Project Title:

RD 2012-3

Design and assembly of fast and light-weight barrel and forward tracking prototype systems for an EIC

Progress report (Q2 FY14 / Q3 FY14) and Proposal (FY15)

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Type of application:	Continuing funding request BNL EIC R&D contract RD 2012-3
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Contents

1 Introduction

This report concentrates on a dedicated tracking system based on micro-pattern detectors focusing on the design and development of fast and light-weight detectors, ideally suited for a future EIC experiment. The science case and basic detector specifications have been documented in a White paper report [1]. The micro-pattern tracking detector system consists of:

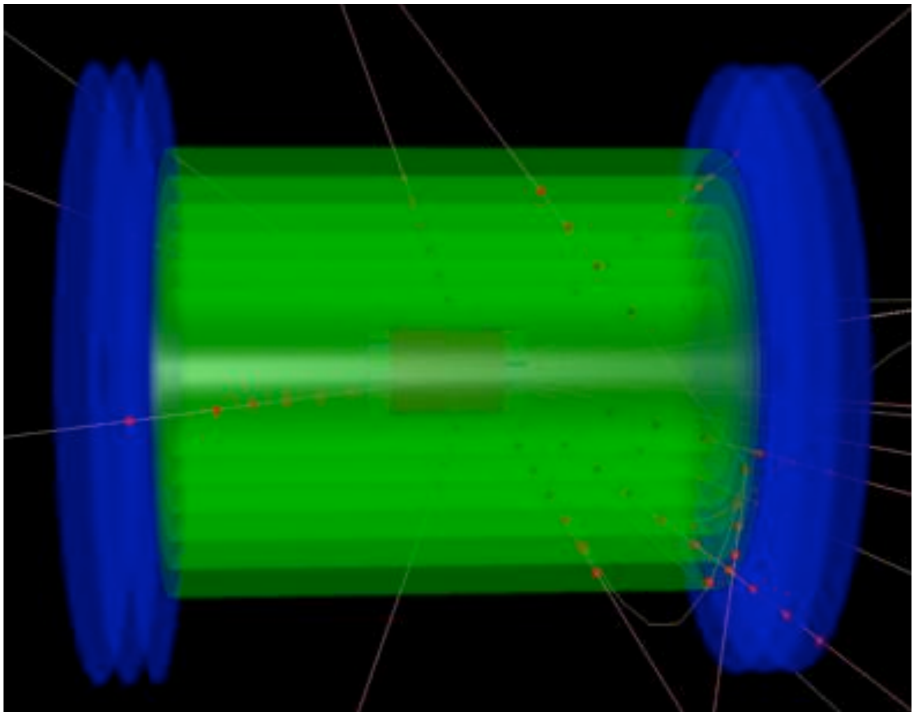


Figure 1: *GEANT simulation of a barrel (green) and rear / forward (blue) tracking system for an EIC detector.*

- Barrel tracking system based on MicroMegas detectors manufactured as six cylindrical shell elements and
- Rear / Forward tracking system based on triple-GEM detectors manufactured as planar segments of three layers in the rear and forward direction.

Figure 1 shows a 3D view of a GEANT simulation for a barrel and rear / forward tracking system which has been started by the R&D program documented in this report. The R&D effort focuses on the following areas:

- Design and assembly of large cylindrical MicroMegas detector elements and planar triple-GEM detectors,

- Test and characterization of MicroMegas and triple-GEM prototype detectors,
- Design and test of a new chip readout system employing the CLAS12 'DREAM' chip development, ideally suited for micro-pattern detectors,
- Utilization of light-weight materials,
- Development and commercial fabrication of various critical detector elements, in particular the commercial development of large single-mask GEM foil production and
- European/US collaborative effort on EIC detector development (CEA Saclay and Temple University).

The report provides an overview of various R&D activities in the 2nd and 3rd quarter of FY14 (Q2 FY14 / Q3FY14) both in the barrel and rear / forward direction following the last meeting of the EIC R&D committee in January 2014. The separate proposal section discusses the needed resources to complete the R&D program for both the large cylindrical MicroMegas detector elements, planar triple-GEM detectors and in particular the urgent need for a dedicated common chip readout system. It should be emphasized that our R&D program is a dedicated development of various elements for a future EIC tracking detector system.

The chip readout system, mechanical support elements and simulations are common R&D efforts for both the MicroMegas and the triple-GEM detector systems. The R&D program profits enormously from funds provided by the BNL EIC R&D contract 'RD 2012-3' which addresses the following items in FY14:

- Forward GEM Tracking detector development:
  - Relocation of three labs at Temple University in September 2014 to the Science Education and Research Center providing outstanding dedicated lab resources by the College of Science and Technology at Temple University consisting of a 2000 sq.ft. Class 1,000 clean room and a separate 800 sq.ft. GEM detector lab,
  - Hire of a new mechanical engineer (James Wilhelmi) with the hire of Professor Jim Napolitano at Temple University which provides local engineering support at Temple University in addition to the technical staff provided by the College of Science and Technology,
  - Extensive characterization of single-mask GEM foils in terms of leakage current and optical uniformity of both small ($10 \times 10\,\mathrm{cm}^2$) and larger ($40 \times 40\,\mathrm{cm}^2$) foils in collaboration with Tech-Etch Inc.,
  - Established reliable commercial source for single-mask produced GEM foils ($10 \times 10\,\mathrm{cm}^2$ - $40 \times 40\,\mathrm{cm}^2$) by Tech-Etch Inc. in collaboration with Temple University and Yale University,
  - Assembly of small ($10 \times 10\,\mathrm{cm}^2$) triple-GEM test detectors,
  - Commissioning of a new CAEN HV system for cluster studies using small $10 \times 10\,\mathrm{cm}^2$ triple-GEM test detectors,

  - Completion of cosmic-ray test stand and ^{55}Fe source scanner,
  - Extensive utilization of DAQ / HV system for detector tests,
  - Procurement of Kapton ring spacers as a novel spacer grid layout,
  - Completion of all testing and tooling stations for the assembly of larger triple-GEM test detectors and
  - Completion of mechanical design of a large triple-GEM detector segment and support structure.

- Barrel MicroMegas tracking detector development:
  - Design, assembly and test of two barrel MicroMegas small radius cylindrical shells,
  - Assembly of CLAS12 MicroMega[illegible]tectors,
  - Test of CLAS12 MicroMegas detectors in cosmic-ray test stand,
  - Test of light-weight, low capacitance flex cables and
  - Test of DREAM chip production versions.

- GEANT simulations of barrel and forward tracking detector setup and

- DVCS physics simulations.

The College of Science and Technology at Temple University provides new, outstanding educational and research opportunities with a strong emphasis on minority students and undergraduate students. Professor Bernd Surrow managed to attract several outstanding students, both foreign and domestic students. The funded BNL EIC R&D contract (RD 2012-3) has provided a huge attraction for students to join the Temple University group under the leadership of Professor Bernd Surrow.

Dr. Maxence Vandenbroucke is working since November 2013 at CEA Saclay focusing on the MicroMegas R&D program. The College of Science and Technology at Temple University generously provided support for a new postdoc Dr. Matt Posik focusing on all GEM R&D aspects, in particular the extensive characterization of single-mask produced GEM foils by Tech-Etch. While Dr. Maxence Vandenbroucke is continuing his engagement with this R&D program as a new staff member at Saclay starting October 01, 2014, we have identified with Dr. Matt Posik an outstanding candidate to continue as a new postdoc on the EIC R&D program presented here, which is in part the basis for our new continued funding request for FY15.

Dr. Franck Sabatie and Professor Bernd Surrow are working on establishing a Ph.D. program between Temple University and Université Pierre-et-Marie-Curie (Paris 6) or Université Paris Sud (Oray) in partnership with CEA (Commissariat l'énergie atomique) Saclay which would allow Ph.D. students to complete their course programs in both France and the US and carry out a thesis research in micro-pattern detector development. Ph.D. students in this program would be supported by both Temple University and CEA Saclay. Temple University is strongly engaged in international programs with several campuses such as the Rome and Tokyo campuses.

2 Progress report - Q2 FY14 / Q3 FY14

2.1 Forward GEM tracking detector development

Overview The highlight of the recent work concerning the GEM detector development is the successful commercial production of single-mask produced GEM foils and the subsequent testing at Temple University. Almost two dozen samples of small GEM foils of $10 \times 10\,\mathrm{cm}^2$ have been measured both electrically in terms of their leakage current performance and their optical properties using the CCD camera setup at Temple University. Large GEM foils have recently been received of $40 \times 40\,\mathrm{cm}^2$ which show equally superb electrical and optical performance. The production of single-mask produced GEM foils has therefore been firmly established. The next and final step concerns the production and testing of large samples up to $50 \times 120\,\mathrm{cm}^2$ in size. All measurements were carried out by Dr. Matt Posik who was hired in spring 2014 with generous support from the College of Science and Technology at Temple University. All GEM lab setups are now fully in place in the current Department of Physics. Preparations are underway to move to the new Science Education and Research Center with state-of-the-art laboratory facilities provided by Temple University for the development of micro-pattern detectors.

Status: Most goals have been achieved in particular the very successful production of single-mask produced GEM foils by Tech-Etch. All testing of electrical and optical uniformity parameters were carried out at Temple University. The assembly of triple-GEM detectors using Kapton ring based spacer grids is delayed until summer 2014 due to the delivery delay of all Kapton rings. All GEM lab equipment items are in place and fully functional including assembly and testing setups along with a complete APV-chip and DAQ readout system.

Laboratory setup and infrastructure at Temple University The College of Science and Technology provided dedicated lab space for the development of micro-pattern detectors focusing in particular on triple-GEM detectors in the current Department of Physics:

- Clean Room ($\sim 500\,$sq.ft.), Class 1,000: Handling of bare GEM foils including leakage current measurements and triple-GEM detector assembly / Microscope inspection of GEM foils.
- Detector lab ($\sim 1000\,$sq.ft.): Testing of triple-GEM detectors including cosmic-ray testing, ^{55}Fe-source testing and gas leak testing. A dedicated DAQ system based on the STAR FGT DAQ system is fully operational.
- CCD camera lab ($\sim 500\,$sq.ft.) exclusively used for the optical scanning of GEM foils.

The maintenance of the clean room is provided by the College of Science and Technology.

The current Department of Physics provides a well-equipped electronics and machine shop. The support from the technical staff was instrumental for the completion of various assembly and testing

Figure 2: *Complete GEM lab infrastructure at Temple University in the current Department of Physics showing a dedicated clean room for assembly and testing (b), the CCD-camera optical scanning table (a) and the actual GEM testing lab (c-e).*

setups. The electronics and machine shop along with the technical staff will be also available once the Department of Physics is located in a new building with the opening of the Science Education and Research Center starting in summer 2014.

Figure 2 provides and overview of the complete GEM lab infrastructure at Temple University in the current Department of Physics showing a dedicated clean room for assembly (b), the CCD-camera optical scanning table (a) and the actual GEM testing lab (c-e).

Figure 3 shows an overview of the new Science Education and Research Center. Professor Bernd Surrow played a leading role in the layout of a dedicated, large Class $1,000$ clean room facility ($1,800\,$sq.ft.) shown in Figure 3 (a). The maintenance of the clean room is fully covered by the College of Science and Technology. The main focus of the research activities are large micro-pattern detector development and silicon sensor handling, testing and assembly. In addition to the Class $1,000$ clean room facility, Professor Bernd Surrow participated in the layout of a dedicated detector lab ($800\,$sq.ft.) shown in Figure 3 (b).

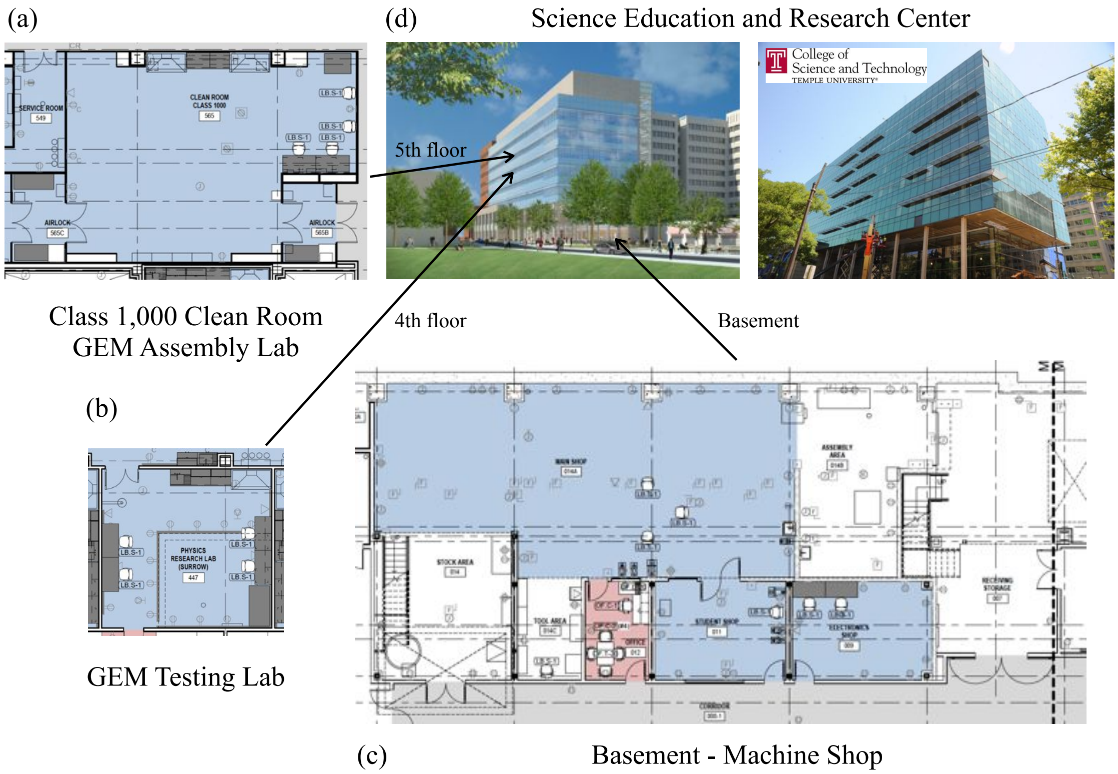


Figure 3: *Overview of the Science Education and Research Center (d) with state-of-the-art laboratory infrastructure based on a large Class 1,000 clean room (a) and GEM testing lab (b) along with a large machine shop (c) providing support for the Temple University research programs within the Department of Physics. The photograph of the SERC building (d) was taken on June 16, 2014.*

Status: GEM lab infrastructure complete and fully functional. Preparations are underway to move to the new Science Education and Research Center in September 2014.

Commercialization of single-mask GEM foil production up to $40 \times 40\,\mathbf{cm}^2$ The Nuclear and Particle Physics community requires large quantities of large-size GEM foils such as for the upgraded CMS muon system and the ALICE TPC upgrade and eventually for an EIC detector. The CERN photolithographic workshop has therefore started a collaborative process with Tech-Etch to transfer the CERN technology [2] to Tech-Etch with the goal in mind to provide commercially produced large GEM foils based on single-mask techniques. The management at Tech-Etch signed all technology transfer agreements. The Temple University group agreed with the Tech-Etch management to start the process with the single-mask production of $10 \times 10\,\text{cm}^2$ GEM foils followed by FGT-type GEM foils (about $40 \times 40\,\text{cm}^2$) based on existing Gerber files. It was agreed that the Temple University group will test those foils and provide feedback to optimize the single-mask production at the Tech-Etch production plant. The Yale University group agreed to provide in addition 55Fe source measurements of single foils. The Temple University group has been hosting ongoing phone meetings between CERN, Tech-Etch, and other institutions including FSU, Stony Brook University, Temple University, and Yale University. Samples of both $10 \times 10\,\text{cm}^2$ (18) and FGT sized $40 \times 40\,\text{cm}^2$ (3) single-mask foils have been received by Tech-Etch. Figure fig:photo-single-mask

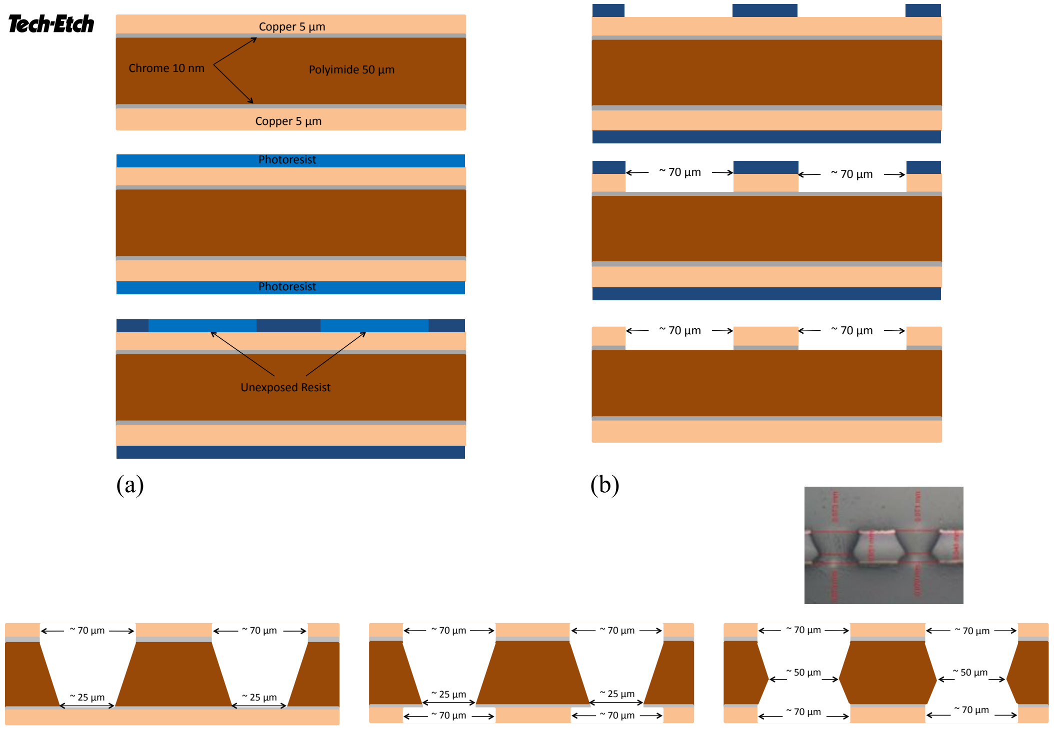
Figure 4: *Photograph of two single-mask produced GEM foils showing B. Surrow holding a large* $40 \times 40\, cm^2$ *GEM foil and M. Posik holding a small* $10 \times 10\, cm^2$ *GEM foil inside the permanent Class 1,000 clean room in the current Department of Physics.*

shows a photograph of two single-mask produced GEM foils showing Professor Bernd Surrow holding a large $40 \times 40\,\mathrm{cm}^2$ GEM foil and Dr. Mat Posik holding a small $10 \times 10\,\mathrm{cm}^2$ GEM foil inside the permanent Class 1,000 clean room in the current Department of Physics at Temple University. The processing steps are illustrated in Figure fig:single-processing. The bare Apical material and copper layers, followed by the coating of photoresist and laser direct imaging is shown in Figure fig:single-processing (a). The removal of unexposed photoresist and copper etching followed by the stripping of photoresist and removal of chrome adhesion layer is shown in Figure fig:single-processing (b). The first polyamide etching in EDA chemistry is shown in Figure fig:single-processing (c) followed by electrolytic etching to remove the backside copper in Figure fig:single-processing (d) and the subsequent second polyamide etching is shown in Figure fig:single-processing (e). A cross-section is shown for comparison.

The production of larger foils is generally limited to a width of about 50 cm due to the size limitation of APICAL base material distributed on standard-size rolls. Going to larger sizes such as those required for future EIC applications requires an upgrade of the production line at Tech-Etch including the purchase of new imaging and larger chemical etching bath setups. This aspect will be discussed below and in the proposal section.

The first type of characterizations performed on a GEM foil are electrical tests. As shown in Figure 6, a GEM foil is first placed in a gas tight plexiglass enclosure in order to provide a safe and dry nitrogen environment. The leakage current is then measured between the unsegmented side and segmented side, i.e. sector side for a GEM foil as a potential difference is applied up to 600 V. With increasing applied voltage, the current is monitored to avoid destructive discharge. The typical leakage current is generally below 1 nA. Figure 7 shows the results of such a measurement, in this case a single-mask FGT sized GEM foil from Tech-Etch.

This setup has been installed in the clean room at Temple University where this measurement



(a) (b)

(c) (d) (e)

Figure 5: *Illustration of the main processing steps showing the bare Apical material and copper layers, followed by the coating of photoresist and laser direct imaging (a). The removal of unexposed photoresist and copper etching followed by the stripping of photoresist and removal of chrome adhesion layer is shown in (b). The first polyamide etching in EDA chemistry is shown in (c) followed by electrolytic etching to remove the backside copper in (d) and the subsequent second polyamide etching is shown in (e). A cross-section is shown for comparison.*

is routinely performed in a clean environment by students as shown in Figure 6. All available single-mask foils ($10 \times 10\,\mathrm{cm}^2$ and all sectors of the FGT sized foils) have been tested. The typical leakage current measured on all single-mask GEM foils was below 1 nA. The excellent electrical properties seen in these foils is primarily due to changing the insulating base material from Kapton to APICAL. Kapton material has been previously used by Tech-Etch which showed clearly a larger leakage current performance typically below 10 nA, rather than below below 1 nA. Tech-Etch agreed with this finding since all GEM foils were independently tested using an identical electrical test setup. Apical is therefore clearly preferred over Kapton material and will from now on be used by Tech-Etch. The original COMPASS paper listed Kapton material based material for GEM foils, which was in fact Apical.

The development of large single-mask GEM foil production requires the setup of dedicated optical measurement tools. The CCD camera setup, as shown in Figure 8 (a), is a microscope coupled to a 2D motorized support to scan GEM foils with high precision. The apparatus is controlled by a MATLAB graphical interface shown in Figure 8 (b). This setup has been used to scan all available single-mask $10 \times 10\,\mathrm{cm}^2$ GEM foils, while a slightly modified version of this set up is currently scanning the single-mask FGT sized foils.

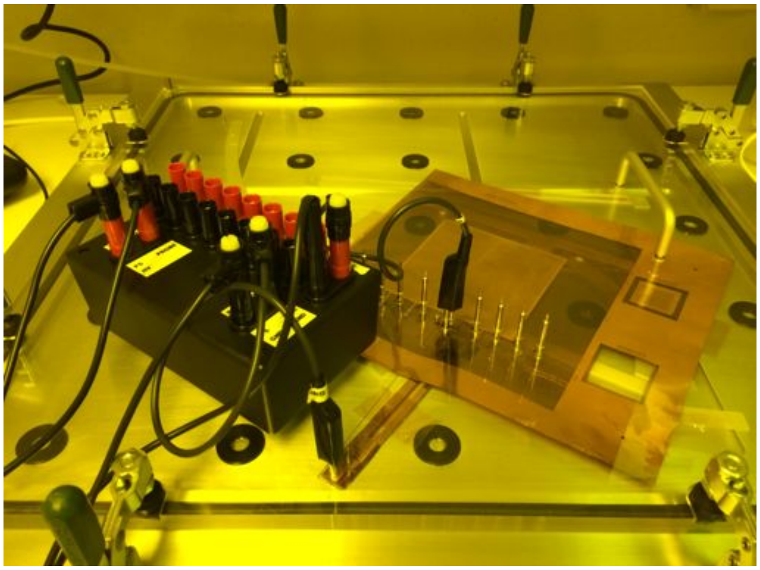


Figure 6: *Setup at Temple University to conduct electrical tests of GEM foils performed mainly by Temple University students.*

All $10 \times 10\,\mathrm{cm}^2$ single-mask foils have been scanned and their geometrical properties, which determine to the amount of gain produced from a GEM foil, have been characterized. This includes measurements of the pitch, inner hole diameter, and outer hole diameter distributions of each foil. Figure 9 show typical distributions of the single-mask $10 \times 10\,\mathrm{cm}^2$ GEM foils. As a consistency check with the measurements achieved by the Temple University group, Tech-Etch measurements of the foils geometrical quantities were also made. Figure 10 shows the cross-section of $10 \times 10\,\mathrm{cm}^2$ GEM foil measured by Tech-Etch, which is consistent with that measured by the Temple University group. It should be noted that the procedure used by Tech-Etch to measure the geometrical parameters of the foils is very different from that of the Temple University group's. The Temple University group measures every hole one the foil, while Tech-Etch measures only nine holes at a much higher magnification. A comparison between the Temple University group's and Tech-Etch's measurements for the average inner and outer hole diameters for each of the $10 \times 10\,\mathrm{cm}^2$ GEM foils can be seen in Figure 11. The error bars associated with the Temple University group's measurements represent the rms spread in the respective distribution. The average pitch measured by the Temple University group was found to be about 138 μm and was very consistent from foil to foil. Additionally, the uniformity of the inner and outer hole diameters over the surface of the foil can influence its gain. The deviation of the inner (outer) diameter from the foil's mean diameter was studied for each $10 \times 10\,\mathrm{cm}^2$ foil. The uniformity of the outer hole diameters showed a deviation of only about $\pm 5 \mu m$ from the mean, while the deviations on the inner hole diameters, which vary more due to their dependence on the etching time, are well below $\pm 10 \mu m$, as shown for a typical uniformity measurement in Figure 12.

If the hole diameter size varies widely across the foils, then this will lead to different amounts of charge being produced as the initial electron passes through holes of different sizes in each of the foils. To help quantify the sensitivity of the track reconstruction capability of a GEM foil due to this effect, a simple track reconstruction exercise was carried out. In this exercise it was assumed that the charge produced from a GEM foil was read out by 20 read out strips that were $520\,\mu m$

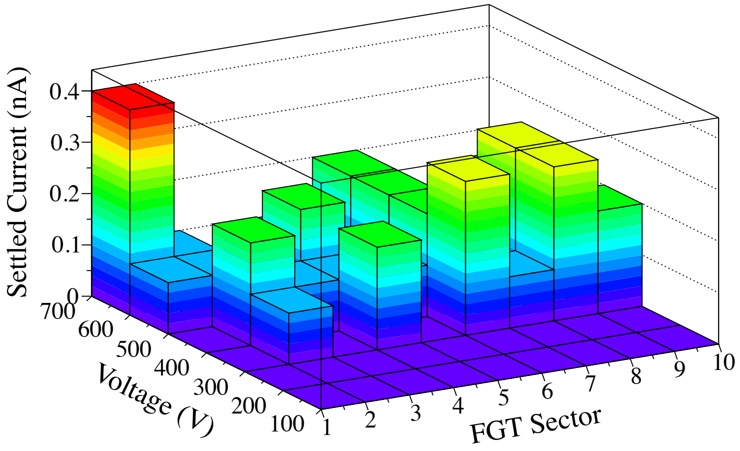


Figure 7: *Measured leakage settled current as a function of voltage and sector (1-9) for a single-mask FGT sized GEM foil (Tech-Etch). The settled current represents the value that our current measurement device (ISEG SHQ 222M) settled at with slight fluctuations around this number. The settled current is accurate to within approximately* $0.5\,nA$.

in length and each strip had a pitch of $600\,\mu m$ and was separated by 80 μm. A random Gaussian shaped charge cloud was then generated at a position x within the range covered by the read out strips (about $-6000\,\mu m \leq x \leq 6000\,\mu m$). Figure 13 shows the amount of charge collected from the charge cloud in each readout strip. The reconstructed position of the particle, is a charge weighted sum given by

$$\langle x \rangle = \frac{\sum\limits_i x_i Q_i}{\sum\limits_i Q_i}, \tag{1}$$

where x_i is the position and Q_i is the charge of the i^{th} read out strip. The reconstructed position sensitivity to the charge was quantified by randomly varying the collected charge on each read out strip by ±5% and ±50%. The reconstructed position was found not to rely too much on the charge fluctuations, as the change in $\langle x \rangle$ between the large charge variations of ±5% and ±50% was only a few μm. The most sensitive quantity to the charge variations was the resolution of the reconstructed position. Although even this was found not to be that significant overall, with the ±5% (±50%) charge variation producing about a 1% (4%) increase in the reconstructed width relative to a reconstructed position with no charge variation.

The optical setup, shown in Figure 8, that was used to scan the $10 \times 10\,\text{cm}^2$ GEM foils had to be slightly modified in order to accommodate the larger FGT sized GEM foils. This required installing a large ($86 \times 76\,\text{cm}^2$) steel plate over the 2D motorized support. This provided a large enough area for the FGT sized foils to lay. The steel framing and glass that the FGT sized foil is encased in was also enlarged so that the entire foil is visible. Due to the limited range of motion of the 2D

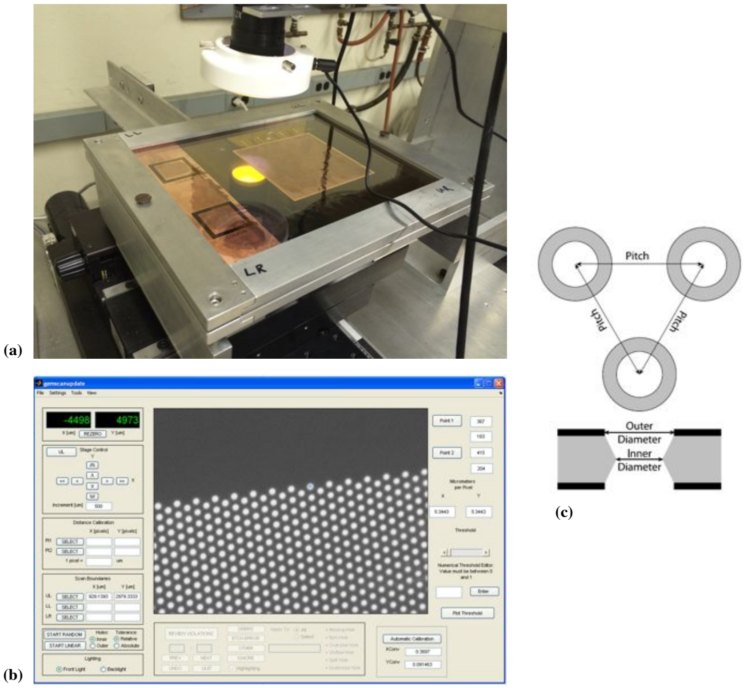


Figure 8: *(a) GEM foil scanner, (b) User interface and (c) Hole geometry of a GEM foil.*

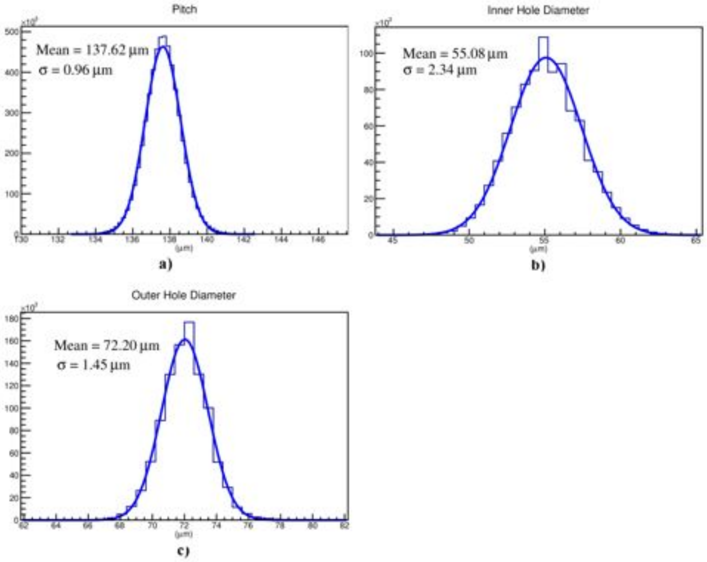


Figure 9: *(a) Pitch distribution, (b) Inner diameter distribution and (c) Outer diameter distribution of a single-mask* $10 \times 10\ cm^2$ *Tech-Etch GEM foil.*

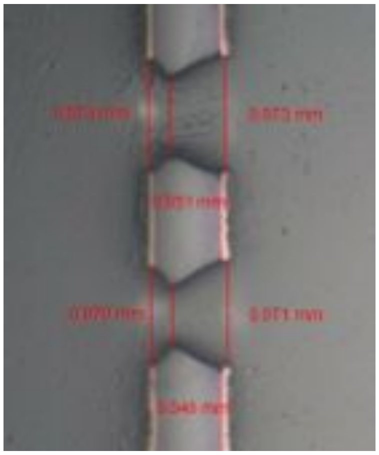


Figure 10: *Cross-section of a Tech-Etch single-mask* $10 \times 10\ cm^2$ *GEM foil.*

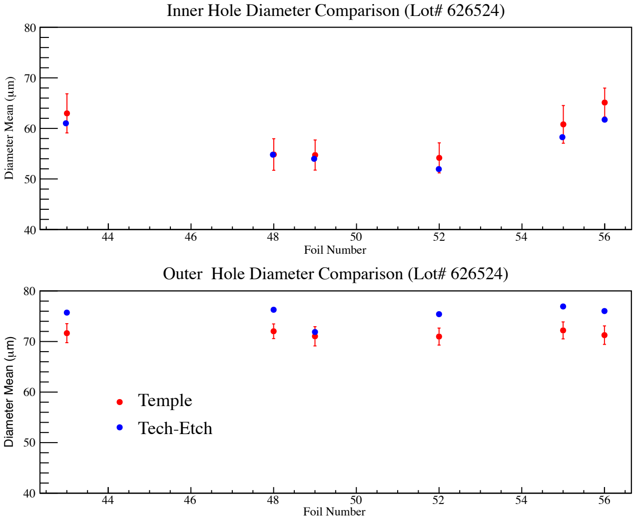
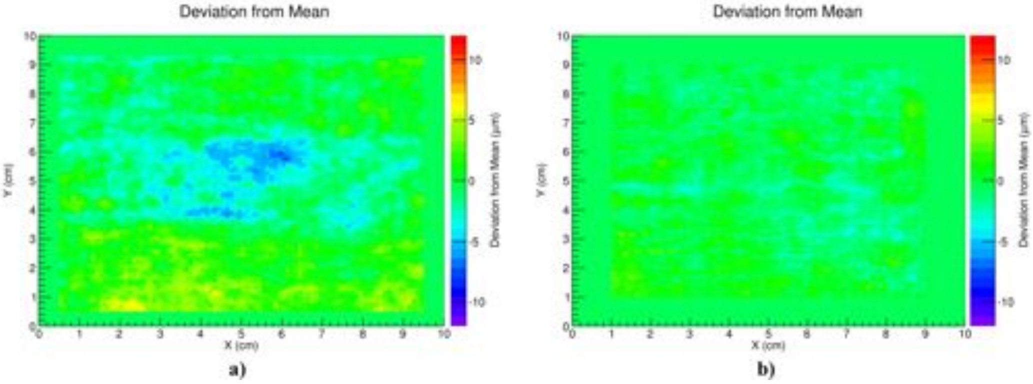


Figure 11: *Tech-Etch and Temple hole diameter measurement comparisons for single-mask* $10 \times 10\ cm^2$ *GEM foils.*



a)

b)

Figure 12: *Typical (a) inner hole diameter and (b) outer hole diameter deviations from the mean for single-mask* $10 \times 10\ cm^2$ *foils.*

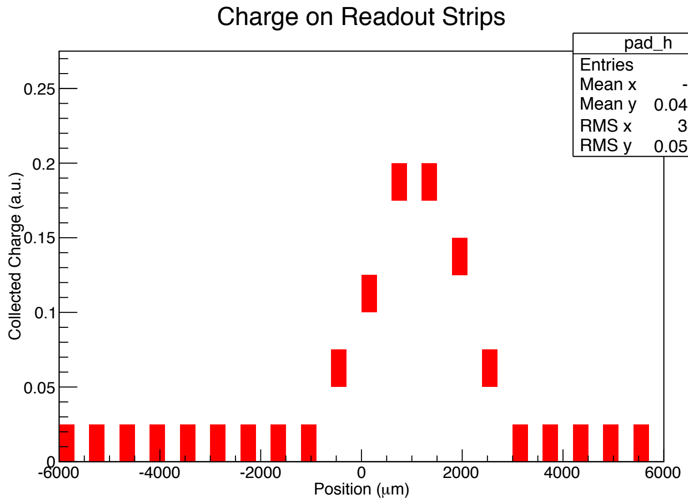


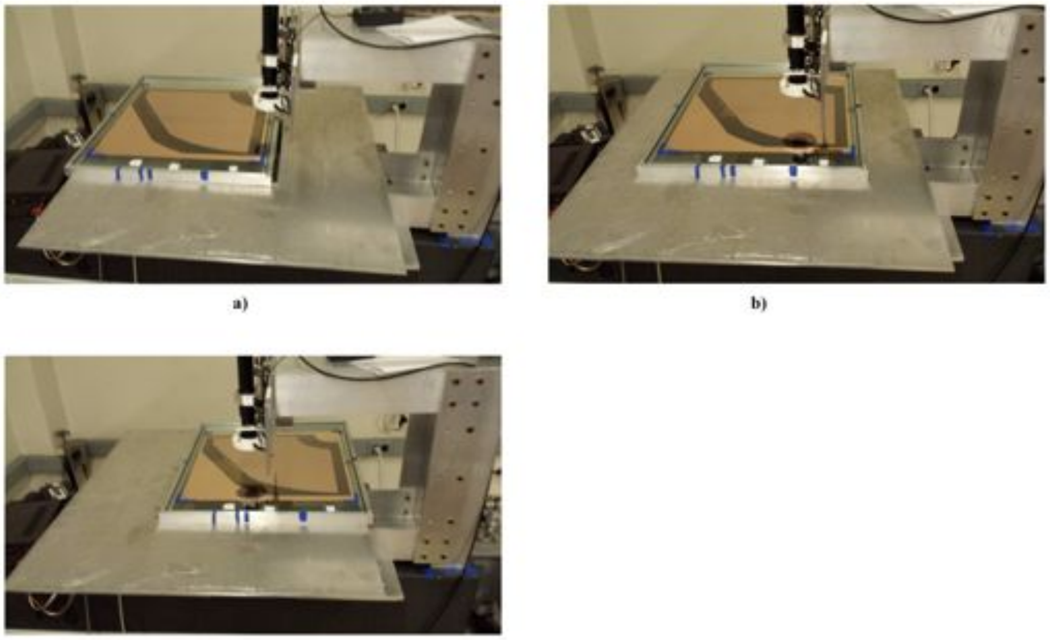
Figure 13: *The amount of charge collected on a simple read out strip geometry.*

support stage, one FGT sized foil needs to be divided into six optical scan regions in order to cover the entire active area of the GEM foil. By positioning the frame containing the foil at three specific locations relative to the CCD camera, three sections of the foil can be scanned. The other three sections of the GEM foil can then be scanned by rotating the frame containing the GEM foil by 180° and positioning it again at each of the three specific locations. The three locations used to complete half of the optical scans of a FGT sized GEM foil can be seen in Figure 14.

The modified optical setup has been completed and single-mask FGT sized GEM foil characterization is underway. Some of the initial scans from one of the six scan regions of a single-mask FGT sized foil have already been analyzed. These initial results appear to be similar with those measured for the single-mask $10 \times 10\,\text{cm}^2$ GEM foils. The pitch and inner hole diameter distributions are shown in Figure 15 for one of the six CCD scan regions.

Status: All available single-mask foils ($10 \times 10\,cm^2$ and FGT sized foils) have been successfully electrically tested. Leakage currents are well below $1\,nA$. Geometrical characterization of all available $10 \times 10\,cm^2$ single-mask GEM foils have been completed. The optical measurement setup have been modified to characterize single-mask FGT sized GEM foils, and measurements are currently underway.

Test of DAQ system and APV-chip readout system A complete APV25-S1 chip based DAQ system has been set up at Temple University. Figure 16 (a) shows a photograph of the VME crate with two readout control modules and 12 readout modules allowing to read out a total of 240 APV25-S1 chips. Also shown is the actual DAQ computer located above the VME crate. A group of 5 packaged APV25-S1 chips as shown in Figure 16 (b) is mounted on a APV readout module which can be connected to a triple-GEM detector such as a small triple-GEM detector of size $10 \times 10\,\text{cm}^2$ or a STAR FGT triple-GEM detector. Figure 16 (c) shows the typical mean pedestal distribution for a APV readout module with five 5 packaged APV25-S1 chips.

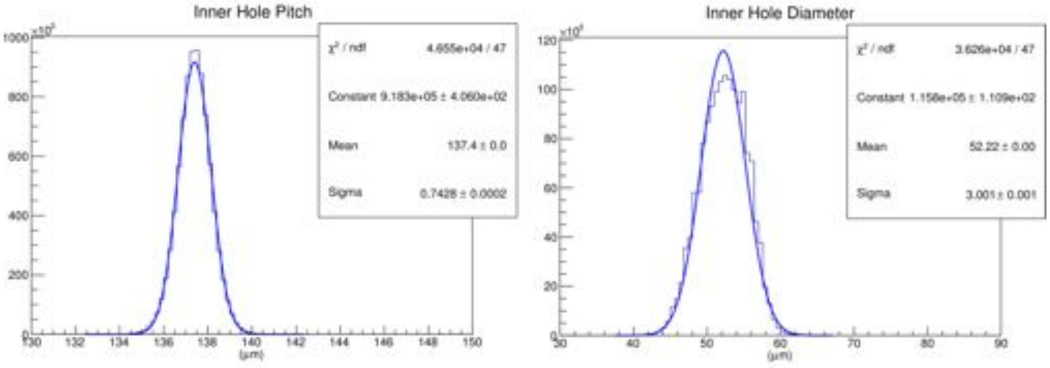


a)

b)

c)

Figure 14: *(a), (b), and (c) show the three specific positions used to scan half of the FGT sized GEM foils. The remaining half of the GEM foil is scanned by rotating the frame with the GEM foil by 180° and repeating the scans at the same three locations.*



a)

b)

Figure 15: *(a) Pitch distribution (b) Inner hole diameter distribution for about 1/6 of a Tech-Etch produced single-mask FGT sized GEM foil.*

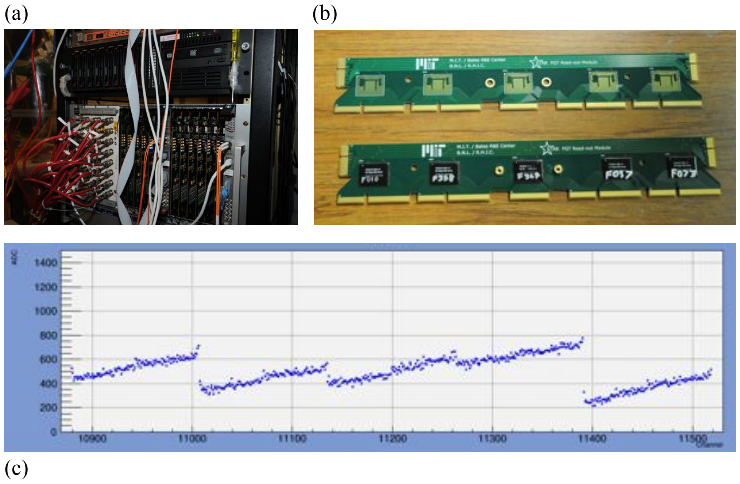


Figure 16: *(a) Photograph of the complete VME DAQ crate with two readout control modules and 12 readout modules allowing to read out a total of 240 APV25-S1 chips together with a APV readout module (b) and the mean pedestal distribution for one APV readout module (c). Also shown in (a) is the actual DAQ computer located above the VME crate.*

Status: Complete APV25-S1-based readout, control and DAQ system functional under routine operation by students.

Commercial fabrication of Kapton rings A novel design of a spacer grid based on arrays of thin-walled Kapton rings between GEM foils has been designed. Figure 17 shows the full technical drawing of both 2 mm and 3 mm versions. Two companies are involved in the manufacturing process. Both have been chosen for cost optimization. American Durafilm in Holliston, MA is providing the Kapton tubing material at a length of 36" and inner diameter of 2". Upon successful microscope inspection at Temple University, this material is then sent to Potomac in Lanham, MD for laser cutting according to our technical drawings shown in Figure 17.

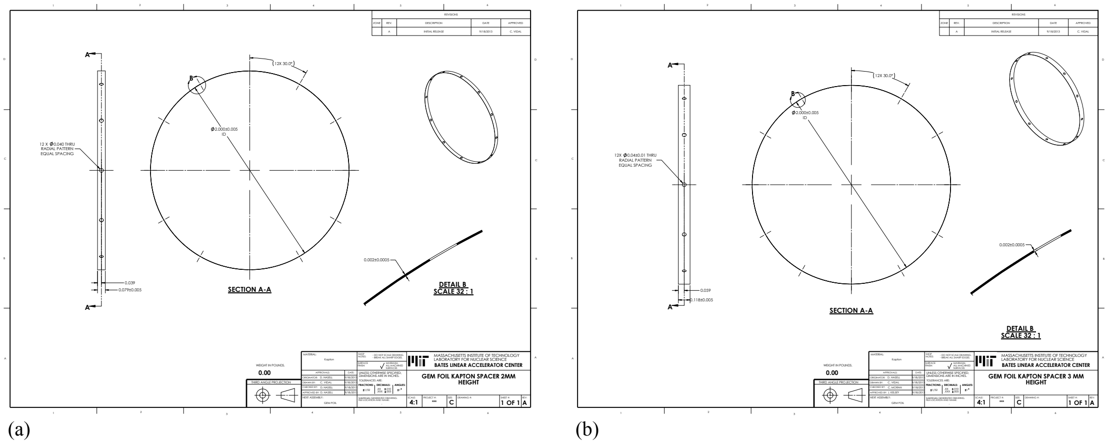


Figure 17: *(a) Kapton ring with 2 mm thickness and (b) Kapton ring with 3 mm thickness.*

Status: Delay in delivery of Kapton tubing material to July 2014 followed by laser cutting of all Kapton rings. Assembly process is expected to start by the end of August 2014.

Setup of assembly tools Assembly and stretching tools exist for FGT-type quarter sections. A new mechanical engineer started in January 2014 as part of the hire of a new senior faculty member at Temple University, Professor Jim Napolitano. The support for our new mechanical engineer is provided by the College of Science and Technology at Temple University. The stretching fixtures have been fully commissioned. Figure 18 shows the complete testing and assembly fixtures for FGT-type triple-GEM detectors. This setup will be used to built a set of four FGT-type triple-GEM detectors with Kapton spacer grids and single-mask produced GEM foils. The testing and assembly fixtures include the leakage current setup (a-b), a microscope inspection station (c), a GEM foil stretching fixture (d), a soldering fixture with a new soldering exhaust fume setup (e) and two assembly fixtures (f) with special covers allowing gas flow after each assembly setup to verify that the leakage current performance has not been altered during a previous assembly step. The testing and assembly fixtures are setup on new stainless clean room tables inside the permanent Class 1,000 clean room in the current Department of Physics and will be moved to the new clean room facility in fall 2014.

Status: All assembly and stretching tools have been setup and are fully functional. The leakage current setup is under routine usage by students at Temple University.

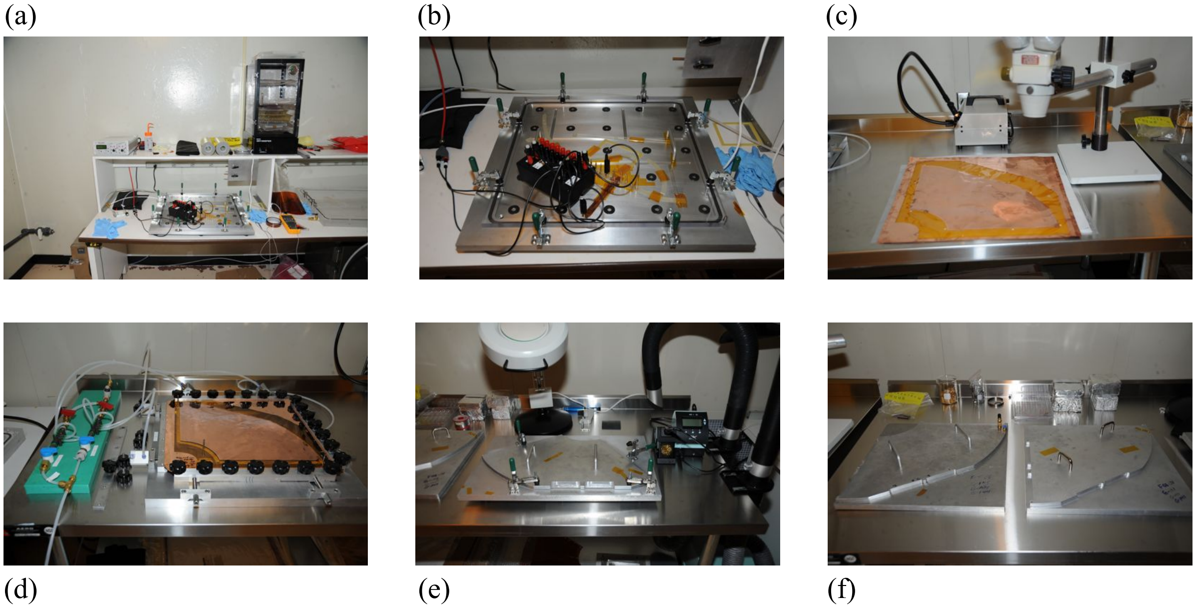


Figure 18: *The testing and assembly fixtures include the leakage current setup (a-b), a microscope inspection station (c), a GEM foil stretching fixture (d), a soldering fixture with a new soldering exhaust fume setup (e) and two assembly fixtures (f) with special covers allowing gas flow after each assembly setup to verify that the leakage current performance has not been altered during a previous assembly step.*

^{55}Fe-source scan setup and large area cosmic-ray test stand Gain calibration is an essential tool in characterizing a triple-GEM detector. The automation of such a measurement has been enabled by the purchase of a Multi-Channel analyser coupled to a precision pre-amplifier (ORTEC 142A) and a pulser for calibration. With the large active area foreseen for the next generation of triple-GEM detectors, it will be necessary to have multiple gain measurements to ensure gain uniformity. With the help of a XY scanning table, shown in Figure 20, we are developing an automated measurement to produce a 2D gain calibration map. In addition, we are preparing a cosmic-ray stand using two large-area scintillator tiles as shown in Figure 19.

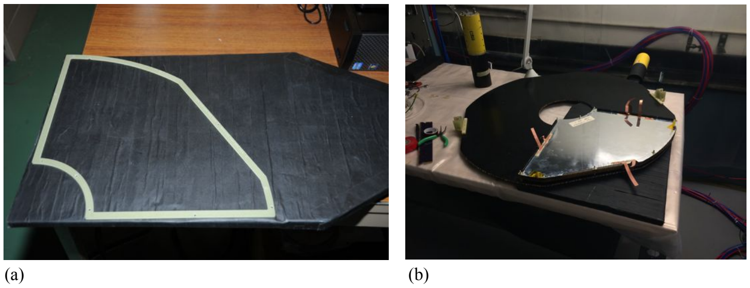

(a) (b)

Figure 19: *Large-area scintillator counters for a dedicated cosmic-ray test stand for FGT-type triple-GEM detectors.*

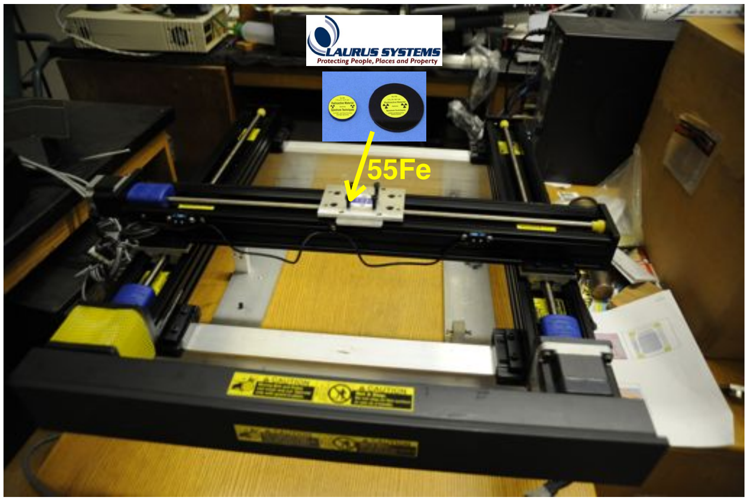


Figure 20: *Scanning table setup for a ^{55}Fe source scan of large GEM foils.*

Status: Operation of scanning table under LabView control. Synchronization of table movement and DAQ operation in progress. Large-area cosmic-ray test stand in preparation. Preparation of special readout card coupled to Multi-Channel analyser is in preparation.

Fabrication of large GEM foil storage units A SolidWorks design model, as shown in Figure 21, has been completed by a Temple University undergraduate student from the Department of Mechanical Engineering. The large units will be manufactured and assembled by the machine shop and will be available for the new SERC building in fall 2014.

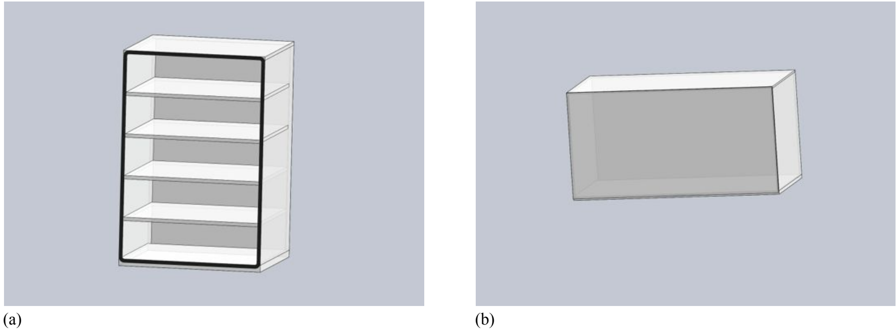

(a) (b)

Figure 21: *SolidWorks layout of nitrogen storage cabinets for GEM foils.*

Status: Fabrication, assembly and installation discussed with machine shop. Storage units will be available for the new SERC building in fall 2014.

Assembly of small triple-GEM prototype chambers In order to test GEM foils inside a detector, four triple-GEM prototype chambers of $10 \times 10\,\mathrm{cm}^2$ have been assembled 22. The tests will focus on the gain uniformity of small single-mask GEM foils and cluster size studies.

Status: Assembly of two test chambers completed. Components for two additional test chambers in preparation including fabrication of frames.

Cluster size studies and HV system commissioning The spatial resolution required at the EIC for the triple-GEM detectors is about $100 - 200\,\mu$m, which is a standard performance for a GEM tracking detector. The spatial resolution results from a complex combination of the distance between electrode (the pitch), the size of the electron signal, and the signal to noise ratio of the detector. As a result, it is difficult to predict the spatial resolution of the detector at the design level and high granularity (small pitch) is often used to ensure the best performances. However this requires expensive readout boards, a large number of electronics channels, and therefore the need for power and cooling. The main idea is to adjust the individual potential difference around each triple-GEM detector layer. A multi-channel CAEN HV system has been acquired and fully commissioned as shown in Figure 23. The cluster studies will start once the small triple-GEM chambers are ready which is expected to be the case by fall 2014.

Status: Commissioning of multi-channel CAEN HV system completed. Cluster studies are expected to start in fall 2014.

Mechanical design of large triple-GEM detector segment and support structure The design of the next generation of triple-GEM detectors for an EIC detector requires minimal dead material and good uniform acceptance. We would like to stress that our mechanical design therefore focuses on lightweight materials and overlapping detector segments. A triple-GEM detector is inherently light. It consists of a stack of Kapton foils for electrodes and GEM amplification, and

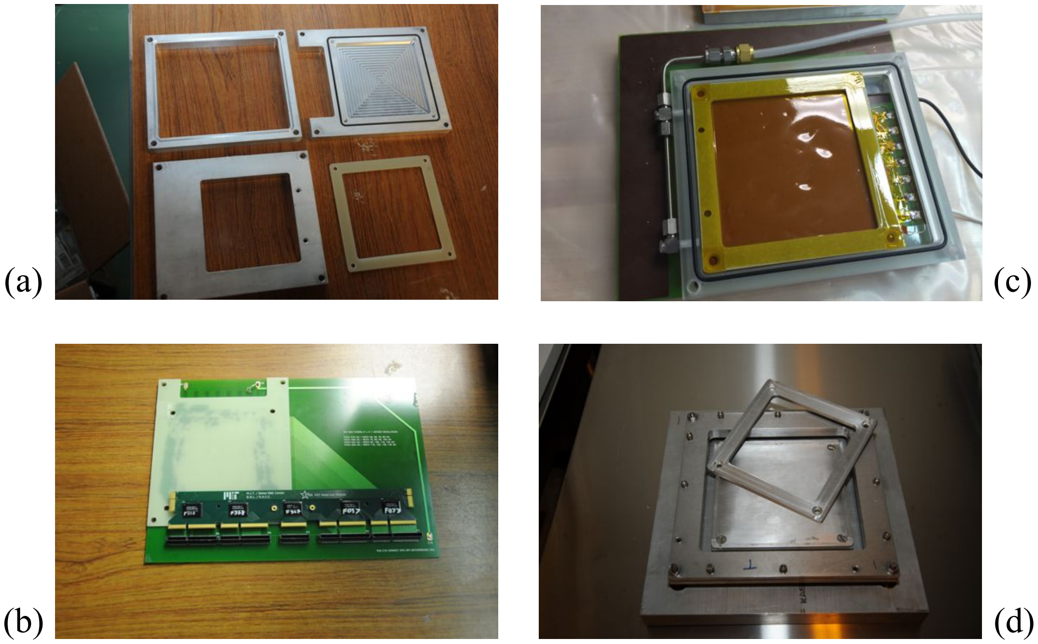


Figure 22: *Components of small triple-GEM prototype chambers of* $10 \times 10\,cm^2$ *(a), readout board with APV board interface (b), completed chamber (c) and stretching fixture (d).*

Mylar foils for gas-tight enclosure. Larger dead material is generally introduced by electronics and services. The idea here is to place all electronics and service components on the outer radial region of the detector (Figure 26 (b) and (d)) providing full mechanical support. This leaves the remaining part of the detector to be extremely light and allows to keep structural support at a minimum inside the active area. The layout of a GEM foil with 11 segments is shown in Figure 27. The preparation of Gerber files is in progress.

Each long segment will be supported on a wheel-like carbon-fiber structure as shown in Figure 24 (a) and (b). The chambers are stacked face-to-face to provide easy access avoiding dead areas between detectors as shown in Figure 25 (a)-(e). A discussion with Eric Anderson, head of the Carbon-Composite (CC) shop at LBL, took place in November 2013 focusing on the feasibility to manufacture the proposed structure. The CC shop at LBL strongly encouraged us that such a structure could certainly be built upon final mechanical design review. The design will be discussed with two new collaborating institutions, Florida Institute of Technology under the leadership of Professor Markus Hohlmann and the University of Virginia under the leadership of Professor Nilanga Liyanage. The EIC R&D committee strongly encouraged such a collaborative effort. The fabrication will begin along with tooling preparation once agreement has been reached of the full design.

Status: SolidWorks design at Temple University completed. Preliminary design discussion with MIT Bates engineering team in April 2014. Collaboration with FIT and UVA building dedicated EIC triple-GEM forward segments. Prototyping of support material at Carbon-Composite shop at LBL planned for fall 2014 after agreement has been reached on the full design.

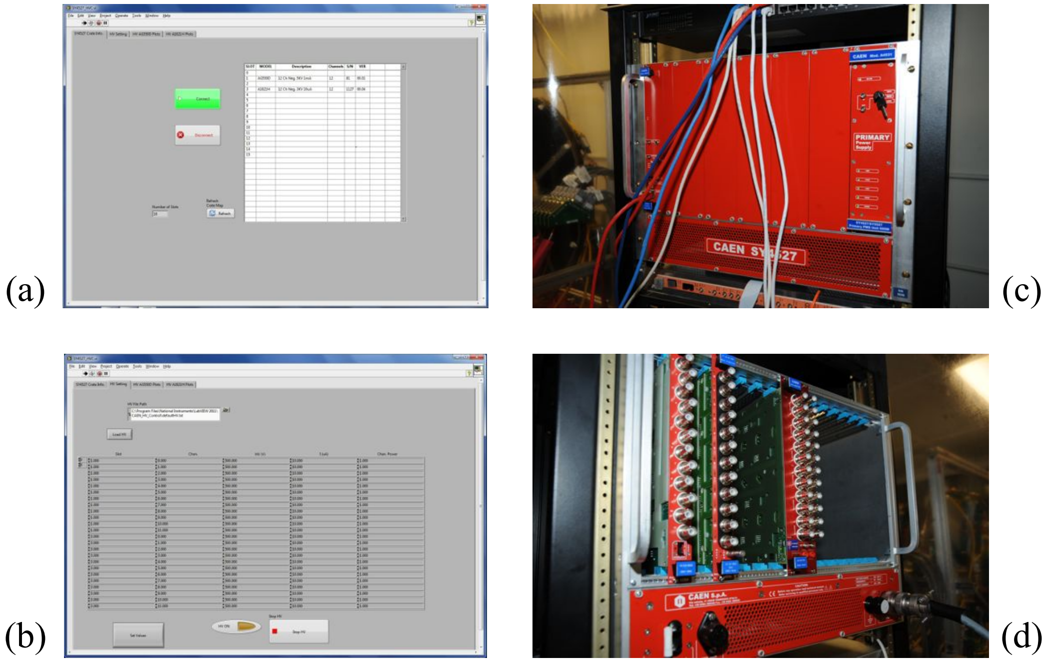


Figure 23: *CAEN HV system showing the front (c) and back-side (d) under lab view control (a-b).*

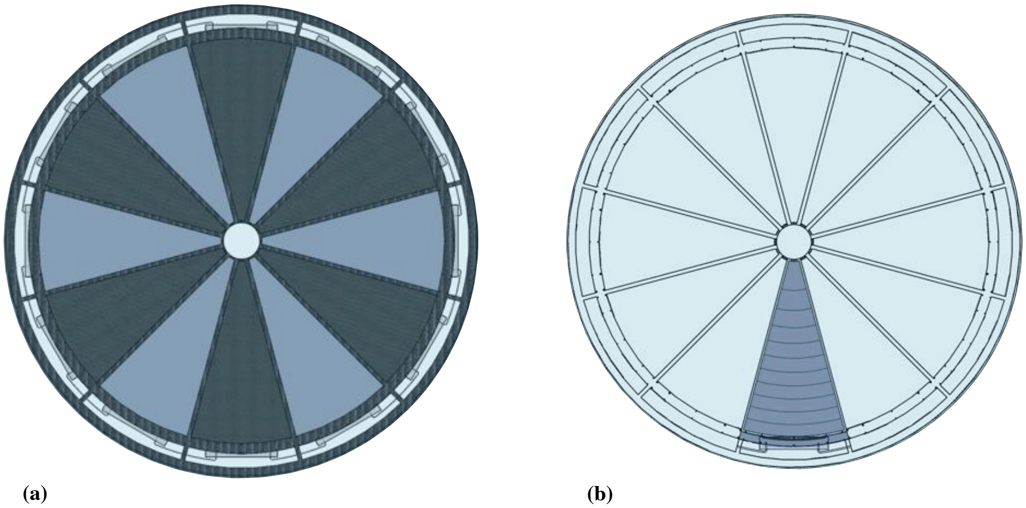


Figure 24: *Disk layout of 12 large triple-GEM detector segments.*

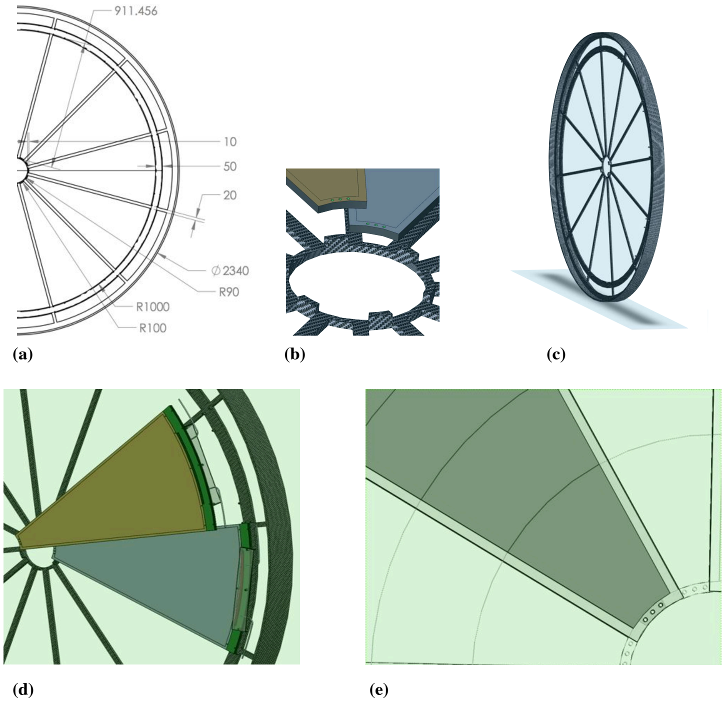


Figure 25: *Details of disk dimensions and support of individual triple-GEM detector segments.*

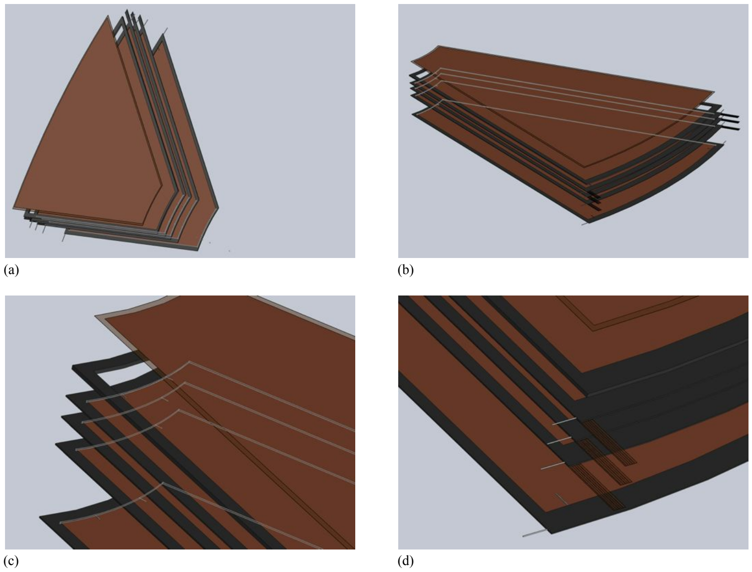


Figure 26: *Detailed view of segment design.*

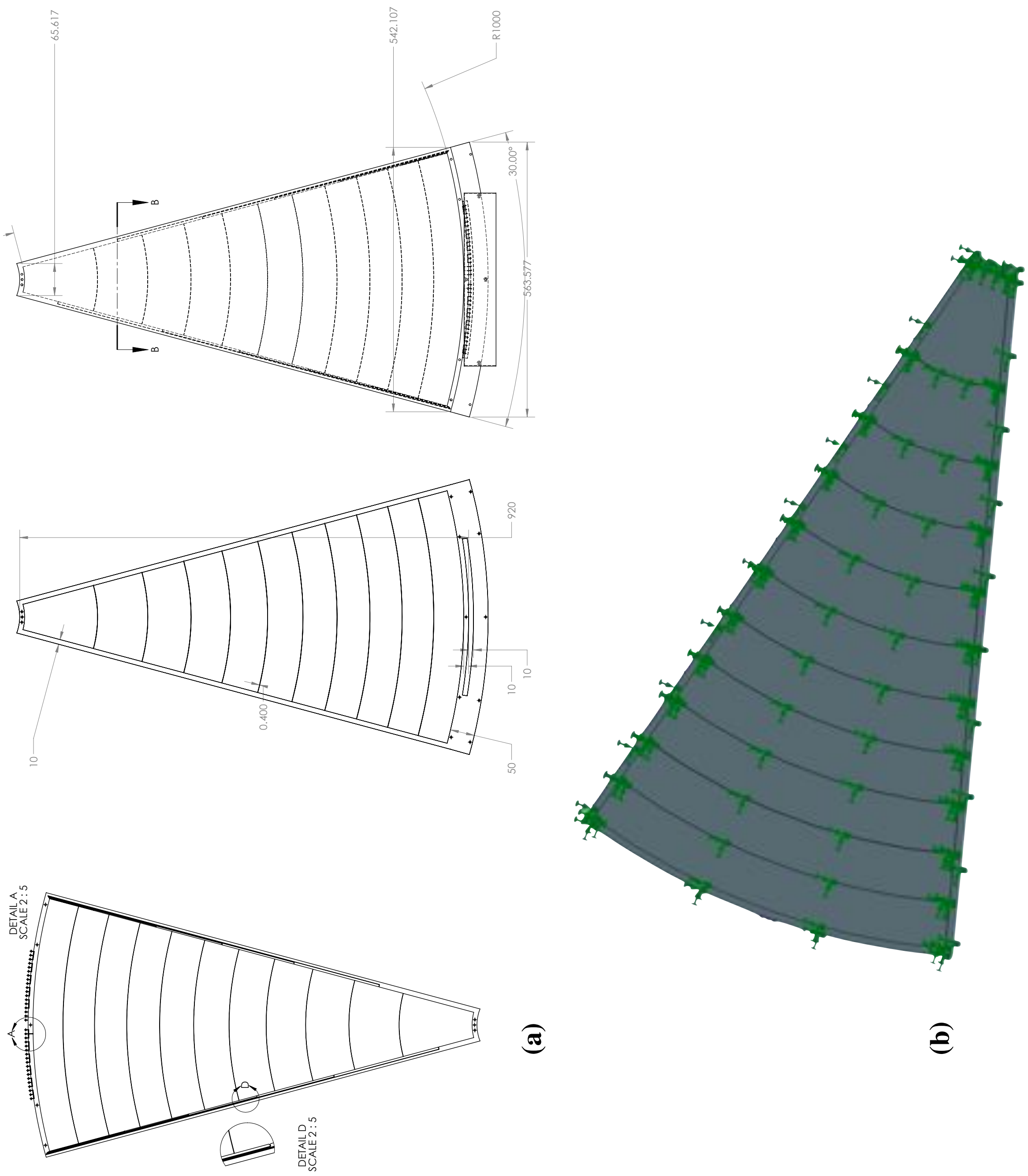
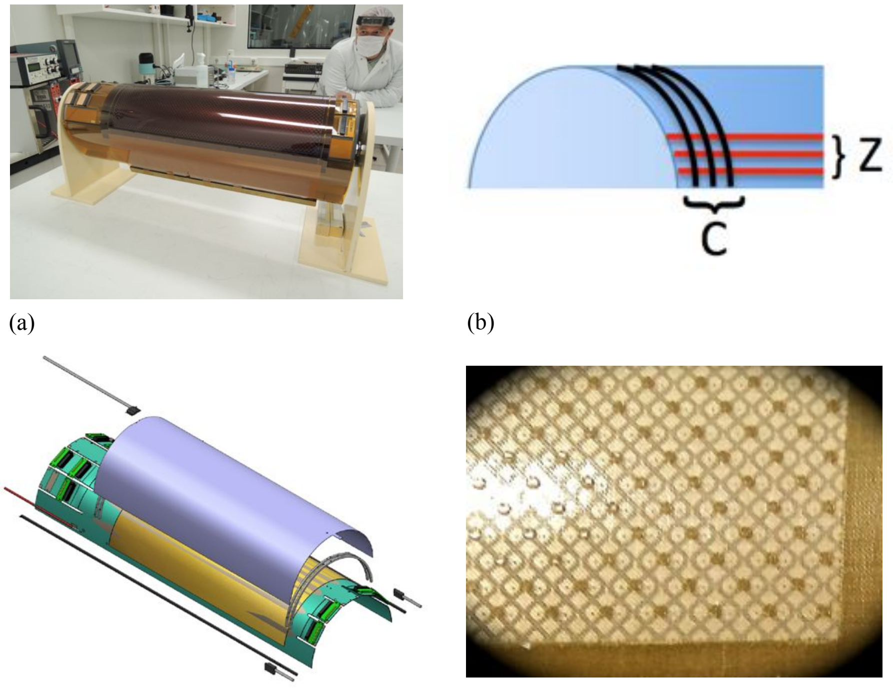


Figure 27: *Layout of large segment GEM foil with 11 sectors.*

2.2 Barrel MicroMegas tracking detector development

Characterization of a cylindrical 2D MicroMegas prototype The barrel MicroMegas R&D program proposes a MicroMegas barrel system as a central tracker for an EIC detector as shown in Figure 1. This barrel system is composed of several layers of cylindrical MicroMegas chambers, covering a radial region of approximately $10 - 60\,\mathrm{cm}$. Due to delays of the production of large radius prototype sectors at CERN covering an azimuthal angle of 60° with a radius of 50 cm, it was decided to start with the development of the smaller radial region sector consisting of a 180°, 10 cm radius prototype shell in partnership with the ASACUSA (Atomic Spectroscopy And Collisions Using Slow Antiprotons) collaboration. This shell would correspond to the inner-most layer of a MicroMegas barrel tracking system. The large bending of the structure is mechanically quite challenging due to large mechanical stress of the micro-mesh and readout electrode. This prototype offers the possibility to work with a full geometrical configuration of a barrel system.



(a) (b) (c) (d)

Figure 28: *Fully assembled prototype in Saclay's cleanroom (a), 2D readout scheme with C-Z strip orientation (b), Exploded view of the prototype (c) and detailed view of the active area with 2D readout diamond pads connected by strips along the C and Z projections seen under the woven micro-mesh (d).*

Prototype description The prototype chamber as shown in Figure 28 consists of cylindrical half with a radius of 9.5 cm and a length of 60 cm. This prototype tracking layer provides measurements of the longitudinal (Z) and transverse (C) coordinates as shown in Figure. 28. The chosen readout pitch of 0.87 mm results in ~250 Z and ~500 C strips per chamber. This detector follows closely the CLAS12 lightweight design and preserves the requirement for a future EIC barrel tracking system.

The characterization of this prototype has focused on the following key points:

- Basic characterization and efficiency measurement,
- Rigidity of the self supporting structure and
- Spatial resolution of a cylindrical MicroMegas and micro-TPC algorithm.

Basic characterization and efficiency measurement The large bending of this prototype creates large mechanical stress of the different materials, in particular the metallic micro-mesh. Nevertheless, due to the high quality production at CERN and assembly at Saclay, this first prototype showed excellent performance. It has been tested in a cosmic ray test bench at Saclay for several days and operated in a very stable fashion. A run of 2.4 millions cosmic ray events were taken during 113 hours. This data set has been used to map the efficiency of the detector as shown in Figure 29.

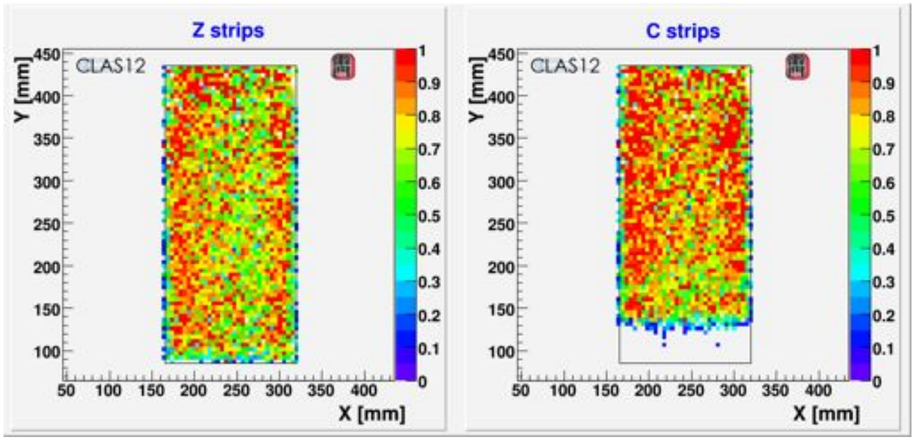


Figure 29: *Efficiency of cylindrical MicroMegas prototype for both projections in Z and C. The inactive area on the C projection corresponds to an unconnected area.*

The overall efficiency has been measured to be 76% in Z and 81% in the C coordinate. These values are lower than the typical efficiency of a MicroMegas detector ($> 98\%$). This is not unexpected taking into consideration the moderate gain and the 3 mm conversion volume. The data has been taken with an operating voltage of 410 V on the MicroMegas for safe operation, which is below the full efficiency operation mode. The use of resistive technology to increase the stability at high gain will be tested for the next generation of detector for an EIC, in particular with the large 60° prototype, expected to arrive in a couple of weeks. The 3 mm conversion gap has been chosen to reduce the effect of the large magnetic field (~ 5 T) of the ASACUSA experiment. In the case of a perpendicular muon track, this gap is too low to provide enough primary electrons. Therefore it lowers the efficiency in the horizontal part of the half cylinder and it explains the lower efficiency in the middle of the 2D plots shown in Figure 33) along the Y axis.

Rigidity of the self supporting prototype Mechanically, the detector consist of a 100 μm FR4 readout printed circuit board with an embedded micro-mesh. The amplification electrode, or micro-mesh, is a 60 μm thick non-magnetic metallic woven mesh held at a distance of $\sim$128 μm from the readout PCB by pillars etched in photosensitive films. The drift electrode is a 250 μm copper coated Kapton structure held by carbon spacers on the side of the detector. The active area does not include any dead space. This lightweight design results in very small material budget as required for an EIC tracking system. This prototype is a unique opportunity to test an EIC-like mechanical design as shown in Figure 30.

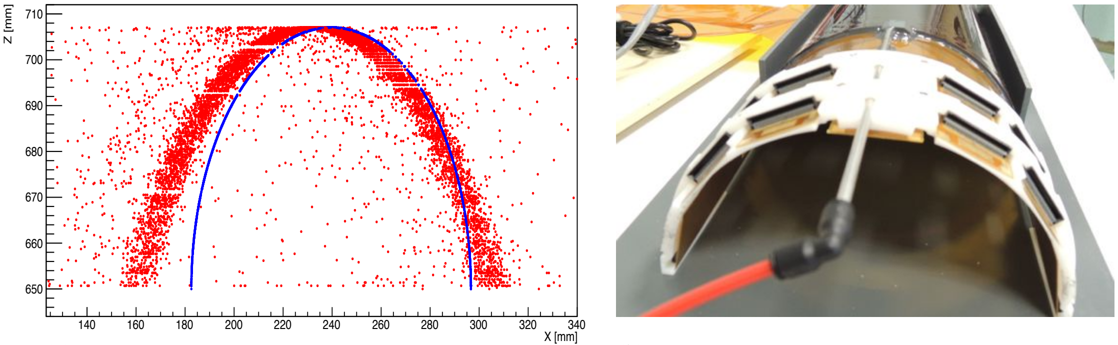
(a) (b)

Figure 30: *Cylindrical MicroMegas prototype in the cosmic-ray test bench (a) and detailed view of the detector edge (b).*

The orientation of the prototype detector in a cosmic-ray test stand (Figure 30) impacted the cylindrical shape due to gravity. As shown in Figure 31, the data have highlighted some minor deformations. The edges are further apart than excepted. Therefore it has been decided to add a mechanical structure on the side of the detectors, outside of the active area, for the next generation of prototype chambers as shown in Figure 31. This mechanical structure has been produced in one piece with 3D printing techniques at Saclay. This would have been very expensive with conventional techniques which would require to machine a large piece of raw material to the required cylindrical shape.

Spatial resolution of a cylindrical MicroMegas and micro-TPC algorithm MPGDs detectors are usually used as planar detectors where the particle track angle with respect to the readout plane is around 90°. When the angle decreases, the charge is smeared over a wider area of the readout plane. The effect on the resulting signal amplitude is shown in Figure 32. This lowers the spatial resolution of tracks that are bend by the magnetic field in an collider-like detector configuration. These low momentum particles are reconstructed with less precision.

When the charge is more spread out, it becomes difficult to reconstruct the position of the incident particle because the signals have a lower amplitude and a weighted mean of the amplitude does not represent the exact position of the impinging particle anymore. That is the reason why a micro-TPC algorithm was studied which uses the time information in the drift volume simiar to a TPC. The impact of the track angle on the resolution has been shown in a MC simulation of the MicroMegas chambers as shown in Figure 33.



(a) (b)

Figure 31: *Comparison between the expected position in the prototype plane (blue dots) and the reconstructed position of cosmic-ray tracks (red dots) (a) and 3D printed mechanical structure developed to correct for deformations (b).*

Figure 33 shows that the different versions of the micro-TPC algorithm perform better at large angles than the standard weighted mean algorithm [A]. The algorithm [B] uses the entry and exit points of the track in the gas volume to extrapolate to the original position. Algorithm [C] uses the full primary electron information to fit a straight line for the extrapolation. Algorithm [D] does the same as algorithm [C] with only using the time information of the first electron arriving at a given strip as in a real detector. All this shows that the method is correct and that the more information is included on the time of arrival of individual primary electron, the better the actual performance. Next generation of electronics will have to aim for the best time resolution possible to exploit these new reconstruction possibilities.

To test the conclusions of this simulation, a planar detector has been mounted on a special mechanical arm to precisely control the angle. The comic ray test bench capabilities in term of spatial resolution are lower than the expected effect. New studies will be performed with more precise detectors.

Status: Full characterization of a half-cylindrical prototype has been performed at Saclay with cosmic rays. This prototype has proven the feasibility of using a MicroMegas detector with minimal material budget. Careful study of the data indicates the need to continue this R&D program with resistive technologies to increase the operational gain. Finally a MC simulation study has shown promising results for the reconstruction of particles at large angle.

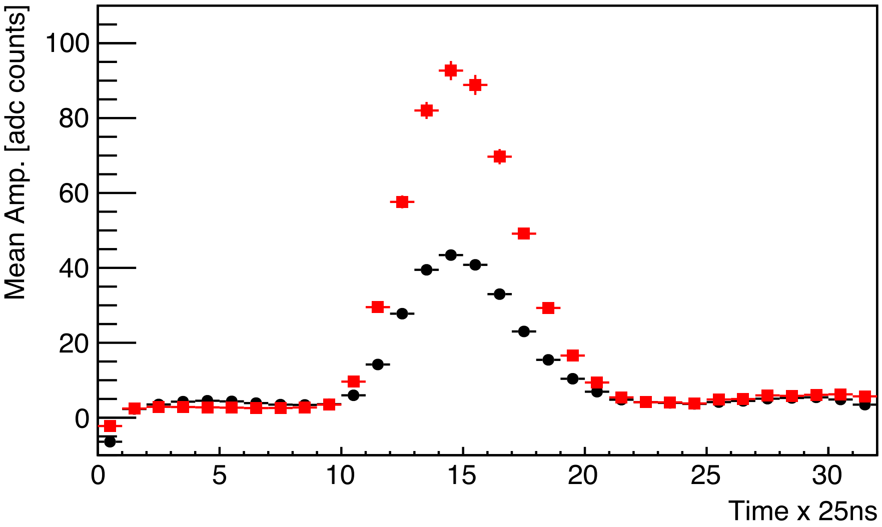


Figure 32: Average amplitude of MicroMegas signals with comic rays. Comparison between the sides of the cylindrical detector (black dots) and central region (red squares). Tracks perpendicular to the readout plane leads to a more concentrated charge that induces a larger signal.

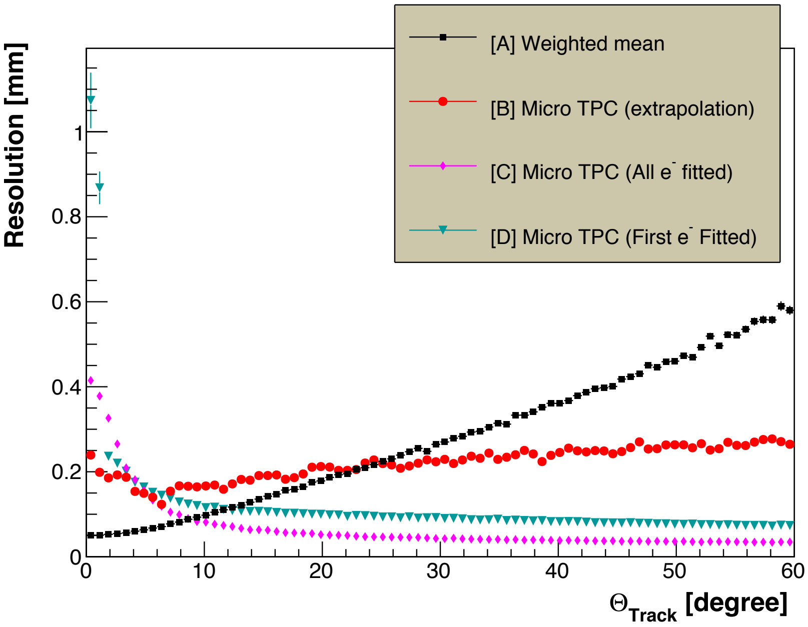


Figure 33: *MC simulation of the spatial resolution of a MicroMegas detector as a function of track angle for different reconstruction algorithms.*

2.3 Front-End Electronics development

The first batch of DREAM ASICs has been successfully produced this year. The production and test of the complete front-end electronics system has recently started. The main components are the Front-End Units (FEU) with 8 DREAM ASICs controlled by one FPGA. The FEU are mounted inside a standard electronics rack as shown in Figure 34 and directly connected to the detectors strips via special flat cables.

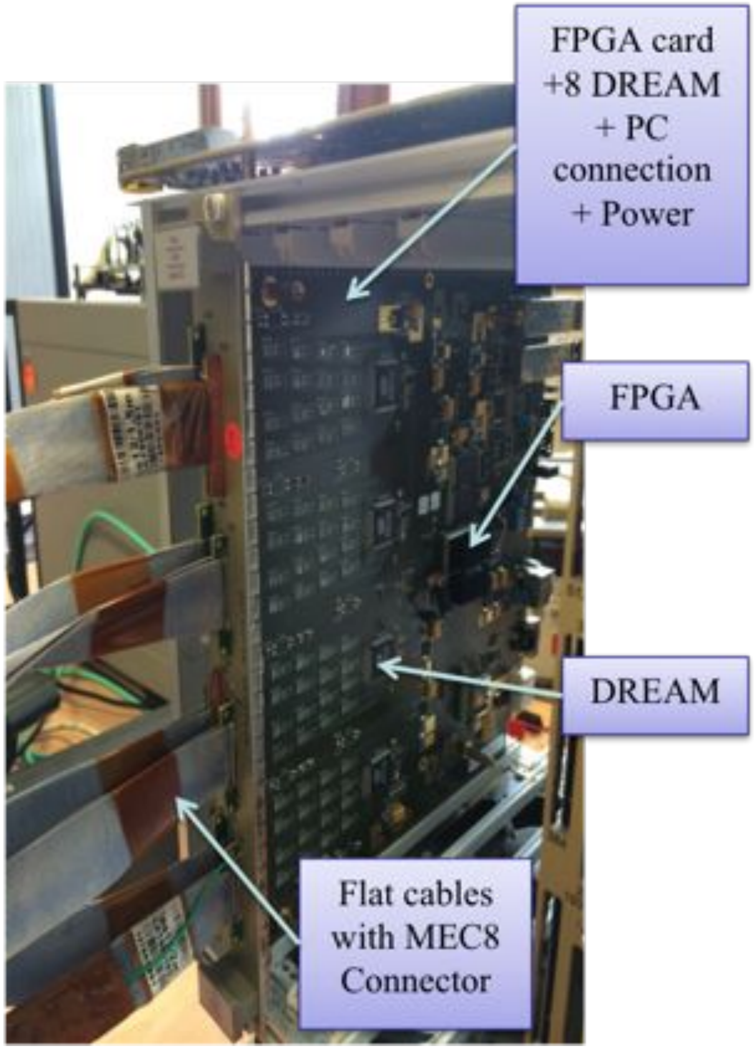


Figure 34: *DREAM front-end electronic card and front-end electronics system.*

The DREAM based system has been successfully tested with MicroMegas detectors. It is now replacing the AFTER/T2K based electronics to read-out 6 tracking chambers of the comics-ray test bench at Saclay. The comparison between the performances of the two systems is shown in Figure 35.

Figure 35 shows that the efficiency is much higher with the DREAM FEE due to better signal to noise performance. When the full efficiency is reached, both systems are significantly above

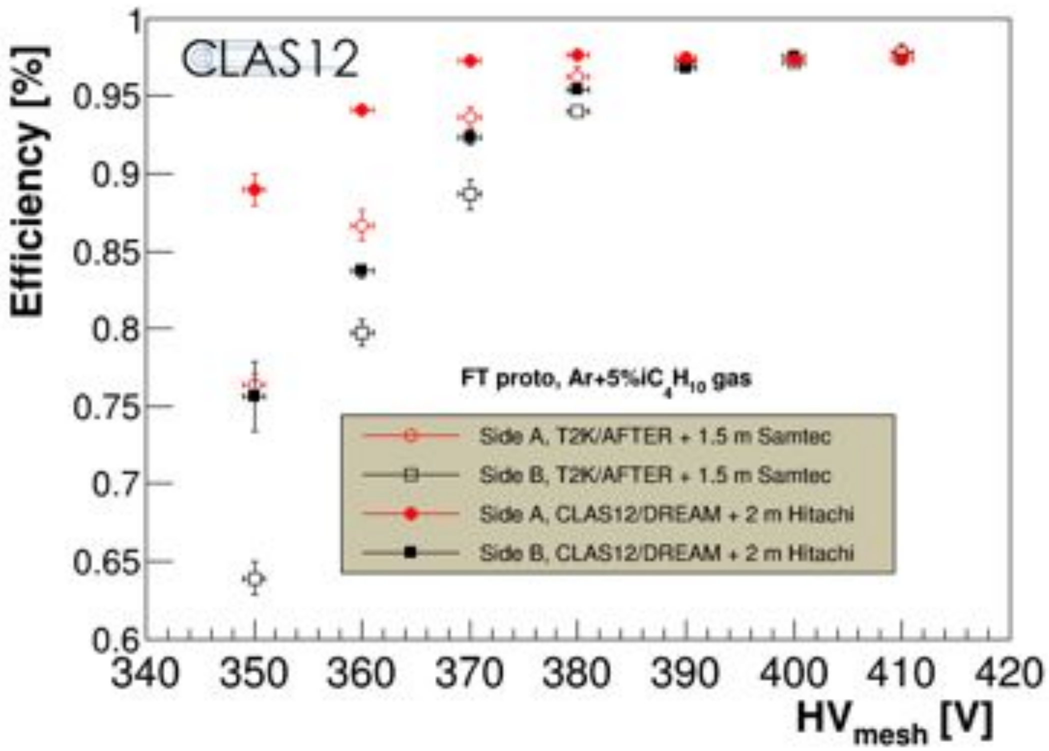


Figure 35: *Efficiency plateau of a CLAS12 prototype with the DREAM and AFTER front-end electronics.*

noise and there is no difference in detector performance. However the full efficiency is reached more than 20 V before with the DREAM chip version which is a significant improvement compared to the AFTER chip version. This was expected since the DREAM chip is optimized for large capacitance detectors unlike other ASICs such as AFTER or the APV-25. DREAM is based on the AFTER ASIC with several improvements in particular in the memory management to increase trigger capabilities. The DREAM system has been successfully tested up to a rate of 10 kHz. The setup of a DREAM chip based readout system for a triple-GEM detector will be discussed in the proposal section.

Status: Successful DREAM chip production and test of complete front-end system.

2.4 Simulations

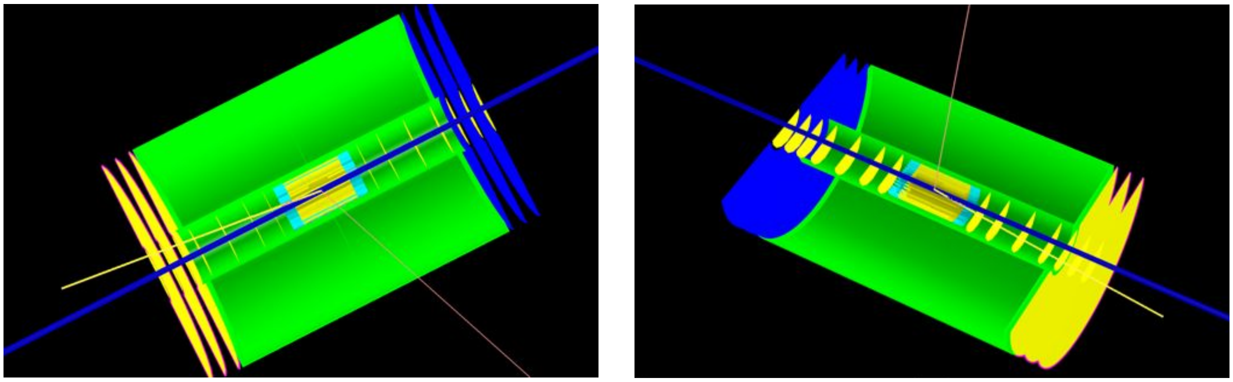
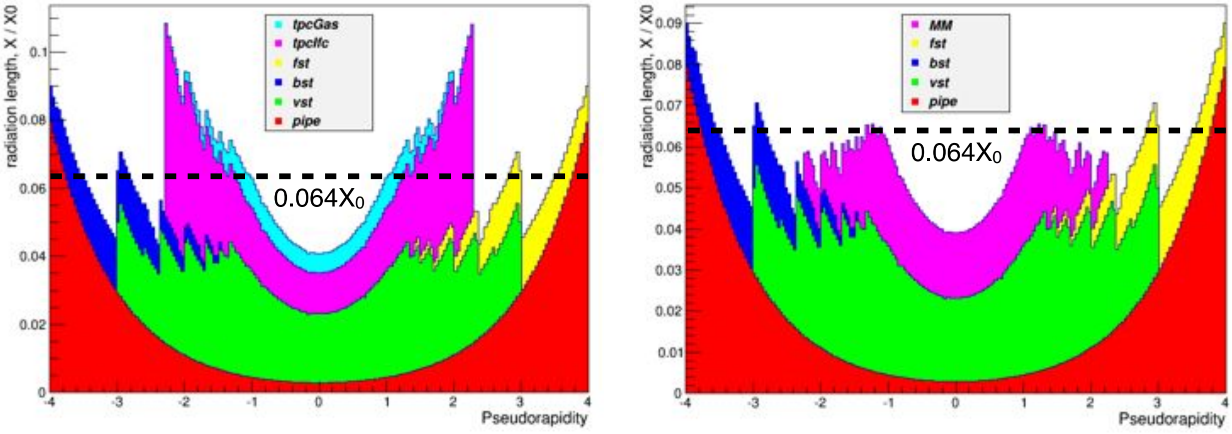

(a) (b)

Figure 36: *Screen captures of DVCS events generated by MILOU within the EICROOT framework.*

The simulation of EIC detector has moved forward focussing on the tracking detectors of the central region. The following milestone have been reached :

- Implementation of the barrel MicroMegas and Forward GEM tracker active volume description,
- Material description of the MPGD detectors,



(a) (b)

Figure 37: *Material scan for a TPC solution (a) and the MicroMegas barrel (b) solution [3].*

- Installation of the EICROOT software framework at CEA which is the first installation outside of the BNL computer facility,
- Simulation of DVCS events using the FORTRAN based generator MILOU based on 15 GeV electrons on 50 GeV protons and

- Test of the software interface between MILOU and EICROOT.

The installation of the EICROOT framework, and, in particular all the necessary packages, turned out to be a rather difficult task outside the BNL computing environment. This has delayed systematic studies with physics events. A major simulation effort is beginning at Saclay to test the performances of the different tracking solutions as proposed here.

The material distribution in GEANT is shown in Figure 37. The MicroMegas detectors are still described with a relatively simple model using extrapolations from the CLAS12 experiment for the barrel and from the STAR experiment for the Forward GEM tracker. These distributions show that the barrel solution seems to compete favorably with a TPC solution in term of material budget.

Status: Realistic material description of the FGT and MicroMegas systems have been implemented in EICROOT and compared to the standard central detector model. EICROOT has been successfully installed on the Saclay's computer grid. DVCS physics events have been generated using the MILOU generator and systematics studies of the barrel performance are beginning.

3 Proposal - FY15

3.1 Forward GEM tracking detector development

The R&D plans concerning the Forward GEM tracking detector efforts will address and complete several items:

- Characterization of large single-mask GEM-foils up to $50 \times 50\,\text{cm}^2$
- Assembly and test of $40 \times 40\,\text{cm}^2$ sectors with Kapton ring spacer grids and single-mask GEM foils
- Cluster size studies and gain 55Fe studies with small triple-GEM detectors of $10 \times 10\,\text{cm}^2$
- Finalize design of large dedicated EIC triple-GEM segment $50 \times 120\,\text{cm}^2$
- Systematic 2D readout foils tests and commercial production of very large 2D readout foils of 50×120 cm^2
- Commercialize production of very large single-mask GEM-foils of 50×120 cm^2

The last three items are the main focus of a dedicated effort of Temple University starting a new collaboration with the Florida Institute of Technology (FIT) group headed by Professor Marcus Hohlmann and the University of Virginia (UVa) group headed by Professor Nilanga Liyanage. Both groups have been so far part of the RD2011-6 EIC R&D program. The EIC R&D committee encouraged varies GEM detector R&D groups to work more closely together. Such efforts already started with the single-mask production of GEM foils with FIT, Temple University and Yale University. Each group has a diverse set of expertise which will be very beneficial for the design, assembly and test of a dedicated EIC triple-GEM forward detector segment. More details for all of the above R&D programs will be provided below.

Characterization of large single-mask GEM-foils up to $50 \times 50\,\text{cm}^2$ The need for large GEM foil production using single-mask manufacturing techniques and their characterizations have already been discussed in chapter 2.1. Significant progress has been made in characterizing the Tech-Etch produced single-mask GEM foils. All $10 \times 10\,\text{cm}^2$ foil characterizations have been finished and the process of characterizing a few remaining FGT sized single-mask GEM foils is underway.

Yale University plans to receive a larger $50 \times 50\,\text{cm}^2$ single-mask GEM foil from Tech-Etch. Arrangements have been made with Yale University to have the $50 \times 50\,\text{cm}^2$ foil shipped to Temple University for characterization of the foil using Temple University's optical analysis tools.

Temple University plans on ordering single-mask $10 \times 10\,\text{cm}^2$, FGT sized ($\sim 45 \times 45\,\text{cm}^2$), and EIC type ($\geq 50 \times 50\,\text{cm}^2$) GEM foils from CERN in order to provide a direct comparison to Tech-Etch's produced single-mask GEM foils. This comparison will help to serve as a systematic assessment of Tech-Etch's foils. Samples of size $10 \times 10\,\mathrm{cm}^2$ are expected to arrive early in July 2014.

An upgrade to Temple University's optical analysis setup will be required to efficiently scan and characterize the larger EIC type GEM foils. The current setup is hindered by a small CCD scan area, which results from short X-Y stage translational limitations. A proposed update to this setup can be found in the following paragraph.

Upgrade of optical CCD scanning setup for large GEM foils up to 50×120 cm^2 The optical analysis setup at Temple University is currently restricted to a CCD scan region of $\sim 10 \times 12\,\mathrm{cm}^2$, due to the limited range of motion in the X-Y stage. Scanning large area GEM foils with Temple University's current optical analysis setup requires dividing the GEM foil into smaller CCD scan regions and repositioning the GEM foil relative to the CCD camera; this is a very time consuming process. A complete scan of an EIC type foil using Temple University's current optical setup would take on the order of two weeks per foils side. Therefore in order to efficiently scan large area GEM foils, there is a plan to upgrade the optical analysis setup to allow the CCD scan region to cover approximately $120 \times 60\,\mathrm{cm}^2$. This would allow for the complete characterization of an EIC type GEM foil in one CCD scan.

Initial designs for the optical analysis upgrade can be seen in Figure 38. This design would take advantage of three new linear stages from Newport, one of which is shown in Figure 38 a). There would be two linear stages that transverse 60 cm along the y-axis and one linear stage that travels 120 cm along the x-axis (axies defined in Figure 38). These new stages will be controlled using two Newport 2-axis motion controllers. A steel plate ($\sim 120 \times 60\,\mathrm{cm}^2$) will be mounted on top of a marble table. The steel plate will have a rectangular inset in the center where a matrix of lights will be placed in order to illuminate the under side of the GEM foil. These lights are needed to measure the inner hole diameters of the foil. Laying over the center inset in the steel plate will sit the GEM foil sandwiched between two glass plates. The two 60 cm linear stages will be mounted to the 60 cm sides of the steel plate, which will be responsible for motion along the y-axis. The 120 cm linear stage will be connected to both 60 cm linear stages and be responsible for motion along the x-axis. The CCD camera will be mounted to the under side of the 120 cm linear stage, and have a ring of LED lights attached to it, which are needed for outer hole diameter measurements of the foil. This setup will allow the CCD camera to span an area of approximately $120 \times 60\,\mathrm{cm}^2$ while the GEM foil remains stationary.

Assembly and test of 40×40 cm^2 sectors with Kapton ring spacer grids and single-mask GEM foils Two problems in realizing large area GEM detectors is maintaining a uniform gap between foils and holding the foils flat. The gap between foils, for a given high voltage configuration, determines the electric field between foils. This in turn determines the amount of charge entering and exiting the holes in the GEM foils and hence the gas transfer. Thus, the gap determines the gain of the GEM detector. For a typical GEM foil gap of 2 mm a variation around ±0.3 mm is acceptable. Holding the foils flat is also important to avoid areas with wrinkles or creases that could lead to electrical breakdown or discharges that could damage the GEM foils or readout electronics.

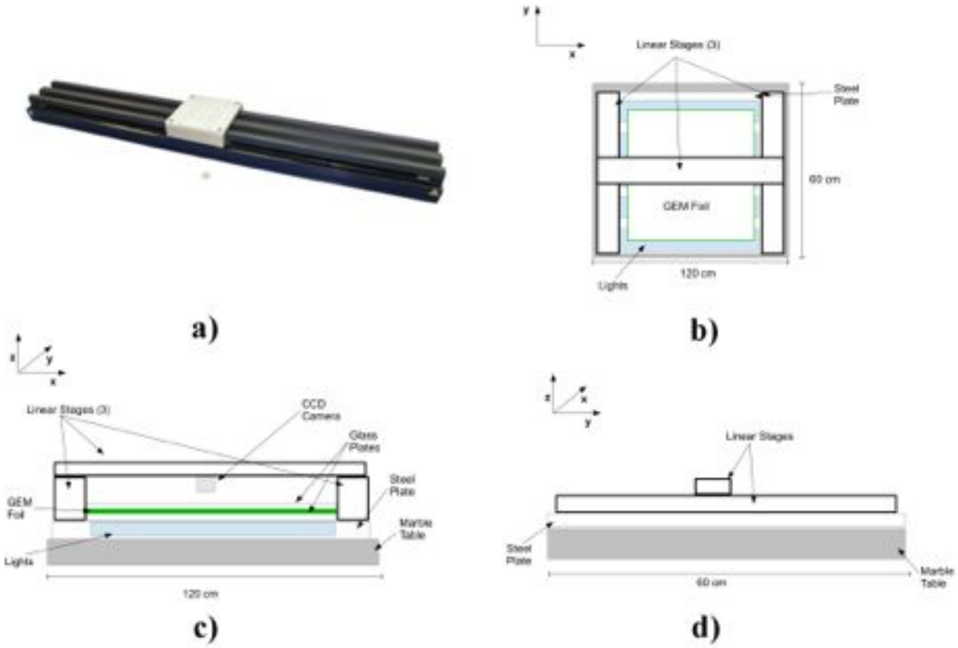


Figure 38: *a) One of three new linear stages from Newport needed for Temple University's optical analysis upgrade. b) Top-down view of the proposed optical analysis upgrade. c) Shows the front side view (looking down the y-axis). d) Shows a side view (looking down the x-axis) of the proposed optical scan upgrade.*

It is planned to built FGT-type triple-GEM detectors using Kapton spacer grids. The design has already been discussed in Chapter 2. We do expect to have all Kapton rings available by the end of summer 2014. Furthermore, we plan to use only single-mask produced GEM foils which have already been received and for one all electrical and optical scan have been successfully completed. It will be necessary to fabricate a mold to initially hold all Kapton rings in place. It has not been decided if gluing Kapton rings together might be necessary.

Cluster size studies and gain 55Fe studies with small triple-GEM detectors of $10\times10\,\mathrm{cm}^2$

The spatial resolution required at the EIC for the triple-GEM detectors is about $100 - 200\,\mu$m, which is a standard performance for a GEM tracking detector. The spatial resolution results from a complex combination of the distance between electrode (the pitch), the size of the electron signal, and the signal to noise ratio of the detector. As a result, it is difficult to predict the spatial resolution of the detector at the design level and high granularity (small pitch) is often used to ensure the best performances. However this means expensive readout boards, a large number of electronics channels, and therefore the need for power and cooling. The goal of this study is to reduce the granularity without compromising the performance.

A new CAEN HV system has been fully commissioned. This system will be used to individually under LabView control adjust each potential difference around each GEM foil. The assembly of small, $10 \times 10\,\mathrm{cm}^2$, triple-GEM detectors is underway. All components all available apart from frames to gluing existing single-mask $10 \times 10\,\mathrm{cm}^2$ GEM foils.

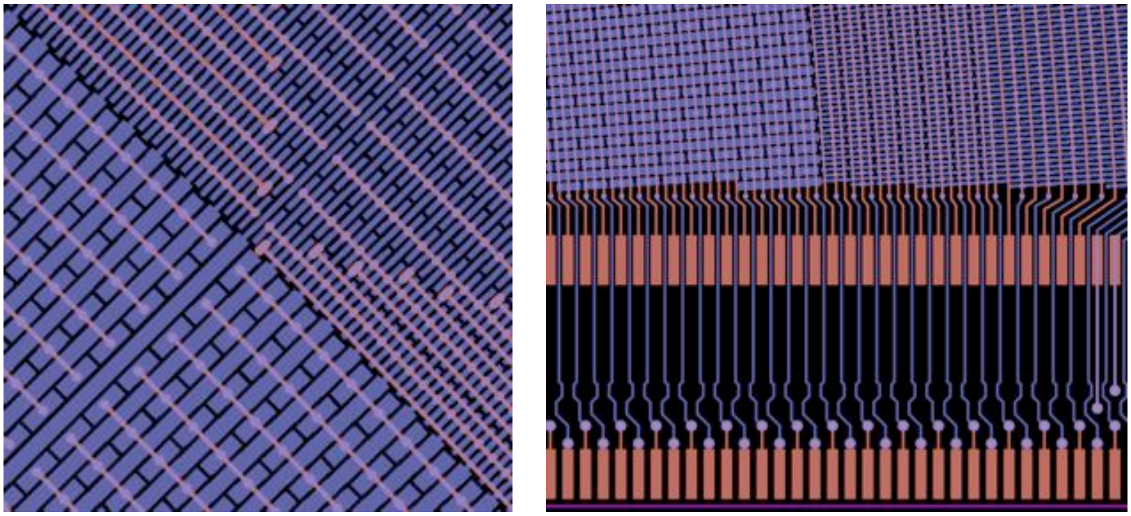
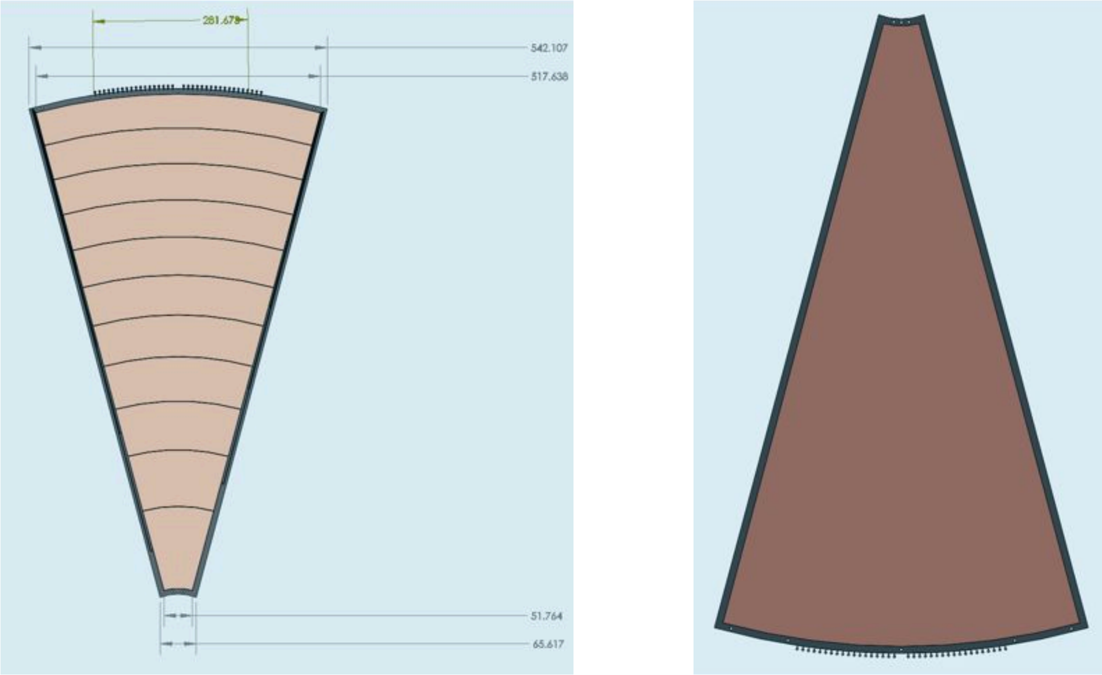


Figure 39: *Details of 2D readout foil layout based on the STAR Forward GEM Tracker showing the radial and azimuthal readout structure along with the pad layout connected multi-pin connectors.*

Finalize design of large dedicated EIC triple-GEM segment $50 \times 120\,\mathbf{cm}^2$ The design foreseen for an EIC forward tracking system consist of 12 chambers covering a disk of a 2 m in diameter. Each detector covers a 30° degree section from 10 cm (inner radius) to 100 cm (Outer radius) as shown in Figure 24. These dimensions give a maximum width of 54.2 cm for the GEM foil which stays within the produceable dimensions. The detectors will consist of a stack of GEM foils and kapton based electrodes glued together. An exploded view of the design is shown in Figure 26. The glued stack of 1 cm width FR4 frames in addition to the spacer grid is believed be enough to be self supportive.

The support of the twelve 30° segments assumes a 'wheel'-like support as shown in Figure 24. Preliminary discussions with an engineer from the MIT Bates engineer team point towards a solution based on carbon-fiber tubes taking advantage of the stiffness of this material. In addition to the lightness of the detectors, most of the detector weight will be located at the outer diameter where the chambers and its services will be supported by an external structure. The main purpose of the wheel is then to keep a rigid positioning of the self-supporting chambers. The Solidworks design will continue at Temple University. This design will be the starting point for a collaborative effort between FIT and UVa to design, assemble and test a large dedicated EIC triple-GEM detector segment.

Systematics 2D readout foils tests and commercialize production of very large 2D readout foils of 50×120 $\mathbf{cm}^2$ The layout of the large triple-GEM detector segment follows in spirit the STAR Forward GEM Tracker design [4]. The FGT does not use a solid 2D readout plane, but a 2D readout foil which has been manufactured by Tech-Etch Inc. based on a separate SBIR grant. Figure 39 shows the main components of the Gerber file of this 2D readout foil providing radial and azimuthal coordinate measurements in one plane using a large number of VIAS connections routed to multi-pin connector pads. Initial discussions with Tech-Etch Inc. indicated that extending the FGT 2D readout foil in size is not an issue. However, an upgrade of



(a) (b)

Figure 40: *GEM foil layout of large triple-GEM segment showing the segmented side (a) and unsegmented side (b). The location of HV pins can be seen at the outer radial region in both drawings.*

the production facility might be as well needed. The layout of the 2D readout plane will be driven by the hit resolution requirement for an EIC detector. It is anticipated that a hit resolution of about $100 - 200\,\mu$m is needed.

It is planned to measure the capacitance and cross-talk for FGT-type 2D readout foils which is a critical parameter for the expected noise performance.

Commercialize production of very large single-mask GEM-foils of 50×120 $\mathbf{cm}^2$ The need for large GEM foil production using single-mask manufacturing techniques has been already introduced in chapter 2.1. Figure 40 shows the layout of the segmented and unsegmented side of a GEM foil segment. Each segment is further divided into 11 individual sectors. The HV connection for each sector is routed on the outer edges separately for even and odd sectors ending up in pin connections on the outer radial area. The planned steps are as follows:

- Prepare Gerber files for GEM foil segment
- Discuss design with Tech-Etch and CERN
- Develop with Tech-Etch a cost plan for the actual production and substantial NRE cost. It is planned in collaboration with FIT and UVa to submit a dedicated funding request for the commercial fabrication of very large single-mask GEM-foils of 50×120 cm^2.

3.2 Barrel MicroMegas tracking detector development

The R&D plans concerning the MicroMegas barrel tracking system will address and complete several items:

- Optimization of material budget
- Optimization of geometry
- Multiplexed readout

The ability to use only one detector for 2D readout structures is extremely useful when one wants to limit the amount of material of the detector, which is critical for EIC applications. In order to do so, we plan to study and optimize the resistive strip pattern, the type of resistive paste to be used but also the routing through multi-layer PCBs. Upon completion of all those R&D subtasks, we plan on fabricating and testing a 2D-curved prototype of the largest possible size offered by the CERN workshop.

Optimization of material budget The main goal is to achieve ~0.1% Xo/layer radiation length. For MicroMegas detectors, the CLAS12 barrel achieved about 0.35% Xo. A significant R&D on all the construction materials is necessary in order to go down by a factor 3 to 4. For instance, the use of ~0.2 μm aluminized polypropylene strips under the resistive layer instead of 5 μm copper strips would decrease significantly the budget material for such a detector.

Optimization of geometry The use of curved MicroMegas detectors for geometry requiring cylindrical symmetry reduced significantly either the dead areas or the amount of material (in case of overlapping planes). Areas of R&D include even further dead-zone reduction, curved-to-curved connection, the use of inverted detectors (detection plane in the inside of the curved PCB) hence double-faced curved detectors.

Multiplexed readout The huge number of channels for barrel detectors in the central region of a collider induces a steep price for any detector technology. The use of genetic multiplexing developed at CEA-Irfu may allow for a large decrease in the channel count. However, this multiplexing is tied to multiplicities expected in the detector and as such, will require optimization after the Monte Carlo tasks are performed.

3.3 Front-End Electronics development

The R&D plans concerning the Front-End electronics development will address several items:

- Setup of a Dream chip based readout system applied to a large triple-GEM detector
- Design/Fabrication of a Very-Front-End-Board (VFEB)
- Studies of packaged/bonded DREAM ASIC
- DREAM ASIC irradiation studies
- Evaluation of a multi-VFEB system

Dream chip FEE system for a triple-GEM detector DREAM has been created specifically for high capacitance detectors (mostly MPGDs) in high rate environment, where limited or no deadtime was an absolute requirement. It was not initially designed for use in a collider environment but some developments are possible for such uses.

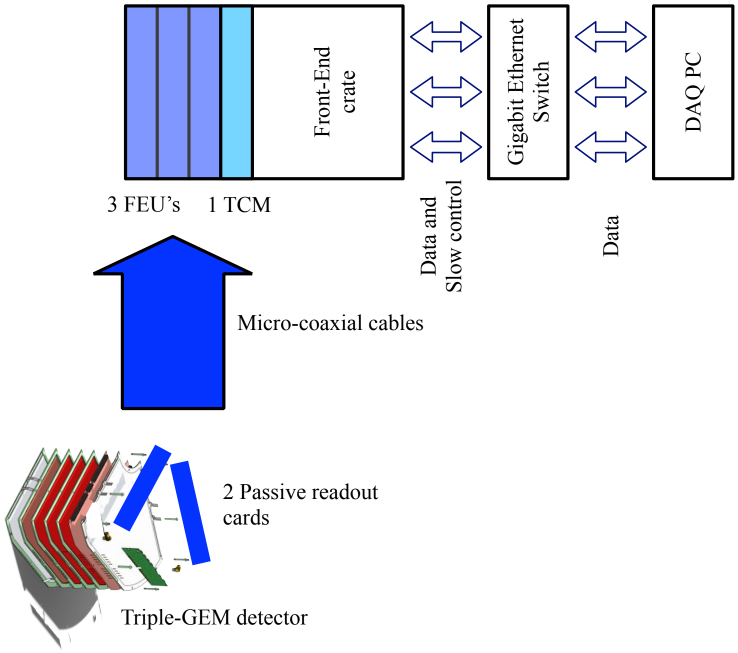


Figure 41: *Schematic of complete Dream chip based readout system for the STAR FGT triple-GEM detector.*

We propose to setup a dream based readout system applied to a large triple-GEM detector using the existing STAR FGT triple-GEM detector. Figure 41 shows an overview of such a setup. The major design required is the design of a passive readout module which provides a link between multi-pin connectors on the triple-GEM detectors and the already tested low-mass flex-cables similar to the MicroMegas system. The remaining Front-End and DAQ part is essentially identical to the MicroMegas application. We plan perform systematic comparison between an APV25-S1 readout system and a DREAM chip system. This R& will be critical to demonstrate the applicability of a common chip system for an integrated barrel / forward EIC tracking system.

In addition, we propose to perform R&D in this domain towards the development of a front-end system to be used for MicroMegas detectors for an EIC. These developments include:

Design/Fabrication of a Very-Front-End-Board (VFEB) Design of a Very-Front-End-Board (VFEB) with only 1 DREAM ASIC which will allow to have the control and digital treatment away from the detector, hence limiting the impact in terms of material budget while keeping the high performance of analog sampling.

Studies of packaged/bonded DREAM ASIC Production of cards with and without spark protection, as well as packaged and bonded DREAM ASIC. We will perform tests and validation with a cosmic ray bench.

DREAM ASIC irradiation studies We plan to evaluate the effect of radiation damage on the front-end electronics and study solutions in case of issues. The irradiation tests will be done at CEA or at CERN, the studies will simply be simulated.

Evaluation of a multi-VFEB system Once one VFEB is validated, we will need to produce a few cards in order to study the distribution of control signals (clock, trigger), of low-voltage and finally of cooling. We will test this using existing equipment for off-detector electronics, such as the MPD card produced at INFN-Genova.

3.4 Simulations

The simulation effort must continue to study the MPGD based solution as a central tracker for en EIC. This will be done by using DVCS event reconstruction as a guide line to study tracking precision and momentum resolution. This proof of concept is a corner stone of this project to demonstrate the advantages or disadvantages of MPGD based central tracking system compare to a TPC solution. The following questions will be addressed :

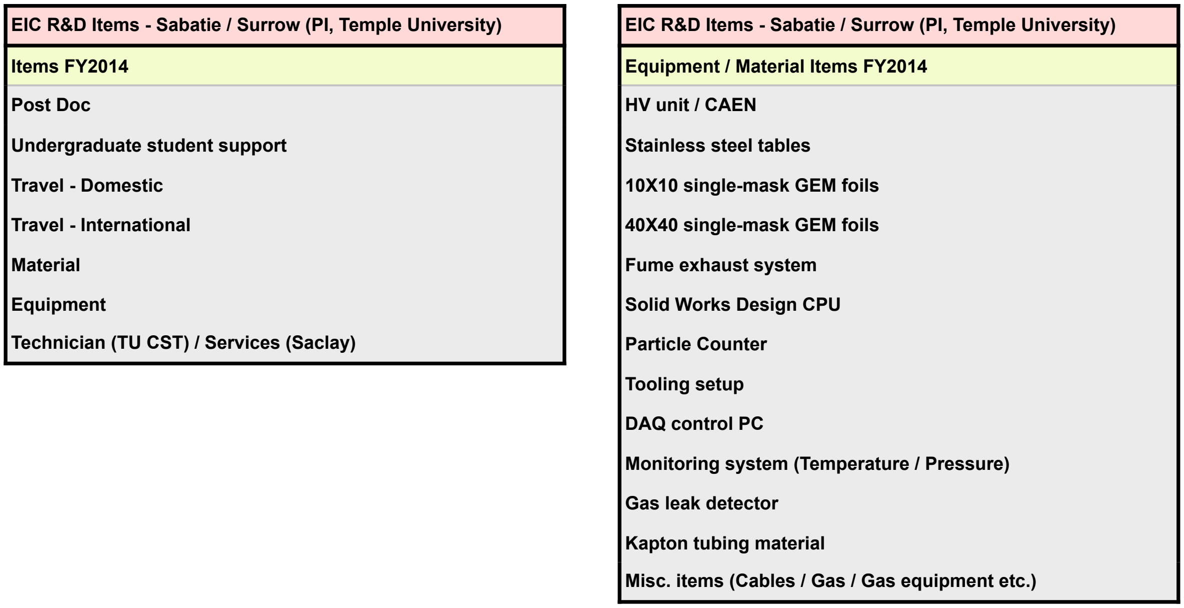
- Systematic studies using MILOU + EICROOT for angular and momentum resolution and effect of material budget,
- Determination of the influence of the forward triple-GEM and barrel geometry,
- Effect of the magnetic field on the tracking performances of the Micromegas barrel,
- Systematic comparison with a TPC and
- Test of innovative cluster algorithms for the barrel system.

It is planned to install the EICROOT tools also at Temple University after the experience gained in doing so at Saclay. The main focus will devoted to kinematic variable resolution studies of a combined barrel MicroMegas and forward triple-GEM system.

4 Budget and Schedule

4.1 Budget overview - FY14

Figure 42 (left) shows a break down of the main categories which the FY2014 grant of $\$295,000$ has been allocated to. The largest part concerns scientific labor ('Post Doc'), travel ('Travel - Domestic'), technical labor provided by the College of Science and Technology and Saclay along with 'Equipment / Material' items. The main 'Equipment / Material' items are shown in Figure 42 (right).



EIC R&D Items - Sabatie / Surrow (PI, Temple University)
Items FY2014
Post Doc
Undergraduate student support
Travel - Domestic
Travel - International
Material
Equipment
Technician (TU CST) / Services (Saclay)

EIC R&D Items - Sabatie / Surrow (PI, Temple University)
Equipment / Material Items FY2014
HV unit / CAEN
Stainless steel tables
10X10 single-mask GEM foils
40X40 single-mask GEM foils
Fume exhaust system
Solid Works Design CPU
Particle Counter
Tooling setup
DAQ control PC
Monitoring system (Temperature / Pressure)
Gas leak detector
Kapton tubing material
Misc. items (Cables / Gas / Gas equipment etc.)

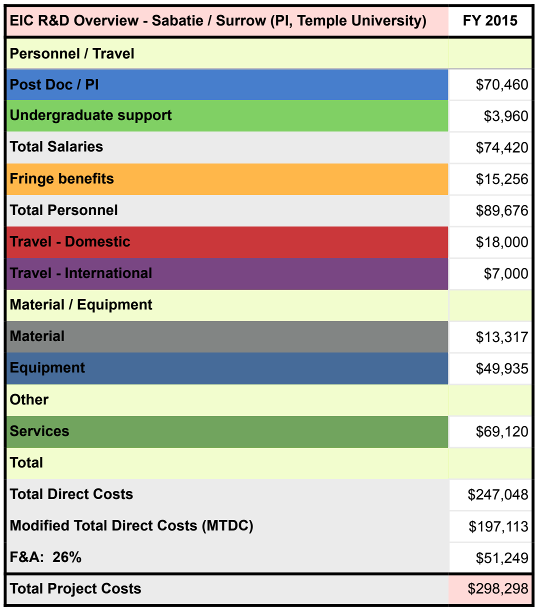
Figure 42: *Main budget categories for the FY2014 grant (left) and 'Equipment / Material' items (right).*

4.2 Funding request - FY15

Figure 43 shows a complete breakdown of the FY2015 budget request:

- Total Direct Costs: $\$247,048$
- Total Project Costs: $\$298,298$

As shown in the pie chart on the right side in Figure 43, the total labor categories in terms of scientific ('Posdoc / PI') and technical labor labor ('Services') amount to about 60% followed by the 'Equipment' category which amounts to 20%.



EIC R&D Overview - Sabatie / Surrow (PI, Temple University)	FY 2015
Personnel / Travel	
Post Doc / PI	$70,460
Undergraduate support	$3,960
Total Salaries	$74,420
Fringe benefits	$15,256
Total Personnel	$89,676
Travel - Domestic	$18,000
Travel - International	$7,000
Material / Equipment	
Material	$13,317
Equipment	$49,935
Other	
Services	$69,120
Total	
Total Direct Costs	$247,048
Modified Total Direct Costs (MTDC)	$197,113
F&A: 26%	$51,249
Total Project Costs	$298,298

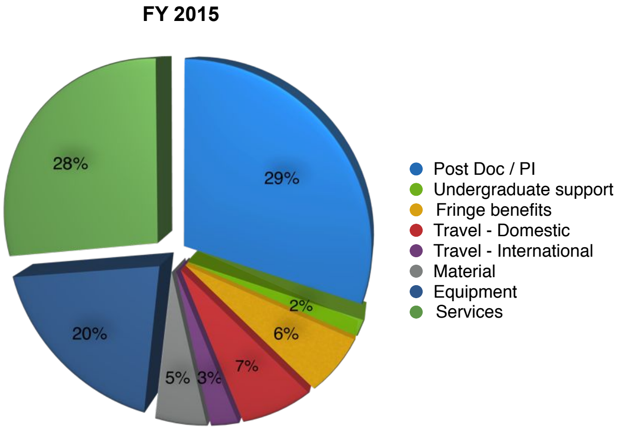
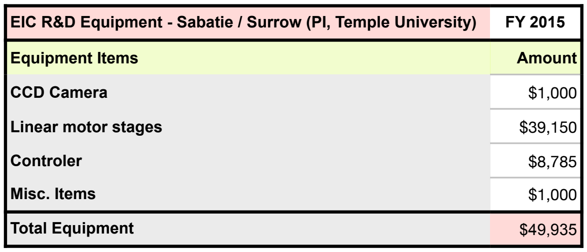
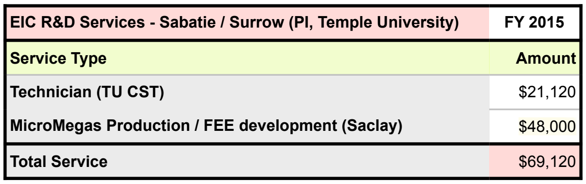


Figure 43: *Total budget breakdown (left) and chart in percent relative to the total direct costs (right).*



EIC R&D Equipment - Sabatie / Surrow (PI, Temple University)	FY 2015
Equipment Items	Amount
CCD Camera	$1,000
Linear motor stages	$39,150
Controler	$8,785
Misc. Items	$1,000
Total Equipment	$49,935



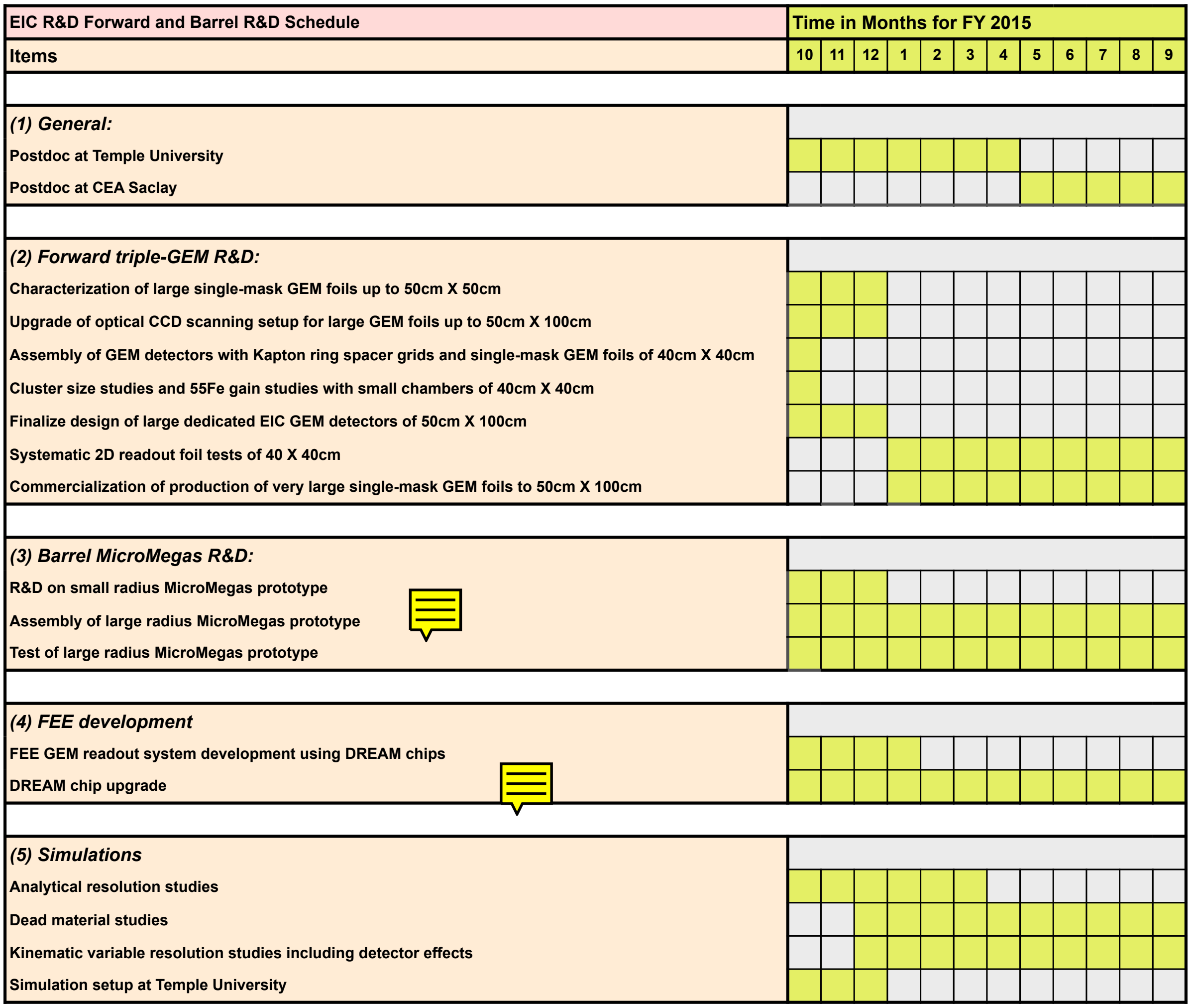
EIC R&D Services - Sabatie / Surrow (PI, Temple University)	FY 2015
Service Type	Amount
Technician (TU CST)	$21,120
MicroMegas Production / FEE development (Saclay)	$48,000
Total Service	$69,120

Figure 44: *'Equipment' (left) and 'Service' (right) budget categories for FY2015.*

The equipment and service items are shown in more detail in Figure 44. The largest service request refers to the FEE development and some minor MicroMegas detector items at Saclay along with technical support at Temple University. It should be emphasized that the support provided by the College of Science and Technology at Temple University for laboratory setups, in particular the clean room setup and maintenance specifically for the GEM development effort is not costed here and is an in-kind contribution. Furthermore, the engineering labor provided by James Wilhelmi is not costed here.

4.3 Schedule summary

The graph in Figure 45 shows an overview of the schedule concerning the main activities of both the forward and barrel R&D efforts along with development work for a dedicated FEE DREAM chip system and simulation efforts.



EIC R&D Forward and Barrel R&D Schedule	Time in Months for FY 2015											
Items	10	11	12	1	2	3	4	5	6	7	8	9
(1) General:												
Postdoc at Temple University	■	■	■	■	■	■	■					
Postdoc at CEA Saclay								■	■	■	■	■
(2) Forward triple-GEM R&D:												
Characterization of large single-mask GEM foils up to 50cm X 50cm	■	■	■									
Upgrade of optical CCD scanning setup for large GEM foils up to 50cm X 100cm	■	■	■									
Assembly of GEM detectors with Kapton ring spacer grids and single-mask GEM foils of 40cm X 40cm	■											
Cluster size studies and 55Fe gain studies with small chambers of 40cm X 40cm	■											
Finalize design of large dedicated EIC GEM detectors of 50cm X 100cm	■	■	■									
Systematic 2D readout foil tests of 40 X 40cm				■	■	■	■	■	■	■	■	■
Commercialization of production of very large single-mask GEM foils to 50cm X 100cm				■	■	■	■	■	■	■	■	■
(3) Barrel MicroMegas R&D:												
R&D on small radius MicroMegas prototype	■	■	■									
Assembly of large radius MicroMegas prototype	■	■	■	■	■	■	■	■	■	■	■	■
Test of large radius MicroMegas prototype	■	■	■	■	■	■	■	■	■	■	■	■
(4) FEE development												
FEE GEM readout system development using DREAM chips	■	■	■	■								
DREAM chip upgrade	■	■	■	■	■	■	■	■	■	■	■	■
(5) Simulations												
Analytical resolution studies	■	■	■	■	■	■						
Dead material studies			■	■	■	■	■	■	■	■	■	■
Kinematic variable resolution studies including detector effects			■	■	■	■	■	■	■	■	■	■
Simulation setup at Temple University	■	■	■									

Figure 45: *Schedule overview concerning the main activities for forward and barrel R&D efforts along with development work for a dedicated FEE DREAM chip system and simulation efforts.*

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