Luminosity, Energy, Polarization Table of Contents

Overview of Luminosity, Energy, Polarization Proposals

Luminosity

At the Linear Collider, one needs not only a measurement of the energy-integrated luminosity, but also, for physics such as threshold scans, knowledge of the differential luminosity, dL/dE. Low-angle Bhabha scattering can in principle provide both, though techniques for determining dL/dE have yet to be demonstrated.

Options for Bhabha detection include calorimetry based on secondary emission (A), fast gas cerenkov calorimetry (B) and silicon devices (C). Information on dL/dE may be obtained indirectly from studies of the beam-beam disruption. Possible techniques for measuring this include laser scattering (D) and coherent beamstrahlung (E).

A.	LCRD	R&D for luminosity monitor	Yasar Onel	Iowa Fairfield
B.	LCRD	A Fast Gas Cerenkov Calorimeter for Bunch-by-Bunch Luminosity Measurement at the Next Linear Collider	John Hauptman	Iowa State
C.	LCRD	Development of thin, fast, radiation hard, 3d-electrode array, silicon radiation sensors	Sherwood Parker	Hawaii
D.	LCRD	Post-IP beam diagnostic monitors	William Oliver	Tufts
E.	UCLC	Beam-beam collision monitoring using Large Angle Beamstrahlung	Giovanni Bonvicini	Wayne State Univ.

Energy

Energy measurement is needed both upstream and downstream of the collision point. Upstream, a beam position monitor-based spectrometer is envisioned, while downstream, the most likely solution is an SLC-style spectrometer that detects the stripe of synchrotron radiation produced as the beam passes through dipole magnets. Success of the BPM-based device depends on electrical and mechanical stability (A). For the downstream spectrometer, groups will look at the feasibility of placing such a system in the extraction line (B) and study a device for SR detection (C).

A.	UCLC	A Demonstration of the Electronic and Mechanical Stability of a BPM-based Energy Spectrometer	Michael Hildreth	Notre Dame
B.	LCRD	Energy Spectrometer Design Study for the Linear Collider Extraction Line	Stan Hertzbach	U Mass.
C.	LCRD	Quartz fiber Cerenkov Detector for precision beam energy spectrometer	Eric Torrence	U Oregon

Polarimetry

The measurement of parity-violating asymmetries in the Standard Model benefits from absolute polarization measurements with a precision of 0.5% or better. Compton-backscattering polarimetry is fast and the physics is well-understood. A detection scheme for scattered photons or electrons will be investigated (A).

A.	LCRD	Polarimetry at LC	Ysar Onel	Iowa Iowa State Fairfield

3.1. A Fast Gas Cerenkov Calorimeter for Bunch-by-Bunch Luminosity Measurement at the Next Linear Collider
(LCRD)

Luminosity, Energy, Polarization

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Iowa State
SLAC
Texas Tech

FY 2003: $16,000

Project name

A Fast Gas Cerenkov Calorimeter for Bunch-by-Bunch Luminosity Measurement at the Next Linear Collider

Classification (accelerator/detector: subsystem)

Accelerator: Luminosity Monitor

Institution(s) and personnel

Iowa State University, Department of Physics:
Oleksiy Atramentov (grad. student), John Hauptman (professor), Mark Kane (student)

Texas Tech University:
Nural Akchurin (professor)

NIPT, Kharkov, Ukraine
Vladimir Atramentov (engineer)

Stanford Linear Accelerator Center:
Thomas Markiewicz (physicist), Michael Woods (physicist)

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Project Overview

Introduction

We will design and construct a gas Cerenkov calorimeter for beam luminosity measurement that is emptied of Cerenkov light between bunch crossings, thus becoming quiescent before the next bunch arrives 1.4 ns later. This calorimeter is explicitly radiation hard, completely insensitive to radioactivation of the calorimeter mass, and blind to $e^{\pm}$ and γ IR backgrounds below 10 MeV. This proposal addresses item ID #56 of the “long list”. This detector is also potentially useful for tagging low angle electrons from two-photon events which are the dominant background to most SUSY channels[1].

Basic Design

A fast nanosecond calorimeter must carry its energy and spatial information in photons, and these photons must be able to exit the calorimeter volume unimpeded. A gas has an index of refraction, *n*, which differs from one by a small amount $\delta \approx 10^{-3}$ where $\delta = n - 1$ and since $\cos\theta_C \approx 1/n \approx 1-\delta$, the generated Cerenkov light is channeled forward at an angle $\theta_C \approx \sqrt{2\delta} \approx 0.05$, which is easier to collect geometrically. The Cerenkov photon yield is approximately $370\theta_C^2$ eV^{-1}cm^{-1} $\approx 700\,\delta$ eV^{-1}cm^{-1} or about one photon per eV per cm for a typical gas.

The collection and transport of the Cerenkov light down highly reflective optical conduits can be accomplished in several ways, two of which are described in more detail in http://www.public.iastate.edu/~oleksiy/NLC/calor2002.pdf. The "lasagna" geometry consists of metal plates with half-round rods evenly spaced on one surface of the plate, and another array of rods on the other side, but shifted with respect to the first by half of a period. These "washboard" surfaces are covered with 2 mil stainless steel shims polished to optical quality. The detector consists of a stack of these plates[2].

The Cerenkov light is generated by shower particles as they cross the gas gaps between the reflecting stainless steel shims, and since the Cerenkov angle is small, a large fraction of the light is channeled down the optical conduits. The light makes typically 10-12 small angle reflections before exiting the 30-cm deep calorimeter. This Cerenkov light co-moves with the shower particles as they traverse the metal medium in depth, forming a thin 50 ps wide pancake of light which exits the conduits at the rear of the calorimeter. We will use aluminized metallic mirrors to redirect the Cerenkov light to PMTs out of the path of the beam. To the extent that wide-angle light is attenuated by multiple reflections and that negligible scintillation light is generated in the gas, the calorimeter is emptied of light in 1ns, and this device becomes completely quiescent between bunches.

The velocity threshold for Cerenkov light emission is $\left(p/E\right)_{th} = 1/n \approx 1-\delta$, and $p/E \approx 1-\frac{1}{2}\left(m/p\right)^2 \approx 1-\delta$, so that $p_{th}/m = 1/\sqrt{2\delta}$, and the momentum threshold for electrons is

$$p_{th}^{e} \approx m_e/\sqrt{2\delta} \approx m_e/\theta_C \approx 11 \text{ MeV/c}$$

comfortably above the β and γ energies of all decay nuclei. The critical energy of a dense metal is typically 10-20 MeV, and therefore most shower electrons will participate in Cerenkov light generation.

Therefore, this luminosity calorimeter has three unique features: (i) it is constructed wholly of metal and gas, and therefore cannot be damaged by any conceivable dose of radiation; (ii) the generation of Cerenkov light is instantaneous, its transport from within the calorimeter volume is at nearly the speed of light, bunched in a 50-ps pancake, and the calorimeter volume is emptied of light well before the next bunch; and, (iii) the Cerenkov threshold is about 11 MeV, and therefore no β ray from any degree of radioactivation will result in Cerenkov light, and all IR $e^{\pm}$ and γ backgrounds below this threshold are invisible.

Crucial tasks are the manufacturing of highly reflective metallic surfaces (a lot of progress has already been done by our collaborators in Ukraine) and the design of a fast phototube readout and DAQ.

Scintillation backgrounds

Presence of 'resident' light due to scintillation backgrounds can be avoided by proper choice of gas. A good gas is beta-butylene with $\delta = 1.31*10^{-3}$ (as good as isobutene) but a scintillation light yield smaller than 10^{-5} that of Cerenkov light[3]. In addition, the isotropic scintillation light is suppressed by the solid angle capture fraction in the lasagna light conduits, and may be further suppressed with respect to the blue-UV Cerenkov light for longer wavelength scintillation light.

Reflecting Surfaces.

Quality of the reflecting surfaces is the most critical aspect of this project. To achieve acceptable resolution our detector requires coefficient of reflection to be better then 97% at grazing incidence. Such reflectivity, by itself, requires that the surface must be optically smooth, roughness should be of the order of $\lambda/2$ (50 nm). This represents a serious engineering challenge. At ISU we managed to achieve relatively good quality but we never managed to obtain polished areas larger than a few sq. inches. Collaborators in Ukraine are investigating various techniques to achieve optical smoothness. They have designed and built two different polishing machines which are now at the stage of fine-tuning and the search of optimal regimes. Also they have to high quality metallization facility where polished surfaces will be aluminized.

Quality control is another non trivial task; non trivial because we need to determine reflectivity at very small angles (few degrees), which is difficult. ISU together with Ukraine developed techniques that will enable not only accurate measurements but also to control each reflecting element in our device.

Geometry and placement.

Our device will be placed in the next-to-beam region, “hugging” the beam pipe, approximately 2 meters from IP. The geometry, “cylindrical lasagna”, is shown in posted figure[2]. Diameter is around 20 cm and the length ~25Xo (~9cm for W). We can also investigate placement of a few interaction lengths of layers of a SiW preshower calorimeter.

Preshower SiW

Placement of SiW preshower module should provide our detector with rather improved x-y resolution and will help improve energy resolution by providing information on depth development fluctuations. Several groups are working on Si (SiW) detectors[4]. We will collaborate with these groups and look into the possible use of a few layers of the existing SiW calorimeter designs.

DAQ

In order to minimize noise in the PMTs it is preferable to place them off shower axis and direct light to them with spherical or cylindrical mirrors. Our detector permits bunch-by-bunch detection of the particles and therefore requires fast photodetectors and digitizers at GHz frequencies. Hamamatsu provides a very fast PMT (H6568)[6], that has a rise time of 200ps, and goes as low as 200nm in wavelength. Commercially available digitizers exist, Maxim max104 2.2 GHz ADC, for example is fast enough, but we also need to transfer digitized signal to fast memory in order to use bunch-by-bunch information for the whole train. We suspect that a XyLinx FPGA with fast memory and integrated logic capabilities will be able to handle this traffic. Bunch-by-bunch readout is pursued by other groups as well[5]; and in order to minimize cost of our project we are going to collaborate with these groups.

Expected Performance

A detailed Geant3 simulation of 100 GeV electrons in an Fe mass has been performed with exact optics for the Cerenkov light in reflective ss tubes. The tubes are 2-mm inner diameter, centered every 5-mm. The calculated energy resolution in this geometry is about 10% for 100 GeV electrons. We are now developing a Geant4 code to simulate the lasagna and hex rod geometries, and to optimize the metal-gas volumes and the light channeling and collection efficiencies. Cerenkov light is generated with a $1/\lambda^2$ distribution, and therefore we prefer to aluminize all metallic surfaces and use PMTs as far into the UV as possible. As mentioned above position resolution as well as energy resolution can be improved by the use of SiW preshower.

Calibration

Both energy and time can be calibrated by pulsing a fast light source into several fibers differing successively by 1.4 ns, and injecting the light into the front end of the conduits.

Description of first year project activities

In the first year we will establish the design of the detector and assess its dual role as both luminosity monitor and two-photon tagging veto for SUSY events. Geometry and mechanical support will be finalized. Performance will be understood based on improved existing Geant4 simulation; the real detector environment, provided by SLAC group, can give us guidance towards further improvement of the performance; optimal geometry of the absorber, as well as optimal materials will be chosen.

We will establish collaborative relationships with groups working on fast DAQ and we will happily use any readout that is developed by another team. For purposes of a beam test requiring only a few channels of readout, we can consider our solution as back-up: Hamamatsu H6568 (subnanosecond, UV, 16 anodes), very fast (GHz) digitizers, similar to now available MAXIM104, and design of very fast bunch-by-bunch storage memory, based on XyLinx FPGA.

In addition delamination of aluminum coating under high doses will be investigated (although this is not considered a problem at NLC).

The first year of work, design and simulations will enable our research team to be ready to start production of a beam ready prototype of the device.

Deliverables

In the first year, we will study both physics and detector issues.

For physics, we will

1. study the role of this gas Cerenkov calorimeter as both a fast luminosity monitor (with very high spatial precision, with or without a SiW preshower) and as a two-photon tagger to reject SUSY background events. We have perused the U. Colorado web site, and will profit from their work; and,
2. perform a detailed Pythia-GEANT4 simulation of two-photon and SUSY events coupled with our detailed detector simulation. We expect to arrive at an optimal design for this dual purpose calorimeter;
3. assess the geometry and placement of this calorimeter within the constraints of the present NLC IR design. Presently, we see no problem with placement about 2 m from the IP and with an outer radius of 15-20 cm.

For detector performance, we will

4. complete our polishing of stainless steel shims, measure the reflectivity at grazing incidence, incorporate these measurements into the physics and detector simulations;
5. use Auto-CAD to complete our mechanical design of a cylindrical lasagna geometry of light conduits; and,
6. follow the DAQ work of other groups on this proposal with the expectation of using their solutions. We will develop only a conceptual solution of our own, but expend no funds on it. At the end of this first year, we expect to present this progress to other

groups with expertise in these problems, and be ready to begin the construction of a small beam-ready module.

Budget (3 year)

This is an estimate of costs for building a beam-ready prototype that can be tested in an electron beam at SLAC. We will involve undergraduate and graduate students, and work in close association with SLAC on reflecting surfaces.

Oleksiy Atramentov is a PhD student working at DØ (Fermilab), only a fraction of the salary is requested for him. No postdocs are anticipated. No summer salary for professors is requested. We will need to make a few trips to SLAC for coordination and communication, and for testing of the module, somewhere in the 3rd year.

Relevant experience.

Nural Akchurin is Technical Head of the Hadronic Forward (HF) quartz fiber calorimeters of the CMS experiment at CERN; co-PI on the Advanced Detector Research dual readout fiber calorimeter; and, a CDF collaborator and expert at calorimeters in general. Oleksiy Atramentov and John Hauptman are D0 collaborators, work on HF at CERN, and are expert at calorimeters. Vladimir Atramentov is a mechanical/electrical engineer and an expert at metals and metallic films.

Institution	Item	1st yr	2nd yr	3rd yr	Total
ISU TTU NIPT	Salary for students (grad.+undergrad.)	$8K	$6K	$6K	$20K
NIPT ISU	Equipment & materials	$5K –	$6K $6K	$7K $10K	$34K
ISU	DAQ*	$4K	$4K	$10K	$18K
Indirect	26% of non-equipment	$3K	$3K	$5K	$11K
Total		$16K	$26K	$38K	$83K
	Grand total (beam ready module)				$83K

[1] Communications from Uriel Nauenberg concerning two-photon backgrounds to SUSY events; http://hep-www.colorado.edu/SUSY/

[2] This picture and several others that give a better visualization of the geometry can be found under www.public.iastate.edu/~oleksiy/NLC/

[3] Heintze, J., et al., NIM A138 (1976) 641; communications from Herb Steiner and Eric Torrence.

[4] Raymond Frey(Oregon), Bruce Schumm (Santa Cruz), David Buchholz (Northwestern), Sherwood Parker (U of Hawaii)

[5] Eric Torrence (Oregon), K. Gan (Ohio), Rick Van Kooten (Indiana U), Yasar Onel (U of Iowa)

[6] Eric Torence in EoI “Quartz fiber Cerenkov detector for precision beam energy spectrometer”

3.2. R&D for luminosity monitor (LCRD)

Luminosity, Energy, Polarization

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Fairfield
Iowa

FY 2003: $0

Project name

R&D for luminosity monitor

Classification (accelerator/detector:subsystem)

Accelerator

Institution(s) and personnel

University of Iowa, Department of Physics and Astronomy:
Yasar Onel (professor) Co-PI, E. Norbeck (professor), J.P.Merlo, A.Mestvirisvili (post-doc), U.Akgun, A.S. Ayan, F. Duru (grad.students), I.Schmidt (Mechanical Engineer), M.Miller (electronics engineer), Jon Olson (undergrad. scholar)

Fairfield University, Department of Physics:
Dave Winn (professor) Co-PI, V.Podrasky (engineer), C.Sanzeni (programmer)

Bogazici University, Department of Physics, Istanbul, Turkey:
Erhan Gülmez (professor)

Cukurova University, Department of Physics, Adana, Turkey:
Gulsen Onengut (professor)

METU, Department of Physics, Ankara, Turkey:
Ramazan Sever (professor)

INFN-Trieste and University of Trieste, Department of Physics, Italy:
Aldo Penzo (professor)

Contact person

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Project Overview

Introduction:

We propose R& D for a novel method for calorimetry at high rates, for doses exceeding 100 Giga Rad. The method collects an amplified secondary emission signal resulting from absorbed radiation sampled in a shower. The basic detector concept consists of absorber plates interspersed with secondary emission surfaces followed by sheet dynodes. The R&D will investigate: (A) materials to obtain high secondary emissive surfaces for mips, based largely on SEM monitors used for accelerator beam diagnostics, and various dynode technologies, based on new planar PMT dynode technologies (electrochemically etched metal dynodes, others) appropriate for gains of few x 1000 per secondary electron; (B) GEANT Monte Carlo of predicted performance based on the results of (A), for incident particles and jets between ~1 GeV-3 TeV, including secondary electron optics; (C) Engineering Point Designs for assembly, vacuum integrity, signal presentation, and costs; (D) Construction & Tests (including raddam) of a single secondary emission detector package at least 5cm x 5cm square.

It is well-established that many secondary emission surfaces are radiation-hard. Typical Sb- coated SS dynodes (g~5) used in most PMT today survive 50-100 GRad of internal electron bombardment, and MgO or BeO dynodes survive higher doses, albeit at lower yield (g~2.5-3). Similar surfaces are used to monitor accelerator beams at high doses. We propose to use SEM surfaces to sample the shower caused by jets and particles in the forward region (3<eta<7). Secondary emission for a m.i.p. typically falls to a gain g between g~ 1.1-1.5. Conservatively, we thus anticipate that 10% of through-going mips will create one secondary electron, and 50% of electrons with energies less than 100 KeV will produce one extra secondary electron. On this basis we estimate, by scaling from scintillator or quartz fiber calorimetry, that with 2.5 cm thick sampling plates in Cu we would detect >10 vacuum secondary electrons/GeV. With a gain of ~1000, this would be sufficient for forward calorimetry (the equivalent of ~1 p.e./GeV, with an intrinsic pre-gain fluctuation of ~30% per p.e., to translate to optical calorimetry), with excellent timing characteristics.

A default gain mechanism is to use large area planar metal dynodes with micro-machined apertures for secondary electron impingement and transport, such as metal meshes, or structures similar those used in the Hamamatsu R5900. The micromachining is a relatively low-cost electrochemical etch. The planar dynodes can be made from ~1 mm thick metal sheets as large as 50 cm on a side. An assembly might use simple insulating supports between secondary emission cathode, dynode and anode plane. The areal size in not a restriction as in a planar PMT assembly, where the glass window thickness becomes prohibitive if the span is unsupported, whereas a metal thickness could be made sufficient for any vacuum and be counted as part of the absorber, and the presence of internal supports of the vacuum envelope (non-glass window) are not as disruptive as in a PMT. For example, the supports might obscure as much as 10% of the SEM cathode or dynode (on a few cm areal scale), with little effect on the performance of a forward calorimeter, as the effective open detection area is not as critical as in a PMT for single photon detection. In one realization, for example, the sem cathode, mesh dynodes, and anode are all supported by simple stackable ceramic support grids, fired from a molded greensheet. The dynodes can be spaced at ~1 mm apart, as in modern PMT. Given that a 10 stage PMT at 2 KV typically has a gain of 10^6, a 5 stage gain section with g=1,000 at 1 KV is reasonable. The SEM cathode, dynode stack, and anode could be less than 1 cm thick. A simple metal package could use ~5-15 mm thick plates on top & bottom to withstand vacuum over a 30+ cm span, with a 1 mm thick x 1 cm deep metal wall between them, with a brazed ceramic fitting on the anode side for feedthru of HV and signal. As an example, an effective 2.5 cm Cu thickness with an effective 1 cm of vacuum SEM detector would have a density ~ 70% of Cu. A tile might be ~3.5-4 cm thick, with a ~30 cm major diameter, in square or hexagonal cross-section to the beam, or even as sectors, with the anode segmented appropriately for the eta-phi sectors, and with appropriate bias for signal and HV to pass through a stacked calorimeter. With care, the dead region between tile edges could be as small as 3-4 mm, which could be ameliorated by alternating overlap in subsequent longitudinal tiles.

For the phase I R&D on this project, we propose studying the possibility of this to a sufficient level where information on performance and cost are sufficient to enable a decision to build a prototype calorimeter in subsequent proposal phases. The R&D will investigate: (A) materials to obtain high secondary emissive surfaces for mips, based largely on SEM monitors used for accelerator beam diagnostics, and various dynode technologies, based on new planar PMT dynode technologies (electrochemically etched metal dynodes, others) appropriate for gains of few x 1000 per secondary electron; (B) GEANT Monte Carlo of predicted performance based on the results of (A), for incident particles and jets between ~1 GeV-3 TeV, including secondary electron optics; (C) Engineering Point Designs for assembly, vacuum integrity, signal presentation, and costs; (D) Construction & Tests (including raddam) of a single secondary emission detector package at least 5cm x 5cm square.

Note: there is no budget request in this proposal at this time. We may apply for funding in the future.

3.3. Energy Spectrometer Design Study for the Linear Collider Extraction Line (LCRD)

Luminosity, Energy, Polarization

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U Mass.

FY 2003: $20,125

Project name

Energy Spectrometer Design Study for the Linear Collider Extraction Line

Classification (accelerator/detector:subsystem)

Beam Instrumentation (L.E.P.) and/or Accelerator (ID: 47)

Institution(s) and personnel

University of Massachusetts at Amherst, Department of Physics:
Stanley S. Hertzbach (professor), Melissa Motew (undergraduate student)

Contact person

Stan Hertzbach
hertzbach@physics.umass.edu
650-926-2507 (at SLAC) until ~20 January 2003; then 413-545-0511.

Project Overview

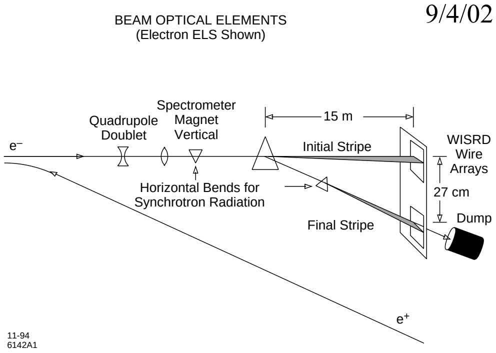
The physics program of the Linear Collider (LC) includes measurement of the masses of newly observed particles, *e.g.*, the SUSY mass spectrum, and an accurate and precise measurement of the top quark mass in a $t\bar{t}$ threshold scan. These require calibration of the LC beam energy and knowledge of the luminosity spectrum. The luminosity spectrum will be measured using a simple physics process, *e.g.*, Bhabha scattering, but knowledge of the beam energy spectrum will be useful in extracting this from the data.

An energy spectrometer in the LC extraction line can make real-time measurements of both the nominal beam energy (to 200 ppm) and the energy distribution of the disrupted beam. The disrupted beam energy distribution is sensitive to details of the collision process, and can be used as one of several real-time diagnostics to stabilize machine operation. A stable beam energy distribution will simplify analysis of threshold scans.

We propose to study the feasibility of an SLC-style energy spectrometer in a LC extraction line. The study will simulate the NLC extraction line and the spectrometer in order to understand the changes required in the extraction line design, the requirements on the spectrometer, and the tradeoffs between the two. In this manner we expect to produce specifications for the spectrometer, just as the physics detector design is driven by specifications from the simulation of important physics processes.

The energy spectrometer concept

The study will consider a spectrometer similar to that used to measure the beam energy in the Stanford Linear Collider (SLC) at SLAC, illustrated below. Before the spectrometer analyzing magnet, the beam passes through a dipole magnet with its field perpendicular



to that of the analyzing magnet. The resulting synchrotron radiation (SR) “stripe” marks the direction of the incoming beam. Similarly, SR generated in a dipole magnet beyond the analyzing magnet marks the direction of the outgoing beam. Measurement of the stripe separation determines the bend angle and the beam energy. With appropriate beam optics, the incoming SR stripe is narrow, and the dispersion due to the analyzing magnet produces a broad stripe from the outgoing beam, which is a measure of the beam energy distribution.

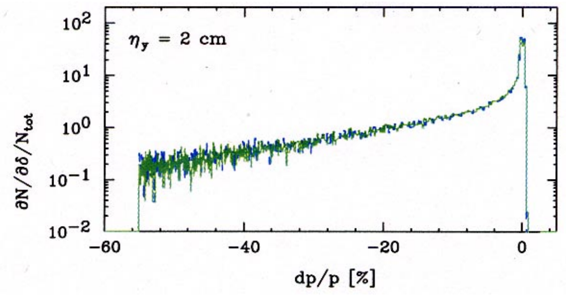
At SLD the SR stripe separation was measured by detecting the secondary emission signals resulting from SR incident on fine wire arrays. Although we are unlikely to address specific detector technologies in the initial stage of this study, we suspect this is not the optimal technology in the LC environment. We will, however, determine the requirements on the detector used to measure the stripe separation.

The accuracy of the spectrometer depends primarily on the analyzing magnet field map, knowledge of the relative orientation of the SR stripes, the SR detector resolution, and surveys of the detector geometry and magnet locations. In operation, the beam trajectory must be controlled within constraints set by these considerations. At SLC the dominant systematic error was the uncertainty in the SR stripe rotations.

Description of first year project activities

Getting started

The NLC extraction line design includes a chicane, in which beam diagnostics are located. Nosochkov and Raubenheimer have studied measurement of the disrupted beam energy distribution, shown here, with a wire scanner at the secondary focus in the chicane. The results are promising, but a wire scanner is invasive, and cannot provide real-time information. We will initially reproduce this study using existing files of disrupted beam trajectories generated by the Guinea Pig code to simulate the beam entering the extraction line. After the additional spectrometer magnets are added to the DIMAD deck, we can compute the SR at the spectrometer detector plane.



Extraction line

Changes in the extraction line might be required if the current small chicane bends do not allow for a SR exit window in the beam pipe, or for the detector to be placed in the SR beams. Another concern is that the small bends might require a detector with the resolution of solid state devices, which may not be suitable for this environment. Alternatively, one could use a mirror to get the SR away from the chicane, and reduce constraints on the detector. In this case we must know the SR heat load on the mirror under a range of conditions, and this raises a number of new issues.

The SR detector

Once the SR at the spectrometer detector plane has been computed, we can study the effects of detector resolution on determination of the nominal energy and the energy distribution. These results will be compared with estimates from simple 'hand' calculations. We will also explore how further extraction line modifications might ease detector requirements.

For a fixed bend angle the SR energy scales as the cube of the beam energy, a factor of ~23 from $t\bar{t}$ threshold to 1 TeV c.m. energy. As this might be a problem for some detector technologies, we will explore varying the geometry to reduce the energy range. However, the disrupted beam energy tail is so broad that the detector must always handle a large range of SR energies, and a correlated range of SR power.

Systematic errors

The dominant systematic error from SR stripe rotations can be studied by simulating the effect of magnet rotations. We will simulate measurement of the relative SR stripe rotation with a beam scan, and again study the effect of the SR detector resolution. Simulation of field irregularities in the spectrometer magnets, and related errors due to orbit variations, seems more difficult, but will be considered.

Any energy measurement has to be corrected for energy loss due to synchrotron radiation between the IP and the spectrometer. We will evaluate this, and its sensitivity to beam orbits, in order to understand the systematic error introduced by this correction.

For threshold scans one must know, to ~1%, the fraction of the beam in the long low energy tail. (D. Cinabro, LCWS 2002) This is the initial goal for measurement of the energy distribution, but we will consult accelerator physicists for additional criteria. We will want to understand the effect of the beam optics, and of any correlation among beam parameters, *e.g.*, energy and angle, that might invalidate the interpretation of the SR stripe width as the energy distribution at the desired accuracy.

First year deliverables

At the end of this study we should understand the requirements on the SR detector resolution and on other aspects of the spectrometer in order to achieve the desired accuracy for the beam energy and energy distribution measurements. We will also determine how well the beam trajectory must be controlled in the spectrometer, and will provide information on the SR photon energies and fluxes to be expected. We should also understand the tradeoffs among the choices, including changes to the extraction line.
In summary, the study should:

- Integrate the spectrometer into the extraction line design.
- Determine specifications for the spectrometer SR detector.
- Understand tradeoffs between extraction line modifications and spectrometer specs.
- Evaluate sources of systematic errors, and their sensitivity to beam orbit variations.
- Perhaps study intra-train variations and the need for bunch-by-bunch monitoring.

Future activities

There may be aspects of the initial study which warrant additional work. A natural extension of this work would be the study of specific SR detector technologies, such as the quartz fiber Cerenkov detector under consideration by the University of Oregon. One issue of concern is the response of the detector to the range of SR energy spectra, and how the beam energy distribution can be unfolded from the detector response. The detector studies could be done either by the detector proponents, in the context of the results of this study, or jointly with UMass.

The working group leaders have pointed out that this study is indirectly useful in planning the Compton polarimeter design. Indeed, at some point the compatibility of the spectrometer design with all other post-IP diagnostics will be a consideration.

The 200 ppm specification is believed to be adequate for the high energy LC physics program, with the exception of the W mass determination, which requires about 50 ppm accuracy. This accuracy may require calibration at the Z pole, and considerations beyond the scope of the currently proposed study. This could be a future extension of the study.

Personnel

Prof. Hertzbach is one of two UMass faculty who shared on-site responsibility for the SLC energy spectrometer during 1996-1998, the last 3 years of SLD running. As part of ongoing work on NLC backgrounds, he is interfacing the DIMAD beam tracking code with the old standalone QSRAD code for computing SR fluxes. This package, and the (currently modest) familiarity with DIMAD, will be useful in the proposed study.

Melissa Motew is a senior UMass physics major, who will complete her degree requirements in December 2002, and is available to work on this project full time until starting graduate school in fall 2003. The project is a good match to her background and an interest in instrumentation. Ms. Motew shared the Physics Department Hasbrouck Award for the outstanding junior major, and was awarded the Youngren Scholarship for undergraduate research by the College of Natural Sciences and Mathematics.

Ms. Motew has worked with the UMass experimental HEP group since the summer of 2001, when Profs. Blaylock, Dallapiccola, and Willocq organized an undergraduate research program. The students were introduced to aspects of high energy physics, accelerators, detectors, statistics, and the tools of HEP analysis. The goal of her most recent project is to study and document the behavior of neural networks, and to use neural networks to improve the spatial and energy resolution of the BaBar calorimeter.

Prof. Blaylock was responsible for implementation of the SLD version of the SLC spectrometer and its data acquisition. He will be on sabbatical leave, and is not formally part of this proposal, but will be available for consultation.

Budget

The requested budget is entirely for the support of Ms. Motew's activities. Included is salary for 32 weeks, January through August 2003, during which period she will work full time on this project. In addition, we request travel funds for Ms. Motew. She will visit SLAC early in the project for orientation, and to get started. We also anticipate that she will travel to SLAC during summer 2003, when Prof. Hertzbach will be at SLAC, and/or to a meeting of the American Linear Collider Physics Group.

Institution	**Item**	**Cost**
UMass	Salary for Ms. Motew (32 weeks)	$ 10,240
UMass	Fringe Benefits (FICA, Workers' Comp)	244
UMass	Travel for Ms. Motew	2,500
UMass	**Subtotal: Total Direct Cost**	**12,984**
UMass	UMass Indirect costs (55%)	7,141
UMass	**Total**	**$ 20,125**

Note: this document is formatted using Microsoft Word, Times New Roman 12 pt. font, 1 inch top and bottom margins, 1.25 inch left and right margins.

3.4. Quartz fiber Cerenkov detector for precision beam energy spectrometer (LCRD)

Luminosity, Energy, Polarization

Contact person: Eric Torrence
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Oregon

FY 2003: $14,899

Project name

Quartz fiber Çerenkov detector for precision beam energy spectrometer

Classification

Beam Instrumentation (Luminosity, Energy, Polarization)

Institution(s) and personnel

University of Oregon, Department of Physics:
Eric Torrence (professor), Paul Csonka (student)

Contact person

Eric Torrence
torrence@physics.uoregon.edu
(541) 346-4618

Project Overview

A measurement of the absolute beam energy with a precision approaching 10^{-4} is needed for many of the physics analyses foreseen at a future LC. One possible scheme to realize this precision is to improve upon the WISRD spectrometer built and operated at the SLC. In this scheme, two horizontal dipole magnets produce stripes of synchrotron radiation which are detected at a downstream target. The separation between these stripes, provided by the bending of a third vertical dipole magnet, is then inversely proportional to the beam energy. One of the dominant systematic errors in the SLC WISRD design was the absolute alignment accuracy of the copper wire arrays used as the downstream synchrotron radiation detector.

We propose to develop a different detector technology for position sensitive detectors using the Çerenkov light produced in an array of fused quartz fibers read out by multi-anode photomultiplier tubes (PMTs). While quartz fibers have been used as the sensitive material in calorimeters for some time, the application of this technique as a position sensitive detector is less common. The advantages of this technology over traditional solid-state detectors like silicon strips are threefold. First, the fused silica fibers are very radiation hard. Second, the Çerenkov threshold of electrons in quartz at E ~ 0.7 MeV provides some tolerance to backgrounds from very soft photons. Third, the PMT readout can in principle be fast enough to keep up with the 1.4 ns bunch spacing of the NLC bunch train allowing for pulse-to-pulse measurements. With typical fiber diameters of ~100 microns, a very finely segmented fast detector can be designed which can operate in the hostile environment near the LC beam line.

This work is being proposed as a single component of the larger effort to produce a reasonable design for a WISRD-style spectrometer for the NLC. The simulation work being proposed by Hertzbach at U.Mass is clearly necessary to specify in detail the desired performance and characteristics of this detector, and we intend to work together as this detector study matures to evaluate whether this technology is a suitable candidate for the final design

This research is currently motivated by the needs of a beam energy spectrometer, but a similar detector could also be useful in various other applications, for example a precision position measurement of the kinematic endpoint in the Compton polarimeter, or imaging synchrotron radiation for other machine diagnostics.

Description of first year project activities

An excellent undergraduate student (Paul Csonka) is currently working with the Oregon group to characterize a pair of Hamamatsu H6568 multi-anode PMTs. With 16 channels per tube, sub-nanosecond rise time, and a very compact profile, these tubes appear to be a suitable solution for the readout of a Quartz fiber Çerenkov detector. This current study will provide a full characterization of the gain, linearity, crosstalk, and stability characteristics of these tubes.

In the coming year, Paul is interested in pursuing the design, construction, and testing of a small prototype fiber array detector as a senior honors research thesis. The idea is to produce a 32 fiber prototype with four detector planes of eight fibers each which will provide a four-fold coincidence for ‘tracking’ incident particles. It is envisioned to use low energy O(1 MeV) electron sources to characterize the performance of this detector.

Since this detector is intended to be sensitive to O(2 MeV) photons rather than electrons, it will also be important to optimize the amount of material used to convert the photons while maintaining a reasonable detection efficiency. We also intend to test a variety of mechanical designs for the fiber array itself to improve the accuracy and stability of positioning the fibers themselves. At the end of his work, Paul will be required to produce a thesis documenting this project.

Most of the equipment needed for this project including shop facilities, data acquisition infrastructure, and the PMTs are available already at the University of Oregon. Support is requested for the student’s salary, some miscellaneous optics supplies, and enough channels of ADC to read out the full prototype module.

Future Activities

Beyond the first year, future work is likely to include a refinement of the prototype design to optimize the performance and cost of a full scale detector. In addition, more detailed design studies, including background estimates, in collaboration with the U.Mass group will be required to advance towards a complete spectrometer design. At Oregon, we are also particularly interested in using a WISRD-style device to measure the shape of the beam energy spectrum in addition to the mean beam energy scale. Further simulation work will be necessary to verify the feasibility of using a Quartz fiber detector for this measurement, or whether other detector technologies should be pursued.

A beam test of a prototype detector would also be highly desirable, and stands as one of the long term goals of this work. One suitable location would be the SLAC A-line where a large bending dipole produces a synchrotron radiation stripe comparable to that needed for a WISRD-style spectrometer. Potentially a beam test could be designed which also includes a prototype of the BPM-style spectrometer proposal being pursued by Hildreth at Notre Dame, thereby testing all beam energy measurement techniques currently foreseen at the NLC.

Eventually, the development of a fast data acquisition system capable of handling the ~1 ns NLC bunch structure will also be required, but it is envisioned that current proposals to develop electronics for other NLC detector components can be leveraged for the spectrometer application as well.

First Year Budget

Institution	Item	Cost
Oregon	Summer + academic year undergraduate salary	$6,500
Oregon	CAEN V792 32ch VME Charge ADC	$4,325
Oregon	Other materials (fibers and assorted optics tools)	$1,000
Oregon	Indirect costs (26%)	$3,074
	Total	$14,899

3.5. A Demonstration of the Electronic and Mechanical Stability of a BPM-Based Energy Spectrometer for an e+e- Linear Collider
(UCLC)

Luminosity, Energy, Polarization

Contact person: Mike Hildreth
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phone: (574) 631-6458

Notre Dame

FY 2003: $54,000
FY 2004: $155,000
FY 2005: $153,000

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

Michael D. Hildreth, University of Notre Dame

Collaborators

Young-Kee Kim, Yury Kolomensky, Lawrence Berkeley National Laboratory and University of California, Berkeley

Joe Frisch, Peter Tenenbaum, Stanford Linear Accelerator Center

Contact Person

M. Hildreth
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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_{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_{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 ($\delta E_{\mathrm{beam}}/E_{\mathrm{beam}} \sim 1-2\times10^{-4}$) 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 $\delta E_{\mathrm{beam}}/E_{\mathrm{beam}} \sim 3\times10^{-5}$ (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 $\delta E_{\rm beam}/E_{\rm beam} \sim 1 \times 10^{-4}$ 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 $\delta E_{\rm beam}/E_{\rm beam} \sim 2 \times 10^{-4}$, 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 $\delta E_{\rm beam}/E_{\rm beam} \sim 2 \times 10^{-4}$, 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.

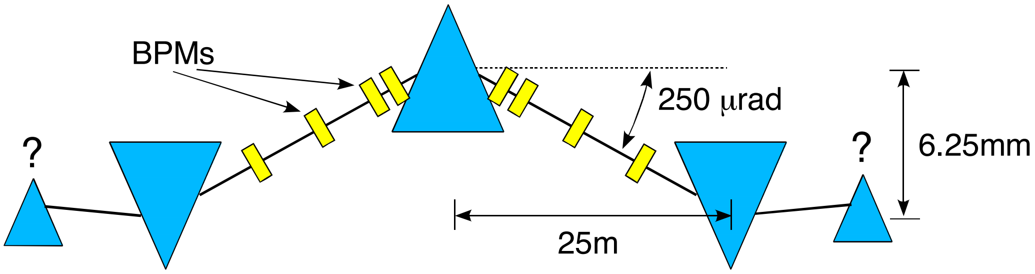

Figure 1: A schematic outline of an accelerator dipole chicane which could accomodate a BPM-based magnetic spectrometer at a future linear collider.

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 componononents; 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

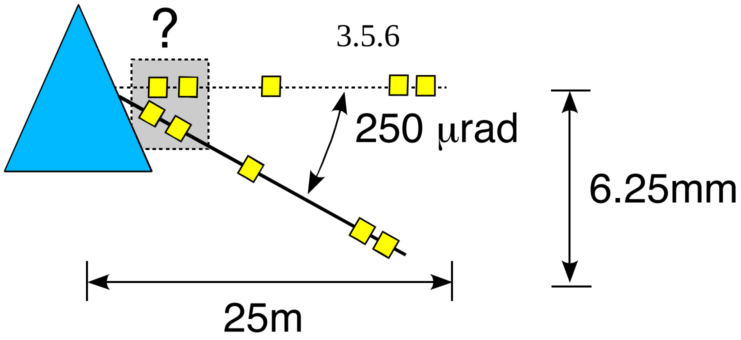

Figure 2: A diagram showing the two cases of: straight-ahead linear trajectory measurement to establish zero deflection; and the motion of the BPMs necessary to measure a deflection of 250μrad. The "?" indicates that it may be possible to design a system with sufficient accuracy that the closest BPM 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

References

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[2] P. Garcia, W. Lohmann, A. Rasperezea, *“Measurement of the Higgs Boson Mass and Cross section with a linear e^+e^- Collider”*, LC-PHSM-2001-054, available from `http://www.desy.de/∼lcnotes/`.

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B. Dehning, *et al.*, *“Status of the LEP-2 Spectrometer Project”*, CERN-SL-2000-038-BI, July 2000, in Proceedings of the 7th European Particle Accelerator Conference, Vienna, Austria, 26 - 30 June 2000. European Physical Society, Geneva, 2000.

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[9] T. Slaton, G. Mazaheri, and T. Shintake, *“Development of Nanometer Resolution C-Band Radio Frequency Beam Position Monitors in the Final Focus Test Beam”*, SLAC-PUB-7921, August 1998.

3.6. Polarimetry at LC
(LCRD)

Luminosity, Energy, Polarization

Contact person: Yasar Onel
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phone: (319) 335-1853

Fairfield
Iowa
Iowa State

FY 2003: $10,000

Proposal to the
University Consortium for a Linear Collider

August 21, 2002

Proposal Name

Optimization of LC detector elements for physics analysis.

Classification (accelerator/detector: subsystem)

Detector: calorimeter (+ tracker).

Personnel and Institution(s) requesting funding

Kelby Andersen, Ed Blucher, Frank Merritt, Mark Oreglia, James Pilcher (University of Chicago)

Collaborators

Argonne National Lab, Northern Illinois University

Contact Person

Mark Oreglia
m-oreglia@uchicago.edu
(773)-702-7446

Project Overview

While much work has been done on the development of individual detector elements for LC detectors, no optimization has been performed to coordinate properties (such as granularity) amongst the tracker and EM+HAD calorimeters for physics analysis. For instance, an analysis tool receiving much attention currently is "energy flow", an aggregate quantitity constructed from tracking and calorimetry information. Without bias towards tracking and calorimetry technologies, we propose to develop simulations of benchmark physics analyses for a variety of detector parameters. More specifically, we propose to focus on minimal Standard Model Higgs boson production (and the main backgrounds) as our physics benchmark. Using current expertise we have in studies of the ATLAS calorimeter, we intend to create energy flow, jet definition, and jet-jet mass algorithms tailored to several choices of calorimeter granularity and longitudinal segmentation; a third parameter would be the particular calorimeter material and its response to different particle types. From these studies we hope to optimise Higgs boson mass resolution and the signal-to-background sensitivity.

In addition to the simulation-based studies, we will develop readout electronics for calorimeter prototypes under study at ANL and NIU. The goal of this electronics development is to beam-test prototypes on a short time scale. For both the simulation work and the electronics design, we anticipate collaborative work with ANL and NIU. In particular, NIU is helping to develop the standard ALCPG simulation package, for which we envision developing a GRID implementation.

A number of institutions are expressing interest in working on "energy flow" (in addition to those mentioned already: U of Illinois at Chicago, U of Kansas, U of Texas at Arlington, U of Colorado, Boston U, U of Oregon, and SLAC). Our group at the University of Chicago is currently working on energy flow assessment and jet definition software for the ATLAS detector at the LHC, and this activity already is being conducted in collaboration with ANL. Thus, it is logical for our group to embark on such studies for the LC, and we intend to do this within the auspices of the LC calorimetry group which is coordinating the activities of the various institutions. However, it is worth noting that the project proposed in this proposal is different from energy flow development insofar as the main target of the study is to optimize the detector systems; energy flow is only one aspect of physics analysis which will be considered.

We expect to have sufficient manpower to produce significant results within the three-year period. Andersen, Blucher, and Oreglia are senior personnel who will devote significant effort to the project. Other senior personnel are performing similar research for the ATLAS experiment and will contribute greatly through their instruction of students and the postdoc(s).

Outreach in this program will be realized through the participation of 2-6 undergraduate students, both University of Chicago students and also REU students from other universities. Every summer, the University of Chicago Physics Department supports 15-20 female and minority undergraduates to participate in physics research programs; we expect to be able to support two of these REU students in the proposed research.

FY2003 Project Activities and Deliverables

In year-1 we will develop a simulation package based on the existing framework, but with more general treatment of the calorimeter options. Using this tool, we will generate datasets of standard physics processes. At the same time, we will be able to integrate into the detector simulations group to develop further the framework for Monte Carlo simulation of physics processes in the 2 standard detector configurations. This study will involve development of (or modification of existing) algorithms for energy flow, jet definition, and jet energy scaling suited to the Higgs boson analysis under study. We especially expect to benefit from comparisons of similar techniques under development by our group for use with the ATLAS detector at the LHC.

Additionally, the new EFI/ANL GRID computing team has expressed interest in creating a platform for large-scale Monte Carlo production which we intend to use for the LC studies.

FY2004 Project Activities and Deliverables

During year-2, physics analyses will be refined and comparisons of signals and backgrounds will be made for the range of detector parameters under consideration. At this point we will be able to comment on how calorimeter technologies under consideration compare to the optimization of our study.

In this year we will also develop electronics for calorimeter prototypes and beam tests of ANL and NIU calorimeter prototypes. The Chicago EFI electronics design group has a long history of development of such systems, and has recently designed the hadron calorimeter electronics for ATLAS. We feel that the ATLAS design can be exploited at low overall design cost.

FY2005 Project Activities and Deliverables

In year-3 decisions on the calorimeter technology should have been made, and we will refine the design of calorimeter electronics. We will also support development of physics analysis and the use of GRID networking for the generation of large Monte Carlo datasets.

Budget justification

The first-year budget supports only undergraduate research assistants and travel. In the remaining years a graduate student is taken on and also a postdoctoral RA is added (at the 50% level in year-2 and full time in year-3); the travel allowance is increased accordingly. The “Other direct” category is for graduate student tuition.

Three-year budget, in then-year K$

Institution: University of Chicago

Item	FY2003	FY2004	FY2005	Total
Other Professionals	0	22	45	67
Graduate Students	0	21	21	42
Undergraduate Students	6	6	6	18
Total Salaries and Wages	6	49	72	127
Fringe Benefits	1	5	10	16
Total Salaries, Wages and Fringe Benefits	7	54	82	143
Equipment	0	0	0	0
Travel	3	5	10	18
Materials and Supplies	0	0	0	0
Other direct costs	0	12	14	26
Total direct costs	10	71	104	185
Indirect costs	5	31	48	84
Total direct and indirect costs	15	102	152	269

3.7. Compton polarimeter backgrounds (LCRD)

Luminosity, Energy, Polarization

Contact person: William Oliver
email: william.oliver@tufts.edu
phone: (617) 627-5364

Tufts

FY 2003: $28,000

Project name

Compton polarimeter backgrounds

Classification (accelerator/detector:subsystem)

Accelerator

Institution(s) and personnel

Tufts University, Department of Physics and Astronomy
William P. Oliver, Professor of Physics

Contact person

William Oliver
william.oliver@tufts.edu
(617) 627-5364

Project overview

Beam polarization is an important feature of the future electron-positron linear collider. The beams can be polarized to enhance the expected Standard Model physics processes, or can be polarized in the opposite sense to suppress the SM background in the search for new physics processes.

An electron beam polarization of 77% was achieved in the operation of the SLC in 1995 for the SLD experiment. The electron polarization was measured to an accuracy of 0.5% using a Compton polarimeter [1]. The polarization was determined by measuring the rate asymmetry of electrons Compton-scattered from a circularly polarized laser beam. The rates were measured near the kinematic endpoint for back-scattering to obtain the largest possible asymmetries hence the greatest possible sensitivity to the beam polarization.

The future linear collider will have beams that are much more intense and more sharply focused than the beams at the SLC. As a result there will be a greater disruption of the beams at the interaction point due to the collective action of the particles in one bunch on the particles in the colliding bunch. In addition to the disruption of the primary beams, the collective action generates two secondary gamma ray beams (beamstrahlung) which have roughly 5% of the power of the colliding beams and are primarily at angles of less than 0.2 mrad to the beam axis. The intense beams at the future linear collider might generate such high backgrounds that it will be necessary to modify the polarization-measurement techniques used so successfully at the SLC [2]. It is the central feature of our proposal that we calculate these backgrounds to determine if design modifications are required.

In the Zeroth-Order Design Report for the Next Linear Collider, the NLC Design Group describes a beam extraction and diagnostic system in which bending magnets separate the primary beams from the beamstrahlung beams to offer two distinct possibilities for monitoring the effects that occur at the interaction point. Because of the high power (10 MW for the primary beams, 0.5 MW for the beamstrahlung beams) the monitors must be able to operate with a minimal amount of material intercepting the beams. Following the monitoring region, bending magnets are used to recombine the primary and beamstrahlung beams and direct them to a common dump.

The ZDR describes a Compton polarimeter in which a circularly polarized laser beam intercepts the primary beam in the separated beam region downstream of the interaction point. In this region the charged particle beam has a dispersion of 20 mm, consequently a laser beam of 50-micron diameter samples the primary beam within a narrow momentum range of 0.25%. The electrons scattered from the laser beam proceed forward to pass through a magnetic spectrometer formed by the downstream bending magnets. The laser-scattered electrons that emerge from the spectrometer are offset from the recombined charged particle beam (and the beamstrahlung beam). For a primary energy of 250 GeV, the electrons scattered from a 1.17 eV laser beam at the kinematic limit for back-scattering have an energy of 46 GeV and are offset by 9 cm from the beam axis in the region downstream of the spectrometer. The detection element of the polarimeter is a Cerenkov counter which is segmented to isolate electrons within certain definite ranges of offset. The rate asymmetry in the Cerenkov counter for oppositely polarized primary beam particles (or oppositely polarized laser beams) is measured to deduce the polarization of the primary beam. The Cerenkov counter segment at 9-cm offset detects the back-scattered electrons thus provides the greatest sensitivity to the beam polarization.

We propose to calculate the background expected in the segmented Cerenkov counter to determine if the current design for the NLC polarimeter provides a signal-to-background ratio adequate to achieve an accurate measurement of the beam polarization. We will calculate the effects of a variety of physics processes to determine the particular sources which produce the most background in the Cerenkov counter.

The principal concern to us is the effect of the 500-kW beamstrahlung beam. The beam axis passes within 9 cm of the segmented Cerenkov counter. Downstream of the spectrometer the beamstrahlung has spread considerably but still remains predominately within 2 cm of the beam axis. However the beam is so intense that the relatively low flux of gamma rays outside the core might still be able to produce effects that seriously degrade the performance of the Cerenkov counter. Since the Cerenkov counter is not in the beam vacuum system there must be a thin window to allow the Compton-scattered electrons to escape the vacuum. The pipe that provides the mount for the thin window must necessarily have a wall located between 2 cm and 9 cm from the beam axis. The wide-angle gamma rays of the beamstrahlung beam could produce electromagnetic showers in the pipe walls that spray background particles into the Cerenkov counter at a rate such that the signal from the Compton-scattered electrons is significantly obscured..

Another background source is the particles from the interaction point which have been scattered at relatively large angles or with relatively large energy losses due to the disruption effects. The transport of these particles through the beam extraction and diagnostic system may not be accurately portrayed by a matrix-element approach. We propose to track these highly scattered particles through the beam extraction system to determine if they pass close enough to the Cerenkov counter to produce substantial background effects.

Description of first-year project activities

We propose in the first year to support a graduate student working full-time carrying out the background calculations for the Compton polarimeter. We propose to begin by importing to Tufts beam-beam interaction software packages (possibly including ABEL or GUINEA-PIG) which are in the public domain. These packages will be used to calculate the beamstrahlung and the disruption of the electron and positron beams at the interaction point. If some aspects of these packages are insufficient for our purposes we would work to extend their capabilities.

We propose to first calculate the backgrounds to be expected due to the interactions of the beamstrahlung beam in the unavoidable material elements in the beam extraction system such as the walls of beam pipes. For this purpose we will construct a GEANT model of the beam extraction system and the segmented Cerenkov counter. The GEANT package will call on EGS to perform the electromagnetic shower simulations. We propose to continue by importing software packages (possibly including TURTLE) so we can proceed to calculate the trajectories of the highly scattered beam particles emerging from the interaction point as they proceed through the beam extraction system. We will determine the extent to which these particles reach the vicinity of the Cerenkov counter and produce background. Finally we will compare the flux of background particles we have calculated to the flux of electrons Compton-scattered from the laser beam to determine if the signal-to-background ratio is large enough to enable an accurate measurement of the beam polarization.

This project provides a good opportunity for a graduate student to learn the challenges and opportunities of a future linear collider. The student would acquire skills essential for an effective contribution to the development of the collider and could acquire the inspiration required to stay with the linear collider project over the long term.

Future work

We want to work in cooperation with the IP Beam Instrumentation Working Group at SLAC. If our simulation work leads to the conclusion that the Compton polarimeter in its present design is vulnerable to expected background, we want to help guide whatever design modifications may be required to achieve a sufficient signal-to-background ratio. We want also to participate in any beam tests of Compton polarimeter prototypes that are carried out in the next few years.

Budget

Institution	Item	Cost
Tufts	Academic year + summer salary for one full-time graduate student	$20,000
Tufts	Indirect costs	$8,000
	Total	$28,000

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   Compton polarimetry at a 1-TeV collider. M. Woods, Int. J. Mod. Phys. A **13**, 2517 (1998), e-print hep-ex/9802009.

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3.8. Beam-beam collision monitoring using Large Angle Beamstrahlung (UCLC)

Luminosity, Energy, Polarization

Contact person: Giovanni Bonvicini
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phone: (313) 577-1444

Wayne State

FY 2003: $8,000
FY 2004: $90,000
FY 2005: $99,000

Proposal to the
University Consortium for a Linear Collider

August 21, 2002

Proposal Name

Beam-beam collision monitoring using Large Angle Beamstrahlung

Classification (accelerator/detector: subsystem)

Accelerator: beamstrahlung monitor

Personnel and Institution(s) requesting funding

Giovanni Bonvicini, David Cinabro, Mikhail Dubrovin, Wayne State University

Collaborators

Yulin Li, Cornell University

Contact Person

Giovanni Bonvicini
giovanni@physics.wayne.edu
313-577-1444

Project Overview

One of the greatest challenges for the successful operation of a Linear Collider (LC) will be to monitor the beam-beam collision. A device which directly observes the transverse sizes of the beams, their offsets, and relative orientation at the collision point and which can be used as soon as the machine turns with weak beams would be an invaluable monitoring and diagnostic system for the LC. We have described a technique using wide angle beamstrahlung photons [1]-[4] that passively and precisely observes the beam-beam collision region and measures the transverse sizes, offsets and orientations with an accuracy better than 10%. Beamstrahlung photons preserve in their polarization information about the forces and torque exerted by one beam on the other. This information is presented concisely in the beamstrahlung diagram which can be used to study and optimize the delivered luminosity [2].

We obtained a three year NSF Major Research Instrumentation grant in September 2001 to build a device to study large angle beamstrahlung at CESR. At this writing we have installed a single-arm, one PMT prototype in the CESR/CLEO interaction region at an angle of 11 mrad from the beam axis. We have obtained data by varying the observation angle, the beam energy, the PMT spectral response (visible, red, or infrared), and the beam-beam offset. We have developed techniques to point the device, which has an angular acceptance of approximately 2×2 mrad^2, to the IP and observe that backgrounds are consistent with our predictions. Specifically in the infrared at nominal CLEO-c conditions we expect the signal rate to be of order $10^2 - 10^3$ times the background. Work to do includes

1. observation of large angle beamstrahlung
2. full installation of a four armed system as described in [4]
3. construction of the beamstrahlung diagram and confirmation of its properties

4. integration of the beamstrahlung system into CESR/CLEO operations to maximize delivered luminosity

The system can also be used to study the beam-beam limit and, with the addition of fast-gating electronics, bunch-to-bunch differences. We have already noted the limitation that the system is not sensitive at low beam currents which are typically used in machine studies.

Our recent studies have focused on coherent beamstrahlung which has not been previously considered. Coherence occurs at wavelengths longer than the bunch length when the beams have a non-zero offset at the collision point. A system that is sensitive to coherent beamstrahlung will provide many benefits including sensitivity to small beam currents and the ability to measure the bunch length by studying the wavelengths of the coherent radiation. At an LC we have considered the spectrum of coherent beamstrahlung as shown in Figure 1. Note that a measurement of the discrete wavelength pattern of coherent beamstrahlung determines the bunch length and the coherent power is enhanced my many orders of magnitude over the incoherent. A system sensitive to coherent beamstrahlung will be sensitive at low beam currents due to the power enhancement and will be able to measure bunch lengths with high accuracy by observing the power spectrum. We are working on a paper describing the properties of coherent beamstrahlung.

We would like to develop the design of a coherent beamstrahlung system for an LC. The incoherent beamstrahlung detector design would start from the suggestion of our former graduate student G. Sun to use elliptical gratings to separate light from the IP and background light[5]. We would like to design and build a coherent beamstrahlung detection system and operate it at LINX[6], which would be an ideal prototype for an LC system, or, if that project does not go forward, at CESR. What we learn from this prototype would be used to design a coherent beamstrahlung device for the LC. Note that at LINX or the LC with bunch lengths of $\sim 100\ \mu$m the coherent beamstrahlung radiation is in the infrared while at CESR with bunch lengths of ~ 1 cm it is in microwaves.

FY2003 Project Activities and Deliverables

Work will be continuing on the funded MRI incoherent beamstrahlung system at CESR. We will make a preliminary design for an LC beamstrahlung monitor system including both incoherent and coherent beamstrahlung radiation detectors.

FY2004 Project Activities and Deliverables

Complete design and simulation studies for an LC beamstrahlung monitor system. Begin design and construction of an incoherent beamstrahlung monitor at LINX preferably or CESR.

FY2005 Project Activities and Deliverables

Install and operate a coherent beamstrahlung detector. Refine the design of an LC beamstrahlung monitor system.

3.8.5

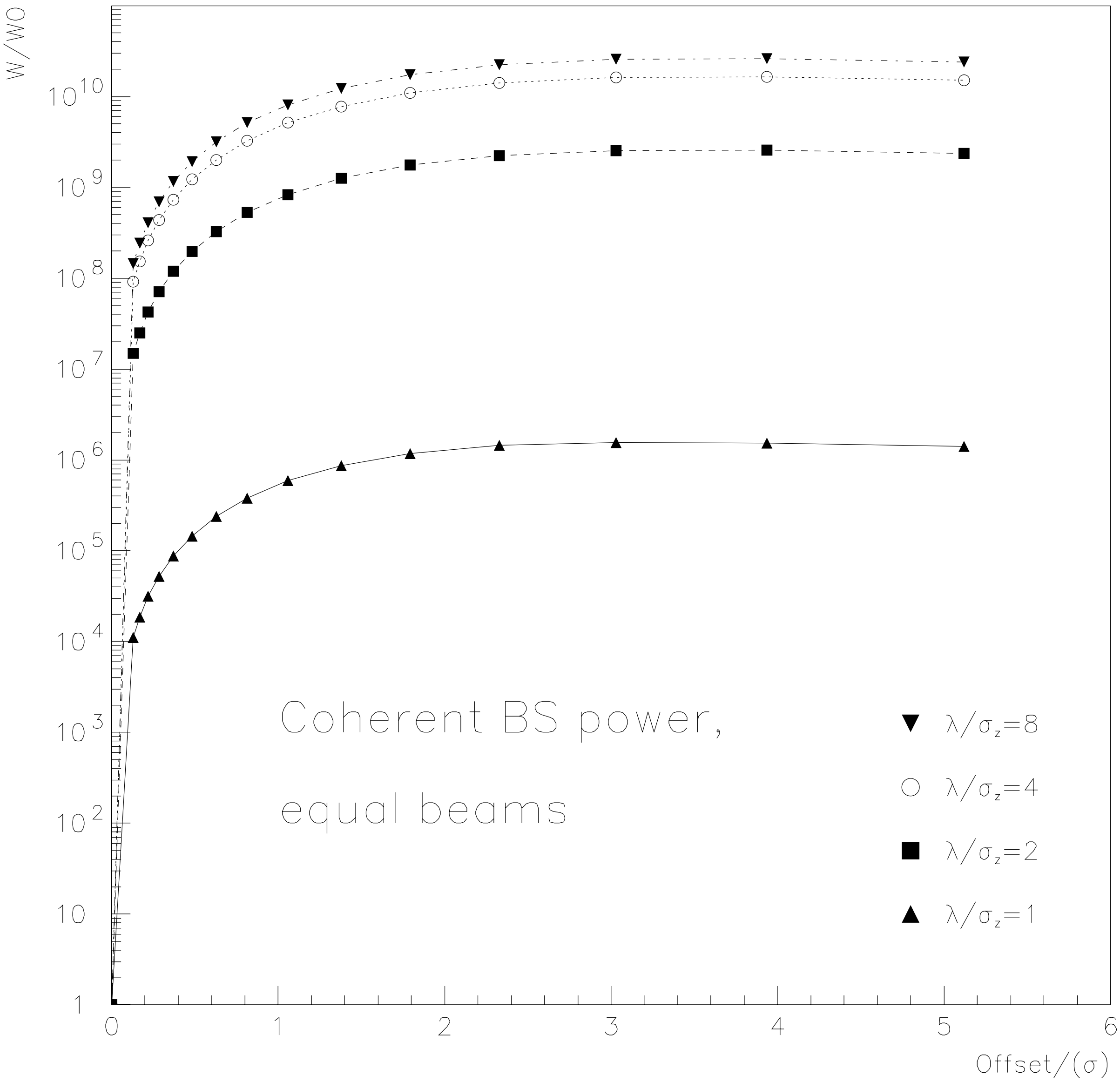

Figure 1: Long wavelength coherent beamstrahlung power, normalized to the zero-offset total incoherent beamstrahlung power at a 500 GeV LC, as a function of the beam-beam offset. and beam length, $r = \lambda/\sigma_z$. The curves for $r = 4$ and $r = 8$ are nearly identical, pointing to the onset of complete coherence. The curve was computed using beams with ten times less current than nominal conditions.

Budget justification

In year 1 some travel money to aid LC collaboration. In year 2 the equipment for the coherent beamstrahlung system and the continuation of funding for our MRI supported post-doc. In year 3 equipment for installation and operation of the coherent beamstrahlung system and continued funding for our post-doc. The post-doc will be doing the design and construction activities discussed above. Indirect costs are 49% of non-equipment costs.

Three-year budget, in then-year K$

Institution: Wayne State

Item	FY2003	FY2004	FY2005	Total
Other Professionals	0	30	40	70
Graduate Students	0	0	0	0
Undergraduate Students	0	0	0	0
Total Salaries and Wages	0	30	40	70
Fringe Benefits	0	7	10	17
Total Salaries, Wages and Fringe Benefits	0	37	50	87
Equipment	0	20	10	30
Travel	5	10	10	25
Materials and Supplies	0	0	0	0
Other direct costs	0	0	0	0
Total direct costs	5	67	70	142
Indirect costs	3	23	29	55
Total direct and indirect costs	8	90	99	197

References

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[3] G. Bonvicini, CESR Colliding Beam Note, CBN-98-12.

[4] N. Detgen *et al.*, CESR Colliding Beam Note, CBN-99-26.

[5] G. Sun, CESR Colliding Beam Note, CBN-98-13.

[6] http://www-project.slac.stanford.edu/lc/linx/

3.9. Development of thin, fast, radiation hard, 3d-electrode array, silicon radiation sensors
(LCRD)

Luminosity, Energy, Polarization

Contact person: Sherwood Parker
email: sher@slac.stanford.edu
phone: (510) 841 2012

Hawaii

FY 2003: $23,517

Project name

Development of thin, fast, radiation hard, 3D-electrode array, silicon radiation sensors

Classification (accelerator/detector:subsystem)

Accelerator—L.E.P. (part of a possible beam monitor system)

Institution and personnel

University of Hawaii, Department of Physics: Sherwood I. Parker (faculty)

Contact person

Sherwood Parker, sher@slac.stanford.edu, 510 841 2012, 510 486 5859

Project Overview

We propose the development of silicon sensors with closely spaced electrodes that penetrate the silicon substrate for uses where either (1) extreme speed, (2) radiation hardness or (3) the ability to detect particles very close to the beam pipe is important. A beam monitor using the process $\gamma\gamma\rightarrow e^+e^-$ that makes use of these properties will be described.

The Sensors

Working in collaboration with Christopher Kenney of the Molecular Biology Consortium and Cinzia Da Via, Jasmine Hasi (currently stationed at the Stanford Nanofabrication Facility), Angela Kok, and Gennaro Ruggiero of Burnel University, we have fabricated and tested such sensors having a thickness of 120 microns. (See Figure 1.)

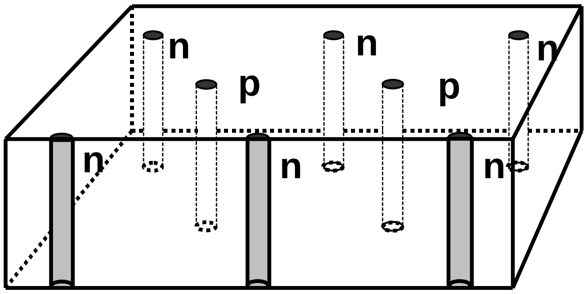

Figure 1: Drawing of part of a 3D sensor with a section through a row of n electrodes.

Initial calculations indicated it should be possible to have sensors with low depletion voltages (5-10V), and great speed and radiation resistance [1]. Published data now show:

1. depletion voltages as low as 5-10V [2],

2. depletion voltages of only 105V after irradiation by 10^{15} 55 MeV protons/cm^2 with a plateau to 150V for sensors without added oxygen and without beneficial annealing [3],

3. a Gaussian fit with $\sigma(E)/(E)$ of 2% to the 14 KeV x-ray line from a ^{241}Am source with no excess of points on the left side from events with partial charge collection [4, Fig. 7].

4. Wall electrode tests indicate it should be possible to fabricate sensors that are sensitive to within several microns of their physical edges [5]. The edges, formed by plasma etching, can also be curved, allowing sensitivity very close to the beam pipe.

Several 3D sensors have recently been combined with fast, low-noise amplifiers provided by Pierre Jarron and Giovanni Anelli of CERN [6]. ^{90}Sr beta rise times, limited by the amplifier speed, have been measured at room temperature to be less than 3.5 ns, with full widths at half max of less than 8 ns, using the relatively slow hole signals and with only 40V bias, even after irradiation by 10^{15} 24 GeV protons/cm^2. (See Figure 2.)

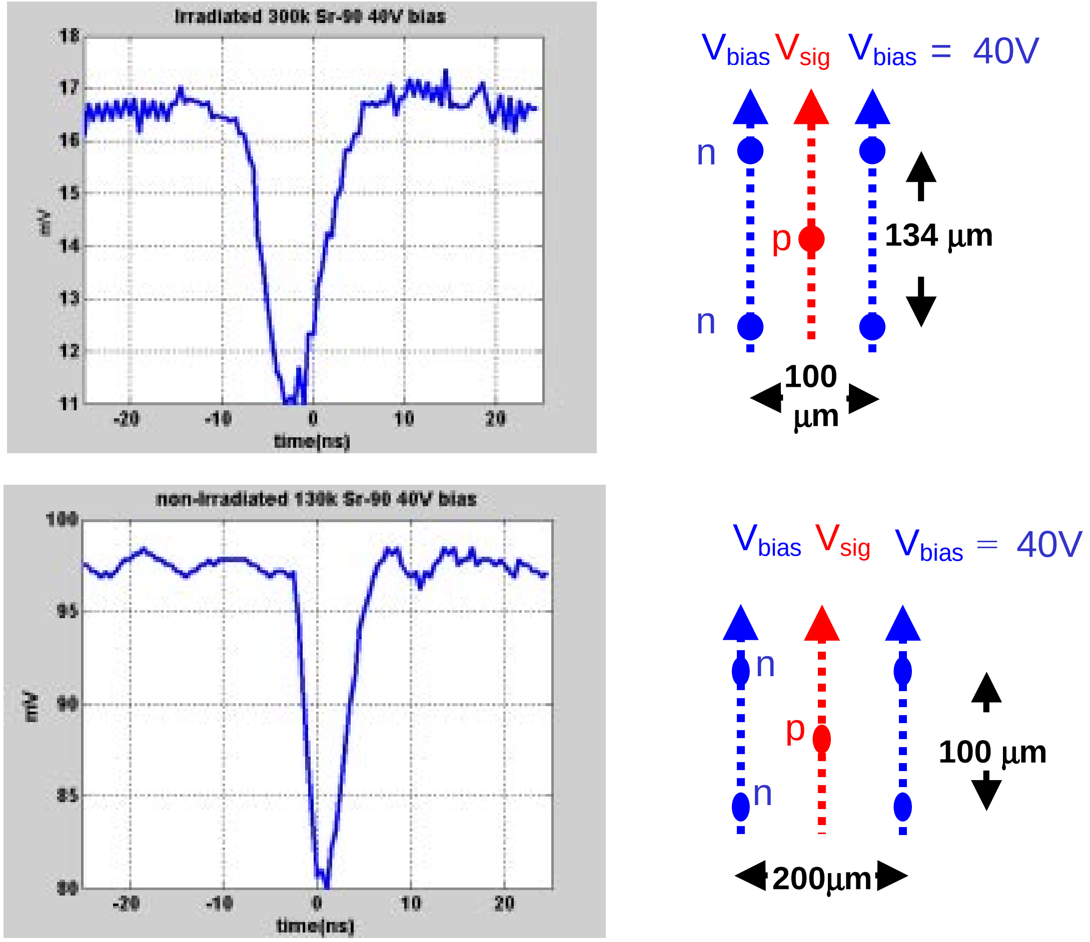

Figure 2. Two sample pulse shapes. The top pulse, from a heavily irradiated sensor (10^{15} 24 GeV protons/cm^2) at room temperature with no beneficial oxygen diffusion and maximum damage from full reverse annealing, has a rise time of 3.5 ns. The bottom pulse from a non-irradiated sensor at 130° K has a rise time of 1.5 ns.

Pulses from 3D sensors can be shorter due to:

(1) shorter collection distances,

(2) higher average fields for any given maximum field, and

(3) for perpendicular tracks, since most of the signal is induced when the charge is close to the electrode (where the weighting field and electrode solid angle are large) the signals are concentrated in time as the track arrives, rather than spread out in time as is the case with planar sensors. (See Figure 3.)

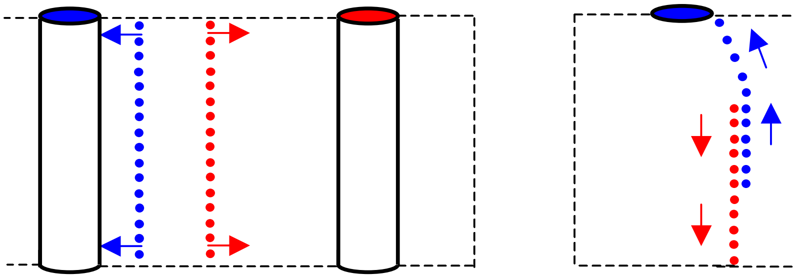

Figure 3. Collection of charge from ionizing tracks in 3D (left) and planar (right) sensors.

The beam shape monitor

This sensor technology should be ideal for the small angle detectors of a beam shape monitor. At linear colliders, a large number of electron-positron pairs are created from $\gamma\gamma \rightarrow e^+e^-$, where one or both photons can come from beamstrahlung or from the Coulomb fields of individual beam particles. The secondary e^+e^- pairs that can escape the beam pipe and be detected have energies, E, typically in the few-hundred MeV range and are created at small angles to the beamline of around $m_{electron}c^2/E$. They then acquire a P_t kick from the electromagnetic field of the rest of the on-coming bunch. If the charges of the created electron or positron and of the bunch are of opposite sign, the particle oscillates around the beam plane and the net acquired P_t is small. If the particle and the on-coming bunch have the same charge sign, P_t may be larger, giving a P_tc/E large enough to produce a substantial angular deflection, with the particle escaping before much beam disruption has occurred. It was found that these large deflection can be used to study σ_x and σ_y of the on-coming bunch [7].

With as many as 10^5 pairs created per bunch crossing, the resultant high occupancy suggests that silicon strip detectors are not suited for this application while CCDs, good candidates in terms of occupancy, would not give the timing information necessary to study possible structures within a train unless some external gating is applied. Simulation work and the development of electronics with sufficient data rate, and time and spatial resolution, for a pixel detector using 3D sensors are now under development by a KEK—Tohoku (HitoshiYamamoto) group [8]. Fig. 4 shows the layout of the beam pipe end of one of the sensors now under fabrication for this project.

Description of first year project activities

The fabrication run now underway is intended, primarily, to test active edge technology. Both the initial fabrication run and this one have multiple designs for sensors intended for different tasks. A number of trapezoidal sensors with 100 μm pixels, intended to be assembled into a partial ring for use as a practice linear collider beam monitor, are included [8]. Other sensor designs on the same wafer might also be used for this project.

Fabrication runs, following the current one, will be split into (1) ones using thin silicon, to reduce multiple Coulomb scattering, with most designs having relatively closely spaced electrodes to provide radiation hardness and speed, and (2) ones with thicker silicon for x-ray detectors, intended for studies in structural molecular biology, where such properties are not so important [9].

The next beam tests, using existing devices, are currently planned to take place at CERN this year. An SPS 100-200 GeV μ or π beam will traverse a set of silicon detectors. We plan to place two sensors on opposite sides of an existing printed circuit board that will also contain two Anelli-Jarron amplifier chips. One sensor will have wall and cylindrical electrodes [5], and one only cylindrical electrodes. The cell dimensions for the latter are given in the bottom part of Figure 2. The main object will be, using an existing telescope, to measure, for a number of bias voltages, the detection efficiency as a function of predicted track position, particularly close to the electrodes. The location of the amplifiers on the card prevents the 3D sensors from being mounted directly in line with each other, so we are planning to measure time resolution on later beam tests.

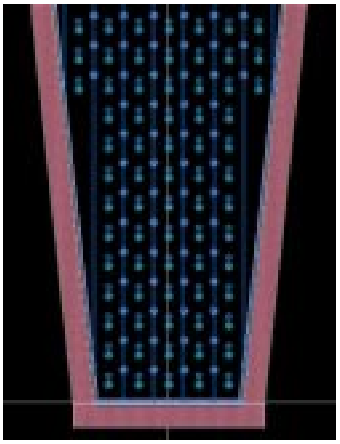

Fig. 4. Layout of beam pipe end of a trapezoidal sensor. The side borders will be etched away in the dicing process. Five columns of pixel electrodes reach the end. Bias is provided by the ganged electrodes between them and by the edge electrodes.

In addition to these tests, we plan to use x-ray and proton micro-beams, and further source tests (^{90}Sr, ^{109}Cd, and ^{241}Am) at room and low (130° K) temperature, with a range of bias voltages, and with revised wiring to remove the intermittent pickup visible on the baselines of Figure 2.

Future devices; future fabrication runs

In the future, we plan to alternate fabrication runs with lab and beam tests, both to further improve the technology, and to provide specialized devices for future experiments. After consultation with other linear collider collaboration members, we would propose adding to the next fabrication run, specific sensor designs specialized for tasks where this technology will produce better results than any other.

The lab at Stanford is currently being converted from 10 cm to 15 cm diameter wafer equipment. The furnaces can take boatloads of 50 wafers, although most runs, being experimental, use a smaller number. Lithography and especially the etching of the electrode holes, is currently done one wafer at a time. Assuming, for example, a process and area yield of about 1/3, a run of twenty 10 cm wafers would contain about 500 cm^2 of devices. After the conversion, with the same assumed yield and a batch of 50 wafers, a run would produce over 2,900 cm^2 of devices.

Any given run could be expected to take perhaps two to six calendar months, depending on equipment availability, the batch size, and the details of the run steps. With dedicated personnel, several runs could overlap, providing the impact on other users was acceptable. Thus, applications needing devices with total areas comparable to several times 500 (later 2,900) cm^2 might be made locally. However, given the multiple uses likely for 3D sensors, including others in high-energy physics and biology, it is also possible one or more commercial companies might decide to buy the plasma etcher needed to make such sensors by the time any large number of devices is needed.

Budget

The proposed budget assumes about one quarter of each of the processed 10 cm diameter wafers would be devoted to this project, and that the costs would be shared with other ongoing projects. There is also the possibility, in the future, of sharing personnel time, with work on the thin wafers taking place while the NIH x-ray wafers are undergoing processes not needing continuous supervision, such as furnace runs, and vice-versa.

Institution	Item	Cost
Hawaii	Stanford Nanofabrication Facility machine charges	$ 3,000
Hawaii	1.5 months time, fabrication engineer	$15,000
Hawaii	silicon float zone wafers, lab supplies	$ 1,500
Hawaii	Indirect costs (20.6%)	$ 4,017
Hawaii	Hawaii total	$23,517

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