Linear Collider Calorimeter Testbeam Study Group Report

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This report summarizes the goals for and available facilities for LC detector testbeam activities for calorimeter working group. It provides requirements for testbeam facilities and detector sizes to meet the goals for calorimeter detector studies. This report also presents availabilities for testbeam at a few laboratories.

1 Introduction

In order to meet the physics requirements at the Linear Collider, jet energy resolutions need to be at the level of $30\%/\sqrt{E}$ that is capable of distinguishing W and Z bosons from jet invariant mass distributions. Currently the best-known method to accomplish this level of energy resolution is using the energy flow algorithm [1] (EFA), assisted by a good momentum resolution of the tracking system. In addition, due to high calorimeter granularity required for good energy-track association and jet angular resolution will likely drive the cost of the readout high for conventional analog calorimeter technology. To keep the cost at a manageable level, retaining position resolution high, various new techniques have been proposed and are under research and development stage. Given the new technologies and the necessity for algorithm developments, it is necessary to start developing testbeam plans with a goal of first stage operation in year 2005 or 2006. The CALICE collaboration [2] has already started considering a testbeam for a few calorimeter options in 2004, however most the detector development activities in North America are not mature enough to participate in CALICE testbeam in time, with the possible exception of the RPC group at Argonne Laboratory. In order to provide testbeam opportunities for most the North America based groups, we report in this document the estimated sizes of calorimeters to contain sufficient energy of the incident particles, both in longitudinal and transverse dimensions. This document also contains information on availabilities of testbeam facilities at various laboratories for these activities.

2 Goals for Testbeam

One of the primary goals of LC testbeam activity is to test the various hardware technologies for their overall feasibilities as calorimeter detectors and to understand the properties and performances of new technologies such as linearity, uniformanity, aging characteristics, signal responses and energy resolutions.

The second goal of the testbeam is for algorithm studies and improvements. In EFA, the hadronic calorimeter (HCAL) is primarily used to measure the neutral hadron component ($\sim 10-15\%$) of the jet energy. It also must have sufficient transverse granularity and longitudinal segmentation to distinguish energy deposits from charged and neutral hadrons, associating the energy clusters with corresponding charged particle tracks in the tracking system to effectively and efficiently remove the charged particle energy from further analysis. Since most of the development of EFA must be carried out with simulation, using many elements of the complete detector (tracker, ECAL, HCAL, etc.), a testbeam program for the calorimeters must be devised to verify that the simulation output realistically models all particle showers. The basic idea is that once a particular detector prototype is modelled realistically in the simulation at the particle shower level, then extrapolation to the full EFA and ultimate energy resolution measurements can be trusted.

The last goal of the testbeam activity is to validate and improve detector simulations. A shower library can be constructed from the collection of a variety of particles in a wide kinematic range for more realistic simulation of jet final states that cannot be effectively produced in a testbeam environment.

To accomplish the above goals, the testbeam setup must be able to provide the following:

- Sufficient single particle shower data at a wide range of energies for EFA development to construct shower libraries at an adequate level.
- Data for digital calorimeter tracking algorithms which provide an understanding of MIP

signals and readout thresholds.

- Detector geometry as realistic as possible so that extrapolation to the full detector in simulation can be done.
- Ability to rotate entire detector for oblique incidence for incident angle dependencies.
- Possible exploration of magnetic field effects (at least for ECAL).
- Ability to monitor transverse and longitudinal shower leakage.
- Flexibility to be able to test various hardware and readout technologies :
  - Signal response and energy resolution
  - Absorber type and thickness
  - Active media types including digital and analog readout schemes
  - Different sampling fractions
  - Readout flexibility (e.g., combining several layers in readout, larger effective pad area)
  - Transverse and longitudinal granularity
  - Aging studies?

3 Requirements for Testbeam Facility

The testbeam facility must be able to provide infrastructure as well as a sufficient variety of particles with a wide range of energies. The time scale for testbeam is expected to be in 2005 or 2006, and could last for several years to test all options and configurations. For EFA tests, a selection of beam particles that matches the particle makeup and energy range in hadronic decays of Z particles is desired. Figure 1 shows the energy range of various particles in hadronic Z decays from Monte Carlo. Photons (or electrons/positrons) with known energies of 500 MeV to 20 GeV or so are needed, with particular emphasis on the lower energy end of this range. Neutral particles - K^0_L, n and $\overline{\mathrm{n}}$, all have similar distributions with a mean of about 10 GeV and a range from 500 MeV to a few tens of GeV. If neutrals with known energies are not obtainable, it may be possible to use protons (for neutrons) and charged pions (for the Kaons) in the same energy range. In any case, charged pions are also needed at a somewhat lower mean energy but with the same range as neutrals. It will be important to obtain both analog energy measurements of these particles as well as complete shower reconstructions at the cell hit level for digital comparisons.

In addition, muons in the range of $1 - 100$ GeV are needed for studies of calorimeter tracking algorithm development and for understanding MiP signals for digital hadron calorimeter threshold and the corresponding efficiency studies.

In summary, we require:

- An independent hall that can be interlocked for hadron runs and has sufficiently large space to assemble and manipulate calorimeter modules. The anticipated maximum sizes of a large hadronic calorimeter module is, though it depends on other factors discussed in section 4, is no larger than $1.3 \times 1.3 \times 1.0$ m^3. This would probably require on the order of 50 m^2 floor space in $5m \times 10m$ configuration.
- A crane that can handle sufficiently large weights for absorber plate assembly and manipulation of the assembled modules. ($10 \sim 15$ tons)

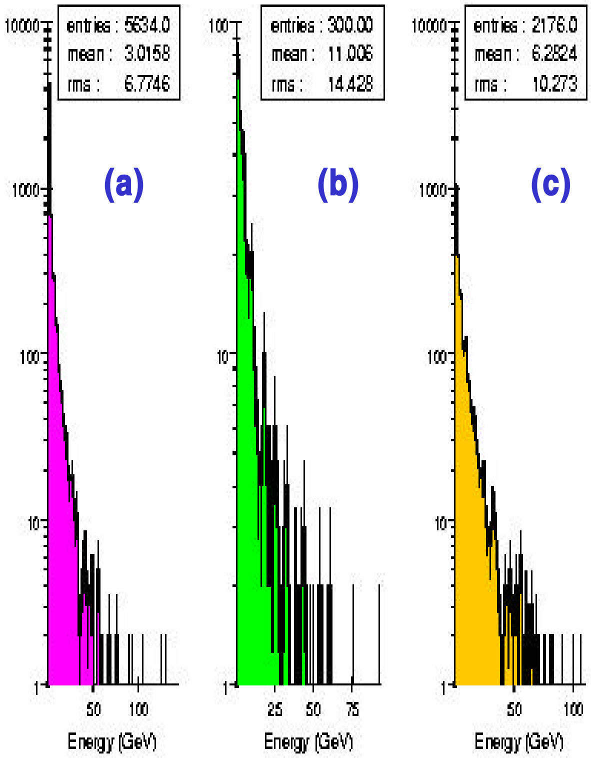

Figure 1: Energy spectra of (a) photons, (b) K_L^0 mesons and (c) charged pions resulting from $e^+ + e^- \to ZZ \to jjjj$ events at $\sqrt{s} = 500$ GeV.

- Chilled water supply for cooling.
- Clean, dry air supply.
- In-house, building gas for common gas, such as ArCO2.
- Beamline capable of providing the following particle types and energies:
  - Electrons and/or positrons
  - Photons
  - Protons
  - Pions and other charged hadrons
  - Neutral hadron beam if possible.
  - Energies of particles: 5 – 150 GeV (If possible as low energies as possible, down to $1 \sim 2$ GeV.) The desired momentum bite of the beam is 1% up to 50 GeV and can be up to 5% at a higher momentum.
  - Muon beam at energies 1 – 100 GeV or so $\to$ This is for calorimeter tracking algorithm studies.
- Beamline equipped with the following:
  - Beam position monitoring devices with position resolution better than 100 μ m.
  - Beam spectrometer for momentum measurements to about 5% precision.

- Beam particle ID and selection devices, such as Cerenkov counter.
- A rotating dipoles that can allow positioning beam as desired.

- Trigger rate no larger than 100Hz.
- Possibly a large magnetic field to immerse calorimeter test setup.

4 Testbeam Detector Requirements

The prototype detector(s) for the testbeam must be flexible enough to allow various active media and absorber types and thicknesses to be tested while also containing a full hadronic shower. Electromagnetic showers are easily contained in a detector of size of several Moliere radii in the transverse direction and of order 30 radiation lengths longitudinally. Figure 2 shows the longitudinal energy deposition and transverse size of a 3 GeV electron in the SD calorimeter. The transverse size corresponds to a maximum layer area of $\sim 11 \times 11$ cm^2. The energy leakage

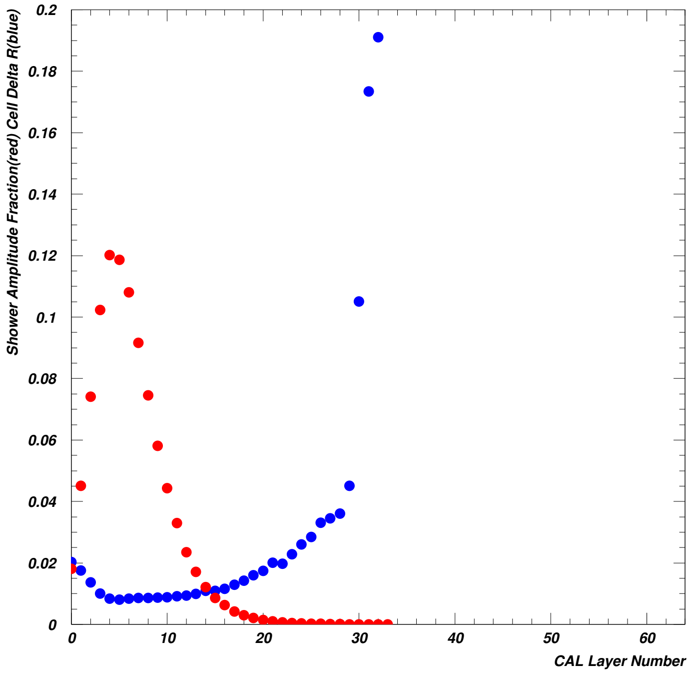

Figure 2: Longitudinal energy deposition (red circles) of a 3 GeV electron in the SD calorimeter, and the average shower radius per layer (blue circles).

out of the ECAL into the HCAL is negligible at a few % level.

Hadron showers are less well defined, and much larger in extent than electromagnetic showers. A charged pion, for example, appears as a MIP until it interacts in the absorber, producing a shower which is very difficult to describe analytically. The MIP part of the pion is contained in a cell or two, but the shower extends throughout the detector. Typically, hadron showers can be contained in a dense sandwich calorimeter of size $\sim 1 \times 1$ m^2 in transverse direction and several interaction lengths longitudinally. Figure 3 shows the fraction of energy

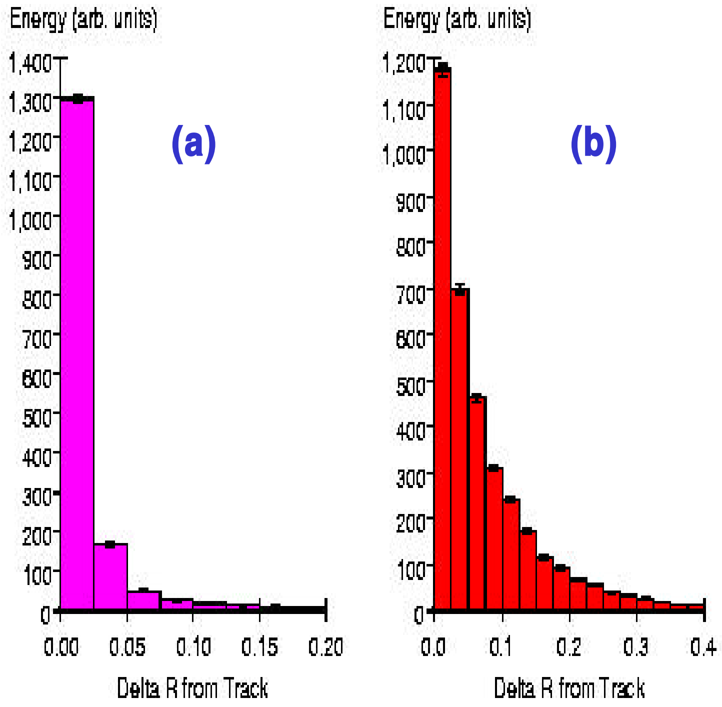

Figure 3: Fractional energy deposit within radii from the extrapolated track position for a 10 GeV π^- in SD ECAL and HCAL.

deposited within various radii in the SD ECAL and HCAL (for a 10 GeV π^-). On average, 94% of the pion energy deposited in the ECAL is contained within a 20×20 cm^2 area per layer. A study of transverse shower progression for each ECAL layer can be performed to provide a possibility of reducing the total number of readout channels by tapering the front part of the detector. In addition, about 20% of 10 GeV charged pions appear as MIPs throughout the entire ECAL volume, thereby being 100% contained within a 20×20 cm^2 transverse layer size.

In the SD HCAL, however, to obtain an average of 90% energy containment requires a transverse size per layer of $\sim 1.3 \times 1.3$ m^2. In an 80×80 cm^2 HCAL combined with a 20×20 cm^2 ECAL, 95% pion energy containment is seen for $\sim$ 35% of the charged pions (10 GeV π^-), while 90% containment is seen for $\sim$66% of the pions. It will be important to tag leakage of shower particles out of both the ECAL and HCAL in all directions, unless large scale readout for over 400k channel is possible.

In digital readout mode, each MIP deposit is counted, and therefore it is important for tuning of the Monte Carlo program. Figure 4 shows the number of hit cells as a function of radius in the SD HCAL. For the 10 GeV π^-, 90% of the hit cells are contained within a 90×90 cm^2 area. For detailed comparison to Monte Carlo, it will even be more important to tag fully contained particle showers when counting hits. However, one must be careful when the detector sizes are minimized to save cost for readout, utilizing veto counters to reject shower leakage outside the detector volume. This will likely bias hadronic shower samples to narrow, well behaved showers.

In order to maximally utilize the testbeam opportunities, the detectors must be prepared to sufficiently mimic the full detector geometry for a full containment of electromagnetic and hadronic showers. In addition to the physical sizes of EM and Hadronic calorimeters for full

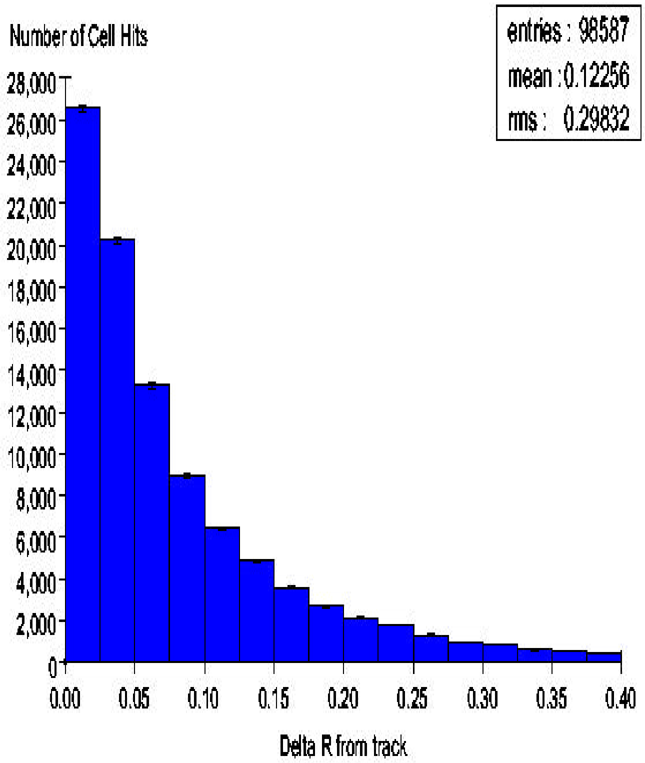

Figure 4: Number of hit cells as a function of radius from the extrapolated track position for a 10 GeV π^- in the SD HCAL.

shower containments, one must also take into consideration:

- For effective EFA development and charged particle association, a tracking detector with good position resolution might be needed. At what level of tracking do we need, if we need one at all? We would expect the position resolution better than 100μ m.
- Is a magnetic field needed to mimic central magnetic field? If so, how do we get the direction of the field and the beam correctly to mimic collider detector situation?
- Absorber plates that have adjustable gaps and adjustable absorber thickness are needed to provide adequate data for sampling weight dependence studies.
- The detector absorber gaps must be flexible so that various sensitive gap technologies can be tested.
- The setup must be capable of varying the incident angle of the particles.
- The DAQ should be able to support sufficient number of readout channels.

Given the need for fine granularity in these calorimeters, the total number of readout channels will likely to become a serious issues. For example, a 30×30 cm^2 ECAL with 30 longitudinal layers at a granularity of 0.5×0.5 cm^2 will require a total of 90,000 readout channels. An HCAL with 1.0×1.0 m^2 and 40 longitudinal readout layers at a granularity of 1.0×1.0 cm^2 will require 400,000 readout channels. Therefore, unless a smarter readout scheme is used, the total number of readout channel will become approximately 7.5×10^5. Various methods of reducing number of DAQ readout channels have been suggested at the Arlington Linear Collider workshop in January, 2003, including a readout scheme for Si/W ECAL and increasing the sizes of HCAL readout cells. For instance, signal from an entire wafer of Si/W ECAL gets digitized locally and is sent onto a serial line. Since each wafer is expected to contain about 1000 detector elements, the total number of readout chennals necessary for Si/W ECAL readout would be on the order of 90 or so which is extremely manageable [3]. This scheme will, however, probably require a custom made DAQ system to receive the signal.

5 Testbeam Simulation Studies

In addition to detector and test beam requirements, it is also necessary to develop a complete (GEANT4) simulation package that includes the testbeam geometry for detailed studies both for preparation for the testbeam program and for analysis of the testbeam data. Some issues that need studies are:

- Can one mimic neutrons with protons?
- Are the foreseen detector sizes both in longitudinal and transverse directions sufficient? What are the biases due to detector sizes?
- What are the optimal readout cell sizes to minmize the cost on number of radout channels without compromising adequate level of granularity for EFA studies?
- What is the impact of inhomogeneity in the calorimeters when mixture of technologies are in use for data taking?
- What are the characteristics of jets from typical events in 500 GeV to 1.5 TeV linear colliders. In particular, what are the energy distributions of hadrons in the jets, for these energies.
- Do we need to fully contain the shower energies? Is it possible to perform all the necessary studies without full shower containment?

After data is taken, we will want to analyze the events in the same way and with much of the same software that we presently use in our simulation studies. This means that the testbeam simulation package should fit into our present LCD software suites - presently JAS and LCDROOT. In this way, we can compare exactly the behavior of particle showers in the testbeam geometry and in the full detector.

6 Software for Testbeam

In order for smooth operation of the testbeam activities including calibration and monitoring, data taking, and rapid analyses for fast feedback to both testbeam and LC detector simulation programs, an adequate level of software needs to be developed. The necessary software categories are:

- A detailed GEANT4 simulation package including the testbeam detector geometry compatible with JAS (and ROOT) analysis formats.
- A data acquisition package including online monitoring capability.

- Various slow control monitoring of detector voltages, currents, environmental parameters, gas, etc.
- Calibration tools and databases.
- Many data analysis tools including calorimeter cell reconstruction, track reconstruction if available, particle ID if necessary, as well as algorithms for cell clustering, energy conversion, and sampling weights. Some of these may be adaptations of existing and future algorithms, so must be flexible enough to deal with the testbeam geometry.
- Since it is anticipated that the full testbeam program extends for several years, a reliable data and code management scheme should be implemented.

Our plan is to build on the excellent LCD software capability currently in use in the Calorimeter Detector subgroup for simulation studies.

7 Remaining Questions

While we have addressed many issues related to testbeam for calorimeter detector development, there are many questions that need to be answered at this point. Some of the remaining questions are:

- When do we start the testbeam? We believe most the technologies that are under research and development stage can be at a sufficient level to participate in a testbeam experiment late 2005 or early 2006. North American calorimeter groups that expressed interest in participating in testbeam are:
  - Si/W ECAL group (R. Frey)
  - Crystal EMC group (U. Mallik)
  - W/Scintillator tile ECAL group (U. Nauenberg)
  - Cerenkov compenstated calorimetry (Y. Onel)
  - Scintillator tile digital hadron calorimeter group (D. Chakraborty)
  - RPC hadron calorimeter group (J. Repond)
  - GEM digital hadron calorimeter group (A. White & J. Yu)
- How many different phases? Two? Three? Given the anticipation that the speed of which the different technologies are being developed and, in addition, we might want to keep the possibility to iterate the given technology after improvement, it is likely that the testbeam runs will need to be multi-phased.
- What is the timing for LC detector preparation?
- How long do we need to run? While each group anticipate a few months level of data taking, overall duration of stay necessary for calorimeter seems to be a long term over a few years, given the anticipation of various speed in which technologies are developed.
- What are the testbeam programs to satisfy all the goals?
- What is needed for DAQ system?

- Where do we run? Do we need to run in many places? Among the facilities, Fermilab's MTBF seems to provide most the particle types the calorimeter groups want in the widest energy ranges. The availability of the facility also seems to be timely for our expectation.
- What are other detector technologies and geometries to be tested that might impact calorimeter measurements and might be necessary for the specific studies for calorimeter? For an extreme example, do we need low angle detectors for electrons from gamma-gamma scattering?

Though, these questions are only the tip of an iceberg, these should provide a good starting point for positioning and preparing ourselves well for a timely testbeam experiment.

8 Possible Testbeam Programs

Several testbeam programs will be needed to meet the goals discussed in section 2. Some of these are:

8.1 ECAL Only Runs

Electromagnetic showers can be studied with electrons, positrons, and photons in separate ECAL-only testbeam runs. Since photons are an important part of any jet reconstruction at a future LC, it will be important to study these particles in testbeams. A good source of low energy photons is that from bremsstrahlung of electrons or positrons in a thin target. A tagging calorimeter with adjustable angular aperture is needed for these measurements. The shower shape of photons compared to electrons and positrons can be determined in these runs and used to tune the full detector simulation. The ECAL will need to be surrounded with scintillator paddles used to veto and/or record leakage.

It may also be possible to place the ECAL prototype in a magnetic field to observe any effects on the shower signals. The results can be compared to the simulation to improve the full detector response for EFA studies.

8.2 HCAL Only Runs

Whether analog or digital, the HCAL response to hadrons must be studied in detail. Runs with pions and protons are needed to determine shower shapes, sampling fractions of the detector, e/h ratio and linearity of the calorimeter, etc. The simplest test of the HCAL is to compare its direct response to pions and protons with that expected from the simulation without any complications of additional detectors or geometries. This program should also be flexible with regard to changes in absorber types and thicknesses and active media.

8.3 ECAL and HCAL Runs

Finally, the combination of ECAL - gap/structure - HCAL is very important for the study of EFAs. To compare directly with the full detector simulation, a prototype setup of the ECAL, any required structure, gaps, etc. between the ECAL and HCAL, and then the HCAL itself must be implemented in as realistic a way as is possible. The ultimate tuning of the full detector simulation will need to be done, e.g., with pion showers that start in the ECAL and extend throughout the HCAL. This test program, involving the full complement of particle types and energies is the most crucial part of the calorimeter testbeam effort.

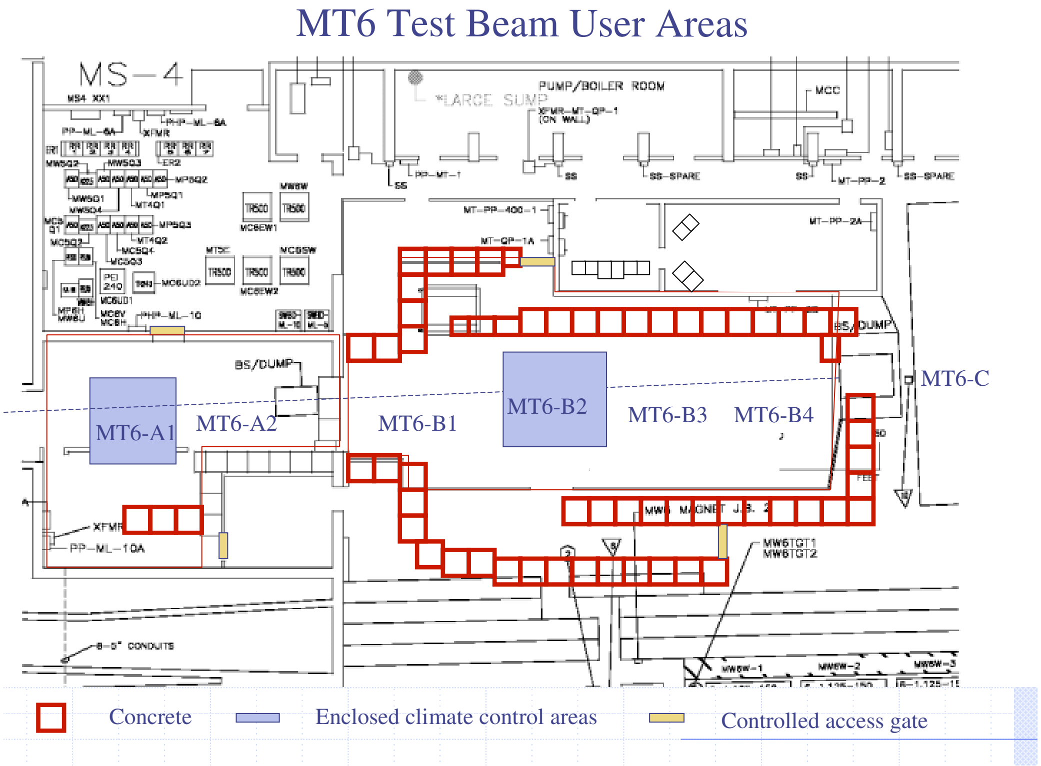

Figure 5: A schematic diagram of the MTBF user area. It shows four possible areas for detector setups and two control rooms.

9 Available Testbeam Facilities

9.1 Fermilab

Fermilab's Main Injector (MI) provides an excellentopportunity for simultaneous running of collider and other fixed target programs. Taking advantage of the feature, Fermilab is constructing a dedicated testbeam facility, the Meson TestBeam Facility (MTBF), on the MTest beamline. MTBF uses 120 GeV protons from MI as the primary beam. Figure 5 shows a schematic diagram of the user area of MTBF. It shows two large size rooms with a 20 ton building crane for construction of test setup that sweeps most the large setup area of the facility. It also provides two control rooms for DAQ and online monitoring.

Table 1: Particle rates in kHz, assuming 10^{10}ppp for one second pulse at the MI flatop.

Particles	$p = 100$GeV/c	$p = 60$GeV/c	$p = 30$GeV/c	$p = 15$GeV/c
π^+	0.56	13.80	13.84	5.42
π^-	0.08	3.85	6.03	3.79
K^+	0.10	0.77	0.25	0.02
K^-	0.00	0.07	0.09	0.01
p^+	85.94	55.62	9.94	1.97
p^-	0.00	0.02	0.18	0.26

The facility provides converters for an electron beam, a Cerenkov counter for particle ID, wire chambers for beam position measurement, and a silicon vertex detector immediately upstream of the testbeam area for accurate positioning of the beam before entering the test setup. MTBF provides a beam of moderate energy particles (5 – 120 GeV) at an intensity of ≤ 1 MHz. Table 1 shows the predicted particle flux assuming a 10^{10} ppp for a one second pulse at the MI flat top. The first beam at MTBF is expected in early 2003.

A longer term (2 $\sim$ 3 years) stay at MTBF will depend strongly on in what condition the testbeam needs to run while staying at the facility. If the activity requires a continuous dedicated beam, it would be less feasible than running parasitically or sharing the space with other activities. This of course will also heavily depend on how much the facility is subscribed at the time of anticipated testbeam experiment.

Currently three MOU's (T926:RICE, T927:BTeV Pixel and T930:BTeV Straw) have been approved for running, and two (T931:BTeV Muon and T932:Diamond Detector) are under consideration. Erik Ramberg is in charge of the project. While the priority of this program is lowest at the laboratory, it does seem to have sufficient management support. According to Ramberg, the lab directorate is concerned about the cost of the test beam program, but has indicated that they will support it if there is a true need for it, and if the users share beam time in a fashion to minimize any wasted beam. The Technical Division, Particle Physics Division and Computing Division have to determine how much they want to support any given project, including those in the test beam. It seems that the divisions would have to be approached individually to discuss the support issue. After an initial verbal agreement with the lab, it would have to be spelled out specifically in the MOU that each test beam installation needs to be written up and be signed by the division heads.

9.2 BNL

BNL has a long history of providing HEP community with test beam for detector research and development. A schematic of the AGS facility is shown in Fig. 6. The testbeam facility is located in area B. A complete description of the facility can be found at `http://server.c-ad.bnl.gov/esfd/` under Experimental Information → Beam Experiments → B2.

Features of the B2 beam line include: Cerenkov counters for limited particle identification, scintillator hodoscopes for triggering and a controllable table with a 2.5 ton capacity. The beamline can be tuned for momenta from 300 MeV/c to 9 GeV/c. The nominal momentum bite is 5% FWHM. This can likely be reduced with a corresponding loss of flux if necessary. The maximum flux is limited by safety constraints to 2×10^5 particles/sec. From Fig. 7, it can be seen that the high proton and pion fluxes are available up to 9 GeV. The electron rate falls off sharply above 1 GeV but remains significant up to 3 GeV. It should be noted that Fig. 7 corresponds to operation with a Pb converter than can be positioned in the beamline to increase the electron flux.

It would appear that the BNL test beam facility is well suited for linear collider calorimeter research and development. The main issue is funding for operation of the facility. Currently, the facility is not supported within the AGS budget and only operates under contractual agreement with users. Marginal operating costs are highly dependent on future operating scenarios. In the event that the RSVP [7] proposal receives final Congressional approval, it is highly probable the B2 test beam will be available for modest outlay. However, it is unlikely that DOE/NSF would directly fund BNL to operate the B2 test beam. It most scenarios, it would be up to the research consortia to request explicit funding for test beam and sub-contract to BNL.

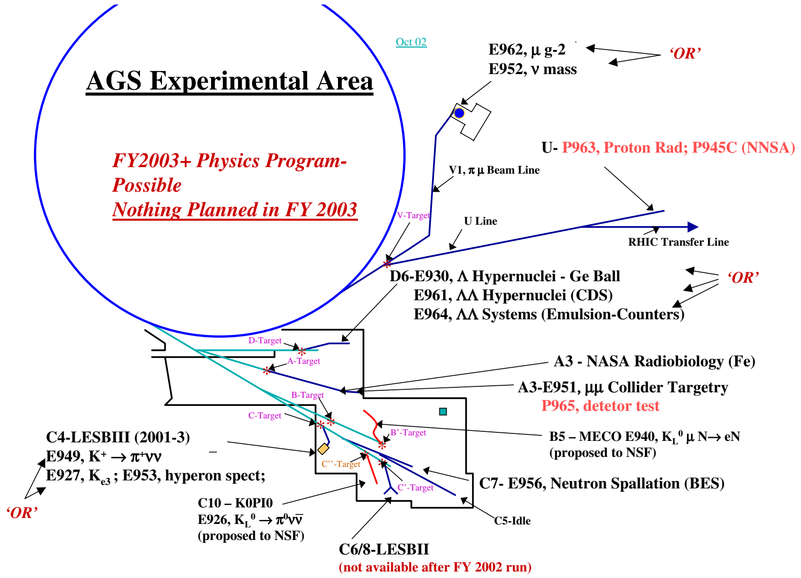

Figure 6: A schematic diagram of BNL AGS facility.

9.3 SLAC

A possibility for testbeam at SLAC exists in the "End Station A" beamline which is operated as a secondary line at a repetition rate of 10 Hz, parasitic on PEP operation for BaBar. The following beams are available :

- Positrons in the energy range of 1 GeV to 45 GeV max, 25 GeV if parasitic on PEP/BaBar). The typical momentum width is $\pm 0.5\%$, controlled by beam collimators. The flux would normally be set at 1 per pulse or lower.

- Gammas from positron bremsstrahlung through a target. The rate can be adjusted to 1 gamma per pulse. A tagging system must be provided by the experimenter. Higher energies can be obtained with diamond crystal radiators (produces coherent bremsstrahlung with peaks dependent on crystal orientation).

- Pions and protons produced in a beryllium target. The flux is 1 particle per pulse. The positron energy is set at 13 GeV to optimize proton yield, but most of the flux is positrons and pions. Protons have been produced at a rate of 4.4×10^{-3} protons per pulse.

9.4 Frascati Test Beam Facility

Marcello Picollo gave a talk on Frascati test beam facility at the Arlington Linear Collider workshop in Janyauary, 2003. The facility is available for experiments presently and is allocating time for testbeam both in primary and parastic modes. The beam has linac time structure. The number of particles can be tuned between $1 - 10^4$. The facility can provide electrons with energy ranging 50 - 750 MeV at a repitition rate of up to 50Hz. The pulse duration is 10 ns, and the maximum current per pulse is 500mA. Up to 10^3 electrons per second are allowed.

9.5 IHEP–Protvino & Other Laboratories

Proposal presented at Prague to use the 70 GeV protons to produce beams of hadrons, electrons, and muons in energy range up to $\sim$ 50 GeV. The repetition rate is 0.1 Hz with a spill time of

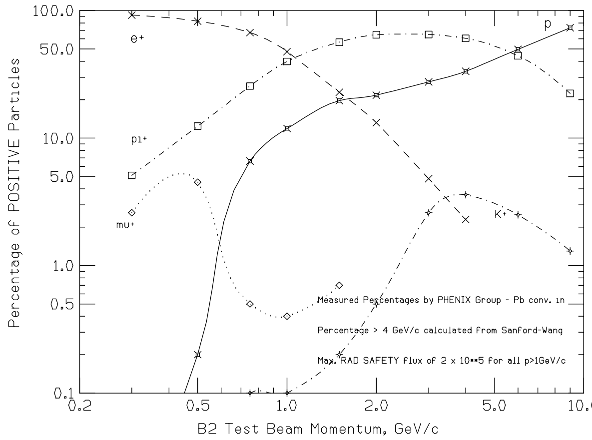

Figure 7: Particle flux distributions of B2 testbeam facility.

1.8 sec. Electron beam in the range 1– 45 GeV is produced with an internal target. It probably needs a beam tagging spectrometer for momentum measurement. Primary hadron beams in the range 33 – 45 GeV. Low energy hadrons can be available using electron beam on target. Cerenkov counter for electrons, hadrons and muon ID exists. The facility is available in 2004 and beyond.

Additional facilities include Jefferson laboratory and KEK, Japan. We do not have sufficient information on the availability of Jefferson laboratory facility other than the fact that there will not be any beam in 2007 – 2007 due to energy upgrade. KEK, Japan, also is not going to be available for testbeam in 2004 – 2007 time period.

9.6 Summary of Facilities

Based the information collected, Table 2 summarizes the available particle types, their momentum ranges, the availability of the facility and the contact persons.

10 Conclusions

In conclusion, in order to meet the time scale for anticipated linear collider construction, testbeam efforts for detector and algorithm developments must be conducted within the next few years. This document reports the studies we have conducted during the past few months to start a more coordinated effort for testbeam for calorimeter working group. We have summarized goals, requirements for detector and testbeam facility, and compiled questions that need to be addressed soon for a timely start of a testbeam experiment. This document represents a work in progress. We certainly hope that most the questions are addressed by the summer 2003 workshop at Cornell.

11 BIBLIOGRAPHY

1. ALEPH Collaboration, Nucl. Inst. Meth. **A360**, 481 (1995).

Table 2: Compilation of test beam facilities, particle types, their momentum ranges, availabilities, and the contact persons.

Facility	Particle Types	Momentum Ranges	Availability	Contact
FNAL-MTBF	$\pi^{\pm}$, p, K, μ, e	5 – 120 GeV	From early 2003	E. Ramberg
SLAC-ESA	γ, e^{+}, hadrons	$E_e < 45$ GeV $E_{had} < 13$ GeV	Current	
BNL-AGSB2	$\pi^{\pm}$, p, K, μ, e	< 10 GeV	Concurrently w/ RSVP Experiment	D. Lowenstein
Jefferson Lab			No in 2007 – 8	
CERN			Bad after 2004	
IHEP-Protvino	μ, e^{+}, hadrons	$E_e < 45$ GeV $E_{had} < 33 - 45$ GeV	From 2004	
Frascati	e	$E_e < 750$ MeV	Current	
DESY	$e^{\pm}$	1 – 3 GeV		
KEK			No in 2004 – 5	

2. CALICE Collaboration, `http://www.calice.cern.ch`.
3. R. Frey, private communication.
4. Fermilab Meson Test Beam Facility, `http://www-ppd.fnal.gov/MTBF-w/`.
5. T. Kobilarcik, "Main Injector Beam to the New Muon and Meson Areas," Fermilab-TM-2105, unpublished (2000).
6. BNL Experiment Support and Facilities Division, `http://server.c-ad.bnl.gov/esfd`.
7. Rare Symmetry Violating Processes, RSVP, experiment, `http://www.bnl.gov/rsvp/`.