Proposal to the University Consortium for a Linear Collider (date: 25-July-2003)

December 20, 2004

Personnel and Institution(s) requesting funding

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Collaborators

none

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Changes Since Preliminary Project Description

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

Project Overview

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

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

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

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

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

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

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

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

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

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

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

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

FY2004 Project Activities and Deliverables

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

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

FY2005 Project Activities and Deliverables

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

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

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

FY2006 Project Activities and Deliverables

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

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

Budget justification

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

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

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

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

Three-year budget, in then-year K$

Institution: Cornell University

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

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

Institution: Purdue University

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

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