Fermilab ILC Test Beam Facilities Workshop Group Report

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Abstract

Fermilab is in a unique position for ILC detector development. It has a considerable amount of available assets in its fixed target area that can be utilized to accommodate much of the ILC detector development beam test program foreseen over the next decade. This document provides a vision for establishing a global, long term ILC detector beam test program at Fermilab. This document includes the assessment of the current existing facilities and the anticipated pace of the ILC detector development and the necessary requirements of beam test facilities to sufficiently support a whole, coherent program of beam tests for the next decade or so. It ends with our vision for establishing a global, long term ILC detector beam test program at Fermilab, with specific recommendations for utilizing Fermilab's current assets and expanding on them.

1. Introduction

Fermilab is currently the only laboratory in the United States that can consistently deliver high-energy beams of particles for use in particle detector development. In fact, it is one of only a very few other such facilities worldwide. These other facilities include CERN, DESY and IHEP-Protvino. Of these, only CERN has a similar capability for delivering multiple beam species in a wide range of momentum, and for much of the calendar year.

For the next 2-3 years, CERN's highest priorities are commissioning the LHC and the attendant experiments and then developing a routine running mode. It is not clear how this will impact their fixed target program, including their extensive test beamlines. Even so, CERN is trying very hard to encourage the ILC detector development community to use their beam test facility as much as they can. While PS and SPS running might be interrupted during the filling cycle of LHC, CERN intends to minimize the interruption to these accelerators to keep its beam test facility up and operating maximally.

Fermilab has one detector beam test facility that is currently in operation - the Meson Test Beam Facility. This facility has been in constant use over the last few years. In addition, the lab has several other fixed target experimental halls and beam lines that could potentially be made available for additional beam test activities. Providing more than one fixed target beam line for beam tests and making it available at a higher duty factor in the near future would make the lab a lot more attractive for the ILC detector community. This, we believe, will help put Fermilab in a competitive position for the future bid of hosting the ILC.

Below we briefly summarize the timeline for developing detector technologies for the ILC, as well as the test beam requirements for the individual detector types. After a description of some of Fermilab's assets that can be devoted to ILC test beams, we conclude by summarizing a vision for the laboratory and by making specific suggestions.

2. A Timeline for ILC Detector Development

We foresee that ILC detector development is a long-term activity that will span well into the next decade. Thus, establishing a beam test facility that would accommodate virtually all such detector development, including design and calibration activities, would be an excellent use of Fermilab's assets and would position the laboratory well to bid for hosting the ILC. Since the calibration facility would exist on the base-camp site of the accelerator, this would provide an ideal condition for experimental groups.
More specifically, the next decade or so can be categorized into three different periods:

- Present – ~2010: Detector technology R&D phase
  - Detector technology research and development
  - Global ILC detector concept development and design (there are a total of 4 concepts being developed)
  - Choice of technologies to be used in various ILC detector concepts
  - CDR for ILC detector concepts by 2010, according to GDE schedule
- ~2010 – ~2017: Global ILC detector design and selection phase and ILC detector construction and calibration phase
  - Remaining performance testing of ILC detector designs
  - Prototype testing of the selected ILC detectors
  - Calibration of the ILC detectors
  - Construction of the detectors
- 2017 and on: ILC Physics Era

Figure 1 shows this rough timeline of the ILC detector development in a graphical manner. Based on the above rough schedule, we anticipate a rich program of detector beam tests for the next 10 – 15 years, just for the ILC.

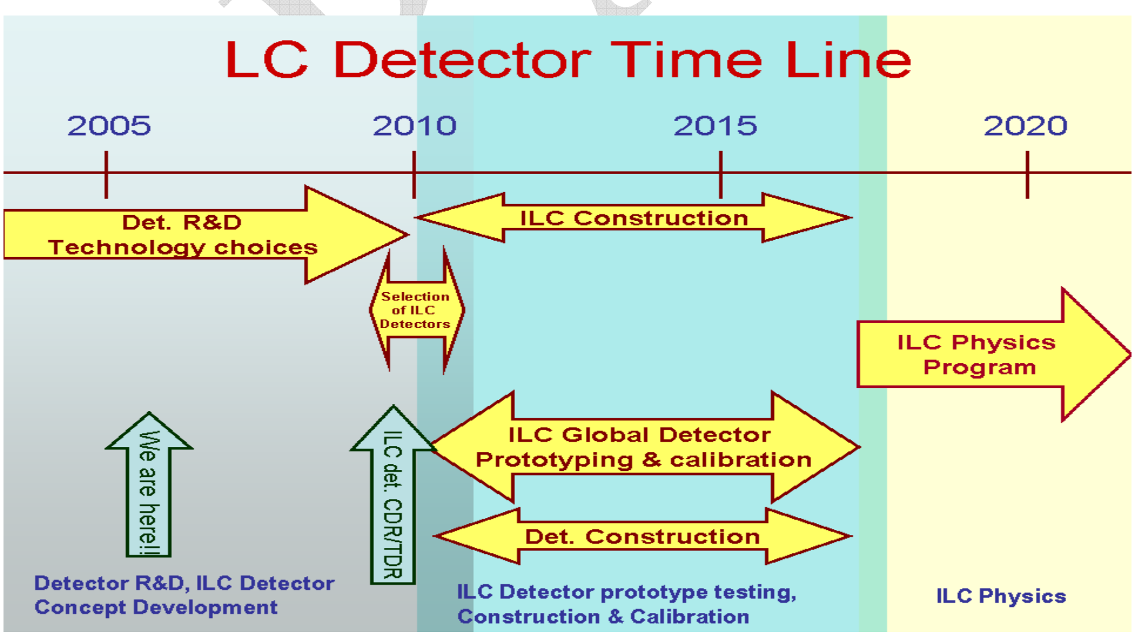

Figure 1 Rough timeline for ILC and its detector development.

Since the technology choices for ILC global detector concepts must be made by the end of this decade, all the detector R&D groups require beams for characterization and performance testing of the detectors. These beam tests will provide sufficient information for global ILC detector concept groups to complete their CDR by the end of the decade.

These activities will then be followed by a global ILC detector prototyping and partial performance testing for the final components in the two detectors planned for the ILC. Once the final selection of the two detector designs are made, the construction begins. During this period, beam test facilities will have to be available for all types of the detectors for their characterization, performance testing and calibration activities.

We know very well from LHC experience that a large number of beam test facilities are needed to meet all the needs. This is certainly the case for the ILC detectors since their required precision will demand large amount of time at a given location.

Based on the rough time line above, it is clear that the community needs a large facility that could accommodate a large number of beam test activities simultaneously. Fermilab is well poised to provide such a facility utilizing its existing assets without requiring significant new funds. These activities also have sufficient coherency to become a well developed experimental program.

3. Requirements from the Detector Community

3.1 Calorimeters

As a precision instrument, the ILC detector calorimeter will be used to measure jets from decays of vector bosons and heavy particles, such as top, Higgs, etc. It will be essential to identify the presence of a Z or W vector boson by its hadronic decay mode into two jets. This suggests a di-jet 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 and therefore the testing of alternate possibilities for detector solutions in a test beam is of utmost importance.

Tests of several concepts for the electromagnetic calorimeter (ECAL), 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 particle flow algorithms (PFA), 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. 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 and Gas Electron Multipliers) 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 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.

Because there are so many beam particle species that need to be tested to understand calorimetery at the required level, ILC calorimetry effectively determines the specifications of any ILC test beam facility. The requirements span the range of particle types (electrons, pions, muons, protons), momenta (1 GeV-120 GeV) and angles of incidence and rate. In addition, even prototype detectors for calorimetry can be large, which puts a burden on the infrastructure of any test beam facility.

The ILC calorimeter detector community has summarized the requirements for test beams in a Fermilab technical document that can be found at:

http://lss.fnal.gov/archive/test-tm/2000/fermilab-tm-2291.shtml

3.2 Tracking detectors

TPC: For the TPC tracking solution, there is a Large Prototpye (LP) R&D program which is being geared up to run at the Eudet (European Detector group) facility. In this case, "large" means about 1m in length. Several "small", ca. 30cm, prototypes have been built and tested in the last few years by several groups. The Eudet facility will be located in a 6 GeV electron beam at DESY. For these initial efforts 6 GeV electrons, combined with cosmic ray tests, will be sufficient, but ultimately higher momenta test beams will be needed. The LP is foreseen to start taking data the latter part of 2007, depending on when the fieldcage and electronics are ready and on how fast the endplates can be developed. Several designs are considered for the endplates: a GEM solution, Micromegas and a SiTPC solution. The testing and data taking of the GEM and Micromegas would last until the end of 2008, at which time some SiTPC prototypes are supposed to be ready. Therefore, DESY will support at least 3 years of LP work. Testing of higher momenta would require a move to Fermilab or CERN. In principle it has been said that the Eudet facility can be transported to Fermilab or CERN, but how practical this would be is unclear at the moment. The requirements for TPC tests at Fermilab would be tagged beams of particles of varying momenta – from 4 GeV or so (to match the DESY results) up to 120 GeV. The TPC tests require a high field, large aperture magnet.

3.3 Vertex detectors

The requirements for vertex detector system are being laid out by groups in the US and in EU. However at the time of the completion of this report, this information is unavailable.

3.4 Muon detectors

The requirements for this detector system are virtually identical to the calorimeter groups' and are described in the previously mentioned technical memo (TM-2291).

3.5 Luminosity monitors

The requirements for this detector system are not clearly known yet at the time of completion of this report. We hope to obtain updated requirements on this and other detector systems through other channels in the ILC community.

4. Current ILC Detector Development Activities and Beam Test Time Line

Given the importance of the detector, the complexity of its development to meet the stringent requirements for ILC physics, and the time required for the development, calorimeter groups dominate the need for beam tests. Vertex, tracking and muon detector groups are gearing up their preparation for beam test in the next 2 – 3 years which would meet the schedule for global ILC community of detector selection time line in 2010 as shown in Fig. 1. This section compiles the current status of various detector groups' status toward beam tests based on the latest information obtained at the ALCPG workshop held in July 2006 at the University of British Columbia.

There are many calorimeter activities currently on going. Several North American groups, European groups and Asian groups are preparing for beam test experiments in the next 2 – 4 years as part of the four ILC detector concept studies; SiD, LDC, GLD and the forth concept.

The RPC digital calorimeter (DHCAL) group in the US has performed a chamber characteristics experiment at MTBF (T955) in Feb. 2006 before Fermilab Tevatron shutdown for D0 and CDF detector upgrades. They tested 3 RPC chambers with 120GeV/c proton beams. They took a total of six hours of data at the varying trigger rate from 70 – 5000 Hz. This group plans to perform another test in Fall 2006 followed by a "Slice test" in early 2007 after the MTBF upgrade using the close-to-final version of ANL-FNAL joint developed DCAL readout chip. This will then be followed by a full scale test using a 40 layer, $1m^3$ prototype in late 2007. While the $1m^3$ prototype test depends heavily on funding, the prospect for the 1m3 prototype is brighter.

The GEM DHCAL group also has performed a beam exposure experiment using a 30cm x 30cm prototype chamber they built with the large scale GEM foils jointly developed with 3M Inc. The group took the chamber to Korea and exposed it to a low energy (10MeV) high intensity electron beam at the Korean Atomic Energy Research Institute irradiation facility. The total exposure to beam was 2×10^{12} electrons per readout pad. This corresponds to a total accumulated charge of $1.6\times10^{-2}\,\mathrm{mC}/\mathrm{mm}^2$. Even though the beam was such a high intensity, no physical or functional damage to the chamber and to the GEM foils have been observed. This group plans to perform a beam test for their chamber characteristic in December, 2006 or January 2007 immediately after the MTBF upgrade. This group will then work jointly with the RPC DHCAL group in the slice test with DCAL chip in early 2007. This will then be followed by another, independent slice test with SLAC's kPix chip in spring 2007. The group will work with the RPC DHCAL group in preparing for $1m^3$ prototype run and plans to perform its full scale beam test in 2008.

At the time of writing this report, the EU contingent of the CALICE collaboration is performing three separate periods of beam tests in August – September, 2006, using their Si-W ECAL and scintillator-Steel AHCAL together with scintillator-steel tail-catcher (TCMT) at CERN's H6 beam line. The Si-W ECAL and the scintillator-steel AHCAL have been exposed to positron beams of momentum up to 6GeV/c at DESY from late 2005 to early 2006, using the full CALICE DAQ system. One sensitive layer of the TCMT was exposed to 3 GeV/c electron beams at DESY in October 2005. The module was then exposed to 16 GeV/c pions and muons as well as 120GeV/c protons at MTBF in early 2006 (T957). The EU contingent of the CALICE collaboration currently plans to move the entire detector system over to Fermilab in early 2007 for long-term detector performance and combined testing. This system is going to be shared by the DHCAL groups described above for their combined performance tests.

Asian scintillator-W ECAL and scintillator based HCAL groups are planning for beam tests in late 2007 or early 2008. The crystal-based calorimeter group in the forth detector concept plans a beam test but its timeline is not quite clear yet.

US muon group completed its initial run at MTBF (T956). The FNAL, Indiana University, Wayne State University and the Notre Dame University jointly constructed a layer of scintillation counter. They plan to take two more beam tests in August and late 2006 and for a longer period runs in 2007. Since the muon counter can concurrently run with the calorimeters, these runs do not necessarily present a conflict with the previously described calorimeter beam tests.

After a discussion with the TPC groups at the ALCPG workshop in Vancouver, both the MPI and the Carlton TPC groups would like to perform their next set of beam tests at Fermilab in 2007. These groups require multi-particle beam and a large bore, high field magnet.

No US groups current plan for beam tests in the immediate future but some Si tracker activities driven by Fermilab Si tracker group are anticipated in 2007. We were told that clearly defined facilities requirements are expected shortly.

The LBNL vertex detector group performed beam tests using the LBNL radiation facility. They will need a pion beam with momentum larger than 5GeV/c in late 2007 or early 2008. European vertex groups anticipate beam tests in 2009 but no clear timeline has

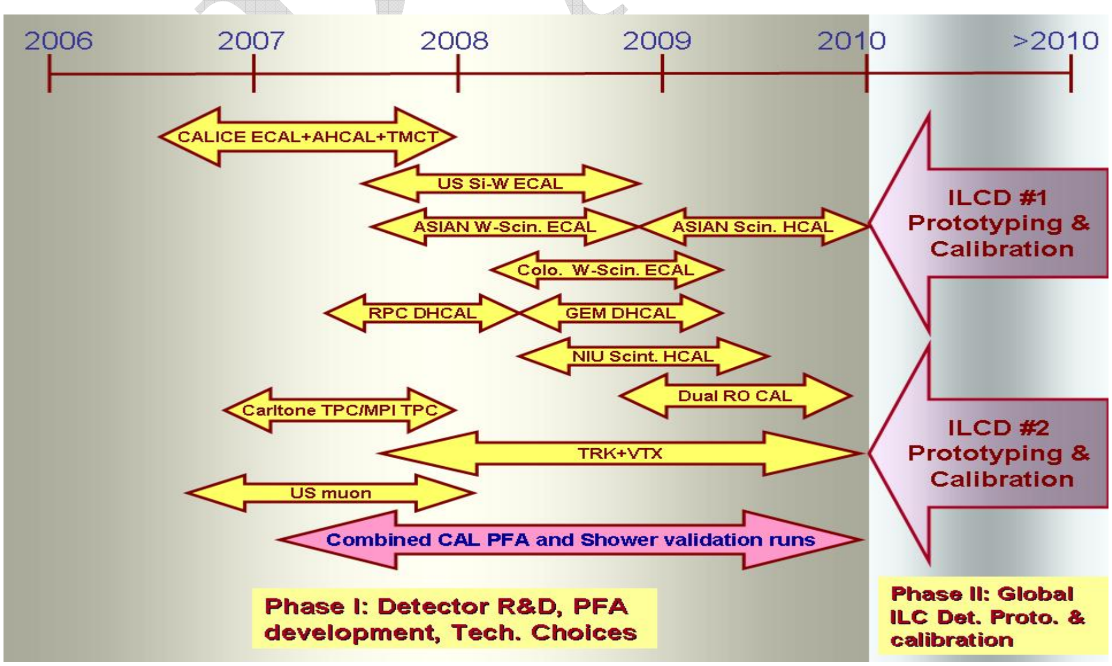

Figure 2 Timeline of expected beam tests activities for ILC detector development

been given.

Based on what we have learned at the ALCPG workshop and the rough ILC detector timeline laid out earlier in the report, Fig. 2 presents a perspective view of the upcoming beam test activities. As can be seen clearly in the picture, due to the timeline driven by the ILC design and construction, the technology choices for detector concept studies must be made before the end of the decade. Thus, many detector groups are planning their beam tests in late 2007 – 2008. However, the available facilities to meet all the demands are currently limited to Fermilab's MTBF and CERN's SPS and PS beam lines. Given the fact that the LHC commissioning will be the highest priority at CERN for the next 1 – 2 years, it is not quite clear what beam test facilities will be availabile at CERN during the critical time period. This not only presents the urgent need for more facilities but also requires better coordination between different detector development projects.

Given these needs, we are planning to host an ILC test beam workshop in January 2007, with strong support from the directorate. We also have been working on including an ILC person in the lab's test beam planning committee in order to incorporate ILC community's plans to an adequate level for an optimal use of the limited facility.

5. Currently Available Fermilab Assets

SwitchYard 120 Slow Spill Beam:

Beam is brought out to the Meson area at Fermilab through a region called the SwitchYard. Thus the beam that arrives in the Meson Detector Building is termed the SY120 beam. This beam is resonantly extracted from the Main Injector at 120 GeV. It is currently split between two lines: MTest and MCenter. The Meson Test Beam Facility is located at the end of the MTest line and the MIPP experiment (Main Injector Particle Production) is located at the end of the MCenter line. There is a decommissioned beamline, MWest, located between these two. It is possible to resurrect that beamline if needed. The same spill structure will thus exist for all beamlines in the Meson area. Currently we have two options for spill structure - one spill is approximately 1 second in length, while the other option is a 4 second long spill. Filling the Main Injector and extracting it slowly to the Meson area takes time away from the rapid cycling of beam to the neutrino program and to the production of anti-protons for the collider program. The SY120 beam is limited to have an effect of 5% or less on these programs, forcing the duty cycle to be low. A typical running condition is one 4-second long spill every minute for 12 hours of the day. If a test beam experiment is buffer readout limited, then it makes more sense to go for the option of having two 1-second long spills every minute for 12 hours of the day. Spill structure decisions are made by the Program Planning Office.

MTest:

The Meson Test Beam line starts with a 40 cm long Aluminum target, located approximately 500 meters upstream of the experimental hall. There are two options for tuning the MTest line: you can tune for the 120 GeV protons that make it through the target, or you can tune for any secondary momentum between 4 and 66 GeV. If the 120 GeV beam is chosen, there is a collimator that is placed into the beamline to restrict beam rates to approximately 500,000 protons per spill maximum. The secondary tunes are lower than that in rate, ranging from about 100,000 particles/spill at 66 GeV, going down to 1000

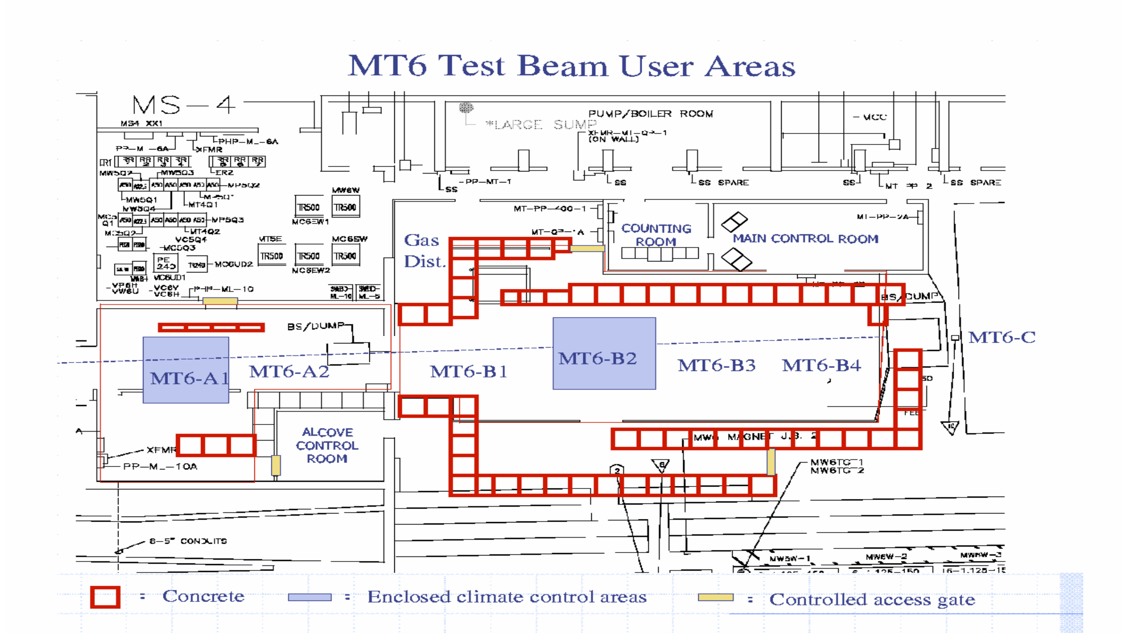

Figure 3 Layout of the user areas in the Meson Test Beam Facility

particles/spill at 4 GeV. The mix of beam particle species is dictated by the physics of the beamline. It is predominately protons at 66 GeV, mostly pions between 8 and 33 GeV and the majority are electrons at 4 GeV. The beamline is monitored by wire chambers, scintillators and two threshold Cerenkov detectors. There are facilities for putting targets into the upstream areas of the beamline. The beamline ends at the Meson Test Beam Facility, which is depicted in Fig. 3. An upgrade to the MTest beamline is being proposed that would put a movable target near the halfway point of the beamline, so that low energy pions (~1 GeV) can survive to the user facility. In addition, attention will be paid to reducing material in the beamline, and new tracking and particle i.d. detectors will be installed.

MCenter:
The MCenter beamline is significantly shorter than the current MTest beamline and is even shorter than the proposed upgrade of MTest. It can be tuned for a wide range of momenta and has two differential Cerenkov detectors located in the beamline for excellent particle i.d. Unlike MTest, the MCenter beamline can be tuned easily for both positive and negatively charged particles. This beamline delivers a wide array of beam species to one of several potential targets currently located in the MIPP experiment. One of the large coils in the 'Jolly Green Giant' spectrometer magnet (where the target and a TPC station are located) is leaking coolant and needs to be repaired for its continued operation. There is a proposal to use the spectrometer for a tagged neutron test beam facility. We believe it is important to keep this equipment functioning since it could easily be used for a testing facility for large scale ILC detectors.

MWest:
The MWest beamline is not currently active. However, the infrastructure for power distribution still exists and this beamline could conceivably be configured for future use. Currently a choice has to be made between delivering beam to MWest or MTest, but this

targeting scheme can be modified.

Neutrino area:
Traditionally neutrino beamlines have accommodated many test beam activities. The area has three large assembly halls (NWA, Lab-E and KTeV hall) that are equipped with large capacity building cranes and other infrastructure to be converted to dedicated beam test area for the future ILC detector beam test activities. We feel that it is important for the lab to maximally leverage its infrastructure and assets to prepare for the future ILC global detector test and calibration activities, and in this regard, Neutrino area presents tremendous opportunity. Therefore, serious planning for converting the Neutrino area into a dedicated area within a 2 – 3 year time scale should begin as soon as possible.

Antiproton Storage Rings:
After the completion of the collider program, the Tevatron will no longer be in use. In addition, the Antiproton facility will no longer have a specific program for which it needs to store antiprotons. There are two storage rings in the facility – namely the Debuncher and the Accumulator. With two rings, it is possible that one could be devoted to creating high intensity, low energy beams, perhaps with an emphasis on electron beam production.

Irradiation Facilities:
Several of the beamlines at Fermilab can support tests of irradiating detectors with high intensity beams. These include:

- Neutron Therapy Facility – beam of neutrons averaging 10 MeV
- Linac – a high intensity beam of 500 MeV protons
- Booster – 8 GeV proton beam
- Switchyard – high intensity 120 GeV beam can be brought on target in M01/2

6. A Plan for Establishing an ILC Beam Test Program at Fermilab

To begin with, there are several problems associated with test beam activities that need to be addressed if we are to continue to build world-class test beam facilities at Fermilab. Test beam work is often viewed as essential, but not real physics. It is thus given low priority. Few papers are published based on results derived from test beams. Test beams are often an afterthought at laboratories and given few resources. And due to their inherent low priority, test beams rarely mimic realistic experimental beams.

One consequence of these problems is that few physicists give test beam research proper respect. Universities in the US typically do not grant PhD degrees for students whose primary research was done at a test beam, nor do post-docs earn faculty positions by spending the bulk of their time at test beams. This is despite the fact that test beams are excellent learning centers for the field of particle physics, requiring users to do hands-on work in designing detectors, electronics, DAQ systems and management activities.

- We feel that Fermilab should embark on a serious long-term commitment to having a set of world class test beam facilities to attract participation in hands-on particle physics research from Universities and other institutions in the U.S. and around the world. The goal of these facilities would be to investigate details of particle production and interaction in matter, develop specific detector technologies, and serve as a focus for particle physics training, around which the university community can base their high energy physics activities.

In addition to this facility development, we feel that Fermilab should encourage detector development and testing within the laboratory by providing R&D funds to be used in partnership with university groups.

6. Recommendations

In this section we list specific recommendations for ILC test beam activities at Fermilab.

6.1 Increase the status of test beam experiments: A good start is to emphasize and promote ILC-detector beam-test activities as experiments. At Fermilab, detector tests are given experiment numbers, but typically do not achieve the status of experiments, subject to internal reviews and giving status reports at All Experimenters meetings. We feel this should change. In addition, a summary of results should be given at the Users' Meeting in June.

6.2 Partnership for Detector R&D and Testing: We feel that small scale funding opportunities for detector development and subsequent beam testing in partnership with university groups should be made available by Fermilab. This would allow small proposals for detector development to be submitted to an internal review committee for evaluation, with competitive bids for available resources and promote strongly the use of Fermilab beam test facilities.

6.3 Resource availability: The laboratory should make engineers and beam line physicists available to customize beam lines to collaboration needs. Computing and technician support should also be available for beam test experiments.

6.4 Upgrade of Meson Test Beam Facility: We recommend that the proposed upgrade to the Meson Test Beam line, with an additional downstream target and low energy transport, should be fully supported.

6.5 Support and upgrade the MCenter beamline, with the intention that this area would eventually become a dedicated ILC test beam facility with the possibility of neutron tagging.

6.6 Develop plans for converting the Neutrino area to eventually become a beam facility in preparation for future ILC detector prototyping and calibration activities.

6.7 Investigate the potential use of one of the storage rings in the Anti-Proton facility as a high duty cycle, high intensity test beam.

6.8 We recommend that the lab create a test beam programming committee with sufficient representation from the ILC community to incorporate ILC needs and schedule.