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International Linear Collider Calorimeter/Muon Detector Test Beam Program
(A Planning Document for Use of Meson Test Beam Facility at Fermilab)

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For the ILC Calorimeter Test Beam Group

Abstract

The linear collider requires a detector with excellent performance to fully exploit its physics potential. In particular, requirements from the measurement of hadronic jet energies indicate a goal of developing the calorimeter with an unprecedented jet energy resolution of 30%/√E or better. In order to meet this challenge, novel technologies and reconstruction techniques are being developed, which need to be tested with particle beams. The recent decision by the International Technology Recommendation Panel (ITRP) concerning the linear collider accelerator technology imposes a time scale of at most a few years for the basic detector design choices. A vigorous test beam program over the next few years is necessary to provide a solid basis for these decisions. In this regard, the International Linear Collider Calorimeter and Muon Detector Test Beam Group submit this planning document to Fermilab. The main goals of the test beam program outlined in this document are to evaluate the different choices of technologies proposed for the calorimeter and to understand, validate and improve the Monte Carlo modeling and simulation of hadronic showers. This document contains a description of fourteen distinct calorimeter and muon detector/tail-catcher groups and their requirements for specific test beam resources. This planning document also lays out time scales and institutional responsibilities for the proposed test beam program. It provides plans for the users of the Fermilab Meson Test Beam Facility, and needs for upgrades to particle energy ranges and intensities, and associated engineering and computing support services.

I. Physics Justification for Testing Calorimeter Prototypes for the Linear Collider Detector

The detectors at the International Linear Collider (ILC) are envisioned to be precision instruments that can measure Standard Model physics processes near the electroweak energy scale and discover new physics processes beyond it. To take full advantage of the physics potential of the ILC, the performance of the detector components comprising the experiment must be optimized, sometimes in ways not explored by the previous generation of collider detectors. In particular, the design of the calorimeter system, consisting of both electromagnetic and hadronic components, calls for a new approach to achieve the precision required by the physics. As a precision instrument, the calorimeter will be used to measure jets from decays of vector bosons and heavy particles, such as top, Higgs, etc. For example, at the ILC it will be essential to identify the presence of a Z or W vector boson by its hadronic decay mode into two jets [1]. This suggests a dijet mass resolution of ~3 GeV or, equivalently, a jet energy resolution $\sigma/E \sim 30\%/\sqrt{E}$. None of the existing collider detectors has been able to achieve this level of precision.

Preliminary studies indicate that a jet energy resolution of $\sim 30\%/\sqrt{E}$ can be obtained by the application of Particle-Flow Algorithms (PFAs) [2]. PFAs use tracking detectors to reconstruct charged particle momenta (~60% of jet energy), electromagnetic calorimetry to measure photon energies (~25% of jet energy), and both electromagnetic and hadronic calorimeters to measure the energy of neutral hadrons (~15% of jet energy). To fully exploit PFAs, the calorimeters must be highly granular, both in transverse and longitudinal directions to allow for the separation of the energy deposits from charged hadrons, neutral hadrons, and photons in three spatial dimensions. For this reason, the optimization of the calorimeter designs for the application of PFAs is absolutely critical to accomplish the physics goals of the ILC.

The developments of PFAs, to date, rely almost entirely on Monte Carlo (MC) models. Their performance depends critically on the details of the hadronic showers, such as the production of secondaries, the interparticle distances, the energy deposition in thin layers, etc.

At present a number of different models [3–6] simulating the hadronic shower development exist. These models differ significantly in several important aspects. To give an example, Figure 1, taken from a presentation by G. Mavromanolakis [7], compares the predicted shower radius for fifteen different MC models of the hadronic shower. Differences of up to 60% are seen. At present there is insufficient experimental data to distinguish between these models. To remedy this situation a large part of the proposed test beam program will be devoted to the detailed measurement of hadronic showers and to the validation of these models.

The design of a precision calorimeter for the ILC detector requires the development and testing of new detector technologies. Tests of several concepts for the electromagnetic calorimeter (ECAL) in standalone mode, with emphasis on the analog energy measurement of electromagnetic showers, are necessary. Here the challenge is to minimize the lateral extent of showers with a dense ECAL, as required for the optimal use of PFAs, while preserving good energy resolution. In addition, novel electronics and schemes for the readout of the active media of these calorimeters need to be tested in a beam environment.

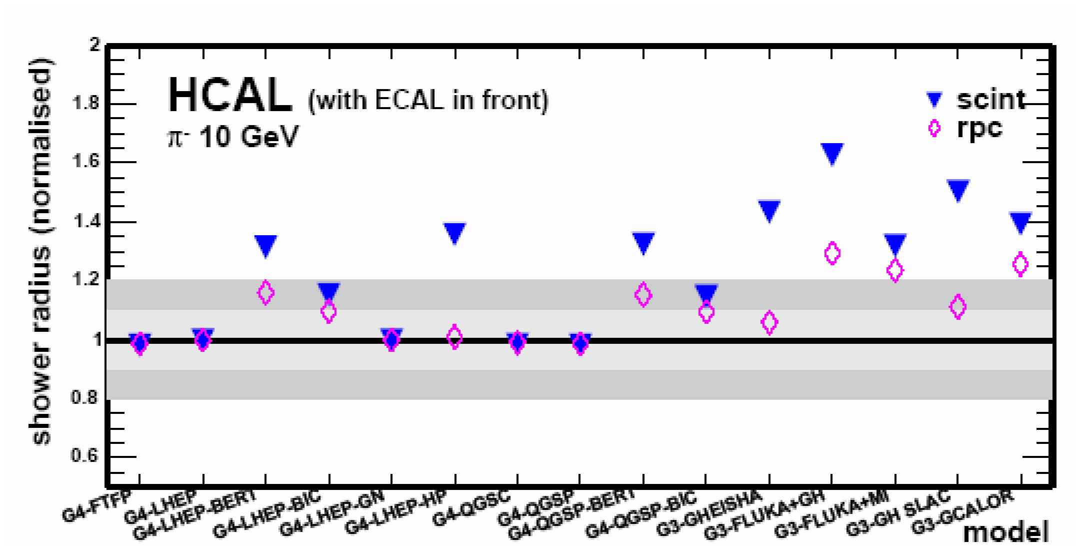

Figure 1. Comparison of the shower radius in a hadronic calorimeter as predicted by fifteen different MC models of hadronic showers. Differences from a few % to as large as 60% between different models can be seen.

For the hadronic calorimeter (HCAL), the requirement of fine grain segmentation has prompted consideration of digital as well as analog readout schemes for several sensitive gap technology choices. The development of a digital HCAL is fairly new and requires standalone testing to validate the unique (to calorimetry) technologies under consideration. Gas detectors (Resistive Plate Chambers [8] and Gas Electron Multipliers [9]) are being explored as active medium. The proposed analog HCAL utilizes scintillator tiles as small as 3 x 3 cm^2 together with a novel electronic readout device mounted directly on the side of the tile. To extend the longitudinal range of detailed measurements of hadronic showers, the tests of the HCAL need to include a muon-detector/tail-catcher located in the back of the HCAL. Two distinct technologies for this device will be tested in this program as well. Furthermore, a muon-detector/tail-catcher will provide the opportunity to capture all of the energy of the hadronic shower which allows us then to develop effective strategies for dealing with energy leakage from relatively thin calorimeters and energy loss in the superconducting (SC) magnet coil upstream of the ILC muon system.

Finally, to validate Monte Carlo models used to develop the PFAs, the entire calorimeter, consisting of ECAL and HCAL, needs to be tested in a wide variety of test beam configurations, including hadron energies as low as 1 GeV and up to 80 GeV, electron energies as high as 25 GeV, and several angles of incidence and impact points. As an alternative to the use of MC models, the test beam data will be used to generate extensive libraries of hadronic showers. Collecting a comprehensive data set with unprecedented granularity will provide a reference for further improvement of hadronic shower modeling that is of paramount importance for the design of a detector for the ILC. Independent of the ILC, the proposed measurements are also valuable in their own right, since they can provide the experimental basis to further the understanding of both calorimetry and hadronic showers.

In addition to the wide range of technical benefits laid out above, we anticipate 10 – 20 publications from this effort. This document also provides a detailed plan requested in the recommendation [10] by the DESY Physics Research Committee (PRC) at its meeting in May 2004, which endorsed the general need for a linear collider test beam program.

II. Calorimeter Technologies To Be Tested

In order to develop a calorimeter system for linear collider detectors, it is necessary to build and test three components: electromagnetic calorimeter (ECAL) modules, hadron calorimeter (HCAL) modules, and an integrated 'tail-catcher' and muon system to be located behind the ECAL, HCAL and SC coil.

For the electromagnetic modules, two designs that use silicon as the active medium between tungsten absorber plates are being developed: one in Europe and the other in the U.S. These two designs differ in the degree of integration of the readout electronics on-board each active layer and in their transverse segmentation. Two further designs use scintillator as the active medium, one from the U.S. with tiles offset by half the widths, and the other from Japan. Finally, there are two hybrid electromagnetic calorimeter designs, one from the U.S. using silicon/scintillator with tungsten absorber and the other from Italy using silicon/scintillator with lead absorber.

The HCAL modules to be tested include both analog and digital approaches. A joint U.S.-European design uses scintillator tiles with analog readout and steel absorber. The two digital hadron calorimeter designs, one from the U.S./Russia, using resistive plate chambers (RPCs) as the active medium and the other, a U.S. effort, using gas electron multiplier (GEMs) charge amplification layers, both use steel absorber. Other dense absorber materials, such as tungsten, are also in consideration.

The muon-system/tail-catcher has three designs, a CALICE [11] (primarily DESY and NIU) scintillator strip-steel option, a scintillator-steel option (UC Davids/FNAL/NIU/Notre Dame/ Wayne State) and an RPC-steel option from Italy.

A significant part of the design and construction of the prototype calorimeters is borne by the CALICE collaboration, currently a group of 24 institutes located in seven different nations. From the U.S., groups at Argonne National Laboratory, Northern Illinois University, and the University of Texas at Arlington are full members of the collaboration.

2.1 Electromagnetic Calorimeters

2.1.1 Silicon - Tungsten

As discussed above, PFAs require a highly segmented electromagnetic calorimeter (ECAL). A natural way of implementing this is with alternating layers of tungsten (W) and silicon (Si) detectors. This scheme employed takes advantage of the small Molière radius of W with Si detectors by using finely segmented pixels of 1 x 1 cm^2 or 0.5 x 0.5 cm^2. The longitudinal profile will have of about 30 layers each of tungsten with thickness 1 to 5 mm, depending on the eventual optimization.

The CALICE collaboration and a consortium of Brookhaven, Oregon, and SLAC (BOS) have developed Si-W ECAL design. A major challenge is to integrate the electronics into the detectors to provide an effective reduction in the number of readout channels by a large factor (of order 1000). Maintaining a small Molière radius requires that the readout gap, including Si detectors and the readout electronics, be kept very thin (~ 1 mm). The implementations of the two designs differ but both are novel and will require testing in a beam. In the BOS case, both analog and digital readout is performed on a single ASIC which is bump-bonded to the Si detectors. The Si detectors themselves have metallization which carries the signals from individual pixels to the ASIC. The CALICE system is still being designed, but is also highly integrated in its present form.

A test beam with electrons of modest energy (~20 GeV) is required to evaluate the new technologies in standalone tests of these ECAL modules. As a separate function the test module will provide a radiator simulating the actual ECAL, with close to the correct segmentation, for the validation of hadron showers in the test beam program. For this function, it is not necessary that the Si-W include the innovations mentioned above. In fact, CALICE is well along in the fabrication of such a Si-W test beam module. This is a full-depth module that will be used for the first round of hadron shower measurements, until the integrated designs become available.

The CALICE ECAL effort is proceeding with construction of prototype and the initial beam test at DESY, while the U.S. effort is funded at the modest detector R&D level. Therefore, the time scale for U.S. ECAL beam tests at Fermilab does not appear to be as certain as the CALICE schedule.

2.1.2 Scintillator – Tungsten

A technology being studied by the University of Colorado group involves alternate scintillator layers offset by half a tile width from each other. This allows 5 x 5 cm^2 tiles to have an effective area of 2.5 x 2.5 cm^2 which improves the spatial resolution. This array is being simulated to determine the improvement in spatial resolution, maintaining the characteristic good energy resolution of scintillator-based calorimetry. This effort is currently not funded sufficiently for construction of prototypes and beam tests.

Independently, a group from Japan, Korea, and Russia is developing a scintillator strip based design, using 3mm thick tungsten plates. Each sensitive layers consists of 20 pieces of strips of size 1cm (W) x 0.2cm (T) x 20cm (L) in x and y directions, providing 1cm x 1cm effective cell size. By adding small-tile layers ghost hits are rejected. A prototype with 30 layers will bea prepared for beam tests.

2.1.3 Hybrid technologies

Two groups are developing a compact hybrid EM calorimeter. Under consideration are sandwich designs with thin tungsten or lead as the absorber. The sampling will be done by thin layers of scintillator-tiles with WLS fiber readout to on-tile B-field tolerant photo-detectors (eg. Silicon-Photo-Multipliers, SiPMs [12]) and by a number of layers of silicon with small pads or strips with an area around 1 cm^2.

The major cost-driver to the Si-W approach is the cost associated with the large area of silicon. This hybrid approach could lead to an ECAL that meets the necessary EM resolution cost effectively, while addressing the granularity requirements at large radius. Most of the proof-of-principle technological R&D is in progress by the proponents of the silicon and scintillator approaches. The concept of a cost-effective solution to a high-granularity ECAL is particularly interesting to overall detector design concepts with large volume gaseous tracking and large ECAL radius. Most of the proof-of-principle technological R&D is in progress by the proponents of the silicon and scintillator approaches.

A European group which consists of Como, ITE-Warsaw, LNF, Padova, and Trieste, has already explored with test beams a design, LC-CAL [13], that uses lead as absorber and three layers of Silicon readout. The Kansas/Kansas-State University groups are investigating the design of an EM calorimeter with substantial sampling by the Silicon layers.

The proposed design of a hybrid sampling ECAL is rather novel and needs test-beam demonstration of performance both as a standalone ECAL and as part of a calorimeter system measuring hadronic particles. The relative sampling by the scintillator and silicon readout needs to be optimized with test-beam data.

2.2 Analog/Semi-Digital Hadron Calorimeter

2.2.1 Scintillator – Steel

The CALICE Collaboration is constructing a scintillator-steel, cubic meter size, hadron calorimeter prototype [14]. The prototype is a finely-grained hadron calorimeter that uses a proven technology for the active medium in combination with novel solid-state photo-detectors. The prototype consists of 38 layers of 5 mm thick scintillator tiles sandwiched between 2cm thick steel absorber plates mounted on a movable stand. The stand is designed to hold both ECAL and HCAL modules and to position them in any direction with respect to the incident beam. The prototype geometry, based on a solid foundation of hardware R&D and simulation studies, will address the goals of technology demonstration, hadron shower MC validation and particle flow algorithm development. The hardware R&D has included detailed tests of tile-fiber optimization, photo-detector characterization and the operation of a 100 channel MINICAL in a low energy electron test beam [15, 16] at DESY while the simulation studies have involved the development of innovative algorithms for shower separation, energy reconstruction and particle flow in the analog and digital environments [17].

The first thirty layers of the prototype have a 30 x 30 cm^2 core instrumented with 3 x 3 cm^2 tiles, followed by tiles of 6 x 6 cm^2 and 12 x 12 cm^2 as one moves out laterally from the center of the layer. The last 8 layers are instrumented with only the 6 and 12 cm tiles.

Each tile has a wavelength-shifting fiber mated to a solid-state photo-detector (Silicon Photomultiplier) sitting on board. The Silicon photo-multiplier is a multi-pixel avalanche photo-diode operated in the limited Geiger mode. The output signal is the analog sum of the binary single pixel signals and thus proportional to the light intensity with the dynamic range being set by the total number of pixels (~ 1000). Due to its small size, high gain and low operating voltage, the device is ideally suited to be mounted directly on scintillator tiles, thus avoiding the mechanical complications and light losses associated with optical fiber routing for a large number of channels.

The prototype granularity has been chosen to meet the following criteria:

a) "Digital" Hadron Calorimetry: Monte Carlo studies have indicated that scintillator cells of size 3x3 cm^2 can be used in the digital or semi-digital modes i.e. with one or few-bit resolution of the readout. Scintillator as the active medium provides the flexibility to trade-off between granularity and dynamic range. With this prototype we will be able to explore the whole range of readout from the purely digital to the fully analog and arrive at a detector optimized for performance and cost.
b) Shower separation: In the PFA paradigm it is particularly important to disentangle the contributions of neutral and charged hadrons efficiently and accurately in a dense environment.

The scintillator HCAL effort is driven by the CALICE collaboration, in particular the institutes from Czech Republic (Prague), Germany (DESY and Hamburg University), Russia (ITEP, JINR, LPI, MEPhI), France (LAL), UK (Imperial, RAL, UCL) and the US (NIU).

2.3 Digital Hadron Calorimeters

2.3.1 Resistive Plate Chambers – Steel

Resistive plate chamber (RPC) are being explored as the active medium of a digitally readout hadron calorimeter. They are based on a simple concept and provide high particle detection efficiency, low noise rates, good position and timing resolution, and low construction cost. R&D efforts showed that the technology based on glass as resistive plates is reliable. Tests of a prototype hadron calorimeter section based on RPCs with digital readout in a particle beam will provide data for the measurement of hadronic showers with unprecedented spatial resolution to validate Monte Carlo modeling of hadronic showers. The proposed prototype test section is 1m x 1m x 1m in size and features 38 layers of 1m x 1m x 20mm steel absorber plates interleaved with 1m x 1m x (6–8)mm active layers (RPC and readout board). The RPCs will be readout digitally with 1x1 cm^2 lateral segmentation. The total number of readout channels is 400,000. The electronic readout system will be built around a front-end ASIC, which is currently being developed jointly by ANL, UTA and Fermilab.

The effort is being borne by groups at Argonne National Laboratory (a member of CALICE), Boston University, University of Chicago, Fermilab, and University of Iowa in U.S. and IHEP, Interphysika, MEPhI, and JINR (CALICE collaboration members) in Russia.

2.3.2 Gas Electron Multipliers – Steel

This technology uses gas electron multiplier (GEMs) [12] foils in an Argon/CO_2 filled volume as the active medium. Charged particles crossing an ionization region release electrons. The electrons drift in an electric field to a multiplication structure composed of two GEM foils. A gain of at least several thousand is achieved. The final electrons are collected on 1cm x 1cm anode pads, which are connected to a charge preamplifier and discriminator with an appropriate threshold to register MIPs. The output is then a "yes" or no as to whether a hit is recorded for a given channel. The readout electronics, both the analog amplification and the digital signal processing, will be handled by an ASIC being jointly developed with the RPC digital hadron calorimeter group at ANL and Fermilab. It is foreseen that the testbeam stack will comprise 38 active layers and the same number of 20 mm steel absorber plates. Each layer will be approximately 1 x 1 m^2 in area, and 8 - 9mm thick. In order to maintain the flatness and geometrical integrity of each active layer, part (~2mm) of the absorber will be used as a "strongback" upon which each layer will be assembled. The anode pads will be an integral part of the PC board forming the readout layer. The 64-channel ASIC's will be mounted at intervals across each PC board. The ASIC's will have a changeable gain: high for the smaller GEM signals, and low for the higher RPC signals. Each active layer will be divided into three sections of approximately 1m x 0.3m dimensions due to the available sizes of GEM foils and PC boards.

The project involves the University of Texas at Arlington (a member of CALICE), the University of Washington, Changwon National University, Korea, and Tsinghua University, China.

2.4 Muon detectors/Tail Catchers

The UC Davis-Fermilab-NIU-Notre Dame-Wayne State (UCD/F/NIU/ND/WS) muon detector R&D group plans to test prototype detectors based on scintillator strips whose cross-sectional dimensions are 1cm X 4.1cm. The strips are arranged in planes where the strips are oriented at 45^o with respect to the edges of the plane's rectangular boundary. The planes come in three sizes: 1m X 0.5m (pre-prototype), 2.5 m X 1.25m (¼ planes) and 5m X 2.5m. U and V planar coordinates for muons are determined by flipping alternate planes about a horizontal or vertical axis. At the present time we plan to test about 8 – 12 planes total, although we will start with fewer. Four ¼ planes will be available the summer of 2005. We plan to use the Fe plates and transporter that is described below for the tail-catcher and muon tracker (TCMT) that is described below.

The light from the scintillator strips is carried to multi-anode photo-multiplier tubes (MAPMTs) via 1.2mm dia. wavelength-shifting fiber, thence to clear fibers. We will test two different MAPMTs, one with 16 - 4mm X 4mm pixels and the other with 64 -2mm X 2mm pixels. The signals will be readout via a system that has been developed at Fermilab for the Minerva experiment. It utilizes a TriP chip, developed for D0, which combines the functionality of the SIFT and SVX chips that is being developed for use in several Fermilab experiments. This board will not only provide 16 channels of amplification and discrimination but it will also be capable of storing the charge in an analog pipeline and subsequently digitizing the data with an 8-bit accuracy after receiving an external trigger. An FPGA is used to latch the time-of-arrival of the discriminated pulses with a resolution of about 2 ns. We anticipate readout for somewhere between 512 and 1024 channels that will typically see several strips.

The goals of the test are to: prove that both the detector planes and the electronics are robust and capable of efficiently delivering muon hits and pulse height amplitude (single particle and calorimetric energy deposits); show that a modest sized system can be stably calibrated; determine the extent to which calorimetry is useful after ~5λ (interaction lengths); determine the energy lost in the superconducting coil that will be located upstream of the muon system; and provide longitudinal and transverse energy profiles of hadronic showers for future design efforts.

The CALICE collaboration is pursuing the construction of a cubic meter sized scintillator-steel device which will serve as both a tail-catcher and muon tracker (TCMT). The TCMT prototype, designed with this dual purpose in mind, will have a fine and coarse section distinguished by the thickness of the steel absorber plates (2cm and 10 cm respectively). The fine section sitting directly behind the hadron calorimeter and having the same longitudinal segmentation as the HCAL, will provide a detailed measurement of the tail end of the hadron showers. This measurement is crucial to the validation of hadronic shower models, since the biggest deviations between models occurs in the tails. The subsequent coarse section will serve as a prototype muon system for any design of a Linear Collider Detector and will facilitate studies of muon tracking and identification within the particle flow reconstruction framework. Additionally, the TCMT will provide valuable data on hadronic shower leakage and punch-through from thin calorimeters and the energy loss in the coil for corrections.

There will be a total of 16 layers (8 fine and 8 coarse) in the TCMT. Extruded scintillator strips, with wavelength shifting fibers mated to SiPM readout, will serve as the active media. The strips will be 1m long, 5cm wide and 5mm thick. These dimensions have been determined based on Monte Carlo studies focused on both calorimetric and muon reconstruction issues. The strips will be oriented perpendicular to each other in successive layers. The TCMT will sit in its own movable cart capable of forward-backward and sideways motion and will use the same electronics as the scintillator-steel hadron calorimeter. The construction of this device is being pursued by CALICE with the engineering contributions from Fermilab.

In addition, the Frascati group is developing a TCMT based on glass RPCs. The RPCs feature a single gas gap and are operated in avalanche mode.

III. Proposed Test Program

There will be three different parts to the testing program. Due to early availability the testing will initiate with electromagnetic calorimeters, followed by standalone tests of hadronic calorimeters including tail catchers, and conclude with combined tests of electromagnetic and hadronic calorimeters. As more prototype calorimeters, both of ECAL and HCAL type, become available, the cycle of standalone followed by combined tests will be repeated. Tests with large, high field magnets are under discussion and will be proposed at a later stage.

We propose to collect of the order of 10^6 events per setting (particle type, energy, angle, and technology), leading to a grand total of the order of 10^8 events for all proposed measurements. The 10^6 events per setting are needed to achieve a statistical precision of better than 1% per bin, taking into account effects of beam spot size, beam momentum spread, contamination from other particles in the beam, and for providing sufficient statistics to subdivide the data sample. The large sample sizes are needed not only to allow tighter beam selection, to minimize systematic uncertainties, but also to analyze the hadron shower data as a function of observables which cannot be pre-configured, like the depth of primary interaction, electromagnetic energy fraction, the number of hadronic interaction vertices, or the longitudinal and lateral containment. Such studies are needed for the optimization of both the single particle energy reconstruction using weighting methods, as well as for particle flow algorithm development. A 1% statistical precision is needed to distinguish between currently available models of hadronic showers which typically differ by 10% for observables, such as shower radius and energy deposition.

3.1 Standalone tests of electromagnetic calorimeters

For the different choices of ECAL technologies the response of the prototypes will be measured in the following configurations:

▪ *Energy Scans with Electron Beams:* Depending on the available energy range of electrons, between 5 and 10 energy points will be measured to establish the linearity of the response and the energy resolution. Also, low energy (<7 GeV) measurements will be used to cross-check with previous measurements performed at DESY.

▪ *Incident Angle Scans:* Measurements with at least three different angles of incidence will be performed. These tests are foreseen using at least two different energy settings.

▪ *Hadronic Shower Development in the ECAL:* Measurements with and without one or two blocks of Tungsten, each ~0.9 λ_I deep will be performed using low-energy (<10 GeV) hadron beams. These tests will provide detailed measurements of hadronic showers, taking advantage of the fine granularity of the ECAL prototypes and the high resolution readout.

The first prototype calorimeter (the CALICE ECAL) will be ready for tests by summer 2005 [18]. Prototypes based on the other technologies will be available by summer 2006 at the earliest, while pre-prototypes might be tested at an earlier date.

3.2 Standalone tests of hadronic calorimeters including tail catchers

Standalone tests of prototypes of the hadronic calorimeter will be performed in the following configurations:

▪ *Energy Scans with Pions and Protons:* Single pion responses, linearity and energy resolution will be measured using a wide range of energies (as low as possible below 3 GeV and up to 66 GeV). The response to protons over the entire momentum range (up to 120 GeV) will be measured as well.

▪ *Incident Angle Scans:* Measurements with at least three different angles of incidence will be performed. The angles will be changed by rotating the table with respect to beam and off-setting the calorimeter structure in depth in order to optimize the lateral containment.. These tests are foreseen using at least two different energy settings.

▪ *Muon Responses:* Measurements with momentum tagged (3 – 20 GeV/c) muons will be performed for muon detection efficiency measurement, testing reconstruction codes and developing calorimeter tracking algorithms.

▪ *Calibration Runs:* For calibration purposes, measurements with defocused muons need to be performed at regular intervals during the testing period.

The first prototype hadronic calorimeter (CALICE Tile-HCAL) and scintillator based tail catcher will be ready for tests by fall of 2005. Prototypes based on the other technologies (RPCs and GEMs) will be available by 2006, possibly preceded by tests of pre-

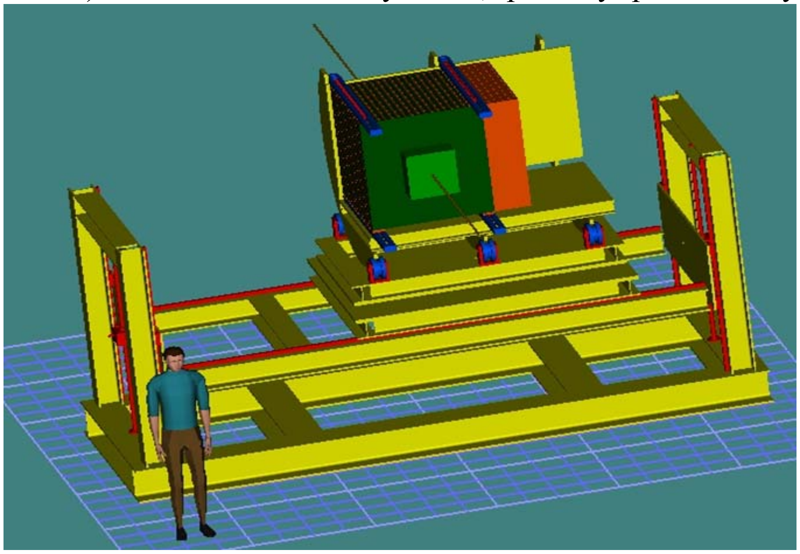

Figure 2 A schematic diagram of CALICE HCAL movable stand. It can hold the entire calorimeter prototype modules, both ECAL and HCAL, and position the setup any direction in all three dimensions.

prototypes. Figure 2 shows a schematic diagram of the CALICE hadronic calorimeter movable stand. The overall width of the stand is 5 m with a 2.8 m movable part to maintain a 1 m horizontal move. The 2.8m movable part width is to accommodate 1.3m detector dimension with a 1 m to slide active layers in and out of the prototype, and the remaining space is taken up by the mechanical support structure to rotate the Tile-HCAL in horizontal position for cosmic ray data taking.

3.3 Combined test of electromagnetic and hadronic calorimeters including tail catchers

The following test program is foreseen for the various combinations of ECAL and HCAL prototypes:

▪ *Electron Energy Scans:* These tests require electrons with the highest achievable energy, to provide a data set with combined ECAL and HCAL information.

▪ *Energy Scans with Pions and Protons:* Single pion responses, linearity and energy resolution will be measured using a wide range of energies (1 – 66 GeV). The response to protons over the entire momentum range (up to 120 GeV) will be measured as well.

▪ *Incident Angle Scans:* Measurements with at least three different angles of incidence will be performed. These tests are foreseen using at least two different energy settings.

▪ *Muon Responses:* Measurements with momentum tagged (3 – 20 GeV/c) muons will be performed for testing reconstruction codes and developing calorimeter tracking algorithms.

▪ *Calibration Runs:* For calibration purposes, measurements with defocused muons need to be performed at regular intervals during the testing period.

The combined tests will start in the winter of 2005 and last until approximately the end of 2008.

3.4 Summary of the proposed test program

The proposed test program and associated time scales is summarized in Table 1

	7 – 12/2005	1 – 6/2006	7 – 12/2006	1 – 6/2007	7 – 12/2007	2008
CALICE ECAL	X					
Other ECALs			X	X		
CALICE HCAL	X	X	X			
Other HCALs			X	X	X	
Combined tests	X	X	X	X	X	X

Table 1. Time scale of the ILC test beam program for various detector systems and technologies.

IV. Personnel and Institutions

The following Tables 2.a and 2.b list all participating institutions and the names of the physicists involved in the test beam program at Fermilab.

Table 2.a Part one of the list of institutions and personnel participating in ILC calorimeter program.

Institutions/Collaborations		Personnel Names
CALICE	Argonne National Laboratory	S.Chekanov, G.Drake, S.Kuhlmann, S.R.Magill, B.Musgrave, J.Repond, D. Underwood, B Wicklund, L Xia
	University of Texas at Arlington	A.Brandt, K.De, V.Kaushik, J.Li, M.Sosebee, A.White, J.Yu
	Northern Illinois University/ NiCADD	G. Blazey , D. Beznosko, D. Chakraborty, A. Dychkant, K. Frances, D. Hedin, D.Kubik, G Lima, R. McIntosh, V. Rykalin, V. Zutshi
	University of Birmingham, UK	C.M.Hawkes, N.K.Watson
	Cavendish Laboratory Cambridge University, UK	C.G.Ainsley, G.Mavromanolakis , M.A.Thomson, D.R.Ward
	Laboratoire de Physique Corpusculaire – Clermont	F.Badaud, G.Bohner, F.Chandez, P.Gay, J. Lecoq, S.Manen, S.Monteil
	Joint Institute for Nuclear Research – Dubna, Russia	V.Astakhov, S.Golovatyuk, I.Golutvin, A.Malakhov, I.Tyapkin, Y.Zanevski, A.Zintchenko , S.Bazylev, N.Gorbunov, S.Slepnev
	DESY – Hamburg, Germany	G.Eigen, E.Garutti, V.Korbel, H. Meyer, R.Poeschl, A.Raspereza, F.Sefkow
	Hamburg University, Germany	M.Groll, R.-D. Heuer, H. Meyer
	Kangnung National University – Kangnung, Korea	G.Kim, D-W. Kim, K.Lee, S.Lee
	Imperial College London, UK	D. Bowerman, P. Dauncey, D.Price, O. Zorba
	University College London, UK	M. Lancaster, M.Postranecky ,M.Warren, M.Wing
	University of Manchester, UK	R.J.Barlow, M. Kelly, N.M.Malden, R. J. Thompson
	University of Minsk, Russia	N.Shumeiko, A.Litomin, P.Starovoitov, V.Rumiantsev, O.Dvornikov, V.Tchekhovsky, A.Solin, A.Tikhonov
	Institute of Theoretical and Experimental Physics – Moscow, Russia	M.Danilov, V.Kochetkov, I.Matchikhilian, V.Morgunov, S.Shuvalov
	Lebedev Physics Institute – Moscow, Russia	V. Andreev, E. Devitsin, V. Kozlov, P. Smirnov, Y. Soloviev, A. Terkulov
	Moscow Engineering and Physics Institute- Moscow, Russia	P.Buzhan, B.Dolgoshein, A.Ilyin, V.Kantserov, V.Kaplin, A.Karakash, E.Popova, S.Smirnov
	Moscow State University Moscow, Russia	P.Ermolov, D.Karmanov, M.Merkin, A.Savin, A.Voronin, V.Volkov
	Laboratoire de l'Accélérateur Linéaire – Orsay, France	B.Bouquet, J.Fleury, G.Martin, F.Richard, Ch. de la Taille, Z.Zhang
	LLR - Ecole Polytechnique – Palaiseau, France	M.Anduze, J.Badier, J-C.Brient, A.Busata, S.Cholet, F.Gastaldi,A.Karar,C. Lo Bianco, P.Mora de Freitas, G.Musat, A.Rouge, J-C. Vanel,H.Videau
	Royal Holloway, University of London	G. Boorman, B. J. Green, M. G. Green, F. Salvatore

Table 2.b Part 2 of the list of the participating institutions and personnel in ILC test beam program.

Institutions/Collaborations		Personnel Names
CALICE	Physique des Interfaces et Couches Minces - Ecole Polytechnique – Palaiseau, France	Y.Bonnassieux, P.Roca
	LPNHE - Université de Paris 6 et 7, France	A. Savoy-Navarro
	Charles University – Prague, Czech	S.Valkar, J.Zacek
	Institute of Physics, Academy of Sciences of the Czech Republic – Prague, Czech	J.Cvach, M.Janata, P. Mikes, L. Tomasek, J. Zalesak, S.Nemecek, I.Polak, J.Popule, M.Tomasek, P.Sicho, V.Vrba, J.Weichert, J. Kubat, L. Masek, B. Pokorny
	Institute of High Energy Physics – Protvino, Russia	V. Ammosov, Yu.Arestov, B.Chuiko, V.Ermolaev,V.Gapienko, A.Gerasimov, Y.Gilitski,V.Koreshev, V.Lishin, V.Medvedev, A.Semak, V.Shelekhov, Yu.Sviridov, E.Usenko, V.Zaets, A.Zakharov
	School of Electric Engineering and Computing Science, Seoul National University	Ilgoo Kim, Taeyun Lee, Jaehong Park, Jinho Sung
	Laboratoire de l'Accélérateur Linéaire – Orsay, France	B.Bouquet, J.Fleury, G.Martin, F.Richard, Ch. de la Taille, Z.Zhang
	Rutherford Appleton Lab., UK	N.K.Watson
University of Chicago		M. Oreglia
University of Oregon		R. Frey, D. Strom
Stanford Linear Accelerator Laboratory		M. Breidenbach
University of Kansas		P.Baringer, A.Bean, D. Besson D.Gallagher, C.Hensel, G.Wilson
Kansas State University		T. Bolton, E. von Toerne, D. Onoprienko
University of Colorado		S. Chen, E. Erdos, U. Nauenberg, M. Nagel, J. Zhang
University of Iowa		Y. Onel, E. Norbeck
University of Washington		T. Zhao
Fermilab		E. Ramberg, R. Yarema, H.E. Fisk
University of Oklahoma		P. Skubic
LC-Cal	INFN LNF, Italy	M. Anelli, S. Bertolucci, M. Cordelli, S. Miscetti
	INFN Padova , Italy	E. Borsato, P. Checchia, C. Fanin, M. Margoni, F. Simsonetto
	INFN Trieste , Italy	B. Nadalut, M. Prest,E. Vallazza
	Universita' dell'Insubria , Como Italy and INFN, Italy	M. Alemi, A. Bulgheroni, M. Caccia
	Institute of Electron Tecnology, Warsaw, Poland	J. Marczewski
Shinshu University, Japan		T. Takeshita
Kobe University, Japan		K. Kawagoe
Kyungpook National University, Korea		K. Cho, D.H. Kim, Y.D. Oh, J.S. Suh
Sungkyunkwan University, Korea		I. Yu
Joint Institute for Nuclear Research, Russia		P. Evtoukhovitch, D. Mzhavia, V. Samoilov, Z.B. Tsamalaidze
Fermi National Accelerator Laboratory		H. E. Fisk, C. Milstene, H. Weerts
Univ. of California at Davis		M. Tripathi
Univ. of Notre Dame		M. Wayne
Wayne State University		P. Karchin
Indiana University		R. V. Kooten

V. Requirements: Beam Composition, Energies and Rates

As discussed in the previous sections, a considerable number of different tests are required over an extended period of time. We will have different requirements at different times, and it is our intention to coordinate these needs with gradual improvements in the test beam as much as possible.

The initial emphasis will be given on electron, pion and muon beams in the range of 3 to 20 GeV/c as discussed in detail below. We will request that the Accelerator Division to attempt delivery of beams down to 1 GeV/c within 6 months of the start of the program.

5.1 Rates

The required rates will be a function of which part of the program is active at a particular time. In general, we need low to moderate instantaneous rates, and high integrated flux, which implies a good duty cycle (i.e. percentage of beam spill time versus total time). This may be accomplished in different ways at different times, e.g. depending on whether NUMI is running or not. Given a 1% duty cycle and a limitation of 100 Hz for data taking, dictated by the data acquisition system and the recovery time of some of the technologies (RPCs), the requested 10^8 events will necessitate 10^8 seconds or about 3 years of data taking. Improvements of the duty cycle to between 3–5% will shorten the data taking periods significantly.   It also is desired to this increase to be distributed through accelerator cycle of 1 minute to compensate for detector latencies and the limited electronics buffer depths.

The current bunching of beam within the 100 kHz resonant extraction is of concern. We require that this bunching be moderated to the extent possible.

5.2 Beam Size

For most of the tests we require a beam spot of the order of 1 cm^2. Some tests will require larger beam spots, e.g. when running with muons for calibration purposes. Here beam spots as large as technically feasible will be useful.

5.3 Requirements by Particle Types

5.3.1 Electrons

We require electron beams in the energy range of 3 GeV/c to 20 GeV/c for the first 6 months and expand to 1 GeV/c to 25 GeV/c after the initial 6 months of running, either with beam momentum spread less than 1% or momentum of each particle in the beam tagged to ±1% in this range, and Čerenkov tagged to high efficiency (better than 99 %), at rates of up to 1 kHz, with no more than a factor of 20 contamination by other particles in the beam.   We will request that attempts to deliver lower energy electrons down to 1GeV/c be made. The material in the beamline must be minimized in order to reduce the radiation which spreads the energy spectrum of the electrons. The momentum tail of the beam must be well understood. It is expected that material reductions will be made with vacuum, helium bags, consideration of beam detector elements, etc. An improvement in the ratio of electrons to other particles may be required as tests progress. Either Čerenkov tagging to achieve a purity of 99.5 % or a modification of the beam operation to achieve this high purity can be used to meet this requirement.

5.3.2 Muons

Muons, momentum selected for some tests, and with a spread of energies for other tests, are required with fluxes no larger than 100 Hz/cm^2 total over the beam, with no more than a factor of 20 contamination by other particles in the beam. In the case that these are momentum selected, they must be Čerenkov tagged. Momentum selected muons in the energy range between 3 and 20 GeV are required.

5.3.3 Pions

For some parts of the program the most stringent requirement is for low rates, a maximum 100 Hz/cm^2, and in some cases, a maximum of 100 Hz total rate, which is limited by the rate the data acquisition can handle. Higher rates will be needed for some tests of the analog HCAL and the tail catcher. At the early stage of the program (summer 2005), energies from 3 to 66 GeV are suitable. The momentum must be tagged to ±1% sigma in the momentum range of 10 – 50 GeV and as precise as possible in other ranges. Čerenkov tagging to differentiate pions from kaons, protons, muons and electrons will be needed. We will require pions with momenta down to 1 GeV/c by spring 2006 or six months into the program. The low energy requirement of pions is driven by the average energies of hadrons in a typical jet in the linear collider environment. Here, the requirements on momentum and Čerenkov tagging are as specified above. It is also required to deliver both charges of pions due to the significant differences observed in simulations between particles and anti-particles.

5.3.4 Protons

Protons and anti-protons in the energy range of 3 to 66 GeV are requested. Again, for some of the program the rates need to be limited to 100 Hz/cm^2, and in some cases to 100 Hz total. The momentum must be tagged to ±1% sigma in the momentum range of 10 – 50 GeV and as precise as possible in other ranges. Protons of momentum up to 120 GeV are also requested. Čerenkov tagging to differentiate protons from kaons and pions/muons will be needed. It is also required to select on the charge of protons due to the significant differences observed in simulations between particles and anti-particles.

VI. Requirements: Floor Space and Infrastructure

6.1 Floor space

In order to allow for scans of the surface of the 1 m^3 prototype hadronic section, a floor space of 5 m laterally and 3 m minimum longitudinally is requested.

6.2 Requirements on crane

A crane with a capacity of 20 tons will be needed to transport the prototype hadronic section into the test beam area. The weight of the prototype section including the scanning table is estimated to be between 10 and 15 tons.

6.3 Gas Needs

Two versions of the hadronic calorimeter, RPCs and GEMs, require a mixture of gases for operation. The gas system will be provided by the detector groups, while the gas is requested to be provided by Fermilab.

6.5 Cooling Needs

A modest amount of cooling water with a temperature close, but above the dew point, is requested.

6.6 Loading Areas

A crane accessible area with a large roll up door for a truck to back in for loading and unloading of prototype is necessary.

VII. Responsibilities by institutions: Non-Fermilab

Table 3 below lists the primary (P) and technical (T) contacts of each detector technology. It also specifies the primary contact for the proposed test beam program as a whole, daily experimental contact for day-to-day operations and the liaison to Fermilab.

The primary and technical contact persons from each technology will be responsible for setting up and operating their own test beam experiment. These contact persons will also be responsible for developing a separate Memorandum of Understanding (MOU) between the test group and Fermilab. This MOU will contain details of the detector that will be installed and the specific amount and type of beam that will be required. Each

Table 3 List of tasks and contact persons for each detector technology. (P) stands for the primary contact and (T) stands for technical contact for the technology. The names without the specifications are to act as both primary and technical contact.

Responsibilities	Beam Test Contact		Institution
Primary Physicist in Charge of Beam tests	J. C. Brient, J Yu		Ecole Polytechnique, University of Texas at Arlington
Daily Experimental Contact	J Repond, V. Zutshi		ANL, NIU/NICADD
Fermilab Liaison	E Ramberg		Fermilab
EM Calorimeter			
Si-Tungsten	CALICE	J. C. Brient	LLR Ecole Polytechnique
	US	D. Strom (P), M Breidenbach (T)	University of Oregon, SLAC
Scintillator-Tungsten	T Takeshita		Shinshu
Scintillator-Si-Tungsten	G. Wilson		University of Kansas
Scintillator-Si-Lead	P. Checchia		INFN Padova
Scintillator-Tungsten	U. Nauenberg (P), E. Erdos(T)		University of Colorado
Hadronic Calorimeter			
Scintillator-Steel (CALICE)	F Sefkow, M Danilov		DESY, ITEP
RPC-Steel (CALICE)	Russian	V Ammosov	IHEP
	US	J. Repond (P) L. Xia (T)	ANL
GEM-Steel (CALICE)	A. White (P), J. Li (T)		University of Texas at Arlington
Muon –detector/Tail-catcher			
Scintillator-Steel (CALICE)	V. Zutshi, F. Sefkow		NIU/NICADD, DESY
Scintillator-Steel Muon Detector	H. E. Fisk		FNAL, UCD, NIU, IU, Univ. of Notre Dame
RPC-Steel	Marcello Piccolo		Frascati

MOU will spell out the specific responsibilities incumbent on both the test groups and Fermilab.

The primary contacts will also be responsible for the following:

- After approval of the MOU and installation of the apparatus, they will ensure that a safety review is completed of the apparatus and that an Operational Readiness Clearance document is signed.
- They will ensure that all experimenters in the group are radiation safety and controlled access trained. Training is available from the ES&H Division.
- All experimenters are familiar with the Procedures for Experimenters (PFX).
- They will ensure that at least one person is present at the test beam facility whenever beam is delivered and that this person is familiar with the experiment's hazards.
- They will ensure that all regulations concerning radioactive sources are followed.
- The Fermilab Policy on Computing is followed by all experimenters.
- They will ensure that their installation is coordinated with other groups using the test beam facility.
- They will ensure that shipping of the detector to and from the test beam facility is the responsibility of the experimenters.
- They will report to the All Experimenter's Meeting at Fermilab on results obtained from the work done in the test beam.

VIII. Responsibilities by Institutions: Fermilab

The following set of responsibilities is divided by Fermilab Divisions. Although the responsibilities in this document are for planning purposes only, the following requests will likely be referred by or made into MOU's originating in this program.

8.1 Accelerator Division

8.1.1 Improve the SwitchYard 120 duty cycle beyond 1% (e.g. by increasing the spill length) to facilitate acquiring the data in a short and manageable time frame. A level of 3 – 5 % would suffice. It is desired, however, that this increase be distributed through the accelerator cycle to compensate for detector latencies and the limited electronic buffer depths.

8.1.2 Best efforts, with available resources, at delivering the varieties of beams discussed in section 5. In particular, an emphasis on supporting:

- Commissioning and delivery of charge selected beam of pions at low momenta, starting at 3 GeV/c for the first 6 months and down to 1 GeV/c after the initial 6 months of running.
- Commissioning of an electron beam over as extensive a momentum range as possible, starting at 3 GeV/c to 20 GeV/c for the first 6 months and expand to 1 GeV/c and 25 GeV/c after the initial 6 months of running.

8.1.3 Assist with modeling of beam-line optics, beam production, beam transport, momentum spread, material for multiple scattering, secondary particle production, and beam purities.

8.1.4 Provide beam diagnostics, beam profile, intensity, momentum bite, etc, information to the experiment via existing Accelerator network and monitoring system and technical assistance in merging them with experimental data.

8.2 Computing Division

8.2.1 Technical assistance in data acquisition, in particular with merging trigger information with calorimeter data, is needed.

8.2.2 Network: Establish and maintain wired and wireless internet connections: 16 wired connections in the MTBF office area, 10 in the counting house, and 10 in the experimental area at 100 Mbits/sec or better. Wireless access points should be reachable from office, counting house and the experimental hall. Two dedicated 1Gbit/sec connections between DAQ system in the counting house and the data recorder computer in the control room are needed; one for primary recording and the other as the backup. The building network bandwidth should be 100 Mbit/sec or better for data transfer to off-site locations.

8.2.3 Data Storage: Data will be stored on tapes (technology to be determined in later dates) and RAID array disks, recorded by a DAQ computer in the office area. Technical support to maintain the recording system and data copy and archival services are needed. We request Fermilab to provide tapes. The anticipated data size for 10^8 events is on the order of 20 Tera-Bytes.

8.2.4 Technical assistance with GEANT4 for construction and running of simulation programs is needed.

8.2.5 Repair services of Fermilab provided electronics and trigger logic, as well as computing equipment.

8.3 Particle physics division

8.3.1 Assistance with minimization of material for electron beam-line, including development of a helium filled beam transport line in the experimental hall.

8.3.2 Maintenance, commissioning and alignment of test-beam detectors, such as scintillation counters, Čerenkov counters, and Silicon tracking detectors.

8.3.3 Provision of beam-line related event data acquisition and assistance with integration of the dedicated detector data acquisition. Assistance with integration of special triggers.

8.3.4 Maintenance of gas supply system

8.3.5 Office space for up to ten people at a maximum.

8.3.6 Provision of rigging and crane operations for all detector installations and removals.

8.3.8 Survey of the positions of beam line component for momentum measurement.

IX. Access to data

All data collected at the test beam will be accessible to all members of a given test beam effort via network transfer from the storage disk array and through tape copies.

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