EIC Detector R&D

Progress Report and Proposal

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, 2016 – December 31, 2016 (Status)

Project Leaders:
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Introduction

This report concentrates on a dedicated tracking system based on micro-pattern 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 micro-pattern 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.

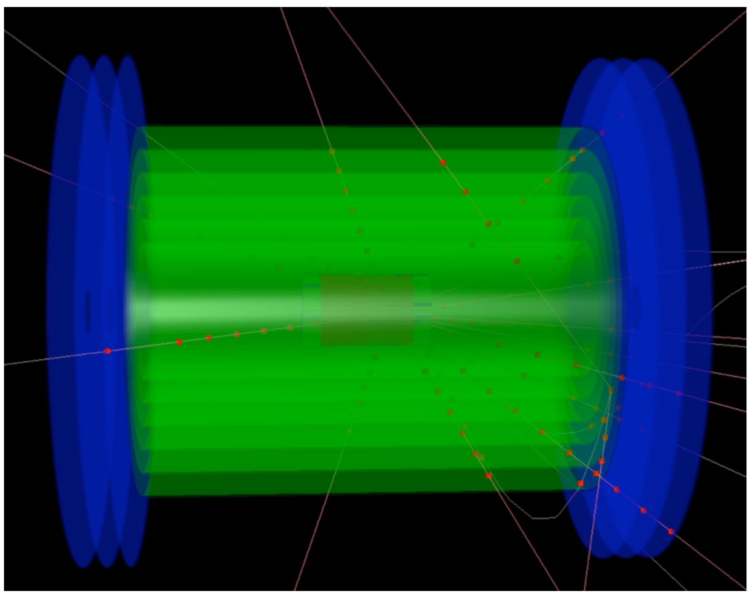

Figure 1: *GEANT simulation of barrel (green) and rear / forward (blue) tracking systems for an EIC detector.*

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 micro-pattern detectors,
- Utilization of light-weight materials,
- Development and commercial fabrication of various critical detector elements and

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

This report provides an overview of various R&D activities in Q4FY16 / Q1FY17 both in the barrel and rear / forward directions following the last meeting of the EIC R&D committee in July 2016. The allocation of funds of $77,580 for FY17 are in the process of being transferred to Temple University. Our new postdoc, Dr. Amilkar Quintero, started on June 01, 2016. He completed his Ph.D. thesis work with the STAR experiment at RHIC on the STAR Heavy Flavor Tracker at Kent State University. He has a lot of experience with tracking software and has prior experience with micro-pattern detectors at CERN while completing a Master's Degree at Florida Institute of Technology with Professor Marcus Hohlmann, our collaborator of the EIC eRD6 program. Dr. Matt Posik was promoted to the rank of Research Assistant Professor in 2016. The bulk of the EIC R&D program was so far carried out by Dr. Matt Posik besides his physics analysis efforts at the STAR experiment. His appointment at Temple University is now shared between the College of Science and Technology at Temple University and the EIC R&D subcontract. Dr. Amilkar Quintero will be trained by Dr. Matt Posik and will share his commitment between the EIC R&D program and the physics analysis program of high-energy polarized p+p spin physics with Professor Bernd Surrow at RHIC covered by his DOE Nuclear Physics base grant. This allows continued progress on both the EIC R&D program supported by the EIC eRD3 sub-contract and the physics analysis program covered by a DOE Nuclear Physics base grant. It is essential to expose a beginning postdoc to both hardware and physics analysis activities for future career opportunities. The College of Science and Technology is strongly supporting the R&D program with both manpower and equipment support. Mr. James Wilhelmi, a mechanical engineer, provides dedicated support for Nuclear Physics research activities at Temple University. We do consider this and the local new machine shop an outstanding resource for our detector development work. In addition, a generous gift provided to the College of Science and Technology at Temple University allowed the purchase of additional laboratory equipment.

It should be emphasized that our R&D program is a dedicated development of various elements for a future EIC tracking detector system. It is the only R&D program which provides an alternative barrel tracking system besides a TPC R&D program. The generic R&D program is expected to be completed by 2018. It is then planned to enter a phase of targeted EIC detector design work focusing on specific prototyping assembly and testing activities in close collaboration with the Florida Institute of Technology and the University of Virginia in preparation of a Technical Design Report required in part for the DOE Critical Decision process. This step will be carried out in general in collaboration with the EIC eRD6 program. It is planned to fully merge both efforts with the completion of the generic R&D program.

Over the last reporting period we have had good success in promoting our EIC R&D research efforts with a presentation at the IEEE conference in November 2016 based on the status of our R&D program [2] and a recent NIM publication [3]. The International Advisory Committee of the International Micro-Pattern Gas Detector conference series asked the eRD3/6 R&D group through Dr. Klaus Dehmelt and Professor Bernd Surrow about the possibility to host the International Micro-Pattern Gas Detector conference in 2017 (MPGD 2017) at Temple University. A presentation was made to the advisory committee during a recent RD51 meeting at CERN on Monday, June 6, 2016 together with one other competing proposal to host the MPGD 2017 conference. On Tuesday, June 14, 2016 we were informed that the International Advisory Committee decided in favor of Temple University and participating institutions of eRD3/6 to host the MPGD 2017 conference. The conference together with a full-day RD51 collaboration meeting will take place on May 22-26, 2017 at Temple University. We do consider the interest by the International Advisory Committee for the eRD3/6 groups to host the next International Micro-Pattern Gas Detector conference as a strong recognition of our R&D program [2, 3, 4, 5] on an international level.

Forward Triple-GEM R&D Program

Past

What was planned for this period?

Over the time period of 07/16 to 01/17, we had planned to carry out R&D efforts in several areas:

1. 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).

2. Design a scaled down (~50 cm long) EIC GEM foil.

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, HV foils and 2D readout 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. Designing of a radiation enclosure needed to operate a 50 keV X-ray tube, which is needed for triple-GEM detector gains and efficiency measurements.

6. Further test the implementation of the DREAM chip with triple-GEM detectors, with the ultimate goal of having the EIC triple-GEM detectors use the DREAM chips.

7. Commercialization of large GEM foils and other components.

What was achieved?

Since the last update in July 2016, there has been progress made in several areas:

1) <u>GEM CCD Scanner</u>

It is vital that our GEM CCD scanner can accommodate larger GEM foils if we would like to measure the GEM foil's geometrical properties. Our previous setup was not suitable to scan foils of 40 cm x 40 cm and larger. The previous setup was meant to scan foils only up to 10 cm x 10 cm. To allow the scanning of larger area GEM foils we designed a CCD scanner around two larger linear stages of 100cm and 80cm travel range. A Solidworks model of the design and an image of the completed assembly are shown in Figure 2.

Figure 2*: (left) Solidworks model of large area CCD GEM scanner design. (right) Completed large area CCD GEM scanner on top of a 4' x 6' optical table inside the Temple University MPGD clean room facility. Note: The optical table of close to $10k was provided by the College of Science and Technology at Temple University through a generous a gift.*

The large area CCD GEM scanner was built on an already existing, Newport optical table (6 ft x 4 ft), which is located in Temple University's Micro-Pattern Gas Detector (MPGD) clean room facility. The machining and assembly of the scanner has now been completed by our mechanical engineer Mr. James Wilhelmi. In addition to upgrading the scanning area of the CCD scanner, the CCD camera used to capture images of the GEM foil was also upgraded. We have now ordered, installed, and verified the functionality of the DMK 23F445 model camera ordered from 'The Imaging Source'. This camera upgrade not only improves the pixel size and resolution of the CCD camera, but also captures images with a larger field of view. The increased field of view should contribute to decreasing the time needed to scan the GEM foils.

We are currently working on calibrations and developing software that will allow us to integrate the motion control of the stages and the camera controls so that we can run an automated scanning procedure. We are also revisiting the image analysis software in hopes to be able to extract the inner and outer hole information from a single image. If successful this would decrease the time needed to scan a foil by a factor of 2.

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

We are planning - as reported earlier - on building 4 triple-GEM detectors, which are based on the STAR FGT [6]. 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 jig for gluing the foils, a design for the HV foil, frame design, readout board design, and soldering station. Those items are all located and already inside our MPGD clean room facility. Figure 3 shows several detector assembly areas of the Temple University MPGD clean room, other areas include the glueing and soldering stations.

All essential components have been ordered and received which include:

- 12 40 cm x 40 cm single-mask GEM foils
- 4 HV foils
- 4 readout foils
- Multi-pin connectors
- Mylar pressure enclosure foils
- Assembly frames
- Ultra sonic bath
- Glue foot pedal dispenser
- Kapton spacer rings
- APV chips
- APV cards
- HV boards
- Glue

In order to take advantage of the MPGD clean room's gas supplies, we have designed, built and are installing a gas panel. This panel will allow us to access the MPGD clean room's nitrogen, argon, and dry air gas lines. These gases will be used for various assembly steps such as leakage current measurements, GEM storage, detector leakage tests, and GEM stretching. Moreover, the gas panel will also have bubblers and a course and fine manometers to control the gas flow into the triple-GEM detector and monitor and control the pressure in the detector during assembly and initial testing.

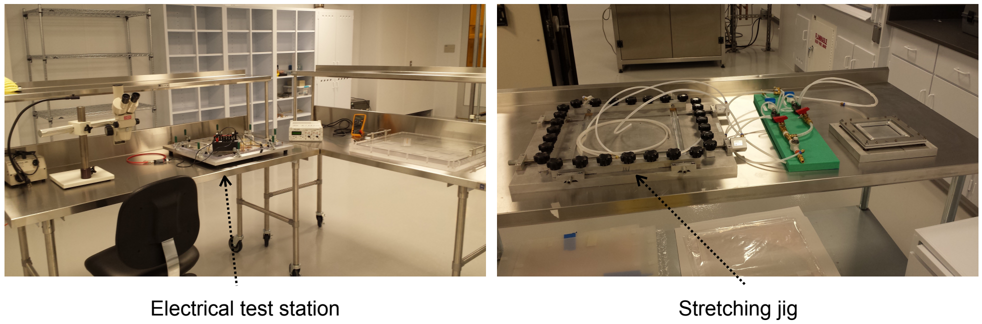

Figure 3: *Electrical test setup and stretching jig inside the MPGD clean room facility.*

We have purchased and received an Elmasonic X-tra 2500 ultra sonic bath, which can be seen in Figure 4. This is a 225 L tank that measures 750 mm (W) x 650 mm (D) x 520 mm (H), and will be used to clean the 40 cm x 40 cm GEM frames. Furthermore, such a large size was selected so that future EIC frames, on the order of 1 meter long, could also be cleaned in the bath. To clean the longer EIC frames we would adopt a method that UVa currently employs when cleaning their Super BigBite frames, where they submerge and clean half of the frame and then rotate it to clean the other half. The ultra sonic bath has arrived and had its European plug refitted with a US model. A work order has already been filed with Temple University facilities to relocate our detector lab's 250 V outlet to a more practical location in the lab. We expect facilities to begin this work shortly after the new year.

Figure 4: *Ultra sonic bath that will be used to clean frames for the 40 cm x 40 cm triple-GEM detector and future EIC frames.*

Figure 5: *Kapton space rings (left). Initial packing scheme for Kapton spacer rings (right).*

We have now received all of the Kapton spacer rings shown in Figure 5. Kapton was chosen as the base material after the vendor (Potomic Photonics) concluded that they would not be able to laser cut Apical material into rings due to issues between the Apical absorption frequency and their laser used for cutting the material. The Kapton rings have a couple of potential advantages over the spacer grid method. First the Kapton rings themselves have a lower material budget than the G10 spacer grids. Secondly, they could offer a cheaper alternative to spacer grids as the triple-GEM detectors become larger and approach a length of one meter. There are many different packing arrangements that the Kapton rings can be implemented within the GEM volume. One initial packing arrangement that we will look at first is shown in Figure 5. Using this packing scheme it appears that Kapton rings will not need to be glued and can simply be placed into the GEM volume as shown in Figure 5. It should be pointed out that the Kapton ring tests were performed by an undergraduate student supported by the College of Science and Technology at Temple University.

Multi-pin connectors providing the connection between each r-phi readout strip on the 2D readout foil and the chip-readout board were soldered commercially by Proxy Inc., who are closely connected to MIT Bates laboratory. A visit to MIT Bates took place to discuss how to ship the readout foils to Proxy Inc. to be soldered. The readout foils were sandwiched between two pieces of G10 material, also known as the readout foil shipping panels. The G10 material was machined to include alignment holes and cut outs which would allow the multi-pin connectors to poke free after being soldered. Figure 6 shows images of the readout foil in the shipping panels (before multi-pins are attached), after the multi-pin connectors are soldered, and an image of the readout foil with multi-pin connectors attached. We have so far received three of the four readout foils with the multi-pin connectors attached. We will be sending the final readout foil to Proxy shortly after the new year.

GEM foil storage and partial assembled triple-GEM detector storage is important for successfully building triple-GEM detectors. As a result we have designed and are now awaiting on parts and assembly of a custom GEM box. The GEM box will measure about 124 cm x 124 cm x 60 cm and will be flushed with nitrogen. Moveable shelving within the GEM box will provide storage of the triple-GEM detector at various assembly stages ranging from bare GEM foils to completed detectors.

Figure 6: *Readout foil in shipping panels (left). Readout foil in shipping panels with multi-pin connectors attached (center). Readout foil with multi-pin connectors attached (right).*

Figure 7 shows the design drawing done by James Wilhelmi, a mechanical engineer for Temple University's Nuclear Physics group. These plans have been submitted to the Temple University machine shop. The GEM box was designed with the EIC in mind. The large volume of the box will allow us in the future to accommodate detectors on the order of 1 meter long.

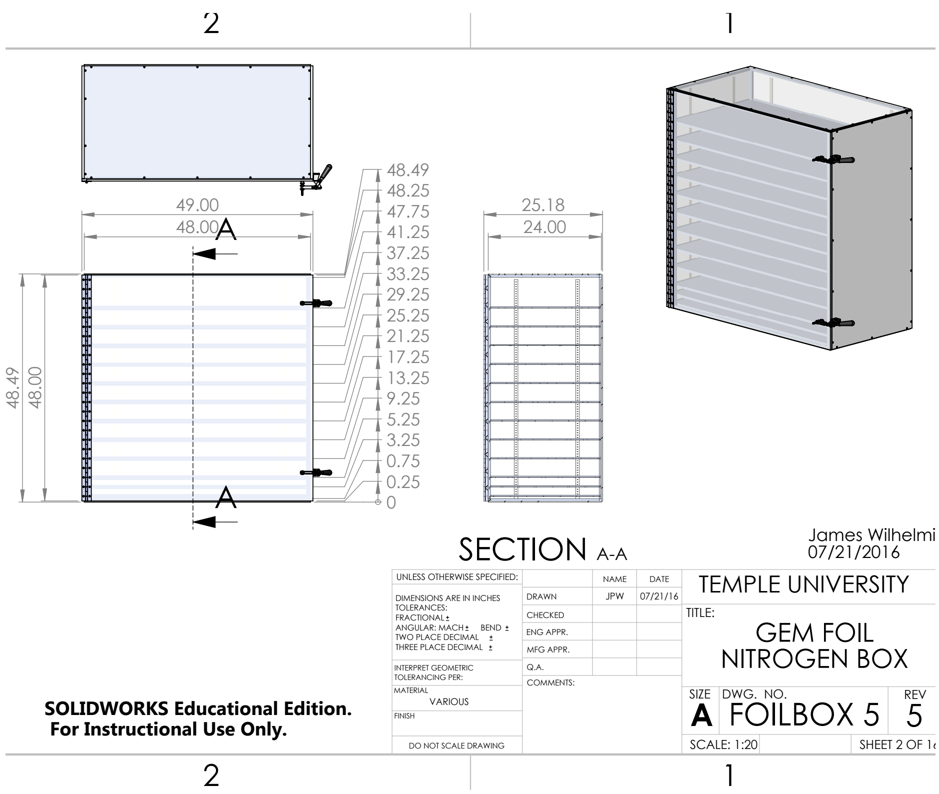

Figure 7: *Design drawings for MPGD clean room GEM storage box.*

3) X-ray Enclosure

The use of a high rate X-ray gun is an excellent way to study triple-GEM detector gain and efficiency performance. We currently have available a 50keV X-ray gun, however its operation requires a full Pb-enclosure. We currently have a working design for an enclosure that will sit on the 4' x 6' optical table that is in our detector lab. It was determined that 1/32" Pb thickness would be needed to operate the X-ray gun without the need of a dosimeter. A commercial supplier, Nelco, has been identified who produces Pb-lined plywood and glass sheets. The Pb-lined enclosure will be cubical having dimensions of 4' x 6' x 5'. One of the 4' x 6' Pb-lined plywood sheets will have cutouts to accommodate the legs of the optical table. With the exception of a 4'x5' and 6'x5' Pb-lined acrylic sheet all remaining sheets will be 1/32" (1/4") Pb (plywood) thick sheets. The Pb-lined acrylic sheets will be located on two sides and provide viewing into the enclosure. We have been in contact with Nelco and are currently awaiting a quote from them.

4) 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 alternative 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

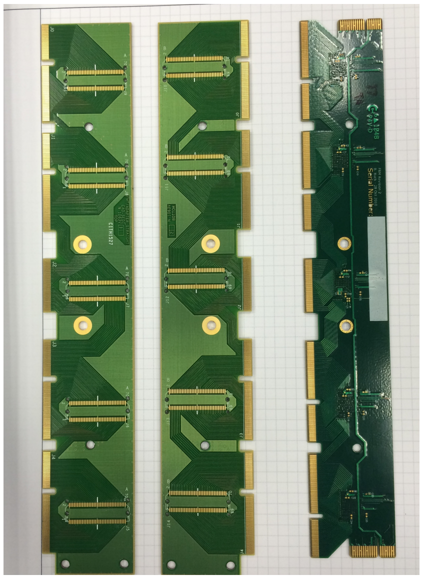

Figure 8: *Two FGT-DREAM cards (left) and one FGT-APV card (right).*

and fabricated FGT-DREAM cards will replace the current FGT-APV cards. Figure 8 shows the two FGT-DREAM cards on the left and one FGT-APV card on the right.

Once the detector was successfully refitted with the DREAM chips, the Saclay group continued characterization of the detector via an ^{55}Fe source and cosmic-rays. The cosmic ray test bench can be seen in Figure 9. It is planned that our postdoc will engage in the analysis of cosmic-ray data sets.

Figure 9: *FGT quarter section of the cosmic-ray test bench at Saclay. 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 photograph.*

5) <u>Commercialization of Large GEM Foils</u>

The further GEM foil production at Tech-Etch will critically depend on larger orders placed by the nuclear and particle physics community. It was decided by the board of directors at Tech-Etch to pause the production of GEM foils until such a viable market becomes available. The LHC Experiments committee (LHCC) at CERN has recently urged the RD51 collaboration to emphasize the need for commercial fabrication. It was explicitly stated during a RD51 meeting that there should be enhanced efforts on industrialization including a statement that the CERN management communicating to the LHC community such as ATLAS and CMS to consider placing orders outside CERN. This is certainly a critical step which the Tech-Etch management is waiting for. The fabrication of 2D readout foils and HV foils will continue at Tech-Etch. However, a potential new source for GEM foil production in the US has been identified. The company in collaboration with Professor Bernd Surrow and Temple University has just submitted a SBIR proposal with the intent to initiate large GEM foil production. If this SBIR proposal will be funded, then Temple University will collaborate with the new company in setting up a commercialized large GEM foil facility. This collaboration will benefit greatly from Professor Bernd Surrow's experience with helping Tech-Etch successfully commercialize GEM foils.

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

All activities have been started and are well underway. Several MicroMegas activities are delayed due to the lack of 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. Matt Posik to Assistant Research Professor, his time able to be allotted to the EIC R&D program has been reduced (~50%). His remaining research commitment will be devoted to physics analysis at RHIC with the STAR experiment. Our new postdoc, Dr. Amilkar Quintero, will be trained by Dr. Matt Posik. He would be 50% dedicated to the EIC R&D program and 50% supported by 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. These foils will not only play a vital role in EIC GEM tracking R&D, but the entire nuclear and particle physics community. A new company has been identified and a new SBIR proposal was submitted in fall 2017. If funded, this would provide a continuation of a US-based commercial supplier.

Construction of 40 cm x 40 cm Triple GEM Detector

All GEM foils have been measured for their leakage current behavior. Satisfactory behavior up to 550V have been found with a leakage current to be less than 1nA. Three of the twelve GEM foils have already been optically analyzed. We are planning to scan the remaining foils with our new scanning setup in spring 2017. The remaining time will be used to gain experience with the usage of an existing mechanical stretching fixture and soldering station for mounting HV pins to each GEM foil. Undergraduate students will assist in this process who are paid for in full by the College of Science and Technology at Temple University. 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.

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.

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 and the energy resolution. 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 and CERN foil quality. It should be mad clear that there is no study on the CERN foil uniformity worldwide at such detail. Recent concerns have been raised of gain non-uniformity of large GEM foils produced at CERN. Our R&D program addresses exactly these issues. A subsequent 2nd NIM publication will complete this effort. Additionally we would also like to study various clustering methods.

GEM CCD Scanner Upgrade

With the assembly completed we are now focusing on developing the automated scanning software and calibrating the GEM scanner. Once this is completed we will scan with the new CCD GEM scanner a foil that has already been analyzed with our previous scanner to ensure everything is working correctly. We would then like to revisit the image analysis software to see if we can further improve it and decrease the scanning time needed for a full foil characterization, which includes measurements of the inner and outer hole diameters and the hole pitch.

GEM Based TRD

We are investigating, in collaboration with Dr. Yulia Furletova of Jefferson Lab, the practicality and feasibility of designing and operating a GEM based TRD providing an important particle-ID system in the forward direction which requires distinguishing large momentum electrons from hadrons.

Barrel MicroMegas R&D Program

Past

What was planned for this period?

In FY16, we had planned to carry out R&D efforts on the DREAM chip application to GEM detectors and 2D curved resistive MicroMegas prototype detectors: this technology has the clear advantage of minimizing the amount of material with respect to two 1D detectors.

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 built 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. 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?

The lack of R&D funding delayed the process of the 2D Micro-meags R&D work. We are hopeful to continue this effort.

Future

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

<u>2D MicroMegas Detector</u>

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?

The remaining part of the eRD3 general R&D program is focusing on its completion without adding any new R&D items followed by a transition to a prototyping and EIC detector design phase in preparation of the DOE Critical Decision process which holds for both the triple-GEM and MicroMegas activities. The highest priority is the postdoc support, needed to complete our generic R&D program. We expect to have our generic R&D program completed by 2018.

Manpower

One postdoc was supported at 100% shared between Dr. Matt Posik (~50%) and Dr. Amikar Quintero (~50%) to allow both to engage in hardware and physics analysis activities.

External Funding

Both groups, Temple University and Saclay did not receive any other grant funding in support of the actual R&D program discussed here. However, it should be emphasized that both institutions provided substantial facility support and the support of manpower such as a new mechanical engineer at Temple University and the support of undergraduate students. In addition, a generous gift to the College of Science and Technology at Temple University allowed the purchase of various laboratory items.

Budget request

The main items for the planned budget request for the FY18 focuses to a large extend on manpower, travel and material, in particular a continuation of the MicroMegas effort. We plan to participate in a new proposal focusing on a GEM-TRD R&D program in collaboration with JLab and UVa.

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, Conference Record to IEEE Nucl. Sci. Symposium, (2016) [arXiv: 1612.03776].

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

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

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

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

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