**Proposal Name** Studies of Gas Electron Multipliers for a Time Projection Chamber for the International Linear Collider

### Classification (subsystem)

Identify accelerator subsystem. Central Tracking Chamber; TPC

### Personnel and Institution(s) requesting funding

Prof. Peter Fisher, Massachusetts Institute of Technology, Cambridge, MA, 02139

Prof. Ulrich Becker, Massachusetts Institute of Technology, Cambridge, MA, 02139

### Collaborators

### Project Leader

Prof. Peter Fisher
fisherp@mit.edu
617-253-8561

### Project Overview

Over the past fifteen years, Time Projection Chambers (TPCs) have developed into robust tracking systems for use at electron-positron colliders as well as fixed target experiments. TPCs provide three dimensional track measurements with high resolution and low channel count. Future linear colliders challenge TPC design: the large number of bunch crossings over a very short time can cause the build up of ions in the drift region resulting in the loss of resolution. Gas Electron Multipliers (GEMs) [1, 2, 3] may provide a solution: as they amplify electrons in a closed channel, the ions remain trapped in the channel where amplification occurred and can be ejected in between bunch crossings. However, current GEM amplification systems need three layers of foils to attain sufficient ($10^3$-$10^4$) gain. We aim to investigate GEM designs which result in higher gain per layer which may allow one or two layer GEMs. At the very least, we aim to find an optimized GEM design which will improve GEMs robustness and uniformity.

GEM foils amplify drift electrons by creating a very high field region in a channel formed by a hole through a highly resistive substrate (usually Kapton). Electrons liberated by high energy particles in the TPC volume drift to the GEM (which may be separated from the drift volume by a grid) and are focussed by the electric field into the amplification channel. Typical field gradients are as large as 100 kV/cm (500 volts applied across a 50 $\mu$m foil) which give gains of a hundred or more in typical gases such as Ar:$CO_2$ (80:20) or P10. Current applications use stacks of three GEMs and achieve gains of up to $10^4$. After the last stage of amplification, the electrons are collected on readout pads which give the position information.

In the first six months of the current award, we have built the infrastructure we need to optimize GEM foils (see below) Fig. 1 and the coming year, we will carry out a systematic study of how the physical parameters of GEM foils influence the gain. In particular, we will study how the diameter and pitch (the spacing between amplification channels) of the amplification channels influence the gain by fabricating GEM foils using the exactly the same processing techniques from the same vendor. A larger amplification channel will collect more electrons, but will have a smaller field gradient (owing to leakage of the field out of the

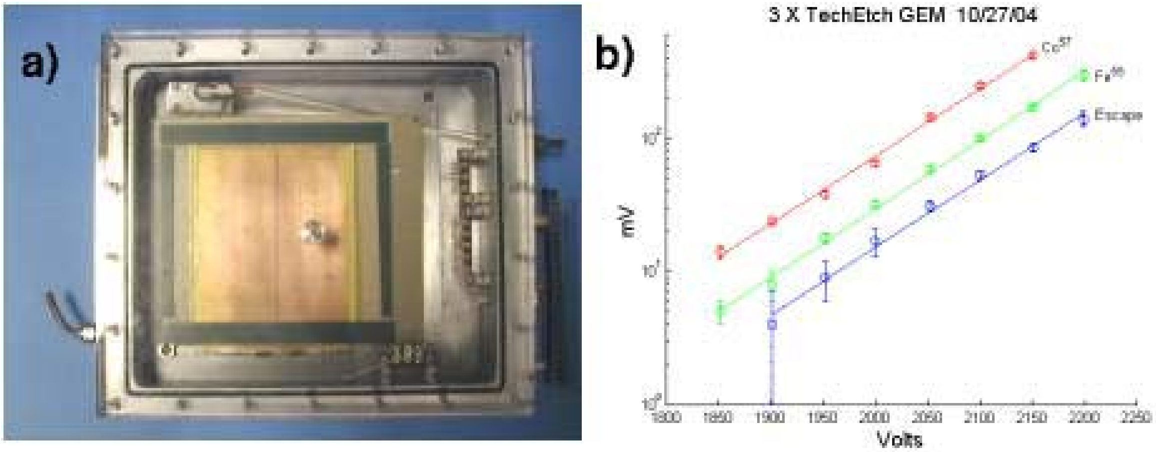


Figure 1: a) Test chamber with triple GEM mounted inside. The chamber was built for another detector study; the test chamber used for the proposed GEM foil studies is of the same design. b) Relative gain measurement of different energy sources with triple GEM shown in a). The GEM foils are made by Tech-Etch.

channel) and thus lower gain. In addition, a foil with a large channel diameter to pitch ratio will be mechanically weaker than a foil with a smaller ratio. We will also measure foils with thicker Kapton substrates: a thicker substrate will allow higher voltage and a longer amplification channel, possibly giving higher gain.

Carrying out these studies requires the fabrication of GEM foils to our specifications and we have developed an industrial partner in Tech-Etch of Plymouth, MA. Tech-Etch [1] is a custom flexible printed circuit board vendor which is able to make custom GEM foils in small (12-20 foil) batches at reasonable cost ($250 per foil). Tech-Etch has made GEM foils which we have working in our lab (Fig. 1) and is part of an SBIR with MIT, BNL and Yale for the STAR experiment at RHIC. As Tech-Etch foils have well defined properties and performance characteristics, our plan is to make modest variations from a reference design.

### Broader Impact

GEM foils find application in a wide range of tracking systems. They form the basis for the tracker in the COMPASS experiment [4] with good results and are a serious option for the ILC TPC [5]. The use of $CF_4$ with GEMs has been considered in medical applications [6] and are proposed for dark matter experiments[7] and double beta decay experiments[8].

Our studies have the two fold purpose of optimizing the mechanical design of GEM foils and continuing to develop a vendor who can provide custom foils at reasonable cost. As the use of GEM foils expands, we expect the work we do in the coming years will have impact of a wide range of experiments and technology.

### Results of Prior Research

In the past six months, we have ordered two sets of twelve GEMs from Tech-Etch, constructed a gas chamber for testing single and multiple GEM foils, completed a first simulation of GEM performance and taken some steps toward developing a new method of GEM quality control.

[1] URL: http://www.tech-etch.com

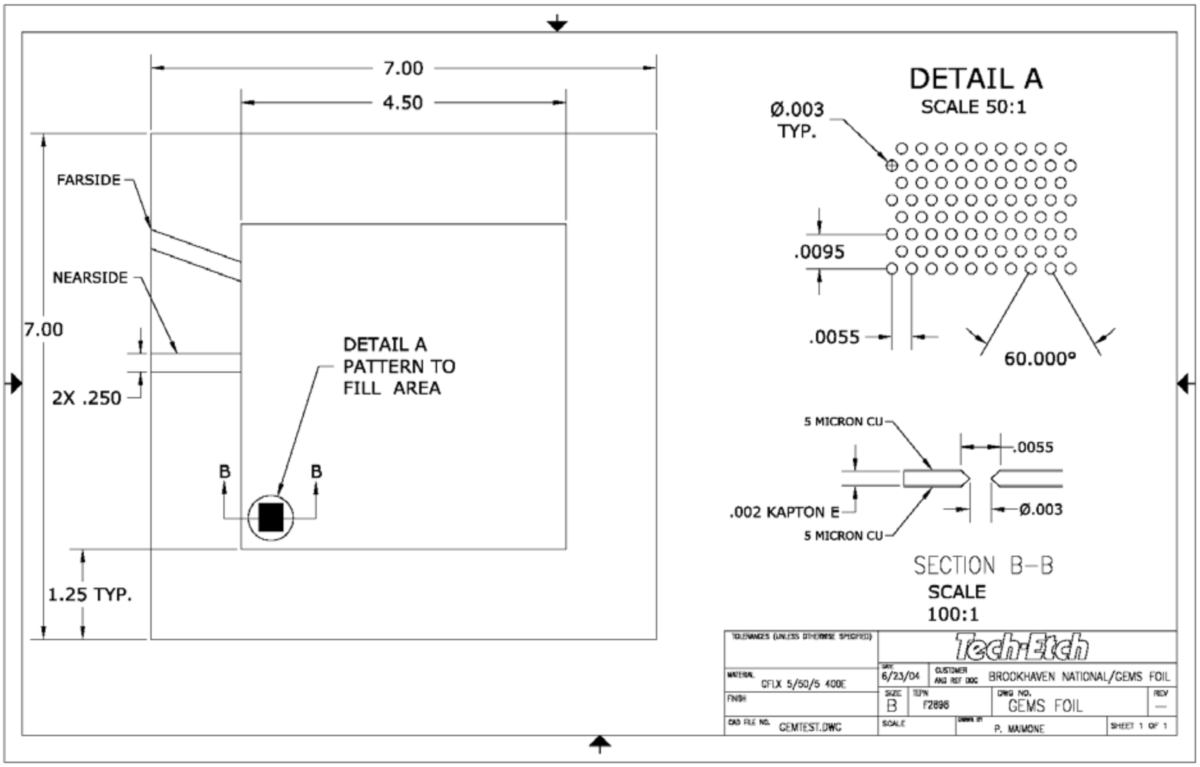


Figure 2: Layout of GEM foils for Tech-Etch for the reference set. All dimensions are inches.

Since we want to study the dependence of GEM performance on hole dimension and spacing, our first order of twelve GEM foils has a proven geometry (Fig. 2) and these GEM foils will be used as a reference set for comparison with other designs. The reference set has been received, mounted and tested: of the twelve foils, six meet our acceptance criteria (Fig. 3) and the best three will form our reference set. We will investigate cleaning the other six foils for later use.

The active region of the second set (referred to as Set 2) of GEM foils has four different electrically separate zones (Fig. 3). Each zone has a different hole diameter, with one zone having the same dimensions as the reference set in order to provide a direct normalization between Set 2 and the reference set. We have asked Tech-Etch to use the same processing sequence (etching time, chemical concentrations, etc.) for Set 2, so, in principle, the gain of Zone B of Set 2 and the gain of the reference set will be the same. This way, we will know that a gain difference observed, for example between Zone A and Zone B results from the different hole size rather than different processing. The Set 2 foils have been ordered and we expect delivery from Tech-Etch in late March.

This work has been carried out by Mr. Scott Hertel and Ms. Marta Lewandoska, who were supported by FY2004 funds.

We will test our GEM foils in a specially constructed chamber shown in Fig. 5. The test chamber has a manifold on the bottom to distribute the gas evenly at moderate flows and works over the pressure range of vacuum to 3 bar. The test chamber has a gas system attached which has a residual gas analyzer, turbopump and simple gas recovery system which will allow us to recover expensive gases. In interesting feature is the externally mounted resistor chain

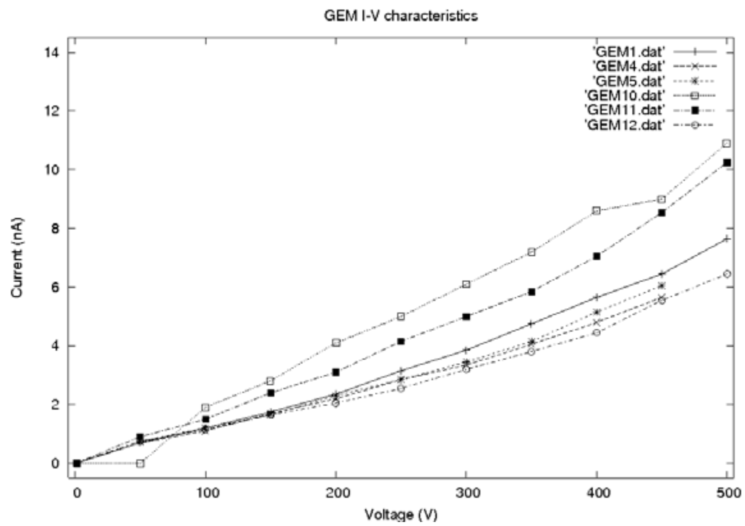


Figure 3: I-V curves for six of twelve reference GEM foils. All have surface resistances of better than $50\text{M}\Omega/\text{cm}^2$ at 500 V, our maximum planned operating voltage.

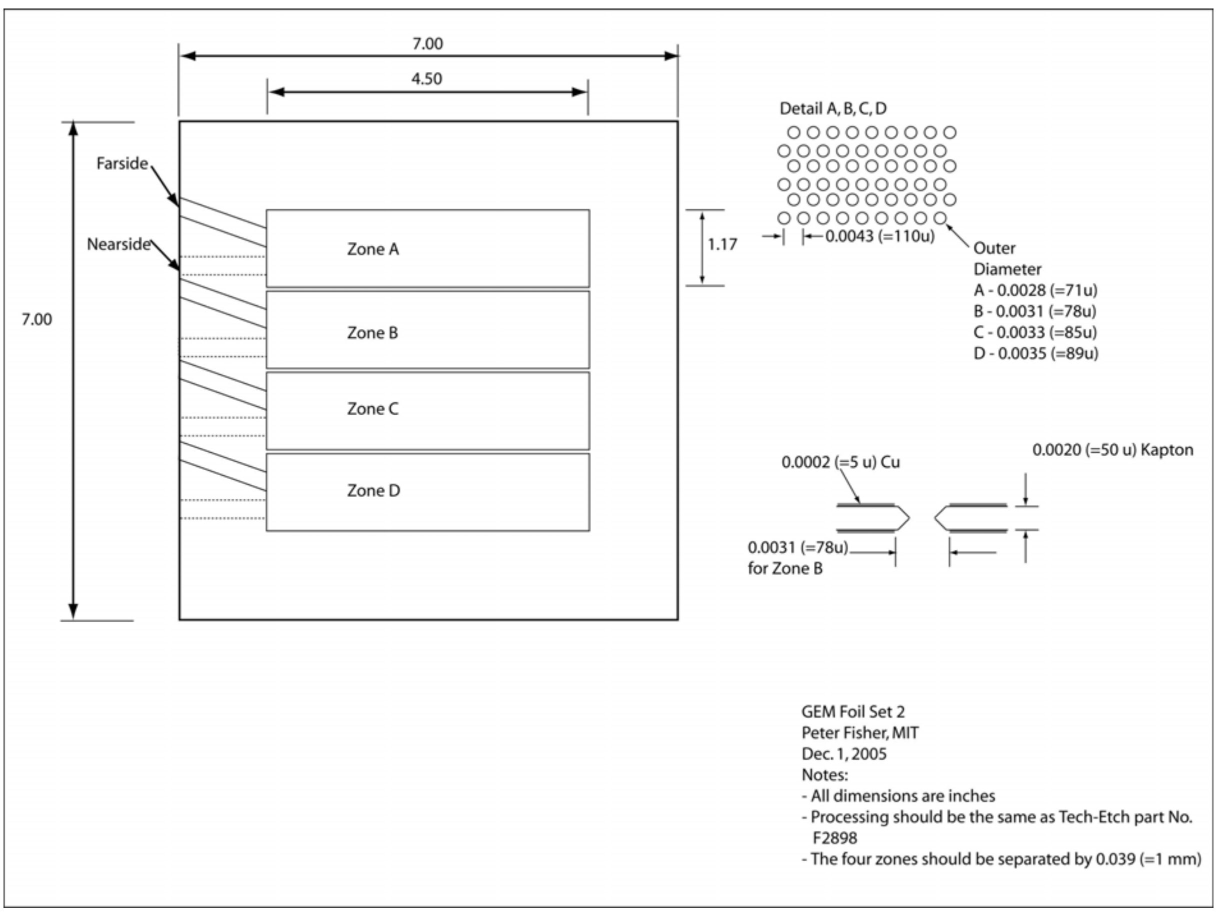


Figure 4: a) Design for GEM foil Set 2 to study the effect of hole size on gain. The processing (etching time, copper thickness, etc.) will be exactly the same as the reference GEM foil set in order to allow direct comparison between the gain of Zone B in Set 2 and the reference set.

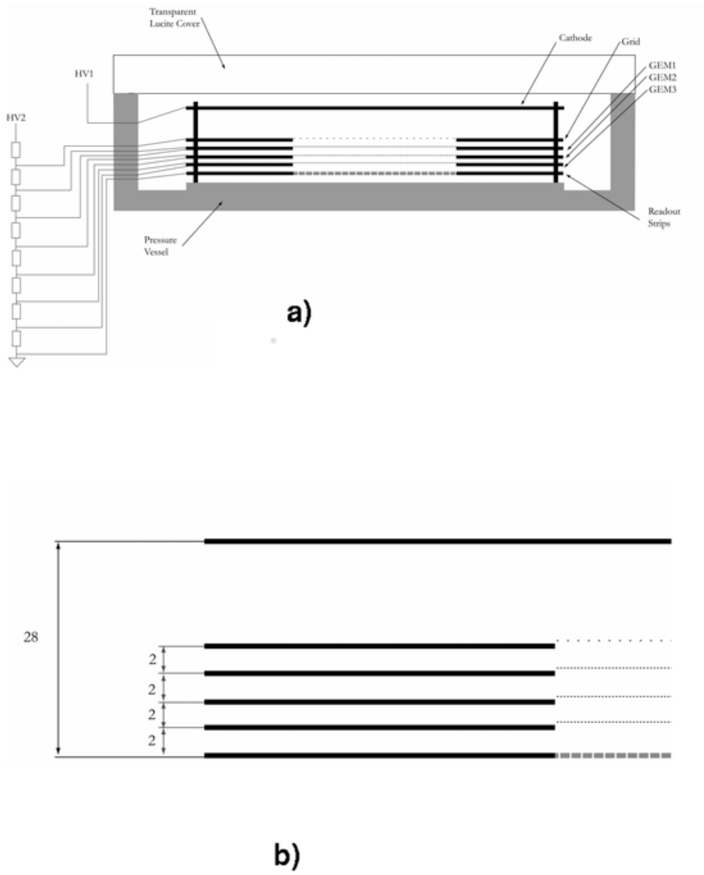


Figure 5: a) Cross section of test chamber for triple GEM foils. b) Detail showing the spacing of the detector components.

which allows the adjustment of foil and transfer voltages without opening the test chamber. The test chamber has been built in our shop and vacuum tested. We are currently mounting the reference GEMs in the chamber. for the initial tests, we plan to use Ar:$CO_2$ (80:20) and P10, which have well known characteristics. We will also carry out some measurements with $CF_4$.

Coding and testing of our simulation is now complete and we have compared our simulation results to data taken on an earlier single GEM setup Fig. 6 [9]. The simulation has two parts: in the first part, MAXWELL 3D (from Ansoft Corp.) computes the electric field for a specific geometry, producing an electric field map. The second part is a single particle mover which moves electrons along the electric field lines, taking diffusion into account. Ionization cross sections are used to compute probability distributions which we then sample to find the gain for each electric field setting. While the agreement between the simulation and data seems reasonable, we do not find the simulation a useful tool for studying the impact of hole geometries on gain and we have decided to direct the effort towards the GEM foil testing. Once we have good data from a number of geometries, we will resume our simulation effort.

This work was carried out in collaboration with Prof. Sekazi Mtinwga, now at Harvard

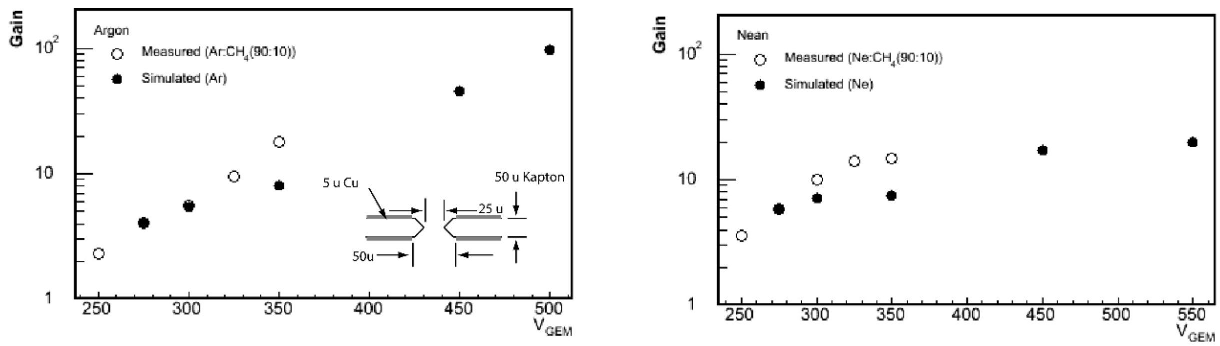


Figure 6: Comparison of gain measurements for a single GEM in argon and neon based gas. The measurements were only of relative gain and have been normalized to the simulation at 275 V.

University and Dr. Oleg Bouianov of SEFT in Helsinki, Finland.

**Facilities, Equipment and Other Resources**

This work has been and will be carried out in our detector lab which is supported by a detector development contract from other DOE funds and MIT Kavli funds. The lab is fully equipped with test equipment, gases, gas handling systems and electronics. There are two attached machine shops: one maned by Mr. Michael Grossman (for whom we request approximately 20% salary to support this project) and the second is the Edgerton Machine shop, an institute supported shop for students. The Edgerton shop is staffed by a full time machinist (Mr. Fred Cote) who teaches a shop course and helps the students with basic machining tasks.

Our detector lab has a long history of gas studies, including a long standing systematic study of gas mixtures documented at http://cyclo.mit.edu. Typically, six to eight undergraduates work in our lab on a number of different gas detector projects.

Undergraduate students run our lab under our supervision. Most students at MIT participate in the Undergraduate Research Opportunities Program (UROP) and we expect two UROP students to complete Senior Theses (which is required by the department) on the GEM studies. Two students, Kasey Ensslin and Julie Wyatt, have completed Senior Theses on earlier GEM studies. Our machinist, Mike Grossman, also provides support and supervision.

**FY2005 Project Activities and Deliverables**

In the early part of FY2005, we will complete the measurements of the performance of the GEM foil reference set and begin the measurement of of the gain characteristics of Set 2, which should be delivered in early March. We anticipate the mounting and acceptance testing of the Set 2 GEMs will take several weeks and the gain measurements will begin in late spring.

Based on what we learn from Set 2, we will submit an order for GEM foil Set 3, which may consist of

- Larger holes: in Set 2, the largest holes have an outer diameter of 90 $\mu$m and a pitch of 110 $\mu$m. If hole size leads to larger, more stable gains, we may try 95 $\mu$ holes with the same pitch or larger pitch.
- Thicker Kapton: most GEM foils use 50 $\mu$m Kapton as the substrate. We may use a 75 $\mu$m substrate, which would imply stronger, more robust GEMs.

We expect to place th order for Set 3 after our study of Set 2, which will be in early Summer 2006. Testing of Set 3 will extend into FY2006.

**FY2006 Project Activities and Deliverables**

In FY2006, we will continue testing Set 3 and, based on the results from Set 3, design two further GEM foil sets for test, Sets 4 and 5. The designs will depend on what we have learned with Sets 2 and 3, but will most likely include 100 $\mu$m thick substrate and larger pitch foils. We will also use the extra foils from Set 2 to in a small TPC (which we are re-instrumenting with readout electronics) for resolution studies using the Bates 1 GeV electron beam.

A TPC for a linear collider requires a detection region covering several square meters. Using the extra GEM foils from Sets 2-3, we will begin designing a two or three layer two-by-two array of 10 cm $\times$ 10 cm GEM foils in order to learn how to design and construct a much larger array for an ILC TPC amplification plane.

**FY2007 Project Activities and Deliverables**

We will conclude the systematic gain measurements of Sets 2-5. If appropriate, we will resume the simulation studies.

The GEM foils produced at Tech-Etch are 10 cm $\times$ 10 cm, so we plan to investigate with Tech-Etch the fabrication of larger foils and study how to tile these foils to cover a large area. We plan to order 20 cm $\times$ 20 cm foils (or larger) with a geometry based on the outcome of our studies from Tech-Etch and build a TPC detection plane of realistic dimension for use in an ILC TPC.

A second study we may undertake is the question of registration of the GEM channels. In a multiple layer GEM amplifier, there is some idea that lining up the channels will result in higher gain. We plan to address this my installing a micrometer and tension system in the our test chamber which will allow us to move the GEM foils in the triple GEM system. A back light will make measuring the alignment of the channels possible.

**Budget justification:**

The amounts requested are as follows:

**Other Professionals:** the requested amount of $10,000 supports 20% of our machinist, Mr. Michael Grossman, who fabricates the test chambers, GEM mounting frames and other hardware used on our project. In FY2005, he will fabricate the GEM mounting frames and a second test chamber. In FY2006, he will fabricate the GEM frames and parts for a multi-GEM amplification plane and in FY2007, he will fabricate a second amplification plane using larger GEMs. he also plays a major role helping and supervising our students.

**Undergraduate Students:** much of the work is a carried out by undergraduate students as part of the Undergraduate Research Opportunities Program (UROP) at MIT. Almost all undergraduate participate in the UROP and, in the physics department, a students UROP project usually leads to a senior thesis. We request support for two full time students.

**Equipment:** covers the purchase of two sets of twelve GEM foils each year from Tech-Etch ($ 6,000, described above) along with materials for making the GEM frames, test chambers and other test hardware. This also includes the purchase of gas used for testing.

**Travel:** covers two trips to ILC meeting to present results. One of us plans to attend the meeting at SLAC in March.

**Materials and Supplies:** covers the replacement of consumables in our lab such as electronic components, tools, test electronics, etc. The experience of the past ten years is that each student uses, loses or breaks $1,000 of lab supplies each year.

**Three-year budget, in then-year K$**

**Institution: MIT** Institution 1

| Item | FY2005 | FY2006 | FY2007 | Total |
|---|---|---|---|---|
| Other Professionals | 10 | 10 | 10 | 30 |
| Graduate Students | 0 | 0 | 0 | 0 |
| Undergraduate Students | 17 | 18 | 18 | 53 |
| Total Salaries and Wages | 27 | 28 | 28 | 83 |
| Fringe Benefits | 3 | 3 | 3 | 9 |
| Total Salaries, Wages and Fringe Benefits | 30 | 31 | 31 | 91 |
| Equipment | 9 | 7 | 7 | 23 |
| Travel | 1 | 1 | 1 | 3 |
| Materials and Supplies | 2 | 2 | 2 | 6 |
| Other direct costs | 0 | 0 | 0 | 0 |
| Total direct costs | 42 | 41 | 41 | 124 |
| Indirect costs | 19.5 | 20.15 | 20.15 | 59.8 |
| Total direct and indirect costs | 61.5 | 61.15 | 61.15 | 183.8 |

## References


[1] F. Sauli. *Nucl. Inst. and Meth.*, A386:531, 1997.

[2] F. Sauli. *Nucl. Inst. and Meth.*, A419:189, 1998.

[3] F. Sauli. *Nucl. Inst. and Meth.*, A505:195, 2003.

[4] A. Bressan et al. *Eur. Phys. J. A*, 19:291, 2004.

[5] P. Wienemann. 32nd international conference on linear colliders, jeju island, korea, 26-30 aug 2002. 2002.

[6] F.A.F. Fraga et al. *Nuclear Instruments and Methods*, A478:357, 2002.

[7] DRIFT and the UK Dark Matter Collaborations. *Nuclear Instruments and Methods*, A513:226–230, 2003.

[8] C. Hall et al. 4th workshop on neutrino oscillations and their origin (noon2003), kanazawa, japan, 10-14 feb 2003. 2004.

[9] K. Ensslin. Gas electron multipliers in a time projection chamber, senior thesis, mit, 2003.