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

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Collaborators

none

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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 $\mathbf{E} \times \mathbf{B}$ 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 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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