MPGD-Based Transition Radiation Detector for Tracking and Electron ID

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Vanderbilt University

EIC User Group & ePIC Joint Collaboration Meeting - July 15th, 2025

JLAB:
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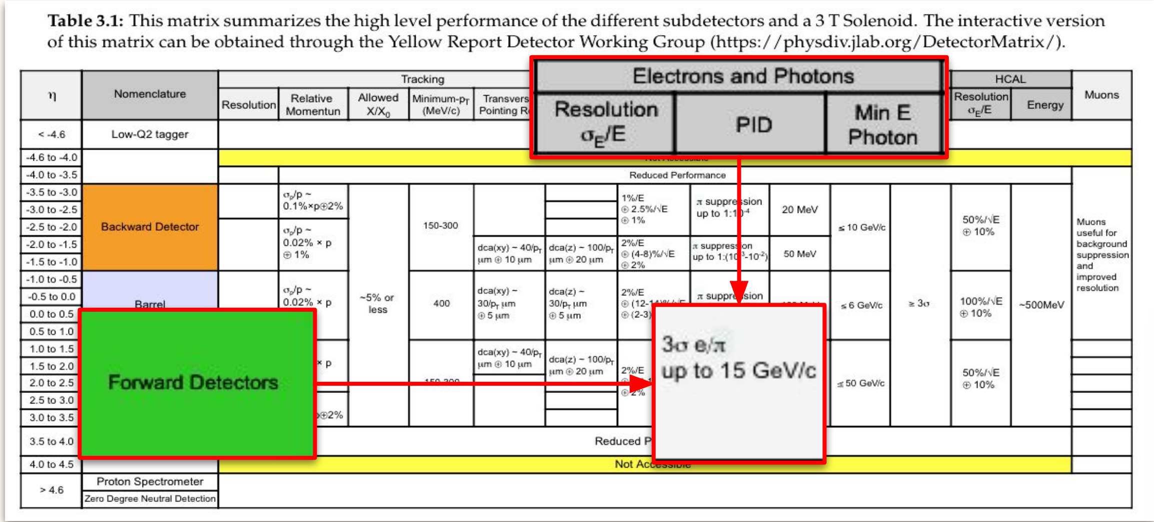
FSU:
Saheli Rakshit, Nizar Septian

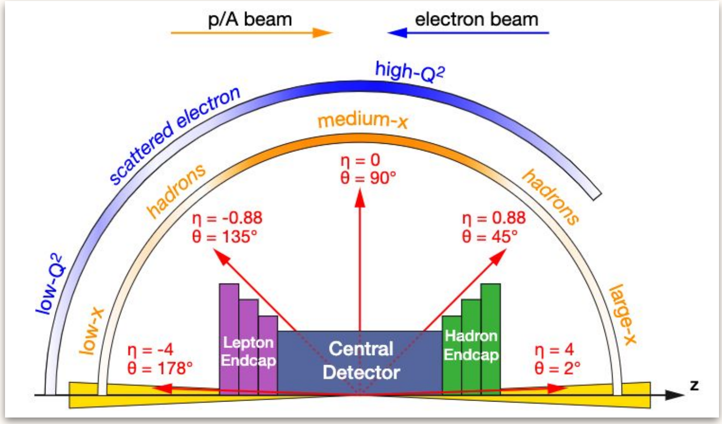
Electron Identification at the EIC

The EIC aims to unlock key questions in QCD and nuclear structure. Precision measurements demand clean data and robust particle identification (PID)

- EIC physics will require precise PID of >3σ separation of *e*'s from charged hadrons across all rapidity regions
- Precision is particularly challenging in the hadron-going direction - high rate of particles boosted in the lab frame means rigorous *e* ID up to at least 15 GeV/c



EIC Yellow Report V1.1



Who Cares About e/π Separation?

Electrons are key in probing the nucleon and nuclear structure via exclusive channels (e.g. J/Ψ)

Pion mis-ID is a major background - especially in inclusive & diffractive final states

Precise *e* ID ensures cleaner signal in e^+e^- decays. Essential for reducing combinatorial background in charmonium studies, cross sections, etc.
Clean electron tagging = cleaner physics

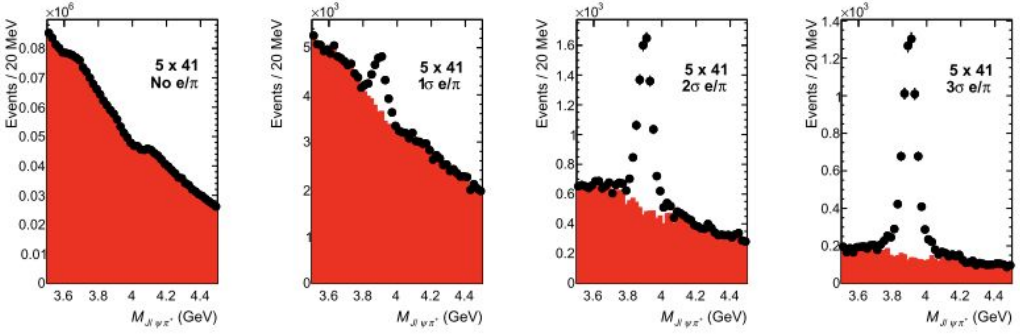


Figure 8.38: Simulated $Z_c^+ \rightarrow J/\psi\pi^+$ mass distribution from smeared simulation for 5×41 GeV beam energies with increasing (left-to-right) e/π separation. The PYTHIA background (red) is significantly reduced relative to the signal by more stringent e/π separation.

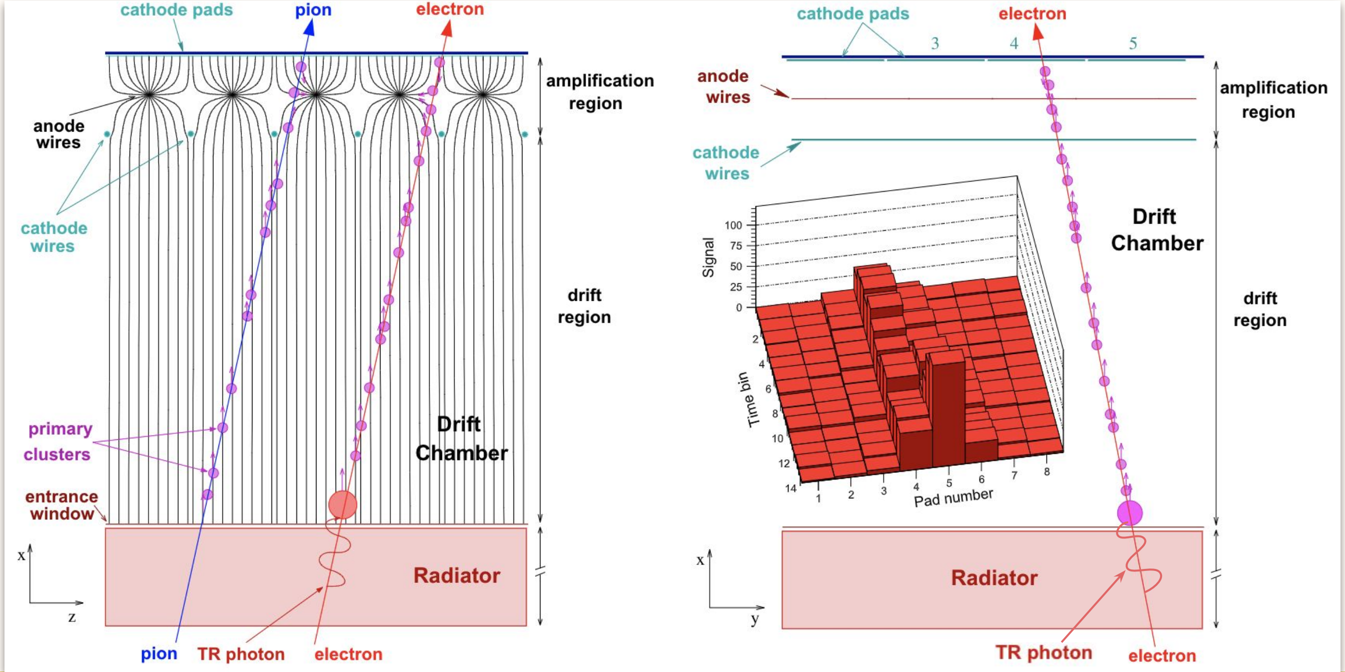
EIC Yellow Report V1.1

Transition Radiation: *e* ID + Charged Tracking

Detect primary ionization, plus TR X-ray clusters (~2-40 keV) created by charged particles crossing boundary between media of different refractive indices

Relativistic e's emit TR, π's do not (TR energy $\propto$ particle's γ-factor)

Goal: high pion suppression factor, with ideal discrimination of e's & π's at 2 GeV/c < p < 100 GeV/c



CERN-EP-2017-222, 2017, 10.1016/j.nima.2017.09.028

MPGD-Based TRDs

Proven use (ALICE, ATLAS, etc.) - but historic limitations
JLab efforts: TRD with triple-GEM amplification (NIM A 10.1016/j.nima.2019.162356)

Benefits Offered:

- Enhanced PID in regions where RICH/TOF coverage is limited
- Opportunity for systematic studies of uncertainties for other *e* ID methods, such as calorimetry
- Low-mass *e* ID method with low radiation length (~few %)
- Additional charged tracking point gained from nature of gaseous detector

Trade Offs:

- Heavy gas consumption ($$$)
- Fast readout electronics (flashADC125) necessary for separating TR from dE/dx ($$$)
- Probability to emit 1 photon per crossing: $\alpha \sim 1/137$. Many layers of radiator material = larger space occupancy than typical for a gaseous tracker

R&D For The EIC

JLab efforts provided proof of concept with MPGD integration, demonstrated in test beams and smaller-scale experiments

Additional work done to explore other MPGDs as potential options for a TRD (μRWELL, μMEGAs), 2022 EIC Generic R&D project funded to explore this concept

A proposal for MPGD-based transition radiation detector/tracker

F. Barbosa[1], L. Belfore[2], C. Dickover[1], S. Furletov[1], Y. Furletova*[1], K. Gnanvo[1], S. Greene[3], L. Kasper[3], N. Liyanage[4], H. Nguyen[4], L. Pentchev[1], M. Posik[5], C. Stanislav[1], B. Surrow[5], S. Tarafdar[3], J. Velkovska†[3], and B. Zihlmann[1]

[1]Jefferson Lab
[2]Old Dominion University
[3]Vanderbilt University
[4]University of Virginia
[5]Temple University

November 10, 2022

Project ID:
Project Name MPGD-based transition radiation detector and tracker
Period: from 10/1/2022 to 09/30/2023

Contact Persons: Yulia Furletova (yulia@jlab.org) and Julia Velkovska (julia.velkovska@vanderbilt.edu)

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 MPGD detector technologies, an MPGD based transition radiation detector/tracker (MPGD-TRD/T) is an ideal candidate for a large area hadron endcap where a high flux of hadrons is expected at the EIC.

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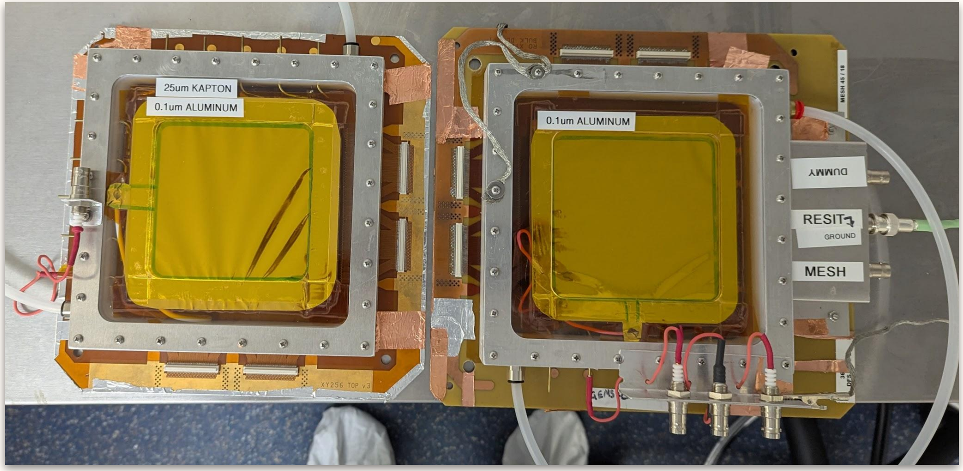
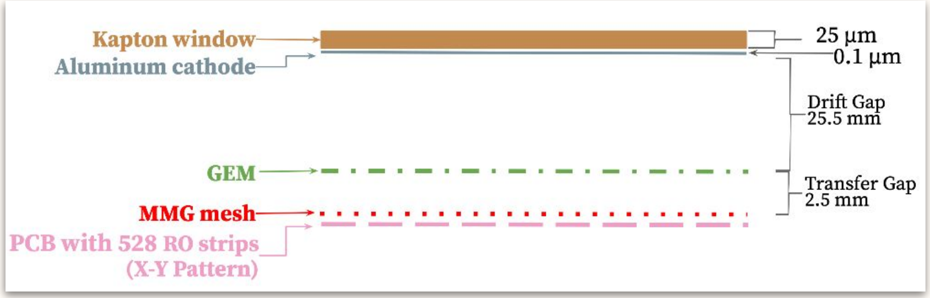
Initial findings:
In a TRD configuration, a single amplification layer can absorb and detect TR, but is insufficient in providing enough signal gain for efficient e/π separation

Apples-To-Apples Performance Comparison

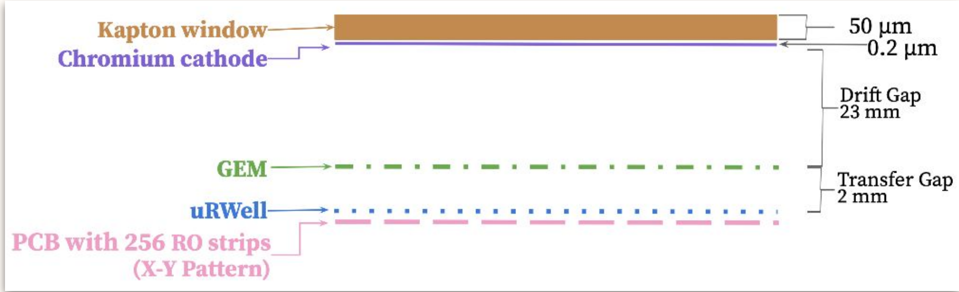
Triple-GEM TRD



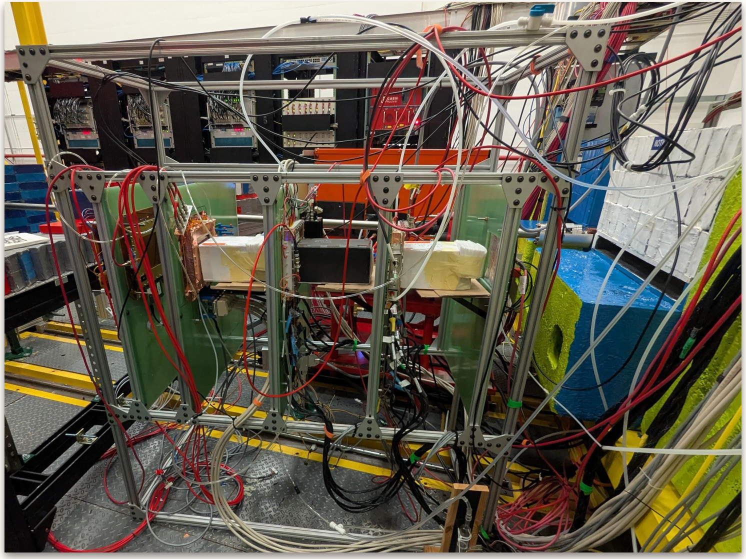
µMEGAs+GEM TRD

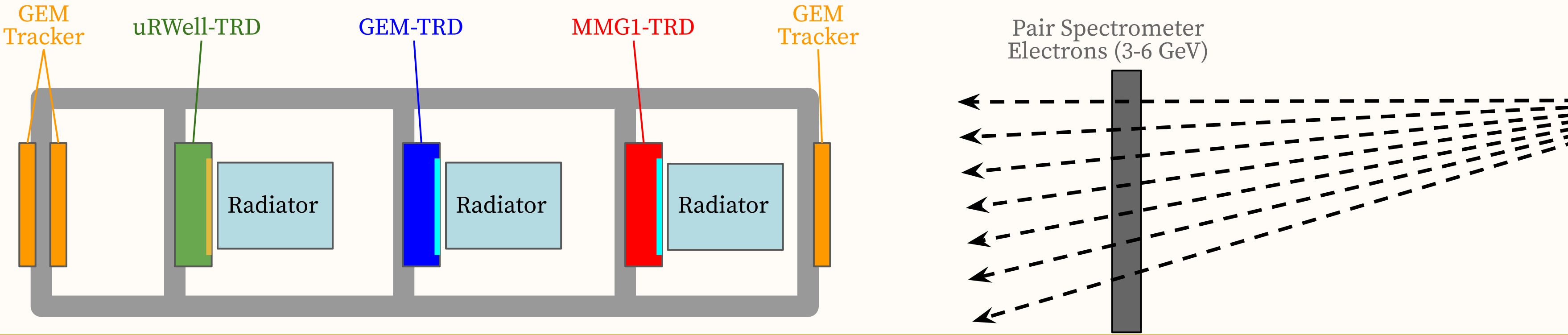


µRWELL+GEM TRD

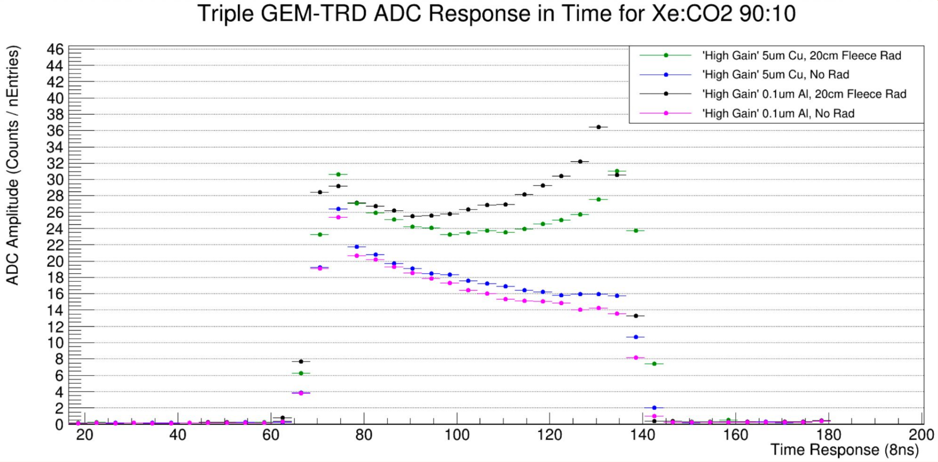


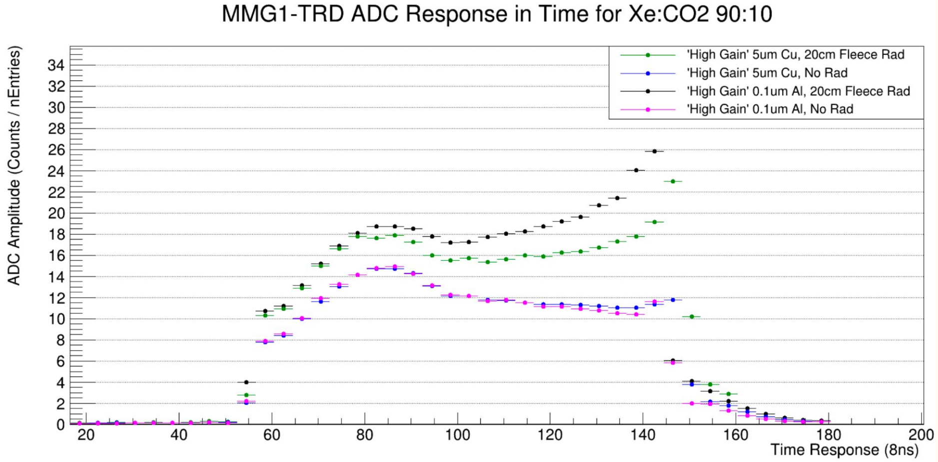
Summer 2025 Test Beam - JLab Hall D

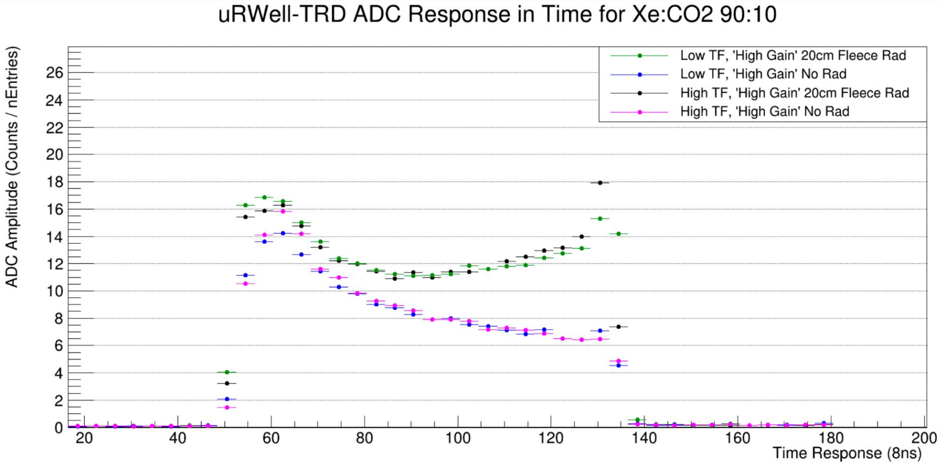




Preliminary Findings

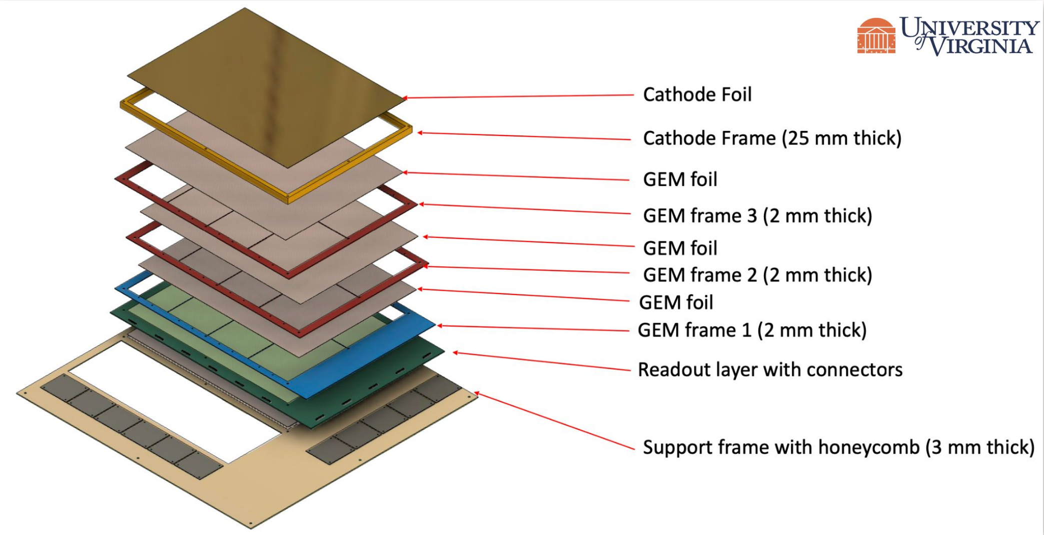


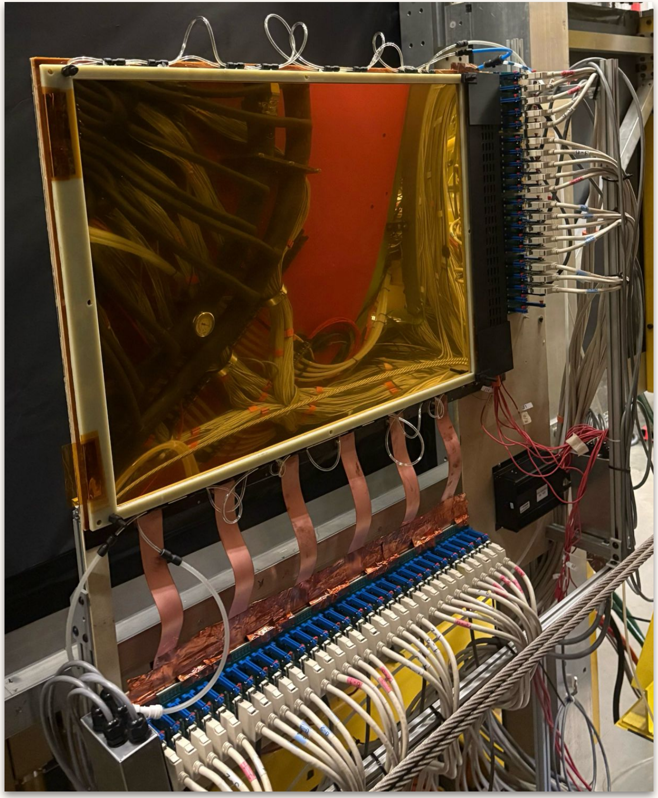




JLab Large-Scale Triple GEM-TRD

- Large scale prototype (696 × 528 mm^2), tested with cosmic, electron beam, and in GlueX experimental acceptance
- Able to investigate operation in a real experimental environment - Provides critical insights invaluable to design & commissioning of the full detector
- Full detector approved for GlueX-III run period





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Scientific Rating: A

Approved for 200 PAC days in Hall D

The PAC considers the program to understand the J/ψ production mechanism critical for the community that aims to use J/ψ for studying nuclear structure.

PR12-24-006

Scientific Rating: A

Recommendation: Approved for 200 PAC days in Hall D

Title: GlueX-III: a path to the Luminosity Frontier in Hall D

Spokespersons: M. R. Shepherd

Motivation: This proposal seeks to continue data-taking using the GlueX spectrometer in Hall D, taking advantage of higher beam current and possibly higher beam energy (up to 12 GeV) to collect an important sample of charmonium photoproduction events. The relatively large-statistics data, including photon polarization, that will be collected by this experiment will allow examination of the photoproduction mechanism for J/ψ, which is currently not established. In addition, GlueX will continue to use data collected with a relatively open trigger to examine the light hadron spectrum, collecting sufficient statistics to be able to carry out partial-wave analysis on some currently statistics-limited light meson final states.

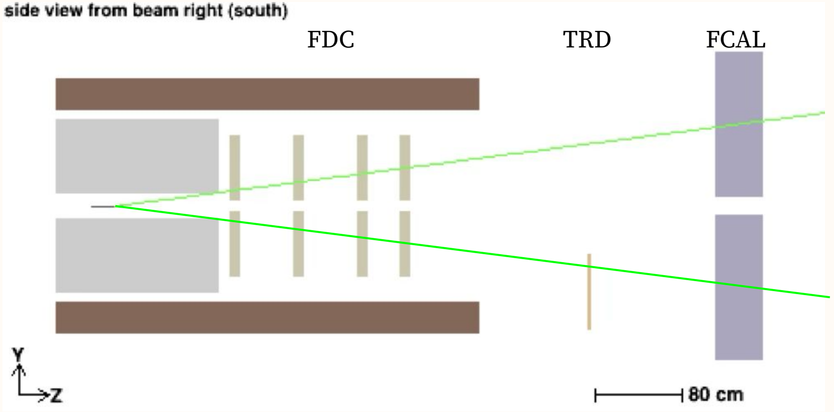
Measurement and Feasibility: There are no technical concerns that the GlueX collaboration will continue their successful data taking. The addition of a TRD will provide additional important capabilities in the electron-pion separation, which suppresses combinatorial backgrounds and make the data samples cleaner for a partial wave analysis. The PAC considers the program to understand the J/ψ production mechanism critical for the community that aims to use J/ψ for studying nuclear structure.

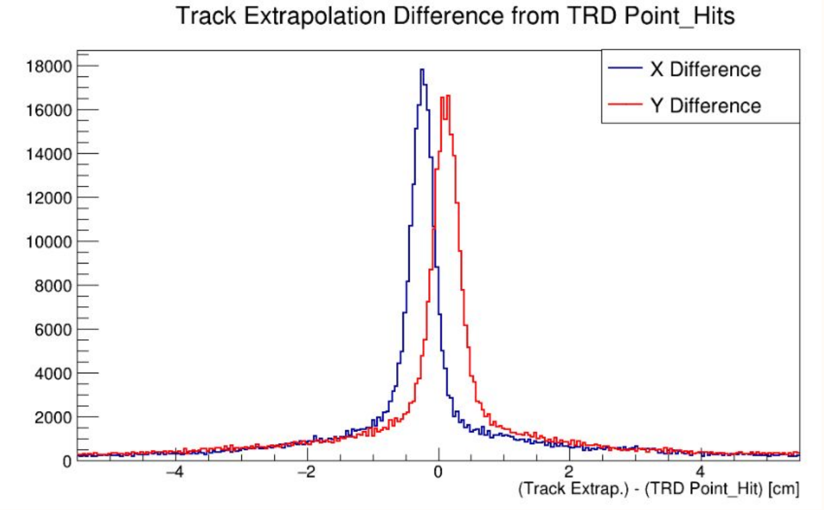
Issues: The experiment should not be run for a significant fraction of the 200 PAC days without the TRD being fully operational. This is because this new subsystem will enhance the quality of the data significantly and might enhance the use of the collected GlueX-III dataset for future analyses not yet planned. Therefore, both JLab and the collaboration should give high priority on finalizing the TRD before GlueX-III data taking starts. The PAC also encourages the GlueX collaboration to give priority to those GlueX-II data analyses that can inform the GlueX-III running.

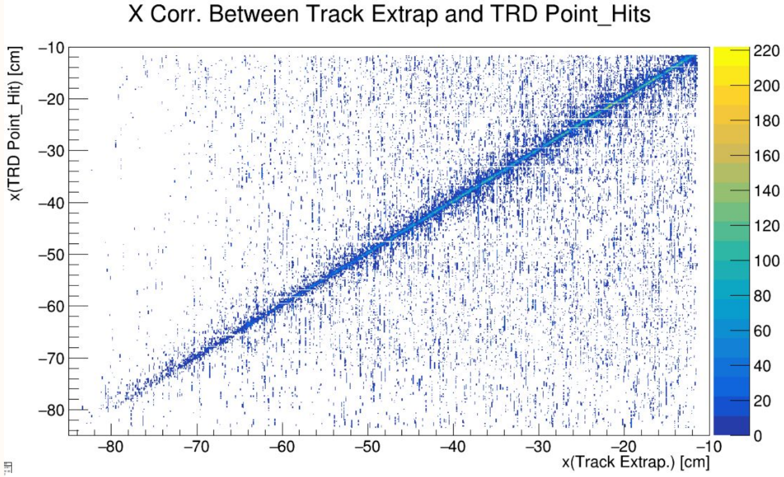
Summary: The PAC agrees that the experiment is very well motivated, and the experimental realization is sound. The addition of the TRD will provide important additional performance enhancement of the GlueX detector and significantly improve the signal to background ratio in general. The PAC therefore recommends approval of the requested 200 PAC days.

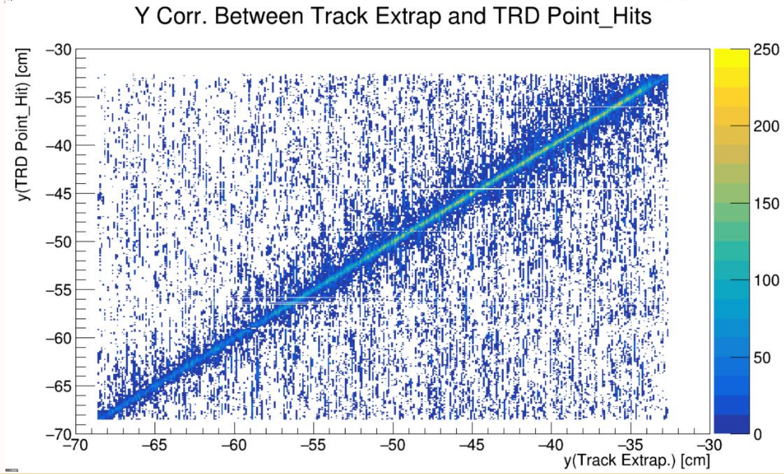
2024 PAC52 PR12-24-006

Charged-Track Matching with GlueX









Summary

- TRDs can offer clean separation of overlapping topologies and increase precision & efficiency of tracking for neighboring detectors
- Integration of a modern micron-scale amplification structure with a TRD stands to improve position res. & particle flux capability in TRDs as a whole
- A MPGD-based TRD is a compelling potential addition to the EIC toolkit, and stands to improve J/Ψ and electron-ID heavy analyses
- Time for R&D is now !

<u>Hardware experience is invaluable in training students and forging well-rounded physicists - EIC community is well-poised to uplift such projects & opportunities</u>

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Thanks! Questions?

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists, Office of Science Graduate Student Research (SCGSR) program. The SCGSR program is administered by the Oak Ridge Institute for Science and Education for the DOE under contract number DE-SC0014664.

Backup

PID: *e* Identification

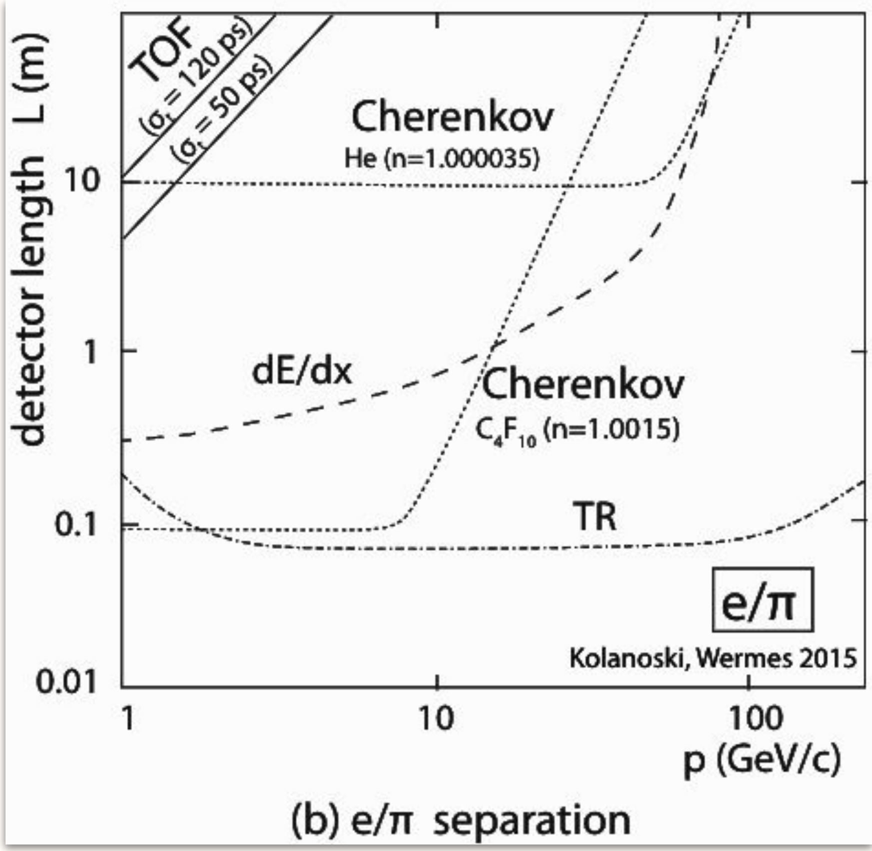
E-Calorimeters: Designed to measure total E of e's & γ's by total absorption (E/p)

Time-of-Flight (TOF)
p $\lesssim$ 2 GeV/c

Energy loss by ionization (dE/dx)
p $\lesssim$ 10 GeV/c

Cherenkov Radiation
0.25 GeV/c $\lesssim$ p $\lesssim$ 20 GeV/c

Transition Radiation (TR)
1 GeV/c $\lesssim$ p $\lesssim$ 150 GeV/c



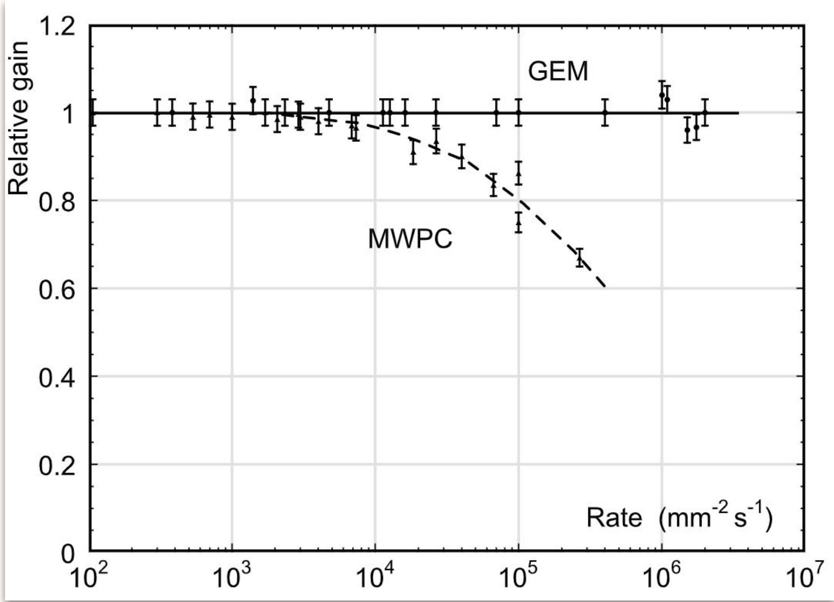
Kolanoski, H., and Wermes, N. "Particle Detectors Fundamentals and Applications." 2020

Micro-Pattern Gaseous Detectors (MPGDs)

Proven use of TRDs in ALICE, ATLAS, etc. but historic limitations - typical wire-chamber signal amplification

Micro-Pattern Gaseous Detectors (MPGDs) are modern gas detectors with micron-scale structures (Ex: GEMs, μMEGAs, μRWELLs)

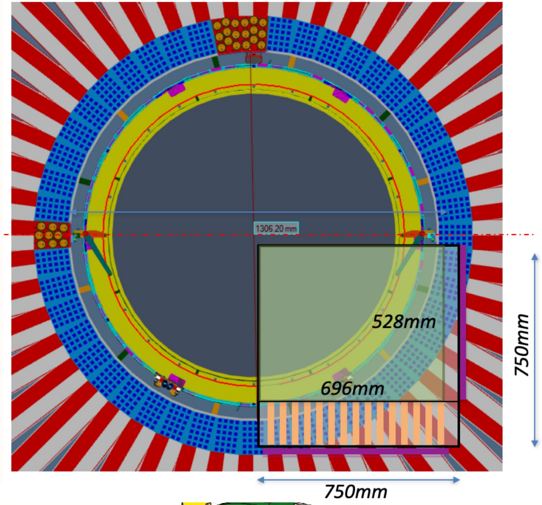
- Provide high granularity spatial resolution & fast signal response
- Leads to reliable use in high-rate ($>10^6$ Hz/mm^2) environments, with improved radiation hardness
- Scalable, flexibility in design, compatible with large detector systems

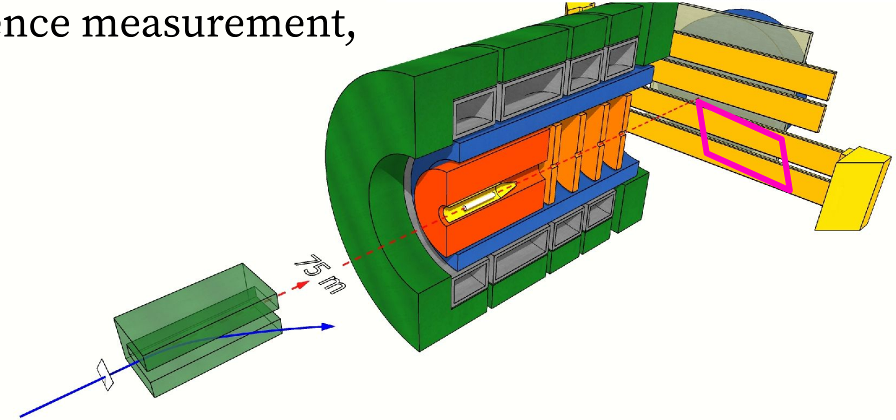


PDG. Review of Particle Physics, vol. 083C01, 2020

Plan & Goals of Recent April Tests

- Test Performance in real GlueX environment (stability, noise, gain, electronics, DAQ rates/data volumes, etc.)
- Collect data for developing TRD integration in GlueX software
- Collect *e, pi* samples to evaluate detector performance w.r.t pion suppression (TR signals from charged track dE/dx deposits)
- Estimate effect of this additional material (~4%) for GlueX physics
- Initially use Ar/CO2 for troubleshooting / reference measurement, then switch to Kr/CO2
- Test prototype of gas regulation system
- Build, install, and test large TR radiator

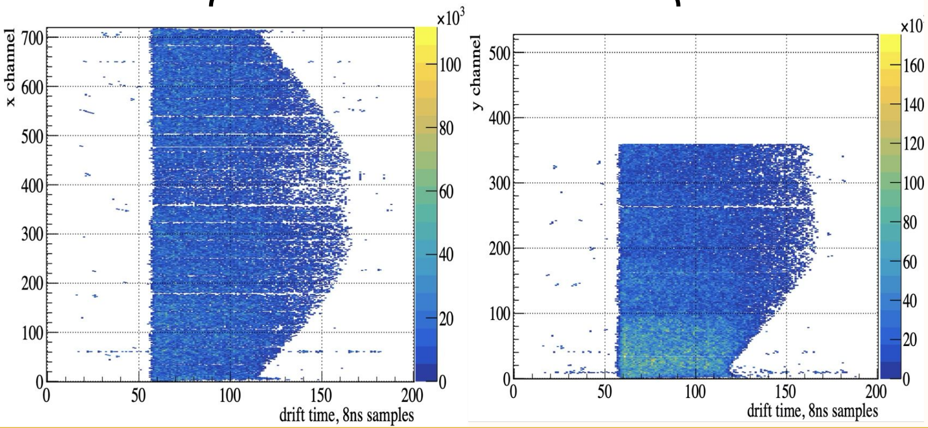




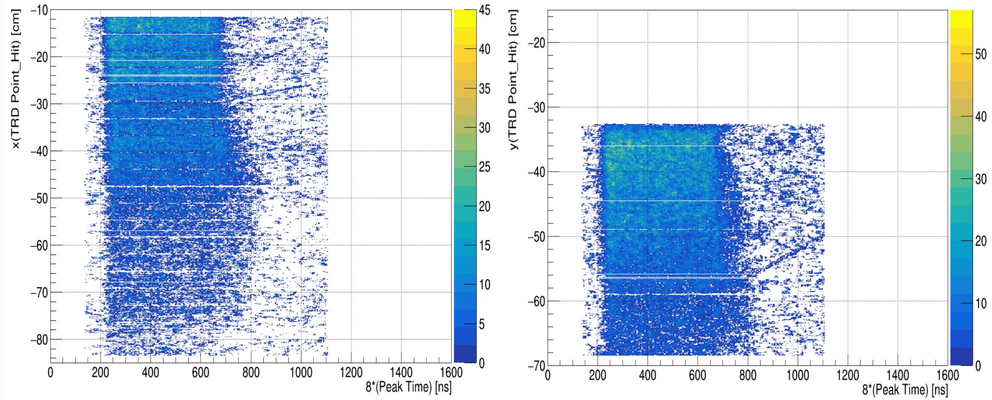
Gas Regulation System

- Portion of the full system to be developed, first time connecting system to a detector
- Multiple benefits realized
  - Conservation of heavy gas
  - Allow fine control of internal pressure (ind. of flow)
  - Reduce window bulging → more uniform E_Field
  - Reduced drift gap size (less HV needed for adequate drift field)
  - Gas analyzer connection on detector output (gas quality monitoring)

<u>Before</u>



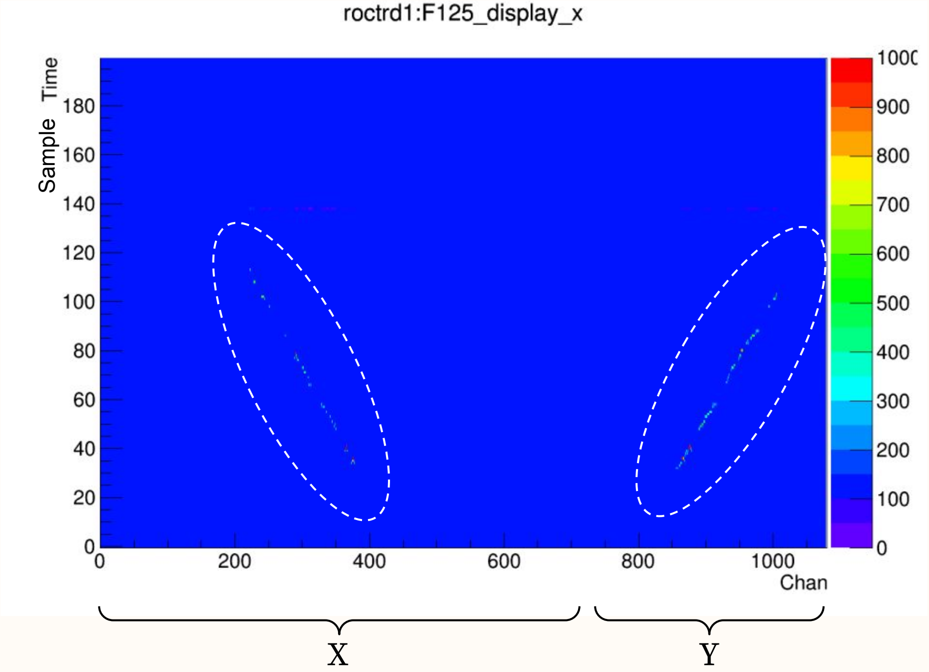
<u>After</u>

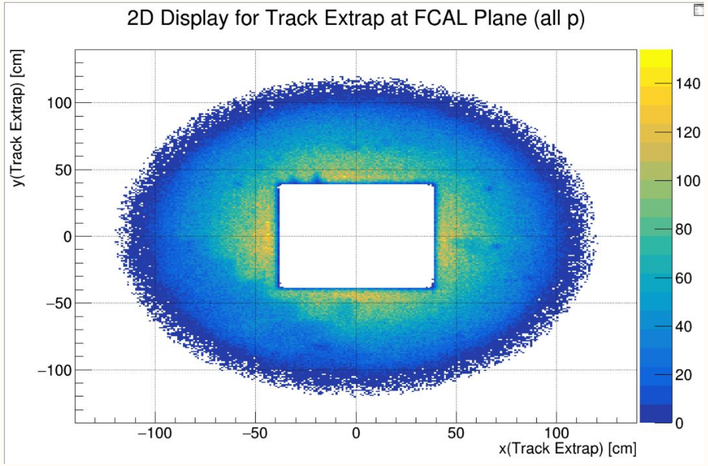


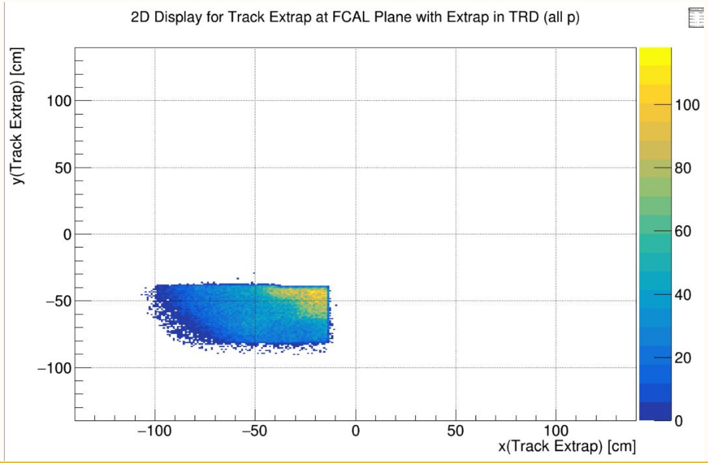
GlueX Software Integration

Detector readout integrated into GlueX DAQ

For these tests: DTRDPoint (3D) objects correlated with GlueX track projections and FCAL Shower info



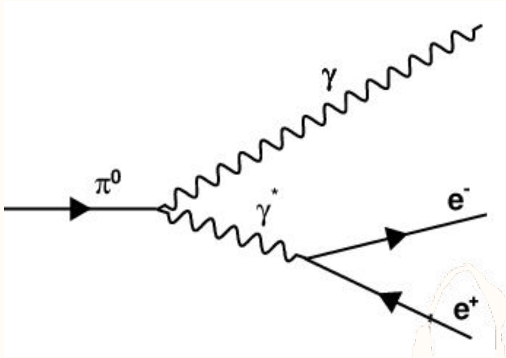




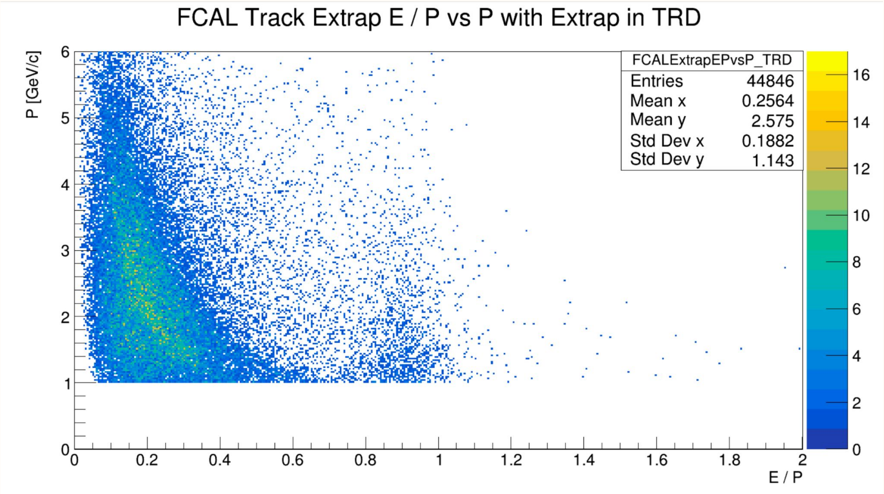
Event Reconstruction

At this time, Ilya has prepared skim files with electron-rich samples using pi^0 Dalitz decays

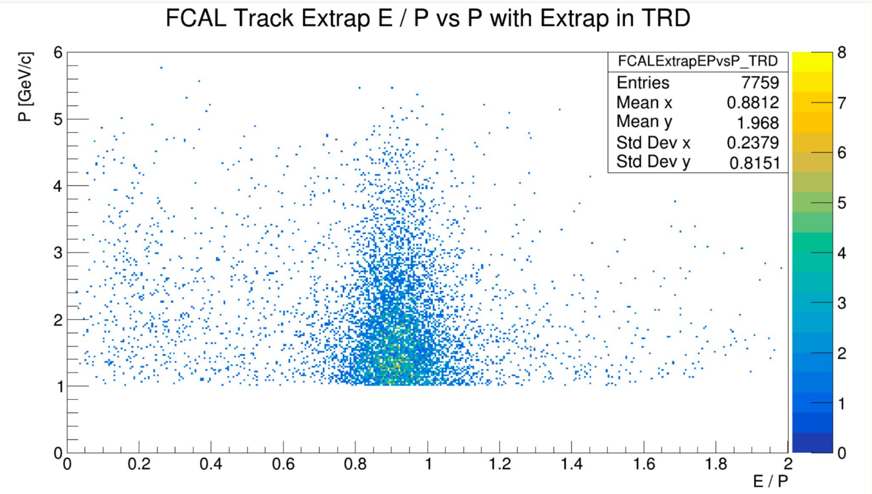
Reconstruction of decays with electrons in final states using these samples generated by Ilya



Before

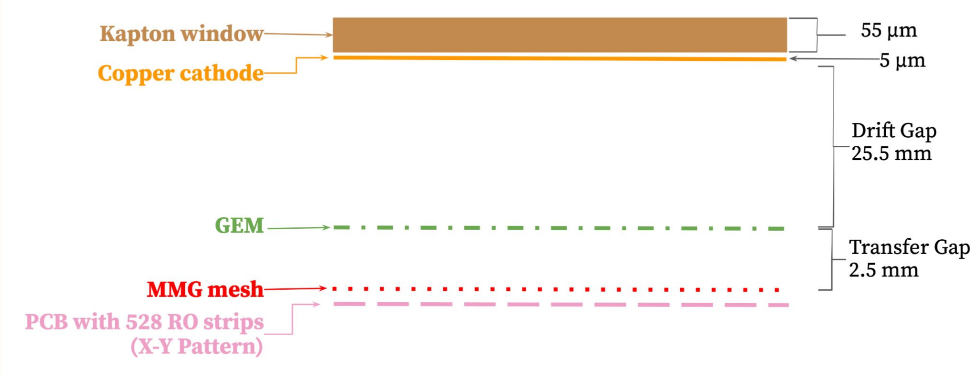


After

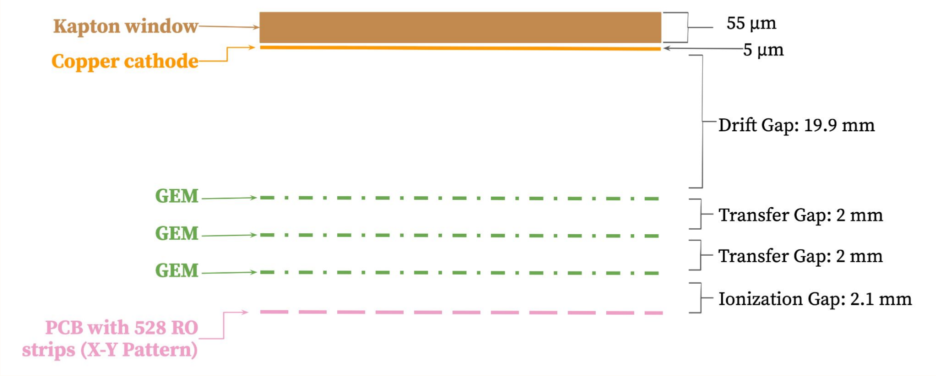


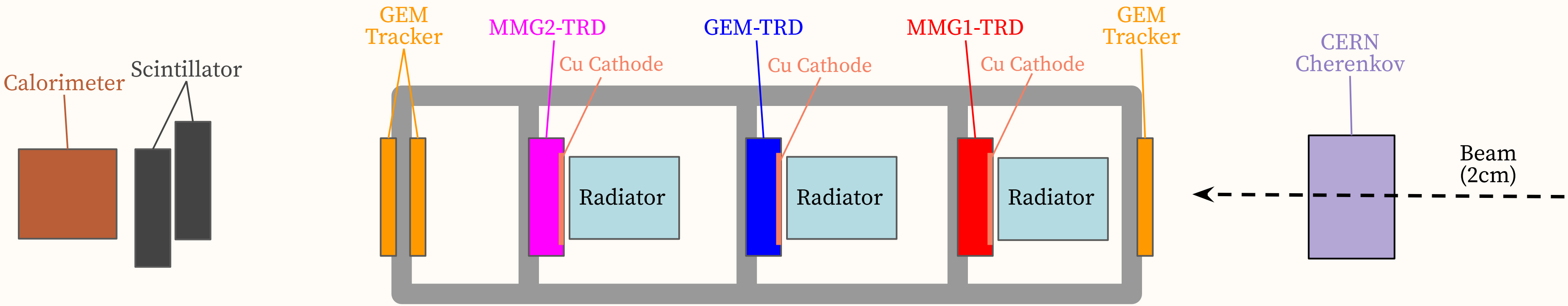
CERN Test Beam - July 2024

MMG1-TRD

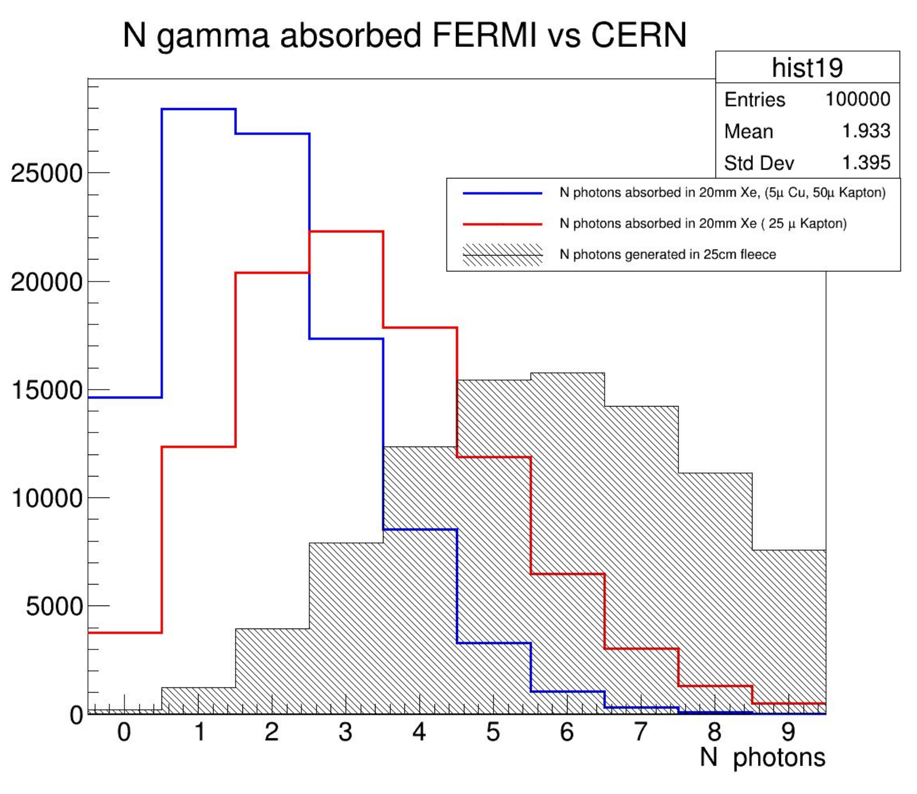


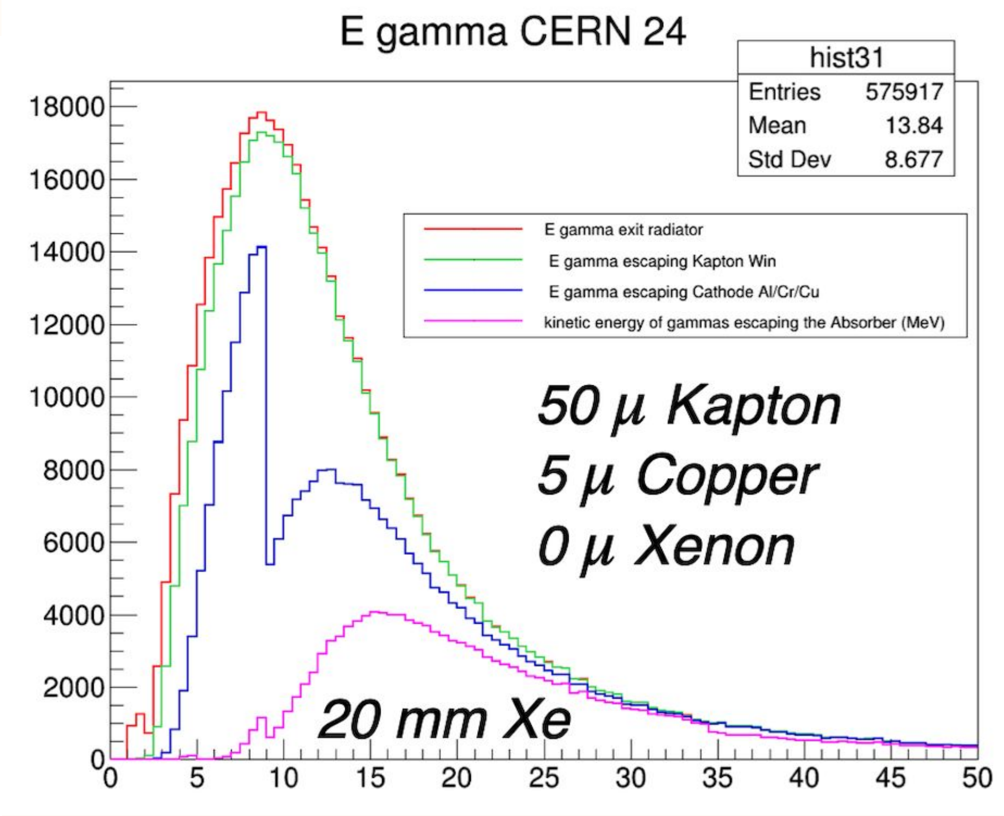
GEMTRD



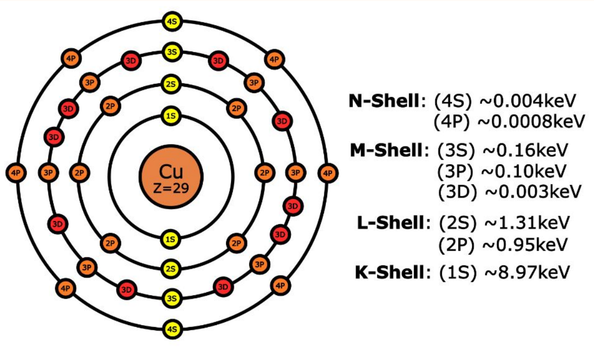


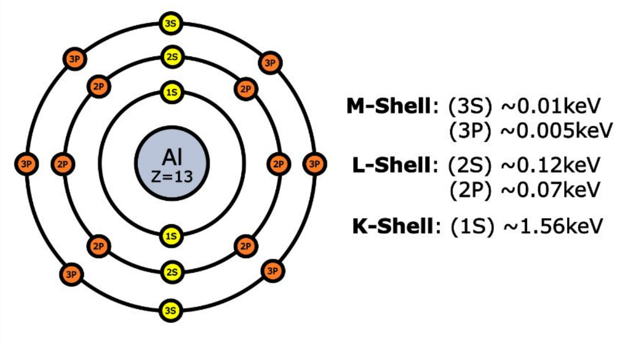
Geant4 Simulation

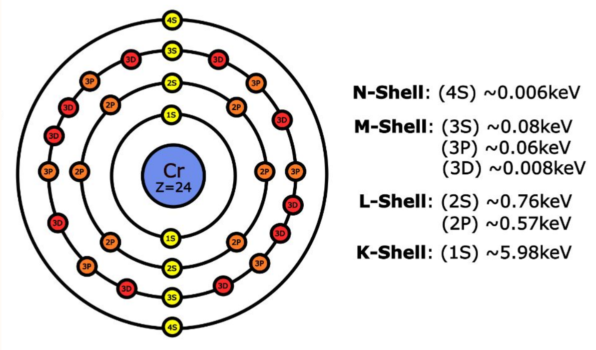


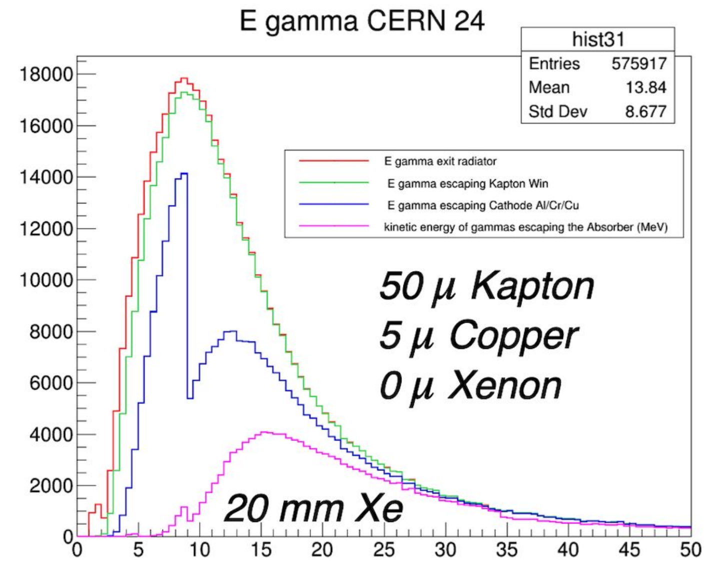


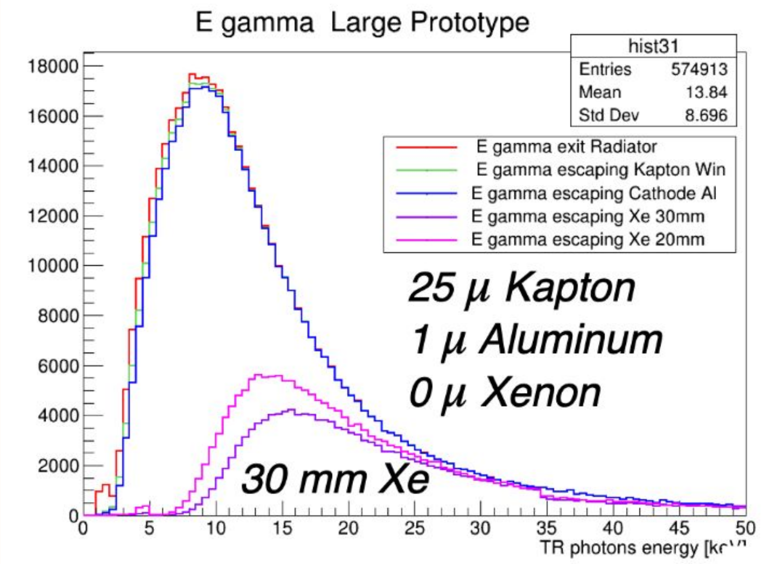
Copper as Cathode Material





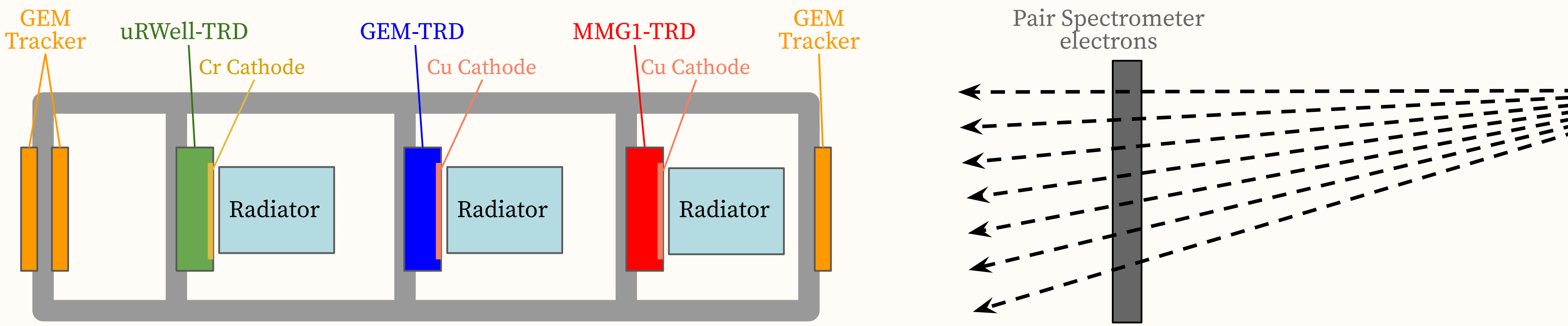




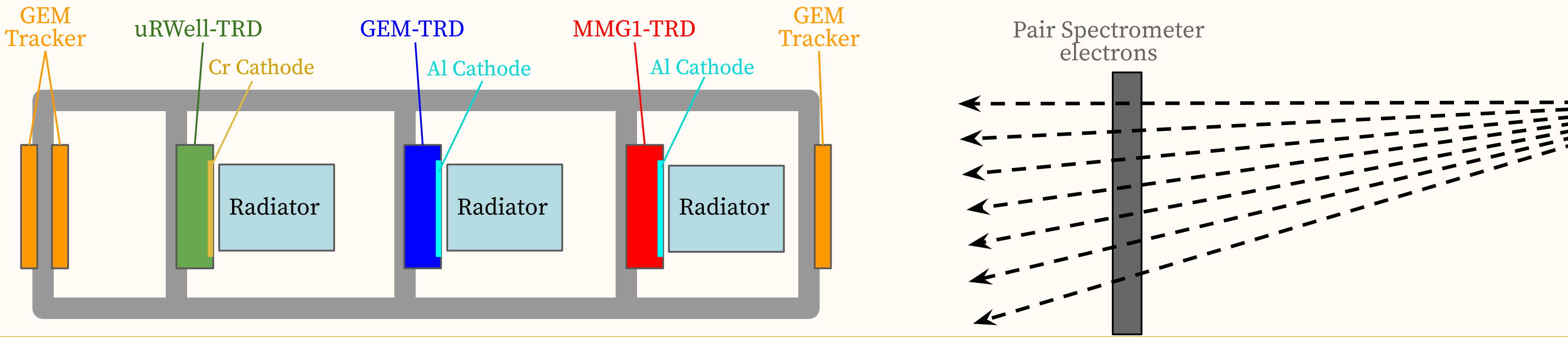


PS 2025 Test Beam Plans

Measurement 1:

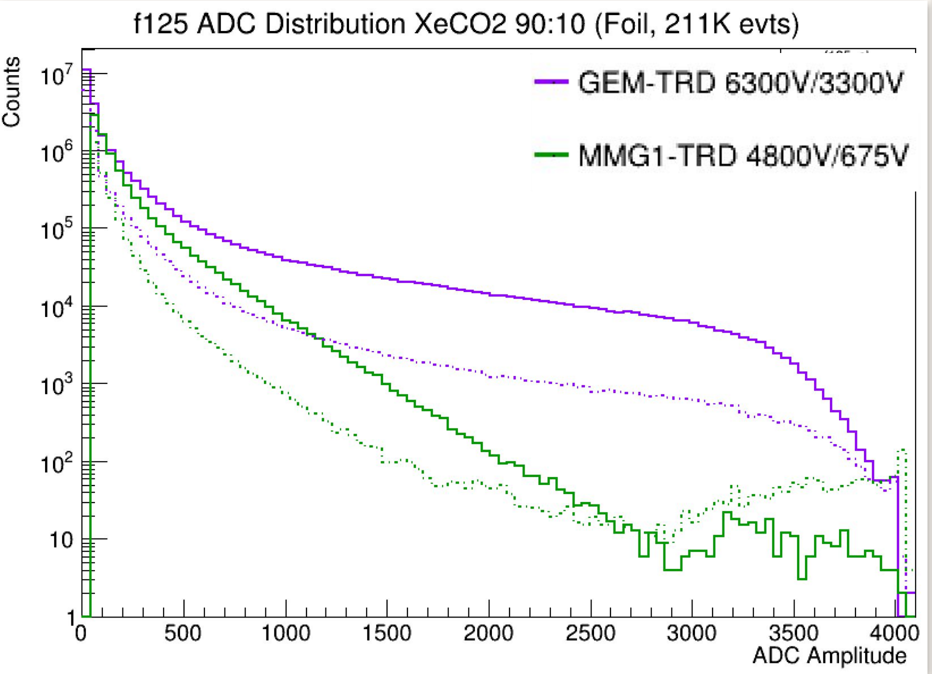


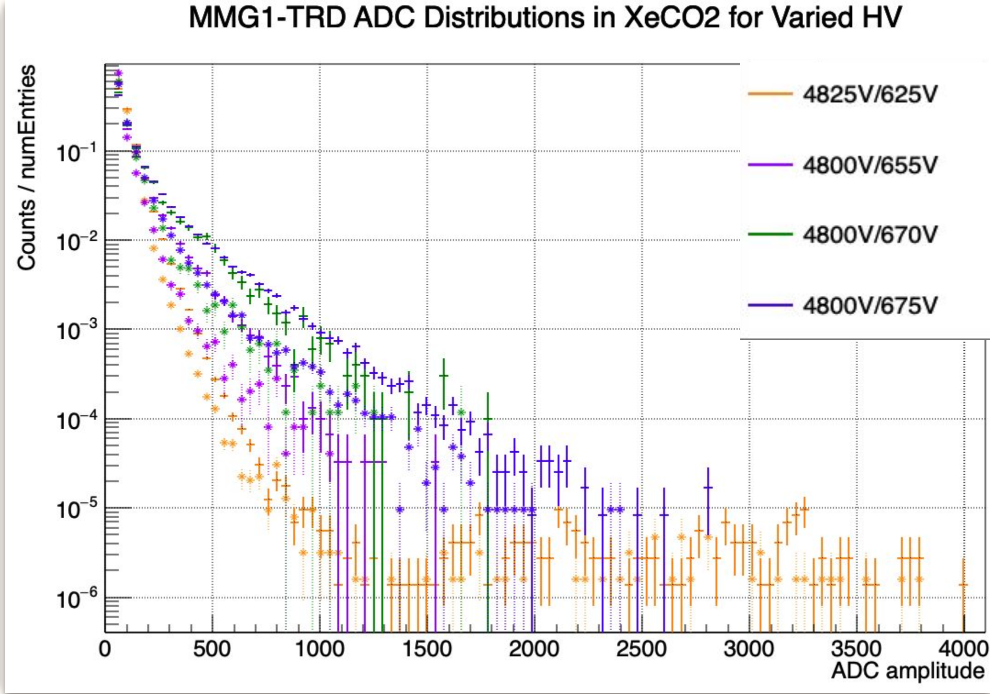
Measurement 2:



FNAL Test Beam: MMG-TRD

- Current conclusion: inefficient gain in MMG TRD
- Single amplification layer may not be enough on its own





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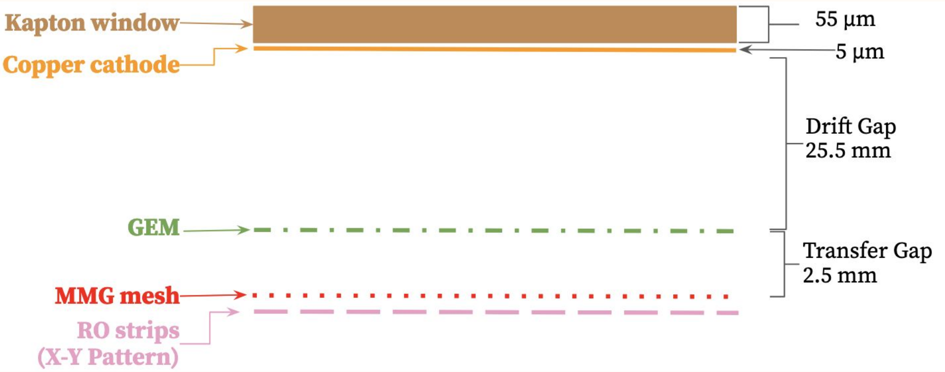
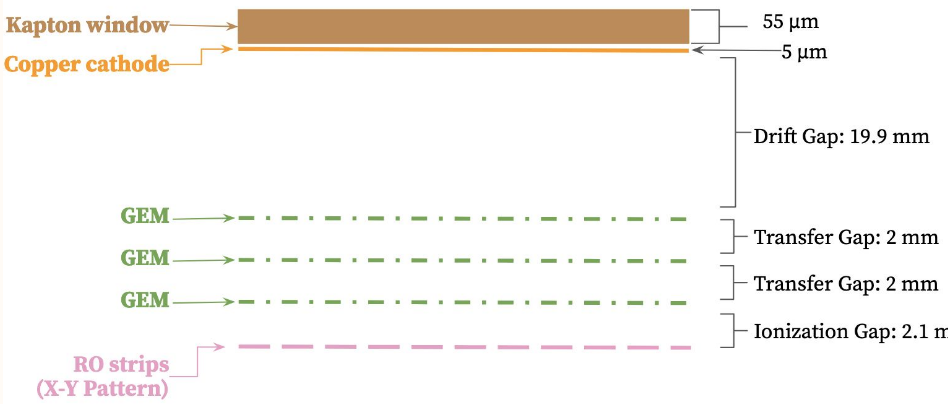
2 Prototypes Successfully Tested

(Gem + MMG) MMG1-TRD

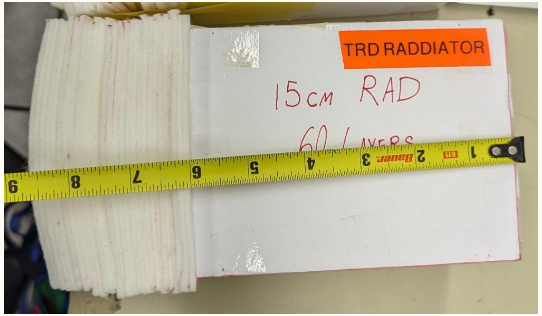


VU (Triple) GEM-TRD



15cm Fleece

23cm Fleece



(15cm / 21cm) Foils

Yellow Report ePIC e/π Capability

Dual-Ring Imaging Cherenkov Detector (dRICH)

- Total PID system must separate *e*'s from charged particles with > 3σ $\pi/K/p$ separation in all rapidity regions

radiator	index	Threshold (GeV/*c*) e	π	K	p
quartz (DIRC)	1.473	0.00048	0.13	0.47	0.88
aerogel (mRICH)	1.03	0.00207	0.57	2.00	3.80
aerogel (dRICH)	1.02	0.00245	0.69	2.46	4.67
C_2F_6 (dRICH)	1.0008	0.01277	3.49	12.34	23.45
CF_4 (gRICH)	1.00056	0.01527	4.17	14.75	28.03

Table 11.40: Table of Cherenkov thresholds for various media.

forward region Technology	Range (GeV/*c*) e - π	π - K
CsI RICH	0.0150 - 20	14.75 - 50
dRICH (aerogel)	0.0025 - 5	2.46 - 16
dRICH (gas)	0.0127 - 18	12.34 - 60
dRICH (overall)	0.0025 - 18	2.46 - 60
TOF (LGAD)	0 - 1	0.00 - 5
TOF (LAPPD 4m 5ps)	0 - 2.5	0.00 - 16
TRD	1.0 – 270.0	–

Table 11.41: Performance ranges for possible forward region detector technologies.

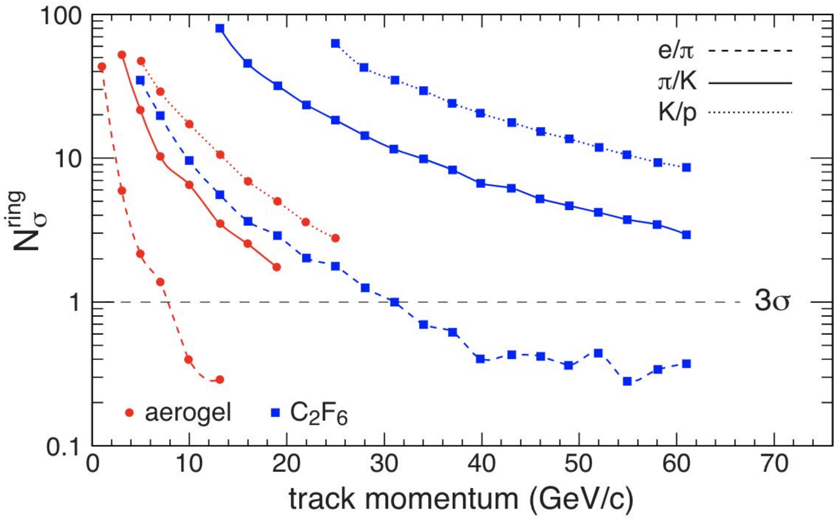


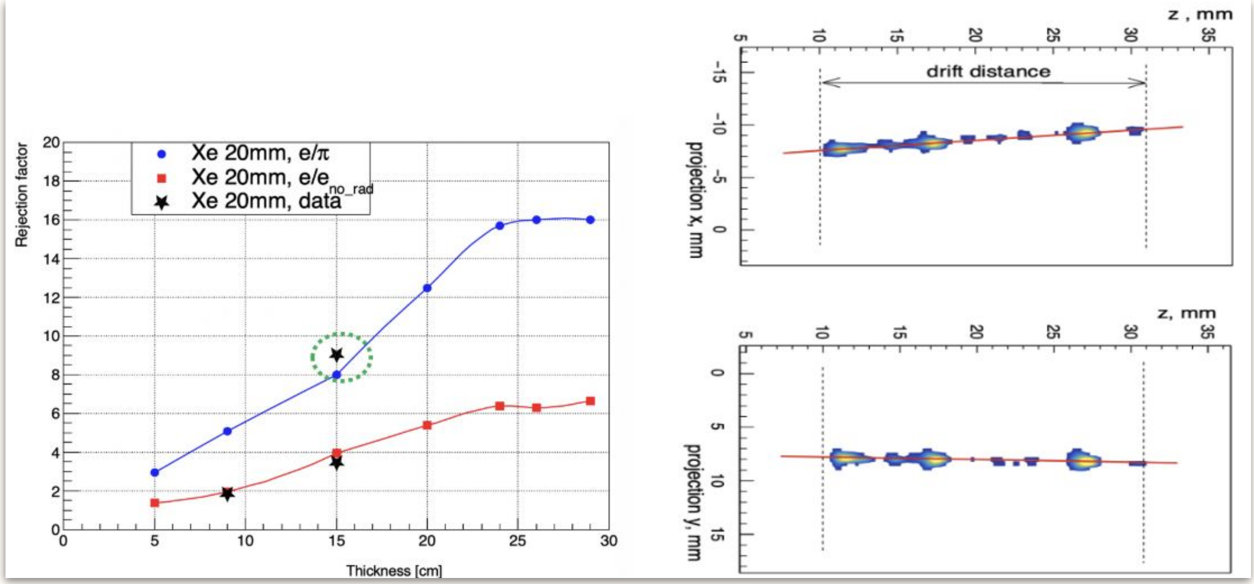
Figure 11.73: Performance of the Dual RICH for a variety of particle species. In each case, the combination of aerogel and gas provides uninterrupted PID across the full range. The device also serves for eID across more than the required momentum range.

Source: EIC Yellow Report v1.1, 2021

"… it is likely wise to supplement the dRICH tracking with a detector that provides an additional space point beyond the radiation volume." - EIC Yellow Report v1.1 2021, pg 532

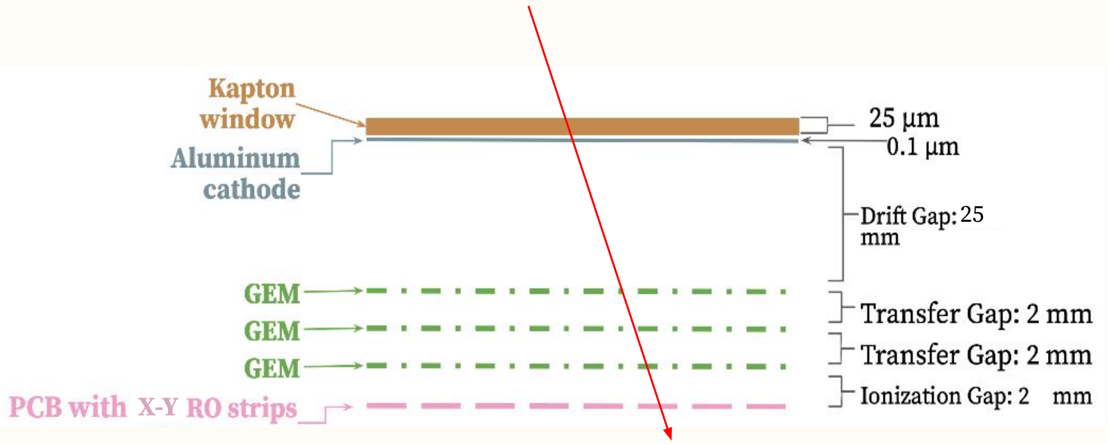
From “A proposal for MPGD-based transition radiation detector/tracker”

“… We performed an intensive R&D program for the GEM-based Transition Radiation Detector (eRD22) for EIC. Our results were presented at conferences and summarized in the publications and progress reports [3, 4]. It was shown that a single module, which consist of a GEM module with 3 cm drift gap and 15 cm TR-radiator as shown in Figs. 2, 3 , could provide a e/π rejection factor of 9 with 90% electron efficiency as shown [below].”



JLab Large-Scale GEM-TRD Construction

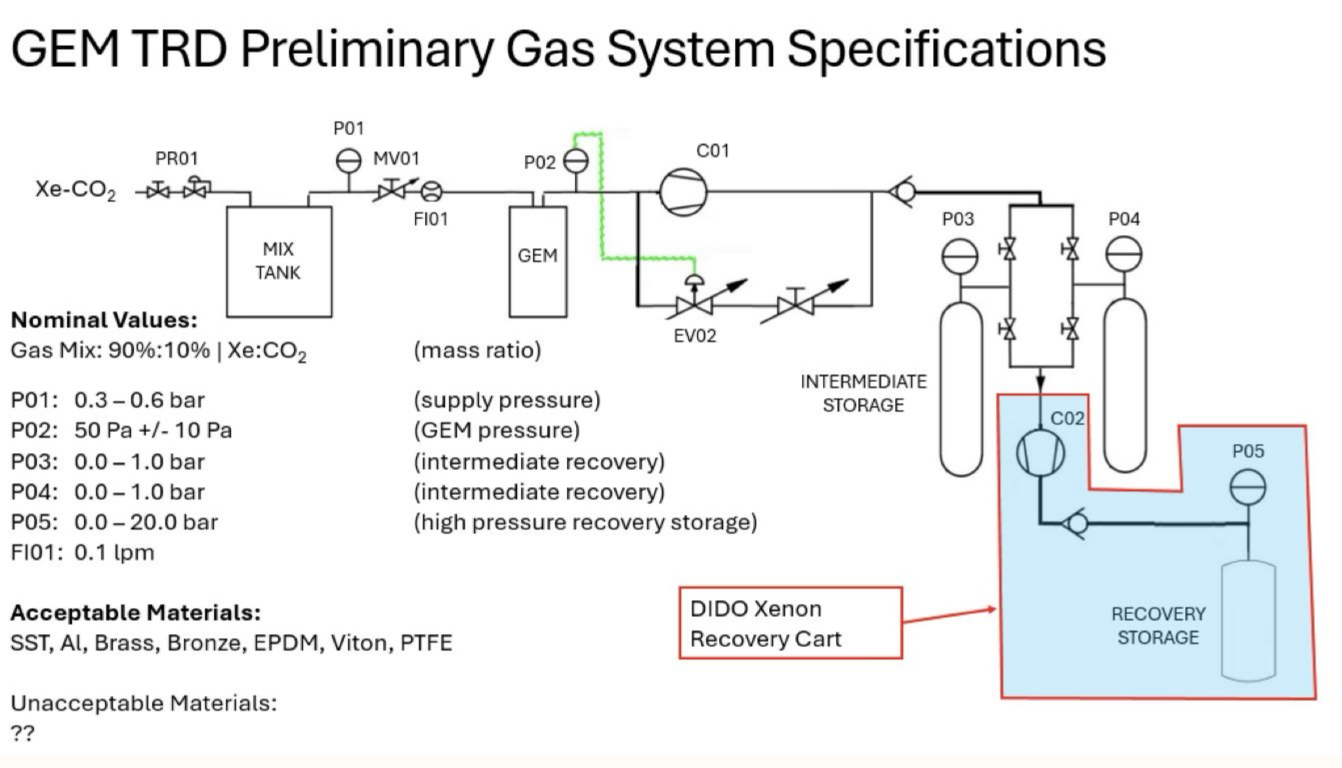
Sensitive area: 720x528 mm^2
Triple-GEM amplification
RO Plane: capacitive charge sharing on X,Y strips on the same plane
RO Strip pitch: 1mm
Drift Gap: 25mm
Cathode: 25*um* Aluminized Kapton
Gas mixture: Xe/CO2 90/10
Radiator: 20cm fleece
Thickness: 4.5% R.L.



Electronics:
1,248 channels
52 GAS-II pre-amps (as for DC) operated at low gain
17 fADC125, but 15 available → 720x360 mm^2

Gas Regulation System

- Pump pulls gas through detector, +/-2pascal regulation inside chamber
- TRDs require heavy gas for efficient X-Ray absorption ($$$)


GEM TRD Preliminary Gas System Specifications

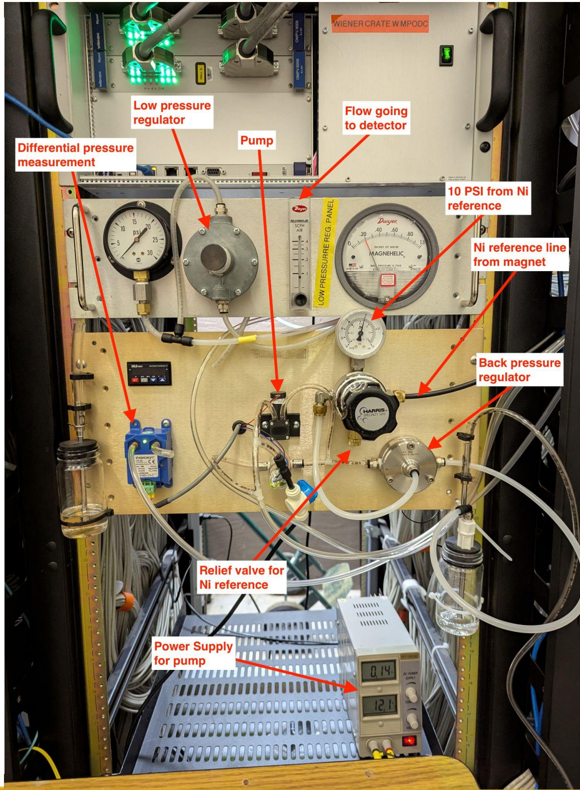
Nominal Values:

Gas Mix: 90%:10% | Xe:CO_2 (mass ratio)

P01: 0.3 – 0.6 bar (supply pressure)
P02: 50 Pa +/- 10 Pa (GEM pressure)
P03: 0.0 – 1.0 bar (intermediate recovery)
P04: 0.0 – 1.0 bar (intermediate recovery)
P05: 0.0 – 20.0 bar (high pressure recovery storage)
FI01: 0.1 lpm

Acceptable Materials:
SST, Al, Brass, Bronze, EPDM, Viton, PTFE

Unacceptable Materials:
??



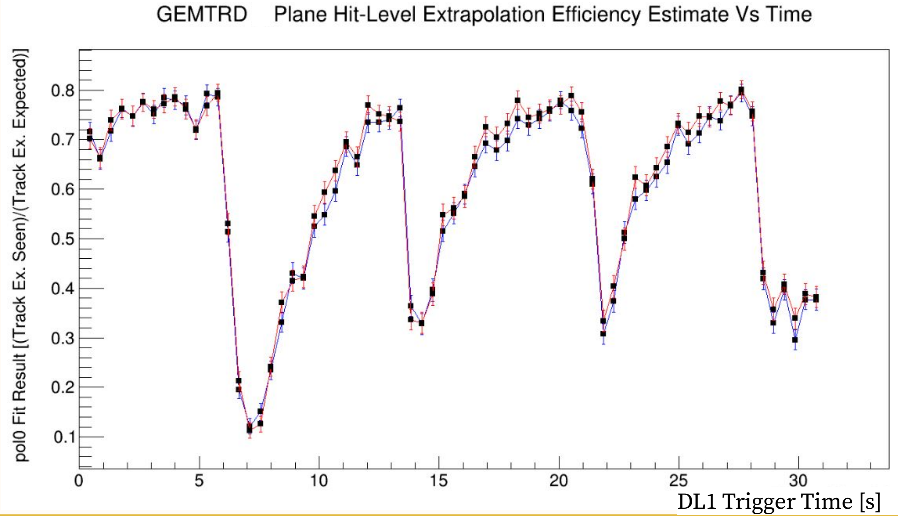
Cyclic Efficiency Behavior

Tests in real experimental environment revealed this issue, potentially saving us much headache in designing/commissioning full detector for GlueX-III

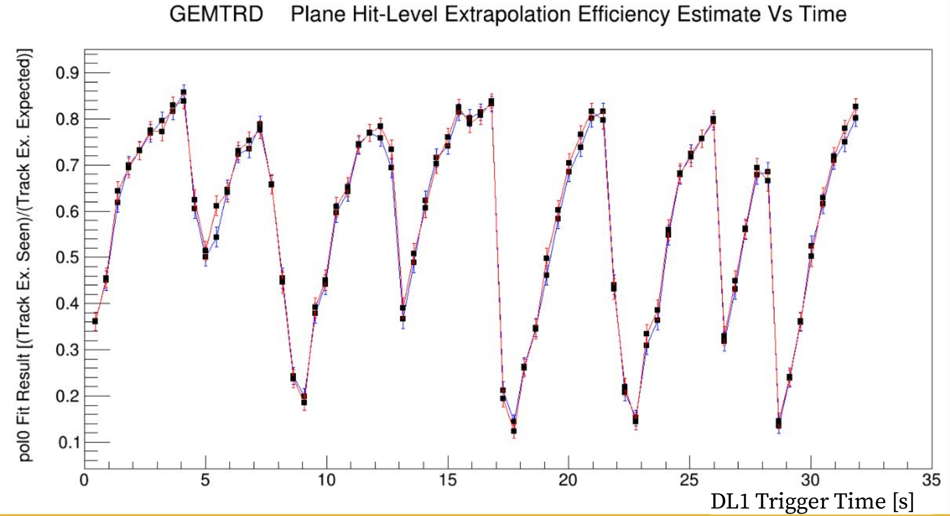
Problem appears to depend on: HV, gain, intensity… But nature of the problem is still unclear. Not seen in previous tests (in PS electron dump)

~200nF capacitance in GEM foil, 10MOhm resistance in divider, roughly gives this time constant

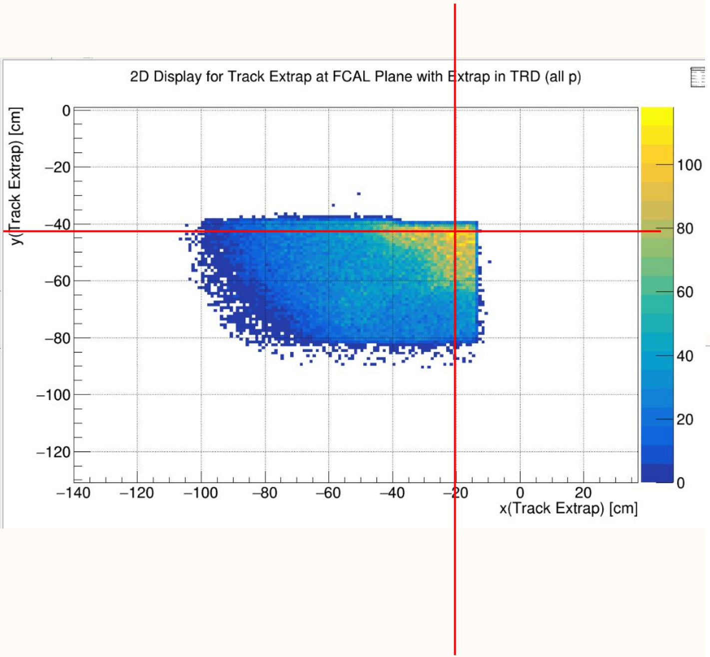
200nA AMO rad, 7000V/3<u>6</u>00V, KrCO2 90:10

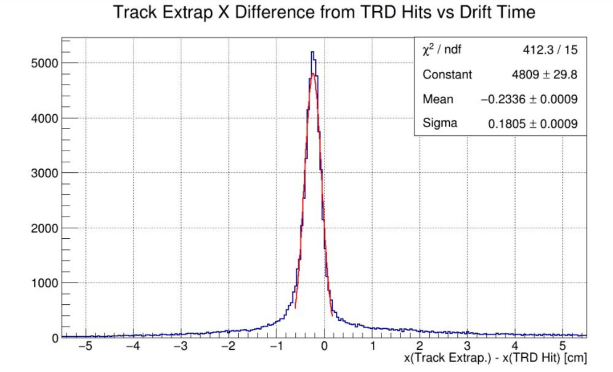


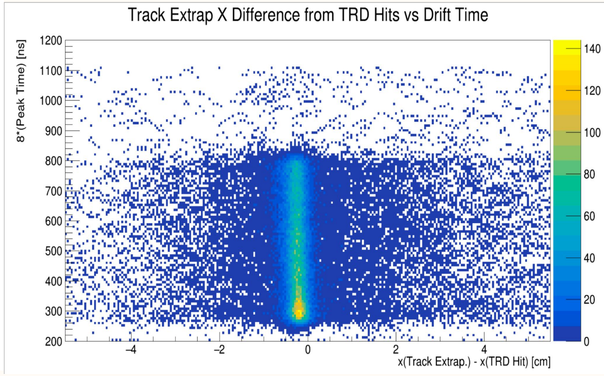
200nA AMO rad, 7000V/3<u>7</u>00V, KrCO2 90:10

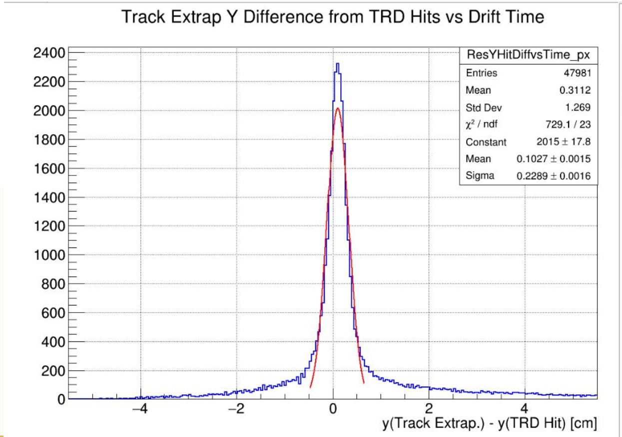


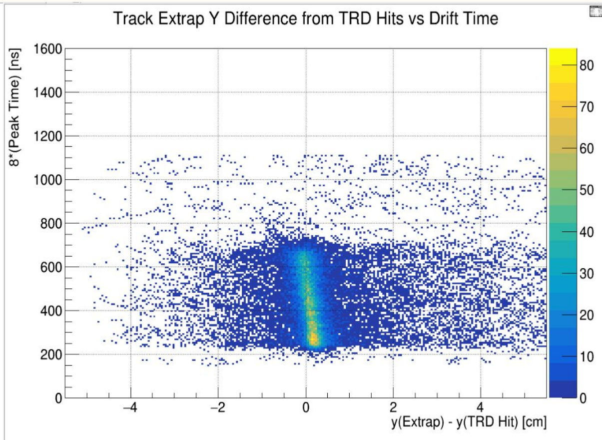
Spatial Resolution







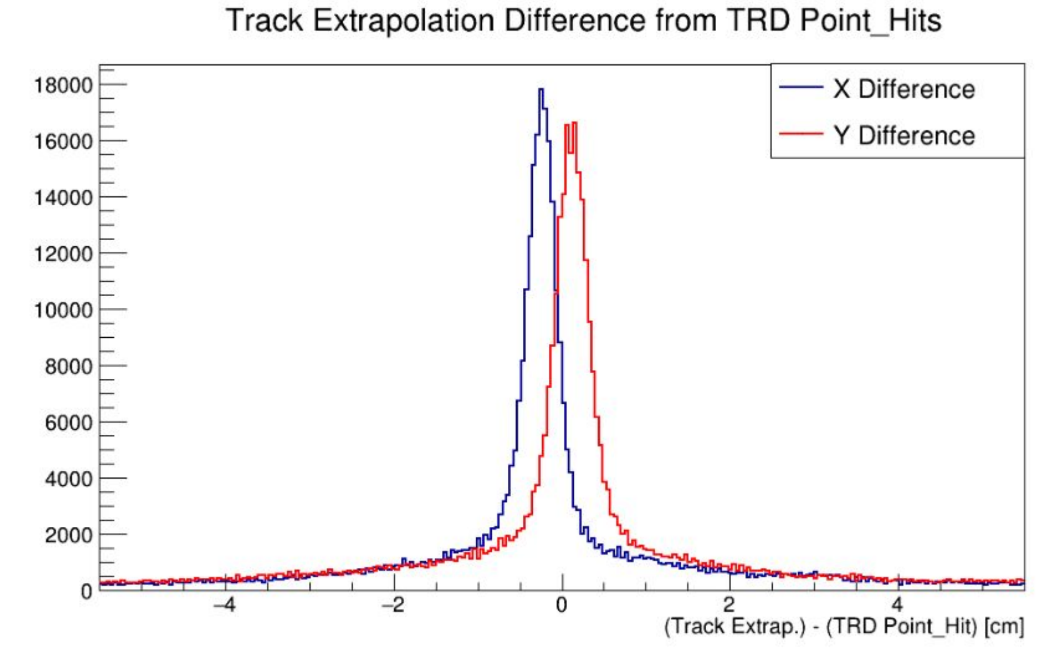




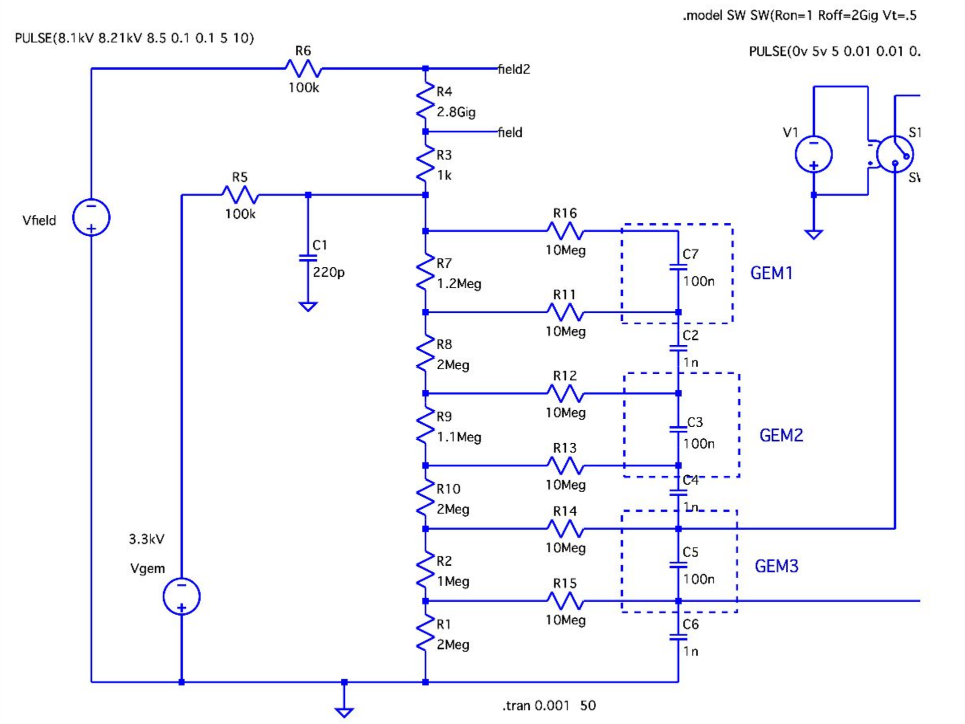
Track Matching

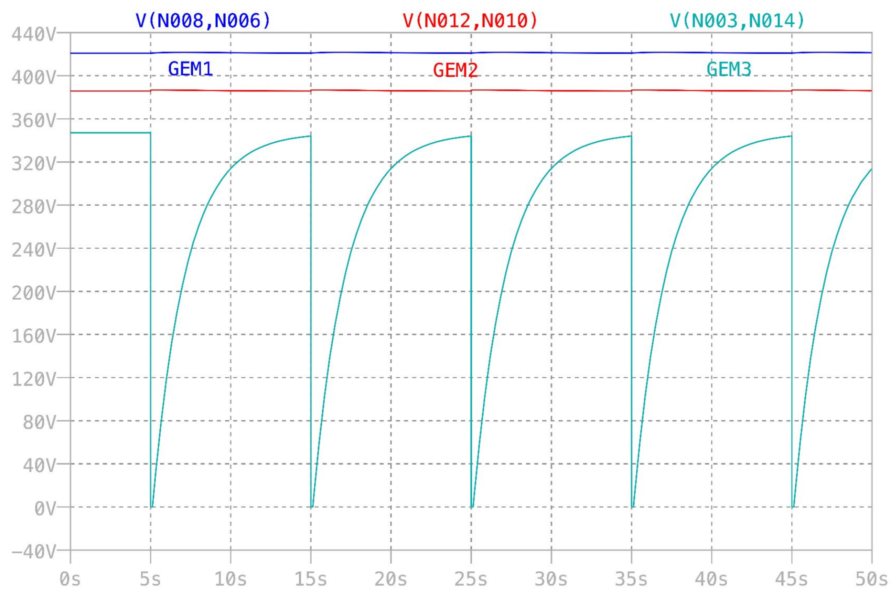
X mean offset: ~-2mm (-2.27mm)

Y mean offset: ~1mm (1.07mm)



Cyclic Behavior



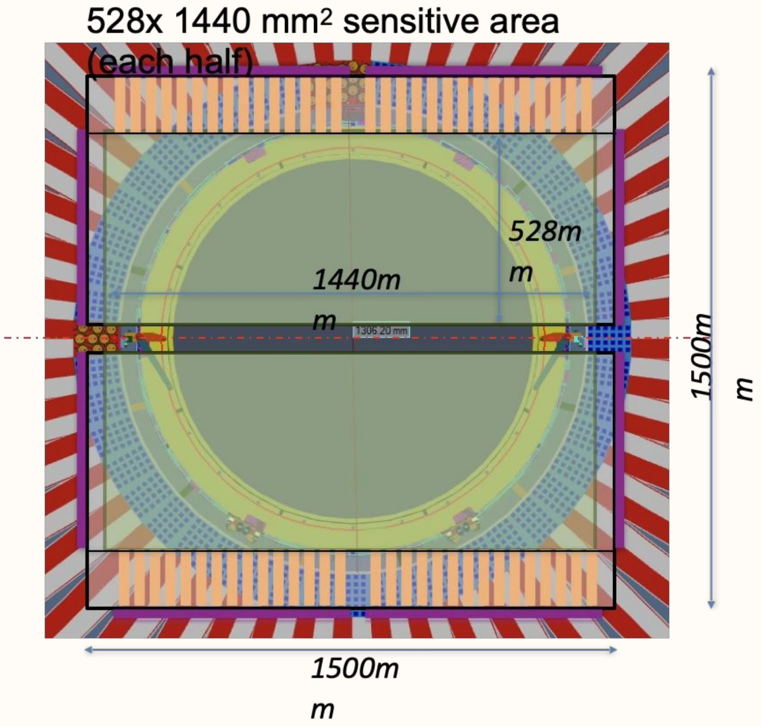


Future Plans

The GlueX-III proposal was based on 1/4 detector; PAC recommended building the full detector to be used during most of the GlueX-III running

Helps with reducing systematics for J/Psi production

- Started working on contract with UVA (2.5y, $264k):
- design the detector
- long-term procurement - GEM foils, readout board from CERN, GEM frames (~1 year)
- Design and fabricate the tolling: foil stretcher, assembly jigs, HV test box etc.
- Prepare clean room and parts, stretch and glue GEM foils
- Assemble detector
- Preliminary tests with cosmics and x-rays



TRD Gas Mixtures

- Operational gas mixture changed from Ar-based mixture to Xe-based → Heavy gases required for efficient X-ray absorption
- Compare various noble gases in terms of absorption power for 20 mm gas thickness. Best gas is Xe
- Xe-based mixture requires higher fields (~2000 V/cm) for a similar drift velocity as Ar (~1000 V/cm). High cost of Xe means closed loop gas system necessary

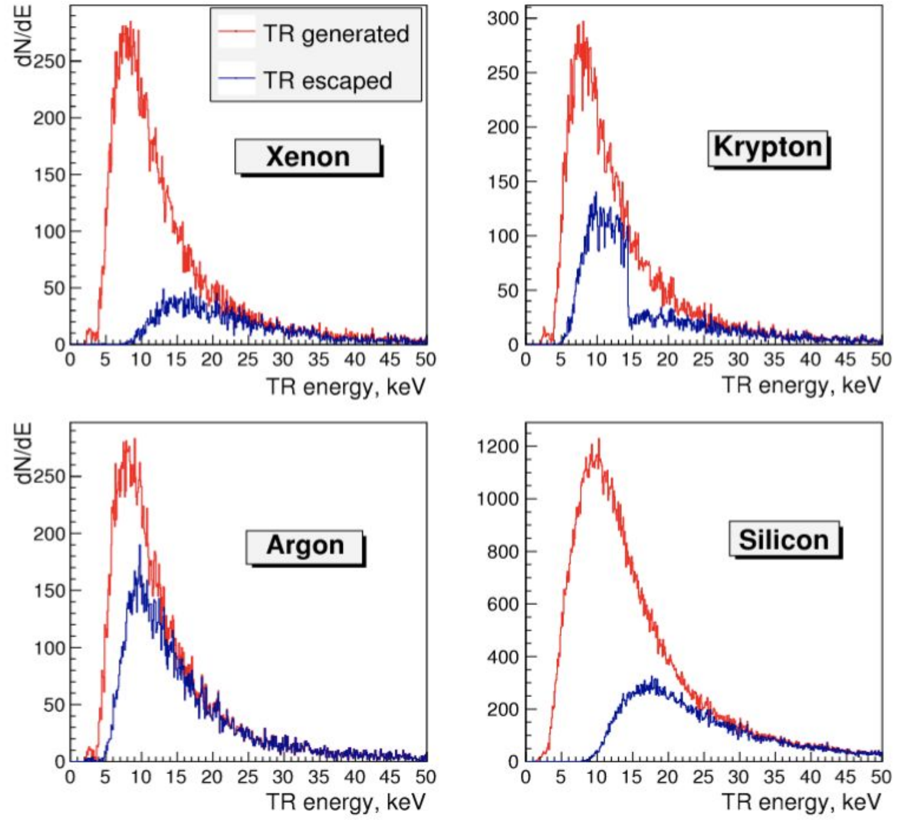


Fig. 3. TR absorption efficiency for different gas mixtures and silicon.

Barbosa, F., et al. NIMA, 2019, 10.1016/j.nima.2019.162356

Essential Processes at the EIC Involving *e* ID (Physics Motivation)

- J/Ψ Production (DIS): Requires reconstruction of *all* particles involved. Transverse spatial distribution of gluons can be obtained from the exclusive x-section of $J/\psi \rightarrow e^+e^-$. Improved *e* ID could increase J/ψ detection efficiency
- Open Heavy Flavor Production: branching ratio of D-mesons is $Br(D^+ \rightarrow e^+ + X)$ ~16% and of B-mesons is $Br(B^\pm \rightarrow e^\pm + \nu + Xc)$ ~ 10%. Due to the large decay length of heavy-flavor hadrons, these mesons will have significant decay vertex displacement
- Exotic Hadrons (XYZ States): In the process $Z^+c \rightarrow J/\psi + \pi^+ \rightarrow e^+ + e^- + \pi^+$ the emergent *e*'s are forward boosted, so their detection is difficult due to several orders of magnitude higher hadronic background. The nature of such exotic states remains unclear, and further investigations are needed