EIC Detector R&D

Progress Report FY17 and Proposal FY18

Project ID: eRD3

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

Period Reported: January 2017 – July 2017 (Status) / FY18 (Proposal)

Project Leaders:
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Date: July 16, 2017

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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 (MM) 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.

An alternative layout for the MM barrel tracking system consists of a TPC together with one inner and outer fast radial MM layer to aid the actual TPC track reconstruction. This option has not been worked out in detail yet.

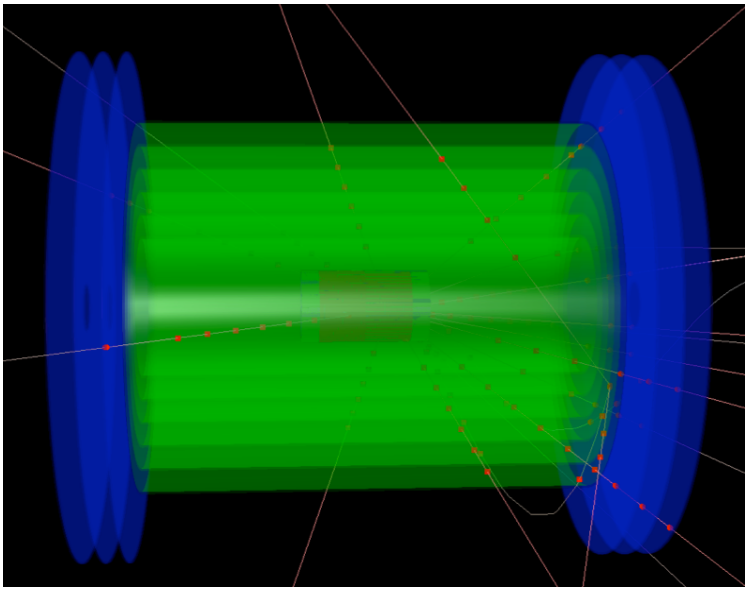

Figure 1: *GEANT simulation of barrel (green) and rear / forward (blue) tracking systems for an EIC detector.*

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).

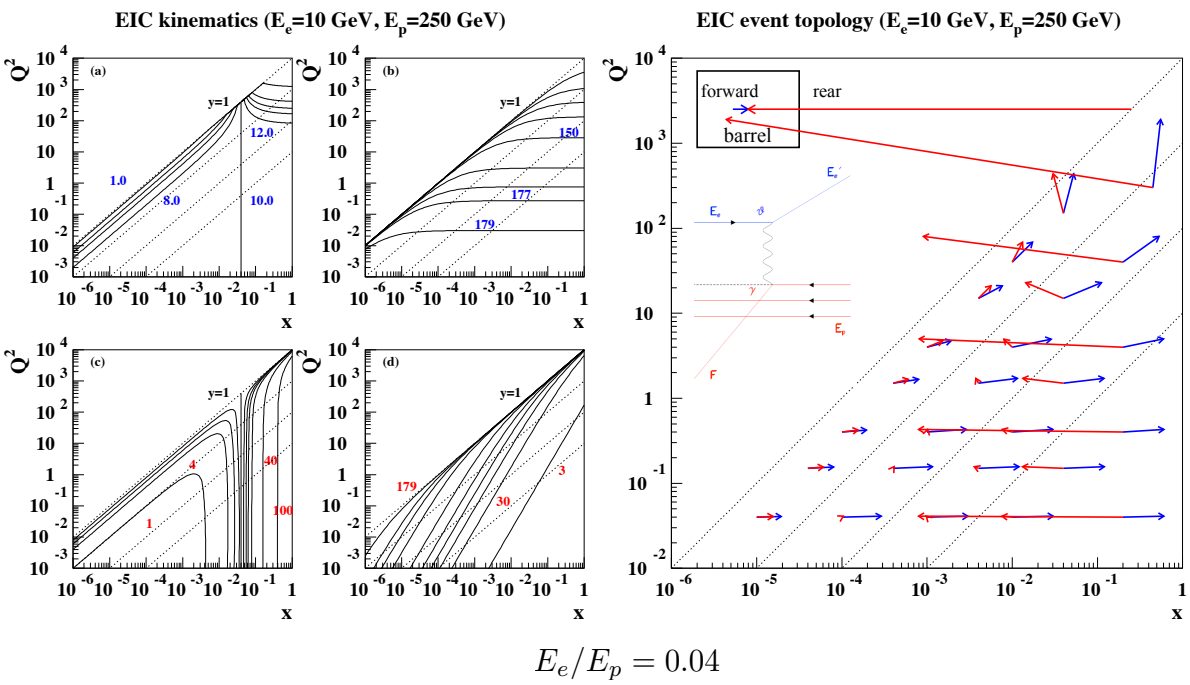

Figure 2: *EIC kinematics shown as isolines (left) and event topology (right) in the Q^2-x plane for 10 GeV (electron) on 250 GeV (proton) beams. Electron variables are shown in blue whereas proton / current-jet quantities are shown in red. The upper left box indicates the initial state configuration of 10 GeV (blue) on 250 GeV (red). The magnitude of each arrow is a reflection of the energy whereas the direction is the polar angle direction.*

The basic kinematic requirements of ep physics will be summarized below. Using basic energy and momentum conservation in ep scattering, the ep event kinematics as shown in Figure 2 in terms of x (or y) and Q^2 can be characterized by the scattered electron in terms of its energy and polar angle or in terms of the struck quark giving rise to a current jet characterized by its respective energy and polar angle. All polar angles are measured with respect to the initial-state proton direction.

At low and moderate Q^2 and low x, both the current jet and the scattered electron have very low energy and are predominantly found in the rear direction. For fixed low and moderate Q^2 and increasing x values, the current jet is moving away from the rear direction into the barrel and eventually at high x in the forward direction. The rear direction is characterized by extremely small

electron energies which is even more pronounced at smaller center-of-mass energies which is generally required for F_L-type measurements. Low dead material ($\leq 1\,\% X_0$), a precision energy measurement ($\leq 10\,\%/\sqrt{E}$) and precise hit localization ($\leq 1\,\mathrm{mm}$) along with precision energy calibration ($\leq 0.5\,\%$) and alignment ($\leq 1\,\mathrm{mm}$) at a rear calorimeter system are critical. The requirements in the forward direction are less stringent due to the larger energies in the final state. This has been shown by both the H1 and ZEUS experiments at HERA which will become even more challenging at an EIC facility due to the smaller beam energies. All of those items turned out to be challenging aspects if not taken care of properly [2]. A triple-GEM forward and rear tracking system provides the needed precision hit localization directly in front of a rear and forward calorimeter system and aids in the understanding of pre-showering and dead material mapping. In the rear direction, a precision hit determination for scattered electrons is indispensable for precise Q^2 reconstruction and critical for probing ep collisions as a function of large to low Q^2. In the forward direction precise hit localization is critical for a) particle track/calorimeter mapping and b) required to enable hit points in front and behind the forward RICH detector system as featured in the JLEIC detector design[1].

This report provides an overview of various R&D activities in FY17 following the last meeting of the EIC R&D committee in January 2017. 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 Masters' Degree at Florida Institute of Technology with Professor Marcus Hohlmann, our collaborator of the EIC eRD6 program. 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 sub-contract. Dr. Amilkar Quintero will be trained by Dr. Matt Posik and will share his commitment between the EIC R&D program (~20%) and the physics analysis program of high-energy polarized p+p physics (~80%) 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 allowed the purchase of additional laboratory equipment, such as two optical tables each at an approximate value of $10k.

It should be emphasized that our R&D program is a dedicated development, in particular the commercial development, of various elements for a future EIC tracking detector system. The

[1] https://eic.jlab.org/wiki/index.php/Main_Page

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 after the completion of the ongoing National Academy of Sciences review of the EIC physics program.

Over the last reporting period we have had good success in promoting our EIC R&D research efforts with presentations given based on the status of our R&D program at the MPGD 2017 conference this past May and the IEEE conference in November 2016 [3, 4], as well as a recent NIM publication [5].

The lack of funding for the MM part concerning the 2D development is a serious concern. It should be emphasized that the MM part is the only dedicated MM tracking system presented so far and currently provides the only alternative to a full TPC option.

The International Advisory Committee of the MPGD conference series selected Temple University to host the Micro-Pattern Gas Detector (MPGD) 2017[2] conference, together with a full-day RD51 collaboration meeting. This conference took place on May 22-26, 2017 at Temple University with about 100 participants from Asia, Europe and North and South America. We do consider the selection by the International Advisory Committee to host the International Micro-Pattern Gas Detector conference as a strong recognition of the EIC R&D program [3, 4, 5, 6, 7] on an international level. It was stated during various overview presentations that the US Micro-Pattern Detector community is centered around the EIC R&D program.

Forward Triple-GEM R&D Program: Progress Report

What was planned for this period?

Over the time period of January - July 2017, we had planned to carry out research in several areas:

1. Finish the upgrade of our CCD GEM scanner, which quantifies GEM foil quality based on geometrical properties, to accommodate GEM foils up to 1 meter long.

2. Construction of several 40 cm x 40cm triple-GEM tracking detectors using commercial single-mask GEM foils, HV foils, and readout foils all produced by Tech-Etch. These detectors will allow us to study and compare the GEM quality of a commercial foil to that of the well

[2] MPGD2017 WWW-page: https://phys.cst.temple.edu/mpgd2017/

established CERN foils. These prototype triple-GEM detectors also allow us to investigate new and exciting ideas of replacing the space grids, which sit between GEM foil layers in a triple-GEM detector to keep the layers from sagging and touching, with thin Kapton spacer rings. The Kapton spacer rings present the potential to reduce both cost and dead material compared to the more conventional spacer grids.

3. Design of a radiation enclosure to operate a 50-keV X-ray tube, which is needed for triple-GEM detector gain and efficiency measurements.

What was achieved?

We have made good progress on the goals that we had planned for the time period of January - July 2017:

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

A CCD GEM scanner allows one to image and optically analyze the geometrical properties of GEM foils, such as the GEM hole pitch, inner hole and outer hole diameters. These properties can be used, in addition to electrical leakage current tests, to determine the foils overall quality. This is not only important when building detectors, but was also found to be a vital component in developing the process used by Tech-Etch to commercialize GEM foils. With the forward tracking designs of a future EIC ranging from about 40 cm up to about 1 m long, it is critical that we update our GEM foil CCD scanner if we want to be able to analyze any potential EIC type foils.

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 100 cm and 80 cm travel range. The large area CCD GEM scanner was built on a new Newport optical table (6 ft x 4 ft), which is located in Temple University's Micro-Pattern Gas Detector (MPGD) clean room facility. The optical table is part of a generous gift provided to the College of Science and Technology at Temple University. 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 image resolution, but also captures images with a larger field of view. The increased field of view contributes to decreasing the time needed to scan the GEM foils. The completed large area CCD scanner can be seen in Figure 3. We have now finished the calibration process of the linear stages and implemented basic imaging software via Matlab so that we can now extract geometrical properties from GEM foils. We have finished initial scans of a well studied 10 cm x 10 cm Tech-Etch foil. These results were then compared to the results measured by our previous system and by Tech-Etch, to serve as a point of reference for the new scanning system. Figure 4 shows the

pitch (left most plots), inner (center plots), and outer (right most plots) hole distributions measured by the small (upper row plots) and large (lower row plots) area CCD GEM scanners.

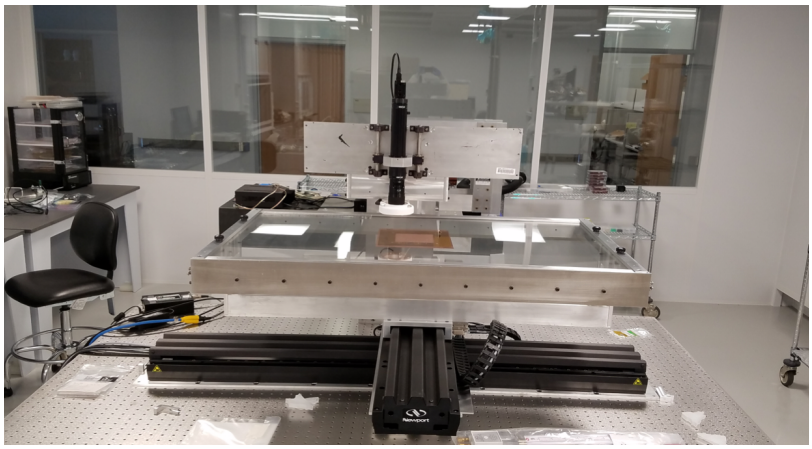

Figure 3: *Completed large area CCD GEM scanner with updated camera on top of a 4' x 6' optical table inside the Temple University MPGD clean room facility. Note: The optical table of close to $10k was provided by the College of Science and Technology at Temple University through a generous gift.*

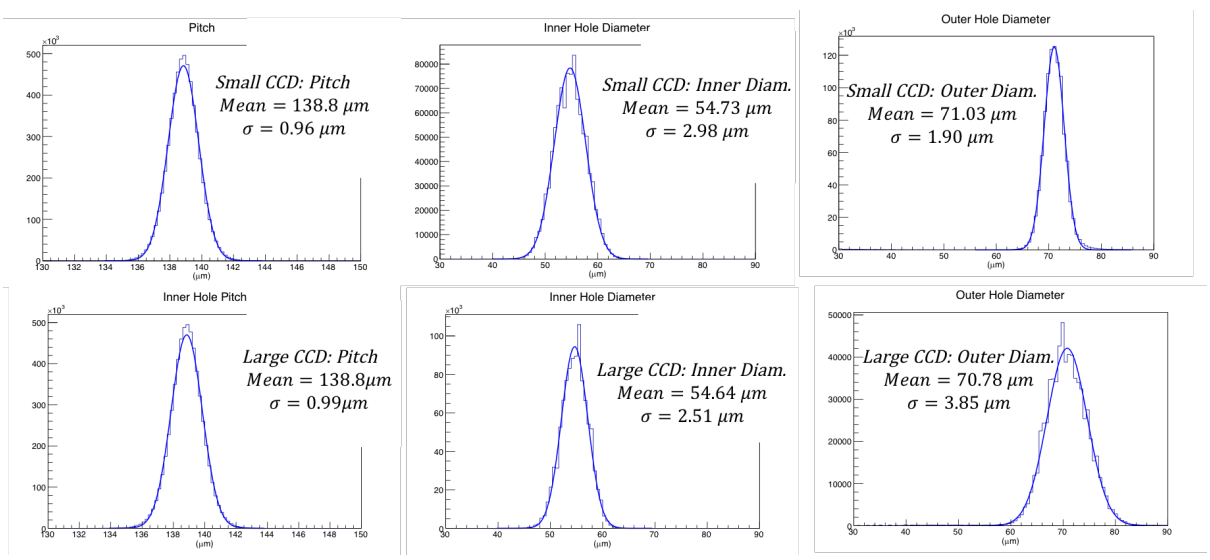

Figure 4: *Comparison of geometrical GEM foil property measurements from a Tech-Etch 10 cm x 10 cm foil using our previous small area CCD scanner (top row) and upgraded large area CCD scanner (bottom row). The left-most plots show the GEM hole pitch distributions, the center plots show the inner hole diameter distributions, and the right-most plots show the outer hole distributions.*

The pitch and inner hole diameter results are in excellent agreement with what was measured with the small area scanner. The outer hole diameter distribution is consistent with what was measured previously with the small area scanner. However there is a wider distribution associated with the large CCD GEM scanner for the outer hole measurements due to the upgraded camera becoming more sensitive to the foil artifacts. Figure 5 shows CCD image comparisons using the upgraded CCD camera compared to the previous CCD camera. From these images, we can see that the field of view in the upgraded camera is much larger, which results in reducing the scanning time. Additionally, the resolution of the upgraded camera is much better than the previous camera.

The scanning of the remaining nine 40 cm x 40 x cm GEM foils was delayed due to issues with the CCD scanning system. When we started scanning the 40 cm x 40 cm GEM foils, we noticed that when the stages are far from the center (~170 mm) there was a resonance that was generated which lead to vibrations in the stages that distorted the images. We have since located the cause of the issue, PID controller parameters, and have corrected it. Scanning of the 40 cm x 40 cm GEM foils are now underway.

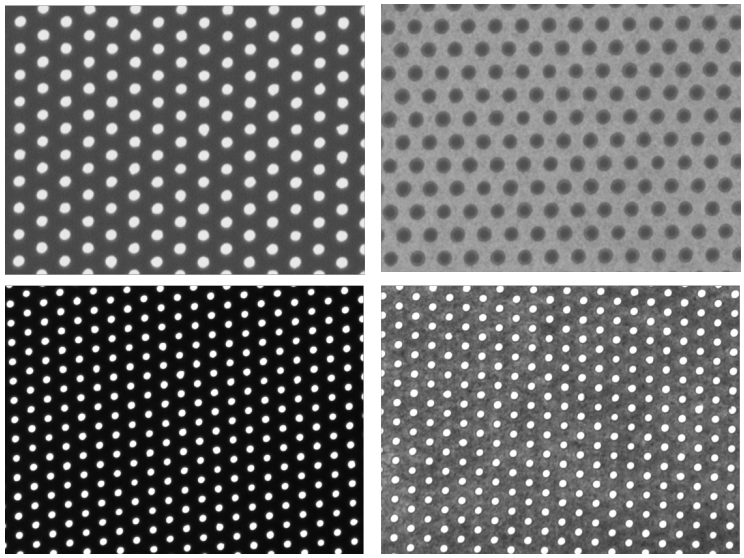

Figure 5*: Compares inner (left-most images) and outer (right-most images) hole CCD images between the previous camera (used with the small area CCD scanner, top row images) and our upgraded camera (used with the large CCD scanner, bottoms row images).*

2. <u>40 cm x 40 cm Prototype triple-GEM Detectors</u>

We are planning on building several triple-GEM detectors (we have enough material for four triple-GEM detectors), which are based on the STAR FGT [8]. 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 inside our MPGD clean room facility. With all essential components needed to assemble a triple-GEM detector already acquired, we just need a couple more components installed into the cleanroom before we can begin production.

One of the components that we just finished installing into the cleanroom is a gas distribution panel, shown in Figure 6. This panel allows us to access nitrogen, argon, and compressed air gas lines that go into the cleanroom. These gases will be needed during the triple-GEM assembly. The nitrogen gas will be used during leakage current testing and to flush through a GEM storage box where bare foils and partially assembled detectors will be able to sit in a nitrogen environment. The argon gas we will use when checking our detector for gas leaks. The compressed air line will be used to supply pressure to our GEM stretcher and glue distribution system. In addition to having the gas distribution panel access the three gas sources, it also allows us to monitor the flow and pressure of a detector that we can hook up to it via bubblers and manometers.

Figure 6*: Gas distribution panel which supplies nitrogen, argon, and compressed air gas. Also has bubblers and coarse and fine manometers to monitor flow and pressure to a detector.*

The other critical piece that we need before we can begin assembling triple-GEM detectors, is a place to store the GEM readout foils, HV foils, and the partially assembled triple-GEM detectors. The ideal location would be a nitrogen environment (supplied from the gas distribution panel), and so we are in the process of building a GEM box that will be able to accommodate GEM foils up to a meter long, as well as partially assembled triple-GEM detectors in various assembly stages. The GEM box design is shown in Figure 7. Once the GEM box is completed we will be able to begin the triple-GEM assembly.

With the gas distribution panel in place, we have started reviewing and running through the process of stretching GEM foils and gluing frames to GEMs. We are currently carrying out these activities using existing GEM foils and frames left over from the STAR FGT detector. Figure 8

shows one of our postdocs and a graduate student carrying out the stretching process on a spare STAR FGT GEM foil. These types of practice runs using existing materials has been very informative and should make assembling the actual prototypes much easier as they will follow the same procedures.

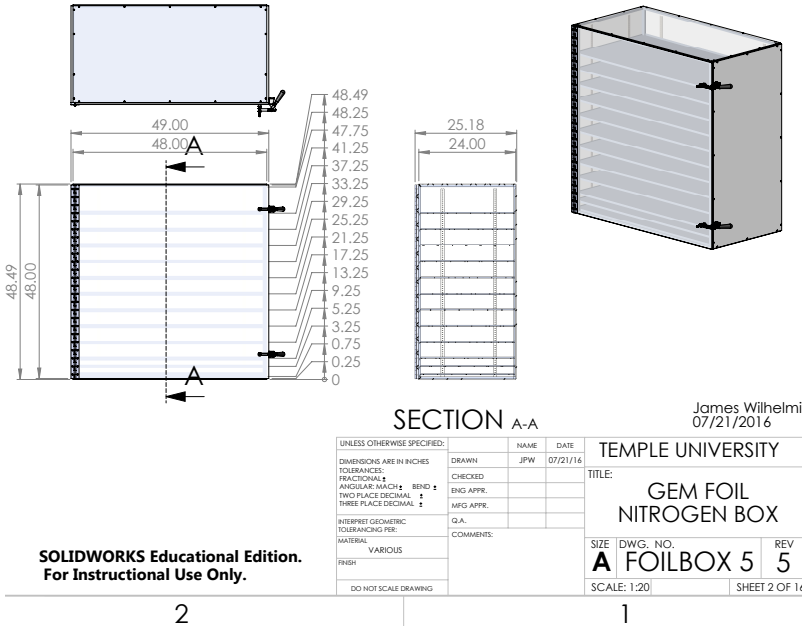

Figure 7: *Design drawings for MPGD clean room GEM storage box.*

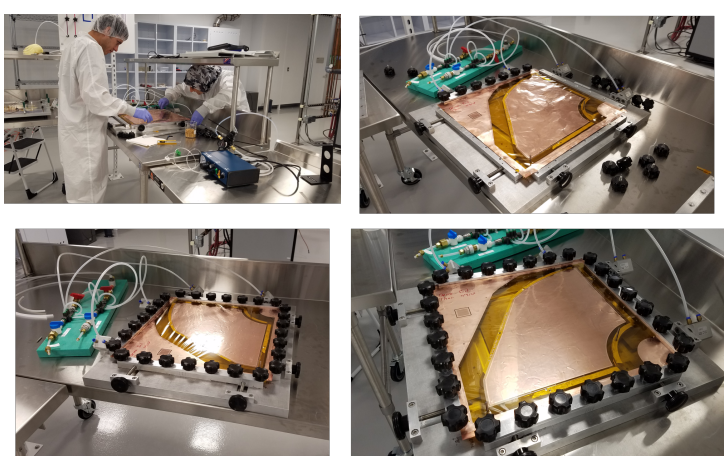

Figure 8: *Practicing the GEM stretching process. Top right: Securing the foil on the stretcher. Bottom left: In the process of stretching at the foil. Bottom right: The stretched foil ready for the frame to be glued to it.*

Another area of the assembly that we have now worked out is the preparation and cleaning of the GEM frames. The frame preparation process consists of several steps, some of which can be seen in Figure 9. The first is to lightly sand the frames in order to remove any fibers protruding from the frame base. Second is to clean the frames in our recently purchased ultra sonic bath. After some discussions with UVa on the ultra sonic bath parameters that they used to clean their Super BigBite GEM frames, we have decided and tested cleaning frames using a similar 15 minute cleaning time at 70° C C. After running the frames through the ultra sonic bath, we have set up a drying area in our class 1000 portable cleanroom, located in our detector lab, for the frames to drip dry.

Figure 9: *Ultra sonic bath (left image). GEM frame drying area inside portable cleanroom (right image).*

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

We were hoping to have the GEM box assembled so that we could begin moving towards the prototype triple-GEM detector assembly. However, a delay in the machining of the GEM box set the completion date back. This is now a top priority in the Temple machine shop with assembly now well under way, completion of the box is expected very soon.

We also expected the large area CCD scanner to be completed by this time, however issues with system resonances had delayed this. We have now identified and fixed this issue.

The design of the radiation enclosure is in progress.

What is planned for the coming months and beyond? How, if at all, is this planning different from the original plan?

In the upcoming months our efforts will be focused on finishing out our already proposed R&D. This includes scanning and optically measuring the remaining Tech-Etch 40 cm x 40 cm single-

mask GEM foils that will be used in several triple-GEM detectors. Installing the GEM box needed to provide bare and exposed detector components with a nitrogen environment.

Once the GEM box is installed we will begin to assemble and test several triple-GEM detectors. These prototype detectors will serve a couple of purposes. First, they will be built from material produced by commercial manufacturers, including the GEM, HV, and readout foils. Secondly, these prototypes will allow us to test a new and exciting idea of using Kapton rings in place of G10 type spacer grids in-between each of the GEM layers in the detector. This has a potential two-fold benefit as it would decrease the detectors overall dead material as well its cost.

In addition, we plan to complete the X-ray enclosure.

Barrel MicroMegas R&D Program

Past

What was planned for this period?

In FY16 / FY17, 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?

In 2016, 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 front-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.

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?

None!

Manpower

Postdoctoral support of 50% was the basis of the FY2017 sub-award. This amount allowed to support both Dr. Matt Posik and Dr. Amilkar Quintero. Dr. Matt Posik worked at the level of 50% of his time on the EIC R&D program whereas Dr. Amilkar Quintero worked at the level of 20% on the EIC R&D program. This level is expected to increase for the proposed 2nd and last year of his postdoctoral appointment.

External Funding

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 Temple University 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.

List of eRD3 Publications

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

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

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, (2016) [arXiv:1612.03776].

Micro-pattern R&D Program: Proposal

Motivation for Research:

Triple-GEM detectors in the forward and rear directions are well suited for EIC tracking. The GEM trackers on their own have good momentum resolution, and when paired with silicon trackers can reduce the momentum resolution to the level of 1-2% [9]. One of the more critical needs for triple-GEM detectors would be to provide a hit position for particles entering the calorimeters on the end caps as stated earlier. This would require several layers of triple-GEM detectors to be placed in front of the calorimeter. GEM detectors are an ideal detector as they are fast detectors and have a low material budget. In addition, mapping dead material in the rear direction is crucial.

We are not requesting money for any new R&D projects this cycle, the money that is being requested here is needed for us to successfully complete our current R&D project of building, testing and publishing the results of our 40 cm x 40 cm triple-GEM detectors. These large area single-mask triple-GEM prototype detectors will be built from materials made commercially (via Tech-Etch) and allow us to directly test the quality of the commercial foils. Although Tech-Etch is not currently producing GEM foils, such a test and hopefully validation of the quality of these foils would be paramount and set a proof of principle for any future GEM manufacture.

Furthermore these prototypes present an opportunity to reduce both the material and cost of a triple-GEM detector through the use of Kapton spacer rings rather than the standard G10 spacer grids. This R&D would not only benefit an EIC, but also the broader nuclear-particle physics community.

The GEM foils that will be used are some of the last 40 cm x 40 cm single-mask GEM foils that were produced commercially by Tech-Etch. These foils were tested for electrical performance, via leakage current, and optically (hole diameters and pitch) via our CCD scanner and were found to be consistent with foils produced by CERN [5]. The goal of the MM program is the completion of the previously presented 2D MM design work profiting from the very successful 1D prototype work.

Work for eRICH and/or JLEIC?

This general R&D of quantifying the quality of commercial GEM foils and the knowledge that is gained from using Kapton rings rather than spacer grids will be beneficial to both the eRHIC and JLEIC designs.

Requested Resources, where they are located and who is in charge of them:

In order for us to finish this R&D project we will need to properly and exhaustively test our detectors. This will require purchasing a few more materials and some support to be able to provide the manpower to carry out the testing.

Testing of the triple-GEM detectors will consist of three parts. The first will involve testing the efficiency of the detector using cosmic rays. Our current detector lab is already equipped with a cosmic ray stand which will be used to carry out this measurement. The second test will involve an Fe-55 source which will be used to measure the gain and energy resolution of the triple-GEM detectors. The third and final test of the detectors will use an X-ray gun to further study the detectors efficiency and gain performance. The results of these tests will then be presented in a publication. Additionally, there is a possibility of having access to a test beam in 2018. If such an opportunity arose, and we were ready, we would consider participating in a test beam with eRD6. This would serve as an excellent way to further test the quality of the commercial GEM foils.

While we are currently equipped to carry out the first test listed above, completing the second and third tests requires the purchase of additional material. The most critical item that needs to be purchased is an Fe-55 source. This will allow us to study the energy resolution of the triple-GEM detector.

We would also like to carry out gain and efficiency studies using our already purchased 50-keV 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 source, 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 have received an initial quote.

Research Yearly Timeline:

- July - Aug.: Assemble first triple-GEM chamber, including gas and leakage current testing
- Aug. - Oct.: Cosmic tests and 55Fe testing
- Oct. - Jan.: Build and test remaining detectors

- Jan.-Feb.: Publish paper

Funding Requests and Budget (Costs for manpower, hardware, and travel):

Budget request:

The main items for the budget request for FY17 are as follows:

- 50% support of postdoctoral research associate (2nd and last year) - **Highest priority**
- Domestic travel (BNL / FIT / JLAB / UVA): $8,250
- International travel (Saclay / IEEE Conference): $5,600
- Material (Triple-GEM assembly): $2,500
- Equipment (MM 2D assembly at Saclay / X-ray enclosure / 55Fe source): $22,000

On-campus overhead rate: 56%.

The full budget breakdown for a total requested amount is shown below in Table 1 displaying the fractional breakdown by category with the largest amount of about 49% referring to the postdoc support as the highest priority.

DOE EIC R&D / eRD3 - Dr. Bernd Surrow (PI) (Temple University)	
	FY 2018
PERSONNEL	
Post Docs (50%)	$28,184
Fringe Benefits	
29.7% on Post Doc	$8,371
Total Personnel	$36,555
Travel - Domestic	$8,250
Travel - International	$5,600
Material	$2,500
Equipment	$22,000
OTHER:	
Total Direct Costs	$74,905
Modified Total Direct Costs (MTDC)	$52,905
F&A: On-Campus Overhead 56%	$29,627
Total Project Costs	$104,531

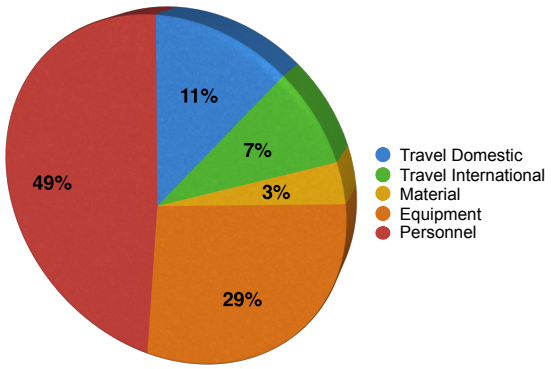

Table 1: *FY18 budget breakdown for eRD3 EIC R&D program.*

3 Budget scenario of nominal, 20% lower, and 40% lower:

- Nominal: GEM assembly + 55Fe source / X-ray enclosure + MM 2D + Travel + 50% Postdoc support
- 20% Lower: 55Fe source / X-ray enclosure + Travel + 50% Postdoc support
- 40% Lower: 55Fe source / X-ray enclosure + 50% Postdoc support

A detailed budget matrix referring to all of the budget categories shown in Table 1 are provided below in Table 2. The above three budget scenarios ('Nominal', '20% Lower', '40% Lower') are mapped to the Table 2 entries.

	GEM Assembly	55Fe Source/ X-ray Enclosure	MM 2D Assembly	Travel (Domestic)	Travel (International)	Postdoc Support	Total:
Temple University	$2,500	$10,000	$0	$8,250	$5,600	$36,555	$62,905
Saclay	$0	$0	$12,000	$0	$0	$0	$12,000
Total:	$2,500	$10,000	$12,000	$8,250	$5,600	$36,555	$74,905

Table 2: *FY18 budget breakdown by category and institution.*

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] B. Surrow, Eur. Phys. J. direct 1, no. 1, 2 (1999).

[3] https://phys.cst.temple.edu/mpgd2017.

[4] M. Posik and B. Surrow, Conference Record to IEEE Nucl. Sci. Symposium, (2016) [arXiv: 1612.03776].

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

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

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

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

[9] A. Kiselev, EIC R&D Tracking meeting, Temple University, May 2017.