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VERSION 921111

TESTING OF COMPONENTS FOR THE GEM DETECTOR AT THE SUPERCONDUCTING SUPER COLLIDER LABORATORY

A PROPOSAL TO THE FERMI NATIONAL ACCELERATOR LABORATORY

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Introduction

The GEM collaboration at the Superconducting Super Collider Laboratory (SSC Lab) proposes to test prototypes and components of a general purpose magnetic detector, to be installed at the SSC in 1997/1998.

These tests would be performed at a dedicated facility at Fermilab, by members of the GEM collaboration, during periods when external beams are available. First use of beams is requested for mid-1994. The currently anticipated total need for beam time in that period, continuing until mid-1995, is 3,000 hours. Similar requests are foreseen for future fixed target periods, at least until 1998. Specific proposals will be submitted when appropriate.

This proposal outlines the beams, real estate and services requested for the test activities. It further discusses a possible implementation, using existing facilities and equipment. A possible schedule of activities is presented.

The major components of the GEM detector are:

Magnet (not subject to beam tests)

Central Tracker

Electromagnetic and hadronic calorimeters

Muon Detector

Data Acquisition System

Trigger and Readout System

The testing activities, planned for each of these components, are described below.

Testing activities

The GEM calorimeter has an emphasis on excellent electromagnetic energy resolution for measuring and identifying electrons and photons. A large fraction of the requested beam time will be dedicated to detailed studies of the performance of the calorimeter components and, where needed, the calibration of the actual modules to be installed in the detector. Of primary importance is the understanding of the calorimeter response to hadrons and electrons over as wide a dynamic range in energy (3 GeV and up) as possible.

The study of possible "pile-up" problems in a high intensity (up to 50 MHz) environment is of importance for calorimeter components, tracking devices and data acquisition hardware.

Position resolution studies are important for tracking devices and for calorimeter components.

Studies of the effects, on the muon detector, of electromagnetic "junk" produced in the calorimeters are mentioned below.

More detailed descriptions of the tests to be performed may be found in Appendices 1-4.

Scheduling, Safety and other Coordination Issues

The GEM collaboration will have a test beam coordinator on site at Fermilab. This coordinator will be the contact person between GEM and Fermilab in matters of safety, scheduling, and other issues related to the use of the test beam facility.

Through this coordinator, the collaboration will keep the Fermilab Program Planning Office appraised of current activities and of long and short term scheduling needs.

In addition, the coordinator will be the GEM contact person in matters of safety. With his Fermilab counterpart, he will review all relevant safety issues and settle them in compliance with Fermilab standards.

We currently see as issues for safety review the following items:

Mechanical Safety: Transporters which accurately position large detector modules.

Oxygen Deficiency Hazards: The electromagnetic calorimeter uses substantial quantities of liquefied cryogens

Flammable gases: Use in wire/gas detectors

Electrical Hazards: AC power wiring. High and low voltage DC power.

Radiation Safety: Controlled access to beam line enclosures. "Spray" from beam particles incident on calorimeter modules or absorber walls. Use of radioactive sources for monitoring purposes.

Material Handling Hazards: During installation and maintenance, the movement of large components present unique hazards.

Structural Hazards: Large, heavy components need to be adequately supported for all anticipated stresses.

Other Environmental Hazards: Any special precautions needed for magnet fringe fields from large aperture magnets.

Beam Requirements

The calorimeter resolution may approach:

$$0.06 / \sqrt{(E)} \oplus 0.005 \quad \text{for electromagnetic calorimetry}$$

$$0.50 / \sqrt{(E)} \oplus 0.02 \quad \text{for hadron calorimetry}$$

For the testing and calibration of the calorimeter components we request beams of the following characteristics:

	Electrons	Pions	Protons
Momentum (GeV)	2 -175	2-650	800 (diffracted beam)
Momentum resolution (dp/p)	0.002	0.01	0.01
Spatial resolution (m)	0.001	0.001	0.002
Purity (tagged) (+)	$\pi/e < 1\times10^{-3}$	$e/\pi < 1\times10^{-4}$	-
Intensity (Hz)	10 - 1,000	10 - 10,000	10 - 10.000 (*)

(+) High energy electrons will be tagged with a transition radiation detector. At lower energies, electron/pion separation will be done with Cherenkov counters. Residual pions will be eliminated off-line through their response in a downstream hadron calorimeter.

Electrons in a pion beam will be eliminated by insertion of an upstream radiator at a beam line focus.

(*) Pile up (high intensity) studies will be done using a 10 msec wide "pinged" beam at several protons per RF bucket.

The testing of the tracker components will be done with the above pion and proton beams.

The testing of the muon detector will partly be done down beam of the calorimeter systems, or behind a five meter deep hadron absorber. We further intend to study the effects, on the muon detector in a magnetic field, of products from electromagnetic interaction in the calorimeter. To do this we request running for a few months, in a high energy (> 400 GeV) tagged muon beam in a volume

2 m [along the beam] x

2 m [horizontally across the beam] x

1 m [vertically across the beam]

with a vertical magnetic field of 0.8 - 1.0 Tesla. The required beam intensity is > 100 Hz. A possible candidate would be the space inside the CCM in NMS (New Muon Lab) or the large analysis magnet in MW (E-706 setup). See Appendix 5 for a discussion of the MWest area.

The beam transport system would be part of the facilities provided by Fermilab (see below).

The readout of the beam spectrometer system would be (at least in part) accessible to the Fermilab Operations Group. This requires that some of its components be compatible

with existing Fermilab equipment. We request that Fermilab provide some of that Fermilab standard equipment, such as:

a. Beam spectrometer proportional chambers (Fenker chambers), with 1 mm wire spacing and 128 mm × 128 mm aperture, with PREP standard readout equipment,

b. Standard SWICs and other standard beam tuning/monitoring equipment as well as connection to the Fermilab EPICURE system, and

c. Cherenkov counter instrumentation head (Pruss counter) to be used in conjunction with beam transport vacuum pipes.

Facilities

We expect to put the test beam facility to the following uses:

1.) Acquisition of data during "beam on" periods.

2.) Installation of, and work on, equipment in the beam line during "beam off" periods.

3.) Assembly of, and other work on, modules adjacent to the beam line.

4.) Debugging work on the equipment to be tested, readout electronics and data acquisition hardware and software.

5.) Monitoring the data acquisition.

6.) Analysis of the test results.

7.) Storage and handling of cryogens.

Items 1.), 2.), 3.) and 4.)

To maximize the use of the available beam time, we request beam line floor space sufficient to have the tracker modules, electromagnetic and hadron calorimeter modules and the muon detector modules simultaneously located in the beam or, at the appropriate location along the beam line, displaced laterally (on rails) to allow other detector modules unperturbed use of the beam. Thus we request a beam area, exclusive of the beam spectrometer, with dimensions:

40 m along the beam line

> 5 m across the beam line horizontally (*)

3 m beam line height above floor level (*)

(*) The electromagnetic calorimeter and the muon detectors require 15 m to one side, and 5 m to the other, of the beam line and 4 m between the beam line and the floor.

Adjacent to this area (within reach of the crane) we request 200 square meters of assembly area.

The design of the calorimeter modules requires a heavy duty crane. 20 ton capacity is necessary. 25-30 ton highly desirable. Both the beam and assembly areas should be accessible to that crane. Crane height should be such that the top of a module under test can be lifted seven meters above floor level.

Each of the detector components will require a transporter. Previous GEM test beam activities have used [T-849 (Kobrak)] the calorimeter transporter built by U. of Wisconsin for the Zeus test [E-790 (Sciulli)]. We request its continuing use. An additional transporter, built with GEM funds at Fermilab will also be used. It is anticipated that the electromagnetic calorimeter will require a special transporter, similar to the one in use for D0 at NWA. This transporter will be designed and built by GEM personnel, in close contact with Fermilab safety people. The range of travel of these transporters will be determined by a balance between the cost of the transporter and the cost, in beam time and other resources, of more frequent re-rigging of modules under test.

We anticipate the need of one megawatt of AC power.

Environmental controls should provide:

temperature	10 deg. C - 25 deg. C
humidity	40% - 55% (This may be handled with separate enclosures)
safety	provisions to deal with ODH problems due to spills of cryogens

Items 4.), 5.) and 6.)

We anticipate that test beam activities take place in two operating modes:

a.) Independent work on different components.

b.) Combined data acquisition (on a trigger-by-trigger basis) by a system of several components.

Mode a.) requires enough facilities (control room, lab, rack and desk space) for simultaneous work by several different groups. There would be a shared area for the trigger and separate areas for the readout and data acquisition and monitoring hardware (See discussion of data acquisition, below).

Mode b.) requires that, on demand, the readout of some of the previously separately read systems be done simultaneously on an event-by-event basis.

To accommodate the requirements for both modes, we request space for forty desks and benches and forty relay racks. Some of the racks will be located next to the beam line. The floor space for the control console(s), relay racks and desks can be provided by 5 - 6 portakamps (or equivalent).

Data Acquisition System(s)

We consider the acquisition of data for the tests of detector components, or systems of detector components, separate from tests of the data acquisition system for the final detector. We intend to avoid, as far as possible, interference between the testing of detector modules and the testing of the eventual GEM data acquisition system.

In a test beam environment, where, by definition, unforeseen circumstances surface frequently, flexibility in the data acquisition system is of importance.

As mentioned above, the test data acquisition system will be configured so that it is possible to acquire data separately from different components or jointly from systems incorporating several components. The use of CAMAC equipment, makes multiple access to the data stream easy. At the same time it enables GEM to develop, where useful, common software modules.

In implementing this system, we hope to be able to profit from the expertise of the Fermilab Data Acquisition Group. Where appropriate, we will use software modules which are currently supported by that group.

GEM proposes to initially use data acquisition computers and work stations of the type used elsewhere at Fermilab and thus be able to profit from their hardware, software, and expertise (See below for pool equipment).

In addition we expect, as a further equipment test, to use one or more prototype versions of the data acquisition system for the GEM detector. These tests would consist of using this prototype to acquire data with an otherwise tested detector module. In the schedule below, testing time for the data acquisition prototype(s) is included in the time slot for the detector module whose data will be acquired by the prototype.

Services

We request that Fermilab provide the following services:

Installation and maintenance of the beam line, experimental floor and counting room and office areas as specified above. We propose a suitable site in Appendix 5.

Development and maintenance of the tune for the beams specified above.

Surveying and alignment of the beam line components and of the modules under test.

Use of the Fermilab communication system (telephones, computer networks, etc.)

Use of the central computing facility. We anticipate that, on an occasional basis, our needs for off-line computing will exceed our capacity. On those occasions we request access to the Fermilab Central Computing facilities. We expect such requests to be small in terms of compute cycles and disk space, and to occur infrequently.

We request equipment support from the PREP pool at a level comparable to the one given to E-790 (Sciulli) and T-849 (Kobrak). We understand that this implies that PREP equipment would be available only as long as the modules are not required by groups engaged in the Fermilab Physics Program.

Possible Beam Lines

The location of a GEM test beam installation will clearly be determined by the Fermilab management from the overall considerations of the Fermilab program.

For the purpose of drafting a possible schedule of activities over the 1993-1995 period, we take as an example the location of such a beam line in either MW (former E-706), the possible use of which is described in Appendix 5, or NM (new Muon Lab).

Detector Modules to be tested

In the central detector, the calorimeter is of a hybrid configuration. The front part is a liquid krypton calorimeter of the "accordion" design. Its cryogenic operation, once approved by Fermilab Safety, will not require periodic surveillance by technicians. A description of some tests already performed, as well as a discussion of the purposes of Fermilab testing, may be found in Appendix 1. This front part is followed by a section which consists, in its present design, of a scintillating fiber sensitive part, imbedded in a converter matrix. A discussion of tests of a scintillating fiber back calorimeter may be found in Appendix 2.

The forward calorimeter will either be cryogenic (liquid krypton and tungsten or brass) or sensitive fibers (liquid scintillator or quartz) in a converter matrix.

The tracking system is compact and designed to operate in a 0.8 Tesla magnetic field. The present baseline design consists of a silicon microstrip inner tracker and an Interpolating Pad Chamber outer tracker. A discussion of central tracker testing at Fermilab may be found in Appendix 3.

The muon system is required to track muons with a precision no worse than 100 μm per layer in the GEM 0.8 Tesla field. Problems to be overcome include relative chamber alignment better than 25 μm over the 5m depth of the barrel system, hadron punchthrough, neutron fluence, and muon Bremsstrahlung. Tests to be performed at Fermilab are described in Appendix 4.

Schedule of Activities (1993-1995)

For planning purposes only, the schedule presented below assumes that the test beam (actual particles) will become available to GEM on 1 October 1994.

1 March 1993	Fermilab approval for GEM test beam activities
1 June 1993	Finalize detailed specifications for test beam line configuration. Begin safety review of beam line and experimental floor setup.
1 October 1993	Beneficial occupancy of the test beam facility for experimenters. Begin configuration of experimental floor, assembly of transporters.
1 January 1994	Safety review of experimental setup. Begin tests of heavy equipment, cryogenic utilities, etc. Installation of cable runs, communications equipment. Availability of PREP equipment. Installation of data acquisition components.
1 March 1994	Triggering and data acquisition equipment in place and installed. Start tests of transporter controls. triggers data acquisition
1 July 1994	Certify performance of transporter controls triggers, data acquisition First detector components arrive at Fermilab. Off-line analysis tests with simulated data
1 September 1994	Detector components installed Final Safety review and approval Cool down of cryogenics Begin continuous manning of installation by GEM personnel

1 October 1994	First beam available Beam line tuning Beam spectrometer commissioning Radiation Safety review Trigger tuning First data acquisition with beam particles	
15 October 1994	Start of regular data taking with stand-alone detector modules.	
	Electromagnetic calorimeter	200 hrs
	Hadron calorimeter	200 hrs
	Forward calorimeter	100 hrs
	Muon detector (concurrent)	---
	Muon detector (dedicated)	100 hrs
1 December 1994	Second round of stand-alone tests	300 hrs
	Begin setup for integrated systems	200 hrs
15 January 1995	Data taking with integrated systems 400 hrs	
15 February 1995	Results of November 1994 - January 1995 tests have generated equipment modifications. Additional tests will begin. Such tests will include work on the central tracker whose first round tests will have taken place at Brookhaven National Laboratory during the 1993/1994 test beam period. The tracker tests will require high flux rates. The second round tests may require beam throughout Spring/Summer of 1995.	

Activities past 1995

At the end of the above schedule, we expect to have concluded the prototype tests.

The certification and calibration of the final "production" modules are expected to be done using facilities at both the SSC Lab and Fermilab. Until late in the decade (close to SSC commissioning time) only Fermilab will have available protons of energies in excess of 200 GeV. Such beams are crucial for understanding the high energy response of calorimeter modules.

Funding

GEM expects that appropriate funding arrangements will be made between Fermilab and GEM in regard to incremental costs to Fermilab for the implementation and operation of the test beam. Subject to any interlaboratory agreements between SSCL and FNAL, GEM will pay for supplies and operating costs associated with the equipment installation and test beam activities themselves. We currently estimate (very roughly) that these expenses will amount to $ 75K - $ 150K per year.

Alternatives

SSCL test beams will not be available until 1996 or, possibly, 1997. The maximum energy will be 170 GeV. 2 TeV test beams may become available with HEB turn-on in 1998, but are not currently being designed. Therefore they may not become available until much later. Therefore the high energy beams necessary for calorimeter calibration and muon punch-through and Bremsstrahlung studies will not be available in the U. S. at least until 1998. In addition, most GEM design work and even module construction must commence before any SSCL test beams are ready. CERN beams may be available, but the difficulty and expense of foreign travel, and the size of the effort involved, make this a much less attractive option than Fermilab beams. For lower energy beams, BNL is a possibility which is being actively investigated by GEM; this may be useful for certain tracker studies.

Summary

The GEM collaboration proposes the installation and operation of a test beam facility, appropriate to test and calibrate the prototypes and components of the GEM detector at the SSC Lab. Beneficial occupancy is requested for late 1993. First use of beam is requested for late 1994. Availability of approximately 1,500 hrs of test beams for the first round (Fall 1994/Winter 1995) of tests is requested. A similar amount of test beam time for the second round (Spring/Summer 1995) is estimated.

Appendix 1

Beam tests on the Krypton EM Calorimeter

In 1992, GEM tested a small prototype accordion calorimeter at BNL, using both Argon and Krypton. Some of the results for krypton are shown in figures A.1-1 and A.1-2. The tests used beams of pions and electrons from 5 GeV/c to 20 GeV/c. Excellent linearity was obtained. The deviation from a straight line in Figure A.1-1 is less than 0.5%. Figure A.1-2 shows the energy resolution for 5, 10, 15 and 20 GeV/c electrons. The straight line is a fit with the parameters $[(6.72 \pm 0.035)\%/\sqrt{(E)}] \oplus (0.0 \pm 0.2)\%$. (After subtracting the beam spread of 0.5% and a measured 0.080 GeV/c measured pedestal width) Although the constant term appears to be small, we must make this measurement at the higher energies available at Fermilab, in order to approach the energy region where the stochastic term becomes small. Such tests, in a system which includes the hadron calorimeter, will be crucial for verifying that such a systems meets the GEM physics goals.

In addition, we must explore as many of the actual features of the calorimeter as possible. This includes, but is not limited to, the effects of cabling, support structures, cracks, and cryostat walls. We intend to also benchmark the detector Monte Carlo to calibrate the full simulation. We will measure pedestal effects in the electronics, including zero suppression, time variation characteristics, and noise measurements. A liquid krypton calorimeter prototype will be tested in conjunction with a scintillating fiber prototype, which will be placed behind it in the configuration to be used in the GEM detector. The combined unit will be mounted on a moveable support system. The philosophy will be to carry out a detailed evaluation of the full scale prototype of a sector of the barrel calorimeter for the purpose of refining and finalizing the design of production modules, and of optimizing the technical and functional integration of the hybrid calorimetry technology chosen for GEM. Similar testing will be performed for the forward calorimeter modules.

Appendix 2

Beam Tests of Scintillating Fiber Calorimeter Prototypes

In 1992, GEM tested seven prototype calorimeter modules based on scintillating fibers in a copper matrix. These modules were of a projective geometry, one of the possible configurations under discussion for the final detector. For 10 GeV pions ,we obtained an energy resolution (by fitting to the data shown in Figures A.2-1), prior to corrections for shower leakage and fiber attenuation, of $0.9/\sqrt{(E)}$. As shown in Figure A.2-2, the "e/π" ratio for energies between 10 and 20 GeV was shown to be 1.08 ± 0.02.

Tests with larger prototypes (to avoid effects of leakage) at the highest possible hadron and electron energies are of importance. The results of such tests, in conjunction with the cryogenic calorimeter modules, are needed to certify that the final detector design will meet the GEM physics goals. Tests of a GEM scintillating fiber calorimeter will also be performed in conjunction with the liquid krypton calorimeter which will be placed in front in the GEM detector. The overall purpose of these tests will be the same as described in Appendix 1 for the krypton portion of the calorimeter.

Appendix 3

The Central Tracker

Full Systems Tests

By 1995 most of the prototyping testing of the active components of the Central Tracker will have been completed, using available electronics. The final design electronics will only become available in 1995, so it is expected that their performance will be tested that year. Another major portion of the tracker effort that year will be to conduct systems tests of the mechanical and support systems (the gas supply, cooling, and mechanical support frame) using the final electronics for the heat load. We request the use of the previously-mentioned "pinged" beam for a period of 600 hours in 1995 (see schedule above).

Appendix 4

The Muon Detector System

There will be several different types of tests of GEM muon chambers at Fermilab:

- Test of a small (0.6m × 0.6m × 0.4m) prototype in a magnetic field of 0.8 Tesla using a high energy muon beam. Questions of muon radiation and pattern recognition will be addressed. A material imitating the calorimeter, or another superlayer of chambers, may be placed in front of the tested chambers at distances from 0.1 to 2.5m.

- The same as above but in a hadron beam of about 100 GeV behind a calorimeter module of an equivalent amount of material for testing of punchthrough and pattern recognition.

- The same as above but without material in front of the chamber, to measure the internal precision, Lorentz - angle effects, etc.

- Tests of a large (up to 6m × 3m × 5m) prototype consisting of three superlayers of muon chambers, structure, and alignment monitors using a high energy (> 200 GeV) muon or possibly hadron beam for tests of performance and alignment of a full scale tower of chambers.

All prototype dimensions and the exact test program are presently under discussion and will be better defined later.

Appendix 5

The Fermilab MWest Experimental Area

At this early date, and without the needed interaction with the Fermilab management, we cannot present a detailed, or even realistic, layout of the GEM testbeam setup. In order to illustrate our current ideas regarding a possible such setup, we show in Figures A.5-1 through A.5-4 a series of conceivable arrangements in what is currently the E-706 space in MW.

As shown in the figures, it appears possible to satisfy most of the GEM requirements with only minor modifications of the current installation. It should be possible to adapt the E–706 cryogenics to GEM requirements and to install the calorimeter transport system on the E–706 rails. The crane has adequate lifting capacity. Support space (counting rooms, control area, offices, etc.) may require, at most, minimal modifications. Discussions are in progress with the current leadership of E706 regarding how a test beams program might be mounted at MWest.

Once a site has been chosen for the GEM testbeam, we intend to work on a more definite layout in consultation with Fermilab personnel.

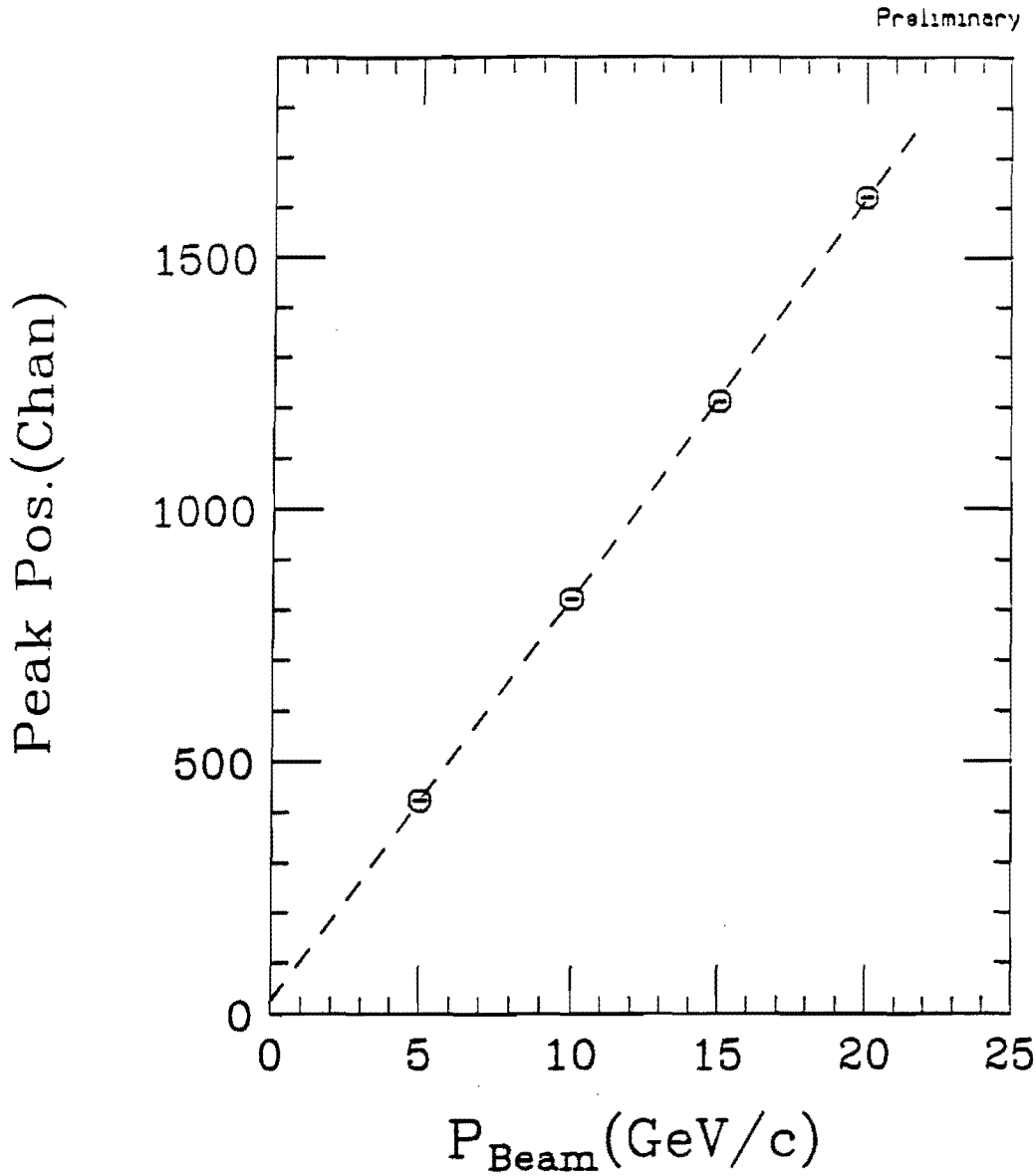

Preliminary
Peak Pos.(Chan)
1500
1000
500
0
0
5
10
15
20
25
P Beam (GeV/c)

Fig. A.1-1

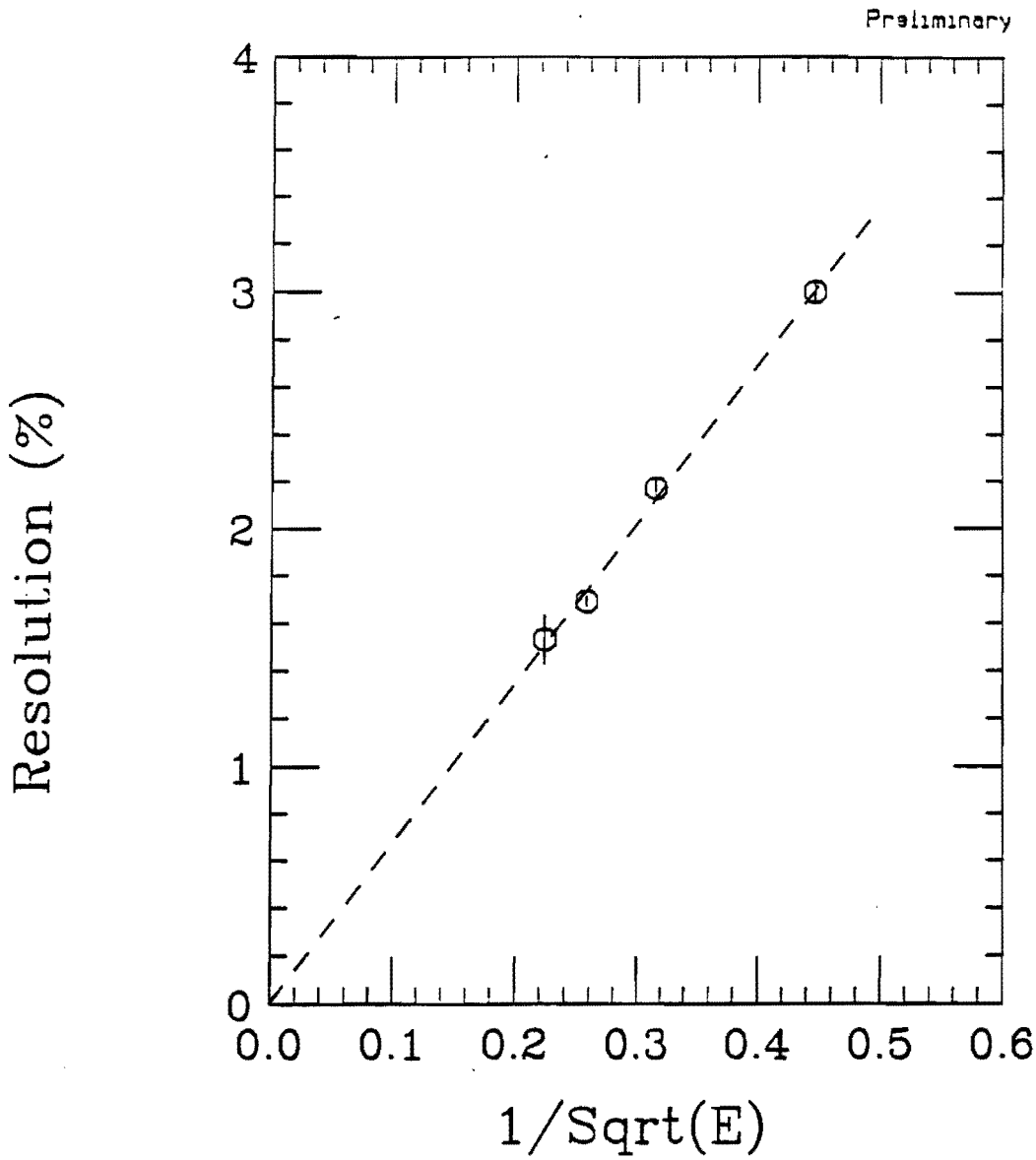


Fig. A.1-2

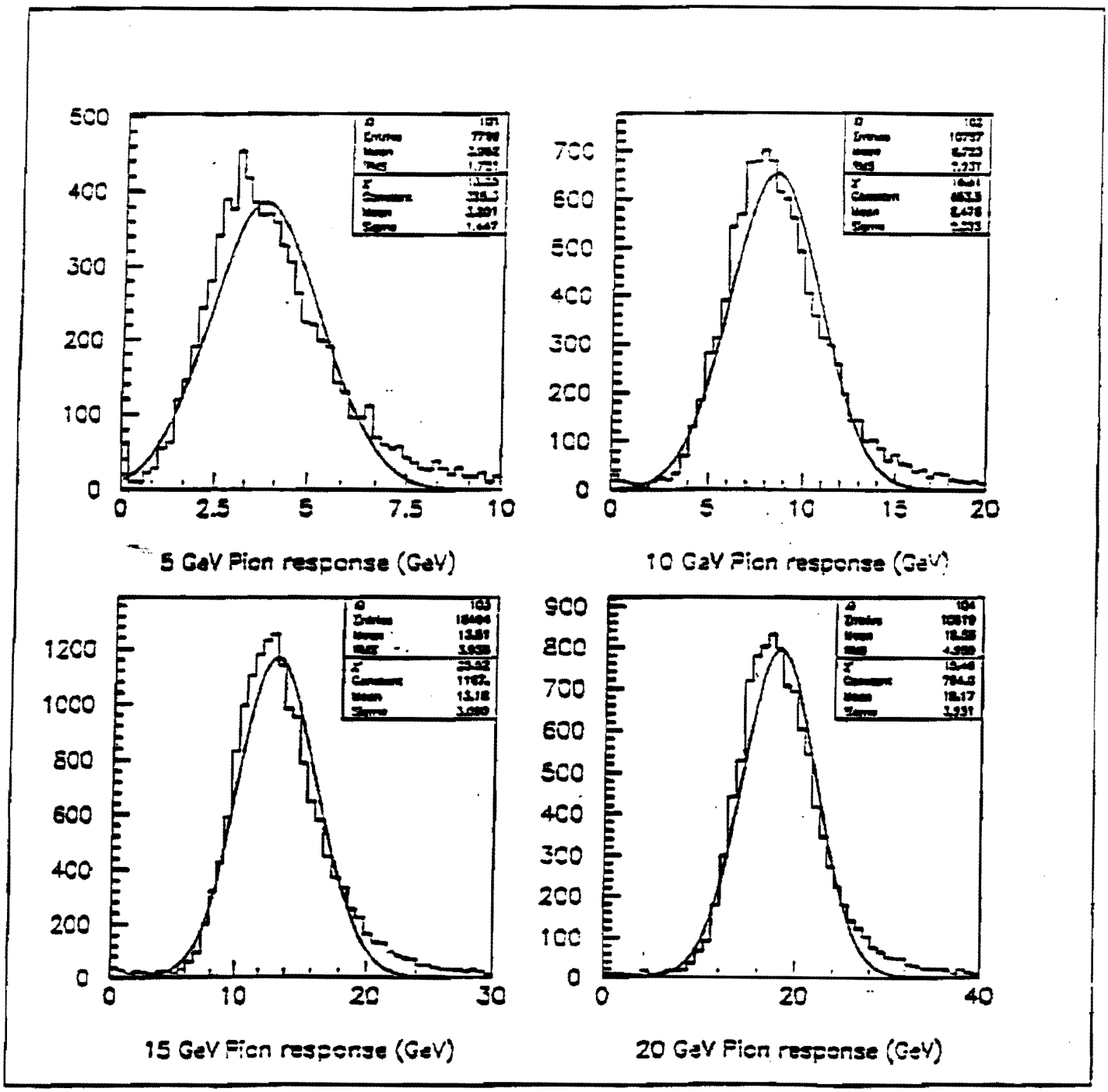

5 GeV Pion response (GeV)
10 GeV Pion response (GeV)
15 GeV Pion response (GeV)
20 GeV Pion response (GeV)

Fig. A.2-1

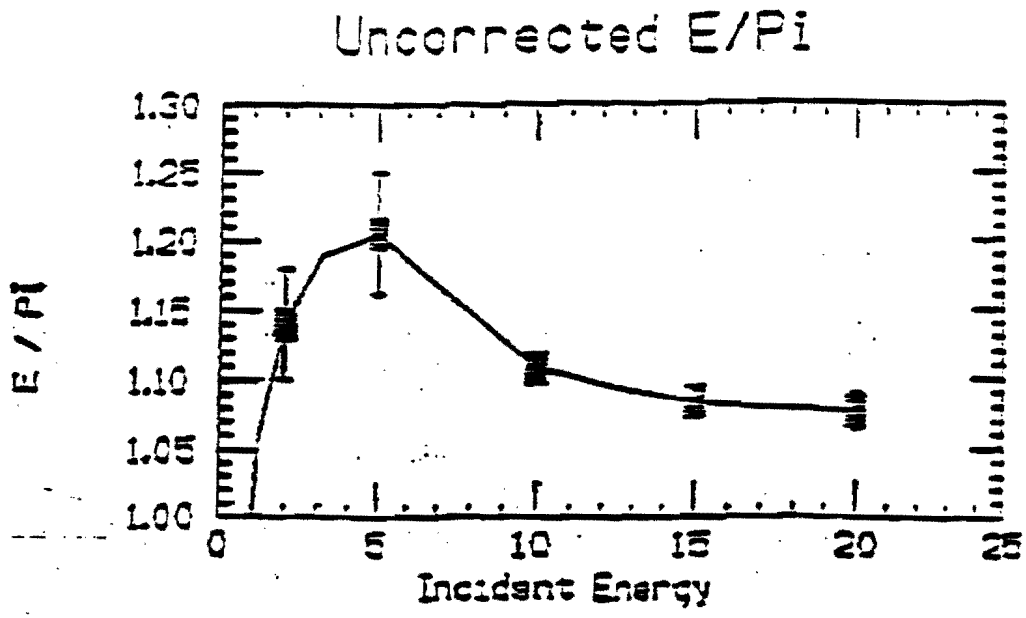

Uncorrected E/Pi
E / Pi
1.30
1.25
1.20
1.15
1.10
1.05
1.00
0
5
10
15
20
25
Incident Energy

Fig. A.2-2

MWEST AREA at FERMILAB

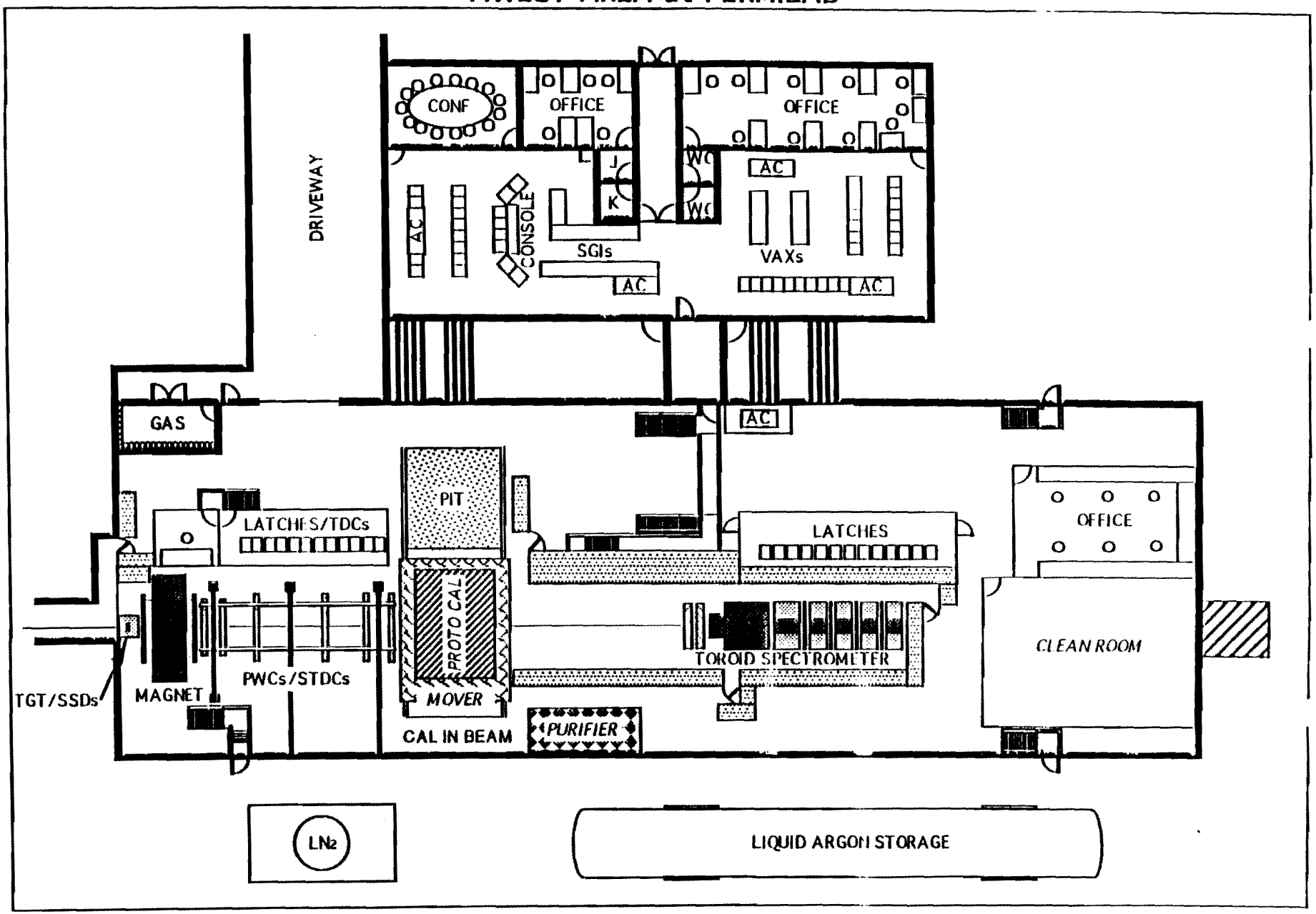


Fig. A.5-1

CALORIMETER PROTOTYPE TESTING
[For Schematic Purposes Only – Not Drawn to Scale]

MWEST AREA at FERMILAB

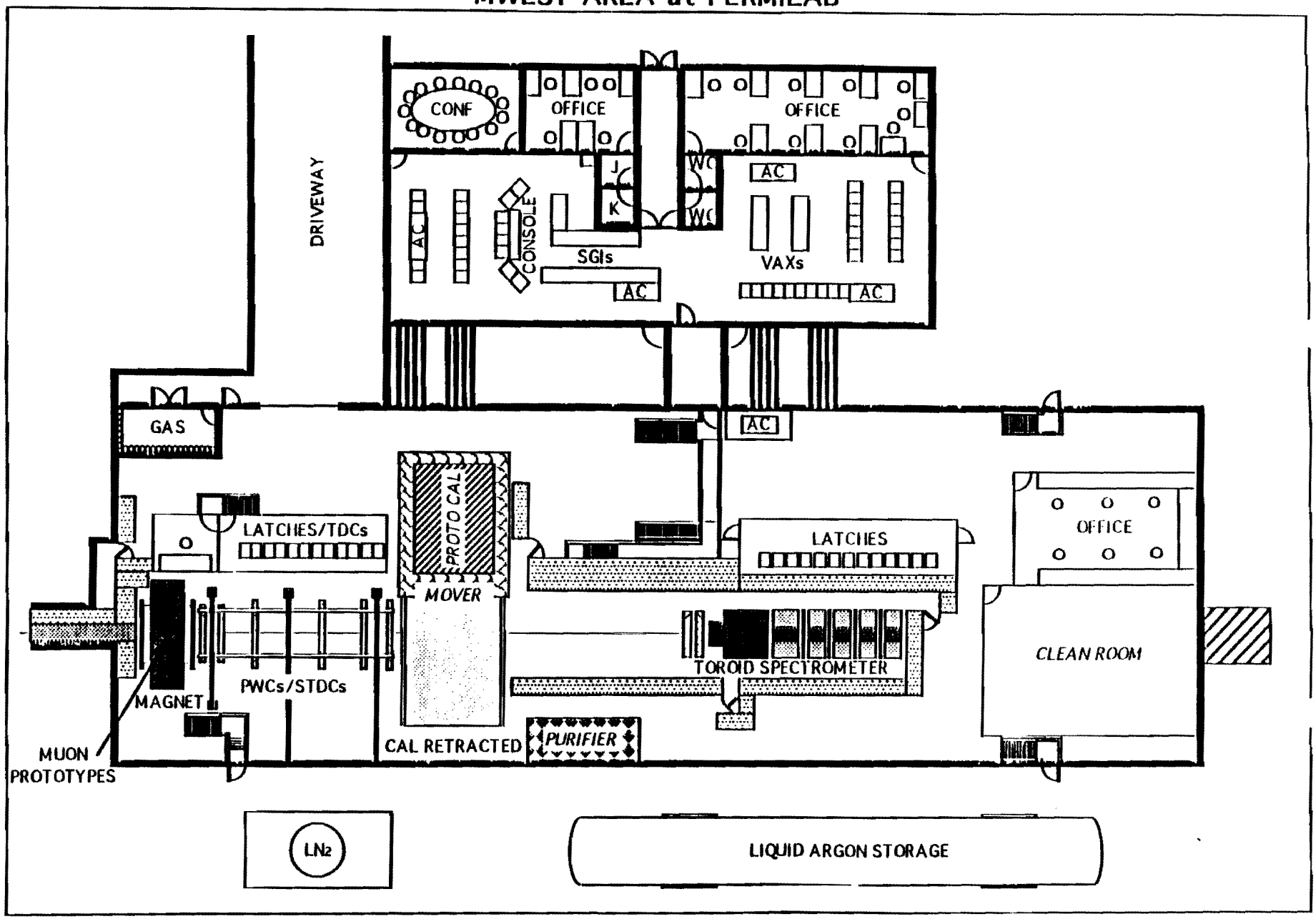


Fig. A.5-2

MUON PROTOTYPE TESTING
[For Schematic Purposes Only – Not Drawn to Scale]

MWEST AREA at FERMILAB

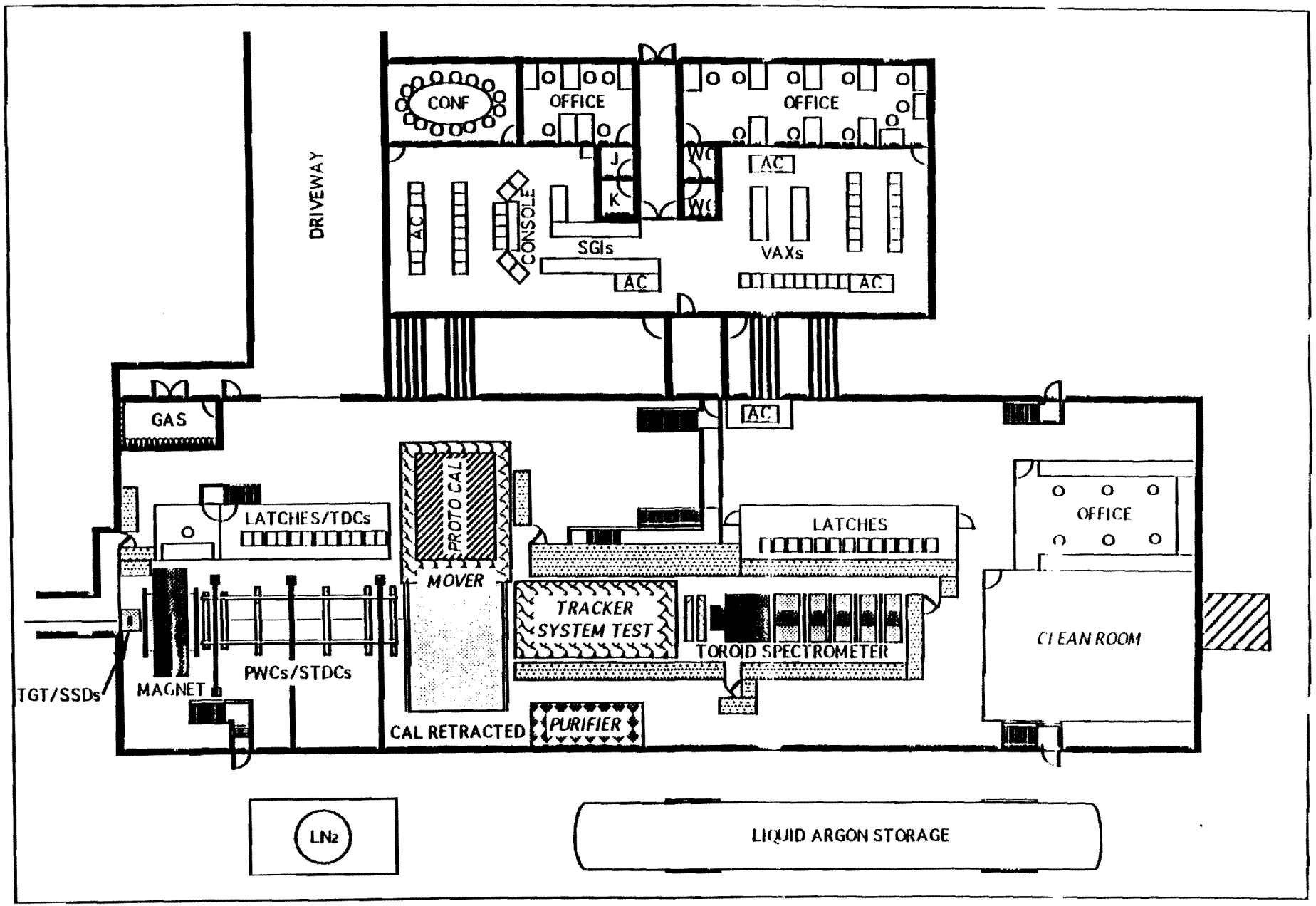
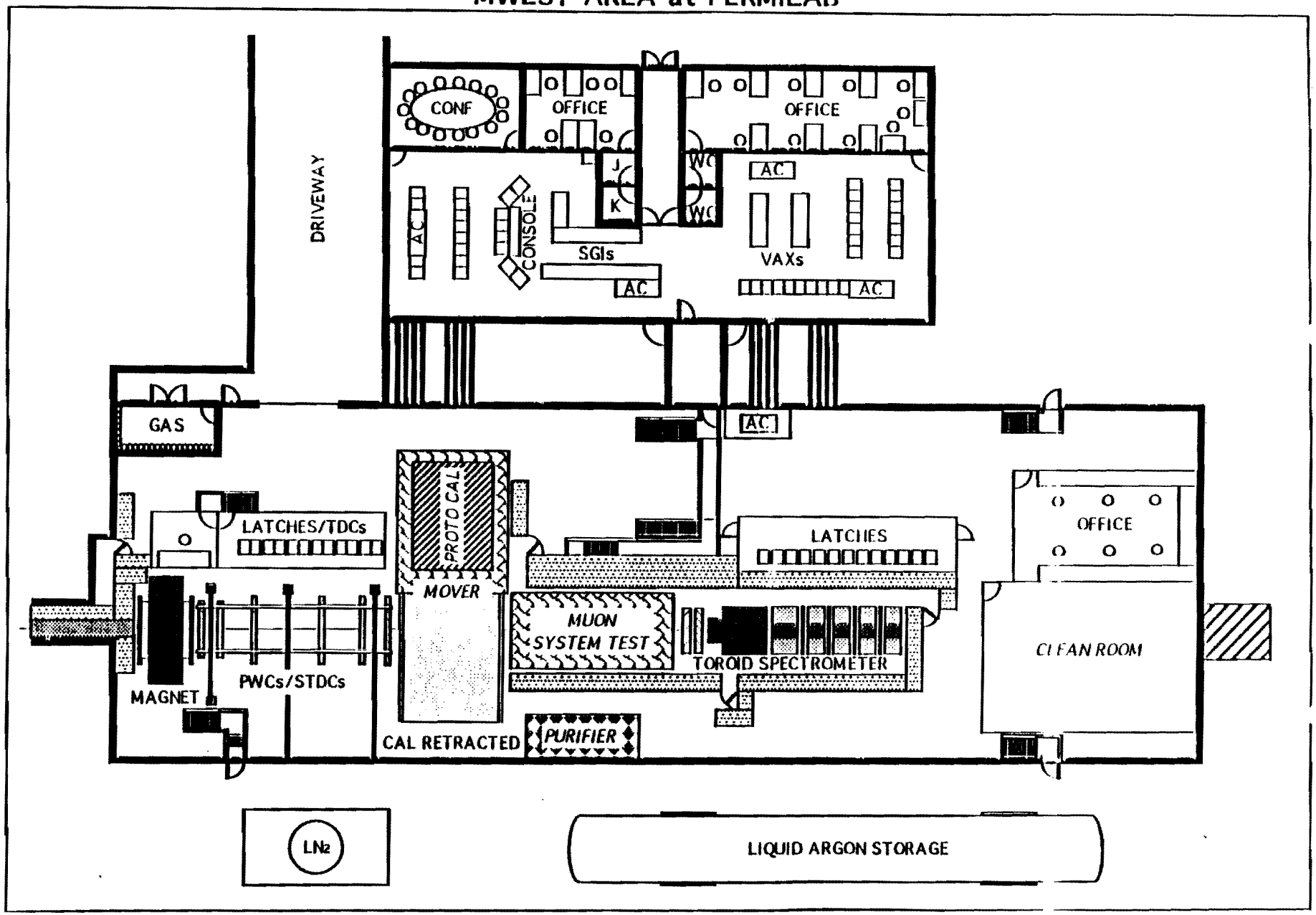


Fig. A.5-3

SETUP FOR TRACKER SYSTEM TEST
[For Schematic Purposes Only – Not Drawn to Scale]

MWEST AREA at FERMILAB



SETUP FOR MUON SYSTEM TEST
[For Schematic Purposes Only - Not Drawn to Scale]

Fig. A.5-4