Date: 28 Dec 2017

EIC Detector R&D Progress Report

Project ID: eRD22
Project Name: GEM based Transition radiation detector and tracker
Period Reported: from 07/2017 to 12/2017
Project Leader: Yulia Furletova
Contact Person: Yulia Furletova

Project members

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Abstract

Transition radiation detectors are used for electron identification in various particle physics experiments. The high granularity of GEM detectors provide precise tracking information for charged particles. When combined with transition radiation options they can provide improved electron identification. Due to the low material budget and cost of GEM detector technologies, a GEM based transition radiation detector/tracker (GEM/TRD/T) is an ideal candidate for large area end-cap detectors.

Past

What was planned for this period?

This is a first year of the eRD22 project. The advisory committee recommended focusing on a GEANT4 simulation of the GEM/TRD setup. Our goal was to finish the main part of the GEANT4 simulation during the first half of the year, and then focus on prototyping and test setup during the second half of the year.

What was achieved?

I. GEANT4 simulation

We have begun the GEANT4 simulation. The radiator and detector thicknesses were optimized for a single chamber. We plan on improving the detector simulation by implementing a digitalization and a multi-layer setup. Our next step will be a calculation of e/pi rejection factors.

The transition radiation (TR) photon yield and TR detection efficiency are the most important parameters for a single chamber optimization. The yield of TR photons is directly related to the thickness of a radiator (R:), while a TR detection efficiency depends on the detector (gas) thickness (D:).

A GEANT4 simulation with different values of radiator R:(3, 5, 7, 10cm) and gas thicknesses D:(20, 30, 40mm) was performed (Fig. 1). The comparison of the absorbed TR photon yield as a function of a detector (gas) thickness is shown for different radiator thicknesses in Fig. 2. As shown in Fig 2, most of TR photons absorbed are in the area close to the entrance (close to radiator). In Fig. 2, the left plot shows the optimum detection distance is around 2 cm. Further increasing of the gas gap does not help with the TR detection efficiency, but could create addition problems due to HV instability. The TR yield could be increased by increasing the radiator thicknesses (Fig. 2 right plot).

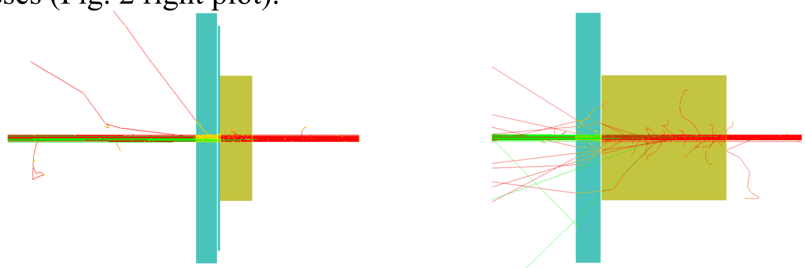


Figure 1. Different setups of GEM/TRDs

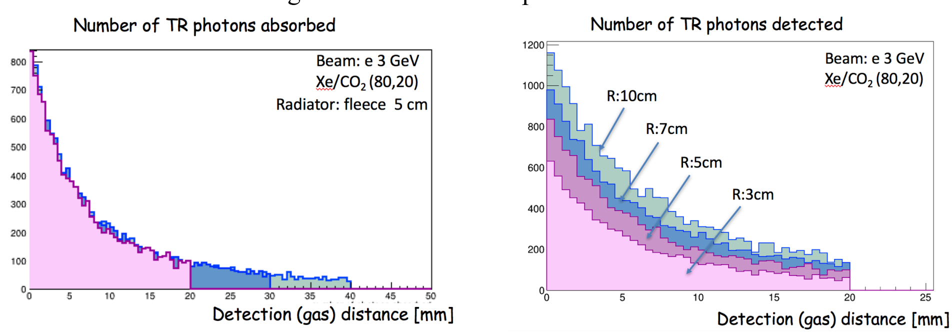


Figure 2. A comparison of an absorbed TR photons as a function of detection(gas) distance for a different radiator thicknesses.

Another important characteristic that has to be taken into account for optimization is the energy spectrum of TR photons. The energy spectrum of generated, absorbed, and escaped TR-photons is shown in Fig. 3. Here one has to pay attention to the fact that most of the soft TR photons will be absorbed inside the radiator. Therefore, instead of generated TR spectrum, the energy spectrum after the radiator (before the detector volume) has to be compared to the TR absorption and escape spectra. TR energy spectra for different gas mixtures are shown in Fig. 4. The absorption efficiency for Xe-based mixtures are much higher than Ar-based mixtures. A detailed comparison of TR spectra for different radiator and detector volumes is shown in Fig. 5 and Fig. 6.

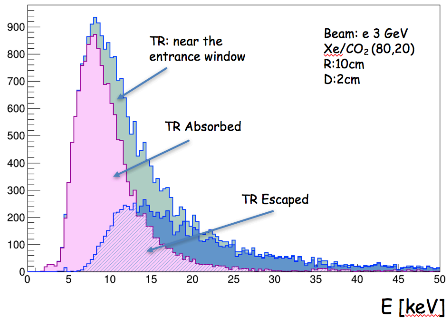


Figure 3. Energy spectrum of generated, absorbed and escaped TR photons for 3 GeV electron beam (left) and pion beam (right).

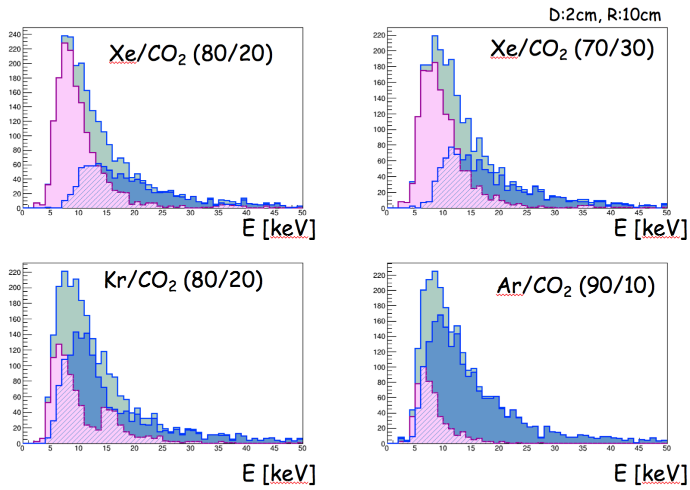


Figure 4. The energy spectrum of absorbed (pink) and escaped (dark blue) TR-photons for different gas mixtures.

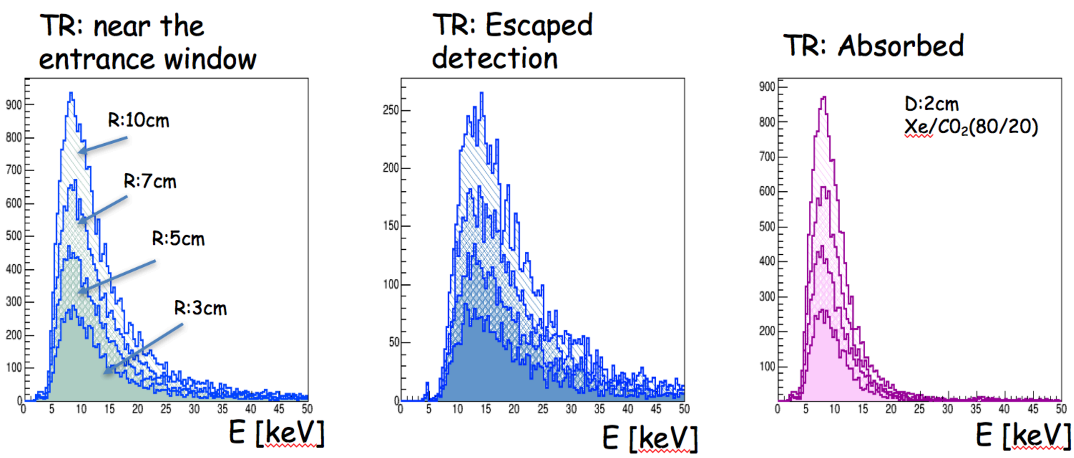


Figure 5. Comparisons of generated, escaped, and absorbed TR spectra as function of TR photon energy for a different thicknesses of a radiator with a fixed detector thickness (2cm).

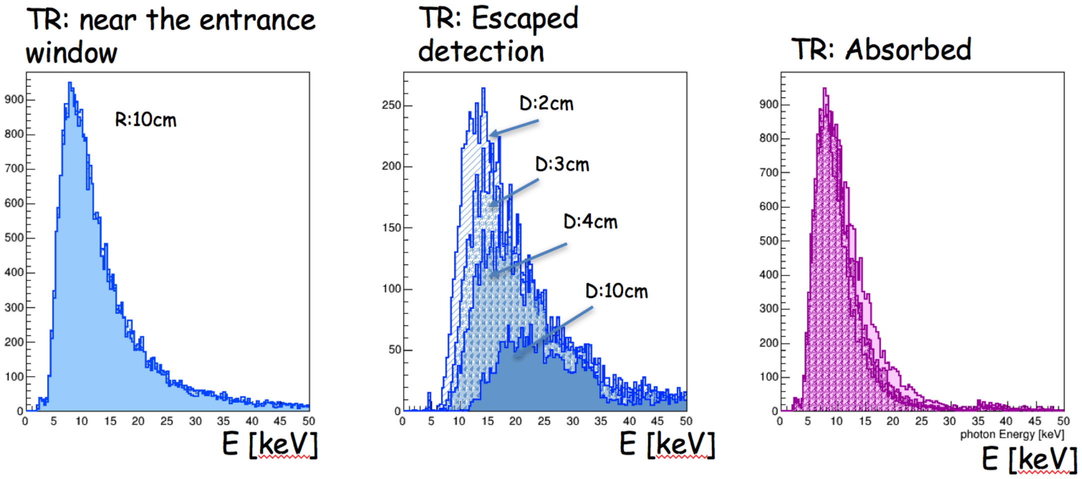


Figure 6. Comparisons of generated, escaped, and absorbed TR spectra as function of TR photon energy for a different thicknesses of a detector volume with a fixed radiator thickness (10cm).

A GARFIELD and a MAGBOLTZ simulations show that operation with Xe gas would require a significant increase of high voltage (HV) in order to achieve similar drift velocity for clusters (Fig. 7) compared to the Ar based detectors. Additionally Xe gas would also lead to different gas gains.

Input from test beam measurements are required to produce a more realistic simulation.

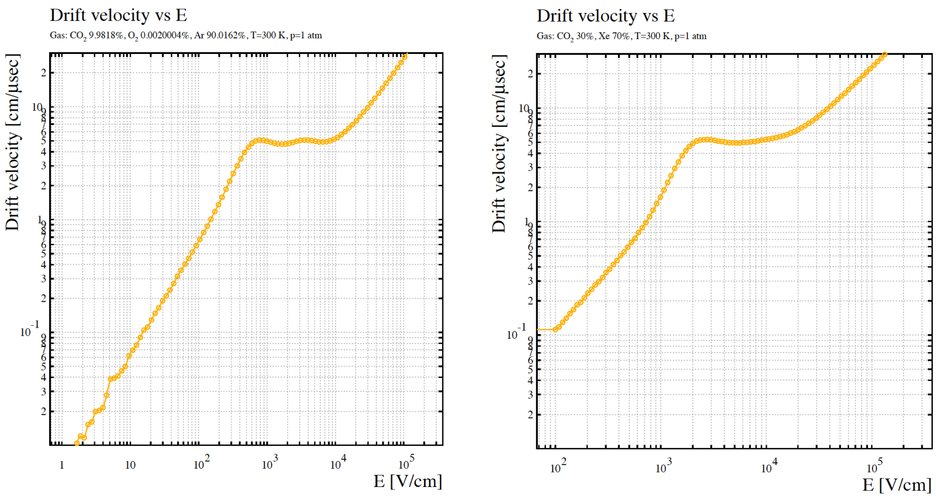


Figure 7. A GARFIELD simulation of drift velocity as a function of applied HV field for $ArCO_2$ (left) and $XeCO_2$ (right) gas mixtures.

II. Test beam measurements

With additional funds provided by the Jefferson Lab, and using an opportunity to perform an early test beam measurement at Hall-D (JLAB) during a CEBAF winter-spring operation, we reprioritized our goals to concentrate on test beam measurements rather than on a simulation. Those measurements will be used to verify our GEANT4 simulation.

a) GEM-TRD prototype.

Based on the first results of the GEANT4 simulation, and taking into account the lessons learned during the previous test beam at JLAB in spring 2016, we prepared a new version of the GEM/TRD prototype. We have implemented a number of modifications (listed below) to minimize the material at the entrance window and optimize the drift field in the drift region of the detector.

- **The detector gas and radiator volumes**

For the GEM-TRD prototype, the gas box has been modified to minimize the gap between the entrance window foil and the drift cathode foil to less than 400 μm (previous prototype had a 4 mm gap). This is a critical change, as it drastically reduces the number of x-ray photons absorbed in this dead area of the detector in the Xe-CO2 gas mixture. As a result, it increases the detection efficiency of the TRD detector. The gas box has also been modified to eliminate the gas leaks that we experienced with the previous prototype. Fig. 8 shows a cross section sketch of the detector design and the improvement from the old prototype to new one.

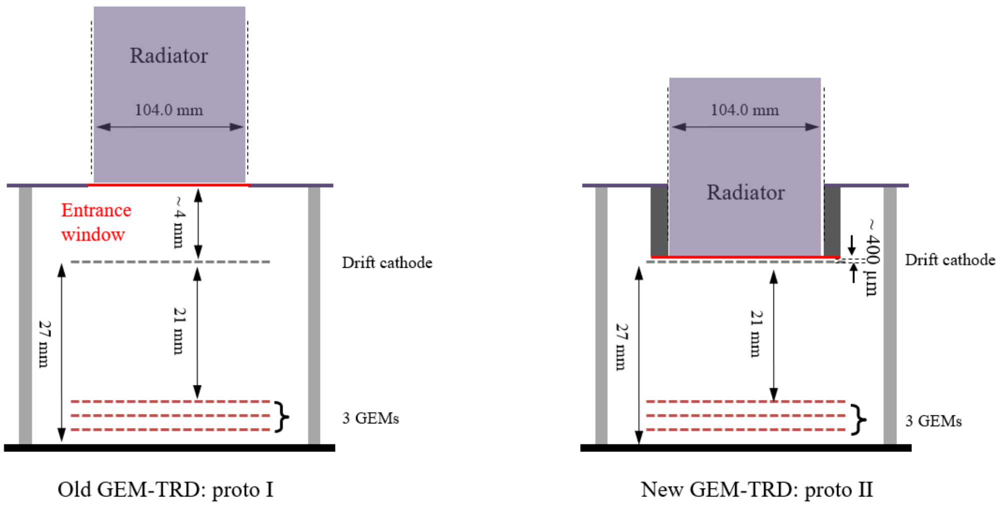
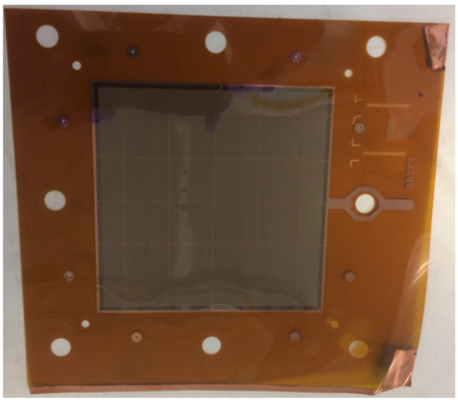


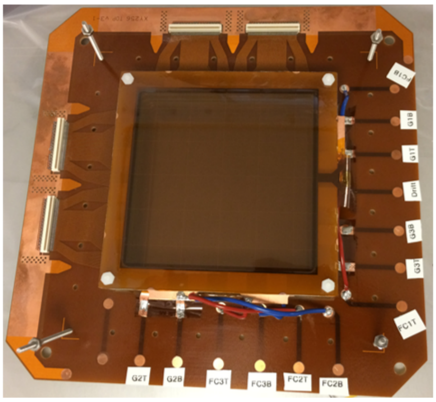
Figure 8. Old prototype with 4 mm gas entrance window (left); New prototype upgraded with 0.4 mm gas entrance window.

- **Chromium drift cathode (Cr-cathode) and entrance window foils**

The drift cathode of the new prototype is made of 50 μm Kapton layer with an ultra-thin layer (0.2 μm) of Chromium (Cr-cathode) as opposed to 5 μm Copper used in the first prototype. This replacement of the Cu by the ultra-thin Cr layer should significantly improve the detection efficiency of the TRD photons by reducing the number of photons that absorbed inside the drift cathode itself. A picture of the Cr-cathode is shown on the left picture of Fig. 9. A 25 μm Kapton foil is used for the entrance window.



Cr drift cathode foil



Drift cathode and GEM stack
on new R/O board

Figure 9. Drift cathode with 200 nm Cr layer (left). Stack of Cr-cathode and 3 GEMs on of the new readout board

- **New design for the 2D strip readout board**

The readout strip layer is the anode layer of the triple-GEM detector. This is usually the layer with the electric pads needed to distribute the voltage to the various stages of the detector. In the TRD configuration, a standard triple-GEM requires 6 more electrode pads for the field cage of the 21-mm drift in addition to the standard 7 electrodes to supply the GEM foils. The 2D X-Y strips readout board was modified accordingly to accommodate the additional HV electrodes. The right image in Fig. 9 shows the stack of the drift cathode and 3 GEM foils with the connection to the HV pads on top modified readout board.

- **Redesign of the voltage divider and HV power supply scheme**

The divider for GEM-TRD prototype has been redesigned to optimize the drift timing performances of the TRD photons (Fig.10). With the voltage divider at an operating voltage of 6.5 kV for Xe-CO2, the field in the drift region is 1.33 kV/cm defining a drift time window of less than 1 us for the 21 mm drift gap.

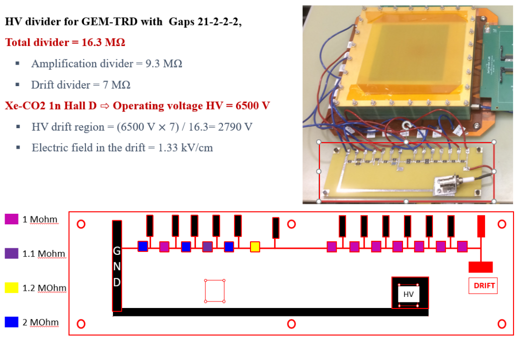


Figure 10. New divider for GEM-TRD proto II

➢ Prototype assembly

The prototype was built from a standard CERN 10 cm × 10 cm triple GEM kit but with the drift volume changed from 3 mm to 21 mm and therefore the need to have a field cage that maintains a uniform field distribution in the full drift volume. The table below shows the different elements of the detector that are relevant to the TR performances.

The X-Y strips readout board has a size of 240 mm × 240 mm with a gas box of a size 200 mm × 20 mm and a thickness of 32 mm. However, the active area of the chamber is 100 mm × 100 mm and the gas thickness in the drift region 21.4 mm including the entrance gas volume.

	Material	Thicknesses
Entrance window foil	Kapton	25 μm
Entrance gas volume	Xe-CO2	400 μm
Drift foil	Chromium + Kapton	Chromium: 0.2 μm Kapton: 50 μm
Drift volume	Xe-CO2	21 mm
3 GEM foils	Cu-Kapton-Cu	Chromium: 6 × 5 μm Kapton: 3 × 50 μm

The prototype was fully tested at UVA and operated with no problem during preparation for a test beam run at JLab in the fall of 2017 (Fig. 11).

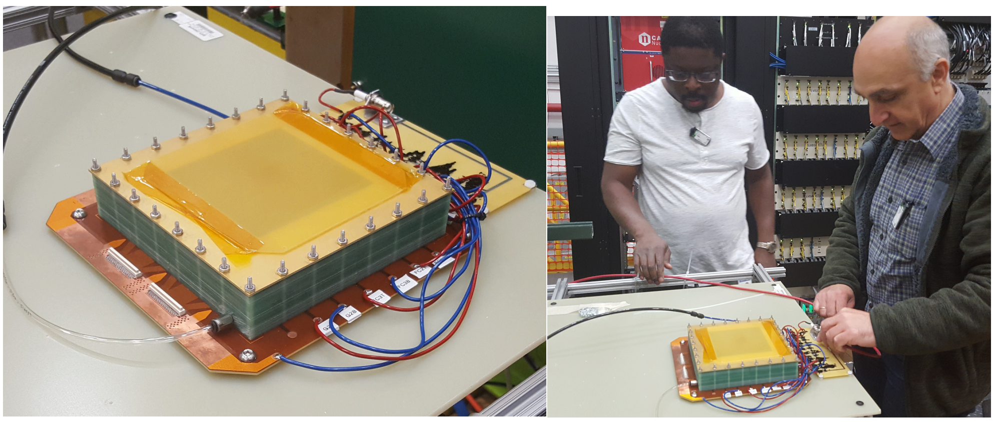


Figure 11. An assembled GEM/TRD prototype

b) Gas system

The GEM based TRD R&D is currently in the very early stages and is still being developed as a proof of principle detector. As such, there is not enough funding available at this time to build a full-fledged gas system, which includes a gas mixer, circulation pumps, gas purifiers, and analyzers. Thus, it was decided to focus some of the available funding on the gas mixing system. This system would allow us to mix custom concentrations of Xe/CO_2 gas, which is the ideal detector gas for TRD detectors. An initial draft of the Xe/CO_2 gas mixing system has been designed, and is shown in the figure 12 below. The main components of the gas mixing system are the two mass flow controllers from Teledyne Hastings (HFC-302). Assuming a nominal gas flow of 50 SCCM and concentration of 70 (Xe)/30 (CO_2), quotes for the flow controllers (~$1,500 each) were obtained with dynamic ranges of 0-40 SCCM and 0-15 SCCM for the Xe and CO_2 controllers, respectively. The gas mixing system also includes filters on each of the gas sources, pressure indicators, and several manual valves on each of the gas lines. An additional item not shown here but currently being investigated is a CO_2 analyzer to provide a cross-check of the CO_2 concentration calculated by the mass flow controller. In addition to the gas lines providing Xe and CO_2, a third gas line was designed to incorporate the use of another gas, which would be useful if N_2, Ar, or a pre-mixed gas wanted to be used instead of a custom mixed Xe/CO_2 gas. Since any gas mixture going through the "other" line would have already been pre-mixed, we can simply use a variable area flow meter to regulate the gas flow (Fig. 12).

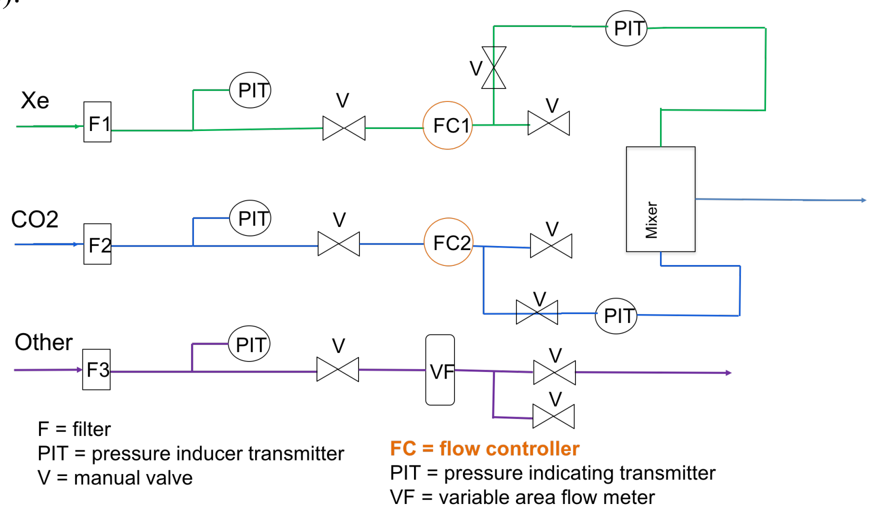


Figure 12. Initial draft of the gas mixer design to mix various concentrations of Xe/CO_2 gas for use with the GEM-based TRD detector.

c) A new readout interface board.

As we learned during the previous beam test with the first GEM/TRD prototype, a standard APV25 readout chip is not capable of covering a full drift range of GEM/TRD. Therefore, we developed and fabricated a new interface board, which is compatible with an existing JLAB Flash-ADC system. With a support of the Jefferson Lab electronics department (a special thanks to Chris Stanislav and Fernando Barbosa), an electrical drawing (PCB design) of such board has been performed (Fig.13). Three interface boards were produced (x-y coordinates, and 1 spare). Each board holds 10 preamplifiers, each preamplifier connects to 24 GEM strips, resulting on a readout of 240 GEM strips per each readout board or X/Y coordinate. A pre-amplifier has GAS-II ASIC chips (3 chips per each preamplifier card) and provides 2.6 mV/fC amplification. A preamplifier has a peaking time of 10 ns. It consumes 50 mWatt/channel and has a noise <0.3 fC. The dynamic range of preamplifiers (where it is linear) is about 200 fC. Fig. 14 shows the final product of the boards with preamplifiers connected to them.

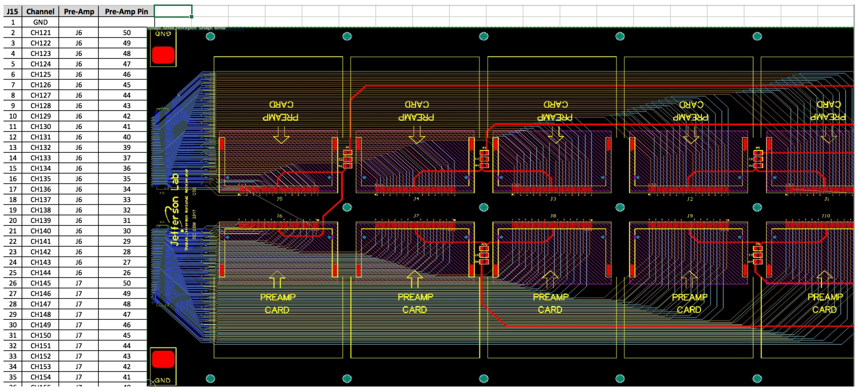


Figure 13. A design of a new readout interface board

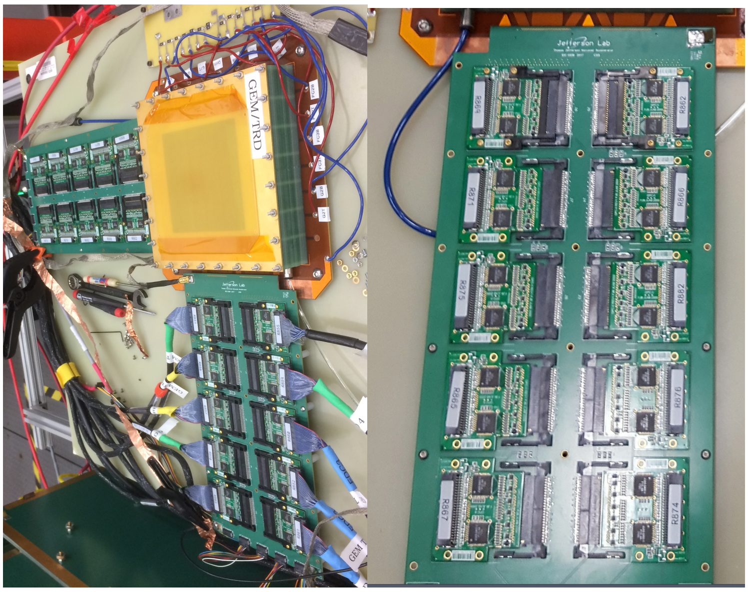


Figure 14. Interface boards attached to GEM/TRD prototype and assembled with pre-amplifiers.

d) Data Acquisition, Triggering, and Monitoring systems (DAQ)

We performed a test of a GEM/TRD prototype with new readout electronics, which included assembling a new Data Acquisition (DAQ) system, as well as Data Quality Monitoring (DQM) and analysis software. The new DAQ is based on a standard JLAB DAQ configuration that consists of a VME crate with readout controller running Linux, Flash-ADC boards and a trigger interface board. The DAQ software is based on CODA libraries, which were also developed at JLAB. All the DAQ components used for the test were borrowed from JLAB (Hall-D). We used 4 fADC125 boards, with 72 channels which were grouped into 3 connectors on the front panel.

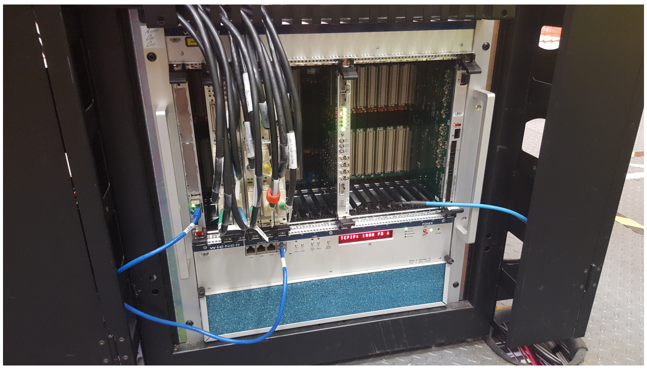


Figure 15. A VME crate with Cetia-PPC, Flash-ADC cards and Trigger Board.

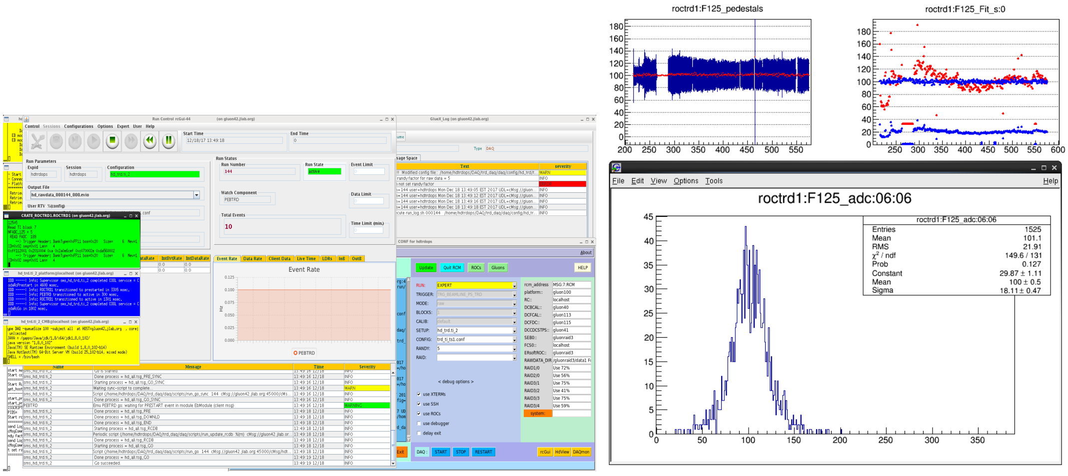


Figure 16. A screenshot of DAQ system (left) and a ROOT based Data Quality Monitor (DQM) with GEM/TRD pedestals (right).

e) Fe55 tests

We performed a Fe55 test with Ar and Xe gas mixtures, and performed high voltage scans to adjusted a gas amplification and to test a signal to noise ratio. During the test we used a CAEN HV module and remote control system (Fig.17).

During the installation of the test setup in the Hall-D(JLAB), we found that pickup noise significantly affected the performance of the GEM-TRD operation. Through the implementation of screening copper foils and some changes in the grounding scheme, we were able to reduce the noise down to an acceptable level (see Fig.18).

Figure 17. A high voltage CAEN module and a HV remote control system.

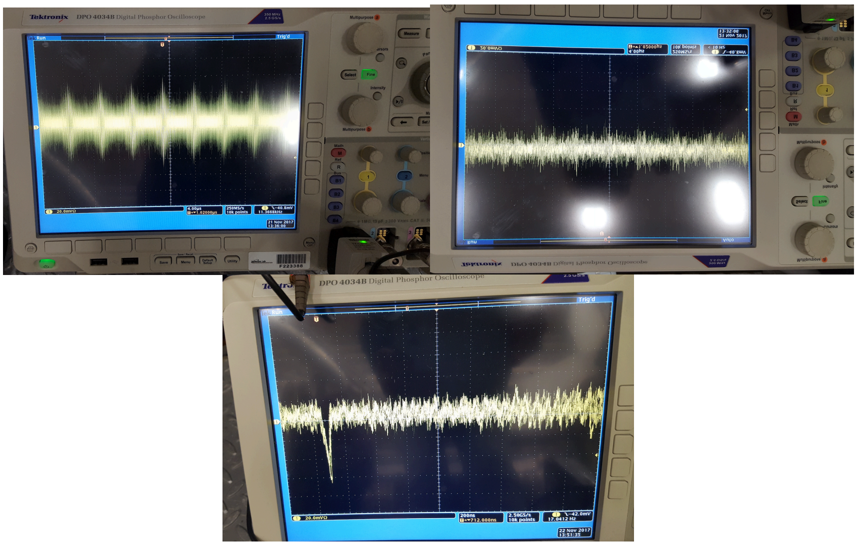


Figure 18. Before (upper left) and after (upper right) solving a grounding problem.
A nice Fe^{55} spectrum has been measured with Ar/CO2 (90/10)gas mixture (lower pict).

f) Mechanical support.

We performed the installation of the GEM/TRD prototype in the Hall-D (CEBAF facility) for further beam tests, which we are planning to perform in Jan-Feb 2018. With a help of the Hall-D engineers and staff (special thanks for Tom Carstens), a prototype was mounted and adjusted on the support structure near the exit window of the pair-spectrometer. (Fig.19). We will use 3-6 GeV electrons coming from the pair spectrometer (Fig. 19 right) in parallel with a setup of multi-wire TRDs. The GEMTRD setup was aligned with respect to a beam. A 10 cm fleece radiator was placed in front of the GEM entrance window.

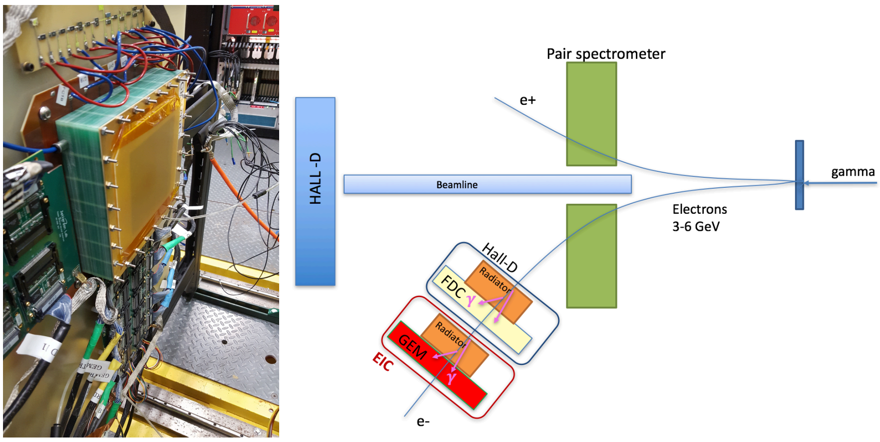


Figure 19. Mechanical support structure and test beam setup at Hall-D (CEBAF).

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

Taking into account that a significant portion of our second year goals have already been performed (designing a new electronics interface electronics, DAQ, HV test, source measurements, etc.), we are planning to continue developing the GEANT4 simulation in the second part of the year, in parallel to taking more beam test measurements and analysing the data.

Future

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

We are planning to continue the GEANT4 simulation. At the moment, we have performed a "hit" level simulation. Valuable input from beam tests will allow us to simulate a "digitized" response of our GEM/TRD detector.
We are planning to continue our test beam measurements at Hall-D (CEBAF). Depending on a results, a new prototyping might be needed. Modifications to the existing high voltage distribution board might also be needed. We are planning to perform tests with different radiators and different gas mixtures.

What are critical issues?

Additional information

Manpower

Include a list of the existing manpower and what approximate fraction each has spent on the project. If students and/or postdocs were funded through the R&D, please state where they were located, what fraction of their time they spend on EIC R&D, and who supervised their work.

None of JLAB, Temple or UVA members are funded by EIC R&D.

Jefferson Lab (JLAB) :		
H. Fenker	Research Scientist	5 %
S. Furletov	Research Scientist	5 %
Y. Furletova	Research Scientist	20 %
L. Pentchev	Research Scientist	5 %
B. Zihlmann	Research Scientist	5 %
Temple University :		
M. Posik	Research Scientist	15 %
B. Surrow	Professor	10 %
University of Virginia (UVA):		
K. Gnanvo	Research Scientist	20 %
N. Liyanage	Professor	10 %
John Matter	Grad. student	5 %
Siyu Jian	Grad. student	5 %

External Funding

Describe what external funding was obtained, if any. The report must clarify what has been accomplished with the EIC R&D funds and what came as a contribution from potential collaborators.

Jefferson Lab provided funds for purchasing parts of GEM-TRD prototype and for a fabrication of interface boards.

Publications

Please provide a list of publications coming out of the R&D effort.

Not applicable due to early stage of the project.