Proposal to the
University Consortium for a Linear Collider

August 23, 2002

Proposal Name

A Demonstration the Electronic and Mechanical Stability of a BPM-Based Energy Spectrometer for an e^+e^- Linear Collider

Classification (accelerator/detector: subsystem)

Accelerator and Detector: Machine-Detector Interface

Personnel and Institution(s) requesting funding

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Project Overview

Much of the physics of the future e^+e^- Linear Collider will depend on a precise measurement of the center-of-mass energy ($E_{\rm CM}$), the differential dependence of luminosity on energy ($\mathrm{d}\mathcal{L}/\mathrm{d}E$), and the relationship between these two quantities and the energy of a single beam ($E_{\rm beam}$). Studies estimating the precision of future measurements of the top mass[1] and the higgs mass[2] indicate that a measurement of the absolute beam energy scale of 50 MeV for a 250 GeV beam ($\delta E_{\rm beam}/E_{\rm beam} \sim 1-2\times 10^{-4}$) will be necessary to avoid dominating the statistical and systematic errors on these masses. If precision electroweak measurements become necessary, the requirements on the beam energy measurement are even more stringent. Studies of a scan of the WW pair production threshold[3] have shown that an experimental error of 6 MeV may be possible, implying a needed precision of $\delta E_{\rm beam}/E_{\rm beam} \sim 3\times 10^{-5}$ (and likely an alteration in accelerator parameters to control $\mathrm{d}\mathcal{L}/\mathrm{d}E$). Provisions must be made in the overall accelerator design to provide adequate beamline space for the devices which will provide these energy measurements. Moving accelerator components well after construction in order to provide additional space for energy measurement instrumentation is likely to be both extremely disruptive and extremely expensive. We are in a situation, however, where no direct energy measurement technique except resonant depolarization (RDP)[4] has provided an energy determination of sufficient precision. Since RDP will not work in a single-pass collider, spectrometer techniques must be developed which meet the specifications demanded by physics measurements.

Previous experimental requirements on precision energy measurements at electron-based accelerators have led to the development of several techniques. At Jefferson Lab, wire scanners, etc.[5] have been used to provide a precision of $\delta E_{\text{beam}}/E_{\text{beam}} \sim 1 \times 10^{-4}$ at beam energies of about 4 GeV. At higher energies, dedicated magnetic spectrometers have been constructed. At the SLC, the WISRD (Wire Imaging Synchrotron Radiation Detector)[6] was used to measure the distance between two synchrotron stripes created by vertical bend magnets which surrounded a precisely-measured dipole that provided a horizontal bend proportional to the beam energy ($\sim$ 45 GeV). This device reached a precision of $\delta E_{\text{beam}}/E_{\text{beam}} \sim 2 \times 10^{-4}$, where the limiting systematic errors were due to the relative alignment between the three dipole magnets and backround issues associated with measuring the precise centroids of the synchrotron stripes. At LEP2, a magnetic spectrometer was incorporated into the LEP ring[7]. A precise map of the magnetic field at a series of excitations allowed a comparison of the nearly-constant bend angle across a range of LEP beam energies. Since a precise calibration using RDP at the Z^0 pole was possible, the spectrometer provided a relative energy measurement between this lower point and and physics energies ($\sim$ 100 GeV). In this case, standard LEP Beam Position Monitors (BPMs) fitted with custom electronics were used to provide the angle measurement. This spectrometer has provided an energy determination at LEP2 energies of $\delta E_{\text{beam}}/E_{\text{beam}} \sim 2 \times 10^{-4}$, where the dominant errors have come from the stability of the BPM electronics.

As can be seen from the above results, LC physics may require between a factor of 5 and 10 more precise energy determination than has been achieved with existing techniques. Bridging this gap is an essentially-technical challenge, where clever engineering solutions to the problems of nanometer-scale stability and resolution will be necessary. We are currently interested in developing a prototype support and position-monitoring system for the "magnetic spectrometer" option for Energy measurement, and, coupled with RF-BPM development at LBL, a protype BPM station which can demonstrate the required accuracy and stability in an electron beam test. The end goal of the proposal is the design of a magnetic-spectrometer-based Energy Measurement system for the LC which can reach the desired precision. The "magnetic spectrometer" option is chosen as the focus primarily because it may be the only technique capable of achieving this goal.

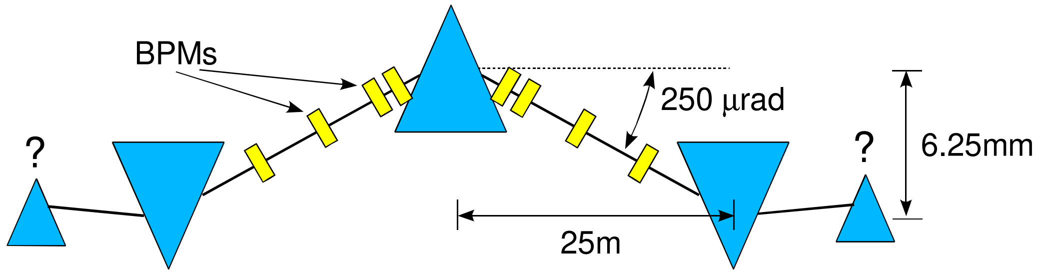

Figure 1: A schematic outline of an accelerator dipole chicane which could accomodate a BPM-based magnetic spectrometer at a future linear collider.

As summarized in Figure 1, a magnetic spectrometer at the LC will consist of a chicane of dipoles, with one central well-measured magnet. To avoid hysteresis effects, this central dipole should be super-conducting rather than a typical iron dipole. In order to make an absolute, stand-alone energy measurement, the main dipole will need to be turned "off", in the situation shown at the top of Figure 2. Once the BPMs measure a straight line, the dipole can be re-energized, and the deflection angle relative to the initial straight line can be measured, determining the energy. In order to do this: the BPM response/gain/calibration must be stable over the time it takes to move the BPMs on the beam center; the position of each of the BPMs relative to the inertial straight line must be known with sufficient accuracy and stability; and the BPMs must be able to be moved repeatedly and accurately over length scales of order 1cm with a precision of tens of nanometers. This proposal seeks to demonstrate the feasibility of each of these conditions.

The exact details of the accelerator optics around the spectrometer have yet to be fleshed out (see

FY2003 deliverables), and in fact will ultimately depend on the achievable stability and resolution. A suitable chicane can be designed which will allow the straight-ahead and deflected beams to pass through to the rest of the accelerator with an acceptable emittance growth while providing a sufficient lever-arm to match the expected BPM position/stability resolution. Given current superconducting magnet technology and the resolution achieved by RF BPMs, drift lengths of order 20 meters with a 500 mrad bend are approximately correct for this system. It is clear that this measurement will not be performed continously; periodic measurements on a week-by-week timescale should be adequate.

Prototyping a BPM-based Energy Spectrometer breaks down into three natural stages:

1. establishment of a reference "straight line" optical system to serve as the reference line for the energy measurement; demonstration of its stability and sensitivity to motion
2. establishment of a means to measure distances perpendicular to this straight line reference in order to determine relative transverse motion of accelerator componenents; demonstration of the sensitivity and stability
3. addition of a BPM triplet or quadruplet to measure beam position, resolution, and stability of position. This last part requires a beam test.

Establishment of an "straight" line is most easily achieved optically in this case with a laser interferometer, which will be set up under vacuum to minimize thermal effects. Monitoring of the relative positions of the BPMs and the optical elements themselves can be achieved using the same techniques that have been developed for the stabilization of the LC Final Focus quadrupoles at SLAC and at the University of British Columbia[8]. We hope to benefit by borrowing many of their techniques and advances. Sensitivity tests at this stage require piezo movers of known calibration, and perhaps a capacitive position encoder.

For the geometry shown in Figures 1 and 2, the required BPM resolution and stability of measurement varies from 15 nm very close to the dipole to 190 nm at a distance of 25 meters. Since RF-BPMs with a resolution of 25 nm[9] have been used at the Final Focus Test Beam at SLAC, the necessary performance in terms of pure resolution has nearly been achieved for the full range of possible BPM positions. Stability over the measurement time, however, has yet to be demonstrated. Development at LBL/Berkeley will focus on these issues, as they will provide the RF BPM componenets which complement the mechanical systems outlined here.

A crucial item for this project is the BPM movers. Advances in technology for nano-manufacturing have come along at an opportune time in order to drastically reduce the cost (and increase the performance) of nano-movers. Several firms have developed or are developing this technolgy. At this stage, an SBIR project with one of the leading developers may be a way of gaining access to this technology in an economical manner. Spectacular performance, such as sub-nm positioning accuracy over multiple *centimeter* travel distance is now available almost "off-the-shelf" at very reasonable cost. It is expected that the mover supports and BPM stands will be based on SLAC magnet stand designs that have successfully demonstrated sub-micron stability. SLAC designers will act as consultants on the support stand design and fabrication.

Once the mechanical and electrical systems have matured, a test of position resolution and stability in a real beamline is essential for the success of the spectrometer. Many beam-induced effects are possible (and were experienced in building the LEP Spectrometer), such that significant beam test time will be necessary in order to iterate on the electronic or mechanical systems if needed. Only then can one arrive at a final design with sufficient performance. As well as contributing invaluable ideas and insights throughout the process, our SLAC collaborators will provide logistical support and coordination for the final stage of the project when beam tests occur.

FY2003 Project Activities and Deliverables

The first year of the project will include the establishment of the linear optical reference using interferometric techniques and measurements of its sensitivity. The transverse monitoring system will also be set up. Development of appropriate nano-movers for the BPM positioning will begin. In parallel, an

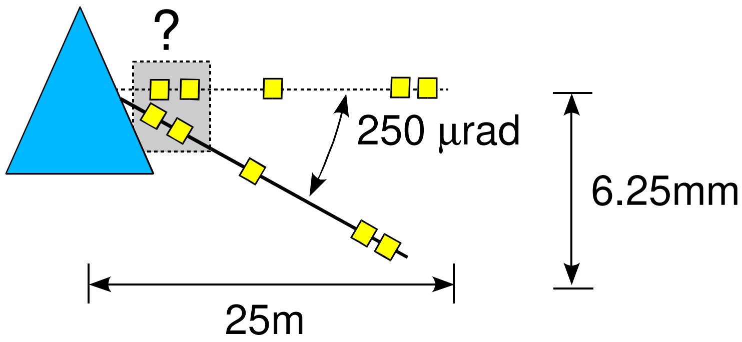

Figure 2: A diagram showing the two cases of: straight-ahead linear trajectory measurement to establish zero deflection; and the motion of the BPMs necessary to measure a deflection of 250μrad. The "?" indicates that it may be possible to design a system with sufficient accuracy that the closest BPM to the dipole can remain stationary and still have sufficient precision on the position measurement to serve as a BPM "anchor" for the measurement.

investigation of the potential locations of such a device in the accelerator lattice will be explored. The first deliverable is a measurement of the power spectrum of random motion transverse to a 5m length of optical anchor. The second deliverable is an optics deck for the NLC and Tesla designs including the energy spectrometer.

FY2004 Project Activities and Deliverables

The second year of the project will include measurements of the stability of a prototype BPM stand transverse to the optical straight line. Vertical and angular stability will also be explored. The second-year deliverables are a mechanical design of a BPM stand with sufficient (10nm at low frequencies) transverse stability to carry the RF-BPMs necessary for the beam test and a design and/or a prototype for the BPM nanomover.

FY2005 Project Activities and Deliverables

The third year will see the completion of the BPM nanomover and the assembly of a BPM test stand sufficient for a beam test of the stability and resolution of the system. Deliverables for the third year will include a measurement of the resolution and stability of the BPM pickup determined from a triplet or quadruplet of RF-BPMs placed in an electron beam. The systematics of these measurements (i.e., dependence on position within the BPM, beam current, beam tails, etc.) will also be pursued. The results of these tests will determine the required footprint of a magnetic spectrometer in the LC design.

Budget justification

The first year's experiments involve setting up the optical interferometer system and making some simple measurements. This will be accomplished by staff members (not included here) with the help of an undergraduate and a half-time graduate student. Sufficient equipment and supply funds are included in order to purchase the interferometer, a vacuum system in which to run it, and piezo movers for testing. Travel funds sufficient for visiting collaborating institutions are included throughout.

The second year will involve mechanical design and fabrication of a BPM support structure. Costs for engineering (1/3 FTE) and fabrication are included. Manpower for mounting this effort will come from an undergraduate student and a full-time graduate student as well as staff (not included).

In the third year, the aid of a half-time postdoc will be enlisted to help carry out the beam test. The nano-mover purchase dominates the equipment costs for this year. Travel costs will increase in order to setup and perform the beam test of the system.

Three-year budget, in then-year K$

Institution: University of Notre Dame

Item	FY2003	FY2004	FY2005	Total
Other Professionals	0	40	35	75
Graduate Students	10	22	24	56
Undergraduate Students	3	3	4	10
Total Salaries and Wages	13	65	63	141
Fringe Benefits	2	12	12	26
Total Salaries, Wages and Fringe Benefits	15	77	75	167
Equipment	20	30	40	90
Travel	2	2	4	8
Materials and Supplies	6	5	5	16
Other direct costs	0	0	0	0
Total direct costs	43	114	124	269
Indirect costs	11	41	41	93
Total direct and indirect costs	54	155	153	362

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