Appendix: UCLC Detector Project Descriptions

July 25, 2003

In this Appendix, the full project descriptions are given for each of the UCLC projects. The numbering scheme is the same as in the proposal's Project Description.

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2 Machine-Detector Interface

2.1 Coherent and incoherent beamstrahlung at the LC

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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.

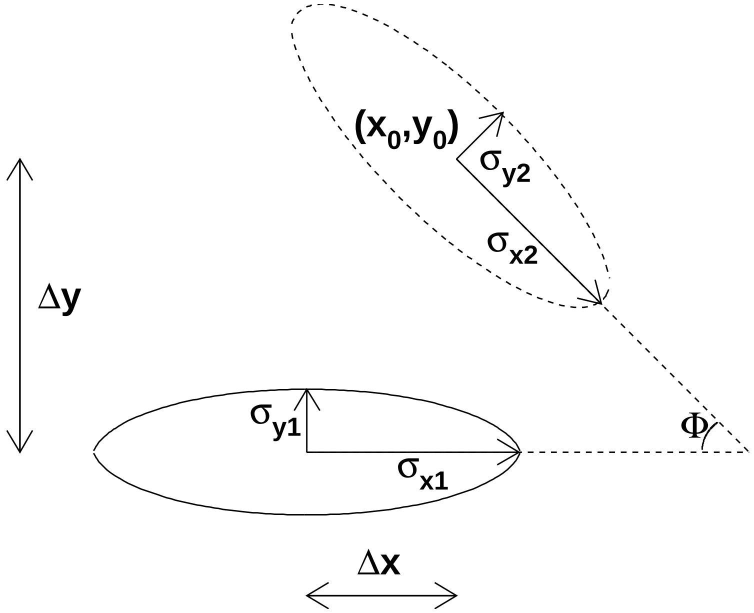

Figure 1: The seven transverse degrees of freedom in the beam-beam collision.

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. 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.

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. Given the

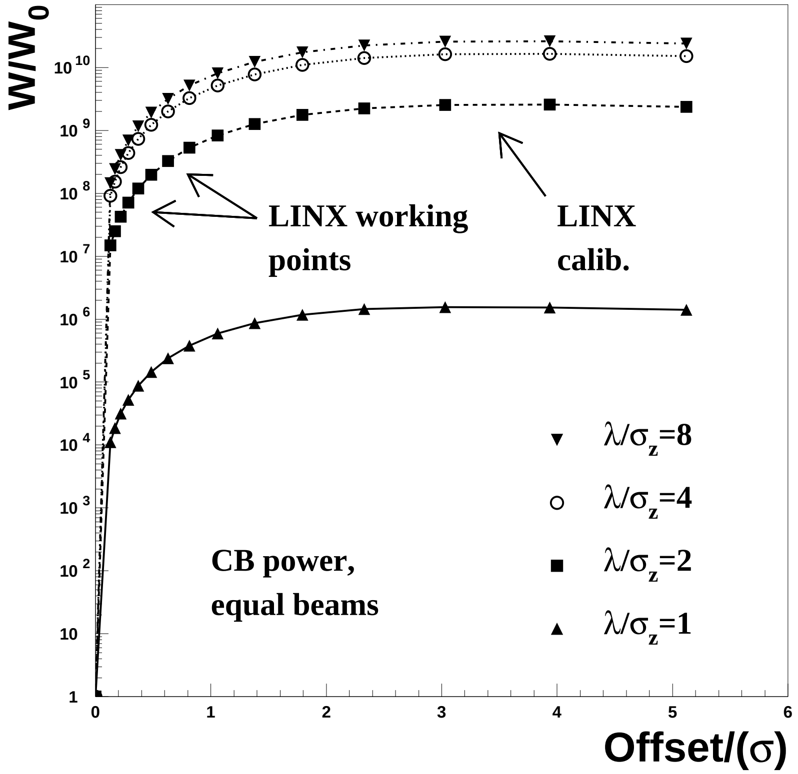

Figure 2: CB yield as a function of the beam-beam offset. The simulations were done with NLC nominal conditions, but weaker beams ($N_1 = N_2 = 0.3 \times 10^{10}, \sigma_{y1} = \sigma_{y2} = 19$nm). Plots are shown for four different wavelength-beam length ratios. The LINX working points are where one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

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.

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.

FY2006 Project Activities and Deliverables

Complete design for both visible and coherent beamstrahlung detector for the LC. Install and operate fast electronics 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, and 0.5 postdocs. 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$

Institution: Wayne State

Item	FY2004	FY2005	FY2006	Total
Other Professionals	22	23	24	69
Graduate Students	0	0	0	0
Undergraduate Students	0	0	0	0
Total Salaries and Wages	22	23	24	69
Fringe Benefits	5	5	5	17
Total Salaries, Wages and Fringe Benefits	27	28	29	84
Equipment	0	15	0	15
Travel	5	5	10	20
Materials and Supplies	0	0	0	0
Other direct costs	0	0	0	0
Total direct costs	32	48	39	119
Indirect costs	16	17	20	53
Total direct and indirect costs	48	65	59	172

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

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

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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 $\delta E_{\rm beam}/E_{\rm beam} \sim 1\times10^{-4}$ 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 $\delta E_{\rm beam}/E_{\rm beam} \sim 2\times10^{-4}$, 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.

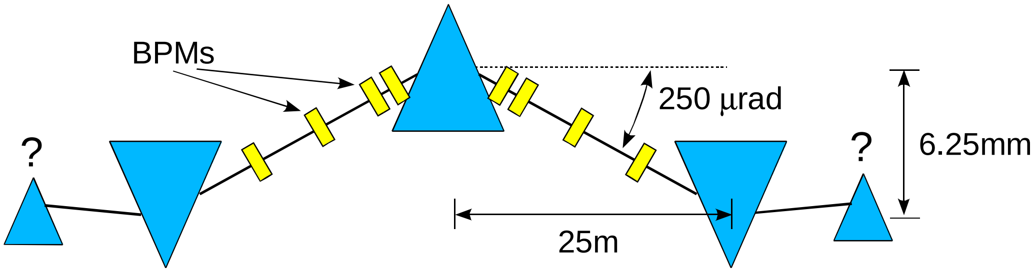

Figure 1: A schematic outline of an accelerator dipole chicane which could accomodate a BPM-based magnetic spectrometer at a future linear collider.

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

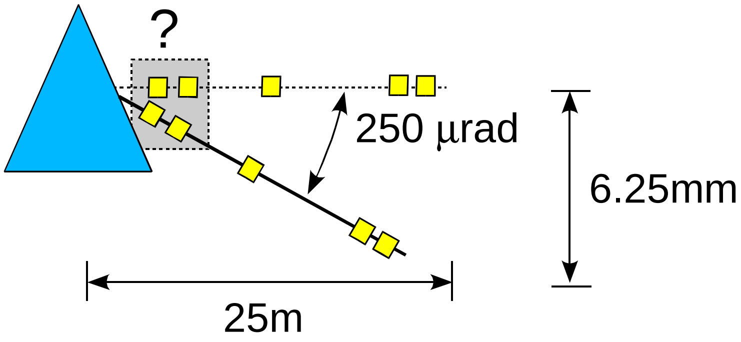

Figure 2: A diagram showing the two cases of: straight-ahead linear trajectory measurement to establish zero deflection; and the motion of the BPMs necessary to measure a deflection of 250μrad. The "?" indicates that it may be possible to design a system with sufficient accuracy that the closest BPM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

Institution: University of Notre Dame

Item	FY2004	FY2005	FY2006	Total
Other Professionals	0	40	35	75
Graduate Students	10	22	24	56
Undergraduate Students	3	3	4	10
Total Salaries and Wages	13	65	63	141
Fringe Benefits	0	8	7	15
Total Salaries, Wages and Fringe Benefits	13	73	70	156
Equipment	20	30	40	90
Travel	2	2	4	8
Materials and Supplies	6	5	5	16
Other direct costs	0	0	0	0
Total direct costs	41	110	119	270
Indirect costs	10	39	38	87
Total direct and indirect costs	51	149	157	357

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3 Vertexing

3.1 Development and design of an LC ASIC for CCD readout and data reduction

3.2 Study of the Mechanical Behavior of Thin silicon and the Development of hybrid silicon pixels for the LC

4 Tracking

4.1 Tracker simulation studies and alignment system R&D

4.2 R&D towards a Silicon drift detector based main tracker for the NLC-SD option

Personnel and Institution(s) requesting funding

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Project Overview

During the past three years our group was partially funded by Fermilab Director's funds and the NSF, in order to develop a scheme in which Silicon drift detectors could be used for the main tracking device in the NLC-SD option. We participated in the design study which led to the SD layout as described in the Snowmass Resource Book. Our main effort during the past three years was two-fold:

a.) to perform simulations that show the physics capabilities of a Silicon based main tracker and compare its performance to the gaseous tracker as proposed for the L-detector option.

b.) to further develop the necessary hardware in terms of the wafers themselves, the mechanical support structure and the front-end/readout electronics based on our original design for the STAR-SVT at RHIC

With respect to a.) Vladimir Rykov has worked with us for the 18 months on simulations and software development and is now employed by RIKEN in Japan. His work's main emphasis was on comparative performance simulations in the existing software framework and a study of the track timing performance of SDD's which can be used in order to distinguish between pile-up events in the detector.Preliminary results show that the tracking efficiency, hit resolution, two-track resolution and momentum resolution obtained with a silicon drift tracker is equivalent or superior to the gaseous tracker option.

With respect to b.) Rene Bellwied and David Cinabro have mostly worked on a new detector layout for the SD main tracker based on the successful STAR Silicon Vertex Tracker, which was constructed and is operated under the leadership of Rene Bellwied. Based on these past projects we propose the following steps for the future:

FY2004 Project Activities and Deliverables

We propose to continue our comparative study of the performance of a main tracker based on Silicon drift detectors. We believe that the existing tracking and pattern recognition code, originally developed for the Large detector (LD) TPC option, can be optimized and used for the 3d SD option. First encouraging results were shown at the Chicago, Santa Cruz, Arlington, and Cornell LC meetings, and can be found on our web-page. We have incorporated the proposed detector layout into the GEANT4 framework and we also intend to port a detector response code from STAR into the LC simulation framework. Finally we would like to adapt a code recently written by a WSU led software group for

STAR which allows track matching between the two main tracking detectors in STAR and the electromagnetic calorimeter in STAR. We believe that this integrated tracking code (IT) can be applied to the SD design in order to simultaneously analyze the information from the vertex detector, the main tracker and the calorimeter in order to optimize and test the energy flow paradigm.

Regarding hardware we propose to layout a first LC specific wafer design in collaboration with the BNL Instrumentation division. In the second half of the year we will submit a prototype design for production to the BNL production lab. Proposed initial changes to the existing SDD design will include:

a.) increase the detector size by using six inch rather than four inch wafers

b.) operate wafers at higher voltage (up to 2500 V) in order to accommodate longer drift length

The first year deliverable would be a version of the LC tracking code fully optimized for an SD style detector and a design and prototype of a LC specific wafer layout

FY2005 Project Activities and Deliverables

We intend to continue our simulation activity and add a testing component to the ongoing hardware effort in order to produce a next generation of Silicon drift detectors. The testing will be performed at WSU and BNL with the postdoc funded through this proposal and graduates students funded by WSU. We propose to further optimize the design and produce a larger prototype batch ($\sim$20) of new Silicon drift detectors. The new iteration will address issues based on the following improvements:

a.) increase the readout pitch in order to reduce the channel count

b.) thin the wafer from 300 microns to 150 microns

The second year deliverables would be a new integrated tracking code for the SD detector option (ITSD) and a second iteration on the LC specific Silicon drift detector prototypes.

FY2006 Project Activities and Deliverables

Our simulation effort and production of prototype improved detectors will continue. In collaboration with the Instrumentation division at Brookhaven National Laboratory we propose to design and produce a new prototype of a CMOS based front-end chip. The major changes compared to the old STAR design are:

a.) use deep sub-micron technology to improve radiation hardness

b.) reduce power consumption to allow air-cooling of the detector

c.) potentially include the ADC stage into the PASA/SCA design

d.) test tape automated bonding of the front-end to the detector rather than wire-bonding

We also propose to begin a design for the mechanical support of the Silicon ladders based on a design used for the Silicon Strip detector layer in STAR.

The third year deliverables would be a final set of prototype detectors, some prototype front-end chips, a conceptual design of a Silicon drift detector main tracker for an LC SD style detector (including support structure and electronics integration), and simulation and reconstruction code for it.

Budget justification

Throughout the three years the budget contains a sub-contract allocation in order to purchase specific component orders produced by the BNL Instrumentation division. For some of these orders the initial materials and supplies will be provided by WSU, and those items are listed under the appropriate category. The collaboration with the BNL Physics department is not supported through this proposal. BNL Physics provides manpower to the simulation and testing effort without financial support from this grant. The WSU overhead rate is 51% for onsite manpower, material and supplies and the first 25 K of a multi-year subcontract (i.e. the contract provision for BNL).

The first year budget emphasises the continuation of our simulation and reconstruction effort. Continuing salary for 50% of a postdoctoral fellow and some travel money is requested. We also initiate the subcontract with BNL for the development of a new wafer layout and electronics design.

In the second year the software and testing effort is increased by raising the postdoc contribution from 50% to 100%. In addition money is required for the purchase of Silicon starting material ($25K) at WSU, continuing mask design ($10K) and the production of a large batch of prototype detectors ($40K) at BNL. More travel money is requested for trips between BNL and WSU related to prototype production and testing as well as participation in LC workshops.

In the third year the software effort continues and additional funding is required for a second round of mask design ($10K), production of the final batch of prototype detectors ($30K), and design and production of prototype front-end chips ($50K) at BNL . More travel money is requested for trips related to prototype production and testing.

Three-year budget, in then-year K$

Institution: Wayne State University

Item	FY2004	FY2005	FY2006	Total
Other Professionals	21	42	44	107
Graduate Students	0	0	0	0
Undergraduate Students	0	0	0	0
Total Salaries and Wages	21	42	44	107
Fringe Benefits (23.7%)	5	10	11	26
Total Salaries, Wages and Fringe Benefits	26	52	55	133
Indirect cost on Salaries	13	26	27	66
Equipment	0	0	0	0
Travel	4	6	10	20
Materials and Supplies	0	25	10	35
Total Equipment, Materials, and Travel	4	31	20	55
Indirect Cost on Equipment etc.	2	15	10	27
Subcontracts	25	50	90	165
Indirect Cost on Subcontracts	12	0	0	12
Total direct costs	55	133	165	353
Indirect costs	28	42	39	109
Total direct and indirect costs	83	175	204	462

4.3 Tracking Detector R&D at Cornell and Purdue Universities

Personnel and Institution(s) requesting funding

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Collaborators

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Changes Since Preliminary Project Description

In the Cornell budget table, indirect costs, including the indirect costs of the Purdue subcontract, have been added. In the Purdue budget table, indirect costs have been added.

Project Overview

Experimental physics goals for a future linear collider create challenging demands on a charged particle tracking detector in regard to both momentum resolution and multi-track separation. Anticipated beam-related background rates place further demands on the detector segmentation. A time projection chamber (TPC) may provide the best combination of detector segmentation and continuous track measurements which would lead to the optimum multi-track separation and noise immunity. However, the segmentation of current technology TPCs is still insufficient for precision reconstruction of linear collider events. In addition, obtaining the spatial resolution necessary to meet the momentum resolution goal is challenging with the current technology.

Events at the linear collider will contain jets with track density on the order of 100 tracks/steradian. Events with this track density have been reconstructed at RHIC experiments and are expected at LHC experiments. However, a tracking goal of the linear collider detector, as described in the "Linear Collider Physics Resourse Book" [1], is the precision measurement of jet energies. This measurement requires aggressive multi-track separation in both azimuth and polar angle. TPCs with multi-wire-proportional-chamber gas-amplification and readout, of which the STAR and ALEPH chambers are typical examples, have pad readouts with a pad size on the order of 1 cm in the azimuthal direction. This segmentation is too coarse to provide the multi-track separation required at the linear collider.

Other tracking goals, such as the precision mass resolution of di-leptons in Higgsstrahlung events and the precision end-point momentum resolution in leptonic supersymmetric decays, lead to a desired resolution of $\sigma(1/\mathrm{p}_t)$ of order $10^{-5}\mathrm{GeV}^{-1}$. This momentum resolution can be achieved only if the TPC spatial resolution is of order 100 μm. This spatial resolution is very challanging with multi-wire-proportional-chamber readout TPCs not only because it represents 1% of the pad size, but also because the radial electric field in the vicinity of the amplification wires leads to a significant spatial distortion.

A TPC readout based on a gas amplification micro-structure such as a GEM or MicroMegas promises to provide both improved segmentation and resolution. Segmentation is improved due to a fundamentally reduced transverse signal size; the signal is created on pick-up pads by electron transport rather than induction. The pad size can then be significantly reduced. Spatial resolution is improved due to the reduced signal size and reduced **E** x **B** distortion of the drift path in the vicinity of the amplification. Operation in a high rate environment is simplified because these readout systems naturally suppress ion feedback into the drift volume.

Significant development and operating experience are required before a full-size design for a detector based on a GEM or MicroMegas amplification can be finalized. The physical width of the charge deposition is small compared to the typical readout pad size used in a traditional readout TPC creating a condition where the signal is often observed on only one pad. Without signal sharing, the spatial resolution is degraded. The use of smaller pads to provide signal sharing may require a prohibitive number of instrumented pads and the signal measurement on each pad may then be limited by ion statistics. Several alternatives have been suggested to optimize the charge deposition width for spatial resolution and segmentation, for example, increased spacing between the amplification elements, resistive anode layers, and chevron shaped pads. Each of these may compromise the segmentation or lead to other operational problems. These alternatives are largely untested. Even with many groups working on these problems, the development will take several years and should not be delayed.

The development of large scale manufacturing of GEMs provides another motivation for initializing TPC research as early as possible. As described below, Purdue is involved in several studies of manufacturing techniques for the purpose of providing large scale production of reliable GEMs. It is expected that the GEM manufacturing will require 3 to 4 years of development. A TPC testing program that includes the capability of using interchangable amplification devices is required as a test bed for the manufacturing development.

We propose to initiate a program of gas chamber tracking detector development. We will study issues of resolution, segmentation, channel count, signal complication, noise, cross-talk, and ion feedback using various readout systems on prototype TPCs.

The TPCs, as well as drift chambers used for track definition, will be built at Cornell. We will test both traditional TPC readouts using anode wire amplification built at Cornell, and alternative TPC readouts using GEM and/or MicroMegas amplification built at Purdue. In studies of the anode wire amplification readouts, we will investigate methods of optimizing the resolution and track separation while varying the wire spacings. These studies will also provide an understanding of the data acquisition (DAQ) system and a baseline for the signal and noise characteristics of the alternative amplification devices. In building and operating the tracking chambers the Cornell group will draw on their extensive experience building drift chambers for the CLEO experiment [2, 3, 4].

GEM and MicroMegas readout modules will be built by the Purdue group who have many years experience developing Micro Pattern Gas Detectors (MPGD) [5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20]. In collaboration with the CERN and Saclay groups, radiation hardness of GEM and MicroMegas foils manufactured at CERN have been studied and excellent radiation hardness has been demonstrated. The first triple-GEM [16] and GEM+MicroMegas detector [17] have been built. The latter has achieved the best signal-to-noise performance in a beam line of any MPGD to date [18] making it very attractive for TPC readout. In addition a new readout mode of a MicroMegas has been developed that promises greater electrical robustness.

GEM manufacturing technology, for readily available samples, has been limited to Kapton lithography. Purdue is involved in several studies of alternative manufacturing techniques. In collaboration with the University of Chicago, a micro-machined large area LEM (large scale GEM) has been built and successfully tested at Purdue. Electrode-less GEMs and MicroMegas, which have greatly reduced material budgets, are also under development. Most recently, the Purdue/Chicago collaboration has worked with the 3M corporation to develop a less expensive, large quanitity, manufacturing process for standard GEMs. These have been delivered and tested at Purdue and CERN. Preliminary results indicate that the performance of GEMs manufactured by 3M is indistiguishable from the performance of those manufactured at CERN.

The development of new manufacturing techniques for GEMs and MicroMegas is important because it may provide reduced cost and procurement time for large scale implementations such as a TPC or a hadron calorimeter. Much of this work is at an early stage; extensive R&D and testing, including radiation hardness studies, will be required. Funding exists for this work and we are not seeking additional funding for it at this time. These studies will be performed by many groups, including Purdue, over the next few years. We expect to incorporate each of the successful alternative manufacturing technologies into a TPC readouts. However, in the first instance we will use CERN built devices. This will ensure that TPC readouts can be designed, tested, and will be operational during year one of this proposal.

We also plan to study detectors in a magnetic field equal to that envisioned for the final detector and in a high radiation environment. The Cornell accelerator group will provide a uniform-field, 4 Tesla, superconducting magnet. The utilities to operate the magnet are available at Cornell.

FY2004 Project Activities and Deliverables

In the first year of a staged build-up of the detector program, we will build drift chambers for track definition and a small TPC with anode wire amplification readout. We will install a limited, but expandable, stand-alone DAQ system at Cornell to provide track definition over a small area and readout for a limited number of TPC channels using commercial flash analog to digital converters (FADC). We will demonstrate the resolution of the track definition system. We will use the initial TPC test chamber to understand the FADC DAQ system, study the time evolution of the signals and make limited resolution measurements. After completing measurements on the anode wire amplification readout we will make similar preliminary measurements on a small TPC with GEM readout. First year tests will be with cosmic rays.

The first year deliverable will be the successful operation of the initial TPC.

FY2005 Project Activities and Deliverables

In the second year, we will build a larger TPC which will accept interchangeable readout planes and expand the coverage of the track definition system. We will expand the DAQ system for both the track definition and the TPC to allow study of resolution and noise effects in larger systems. The proposed DAQ system will provide readout for a 256 channel TPC which will allow us to measure tracks in about 20 layers, each about 13 pads wide. The size of this detector will be sufficient for cross-talk studies and to measure the track trajectory with less reliance on extrapolation of the track from the drift chambers. Measuring the track trajectory internally in the TPC provides a more precise determination of the resolution and will be particularly important when measurements are made in a magnetic field. We will continue to use cosmic rays which will be sufficient based on previous experience of making successful measurements of resolution and efficiency using test chambers with smaller detector acceptance [4].

We will study resolution and track separation, as well as signal time development and noise characteristics with several different readout planes installed on the TPC. For the case of readout planes with anode wire amplification, we are particularly interested in increasing the anode wire density while decreasing the anode-cathode spacing. For the cases of readout planes with multiple GEMs, MicroMegas and hybrid amplification, we plan to vary the amplification-stage voltages and spacings and the pad segmentation as a means of optimizing the signal separation and spatial resolution. We will also study the effects of various methods of spreading the signals such as resistive anode layers. Ion feedback suppression, expected to be superior in MicroMegas relative to GEMs, will be measured for each amplification system using a common TPC. Measurements in a magnetic field may be started in the second year but we defer that deliverable to the third year.

The second year deliverable will be a systematic study of the track separation and position resolution with various readout planes.

FY2006 Project Activities and Deliverables

In the third year we will continue the detector studies in a magnetic field and will also make measurements with a large photon background.

The third year deliverable will be the continuation of the systematic study of the track separation and position resolution in a magnetic field.

Budget justification

The first year equipment budget for Cornell provides for a minimal DAQ and HV system to operate the track defining drift chamber and a small TPC. This includes some initial costs associated with the expandable system: a VME crate and a HV frame and HV power supplies. The second year equipment budget for Cornell provides for an expansion of the DAQ for use with a larger test device. The major expenditure is in the FADC modules. As an alternative, it may be possible to use TPC readout electronics developed for the STAR experiment for the readout of a larger test device. This system would provide a reduction in cost and more channels. As the STAR readout is VME based; most of the equipment purchased in the first year for the initial system would be used with this alternative. We will fully investigate the feasibility of using the STAR electronics after the first year. The third year equipment budget for Cornell provides for further expansion of the DAQ system, maintenance of existing equipment and/or the purchase of items not yet foreseen. The Cornell budget includes funds for travel to Purdue as part of the collaborative effort.

Cornell will provide reallocation of resources to this this project in the form of support for research staff (Dan Peterson) and technical staff and machine shop time to construct the chambers. Cornell will provide the custom components to construct the drift chambers. In addition, Cornell will provide the cost of designing and constructing the analysis magnet.

The yearly Purdue equipment budget provides for the purchase of unmounted GEM and MicroMegas devices from CERN and 3M and the manufacture of printed circuit pad readout in the U.S. Purdue is also requesting funding to support two undergraduate students per year at 20 hrs a week, 40 weeks a year. The students will work exclusively on this project. Ian Shipsey has had over twenty undergraduates work with his group since 1992. This has been a very productive arrangement both for the group and the students resulting in several publication [10, 14, 15, 16, 19].

Purdue engineers and post doctoral physicists will work on the design and testing of the devices but derive their salary support from base funding. Machine shop charges will likewise be derived from base funding. Clean-room, testing, and assembly facilities at Purdue will be made available for this work at no charge.

Three-year budget, in then-year K$

Institution: Cornell University

Item	FY2004	FY2005	FY2006	Total
Other Professionals	0	0	0	0
Graduate Students	0	0	0	0
Undergraduate Students	0	0	0	0
Total Salaries and Wages	0	0	0	0
Fringe Benefits	0	0	0	0
Total Salaries, Wages and Fringe Benefits	0	0	0	0
Equipment	52	121	74	247
Travel	2	2	2	6
Materials and Supplies	0	0	0	0
Other direct costs	0	0	0	0
Purdue subcontract	34	34	34	102
Total direct costs	88	157	110	355
Indirect costs(1)	10	4	8	21
Total direct and indirect costs	98	161	118	377

(1) Includes 25% of first $25K subcontract costs

Institution: Purdue University

Item	FY2004	FY2005	FY2006	Total
Other Professionals	0	0	0	0
Graduate Students	0	0	0	0
Undergraduate Students	16	16	16	48
Total Salaries and Wages	16	16	16	48
Fringe Benefits	0	0	0	0
Total Salaries, Wages and Fringe Benefits	0	0	0	0
Equipment	10	10	10	30
Travel	0	0	0	0
Materials and Supplies	0	0	0	0
Other direct costs	0	0	0	0
Total direct costs	26	26	26	78
Indirect costs	8	8	8	24
Total direct and indirect costs	34	34	34	102

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4.4 Negative Ion TPC as the LC main tracker

Personnel and Institution(s) requesting funding

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Project Overview

The novel gas detector technology called Negative Ion TPC (NITPC) is a strong candidate as a main tracker for the Linear Collider. The technique utilizes a special, electronegative gas mixture to transport negative charge from track to detector plane in the form of negative ions rather than electrons. The slow drift speed and strong thermalization of the drifting ions result in a number of advantages important for an NLC tracker, listed below. A 1 m^3 NITPC has been working for one year as a directional Dark Matter detector, unattended for weeks at a time, providing proof that the concept works in practice[1]-[2]. A new, larger Dark Matter NITPC was proposed this year.

The NITPC option provides some unique options for the LC. These include the smallest amount of total chamber material, the possibility to have a gas tracker in place of the Silicon Detector, and according to our simulation, best momentum resolution. The extreme versatility of the device affords the possibility to control crucial parameters, such as the backgrounds.

Our proposal was criticized last year for lacking extensive simulation as a tracker. That simulation has been performed during the last year and the results support the contention that a NITPC is a superior tracker candidate[3]. We note that the contentious issue of background rejection was tackled by assuming a worst case scenario (TESLA bunch train, low magnetic field, Table 2). We also note that at the NLC or JLC the NITPC will always have lower backgrounds than a regular TPC, due to lower gas density (Tables 1 and 2).

The detector model we chose is particularly simple (likely, it can be improved), but we were able to produce significant simulation in a finite amount of time. It is an unusual model compared to standard TPCs. Its main features are summarized here:

1. the TPC has 6 detector planes, and 12 drift gaps along the azimuth. Ion drift is not affected by the magnetic field up to 6T, and azimuthal drift provides the best momentum resolution. The azimuthal TPC also is much less affected by backgrounds than an axial TPC.
2. it contains far less material than a regular TPC, mostly along the six detector planes. It was assumed to have 4×10^4 electronics channels, as opposed to 2×10^6 for the "standard" TPC[4]. Also the sampling rate was assumed to be 10 MHz as opposed to 20 MHz[4].
3. the detector offers extreme versatility at a time when an ultimate figure of merit has not been determined. Besides the drift direction and the amount of material being an option, the detector can

Parameter	Value	Comment
Electron capture cross section	80 MBarn	-
v_d(E=0.2 kV/cm)	430 cm/sec	
v_d(E=0.4 kV/cm)	860 cm/sec	
v_d(E=0.8 kV/cm)	1500 cm/sec	mobility decreasing toward saturation
Diffusion, $\sigma_l \sim \sigma_t$	0.07mm$\sqrt{L(cm)/E(kV/cm)}$	
Negative Ion stripping mean free path	$\sim 10\mu m$	At 100μm from wire center
Gain	7700	Sense wire voltage 2730 V

Table 1: He/CS_2 80/20 parameters measured in a mini-NITPC with 9 mm pitch and 5 mm gap n endcap MWPC. From dE/dx to avalanche, we list electron capture probability, drift velocity and diffusion, ion stripping probability, and gain.

work equally well with a smaller radius (lower cost and much lower backgrounds in exchange for a factor of two in momentum resolution), effectively competing with the Silicon Detector. We are unaware of other gas trackers being suitable candidates for the smaller detector option.

4. The concept can work as well with any of the recently developed microchambers (e.g., GEM or MicroMegas), whose reliability record is not close to the one of the NITPC, though we question the large increase in material that microchambers and the attendant electronics would introduce.
5. We note that the tendency of microchambers to spark is strongly suppressed by any electronegative gas. Our gas, CS_2, is also the strongest UV quencher used in gas detectors.

The detector plane, as simulated, consisted of a drift grid (not shown in Fig. 1), a set of sense wires, and a double set of daisy-chained pads, one running NW-SE and the other running NE-SW. A hit is defined as a triple coincidence of wire, strip(s) NW-SE, and strip(s) NE-SW. The electronegative gas parameters are listed in Table 1. The detector parameters, for a NITPC and a comparison conventional TPC, are summarized in Table 2. The factor of 100 in longitudinal sampling, compared with a standard TPC, is crucial to understand the difference in performance.

Besides regular backgrounds, the simulation had to address the possibility of combinatorial backgrounds. It was straightforward to show that these backgrounds are small[3]. Further algorithms, currently under development, will optimize pulse asymmetry cuts between strip and strip and strips and wire. We expect combinatorial backgrounds to be totally negligible with a large safety factor.

Background was supposed to be the make-or-break issue. The very slow drift time of the NITPC integrates over the whole train. This is not a disadvantage at the NLC, compared with a conventional TPC, because both TPCs integrate over the train. At TESLA, however, there is a difference of a factor of 19 between the integrated flux of the NITPC and that of a TPC. This factor is mitigated by the lower gas density (Table 2, factor of 2), and also by two other smaller factors, leaving a total factor of 6. Table 2 also shows that the NITPC at 6T (Silicon Detector option) has a lower background rate than the TPC (Large Detector option), while having approximately the same momentum resolution (cfr. with Fig. 2 below). Still, a typical NITPC event raw size was 1GByte for TESLA.

The detector underwent a full GEANT4 simulation, using the chamber parameters of Table 2. The backgrounds were simulated using the programs available at[5], and the NLC photon rate was multiplied by 6.0 to obtain the TESLA photon rate.

Parameter	Classic TPC	NITPC	Comment
Mag. Field	3T	3T	
average drift dist.	1.35 m	0.33 m	
N of samples/track	100	10^4	N_e for NITPC
N of el./sample	140	1	
transv. diffusion, $\langle\sigma_t\rangle(\mu\text{m})$	680	400	$\langle\sigma_t\rangle = (2/3)\sigma_{max}$
long. diffusion, $\langle\sigma_l\rangle(\mu\text{m})$	$\gg 680$	400	accounting drift distance
TPC surface charge (nC)	0.4	5	space charge distortion par.
TPC cage	N/A	N/A	thicker in NITPC
Detector membranes	0	0.5% X_0	for perp. tracks
Endcap material	N/A	0.5% X_0	No endcaps in NITPC
NLC background density (a.u.)	1	0.5	LD, lighter gas mixture
TESLA background density (a.u.)	0.05	0.3	LD
NLC background density (a.u.)	1	0.05	Small Detector, 6T
TESLA background density (a.u.)	0.05	0.03	Small Detector, 6T

Table 2: A comparison of parameters of a state-of-the art TPC[4] and a preliminary design for the NITPC. For the purpose of comparison, an azimuthal NITPC is considered with 6×2 segments. For the last two rows, the comparison is between a LD TPC and a SD NITPC.

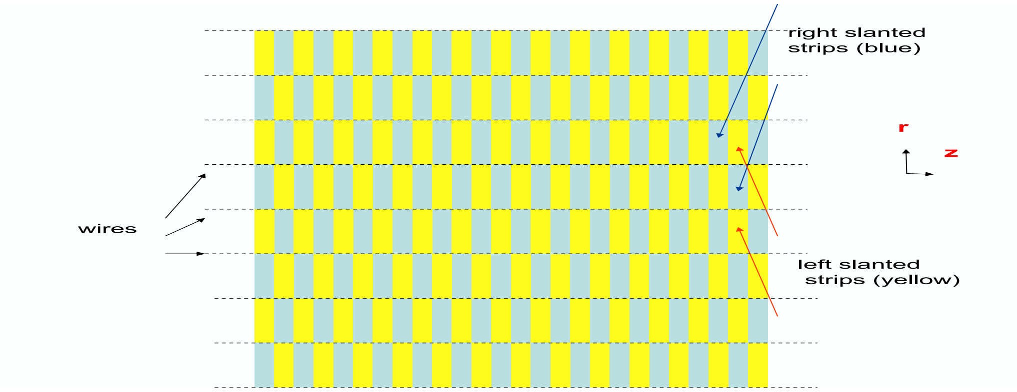

Figure 1: The detector surface layout scheme. The wires are strung vertically, and readout pads are daisy-chained to form strips. Black pads are chained along the NE-SW diagonals, and white pads are daisy-chained along the NW-SE diagonals.

A pre-filter was used to reduce data. Background events fall mostly in two categories, single "dots" of ionization (expanded by diffusion) and longer electron tracks nearly along the $z-$axis. In both cases, in out geometry, they tend to illuminate a single wire, making the pattern distinguishable from a genuine track. Clusters of "good" hits were further compacted into a "macro-hit" which was the center of gravity of many hits. The reduction factors due to the pre-filter are summarized in Table 3. With the backgrounds under control, one should be concerned with space charge effects. We note that this detector has a capacitance 12.5 times larger than the TPC (Table 2). Under all the background scenarios considered in Table 2, the NITPC will suffer less space charge effects than a TPC. The TPC will also have no gating grid, so that space charge is a measured quantity and is usable for corrections.

A Helix finder, like that of the BaBar TPC, was used in the NITPC to reconstruct the tracks. The

performance parameter	value
background suppression factor	20
data reduction factor after clusterization	1000
efficiency for signal	0.92
output number of hits	7×10^4
S/B	0.2

Table 3: Data reduction software performance.

momentum is shown in Fig. 2. Its average efficiency for tracks of $p_t < 0.5$ GeV and $\cos\theta > 0.8$ was 0.975. Some high-p_t tracks lying in the read-out planes are poorly reconstructed, as can be seen in figure 3. The algorithm was never improved to account for these tracks, though it can be at a further stage of development. Excluding those tracks, efficiency becomes as high as 0.995.

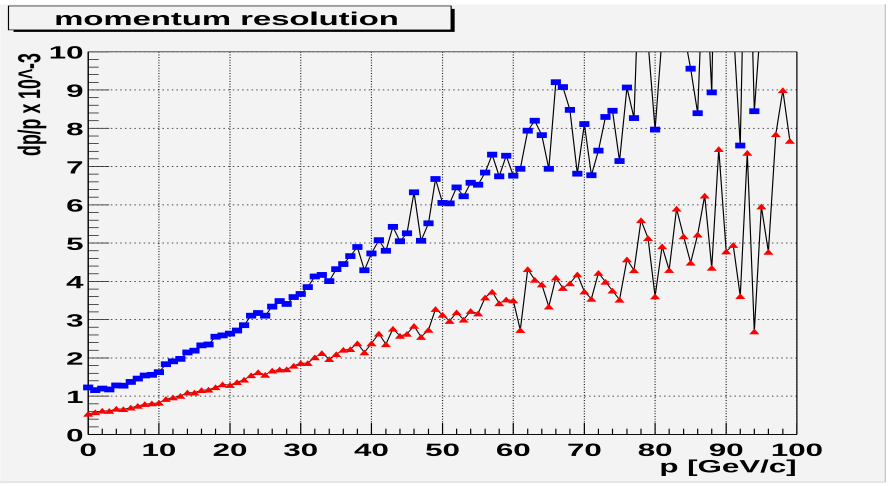

Figure 2: Momentum resolution versus momentum, as produced by our simulation, for regular TPC and the NITPC. Red triangles: NITPC. Blue squares: TPC.

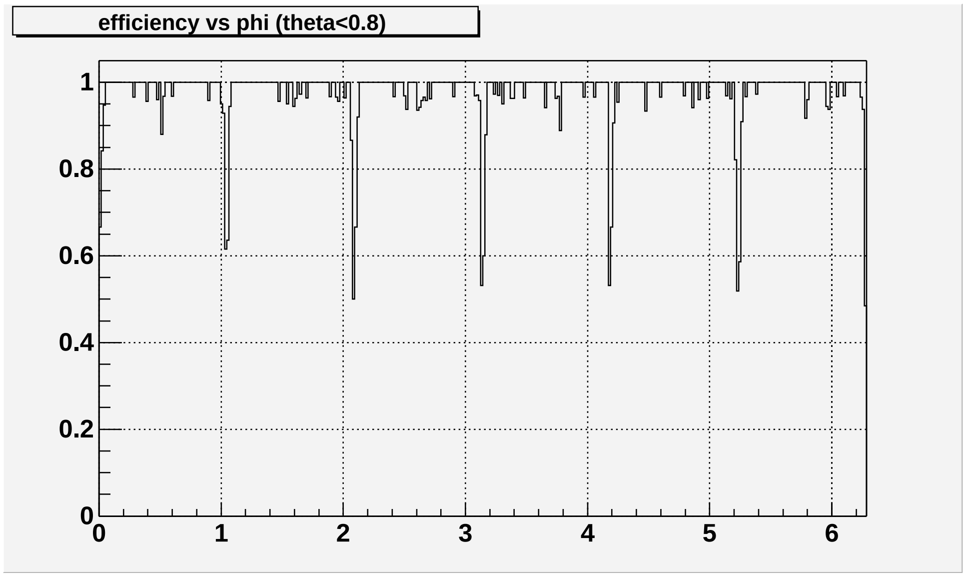

Figure 3: Helix finder efficiency vs. ϕ. The ϕ points of low efficiency coincide with those of read-out planes.

FY2004 Project Activities and Deliverables

With most of the simulation behind us, we wish to concentrate on building a viable prototype to show that the resolution and background tolerance are as advertised. In year 1, we will make some preliminary tests of other known electronegative gases, and measure the ageing properties of electronegative gas mixtures. We will also design a prototype for test beam purposes.

FY2005-2006 Project Activities and Deliverables

In year 2 and 3 we will build and operate a 30X30X30 cm^3 prototype.

Budget justification

The design, building and operation of a one cubic foot module will require 1/4 of a postdoc, one graduate student, and undergraduate help. We assume that we will not buy all the needed electronics, to reduce costs, and will use a multiplexing scheme to read the whole chamber. Parts of the device will be built in the WSU machine shop.

Three-year budget, in then-year K$

Institution: Temple University

Item	FY2004	FY2005	FY2006	Total
Other Professionals	12	13	13	38
Graduate Students	18	19	20	57
Undergraduate Students	8	8	8	24
Total Salaries and Wages	38	40	41	119
Fringe Benefits	7	7	7	21
Total Salaries, Wages and Fringe Benefits	45	47	48	140
Equipment	0	5	7	12
Travel	2	2	2	6
Materials and Supplies	1	1	1	3
Other direct costs	0	0	0	0
Total direct costs	48	55	58	161
Indirect costs	24	28	29	81
Total direct and indirect costs	72	83	87	242

Institution: Wayne State University

Item	FY2004	FY2005	FY2006	Total
Other Professionals	0	0	0	0
Graduate Students	0	0	0	0
Undergraduate Students	2	2	2	0
Total Salaries and Wages	0	0	0	0
Fringe Benefits	0	0	0	0
Total Salaries, Wages and Fringe Benefits	0	0	0	0
Equipment	0	0	0	0
Travel	3	3	3	9
Materials and Supplies	5	5	5	15
Other direct costs	0	0	0	0
Total direct costs	10	10	10	30
Indirect costs	5	5	5	15
Total direct and indirect costs	15	15	15	45

References

[1] D.P. Snowden-Ifft, C. J. Martoff and J.M. Burwell, Phys.Rev.D61:101301,2000

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[3] A. Schreiner, Tracking Group Talk, NLC Meeting, Cornell Univ., July 2003; http://motor1.physics.wayne.edu/∼schrein/science/nitpc.htm

[4] D. Karlen, Tracking Group Talk, NLC Meeting, Cornell Univ., July 2003; R. Settles, ibid.

[5] http://www.slac.stanford.edu/accel/nlc/local/systems/beamdelivery/geant/LD/

4.5 Straw Tube Wire Chambers for Forward Tracking in the Linear Collider Detector

5 Calorimetry

5.1 Development of particle-flow algorithms, simulation, and other software for the LC detector.

Personnel and Institution(s) requesting funding

G. Blazey, D. Chakraborty, J. G. Lima, A. Maciel, J. McCormick, V. Zutshi.
Northern Illinois Center for Accelerator and Detector Development/ Northern Illinois University

Collaborators

S. Magill et al., *Argonne National Laboratory*,
J. Yu et al., *University of Texas at Arlington*,
N. Graf et al., *Stanford Linear Accelerator Center*,
M. Oreglia et al., *University of Chicago*,
R. Frey et al., *University of Oregon*,
U. Nauenberg et al., *University of Colorado, Boulder*,
G. Wilson et al., *University of Kansas*,
U. Mallik et al., *University of Iowa*,

Contact Person

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Project Overview

The Northern Illinois University(NIU)/Northern Illinois Center for Accelerator and Detector Development (NICADD, `http://nicadd.niu.edu`) group is interested in calorimeter R&D for the proposed LC. Our group proposes to develop, in simulation and in prototype, designs for a hadron calorimeter (HCal) optimized for jet reconstruction using particle-flow algorithms (PFA, see below), also known as energy-flow algorithms (EFA). Simulations/algorithm development and hardware prototyping are envisaged as the two main components of our efforts. This proposal addresses the first component while the second is the subject of a separate proposal.

An e^+e^- linear collider is a precision instrument that can elucidate Standard Model (SM) physics near the electroweak energy scale as well as discover new physics processes in that regime, should they exist. In order to get the most out of the potential anticipated from a machine of this type, the collection of standard high energy physics detector components comprising an experiment must be optimized, sometimes in ways not yet realized at current experiments. One such example is the hadron calorimeter which will play a key role in measuring jets from decays of vector bosons and other heavy particles such as the top quark, the Higgs boson(s), etc. In particular, it will be important to be able to distinguish, in the final state of an e^+e^- interaction, the presence of a Z or a W boson by its hadronic decay into 2 jets. This means that the dijet mass must be measured within ~ 3 GeV, or, in terms of jet energy resolution, $\sigma(E) \approx 0.3\sqrt{E}$ (E in GeV). Such high precision in jet energy measurement cannot be achieved by any existing calorimeter. Similar precision in measurements of jet and missing momentum will be crucial for discovery and characterization of several other new physics processes as well as for precision tests of the Standard Model. Such ambitious objectives place stringent demands on the performance of the caloriemters working in tandem with the tracking system at the LC, which will require development of new algorithms and technology in this sphere.

The most promising means to achieving such unprecedented jet energy resolutions at the LC is through particle-flow algorithms (PFA), which seek to separate and measure in a jet clusters of energy initiated by neutral hadrons, carrying, on average, only $\sim 11\%$ of a jet's total energy. The tracker is used to measure with much better precision the charged components ($\sim 60\%$ of jet energy) and the electromagnetic calorimeter (ECal) to measure the photons with a resolution $\sigma(E) < 0.15\sqrt{E}$ ($\sim 25\%$ of jet energy). A net jet energy resolution of $\sigma(E) \approx 0.3\sqrt{E}$ is thus achievable by using the HCal only to measure the charged hadrons with a resolution $\sigma(E) \approx 0.6\sqrt{E}$.

A calorimeter designed for PFAs must be finely segmented both transversely and longitudinally for 3-D shower reconstruction, separation of neutral and charged clusters, and association of the latter to corresponding tracks. This requires a realistic simulation of both the physics processes and the shower development that occurs in materials. The design optimization requires the simulation, graphics, and analysis packages to be highly flexible, which can only be achieved through careful design and implementation of the software itself. Very large numbers of events will have to be simulated to evaluate the impact of competing designs on physics capabilities. Much of the physics in question is beyond the SM, requiring simulataneous coverage of broad ranges of undetermined parameters. Parametrized fast simulation programs will thus have to be developed once the algorithms have been stabilized. Parametrization of PFAs will require much work, and is one of our key objectives.

In January 2002, members of NIU, UTA (the University of Texas at Arlington), and ANL began collaborating on PFAs, simulations, and software development efforts. Many of the results that emerged through discussions at our regularly scheduled meetings have been presented at the CALOR 2002 conference; ECFA/DESY meetings at St. Malo, Prague, and Amsterdam; the American LC workshops in Santa Cruz, Arlington, and Ithaca; and at the International LC Physics and Detector Workshop in Korea.

Towards the optimization of the HCal design, the NIU+ANL team have started investigating both analog (cell energy measurements) and digital (hit counting) readout methods as functions of the cell size. Our preliminary findings indicate that for small enough cell sizes, the digital method yields a more precise measurement of the hadron energy, suggesting that hit density fluctuations are smaller than energy fluctuations in a hadronic shower. Three independent approaches to the implementation of an PFA are taking shape. These will help us determine the optimal cell sizes and geometry for best charged/neutral hadron shower separation in jets within the context of some specific overall detector parameters. Our HCal optimization efforts can be summarized as follows:

HCal absorber/active media properties: The detector simulation and analysis of physics events within the Java Analysis Studio (JAS)-based software environment developed at SLAC, is flexible in the choice of absorber and active media type and thickness within the limits of the HCal volume. NIU has recently put together a GEANT4-based detector simulation package to work within this environment, and produced many data sets spanning a range of cell shapes and sizes, and particle types. Teams from ANL and SLAC, in addition to NIU, are studying a wide variety of events simulated with this package. We will optimize the HCal by comparing dense materials (W, Pb) to less dense ones (Cu, Stainless Steel, Brass) as absorbers using as performance measures the containment of hadronic showers, the density of hits, and single particle energy resolution.

HCal transverse granularity/Longitudinal segmentation: We plan to optimize the 3-D granularity of cells for the most promising PFAs and then determine an optimal active medium for the desired cell size. The methods developed here are generalizable to different total detector geometries, i.e., SD, LD, TESLA, ... The basic performance measure here is the ability to separate showers from charged and neutral hadrons - the key to any PFA.

Analog vs. digital readout: Once the optimal 3-D granularity has been determined, the choice of the readout method can be evaluated by comparing jet resolutions with both analog and digital readout. It may be prudent to consider both the best analog and the best digital version of the HCal for eventual evaluation with test beams provided both prove petentially capable of of meeting the energy resolution requirement. Testing both options will allow for future advances in readout technology which might favor one option over another.

Particle-flow algorithms: For the first time in calorimeter development, it is necessary to include the reconstruction program in the optimization of the detector. It is anticipated that the choice of PFA will play a key role in the ultimate achievement of thte best jet energy resolution. As a first step, we plan to implement an PFA that does not require calorimeter cell clustering. Rether, it relies on associating calorimeter cells to extrapolated tracks, substituting the track momentum for the calorimeter energy measurement, finding photons in the ECal based on analytical shower shapes, applying an appropriate jet algorithm with the tracks and photons as input, and finally, associating the remaining calorimeter cells within the jet cone to the jet (these are predominantly due to neutral hadrons).

The NIU group has been working on simulation software since early 2002 and has made significant progress. All of the current American LCD simulation software, both event generation and a detector simulation based on the “GISMO” package, has been ported to the Linux platform. Since April, 2002, we have been processing simulation requests from several groups engaged in LC R&D on a 40-node Linux farm allocated to us by Fermilab. We have recently developed, in close collaboration with the ALCPG simulation group, a GEANT4-based simulation package based on standard C++ that is completely independent of any specific analysis platform. The new package, named “LCDG4”, fully complies with the model put forth by the simulation group, and adds some useful functionalities to it. Upon completion of tests currently underway, this package is expected to become the standard for ALCPG. Subsequently, it should be integrated into the U. of Chicago/ANL GRID facility currently under development. We organized a workshop at NIU/NICADD in November, 2002 (`http://nicadd.niu.edu/ws/`), to bring the groups together, chart a plan, and set out in an organized manner.

Further, as members of the CALICE collaboration (CAlorimeter for the LInear Collider with Electrons, `http://polywww.in2p3.fr/flc/calice.html`), and in active cooperation with our counterparts in the TESLA collaboration, we are working very closely with our European colleagues. In particular, the TESLA group has its own Geant4-based simulation package, called “Mokka”, which has a somewhat more powerful geometry description system, but lacks the flexibility and modern input-output options of LCDG4. We are working together to combine the best features of both, plus a more advanced geometry description system, into a universal package that can be used to compare different detector designs and algorithms in a uniform manner. To this end, we are exploring the possibility of reviving GDML (Geometry Description Markup Language, a Geant4-specific extension of XML), and making steady progress.

Among the members of our group we have adequate experience in calorimeter hardware, electronics, reconstruction software, and algorithm development. We anticipate close collaboration with other groups who have similar interests. Active links have been established with ANL, SLAC, U. of Chicago, DESY, members of the CALICE collaboration, and several other institutions.

Activities outlined in this proposal are also synergistic to the proposals for hardware prototyping of different technology choices. We will maintain close communication with the groups involved in hardware development for the ECal and the HCal.

FY2004 activities and deliverables

During the first year we will concentrate on two things: first, preparation of a comprehensive design document for the simulation software suite (in collaboration with several groups across the world), and second, development of PFAs for the electromagnetic and hadronic calorimeters. Both analog and digital versions of the algorithms will be investigated for the hadronic section. The first year deliverable will be a first version of a class of particle-flow algorithms based on full simulation and reconstruction of the calorimeter and the tracking system. Completion of the simulation design document is also foreseen, although it depends to a large extent on other groups as well. In addition, the standard GEANT4-based simulation facility (farm+server) will be available for to the entire LC community through a web-based request form.

FY2005 activities and deliverables

Apart from further tuning of the algorithms, extensive studies of critical physics processes will be carried out to understand the impact of the calorimeter performance on the physics program of the Linear Collider. These studies will employ analog and digital versions of our PFAs. The second year deliverables will be a quantified assessment of physics reach vs calorimeter performance for the Linear Collider with a clear statement on the desirability of a digital or analog option for the hadronic calorimeter.

FY2006 activities and deliverables

In the third year we will embark on the development of parameterized simulations of the particle-flow algorithms. The technology and geometry are expected to have been narrowed down by that time setting the stage for such parametrized fast simulation for extensive physics studies. The third year deliverable will be a fast simulation program based on PFAs. Also in the plans for the third year is a detaield simulation program for the different prototype modules that are expected to be studied at a test beam facility in 2006.

Three-year budget, in then-year K$

Item	FY2004	FY2005	FY2006	Total
Post-doctoral Associates	21.0	43.3	44.6	108.8
Graduate Students	19.5	20.1	31.0	70.6
Undergraduate Students	0	0	0	0
Total Salaries and Wages	40.5	63.4	75.6	179.4
Fringe Benefits	9.2	19.0	19.6	47.9
Total Salaries, Wages and Fringe Benefits	49.7	82.4	95.2	227.3
Equipment	0	25.0	23.0	48.0
Travel	10.0	20.6	21.2	51.8
Other direct costs	0	0	0	0
Total direct costs	59.7	128.0	139.4	327.1
Indirect costs (26% of non-equipment)	15.5	26.8	30.3	72.6
Total direct and indirect costs	75.3	154.8	169.7	399.7

Budget justification

The first year's activities revolve around the development of particle-flow algorithms. This will involve NICADD staff members (not included in the budget shown here), 0.5 FTE post-doc and 1.0 FTE graduate student. Optimization and detailed performance studies of the algorithm will be carried out in the second year by 1.0 FTE graduate students and 1.0 FTE post-doc with additional support from NICADD staff. During the third year, the development of parameterized simulations will be supported by 1.0 FTE post-doc, together with 1.5 FTE graduate students. Communication of progress and exchange of ideas through international workshops and conferences will be crucial for our endeavor to have a global impact. We estimate four domestic trips at $1.5K each and two international trips at $2.0K each during the first year, and twice as many in the second and third years. The equipment cost accounts for a 10-CPU Linux mini-farm + file server which will be needed in early FY05 to augment the allocation from Fermilab, as the simulation service enters a serious production phase. The capacity will have to be doubled toward the end of FY 2006.

Existing Infrastructure and available resources

The above requested resources will be augmented by the following support, totaling approximately $500K, from other sources:

(a) NIU/NICADD personnel,
(b) ANL personnel,
(c) Computing hardware and support provided by NICADD,
(d) 40-CPU Fermilab Linux farm (run by NIU personnel). These machines are relatively old, with per-CPU-capacity roughly a quarter of those requested in this proposal.

5.2 RPC Studies and Optimization of LC detector elements for physics analysis.

Personnel and Institution(s) requesting funding

Ed Blucher, Mark Oreglia (University of Chicago)

Collaborators (Not receiving funding from this subaward)

Argonne National Lab, Northern Illinois University

Contact Person

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Project Overview

We are studying performance aspects of glass RPC chambers in collaboration with Jose Repond at ANL. The goals of this research are to establish (with great care!) the reliability and failure modes of RPCs and to design and construct a cubic-meter prototype RPC digital calorimeter for test beam evaluation late in 2005. The University of Chicago group, including Harold Sanders and Fukun Tang of our Electronics Development Group, will design some of the readout electronics for calorimeter RPC prototypes under study. Oreglia, Blucher and students will continue their studies of RPC performance in a manner complementary to what the ANL group is doing.

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

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

We expect to have sufficient manpower to produce significant results within the three-year period if we can bring a new postdoc on board. Blucher and Oreglia are senior personnel who will devote significant effort to the project. Other senior personnel are performing similar research for the ATLAS experiment and will contribute greatly through their instruction of students and the postdoc.

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

FY2004 Project Activities and Deliverables

In year-1 we will continue our assessment of RPC surface damage and optimization of gas mixtures. With the goal of a significant beam test in 2005, we will also design DAQ boards for a large-channel prototype RPC calorimeter which we are working on with ANL. The design work will be conducted by the EFI Electronics Shop under the direction of Harold Sanders.

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

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

FY2005 Project Activities and Deliverables

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

In this year we will manufacture the DAQ electronics for the beam tests of the RPC calorimeter prototypes.

FY2006 Project Activities and Deliverables

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

Budget justification

The first-year budget supports 50% of a postdotoral research associate, one full-time equivalent undergraduate research technician (at the maximum work time allowed by the University), and salary for an additional (non-undergraduate) research technician during the summer months; the latter is likely to be a pre-matriculation graduate student, and this salary is in the “Other” category. The research associate and the research technicians will assist in testing of the RPC DAQ electronics, conduct beam studies of prototype chambers, develop energy-flow analysis software for Linear Collider calorimetry, and conduct analysis of LC tracker, electromagnetic calorimeter and hadron calorimeter integrated systems with the goal of optimizing the system granularities for optimum physics analysis potential. Travel funds are requested for transport to collaboration meetings and testbeam facilities (both domestic and international). Electronics shop labor and parts for the design of one major DAQ board is also included. The “Other direct” category is for electronic shop labor.

In the followinging years the electronic shop fraction ramps down, the postdoctoral research associate is on at 100%, and the travel allowance is increased to allow for increased testbeam activity.

Fringe benefits are calculated on the postdoctoral research associate salary at rates of 20.4%, 20.9%, and 21.4% for years 1,2,3, respectively. Likewise, the summer fringe benefit rate on the student research technians is 7.7%, 8.2%, and 8.7% in years 1,2,3, respectively. Indirect costs are applied at a fixed rate of 52.5% on salaries, fringe benefits, and travel; oversight by Merle Schmitt, Director of the Division of Cost Allocations, Department of Health and Human Services, 1301 Young Street, Room 732, Dallas,TX, (214) 767-3261.

Three-year budget, in then-year $

Institution: University of Chicago

Item	FY2004	FY2005	FY2006	Total
Postdoc RA	22500	46125	47278	115903
Other Professional	4950		4950	4950
Undergraduate Students	6400	6400	6400	19200
Total Salaries and Wages	33850	57475	58628	149953
Fringe Benefits	5187	10276	10792	26254
Total Salaries, Wages and Fringe Benefits	39037	67751	69420	176207
Equipment	0	0	0	0
Travel	2500	5000	7500	15000
Constructed Equipment	8000	10000	0	18000
Other direct costs (Labor)	35000	10000	5000	50000
Total direct costs	84537	92751	81920	259207
Indirect costs	21807	38194	40383	100384
Total direct and indirect costs	106344	130945	122303	359591

5.3 Investigation and Design Optimization of a Compact Sampling Electro-magnetic Calorimeter with High Spatial, Timing and Energy Resolution

5.4 Design and Prototyping of a Scintillator-based Digital Hadron Calorimeter.

5.5 Fast Response Tile Scintillation Development for Calorimetry and Tracking in NLC Detectors

Personnel and Institution(s) requesting funding

B. Baumbaugh, M. Hildreth, D. Karmgard, A. Kharchilava, J. Marchant,
M. McKenna, R. Ruchti, M. Wayne, J. Warchol, M. Vigneault
University of Notre Dame, Notre Dame, Indiana 46556

Contact Person

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Project Overview

Scintillation detection has a long history in particle physics. Scintillators are used for example in particle tracking and calorimetry (e.g.; the DØ fiber tracker and the Compact Muon Solenoid (CMS) calorimeters), and many other particle measurement systems. High luminosity accelerators such as the Next Linear Collider (NLC) present a new set of challenges for the development of scintillation detectors which can function effectively in short time, high radiation environments. The challenge is to develop new types of Wave Length Shifting (WLS) fibers which are fast, radiation hard, and efficient. Such a development would have immediate application to both Calorimetry and particle track triggering. The effort to develop such materials requires efforts in the chemistry of scintillating plastics and the geometry of the WLS. This proposal concentrates on the study of the geometric properties of WLS fibers.

These proposed studies have a possible application in many parts of an LC detector. They could be applied to fast triggering and particle tracking as well as calorimetry and calorimeter based clustering. They also have many possible applications outside of high energy physics (e.g.; fiber optic communications). A complimentary study which is necessarily a part of our proposal is that of the photo-sensor system. We shall, in undertaking this study, also have to consider the various possible methods of photo-detection (HPDs, APDs, Photomultiplier's, VLPC, etc.) to find the best possible match for an improved system of WLS fibers.

This proposal seeks to incorporate fast wave-shifting fibers to read out small scintillating tiles for fast timing in calorimetry and preshower/track-triggering applications in LC detectors.

Our objectives are several-fold:

1. Compare and study the performance of conventional Y11/K27 wave-shifter fiber embedded in small standard scintillation tile materials such as Bicron 408 with new, much faster and brighter wave-shifters. If successful, these new materials would provide superior timing information to conventional materials for calorimetry and triggering applications;
2. Develop improvements in fiber-optic light timing by special shaping of the ends of fiber waveguides;
3. Reduce the number of readout channels for fiber-based detectors through the chaining of spaced, non-adjacent scintillating tiles on a single wave-shifting fiber.

The first task involves comparative studies of BC408 scintillator tiles read out with Y11 wave-shifter fiber and BC408 tiles read out with fiber containing recently developed wave-shifter dyes such as

DSB1 and DSF1. The new wave shifters are a factor of 3 faster than Y11 (2.5 ns vs. 8 ns), with a brightness improvement of up to 50%. These would afford significantly improved timing information for preshower and triggering detectors. Tests will be carried out using radioactive sources to study efficiency and uniformity of response. Photo-sensors will be conventional, red-extended multialkali photomultiplier tubes.

The second task involves optical interface modification at the ends of wave-shifter fibers. In most detector applications, the bulk of the light signal within a scintillating or wave-shifter fiber propagates near the critical angle. In a multiclad fiber with core of index 1.59 and outer clad of index 1.42, this angle is approximately 27 degrees relative to the fiber axis. By tapering the end of the fiber (like sharpening a pencil) to approximately this angle, light trapped at the critical angle will emerge from the surface parallel to the fiber axis. This axial light can then be injected into any fiber waveguide (for example PMMA core or even quartz fiber) and can be transmitted with less optical absorption and over a potentially shorter optical path than would otherwise be possible. Such a technique is also applicable to improved timing performance for a calorimeter or trigger detector. For these studies, light excitation would be via blue LEDs and light detection via pin diodes.

The third task is a scheme to reduce the number of readout channels in a multi-channel scintillation tile detector through the multiplexing of non-adjacent scintillating tiles of small size through a common wave-shifter fiber. For example, a series of 100 small, optically isolated, scintillation tiles of 2.5 cm length and 2.5 cm width are arranged end-to-end in a column and lying in a plane. Rather than having 100 individual fiber readouts for these tiles, every 20th tile is read out by a common wave-shifter fiber. (Tiles 1, 21, 41, 61, 81 have a common readout; tiles 2, 22, 42, 62, 82 have a common readout, etc.) In this configuration, the tiles are spaced 50 cm apart along a fiber, corresponding to a light signal timing difference of approximately 3 ns between successive tiles. If the signal arrival time at a photosensor is measured, then the tile producing the signal (and its location) is identified. In this example, a factor 5 reduction in the number of electronics channels results. Our objective is to determine the minimum effective tile separation possible for a given combination of scintillator and wave-shifter. Here, the identification of new, fast wave-shifter materials (first task above) is a major aid to such readout scheme. The optical signals can be detected with photomultipliers or visible light photon counters (VLPC).

FY2004 Project Activities and Deliverables Project activities for the first year are the preliminary testing of the described systems. We intend to conduct an extended feasibility study to determine if the ideas presented have merit. In addition to the construction of a test stand and basic measurements, we will use the data gathered to generate software simulations of the systems. We may then use these to more rapidly study the details of various design possibilities. The first year deliverable is a complete feasibility study.

FY2005 Project Activities and Deliverables Presuming that the first years efforts bear fruit, project activities in the second year center around building a working prototype system using the elements described in this proposal. The deliverables are the prototype and documentation of the physics capabilities of the system.

FY2006 Project Activities and Deliverables In the third year the project aims to take the lessons learned from the working prototype system to design a detector subsystem compatible with the needs of an NLC detector. The deliverables are a Technical Design Report of such a system.

Budget justification

Because of the long-range of the Linear Collider Program, we are anxious to leverage on the QuarkNet program and draw in high school teachers and students (in the summer between their junior and senior years) to work on the project, under the supervision of an experienced technician and guided by part-time graduate students. This will afford a direct education/outreach component to the R and D program and will afford the teachers and students the opportunity to participate directly in the development of state-of-the-art new techniques for particle detection and measurement.

We request half-time support and later full-time support for a technician to coordinate the design and fabrication of the test assemblies of the scintillation tile and wave-shifter arrays. This individual will, with the assistance of a graduate student, supervise the work of a high school teacher and several high school students during the summer to construct tile/fiber networks and to develop a test station to evaluate the performance of these structures. The graduate student will be supported from base grant funds.

An additional facility will be developed to shape the ends of optical fibers with the aim of developing optical connectors to adjust the phase space of the light propagating in the fibers to reduce propagation time and improve light transmission in optical fibers of long length.

Funds are requested for summer support of a high school teacher and two high school students. Equipment funds for the purchase of fast photo-sensors and materials funds for scintillating tiles and wave-shifting fibers are requested. A very modest travel budget is included to support several laboratory and vendor visits.

Indirect costs are estimated at 48.5% of modified total direct costs according to University of Notre Dame Accounting Practices.

Three-year budget, in then-year $

Institution: University of Notre Dame

Item	FY2004	FY2005	FY2006	Total
Technician	19,200	19,700	40,700	79,600
HS Teacher	5,200	5,350	5,500	16,050
HS Students (2)	3,000	3,100	3,200	9,300
Travel	1,000	1,500	2,000	4,500
Equipment	2,500	2,500	2,500	7,500
M&S	2,500	2,500	2,500	7,500
Indirect Costs	11,010	11,495	21,922	44,426
Total	44,410	46,145	78,322	168,876

6 Muon System

6.1 Scintillator Based Muon System R&D

Personnel and Institution(s) requesting funding

Gerald Blazey, Dhiman Chakraborty, Alexandre Dychkant, David Hedin,
Jose G. Lima, Arthur Maciel, Northern Illinois University, DeKalb, IL
Mitchell Wayne, University of Notre Dame, Notre Dame, IN

Collaborators

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Project Overview The linear collider detector design includes a muon system that will identify muons, as distinct from hadrons, primarily by their penetration through the iron flux return. Because the proposed calorimeters are thin in terms of interaction lengths, hadronic showers will leak into the muon steel. The proposed energy-flow algorithms anticipate measuring jet energies by using charged particle momenta, EM shower energies for neutral pions, and hadron calorimetry for neutrons and K_L's. Fluctuations of the neutral hadron energies leaking from the hadron calorimeter will degrade the energy resolution. An adequately designed and proven muon system could be used to measure the energy escaping detection and improve the energy resolution of the detector. It is in this context that we propose an R&D program for a scintillator-based muon detection and identification system.

The general layout of the barrel muon detectors consists of planes of scintillator strips inserted in gaps between 10 cm thick Fe plates that make up octagonal barrels concentric with the e+e- beamline. The scintillator strips, with nominal width of 5 cm and 1 cm thickness, will contain one or more 1 mm diameter wavelength shifting (WLS) fibers. The investigation of optimal strip properties and sizes is a part of this project.

Light produced by a charged particle will be transported via clear fibers to multi-anode photomultipliers located outside the Fe yoke where it will be converted to electronic signals. Nominally there are 16 planes of scintillator with alternating strips oriented at $45°$ with respect to a projection of the beam line onto the planes.

Given a substantial knowledge base from experiments like MINOS, CDHS and others one might ask if an R&D effort on a scintillator-based muon system is necessary. In fact, it is. There are significant differences in the environments for neutrino experiments and the proposed linear colliders. For the LCD, detectors must be robust and ready to withstand 20 years of beam time in a radiation environment. The geometry and packaging of the scintillator detectors are very challenging. There is much in the way of mechanical engineering of the iron, fiber and cable routing, etc. that needs to be determined at an early stage to ensure that important details for the largest LC detector system are not overlooked.

FY2004 Project Activities and Deliverables

NIU Software Development: a C++/GEANT4 stand-alone representation of a preliminary muon detector sub-subsystem. Package framework, and implementation of (i) modularity towards an easy plug-in of different sub-detectors (trackers, calorimeter) (ii) detector geometry and parameter input as decoupled as possible (e.g. external data bases) from simulation code, for easy changes in detector characteristics. This project is to be coordinated with other LCD sub-detector developers, towards a sub-systems compatible and flexible full detector simulation package. In parallel, development of muon tracking algorithm for continuous assessment of detector model development.

The first year deliverable will be an initial package for the GEANT4 based physics event simulation; a general framework capable of hosting all subdetectors, a preliminary description of the muon subsystem, and a muon stand-alone tracking algorithm.

NIU Hardware Development: joint work with Fermilab for the commissioning of a scintillator extrusion facility. Design of a Test Stand for the Quality Control of extruded scintillator plates. Initial studies of techniques to embed fibers into the muon strips.

Deliverables will include the production of extruded scintillator strips and inital measurements of their properties compared to standard methods of producing counters. This will require the manufacture of a die.

UND Hardware Development: Devise a fiber routing scheme. Create a technique for the splicing/joining of WLS and Clear fibers. Decide on the specifications, and order the WLS fibers.

FY2005 Project Activities and Deliverables

NIU Software Development: Continued development of the simulation package described in the previous item. Completion of the muon system representation according to the then current detector design. Coupling to the other subdetectors. Simulation based studies of detector parameter trade-offs and optimization.

The second year deliverable will be a simulation package providing fast and reliable access to different detector design characteristics and parameter choices. With it, we expect to achieve a solid understanding of the muon system tracking ability, fake rates, and sub-systems integration, such as the inter-dependence of parameter choices and the mutual assistance with calorimetry and cenral tracking for particle ID, energy flow and energy/momentum resolution.

NIU Hardware Development: Measurements of the performance (such as light yield and resultant efficiencies and time resolutions) as a function of paramters such as position along the strip, fiber placement and number of fibers, and counter length. Comparisons will be made between extruded and non-extruded strips. At least one additional size die will be made and prototype strips manufactured.

Deliverables will include a better understanding of the performance of strips of various lengths, widths, and fiber placement. Combined with the simulation effort, this can be used as a guide for an initial choice of counter dimension and mechanical properties.

UND Hardware Development: Quality assurance on WLS and Clear fibers. Design and use a system to measure optical transmission. Engineering design of prototype light guide manifolds.

FY2006 Project Activities and Deliverables

NIU Software Development: Completion of the muon simulation, track reconstruction and analysis software. Completion of all simulation based studies of detector design characteristics and parameter optimization.

The third year deliverable will be a mature package for the GEANT4 based physics event simulation, reconstruction and analysis; documented, external user friendly, able to host the then available non muon sub-detectors, and with a version-controlled description of the muon sub-system, holding the necessary detail for physics reach studies.

NIU Hardware Development: Produce a significant number of pre-production prototypes to understand production details, costs, and uniformity. Depending on the needs of other R&D efforts, these counters could then be installed and used in test beams (e.g. calorimeter tests).

Deliverables will include the produced counters. Also a third year deliverable (both hardware and software) should be a significant contribution to the muon system TDR.

UND Hardware Development: Production of prototype manifolds for eight planes. Test manifolds, install the manifolds with light guides for the eight planes.

Budget justification

All NIU salaries for professional support staff (including electronics, computing, and machine shop personnel) will be provided by the Department, the State, or other grants. The NIU budget requests support for an undergraduate student through the REU program and for the summer support for a masters graduate student. It is our experience that students at this level are well-matched to the R&D tasks in this proposal. Three NIU undergraduates worked on LC muon related tasks (both simulation and detector R&D) during the Summer of 2002, and this request will aid in continuing student involvement.

The NIU budget requests K$5.4 in materials and supplies (such as scintillator, fiber, PMTs) which will be used in the construction of prototype counters. Travel funds of K$3 are requested to support international and domestic travel.

NIU grant matching funds for the support on LC muon R&D are primarily from the State of Illinois' HECA program. This provides the salary for Dychkant, and partial support for Maciel and Hedin. In addition, HECA funds will provide K$9 for student support, K$15 for equipment and M&S, and K$2 for domestic travel.

UND requests support for the mechanical engineering associated with fibers: routing and layout, optical coupling of clear and WLS fibers. Manifold engineering, such as mold development using carbon fiber, epoxy techniques. The UND budget must also cover materials such as fibers, manifold parts etc.

Changes since original project submition in Sept. 2002

The project scope, activities and expenses have not changed, but the budgets and budget justifications were shifted by one year – to conform to the UCLC(NSF) guidelines – for a start on Oct 1, 2003 (US Federal FY04). Other (minor) adjustments simply reflect updated university costs and revised subcontracting overhead requirements. Requested totals have been preserved.

Three-year budget, in then-year K$

Institution: Northern Illinois University.

Item	FY2004	FY2005	FY2006	Total
Other Professionals	0	0	0	0
Graduate Students	4.7	4.7	4.7	14.2
Undergraduate Students(REU)	3.0	3.0	3.0	9.0
Total Salaries and Wages	7.7	7.7	7.7	23.2
Fringe Benefits	0	0	0	0
Total Salaries, Wages and Fringe Benefits	7.7	7.7	7.7	23.2
Equipment	0	0	0	0
Travel	3.0	3.0	3.0	9.0
Materials and Supplies	5.4	5.4	5.4	16.2
Other direct costs	0	0	0	0
Total direct costs	16.1	16.1	16.1	48.4
Indirect costs (*)	4.2	4.2	4.2	12.6
Total direct and indirect costs	20.3	20.3	20.3	61.0

(*) 25% on REU (=K$0.8) and 26% on remainder (=K$3.4)

Institution: University of Notre Dame

Item	FY2004	FY2005	FY2006	Total
Other Professionals(1)	7.0	8.0	10.0	25.0
Graduate Students	3.0	7.0	8.0	18.0
Undergraduate Students	0	2.0	2.0	4.0
Total Salaries and Wages	10.0	17.0	20.0	47.0
Fringe Benefits(2)	1.4	1.6	2.0	5.0
Total Salaries, Wages and Fringe Benefits	11.4	18.6	22.0	52.0
Equipment	9.0	9.0	5.0	23.0
Travel	0	0	0	0
Materials and Supplies	0	0	0	0
Other direct costs	0	0	0	0
Subcontract	20.31	20.31	20.31	60.93
Total direct costs	40.71	47.91	47.31	135.93
Indirect costs(3)	15.379	11.296	10.67	37.345
Total direct and indirect costs	56.089	59.206	57.980	173.275

(1) Engineering work

(2) 20% of “Other Professionals”.

(3) 48.5% of “MTDC” and “1st $25,000 of Subcontract”.