EIC Detector R&D Progress Report

Project ID: eRD3

Project Name: Design and assembly of fast and lightweight barrel and forward tracking prototype systems for an EIC

Period Reported: July 01, 2015 – December 31, 2015 (Status)

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Date: December 31, 2015

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Introduction

This report concentrates on a dedicated tracking system based on micropattern detectors, which focuses on the design and development of fast and lightweight 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 micropattern tracking detector system consists of:

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

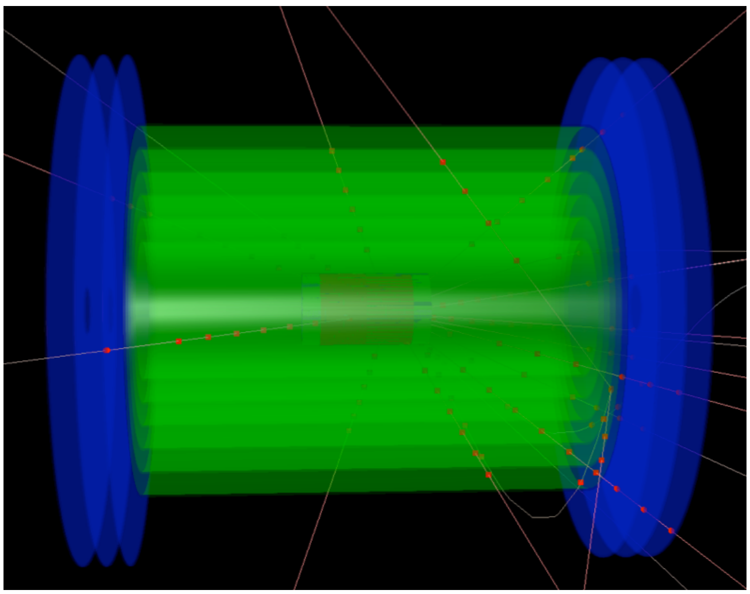


Figure 1: *GEANT simulation of barrel (green) and rear/forward (blue) tracking systems for an EIC detector.*

Figure 1 shows a 3D view of a GEANT simulation for a barrel and rear / forward tracking system which has been initiated 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 micropattern 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

- European/US collaborative effort on EIC detector development (CEA Saclay and Temple University).

This report provides an overview of various R&D activities in FY15/16 both in the barrel and rear / forward directions following the last meeting of the EIC R&D committee in July 2015. The allocation of funds of $104k for FY16 as stated in the award letter from August 2015 has not yet been obtained. As a result various orders are on hold, including the hire of a new post-doc. It should be emphasized that our R&D program is a dedicated development of various elements for a future EIC tracking detector system.

Over this time period we have had good success in promoting our EIC R&D research efforts. We have successfully published our results of the electrical performance and optical quality of commercially available single-mask GEM foils, produced by Tech-Etch, in NIM A [2]. We were also able to present and summarize these results at this year's IEEE conference [3].

Forward Triple-GEM R&D Program

Past

What was planned for this period?

Over the time period of 7/15 to 01/16, we had planned to carry out R&D efforts in several areas

1. The continuation of establishing the commercialization of large area GEM foils from Tech-Etch. This includes fine-tuning the Tech-Etch 50 cm x 50 cm GEM foils and upgrading their facilities to accommodate foils on the order of 1 meter long.
2. Finalize an EIC GEM foil design, in collaboration with eRD6, that will serve as a common GEM foil used in three unique forward/rear triple-GEM tracking detectors from three different groups (Temple University, Florida Institute of Technology, and University of Virginia).
3. Upgrade our current GEM CCD scanner, which quantifies the geometrical properties of GEM foils, to accommodate large area GEM foils (> 50 cm long).
4. Construction of 40 cm x 40 cm triple-GEM detectors using Tech-Etch produced single-mask foils. These detectors will allow us to
    - Investigate new methods of separating the foil layers via spacer rings, in an effort to further reduce the material budget of the detector.
    - Characterize the detector gains via cosmic rays and X-rays.
    - Study clustering schemes using our already developed and commissioned CAEN HV system.
5. Construction of 10 cm x 10 cm triple-GEM detectors using Tech-Etch produced single-mask GEM foils.

6. Implement the DREAM chip into the existing STAR FGT triple-GEM detector, with the ultimate goal of having the EIC triple-GEM detectors use the DREAM chips.

What was achieved?
Since the last update in July 2015, there has been progress made in several areas.

<u>Tech-Etch GEM Foil Development</u>

Tech-Etch is continuing their commercialization process of large area GEM foils. They are in their final stages of optimizing their production process of 50 cm x 50 cm GEM foils. Final 50 cm x 50 cm GEM foils are expected to be shipped to Temple University soon for further analysis via optical scanning.

Furthermore, Tech-Etch is looking into ways that would allow them to produce GEM foils on the order of 1 meter long. Foils of this size are not only desired by other future experiments/detectors in the nuclear-particle physics community, but are also critical to the EIC GEM detectors. One way for Tech-Etch to produce GEM foils on the order of 1 meter long is to upgrade their production equipment (etching baths etc.) so that they can accommodate longer foils. This is currently on ongoing endeavor at Tech-Etch. In light of recent information from CERN, Tech-Etch might also be looking into a new method of foil etching, in which the foil is wrapped around a structure and placed in the etching bath, rather than just laying the foil down in the bath. Such a method could allow Tech-Etch produce longer foils without the need of extending their etching baths or taking up more valuable floor space. The technical practicalities of using this method and the size of the foil that it could yield without any major upgrades would need to be investigated.

Tech-Etch's main concern is that there is not an actual market for large area GEM foils, which makes it difficult for them to justify investing internal resources into developing such a project.

<u>EIC GEM Foil Design</u>

In collaboration with eRD6, the three institutions (Temple University, Florida Institute of Technology, and University of Virginia) have finalized the design of an EIC GEM foil. This common design will be used to produce three unique triple-GEM detectors, with each of the three institution using different assembly and readout techniques. More details of the assembly and readout differences between the institutions can be found in ref [4] and in the eRD6 progress report.

In addition to the production of full fledged EIC GEM foils (~ 1 meter long), we feel that it would be advantageous to proportionally scale the EIC GEM foil design down such that the foils measure some where on the order of 50 cm long. This would allow us to order the foils right away from Tech-Etch and not have to wait for any production facility upgrades to start/complete. We could then begin building a scaled down version of our

EIC triple-GEM detector. We are currently in the process of scaling down the current EIC GEM foil design.

GEM CCD Scanner

With Tech-Etch already producing GEM foils on the order of 50 cm long, and in anticipation of receiving even larger (~ 1 meter long) GEM foils from both Tech-Etch's upgraded facilities and CERN, it is a vital that our GEM CCD scanner can accommodate the larger GEM foils if we would like to measure the GEM foil's geometrical properties. Currently our CCD scanner is unable to measure foils that are 50 cm long (Previous 50 cm x 50 cm Tech-Etch foils needed to have the dead material cut away in order to fit on our scanning stage.). To allow the scanning of larger area GEM foils, two upgrade scenarios were considered and have now been thoroughly investigated.

The first upgrade scenario involves wrapping a GEM foil long-ways around a hollow cylindrical piece of acrylic (Figure 2a). The plastic cylinder would then sit on a rotational stage (Figure 2b) allowing for 360 degrees rotation of the cylinder. The CCD camera would then be mounted on a vertical motion stage (Figure 2c) that would allow us to scan the width of the foil (~60 cm). Additionally a laser system would need to be implemented to insure that the camera is always in focus with the rotating cylinder. This can also be seen in Figure 2a. Obtaining an estimate from Newport, such a system consisting of the rotational stage and vertical linear stage would cost approximately $30,000. This does not include the cost of the motor drivers, motion controller, focusing laser, or the cost of producing a large acrylic cylinder.

The second, and preferred, upgrade method is to use two linear stages of 100 cm and 80 cm travel range, shown in Figure 3, to build a larger x-y scanning stage. The estimate from Newport on these two linear stages is approximately $24,000, but no additional cost would have to go into purchasing/machining a cylindrical structure for the GEM foil, as it can simply be placed on a flat piece of acrylic or glass. An additional advantage to using this method is that our current GEM scan software can be used. If we were to pursue the cylindrical scanner, then all new software would need to be written and algorithms used in order to analyze the camera images.

The GEM CCD scanner will be built on an already existing, new Newport optical table (6 ft x 4 ft), which is located in Temple University's permanent class 1,000 clean room.

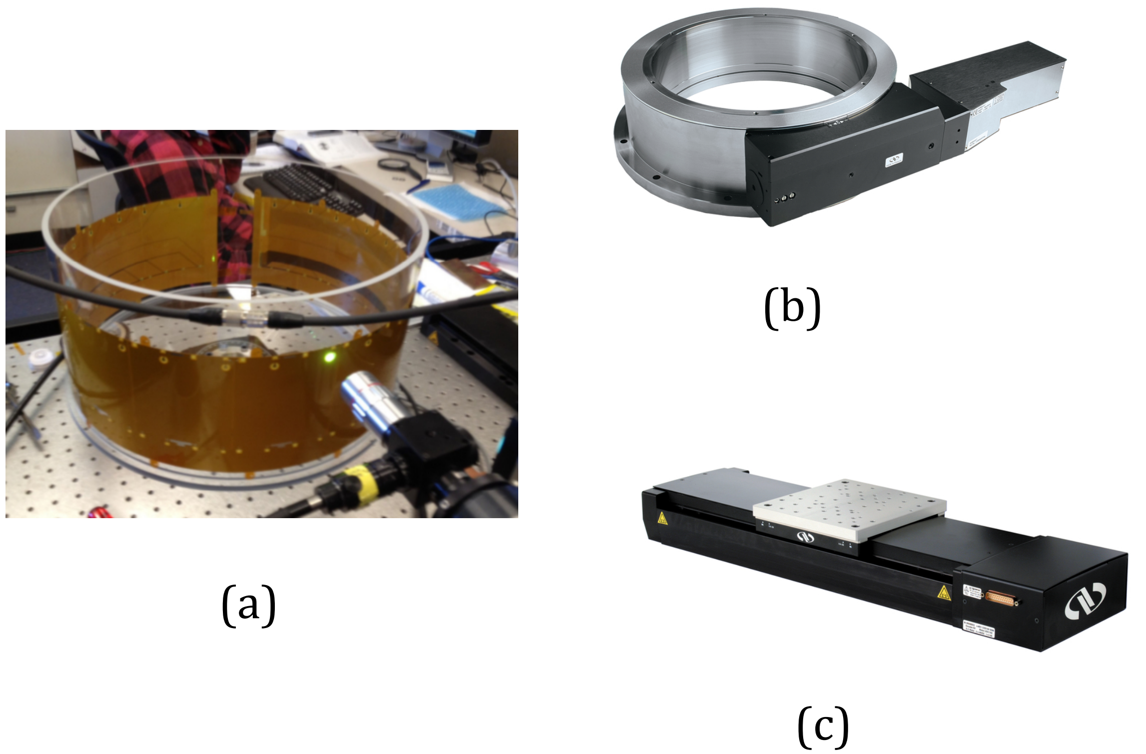


Figure 2: *Components needed for cylindrical CCD scanner. (a) Setup used by Dr. Carl Haber (LBNL) to preform his tubular imaging. A foil wrapped around a plastic cylinder can be seen, along with a laser setup used for focusing the camera. A similar setup would be mimicked for the GEM foils. (b) Newport rotational stage that would be needed to rotate GEM foil. (c) Linear stage that would be needed to vertically move the CCD camera to cover the height of the rotating cylinder.*

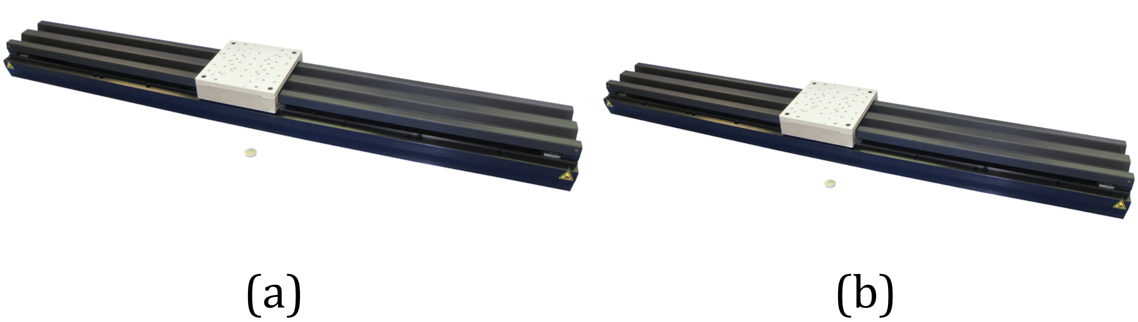


Figure 3: *The two proposed linear stages by Newport, (a) 100 cm and (b) 80 cm, that would be used to construct a larger x-y transitional stage.*

Tech-Etch Triple-GEM Detector (40 cm x 40 cm)

Now that Tech-Etch has finalized their single-mask commercial GEM foils up to 40 cm long, we are ready to assemble triple-GEM detectors to fully characterize the foils performance. To do this we are planning on building 3 triple-GEM detectors, which are based on the STAR FGT [5]. The FGT design was chosen to save both money and time. Temple University already has all of the tooling specific to the FGT design that is needed to build a triple-GEM detector. This includes a nitrogen enclosure for leakage current testing, a stretching rig for gluing the foils, a design for the HV foil, frame design, readout board design, and soldering station.

We have already placed an order with Tech-Etch to produce 9 40 cm x 40 cm single-mask GEM foils, 3 HV foils, and 3 readout boards, and will order the frames shortly. The expected ship time for the GEM foils, HV foils, and readout boards is January 8, 2016. We currently already have the remaining materials needed to complete the triple-GEM detector, which include mounted APV chips and HV boards.

While constructing the triple-GEM detectors, we are going to investigate using spacer rings to separate the foil layers in effort to further reduce the material budget. After seeing the leakage current comparisons between foils using Kapton and Apical as their base material [2] (Apical seemed to have better electrical properties), we had decided to switch the spacer material from Kapton to Apical. However after several tests the vendor (Potomic Photonics) concluded that they would not be able to cut the tube of Apical material into rings due to issues between the Apical absorption frequency and their laser used for cutting the material. As a result we will be placing an order for Kapton spacer rings shortly.

With 9 new GEM foils being ordered, we would like to characterize them via leakage current and optical scanning before building them into a triple-GEM detector. As a result starting in January 2016 two undergraduate students, paid for in full by the College of Science and Technology at Temple University, will begin working in the lab to perform the leakage current measurements and optical scans of the foils. We will also have them help work towards automating the leakage current measurements via LabView or Matlab. Having the leakage current measurements automated will be beneficial when wanting to study the time dependence of the leakage current.

DREAM Chip Readout

Given that the production of the APV chip, commonly used to readout information in GEM detectors, has now been stopped for some time, an alterative readout solution needs to be found. The DREAM chip, which is similar to the APV chip and is being used for CLAS12 [6], has been marked as a good substitute for the APV chip.
Temple University has sent Saclay a triple-GEM detector, based on a STAR FGT quarter section, which used the APV chips for readout to be refitted with DREAM chips.

CEA Saclay has successfully designed and built a transition card to connect a FGT quarter section to their current DREAM front-end-electronics. The newly designed and fabricated FGT-DREAM cards will replace the current FGT-APV cards. Figure 4 shows the two FGT-DREAM cards on the left and one FGT-APV card on the right.

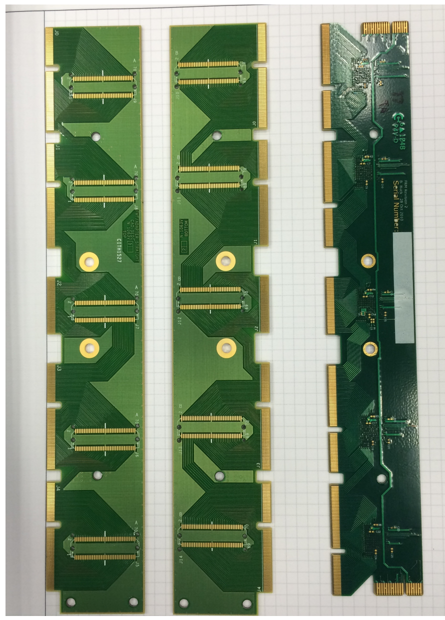
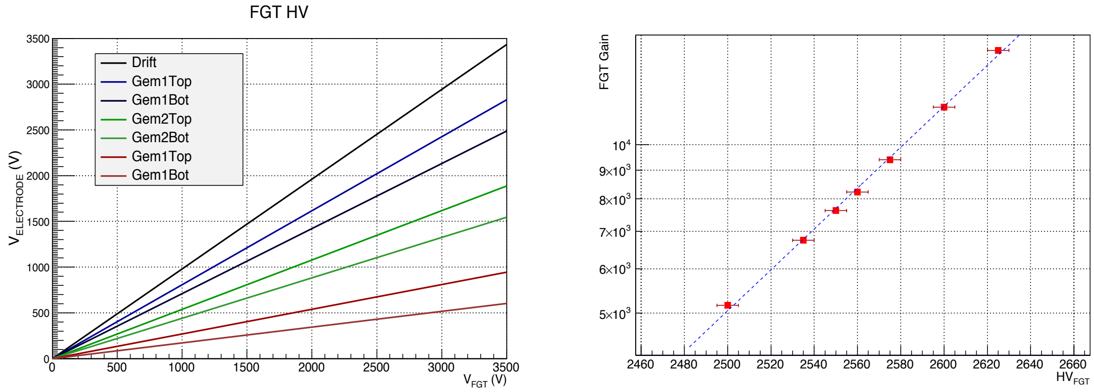


Figure 4: *Two FGT-DREAM cards (left) and one FGT-APV card (right).*

Once the detector was successfully refitted with the DREAM chips, the Saclay group began preliminary characterization of the detector via an ^{55}Fe source and cosmic-rays. It should be noted that there is a slight mapping issue with the transition card, as such the following results are only preliminary and serve as an early look at the FGT performance using the DREAM chips.

Using an ^{55}Fe source, the GEM electrode voltage was measured as a function of FGT applied voltage for each GEM layer (Figure 5a). Figure 5b shows the FGT gain measured as a function of the applied FGT HV.

In addition to the ^{55}Fe gain measurements, the Saclay group was also able to use their existing cosmic-ray test bench, which they also use to test their Micromegas barrel, to perform an initial assessment of the FGT's efficiency. The cosmic ray test bench can be seen in Figure 6. The initial results of the cosmic-ray characterization already look very good even with the known mapping issue. The results can be seen in Figure 7, where the GEM supports and HV sectors can clearly be seen, along with a dead GEM sector. These features are highlighted in Figure 7b. Discarding these less effective areas the efficiency of the detector was measured to be better than 95%.



(a) (b)

Figure 5: *(a) HV configuration of the FGT electrodes with respect to the HV of the HV board. (b) FGT gain measurement using an ^{55}Fe source in Ar/iC4H10 95/05 gas.*

Figure 6: *FGT quarter section of the cosmic-ray test bench. The blue cables connect the DREAM FEE to the FGT's transition card. The Micromegas barrel can also be tested at the same time, as seen in the photo.*

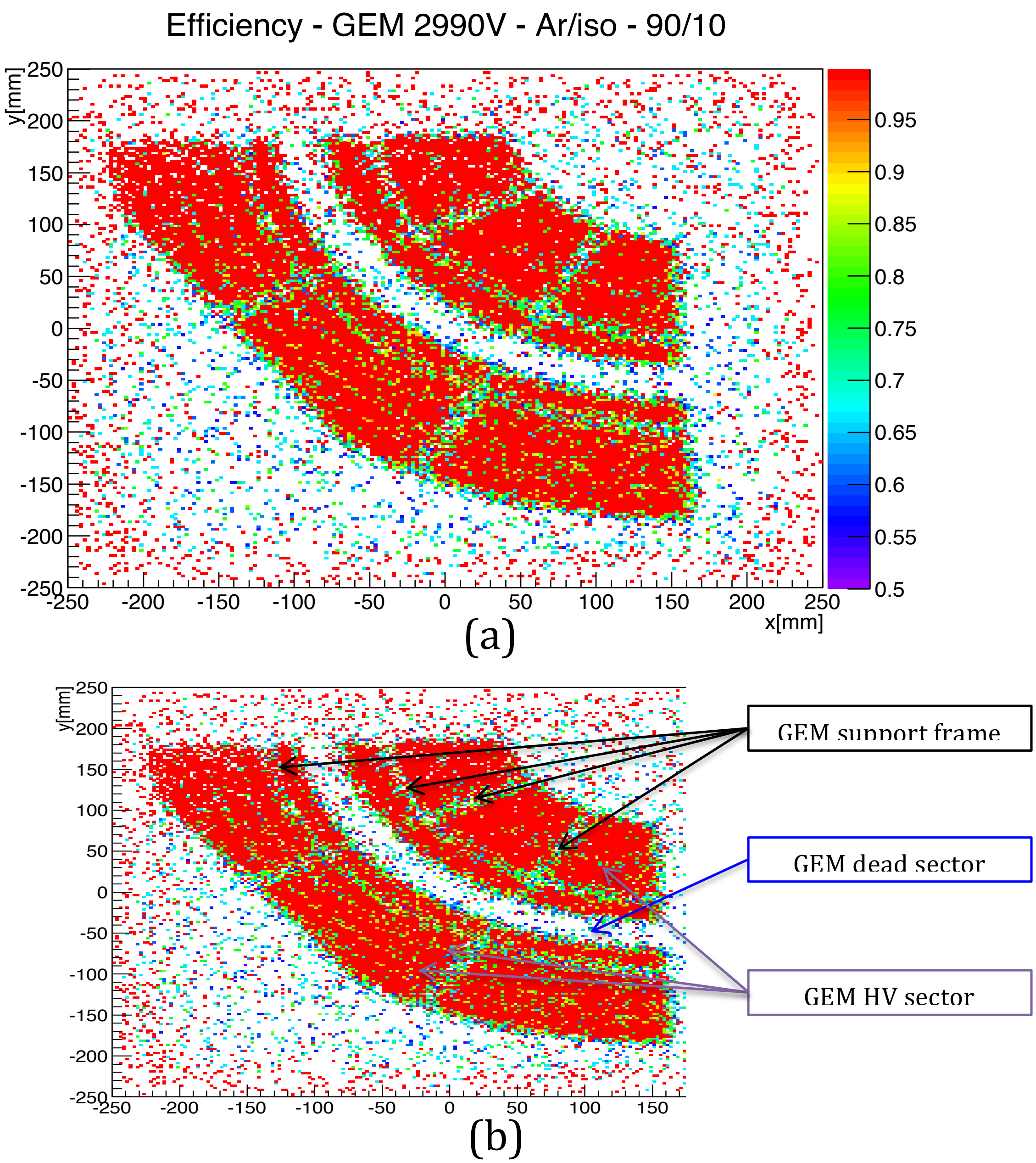


Figure 7: *Initial 2D efficiency map of the FGT via cosmic-rays. (b) labels the clearly seen FGT structure in the efficiency map.*

What was not achieved, why not, and what will be done to correct?

<u>Tech-Etch Triple-GEM Detector (10 cm x 10 cm)</u>

Delayed due to FY16 funding.

Future

What is planned for the next funding cycle and beyond? How, if at all, is this planning different from the original plan?

Post-Doc

With the recent promotion of Dr. Posik to Assistant Research Professor, his time able to be allotted to the EIC R&D program has been reduced (~50%), as a result we would like to hire a new post-doc who would be 50% dedicated to the EIC R&D program and 50% supported by Dr. Professor Surrow's DOE research grant. This work sharing allows the continuation of our R&D efforts.

Commercialization of Large GEM Foils

The most critical item that needs funding is the continuing development of commercially available large area GEM foils from Tech-Etch. These foils will not only play a vital role in EIC GEM tracking R&D, but the entire nuclear and particle physics community. A detailed proposal for the continuation of large area GEM foils can be found in the eRD6 proposal.

In the mean time we plan on ordering scaled down EIC GEM foils from Tech-Etch that are on the order of 50 cm long. This will allow us to further characterize larger foils from Tech-Etch and begin building our EIC tracker prototype.

Construction of 40 cm x 40 cm Triple GEM Detector

After the construction of the Tech-Etch single-mask triple-GEM detector, we plan on using our already existing cosmic ray test setup to characterize the gain and performance of the detectors. We would then like to repeat these tests using our mini x-ray tube, however to do this we would need to purchase material to build a safety enclosure complete with an interlock system that will house our mini x-ray tube. We are currently working with Temple University EHRS to get more details on the required safety measures needed.

In addition to using the mini x-ray tube, we would like to purchase an ^{55}Fe source to map the gain of the detector as a function of position. These gains can then be correlated to foil hole uniformity that we obtained via our optical scanning of the individual foils. The accumulation of these studies should provide a clear determination of the Tech-Etch foil quality and hopefully lead to a second NIM publication. Additionally we would also like to study various clustering methods.

GEM CCD Scanner Upgrade

With the decision made to upgrade our current CCD scanner to a larger 2D translational stage, we can now begin to purchase the material needed and build our upgraded CCD scanner.

Barrel Micromegas R&D Program

Past

What was planned for this period?

Over the time period of 7/15 to 01/16, we had planned to carry out R&D efforts in a couple of areas

- 2D curved resistive Micromegas prototype detector: this technology has the clear advantage of minimizing the amount of material with respect to two 1D detectors.
- Electronics: Design and fabrication 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.

What was achieved?

During this period the Saclay group was able to successfully design, build and test a transition card to connect a FGT quarter section triple-GEM detector to their current DREAM fron-end-electronics. To connect the FGT to the DREAM electronics, a passive transition card was build to connect the 2 "super-connectors" of one FGT quarter section to the MEC8 connectors used with the DREAM front end electronics. This FGT-DREAM card replaces the FGT-APV cards and allows the detector to readout using the DREAM chips rather than the APV chips, as described in the Forward Triple-GEM section and shown in Figure 4.

The FGT quarter section was tested using cosmic rays and found to be over 95% efficient, which can be seen in Figure 7, and was described in the Forward Triple-GEM section.

In addition to the GEM readout electronics work, the Saclay group has also continued further cosmic ray testing of their 1D Micromegas barrel detector.

What was not achieved, why not, and what will be done to correct?

We are waiting on the R&D funding allocated in the award letter to become available. Once it does we plan on pursuing the 2D Micromegas R&D work.

Future

What is planned for the next funding cycle and beyond? How, if at all, is this planning different from the original plan?

2D Micromegas Detector

With the success of the two 1D Micromegas detectors presented in the last progress report, we would like to continue the development of the cylindrical Micromegas detector by building a large 2D curved resistive Micromegas detector.

What are the critical issues?

After accessing our requests, we would like to highlight one crucial request, the continuation of large GEM development at Tech-Etch. Without funding for this program, Tech-Etch is likely to shift its interest elsewhere and the program may be terminated. With no other source consistently producing GEM foils this would leave CERN as the only GEM distributor (see the combined eRD6 proposal).

Manpower

One postdoc was supported at 100%.

External Funding

Both groups, Temple University and Saclay did not receive any other funding in support of the program discussed here.

Publications

1. M. Posik and B. Surrow, Nucl. Instrum. Meth. A **802**, (2015) 10.
2. M. Posik and B. Surrow, Conference Record to IEEE Nucl. Sci. Symposium, (2015) [arXiv:1511.08693].
3. A. Zhang *et al.*, Conference Record to IEEE Nucl. Sci. Symposium, (2015) [arXiv:1511.07913].

Budget Request

We anticipate a funding request for the next funding cycle to be around ~$150k. This estimate includes:

- Post-doc support for FY17
- EIC R&D related travel
- Building a safety enclosure for the mini x-ray tube
- Ordering scaled down EIC GEM foils from Tech-Etch
- Development of a 2D Micromegas barrel detector

References

[1] A. Accardi *et al.*, Report on 'Electron Ion Collider: The Next QCD Frontier- Understanding the glue that binds us all', arXiv 1212.1701 (2012).

[2] M. Posik and B. Surrow, Nucl. Instrum. Meth. A **802**, (2015) 10.

[3] M. Posik and B. Surrow, Conference Record to IEEE Nucl. Sci. Symposium, (2015) [arXiv:1511.08693].

[4] A. Zhang *et al.*, Conference Record to IEEE Nucl. Sci. Symposium, (2015) [arXiv:1511.07913].

[5] B.Surrow, Nucl. Instrum. Meth. A **617**, (2010) 196.

[6] https://www.jlab.org/Hall-B/clas12-web/