

Development of a Micro Pattern Gas Detector Readout for a TPC

Classification: subsystem

Detector: tracking

Personnel and Institution(s) requesting funding

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Project Overview

Motivation

A tracking detector with unprecedented performance, in both multi-track separation and momentum resolution, will be required to meet the experimental physics goals of the future linear collider. A time projection chamber (TPC) may provide the best combination of detector segmentation and continuous track measurements that would lead to the optimum multi-track separation and noise immunity. However, as described below, the segmentation of current technology TPCs is insufficient for precision reconstruction of linear collider events. In addition, obtaining spatial resolution that is required to meet the momentum resolution goal is challenging with the current technology. We proposed to study improvements to a TPC readout in an effort to develop the segmentation and resolution required for the linear collider program.

Multi-track separation, which leads to efficient track reconstruction, is required for an “energy flow analysis”, the precision measurement of jet energies using tracking information to determine the charged energy component $\{1\}$. Energy flow analysis will require efficient track reconstruction within jets where the track density is of order 100 tracks/steradian. TPCs using wire anode gas-amplification, of which the STAR and ALEPH chambers are typical examples, have pad readouts with segmentation of order 1 cm in the azimuthal direction. This segmentation is insufficient for reconstructing tracks in dense jets. For example, consider a TPC with 4 cm longitudinal segmentation

and a two-pad FWHM pad response function. The solid angle segmentation would be about 10^{-3} steradian at a detector radius of 1 meter. Thus, the occupancy within a jet would be 10% - a challenging environment for track reconstruction. In a simulation of digitized detector response {2}, a 1 cm pad width was shown to provide only 94% reconstruction efficiency while a pad width of 2 to 3 mm is required for the ultimate resolution. Simply increasing the detector segmentation in a wire anode TPC will not result in increased reconstruction efficiency because the signal width is determined by the inductive readout. A gas-amplification technology with signal width less than 2 mm is required to take advantage of increased readout segmentation.

Spatial resolution, which determines charged particle momentum resolution, is also limited in wire anode TPCs. Charged particle momentum resolution, $\sigma(1/p)$, of order $10^{-5}/\text{GeV}$ is required to determine the Higgs mass through the precision measurement of the recoil mass of di-leptons in Higgsstrahlung events {3,4}. Similar momentum resolution is required to measure the end-point momentum in leptonic supersymmetric decays. This momentum resolution can be achieved only if the TPC spatial resolution is of order $100\mu\text{m}$. This spatial resolution is very challenging in a wire anode TPC not only because it represents 1% of the pad size but also because the radial electric field in the vicinity of the wires leads to a significant spatial distortion.

A TPC readout based on a micro-pattern-gas-detector (MPGD) gas-amplification device such as a GEM {5} or MicroMegas {6} 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{ExB} distortion of the drift path in the vicinity of the amplification device. Operation in a high rate environment may be simplified because these readout systems are expected to naturally suppress ion feedback into the drift volume.

The world linear collider TPC study

Several groups in Europe, Canada, and Asia are currently studying gas-amplification devices in prototype TPCs. Groups from Victoria {7}, DESY {8}, Karlsruhe {9}, and Aachen {10} have been studying GEM gas-amplification. The Saclay/Orsay/Berkeley {11} group has been studying MicroMegas gas-amplification. The Carleton {12} group has been studying MicroMegas gas-amplification with an additional resistive foil over the pad plane to control the pad response function. The Asia/MPI/DESY {13} group has made measurements with wire gas-amplification. Results from the individual groups and recent reviews {14} of this work have been presented at the linear collider workshops. Results from these groups are encouraging; several groups report spatial resolutions of less than $100\mu\text{m}$ with MPGD devices. However, the results are preliminary. The resolution is not as good as expected from simulations. It is recognized within the linear collider TPC community that the measurements of different gas-amplification devices are difficult to compare because they are taken by different groups under various conditions {15}. In addition, there are sometimes discharge problems in the gas-

amplification devices that must be understood. Significant development and operating experience are required before a full-size design for a detector incorporating a GEM or MicroMegas can be finalized. Even with many groups working on these issues, the development will take several years and should not be delayed.

The Cornell/Purdue R&D program

We have initiated a TPC detector development program. We will study issues of resolution, segmentation, signal width, noise, cross-talk, and ion feedback using various readout systems on prototype TPCs. The TPCs will be built and operated at Cornell. We will study TPC readouts using both traditional wire anode wire gas-amplification built at Cornell, and TPC readouts using GEM and/or MicroMegas gas amplification built at Purdue.

The Cornell/Purdue program is a part of, and coordinated with, the world TPC study. We regularly present at the regional and international workshops including the January 2005 TPC R&D mini-workshop {16} held in conjunction with the Meeting on ILC Detectors with Gaseous Tracking {17}. We will add to the body of MPGD gas-amplification TPC operational knowledge by building on our experience of operating large tracking chambers and MPGD development.

The recently completed Cornell TPC (see "Progress") can easily be configured with various readout modules. While other groups typically make measurements using one gas-amplification device, we will be able to make direct comparisons of several gas-amplification devices using with the same drift cage and readout electronics.

We plan to make ion feedback (also known as "back-drift") measurements using an instrumented drift cage termination grid. Again, direct comparisons between several gas-amplification configurations will be possible. The ion feedback dependence on biasing can be readily measured because biasing for the gas-amplification device, as well as the drift cage field, can be adjusted from outside the gas volume.

As described below (see "Expertise"), Purdue is involved in several studies of manufacturing techniques for the purpose of providing large scale production of reliable GEMs, and MicroMegas. It is expected that the MPGD manufacturing will require 3 to 4 years of development. 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 in a linear collider. 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 TPC readouts. The Cornell TPC will be used to test and compare MPGDs that are manufactured with new techniques as well as devices produced at CERN. In the first instance, we will test a recently produced MicroMegas.

As the world TPC study evolves, the Cornell/Purdue group plans to become involved in scaling a MPGD readout to a full size detector. We will use our TPC to study problems associated with assembling an array of MPGD devices to cover a large area. On a time scale of about three years, groups involved in the world TPC study plan to construct a large prototype. First discussions of the design of the large prototype and how to divide the tasks involved the construction are just beginning. We plan to participate by designing and building a component such as the thin endplate support frame and the mounting scheme for the readout elements or the field cage.

Our coordination with the world TPC study will be strengthened by cooperating on projects of mutual interest with the Carleton group consisting of Prof. Alain Bellerive and Dr. Madhu Dixit. The proposed infrastructure will enable us to make a direct comparison of Carleton MPGD readout devices with those prepared at Purdue. This will help in reducing systematic uncertainties and in optimizing the readout design for the MPGD TPC. The partnership between Carleton and Cornell/Purdue will benefit from the proximity of Ottawa and Ithaca.

Expertise

The Cornell group has extensive experience building and commissioning drift chambers for the CLEO experiment {18}. For the CLEO II drift chamber {19}, the Cornell group developed thin structures for inner and outer segmented cathode readouts. In the design stage of the CLEO III drift chamber {20}, the Cornell group developed specialty parts and machining practices with commercial vendors. Prototype chambers were used to study questions of gas properties, insulating feed-through breakdown, electronics characteristics and mechanical issues for the endplate. The CLEO III drift chamber {21}, installed in 1999, has been extremely reliable with superior spatial resolution. Most recently, the Cornell group constructed and commissioned a 6-layer inner drift chamber for the CLEOc program {22}. Two significant issues were resolved in this project: integrating the chamber design with the existing interaction vacuum chamber and focusing elements, and reducing the sensitivity to electronic noise transmitted by the beam pipe.

The Purdue group has many years of experience developing MPGDs {23-37}. 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 {34} and GEM+MicroMegas detector have been built. The latter has achieved the best signal-to-noise performance in a beam line of any MPGD to date {35} 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 {38}. Electrode-less GEMs and MicroMegs, which have greatly reduced amounts of material, are also under development. The Purdue/Chicago collaboration has worked with the 3M Corporation to develop a less expensive, large quantity, manufacturing process for standard GEMs.

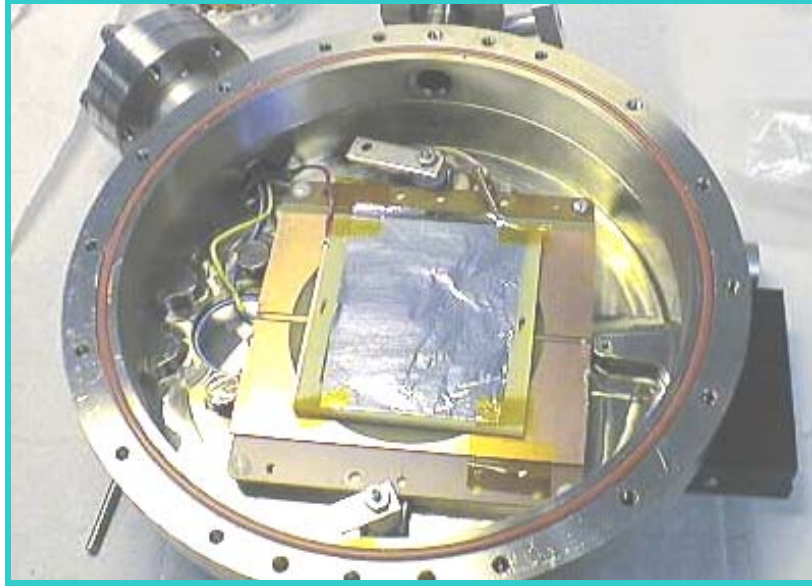


Figure 1: A MicroMegs produced by the 3M Corporation in collaboration with Purdue University mounted for testing. The cover of the high purity stainless steel gas chamber is removed for display.

These have been delivered and tested at Purdue and CERN. Preliminary results indicate that the performance of GEMs manufactured by 3M, when appropriate materials are used and the process is carefully controlled, is indistinguishable from the performance of those manufactured at CERN {39,40,41}. More recently, Purdue has collaborated with 3M to develop the first mass-produced MicroMegs. These have been delivered {42} and are being tested as shown in Figure 1.

Work described in this section and in “Progress” has been supported at Cornell by NSF cooperative agreement PHY-0202078, 4/1/2003 – 3/31/2008, entitled "Support of the Cornell Electron Storage Ring (CESR) Facility. Work at Purdue has been supported by DoE grant DE-FG02-91ER40681, 1991-present, entitled "An Experimental High Energy Physics Program at Purdue University".

Progress

In the past year, the Cornell group has constructed and commissioned a TPC, shown in Figure 2, with a 64 cm drift field and 10 cm square readout aperture. To commission and operate the TPC, Cornell has purchased high voltage and data acquisition (DAQ) systems. The high voltage system provides 20kV for the drift potential as well as biasing voltages



Figure 2: Time Projection Chamber at Cornell University. The drift cage has an inner diameter of 14.6 cm and length of 64 cm.

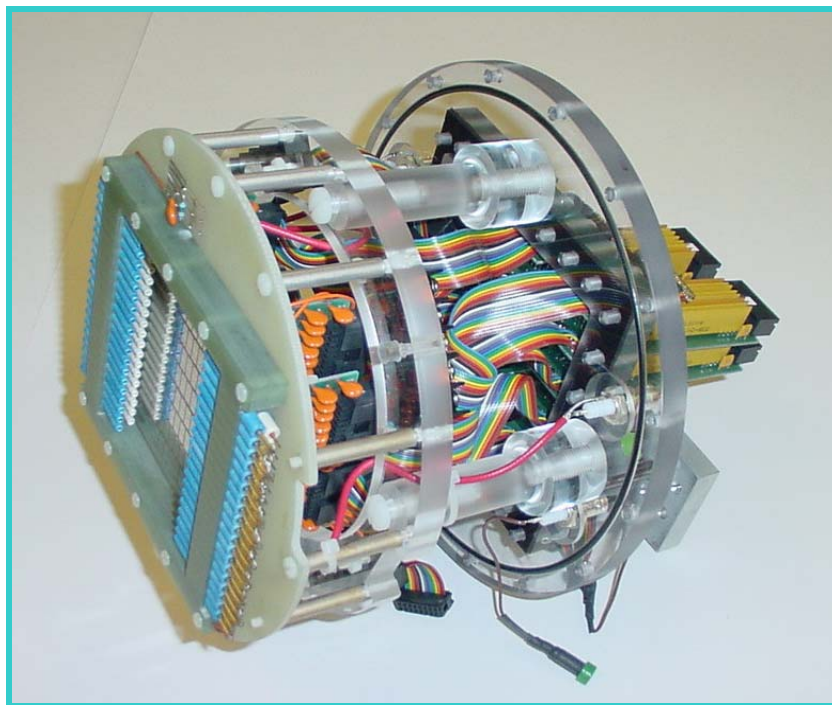


Figure 3: TPC Readout Module. A wire gas-amplification section is mounted in front of the pad board on the left. Pad biasing voltage distribution cards are mounted behind the pad board.

for the gas-amplification devices. The VME based DAQ has low noise power supplies to improve the signal sensitivity for prototype detectors. TPC signals are digitized with commercial flash-ADCs. Cornell has purchased four 8-channels flash-ADC units with 105 MHz sampling rate, +/- 200mV input range, and 14 bit resolution. These units

sample continuously, storing results in a circular buffer. This provides sensitivity at zero drift time.

The TPC accepts interchangeable readout sections. A wire gas-amplification readout, shown in Figure 3, is currently installed and being tested. A coarse pad pitch, 5mm by 10mm, was chosen because it allowed us to demonstrate the TPC operation with a minimum number of channels. The first cosmic-ray events were recorded in January 2005. Experience gained in operating the drift field and data acquisition system will allow us to concentrate on issues involving the new gas-amplification devices.

Interim Activities

A number of activities will proceed without additional funding. With the successful commissioning of our TPC in January 2005, we will continue with measurements using our present readout pad board design and limited, 32 channel, DAQ. We will complete baseline resolution measurements using our original wire gas-amplification stage as well as a variation with reduced anode-pad spacing. We will then study several 3M-produced MicroMegas and GEMs and CERN-produced GEMs. The use of individual pad boards for each gas-amplification device will simplify mounting these sensitive devices in the TPC. For each of the tested gas-amplification stages, resolution and operational stability measurements will be made with three of the gas mixtures currently used by other groups in the world TPC study: Ar-CO₂(90:10), "P10" Ar-CH₄(90:10), and "TDR gas" Ar-CH₄-CO₂(93:5:2), and with variations in the biasing.

Resolution measurements will be limited by the 5mm pad pitch of our present readout. While the resolution provided by MPGD gas-amplification is a fraction of a millimeter, measurements of the intrinsic resolution can be made only with tracks near the boundaries between pads. Precise, high statistics, measurements will require smaller pads and more readout channels.

1st Year Project Activities and Deliverables

The first year of funding provides for several equipment upgrades. We require an increase in the number of readout channels in our DAQ for resolution measurements using smaller pad pitch. An additional power supply module is needed to provide more flexibility and control of biasing voltages. We must acquire instrumentation for the ion feedback measurements. Smaller items include revised readout pad boards, improved preamplifiers, other components in the readout chain, and chamber gas.

Our deliverable will be precision resolution measurements using 2 mm pad pitch with several gas-amplification devices and several gas mixtures. These measurements will provide a direct comparison of the various devices with other experimental conditions held constant. Ion feedback for the various devices will be compared.

These measurements will be made with cosmic rays in zero magnetic field. Several other groups have made measurements in magnetic fields that show no degradation of the

MPGD gas-amplification and confirm that the diffusion contribution to the spatial resolution is reduced. Our goal, at this time, is to provide a direct comparison of the different gas-amplification devices and to study the operational stability.

2nd Year Project Activities and Deliverables

Our deliverable in the second year will be to use the TPC to measure the resolution degradation and other issues associated with assembling an array of MPGD devices to cover a large area. Also, we will continue measurements of various gas-amplification devices and make measurements in a magnetic field if relevant and if funding exists. These activities will require a further expansion the DAQ system.

In the second year, we anticipate that the world linear collider TPC group will collaborate to design a large prototype. The expertise of the Cornell/Purdue groups will provide valuable input to that design.

3rd Year Project Activities and Deliverables

In the third year of this project, we anticipate that the world TPC group will collaborate to build the large prototype. We expect to contribute by taking responsibility for the design and construction of a major component. There are several possibilities that would match our expertise: for example, the endplate support frame, a composite field cage structure, or readout modules. The distribution of the responsibilities will be decided by the participants at a later date.

The deliverable will be the component of the collaborative large prototype.

Additional Budget Justification Discussion

The first year equipment budget for Cornell provides for an expansion of the DAQ for use with a readout module with smaller pad pitch. The major expenditure is the FADC modules. We can efficiently carry out the first year program with an increase to 96 channels. The budget reflects the purchase of additional flash-ADC units matching our current units. These are expensive but provide dependability, low noise, and measurements at zero drift time that are difficult with common start units. The 100 MHz sampling rate will be useful in separating an inductive component of the signals. As an alternative, we will investigate other units that may provide adequate performance at reduced cost/channel and that are compatible with our VME DAQ.

The second 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 and other costs to cover measurements in a test magnet at DESY.

The third year equipment budget can not be predicted until the responsibilities are distributed among the collaborators in the world TPC study. Based on our experience, the

requested amount, \$50K, would be suitable for construction of a composite field cage of this size or some fraction of the readout modules. It is probably not a sufficient amount to fabricate a lightweight endplate support frame. If we take this responsibility, it would be necessary to share the cost of this component with another collaborator.

Purdue is requesting funding to support two undergraduate students each year at 20 hours per week, 40 weeks a year. The students will work exclusively on this project. Benefits of involving undergraduate students in the program are described under "Broader Impact"

Resource Reallocation

Cornell has provided a reallocation of resources to construct the TPC. The cost of materials, circuit boards, and commercial electronics has totaled \$55K. Cornell has also provided a computer to read out the DAQ and the spare custom components to construct wire gas-amplification stage as well as the preamplifiers. Cornell is providing a continuing reallocation of resources to this project in the form of support for research staff (Peterson) as well as technical staff, machine shop time, and computer support.

Cornell supports two graduate students working on this project. Laura Fields is a third year Ph.D. candidate who has programmed the interface to the DAQ. She will also work on the instrumentation for the ion feedback measurements. Peter Onyisi is a second year graduate student working on the slow control interface to the HV system.

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. Use of clean-room, testing, and assembly facilities at Purdue will be provided to this project at no charge.

Broader Impact

D. Peterson mentored an RET participant from an underrepresented group during the summer 2004 working on one aspect of the interface to the DAQ. It is anticipated that other REU/RET participants will work on this project in the future.

I. 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 publications {28,32,33,34,36,37}. Currently, three undergraduate students are working on MPGD with the group. The Purdue group also takes participants from the Purdue REU program.

As described under "The Cornell/Purdue R&D program", the TPC infrastructure will be used in a partnership with researchers from Carleton University in Canada.

Each year, approximately 500 people tour the Cornell University Wilson Laboratory facility. The accessibility of the TPC laboratory to the public promotes a greater understanding of particle physics tools.

Three-year budget, in then-year \$ Institution: Cornell University

	FY2005	FY2006	FY2007	Total
Other Professionals	0	0	0	0
Graduates 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	42573	40000	50000	132573
Travel	0	6000	0	6000
Materials and Supplies	12113	5290	0	17403
Other Direct Costs	0	0	0	0
Subcontract (Purdue)	24416	24416	24416	73248
Total Direct Costs	79102	75706	74416	229224
Indirect Costs	7026	6549	0	13575
Subcontractor Indirect Costs	6348	152	0	6500
Total Indirect Costs	13374	6701	0	20075
Total direct and Indirect Costs	92476	82407	74416	249299

Three-year budget, in then-year \$ Institution: Purdue University

	FY2005	FY2006	FY2007	Total
Other Professionals	0	0	0	0
Graduates Students	0	0	0	0
Undergraduate Students	16000	16000	16000	48000
Total Salaries and Wages	16000	16000	16000	48000
Fringe Benefits	63	63	63	189
Total Salaries Wages and Fringe Benefits	16063	16063	16063	48189
Equipment	0	0	0	0
Travel	0	0	0	0
Materials and Supplies	0	0	0	0
Other Direct Costs	0	0	0	0
Total Direct Costs	16063	16063	16083	48189
Indirect Costs	8353	8353	8353	25059
Total direct and Indirect Costs	24416	24416	24416	73248

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