Tracking Table of Contents

Draft

Overview of Tracking Proposals

The tracking system at the Linear Collider will consist of both a central tracker and a forward tracking system. The choice of technology for the central tracker remains open. The most mature candidates are a large-volume TPC, an axial drift chamber, and an all-silicon tracker. The main criteria in selecting among these options will be the ability to achieve the needed momentum resolution, the ability to maintain performance in the presence of potentially large accelerator backgrounds, the ability to interface appropriately with a precision calorimeter, and cost. Complete evaluation of the various technologies requires well-defined physics requirements, hardware development and, in order to assess efficiency and sensitivity to backgrounds, mature pattern recognition software.

Physics Simulation

Physics simulations have clarified many of the design goals for the LC detector, including the central tracker. Studies of sparticle production and decay are needed to establish more quantitatively the physics requirements on momentum resolution, including for low momentum tracks (A).

A.	UCLC	Tracker simulation studies and alignment system R&D	Keith Riles	U Michigan

Silicon Central Trackers

Silicon central trackers have the advantage of compactness. Two groups plan to develop the design for a silicon strip detector. One (A) will address pattern recognition in such a device. They will start by developing stand-alone pattern recognition in a CCD vertex detector, and then incorporate reconstruction algorithms for use with an axial-only silicon strip tracker. Another group (B) will use simulations to optimize sensor readout (*e.g.*, shaping time) and will develop a prototype readout chip.

The silicon drift detector is an attractive option because it is compact and offers 3-D space points, which should make pattern recognition more robust in the presence of background. One project (C) will further develop this technology. The group will continue developing the necessary simulation and reconstruction algorithms. On the hardware side, they will work to increase wafer size, extend the drift length, reduce the channel count and bring the wafer thickness to 150 microns. Finally, they plan to develop a CMOS-based front-end chip.

A “real-time” tracking device alignment system will be important at the Linear Collider, particularly for a low-mass, non-rigid silicon tracking system (A - listed in the section on *Physics Simulation*.)

A.	LCRD	Tracking Software Optimization for the Silicon Detector Option	Milind Purohit	U South Carlolina
B.	LCRD	Use of Silicon Strip Detectors in Low Duty-Cycle Applications	Bruce Schumm	UC Santa Cruz
C.	UCLC	R&D towards a Silicon drift detector based main tracker for the NLC-SD option	Rene Bellwied	Wayne State U

TPC Central Tracker

A TPC would offer low mass and 3-D space points. A number of groups will work on TPC development. Two intend to improve fabrication techniques for GEMs. One of these groups (A) will focus on photo-lithography and use simulation to optimize design. A second group (C) will use prototype TPC's with GEM and MicroMegas readout to explore resolution, segmentation, noise, ion feedback, etc. Track reconstruction software that uses local track segments rather than the global hit approach of the existing tracking software will be developed (D). This software works for both a 3-D or an axial-only tracker.

A novel alternative tracker is the Negative Ion TPC, whose hallmark is its very slow drift velocity. One group (E) plans both to simulate the performance of such a tracker and to develop a prototype.

A.	LCRD	Fabrication and investigation of Gas Electron Multipliers for charged particle tracking	Peter Fisher	MIT
C.	UCLC	Tracking Detector R&D at Cornell and Purdue Universities	Dan Peterson	Cornell
D.	UCLC	Application of CLEO Tracking to a TPC	Dan Peterson	Cornell
E.	UCLC	Negative Ion TPC as the LC main tracker	Giovanni Bonvicini	Wayne State U

Intermediate Trackers

One group (A) will pursue its studies of a fast scintillating fiber intermediate tracker. The group will establish the effect on momentum resolution and the impact of being able to distinguish tracks produced in different NLC bunch crossings. They will also study a prototype using cosmic rays.

A.	LCRD	Studies of the Use of Scinitillating Fibers for an Intermediate Tracker which Provides Precise Timing and Bunch Identification	Rick Van Kooten	Indiana U Notre Dame

Forward Trackers

Forward tracking is more important at the Linear Collider than at previous e^+e^- machines because of the increased contributions of *t*-channel processes at the high center-of-mass energies. Forward tracking is also important for differential luminosity measurement. One group (A) will concentrate on the development of pattern recognition algorithms in order to help define the design of a forward tracker. Another (B) will explore the use of straw tubes for forward tracking, and a third (C) will study the use of a GEM-based device.

A.	LCRD	Development and Testing LC Forward Tracking	Michael Strauss	U Oklahoma
B.	UCLC	Straw Tube Wire Chambers for Forward Tracking in the Linear Collider Detector	Keith Baker	Hampton U
C.	LCRD	Evaluation of a GEM based Forward Tracking Prototype for the NLC	Lee Sawyer	Louisiana Tech U

5.1. Development and Testing Linear Collider Forward Tracking (LCRD)

Tracking

Contact person: Michael Strauss
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phone: (405) 325-3961

Oklahoma

FY 2003: $41,708

Project name

Development and Testing of Linear Collider Forward Tracking

Classification (accelerator/detector:subsystem)

Detector: Tracking

Institution(s) and personnel

University of Oklahoma, Department of Physics:
Michael G. Strauss (Associate Professor), Post-doctoral researcher (To Be Named)

Contact person

Michael Strauss
mgstrauss@ou.edu
(405) 325-3961 ext. 36311

Project Overview

Traditional e^+e^- tracking detectors have provided excellent track finding and track resolution in the central region, but diminished capability in the forward direction. However, the Linear Collider (LC) detector will require excellent forward tracking to attain the maximum physics potential. For instance, certain production and decay modes of supersymmetric particles are peaked in the forward direction. Some important Standard Model processes, like *WW* production are also predominantly along the beamline. Quality forward tracking will be required to maximize the ability to do certain physics. This can be accomplish by developing forward tracking that uses minimal material in order to preserve momentum resolution of the order $1/p_t = 10^{-4}$ GeV^{-1}.[1] At present, few studies have been done to choose tracking hardware options or develop software algorithms to assure quality track finding and resolution in the forward direction.

We propose a systematic software effort to understand tracking capabilities in the forward direction, to about 110 mrad from the beamline. A realistic simulation will include beam related backgrounds, accurate simulations of charge deposition, applying reasonable hit finding and merging algorithms, and developing and testing track finding algorithms. Such an effort will allow an informed choice for forward tracking technologies and design parameters. We will help determine the essential hardware components needed to assure quality tracking and physics capabilities in the forward direction, and to eventually develop quality pattern recognition and tracking algorithms in the forward direction. The software tools we develop will be used to facilitate future physics studies.

At the end of this project, which may extend for more than one year, we hope to answer questions such as:

1) What detector design maximizes the forward tracking potential?
2) Are three-dimensional technologies necessary for tracking in the forward direction?
3) Can reasonable resolution and pattern recognition be performed to 110 mrad?
4) Does beam-related background interfere with tracking capabilities in the forward region?

Description of first year project activities

During the first year, we would hire a post-doctoral researcher who will develop and adapt tools for LC forward track finding.

There are a number of tools that have been developed within the high-energy community, or are being developed within the Linear Collider community that can be adapted for the purpose of understanding tracking in the forward region. For instance, reasonable forward tracking has been attained by the DØ collaboration using tracking code named TRF++. Tools and algorithms developed for TRF++ can be used as a first test of forward tracking in the LC environment. These tools should be interfaced with the LC simulation package using Gismo that has been developed at SLAC. Other LC Monte Carlo simulation efforts, such as a complete simulation of the beam line, will be incorporated into a realistic simulation of the forward tracking. By integrating tools that have been developed within the High Energy community and current linear collider software tools, and by developing new algorithms and tools, a comprehensive and precise understanding of forward tracking will emerge. This will lay the foundation for answering detailed questions about the capability of the LC detector to do forward tracking.

If these tools and simulations are inadequate to answer all of the questions listed above, then we will develop new ones. The tools and algorithms developed can be distributed to the Linear Collider community for further study. After one year we expect to have implemented existing tools into a unified package and to have preliminary conclusions regarding technology and algorithms to use for forward tracking. Further work will probably need to be done to develop and optimize future algorithms.

These studies will be done in collaboration with other groups working on tracking hardware and software, as well as coordinated with the SLAC and LBNL simulation and reconstruction groups. Groups at Louisiana Tech and Hampton University are investigating the possibility of using Gas Electron Multipliers (GEMs) as charge amplifiers and/or collectors in the forward region.[2] We will cooperate with these and other universities that are developing hardware that may be used for LC forward tracking. Other forward tracking options, like the combination of silicon and straw chambers proposed for the TESLA detector, should also be considered.[3] As technologies are developed and proposed, we will coordinate our effort to test the tracking capabilities of different techniques. We will also collaborate with groups developing tracking algorithms for the central detector.

Qualifications of Personnel and Budget Justification

The contact person for this EOI, Michael Strauss, has significant experience developing and testing tracking software. He co-authored the track finding and fitting algorithms used in the original TPC detector at the PEP collider. He also developed and wrote the tracking software for the SLD CCD-based vertex detector. This software linked Central Drift Chamber tracks to CCD hits, and also found "stand-alone" tracks in VXD-3. He has also been involved with the DØ tracking group and has some knowledge of the TRF++ tools and algorithms available. In order to actually implement and test tracking algorithms, a post-doctoral researcher will be necessary.

Budget

Institution	Item	Cost
Oklahoma	One-half FTE Post-Doctoral Researcher Salary plus Fringe Benefits	$28,665
Oklahoma	Oklahoma Indirect Costs	$13,043
	Grand total	$41,708

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[1] Joint R&D Proposal for Linear Collider Tracking, B Schumm, et.al., May 1, 2001.
[2] See Section on GEMs in this proposal.
[3] TESLA Forward Tracking and Measurement of Luminosity-Spectrum, Klaus Mönig, www-lc.fnal.gov/proceedings/d3_vertex/moenig_tracking_2.ps.

5.2. Evaluation of a GEM based Forward Tracking Prototype for the NLC (LCRD)

Tracking

Contact person: Lee Sawyer
email: sawyer@phys.latech.edu
phone: (318) 251-2407

Louisiana Tech

FY 2003: $37,490

Project name

Evaluation of a GEM based Forward Tracking Prototype for the NLC.

Classification (accelerator/detector:subsystem)

Detector:Tracking

Institution(s) and personnel

Louisiana Tech University, Center for Applied Physics Studies:
Lee Sawyer (*), Tony Forest, Z.D. Greenwood, Neeti Parashar (professors)

Louisiana Tech University, Institute for Micromanufacturing
Phillip Coane (Senior Engineer)

Contact person

Lee Sawyer
sawyer@phys.latech.edu
(318) 251-2407

Project Overview

Several groups are currently exploring the fabrication of tracking detectors based on the use of gas electron multiplier (GEM) foils [1]. This includes the proposed Time Projection Chamber (TPC) as well as the digital calorimeter option for the hadronic calorimeter. We propose to evaluate a forward tracking ionization chamber for the next linear collider which uses a gas electron multiplier as a preamplifier and will permit single particle tracking.

A GEM is a perforated foil of insulating material approximately 50 μm thick and coated on both sides with a thin conductor approximately 5 μm thick. The holes have a radius on the order of 50 μm and are in a grid pattern in which the distance between adjacent holes is on the order of 150 μm. The photo-lithography based technology to construct this preamplifier was developed at CERN by Fabio Sauli and collaborators [2]. When used as a preamplifier in front of a micro-pattern device, like a multiwire proportional chamber, the signal is amplified up to 10^5 [3] and can operate in harsh radiation environments up to at least 2 Mrad. Charge multiplication occurs when the electrons pass through the foil holes whose sides have had an electric potential difference applied to produce electric fields on the order of 40kV/cm. A typical GEM detector electric field is shown in Fig. 1 (taken from [4]). With 2 GEMs serving as preamplifiers, the charge can be detected directly on a segmented printed circuit board [5].

As an application of GEM technology in subdetector systems at the Next Linear Collider (NLC), we will explore the use of GEM-based detectors in forward tracking. Forward tracking will potentially be more important at the NLC than at previous e+ e- colliders, as many interesting SUSY processes have differential cross sections peaked in the forward direction. It will also be important to accurately measure differential luminosity cross-sections at the NLC, with angular resolutions on the order of 0.1 mrad [6]. The GEM strategy offers the possibility of achieving the necessary spatial resolutions with a detector that is radiation-hard, high rate, and compact. Timing resolutions on the order of 14 ns have been measured with GEM detectors having a 3 mm gap. Research needs to be done to understand if faster timing can be achieved, possibly with microstrip gas chambers using a GEM foil preamplifier.

An evaluation of GEMS for use in the inner tracking system of HERA-B concluded that they are better suited for the harsh radiation environments of their experimental setup [7]. We would like to expand on their work to determine if a GEM based forward tracking system is suitable for the NLC.

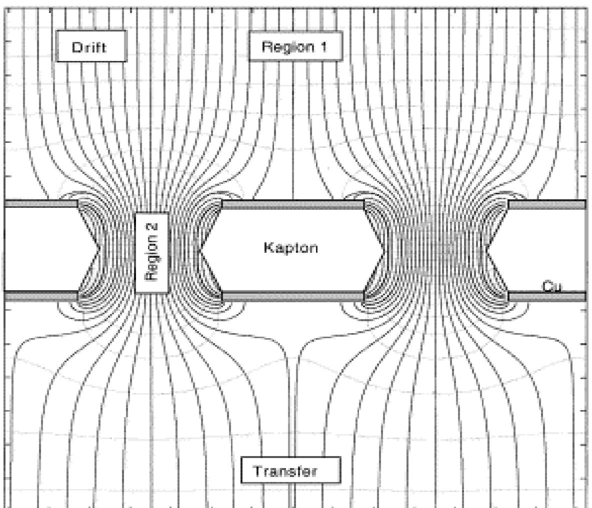

Figure 1 Electric field lines in an operating GEM. Taken from [4].

Outstanding issues to be addressed by this proposal involve a determination of the expected rates, lowest achievable scattering angle, desirable tracking resolution, readout rate and acceptable radiation length for use of this device.

Currently, we have obtained a Monte Carlo from the Kansas group to determine the rates expected in this device as a function of polar angle. This will tell us how close to the central axis we may use the forward tracker. We will also determine the minimum acceptable forward tracking resolution based on the results of the simulation. The optimal readout rate for a GEM based forward tracker will be obtained by performing several tests of a prototype device. To minimize radiation length, the typical G-10 printed circuit board anode will be replaced with less dense material (*e.g.* kapton).

We will establish a testing facility for the GEM based prototype tracking system. First, a GEM foil will be purchased from Sauli at CERN and mounted in an ionization chamber with a 2-D printed circuit board charge collector. A series of tests will be done to double check the integrity of the GEM foil for shorts and other possible defects. An existing cosmic ray based test stand will be used to determine the tracking characteristics of the device. A data acquisition system is already in place with ADC and TDC readout electronics for 8 GEM channels. At a future date, tests using a 1 GeV electron beam will also be done to evaluate readout performance as well as radiation hardness issues.

Another area of focus will be to evaluate an effective readout scheme. The high cost of instrumenting the thousands of channels within a 30x30 cm^2 area forces the use of such cost saving measures as multiplexing. The challenge is to determine the optimal level of multiplexing which will yield an acceptable signal to noise ratio. The Heidelberg

ASIC laboratory in collaboration with a group from Max Planck Institute developed a highly integrated readout chip called ``HELIX 128 " which can read out 128 anode strips at 10 MHz and store the information for 12 μs in a pipeline [8]. In the case of the next linear collider, a simulation will be used to determine what level of multiplexing will be needed. We can then investigate if it is desirable to adapt the ``HELIX 128" to serve a similar function for the forward tracking device proposed here or use alternative methods.

Expertise

This research project represents collaboration between the Institute for Micromanufacturing and the Center for Applied Physics Studies at Louisiana Tech University. The Institute for Micromanufacturing has the facilities for fabrication of readout cathodes and GEM foils, if needed. The Center for Applied Physics Studies contains the high energy and medium energy physics groups who will be developing the GEM detectors. The collective experiences of the Center for Applied Physics Studies members will ensure the development a GEM-based forward tracking prototype.

Currently the high energy physics group consists of Lee Sawyer, Z.D. Greenwood, and Neeti Parashar. All are members of the D0 experiment at Fermilab, and have extensive experience in detector development and simulations. The Louisiana Tech group built and installed portions of the Intercryostat Detector for the D0 upgrade, while Dr. Parashar was involved with development of the CDF and D0 muon detectors, and the proposed CDF fiber tracker. Dr. Sawyer has worked on the D0, SDC, and ATLAS calorimeter systems, while Dr. Greenwood has built a number of neutrino detectors and is currently involved in Run IIb upgrades to the D0 Silicon Tracker.

Tony Forest is a member of Louisiana Tech's medium energy group, with experiments at Jefferson Lab. He is developing GEM-based trackers for the proposed QWEAK experiment at JLAB. His experience with tracking in that detector system will be used in developing the forward tracking prototype.

References

[1] For a general discussion of GEM detector technology, see the papers listed on http://www.jlab.org/~gen/detectors/literature_gem.html
[2] F. Sauli, Nucl. Instr. and Meth., A 386 (1997) 531.
[3] W. Beaumont, et. al. , Nucl. Instum. and Meth. A 419 (1998) 394.
[4] B. Schmidt, Nucl. Instrum. and Meth. A 419 (1998) 230.
[5] A. Bressan et. al., Nucl. Instrum. and Meth A 425 (1999) 262.
[6] "Linear Collider Physics Resource Book for Snowmass 2001", American Linear Collider Working Group.
[7] Y. Bagaturia et. al., hep-ex/0204011.
[8] http://wwwasic.kip.uni-heidelberg.de/~trunk/projects/Helix/

Description of first year project activities

During the first year of funding we will build forward tracking detector prototype using GEM foils from Sauli at CERN and perform the tests outlined above. We will also begin simulations of the forward region of an NLC detector, and work in conjunction with other groups interested in GEM technology on prototype trackers.

We request funding for a graduate student to work on testing the detector prototype, travel to NLC meetings, supplies, materials, and indirect costs. As justification for the travel request, our current DoE grant travel budget is entirely budgeted for trips for the D0 experiment at Fermilab. We plan trips to NLC working group meetings, as well as to other institutions working on GEM fabrication. These are beyond the scope of our baseline funding.

The specific material request is as follows: $300 for GEM foils, $700 the prototype gas chamber, $1,000 for the gas system, $4,000 for electronics (in particular the multiplexing readout chips), $1,000 to manufacture the readout cathode.

If the proposed system proves to be a viable forward tracking system for the NLC, we foresee requesting additional funding for refining the detector prototype in Years 2 and 3 with a similar profile as the first year.

Budget

Forward Tracker Construction:	
Materials	$ 7,000
Testing and Detector Studies:	
Graduate Student	$14,000
Fringe for student	$ 2,660
Supplies	$ 1,000
Miscellaneous:	
Travel	$ 4,000
Indirect	$ 8,830
TOTAL	$37,490

5.3. Straw Tube Wire Chambers for Forward Tracking in the Linear Collider Detector (UCLC)

Tracking

Contact person: Keith Baker
email: baker@jlab.org
phone: (757) 727-5820

Hampton

FY 2003: $32,500
FY 2004: $95,700
FY 2005: $100,100

Proposal to the University Consortium for a Linear Collider

August 23, 2002

Proposal Name

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

Classification

Detector: Forward Tracking

Personnel and Institution(s) requesting funding

O. K. Baker, Hampton University K. McFarlane, Hampton University V. Vassilakopoulos, Hampton University

Add more lines for additional institutions, if needed.

Collaborators

Hampton University: O.K. Baker, K. McFarlane, V. Vassilakopoulos

Other HBCU's and personnel will be added as part of the Center for the Study of the Origin and Structure of Matter (COSM), a NSF-funded Physics Frontiers Center.

Contact Person

O. Keith Baker
baker@jlab.org
757-727-5820

Project Overview Hampton University proposes to perform research and development of a straw-tube based wire chamber for charged particle tracking in the Linear Collider Detector. One proposed detector layout would use straw tubes for forward tracking at large radii. Such a layout is necessary (forward tracking) in order to ensure hermiticity and for luminosity measurement. The Forward Chamber (FCH) would extend radially from the Time Projection Chamber inner radius to just below the outer radius of a suggested Time Projection Chamber (TPC) field cage. There would be several layers of straw tubes with several different wire orientations, including stereo wires.

Hampton University, a member of the ATLAS Collaboration at the LHC, is part of the US group constructing the barrel Transition Radiation Tracker (TRT) for the Inner Detector. The TRT is a straw-tube based gaseous wire chamber capable of handling event rates as high as 18 MHz per 0.75-meter long (half-) straw. This system will be a charged particle tracking device as well as a particle identification detector, especially for electron-hadron separation. There will be strong overlap and synergy between the current LHC activity and the proposed NLC research and development. The tools and techniques used in one case will benefit the other. The Hampton University group will continue to work on LHC detectors and simulations during the time of this NLC activity.

Hampton University proposes to apply the experience and technical knowledge gained from this project to the tracking working group of the Liner Collider community. We will extend the work done for the LHC detector to tracking in the forward direction where the TPC and the LC vertex detectors performance would either not exist or be degraded compared to the central region. The use of CF_4 gas in tracking chambers serves two purposes: (1) It is a fast gas, that is the charged particle drift velocity in a gaseous mixture containg this compound is approximately 100 μm/ns. Fast gas recovery times in tracking chambers means higher rates can be handled. (2) It acts as a cleaning agent under certain conditions. Chambers may be effectively regenerated by flushing with a mixture including CF_4 without having to physically remove the chamber to clean it of silicon deposits (silicon deposits on wires degrade the chamber performance over time in a high rate environment).

In contrast to the benefits, there can be rather severe ageing effects on chambers that use CF_4 in a high rate environment; this has been seen in our development of LHC wire chambers. Recognizing that the LC charged particle event rate will be a small fraction of that expected (and planned for) at the LHC, there are still several outstanding tracking issues that need to be addressed for gaseous detectors. The Hampton group proposes to study the following issues for LC tracking:

FY2003 Project Activities and Deliverables

1. The effect of CF_4 gas on detector components in the LC environment. These components include (i) gold-plated tungsten wire, (ii) straw walls, and (iii) electronics boards that come into contact with this gas This will have two phases. In Phase One (FY2003) we will bring the proposed system (gas, irradiation, electronics, DAQ, test chamber) into operation and get results from short-term tests. We will build a gas system capable of handling a two or three component mixture. The group will also deliver a report on our experience (from ATLAS TRT development) with CF_4 in a high radiation environment. Although the rates at the LC will be lower than at the LHC, the work should be useful to this collaboration for long term stability and efficiency issues for the LC.

2. The use of thin-walled straw-tube wire chambers for charged particle tracking, including an analysis of the requirements on a drift tube system for forward tracking. This would include estimates of occupancy, and ionization current. Additionally, we will build and test a small straw-tube wire chamber to be used with this gas system. It is expected that this work will carry over into the next fiscal year. In order to carry out this work, the Hampton group will need to build an irradiation system providing high ionization currents, since the deleterious effects from CF_4 show up only when high ionization is present. The straw tube wire chambers that Hampton is helping to build for the LHC can handle rates in excess of 10 MHz per one meter long straw. An X-ray system capable of providing this ionization current will be purchased and assembled. (The reason for high ionization is so that a 10-year or so LC run could be simulated in a six-month test run, for example.)

3. Detector simulations of forward charged particle tracking at the LC. The code will be a modification of the LHC detector simulation software.

FY2004 Project Activities and Deliverables

1. Improved tracking algorithms for LC events. We will improve upon code already being used for tracking using straw-tube based gaseous detectors.

2. Phase Two (FY2004) referenced above will be implemented. We will complete long-term testing of the gas system and components under irradiation and report on the results. This activity will make use of the Hampton University experience with the ATLAS TRT straw-tube modules.

FY2005 Project Activities and Deliverables

1. Define an initial detector geometry for a straw tube forward tracker;

2. Continue detector simulations of charged particle tracking at the LC. The code will be a modification of the LHC detector simulation software. LC tracking code based upon the initial forward tracker design that can be used in physics studies will be developed.

Budget justification

In order to carry out this research and development program, we request funds to partially support a single postdoctoral researcher for years FY004 and FY005. The postdoc will use facilities on the Hampton University campus, in conjunction with the group of PhD-level researchers and students already in the LHC group. The equipment and materials/supplies needed for this study are shown below; the equipment and materials/supplies request is included in the FY003 request. The requested budget for a three year period is shown below in thousands of US dollars:

Equipment: X-ray source: $7k X-ray enclosure: $4k Chamber HV supply and test/measurement equipment: $4k Data Acquisition Equipment: $10k

Supplies: Gases: $3k Plumbing parts, etc. $2k.

The postdoctoral researcher will assist with detector research and development, detector simulation, and code development for straw tube wire chamber tracking. There will be two undergraduate student workers for the duration of the research and development project.

The indirect cost is 49% of all items except equipment. Student support for this project will come from the Hampton University Center for the Study of the Origin and Structure of Matter (COSM), an NSF-supported Physics Frontiers Center.

Three-year budget, in then-year K$

Institution: Hampton University

Item	FY2003	FY2004	FY2005	Total
Other Professionals	0	50.0	52.5	102.5
Graduate Students	0	0	0	0
Undergraduate Students	0	0	0	0
Total Salaries and Wages	0	50	52.5	102.5
Fringe Benefits	0	9.2	9.7	18.9
Total Salaries, Wages and Fringe Benefits	0	59.2	62.2	121.4
Equipment	25.0	0	0	25.0
Travel	0	0	0	0
Materials and Supplies	5.0	5.0	5.0	15.0
Other direct costs	0	0	0	0
Total direct costs	30.0	64.2	67.2	161.4
Indirect costs	2.5	31.5	32.9	66.9
Total direct and indirect costs	32.5	95.7	100.1	228.3

5.4. Fabrication and investigation of Gas Electron Multipliers for charged particle tracking
(LCRD)

Tracking

Contact person: Peter Fisher
email: fisherp@mit.edu
phone: (617) 253-8561

MIT
NCA&T

FY 2003: $0

Project name

Fabrication and investigation of Gas Electron Multipliers for charged particle tracking

Classification (accelerator/detector:subsystem)

Detector:tracking

Institution(s) and personnel

Peter Fisher – MIT
Ulrich Becker – MIT
Sekazi Mtingwa – NCA&T/MIT

Contact person

Peter Fisher
fisherp@mit.edu
(617)-253-8561

Project Overview

Gas Electron Multipliers (GEMs) provide an alternative means of gas amplification of drift electrons in Time Projection Chambers and other gas tracking chambers. A GEM consists of a 50 - 100 μm thick insulating foil with metallic coating on both sides. Small (50 – 100 μm) holes create a region of high (~6 MV/m) electric fields where multiplication can occur, which would give a gain of 300-500 over the thickness of the GEM. We have undertaken the fabrication and study of GEMs for particle detection for a variety of new applications, including a large TPC for a linear collider.

Description of first year project activities

The fabrication will take place in the Microsystems Technology Laboratory (MTL) at MIT. The Experimental Materials Laboratory in MTL has the capability to make micro-mechanical devices up to 4 inches in diameter using almost any substrate. As a first step, we are fabricating GEMs using copper plated Kapton. The masks have been fabricated, Figure 1 and the fabrication process is in development. The performance of these GEMs will be assessed using the small TPC we have built, which is currently operating with a GEM made at CERN. We have also developed an electrostatic simulation of our first GEM devices, Figure 2, which we will use to optimize the geometry.

If our efforts to fabricate GEMs are successful, we will provide GEMs to other members of the NLC R&D community for testing and further development of mounting techniques, readout and performance studies.

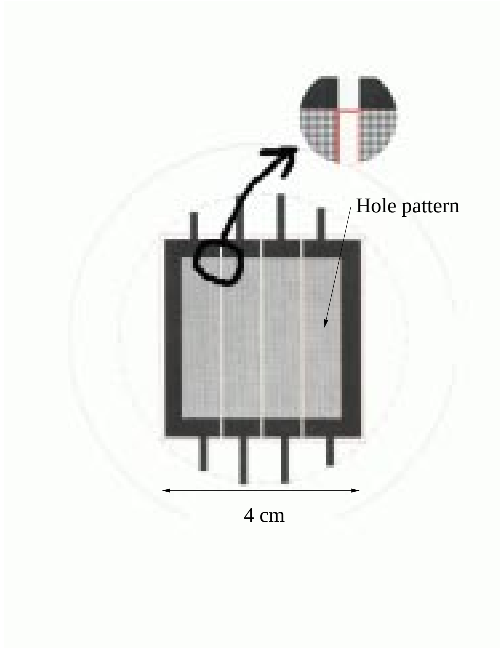

Figure 1 - GEM mask showing four separate device configurations.

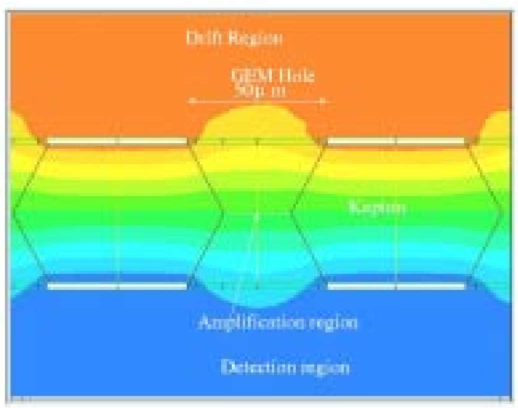

Figure 2 - Potential map of a single GEM hole.

Budget

This work is supported by existing funds and we are not making a request for funds in the first year. In the second year, we may request travel funds to attend NLC meetings and any additional funds necessary for NLC specific work.

5.5. Studies of the Use of Scintillating Fibers for an Intermediate Tracker which Provides Precise Timing and Bunch Identification (LCRD)

Tracking

Contact person: Rick VanKooten
email: rvankoot@indiana.edu
phone: (812) 855-2650

Fermilab
Indiana
Notre Dame

FY 2003: $39,500

Project name

Studies of the Use of Scintillating Fibers for an Intermediate Tracker which Provides Precise Timing and Bunch Identification

Classification (accelerator/detector:subsystem)

Detector: Tracking

Institution(s) and personnel

Indiana University (Bloomington), Department of Physics:
Richard J. Van Kooten (associate professor), to be named (50% LC postdoc)

University of Notre Dame, Department of Physics:
Barry Baumbaugh (engineer), Michael Hildreth (assistant professor),
Randy Ruchti (professor), Mitchell Wayne (professor),
Jadzia Warchol (research professor)

Fermi National Accelerator Laboratory
Alan Bross (Physicist)

Contact person

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(812) 855-2650 Fax: (812) 855-0440

Project Overview

The performance and capabilities of the charged particle tracking in either a TPC-based large LC detector or silicon-based detector can be enhanced by the presence of an intermediate tracker at radii just below the inside radius of the TPC, or in a silicon strip device, particularly with long strips, either inside or outside the central tracker. In the case of a TPC-based detector, such a device would link tracks between the vertex and central tracking detectors, improve pattern recognition, and provide a reliable and stable measurement points close to the TPC for use in the calibration of the TPC and monitoring variations of its characteristics with time. An intermediate tracker built from scintillating fibers has the advantages of very compact radial extent, simplicity of operation, and good single-hit resolution (80-100 μm). Possibly most importantly, in both tracking scenarios a scintillating fiber tracker can offer high-precision timing of tracks in events.

The current NLC/JLC machine design provides beams composed of trains of many (>100) bunches with bunch spacings of 1.4 ns. Large rates (10's of nb) of two-photon interactions are expected both from interactions of virtual photons from each beam and virtual photons with real photons from beamstrahlung. During the crossing of each bunch train one expects many of these two-photon interactions that result in “mini-jets” of particles spraying into the detector. The overlap in the tracking devices of the much more prevalent “mini-jets” with the e^+e^- interaction events of interest can be a problem if bunches are not identified in time which would allow the removal of extraneous particles from the analysis. Simulation studies already performed show significant impact on Higgs events with missing energy when two-photon events from prior or subsequent bunches are overlaid on top of the event of interest[1]. An example from these studies is shown in Fig. 1(a) which shows the extraction of the *WW*-fusion cross section to a precision of 3.5% (statistical) using 500 fb^{-1} of data at a center-of-mass of 350 GeV by fitting to the missing mass distribution in identified $\nu\nu bb$ events. Fig. 1(b) shows the templates determined from the Monte Carlo simulations used to separate the *HZ* and *WW*-fusion contributions. Overlaying a single 2-photon event onto each event results in a shift of these templates, which if not taken into account, would result in a 2.0% systematic error, a significant effect compared to the 3.5% statistical error. A good knowledge this background and how they are distributed inside of detected events is needed. The planned resolution of a TPC tracking subdetector would result in integration of these two-photon events over 4–5 bunches, whereas a system with sub-nsec timing could identify from which individual bunch the tracks have originated.

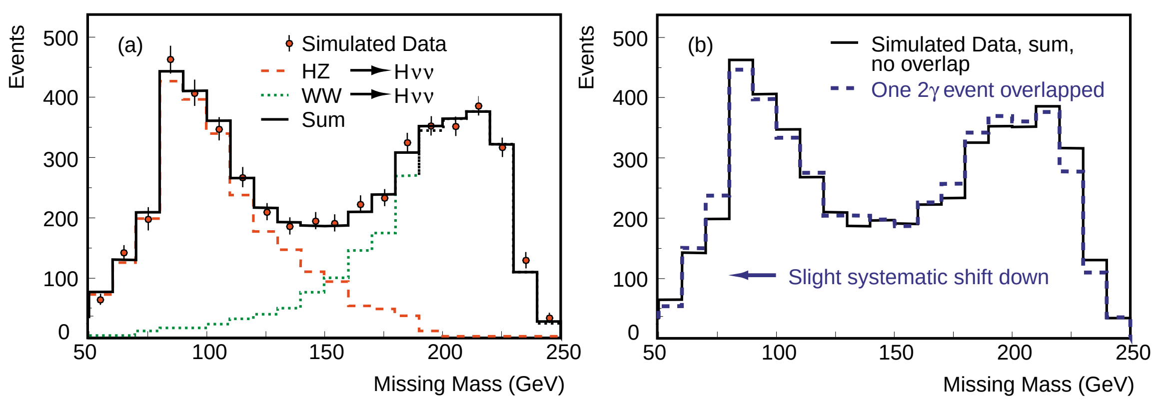

Figure 1: (a) Fits to the missing mass distribution in simulated $\nu\nu bb$ events (500 fb-1 at center-of mass of 350 GeV) to extract the *WW*-fusion Higgs cross section. (b) Effect on fit templates when one two-photon event is overlaid on each event.

Using a scintillating fiber intermediate tracker coupled by clear fiber to visible light photon counters (VLPC'S, Si:As devices manufactured by Boeing[2]) read out by the SVXIIe (or more recent versions such as the SVXIV) chip, it may be possible to achieve time resolutions less than 1 ns to associate tracks with individual bunches as well as complement time measurements in the TPC or silicon tracker. Prior studies have shown that the dominant effects determining time resolution are light intensity and the flourescence decay time of the scintillator light, i.e., time dispersion of photons within the fiber is not as important. These same studies indicate that having higher gain in the VLPC, more light production from the fibers, or faster scintillator could yield the needed improvement in time resolution.[3]

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[1] R. Van Kooten, *Studies of Event Overlap in Higgs Events: Need for Bunch ID*, presented at Chicago Linear Collider Workshop, Gleacher Center, Chicago, IL, 8 Jan. 2002 and available at `http://hep.physics.indiana.edu/~rickv/nlc/overlap_chicago.pdf.`

[2] Boeing Electronic Systems, 3370 Miraloma Ave., Anaheim, CA 92803; M.D. Petroff *et al*., Appl. Phys. Lett. **51** (1987) 406.

[3] A. Bross et al., *Nucl. Instr. Meth*. **A394** (1997) 87.

Using the resources and expertise developed within our groups and the DØ collaboration from working on the successful Scintillating Fiber Tracker[4] in the DØ detector at Fermilab, we propose to demonstrate the feasibility of sub-ns timing in a scintillating tracker device. This project would answer important questions regarding the impact of NLC/JLC beam structure and thus accelerator technology choice on detector design.

Description of first year project activities

We propose to investigate the potential for precision system timing using an intermediate scintillating fiber tracker. Using an existing cosmic ray test stand[5] at Lab 3 at FNAL, layers of prototype scintillating fiber ribbons from DØ will be mounted on carbon fiber scintillators approximating the inner radius carbon fiber structure of a TPC. External precision position measurements will be provided by existing layers of proportional drift tubes. Alternatively, a radioactive source at a known position along the fiber can be used and the scintillating fiber read out from both ends. The timing resolution can be determined from the width of the distribution of time difference measurements from the ends. Front-end electronics and DAQ will be modified as needed to be able to allow faster readout of the VLPC's present in the prototype set-up to approach desired time precisions. Variables affecting timing resolution will be studied and attempts will be made to model resolutions using simulations. Tests will also be made using cosmic ray samples to confirm overall system time and position resolutions.

We will be able to exploit an existing effort at FNAL aimed at using fast timing information in the DØ fiber tracker for a *z* position measurement. Currently, a replacement[6] for the CFT readout electronics is being designed to allow the readout to proceed at the 132 ns Tevatron bunch crossing interval which will occur in the latter stages of Run II. For as long as the collider runs instead at the 396 ns crossing rate, the two extra data pipelines on the custom ASIC can be used to provide timing information through a time-to-amplitude converter. Simulations of photon propagation convoluted with the measured response of the discriminators on these boards suggest that a timing resolution of 2 ns can be achieved using only one end of each fiber (the CFT readout is at only one end of the detector; the other end of each fiber is polished to provide reflected photons). Once these boards are available, we can perform tests using the existing DAQ system without major modifications, using both ends of the fibers to provide better resolution. Further modifications to the design may be possible depending on our results.

Accompanying simulations incorporating an intermediate layer of scintillating fibers both at the inner radius and outer radius of a TPC or silicon tracking based detector in a LC detector will be to determine impact on track parameter resolutions. For the TPC option, as shown in Fig. 2, the measurement points tend to offset the addition of the

[4] A. Bross et al., *The D0 scintillating fiber tracker*, published in Proceedings of Notre Dame 1997: Scintillating Fiber Detectors, World Scientific; B. Baumbaugh, IEEE Trans. Nucl. Sci.**43** (1996) 1146.
[5] Described in P. Baringer *et al.*, *Cosmic Ray Tests of the DØ Preshower Detector*, Nuc. Inst. and Meth. **A469** (2001) 295.
[6] J. Estrada, C. Garcia, B. Hoeneisen, and P. Rubinov, *MCMII and the Trip Chip*, DØ note 4009, August 2002.

material of the fibers and neither the momentum resolution nor impact parameter resolution is degraded.[7] More complete simulations will be performed to investigate its impact on track pattern recognition.

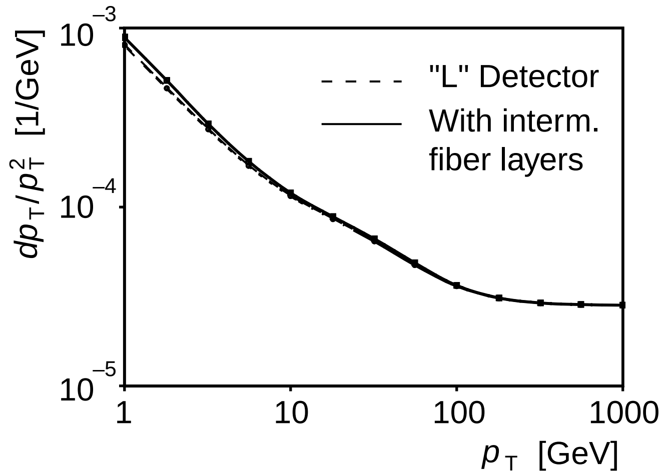

Figure 2: Transverse momentum resolution adding two axial and two stereo layers of scintillating fibers with a total thickness of 0.7%X_0 at a radius of 48 cm (inner radius of TPC) to the LD-MAR01 detector[8] assuming a point resolution of 100 μm.

Monte Carlo physics analysis focusing on Higgs physics including a more complete detector simulation and more comprehensive two-photon event generation will be continued to investigate the effects of overlapping events. These results will be used to compare results obtained when integrating and overlapping events over several bunches to analysis when bunch identification is available.

Both the Indiana and Notre Dame groups have experience with scintillating fibers, VLPC's, the related DAQ components, and the cosmic ray test stand through their work on the central scintillating fiber tracker of the DØ upgrade detector. They have also collaborated in the past as part of this subdetector in the fabrication of clear fiber optic waveguides carrying the light from the scintillating fibers to VLPC's. Personnel will work part-time on the project, and 50% of the Indiana postdoc is dedicated to linear collider R&D and this proposed work. The funding of 50% of the Indiana postdoc is already included in the Indiana Task A DoE base grant and is not being requested here. The remaining 50% (to work on the DØ collaboration) has been secured from Indiana University over the next three years.

Both Fermilab and Notre Dame have extensive expertise in scintillator development. As part of SBIR and STTR projects[9], they have collaborated with the Ludlum Corporation and the University of Pennsylvania to produce several new dyes with larger light-yields and faster decay times. The current DØ scintillating fibers use PTP and 3HF dyes for the initial fluorescence and wavelength-shifting, respectively. Some of these are currently being fabricated into 800 micron and 1 mm fibers for light yield and timing tests in a “detector-ready” geometry. If these tests are successful, it is

[7] Using `LCDTRK` (`http://www.slac.stanford.edu/~schumm/lcdtrk20011204.tar.gz`), author B.Schumm.
[8] `http://www-mhp.physics.lsa.umich.edu/~keithr/LC/baselines_mar01.html.`
[9] K. Andert, et al., *Scintillator and Waveshifter R&D in Quarknet/RET*, to appear in the proceedings of DPF 2002, Williamsburg, VA, May 2002.

possible that the performance of our proposed system could be substantially enhanced. The current DØ scintillating fibers use PTP and 3HF dyes for the initial fluorescence and wavelength-shifting, respectively.

The funding request is shown below and is for the first year only. Results from the studies of the first year will determine the direction of research the following years when different scintillating fiber formulations, different versions of VLPC sensors, and improved electronic and DAQ readout could be pursued. Finally, the embedding of such scintillating fibers into calorimeter systems allowing precise timing of neutral clusters as well could be considered in the future depending on the success of this R&D direction.

Budget (First Year)

Institution	**Item**	**Cost**
Indiana	Modification of existing prototype ribbons (3 layers, 128 fibers each, 60 cm long)	$2,000
Indiana	Re-use of clear fibers, optical connectors	$2,000
Notre Dame	Refurbished VLPC readout system: modified analog electronics	$12,000
Indiana	Consumables for cosmic ray test stand (gas for PDT system; LNHe, LN for VLPC cryogenics)	$4,000
50% Indiana 50% Notre Dame	Faster DAQ components, partial instrumentation with 32 channels of fast TDC	$10,000
Indiana	Test equipment, fast digital storage oscilloscope	$9,500
Indiana/Notre Dame	Indirect costs (N/A, equipment only)	$0
FNAL	Use of existing cosmic ray stand; consulting with experts	$0
	Total	**$39,500**

5.6. Application of CLEO tracking to a TPC (UCLC)

Tracking

Contact person: Dan Peterson
email: pls@lns.cornell.edu
phone: (607) 255-8784

Cornell

FY 2003: $7,000
FY 2004: $4,000
FY 2005: $4,000

Proposal to the University Consortium for a Linear Collider

August 30, 2002

Proposal Name Application of CLEO tracking to a TPC

Classification (accelerator/detector: subsystem)

Detector: tracking

Personnel and Institution(s) requesting funding

D. P. Peterson, R. S. Galik, B. K. Heltsley, Cornell University

Collaborators

none

Contact Person

Dan Peterson
dpp@lns.cornell.edu
(607)-255-8784

Project Overview

Hardware studies of proposed tracking detectors for the linear collider provide measurements of spatial resolution and signal width characteristics in controlled, low track-multiplicity conditions. However, detector performance in terms of track-parameter resolution and track-reconstruction efficiency, in the complex event environment expected at the linear collider, must be inferred through simulation. Simulations can include most of the effects that distort the detector signals, including noise, hit efficiency, signal overlap, and non-Gaussian tails of the response functions. While simulated events can be made to closely match real data, the ability to provide relevant predictions of the tracking resolution and efficiency in high track-multiplicity events also requires a mature pattern recognition algorithm. The ability to make informed comparisons of competing tracking technologies requires such mature pattern recognition, optimized to tolerate signal complications, for each technology.

We propose to develop a track pattern recognition algorithm for a time projection chamber (TPC) that is based on the algorithm currently used by CLEO. The goal is to develop a mature algorithm that will provide relevant, robust predictions of the tracking resolution and efficiency in simulations of various TPC readout configurations while varying the signal complications described above.

CLEO successfully uses a pattern recognition algorithm employing an initial phase based on identifying unbroken strings of low precision "hits" in the dense array of readout cells of a small cell drift chamber. The localized strings are readily identified in very complicated events; we anticipate an advantage in noise rejection over more global approaches to pattern recognition. This method is adaptable to a TPC because the CLEO drift chamber cell-level information and granularity are similar to that of the pad level information provided by a TPC. The track density in a TPC at the linear collider can be similar to that observed in CLEO when TPC hits are pre-selected to come from roads limiting the z projection.

The optimization of any track reconstruction algorithm to handle special cases (e.g., curling tracks, kinked tracks, highly overlapped tracks, pattern recognition in an extreme noise environment) is dependent on an understanding of how an approach fails in such cases. The current CLEO pattern recognition benefits from a diagnostics package that provides graphical and console information at intermediate steps of the algorithm. The developer is able to make detailed investigations of conditions leading to the final result. The diagnostics package, including the graphics, would be applied to the TPC implementation and is particularly suitable for conversion to JAVA.

While the algorithm is currently coded in FORTRAN our ultimate goal is to fully convert it to an object oriented language for compatibility with existing full-detector simulation efforts that use physics event generators.

To provide results in the short term, efforts are underway, with the help of Mike Ronan of LBL, to wrap the FORTRAN version in JAVA for compatibility with the LCD simulation package. At this time, the LCD package does not provide a full simulation of signals. However, signal simulation, and distortion, can be added to an interface between the LCD package and the pattern recognition package. The FORTRAN version can also be used, in a stand-alone way, to predict tracking resolution and efficiency for tracks in jets parameterized in terms of track density, taking into account many of the signal complications.

FY2003 Project Activities and Deliverables

In the first year, we will complete various modifications of the FORTRAN version including detector specific changes and structural changes that will facilitate the the conversion to an object oriented language. The conversion to an object oriented language will be started. We will complete the wrapping of the FORTRAN version in JAVA and measure tracking efficiency within the LCD simulation package.

The first year deliverable will be a report on the variation of track-parameter resolution and track-reconstruction efficiency with respect to track momentum, track density, spatial resolution of the detector, detector segmentation, signal width in r-ϕ and z, and noise density. It will use only a TPC with idealized geometry with detector signal response added to the FORTRAN program.

FY2004 Project Activities and Deliverables

In the second year, we will continue the conversion to an object oriented language. We will make changes to the pattern recognition to maintain compatibility with the LCD full-detector simulation as that effort evolves to includes more detector geometry and signal response.

The second year deliverable will be a more refined report on the variation of track-parameter resolution and track-reconstruction efficiency including detector geometry and signal response and noise generation provided by the LCD full-detector simulation.

FY2005 Project Activities and Deliverables

In the third year, we will complete the conversion to an object oriented language and compatibility with an existing full-detector simulation effort. We will complete detector design simulation studies in response to the needs of the community.

Budget justification

Cornell will provide reallocation of resources to this project in the form of support for research staff who will supervise the students and complete most of the tracking-device specific adaptation of the code (D. Peterson) and coordinate the conversion to an object oriented language (B. Heltsley). In addition, much of the coding will be performed by students supported by the Cornell LEPP base grant. However, funding is required for an additional desktop computer installation with an enlarged screen area that is compatible with the diagnostic graphics. Funding is also required for travel for consultation with others working on track simulation.

Three-year budget, in then-year K$

Institution: Cornell University

Item	FY2003	FY2004	FY2005	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	3	0	0	3
Travel	4	4	4	12
Materials and Supplies	0	0	0	0
Other direct costs	0	0	0	0
Total direct costs	7	4	4	15
Indirect costs	0	0	0	0
Total direct and indirect costs	7	4	4	15

5.7. Tracking Detector R&D at Cornell and Purdue Universities (UCLC)

Tracking

Contact person: Dan Peterson
email: dpp@lns.cornell.edu
phone: (607) 255-8784

Cornell
Purdue

FY 2003: $80,000
FY 2004: $149,000
FY 2005: $102,000

Proposal to the University Consortium for a Linear Collider

August 29, 2002

Proposal Name

Tracking Detector R&D at Cornell and Purdue Universities

Classification (accelerator/detector: subsystem)

Detector: tracking

Personnel and Institution(s) requesting funding

D. P. Peterson, R. S. Galik, Laboratory of Elementary Particle Physics, Cornell University
J. Miyamoto, I. P. J. Shipsey, Physics Department, Purdue University

Collaborators

none

Contact Person

Dan Peterson
dpp@lns.cornell.edu
(607)-255-8784

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 track separation. Anticipated beam-related background rates place further demands on the detector segmentation. A time projection chamber (TPC) may be the best solution to provide the detector segmentation required for track separation and noise immunity. However, obtaining the spatial resolution necessary to meet the momentum resolution goal is challenging with a TPC.

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. 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 is 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 narrower than the typical read-out pad size used in a traditional TPC, which creates a condition where the signal is often observed on only one pad. Without signal sharing, the spatial resolution would be 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. Alternative methods of spreading the signal, to be consistent with the use of larger pads, may compromise the segmentation. Optimization of the design is needed to provide both the required resolution and segmentation.

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 read-out systems on prototype TPCs.

The TPCs, as well as the 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 [1, 2, 3].

GEM and MicroMegas readout modules will be built by the Purdue group who have many years experience developing Micro Pattern Gas Detectors (MPGD) [4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19]. 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 [15] and GEM+MicroMegas detector [16] have been built. The latter has achieved the best signal-to-noise performance in a beam line of any MPGD to date [17] 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. It is important to study new manufacturing techniques for GEMS and MicroMegas, but this work is at an early stage, and extensive R&D and testing, including radiation hardness studies, will be required. Funding exists for this work; we are not seeking additional funding at this time. These studies will be performed by many groups, including Purdue, over the next few years. We are making contact with other groups investigating the new manufacturing techniques. If any of the alternative manufacturing technologies are successful we expect to incorporate them into a TPC readout. 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.

FY2003 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.

FY2004 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 use cosmic rays; the detector acceptance will be larger than that of test chambers we have used for previous cosmic ray studies of resolution and efficiency [3].

We will study resolution and track separation, as well as signal time development and noise characteristics with several different read-out planes installed on the TPC. For the case of read-out 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. Ion feedback suppression, expected to be superior in MicroMegas relative to GEMs, will be measured for each amplification system using a common TPC. We will also study the effects of various methods of spreading the signals within pad layers as well as limiting the signal spread to adjacent layers. 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.

FY2005 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 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's group has had over twenty undergraduates work with the group since 1992. This has been a very productive arrangement both for the group and the students resulting in several publication [9, 13, 14, 15, 18].

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	FY2003	FY2004	FY2005	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
Total direct costs	54	123	76	253
Indirect costs	0	0	0	0
Total direct and indirect costs	54	123	76	253

Institution: Purdue University

Item	FY2003	FY2004	FY2005	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	0	0	0	0
Total direct and indirect costs	26	26	26	78

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5.8. Tracking simulation studies and alignment system R&D (UCLC)

Tracking

Contact person: Keith Riles
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Michigan

FY 2003: $45,000
FY 2004: $88,000
FY 2005: $129,000

Proposal to the University Consortium for a Linear Collider

August 15, 2002

Proposal Name

Tracker simulation studies and alignment system R&D

Classification (accelerator/detector: subsystem)

Detector: tracker

Personnel and Institution(s) requesting funding

K. Riles, H. Yang, J. Yamamoto, Physics Department, University of Michigan

Contact Person

K. Riles
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(734) 764-4652

Project Overview

Introduction

The University of Michigan group has a long-term interest in helping design and construct the central tracking system for a linear collider detector. This interest is driven not by a particular favorite technology, but by the critical importance of charged-particle tracking to the physics processes we wish to investigate, which include Higgs production and decay, along with certain supersymmetric channels.

Results of Prior Research

We have contributed extensively to linear collider simulation studies, both in technical tracking reconstruction issues and in evaluating physics analysis demands upon tracker performance. Riles has served as a co-convener of the linear collider central tracking working group since 1998, sharing leadership responsibilities in different years with Dean Karlen, John Jaros and Bruce Schumm. Riles has shared responsibility for organizing working group meetings, evaluating baseline tracker designs, coordinating tracking simulations, creating & maintaining the group web site, and assembling annual joint R&D proposals.

As part of the baseline tracker design optimization, Riles wrote a stand-alone Monte Carlo hit generator and 3-d helical track fitter to study the effects of multiple scattering on particle momentum resolution *vs* momentum and *vs* polar angle for various tracker configurations. This work served as an independent cross check of the resolution studies carried out by Bruce Schumm using an analytic Billoir approach.

Yang began linear collider studies in fall 2000. He has been carrying out two related studies in parallel: 1) Studies of Higgs physics capability and 2) influence of central tracking performance on Higgs physics. As a member of the Higgs working group, he has evaluated the precision with which the Higgs mass and cross section can be evaluated at 350 GeV and 500 GeV center of mass energies. This study has used both the JAS fast Monte Carlo and the full simulation packages. Yang has independently confirmed and improved upon preliminary findings by European groups with the use of a more sophisticated and powerful fitting technique, based on Monte Carlo event interpolation. In parallel, Yang has examined the influence of central tracker parameters on the Higgs mass precision. In addition, he has assisted the SLAC simulations group in comparing the tracker's performance in full Monte Carlo simulations *vs* performance in parametrized fast Monte Carlo simulations. He has given numerous presentations on Higgs physics and tracking at various linear collider workshops and at Snowmass 2001[1, 2]. Yang's studies of the Higgsstrahlung process are nearly complete and find that current baseline tracker designs in the U.S. are close to where improved resolution does not yield comparable improvement in Higgs mass resolution, because of expected intrinsic beam energy spread in present accelerator designs.

Research Plan

Simulation Studies

In the coming years we wish to extend the above Higgs studies to supersymmetry final states to understand quantitatively whether they impose more or less stringent requirements than Higgsstrahlung on tracking resolution. In particular, we will begin by exploring the slepton production channel, where one can determine slepton and neutralino masses from the end-points of the final-state lepton spectra. The sharpness of the end-points will be governed in part by track resolution. We wish to quantify the influence of tracking resolution on sparticle mass resolution. We expect there to be two distinct regions of importance: 1) high-momentum end-points where the same effects seen in our Higgs analysis are expected to be important; and 2) low-momentum end-points where multiple scattering may prove important.

One of the outstanding issues in comparing a gaseous central tracker to a silicon system is the importance of the greater material burden in the silicon design to low-momentum track resolution. It has been suggested by members of the linear collider supersymmetry working group that for significant regions of supersymmetry parameter space, momentum resolution in the 1-10 GeV range will limit the precision with which supersymmetry particle masses can be determined. If true, then the desire for precise sparticle mass determination may well govern the choice of barrel tracker technology. We wish to explore this possibility quantitatively, taking into account other known sources of sparticle mass resolution degradation. The University of Colorado group led by U. Nauenberg has carried out a series of studies of slepton final states for the linear collider supersymmetry group, including studies of sparticle mass determinations. We expect to work closely with the Colorado group in extending their existing analyses to address tracking performance requirements quantitatively. In addition, we will continue contributing to the tracking infrastructure development, where we have taken responsibility for more sophisticated hit merging and for evaluation of track reconstruction performance.

Alignment System

We also wish to carry out R&D on precise alignment of the linear collider tracking subsystems. The unprecedented excellent track momentum resolutions contemplated for a linear collider detector will demand minimizing systematic uncertainties in subdetector relative alignments. At the same time, for reasons discussed above, there is a strong desire for a very low material tracking system. In the case of a silicon main tracker and in the case of silicon forward disks (envisioned in all linear collider detector designs now on the table), the low material budget may lead to a structure that is far from rigid. The short time scales on which alignment can change (e.g., from beam-driven temperature fluctuations) probably preclude reliance on traditional alignment schemes based on detected tracks, where it is assumed the alignment drifts slowly, if at all, during the time required to accumulate sufficient statistics. A system that can monitor alignment drifts "in real time" would be highly desirable in any precise tracker and probably essential to an aggressive, low-material silicon tracker. The tradeoff one would make in the future between low material budget and rigidity will depend critically upon what a feasible alignment system permits.

We propose to investigate the capability of existing precise alignment schemes and to develop a system customized to the needs of a linear collider detector. Two natural candidate schemes to explore include the Rasnik alignment system implemented for the CDF detector and the Frequency Scanned Interferometer (FSI) system being developed for the ATLAS detector. Both are designed to achieve 1-D or 2-D point resolutions of order 1 micron, which should be adequate for a linear collider tracking system. The Rasnik system is based on many CCD cameras trained on 2-D images whose positions are sensitive to relative misalignments. The FSI system is based on multiple interferometers fed by optical fibers from the same laser source, where the laser frequency is scanned and fringes counted to obtain a set of absolute lengths. Given the desire for low material burden in a silicon tracker, it's not clear that either system in its present design will be appropriate for a linear collider detector, although the FSI method seems more promising in that respect and is the one we will at least initially focus upon. As an active member of the LIGO Experiment since 1997 and leader of the LIGO Scientific Collaboration's Detector Characterization Working Group, Riles has acquired expertise in precise interferometry, including beam modulation techniques that may usefully enhance the FSI method. As part of our R&D effort, we would explore these and perhaps other alternative methods of optical metrology.

It should be noted that the methods developed for central and forward tracker alignment may also prove useful for a vertex detector, where again, there is a strong desire for thin detector material that may be subject to short-term position fluctuations. Similarly, the methods developed here may prove useful for alignment monitoring of accelerator components far upstream of the detector (e.g., in the main linacs). Given the natural wide distribution of accelerator components *vs* a relatively compact tracker system, however, it's not clear that a tracker solution will be cost effective for the accelerator. In any case, we will stay cognizant of vertex detector and accelerator needs and explore these possibilities, as the tracking alignment system design evolves.

FY2003 Project Activities and Deliverables

During the first year we will carry out simulation studies of the tracking performance requirements imposed by measurements of slepton production, specifically imposed by desired precision on sparticle masses. We will write a detailed technical report on our findings in which the gaseous and silicon tracker designs are compared quantitatively.

We will also initiate a program of alignment R&D. Specifically, we will acquire the components for and build a demonstration-level frequency-scanned interferometer on an optical bench. We will purchase a relatively inexpensive commercial laser for the initial studies, one without the performance tolerances (tuning range, frequency stability) needed for a final production alignment system. In parallel, we will come up with a conceptual design of an alignment scheme for the American baseline silicon barrel tracker and the silicon forward disk trackers and write a general simulation program that allows the performance evaluation of various schemes. It is envisioned that hundreds of absolute length measurements between pairs of reference points would be used in a global fit to determine the local and global alignment parameters of the tracking subsystems. A progress report on this effort will be delivered no later than the winter 2004 American linear collider physics group meeting.

FY2004 Project Activities and Deliverables

Simulation studies in the second year will depend on findings from the first year on slepton production. We expect, however, to investigate other supersymmetry channels involving isolated leptons whose precise measurement imposes stringent performance requirements on the tracker. Chargino production is a natural channel to investigate. We will deliver a technical report on our findings.

Using the FSI infrastructure put together in the first year, we will carry out measurements on the bench of performance and explore modifications to improve absolute precision, robustness, and measurement speed. A technical report will be written on our findings.

FY2005 Project Activities and Deliverables

We anticipate that our supersymmetry/tracking simulation studies will have been completed to satisfaction by the start of the third year, but depending on what has been learned, we may wish to pursue certain specific topics in further detail. If so, another technical report will be written on our findings.

We hope by the start of the third year to have a concrete design in hand for a full alignment system and to have evaluated singly the primary issues affecting that design. At that point we would wish to build a partial prototype of the system to test system integration issues, including miniaturization of the components tested previously on the optical bench. We expect to continue deferring the purchase of a commercial laser with the frequency tuning range and stability envisioned for the final system. If such a laser is indeed needed to satisfactorily address outstanding R&D issues, however, we would expect to request a grant supplement when the time comes. We do not request funding for its purchase here.

Budget justification

In the first year, we request funding here for a half-time graduate student, for employment of undergraduates, for the purchase of the components needed to build a bench-level frequency scanned interferometer, and for travel to biannual linear collider meetings.

In the second year, we request funding for a half-time postdoctoral fellow, for two half-time graduate students, for employment of undergraduates, for additional optical equipment to enhance the frequency scanned interferometer, and for travel.

In the third year, we request funding for a quarter-time technician, a half-time postdoctoral fellow, for two half-time graduate students, for employment of undergraduates, for components of a partial alignment system prototype, and for travel.

Three-year budget, in then-year K$

Institution: University of Michigan

Item	FY2003	FY2004	FY2005	Total
Other Professionals	0	0	15	15
Postdoctoral Fellow	0	21	22	43
Graduate Students	7	14	15	36
Undergraduate Students	3	3	4	10
Total Salaries and Wages	10	38	55	103
Fringe Benefits (@28%)	3	11	15	29
Total Salaries, Wages and Fringe Benefits	13	49	70	132
Equipment	20	10	25	55
Travel	3	3	3	9
Materials and Supplies	0	0	0	0
Other direct costs (tuition)	5	12	12	29
Total direct costs	41	74	110	225
Indirect costs (@26%,excl. tuition/equipment)	4	14	19	37
Total direct and indirect costs	45	88	129	262

References

[1] H. Yang and K. Riles, "Measurement of Higgs Mass and Cross Section at a Linear Collider", to appear in the Snowmass 2001 Proceedings.

[2] H. Yang and K. Riles, "Impact of Tracker Design on Higgs Mass and Cross Section Resolutions", to appear in the Snowmass 2001 Proceedings.

5.9. Tracking Software Optimization for the Silicon Detector Option (LCRD)

Tracking

Contact person: Milind Purohit
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phone: (803) 777-6996

South Carolina

FY 2003: $31,250

Project name:

Tracking Software Optimization for the Silicon Detector Option

Classification (accelerator/detector:subsystem)

Tracking: Vertex CCD and Silicon Strip Detector

Institution(s) and personnel

University of South Carolina, Department of Physics & Astronomy:
Milind V. Purohit (Professor), Achim W. Weidemann (Research Professor)
+ ½ time of one new post-doc

Contact person

Milind V. Purohit
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(803) 777-6996

Project Overview

Tracking is a crucial component of the Linear Collider Detector and the track detectors must be optimized for cost, efficiency, size, robustness against beam backgrounds and for minimization of fake tracks in reconstructed events. The silicon detector option has 5 vertex CCD layers and outer silicon planes. Tracking code already exists for 3D hits, but several optimization questions (described below) need to be answered with existing code or code that may have to be written.

Description of first year project activities

Software work will be done to address all the following questions and issues.

Development work underway is exploring very low-mass Si strip options for the LC central tracker (see http://scipp.ucsc.edu/~schumm/nlc/adv_det_01.ps). We want to explore whether this will work from standpoint of pattern recognition. Several questions come to mind: is it necessary to have silicon drift planes outside the vertex detector, or are silicon strip planes adequate? Can the CCDs be used to find tracks using axial-only silicon strips to confirm them and reduce fake track backgrounds? In the case of large beamsstrahlung background, can we start the tracking with outer planes, using the vertex detector only for vertex region track error reduction?

This work will be initiated and supervised by Purohit. Simulation software will play a large role in this effort and will require communication and assistance from the simulation group. Weidemann will serve as liaison with Norman Graf (to help with software troubleshooting).

For now, we will specifically focus on two issues:

1. Use of the existing 3-d pattern recognition code (i.e., code that relies on hits from intrinsically 3-d detectors) to explore capabilties of the CCD vertex detector for stand-alone tracking, as a function of background level.
2. Exploration of reconstruction algorithms for use with an axial-only silicon strip tracker. This work will be informed by what is learned with the stand-alone CCD studies.

Future work

Writing pattern recognition and track reconstruction code for many detector options is a rather large task and will ultimately require the dedicated work of many people over many years. Much of this needs to be done now, in order to arrive at an optimum detector. As such, the software project is more than a year long by itself.

Mainly though, our plan in the long term is to focus on the impact on physics studies: how would Higgs, SUSY etc. physics yields and resolutions depend on the different trackers. The silicon strip code developed should be useful to differentiate between strip, drift and TPC-based trackers.

Budget

While Purohit has tracking experience from silicon hardware and tracking software on E791, his research time is primarily spent on BaBar and of course, he has teaching duties. Weidemann is principally interested in positron polarization at the Linear Collider. Hence, he will be occupied with his research and service work on BaBar where he spends more than 50% of his time, and with the positron polarization experiment, but is interested in contributing to this work as much as possible, principally with simulation troubleshooting and other help. Ideally then, a postdoc working with Purohit would be best able to handle the bulk of this work.

The new postdoc will be expected to spend only half time on this project, the other being a BaBar thesis research topic. Funding for this other half will come from the regular USC grant from DOE. We have the funding for ½ a postdoc in that grant as well as a need for a postdoc to do research using BaBar data and produce publishable results. Therefore, we are asking for half a postdoc's expenses. We expect that the ½ post-doc salary at approximately $22,000 will be the major expense. The post-doc (and the rest of us) may need to attend approximately one meeting a year dedicated to Linear Collider work (travel to destinations other than BaBar-related meetings).

Institution	Item	Cost
USC	½ postdoc salary	$22,000
USC	Travel to LC-only meetings	$3,000
USC	Indirect costs	$6,250
USC	Total	$31,250

5.10. Use of Silicon Strip Detectors in Low Duty-Cycle Applications (LCRD)

Tracking

Contact person: Bruce Schumm
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phone: (831)-459-3034

UC Santa Cruz

FY 2003: $0

Project name

Use of Silicon Strip Detectors in Low Duty-Cycle Applications

Classification (accelerator/detector:subsystem)

Detector:tracking

Institution(s) and personnel

Santa Cruz Institute for Particle Physics:
David Dorfan (professor), Chritian Flacco (graduate student), Hartmut Sadrozinski (professor), Bruce Schumm (associate professor), Ned Spencer (engineer), Abraham Seiden (professor)

Contact person

Bruce Schumm
schumm@scipp.ucsc.edu
(831)-459-3034

Project Overview

The low duty-cycle of proposed Linear Collider designs offers the possibility of optimizing the design of silicon strip sensor readout. By cycling the power off when beams are not in collision, a power savings significant enough to avoid the need for active cooling of the readout should allow a substantial simplification of the mechanical design of the detector. The use of long shaping-time electronics should allow for the development of ultra low-noise readout, with a corresponding dividend in ladder length and detector thickness. If successful, the development of such a readout would permit the construction of a silicon-strip based central tracker with a resolution fully competitive with a gaseous tracker, and with minimal material in the forward support structure. Such a system may well present significant advantages in terms of exploiting Linear Collider physics. We propose to develop a prototype readout chip based on a ¼-micron mixed-signal process available from TSMC via the MOSIS consortium.

Funding for this work has already been granted via the US Department of Energy's Advanced Detector Research and Development initiative. The full text of that proposal is available at http://scipp.ucsc.edu/~schumm/nlc/adv_det_01.ps.

Description of first year project activities

In the first year, we plan to perform simulations that will allow for the optimization of the readout shaping time, in order to balancing the competing requirements of noise suppression, radiation damage, and temporal resolution. We will also perform simulations that will inform the development of the analog response readout, given the need for accurate measurements for minimum-ionizing particles (for centroid finding), and cruder measurements over a very broad dynamic range in the $1/\beta^2$ region (for identifying slow-moving heavy particles). These simulations will be carried out by UC Santa Cruz graduate student Christian Flacco. We will also begin the design of the prototype readout chip with Ned Spencer, who will be the lead engineer on the project. Finally, we will begin the development of a prototype long ladder for tests of the readout chip.

Budget

As mentioned above, this initiative has already been funded by the DOE ADR program. No additional support is being requested for this work.

5.11. R&D towards a Silicon drift detector based main tracker for the NLC-SD option (UCLC)

Tracking

Contact person: Rene Bellwied
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Wayne State

FY 2003: $82,000
FY 2004: $174,000
FY 2005: $202,000

Proposal to the
University Consortium for a Linear Collider

August 14, 2002

Proposal Name

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

Classification (accelerator/detector: subsystem)

Detector: Tracking

Personnel and Institution(s) requesting funding

Rene Bellwied, David Cinabro, Vladimir Rykov, Wayne State University

Collaborators

David Lissauer, Francesco Lanni, Vivek Jain, Brookhaven Physics Department

Veljko Radeka, Zheng Li, Wei Chen, Brookhaven Instrumentation Division

Contact Person

Rene Bellwied
bellwied@physics.wayne.edu
313-577-5407

Project Overview

During the past two 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 two 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 past 18 months on simulations and software development. He was partially funded by the linear collider R&D funds. 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.

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 projects of the past two years we propose the following steps for the future:

FY2003 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 by Vladimir were shown at the Chicago and Santa Cruz LC meetings. We have an agreement with Norman Graf's group that we will provide a full GEANT based geometry definition of our proposed tracker before the fall of 2002. 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 electro-magnetic 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

FY2004 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.

FY2005 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 49% 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	FY2003	FY2004	FY2005	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	27	41	37	105
Total direct and indirect costs	82	174	202	458

5.12. Negative Ion TPC as the NLC main tracker (UCLC)

Tracking

Contact person: Giovanni Bonvicini
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Temple
Wayne State

FY 2003: $32,000
FY 2004: $35,000
FY 2005: $93,000

Proposal to the University Consortium for a Linear Collider

August 28, 2002

Proposal Name

Negative Ion TPC as the LC main tracker

Classification (accelerator/detector: subsystem)

Detector: main tracker

Personnel and Institution(s) requesting funding

Giovanni Bonvicini, Alexander Schreiner, Wayne State University

C. J. Martoff, Rachid Ayad, Temple University

Collaborators

D. Snowden-Ifft, Occidental College

Contact Person

Giovanni Bonvicini
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313-577-1444

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 endcap 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, providing proof that the concept works in practice [1].

We propose to spend one year developing and testing a small prototype, to dispel any doubt that a tracking device can be built with parameters similar to Tables 1 and 2. In year 2 and 3, we propose to advance the concept to a full design.

A NITPC solution could be considered for the so-called Large Detector option for the linear collider (LD), but we feel that it fits best the so-called Small Detector (SD) option[1]. The advantages of the SD are well known and include low cost and relatively low backgrounds. We are unaware of other gas tracker candidates for the SD. One important reasons for the fit is that the NITPC will work unaffected by magnetic fields of up to 6T.

With the slow macro-pulse structure of NLC machines, the slow drift does not incur any penalty from background tracks or track overlap relative to a conventional TPC. A comparison between a large TPC

[1]We rename the Silicon Detector so as to accomodate the NITPC.

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, $\sigma_l \sim \sigma_t$	$0.07\text{mm}\sqrt{L(cm)/E(kV/cm)}$	
Negative Ion stripping mean free path	$\sim 10\mu m$	At $100\mu m$ 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.

and a Small NITPC at TESLA remains favorable (see our NITPC webpage FAQ[2]), once the LD and SD background levels and gas density are taken into account.

We are considering drift gaps as short as 25 cm and as long as one meter and drift fields of order 1 kV/cm. Such fields are well within the E/P envelope which has been studied already in these detectors[3]. The eventual MT would have as few as one segment (radial NITPC in the SD, 50 cm drift) to as many as eight segments (axial NITPC in the LD, 25 cm drift).

In July-August 2002 we measured the properties of an atmospheric pressure electronegative gas mixture, He/CS_2 80/20. The results, shown in Table 1, were so (surprisingly) good that it became immediately apparent that a NITPC could be a strong candidate for linear collider instrumentation. A paper is being prepared that discusses the physics prospects of the NITPC, based on these results.

Here we discuss in more detail the advantages of a NITPC, and why the technique ought to be studied in detail. Four major differences compared to a regular TPC are:

- the drift velocity is very slow (Table 1), allowing a much larger number of samplings along the drift direction, and increasing detector granularity. The low drift velocity also results in small or negligible Lorentz angles, so that all three drift directions (axial, radial, and azimuthal) can be freely considered to obtain the best design.
- transverse *and longitudinal* diffusion remains thermal up to high drift fields (Table 1)
- CS_2 is unaffected by trace amounts of other electronegative compounds (oxygen), so that long drift times can be attained.
- sparking is strongly suppressed by the photon and electron quenching properties of the gas. Drift fields of a kV/cm have been produced and maintained in test TPCs using simple, open wire field cages.

There are three aspects that need to be studied carefully in the first year.

- which TPC drift configuration (axial, azimuthal, radial) is best suited for the LC, and with what detailed parameters (drift gap, drift field)?
- which gain and readout structures are best suited for the NITPC (wire planes, GEM or Micromegas)?
- with the very small FADC occupancies we expect, can we adopt novel, low mass detector planes?

Both momentum resolution and background tolerance depend on the parameter $\sigma/\sqrt{N}$, where σ is the detector resolution and N is the number of samples along the track. σ depends on many parameters, including B-field effects (which can both increase and decrease the resolution), electronic noise, longitudinal and transverse diffusion, longitudinal and transverse sampling, multiple scattering, and pad

Parameter	Classic TPC	NITPC	Comment
z-samples(1/m)	1000	105000	NITPC low drift velocity
r-samples(1/m)	200	333	-
θ-samples(1/m)	400	333	-
N (1/m)	200	2400	r-samples for TPC, N_e for NITPC
diffusion, $<\sigma_t>$ (μm)	400	270	$<\sigma_t>=(2/3)\sigma_{max}$
diffusion, $<\sigma_l>$ (μm)	>> 400	270	-
Random triplets	0	?	-
TPC surface charge (nC)	0.4	5	space charge distortion par.
TPC cage	N/A	N/A	thicker in NITPC
Detector membranes	0	0.3% X_0	for perp. tracks
Endcap material	N/A	0.3% X_0	No endcaps in NITPC
NLC background density (a.u.)	1	0.05	lighter gas mixture and lower bkg. rates
TESLA background rate (a.u.)	0.05	0.03	

Table 2: A comparison of parameters of a state-of-the art TPC[5] and a preliminary design for the NITPC. For the purpose of comparison, an axial NITPC is considered with 40 cm segments. For the last two rows (background rates), the comparison is between a LD RTPC and a SD NITPC.

size. The NITPC holds an uncontroversial advantage over a RTPC in longitudinal sampling (2 orders of magnitude) and longitudinal diffusion (roughly one order of magnitude), Table 2.

N is usually the number of pads illuminated by a track. In the case of the NITPC, the low drift velocity and high gain (Table 1) conspire to make it possible to detect each ion individually[4], Table 2, effectively recovering maximal information. Note that the electronic noise contributions do not increase much, as this chamber counts electrons as opposed to measuring charge.

The introduction of detector planes inside the tracking volume would increase multiple scattering and photon conversion (both signal and background) and so it needs to be further studied. It is clear that conventional TPC pad arrays can not be used as they imply too much material (one amplifier and one cable per pad). Depending on the actual dimensions, drift field and speed, and diffusion, such planes may not in fact be required.

We stress that a novel detector plane will be a major part of the hardware R&D, as we make this powerful technology available to particle physicists. We also note that the two-layer strip detector we propose below has already been built (by a CERN-College de France collaboration) in a microstrip version[6]. With a NITPC already operating, a radial TPC already operating[7], and a double-strip plane already built, there is nothing totally untested in our idea.

As a starting point we consider an "astrophysics-style" detector planes such as that of Ref.[8]. It has the customary grid dividing the drift region from the gain region, one set of wires and one set of pickup strips. It lacks field wires (replaced by an appropriate voltage difference between strips and wires) and the electronics is located at the rim of the detector plane. There is no gating grid[2].

The system reduces detector plane material dramatically but introduces hit ambiguities. We introduce the strip system sketched in Fig. 1, with a chessboard pad pattern and daisy-chaining along the diagonals, so that a hit becomes an unambiguous triplet. The system will work due to the very low FADC occupancy we expect.

By now we have received many comments about the possible problems encountered by a NITPC at a linear collider. Please see the NITPC FAQ[2] for more details. The major ones are summarized as follows:

- **the NITPC will observe more backgrounds than a RTPC at TESLA due to the slow drift.** If the NITPC is a Small Detector, then the NITPC will see less backgrounds than a RTPC, whether at TESLA or NLC. The one difference is that at the NLC the difference is of order 20,

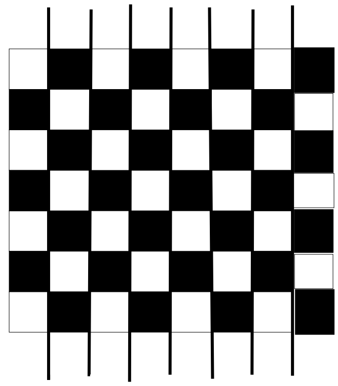

Figure 1: The detector surface layout scheme. The wires are strung vertically, and readout pads are daisy-chained to form strips. Black pads are chained along the NE-SW diagonals, and white pads are daisy-chained along the NW-SE diagonals.

at TESLA only a factor of two or less. Please see the NITPC FAQ[2]. On top of that, we expect a granularity two orders of magnitude better than a RTPC (Table 2) which will increase the background tolerance substantially.

- **the higher gain and backgrounds will result in higher space charge.** Obviously if a GEM scheme is ultimately adopted, space charge will not be a problem. But even without GEM, the NITPC is far more resistant to space charge than a RTPC, by about a factor of 30[2].
- **the NITPC has too much material.** We agree that RTPC detector planes inside the tracking volume would be unacceptable, but this device will have novel, low-mass detector planes with the two biggest offenders (pads and sense wires) removed. We note that multiple scattering errors are expected to be non-dominant at the LC, and that the excellent dE/dx resolution afforded by single electron detection will help identify pairs in dense jets (an advantage not present in silicon detectors). Most important, we expect the material in this device to compare favorably with the silicon detectors considered for the SD.

The challenges facing a NITPC (those that are certifiably harder in a NITPC than in a RTPC) include detector plane alignment and careful design of the drift and gain electric field. These will be addressed as our simulations progress.

FY2003 Project Activities and Deliverables

In Year 1 we will build a small device, of order one liter volume. The device will confirm that single electron detection, and low mass, chessboard-like detector planes can be built and operated.

FY2004-2005 Project Activities and Deliverables

In year 2 we will perform a series of tests, including operating the device in high background conditions (provided by firing a X-ray tube when a cosmic trigger is generated) and in high magnetic fields. We will also test other electronegative gases which are known to have high gain. In year 3 a full design effort will be undertaken which will address alignment issues.

Budget justification

In years 1, we will need the equipment and material money to build the mini-TPC. In Year 2, material and travel money is increased as we test the chamber extensively. In year 3, a postdoc position is requested to run design software as well as extensive simulations.

Three-year budget, in then-year K$

Institution: Wayne State University

Item	FY2003	FY2004	FY2005	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	0	0	0	0
Travel	2	2	2	6
Materials and Supplies	0	0	0	0
Other direct costs	0	0	0	0
Total direct costs	0	0	0	0
Indirect costs	1	1	1	1
Total direct and indirect costs	3	3	3	9

Institution: Temple University

Item	FY2003	FY2004	FY2005	Total
Other Professionals	0	0	46	46
Graduate Students	0	0	0	0
Undergraduate Students	0	0	0	0
Total Salaries and Wages	0	0	46	46
Fringe Benefits	0	0	12	12
Total Salaries, Wages and Fringe Benefits	0	0	58	58
Equipment	18	9	0	27
Travel	2	5	2	6
Materials and Supplies	5	10	0	15
Other direct costs	0	0	0	0
Total direct costs	25	24	60	109
Indirect costs	4	8	30	42
Total direct and indirect costs	29	32	90	151

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