module, trigger module, data collection modules and Linux based data computer. A block diagram of the readout system is shown in Figure 7. Readout of the detectors will require 2 ADC boards. The digitizer electronics will be located in a second short rack located in MT6 area near the detectors.

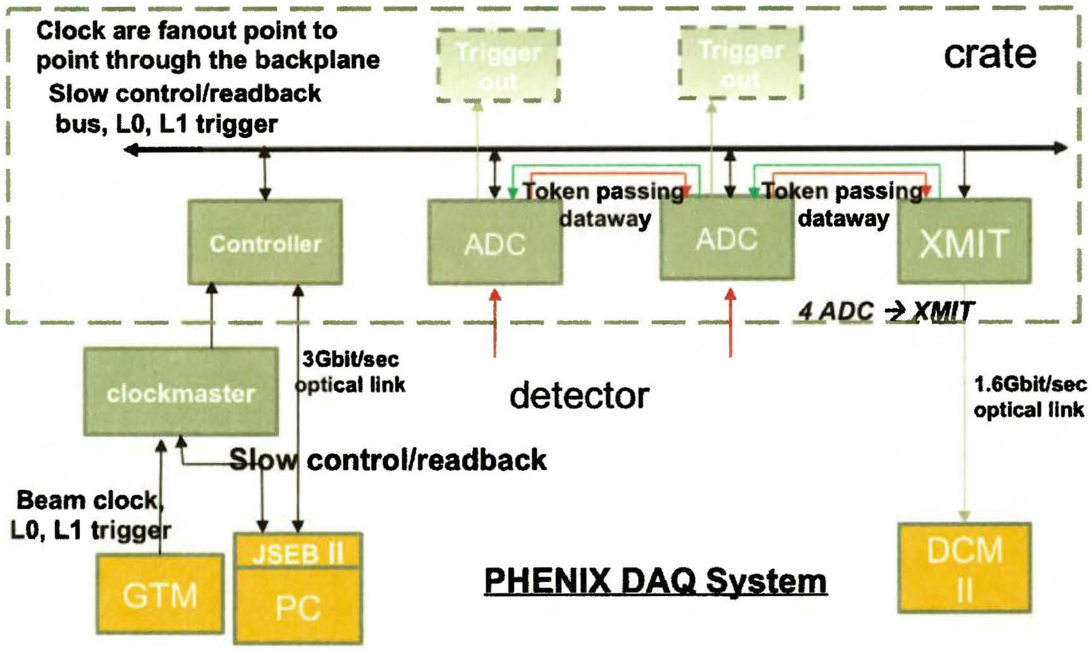


Figure 7: Block diagram of the second-generation sPHENIX digitizer electronics.

All electronics are custom designed and built following industry standards. All power systems are fused appropriately and safety grounded. Design schematics for all custom electronics, and data sheets for commercial electronics will be provided in advance of safety review.

The experimenters do not anticipate any requests of equipment from the PREP pool. However, should unanticipated needs arise (e.g. failed NIM module) limited access to the PREP pool may be required.

The experimenters plan to have most of their devices on a private network with one machine acting as gateway between the internal network and external network.

2.3.3 Description of Tests

The EMCal and HCal modules will be assembled and tested at Brookhaven National Laboratory prior to shipping to FNAL during the last week of March 2016. Once they arrive, unpacking and re-assembly of the detectors and cosmic ray running on the floor area outside MT6.2 beam line area will take place. During the week of April 1, 2016, the detectors will be relocated into the MT6.2 test area by lowering the table with the inner and outer HCal and cryostat through the hatch above the MT6.2-D area and final preparations will be made for an ORC. The EMCal will be located on the motion table in the MT6.2-B area with a helium tube in front.

The first week of running will be dedicated to the characterizing the beam under different beam tunes, understanding the operation of the PbGl, differential Cerenkov counter and MWPCs, commissioning the EMCal and HCal detectors, and characterization of the EMCal while it is positioned on the MT6.2-B motion table. The second week will be used to characterize the inner and outer HCal. The last 2 weeks will be used to do combined studies of the EMCal and HCal in several orientations of the detectors with respect to the beam line, and beam energies.

2.4 SCHEDULE

The basic run plan is as follows:

1. March 21-25, 2016: Shipment of HCal and EMCal detectors and associated electronics to FNAL.

2. March 28- April 4 2016: Final assembly of the HCal and EMCal detectors, commissioning of electronics and cosmic ray running outside of the M-Test beam line area

3. April 5-7, 2016: Move EMCal and HCal detectors to MT6.2 and prepare for ORC. EMCal will be installed up stream near entry point of beam in the MT6.2-B area. HCal will be located on the floor of the MT6.2-D area. Concrete porch is not used.

4. April 8-13 2016: Detailed studies of the MTest beam under different tune conditions using the FTBF MPWCs, Cerenkov counter and PbGlass detectors. Commissioning of EMCal and HCal detectors. Detailed studies of the EMCal with 120 GeV proton and low energy mixed beam. Parasitic testing of the HCal with 120 GeV protons and cosmic rays

5. April 14-20 2016: Detailed studies of HCal only. Move EMCal to MT6.2-D in front of HCal. Initial combined running of both detectors

6. April 21-27, 2016: Combined data taking, resolution, e/h and e-π measurements.

7. Continued running with detector +/- 5 degrees in the phi direction.

8. May 3, 2016: Disassembly test setup, relocate outside of MT6 area beam line area

9. Summer of 2016: Reconfigure HCal for high rapidity configuration. Reconfigure EMCal with 2-D projective towers

10. November 2016: Additional running with detector in high rapidity configuration.

VII. RESPONSIBILITIES BY INSTITUTION – NON FERMILAB

- BROOKHAVEN NATIONAL LABORATORY:
  - HCal and EMCal detectors: $100K
  - Readout and DAQ electronics: $10K
  - Support table for HCal and EMCal detectors.
  - Installation and commissioning of detectors
  - Staffing of data taking shifts
  - Data analysis
- Georgia State University
  - Construction of HCal detector
  - Installation and commissioning of detectors
  - Staffing of data taking shifts
  - Data analysis
- Iowa State University
  - Construction of HCal
  - Installation and commissioning of detectors
  - Staffing of data taking shifts
  - Data analysis
- University of Colorado
  - Staffing of data taking shifts
  - Data analysis
- University of Illinois
  - Construction of EMCal
  - Installation and commissioning of the EMCal
  - Staffing data taking shifts

    - Data analysis

- University of Michigan
    - Staffing data taking shifts
    - Data analysis

IV. RESPONSIBILITIES BY INSTITUTION – FERMILAB

4.1 FERMILAB ACCELERATOR DIVISION:

4.1.1 Use of MTest beam line as outlined in Section II. [0.25 FTE/week]

4.1.2 Maintenance of all existing standard beam line elements (SWICs, loss monitors, etc.) instrumentation, controls, clock distribution, and power supplies.

4.1.3 Scalars and beam counter readouts will be made available via ACNET in the MTest control room.

4.1.4 Reasonable access to the equipment in the MTest beam line.

4.1.5 Connection to beams console and remote logging (ACNET) should be made available.

4.1.6 The test beam energy and beam line elements will be under the control of the AD Operations Department Main Control Room (MCR). [0.25 FTE/week]

4.1.7 Position and focus of the beam on the experimental devices under test will be under control of MCR. Control of secondary devices that provide these functions may be delegated to the experimenters as long as it does not violate the Shielding Assessment or provide potential for significant equipment damage.

4.1.8 The integrated effect of running this and other SY120 beams will not reduce the neutrino flux by more than an amount set by the office of Program Planning, with the details of scheduling to be worked out between the experimenters and the Office of Program Planning.

4.2 FERMILAB PARTICLE PHYSICS DIVISION:

4.2.1 The test-beam efforts in this TSW will make use of the Fermilab Test Beam Facility. Requirements for the beam and user facilities are given in Section II. The Fermilab Particle Physics Division will be responsible for coordinating overall activities in the MTest beam-line, including use of the user beam-line controls, readout of the beam-line detectors, and FTBF computers. [6.5 FTE/week]

4.2.2 Setting up and maintaining of the differential Cherenkov counter.

4.2.3 Use of a pb-glass block and phototube for cross calibration of EMCal energy response.

4.2.4 Use of the 4 MWPC detectors to measure incident particle trajectories.

4.2.5 Installation of Helium beam pipes upstream of the EMCal detector.

4.2.6 Crane support to move detectors into and out of beam enclosure.

4.2.7 Conduct a NEPA review of the experiment.

4.2.8 Provide day-to-day ESH&Q support/oversight/review of work and documents as necessary.

4.2.9 Provide safety training as necessary, with assistance from the ESH&Q Section.

4.2.10 Update/create ITNA's for users on the experiment.

4.2.11 Initiate the ESH&Q Operational Readiness Clearance Review and any other required safety reviews.

4.3 FERMILAB SCIENTIFIC COMPUTING DIVISION

4.3.1 Internet access should be continuously available in the MTest control room.
4.3.2 See Appendix II for summary of PREP equipment pool needs.
4.3.3 Set-up of a private network, and connection to Fermi-network [0 FTE]

4.4 FERMILAB ESH&Q SECTION

4.4.1 Assistance with safety reviews.
4.4.2 Provide safety training, with assistance from PPD, as necessary for experimenters. [0.2 FTE]

V. SUMMARY OF COSTS

Source of Funds [$K]	Materials & Services ($k)	Labor (FTE/week)
Accelerator Division	0	0.5
Particle Physics Division	2	6.5
Scientific Computing Division	0	0
ESH&Q Section	0	0.2
Totals Fermilab	$2.0K	7.2
Totals Non-Fermilab		

VI. General Considerations

6.1 The responsibilities of the Spokesperson and the procedures to be followed by experimenters are found in the Fermilab publication "Procedures for Researchers": (http://www.fnal.gov/directorate/PFX/PFX.pdf). The Spokesperson agrees to those responsibilities and to ensure that the experimenters all follow the described procedures.

6.2 To carry out the experiment a number of Environmental, Safety and Health (ESH&Q) reviews are necessary. This includes creating an Operational Readiness Clearance document in conjunction with the standing Particle Physics Division committee. The Spokesperson will follow those procedures in a timely manner, as well as any other requirements put forth by the Division's Safety Officer.

6.3 The Spokesperson will ensure at least one person is present at the Fermilab Test Beam Facility whenever beam is delivered and that this person is knowledgeable about the experiment's hazards.

6.4 All regulations concerning radioactive sources will be followed. No radioactive sources will be carried onto the site or moved without the approval of the Fermilab ESH&Q section.

6.5 All items in the Fermilab Policy on Computing will be followed by the experimenters. (http://computing.fnal.gov/cd/policy/cpolicy.pdf).

6.6 The Spokesperson will undertake to ensure that no PREP or computing equipment be transferred from the experiment to another use except with the approval of and through the mechanism provided by the Scientific Computing Division management. The Spokesperson also undertakes to ensure no modifications of PREP equipment take place without the knowledge and written consent of the Computing Sector management.

6.7 The experimenters will be responsible for maintaining both the electronics and the computing hardware supplied by them for the experiment. Fermilab will be responsible for repair and maintenance of the Fermilab-supplied electronics. Any items for which the experiment requests that Fermilab performs maintenance and repair should appear explicitly in this agreement.

At the completion of the experiment:

6.8 The Spokesperson is responsible for the return of all PREP equipment, computing equipment and non-PREP data acquisition electronics. If the return is not completed after a period of one year after the end of running the Spokesperson will be required to furnish, in writing, an explanation for any non-return.

6.9 The experimenters agree to remove their experimental equipment as the Laboratory requests them to. They agree to remove it expeditiously and in compliance with all ESH&Q requirements, including those related to transportation. All the expenses and personnel for the removal will be borne by the experimenters unless removal requires facilities and personnel not able to be supplied by them, such rigging, crane operation, etc.

6.10 The experimenters will assist Fermilab with the disposition of any articles left in the offices they occupied.

6.11 An experimenter will be available to report on the test beam effort at a Fermilab All Experimenters' Meeting.

SIGNATURES:

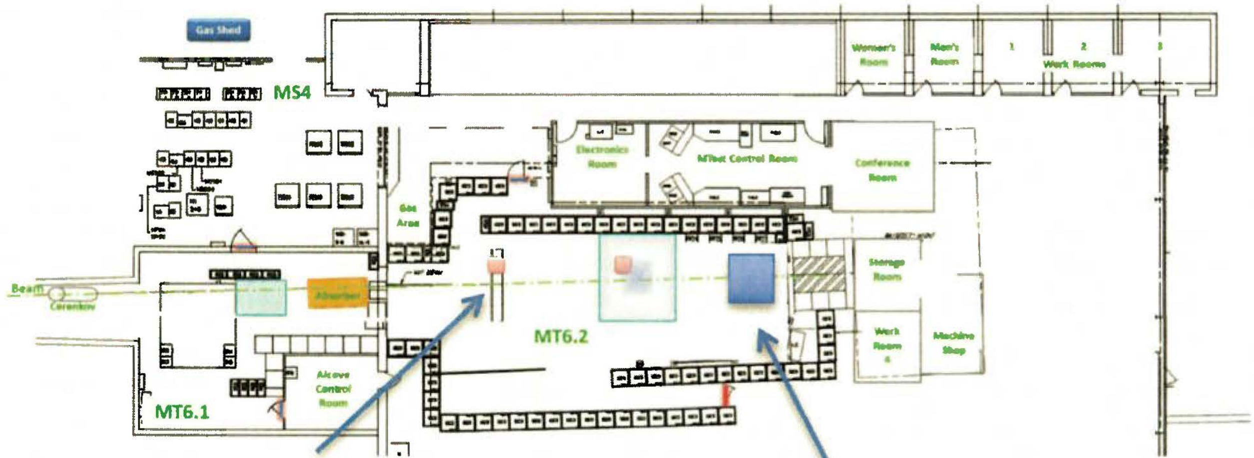
The spokesperson is the official contact and is responsible for forwarding all pertinent information to the rest of the group, arranging for their training, and requesting ORC or any other necessary approvals for the experiment to run.
The spokesperson should also make sure the appropriate people (which might be everyone on the experiment) sign up for the test beam emailing list.

Eric J. Mannel ______________________________ 3/10 / 2016
Eric J. Mannel, Experiment Spokesperson

APPENDIX I: MT6 AREA LAYOUT

For the EMCal the experimenters want to the use upstream region of the MT6.2 test area. For HCal and combined EMCal-HCal testing the experimenters want to use the most downstream region of the MT6.2 test area on the floor. The most likely method of getting the EMCal and HCal detector system into the MT6.2 test area is through the hatch directly above this area.

MTEST AREAS



Preferred location of EMCal standalone test. Preferred location of EMCal and HCal.

Controlled Access Gate with Key Tree

Climate Controlled Area

Remote Controlled Motion Table

Disabled Controlled Access Gate

APPENDIX II: EQUIPMENT NEEDS

Provided by experimenters:

1. HCal with all associated readout electronics.
2. EMCal with all associated readout electronics.
3. Data acquisition electronics and computers
4. Power supplies for all electronics
5. Signal and power cables for all HCal and EMCal electronics

Equipment Pool and PPD items needed for Fermilab test beam, on the first day of setup.

PREP EQUIPMENT POOL:

Description

The experimenters may require a few NIM logic and discriminator modules for triggering. A detailed request will be provided in advance of beam operations.

PPD FTBF:

Description

Use of the MWPC tracking system (4 stations) and associated electronics.

Use of a pb-glass block and phototube for cross calibration of EMCal energy response.

Scintillator counters (including PMT's) to provide a veto for beam halo and identify leakage out the back of the detector. For the counters at the back of the detector, they will need to cover an area 1m^2.

HV to operate PMTs for Pb-Glass and scintillator counter PMTs.

Use of MTEST Cerenkov counter for electron ID up to 8 GeV

APPENDIX III: - HAZARD IDENTIFICATION CHECKLIST

Items for which there is anticipated need have been checked. See next page for detailed descriptions of categories.

Flammable Gases or Liquids		**Other Gas Emissions**		**Hazardous Chemicals**		**Other Hazardous /Toxic Materials**
Type:		Type:			Cyanide plating materials	List hazardous/toxic materials planned for use in a beam line or an experimental enclosure:
Flow rate:		Flow rate:			Hydrofluoric Acid	
Capacity:		Capacity:			Methane	
Radioactive Sources		**Target Materials**			Photographic developers	
	Permanent Installation		Beryllium (Be)		PolyChlorinatedBiphenyls	
	Temporary Use		Lithium (Li)		Scintillation Oil	
Type:			Mercury (Hg)		TEA	
Strength:			Lead (Pb)		TMAE	
Lasers			Tungsten (W)		Other: Activated Water?	
	Permanent installation		Uranium (U)			
	Temporary installation		Other:	**Nuclear Materials**		
	Calibration	**Electrical Equipment**		Name:		
	Alignment		Cryo/Electrical devices	Weight:		
Type:			Capacitor Banks	**Mechanical Structures**		
Wattage:		X	High Voltage (50V)		Lifting Devices	
MFR Class:			Exposed Equipment over 50 V	X	Motion Controllers	
		X	Non-commercial/Non-PREP		Scaffolding/ Elevated Platforms	
			Modified Commercial/PREP		Other:	
Vacuum Vessels		**Pressure Vessels**		**Cryogenics**		
Inside Diameter:		Inside Diameter:			Beam line magnets	
Operating Pressure:		Operating Pressure:			Analysis magnets	

Window Material:		Window Material:			Target	
Window Thickness:		Window Thickness:			Bubble chamber	

Other Gas Emission

Greenhouse Gasses (Need to be tracked and reported to DOE)

- ☐ Carbon Dioxide, including CO_2 mixes such as Ar/CO_2
- ☐ Methane
- ☐ Nitrous Oxide
- ☐ Sulfur Hexafluoride
- ☐ Hydro fluorocarbons
- ☐ Per fluorocarbons
- ☐ Nitrogen Trifluoride

Nuclear Materials

Reportable Elements and Isotopes / Weight Units / Rounding

Name of Material	MT Code	Reporting Weight Unit Report to Nearest Whole Unit	Element Weight	Isotope Weight	Isotope Weight %
Depleted Uranium	10	Whole Kg	Total U	U-235	U-235
Enriched Uranium	20	Whole Gm	Total U	U-235	U-235
Plutonium-242[1]	40	Whole Gm	Total Pu	Pu-242	Pu-242
Americium-241[2]	44	Whole Gm	Total Am	Am-241	–
Americium-243[2]	45	Whole Gm	Total Am	Am-243	–
Curium	46	Whole Gm	Total Cm	Cm-246	–
Californium	48	Whole Microgram	–	Cf-252	–
Plutonium	50	Whole Gm	Total Pu	Pu-239+Pu-241	Pu-240
Enriched Lithium	60	Whole Kg	Total Li	Li-6	Li-6
Uranium-233	70	Whole Gm	Total U	U-233	U-232 (ppm)
Normal Uranium	81	Whole Kg	Total U	–	–
Neptunium-237	82	Whole Gm	Total Np	–	–
Plutonium-238[3]	83	Gm to tenth	Total Pu	Pu-238	Pu-238
Deuterium[4]	86	Kg to tenth	D_2O	D_2	
Tritium[5]	87	Gm to hundredth	Total H-3	–	–
Thorium	88	Whole Kg	Total Th	–	–
Uranium in Cascades[6]	89	Whole Gm	Total U	U-235	U-235

[1] Report as Pu-242 if the contained Pu-242 is 20 percent or greater of total plutonium by weight; otherwise, report as Pu 239-241.

[2] Americium and Neptunium-237 contained in plutonium as part of the natural in-growth process are not required to be accounted for or reported until separated from the plutonium.

[3] Report as Pu-238 if the contained Pu-238 is 10 percent or greater of total plutonium by weight; otherwise, report as plutonium Pu 239-241.

[4] For deuterium in the form of heavy water, both the element and isotope weight fields should be used; otherwise, report isotope weight only.

[5] Tritium contained in water (H2O or D2O) used as a moderator in a nuclear reactor is not an accountable material.

[6] Uranium in cascades is treated as enriched uranium and should be reported as material type 89.

TSW for T-1044: **sPHENIX Calorimetry Tests**

The following people have read this TSW:

3 /29/ 2016

Patty McBride, Particle Physics Division, Fermilab

JONATHAN LEWIS, PPD

Paul C Garapato for Sergei Nagaitsev 3 /24/ 2016

Sergei Nagaitsev, Accelerator Division, Fermilab

3 /24/ 2016

Martha Michels, ESH&Q Section, Fermilab

4 / 1 / 2016

Robert Roser, Chief Information Officer, Fermilab

3 /31/ 2016

Joe Lykken, Chief Research Officer, Fermilab

Fermilab

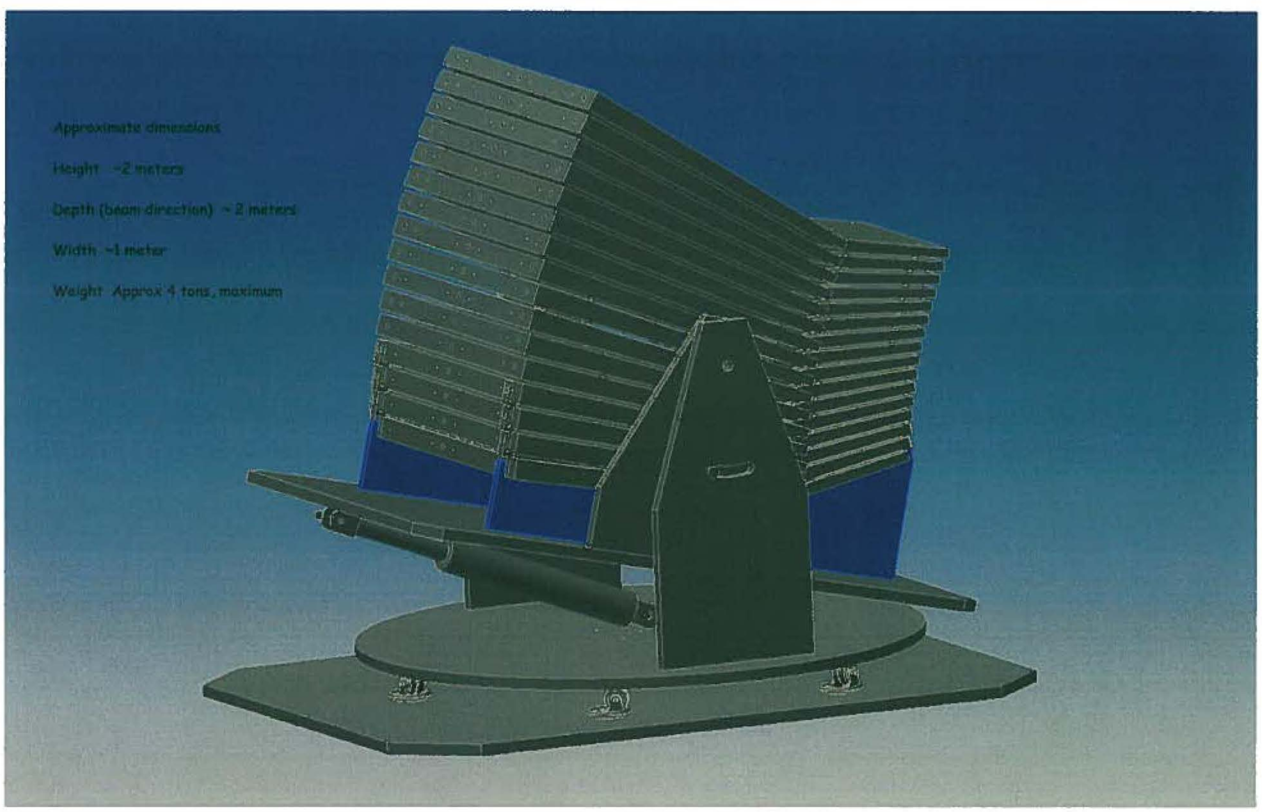
Directorate

TECHNICAL SCOPE OF WORK
FOR THE 2014 FERMILAB TEST BEAM FACILITY PROGRAM

T-1044

sPHENIX Calorimetry Tests

December 19, 2013



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INTRODUCTION

This is a technical scope of work (TSW) between the Fermi National Accelerator Laboratory (Fermilab) and the experimenters of PHENIX collaboration who have committed to participate in beam tests to be carried out during the FY2014 Fermilab Test Beam Facility program.

The TSW is intended primarily for the purpose of recording expectations for budget estimates and work allocations for Fermilab, the funding agencies and the participating institutions. It reflects an arrangement that currently is satisfactory to the parties; however, it is recognized and anticipated that changing circumstances of the evolving research program will necessitate revisions. The parties agree to modify this scope of work to reflect such required adjustments. Actual contractual obligations will be set forth in separate documents.

This TSW fulfills Article 1 (facilities and scope of work) of the User Agreements signed (or still to be signed) by an authorized representative of each institution collaborating on this experiment.

Description of Detector and Tests:

The sPHENIX upgrade to the PHENIX detector is designed to study jets in heavy ion collisions at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory and address questions about the nature of the perfect fluid quark-gluon plasma. The upgrade consists of a 2 Tesla superconducting magnetic solenoid of radius 70 cm surrounded by electromagnetic and hadronic calorimeters with uniform coverage over a rapidity range of $|\eta| < 1$ and 2π in azimuth. The sPHENIX detector concept takes advantage of technological developments to enable a compact design with excellent performance. A tungsten-scintillator electromagnetic calorimeter read out with silicon photomultipliers (SiPMs) allows for a physically thin device, which can operate in a magnetic field, without the bulk of photomultiplier tubes and the need for high voltage distribution. The smaller electromagnetic calorimeter also allows the hadron calorimeter to be less massive, and the use of silicon photomultipliers for the hadron calorimeter allow for nearly identical electronic readout for the two major systems.

The requirements for the sPHENIX electromagnetic calorimeter lead to a design that is compact (i.e. has a small Molie`re radius and short radiation length), has a high degree of segmentation (0.024×0.024 in η and φ), and can be built at a reasonable cost. Since the calorimeter will be located just outside the coil of the solenoid, it will also have to operate in the rather strong fringe field of the magnet. This has lead to an electromagnetic calorimeter design consisting of alternating layers of tapered tungsten plates and scintillating fibers. The light fibers are closely packed together at the front of the detector and fan out at the back to make the device projective. Fibers are grouped together to form individual towers and are coupled to light mixing blocks to randomize the light, which is read out by SiPMs mounted on the mixing block.

The HCal hadronic calorimeter, a key element of sPHENIX, performance requirements are directly tied to the physics goals of sPHENIX. The focus of sPHENIX on measuring jets and dijets in heavy ion and proton collisions leads to a requirement of good energy resolution, $\sigma_E/E =$ 100%/ sqrt(E) and transverse segmentation of the HCal, $\Delta\eta \times \Delta\varphi \approx 0.1 \times 0.1$ over a rapidity range of $|\eta| < 1.1$ with minimal dead area. The combination of the EMCal and HCal needs to be at least $6\lambda_{int}$ lengths deed in order to absorb 97% of impinging hadrons with momenta below 50GeV/c. The electromagnetic calorimeter is □ $1\lambda_{int}$ thick, so an iron-scintillator hadronic calorimeter should be □ $5\lambda_{int}$ deep. The thickness of the HCal is driven by physics needs, but these needs dictate a device of sufficient thickness that, with careful design, the hadronic calorimeter can also serve as the return yoke for the solenoid.

These performance requirements lead to an HCal design that consists of 2 sections, inner and outer, 1.5 and 3.5 interactions lengths deep respectively. Both in the inner and outer segments are constructed of tapered iron absorber plates, tilted $\pm 5^{\circ}$ with respect to a radius vector perpendicular to the beam axis. The plates for the inner and outer sections are tilted in opposite directions resulting in a 10° angle with respect to each other and staggered by half the thickness of the plates. The gaps between the iron gaps are 8mm wide and contain individually wrapped 7 mm thick scintillating tiles with a diffuse reflective coating and embedded wavelength shifting fibers following a serpentine path. Fibers from the tiles forming a tower are coupled directly to a SiPM mounted on the detector for readout.

The goals for this test beam experiment are to verify the performance of the electromagnetic and hadronic calorimeters for hadrons with energies ranging from a few GeV to 50GeV and a variety of geometrical orientations of the detectors to the impinging particles, In addition, the tests will allow a testing of the electronics that are being designed for the calorimeter readout. In order to accomplish these goals, the experimenters anticipate an initial 5 weeks effort at the M-Test facility. The first 3 weeks would be devoted to detector assembly and testing, followed by 2 weeks of beam tests. Details of the proposed schedule can be found in Section 2.4.

1. PERSONNEL AND INSTITUTIONS:

Spokesperson: Eric Mannel

Lead Experimenter in charge of beam tests: John Haggerty

Fermilab Experiment Liaison Officer: Aria Soha

The group members at present are:

	Institution	Country	Collaborator	Rank/Position	Other Commitments
1.1	Brookhaven National Laboratory	USA	Achim Franz	Scientist	PHENIX
			Mickey Chiu	Scientist	PHENIX
			John Haggerty	Scientist	PHENIX
			Edouard Kistenev	Scientist	PHENIX
			Eric Mannel	Scientist	PHENIX
			Martin Purschke	Scientist	PHENIX
			Chris Pinkenburg	Scientist	PHENIX
			Ann Sickles	Scientist	PHENIX
			Craig Woody	Scientist	PHENIX
			Bob Azmoun	Physics Associate	PHENIX
			Sean Stoll	Physics Associate	PHENIX
			Steve Boose	Elect. Engineer	PHENIX
			Don Lynch	Mech. Engineer	PHENIX
			Rich Ruggerio	Design Engineer	PHENIX
			Michael Lenz	Technician	PHENIX
1.2	Georgia State University	USA	Xiaochun He	Professor	PHENIX
			Liang Xue	Post-Doc	PHENIX
1.3	Oak Ridge National Laboratory	USA	Ken Read	Professor	PHENIX
			David Silvermyr	Scientist	PHENIX
			Paul Stankus	Scientist	PHENIX
			Matt Wysocki	Post-Doc	PHENIX
1.4	Ohio University	USA	Justin Frantz	Professor	PHENIX
1.5	University of Colorado	USA	Jamie Nagle	Professor	PHENIX
			Andrew Dare	Post-Doc	PHENIX
			Darren McGlinchey	Post-Doc	PHENIX
			Theo Koblesky	Graduate Student	PHENIX
			Shawn Beckman	Undergraduate	PHENIX

II. EXPERIMENTAL AREA, BEAMS AND SCHEDULE CONSIDERATIONS:

2.1 LOCATION

2.1.1 The beam test(s) will take place in the MT6.2D area on the concrete blocks currently positioned there.

2.1.2 The experimenters request additional space, 3m by 4m outside the beam line enclosure for initial setup and debugging of the readout system. The space should have access to electrical power for electronics, plus a 220-3phase AC outlet for the detector table, 2 tables to serve as work surfaces, and 1 standard height rack. In addition a cabinet for storage will be needed.

2.2 BEAM

2.2.1 BEAM TYPES AND INTENSITIES

Energy of beam: 1 GeV – 60 GeV
Particles: pions/muons/electrons
Intensity: 10k – 100k in units of particles/ 4 sec spill
Beam spot size: about 1cm^2

2.2.2 BEAM SHARING

During dedicated running, limited running of parasitic upstream experiments will be considered provided they do not insert a significant amount of material in the beam, and can be readily moved out of the beam for cross calibration to understand the effects of the material presented. Given the type of detector, electromagnetic and hadronic calorimetry and being located in the downstream portion of the MT6.2 test area, downstream parasitic operations are not possible.

In the beam direction, the EMCal is ~18X_0 and 1 λ_{int}, and the HCal is ~35 X_0 and 5 λ_{int} in length.

2.2.3 RUNNING TIME

The experimenters request a total of 5 weeks time, during the period Jan 15, 2014 to Feb 25, 2014. The first 2 weeks are for parasitic setup and testing outside the MTest beam line and the last 3 weeks are for final installation, commissioning and running. During initial setup the experimenters request parasitic access to the test area for setup and early commissioning of the detectors and associated electronics.

The experimenters anticipate running during the standard operational hours of the M-Test beam line. During the initial startup phase, frequent accesses of varying length are anticipated to commission the system. Once commissioned, the experimenters anticipate several accesses per day to re-position the detector to study geometrical properties of the detector and changes in the beam tune to understand the energy response of the detectors. See section 2.4 for total run time and long-term schedule.

2.3 EXPERIMENTAL CONDITIONS

2.3.1 AREA INFRASTRUCTURE

The sPHENIX HCAL is a steel-scintillator calorimeter measuring 1.2m x 1.7m x 1.3m (w x d x h), and weighing an estimated 8,000 lbs. with support structure and is shown in Figure 1. The support structure allows it to rotate about the x and y-axis. The structure sits on a moveable lift table that will allow it to move horizontally along the x-axis (perpendicular to the beam) and vertically along the y-axis. The HCal consists of 16 towers (4x4) with Silicon Photomultiplier (SiPM) readout on both the front and back of the detector. The SiPMs and associated temperature compensating electronics will be mounted directly on the HCal with analog signals being driven over shielded cable to digitizers located in an electronics crate located near the detector. The HCal will have a total of 32 readout channels.

Surrounding 5 sides of the detector will be scintillator panels to measure the energy leakage from the HCal. Each panel will be readout by a PMT using the same electronics as the SiPMs, for a total of 5 additional readout channels.

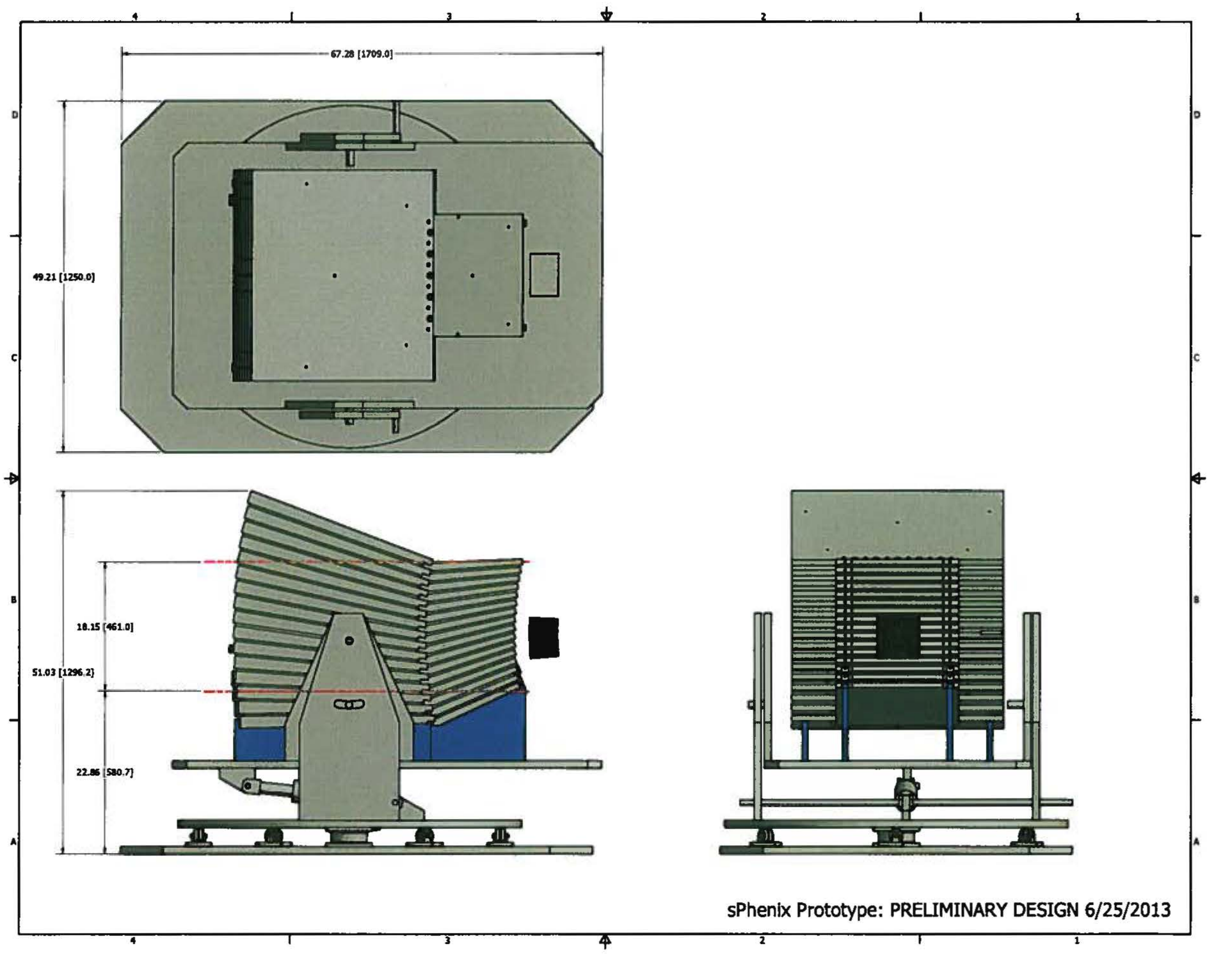


Figure 1: HCal prototype module drawing on support base. The base allows the detector to be rotated about the vertical axis and tilted about the horizontal axis. Not shown are scintillator panels mounted on 5 sides to measure leakage energy. Shown in front of the HCal is the approximate location of the EMCal. Not shown is the support stand for the EMCal which will be attached to the base plate.

Surrounding the HCal on 5 sides will be scintillator panels (not shown in the figure) to measure leakage energy from each side. Each panel will be readout with a standard PMT with the analog signals digitized in local crate. There are a total of 5 channels for the scintillator panels.

The sPHENIX electromagnetic calorimeter is a tungsten-scintillating fiber calorimeter measuring approximately 18 x 18 x 13 cm^3 and weighing approximately 100 lbs. 1 mm diameter scintillating fibers are sandwiched between 2 tapered tungsten plates. The fibers are held between the plates with glue. Multiple tungsten-fiber sandwiches are then glued together to form the electromagnetic calorimeter. A 7x7 array of 2x2 cm^2 mixing blocks is attached to the downstream end of the EMCal and readout using SiPMs. The EMCal will be mounted on a stand in front of the HCal and allow it to move horizontally and vertically with respect to the HCal to allow it to remain on the beam line for different orientations of the HCal as it moved. The EMCal is shown in figure 1. The EMCal will use the same electronics as the HCal, with a total of 49 channels of readout electronics.

A common electronics design, as described in section 2.3.2 reads out both the HCal and EMCal. All triggered digitized signals will be readout by a PHENIX DAQ system located in the control room, and capable of 7KHz operation.

The experimenters request the use of the MWPC tracking stations and associated readout electronics. Location of chambers will be upstream of the HCal and EMCal to provide tracking of the incident beam particles. Positioning of the tracking station locations should be selected to give an impact position on the EMCal and HCal modules to better then 1mm. The location of the final tracking station needs to provide sufficient space around the EMCal and HCal modules to allow them to be repositioned for geometrical studies.

Additional instrumentation needs include the use of a pb-glass block and phototube for cross calibration of EMCal energy response. Two scintillator trigger counters (including PMT's), measuring approximately 1x1 in^2, and use of the differential Cerenkov counter for electron ID up to 8 GeV.

The experiment will also need two 220V 3-phase AC outlets installed, one in the electronics room, and one in the requested pre-beam work area.

2.3.2 Electronics and Computing Needs

The HCal and EMCal readout is based on Silicon Photomultipliers (SiPMs) from Hamamatsu. A local temperature compensation circuit monitors the local temperature of the SiPM and adjusts the SiPM bias voltage to provide constant gain. SiPMs gains have a linear dependency of the gain on both the bias voltage and temperature. By adjusting the bias voltage over the operational range of the device, it is possible to adjust to the gain of the SiPM to compensate for temperature variations. A functional diagram of the temperature compensation and amplification circuit is shown in figure 2. Local logic uses the output of a thermistor mounted next to the SiPM to provide a DC offset to the bias that corrects the gain of the SiPM for temperature.

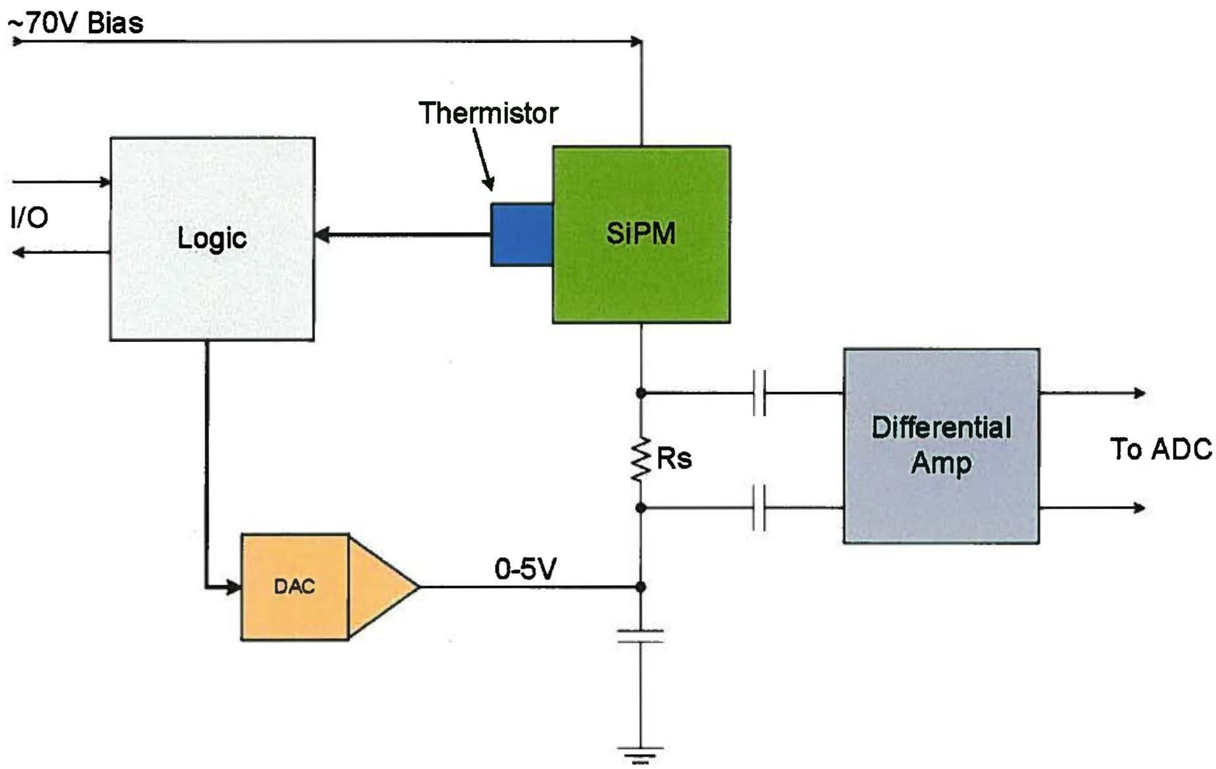


Figure 2: Block diagram of the SiPM temperature compensation circuit for the sPHENIX EMCal and HCal detectors.

The Front End Electronics (FEE) consists of 3 modules, the sensor/preamp board, the preamp interface board, and the controller board, are shown in figure 3. The SiPM, preamp and thermistor are located on a small board that is mounted on the HCal module with the light fibers from a single tower attached to it. The preamp interface board multiplexes the analog signals from 16 SiPMs onto a common data cable, and provides low voltage, bias and control signals to the sensor/preamp board. The controller board provides the temperature compensation for the SiPMs. A local CPU uses the thermistor inputs to bias adjustment for each SiPM channel. Overall gain for each SiPM can be adjusted by changing the DC offset of the bias by a fixed value. The parameters required for thermal compensation are downloaded from a local PC via a RS-485 serial interface. The circuit design for both the EMCal and the HCal is the same, however, due to differences in the topology of the fibers for the 2 detectors, the packaging of the electronics will be customized for each detector.

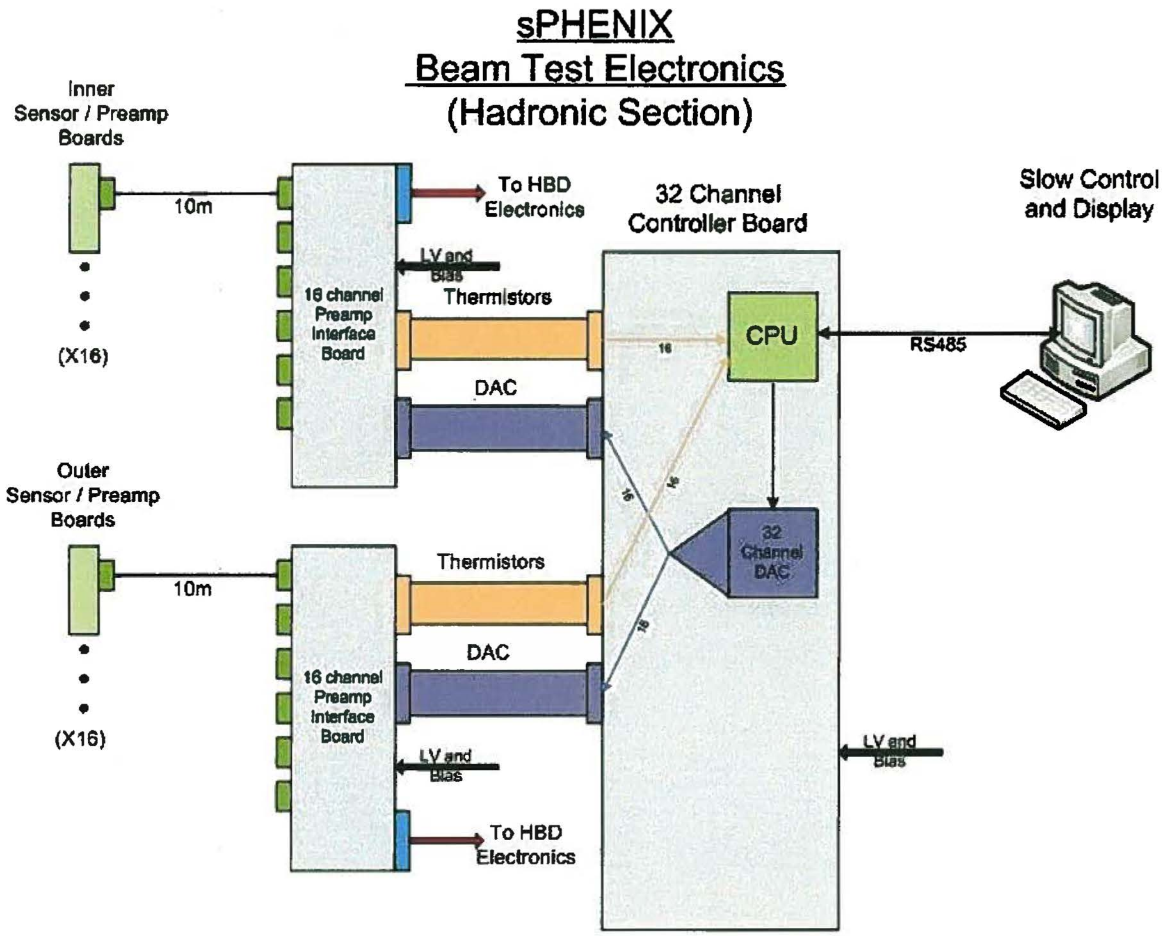


Figure 3: Front End Electronics (FEE) for the HCal. The EMCal electronics circuit design is the same, however, the layout topology is different to accommodate the difference in the topology of the fibers for the detector.

The analog signals are digitized and buffered by a front-end digitization system that was originally designed and used by the PHENIX HBD detector. The digitized events are readout using a PHENIX style DAQ system consisting of a timing module, trigger module, data collection modules and Linux based data computer. A block diagram of the HBD readout system is shown in figure 4. Readout of the detectors will require 2 ADC boards. The readout system will require a total of 2 crates of PHENIX electronics in the control room, along with Linux based computers for control and data logging.

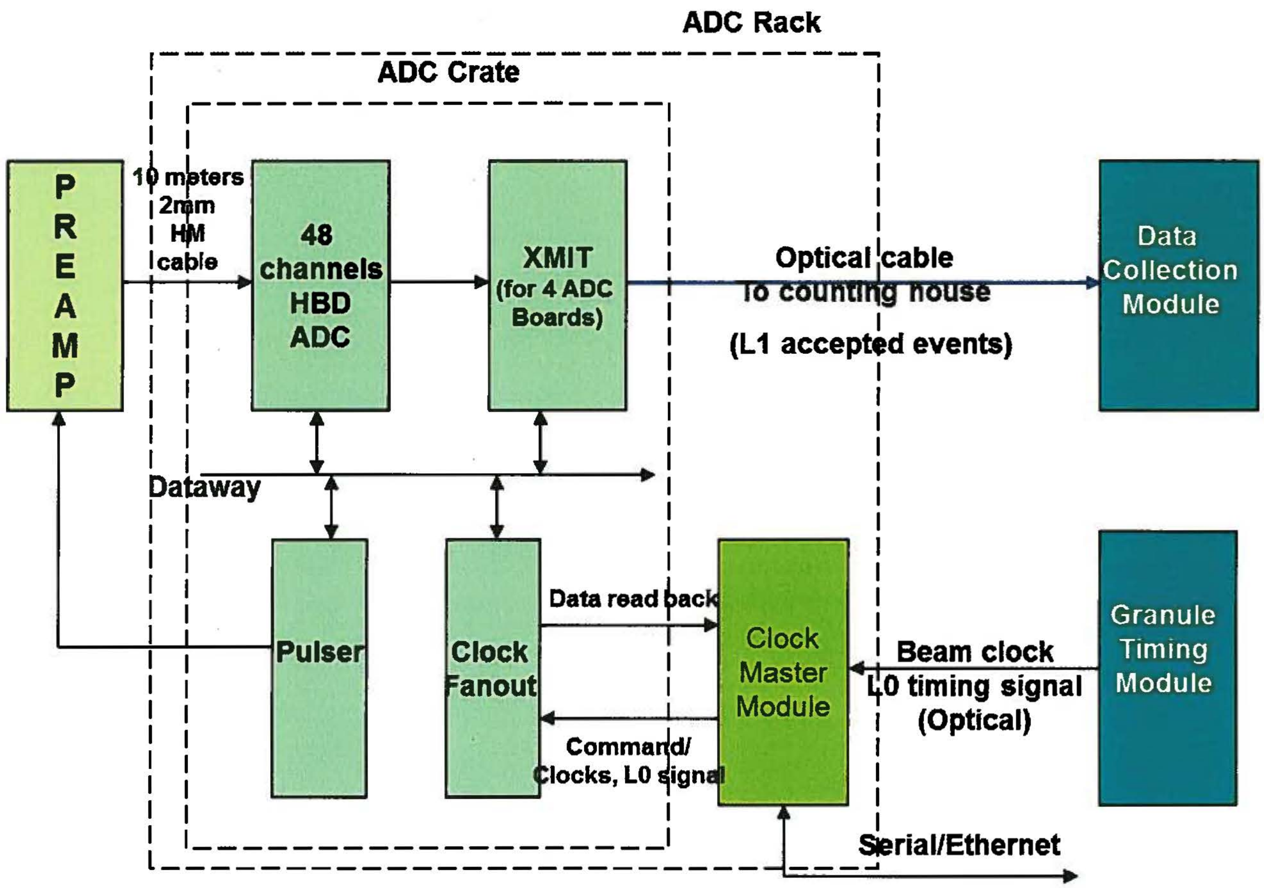


Figure 4: Block diagram of the HBD electronics that will be used for the HCal and EMCal readout.

All electronics are custom designed and built following industry standards. All power systems are fused appropriately and safety grounded. Design schematics for all custom electronics, and data sheets for commercial electronics will be provided in advance of safety review.

The experimenters do not anticipate any requests of equipment from the PREP pool. However, should unanticipated needs arise (e.g. failed NIM module) limited access to the PREP pool may be required.

The experimenters plan to have most of their devices on a private network with one machine acting as gateway between the internal network and external network. A similar setup was used for the T-1038 PHENIX MPC-Ex effort.

2.3.3 EMCal Calibration System

A solid-state laser will be used to calibrate the EMCal periodically during data taking. The laser head, mounted in a fully enclosed box, and the control unit will be located the detector. An optical fiber will be connected directly to laser head and transmit the laser pulses to the EMCal detector. At the EMCal, an optical splitter will split the light into 49 fibers which will be directly coupled to the optical cavities on the back side of the EMCal.

The laser is a Picosecond Diode Laser from Advanced Laser Diode Systems, class 3B model PiL040X, producing 420 nm laser pulses, 50 ps wide at frequencies up to 1Mhz. The optical power output, P_o, is 1mW with a peak power output, P_p, of 1000 mW.

2.3.4 DESCRIPTION OF TESTS

The EMCal and HCal modules will be assembled and tested at Brookhaven National Laboratory in the second half of 2013. During the first 2 weeks of January 2014 the detectors will be transported to FNAL. Once they arrive, final assembly of the detectors and cosmic ray running on the floor area outside MT6.2 beam line area will take place. During the week of Jan 29, if possible, the detectors will be relocated into the MT6.2 test area parasitic to T-1042 operations.

The week of Feb 5, 2014 will be used for final installation and commissioning of the HCal and EMCal detectors, electronics and the MWPC tracking system. During this period limited beam requirements are anticipated for short periods with beam use increasing as the detectors and electronics are commissioned.

During the period of Feb 12-25 the experiment plans on taking fixed length runs at energies ranging from 1-60 GeV for pions in 5 GeV steps and electrons from 0.5 GeV to 16 GeV.. Following each energy scan, a control access is required to change the orientation of the detectors with respect to the nominal beam. Data taking at 10 geometrical orientations, and 6 different energy settings per orientation, are required. Each data set is expected to require 2 hours of beam time, requiring a total of 120 hours of beam time. Assuming 12 hours of beam operations per day, 2 weeks (14 days) of beam operations is sufficient to fulfill our beam requirements.

Data analysis will commence with data taking and continue following the test beam operations. Based on the results of the analysis additional beam time may be requested.

2.4 SCHEDULE

The basic run plan is as follows:

1. Jan 1-14, 2014: Shipment of HCal and EMCal detectors and associated electronics to FNAL.

2. Jan 14-28 2014: Final assembly of the HCal and EMCal detectors, commissioning of electronics and cosmic ray running outside of the M-Test beam line area

3. Jan 29-Feb 4 2014: Move EMCal and HCal detectors to MT6.2 area parasitic to T1042 operations if possible.

4. Feb 5-11 2014: Final commissioning of detectors and electronics, incorporation of tracking system into sPHENIX DAQ system.

5. Feb 12-25 2014: Test beam operations using secondary pion and muon beams. During this time we anticipate doing beam energy scans and geometric scans. Duration of the energy scans will depend on the event rates. Geometric scans will require short

controlled access to change the geometrical orientation of the detectors with respect to the beam line.

6. March 2014: Analysis of test data
7. April 2014: Based on analysis of data taken in February, one week of additional test beam access may be requested. If no additional beam time is required, the experimenters will disassemble the detectors and transport them back to BNL.

II. RESPONSIBILITIES BY INSTITUTION – NON FERMILAB

- <u>BROOKHAVEN NATIONAL LABORATORY:</u>
    - HCal and EMCal detectors: $100K
    - Readout and DAQ electronics: $10K
    - Lift table for HCal and EMCal detectors.
    - Installation and commissioning of detectors
    - Staffing of data taking shifts
    - Data analysis
- <u>Georgia State University</u>
    - Installation and commissioning of detectors
    - Staffing of data taking shifts
    - Data analysis
- <u>Oak Ridge National Laboratory</u>
    - Installation and commissioning of detectors
    - Electronics Support
    - Staffing of data taking shifts
    - Data analysis
- <u>University of Colorado</u>
    - Installation and commissioning of detectors
    - Staffing of data taking shifts
    - Data analysis

IV. RESPONSIBILITIES BY INSTITUTION – FERMILAB

4.1 FERMILAB ACCELERATOR DIVISION:

4.1.1 Use of MTest beam line as outlined in Section II. [0.25 FTE/week]

4.1.2 Maintenance of all existing standard beam line elements (SWICs, loss monitors, etc) instrumentation, controls, clock distribution, and power supplies.

4.1.3 Scalars and beam counter readouts will be made available via ACNET in the MTest control room.

4.1.4 Reasonable access to the equipment in the MTest beam line.

4.1.5 Connection to beams console and remote logging (ACNET) should be made available.

4.1.6 The test beam energy and beam line elements will be under the control of the AD Operations Department Main Control Room (MCR). [0.25 FTE/week]

4.1.7 Position and focus of the beam on the experimental devices under test will be under control of MCR. Control of secondary devices that provide these functions may be delegated to the experimenters as long as it does not violate the Shielding Assessment or provide potential for significant equipment damage.

4.1.8 The integrated effect of running this and other SY120 beams will not reduce the neutrino flux by more than an amount set by the office of Program Planning, with the details of scheduling to be worked out between the experimenters and the Office of Program Planning.

4.2 FERMILAB PARTICLE PHYSICS DIVISION:

4.2.1 The test-beam efforts in this TSW will make use of the Fermilab Test Beam Facility. Requirements for the beam and user facilities are given in Section II. The Fermilab Particle Physics Division will be responsible for coordinating overall activities in the MTest beam-line, including use of the user beam-line controls, readout of the beam-line detectors, and FTBF computers. [6.5 FTE/week]

4.2.2 Setting up and maintaining of the MWPC tracking system (4 stations), and differential Cherenkov.

4.2.3 Use of a pb-glass block and phototube for cross calibration of EMCal energy response.

4.2.4 Two scintillator trigger counters (including PMT's). Scintillator should measure approximately 1x1 in^2.

4.2.5 Crane support to move detectors into and out of beam enclosure.

4.2.6 Conduct a NEPA review of the experiment.

4.2.7 Provide day-to-day ESH&Q support/oversight/review of work and documents as necessary.

4.2.8 Provide safety training as necessary, with assistance from the ESH&Q Section.

4.2.9 Update/create ITNA's for users on the experiment.

4.2.10 Initiate the ESH&Q Operational Readiness Clearance Review and any other required safety reviews.

4.2.11 Installation of 220v 3-phase outlets [$2k]

4.3 Fermilab Scientific Computing Division

4.3.1 Internet access should be continuously available in the MTest control room.
4.3.2 See Appendix II for summary of PREP equipment pool needs.
4.3.3 Set-up of a private network, and connection to Fermi-network [0 FTE]

4.4 Fermilab ESH&Q Section

4.4.1 Assistance with safety reviews.
4.4.2 Provide safety training, with assistance from PPD, as necessary for experimenters. [0.2 FTE]

SUMMARY OF COSTS

Source of Funds [$K]	**Materials & Services** ($k)	**Labor** (FTE/week)
Accelerator Division	0	0.5
Particle Physics Division	2	6.5
Scientific Computing Division	0	0
ESH&Q Section	0	0.2
Totals Fermilab	$2.0K	7.2
Totals Non-Fermilab		

I. GENERAL CONSIDERATIONS

6.1 The responsibilities of the Spokesperson and the procedures to be followed by experimenters are found in the Fermilab publication "Procedures for Researchers": (http://www.fnal.gov/directorate/PFX/PFX.pdf). The Spokesperson agrees to those responsibilities and to ensure that the experimenters all follow the described procedures.

6.2 To carry out the experiment a number of Environmental, Safety and Health (ESH&Q) reviews are necessary. This includes creating an Operational Readiness Clearance document in conjunction with the standing Particle Physics Division committee. The Spokesperson will follow those procedures in a timely manner, as well as any other requirements put forth by the Division's Safety Officer.

6.3 The Spokesperson will ensure at least one person is present at the Fermilab Test Beam Facility whenever beam is delivered and that this person is knowledgeable about the experiment's hazards.

6.4 All regulations concerning radioactive sources will be followed. No radioactive sources will be carried onto the site or moved without the approval of the Fermilab ESH&Q section.

6.5 All items in the Fermilab Policy on Computing will be followed by the experimenters. (http://computing.fnal.gov/cd/policy/cpolicy.pdf).

6.6 The Spokesperson will undertake to ensure that no PREP or computing equipment be transferred from the experiment to another use except with the approval of and through the mechanism provided by the Scientific Computing Division management. The Spokesperson also undertakes to ensure no modifications of PREP equipment take place without the knowledge and written consent of the Computing Sector management.

6.7 The experimenters will be responsible for maintaining both the electronics and the computing hardware supplied by them for the experiment. Fermilab will be responsible for repair and maintenance of the Fermilab-supplied electronics. Any items for which the experiment requests that Fermilab performs maintenance and repair should appear explicitly in this agreement.

At the completion of the experiment:

6.8 The Spokesperson is responsible for the return of all PREP equipment, computing equipment and non-PREP data acquisition electronics. If the return is not completed after a period of one year after the end of running the Spokesperson will be required to furnish, in writing, an explanation for any non-return.

6.9 The experimenters agree to remove their experimental equipment as the Laboratory requests them to. They agree to remove it expeditiously and in compliance with all ESH&Q requirements, including those related to transportation. All the expenses and personnel for the removal will be borne by the experimenters unless removal requires facilities and personnel not able to be supplied by them, such rigging, crane operation, etc.

6.10 The experimenters will assist Fermilab with the disposition of any articles left in the offices they occupied.

6.11 An experimenter will be available to report on the test beam effort at a Fermilab All Experimenters' Meeting.

SIGNATURES:

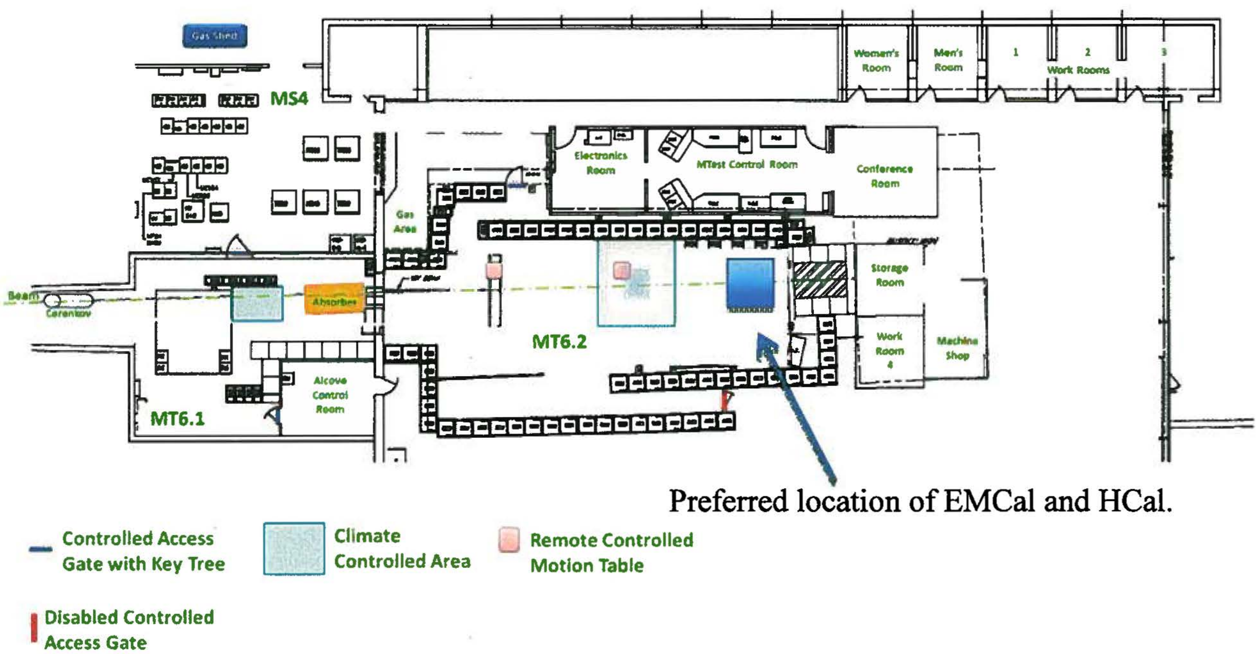
The spokesperson is the official contact and is responsible for forwarding all pertinent information to the rest of the group, arranging for their training, and requesting ORC or any other necessary approvals for the experiment to run.
The spokesperson should also make sure the appropriate people (which might be everyone on the experiment) sign up for the test beam emailing list.

Eric J. Manel, Experiment Spokesperson — 1 / 6 / 2014

APPENDIX I: MT6 AREA LAYOUT

The TOF system requires 2 locations with sufficient separation to measure the difference in the time-of-flight for the beam particles. For the forward detector the experimenters request use of the motion table that is installed in the forward region of MT6.2 area. For the rear detector the experimenters request a location just down stream of the climate controlled area. For the EMCal and HCal the experimenters want to the use the most downstream region of the MT6.2 test area on the concrete blocks that are located there. The most likely method of getting the EMCal and HCal detector system into the MT6.2 test area is through the hatch directly above this area.

MTEST AREAS



APPENDIX II: EQUIPMENT NEEDS

Provided by experimenters:

1. HCal with all associated readout electronics.
2. EMCal with all associated readout electronics.
3. TOF Detectors and associated readout electronics
4. Data acquisition electronics and computers
5. Power supplies for all electronics
6. Signal and power cables for all HCal and EMCal electronics

Equipment Pool and PPD items needed for Fermilab test beam, on the first day of setup.

PREP EQUIPMENT POOL:

Description

The experimenters may require a few NIM logic and discriminator modules for triggering. A detailed request will be provided in advance of beam operations.

PPD FTBF:

Description

Use of the MWPC tracking system (4 stations) and associated electronics.

Use of a pb-glass block and phototube for cross calibration of EMCal energy response.

Two scintillator trigger counters (including PMT's). Scintillator should measure approximately 1x1 in^2.

HV to operate PMTs for Pb-Glass and Trigger counter PMTs.

Use of MTEST Cerenkov counter for electron ID up to 8 GeV

APPENDIX III: - HAZARD IDENTIFICATION CHECKLIST

Items for which there is anticipated need have been checked. See next page for detailed descriptions of categories.

Flammable Gases or Liquids		**Other Gas Emissions**		**Hazardous Chemicals**		**Other Hazardous /Toxic Materials**
Type:		Type:			Cyanide plating materials	List hazardous/toxic materials planned for use in a beam line or an experimental enclosure:
Flow rate:		Flow rate:			Hydrofluoric Acid	
Capacity:		Capacity:			Methane	
Radioactive Sources		**Target Materials**			Photographic developers	
	Permanent Installation		Beryllium (Be)		PolyChlorinatedBiphenyls	
	Temporary Use		Lithium (Li)		Scintillation Oil	
Type:			Mercury (Hg)		TEA	
Strength:			Lead (Pb)		TMAE	
Lasers			Tungsten (W)		Other: Activated Water?	
	Permanent installation		Uranium (U)			
X	Temporary installation		Other:	**Nuclear Materials**		
X	Calibration	**Electrical Equipment**		Name:		
	Alignment		Cryo/Electrical devices	Weight:		
Type:	420 nm diode laser		Capacitor Banks	**Mechanical Structures**		
Wattage:	P_o= 1 mW/ P_f= 1000mW	X	High Voltage (50V)		Lifting Devices	
MFR Class:	3B		Exposed Equipment over 50 V	X	Motion Controllers	
		X	Non-commercial/Non-PREP		Scaffolding/ Elevated Platforms	
			Modified Commercial/PREP		Other:	
Vacuum Vessels		**Pressure Vessels**		**Cryogenics**		
Inside Diameter:		Inside Diameter:			Beam line magnets	
Operating Pressure:		Operating Pressure:			Analysis magnets	
Window Material:		Window Material:			Target	
Window Thickness:		Window Thickness:			Bubble chamber	

TSW for T-1044: **sPHENIX Calorimetry Tests**

The following people have read this TSW:

Michael Lindgren, Particle Physics Division, Fermilab — 1/8/2014

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Robert Roser, Scientific Computing Division, Fermilab — 1/9/2014

Martha Michels, ESH&Q Section, Fermilab — 1/13/2014

Greg Bock, Associate Director for Research, Fermilab — 1/14/2014

Stuart Henderson, Associate Director for Accelerators, Fermilab — 1/14/2014