Extraction Line Energy Spectrometer

Classification (subsystem)

Machine-Detector Interface

Personnel and Institution(s) requesting funding

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Project Leader

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Project Overview

A measurement of the absolute collision energy with a relative precision approaching 10^{-4} is a critical component of the linear collider physics program. Measurements of the top quark and Higgs boson masses to 50 MeV can only be performed if this level of precision is achieved. We propose a two-year program to complete the conceptual design of a downstream beam energy spectrometer capable of this level of precision, initial beam tests to validate this design, and simulation studies to show how this beam energy measurement can be combined with other available information to determine the luminosity-weighted collision energy.

The downstream spectrometer design is based on the WISRD spectrometer which provided a continuous absolute energy scale measurement with a precision of 2×10^{-4} during the eight years of SLC operation at SLAC.[1] In the WISRD scheme, shown in Figure 1, two horizontal dipole magnets produce stripes of synchrotron radiation that are detected at a downstream wire array. The separation between these stripes, provided by the bending of a third vertical dipole magnet, is then inversely proportional to the beam energy.

In the current strawman design for the ILC, we propose to insert a chicane or bump in the extraction line and use wiggler magnets to produce the signal synchrotron stripes. The detector plane would be constructed from quartz fibers which would detect Cherenkov radiation from secondary electrons produced by the incident synchrotron radiation. The advantages of quartz fibers over wires include simple readout with multi-anode PMTs, reduced RF pickup from the beam passage, and a natural energy threshold at 200 keV.

In addition to the design and optics layout in the extraction line for the ILC spectrometer, we propose to test the detection of O(1 MeV) photons via secondary electron Cherenkov radiation in quartz fibers with a dedicated beam test at SLAC End Station A (ESA). This test is envisioned in FY05 or FY06, and is the first step towards a full-scale spectrometer prototype which we would foresee in roughly five years time.

This work is being proposed as a single component of a broader coordinated effort to provide the beam instrumentation necessary for the LC physics program. The downstream spectrometer is seen as a complimentary effort to the upstream BPM-based spectrometer which is being pursued by other groups. In addition, the critical question of how to stitch together the various beam-based measurements and physics reference reactions to determine the luminosity-weighted collision energy at the interaction point must also be answered. Coordination of a world-wide effort to demonstrate an answer this question by the end of this year is also part of this proposal.

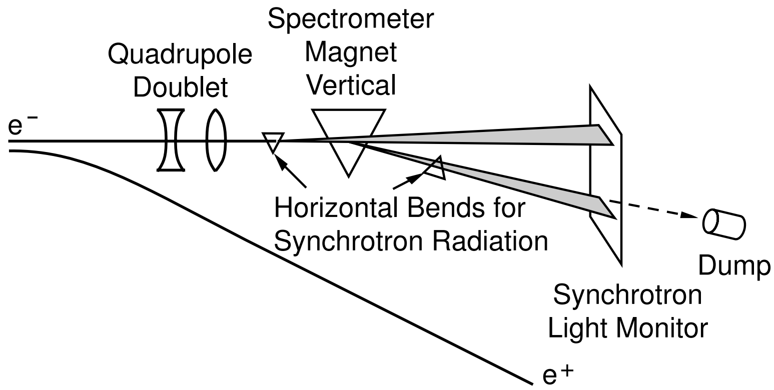

Figure 1: The SLC WISRD energy spectrometer

Broader Impact

An important part of the linear collider research which has been performed at the University of Oregon is the involvement of undergraduate Physics students in the research and design process. Three undergraduates have been directly involved in the spectrometer project over the last two years, and all three have made important contributions to the design. The first, Paul Csonka, actually built by himself the prototype quartz fiber detector which will be tested at SLAC ESA. The other two, Brooks Harrop and Matt Sternberg, have played central roles in the design of the ESA beam test and the ILC extraction line spectrometer respectively. We intend to continue to use undergraduate students as in integral part of this project, providing an important and unique opportunity for our students to learn HEP techniques and participate in HEP research.

This project was one of the first test beam proposals made to SLAC to use the ESA facility as a test-bed for linear collider beam instrumentation and other tests related to the LC interaction point.[2] This initiative, organized by Torrence and Mike Woods (SLAC) is viewed as an important effort to build up the ESA capabilities for test beams and make the lab aware of the interests and needs in this area within the LC community.

Results of Prior Research

This project has been funded since FY03 by DOE with University LC R&D funds. In that time, we have constructed a prototype quartz fiber detector with eight 100 micron fibers and eight 600 micron fibers on a 1 mm pitch read out using a Hamamatsu R6568 (16 channel) multi-anode PMT. Figure 2 shows the R6568 with the 16 fibers from the prototype detector coupled in from the right. This detector is intended to be installed in ESA sometime this year. The primary motivation is to measure directly the yield of Cherenkov photons to validate the Monte Carlo models needed to design the ILC extraction-line spectrometer. A secondary motivation is to test the detector design and look for other unexpected sources of background in the detector. Possible examples include stray beam particles, scintillation, or RF pickup. We have also assembled a small test-stand with light box to test various coupling schemes of quartz fibers to MAPMTs. Some efforts were made to measure the yield of Cherenkov photons in 100 micron quartz fibers using a miniature cosmic ray telescope. These initial tests showed that Cherenkov photons were being produced, but work continues to improve the system such that quantitative measurements of the yield can be performed.

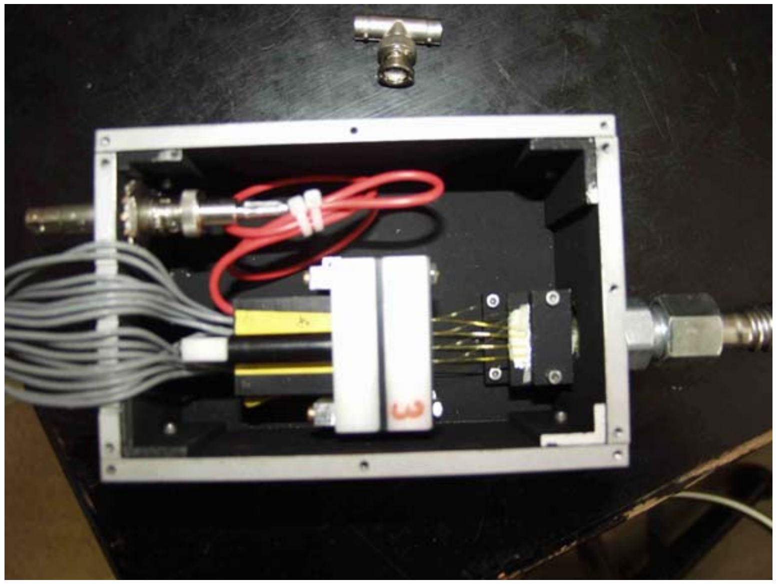

Figure 2: The PMT used to read out the prototype Quartz fiber detector is shown.

Work has also progressed in association with Mike Woods and Ray Arnold at SLAC on the specific design of the ESA beam test (SLAC T-475).[3] To reduce costs, half of a chicane (two dipoles) would be constructed using recycled SPEAR 10D45 dipoles. These magnets will provide a dogleg in the high-energy ESA beam, and synchrotron radiation would be produced using an old SPEAR wiggler magnet which can also be salvaged. The critical energy of the wiggler magnet is 0.9 MeV for a 29 GeV electron beam which is adequate to produce a detectable Cherenkov signal through Compton electrons produced in material near the fibers. The expected backgrounds from the bend magnets, with critical energy of around 0.1 MeV, is essentially zero.[4] The layout of the ESA test program including T-475 is shown in Figure 4. Exact details of cost and schedule are currently being worked out.

In addition, work has begun using the extraction line optics decks produced at SLAC for the ILC strawman beam delivery design to asses the ILC spectrometer performance and provide feedback to the optics design. The current extraction line, produced by Yuri Nosochkov at SLAC, is shown in Figure 3. The first bump would be the location of the spectrometer dipoles and wigglers. This spectrometer bump has been separated from the polarimeter chicane in this design to allow the synchrotron radiation detectors to be situated near the secondary focal point.

Facilities, Equipment and Other Resources

The University of Oregon has a well equipped machine and electronics shop which has been used to construct the prototype quartz fiber detector. The capabilities of this shop include high-vacuum fabrication, and if necessary the complete detector and beampipe package can be constructed locally at Oregon. In addition, we plan to use the existing capabilities of SLAC End Station A, including data acquisition infrastructure, along with technical support provided by SLAC to provide the beam for this test.

Some of the Oregon research staff resident at SLAC, namely Nick Sinev and Olya Igonkina, will likely be enlisted to support the installation and operation of the equipment in the T-475 beam test.

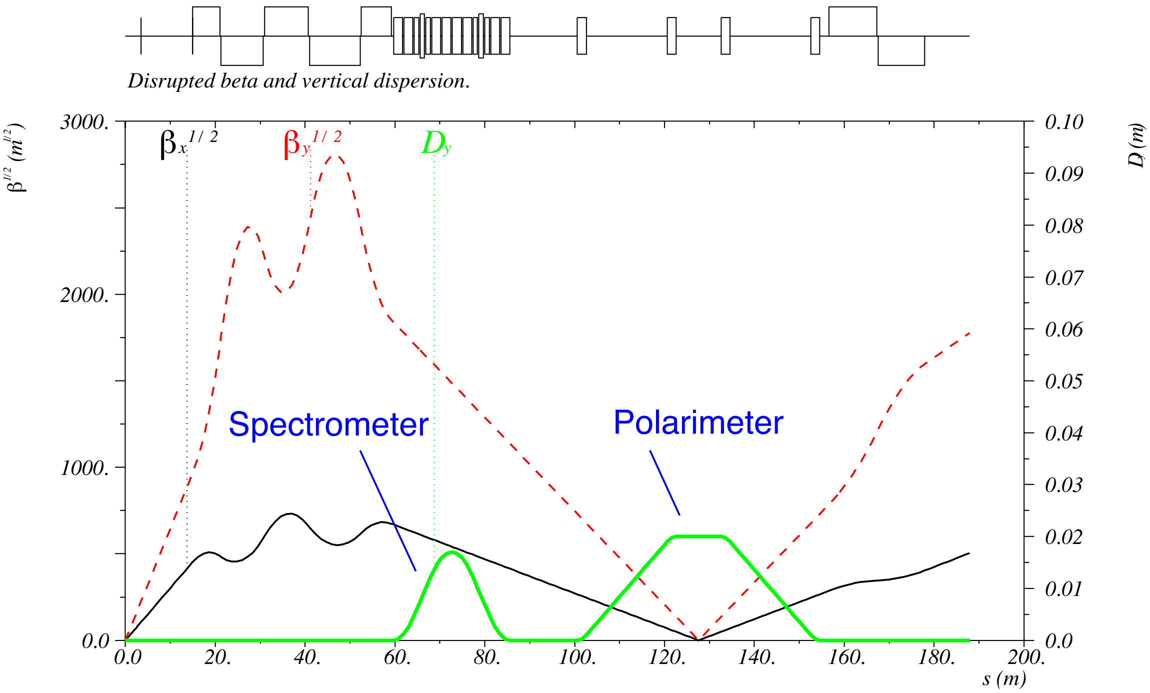

Figure 3: Current ILC extraction line layout for 20 mRad crossing angle.

FY2005 Project Activities and Deliverables

There are three specific tasks scheduled for FY05.

First, the conceptual design of the extraction line spectrometer will be completed. The current optics deck will be translated into a Geant4 description as part of the BDSIM project lead by Grahame Blair of Royal Holloway. We will use this code to assess the spectrometer performance, expected resolution, and backgrounds for realistic disrupted beams simulated by GuineaPig. From the results of this simulation work, the design will be iterated until the necessary energy resolution can be achieved.

Second, the prototype detector which has already been built will be prepared to be installed in SLAC ESA. It is not clear at this time whether the actual test beam will be run during FY05 or FY06, but final preparations including construction of a detector stand on a movable stage can be finished this year.

Third, an effort has begun to demonstrate in a Monte Carlo exercise that the combined information available in detectors like the downstream spectrometer combined with the physics reference reactions like Bhabha scattering actually provide all of the information necessary to measure the luminosity-weighted collision energy to the precision needed for the physics program. The idea is extract the luminosity spectrum using only experimentally available information and then use this extracted spectrum to calibrate a measurement of some physics reference reaction, like the Higgs boson mass. By investigating this process under a variety of simulated machine operating conditions and possible operational pathologies, we intend to verify that this procedure is robust against machine conditions. This work, currently being coordinated by Torrence and Stewart Bogart (UCL), is expected to have completed a first round by the Snowmass meeting this Summer. More detailed iterations on this study will likely continue in FY06.

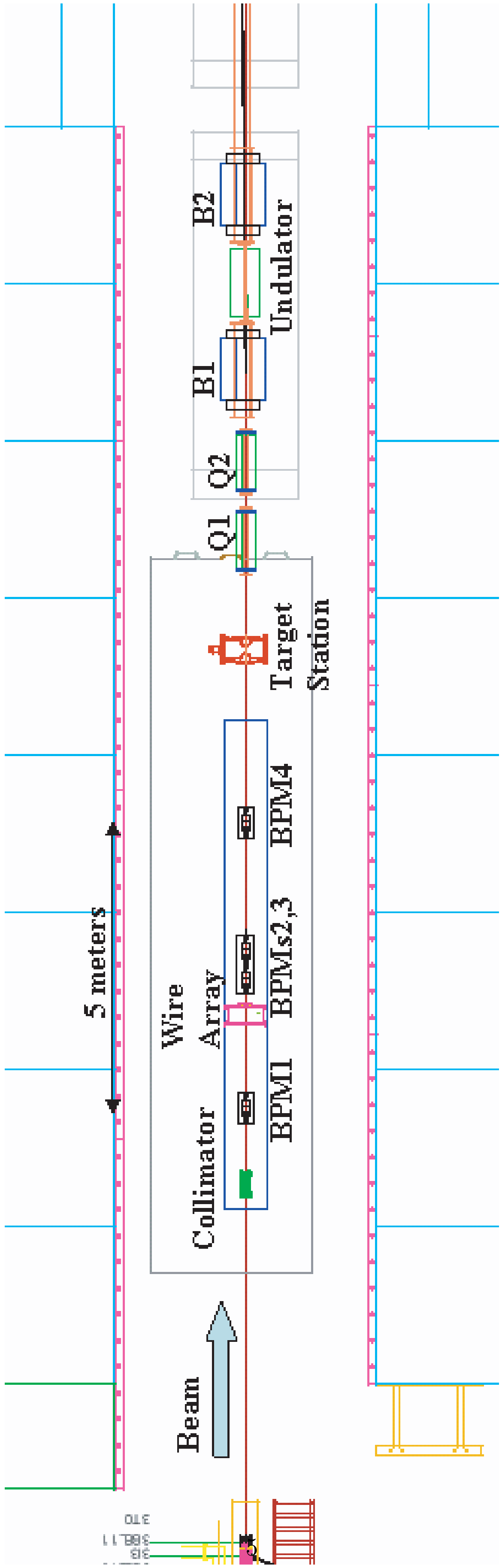

Figure 4: Layout of end station A including magnets for T-475 at the far downstream end. The quartz fiber detector will sit an additional 30 meters downstream.

FY2006 Project Activities and Deliverables

The downstream spectrometer is also an ideal place to measure the energy width of the machine, along with tracking the long energy tail produced by the disruption at the collision point. In the second year of this proposal, it is foreseen to extend the design study in the ILC extraction line to include the performance of this device to make beam energy width measurements and measurements of the long disrupted energy tail. It is also expected to develop a more detailed detector simulation within Geant4 and begin the process of evaluating the backgrounds expected in this device.

The ability to measure the energy profile of the disrupted beam directly with the downstream spectrometer would open up a potentially useful diagnostic of the collision properties of the machine at the interaction point. Initial Monte Carlo studies by one of our Graduate Students (Jeff Kolb) indicates that there may be enough information in this disrupted energy tail to correct for collision biases at the interaction point, although this study was essentially done at the MC truth level. Once a realistic simulation of the extraction line and spectrometer detector is available within Geant4, this study can be revisited with more realistic conditions.

It is very likely that the ESA beam tests will not actually run until FY06, or a second prototype detector constructed based on what is found in the first tests. We already have an 64 channel PMT (H7546) from which we would like to build a more realistic prototype detector with 64 wires arrayed on a finer pitch. In addition to the quartz fiber detector, it is foreseen to have a diagnostic detector imaging the visible synchrotron light onto a gated CCD camera upstream. Interested collaborators in this project have been identified, and we are currently discussion how best to coordinate this interest into the effort. This visible synchrotron light could potentially also be used to measure the beam energy directly, or it may be a better detection technology to measure the beam energy width. Imaging synchrotron light has been used at LEP and ESA for some time as a monitor of bunch size and energy profile, but significant technical problems remain in making a calibrated absolute position measurement using this sort of device.

In the long term, the goal is to produce a full-blown spectrometer prototype running in ESA which demonstrates the 10^{-4} goal of the ILC physics program. This work would be coordinated in conjunction with the BPM spectrometer effort such that the two devices can be directly compared to each other. Funding for this work is not currently being requested, as this is seen as coming several years in the future.

Budget justification

We are requesting support for two undergraduate students and half of a graduate student to continue the design work which has been ongoing at the University of Oregon. The other half of the graduate student will either be supported by the University of Oregon physics department as a teaching assistant, or will be funded out of our main DOE grant. In addition, travel funds are requested in the second year ($600/student) to allow the undergraduates to participate in a one-week test beam run at SLAC. Further funds are requested to allow Torrence to more fully participate in the ILC Machine-Detector Interface activities which are being held on the machine side. These funds (approx. $2500) would allow Torrence to attend one additional meeting in Europe or Asia per year, such as the ILC Beam Delivery workshop scheduled for 20-23 June in London.

Equipment money of $1800 per year is requested to build remaining hardware needed for the ESA beam tests, including mechanical mounts for the detector and beam line elements to be installed in ESA. Some of this money will also be used to construct the second prototype detector based on a 64 channel PMT which has already been purchased with previous LC R&D funds.

Two-year budget, in then-year dollars

Item	FY2005	FY2006	Total
Graduate Students	20,325	21,494	41,819
Undergraduate Students	12,701	13,336	26,037
Total Salaries and Wages	33,026	34,830	67,856
Equipment	2,266	2,520	4,786
Travel	0	1,512	1,512
International Travel	3,175	3,215	6,390
Total costs (1)	38,467	42,077	80,544

(1) All costs include benefits and 26% overhead

References

[1] J. Kent *et al.*, "Precision Measurements of the SLC Beam Energy," Presented at IEEE Particle Accelerator Conf., Chicago, Ill, Mar 20-23, 1989.

[2] Y. Kolomensky *et al.*, "Beam Instrumentation Tests for the Linear Collier using the SLAC A-Line and End Station A," SLAC-LOI-2003.2, October 2003.
`http://www.slac.stanford.edu/grp/rd/epac/LOI/LOI-2003.2.pdf`

[3] E. Torrence, "Test Beam Request for a Synchrotron Stripe Energy Spectrometer," SLAC-T-475, June 2004.
`http://www.slac.stanford.edu/xorg/lcd/ipbi/notes/syncspec_T475.pdf`

[4] R. Arnold and E. Torrence, "Rough Layout and Rate Estimate for Beam Test in SLAC ESA of Synchrotron Radiation Detector Prototypes for LC Beam Monitor," IPBI TN-2004-7, July 2004.
`http://www.slac.stanford.edu/xorg/lcd/ipbi/notes/tn_synchrate.pdf`