Luminosity, Energy, Polarization

Luminosity, Energy, Polarization Table of Contents

Overview of Luminosity, Energy, Polarization Proposals

One distinct advantage of the Linear Collider is the well-defined initial state in the collision process. Realizing this advantage, however, requires adequate measurements of the beam properties at the interaction point (IP). These measurements present some new challenges in beam instrumentation, and the proposals described here address these challenges. An ALCPG Working Group[1] has been formed with the charge of ensuring that the beam instrumentation is optimized for the LC physics goals. This group has produced a *white paper* describing the measurement goals for luminosity, luminosity spectrum, energy, and polarization.[2] The *white paper* describes a strategy for realizing these goals using both beam-based instrumentation and analyses of physics processes at the IP.

A Letter of Intent was recently put forward to the SLAC PAC to start a beam instrumentation test facility in End Station A (ESA).[3] The beams available in ESA (as used by the E158 collaboration) have characteristics very similar to that expected at an X-band linear collider. With a 10% χ_0 radiator, a disrupted beam with an energy spectrum and angular dispersion comparable to that expected after the LC IP can also be created. Direct tests of energy spectrometry, polarimetery, and pair monitors (with a solenoid around the target) are envisioned. This idea has received support from the lab, and it is expected that beam time will be available to test many of the devices proposed in this section starting as early as 2005.

Luminosity

Precision extraction of cross sections depends on accurate knowledge of the luminosity. For many measurements, such as those based on threshold scans, one needs to know not only the energy-integrated luminosity, but also the luminosity as a function of energy, *dL/dE*.

Low-angle Bhabha scattering detected by dedicated calorimeters can provide the necessary precision for the integrated luminosity. Options include secondary emission (A) and fast gas Cerenkov (B) calorimetry in the polar angle region from 40-120 mrad. Acollinearity and energy measurements of Bhabha, $e^+e^- \to e^+e^-(\gamma)$, events in the polar angle region from 120-400 mrad can be used to extract *dL/dE* and are under study. Additional input from measurements of the beam energy spread and beam parameters that control the beamstrahlung spectrum will improve this determination of *dL/dE*. Techniques include measuring the angular distributions of e^+e^- pairs (C) in the polar angle region from 5-40 mrad, and measuring the polarization of visible beamstrahlung in the polar angle region from 1-2 mrad (D).

All the proposed detectors may also be used for real time luminosity monitoring and tuning. The locations of some of these detectors in the forward region of an NLC Detector are shown in Figure 1.

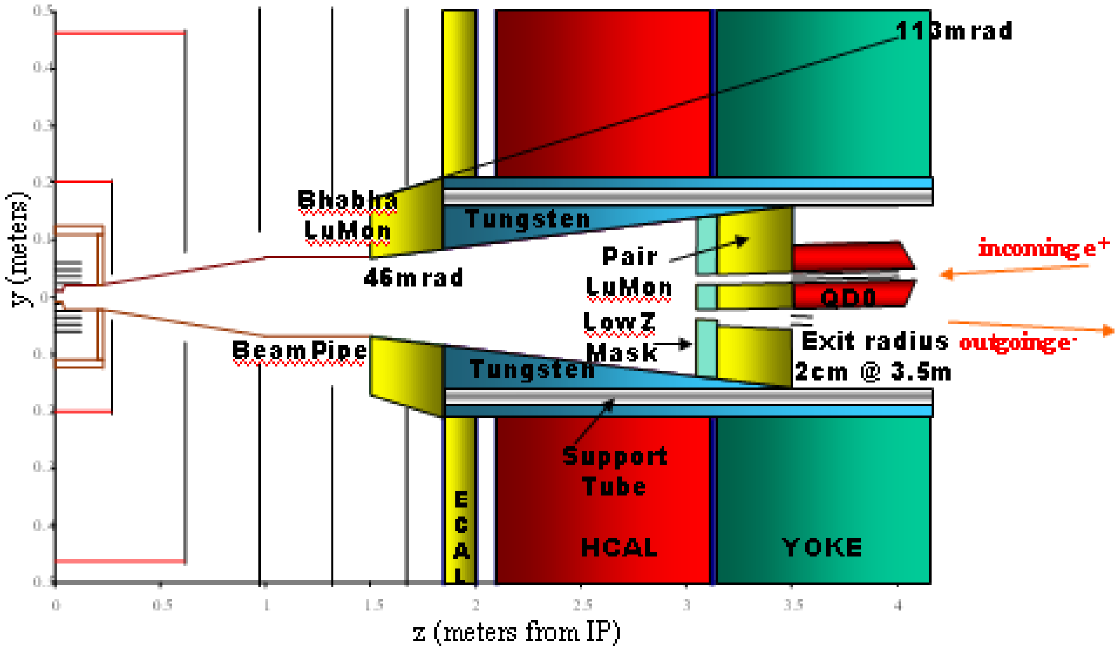

Figure 1: Forward Region of the (proposed) NLC Silicon Detector

A.	LCRD 3.2	R&D for luminosity monitor	Yasar Onel	Iowa Fairfield
B.	LCRD 3.1	An Explicitly Radiation-Hard Fast Gas Cerenkov Calorimeter for Bunch-by-Bunch Luminosity Measurement at the Next Linear Collider	John Hauptman	Iowa State
C.	LCRD 3.9	Development of thin, fast, radiation hard, 3d-electrode array, silicon radiation sensors	Sherwood Parker	Hawaii
D.	UCLC 3.8	Coherent and incoherent beamstrahlung at the LC	Giovanni Bonvicini	Wayne State Univ.

Energy

Beam energy measurements with an accuracy of (100-200) parts per million are needed for the determination of particle masses, including m_{top} and m_{Higgs}. Energy measurements both upstream and downstream of the collision point are foreseen by two different techniques to provide redundancy and reliability of the results. Upstream, a beam position monitor-based spectrometer is envisioned to measure the deflection of the beam through a dipole field.(A) Downstream of the IP, an SLC-style spectrometer is planned to detect stripes of synchrotron radiation (SR) produced as the beam passes through a string of dipole magnets.(B) The downstream SR spectrometer (B) also has the capability to measure the beam energy spread and the energy distribution of the disrupted (from beam-beam effects) beams.

A.	UCLC 3.5	A Demonstration of the Electronic and Mechanical Stability of a BPM-based Energy Spectrometer for an Electron-Positron Linear Collider	Michael Hildreth	Notre Dame
B.	LCRD 3.4	Extraction line energy spectrometer	Eric Torrence	U Oregon

Polarimetry

Precise measurements of parity-violating asymmetries in the Standard Model require polarization measurements with a precision of 0.5% or better. High statistics Giga-*Z* running motivates polarimetry at the 0.1% level. The primary polarimeter measurement is envisioned to be a Compton polarimeter located in the extraction line. For evaluation of systematic errors, it is desirable to compare results from measurements of backscattered electrons and photons, and also to compare results from single and multi-Compton counting. Quartz detectors will be investigated for both scattered photons and electrons (A, C) and a study of expected backgrounds will be carried out (B). Most of the LC physics program requires longitudinal polarization for the colliding beams, but if both electron and positron beams are polarized the physics reach can be improved with additional measurements using transverse polarization asymmetries. One can infer the transverse polarization from knowledge of the spin rotator settings, measurements of the spin transport matrix and measuring how close the longitudinal polarization component is to 0. Direct transverse polarization measurements will also be investigated.(C)

A.	LCRD 3.6	Polarimetry at LC	Yasar Onel	Iowa Iowa State Fairfield
B.	LCRD 3.7	Compton Polarimeter Backgrounds	William Oliver	Tufts
C.	LCRD 3.10	Polarimeter with a Quartz Fiber Calorimeter	Stefan Spanier	Tennessee

References

1. http://www.slac.stanford.edu/xorg/lcd/ipbi
2. D. Cinabro, E. Torrence and M. Woods, *Status of Linear Collider Beam Instrumentation Design*, ALCPG-Note-2003-001, http://www.slac.stanford.edu/xorg/lcd/ipbi/white.pdf
3. http://www.slac.stanford.edu/grp/rd/epac/LOI/LOI-2003.2.pdf

3.1. An Explicitly Radiation-Hard 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
Oregon
Purdue
NIPT (Ukraine)

Year 1: $41,600
Year 2: $41,600
Year 3: $41,600

An Explicitly Radiation-Hard Fast Gas Cerenkov Calorimeter
for Bunch-by-Bunch Luminosity Measurement
at the Next Linear Collider

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13 November 2003

1 Abstract

We present the design and current progress on a new optical gas Čerenkov calorimeter that is explicitly radiation-hard, completely insensitive to radioactivation of the calorimeter mass, immune to all $e^{\pm}/\gamma$ IR backgrounds below 10 MeV, flushed of signal between bunch crossings and capable of measuring the luminosity bunch-by-bunch every 1.4 ns. This calorimeter would function as both a luminosity monitor[1] and a 2γ-veto in SUSY final states[2] and be positioned in the small angle region between 5 mrad and 120 mrad at 2 meters from the interaction point. We propose to design, build and test a prototype gas Čerenkov detector of this novel design.

2 Introduction and Basic Ideas

Radiation-hardness is difficult to achieve with atoms in a solid since any damage remains fixed in place within the active medium. Liquids can be recycled, but the generation of ionization or scintillation signals in liquids is slow, and the generaton of fast Čerenkov light is at large angles, implying complicated light-gathering devices such as fibers and mirrors.[3] A gas can be recycled and, furthermore, has several other consequential properties that led us to this 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. These considerations led us to design a Čerenkov calorimeter whose light-generating medium and light-transmitting medium is a gas. A typical gas has an index of refraction, n, which differs from one by a small amount,

$$n = 1 + \delta, \qquad \delta \approx 10^{-3}$$

and the generated Čerenkov light is channelled forward at an angle $\theta_C \approx \sqrt{2\delta} \approx 0.045$, which is easier to collect geometrically in a calorimeter geometry with axial optical conduits tilted with respect to the particle direction by about θ_C.

The collection and transport of the Čerenkov light down highly reflective optical conduits can be accomplished in several ways, described in Sec. 3, but can be generically thought of as tubes reflective on the inside and buried inside the metal mass of the calorimeter.

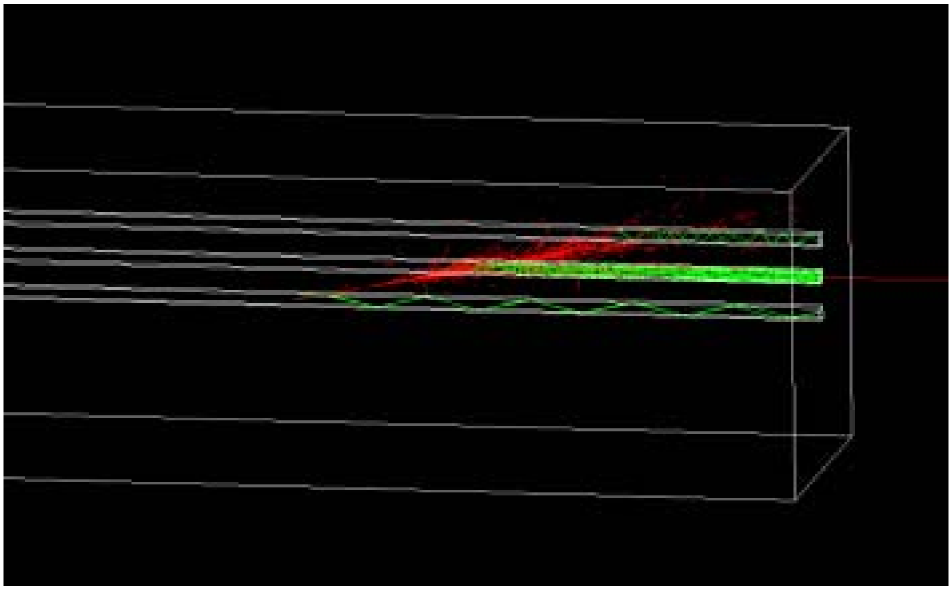

Figure 1: G4 simulation of an electron crossing a gas gap and generating Čerenkov light that travels down the optical conduits.

The Čerenkov light is generated by shower particles as they cross the gas gaps, illustrated in Fig. 1, and a large fraction of the light is channelled down the optical conduits. The light makes typically 10-12 small angle reflections before exiting the rear of a 30-cm deep calorimeter. Within the calorimeter medium, the Čerenkov light and the electromagnetic shower particles travel at nearly c and co-move in a pancake perpendicular to the shower axis. The shower particles are absorbed out in depth as the Čerenkov light builds up in depth, and a 12-ps pancake of light exits the rear of the calorimeter, its time dispersion dominated mostly by geometry. We will use a one-bounce aluminized mirror to focus and redirect the light to PMTs out of the path of the beam.

The Čerenkov angle is given by

$$\cos\theta_{\rm C} = 1/n\beta \rightarrow 1/n \approx 1 - \delta,$$

and expanding the cosine as $1 - \theta_{\rm C}^2/2$ gives the Čerenkov angle $\theta_{\rm C}$,

$$\theta_{\rm C} \approx \sqrt{2\delta} \approx 0.045.$$

The Čerenkov light yield in the visible is approximately

$$dN/dx = 370\sin^2\theta_{\rm C} \quad {\rm eV}^{-1}{\rm cm}^{-1} \approx 370 \times 2\delta \approx 0.75\ \check{C}\ {\rm photons/cm \cdot eV}.$$

The velocity threshold for Čerenkov light emission is

$$\beta_{\rm th} = (P/E)_{\rm th} = 1/n \approx 1 - \delta,$$

where $P/E \approx 1 - (m/P)^2/2 \approx 1 - \delta$, or $P/m = 1/\sqrt{2\delta}$, so the momentum threshold for electrons is

$$P_{\rm th}^{\rm e} \approx m_{\rm e}/\sqrt{2\delta} \approx m_{\rm e}/\theta_{\rm C} \approx 11\ {\rm MeV/c}.$$

The critical energy of a typical metal is 10-20 MeV, comfortably above the Čerenkov threshold, and therefore most shower electrons will participate in Čerenkov light generation. The Čerenkov threshold is higher than the binding energy per nucleon, and therefore no nuclear decay, either β or γ, can generate Čerenkov light in the gas. Therefore, this luminosity calorimeter has three unique features:

1. it is constructed wholly of metal and gas, and is therefore extremely radiation-hard aside from presently unknown atomic and molecular effects at 100 MRad doses;

2. the generation of Cerenkov light is instantaneous, its transport from within the calorimeter volume is at nearly the speed of light, bunched in a 12-ps pancake, and the calorimeter volume is emptied of light well before the next bunch arrives; and,

3. the Cerenkov threshold is about 11 MeV, and therefore no nuclear decay from any degree of radioactivation will result in Cerenkov light, and in addition, all $e^{\pm}$ and γ backgrounds below this threshold, generated by the beam and masks or backscattered from the detector, are invisible.

The crucial tasks are the manufacturing of highly reflective metallic surfaces, the optics to transport the output light to photodetectors, and the design of a fast phototube or silicon-PMT readout and DAQ.

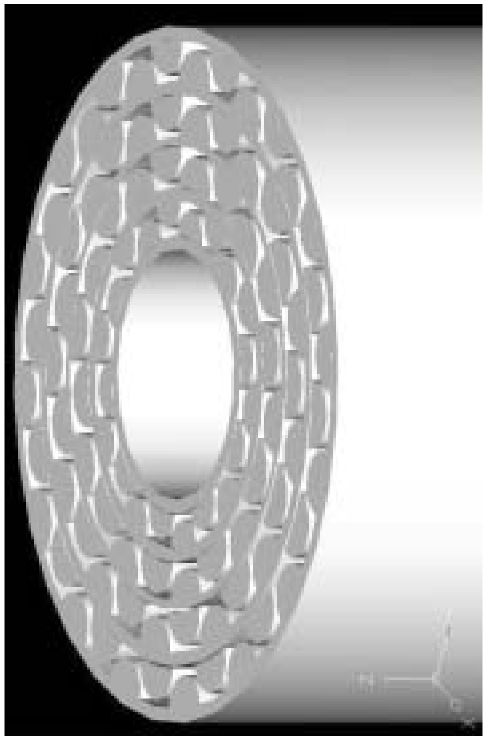

Figure 2: The "lasagna" geometry for the radiator and the optical light conduits; this geometry has the advantage that the metallic reflecting surface can be separately prepared and then attached to the radiator structure.

The presence of resident light due to scintillation backgrounds can be avoided by using beta-butylene with $\delta = 1.31 \cdot 10^{-3}$ (as good as isobutane) but with a scintillation light yield smaller than 10^{-5} that of Cerenkov light[6]. In addition, the isotropic scintillation light is suppressed by the solid angle capture fraction in the light conduits, and may be further suppressed with respect to the blue-UV Cerenkov light for longer wavelength scintillation light. 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 NLC bunches.

We believe that the metallic structures, even the thin metallic coatings, cannot be damaged by any dose of radiation primarily because the energy density is far below ionic bonding energies. The gas can be recycled, we only need a gas with a $\delta > 0.5 \cdot 10^{-3}$, and most importantly this gas will not reside in an electric field with consequence carbonization and polymerization processes taking place. We suspect that many gases will survive a GRad dose without molecular degradation, and we will study and test candidate gases. Therefore, our present understanding is that this device will not fail by design, and that this calorimeter is essentially indestructible under even very large radiation doses.

The quality of the reflecting surfaces is the most critical aspect. Achieving acceptable resolution requires a coefficient of reflection better than 98% at grazing incidence. Such reflectivity, by itself, requires that the surface must be optically smooth, i.e., the "roughness" should be of the order of 50 nm. At ISU we have managed to achieve relatively high quality but we have not obtained polished areas larger than a few square inches. Our collaborators in Ukraine are investigating various techniques to achieve optical smoothness, Fig. 3 and they have designed and built two different polishing machines now in use. They have a high quality metallization facility where polished surfaces can be aluminized.

Figure 3: We have made our own smoothness measurements with a Linnik interferometer yielding the output interferograms shown in this figure. On the left is a commercial very high quality mirror (Al+Ni+Aluminum substrate, \$100/in^2), and on the right is our polished stainless steel shim with slightly better smoothness. A Linnik interferometer is good at measuring the depth of surface imperfections.

3 Designs and Variations

A detailed design involves a choice of metal for the calorimeter mass, reflecting surface, conduit design, and light transport away for the calorimeter.

Metals Tungsten (W) has excellent density and strength and also a surface with good reflective properties, but it is difficult to machine and to polish. Brass has good density and strength and is easy to polish, but a highly polished surface is difficult to achieve. Stainless steel (SS) is a good compromise. A working module, however, can be constructed from any of these metals. Several geometries allow the separation of the reflectivity function from the calorimeter mass, so that, for example, an aluminum or stainless reflecting shim can cover a poorly refecting metal. One of many solutions with high promise is: tungsten hexagonal rods, evaporated with nickel that can be melted like glass on a metallic surface, then aluminized and finally coated with a thin layer of evaporated gold (20-40 atoms thick) to prevent oxidation of the aluminum but retain the reflective properties of Al in the UV.

Geometries This device would be hugging the beam pipe, extending out to a radius of approximately 35 cm, and two meters from the IP. There are several conceivable geometries, and we list the more likely ones for our purposes:

- Metallic tubes reflective on the inside, about 2mm in diameter and spaced 5 mm apart within the calorimeter mass. This requires polishing an interior surface such as stainless steel;
- Hexagonal metal rods, 1-cm in diameter and about 30 cm long, polished and aluminized on the six sides, shown in Fig. 4. These rods are arranged in a hexagonal mosaic pattern such that the space between adjacent rods is about 1 mm. The advantages are a uniform calorimeter structure throughout, all components are identical, relative ease of manufacturing and polising the hex rods, and ability to use W, brass or SS. The rods need to be cantilevered from a front plate with possible additional support at the rear without blocking much light;
- Octagonal rods stacked such that square conduits are available to carry the light. Mechanical support is relatively easy, and the rods can either be polished themselves or wrapped by polished shims; and,
- Cylindrical "lasagna" geometry[4] where the metallic radiator is covered with a reflecting metallic shim, as shown in Fig. 2. The cylindrical geometry matches the beam geometry, and the calorimeter mass and reflecting surfaces of the shims are separated.

A SiW preshower module would provide improved spatial resolution and also provide depth development information for improving energy resolution. Several groups are working on Si-W detectors[7]. We will

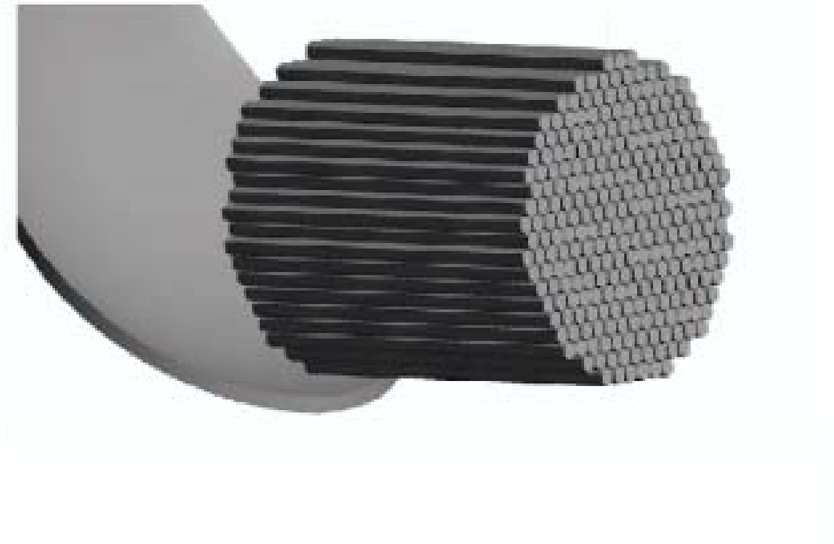

Figure 4: The geometry of a hexagonal rod calorimeter. Rods are about 8-10 mm in diameter and the gas gapa are about 1-2 mm.

collaborate with these groups and look into the possible use of a few layers of the existing SiW calorimeter designs. A silicon-tungsten pre-shower in front of this calorimeter is illustrated in Fig. 5.

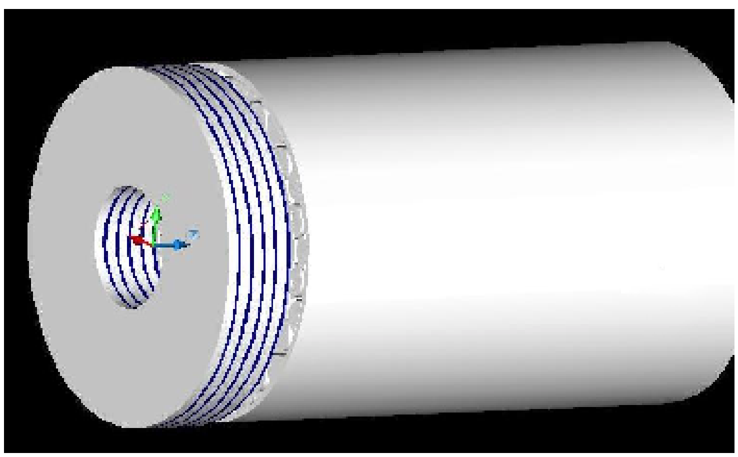

Figure 5: The "lasagna" with a few radiation lengths of Si-tungsten tracking in front.

Gases We require a gas with (i) sufficiently large δ, say $\delta > 0.7 \cdot 10^{-3}$, for Čerenkov photon yield that (ii) does not scintillate, and that (iii) will not carbonize or polymerize under a large dose. Most gases satisfy (i); β-butylene satisfies (i) and (ii), but its properties for (iii) are unknown; CO_2 and isobutane may be acceptable except for (iii); we would not use O_2 (to avoid oxidation) nor N_2 (to avoid scintillation); and, we would not use a noble gases which are moderate atomic scintillators. On the other hand, we could use strong quenching to solve (ii). Gas investigations and tests will go in parallel simulations and metallic studies.

Fast Readout The PMTs (or Si-PMTs) must be shielded and Čerenkov light directed to them with spherical or cylindrical mirrors. Bunch-by-bunch readout requires fast photodetectors and digitizers at GHz frequencies. Hamamatsu provides a very fast PMT (H6568)[6], that has rise and fall times of 170ps, and is sensitive down to 200nm. Commercially available digitizers exist, MAX104 2.2 GHz ADC, for example is fast enough, but we also need to transfer digitized signal to fast memory. We suspect that a XiLinx FPGA or ASIC[9] 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[10]; and we plan to collaborate with these groups.

4 Expected Performance

Both Geant3 and Geant4 simulations of 100-500 GeV electrons in Fe and Pb masses have been performed with exact optics for the Cerenkov light in reflective SS tubes 2-mm inner diameter and centered every 5-mm. The calculated energy resolution in this geometry is about 10% for 100 GeV electrons, and about 5% for 500 GeV electrons. The width of the Čerenkov light pancake is about 12 ps, Fig. 6. We are now developing a Geant4 code to simulate the more complicated lasagna and hex rod geometries, and to optimize the metal-gas volumes and the light channelling 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.

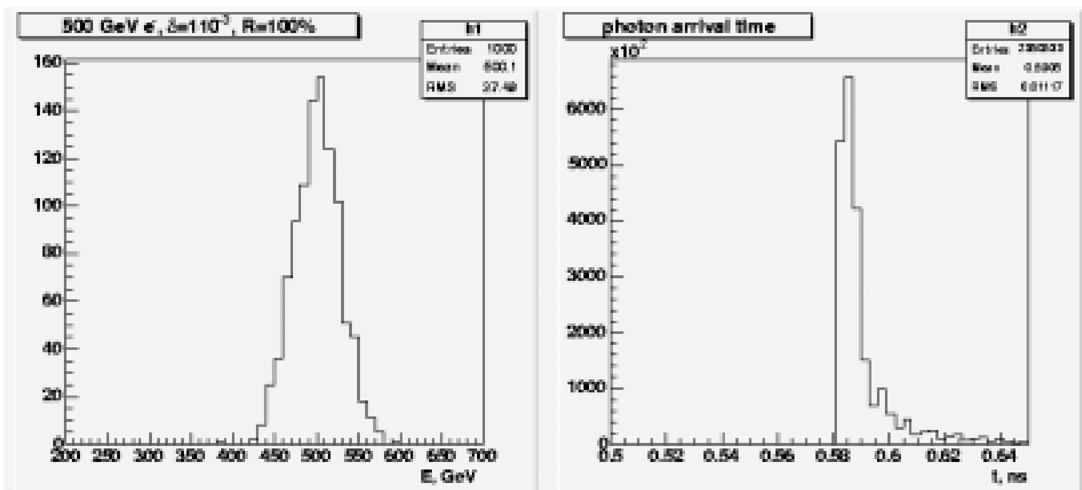

Figure 6: (a) The pulse height distribution for 500 GeV e$^-$ in a tube geometry showing and energy resolution of about 5%; and, (b) the time distribution of the Čerenkov light at the output end of the calorimeter showing the 12 ps width of the pancake in time. This is not an optimized design.

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. We are building such a blinking Čerenkov light source using a β source, a FODO cell, a permanent magnet bending field and a momentum defining slit.

The capability of this device to tag showers bunch-by-bunch, whether Bhabha scatters, low energy electron pairs, or 2-γ electrons, is a large factor of about 100 in effective background rejection. Both the energy and spatial resolutions will scale like $k/\sqrt{E}$ and we calculate that the energy resolution at 500 GeV will be 5% or better, and we guess that the spatial resolution will be better than 1 mm.

5 Progress

A recent talk at the Cornell workshop[11] describes our work and expectations. In the first few months we have simulated two geometries, achieved and measured reflectivity on a stainless surface as good as the best commercial metallic mirrors, developed several geometrical designs, and investigated metals for the detector mass. We will assess its dual role as both luminosity monitor and two-photon tagging veto for SUSY events[2]. Geometry and mechanical support will be finalized, and performance will be understood based on our Geant4 simulation, including the detector environment[8].

The final physics design will be driver by a complete Pythia-G4 simulation of Bhabha and 2γ events done in collaboration with our SLAC colleagues. We will establish collaborative relationships with groups working on fast DAQ and we will happily use any readout that is developed by another team[10]. We do not believe that delamination of an aluminum or nickel coating under high doses will be a concern, but it will be investigated.

6 Summary

We believe that this relatively simple technology will not only survive the extreme doses at small angles at the NLC, but also provide energy and spatial measurements in segmented towers every 1.4 ns for the multiple purposes of bunch-by-bunch luminosity beam tuning and of 2γ-event tagging during physics running.

References

[1] "Beam Instrumentation Tests for the Linear Collider using the SLAC A-Line and End Station A", E. Torrence, K. Moffeit, M. Woods, and D. Cinabro, SLAC-LoI-2003.2, 14 Oct 2003.

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

[3] Indeed, the low light yield in quartz-fiber calorimeters, about 4% of all generated light, is a direct consequence of the large index of refraction and consequent large Čerenkov angle.

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

[5] "Vacuum Ultraviolet Spectroscopy I", Ed. J.A. Samson and D.L. Ederer, Acad. Press, 1998.

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

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

[8] The geometry and the radiation environment is provided by SLAC group, in particular Takashi Maruyama and Michael Woods. This gives us guidance towards further improvement of the performance and connects us to reality.

[9] The PMT output waveform digitizer made for NESTOR at LBNL can reach 3 GHz and would be perfectly suitable for our needs when operated at 1.4 GHz, that is, one digitization on the Čerenkov light pulse and the next digitization between light pulses. This would give a measure of light not associated with the narrow Čerenkov light pulse from the IR. This is called the Analog Transient Waveform Digitizer (ATWD) and recently noted in the CERN Courier, November 2003, p.23.

[10] Eric Torrence (Oregon), et al., fast DAQ system.

[11] Talk by Oleksiy Atramentov, American Linear Collider Workshop, 13-16 July 2003, Cornell University, http://www.slac.stanford.edu/xorg/lcd/ipbi/cornell03/ cornell_atramentov.ppt

7 Budget and Justification: 2004-06 (3 years)

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

Oleksiy Atramentov is a PhD student working at Fermilab, only a fraction of the salary is requested for him. No postdocs are anticipated. No summer salary for senior physicists is requested. We will need to make a few trips to SLAC and American Linear Collider meetings for coordination and communication and for testing the module, sometime in the third year.

Fund transfers to collaborating institutions will be accomplished by ISU Services Agreements to minimize accounting bureaucracy.

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 (DREAM), 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. Virgil Barnes is a CMS collaborator, works in CDF, and is investigating silicon PMTs and stainless steel tubing. Thomas Markiewicz, Michael Woods and Eric Torrence are expert on Linear Collider instrumentation.

Materials and Metallization: We expect to use the aluminization and metallization facility at Fermilab, NIPT, and/or an equivalent facility at SLAC, for the critical surfaces we require. We believe the $10K/y for materials and the $10K/y for metallization and optical quality aluminization and optical engineering will enable us to purchase and metalize several options (Al, Ni, Au on to W, SS, brass) before we make the decisions for construction.

Institution	Item	1^{st} year	2^{nd} year	3^{rd} year	Total
ISU	Salary physics majors Salary graduate students	$ 6.0K $ 4.0K	$ 6.0K $ 4.0K	$ 6.0K $ 4.0K	$18.0K $12.0K
ISU	Materials and supplies	$10.0K	$10.0K	$10.0K	$30.0K
ISU	Metallization and Optical	$10.0K	$10.0K	$10.0K	$30.0K
ISU	Travel	$ 3.0K	$ 3.0K	$ 3.0K	$ 9.0K
Indirect	26% of non-equipment	$ 8.6K	$ 8.6K	$ 8.6K	$25.7K
Total		$41.6K	$41.6K	$41.6K	$124.8K

3.2. R&D for luminosity monitor (LCRD)

Luminosity, Energy, Polarization

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email: yasar-onel@uiowa.edu
phone: (319) 335-1853

Fairfield
Iowa
Bogazici (Turkey)
Cukurova (Turkey)
META (Turkey)
INFN (Italy)

Year 1: $35,140
Year 2: $37,650
Year 3: $40,000

Project name

R&D for luminosity monitor

Classification (accelerator/detector:subsystem)

Detector: IPBI / 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, J.Olson (grad.students), I.Schmidt (Mechanical Engineer), M.Miller (electronics engineer), K.Dolan, D.Monner (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)

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Ramazan Sever (professor)

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Project Overview

Introduction:

The forward angle calorimeter for the LC will have large counting rates and be exposed to large radiation doses, of the order 1.0 Grad/yr. The forward detector region is shown in figure 1 and Ref [1]. The luminosity detectors are needed for a) Pair-LuMon region from 6-36 mrad for luminosity tuning. (Electron and positron are low energy ~1 GeV) and b) Instrumented mask region from 36-117 mrad for determining absolute luminosity from Bhabhas (high energy). This concept is discussed in ref [2].

We will explore two types of detectors, the PPAC (low pressure Parallel Plate Avalanche Detector) and the SED secondary emission detector.

PPAC

A calorimeter, made of PPAC, consists of heavy metal absorber, in which the shower develops, and detectors to sample the intensity of the shower.

The proposed research will develop a new type of detector that is fast (sub-nanosecond) and not subject to radiation damage. The electrical signal is generated and amplified in the detector itself. There is no need for photodetectors for PPAC.

The interior of the PPAC detector is a low pressure gas or vacuum and so must have heavy walls to withstand the atmospheric pressure. These walls will be chosen to match the material of the absorber so that they constitute part of the absorber.

A typical PPAC is two flat plates separated by 2 mm with a voltage of 750 V between them with a filling gas of 20 torr of isobutane. The charged particles passing through the gas produces ionization and the multiplication is achieved by applying a sufficiently large voltage to cause each electron to produce an avalanche. The avalanche results in current gains of 10^4 to 10^5.

For use in a calorimeter it is better to have two heavy, grounded plates to withstand the pressure and a single, thin plate at high voltage between them. To test the performance of the detector we will make a double PPAC in which there are three thin plates, the middle one grounded. Signals are taken from the two thin plates at high voltage. A comparison of the signal from the two sides allows a measurement of the energy and time resolution of the detector.

The following is the proposed course of action for testing the performance of the double PPAC:

1. Test of PPAC at the Advanced Photon Source using 80 ps pulses of 7 GeV electrons to create electromagnetic showers.

   Electromagnetic showers will be generated by allowing the halo of the beam to strike the edge of the beam pipe. The number of electrons contributing to the shower can be varied by small changes in the beam-line magnets. Since all of the electrons in the bunch are essentially simultaneous the shower will appear in the detector as if it were caused by a particle of arbitrarily high energy. This test will be done with a double PPAC, two PPACs in series so that the same shower goes through both detectors. We expect excellent energy resolution. The PPAC signal from a shower is generated by hundreds of simultaneous but independent ionization events.

2. Search for a gas to use in a PPAC that will not be subject to aging problems.

   A PPAC can be constructed of materials that are extremely resistant to radiation, i.e. metals and ceramics. However under extreme radiation conditions isobutane will polymerize to form non-volatile materials. These can be removed by cleaning the detector, but it would be better if they were not formed in the first place. There are a number of promising gas mixtures. We are confident that we can find one that, if it does not cure the problem entirely, will at least be better than isobutane.

E. Norbeck has had considerable experience with low-pressure gas detectors. Part of this experience is given in his paper on heavy gases in charged particle detectors [Nucl. Instr. and Meth. A314 (1992) 620.]. We will construct a simple PPAC with a collimated alpha source inside for testing the various gas mixtures.

3. Wall materials

We will do simulations to determine the material for the walls of the detector that will result in the best signal. A secondary emissive surface, as described below, may lead to better performance of a PPAC.

Secondary Emission Detector

This 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); (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 calorimeters. 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 the 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 polar-angle 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.

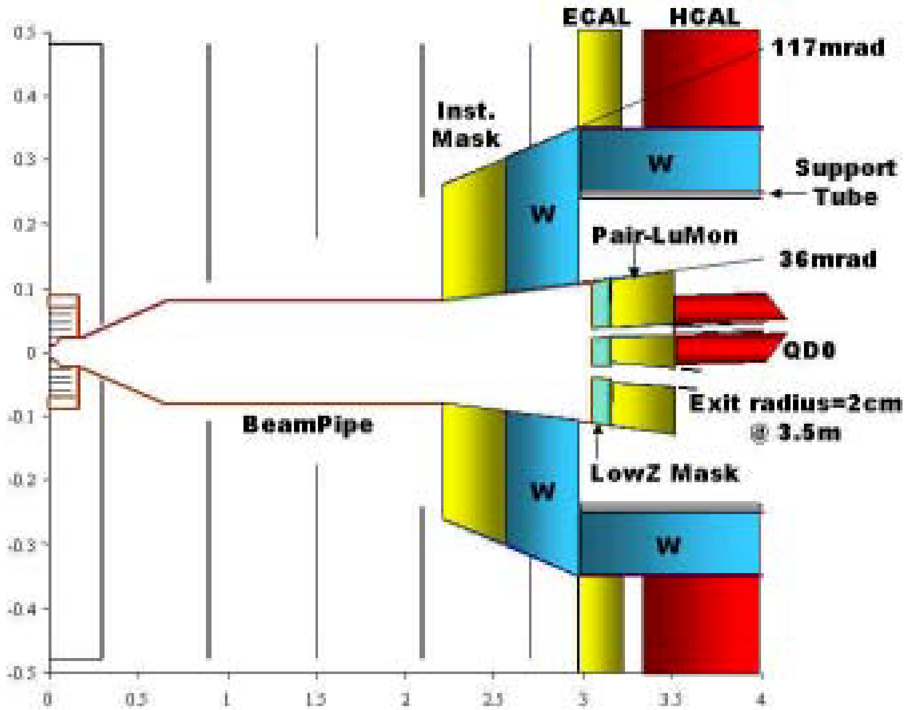
For the phase I R&D on this project, we propose studying the possibility of this to a sufficient level where information on performance and cost are sufficient to enable a decision to build a prototype calorimeter in subsequent proposal phases. The R&D will investigate: (A) materials to obtain high secondary 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 response of incident electrons between ~10 MeV – 250 GeV, 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.

We will be collaborating with the group of Dr. M. Woods/SLAC and Eric Torrence/U. Oregon on this research.

Institution	Item	FY04	FY05	FY06
Iowa	Partial support for post-doc	$16.0k	$8.0k	-
Iowa	Partial support for grad. student	-	$6.0k	$6.0k
Fairfield	Support for undergrad. student	$6.0k	-	$6.0k
Iowa	Detector/Raddam testing/operations	-	$5.0k	-
Fairfield	Detector/Raddam testing/operations	-	$5.0k	-
Fairfield	Secondary Emission Detector Package	-	-	$10.0k
Iowa	Engineering	-	-	$6.0k
Iowa	Travel	$3.0k	$3.0k	$2.0k

Fairfield	Travel	$3.0k	$3.0k	$2.0k
	Indirect cost @ 25.5%	$ 7.14k	$ 7.65k	$ 8.0k
	Grand total	$35.14k	$37.65k	$40.0k

Figure 1:



NLC Forward Masking, Calorimetry & Tracking 2003-04-01

References

[1] http://www-sldnt.slac.stanford.edu/nlc/configs/2003/plots/Forward_Tracking_NLC_LD.jpg

[2] http://www.slac.stanford.edu/xorg/lcd/ipbi/notes/white.pdf

[3] Secondary Emission(SE) Rad-Hard Fast Calorimetry
http://jazz.physics.uiowa.edu/talks/LC_Addendum/SECalDOEDetRD_v2_web.doc

[4] LC Proposal Addendum: "New Calorimeter Technologies for NLC"
http://jazz.physics.uiowa.edu/talks/LC_Addendum/HCal-Cherenkov.ppt

[5] Secondary Emission Modules
http://pion.physics.uiowa.edu/HEP-web/RnD/docs/RnD_LC_SEM.ppt

[6] Gas Detectors for High Energy EM and Hadronic Showers
http://pion.physics.uiowa.edu/HEP-web/RnD/docs/RnD_LC_PPAC.ppt

[7] Secondary Emission Modules
http://pion.physics.uiowa.edu/HEP-web/RnD/docs/RnD_LC_SEM_ONEL_WINN.ppt

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. Extraction line energy spectrometer (LCRD)

Luminosity, Energy, Polarization

Contact person: Eric Torrence
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Oregon
Massachusetts

Year 1: $31,591
Year 2: $50,142
Year 3: $50,752

Project name

Extraction line energy spectrometer

Classification

Beam Instrumentation (Luminosity, Energy, Polarization)

Institution(s) and personnel

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

University of Massachusetts, Department of Physics:
Stan Hertzbach (professor)

Contact person

Eric Torrence
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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. In addition, diagnostics sensitive to the disrupted beam energy spread, particularly with fast sampling times, will be necessary to understand the differential luminosity spectrum (dL/dE) at the IP. One possible scheme to realize this precision is to build a WISRD-style spectrometer in the extraction line downstream of the IP. The WISRD spectrometer provided a continuous absolute energy scale measurement with a precision of ~2 10^{-4} during the eight years of SLC operation.[1] DAQ software and WISRD operation at the SLC were the responsibility of members of the UMass group. In the WISRD scheme, shown in Figure 1, two horizontal dipole magnets produce stripes of synchrotron radiation that 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.

We propose to design a similar device that would work in the NLC extraction line (or a Tesla-style superconducting linear collider provided there is a crossing angle at the IP). Several features of the NLC environment make this design challenging: the large beam energy, the high expected backgrounds, the disrupted beam coming from the IP, the NLC bunch structure, and the machine constraints on the extraction line optics. In addition, this device should provide more precise information on both the absolute energy scale and the disrupted beam energy spectrum than achieved at the SLC. If possible this information should also be available on a bunch-by-bunch basis. The goal of this proposal is to provide a complete design of a workable NLC spectrometer including a design for a prototype device which could be tested in the SLAC end station A in about 3 years.

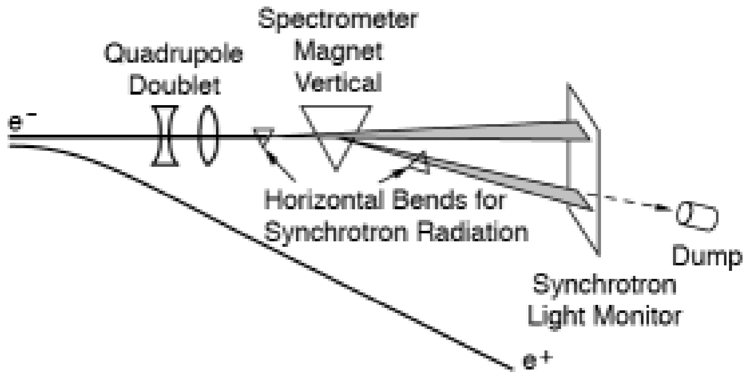

Figure 1: The SLC WISRD energy spectrometer

This work is being proposed as a single component of the larger effort worldwide to design the beam instrumentation necessary for LC physics. In the NLC beam instrumentation design, redundant information is provided by an upstream BPM-based spectrometer and this downstream WISRD-style device. In addition, physics measurements of the radiative return processes ($e^+e^- \rightarrow \mu^+ \mu^- \gamma$) provide a cross-check of the luminosity-weighted mean collision energy.[2]

Review of project activities

Both the Oregon group and the UMass group received funding in FY03 to begin exploring this topic. The research so far has followed two major lines of investigation. The UMass group has begun looking at the layout and design of the extraction line optics with beam simulations including synchrotron radiation, while the Oregon group has explored a new concept for the synchrotron radiation detector which could be operated at speeds up to 1 ns. In the future, it is expected that these two programs will become more integrated, producing a complete simulation of the extraction line optics and detector geometry for detailed studies (including machine and physics backgrounds) of the spectrometer performance. It is also expected that this work will proceed in close coordination with the polarimeter design, which shares the same location in the extraction line, and will need many of the same basic simulation tools.

Activities at Massachusetts

Stan Hertzbach and an undergraduate student (Caleb Mills) have begun to study the optics design of the NLC extraction line. Using the extensive experience of the UMass group in machine simulations and synchrotron radiation, a set of simulation studies were performed and presented at the Cornell workshop in July `03.[3] These studies have already shown that some optics modifications from the original extraction line design, shown in Figure 2, are probably necessary in order to accommodate a high-precision WISRD-style spectrometer. The secondary focus, currently placed at the center of the four magnet chicane, should actually be at the plane of the WISRD synchrotron light detectors to give the best resolution on the synchrotron stripes. Also, the 1 mRad bends foreseen in the baseline design do not allow synchrotron stripes produced anywhere in the chicane region to exit the 1 mRad beamstrahlung stay clear. Additional bending, for example, stronger chicane magnets, will be needed for any workable design. It was also verified by the UMass study that placement of additional stripe magnets (not currently in the baseline extraction line design) will not significantly increase the particle losses in the extraction line.

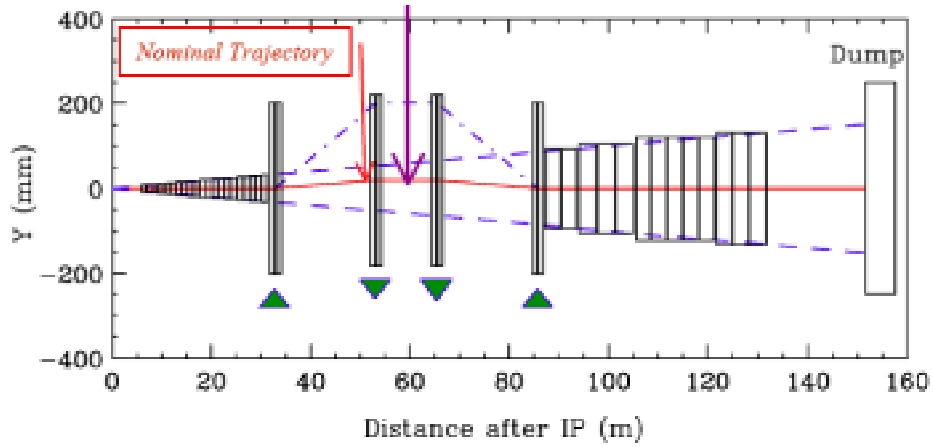

Figure 2: Baseline NLC extraction line layout

Activities at Oregon

In the SLC WISRD spectrometer, the synchrotron light was detected on an array of thin copper wires with 100 micron pitch. We have proposed to explore the possibility to replace this detector with an array of fused silica fibers read out by multi-anode photomultiplier tubes (PMTs). A thin radiator would convert the hard synchrotron radiation into e^+e^- pairs which would then be detected in the fused silica fibers by Cherenkov radiation. While a similar technique has been utilized with fused silica fibers in calorimeters for quite some time, the application of this technique as a position sensitive detector is less common. The advantages of this technology over either wires or other traditional solid-state detectors like silicon strips are fourfold. First, the fused silica fibers are very radiation hard. Second, the Cherenkov threshold of electrons in fused silica 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 without complicated front end electronics. Fourth, the dynamic range of this detector can be easily varied by many orders of magnitude by simply adjusting the gain of the PMT. 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 project was already funded in FY03, and in that time we have acquired two Hamamatsu R6568 multi-anode PMTs, a variety of fibers (both scintillating and fused silica), and assembled a light box and data acquisition system to facilitate testing in our lab. Response as a function of fiber position for both 100 micron and 500 micron fibers has been measured to determine the optimal geometry for coupling the light from the fibers into the PMT. A typical response curve is shown in Figure 3. Relative channel gain and long term stability has also been measured and found to be in good agreement with the Hamamatsu specifications.

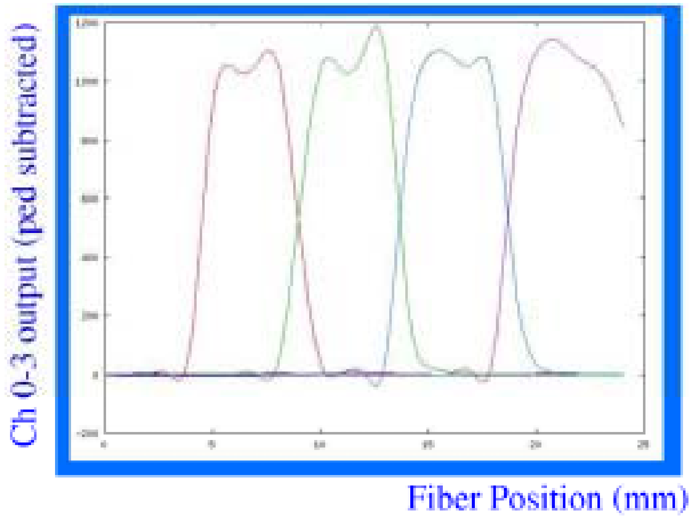

Figure 3: Measured response functions for R6568 PMTs to bare 100 micron fused silica fibers

Detecting Cherenkov photons from fused silica fibers in a tabletop lab setup is not easy. We have built a miniature cosmic ray telescope consisting of two planes of 400 micron square scintillating fibers with an active area of about 1 cm x 30 cm. Between these two trigger planes, we sandwich an array of sixteen 600 micron fused silica fibers. This configuration provides a cosmic ray trigger rate of about 0.1 Hz and provides enough data to convincingly demonstrate that Cherenkov photons are being produced in the fused silica fibers. We have roughly measured the efficiency of observing a photon to be 0.5% per triggered cosmic ray.

Description of FY04 project activities

At UMass, Hertzbach intends to continue the studies presented at Cornell in the Summer of 2003, but without the assistance of an undergraduate for the coming year. For this reason, funds are not being requested in FY04. For the following year, it is expected that another undergraduate student, or part-time grad student, will be hired to make detailed studies with the tools developed by Hertzbach during `04, with the ultimate goal of developing a working spectrometer design and studying the performance of this device in detail. For reasons unrelated to instrumentation, the baseline NLC extraction line length has been increased by about 100 m. It is important that spectrometer requirements be included in the redesign of the extraction line, and we will work with this in mind.

At Oregon, our excellent undergraduate student (Paul Csonka) will soon be leaving the group to pursue graduate studies in engineering. He has already designed a prototype detector based on fused silica fibers which would be suitable for a beamtest to prove the principle of detecting synchrotron radiation in this manner. The device has eight 100 micron fibers and eight 600 micron fibers read out by a single H6568 multi-anode PMT. Paul is currently building this detector and will complete the prototype before he leaves some time this Winter.

The immediate goals of the Oregon group are to assemble the additional equipment needed for a quick beam test of this device at SLAC in End Station A. For building a final detector, it would be useful to increase the channel count significantly, so we would also like to explore the characteristics of the H7546 which is an 8x8 version of the H6568 for a total of 64 channels in one PMT.

Beyond the hardware efforts, we want to start developing an EGS4 or Geant simulation of the expected detector performance which can be validated with the test beam results from this first prototype. Also, this detector simulation can be merged with the beamline simulation tools developed at U. Mass. to begin to characterize the performance of a complete spectrometer system. The H7546 phototube tests will be performed by a new undergraduate student using the existing teststand setup, while the simulation activity is expected to be started by one of our second year graduate students this coming summer.

Future Activities

There is a growing interest around the world in beam instrumentation issues for a linear collider. A letter of intent, to which we are signatories, has been presented to the SLAC PAC stating an interest in using the beam at SLAC in the End Station A to test a wide variety of beam instrumentation detectors. In addition, a rather large proposal has been granted to groups in the UK by their funding agency to provide money in the next few years for beam delivery and interaction region R&D. There are also plans in Europe to submit a grant to the EU requesting funds which would support the European part of an international linear collider design team. Both the UK and European efforts expect part of this money to be devoted to beam instrumentation including spectrometry.

Until it is known exactly how these initiatives are received and how this effort will be coordinated worldwide, it seems premature to project a budget for building a prototype spectrometer for a beam test. The goal of the budget currently proposed is to complete a preliminary spectrometer design and prepare, where possible, the groundwork for a consolidated spectrometer test (including the BPM-based technique) probably in 2006. An earlier test of the fused silica fiber detector is also foreseen.

Budget Request

Institution	Item	FY04	FY05	FY06
Oregon	Undergrad salary	$6,825	$6,825	$6,825
Oregon	50% grad student salary	18,766	$19,817	$20,927
Oregon	H7546B-03 64 channel multi-anode PMT	$2,000		
Oregon	Prototype detector materials (fibers, readout cables, connectors, etc.)	$1,000		
Oregon	Two Bertan 1 kV PMT power supplies		$500	
Oregon	Travel	$3,000	$3,000	$3,000
Oregon	Total	$31,591	$30,142	$30,752
U. Mass	Undergrad or partial grad student salary		$8,000	$8,400
U. Mass	Fringe Benefits		$400	$420
U. Mass	Travel		$3,990	$4,970
U. Mass	Software Licenses		$1,400	
U. Mass	Indirect Costs (45%)		$6,210	$6,210
U. Mass	Total	$0	$20,000	$20,000
	Project Total	$31,591	$50,142	$50,752

Budget Discussion

Along with money for students and modest lab hardware, this budget requests travel money to allow both Torrence and Hertzbach to more fully participate in international linear collider meetings. Some travel money will be used for the students, to increase their involvement in the project. It is expected that significant coordination of activities worldwide will be necessary once a technology decision has been made in 2004. Greater US participation in the European and Asian regional meetings will significantly improve the communication and level of coordination between the activities in the three regions. Benefits and overhead have been included in the above budget numbers for Oregon.

[1] J. Kent *et al.*, "Precision Measurements Of The SLC Beam Energy," Presented at IEEE Particle Accelerator Conf., Chicago, Ill., Mar 20-23, 1989.
[2] D. Cinabro, M. Woods, and E. Torrence, "Status of Linear Collider Beam Instrumentation," ALCPG-03-0001, http://www.slac.stanford.edu/xorg/lcd/ipbi/notes/white.pdf.
[3] http://www.slac.stanford.edu/xorg/lcd/ipbi/cornell03/E_Spect_ALCPG-Cornell-mod.pdf.

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

Luminosity, Energy, Polarization

Contact person: Mike Hildreth
email: mikeh@undhep.hep.nd.edu
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Notre Dame

Year 1: $51,185
Year 2: $148,800
Year 3: $157,315

2 Machine-Detector Interface

2.1 A Demonstration of the Electronic and Mechanical Stability of a BPM-Based Energy Spectrometer for an Electron-Positron Linear Collider

Personnel and Institution(s) requesting funding

Michael D. Hildreth, University of Notre Dame

Collaborators

Yury Kolomensky, Lawrence Berkeley National Laboratory and University of California, Berkeley

Joe Frisch, Peter Tenenbaum, Stanford Linear Accelerator Center

Project Leader

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Changes Since Preliminary Project Description

The budget was reduced to reflect current accounting of fringe benefits on graduate students and to more properly account for the time spent by professionals on the project.

Project Overview

Much of the physics of the future e^+e^- Linear Collider will depend on a precise measurement of the center-of-mass energy ($E_{\rm CM}$), the differential dependence of luminosity on energy ($\mathrm{d}\mathcal{L}/\mathrm{d}E$), and the relationship between these two quantities and the energy of a single beam ($E_{\rm beam}$). Studies estimating the precision of future measurements of the top mass[1] and the higgs mass[2] indicate that a measurement of the absolute beam energy scale of 50 MeV for a 250 GeV beam ($\delta E_{\rm beam}/E_{\rm beam} \sim 1{-}2\times10^{-4}$) 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 $\delta E_{\rm beam}/E_{\rm beam} \sim 3\times10^{-5}$ (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.

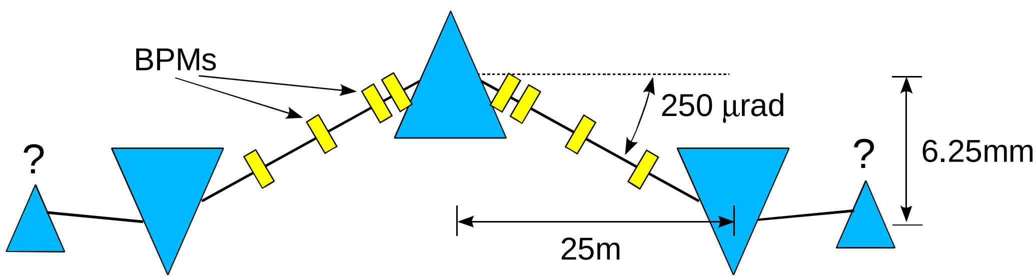

Figure 1: A schematic outline of an accelerator dipole chicane which could accomodate a BPM-based magnetic spectrometer at a future linear collider.

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 compononents; 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.

FY2004 Project Activities and Deliverables

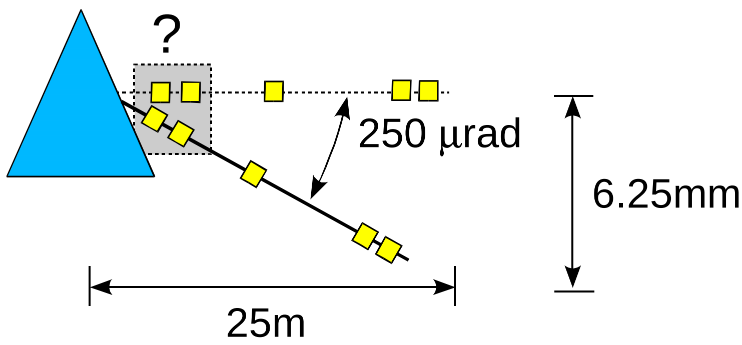

Figure 2: A diagram showing the two cases of: straight-ahead linear trajectory measurement to establish zero deflection; and the motion of the BPMs necessary to measure a deflection of 250μrad. The "?" indicates that it may be possible to design a system with sufficient accuracy that the closest BPM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

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 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.

FY2005 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.

FY2006 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$: University of Notre Dame

Item	FY2004	FY2005	FY2006	Total
Other Professionals	0	40.000	35.000	75.000
Graduate Students	10.000	22.000	24.000	56.000
Undergraduate Students	3.000	3.000	4.000	10.000
Total Salaries and Wages	13.000	65.000	63.000	141.000
Fringe Benefits	0	8.000	7.000	15.000
Total Salaries, Wages and Fringe Benefits	13.000	73.000	70.000	156.000
Equipment	20.000	30.000	40.000	90.000
Travel	2.000	2.000	4.000	8.000
Materials and Supplies	6.000	5.000	5.000	16.000
Other direct costs	0	0	0	0
Total direct costs	41.000	110.000	119.000	270.000
Indirect costs	10.185	38.800	38.315	87.300
Total direct and indirect costs	51.185	148.800	157.315	357.300

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3.6. Polarimetry at LC (LCRD)

Luminosity, Energy, Polarization

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Fairfield
Iowa
Iowa State
Karlsruhe (Germany)
Bogazici (Turkey)
Cukurova (Turkey)
META (Turkey)

Year 1: $20,100
Year 2: $45,100
Year 3: $37,650

Project name

Polarimetry at LC

Classification (accelerator/detector:subsystem)

Detector: IPBI / Accelerator

Institution(s) and personnel

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

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

Iowa State University, Department of Physics:
Walter Anderson (professor)

Forschungszentrum Karlsruhe, Germany:
Robert Rossmanith (professor)

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

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

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Project Overview

Introduction:
A high (~80%) and precisely known electron beam polarization is considered as a key feature at LC to detect and unambiguously interpret new physics signals [1]. Accurate measurements of beam polarization will be needed. The goal for the precision polarimetry is 0.25% as explained in [2]. Primary polarimeter is currently envisioned to be similar to SLD polarimeter, measuring the asymmetry of Compton-scattered electrons near the kinematic edge using a threshold gas Cherenkov counter. Our goal for this proposal is to investigate alternate polarimeter schemes.

i) use of a quartz fiber calorimeter (or counter) for either the Compton-scattered gammas or electrons
ii) W-pair asymmetry using forward W-pairs; determining forward detector requirements to do this.

Following the remarkable success of Compton backscattering polarimeters [3] at SLC and LEP, this method is a prime choice also at LC [4].

Detection schemes
The performance of electron polarimeters in the challenging environment at LC will crucially depend on the detection schemes for scattered electrons or photons. Quartz Fiber Calorimeters [5] have been proposed for a number of applications in extreme experimental conditions of very severe radiation levels both at hadron and lepton machines. Extensive studies have been carried out for the design of large detectors and realistic beam tests on full scale prototypes [6] have been performed recently. In particular, the Iowa group has been leading an effort aimed at building a very forward QFC (HF) for the CMS experiment at LHC [7] since 1994. The available information and know-how collected give evidence that such a type of detector would respond ideally to the highest level of requirements for a LC polarimeter, as already demonstrated at SLC [8]. QFC are radiation hard at the level of more than 2 Grad. The 0.2 MeV Cerenkov threshold makes the detector insensitive to a large fraction of soft radiation. With high-Z absorber material (for instance tungsten), the showers corresponding to high energy electrons or photons are completely contained in a compact device. Their transverse size is so small to provide an excellent position resolution and angle determination. The flexibility in the QF arrangement and in the PM readout can be matched to the required granularity for space resolution and density for energy resolution. The basic formalism for Compton polarimeter is given in Ref [9].

R&D Program
Our R&D study of a QFC designed for a LC polarimeter will largely benefit from our experience on the QF technology and the calorimetry properties of such devices. We gained this experience in the design and tests of the prototypes for the HF calorimeter of CMS. This extensive work background means substantial savings of time, efforts and costs in case of a specific project for a LC polarimeter detector. We will begin our R&D effort with studies and simulations to determine requirements for a QFC polarimeter and investigate its systematics. We will compare single and multi-Compton operation, and compare electron and gamma measurements. We intend to design and build a prototype

QFC module of sub-millimetric granularity using multi-anode PMT (16 or 64 channels) for the QF readout. The prototype will be tested over a broad energy range relevant for scattered electrons and backward scattered photons.

We propose to perform detailed simulation and engineering studies during the first year, to investigate the role of this calorimeter for the electron detection and electron energy resolution and photon detection.

We hope to finalize the conceptual design of the polarimeter towards the end of the first year, and during the second year, to start design-studies for W-pair asymmetry and we will completer Compton polarimeter studies, hardware and beam test in the third year.

Conclusions

A QFC with optimized granularity and energy resolution for high energy EM Showers appears to be an essential component of an electron beam polarimeter at LC. Its advantages are radiation hardness, soft background rejection, good localization, and directional precision as well as energy resolution. Our group has ample experience with this type of detector, as well as with the use of multi-anode PMT [10]. Such accrued competence gives us complete confidence in our ability to design, build and test a prototype in order to demonstrate its suitability for polarimetry at LC in a timely and cost-effective fashion.

Relevant Experience

- Project leaders Y. Onel and A. Penzo have worked in the field of Experimental HEP Spin Physics and polarization for many years. They invented the "Spin Splitter" concept to polarize anti-matter in a storage ring with Robert Rossmanith. R. Rossmanith has also developed and designed the LEP polarimeter.
- Y. Onel and A. Penzo were co-spokesmen for the proposal on Nucleon Spin Studies with polarized proton and anti-proton beams at FNAL (E863). Onel/Penzo have edited two books in the field of spin/polarization physics, namely Spin and Polarization Dynamic in Nucleon and Particle Physics (World Scientific, 1990) and Trends in Collider Spin Physics (World Scientific, 1997).
- Y. Onel and A. Penzo were also involved in the Ultrafast Readout with multi-anode PMT development RD17 at CERN.
- Y. Onel and D. Winn have jointly proposed the quartz fiber calorimetry for the CMS forward Calorimeter (HF) in January 1994 after prototyping the quartz fiber calorimetry using SSC GEM closeout finds. There are now 6 U.S. and 9 international institutions (15 in total) in the CMS-HF group.

- The U.S. CMS HF group at Iowa was responsible for:

1- HF detector prototypes
   a. Engineering design of prototypes and preproduction prototypes and manufacturing the modules and components (in the machine shop at University of Iowa.)
   b. Engineering design and manufacturing of the Readout box for the preproduction modules (in the machine shop at University of Iowa.)
   c. Engineering design and manufacturing of the optical system for the preproduction modules.

   d. Engineering design of the HF calibration system (LASER and LED) and development of source calibration systems for the preproduction modules.
   e. Production and engineering design of the HCAL LED drivers (HB, HE, HO and HF) and manufacture of prototypes in the electronic shop at the University of Iowa.

2- Selection and purchase of US quartz fibers in addition to the responsibilities of procurement procedures, contracts, insurance, quality control at manufacturer (CMS IN 2002/028) and delivery schedules and final delivery.
3- Fiber radiation damage tests and studies at Iowa LIL/CERN facilities
4- Selection and purchase of Photomultiplier Tubes (PMT's) in addition to the responsibilities of procurement procedures, contracts, insurance, delivery schedules and final delivery.
5- Construction of the CMS-HF IOWA PMT test station facility.
6- Test and quality control of the HF PMT's and maintenance of a web-based database.
7- Design and construction of the HF light guides for the first two wedges (2 of 36) in the University of Iowa machine shop. Procurement of the light guide material for the remaining 34 wedges.
8- Design and construction of the source distribution mechanics, including source tubing couplers and coupler pins in the (University of Iowa machine shop.)

Deliverables

We will concentrate on the Monte Carlo simulations in FY04. We will produce a Report/Research Document showing the results and the details of our Monte Carlo simulations for the specific geometries and configurations as shown in our proposal to design a Cherenkov Calorimeter for LC.

We will initially focus on the simulations/study necessary for developing the detector requirements and estimating systematic errors. If we are successful in 04, we propose to continue with our R&D by constructing a prototype in 05-06. We will be collaborating with the group of Dr. M. Woods/SLAC and Eric Torrence/U. Oregon on this research.

Budget

Institution	Item	FY04	FY05	FY06
Iowa	Partial support for grad. student	$6.0k	$6.0k	$6.0k
IowaState	Partial support for grad. student	-	-	$6.0k
Fairfield	Support for undergrad. student	$6.0k	$6.0k	$6.0k
Iowa	Quartz Fiber (QP) 2km	-	$5.0k	-
Iowa	Copper Absorber	-	$4.5k	-
Fairfield	5 Multi-anode PMT (H6568)	-	$9.0k	-
Iowa	Engineering	-	$6.0k	-
Iowa	Travel	$2.0k	$2.0k	$4.0k
IowaState	Travel	-	-	$4.0k
Fairfield	Travel	$2.0k	$2.0k	$4.0k
	Indirect cost @ 25.5%	$ 4.1k	$ 4.6k	$ 7.65k
	Grand total	$20.1k	$45.1k	$37.65k

Available equipment: FERA ADC 160 channels, discriminators, DAQ equipment, 1 16-channel H6568 PMTs, and calibration electronics and equipment to test QF Calorimeter (LED systems, Laser systems, PIN diodes systems, and radioactive source calibration)

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3.7. Compton polarimeter backgrounds (LCRD)

Luminosity, Energy, Polarization

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Tufts
SLAC

Year 1: $14,000
Year 2: $14,000
Year 3: $0

Project name

Compton polarimeter backgrounds

Classification (accelerator/detector:subsystem)

Detector: IP Beam Instrumentation (LEP)

Institutions and personnel

Stanford Linear Accelerator Center
Ken Moffeit, Mike Woods

Tufts University
William Oliver, Professor of Physics

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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], which measured the rate of longitudinally-polarized electrons Compton-scattered from a circularly polarized laser beam. The polarization was determined from the rate asymmetry for electron and laser photon spins aligned compared to anti-aligned. 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.

At a future Linear Collider (LC), the electron beam polarization is expected to be 80-90% and physics motivates determining the beam polarization to an accuracy of 0.25% or better.[2] Compton polarimeters, similar to the SLD polarimeter, are being designed for the LC to achieve this measurement goal.[2] The LC 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 disrupted beams and intense beamstrahlung can generate high backgrounds, so it is necessary to carefully incorporate polarimeter design considerations into the design of the extraction line optics. It is the central feature of our proposal that we calculate these backgrounds to determine what design modifications are required for both the extraction line optics and for the polarimeter detector.

The (current) NLC beam extraction line is described in Reference [3]. It includes a chicane to separate the primary beam from the beamstrahlung beam to facilitate beam diagnostic measurements, including a precision Compton polarimeter. Because of the high power (10 MW for the primary beams, 0.5 MW for the beamstrahlung beams), the beam monitors must be able to operate with a minimal amount of material intercepting the beams. Following the chicane, the primary and beamstrahlung beams are directed to a common dump.

The IP Beam Instrumentation Group describes current plans for beam diagnostics in the beam extraction line in Reference [4]. The Compton polarimeter laser beam intercepts the primary beam in the middle of the extraction line chicane, 60 meters downstream of the Interaction Point. In this region the charged particle beam has a dispersion of 20 mm, consequently a laser beam of 200-micron diameter samples the primary beam within a narrow momentum range of 1.0%. 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 beam 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 polarimeter detector is a threshold gas Cerenkov counter that is segmented in the bend plane to provide rate measurements of the Compton-scattered electrons in different momentum bins. The rate asymmetry (comparing rates for electron and photon spins aligned versus anti-aligned) measured by the Cerenkov counter segment at 9-cm offset (detecting the back-scattered electrons) 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 that produce the most background in the Cerenkov counter.

The principal concerns to us are effects of the 500-kW beamstrahlung beam and the disrupted primary beam. The beam axis passes within 9 cm of the segmented Cerenkov counter. At the Cerenkov counter, the beamstrahlung has spread considerably, but 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 still might 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 this 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.

The disrupted primary beam includes electrons scattered at large angles or with relatively large energy losses. The transport of these particles through the beam extraction and diagnostic system might not be accurately portrayed by a matrix-element approach. We propose to track these highly scattered particles through the beam extraction system to calculate their effect on the Cerenkov counter.

Other background sources that we will consider are:

i) synchrotron radiation in the extraction line dipoles and quadrupoles
ii) beam-gas interactions
iii) radiative Bhabhas
iv) pairs generated from the beam-beam interaction

Description of the two-year project

1. SLAC We will use MAT-LIAR simulations for the incident beams at the IP using NLC-500 parameters. We will use GUINEA-PIG to simulate the beam-beam interaction to generate the disrupted primary beams, the beamstrahlung beams, and also the radiative Bhabhas and pairs. We will provide the extraction line optics geometry and the relevant geometry for the Compton laser system and detector. The initial setup for this resembles the SLD polarimeter geometry, but will evolve to optimize performance for the LC. Calculations of the propagation of the disrupted primary beams through the extraction line were reported in July 2003 to the American Linear Collider Workshop at Cornell [5].

2. Tufts We propose to calculate the Compton polarimeter background with the aid of a graduate student who is supported half time by this grant. In preparation for our calculation, we have downloaded a GEANT-3 model of the NLC beam extraction system from the web site of the IP Beam Instrumentation Working Group at SLAC. The GEANT program is now running successfully at Tufts. We have carefully checked the Fortran code and performed numerous test runs to be sure the program is giving the expected results in simple situations. The results of these test runs were reported at the American Linear Collider Workshop in July 2003 [6]. We have added a model of the beam pipe to the GEANT program because this pipe might be an important source of background in the Cerenkov counter.

We propose in the first year of the project to calculate the effect on the Cerenkov counter of the scattered primary particles emerging from the interaction point as they proceed through the beam extraction system. For this purpose we will augment the GEANT program to model the segmented Cerenkov counter, including its walls and pre-radiator. The initial calculation will be based on an existing file of 15,000 primary particles emerging from the beam-beam interaction region as calculated by the GUINEA PIG program. We have downloaded this file (beam1_IP.dat) from the IPBI web site. We propose to calculate the extent to which the more highly scattered primary particles scrape the walls of the extraction system and generate electromagnetic showers that spray secondary particles into the Cerenkov counter. We will also calculate the synchrotron radiation generated by the primary particles as they pass through the bending magnets of the beam extraction system. The synchrotron radiation will be tracked through the extraction system to determine the effect on the Cerenkov counter. After completing the initial calculation, we will extend the calculation to a much larger sample of disrupted beam particles to determine the background more accurately.

In the second year of the project we propose to turn to the calculation of the background due to the interactions of the beamstrahlung beam in the unavoidable material elements in the beam extraction system. In this calculation we will pay particular attention to the flange that supports the thin window through which the Compton-scattered electrons emerge from the vacuum, and to the wall of the beam pipe adjacent to the Cerenkov counter. The principal background in the Cerenkov counter is likely to be the result of wide-angle beamstrahlung radiation. We also plan to track radiative Bhabhas and pairs generated at the IP to see if they cause any significant background. We will also consider beam-gas interactions as a source of backgrounds.

Two of the design parameters we will consider in these studies are the Compton laser wavelength and the thickness of the pre-radiator for the polarimeter detector. Switching to a 2.33 eV laser results in the Compton-edge electrons being 19 cm from the beam axis, 10 cm greater than for the 1.17 eV laser. The pre-radiator in front of the polarimeter detector enhances the signal from the Compton-scattered electrons, but a thick pre-radiator makes the calculation of the analyzing power for the detector more difficult. We plan to achieve a system design that allows for a thinner pre-radiator than was used for the SLD polarimeter, while ensuring a good signal-to-background ratio.

The project provides a good opportunity for a graduate student to learn the challenges and opportunities of the 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 LC project over the long term.

In the proposed project we expect to continue to work in cooperation with the IP Beam Instrumentation Working Group. 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 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 for 2004

Institution	Item	Cost
Tufts	Academic year + summer salary for one half-time graduate student	$10,000
Tufts	Indirect costs	$4,000
	Total	$14,000

Budget for 2005

Institution	Item	Cost
Tufts	Academic year + summer salary for one half-time graduate student	$10,000
Tufts	Indirect costs	$4,000
	Total	$14,000

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3.8. Coherent and incoherent beamstrahlung at the LC (UCLC)

Luminosity, Energy, Polarization

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

Wayne State

Year 1: $7,550
Year 2: $75,511
Year 3: $59,929

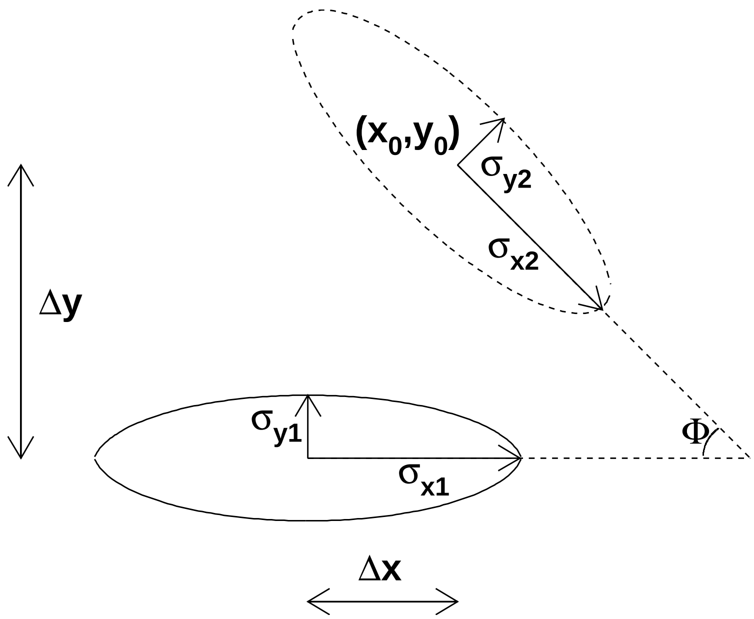

Figure 1: The seven transverse degrees of freedom in the beam-beam collision.

2.2 Coherent and incoherent beamstrahlung at the LC

Personnel and Institution(s) requesting funding

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

Project Leader

Giovanni Bonvicini
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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 on with "weak" beams would be an invaluable monitoring and diagnostic system for the LC. Fig. 1 shows the seven $transverse$ degrees of freedom (dof) that can affect the beam-beam overlap and therefore the luminosity.

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%. This technique is the only one known that can map six of the seven dof [2], and it is also in advanced state of testing at CESR.

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. We installed in June 2002 a single-arm, one PMT prototype in the CESR/CLEO interaction region at an angle of 11 mrad from the beam axis. We 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.

Following the successful testing, in July 2003 we installed the first 1/4 of the full device and we will take data as soon as the CESR beams attain sufficient intensity. Things to do include

1. observation of large angle beamstrahlung (this depends solely on attaining a beam current of order 30% of the nominal current)
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

There is a potentially broad beam physics program attached to the CESR device, including the study of the beam-beam limit and, with the addition of fast-gating electronics, bunch-to-bunch differences. We plan to buy some of such electronics with the funds requested here as this electronics is a must for the LC, and test and use it at CESR. At the NLC, the bunch-to-bunch spacing is 1.4 nsec, to be compared with 14 nsec at CESR. If we will develop a coherent beamstrahlung detector for CESR, as described below, we will need reuse the fast-gating electronics for that application as well.

Our recent studies have focused on beamstrahlung at the LC. Our findings are described in Ref.[5]. We compute a strong visible signal at the NLC, and a full detector simulation will be performed next. The LC environment is different from CESR in that the beams will jitter from one collision to the next. Ref. [2] assumed the steadily varying, continously monitored CESR beams ("beam-beam drift"). The impact of jitter is to reduce the dimensionality of the monitored dof from six to four [5].

Another problem we have noted is that, due to the overall cubic dependence of the signal on the current, visible beamstrahlung does not lend itself to the study of the machine during early turnon. To make up for the loss of information, and the lack of signal early in the game, we have introduced the concept of monitoring the coherent, microwave part of the beamstrahlung spectrum. 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 "weak" (low current, high-size) beams and the ability to measure the bunch length by studying the wavelengths of the coherent radiation. Coherent beamstrahlung power, for equal, weak beams colliding with varying offsets, is shown in Figure 2. Ref. [5] notes that one of the advantages of coherent beamstrahlung is that the rates are so abundant that they can be considered free of background from any source of synchrotron radiation.

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. Ref. [5] concludes that coherent beamstrahlung adds two extra dof to the information provided by visible beamstrahlung, effectively recovering almost complete visualization of the beam-beam interaction.

We have also continued development of the design of an incoherent beamstrahlung detector for the NLC, as described in our presentation at the NLC workshop in Arlington, January 2003.

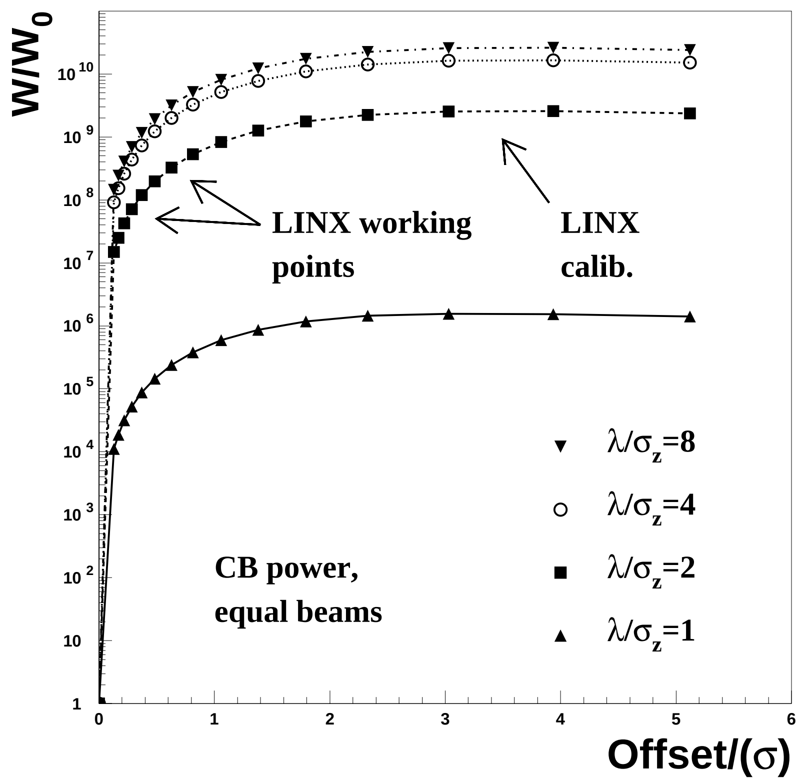

Figure 2: CB yield as a function of the beam-beam offset. The simulations were done with NLC nominal conditions, but weaker beams ($N_1 = N_2 = 0.3 \times 10^{10}, \sigma_{y1} = \sigma_{y2} = 19$nm). Plots are shown for four different wavelength-beam length ratios. The LINX working points are where one may measure beam jitter, and calibrate the device. The markers locate the points where the simulation was performed.

Given the chance, LINX[6] is a perfect opportunity to pioneer a coherent beamstrahlung detector, because of the very short beam length, and the LINX major goal of measuring beam jitter at the nanometer level (which this device can do accurately and conclusively).

If LINX does not go forward, we may consider trying for first detection at CESR. Here this device would be less useful (mostly replicating the information of the present beamstrahlung detector) and the EM wave detection (microwave versus far infrared) different from the LC case. However, a preliminary survey of the CESR beam pipe has shown an excellent location at 3m from the IP, where background RF (from the beam charge image, and surrounding accelerator components) is expected to be very low. We note that the location has button-shaped beam position monitors (BPM), and we are considering doing exploratory work there by studying the frequency spectrum of those BPMs.

The SLAC Test Beam facility (FFTB) may prove useful for evaluating incoherent beamstrahlung backgrounds at the linear collider. Incoherent beamstrahlung backgrounds were calculated reliably within one order of magnitude at both the SLC and at CESR, but similar calculations for the NLC are less mature. Backgrounds to coherent beamstrahlung are dominated by RF generation near the microwave detector (most notably discontinuities in the beam pipe), so the FFTB will be an unreliable predictor of the background at the linear collider. Nevertheless, we will follow our CESR experience in detecting coherent radiation using BPMs with exploratory work at the FFTB in 2006. The instrumentation we propose has no real precedent and we wish to have proof positive that there are no unexpected problems.

FY2004 Project Activities and Deliverables

Work will be continuing on the funded MRI incoherent beamstrahlung system at CESR. We will complete a preliminary design for an LC beamstrahlung monitor system including both incoherent and coherent beamstrahlung radiation detectors, which have to share the same solid angle (approximately from 1 to 1.5 mrad).

FY2005 Project Activities and Deliverables

Continue design and simulation studies for an LC beamstrahlung monitor system. Purchase and test fast-gating electronics, a common need for the NLC and CESR. Analyze the frequency spectrum of CESR BPM, to study coherent beamstrahlung.

FY2006 Project Activities and Deliverables

Complete design for both visible and coherent beamstrahlung detector for the LC. Install and operate fast electronics at CESR. Use the incoherent CESR prototype at the FFTB, and explore coherent backgrounds using experience with BPMs at CESR.

Budget justification

We need 50% of a postdoc to perform the background simulation and the optics optimization for both detectors. The challenge for the visible detector is in background minimization (several methods possible, see Ref.[5]), detector pixelization, and optics. The challenge for the coherent detector is in detector choice, and in designing a fast DAQ system with a dynamic range of at least eight orders of magnitude. We also need to make sure that the large RF power associated with the beam charge image does not induce a large noise.

In year 1 some travel money. In year 2 travel money, 0.5 postdocs and equipment money for fast-gating electronics. In year 3 travel money and 0.5 postdocs.

Indirect costs are 51% of non-equipment costs.

Three-year budget, in then-year K$: Wayne State University

Item	FY2004	FY2005	FY2006	Total
Other Professionals	0	23.000	24.000	47.000
Graduate Students	0	0	0	0
Undergraduate Students	0	0	0	0
Total Salaries and Wages	0	23.000	24.000	47.000
Fringe Benefits	0	5.451	5.688	11.139
Total Salaries, Wages and Fringe Benefits	0	28.451	29.688	58.139
Equipment	0	25.000	0	25.000
Travel	5.000	5.000	10.000	20.000
Materials and Supplies	0	0	0	0
Other direct costs	0	0	0	0
Total direct costs	5.000	58.451	39.688	103.139
Indirect costs	2.550	17.060	20.241	39.851
Total direct and indirect costs	7.550	75.511	59.929	142.990

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[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

Year 1: $23,517
Year 2: $34,974
Year 3: $34,974

Project name

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

Classification (accelerator/detector:subsystem)

Accelerator—L.E.P. (detector for low energy e^+e^- pairs for luminosity optimization)

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 are developing silicon sensors with closely spaced electrodes that penetrate the silicon substrate for uses in which 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, and Angela Kok of Burnel University, we have fabricated and tested sensors that are 120 and 180 microns thick. (See Figure 1.) All recently fabricated sensors have active edges—etched, rather than sawed edges, in which implant and oxidation steps have made the edges into an electrode.

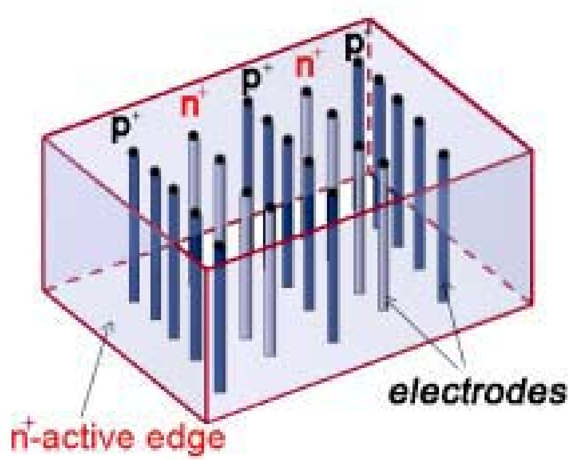

Figure 1: Schematic sketch of a 3D sensor.

Initial calculations indicated it should be possible to have sensors with low depletion voltages 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. Tests with wall electrodes, fabricated from trenches with steps that were similar to those for our new active-edge electrodes, indicated high collection efficiency [5].

Pulses from 3D sensors can be shorter because:

(1) Collection distances are shorter.

(2) For any given maximum field, average fields can be higher.

(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.

(4) Since both electrode types can be contacted on the same surface, readout of both using dc coupling on one set and ac coupling on the other, would allow correction of timing jitter due to track location.

We have measured pulses from a 3D sensor exposed to betas from a ^{90}Sr source, in which only (1) and (2) apply. Several preliminary pulses were shown in last year's sub-proposal.

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 [6].

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 [7]. A timing resolution of 19 ns has now been demonstrated.

Description of first year project activities

We will describe results for more than the two months since funding was received at the end of July. The technology we have been developing can be used for several projects, the wafers we have been fabricating have devices for all of them, and we have had funds from our European and Japanese collaborators, and from the National Institutes of Health. This has allowed us to start work on the technology and sample devices for beam shape monitoring some time ago.

The fabrication runs recently completed were 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 [7]. Other sensor designs on the same wafer might also be used for this project.

Two kinds of active-edge sensors have been fabricated: those with interior planar electrodes and 3D active edges, and those with 3D electrodes throughout. The former require fewer fabrication steps and have no interior insensitive regions. Full 3D sensors will have narrow insensitive regions inside their interior electrodes, but can have much greater resistance to radiation damage, and much greater speed, and so are more suitable for the beam shape monitor.

Active-edge tests, not yet published, have used sensors from recently completed runs. Both those with an x-ray microbeam at the LBL Advanced Light Source during July and with a 100 GeV muon beam at CERN in September, show that active-edge sensors are, in fact, sensitive to within several microns of their physical edges. The edges, formed by etching, rather than sawing, can also be curved, allowing sensitivity very close to the beam pipe. Figure 2 shows data from a planar/3D active edge sensor. Figure 3 shows data from a full 3D sensor.

Several 3D sensors have recently been combined with fast, low-noise amplifiers provided by Pierre Jarron and Giovanni Anelli of CERN [8]. ^{90}Sr beta rise time distribution, limited by the amplifier speed, have been measured at room temperature to be about 3.5 ns, with full widths at half max of about 9 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 4.)

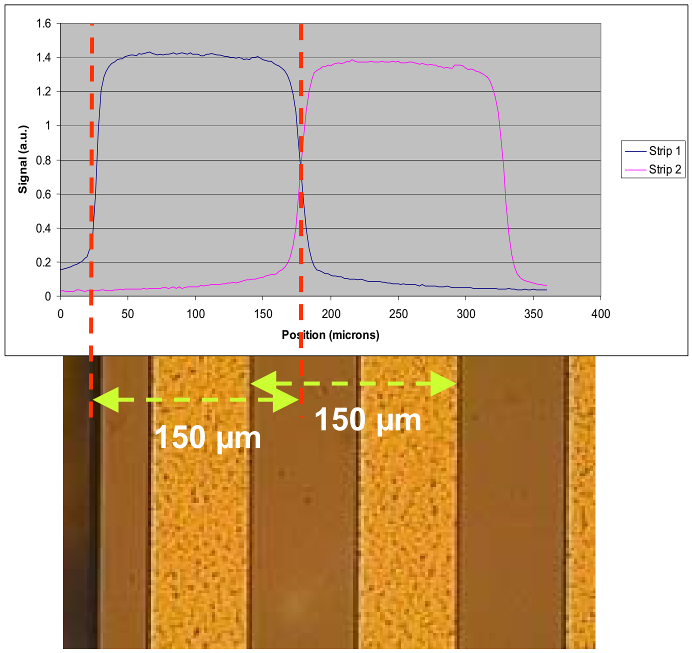

Figure 2. Pulse heights from the first two channels of a planar sensor, scanned on a precision stage, under a 2-µm, 12 KeV x-ray beam. Below, at the same scale, is a photograph of the sensor. The channel 1-2 signal cross point is aligned with the 1-2 midpoint on the photograph. The left-side tail on channel 1 is due to reflected gold x-rays from the sensor holder and to leakage current. The right side tail, and both tails from channel 2 also have a contribution from charge sharing. The sensor was biased at 20V.

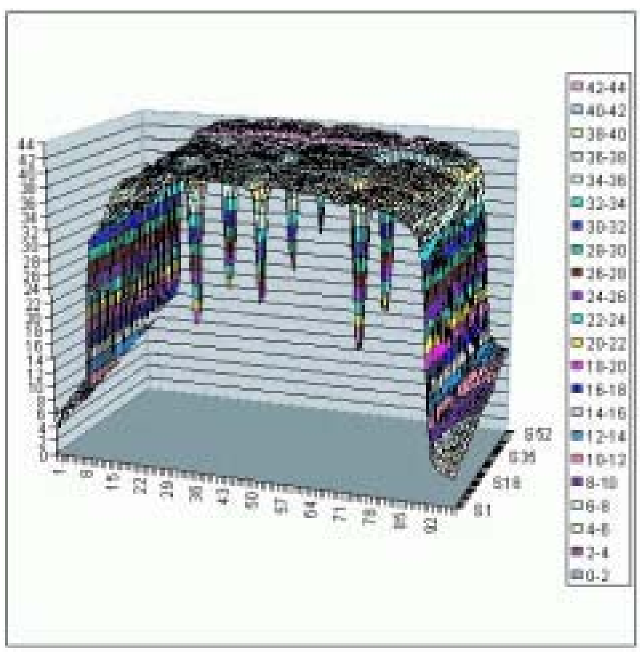

Figure 3. Signal from a scanned full 3D (center and edges) sensor showing both active edge sensitivity, and reduced sensitivity in central electrode regions.

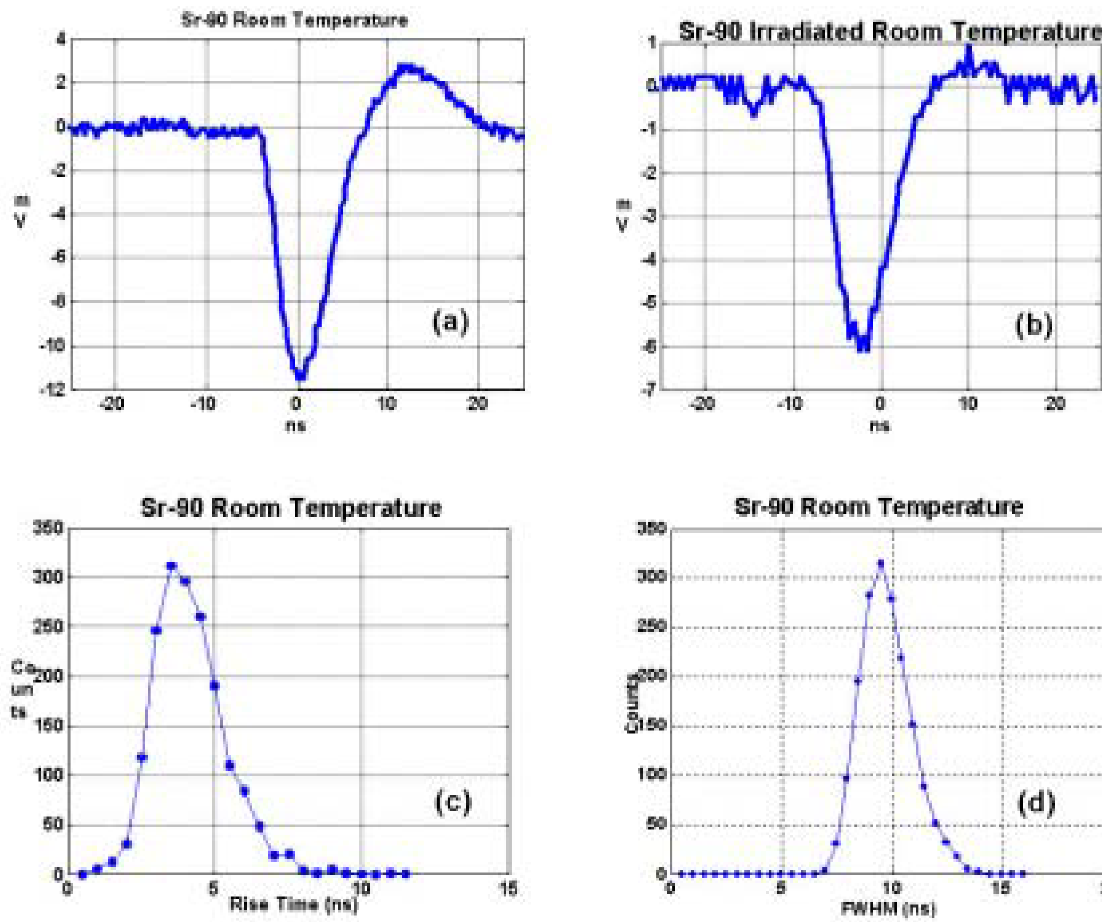

Figure 4. (a) Beta pulse from an unirradiated, 100 µm x 200 µm-cell size, 3D sensor. The overshoot can be reduced, but with longer rise times. (b) Pulse from a non-oxidized, room temperature sensor irradiated with 10^{15} 24 GeV protons/ cm^2. (c,d) Distribution of rise and full-width, half-max times, for a 100 µm x 200 µm-cell size sensor.

Future devices; future fabrication runs

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].

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.

Fabrication runs will take from two to six months, depending on equipment availability, batch sizes, and the details of the run steps, and could produce total silicon areas comparable to several times 500 (later 2,900) cm^2. With dedicated personnel, several runs could overlap in time. 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 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 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. For the second and third years, we assume more devices are needed, and that we will have runs where half, rather than one quarter of the wafer area, will be devoted to sensor fabrication. It is assumed read out electronics development, testing, and assembly continue in Japan.

Item	Year 1	Year 2	Year 3
Stanford Nanofabrication Facility machine charges	$ 3,000	$ 5,000	$ 5,000
1.5 months time, fabrication engineer and/or technician	$15,000	$22,500	$22,500
silicon float zone wafers, lab supplies	$ 1,500	$ 1,500	$ 1,500
Indirect costs (20.6%)	$ 4,017	$ 5,974	$ 5,974
Hawaii total	$23,517	$34,974	$34,974

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3.10. Polarimeter with a Quartz Fiber Calorimeter (LCRD)

Luminosity, Energy, Polarization

Contact person: Stefan Spanier
email: spanier@slac.stanford.edu
phone: (865) 974-0597

Tennessee

Year 1: $13,050
Year 2: $14,500
Year 3: $13,775

Linear Collider R&D Proposal
October 24, 2003

Polarimeter with a Quartz Fiber Calorimeter

Luminosity, Energy, Polarization

Steve Berridge, William Bugg, Yuri Efremenko,
Yuri Kamyshkov, Stefan Spanier

University of Tennessee

Funding FY 2004:	\$13,050
Total Funding 3 Years:	\$41,325

Contact person	:	Stefan Spanier
Email	:	spanier@slac.stanford.edu
Phone	:	865 974 0597

1 Introduction

The use of polarized electron and positron beams in a future Linear Collider will ensure a full exploitation of the physics potential. A well defined initial spin state allows precision spectroscopy of new states, precise asymmetry measurements allow access of physics beyond the limit given by an unpolarized machine. Therefore, polarized electrons have been part of the different Linear Collider proposals and presently a undulator-based production of polarized positrons is underway (E166) [1].

The polarization of electrons at SLC has been diagnosed with a Compton polarimeter. Independently of a Cherenkov Compton-electron detector back-scattered 2.33 eV circularly polarized photons have been detected with a quartz fiber calorimeter (QFC) with 1.4×1.4 cm^2 entrance area and 16.5 cm length which was placed about 11 m behind the laser-electron interaction point. Longitudinal polarization causes an energy flow asymmetry in the calorimeter while transverse polarization translates into an average displacement of the shower centroid. The quartz fiber calorimeter was built by the High Energy Physics group of Tennessee. The precise measurements of the electron beam polarization allowed a determination of $\sin^2\theta_W^{eff}$ with a relative precision of 0.1% at SLD [2].

We propose to study the application of this technology for the polarization measurements at the linear collider. It is important to develop a scheme in an early stage of the design phase of a linear collider since the placement of polarimeter components occurs close to the beamline. The conditions for the longitudinal polarization measurement of electron and positron beam are relaxed for a 500 GeV beam energy compared to SLC while the transverse polarization is more challenging and needs an improved method. We want to explore if a measurement in terms of spatial asymmetry in the calorimeter is feasible. Here methods have to be developped to avoid the hostile beamstrahlung environment at NLC (e.g. exchangable device). Furthermore, the application in a pair-production spectrometer will be explored - we would provide two calorimeters behind a pair production target off the beam axis to detect the electron and positron.
In addition, a potential large irradiation dose may affect the light output of the QFC. Therefore, we propose in a first year to simulate a potential experimental setup based on the quartz fiber calorimeter and study the material.

This technology has the advantage that it is

- applicable to longitudinal and transverse polarization measurements,
- radiation hard (all photon-based polarization methods receive extreme radiation),
- compact (see small dimensions of the SLC calorimeter),
- unaffected by low energy background due to the Cherenkov threshold,
- fast signal (Cherenkov light production),
- and relative non-expensive.

Furthermore, we want to study potential new readout schemes which increase the radiation robustness of the setup. To avoid readout fibers as were implemented in the QFC of SLC which have to run through the highly irradiated area close to the beamline we study the imaging of the photons on CCDs or multichannel photomultipliers (flat panel) using mirros. The photons will travel in air (material free space). We will read x and y coordinates of the Cherenkov light emission in the quartz layers. We also plan to irradiate the quartz material at the HFIR reactor of Oak Ridge National Laboratory (ca. 20 GRad/month photon rate from a spent fuel element) to obtain information about material defects which introduce inhomogenities in the energy measurement. This rate (also smaller rates are available) will simulate cases in the linear collider radiation environment. The measurement of attenuation and annealing of the quartz material are of wider interest since it is used for other proposed detectors at the linear collider.

2 First Year Activity

Our program will extend over several years and should accompany the design and building phase of the linear collider.

In the first year we will study the application of the quartz fiber calorimeter in a Compton polarimeter at the linear collider. Our technique will also be applicable to alternative photon based polarization measurements, e.g. a pair spectrometer for converted Compton photons or for a polarimeter using synchrotron radiation created by high-field-intensity wiggler magnets [3]. We intend to study several scenarios. We re-use detector simulation code from our SLC calorimeter and adopt it to the linear collider environment. We will also explore alternative readout schemes for quartz fibers with proximity focussing on the photo-detector. We will test potential photo-detectors for the calorimeter to obtain realistic input. Furthermore, we transport the existing SLC quartz fiber calorimeter from SLAC to Tennessee to inspect its components for radiation damage effects and perform attenuation measurements. The modification of existing simulation code and the development of new code will be performed by an undergraduate student, Gail Gzasowski, working with the high energy physics group at Tennessee. A potential readout scheme is shown in Figure 1.

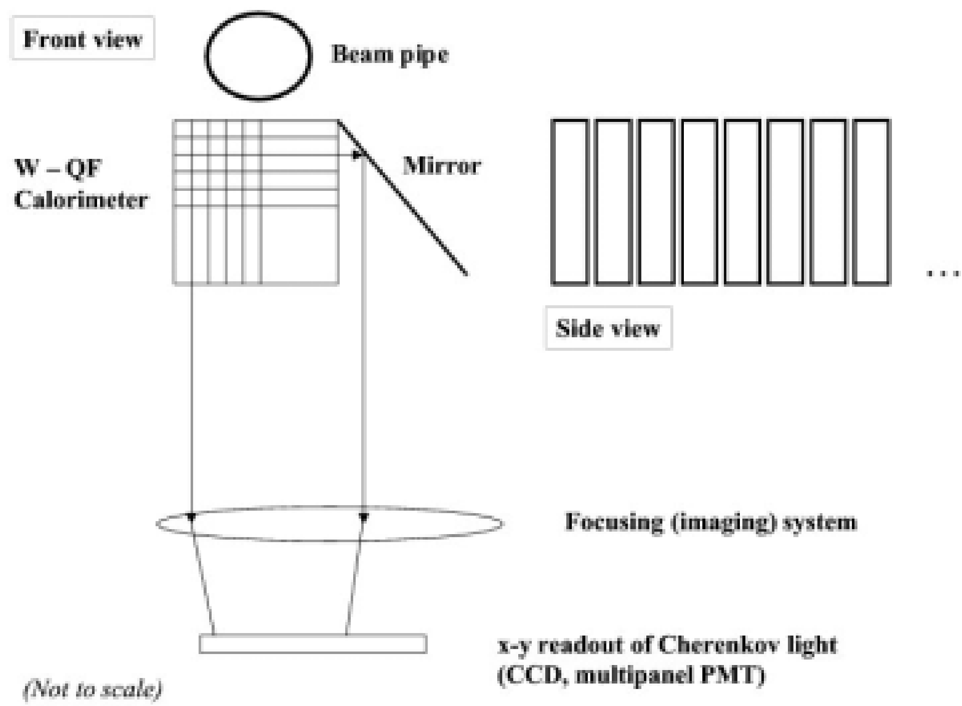

Figure 1: *Schematic drawing of a potential scenario for the quartz fiber calorimeter readout.*

3 Future Activity

For a promising design of the polarimeter based on the QF calorimeter and readout scheme we want to prepare a test setup at the University in the second year. In particular a careful study of the attenuation in the quartz introduced by irradiation and possible ways to anneal will then be necessary using a photo spectrometer. Radiation damage measurements are projected to take place at Oak Ridge National Laboratory in the second or the third year.

4 First Year Budget

The first and second year will show if the technique should be persued. The budget for year 2 and 3 is a preliminary estimate.

Item	FY 2004	FY 2005	FY 2006
Summer + academic year undergraduate salary	$7000	$7000	$7000
optical equipment, photo/laser diodes setup	$1000		
transport of SLC calorimeter	$1000		
CCD, PMT, readout equipment		$3000	
Trip to beam test			$2000
Irradiation test			$500
Indirect costs UTK (45% on campus)	$4050	$4500	$4275
Total	$13050	$14500	$13775

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1. E 166 LCRD proposal, 2004 (see this document).

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