PROPOSAL TO STUDY A LARGE LIQUID ARGON-URANIUM ABSORBER CALORIMETER

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1. INTRODUCTION

This document proposes a comprehensive program to implement and study a large scale liquid argon-uranium absorber calorimeter sytem in a Fermilab beam. This system is modelled after and contains many of the components of the calorimeters being constructed for use in the DØ Detector at Fermilab. It is also a test bed for testing techniques for possible SSC calorimeters. This program involves the construction of calorimeter modules and supports; a 4000 gallon liquid argon cryostat and associated cryogenics; a transporter capable of precisely positioning a 100 ton load in three dimensions; a clean electronic environment; and prototype electronics and data acquisition system. It is expected that this system will be a permanent installation in a Fermilab test beam, allowing continued use as a reference for data being taken at DØ.

The scope of this project is comparable to most present day fixed target experiments. At its peak we expect involvement of 20-30 physicists from half a dozen institutions. The need for this program has also been widely recognized - all of the major collider detectors (UA1,UA2,CDF) have engaged in such programs. Such efforts have been indicated by the studies and workshops concerned with SSC detector R&D. In the case of the DØ detector there is the added complication of installing and operating a large cryogenic system. We have sought support for this program in prior R&D funding requests. The scarcity of these R&D funds, and the neccessity of using DO Detector Equipment funds to carry out crucial model development for the detector, has led to a continuous deferral of the items needed to mount the test beam program proposed here. We are now in danger of losing the opportunity to pursue this program in the timely fashion needed in order to give useful information for feedback into the design and construction work on the DØ detector. Some of the larger items needed (cryostat and transporter) have lead times of 6-9 months. Deferral of such purchases to the next fiscal year could have detrimental consequences for the entire DØ program. Successful operation of the test beam system will substantially reduce the risks involved in commissioning a system as large as DØ We are, therefore, submitting this request for supplemental funds to support this test beam program, so that it can proceed in parallel with the construction of the detector.

One of the major advantages of the liquid argon technique in calorimetry is that in an ideal calorimeter of given absorber and gap geometry (capacitance and sampling fraction), the response or calibration is everywhere the same. Thus it is only necessary to know the gains of the individual electronic channels, and the response of one typical calorimeter stack to know the calibration of the entire system. In a real detector, constraints imposed by modularity (for ease of construction and handling), mechanical support and cryogenics, introduce non-uniformities in the calorimeter (e.g., module boundaries, support structures, and cryostat walls) which introduce deviations from the uniformity of response of an ideal detector. These effects are difficult to simulate reliably by Monte Carlo techniques, and must be studied by direct measurement. Thus, we do not need to measure the response of each and every module, but do need to measure the response of each particular area of non-uniformity. For DØ this requires measurement of the response of the azimuthal gaps between endcap modules of both the central and endcaps; transition region between central and endcap calorimeters; and the region around the beam pipes. These regions are illustrated in Figs. 1 and 2. Full scale replicas of these regions will be used to make these measurements.

One of the questions that will be answered in the test-beam studies is whether additional read-out elements (without absorber material), located between the central and endcap calorimeters, can provide significant information concerning energy loss and fluctuations in the dead material of the cryostat walls, etc. Preliminary Monte Carlo studies indicate that such "massless gaps" could prove to be quite useful in minimizing backgrounds for interesting events that have missing transverse energy. We plan to study the utility of such gaps in appropriate locations between modules in the test-beam cryostat.

The measurements will be used for several purposes. First, the measurements of module response as a function of particle type, energy and angle of incidence will be used to construct a complete map of the response of the detector. These measurements will be used to check the reliability of Monte Carlo programs simulating particle (especially hadronic) cascades in the detector. The measurements will also be used in conjunction with collider event generation programs (e.g. ISAJET) to construct the overall resolution in Pt. Using these measurements we shall also be able to simulate the detector response at any point in the cascade with real showers from the map. This is crucial since most of the CPU time used by shower simulation programs is spent generating the low energy end of the cascades. It will also be important to measure the ability of the calorimeter to distinguish pions from electrons, since DØ has no central field to aid this selection.

An important feature of a permanent test beam installation is that if new physics effects are discovered, one can return to the test beam setup to make the measurements necessary to understand whether these new effects are instrumental or real.

In the near term, the test beam installation provides us with a facility to test many of the features of the D0 detector, and provide feedback for development. Included in this are such things as connectors, cables, feedthroughs (which are the most vulnerable points on the cryostat), and the techniques for opening and closing the welded vessels. This will also be our first opportunity to cool a large section of the detector, providing important data on correlations of cooldown rate with temperature gradients in the absorber stacks, and to measure directly the associated thermal stresses. The test beam represents the first realistic opportunity to establish a low electronic noise environment such that global measurements of energy deposition will not be dominated by very low level coherent noise in the detector. Since this installation will use prototypes of the actual DØ system from modules through data acquisition, this will be a stringent test of the ultimate system.

Another important aspect of the program consists of providing the opportunity to operate a model detector before its use in DØ, so that skill and experience will have been acquired before the first pbar-p run. This applies, in particular, to questions such as monitoring of the physical detector (e.g., temperature, argon purity, etc.) and the understanding of the absolute and relative calibrations (e.g. reproducibility, test pulse vs. particle response, rate dependence, and cosmic ray or muon calibration). Indeed preparation of calibration files and the establishment of the software organization is one of the prime motivations for the calibration/test effort.

The data taken in this program will provide the first opportunity for developing many of algorithms necessary for triggering and analysis. In particular tests of clustering algorithms, which may limit jet energy resolution, need to be tested in a controlled environment.

Finally, there is an important sociological function of the test beam program. DØ is in a construction phase that will continue for 3 to 4 years before the detector is complete and competitive physics begins to emerge. The test beam program provides an opportunity for data taking and analysis in the relatively near future. This is critical for careers of many young post-docs. It also provides a training ground for graduate students in an environment in which they can take responsibility for a wide range of hardware and software tasks before the detector is completed.

In summary, we are requesting support for an important program that will make vital contributions to our understanding of the physics processes inherent in liquid argon calorimetry. Such understanding is of particular benefit for assessing designs of future detectors. This program will speed the start up of DØ and provide the tools for analysis of data. It has been delayed due to the lack of sufficient R&D funding, and with the expected shortfall of equipment funds this year, it is in danger of being further delayed to a point where it would not be of value for development of the detector. It is clear that data from the DØ detector cannot be analyzed without this program, the only question is when this test beam effort is launched. We urge that funds be provided now, which will then also ensure a faster and more efficient turn on of the DO detector.

2. OVERALL DESCRIPTION OF THE SETUP

In order for our measurements to be representative for our collider experiment, we intend to use standard DØ calorimeter modules, equipped with the final read-out electronics, and housed in a cryostat equipped with feedthroughs, wiring, and filters closely resembling those to be used in the DØ experiment. The data acquisition system will contain the basic components of the final one, with the modifications necessary to cater to the special needs imposed by the test beam environment. Because of the small signals generated in the argon calorimeters, a Faraday cage is required to emulate the shielding provided by the drift tubes and iron toroids of the DØ detector.

We propose to set up in the Chicago Cyclotron pit of the old muon lab (NWA beam). Given the extensive test/calibration program envisaged, we anticipate to occupy this location for at least two years past the beginning of our data taking at the collider.

The detector modules to be tested (see section 3) will be contained in a cryostat (see section 7) which will be large enough to house all module configurations that we intend to study. The cryostat is supported by a transporting system (see section 8) allowing all movements necessary to expose every type of tower of the calorimeter to the beam, under a wide range of angles of incidence. The whole apparatus will be surrounded by a Faraday cage (see section 10).

A schematic representation of the overall layout is shown in Figure 3. Some of the readout electronics and data acquisition hardware will be installed in portakamps outside the building.

Design work and studies on most of the items described here are still in progress.

3. CALORIMETER ARRAYS TO BE USED

Sections of the DO calorimeter are to be measured and calibrated, for the angular regions covered by the detector. We are planning to use two arrays, which we call "Array 1" and "Array 2". Array 1 is shown in Figures 4 and 5, and consists of one-eighth of the full azimuth of the central electromagnetic and hadronic calorimeter and one-eighth azimuth of the endcap hadronic calorimeter. The cryostat will be positioned so that the beam simulates particles from the collider interaction in the polar angle range 23 to 145 degrees and the azimuthal range -10 to +14 degrees. Array 2, shown in Figures 6 and 7, consists of endcap modules, including the entire inner hadronic, a one-eighth azimuth section of the middle hadronic, and a special one-eighth section of the electromagnetic modules. The polar angular coverage here will be 15 to +30 degrees in theta and -14 to +14 degrees in azimuth. Since the inner hadronic modules weigh 38 tons each, we do not plan to make a spare just for test beam use, therefore, requiring the calibration of this module must be completed before its scheduled installation in DØ.

In order to simulate and calibrate the performance of the eventual calorimeter configurations, several modules will have to be positioned in the test-beam cryostat in such a way that there will be a substantial volume of liquid argon between the beam-entry wall and the front calorimeter module. This will not be the case for the final configuration in the DØ experiment. Consequently, we plan to introduce low-density material ("Argon excluders") into the dead-argon region of the test-beam cryostat to exlude the liquid, and, thereby, provide closer simulation of the final conditions.

4. HIGH ENERGY BEAM REQUIREMENTS

4.1 Energy Range

Particles are required from 10 to 160 GeV/c. The lower cutoff is determined by the minimum value at which one can expect to obtain a reasonable intensity (see below) with good particle ID. The maximum is determined by the current beam configuration.

4.2. Intensity

The data acquisition system will allow reading up to 5000 events in a 10 second spill. Rates down to a few per spill, as will occur at the low-energy end of the usable energy range, can still be expected to give minimal calibration data when integrated over a period of several hours, but extensive studies of leakage, crack effects, uniformity, angular dependences and tails of distributions will require much higher fluxes, and higher intensity to be directed to the NW target.

4.3. Particle Identification

(a) A muon beam will be defined by particles surviving transmission through the calorimeter and a downstream filter.

(b) A pure pion beam will be needed with electron contamination of less than 0.1%, and utilizing an electron veto using two Cherenkov counters.

(c) An electron beam generated by conversion of photons, near the target.

4.4 Momentum Resolution

We require a beam momentum resolution of a few tenths percent. This will be achieved using PWC's bracketing the last bend string in the main muon-lab beam line.

5. LOW ENERGY BEAM REQUIREMENTS

5.1 Need for Measurements at Low Energies

Previous measurements by several groups have shown (see Fig. 8) that the response of various calorimeters to electromagnetic and hadronic particles of low energy (below a few GeV) deviates considerably from that expected when extrapolating from high energy measurements. The energy dependence appears to depend on details of the calorimeter construction.

Since at Tevatron-collider energies a considerable fraction of the produced particles (in particular, jet fragments) have low energy, a good knowledge of the low energy response of our calorimeter is essential to understand jet properties. It is crucial, therefore, to extend the measurement of the response of our calorimeter to energies lower than those accessible in the present high energy version of the NWA beam.

5.2. Energy Range

Ideally, the low energy beam line would provide usable intensity down to 1 GeV/c or less, and up to a value that overlaps with the lowest momentum measured with the high energy beam line (~10 GeV/c). Design is in progress on a low-energy beam from a target close to the test setup that will cover this range. The momentum bite of the beam is expected to be quite large (20%), and we will use beam PWC's and time of flight counters to determine particle momentum.

5.3 Intensity

Particles for the low energy beam line will be produced in a tertiary target. Intensity will decrease as the tertiary beam is tuned to lower momentum. We expect that for a primary intensity of 2 x 10" protons/spill, we can achieve several particles/spill even at the lowest energies. In order to increase these rates, we expect to request an extended period of high primary intensity directed on the NW target.

5.4. Momentum Resolution and Particle Identification

In order to maximize the flux incident on a calorimeter tower, the low energy beam line will be operated as a broad-band focusing spectrometer. Wire chambers of modest spatial resolution will give adequate momentum resolution (1-2%). TOF counters with good (~100ps) time resolution will be necessary to provide e/pi discrimination below around 1 GeV/c.

6. RUNNING SCHEDULE

6.1 Near Term Plans

For the 1987 running cycle, we plan to concentrate efforts on those items that require the most immediate attention. First, a large sample of the electronics (around 2000 channels) must be tested in a realistic environment, with beam incident on final calorimeter modules. This is required by the procurement schedule for the electronics. We are particularly interested in testing the linearity, cross-talk and rate dependence as well as the dynamic range of the readout electronics in the case of electromagnetic showers. The calorimetry array to be used will be three central calorimeter electromagnetic modules. At the conclusion of these electronics tests we will be in a position to test individual prototype modules for both the central and endcap calorimeters, before full scale production of most of these modules begins. For these initial tests, we will use the smaller cryostat (used in the 1985 tests) with very limited position control. The location of these tests will be downstream of the NWA pit, allowing preparations for the long-term tests to continue without interference. A Faraday cage is still required, but can be much smaller than the one used in the long-term tests (see section 10). Also, filtered AC power and water cooling of the electronics will be required. Read-out electronics and data acquisition systems are scheduled to be operational for an electronics system test by the beginning of 1987.

6.2 Long Term Plans

The design of the cryostat and transporter has been completed by Chicago Bridge and Iron Company, and is in the process of review by DØ. The long lead time in the construction of these items requires that we begin construction as soon as possible, so that we may be ready to take beam in the first running cycle after the spring of 1988. Design of the full Faraday cage is also continuing, and we plan to begin construction by the end of the 1987 run. A particularly urgent phase will be the calibration of the inner hadronic module of the end cap calorimeters, since the module to be used will also be installed in the detector at DØ, while all the other modules to be tested will remain a permanent part of the test beam system. Thus we will have to ensure that testing of the inner hadronic module does not become the critical path to completion of the DO detector.

7. CRYOSTAT

7.1 Description

The main cryostat parameters are listed in Table 1. Figures 4 and 6 show the end views of module setups for the two Arrays, and Figure 9 shows the top view of the cryostat. The inner vessel will have heads welded to the cylindrical shell, a design favored from a safety standpoint and used in the DØ Detector. Since the test beam cryostat will be opened and resealed approximately 6 times, an extra 6 inches has been provided at each end of the inner vessel. The outer shell will have flanges. With modules and argon excluders installed, the liquid volume will be about 4000 gallons. The maximum loaded weight of the cryostat is about 95 tons: 60 tons of modules, 15 tons of cryostat, 20 tons liquid argon. The design includes thin-walled windows covering small areas on the cylindrical portion of the cryostat and on one of the heads. These windows are on both inner and outer vessels. Design has been, and fabrication will be done to ASME standards, with experienced outside consultants and contractors. Previous experience indicates a fabrication time of 6-9 months; thus, we should be in a position to test the inner hadronic module early in 1988, if the cryostat is ordered this year.

TABLE I

<u>Inner Vessel</u>

Material	Stainless Steel
Inner radius	54 inches
Cylindrical section, length	183 inches
Wall thickness	1/2 inch
Head-to-head outside dimension, length	220 inches

Radius of head	109 inches
Thickness of head	3/8-inch
Head attachment to shell	Weldment
Approx. weight of shell and head	6.3 tons

Outer Vessel

Material	Stainless Steel
Inner radius	57.625 inches
Cylindrical section, length	193 inches
Wall thickness	3/8 inches
Extended cylindrical section on each head	19.5 inches
Head-to-head outside dimension, length	232 inches
Radius of Head	109 inches
Thickness of head	3/8-inch
Head attachment to shell	Flange
Approx. weight of shell and head	7.2 tons
Vacuum Gap	3.125 inches
Liquid Load	approx. 4,000 gallons
	approx. 20 tons

Module Loads

	Weight Each	Weight Total
Array 1		
4 CC EM	1,350 lbs.	5,400 lbs.
2 CC FH	18,350	36,700
2 CC CH	15,800	31,600
2 EC MH	9,000	18,000
2 EC OH	10,000	20,000
		111,700 lbs. 56 tons

Array 2

1 EC Inner Hadron	74,300	74,300
2 EC Middle Hadron	9,000	18,000
Special EC EM Small	950 est	950 est
		93,250 lbs. 47 tons

Cooling Coil Limit

Distance from top — 8 inches

Liquid Level

Distance from top — 18 inches
(allows for 2 inches clearance with)
(+/-15 degree cryostat rock)

2 Inside Transverse Posts C/L to C/L — 56 inches
2 Inside Longitudinal Posts C/L to C/L — 100 inches

Signal Port
2 Signal Ports, 8-inch dia. — 30 degrees from vertical axis

8. TRANSPORTER

8.1. Requirements

(a) Load capacity design greater than 150 tons.
(b) Motions for four degrees of freedom to simulate the three coordinates needed to describe a particle's trajectory through the calorimeter.

(1) horizontal translation (+/- 7 feet)
(2) vertical translation (+/- 1 foot)
(3) rotation about cryostat vertical axis (+/- 180 deg)
(4) rolling about cryostat. cylindrical axis (+/- 15 deg)

(c) Positional accuracy required: +/- 0.1 inch.

(d) Must accomplish motions within existing pit area at muon lab.

(e) Must meet AISC code for steel structures subjected to cryogenic temperatures.

8.2. Transporter Components

The transporter can be divided into five main substructures shown in Figures 10 and 12.

(1) Welded to the bottom of the outer cryostat are two rocker ribs each of which is supported by two concave rollers. A mechanical actuator arrangement is planned to provide for the rolling motion of the cryostat on these rollers.

(2) The concave rollers are attached to a circular turntable which lies directly beneath the cryostat. The turntable consists of a sandwiched structure of steel plates and reinforcing I-beams. Attached to the bottom of the turntable is a large-diameter bearing race which allows the turntable to rotate about its vertical axis.

(3) Directly under the turntable is the transporter's main platform made of the same type of sandwiched structure as the turntable. The upper surface of the main platform provides the rolling surface for the tapered rollers on the turntable. Attached to the underside of the main platform are four large jacks which allow for the required vertical translation. Motor/gear arrangements on this platform will drive the jacks as well as the turntable.

(4) The four jack pads are anchored to a guide frame which lies beneath the main platform. Four flat rollers are located on the bottom side of the frame, directly under the jack pads.

At the corners of the guide frame are guiding posts which serve the purpose of absorbing any lateral forces and keep them from being transmitted to the more brittle jack screws; and to guiding the vertical translation of the main platform in order to maintain the required 0.1 inch positional accuracy.

(5) The guide frame's flat rollers run on two hardened steel tracks set on top of I-beams. The I-beams in turn straddle the two large caissons in the bottom of existing pit. Driven by a lead screw, the guide frame on its track provides for the horizontal translation.

9. LOADING SYSTEM

As much as 60 tons of assembled modules must be loaded into the cryostat at one time. This task is complicated by the fact that the two existing 7.5 ton cranes in the muon lab will not be able to lift this load.

The module array will be assembled and cleaned as it sits on loading rails on the floor beside the pit. When ready, long rails will be aligned with the assembly rails, extended through the cryostat, and the winch used to pull the assembly into the cryostat. When the module assembly reaches its desired location in the cryostat, the transporter will be used to raise the cryostat, transferring the load in an even fashion to the transporter. At this time, the assembly will be bolted to the support posts in the cryostat. When the load is removed from the rails, the rails are drawn out of the cryostat using overhead cranes, leaving the loaded cryostat ready for capping. Further design work on this scheme is in progress.

10. FARADAY CAGE

Since our preamplifiers collect unamplified charge, our measurements are extremely sensitive to noise. To protect the read-out electronics from external noise sources is the enclosure of the entire test beam apparatus will be enclosed in a Faraday cage, which will cover the entire area of the CCM pit (see Fig. 3) and extend vertically from about 7 feet below floor level to about 15 feet above floor level. It will have entry points for power (filtered 480-volt 3-phase), for cryogenic services, for water cooling of the electronics, and for personnel. Large panels on upstream and downstream walls of the cage will be removable, along with smaller sections of the roof, to allow loading of the modules into the cryostat. Current design of the cage includes a steel structural frame, with walls of fire-resistant plywood and sheet steel. Inside the cage will be a ground level catwalk that extends along two sides, allowing access to the transporter at any point of its motion. Flexible cryogenic lines will extend to fixed isolation joints on the cage from the cryostat. Signals taken from the baseline subtractors (BLS) mounted on the transporter near the cryostat will be cabled through a conduit into ADC racks in trailers outside the cage.

Because of the envelope of motion of the cryostat and transporter, the size of the cage approaches that of a small building. Questions of cryogenic and radiation safety must be addressed, since occupancy of the cage by two or more people is anticipated for a large fraction of the time. Design of the cage is being worked out by members of DO and Fermilab.

For the near term plan, the Faraday cage required to surround the small cryostat and 2000 channels of readout electronics is much smaller. A preliminary layout is shown in Figure 14. This cage will still have to accommodate filtered AC power and cooling for the electronics.

11. CRYOGENIC SERVICES AND CONNECTIONS

11.1 Storage Dewars.

For safety reasons, we also require a LAr storage cryostat, and we have asked Fermilab to provide one. While it is in principle possible to fill the test cryostat directly from a LAr storage truck, we would have little control over flow rates and thus it would be extremely difficult to ensure that the pressure inside the test cryostat never exceeds the maximum design pressure. Furthermore, in the absence of a storage dewar one would have to dispose of 4000 gallons of LAr after each run, creating possible ODH problems. A standard LN2 cryostat would be adequate for LAr storage. In addition we will use a LN2 storage dewar presently at the Muon lab for the LN2 required for cooldown and maintenance of the calorimeter and LAr storage.

11.2. Liquid Transfer Lines

Two cryogenic lines, vacuum insulated, low loss type, will have to be provided.

(1) A LN_2 line, which will connect the LN_2 storage dewar to the cooling coil inside the test cryostat. This line has to remain connected while the test cryostat is moved to any position within the transporter's range. This line will enter the test cryostat at the top, in the center of the cryostat. The line has to be designed for a maximum operating pressure of at least 4.2 atm, corresponding to a LN2 temperature of 92K. In addition, this line will have to have a removable section with bayonet mounts to allow loading of the cryostat.

(2) A LAr fill line, which needs to remain connected to the test cryostat only during filling, i.e. while it is in a well defined fixed position. Thus the flexible portion of this transfer line has to accommodate only the alignment tolerances of approximately +/- 6 inches. For safety reasons, the line should withstand 4 atm, although its operating pressure will be only slightly above atmospheric.

11.3 Vent Lines.

Vent lines will have to be provided, both for the LN_2 and LAr venting. The nitrogen vent line should be capable of handling up to approximately 100 cfm to accommodate all needs including the larger demand during cooldown. The argon vent line serves only for emergency relief. In any routine mishap (too rapid fill, failure of LN_2 supply) a capacity of 100 cfm would be adequate. Safety and code considerations will define the final vent line size.

These vent lines have to be connected to the test cryostat in any position or orientation allowed by the transporter. This will require a fairly sophisticated flexible line and it may be much cheaper to provide one line only to serve both as argon and nitrogen vent line.

11.4. Flow Diagram. A simplified flow diagram is shown in Figure 15.

12. CRYOGENIC CONSIDERATIONS

Both temperature gradients and argon purity in the test beam cryostats will be monitored using a VME system, in a fashion similar to that foreseen for the final DØ detector. Special purpose modules (MIL-1553) currently being developed for DØ, driven by controllers in VME crates, are being evaluated as the read out system for temperature sensors. The compatability of the MIL-1553 units with thermocouples and silicon diodes is presently under study.

Oxygen purity will be monitored using pulse-height information from test cells located within the cryostats; the cells will contain both Alpha and Beta particle radioactive sources.

Cryogenic safety considerations will have to be worked out with Fermilab. The existing DO safety review panel has had its charge extended to cover the appropriate reviews in NWA for the test beam cryostat and ODH procedures.

A LAr volume of about 4000 gallons inside a Faraday cage enclosure, presents a situation which requires very careful planning. Our operations plan includes the condition that several persons will be at times working inside the main cage, close to the cryostat, while pulser signals, or a weak beam, are being delivered to the calorimeter inside the cryostat. The pit, and particularly the region below the cage floor, is available for containing liquid spills.

13. BEAM INSTRUMENTATION

The beam instrumentation for the beam line and the trigger logic will consist of the items in the following list.

(1) Beam Chambers:
Experience from our previous tests indicate that, in order to track adequately and efficiently individual beam particles entering the test calorimeter, 8X and 8Y wire planes of MWPC's will be needed, each from 64 to 128 wires with 1 mm wire spacing. For the low energy beam, additional planes will be necessary.

(2) Trigger Scintillator Telescope: Four small scintillation counters (1"X1" to 3"X3") and a "beam hole" veto counter to define a beam particle trigger.
(3) Background Veto and Tag Hodoscopes: Four large area scintillation counter hodoscopes (5ftX5ft), 2 in front of the calorimeter to veto beam halo and wide angle background and 2 behind to tag muons and non-interacting hadrons.
(4) Trigger Logic (standard units from PREP): To define various beam particles (electrons, pions, muons) and calibration triggers (pedestals, pulser etc).
(5) Miscellaneous Logic (standard units from PREP): To tag various trigger species, measure rates, record pulse height, time of flight, gate width, power-supply voltage, noise, temperature, spill and other information.
(6) Time of Flight Setup: To separate electrons from hadrons up to 2 GeV. Overall resolution better than 200 psec (rms).
(7) Two Cherenkov counters (presently in the beam line): for electron identification.
(8) TRD counters to improve electron identification.

14. READOUT ELECTRONICS

The calorimeter signals will be processed by a system of preamplifiers, base-line substractors, and ADC's. The system will be a subset of the final DØ electronics, built of 'real' DØ components in a configuration that resembles the DØ experiment as closely as possible.

The signals formed by the collection of charge in each calorimeter cell will be transported to preamps mounted on the outside of the cryostat by twisted-pair cables, fed through the cryostat wall by means of eight 27-layer printed circuit boards. Each feedthrough board will carry signals from the liquid argon environment to the atmosphere outside while rearranging the signal into projective towers. The lower 'inside' portions of the feedthrough boards reside in argon boil-off gas at the top of the detector and not in the cold liquid itself. Heaters on the boards will maintain them at room temperature to prevent icing.

Signals from the feedthrough will pass along short cables to reamps mounted nearby on the cryostat. A total of 48 preamp boards, each containing 48 surface-mount preamp hybrids, will be enclosed in a shielded box of the final design to be used in the DØ experiment. The preamps will be cooled by water-chilled dry nitrogen and powered by specifially designed power supplies mounted directly beneath the preamp box.

The amplified signals will pass down 60-foot heavily shielded twisted-pair cables (as in the DØ setup) to Base Line Sustractors housed in three crates in a rack mounted on the cryostat transporter turntable. Using two sample-and-hold circuits, the Base Line Subtractors from the difference of the amplitudes of the signal at its peak and before the arrival of the pulse.

The analog output signals are differentially driven down heavily-shielded 150-foot cables (again, as in the DØ experiment) to ADC's in the counting room outside the experimental hall. The ADC's digitize the signals, subtract pedestals, and suppress empty channels by eliminating signals within individual, symmetric cuts. These fully processed signals are read out into a data buffer by the data acquisition system in the manner intended for DØ.

The entire electronic system will have been thoroughly debugged and tested prior to installation at the beam site.

15. DATA ACQUISITION AND ON-LINE COMPUTER SYSTEM

The data acquisition and online system will be identical in design to that being assembled for the DØ detector, as well to systems already in operation at several DØ institutions. Overall, the system has two basic components: an array of MicroVAX-II processors which perform the Level-2, or software trigger and a host system which supports data logging and online interactions with users. In a data acquisition design, even data flows from the digitization crates directly into the external ports of memory associated with a specific MicroVAX-II processor. A number of such nodes are arranged in a "farm," with successive events being directed to different nodes by a "supervisor" MicroVAX. To perform its direct control functions the Supervisor is interfaced with the Level-1 (hardware) trigger, with the electronics readout modules, and with the individual level-2 nodes. In addition to these interfaces, the Supervisor and the nodes are networked together via Ethernet, which serves as the medium for communication with the host online system including program downloading and commands from users. The host system collects those events which pass the Level-2 selection and records them in disk files tape. It provides the framework through which experimenters issue commands to control the data taking, to monitor the detector, and to perform selected analysis tasks on the events. The host system is connected via DECNET to HEPNET, a vital link for program management as well as efficient use of the system.

The specific configuration of the data acquisition for the beam test will include 6 MicroVAX-II Level-2 nodes, plus the Supervisor. Each node will have two channels of dual-port memory, and correspondingly two data bases which connect the readout electronics to each of the nodes. Thus, the maximum data rate into a node will be 2*40 or 80 Mbytes/second. Both the number of dual-port channels per node and the number of nodes are easily increased; these values are appropriate for the event rates expected. The host system will be based on a MicroVAX-II running VMS, with a RA-81 456 MByte disk drives and two 6250 tape drives. Two drives are needed to support the high recording rate; as opposed to their role in DØ, the Level-2 processor will primarily repackage rather than filter events. To support the analysis activity, a printer and a number of terminals will also be included. Among these terminals will be two VAXstation/RCs, linked to the host system via Ethernet, and enabling both graphics as well as specific cpu-intensive online analysis tasks.

16. CONTROLS FOR TRANSPORTER MOTION

The four motions of the transporter (described above in section 8) are to be controllable with sufficient precision so that it will be possible to reach any desired position with accuracy of 2 or 3 mm in each of the three space coordinates at the entry and exit points along the nominal test beam trajectory.

In order to use accelerator time efficiently, it will be necessary to change positions rapidly and precisely. This requires that the drive motors be operated and monitored by computer, in a mode similar to that used for the typical Fermilab collimator control. In addition, these controls will have radiation safety interlocks.

17. STRUCTURES IN THE PIT

(1) The existing pit area (40 ft x 30 ft x 10 ft) is sufficiently large to accommodate all expected motions of the transporter/cryostat system. The two large caissons at the bottom of the pit (20 ft x 5 ft x 3 ft) are anchored in bedrock and will form an excellent support for the I-beam rails that will carry the transporter. Blueprints show that the caissons' foundations are anchored in bedrock.

(2) In the event of a cryogenic spill, argon will be channeled through the floor of the Faraday cage into the pit. To minimize vaporization the pit will have an insulating lining made of wood and foam.

(3) A 10,000 cubic feet/minute vent fan is located on the East side of the pit along with its duct system. This will aid in venting argon if a spill occurs.

(4) A water sump pump is located below the floor of the pit and will have to be employed as water sometimes floods the bottom of the pit (as much as 2 feet of water has been reported).

(5) Loading system structures near the pit (section 9) will have to be accommodated, especially the assembly area which will be used extensively.

6) Servicing platforms and ladders may also be needed, although it is expected that some of these structures will be attached directly to the platforms of the transporter.

(7) Cryogenic services (LAr, LN2) and electrical cables will also have to be accommodated within the pit area (details to be determined).

18. TEST BEAM BUDGET AND INSTITUTIONAL RESPONSIBILITIES

We present below an estimated budget for carrying out the extensive program of tests and calibration, described in the previous sections. This budget includes all of the items that will be needed, but does not include those items which will later be transferred to the DØ detector. With these guidelines, we believe that this effort should properly be supported on R&D funds rather than DØ equipment funds. It should be noted, however, that due to the urgent need to develop some of the systems (e.g., electronics, microprocessor farm, cryostat and transporter design), we actually have begun purchasing these systems using DØ equipment funds, "in support of R&D." We have included these items in the budget, because we feel that they properly belong here. We are requesting the full budget, including expended funds, in order to reimburse the detector for equipment funds used to support this R&D effort. In addition, we have made requests for support of parts of this effort to the FNAL Research Division, and to a much lesser extend to the NSF.

Following the budget is a matrix which assigns responsibilities for budget items to the participating institutions. Each of these institutions will submit an independent proposal to the DOE, requesting support for their contributions. It should be noted that all of the budget items must be funded in order to carry out this program successfully, and in a timely fashion.

TEST BEAM BUDGET

1. Engineering

Cryostat	39,000	
LAr monitoring	10,000	
Cryogenic system	24,000	
Transporter	42,000	
Pit structures	35,000	
Faraday cage	15,000	
HV feedthroughs	5,000	
Massless gaps	2,000	
Total Engineering		172,000

2. Cryostat

Vessel (including nozzles/ports, cooling loops)	210,000	
Installation/test	35,000	
Installation fixtures	25,000	
Module installation	100,000	
Total Cryostat		370,000

3. LAr Monitoring

LAr temp. monitoring	68,000	
LAr purity monitoring	23,400	
Total LAr Monitoring		91,400

4. Cryogenic System

Cryogenic piping (moving)	45,000	
Cryogenic piping (fixed)	20,000	
Vacuum pumps	20,000	
Regulators and valves	40,000	
Room temp. piping	30,000	
Control instruments	40,000	
Transportation & installation	13,000	
LAr storage dewar	60,000	
LN2 storage dewar	(exists)	
Technical support (manpower)	34,000	
Total Cryogenic System		302,000

5. Transporter

Structure		110,000	
Drive mechanism			
rolling	30,000		
rotation	28,000		
elevation	40,000		
translation	23,000		
Total drive mechanism		121,000	
Power wiring		8,000	
Motor controls with control center		12,000	
Position monitor		6,000	
Control wiring		8,000	
Transport & installation		15,000	
Total Transporter			280,000

6. Pit Structures

Access facilities (catwalks,ramps,ladders...)		23,000	
Module loading			
rails		50,000	
loading carriages			
carriage array 1	25,000		
carriage array 2	20,000		
Total loading carriages		45,000	
Articulate cable trays		10,000	
LAr containment (lining)		5,000	
Supports for F. cage/transp.		1,000	
Technical support (manpower)		11,000	
Total Pit Structures			145,000

7. Calorimeter Readout Electronics

Feedthroughs		17,500	
Preamps		32,200	
BLS		47,550	
ADC's		18,430	
Signal cables		32,250	
Pulser system		4,000	
Total Calorimeter Readout			151,930

8. Electronics environment

Faraday cage			
structure & walls	45,000		
doors	22,000		
other penetrations	10,000		

electrical needs	20,000		
air conditioning	15,000		
safety (ODH,fire,rad.)	20,000		
assembly and install.	52,000		
Total Large Faraday Cage		184,000	
Small Faraday cage			
Material			
wood frame)			
steel sheet metal)			
walls)	10,000		
thick Al floor)			
assembly/install.	31,000		
Total Small F. Cage		41,000	
Isolation transformer		10,000	
Cooling		3,000	
Total Electronics Environment			238,000

9. <u>High Voltage</u>

HV feedthrough 2@8000		16,000	
HV supplies 100ch.@200		20,000	
HV cables 100ch.@30		3,000	
Technical support (manpower)		4,000	
Total High Voltage			43,000

10. <u>Electronics Monitoring</u>

LV monitoring			
electronics temp. monitoring			
HV monitoring			
Total Electronics Monitoring			25,000

11. <u>On-line Computer System</u>

Host computer system			
MicroVAX-II Q5 (16Mbyte)	48,000		
addn'l RA81 disk	11,350		
6250bpi tape drives			
2@15,000	30,000		
Decserver-200 LAT	1,780		
Ethernet hardware	3,600		
QMS L-800 laser printer	7,400		
Decnet link	1,400		
VAXstation-II/RC			
2@9900	19,800		
terminals 3@800	2,400		
Total Testb. Host Comp. Syst.		125,730	
Level 2 processor			
microprocessor & 5Mbyte			
6@6290	37,740		

DEQNA 6@1185	7,110		
backplanes+cardguides 3@2600	7,800		
dualport memories & ctrl 6@3000	18,000		
Total Level 2 Processor		70,650	
Supervisor system			
microprocessor & 5Mbyte	6,290		
DEQNA	1,185		
backplane+cardguides	2,600		
interfaces	1,400		
Total Supervisor System		11,475	
Electronics readout			
buffer/data cable drivers	2,000		
readout sequencer	1,500		
Total Electronics Readout		3,500	
Cables & Level 2 Power			
cables	3,500		
power supplies	2,000		
Total Cables & Level 2 Power		5,500	
PC IBM-AT for monitoring		6,000	
Software		25,200	
Total On-line Computer System			248,055

12. <u>Calorimeter Module Arrays</u>

CC			
CCEM 4 @ 22,147	88,588		
CCFH 2 @ 155,133	310,266		
CCCH 2 @ 58,023	116,046		
shipping	10,969		
Total CC Testbeam Modules		525,869	
ECH			
ECMH 2 @ 60,227	120,454		
ECOH 2 @ 38,205	76,410		
Total ECH Testbeam Modules		196,864	
ECEM			
ECEM special module		101,300	
DO simulation structures			
LAr excluder	20,000		
walls, brackets	5,000		
Total Simul. Structures		25,000	
Total Calor. Mod. Arrays			849,033

13. <u>Trigger/Beam Counters</u>

Cosmic ray telescope		15,000 (mostly spent)
Beam-defining counters		
PWC on cryostat	5,000	
veto counter	2,000	
beam spectrometer	10,000	

TOF system	10,000		
TRD module	(exists)		
Total Beam Defining Counters		27,000	
Total Trigger/Beam Counters			42,000

TOTAL TEST BEAM COST.....................................$2,957,418

TEST BEAM MONEY MATRIX
(K$)

	BUDGET	BROWN UNIV.	UNIV.OF FLORIDA	FLORIDA STATE U.	INDIANA UNIV.	UNIV.OF PENNSYL.	UNIV.OF ROCHESTER	STATE UNIV.OF NEW YORK AT STONY BROOK
1. Engineering	172					172		
2. Cryostat	370					25	345	
3. Monitoring	91						91	
4. Cryogenics	302			302				
5. Transporter	280					280		
6. Pit Structures	145		145					
7. Electronics	152	152						
8. Faraday Shield	238							238
9. HV	43						43	
10. Monitoring	25	25						
11. DAQ	248	223			25			
12. CC Modules	526		247	60				219
EC Modules	197				197			
EC EM Modules	101				101			
LAr Excluders	25						25	
13. Beam Detectors	42			42				
Total	2957	400	392	404	323	477	504	457

FIGURE CAPTIONS

Fig. 1a: Cutaway view of the DØ detector.

Fig. 1b: Layout of DØ calorimetry showing transition from central to endcap calorimeters.

Fig. 2: End view of central calorimeter showing azimuthal cracks.

Fig. 3: Top view of the layout in the muon lab. The CCM pit and the Faraday cage are shown.

Fig. 4: End view of the "Array 1" setup.

Fig. 5: Isometric view of the central and encap modules to be used in Array 1; the motion of the array with respect to the beam is indicated.

Fig. 6: End view of the "Array 2" setup.

Fig. 7: Top view of the "Array 2" setup. The modules for the EC measurements (a special ECEM module, the inner hadron module and a MFH module) are shown in the cryostat. The theta range for the measurements and the position of the beam entrance window are indicated.

Fig.8: Calorimetry response vs. energy, as measured by various groups, showing the strong energy dependence of the relative e/hadron response for low energies.

Fig.9: Top view of the cryostat. Dimensions of the vessels (diameter and length) and the wall thickness are indicated.

Fig.10: End view of the cryostat on the transporter. The main parts of the transporter are indicated.

Fig.11: Side view of the transporter with the cryostat.

Fig.12: Top view of the transporter.

Fig.13: Plan view of the Faraday cage. The structural members of the cage, the catwalk, and a typical location of the cryostat are indicated.

Fig.14: Schematic of the small Faraday cage for the 1987 run.

Fig.15: Simplified cryogenics flow diagram.

D-ZERO DETECTOR

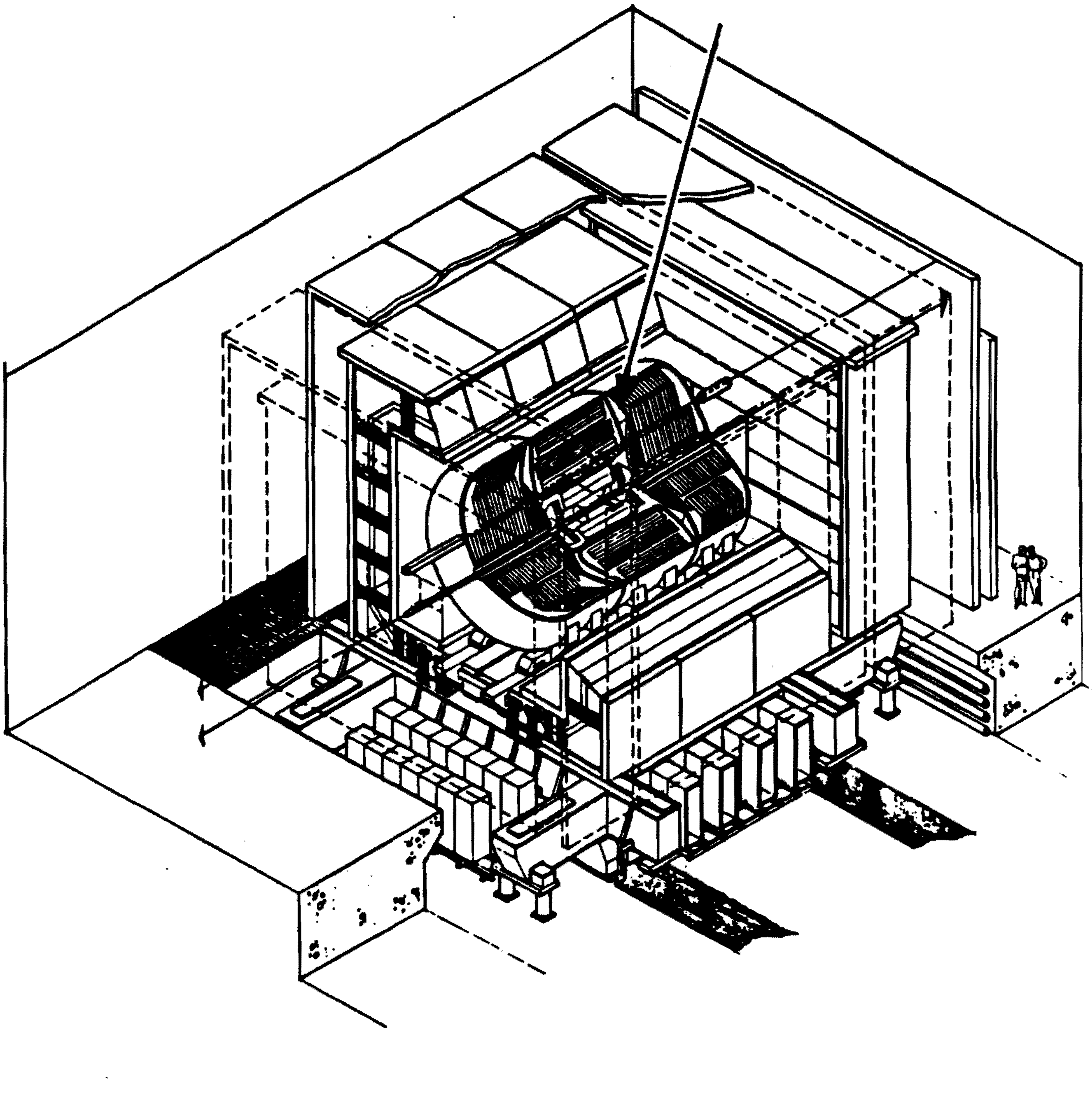


FIG. 1a

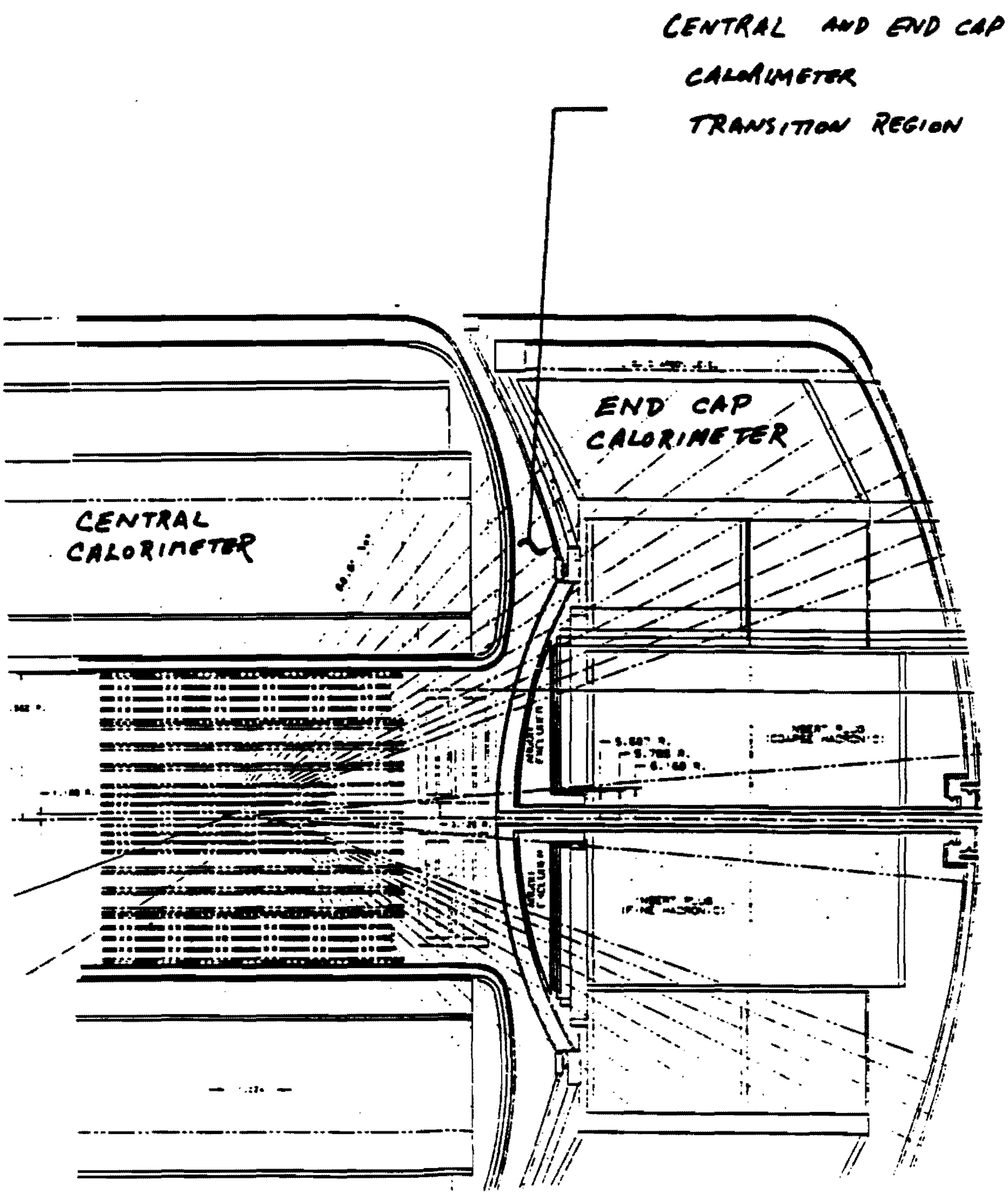

CENTRAL AND END CAP
CALORIMETER
TRANSITION REGION
END CAP
CALORIMETER
CENTRAL
CALORIMETER

FIG. 1b

END VIEW OF CENTRAL CALORIMETER
(PARTIAL SECTION)

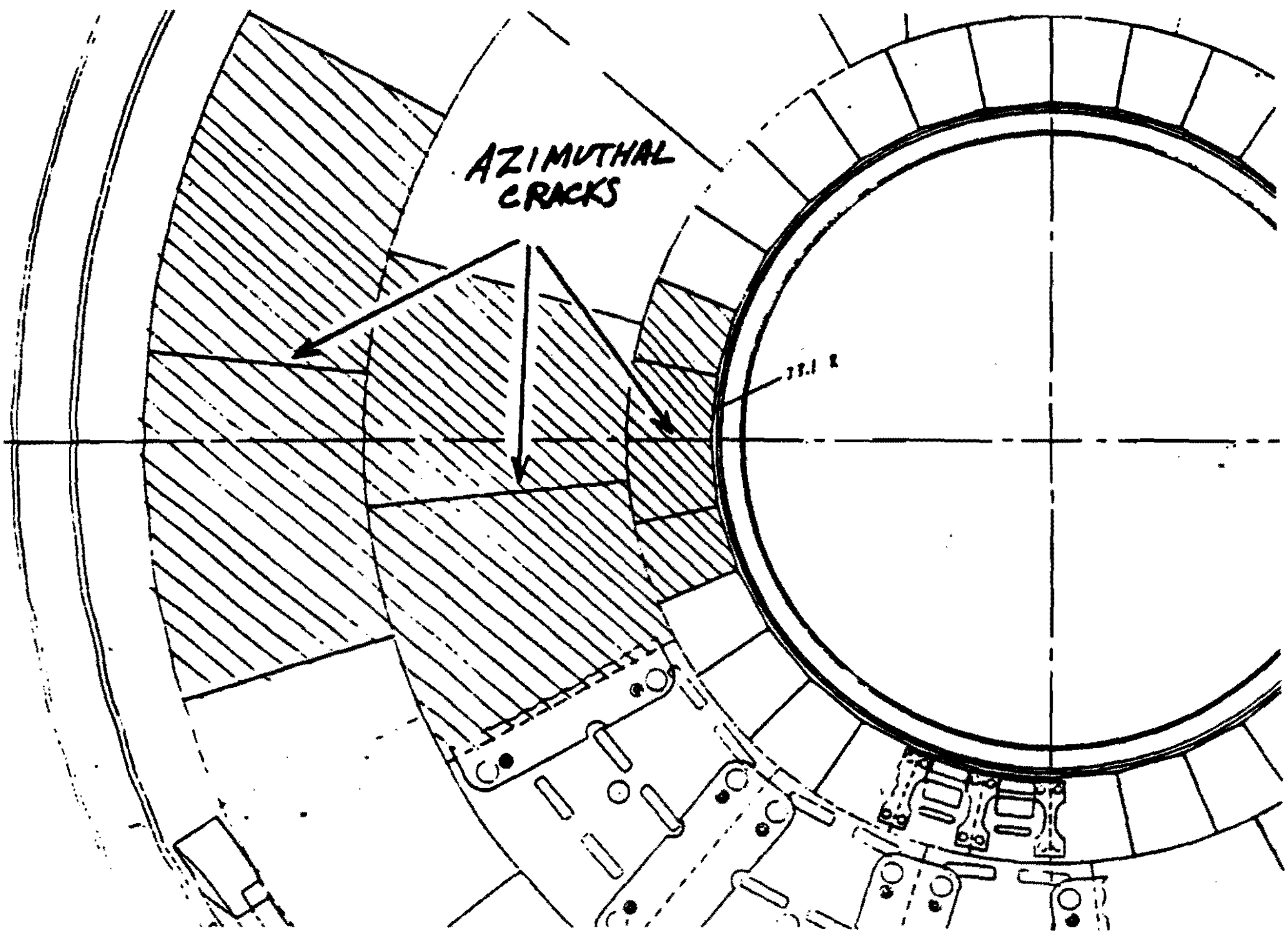


FIG. 2

LAYOUT OF MUON LAB

TOP VIEW

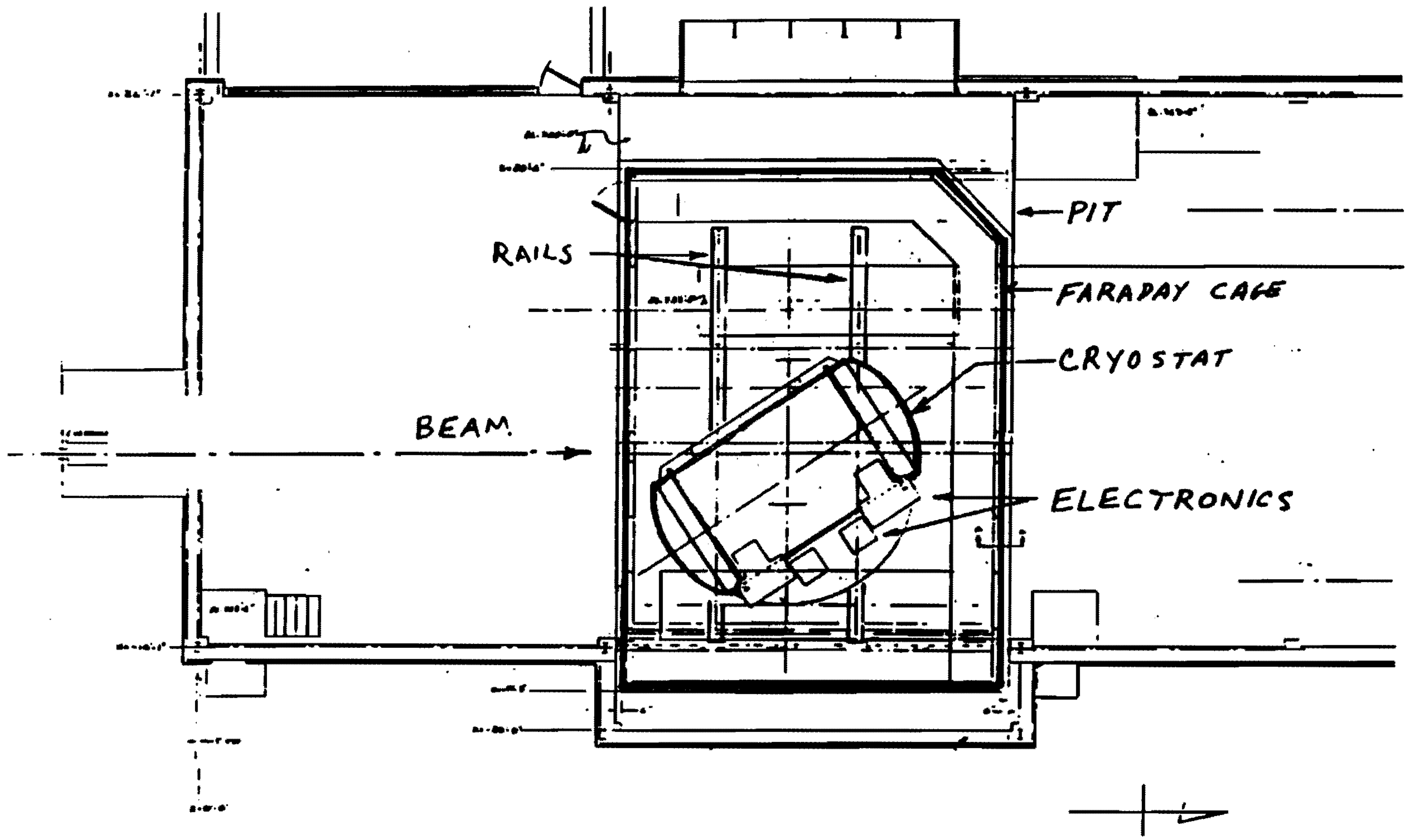


FIG. 3

TEST BEAM CRYOSTAT

ARRAY 1 CC MODULES

END VIEW, AT NORMAL ROLL POSITION

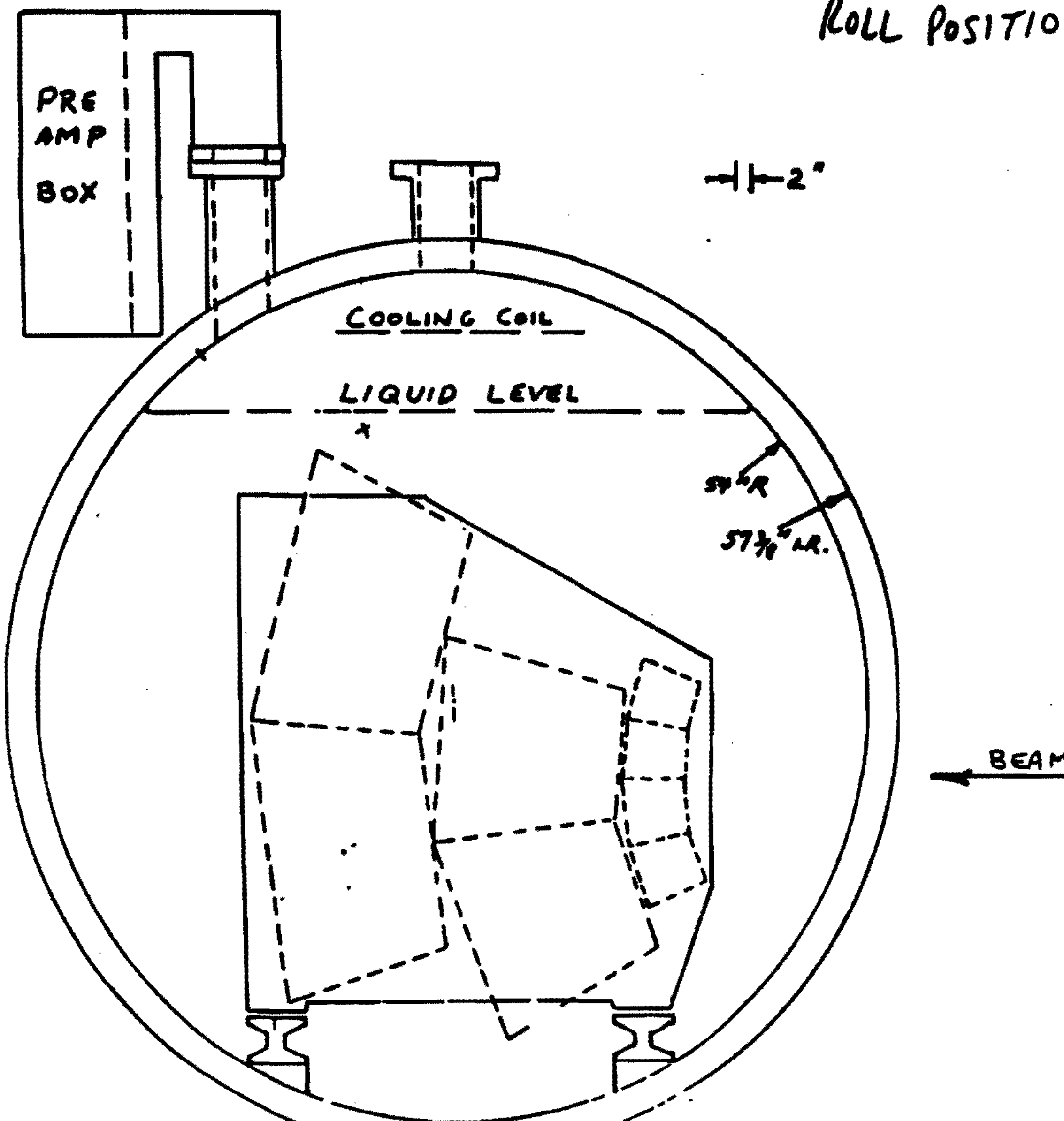


FIG. 4

FERMILAB ENGINEERING NOTE	SECTION	PROJECT	SERIAL-CATEGORY	PAGE
		DØ-TEST	UPenn	2006

SUBJECT	NAME
ARRAY 1 - ISOMETRIC VIEW TEST BEAM SCANS	R.E. RULAND
	DATE: 11/5/86

ARRAY 1 -- SHOWING:

- LOCATION WITHIN THE INNER VESSEL SHELL
- TEST BEAM SCAN RANGE IN θ & φ
- DØ BEAM AXIS & EFFECTIVE COLLIDING BEAM VERTEX, V_o

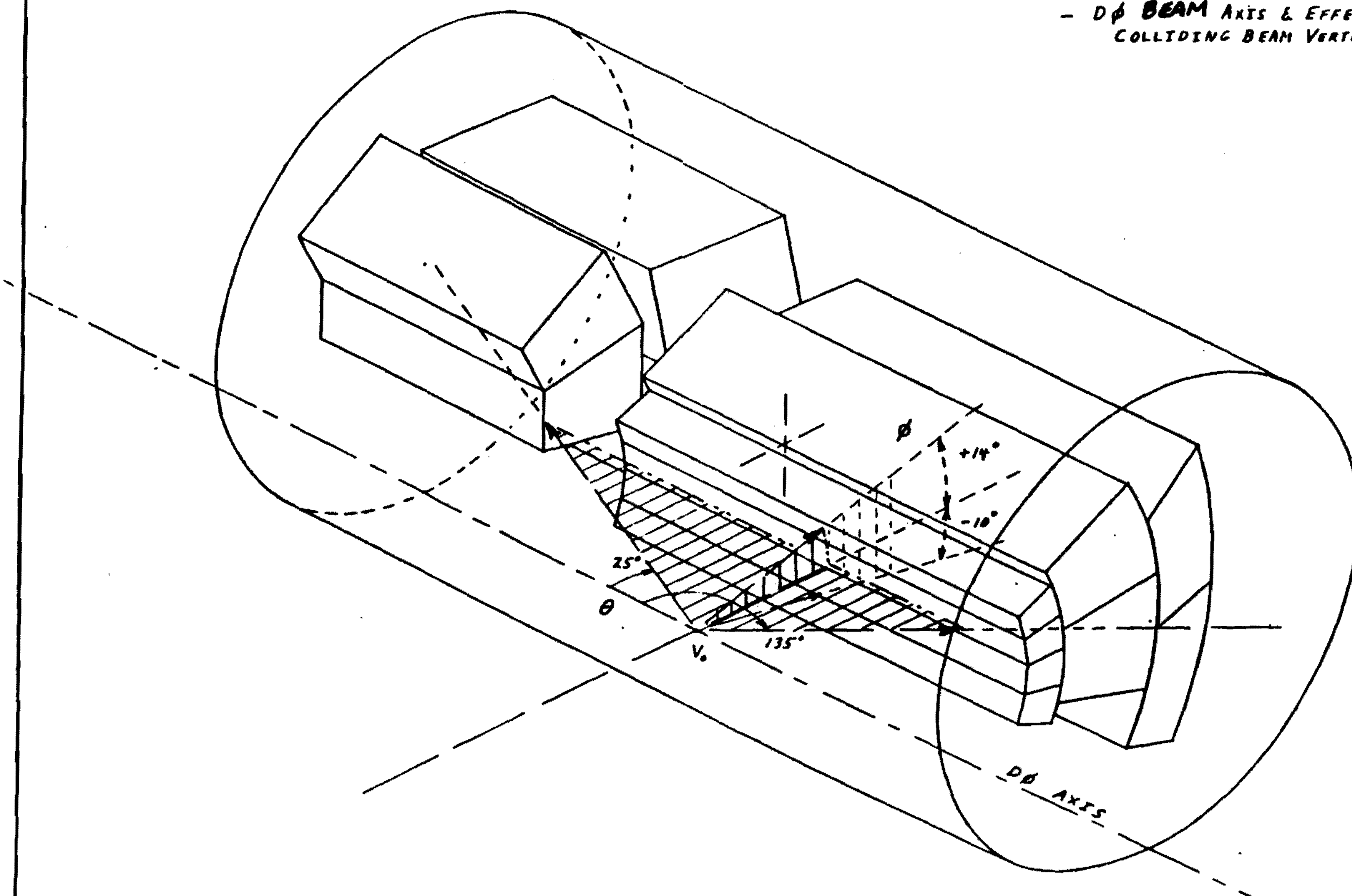


FIG. 5

ARRAY 2

END VIEW

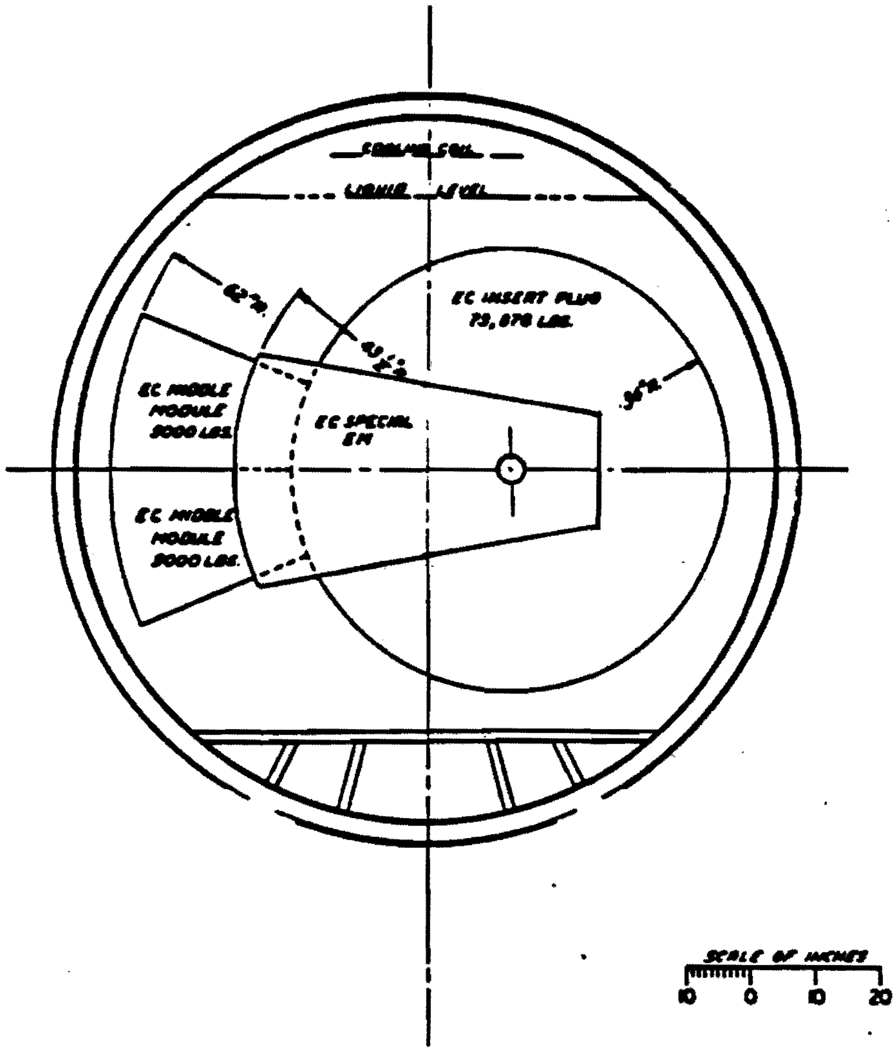


FIG. 6

ARRAY 2 SETUP

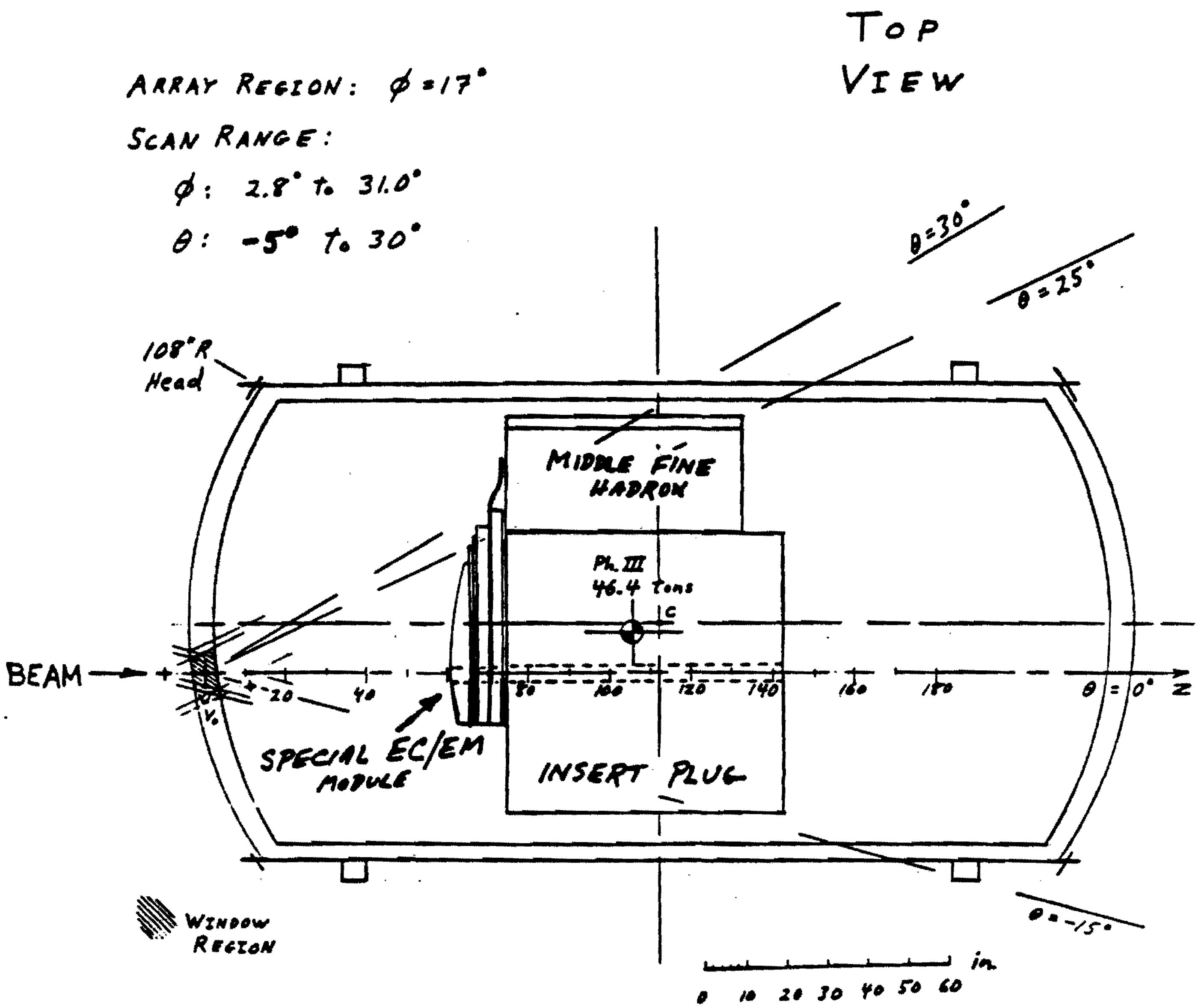
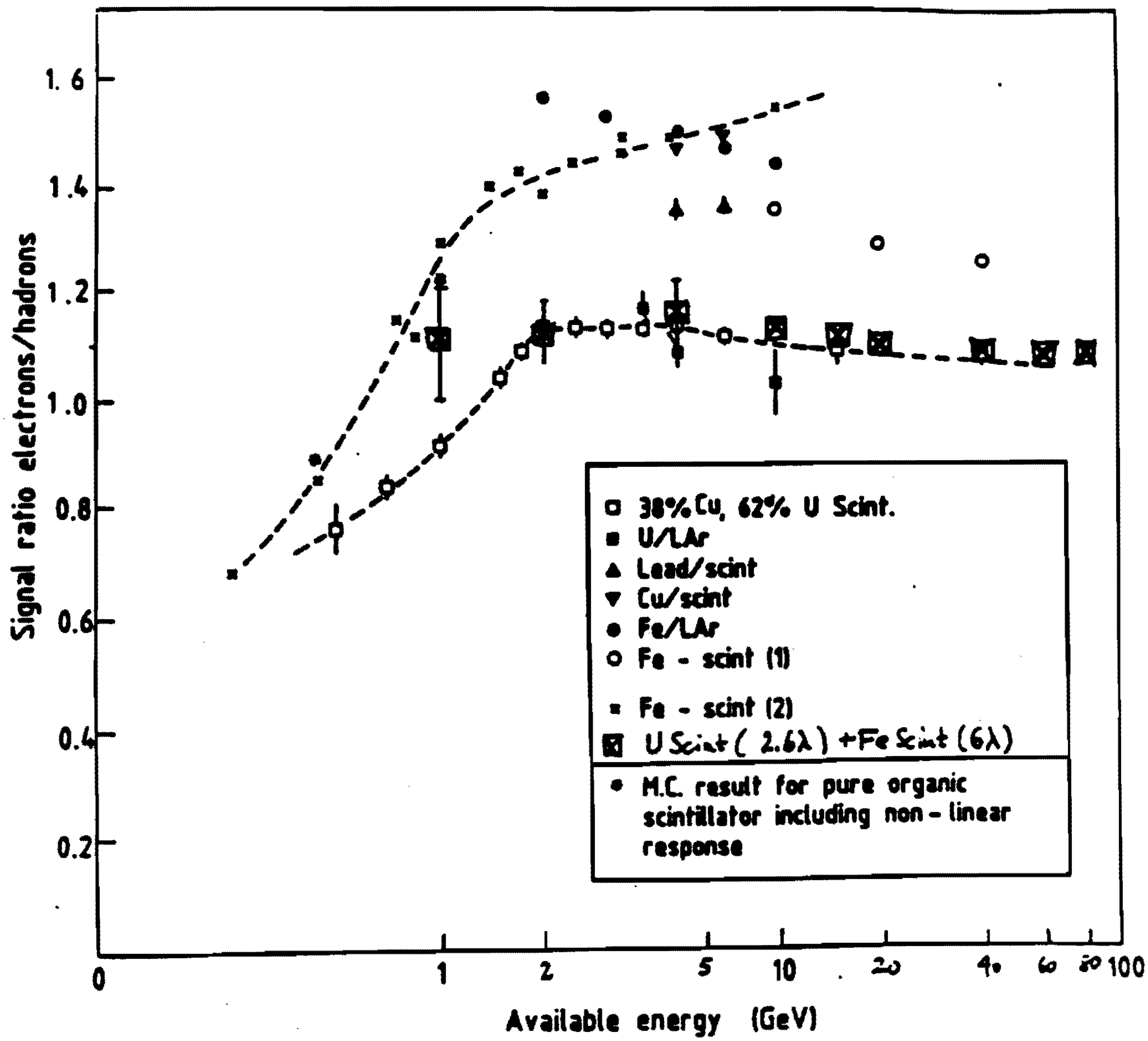
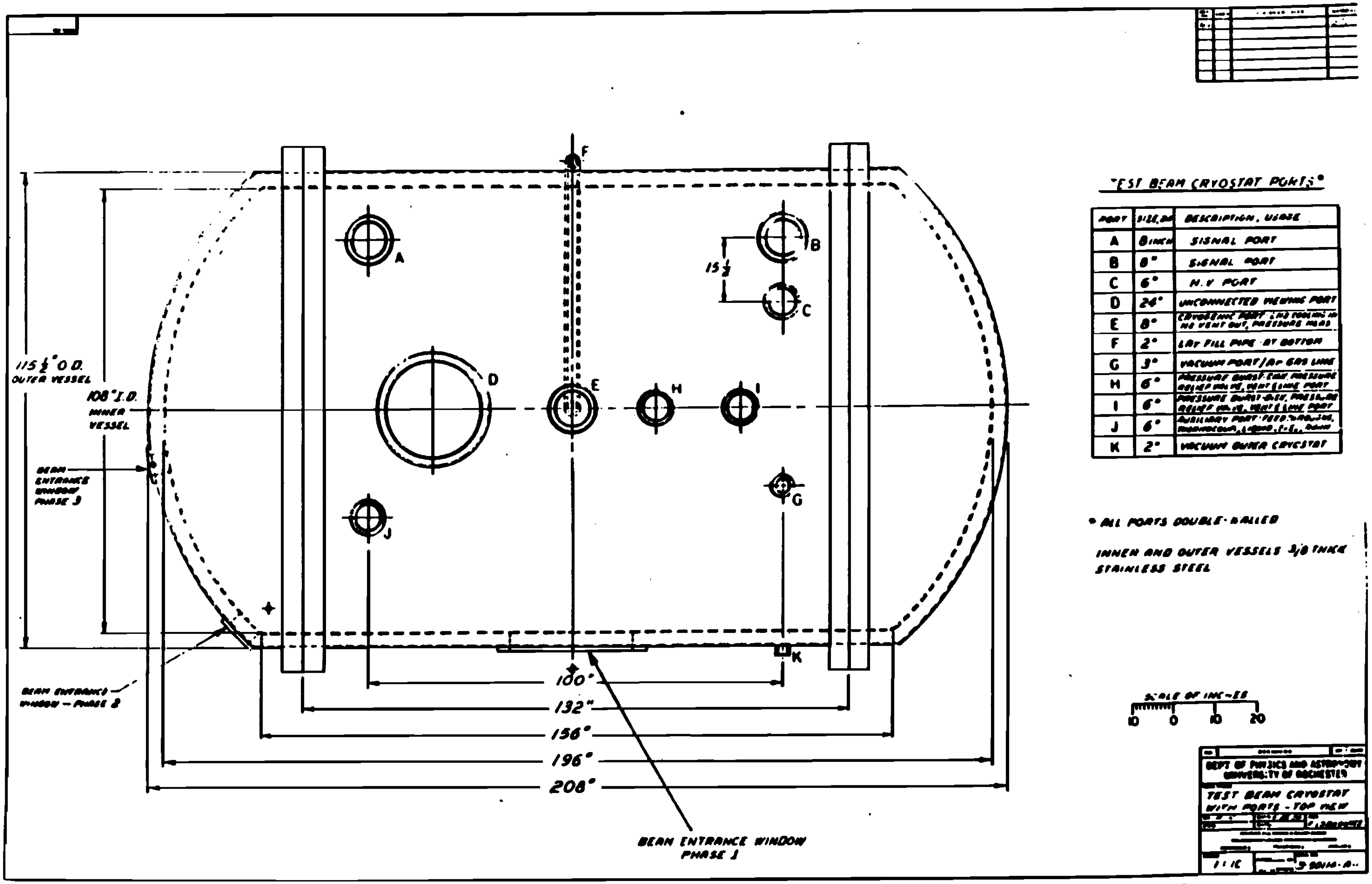


FIG. 7



Signal ratio electrons/hadrons
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
1
2
5
10
20
40
60
80
100
Available energy (GeV)
38% Cu, 62% U Scint.
U/LAr
Lead/scint
Cu/scint
Fe/LAr
Fe - scint (1)
Fe - scint (2)
U Scint (2.6λ) +Fe Scint (6λ)
M.C. result for pure organic scintillator including non - linear response

FIG. 8



"TEST BEAM CRYOSTAT PORTS*"
PORT
DESCRIPTION, USAGE
A
SIGNAL PORT
B
SIGNAL PORT
C
H.V PORT
D
UNCONNECTED VIEWING PORT
E
F
LAr FILL PIPE AT BOTTOM
G
VACUUM PORT/Ar GAS LINE
H
I
J
K
VACUUM OUTER CRYOSTAT
* ALL PORTS DOUBLE-WALLED
INNER AND OUTER VESSELS 3/8 THICK STAINLESS STEEL
SCALE OF INCHES
10 0 10 20
115 1/2" O.D. OUTER VESSEL
108" I.D. INNER VESSEL
BEAM ENTRANCE WINDOW PHASE 3
BEAM ENTRANCE WINDOW - PHASE 2
BEAM ENTRANCE WINDOW PHASE 1
15 1/2
100"
132"
156"
196"
208"
DEPT OF PHYSICS AND ASTRONOMY UNIVERSITY OF ROCHESTER
TEST BEAM CRYOSTAT WITH PORTS - TOP VIEW

FIG. 9

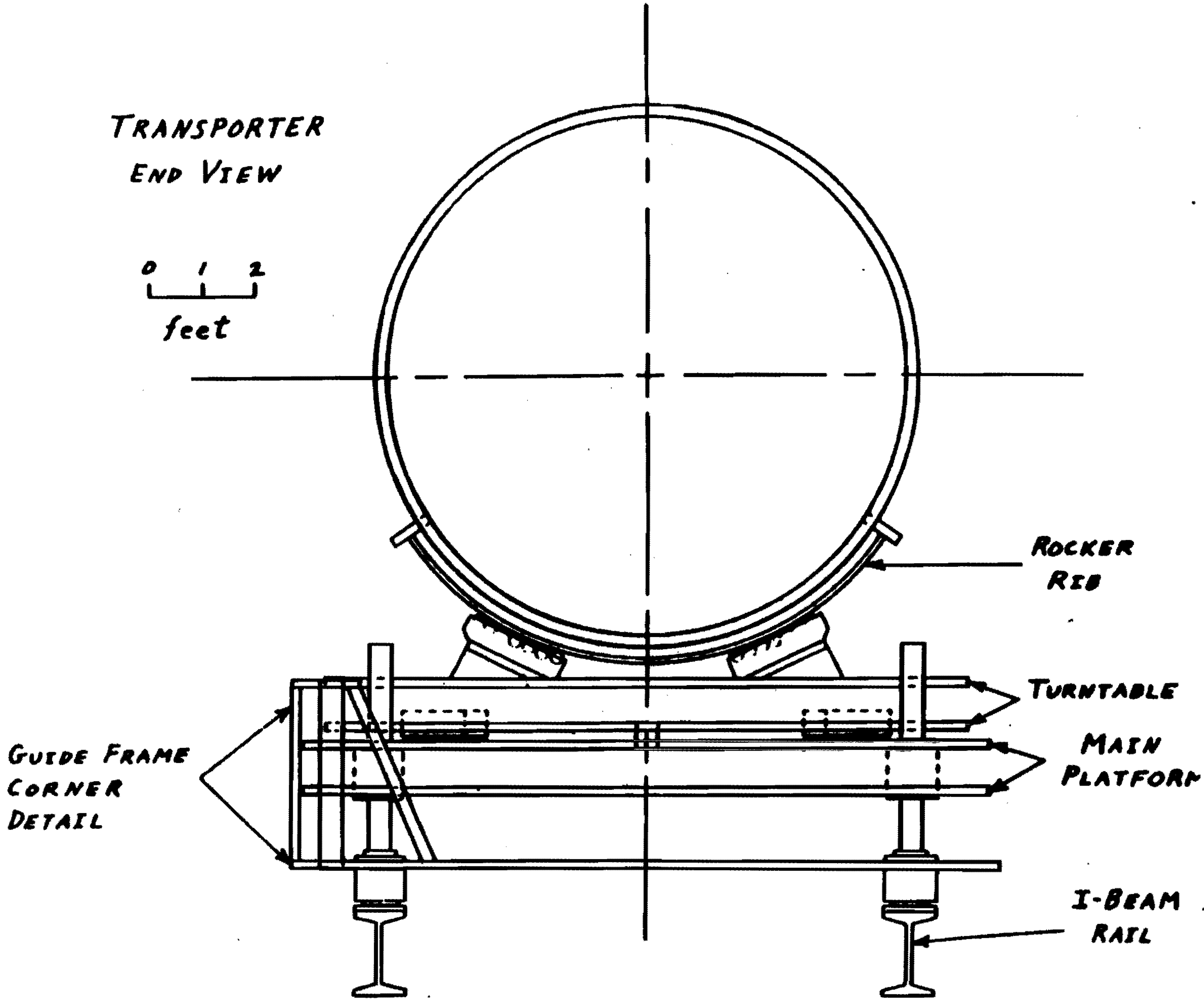

TRANSPORTER
END VIEW
0 1 2
feet
ROCKER
RIB
TURNTABLE
GUIDE FRAME
CORNER
DETAIL
MAIN
PLATFORM
I-BEAM
RAIL

FIG. 10

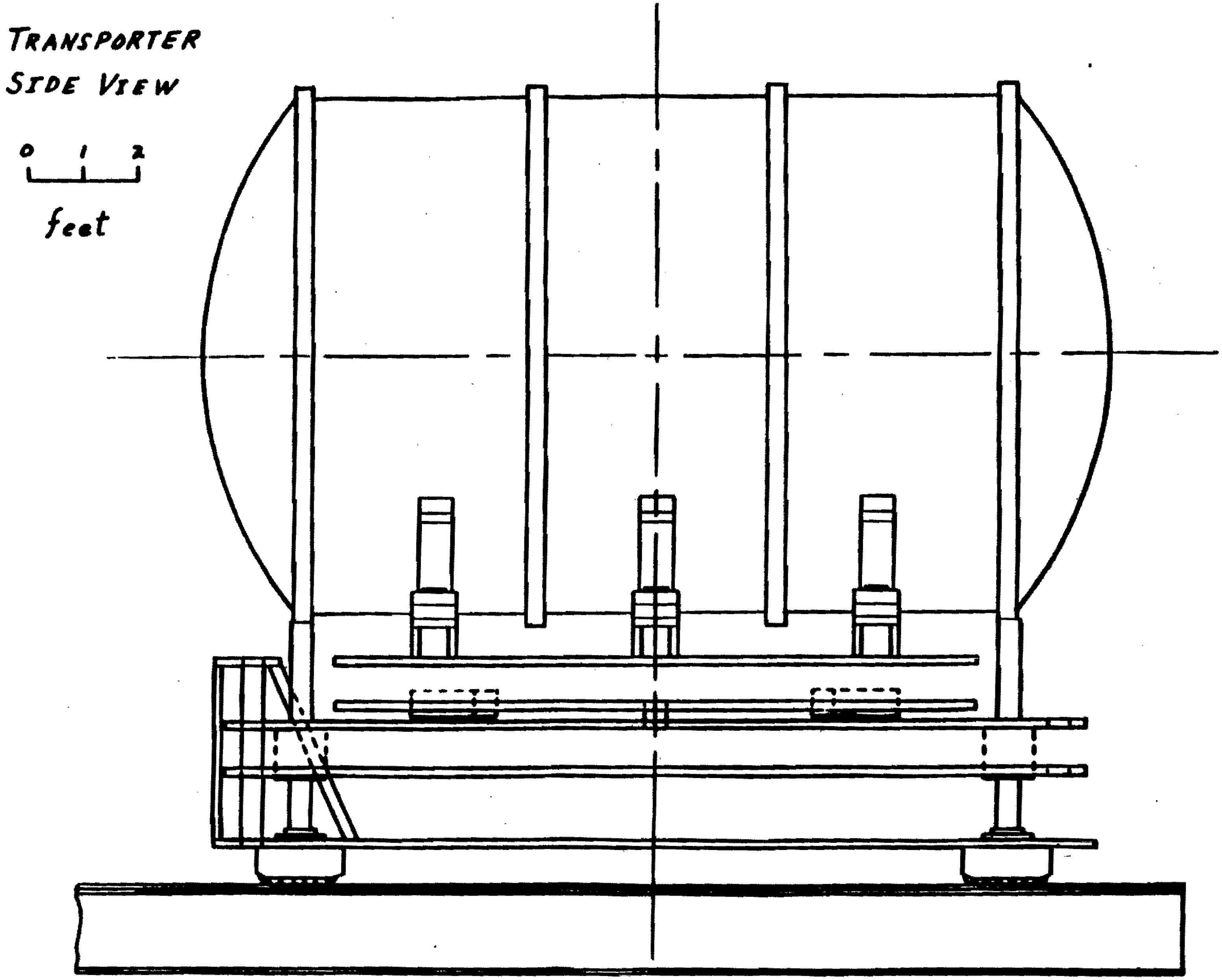


FIG. 11

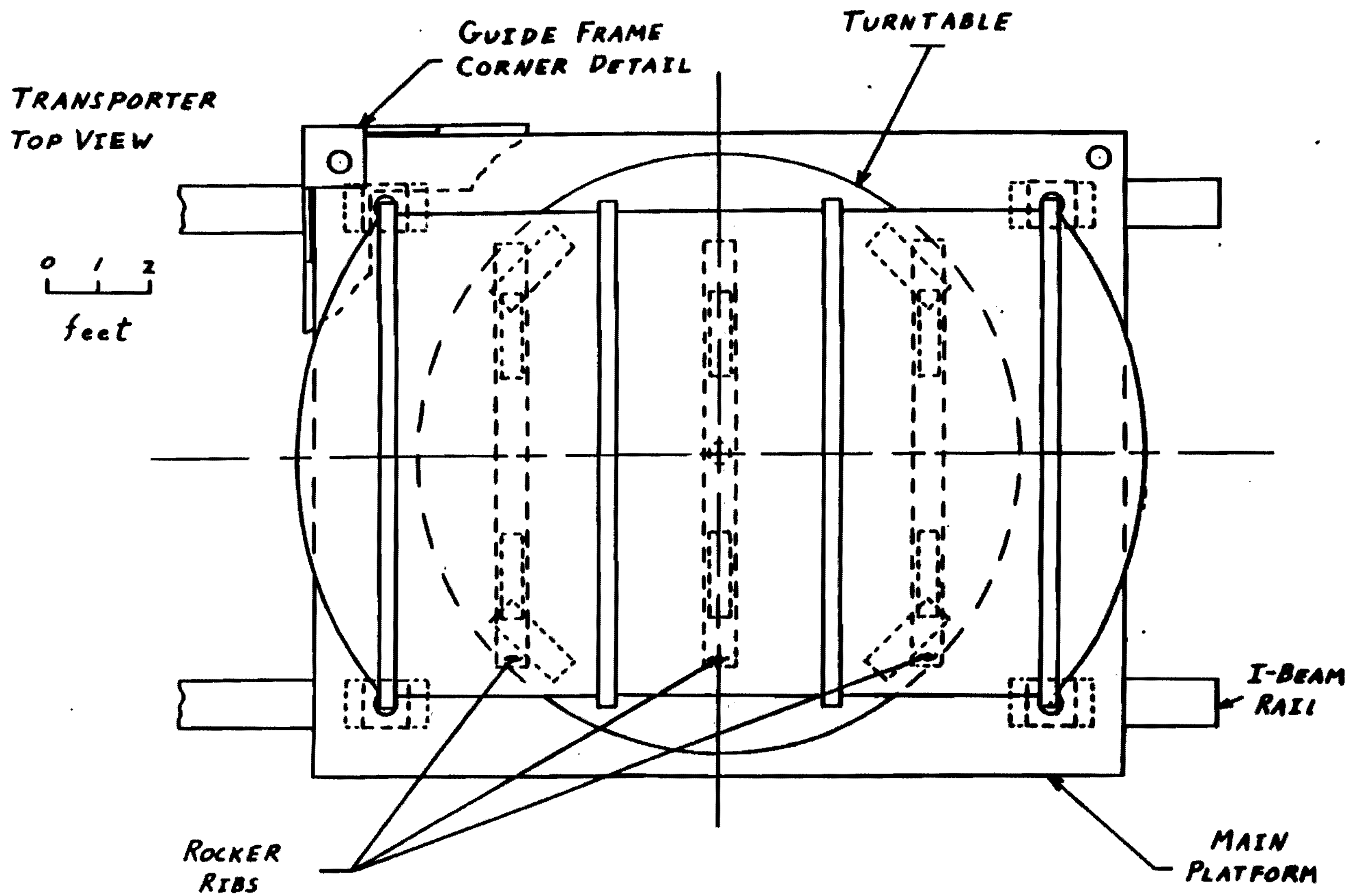

GUIDE FRAME
CORNER DETAIL
TURNTABLE
TRANSPORTER
TOP VIEW
0 1 2
feet
I-BEAM
RAIL
ROCKER
RIBS
MAIN
PLATFORM

FIG. 12

LAYOUT IN THE FARADAY CAGE

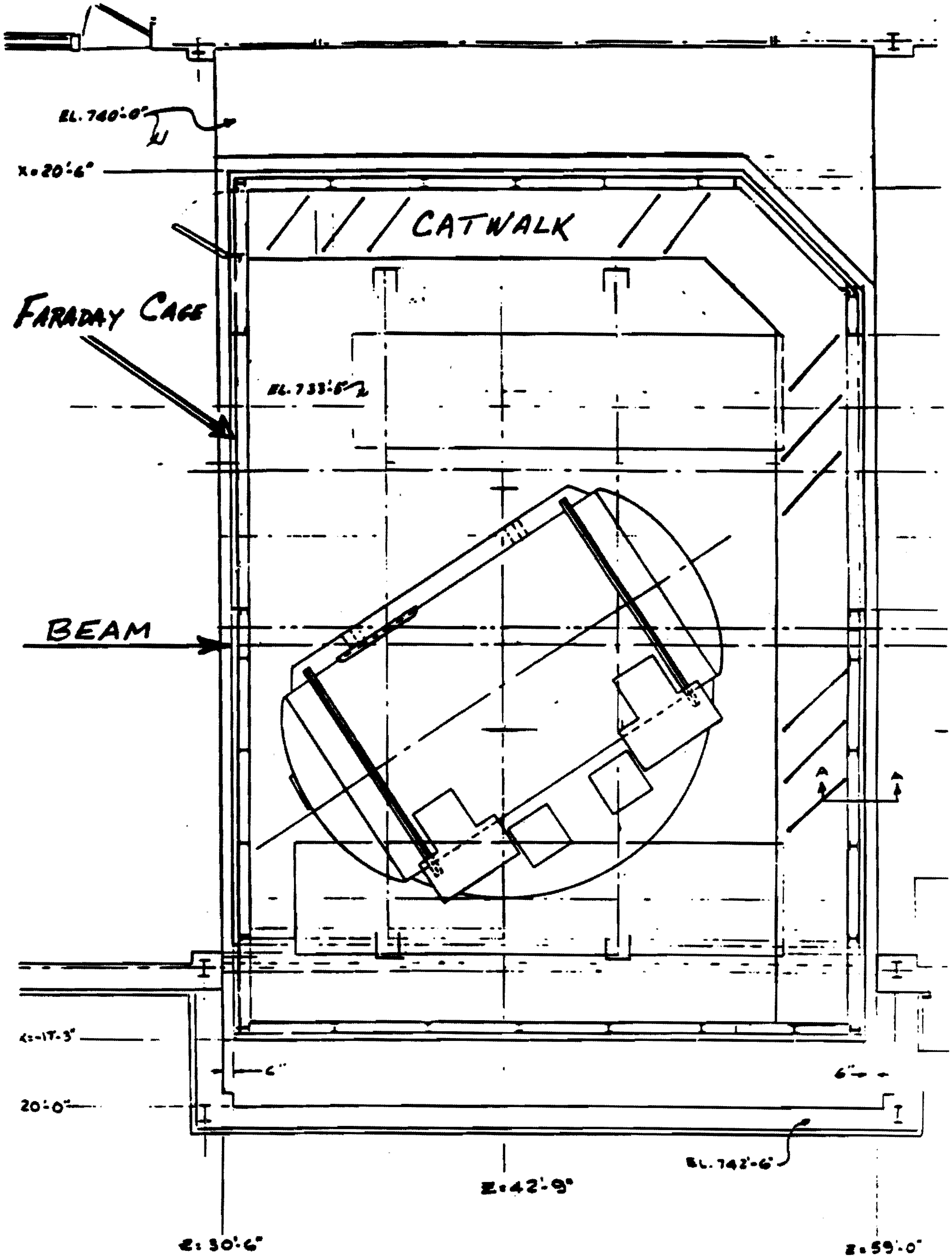
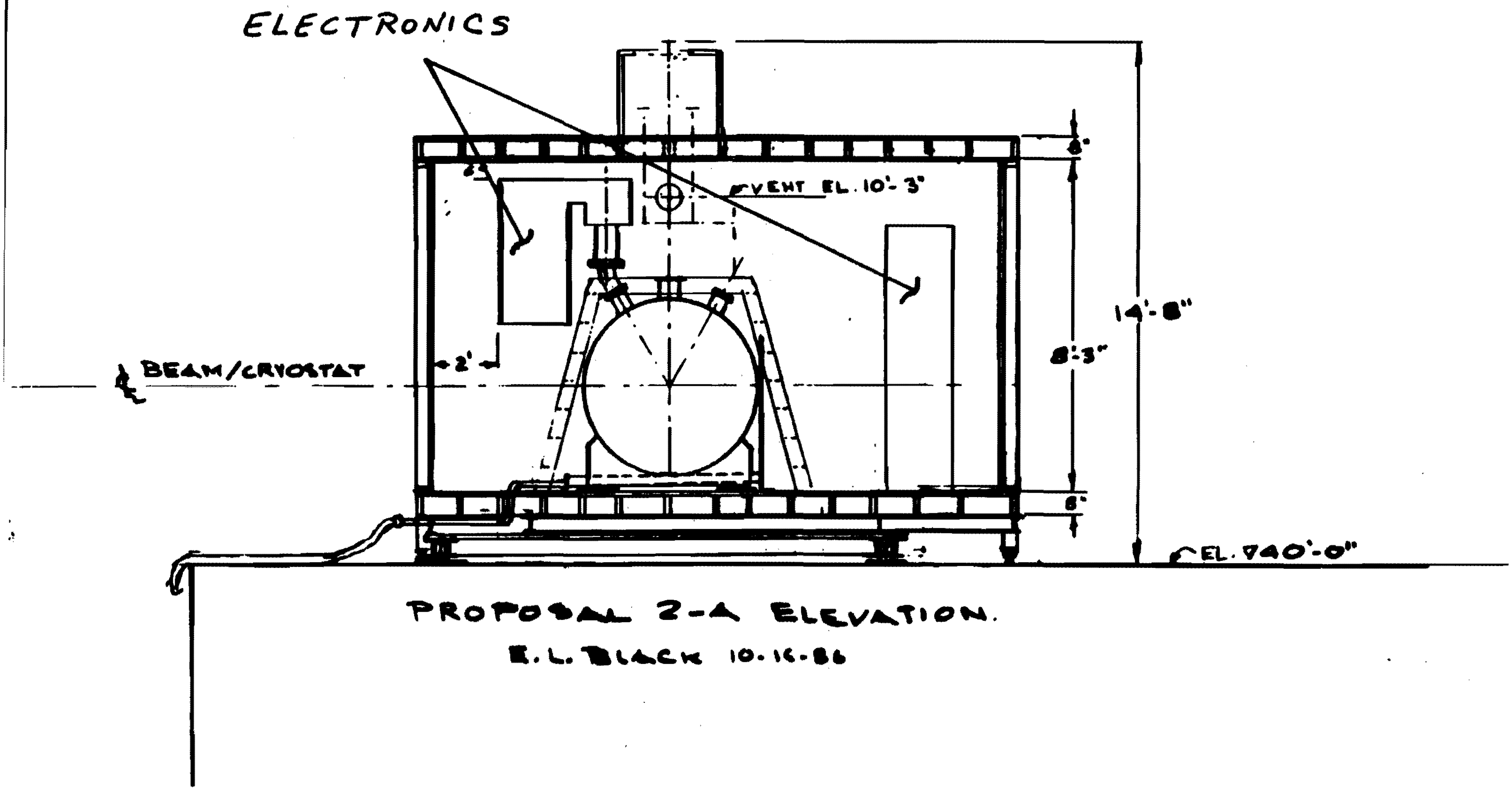


FIG. 13

SMALL

FARADAY CAGE



PROPOSAL 2-A ELEVATION.

E. L. BLACK 10.16.86

FIG. 14

TEST BEAM CRYOSTAT

SIMPLIFIED FLOW DIAGRAM

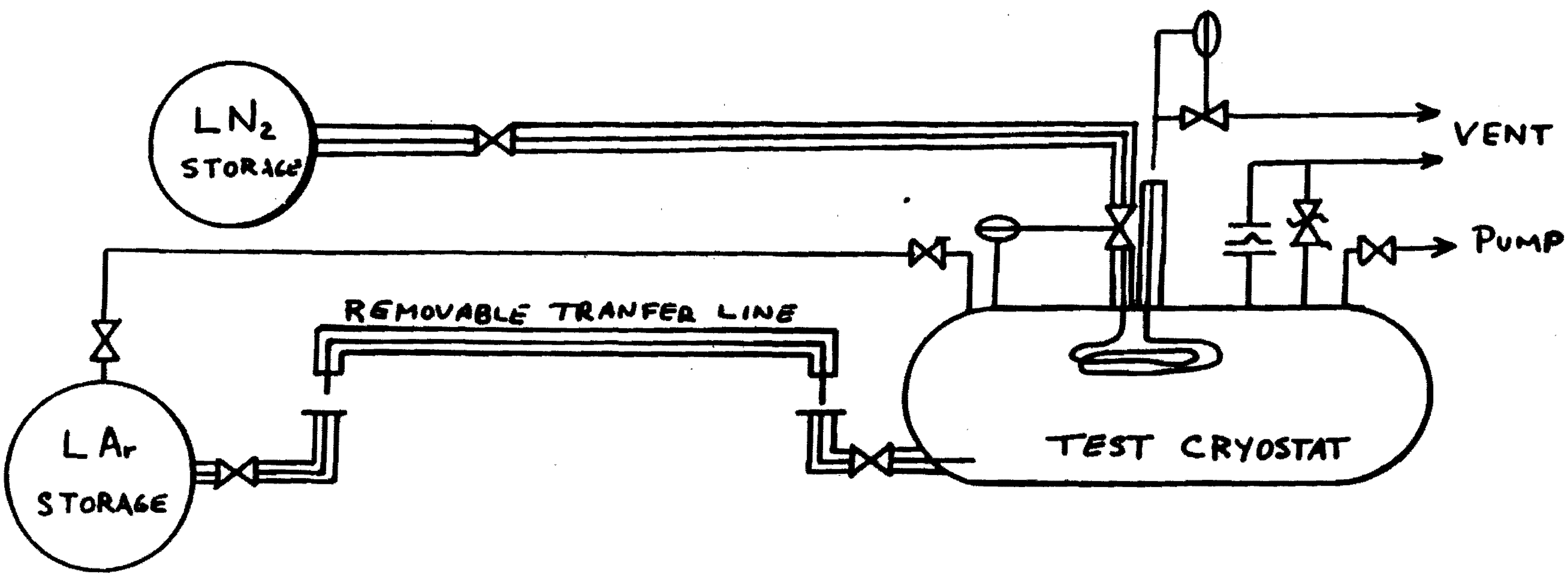


FIG. 15