Project Title:

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

Progress report (Q4 FY13 / Q1 FY14)

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Type of application:	BNL EIC R&D contract
Proposed Project Period:	October 01, 2013 - September 30, 2014
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1 Introduction

The detector specifications for the EIC science case have been discussed during a long INT workshop series in fall 2010 [1]. The science case has been documented in a White paper report [2]. The BNL and Jefferson Lab teams have come up with a preliminary detector design, including details on several tracking systems needed to achieve the proposed physics program. A side view of an EIC detector concept is shown in Figure 1. This progress report concentrates on two distinct tracking regions of our approved R&D program on the design and development of fast and light-weight prototype tracking systems:

- Barrel tracking system based on MicroMegas detectors manufactured as cylindrical shell elements and
- Forward tracking system based on triple-GEM detectors manufactured as planar segments.

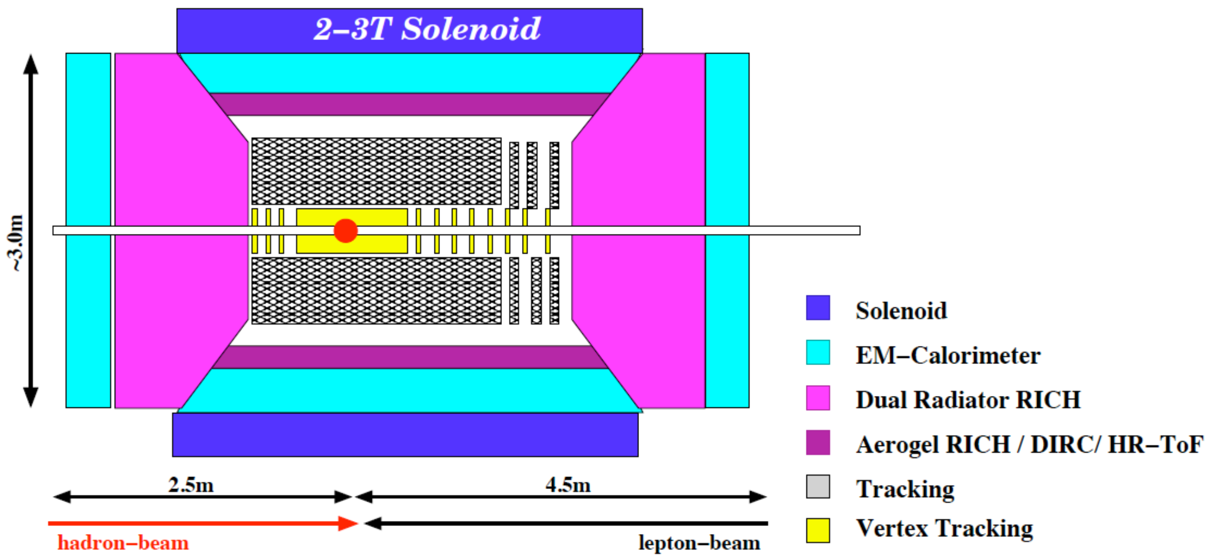


Figure 1: *Side view of an EIC detector concept.*

The barrel and forward tracking systems are shown as gray hashed areas in the EIC detector concept labeled 'Tracking' in Figure 1. 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
- Utilization of light-weight materials

- Development and commercial fabrication of various critical detector elements
- European/US collaborative effort on EIC detector development (CEA Saclay, MIT and Temple University)

Figure 2 shows a 3D view of the barrel and forward tracking region. This progress report provides an overview of various R&D activities in the 4th quarter of FY13 (Q4 FY13) and the 1st quarter of FY14 (Q1 FY14) both in the barrel and forward/backward region following the last meeting of the EIC R&D committee in June 2013.

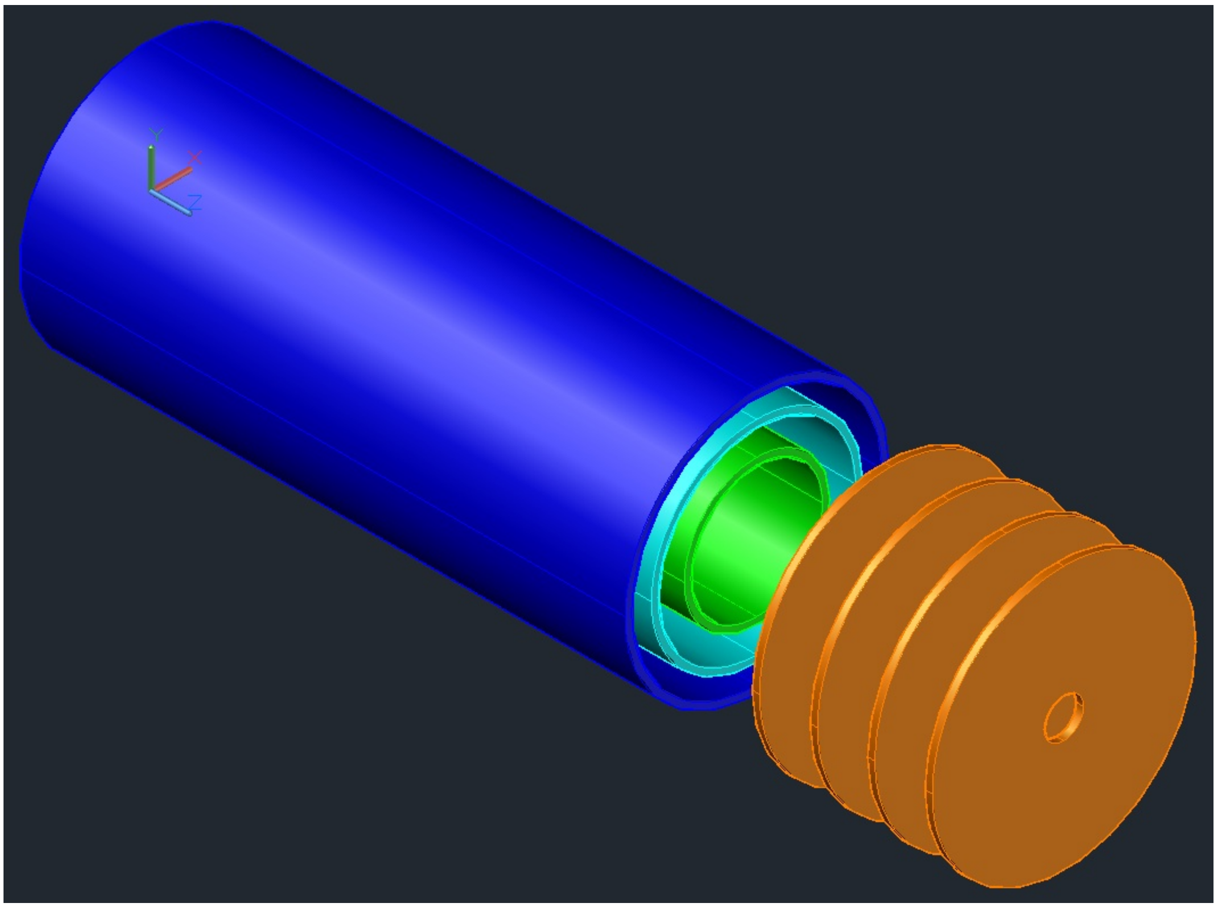


Figure 2: *Illustration of a barrel and forward tracking system for an EIC detector.*

It should be emphasized that it is in particular the chip readout system which provides a common R&D effort for both the MicroMegas and the triple-GEM detector systems. The R&D program profits enormously from generous funds provided by a BNL EIC R&D contract which addresses the following items in FY14 which have been presented to the EIC R&D committee in June 2013:

- Forward GEM Tracking detector development
  - Completion of two lab setups in the current Department of Physics at Temple Univeristy

- Relocation of both labs in summer 2014 to the Science Education and Research Center providing outstanding dedicated lab resources by the College of Science and Technology at Temple Univeristy
- Characterization of GEM foils in terms of leakage current and optical uniformity
- Assembly of small ($10 \times 10\,\mathrm{cm}^2$) triple-GEM test detectors
- Setup of cosmic-ray test stand and ^{55}Fe source scanner
- Setup of DAQ and HV system
- Design of novel Kapton ring spacer grid and identification of commercial production source
- Mechanical design studies and prototyping of large triple-GEM detector segment and support structure
- Commercialization of large GEM foil production using single-mask manufacturing techniques

- Barrel MicroMegas tracking detector development
  - Test of two CLAS12 MicroMegas detectors in cosmic-ray test stand
  - Test of light-weight, low capacitance flex cables
  - Test of DREAM chip production versions
  - Design and prototyping of large MicroMegas cylindrical detector segments
- GEANT4 simulations of barrel and forward tracking detector setup

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 and Dr. Maxence Vandenbroucke managed to attract several outstanding students, both foreign and domestic students. More than 50% are considered minority students. The College of Science and Technology established an Undergraduate Research Program (URP) to encourage undergraduate student participation in research. This program is similar in spirit to the MIT Undergraduate Research Opportunity Program (UROP). The generously funded BNL EIC R&D contract has provided a huge attraction for students to join the Temple University group.

Dr. Maxence Vandenbroucke is currently spending a period of at least six months since November 2013 at CEA Saclay focusing on the MicroMegas R&D program.

2 Progress report - Q4 FY13 / Q1 FY14

2.1 Forward GEM tracking detector development

Overview The progress on Forward GEM tracking activities is clearly driven by the hire of Dr. Maxence Vandenbroucke as a Postdoctoral Research Fellow on October 01, 2012 along with five undergraduate students at Temple University. All test setups are by now in place in the current Department of Physics at Temple University utilizing an existing dedicated clean room along with a large detector lab. Dr. Maxence Vandenbroucke worked at Temple University until November 2013 and is now for at least six months at CEA Saclay (France) focusing on the MicroMegas R&D effort. The MIT effort under the leadership of Dr. Doug Hasell is mainly geared towards the development of spacer grids for large area triple-GEM detectors. In addition, the engineering expertise at MIT Bates with Ben Buck (Electrical engineer) and Jason Bessuille (Mechanical engineer) was and will be instrumental for the layout of both the chip readout system and the mechanical design.

Status: Most goals have been achieved apart from the beginning process to manufacture large single-mask produced GEM foils at CERN and receive first samples of single-mask produced foils from Tech-Etch. A review of the mechanical design by the MIT Bates engineering team is required before placing an order at CERN. Tech-Etch is expected to provide first samples in January 2014. A commercial source for Kapton rings has been identified and it is expected to start the assembly of a full Kapton-ring based triple-GEM detector in spring 2014. All testing setups (leakage current and CCD optical scanning) and assembly tools are in place. A full DAQ system has been set up and commissioned.

Laboratory setup 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. The facilities in the current Department of Physics provided are:

- Clean Room (~ 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 (~ 1000 sq.ft.): Testing of triple-GEM detectors including cosmic-ray testing, ^{55}Fe-source testing and CCD camera scan testing. A dedicated DAQ system based on the STAR FGT DAQ system is now available.

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. One head engineer (Ed Kaczanowics) including a mechanical technician (Matt McCormick) and electronics technician (Richard Harris) work as a team for research needs of the physics faculty. The technical team provided excellent support completing the Temple University GEM lab. The electronics and machine shop along with the technical staff will be also available once the physics

Figure 3: *(a) Portable TerraUniversal Cleanroom and gas system. (b) Portable TerraUniversal Cleanroom and DAQ and slow-control system. (c) Inside the TerraUniversal Cleanroom showing a work bench area for leakage current measurements along with an ISEG HV supply, particle counter and gas rack. (d) STAR Forward GEM Tracker inside the portable TerraUniversal Cleanroom.*

department is located in the new building housing the Science Education and Research Center starting in summer 2014.

Figure 3 shows the detector lab in the current Department of Physics at Temple University focusing on various setups of the triple-GEM R&D effort. A portable cleanroom was purchased from funds provided by the BNL EIC R&D contract. This room is currently located in the detector lab and will be transferred to the new detector lab in the Science Education and Research Center starting in summer 2014.

Figure 4 shows an overview of the new Science Education and Research Center. Professor Bernd Surrow continued to play over the last six months an integral part in the layout of a dedicated, large Class $1,000$ clean room facility ($1,800\,$sq.ft.) shown in Figure 4 (b). 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.).

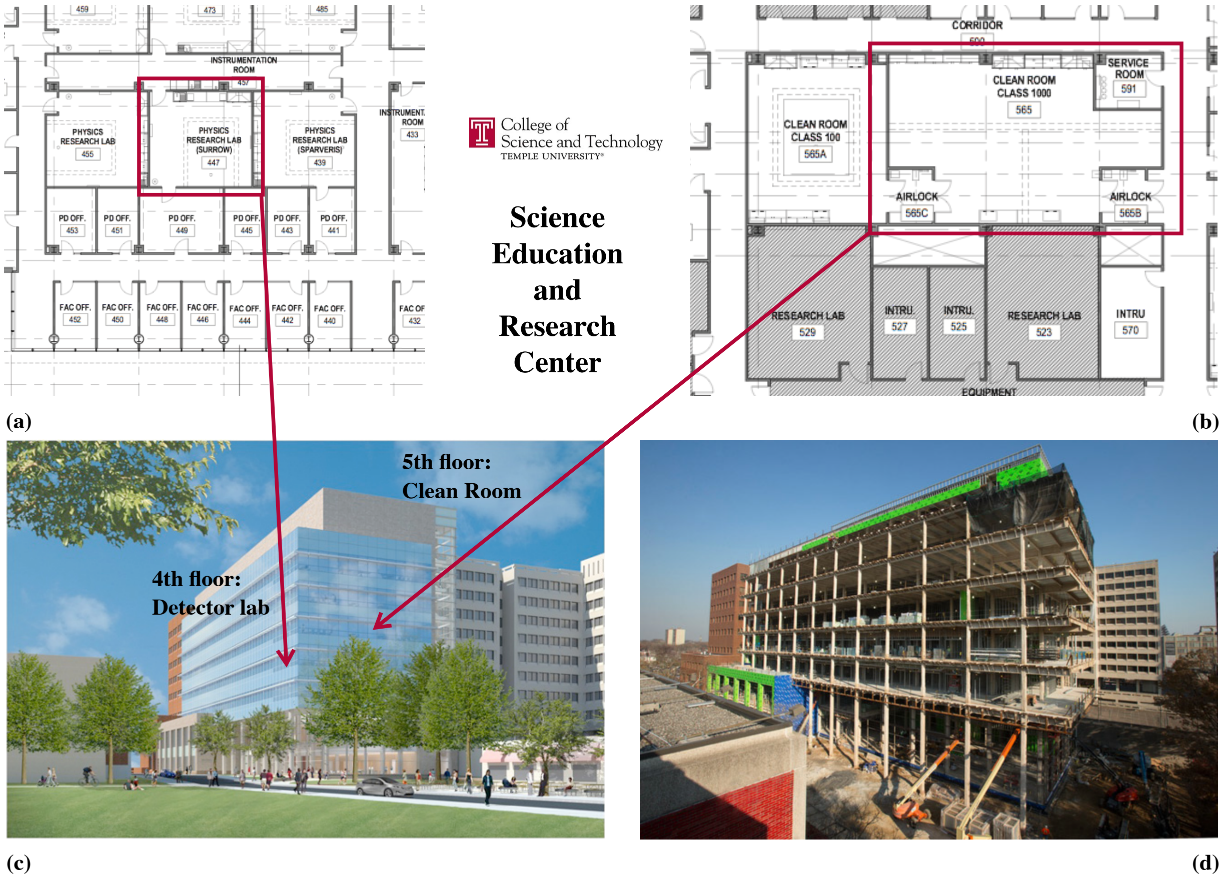


Figure 4: *Overview of the Science Education and Research Center by design (c) and under construction (d) together with the layout of the new detector lab (a) and Clean Room facility (b).*

Status: Lab setup ready including DAQ system.

GEM foil characterization - Leakage current The first type of characterizations performed on a GEM foil are electrical tests. As shown in Figure 5, 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 a few nA. Figure 6 shows the results of such a measurement where one can see that the current increases with the applied voltage for the different sectors of a GEM foil, in this case a GEM foil from the STAR Forward GEM Tracker (FGT).

This setup has been installed in the cleanroom at Temple University where this measurement is routinely performed in a clean environment by undergraduate students as shown in Figure 5. All available foils have been tested. The setup is ready to test samples of single-mask produced foils by Tech-Etch which are expected to arrive in January 2014.

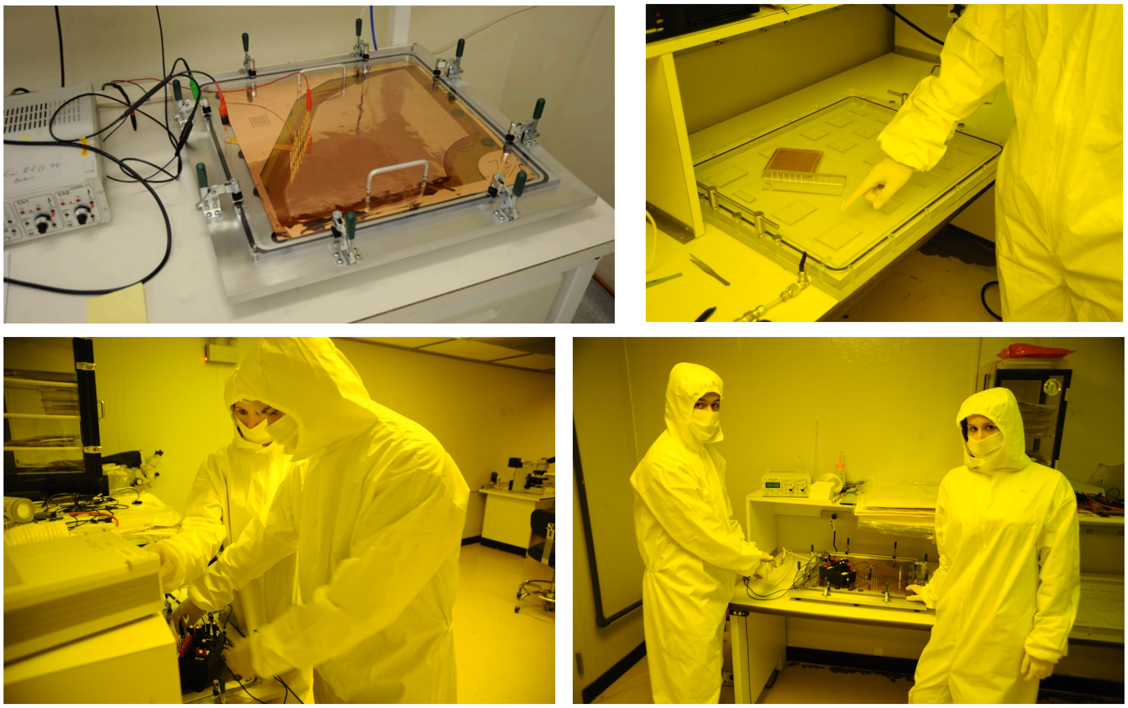


Figure 5: *Setup at Temple University to conduct electrical tests of GEM foils performed by undergraduate students.*

Status: Setup ready for single-mask GEM foil measurements. All available foils which are needed for the assembly and test of a Kapton-ring triple-GEM detector have been tested.

GEM foil characterization - Optical scan / CCD camera setup 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 7 (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 7 (b). Two undergraduate students are routinely capable of scanning GEM foils. Several improvements have been made over the last six months. The setup is also ready to characterize samples of single-mask produced GEM foils by Tech-Etch.

Status: Setup ready for single-mask GEM foil measurements.

Assembly of small triple-GEM prototype chambers In order to test GEM foils inside a detector, two triple-GEM prototype chambers of $10 \times 10\,\mathrm{cm}^2$ have been assembled by undergraduate students at Temple University as shown in Figure 8. A closer view of one of these chambers is shown at the bottom of Figure 8, these detectors have been used in a cosmic ray setup shown in Figure 9. The characterization using an ^{55}Fe source has started using a hand-held Multi-Channel analyzer (MCA).

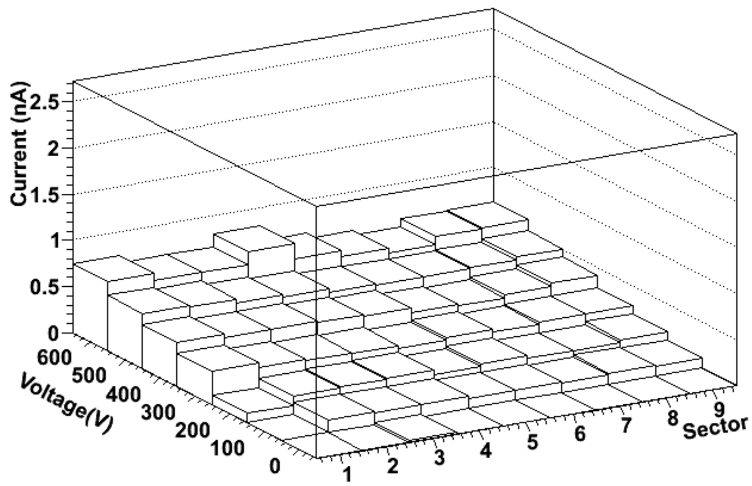


Figure 6: *Measured leakage current as a function of voltage and sector (1-9) for a GEM foil (Tech-Etch) of the STAR Forward GEM Tracker.*

Status: Assembly of test chambers completed. Completion of tests with MCA planned for spring 2014.

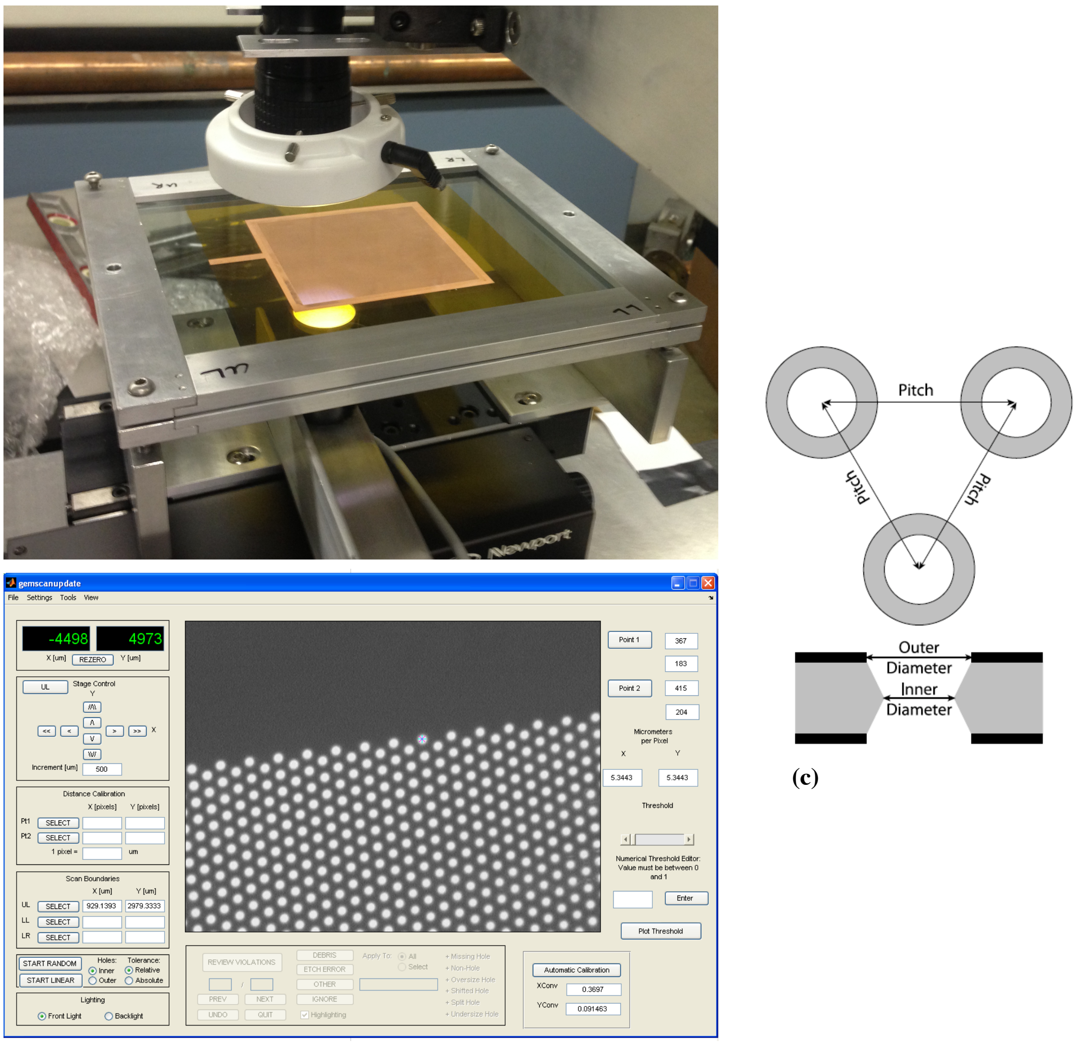
^{55}**Fe-source scan setup** Gain calibration is an essential tool in characterizing a triple-GEM detector. By using the double-peak structure of a X-ray energy spectrum of an ^{55}Fe-source, one can measure precisely the absolute gain of a triple-GEM detector. The automation of such a measurement has 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 10, we are developing an automated measurement to produce a 2D gain calibration map. This map will have the advantage of taking into account all types of gain fluctuations due to the GEM amplification stage, the thickness of the induction gap and the large capacitance variation inherent to large GEM detectors. This gain map could later be used for data correction and tracking improvement in an experiment.

Status: Operation of scanning table under LabView in progress. Synchronization of table movement and DAQ operation planned for spring 2014.

Commissioning of DAQ system and APV-chip readout system A complete DAQ system has been set up at Temple University which is based on a copy of the STAR Forward GEM Tracker (FGT) DAQ system. Figure 11 (a) shows a photography of the DAQ and slow control setup, (b) the modified Wiener VME crate and (c) the DAQ computer and modified Wiener VME crate. Besides the actual DAQ system, the crate provides also three slots for ISEG HV supplies of eight channels each. The DAQ system and HV system was completed in September 2013. In addition to the actual hardware, the full run control software along with slow control software and GUI for HV and gas control and monitoring has been developed.

(a)

(b)



(c)

Figure 7: *(a) GEM foil scanner, (b) User interface and (c) Hole geometry of a GEM foil.*

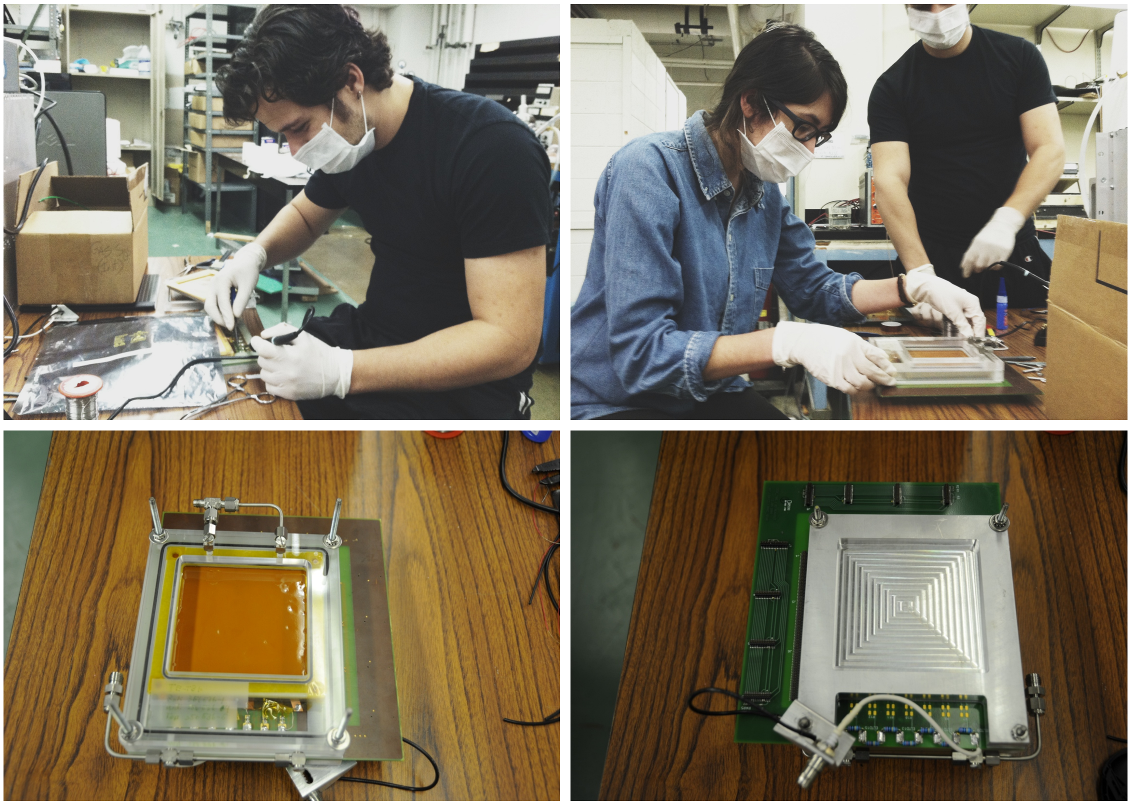


Figure 8: *Assembly of triple-GEM prototype chambers of* $10 \times 10\,cm^2$ *by undergraduate students at Temple University.*

Status: DAQ and slow control system completed and operational.

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 Mylar foils for gas-tight enclosure, as shown in the exploded view in Figure 12 (a) and (c). 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 12 (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 13. The preparation of Gerber files has started, which is required for manufacturing foils at CERN in spring 2014.

Each long segment will be supported on a wheel-like carbon-fiber structure as shown in Figure 16 (a) and (b). The chambers are stacked face-to-face to provide easy access avoiding dead areas between detectors as shown in Figure 17 (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

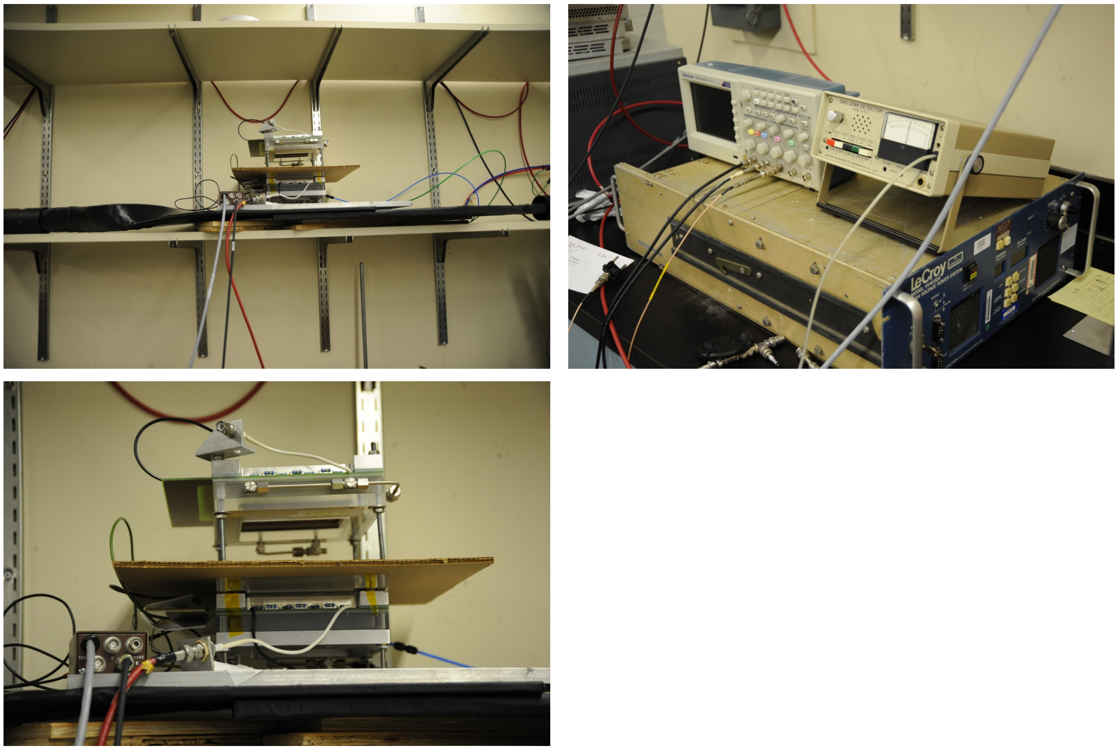


Figure 9: *Cosmic-ray setup at Temple University using* 10×10 cm^2 *prototype triple-GEM detectors.*

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 positive feedback on our design encouraged us to prototype certain support elements in spring 2014 after the review of the overall mechanical design by the MIT Bates engineering team.

Status: SolidWorks design at Temple University completed. Review by MIT Bates engineering planned for 2nd quarter in FY14. Prototyping of support material at Carbon-Composite shop at LBL planned for spring 2014.

Design and fabrication of large GEM foil storage units A preliminary SolidWorks design model, as shown in Figure 14, has been completed by a Temple University undergraduate student from the Department of Mechanical Engineering. The College of Science and Technology strongly supports interdisciplinary research efforts, in particular involving students. The layout has to be large enough to accommodate larger GEM foils of segments which we expect to receive in spring 2014 along with existing FGT-type GEM foils.

Status: SolidWorks design completed. Discussion of design with TU CST mechanical engineer E. Kaczanowics in January 2014 and fabrication and assembly at Temple University in spring 2014.

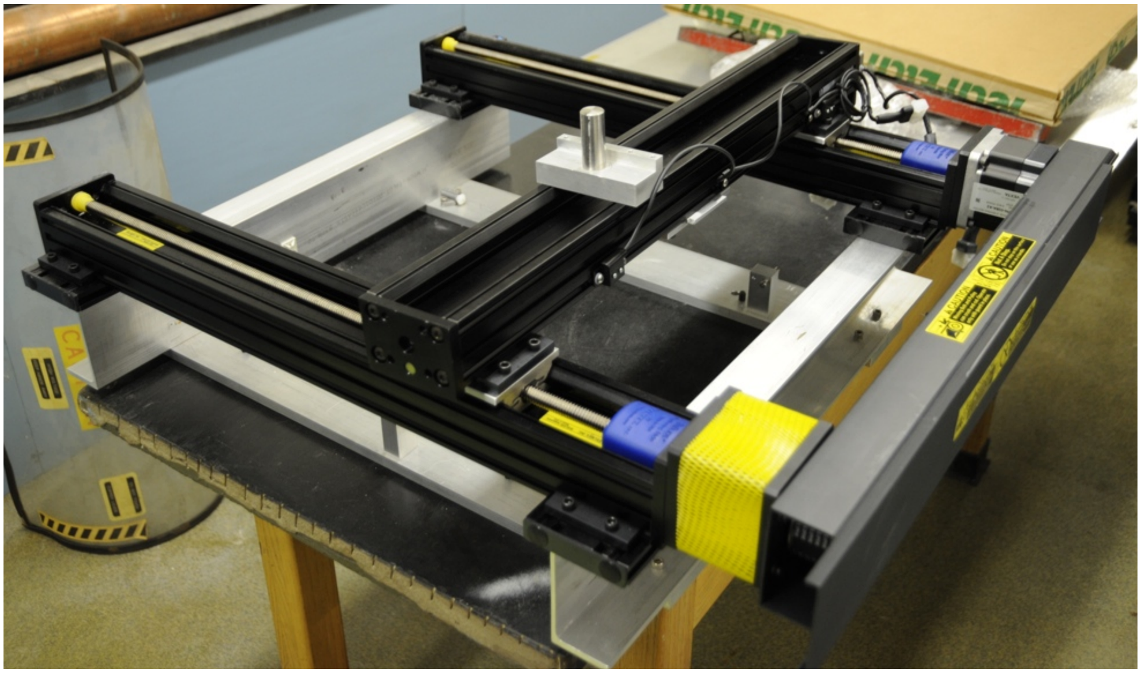


Figure 10: *Scanning table setup for a ^{55}Fe source scan of large GEM foils.*

Setup of assembly tools and design and preparation of large assembly tools Assembly and stretching tools exist for FGT-type quarter sections. A new mechanical engineer will start 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. These tools will be used to build a triple-GEM FGT-type detector using Kapton rings in spring 2014. It is then planned to design and prepare all necessary assembly tools for large triple-GEM detector segments.

Status: All assembly and stretching tools exist for FGT-type detector segments. The design and preparation of larger assembly tools will start in spring 2014 by a new mechanical engineer.

Kapton ring design and commericial fabrication A novel design of a spacer grid based on arrays of thin-walled polyamide (e.g. Kapton) rings between GEM foils has been presented in June 2013. The design of this idea has been finalized. Furthermore, a company has been identified (POTOMAC, Lanham, MD) to manufacture samples of both 2 mm and 3 mm thick Kapton rings as shown in Figure 15. An order has been placed and we do expect to start with the assembly of an FGT-type triple-GEM detector using Kapton rings in spring 2014 with the hire of a new mechanical engineer.

Status: Kapton ring design finalized. Commercial source for fabrication identified (POTOMAC, Lanham, MD). Expect to start with assembly of Kapton ring based triple-GEM detector in spring 2014.

(a) (b) (c)

Figure 11: *(a) Photography of DAQ and slow control setup. (b) Photograph of modified Wiener VME crate. (c) Photography of DAQ computer and modified Wiener VME crate.*

Commercialization of single-mask GEM foil production The commercial fabrication of $10 \times 10\,\mathrm{cm}^2$ GEM foils along with larger GEM foils has been established by Tech-Etch in collaboration with BNL, MIT, Temple University and Yale University. The actual fabrication employs glass masks for the photolithographic process for a given user defined layout of GEM foils using a standard Gerber-file. The chemical etching is based on a double-sided etching process. It has been pointed out by the photolithographic workshop at CERN that larger sizes are limited by this process requiring very precise alignment of both masks on either GEM foil side [3]. It has therefore been suggested to use a single-mask production process. This process has been established at CERN [4].

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 to Tech-Etch with the goal in mind to provide commercially produced large GEM foils. 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 $10 \times 10\,\mathrm{cm}^2$ GEM foils followed by FGT-type GEM foils 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

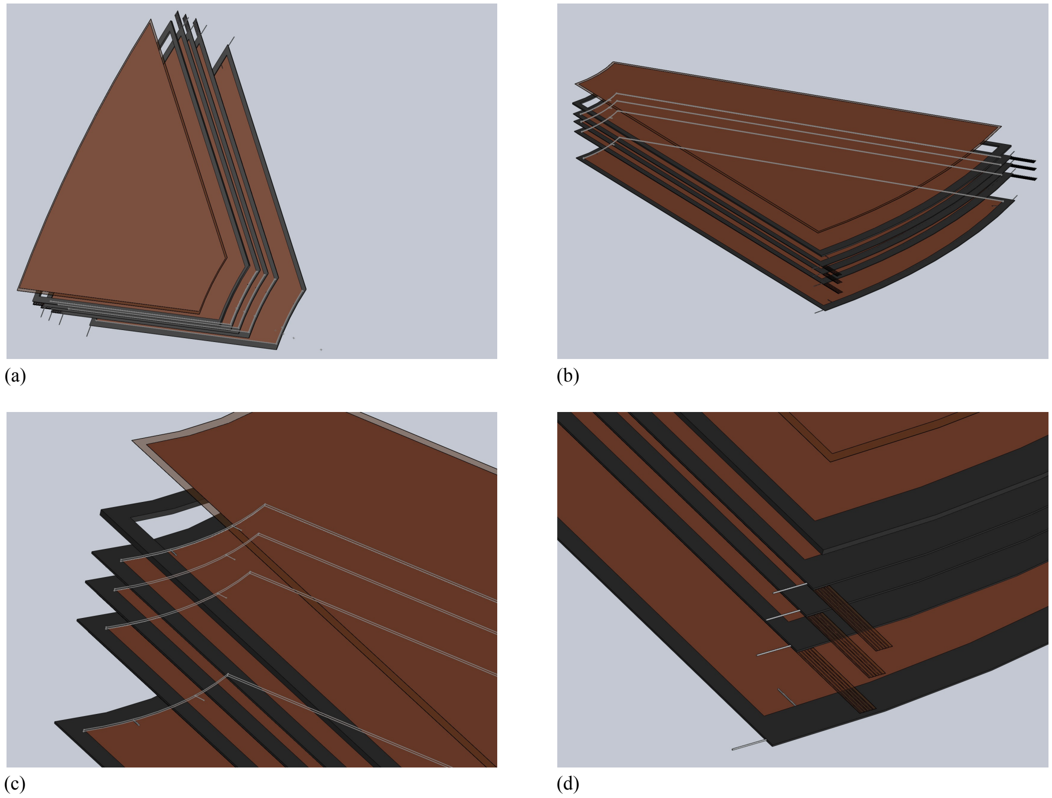


Figure 12: *Detailed view of segment design.*

production plant. Weekly phone meetings have been arranged by the Temple University group to foster the collaboration between CERN, Tech-Etch and other institutions including FSU, Stony Brook University, Temple University and Yale University. It is expected that we receive small samples in January 2014. A visit to CERN from Tech-Etch and Professor Bernd Surrow is planned for early 2014.

The production of larger foils is generally limited to a width of about 50 cm due to the size limitation of Kapton 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 process would clearly benefit from a new SBIR[3] proposal, provided that the strict company size limitation of 500 employees can be solved. This issue has been brought to the attention recently to the DOE NP SBIR program manager. A major commitment that Tech-Etch has already been made in recent discussions with the Temple University group is the fact that Tech-Etch will develop the large-size single-mask production of GEM foils even if SBIR funds would not be available. The management at Tech-Etch has agreed following various discussions to invest already at this stage in a pilot project focusing on the development of small single-mask produced GEM foils. The principal chemical etching baths have all been set up. The main discussion over the last weeks focussed mainly on processing steps.

[3]Small Business Innovative Research, US-DOE funded program to foster collaboration of small companies and research institutions

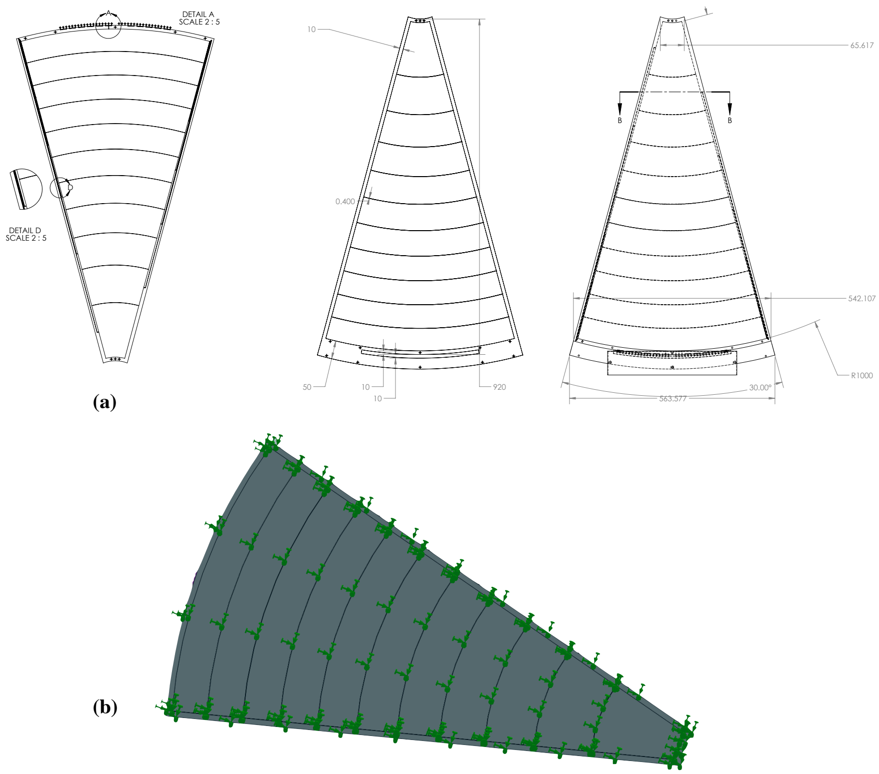
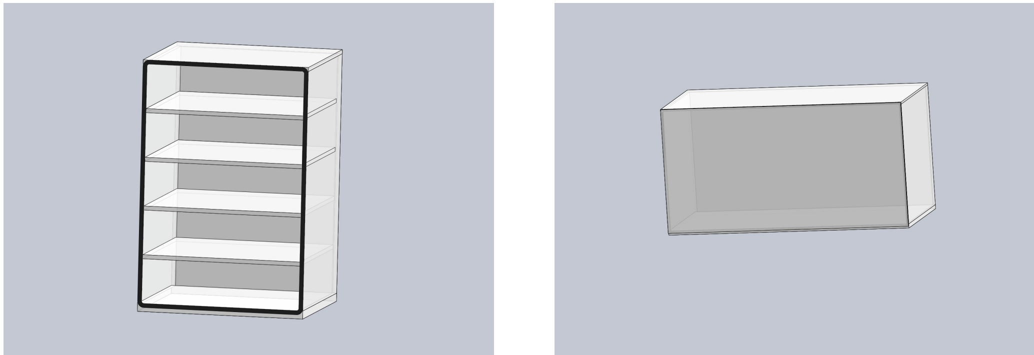


Figure 13: *Layout of large segment GEM foil with 11 sectors.*

Status: Weekly phone meetings between CERN, Tech-Etch and various institutions focusing on the transfer of single-mask production techniques. Small samples are in preparation and are expected for tests in January 2014.

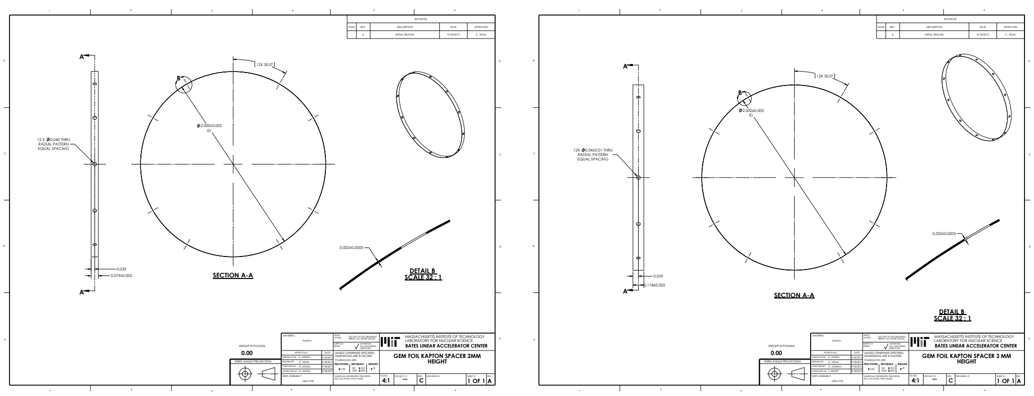
Cluster size studies The spatial resolution required at the EIC for the triple-GEM detectors is about $100 - 200\,\mu$m, which is a standard performance for a GEM tracking detector. The spatial resolution results from a complex combination of the distance between electrode (the pitch), the size of the 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 goal of this study as presented in June 2013 is to reduce the granularity without compromising the performance. The main idea is to adjust the individual potential difference around each triple-GEM detector layer. A multi-channel CAEN HV system has been identified and purchased and is expected to available in spring 2014.

Status: Commissioning of multi-channel CAEN HV system is expected to start in spring 2014 followed by the actual measurements after May 2014 once Dr. Maxence Vandebroucke returns to Temple University.



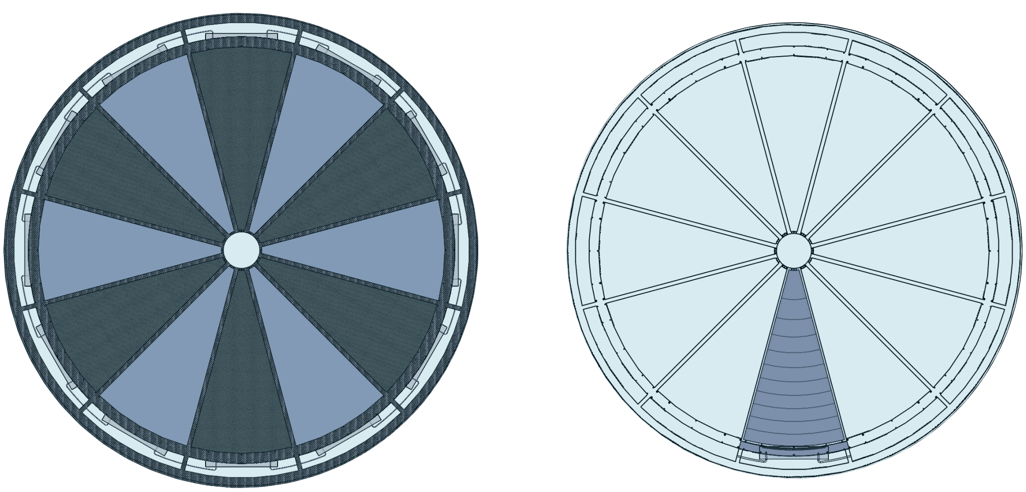
(a) (b)

Figure 14: *SolidWorks layout of nitrogen storage cabinets for GEM foils.*



(a) (b)

Figure 15: *(a) Kapton ring with* 2 mm *thickness and (b) Kapton ring with* 3 mm *thickness.*



(a) **(b)**

Figure 16: *Disk layout of 12 large triple-GEM detector segments.*

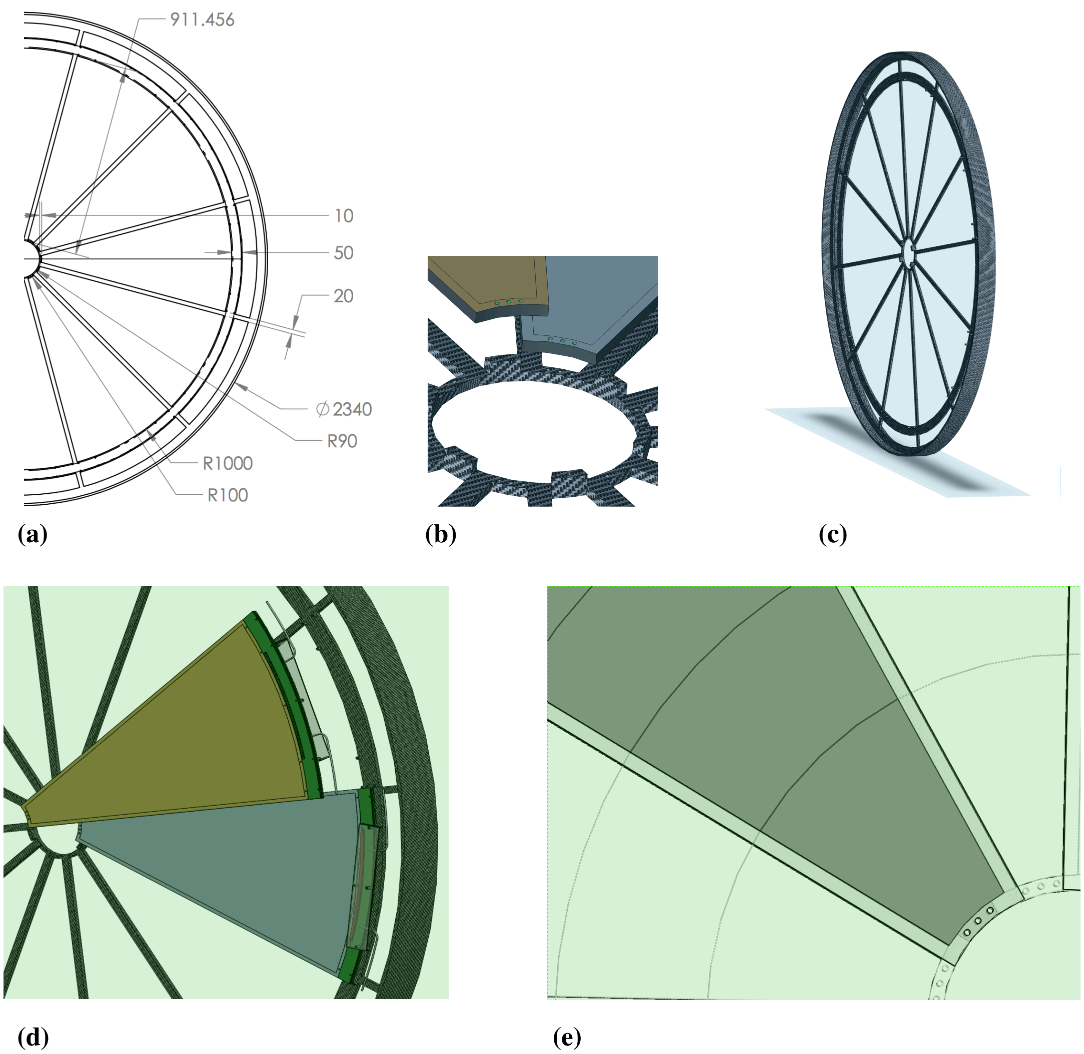


Figure 17: *Details of disk dimensions and support of individual triple-GEM detector segments.*

2.2 Barrel MicroMegas tracking detector development

Overview Almost all of the FY13 R&D efforts for our proposal were put towards the forward GEM detectors, as initially planned. The late arrival of our common postdoc in December 2013 has severely limited our ability to make progress on the detector side. However, part of the development steps proposed for the MicroMegas barrel could still be achieved in this first phase of our proposal, thanks to the large synergy with the Jefferson Lab CLAS12 project.

Status: Dr. Maxence Vandenbroucke has started the MicroMegas R&D program at Saclay in December 2013.

Large curved resistive bulk detectors Once funds are available, we will build two large-size curved resistive MicroMegas detectors. In the meantime, we are currently working on the Gerber files and assembly tooling. We expect to order the detectors at the beginning of 2014 and receive them around March 2014. Characterization of these detectors will be the next logical step.

Status: Transfer of funds from Temple University to Saclay in progress needed to order various MicroMegas detector components.

The Dream ASIC The initial version of the Dream ASIC has been successfully validated in 2012. The final revision of the ASIC, modified according to the new, updated requirements of the CLAS12 Micromegas vertex tracker, has been submitted for production by the end of 2012 and a first set of 360 chips has been received during the summer 2013. The V1 Dream ASICs have a larger choice of shaping time, a better noise immunity and an improved trigger primitive generation scheme with the programmable multiplicity level. The tests of the first set revealed high yield of 85% of the manufacturing process. Production of the second set of 1000 chips is underway. The packaged ASICs are expected in March 2014. The performance of both versions of the Dream ASICs has been compared to the performance of their predecessor AFTER chip. It has been shown that for the large capacitance MPGDs the signal to noise ratio improves by 15-20% as predicted by simulations. A 20 kHz trigger rate operation has been demonstrated as well. The sampling and the analog readout frequencies of respectively 40 MHz and 32 MHz have been achieved. Though primarily designed for MPGDs acquisition systems, the chip has been successfully used for multi-channel PMT readout in the RICH environment. During the PMT tests the timing resolution of $\sim$3 ns has been obtained, while the self-triggering capability of the ASIC allowed gathering quickly large sets of the PMT dark noise data with the reliable statistics.

A 512-channel electronics card called front-end unit (FEU) has been developed and two prototypes have been produced (Figure 18). Among other components, a FEU houses 8 Dream circuits, an 8-channel 40 MHz Flash ADC, a Xilinx Virtex-6 FPGA and two small form-factor pluggable interface modules, one used as a 2.5 Gb/s optical readout link and another as a GE interface. The FPGA processes the incoming trigger signals, initiates the Dream readout over the ADC, performs various data processing operations (pedestal equalization, common mode noise subtraction, zero suppression), formats and delivers the event data either to higher data concentration levels (e.g.

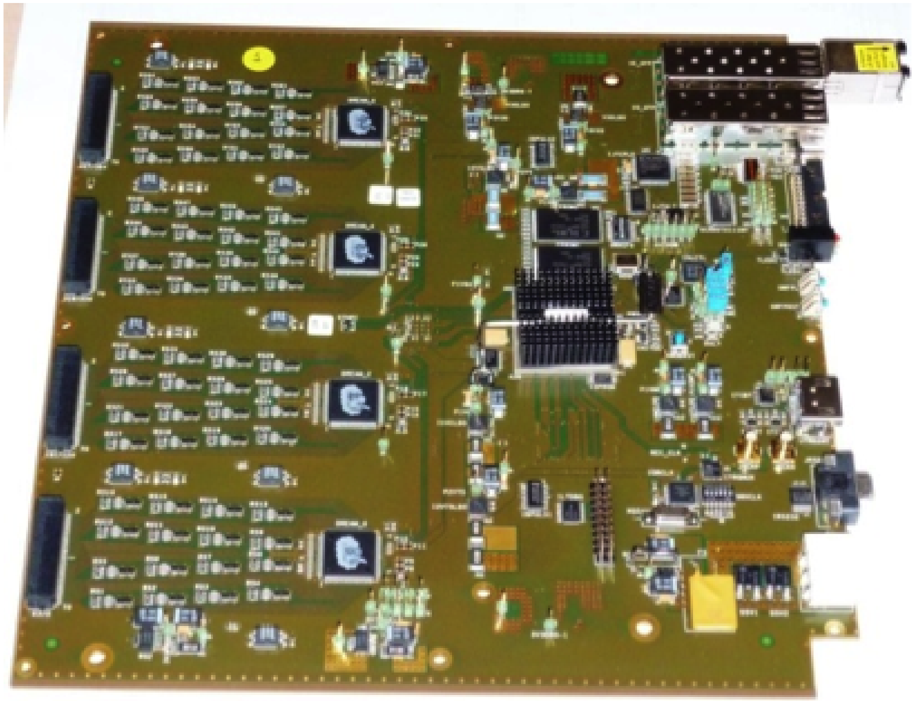


Figure 18: *A 512-channel frontend unit prototype: 4 out of the 8 Dream ASICs can be seen.*

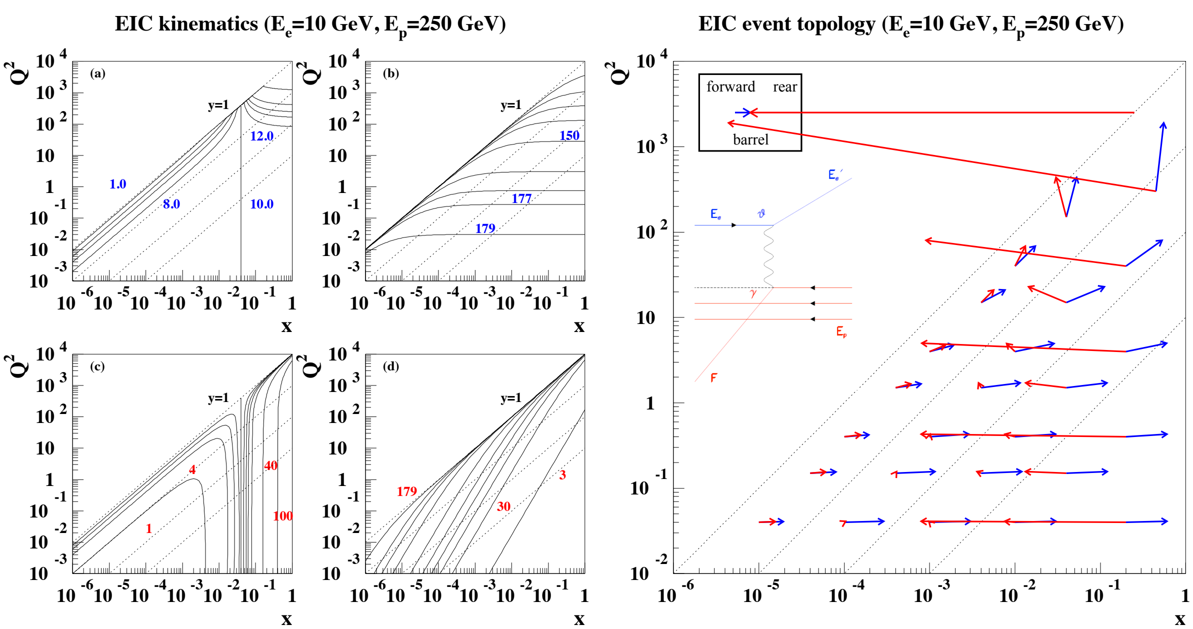
over the optical link to an event builder) or directly to an acquisition PC (over a GE network). The functionality of the FEU prototypes has been validated. The operation of the boards in 1.5 T magnetic field has been demonstrated. The readout of large CLAS12 Micromegas detector prototypes (strip capacitance of 80 pF) over up to 2 m long micro-coaxial cables (strand capacitance of 100 pF) exhibits low noise of approximately 2100 e- when the common mode noise subtraction is performed within the FEU FPGA firmware. Both FEU prototypes are equipped with the initial version of the Dream ASICs. A production of 12 pre-series FEU boards with the final revised Dream chips is ongoing. The boards are expected by the end of 2013. The production of about 70 units is planned during the spring of 2014.

Status: All developments are very promising for our EIC R&D proposal and completes the first phase of our program.

2.3 GEANT4 tracking detector simulations

Simulation tools provided by the BNL EIC group have been used focusing on the outer barrel and forward tracking region which is the main focus of this proposal aiming for the following aspects:

- Implementation of barrel and forward tracking layers
- Study of hit reconstruction and transverse momentum resolution for different assumed readout structures for both the MicroMegas and triple-GEM tracking systems
- Study of kinematic variable resolution in addition to existing analytical acceptance and resolution studies as shown in Figure 19 for the case of 10 GeV electron on 250 GeV proton beams.



$E_e/E_p = 0.04$

Figure 19: *Analytical acceptance and resolution study showing the direction and size of the energy of the final electron and struck quark in the $Q^2 - x$ plane for different $Q^2 - x$ combinations.*

An important part of this R&D effort consists of detailed studies of an EIC detector through GEANT-like simulations. This effort has started at Temple University using the newly released EICROOT framework. Studies have been conducted to serve as a general guideline for further simulations. The following aspects of the program are being developed :

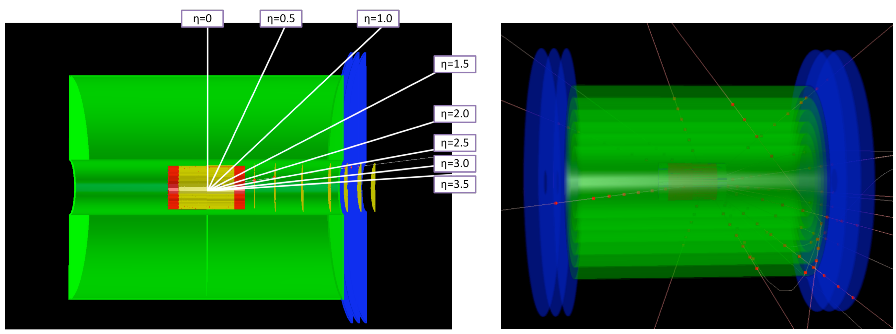
- Setup of the EICROOT software framework
- Implementation of the GEM tracking detectors geometry and material

- First implementation of the MicroMegas barrel detector system
- Study of the impact of the general dimensions of the GEM-Tracker
- Study of hit reconstruction and transverse momentum resolution for different assumed readout structures for both the MicroMegas and triple-GEM tracking systems

The progress of these preliminary studies are detailed below :

- First geometry of the FGT and the MicroMegas barrel

  The standard simulation package is based on an eSTAR-like detector with a TPC, a silicon micro-vertex detector, a barrel calorimeter, a silicon forward tracker, and a Foward/Backward GEM tracking system based on the STAR FGT. The later has been modified to match the foreseen size of our system. A total of 3 FGT disks have been implemented with an active area from 10 to 100 cm in radius covering $1 < \eta < 2.5$ including a realistic material budget. The MicroMegas barrel consists of 6 cylindrical detectors in place of the TPC. The material description is not yet fully included (Figure 20).



(a) (b)

Figure 20: *Geometry model of the EIC detector with EICROOT. Cross-section of the setup with a TPC as a central tracking device (left), and an event using the MicroMegas barrel (right).*

- Comparison between the Micromegas barrel and a TPC

  As a first exercise, a crude comparison between a TPC with a resolution of 1 mm in the R-Φ plane and 2 mm in Z and the MicroMegas barrel with a resolution of 100μm has been made. A box generator of π^- at 5 ± 0.5GeV is placed at the interaction point and the momentum resolution of the full system is studied. Despite of a larger number of hits along the track, a TPC gives a resolution of $\frac{\Delta P}{P}$ of $\sim$ 4% where it is 0.7% for a MicroMegas barrel. This is not meant to be a fully realistic number since the MicroMegas material is not yet included in the model, however it shows how a MicroMegas solution could be a realistic alternative to a TPC as a central tracking detector.

- Study of the impact of the size of the GEM tracking within a TPC based EIC detector setup

  One of the key parameter for the GEM tracker is the size of the acceptance to be covered. The raw material (GEM foils) is being limited to $\sim$50cm in width, the outer radius of the

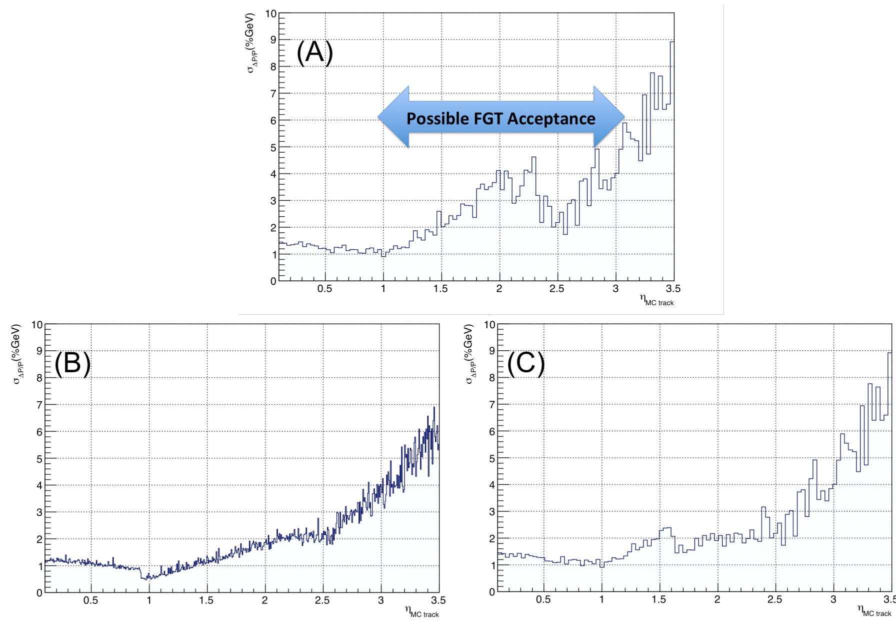


Figure 21: *.Momentum resolution in respect to the pseudo rapidity. Without the GEM tracker* ***(A)****, with a GEM tracker covering η from 1 to 2.5* ***(B)****, and with a FGT covering η from 1.7 to 2.3* ***(C)****.*

system defines the number of chambers per disk and their overall geometry. Therefore it is crucial to have a good estimation of this parameter early in the R&D process.

Fig.21 (A) shows the momentum resolution of a TPC based EIC spectrometer as a function of pseudo-rapidity. The region covered by the TPC is $\eta = 0$ to $\eta = 1$. A bump is seen where the active volume of the TPC decreases which corresponds to the potential GEM tracker acceptance. Fig.21 (B) shows the same simulation with a detector covering $\eta = 1$ to $\eta = 2.5$ (inner radius of 10cm and outer radius of 100 cm). Fig.21 (C) corresponds to a smaller apparatus covering η from 1.7 to 2.3. This shows the importance of having an outer radius around 1m (or that matches the outer radius of the central tracker). Similar simulations have shown that the inner radius depends on the position of the MicroMegas detectors. The presence of the FGT material decreases the momentum resolution in the acceptance of the forward silicon tracker when placed in front of them.

Status: This ongoing simulation effort is carried out by Temple University and CEA Saclay which will intensify to provide important answers needed by the design of an EIC detector system.

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