eRD22 GEM-TRD/T R&D Progress Report

F. Barbosa[1], H. Fenker[1], S. Furletov[1], Y. Furletova*[1], K. Gnanvo[2], N. Liyanage[2], L. Pentchev[1], M. Posik[3], C. Stanislav[1], B. Surrow[1], and B. Zihlmann[1]

[1]Jefferson Lab
[2]University of Virginia
[3]Temple University

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Project Leader: Yulia Furletova
Contact Person: Yulia Furletova

Abstract

Transition radiation detectors are widely used for electron identification in various particle physics experiments. For a high luminosity electron-ion collider a high granularity tracker combined with a transition radiation option for particle identification could provide additional electron identification/hadron suppression. 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 hadron endcap where a high flux of hadrons is expected at the EIC.

*yulia@jlab.org

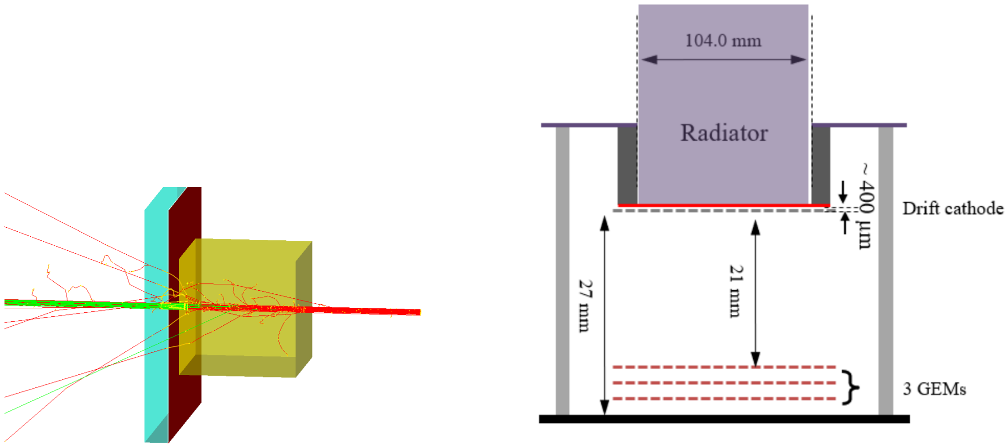

Figure 1: Geant4 simulation of TRD setup, including dead-regions at en trace-window.

1 Introduction

Identification of secondary electrons plays a very important role for physics at the Electron-Ion Collider (EIC). J/ψ has a significant branching ratio for decays into leptons (the branching ratio to electrons (e^+e^- pair) is similar to muons ($\mu^+\mu^-$ pair) and is at the order of 6%). The branching ratio of D-mesons is Br($D^+ \to e + X$) $\sim$ 16% and the branching ratio of B-mesons is Br($B^\pm \to e + \nu + X_c$) $\sim$ 10%. By using more sophisticated electron identification the overall J/ψ and open charm or beauty mesons efficiency could be increased and therefore statistical uncertainties could be improved. Electron identification is also important for many other physics topics, such as spectroscopy, beyond the standard model physics, etc. A high granularity tracker combined with a transition radiation option for particle identification could provide additional information necessary for electron identification or hadron suppression.

The scope of this project is to develop a transition radiation detector/tracker capable of providing additional pion rejection (>10-100).

2 PAST

- *What was planned for this period?*
  This is a second year of the eRD22 project. The advisory committee recommended focusing on a GEANT4 simulation of the GEM/TRD setup in the first stage of the project. Our goals were to simulate a GEM-TRD setup, optimize the setup for better electron identification, build a prototype and perform the test-beam measurements, which would allow us to compare a simulation and a real response of the detector.

- *What was achieved?*

GEANT4 simulation

We performed a GEANT4 simulation and optimized the radiator and detector thicknesses for a single chamber (Fig. 1), described in the previous report in more details.

GEANT4 has classes for simulation of TR photons. The classes include models for regular radiator (G4XTRRegularRadModel) and irregular, gamma-distributed radiator foil and gas gaps between foils, (G4XTRGammaRadModel). Both models can be transparent or can take into account TR photon absorption. We used G4XTRGammaRadModel model for our fleece radiator, which could be simulated in GEANT4 as an irregular type of radiator with a certain density and two parameters (α_1, α_2), which define a spread of materials and air-gaps within a radiator. We optimized a thickness of TR-radiator. Due to the self-absorbing property of the radiator, soft photons (3-6 kEv) generated within first few centimeters of the TR-radiator will be absorbed, leading to an increase in the hard X-ray photon spectrum at the exit from a radiator. A thin layer of

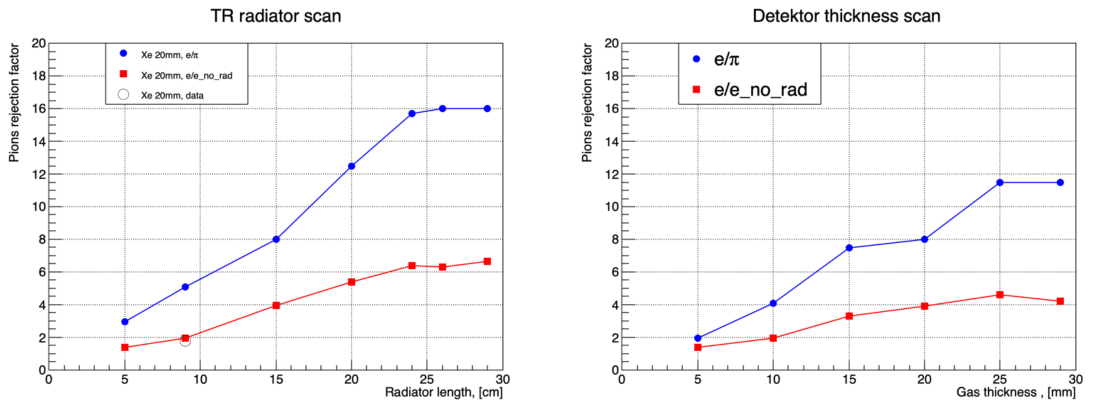

Figure 2: Rejection as a function of a thickness of a TR-radiator (left) and Xe-based detector thickness (right)

Xe-based detector will not be effective to detect hard X-ray photons.

As one could see in Fig. 2 (left), rejection power is saturated after 22cm of radiator for our GEM detector with 21mm gas thickness, including 400μm of dead gas layer in front.

Simulation of the detector drift-volume includes a simulation of "dead-material", which consists of 75μm of mylar-foil and 400μm of Xe-filled gap between the drift-cathode and the entrance window, as shown on Fig.1. The presence of this "dead"-region, leads to an inefficiency of low energy TR-photon absorption and has to be minimized.

Fig. 2 (right), also shows saturation of the rejection power for gas thickness more than 25mm, for radiator thickness of 15cm.

Table 1 summarizes the rejection power for different radiators and Xe-filled detector volumes.

Detector	Dead material in front	Radiator	e/π	$e/e_{no\ radiator}$	$DATA_{e/e_{noR}}$
20 mm	no dead material	20 cm	14.4	6.3	
20 mm	400 μm Xe, Kapton 75μm	20 cm	12.5	5.38	
20 mm	as above	5 cm	2.94	1.37	
20 mm	as above	9 cm	5.07	1.97	1.8
20 mm	as above	15 cm	8.0	3.94	
20 mm	as above	26 cm	16.0	6.3	
20 mm	as above	29 cm	16.1	6.66	
29 mm	400 μm Xe, Kapton 75μm	15 cm	11.5	4.22	
25 mm	as above	15 cm	11.55	4.62	
15 mm	as above	15cm	7.54	3.33	
10 mm	as above	15 cm	4.01	1.97	
5 mm	as above	15 cm	1.96	1.38	

Table 1: Rejection factor corresponding to 90% of electron efficiency

First test-beam measurements and comparisons with simulation

During this half of the year we focused on a calculation of e/π rejection factor using simulated data, as well as the extraction of e/π rejection using real data.

During the last year we performed test beam measurements with a GEM-based transition-radiation detector, described in the previous reports in more detail, using an electron beam provided at the JLAB/Hall-D facility (Fig.3. We used a prototype, assembled at UVA, which had a 2.1 cm of drift-volume (Xe-gas thickness), as well as a 9cm of fleece TR-radiator.

We performed the first measurements of GEM-TRD/T prototype with a Xe gas mixture. A comparison of the detector responses with and without radiator is shown in Fig. 4 left plot (red and blue lines respectively). We performed a test with different radiators. We used ZEUS-TRD radiator material (PP fibers with a random fiber orientation, and material density of 0.083g/cm^3)

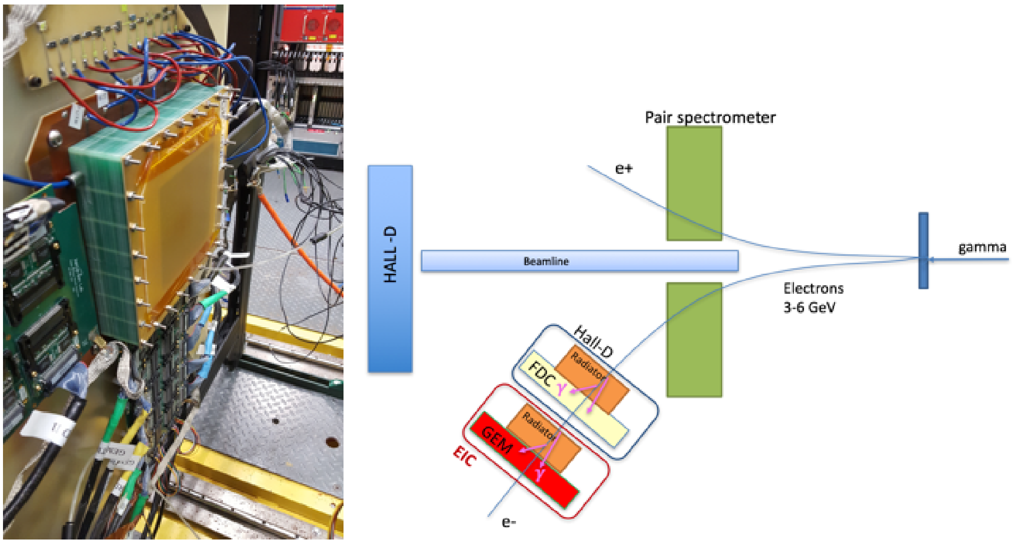

Figure 3: Test beam setup at Hall-D (CEBAF).

(Fig. 4 left plot). We also performed a test with a regular structure radiator which had ca. 200 13μm Mylar foils separated by 180μm spacers made from nylon net. The performance of our system with this type of radiator is shown in Fig. 4 (right).

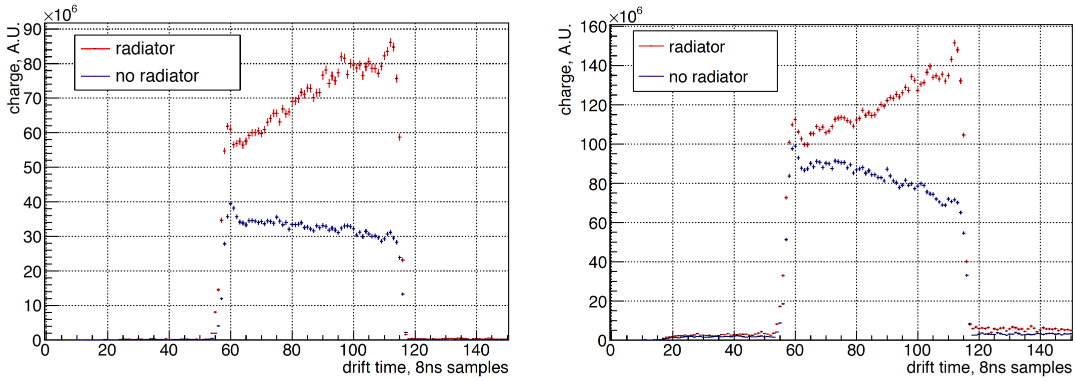

Figure 4: Preliminary results with different radiator materials: fleece (left) and regular foils (right)

Since we had only an electron beam, we compared only the electron response of the detector in two configurations with radiator and without radiator, where response of the detector without TR-radiator we used to "mimic" a pion response.

The difference between e/π rejection factor and $e_{with\ radiator}/e_{no\ radiator}$ TR-radiator for different thicknesses of radiator and Xe-based detectors is shown on Table 1. As one could see, due to a lower average dE/dx for pions, compared to electrons, e/π rejection factor is much higher then for $e_{with\ radiator}/e_{no\ radiator}$ case.

For e/pi rejection factor we analyzed the amplitude and arrival time of each individual cluster along the drift time. We also calculated the total number of clusters and the number of clusters within sub-segments (the total drift volume was subdivided into 20 slices(Fig. 5). This allowed us to study the number of clusters as well as the average energy loss within a sub-segment of the drift volume.

All this information (ca. 20 variables) was used as input for likelihood and artificial neural network (ANN) programs, such as JETNET or ROOT-based (Multi-layer Perceptron). The ANN system was trained with MC samples of incident electron and pions. Then an independent sample was used to evaluate the performance. An example of such a training procedure is shown in Fig. 5.

We require a 90% efficiency for our electron identification. The neural network output for e/π identification is shown in the left two plots of Fig 6 and $e_{with\ radiator}/e_{without\ radiator}$ is shown in

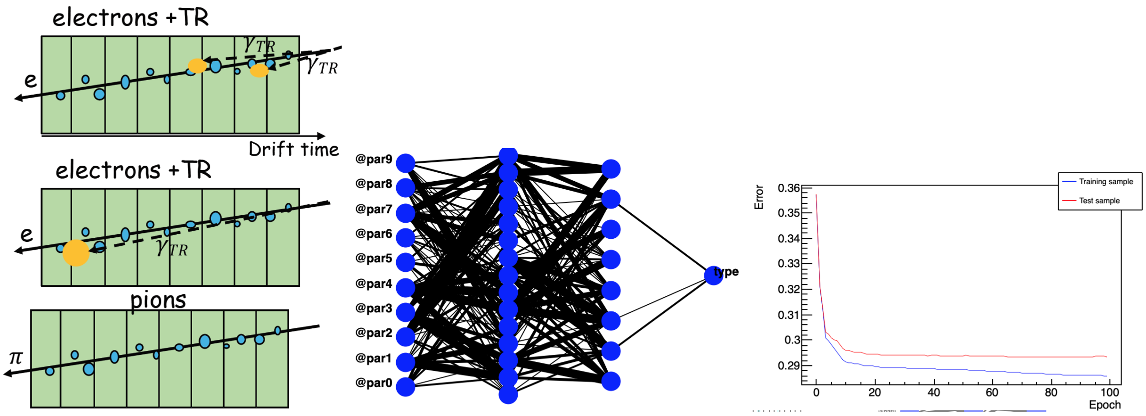

Figure 5: Schematic view of regions along the drift time used for e/*pi* identification (left). Training procedure with Root-based ANN (middle) and ANN training efficiency (right)

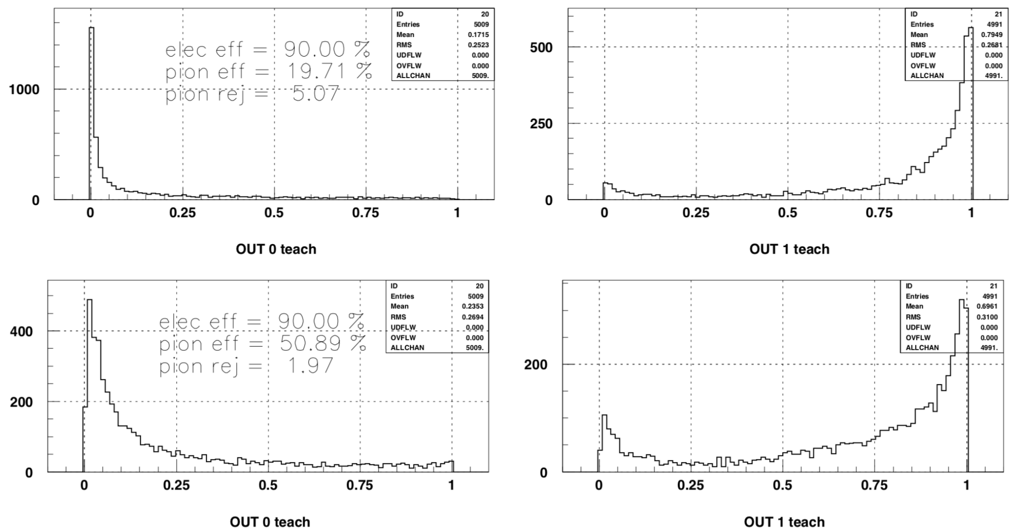

Figure 6: Neural network output for e/π identification (upper plots) and for electrons with radiator and without radiator(bottom plots) for Monte Carlo samples.

the two right plots.

We were able to achieved a rejection factor of 2.4 (4.5) with a 2cm (4cm) of Xe and 10cm of radiator(fleece). Requiring 70% electron efficiency a rejection factor of 12 (17) could be achieved for 2cm (4cm) of Xe and 10cm of radiator.

The Root-based neural-network (Multi-Layer Perceptron) output for a single module (left) and propagation for 3 modules (right) for real data sample are shown in Fig 7. Signal histogram (red) on these plots corresponds to electrons passing through radiator and background histogram (blue) corresponds to electron signal without radiator.

As was mentioned above, we performed test-beam measurements with an electron beam only, and pion rejection (see below) was estimated as a response for electrons without radiator (e_{wr}). A pion efficiency (e_{wr}) as a function of electron efficiency for a single module (left) and sets of 3 modules (right) is shown on Fig. 8. As one can see, for electron efficiency of 70%, pion efficiency is ca. 20% which corresponds to pion rejection factor of 5. For 3 modules with 70% electron efficiency, pion efficiency is ca. 2% (or a rejection factor 50).

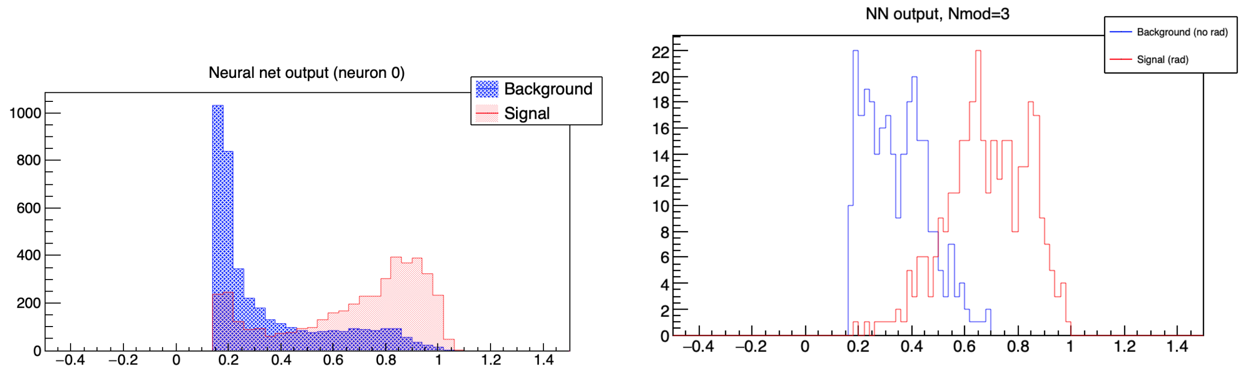

Figure 7: MLP output for a single module (left) and propagation for 3 modules (right) for real data sample.

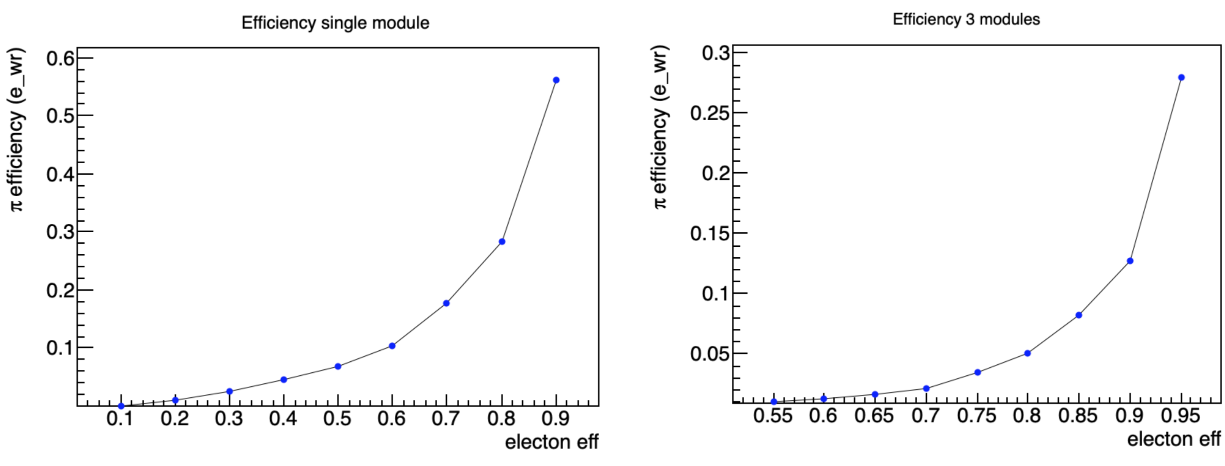

Figure 8: Pion efficiency (e_{wr}) as a function of electron efficiency for a single module (left) and sets of 3 modules (right) for test beam measurements

3 PLANS

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

Our gas mixing system is ready to use. We are planning to continue our test beam measurements at Hall-D (CEBAF) and perform measurements with different gas mixtures.

We are planning to test a new prototype with Chromium GEM foils (Cr-GEMTRD proto II). Cr-GEMTRD prototype will be based on the exact same design as in Fig. 1 with the only modification being that the standard Copper GEM foils will be replaced by Chromium GEM foil. The prototype with standard Copper GEM foils has been re-assembled and tested at UVA (Fig. 9).

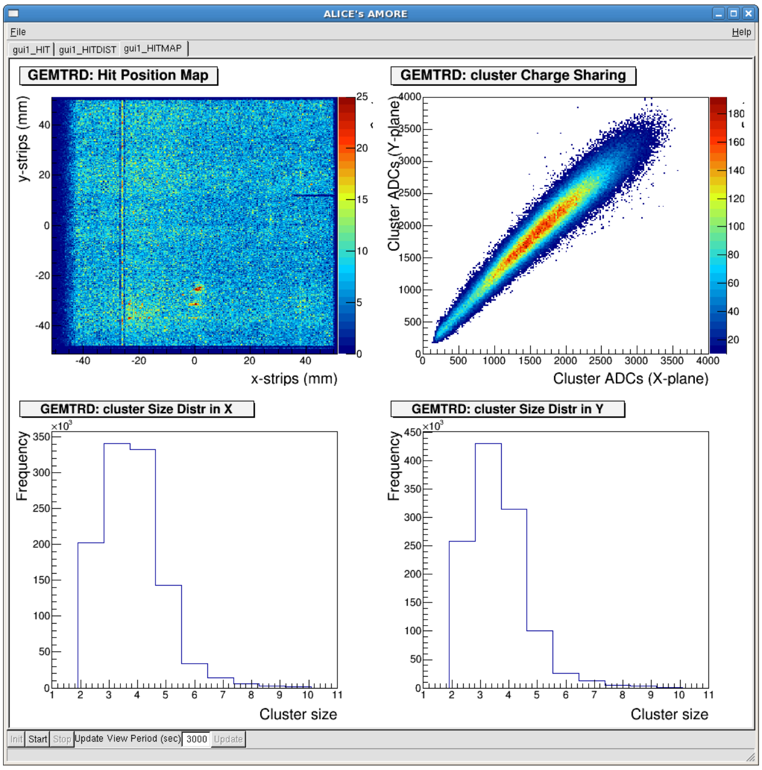

Figure 9: Performance of GEM-TRD module with Fe^{55}

Both prototypes will be tested this fall in Hall-D at JLab to compare the effect of the GEM Copper electrode on the overall detection efficiency in Xe mixture gas.

The gas mixing system is completed, operational and ready to use during our next test beam measurements.

Over the next year we will continue to analyze our data and work toward finalizing our results for publication.

3.2 *What are critical issues?*

We have identified a several issues and studies which should be pursued in addition to those in our original plans as important steps towards the realization of a new generation of transition radiation detectors as a part of the EIC project.

We still observe an effect of loss-of-charge (or non-uniformity) in a distribution of charge along the drift volume (blue line on Fig. 4) for particles passing the area without radiator. One of the explanations could be a purity of gas-mixture. An additional piece of equipment that we recently purchased is a gas analyzer. The gas analyzer will serve two main purposes. The first is that it will allow us to measure the concentrations of the Xe and CO2 gasses that make up the TRD gas. This would allow us to verify and test the performance/accuracy of our mass flow controllers. Additionally the gas analyzer will allow us to begin quantifying and monitoring contamination within the TRD gas. Such knowledge will help in understanding the detector signal responses and will help if and when a gas re-circulation system is installed.

During this year we mostly focused on an optimization of the transition radiation performance of our prototype. Since we are going to use it also as the tracking detector, we would like to evaluate the performance of our prototype as a tracker. Available electronics allowed as to use the drift time information of each individual cluster along the particle trajectory. We are planning to minimize an overall noise level from our detector to be more efficient for low-energy clusters, which are needed for tracking.

We are planning to continue collaboration with the streaming readout consortium to work together towards a realization of inexpensive readout chips which would allow us to use it for further GEM-TRD prototypes. An inexpensive readout would allow us to check performance of a GEM-TRD system with multiple layers and would allow us to perform a test with electron and pion beams (for example, at Fermilab or CERN).

3.3 Publications

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

Not applicable due to early stage of the project.

4 Acknowledgments

We would like to thank whole JLAB Hall-D collaboration, in particular E. Chudakov, for their continues support during a test beam period.