Project Name: eRD3/eRD6, Proposal for targeted detector R&D towards an EIC detector

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Date: June, 2016

Introduction

On January 28, 2011 the first call for proposals for R&D leading to detectors at the EIC was put forth. In the more than 5 years that have passed, tremendous progress has been made. From the EIC R&D program multiple test beam experiments have been performed and numerous publications have resulted. The field is now in a position to rightly boast of having vibrant and effective progress in generic detector R&D. Although the proponents of the current R&D efforts have proved repeatedly our effectiveness in continuing the interesting work that we have begun, we also realize that the broader landscape of EIC has changed dramatically over the past 5 years. Specifically, there are now full detector designs (with varying degrees of detailed simulations) including BeAST, ePHENIX, and the Jefferson Lab design. Furthermore, the EIC is now included as the highest priority for new construction in the recent NSAC long-range plan and is making steady progress toward the so-called CD0 (mission need) stage of approval. It is therefore incumbent upon the EIC R&D program to adjust our goals and techniques to these new and very positive realities.

The eRD3 and eRD6 efforts have been the leaders in development of tracking technologies leading toward the EIC. Indeed, the commonality of our approach toward this task has prompted the committee to suggest and our colleagues to implement an ever-closer relationship among the groups. Although currently separately funded projects, these groups have developed a common large wedge foil GEM design that combines the years of experience into a single design and cost savings in the NRE required to produce these units. Talks about when and how to merge these efforts have been ongoing for more than a year and have now reached a conclusion. This document is put forth to explain our reasoning behind the solution and to clarify for the committee why they are reading three documents (instead of one or two) from our collaborators.

The members of eRD3 and eRD6 held the most recent of our joint meetings in early June 2016 and reached an agreement on how to both merge efforts in recognition of the commonality among our interests and to redirect our efforts in a manner sensitive to the progress in the EIC. We further recognize that there remains unfinished business in our generic R&D programs started at the advent of the EIC R&D program. Our solution is as follows: The eRD3 and eRD6 groups will merge to form a new group dedicated to tracking for the eventual electron-ion collider. The research efforts of this new group will be entirely "targeted R&D", meaning that each project has a clearly identifiable link to at least one of the major detector designs that have been developed. Remaining "generic R&D" (not tied to an identifiable detector design) will be completed under the guise of the existing groups.

As consistent with the committee request, all submitted documents contain both a progress report of past accomplishments (clearly separate for eRD3 and eRD6) and an outline of future work (separate work finishing generic R&D but common for future targeted R&D). Rather than attempt to combine those documents into a single one, we have taken an alternative strategy with the intent of simplifying and clarifying the snapshot of our merger-in-progress. The eRD3 and eRD6 documents (that were basically complete prior to the conclusion of our discussions) have been left intact. Both documents contain elements that neatly fit into the categories of completing existing generic R&D efforts as well as those that are best labelled as targeted research. This document is written as an overview with the purpose of distinguishing the parts of the program that are generic from those that are targeted.

We anticipate that future requests will be entirely comprised of targeted research and thereby reflect not only the completion of the merger between eRD3 and eRD6, but also a new direction of our efforts reflecting the broad state of affairs in the field.

As a brief aside, the International Advisory Committee of the International Micro-Pattern Gas MPGD-Detector conference just selected the eRD3/6 R&D groups after their bid to host the next MPGD conference in 2017 at the Temple University.

Description of the proposed projects by institute

Brookhaven National Lab:

BNL will complete its generic R&D on the hybrid TPC/Cherenkov detector during the coming R&D period and will publish the results. This follows the completion of our work on the Minidrift GEM detector, which was completed during the last period and resulted in a publication in the IEEE TNS that is due to be published in June 2016. Our emphasis will now switch to a more focused effort on developing a high performance TPC for EIC. This will build on our efforts and experience to design and build the TPC prototype for the hybrid TPC/Cherenkov detector, and will utilize this prototype for further studies. We plan to develop new and improved readout structures for the TPC by first simulating the detailed detector performance using the 3D Monte Carlo that we have begun to develop, which will guide us in the design of these new readout patterns. We will then have the most promising of these patterns fabricated and will test them in our existing TPC prototype detector. This will also have utilized our various testing facilities at BNL. In addition, we will study the ion back flow in various TPC structures and try and develop ways to minimize this in an actual detector. Finally, we will collaborate with Stony Brook University on developing a new field cage design for a large scale prototype TPC for EIC.

Florida Institute of Technology:

The three EIC detectors currently being proposed (BeAST, ePHENIX, JLAB IP1 central detector) feature virtually identical conceptual designs for the forward and backward tracking regions. In all three detector designs, both regions are instrumented with tracker disks made from large-area GEM detector modules that provide acceptance from close to the beam pipe out to a radius of about one meter (Figure 1). Florida Tech as member of the forward tracking group (Florida Tech, U. of Virgina, Temple U.) within the eRD3/6 consortia is conducting R&D that directly targets the development of affordable low-mass GEM detectors for this common subdetector system. We anticipate that this work will ultimately lead to the technical design report for the forward tracker of the EIC detector.

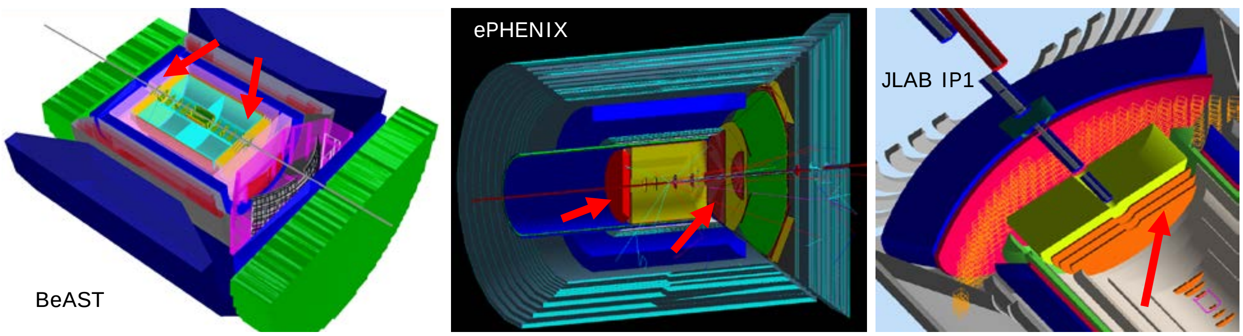


Figure 1 Commonality of the design of the forward and backward tracking regions with GEM detector disks (red arrows) in the currently proposed EIC detectors.

INFN Trieste:

The R&D program devoted to further development of hybrid MPGDs for single photon detection, also synergic to TPC read-out sensors, is fully detector oriented. The program covers three years of activity.

The hybrid detector architecture consists in three multiplication stages: two THick GEMs (THGEM) layers, the first one coated with a CsI film and acting as photocathode, followed by a MicroMegas (MM) multiplication stage. The two THGEMs are staggered: this configuration is beneficial both to reduce the Ion BackFlow (IBF) and to increase the maximum gain at which the detector can be operated exhibiting full electrical stability. An original element of the hybrid MPGD photon detector is the approach to a resistive MM by discrete elements: the anode pads facing the micromesh are individually equipped with large-value resistors and the HV is provided, via these resistors, to the anode electrodes, while the micromesh is grounded. A second set of electrodes (pads parallel to the first ones) are embedded in the anode PCB: the signal is transferred by capacitive coupling to these electrodes, which are connected to the front-end read-out electronics.

The program main motivation and goal is to make the concept of gaseous detectors of single photons mature for the challenging requirements of a high-momentum RICH counter in a collider environment. At a collider, the radiator length is limited therefore (i) a larger number of detected photoelectrons per radiator unit length has to be obtained and (ii) the shorter lever arm implicit in a shorter radiator region imposes fine space granularity. Moreover, (iii) the environment is a high-rate one, a feature that imposes an extra effort to control and reduce the Ion BackFlow (IBF) to the photocathode. The proposed R&D program aims at developing a hybrid MPGD able to cope with all the specific requirement illustrated above: the ultimate goal of the R&D is to obtain a medium-size prototype matching the requirements listed above. The medium size, namely a detector with active surface of about 30 x 30 cm^2 is a choice dictated by economic considerations: when the detector is established, the engineering towards larger size will be the main objective of the following R&D program.

Gaseous sensors with very low IBF and high granularity are also requested to read-out TPCs. Therefore, the hybrid MPGD developed for a high-momentum RICH counter for colliders are immediately matching two of the key requests for TPC sensors. A third requirement is present in this application, namely to preserve a fine resolution dE/dx measurement. The approach we propose is in principle able to match also this requirement: in fact, the resistive MMs by discrete elements do not suffer of the charge diffusion at the anode that tends to spoil the energy resolution.

Stony Brook University:

In collaboration with the BNL group we are planning to work on the understanding of the magnitude of ion back flow in a TPC and plan to purchase necessary equipment and test it under test beam condition. Ion back flow is problematic for TPC performance in a specific environment and we are working on providing a TPC that does not need to be gated. TPCs in future applications will profit from a gate-less operation and this will be the trend for future TPCs wherever they will be used in collision experiments. A TPC is also planned to be part of ePHENIX, one of the detectors that is foreseen to be a day-1 detector to perform EIC physics. This is targeted detector R&D specific to one or more of the EIC detector concepts. All EIC detector concepts that will have a TPC as central tracking device will profit from operating with a gate-less device.

As we have showed with our RICH prototype in the SLAC testbeam (see publication IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 62, NO. 6, DECEMBER 2015) the top GEM can be operated as a device with gain one and it will be suited to act as a gate-less ion back flow blocker in a GEM-readout for a TPC.

Temple University and Saclay:

The request presented here builds upon the eRD3 generic R&D program, targeted towards a larger triple-GEM sector element which is consistent with the BEAST detector simulation layout and features the following aspects:

- 30 degree sector with Δr~60cm.
- Minimizes dead material by employing 2D readout foils and spacer rings.
- Commercially produced components from vendors which produced various components already for the generic R&D effort.
- DREAM-chip readout system.
- Minimal dead material achieved by gluing all components / frames. This compliments two different assembly technique that will be used by UVa and FIT.
- 2D readout foil with multi-pin connectors consistent with prior generic R&D work.

University of Virginia:

As mentioned in the description of Florida Institute of Technology, current EIC detector conceptual designs are all using large-area GEM modules to be arranged in disk layer configuration to instrument their forward tracking regions. As part of the forward tracking group (FT group) of the eRD6/eRD3 consortium, which also include Florida Tech and Temple U., UVa has concentrated its R&D effort on the development of large GEM to address the requirements specific to an EIC FT environment.

The focus of the UVa R&D work is to:

- Study the performance of a new fine pitch 2D flexible stereo-angle (U-V) strip readout ⇨ Achieve excellent spatial resolution with minimum electronic channels
- Continue the study of the low material Cr-GEM foil ⇨ Minimize multiple scattering …
- Investigate new assembly techniques of large GEMs ⇨ Reduce cost

Weizmann Institute of Science:

The group conducts research on the multilayer micropattern detectors in order to increase the detector performance. This research has direct implications for a TPC foreseen to be used in the ePHENIX detector.

The first direction involves optimization of the multi-GEM stack for improving the space charge problem in the TPC, or to improve the IBF characteristics. There are several steps in the plan how that can be achieved beyond the parameters previously measured by the ALICE research groups:

1. Choosing different gas mixtures. The gas system allows testing any gas combination by readjusting gas flow meter settings.

2. Changing the field configuration inside the GEM stack. Both items 1 and 2 were thoroughly studied by the ALICE collaboration, and mentioned here are tools for additional studies.
3. Adding GEM layer. Addition GEM should further suppress the IBF and if properly configured with the electric field to be in gain=1 regime can further suppress the IBF
4. Using additional mesh instead of GEM and changing drift/transfer field ratio.
5. Using GEMs with so-called “cobra” pattern that allows more effectively redirect ions onto GEM electrodes.
6. Altering GEM pitch, using so-called small pitch (90um) and large pitch (200um) GEMs.
7. Explore a possibility to effectively misalign holes in the construction of the GEM stack of the same pitch to improve the IBF suppression due to geometric factor.

The second research direction is the design of a GEM readout module prototype. The prototype uses different concept compared to previously built multi-GEMS readout elements. The concept is shown in Figure 2.

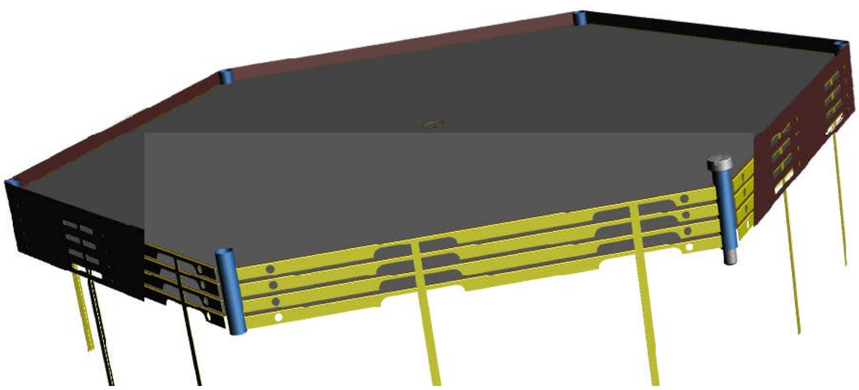


Figure 2 A four-layer GEM read-out element assembly view. Some elements are to be removed in the assembly procedure. The voltage divider (not shown) is integrated in the element structure.

The readout element is a standalone module, which has several crucial advantages:

1. Almost frameless design (approximately 600um between holes of adjacent modules) allows reducing inactive areas in the detector to a percent level. Residual areas that never fully shadow one single pad would result in a signal reduction rather than in a signal loss. Thus, this design, then proven to work, can be considered virtually a “no dead area” design.
2. Geometry of the GEM elements can be tailored to fit the entire fiducial area.
3. Loss of a single element has small impact on the TPC performance.
4. Each element is build out of approximately 100cm^2 GEMs. Such GEMs can be produced in large quantities at lower cost compared to larger GEMs of the equivalent area.
5. Uniformity of small GEMs is typically better than that of the large GEMs due to less demanding tolerance during the manufacturing stage.
6. Small size of the element may, in principle, allow to (miss-)align holes in different GEM layers for better IBF suppression.

7. Production, and more importantly, testing of GEM elements can be effectively done in parallel by several groups to keep up on the scheduler and to ensure the highest quality of the final detector.
8. Since the element is assembled in its final configuration already at the testing stage it can be fully calibrated before being mounted onto TPC.
9. Low cost of individual element allows pre-selecting the best elements to be used in the experiment and keeping the rest as a contingency.
10. Such element better suites to be used in future HBD-like detectors, there GEMs need to be coated with CsI. Pre-tested and coated element can be installed into its final position avoiding intermediate assembly required in a layer-by-layer procedure.

Funding requests for targeted detector R&D per institute

Brookhaven National Lab:

Budget items related to new focused R&D activities:

1. Expendable materials and supplies for gas detector lab - $10K
2. Travel - $5K
3. Design and materials for new chevron readout patterns - $10K
4. Parts and materials for investigation of GEM/Micromegas operation - $10K

Total without overhead - $35K
Total with overhead - $52.5K

Florida Institute of Technology:

Florida Tech and U. Virginia have already been funded in the last cycle to procure common large GEM foils for a 30-degree prototype module targeted at the EIC forward/backward tracker. In this cycle, all funding requested by Florida Tech is for the realization and test of this module. Specifically, Florida Tech requests funds for the production of the readout foil at CERN and the procurement of stiff mounting frames and other small assembly parts for this prototype module and for the manpower required to carry this project out. Details of this funding request are shown in the following table:

Forward tracking: large-area GEM with zigzag strip readout		
Personnel (post-doc, Aiwu Zhang)	$100k	12 months, fully loaded
GEM readout foil	$9k	From CERN
GEM assembly parts	$6k	Frames, O-ring, connectors, etc.
Supplies & material	$2k	Gas, T/P monitor, etc.
Travel	$7k	Beam test(s); conference, consortium meetings
Total	**$124k**	

INFN Trieste:

The funding request for this R&D activity is presented in table 1, where the bare requests are listed and also the overhead is included assuming the typical INFN rate of 20%. The request includes 3 main chapters:

• the financial support for a postdoc fully dedicated to the project: the contribution of a dedicated personnel unit will offer a crucial boost to the R&D program; $33k corresponds to one-year postdoc salary in Italy;

• traveling resources, mainly to have the possibility of closer interaction with the whole RD6 Consortium and to follow the evolution of the EIC project: 3 trips to US per year require about $9k; a minor support is requested for material procurement, to interact with the producers when non-standard components are needed and for the construction of specific detector elements that must be produced at CERN: this needs is estimated to be $3k per year;

• Consumables have to cover prototype components and prototype operation costs; the needs for the first year are already well defined and are listed in the following, while the request for the following years indicate a reasonable envelop and the details will be spelt out year by year.

	requested founding (k$)	(k$)	(k$)	**total** (k$)
year	**2017**	**2018**	**2019**	
item				
manpower (1 unit for the 3 years of the project duration)	33	33	33	99
travelling (3 trips to US per year + trips for material procurement and construction)	12	12	12	36
consumables (specific for each year, according to the project time-lines)	30	30	30	90
total	**75**	**75**	**75**	**225**
total adding overhead (at 20% level)	**90**	**90**	**90**	**270**

Stony Brook University:

We will be purchasing equipment for testing ion back flow blocking and will need funding for verifying it under testbeam conditions. Furthermore, we are requesting support for traveling.

1. Purchase of IBF-GEM foils - $5k

2. Expendable materials and supplies - $5k

3. Support for beam test - $10k

4. Travel - $5k

Total without overhead - $25k

Total with overhead - $40k

Temple University and Saclay:

Funding request: $43,200

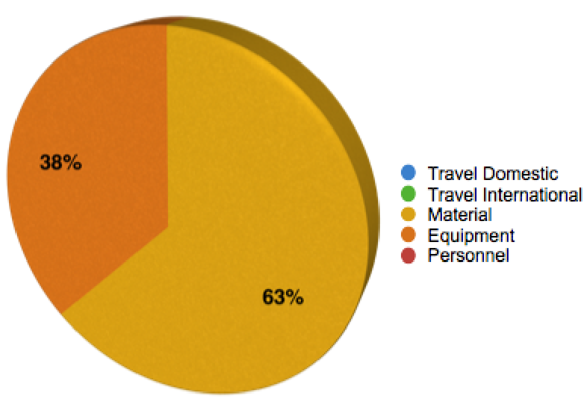
Justification:

- 3 GEM foils ($7,500) (Temple University)
- 1 2D readout foil with multi-pin connectors ($3,000) (Temple University)
- 1 HV foil ($500) (Temple University)
- 6 sets of frames ($1500) (Temple University)
- Tooling ($5000) (Temple University)
- Labor / Machining ($2500) (Temple University)
- DREAM-chip readout DAQ system ($12000) (Saclay)

All engineering cost items will be covered by Temple University. Labor for machining of parts at Temple University is part of this funding request. The full cost-breakdown for this combined submission of eRD3/eRD6 is shown in Table 1 below and mounts to $43,200 including overhead.

Table 1 Full budget breakdown including overhead (56%) for eRD3/eRD6 request from Temple University / Saclay.

DOE EIC R&D / eRD3/6 - Dr. Bernd Surrow (PI) (Temple University)	
	FY 2017
PERSONNEL	
Post Docs	$0
Fringe Benefits	
29.9% on Post Doc	$0
Total Personnel	$0
Travel - Domestic	$0
Travel - International	$0
Material	$20,000
Equipment	$12,000
OTHER:	
Total Direct Costs	$32,000
Modified Total Direct Costs (MTDC)	$20,000
F&A: On-Campus Overhead 56%	$11,200
Total Project Costs	$43,200



University of Virginia:

The Forward Tracking group have developed a common GEM foil design to build several prototypes of an EIC FT GEM modules, with each institution proposing to investigate a different assembly technique and readout strip structures. The fabrication of the foils is ongoing at CERN. For the current cycle, we are requesting the funding for the design and fabrication other key elements of the large triple GEM prototype, such as the fine pitch 2D (U-V) strips readout board and GEM support frames. The goal is to assemble and test in the lab prototype and prepare for a beam test campaign for the next cycle in 2017. Below is a table summarizing the funding request.

EIC Forward Tracking Detector: Large Area GEM with fine pitch U-V strip readout		
U-V) strips readout board with Zebra Connection + adapters	**$10k**	From CERN (Switzerland)
Support frames for GEMs and readout board	**$4k**	RESARM (Belgium)
Supplies and accessories	**$3k**	Gas, HV system, electronics …
Support for undergraduate student	**$5k**	Construction and test of the prototype
Travels	**$3k**	Conference, collaboration meeting
Total (w/o overhead)	**$25k**	
Total (w/ overhead)	**$30k**	

Weizmann Institute of Science:

We will be purchasing GEM foils. Since currently the producer of GEMs is CERN, the cost of a single framed foil costs approximately $450. A non-standard GEM costs $600-$700 depending on design. Additional expense may include tooling ($300) and design work ($300). Depending on the research we would ask $10k to be spent on design and production of GEMs.

Another budget item is running the lab, which includes consumables such as gases, cleaning materials, IT service, small tooling and similar. Typical cost is $700 per month, $8.4k per year.

Expense	Amount
Design and production of GEM elements and tooling	$10k
Operation of the detector lab (consumables, tooling, IT support, etc.)	$8.4k
Total w/o overhead	$18.4k