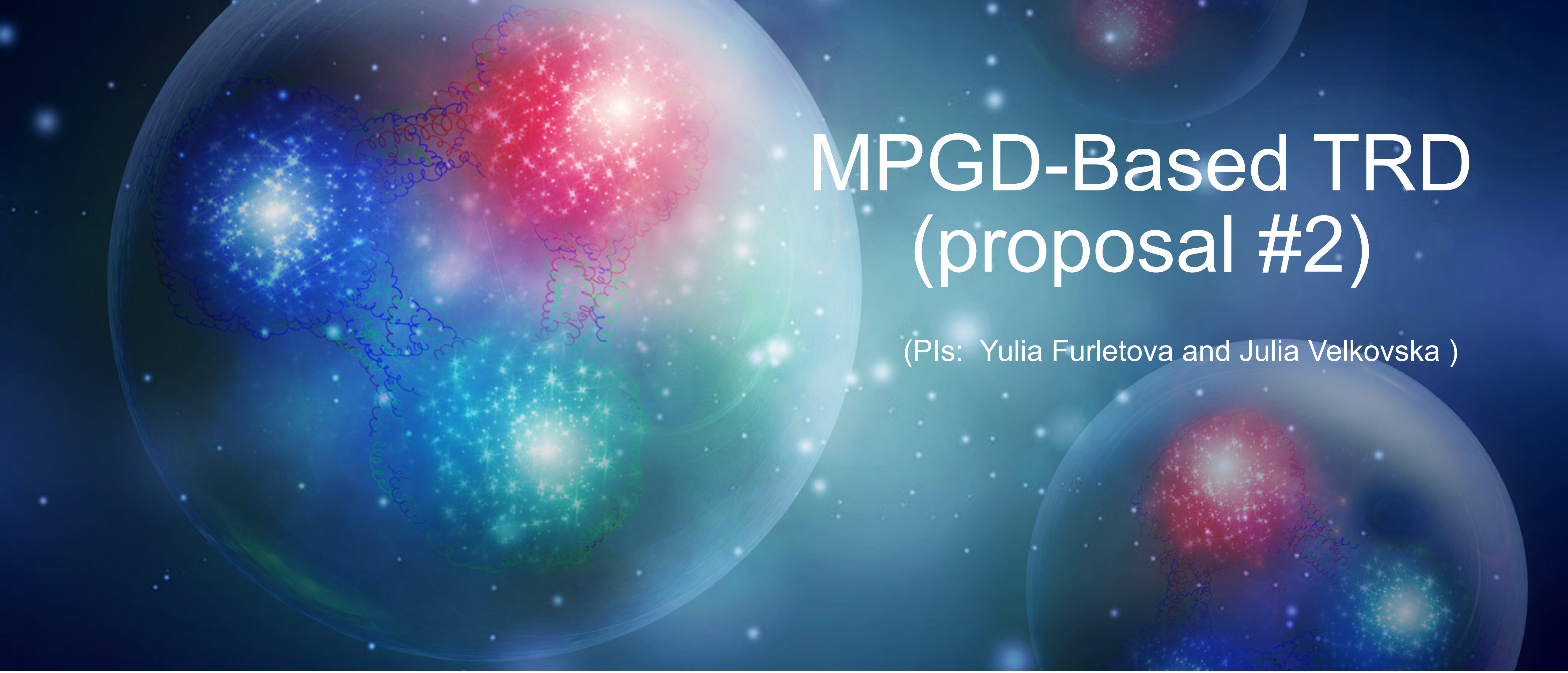


MPGD-Based TRD (proposal #2)

(PIs: Yulia Furletova and Julia Velkovska)

Yulia Furletova (JLAB)
The EIC generic R&D meeting
(Nov 15-16, 2022)

Our team:

- ➢ Jefferson Lab:
  - ✓ Fernando Barbosa
  - ✓ Cody Dickover
  - ✓ Yulia Furletova
  - ✓ Sergey Furletov
  - ✓ Kondo Gnanvo
  - ✓ Lubomir Pentchev
  - ✓ Chris Stanislav
  - ✓ Beni Zihlmann

- ➢ Temple University
  - ✓ Matt Posik
  - ✓ Bernd Surrow

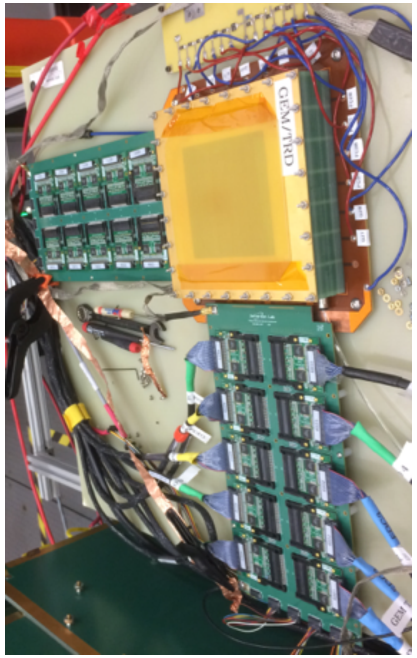
- ➢ Old Dominion University
  - ✓ Lee Belfore

- ➢ University of Virginia
  - ✓ Nilanga K. Liyanage
  - ✓ Hương Nguyen

- ➢ Vanderbilt University
  - ✓ Senta V. Greene
  - ✓ Lauren Kasper
  - ✓ Sourav Tarafdar
  - ✓ Julia Velkovska

1. Please clarify what work was already partially addressed within eRD22, and what lines of R&D are new.

(eRD22)



- The eRD22 proposal was submitted and approved in January 2018
- A main goal was to demonstrate a **proof of principle** for an operation of GEM-based TRD. TRD provides e/π rejection for particles with E>2GeV
- We performed a **standalone Geant4 simulation** of the setup: optimization of TR-radiator thicknesses and gas volume - before the prototype assembly.
- We developed a prototype, which was **optimized for the TR applications.**
- We performed a studies with various **Xe-based** gas mixture, performed optimization of HV.
- We made a specification for front-end electronics.
- Due to covid , our testbeam at Fermilab (e and hadron beam) was cancelled We used JLAB setup **(e-only) beam** to estimate e/pi rejection factor.

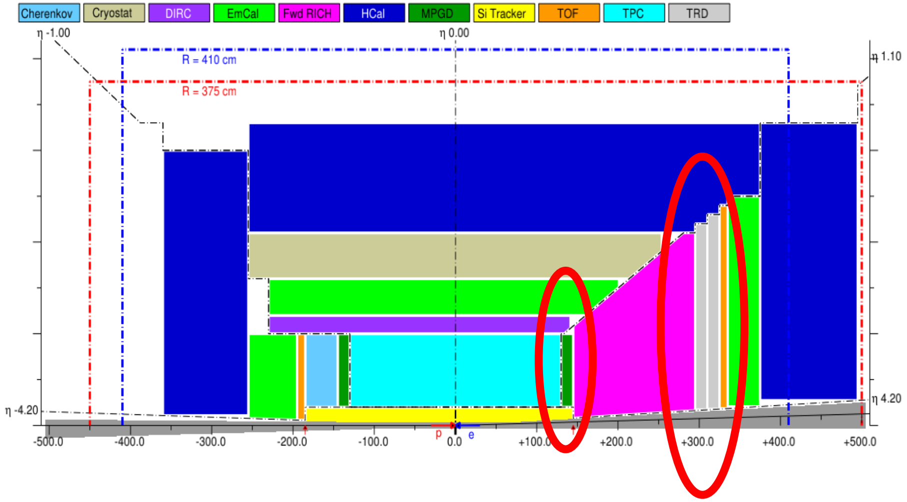
1. Please clarify what work was already partially addressed within eRD22, and what lines of R&D are new.

(Proposed program of work and deliverables)

- Main goal is to continue **to mature and optimize the MPGD-based Transition Radiation detector** design to be ready for a large-scale detector production for the EIC detector upgrade (ePIC)

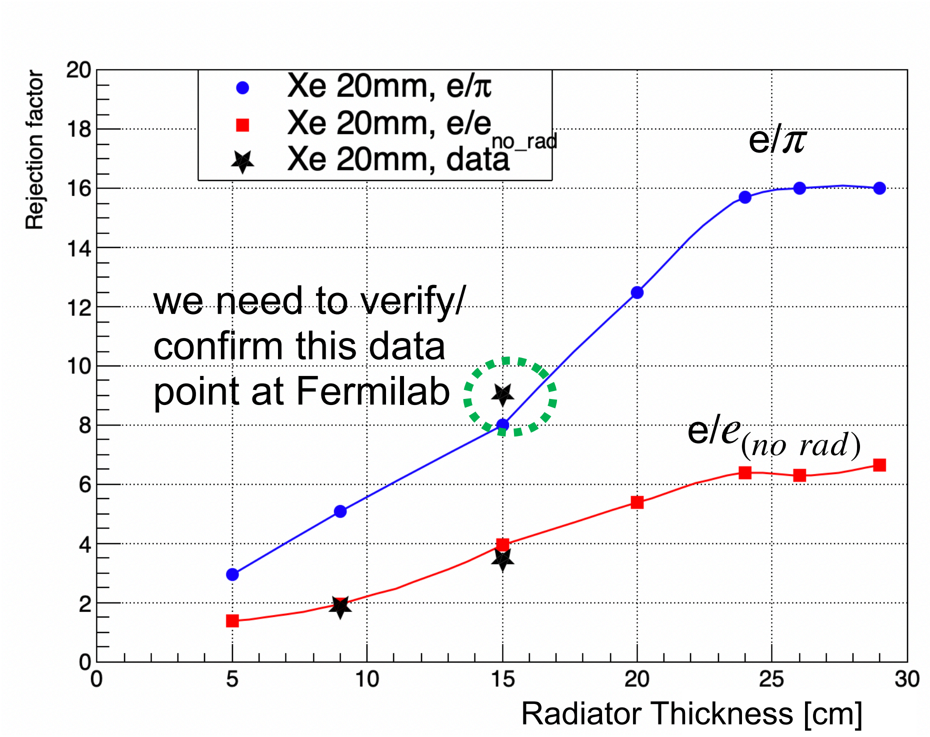
- and/or as a complementary detector technology for the second detector at EIC.

  - provide addition PID: e/π separation (for E > 2 GeV)
  - provide a track segment in front or behind the dRICH



e/π performance

- Electron beam-only with and without radiator (red line)
- Data points are in a good agreement with MC predictions



- Due to the lab and facilities closures due to COVID we were not able to perform a test at Fermilab.
- For e/π data point : compared data at the different locations: pair-spectrometer (e-beam only) vs Glue-X setup (mainly hadrons) .
- **Need to validate this point at Fermilab with e and pion test beams.**

Prototyping

We propose to perform a series of tests of different MPGD-based TRDs to study the characteristics of the **signal collection**, to optimize the **material budget** and other operation parameters (HV, etc)

Different readout configurations will be investigated aiming to minimize the detector noise level, **to optimize the number of readout channels**, and the detector **spatial resolution**.

For each design, measurements will be performed to charactarize the noise levels, gain uniformity, to perform HV and drift-time optimizations and establish baselines.

Micromegas prototype at Vanderbilt and μRWELL prototype at JLab

- **single amplification structure** MPGD that will replace the stack of 3 GEM foils (material budget)
- The amplification structure itself is very similar to a GEM foil. TRD prototypes will be based on either bulk or microbulk technology, so just one structure.
- MMG and μRWELL **do not require stretching and framing foils** unlike GEMs (benefit for large scale detectors)
- 10x10cm with **capacitive-sharing strip/pads or zig-zag** readouts to reduce channel counts while maintaining high spatial resolution capability.

Different TR-radiators.

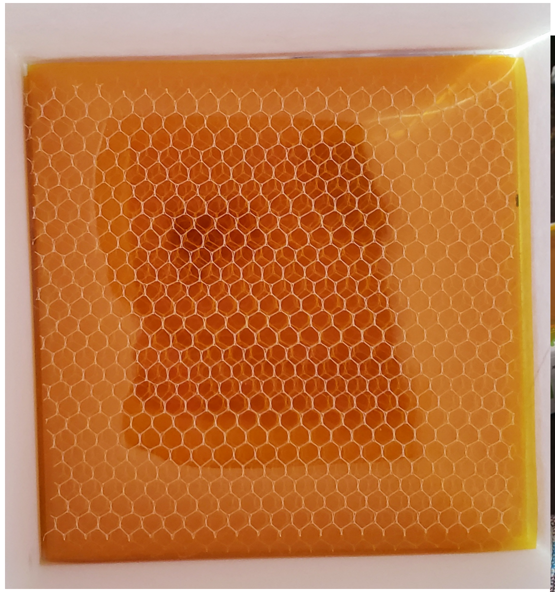
- We continue to search and test different types of radiators
- Goal: to find low material budget, but high TR-yield radiators
- The TR-energy spectrum is very important (minimum of self-absorption)

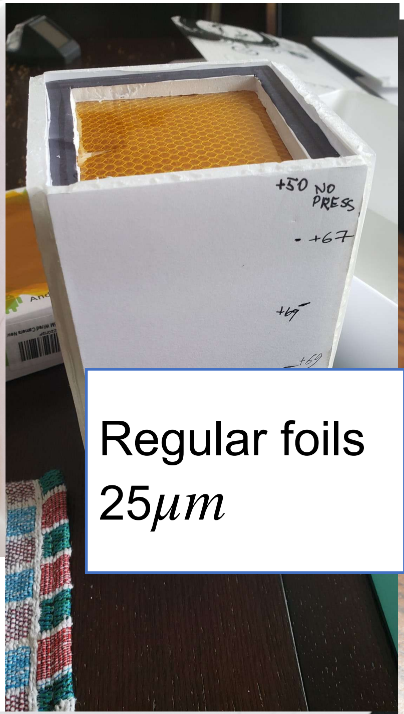
Single module (X/X0) :

Radiator (10cm) ~ 1.5 % X_0 for fleece (could go down with mylar foils)

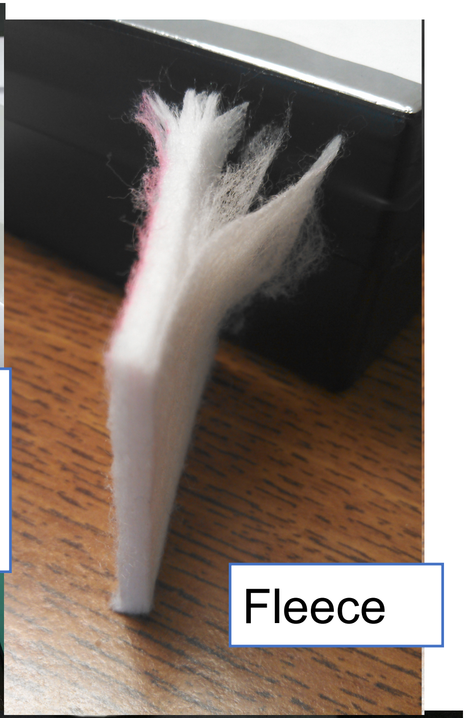
Xenon gas (2.0 cm) ~ 0.1% X_0

MPGD with readout at active area ~ 0.5-1.5% X_0

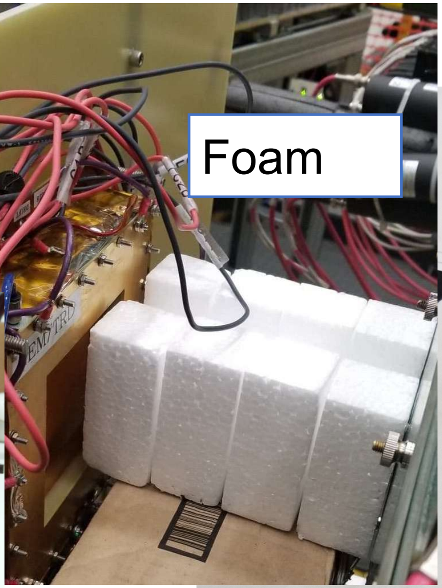




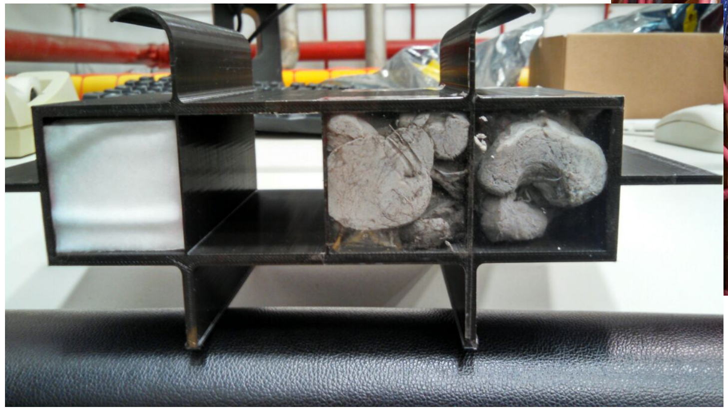
Regular foils 25μm

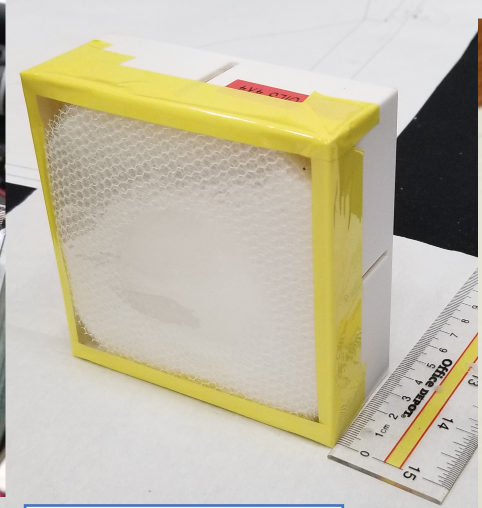


Fleece



Foam

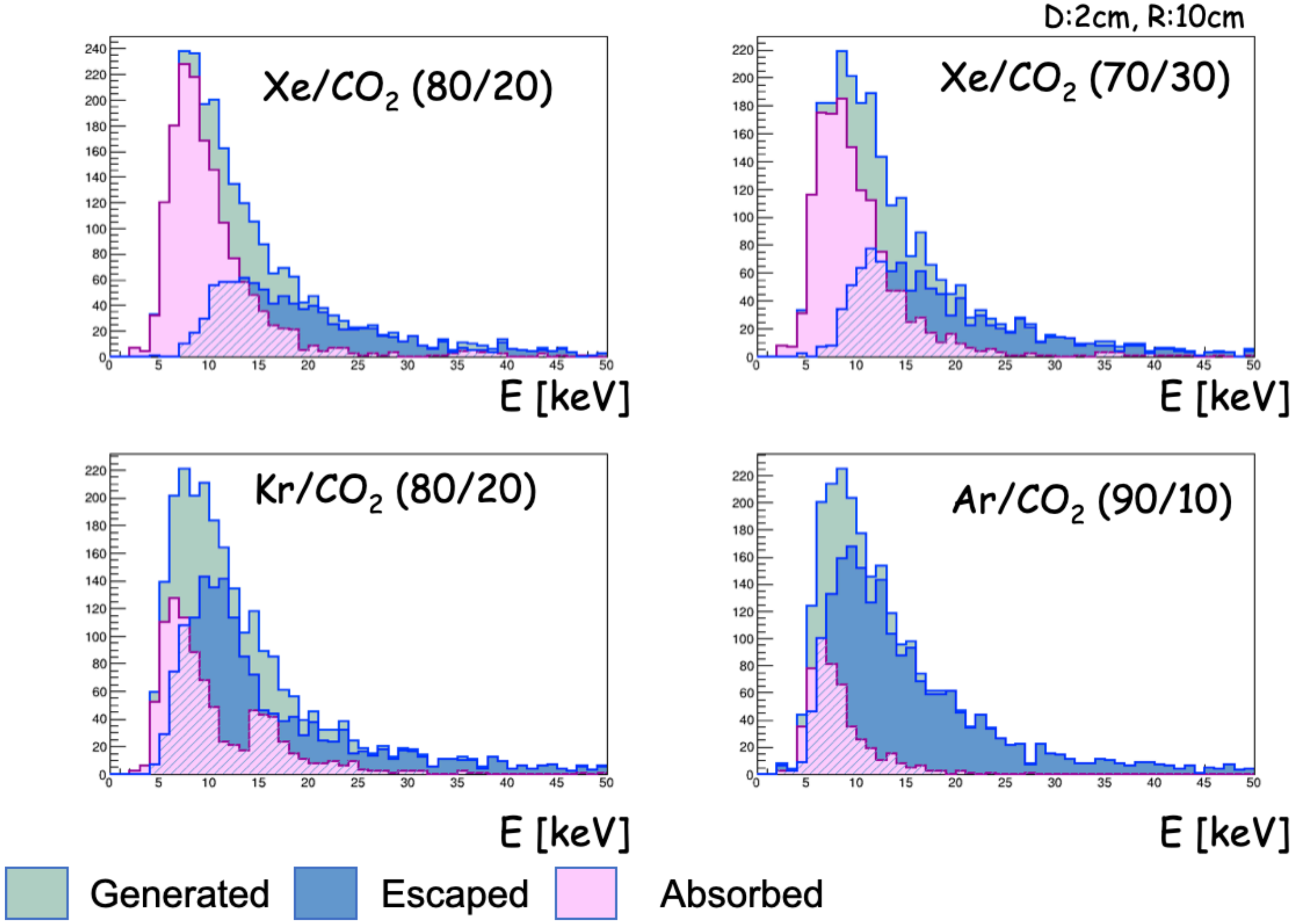




Regular foils

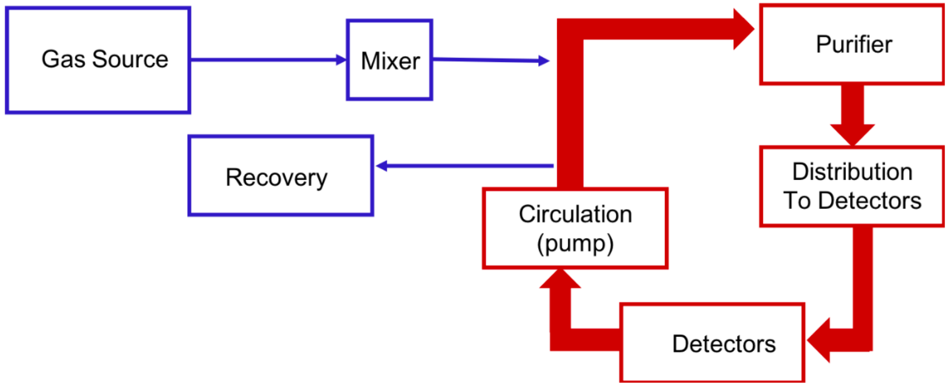
Gas system and gas mixture

In an effort **to reduce the cost of gases** needed to operate MPGD-based TRD we would like to perform a new series of tests with different Xe/Kr/CO2-based gas mixtures.



We plan to begin designing a small Xe gas cleaning and recirculation system to use with our MPGD-TRD prototypes.

For the implementation of these modules we plan to build off the knowledge and expertise of the ATLAS experiment at CERN, who also installed a Xe recirculation gas system for their TRT detector.



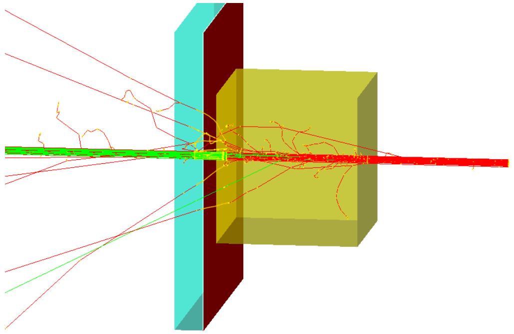
Simulation

A standalone simulation of GEMTRD was used to study and optimize the detector setup (gas volume, radiator thickness, etc)

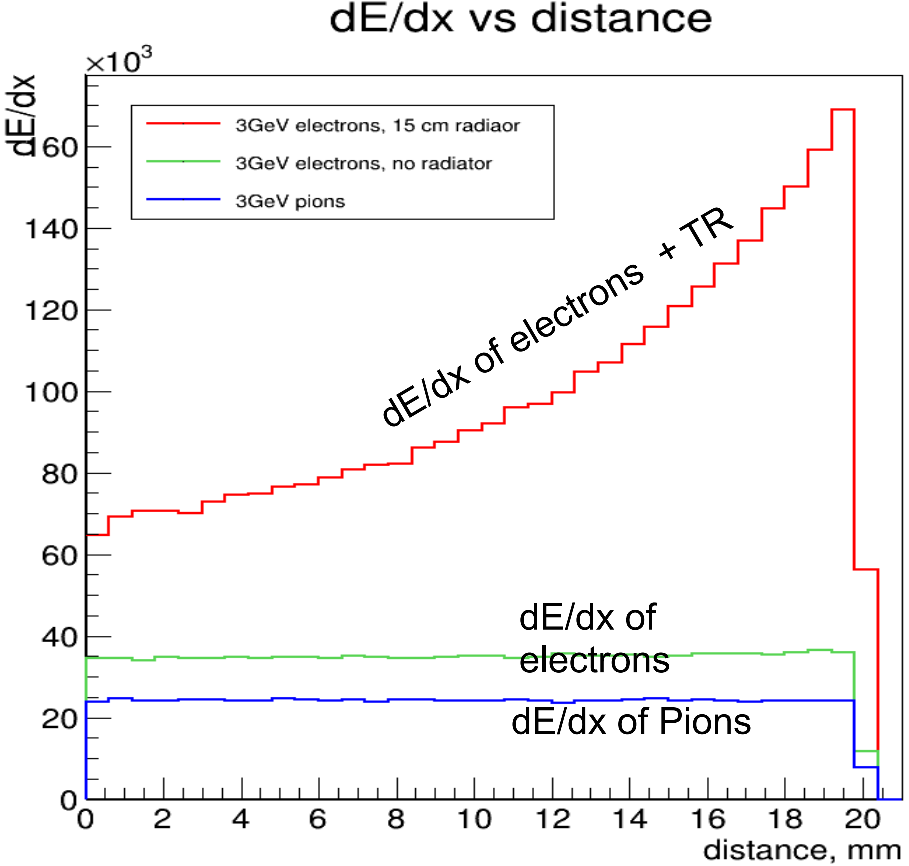
Planning to perform a Geant4 simulation with the **integrated detector** in the ePIC (and/or Det-2) simulation software.

- The simulation studies will focus on **PID performance** of MPGD-TRD in association **with the Calorimeter** in the hadron endcap.
- also study the **track angular resolution**, the effect of having additional tracking information from the MPGD-TRD and how it may assist in the performance of **dRICH** (already underway)

MPGD-TRD (absorber and radiator) has been partially already implemented in both Fun4All and DD4Hep (studies are underway) .



Energy deposition (dE/dx + TR) vs drift distance

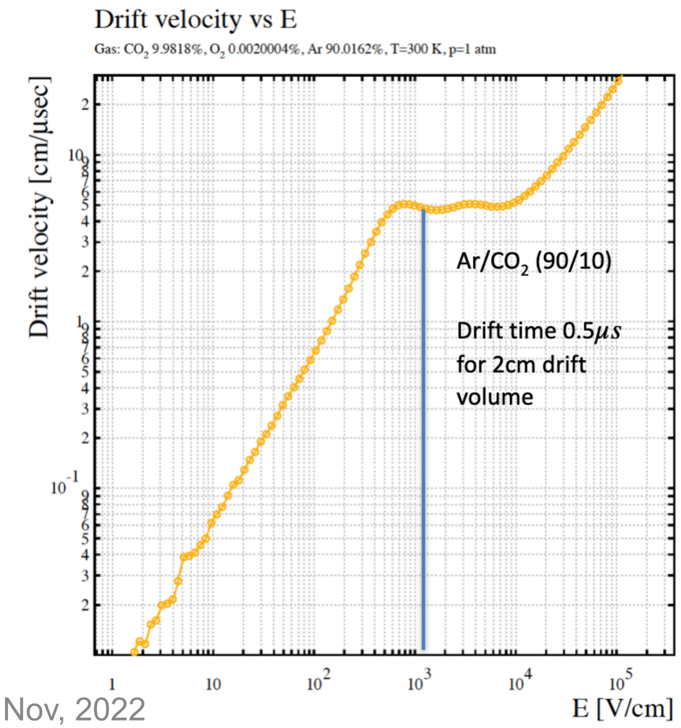


Simulation: Detector hardware

During the eRD22 studies we used **GARFIELD and MAGBOLTZ** simulation to optimize operation of the GEMTRD module with Ar and Xe mixtures (drift-time, HV, etc)

For this proposal we would like to use standalone simulation packages like Magboltz, Heed and Finite Element Analysis software (ANSYS) to understand the properties of various proposed gas mixtures (**Kr vs Xe)** and also for designing the **field cage.**

While the gas properties will be stuided in Magbohtlz and Heed, the design and the need of a field cage will be studied in ANSYS. The study of the properties of the gas mixture will be helpful in optimizing the drift field.

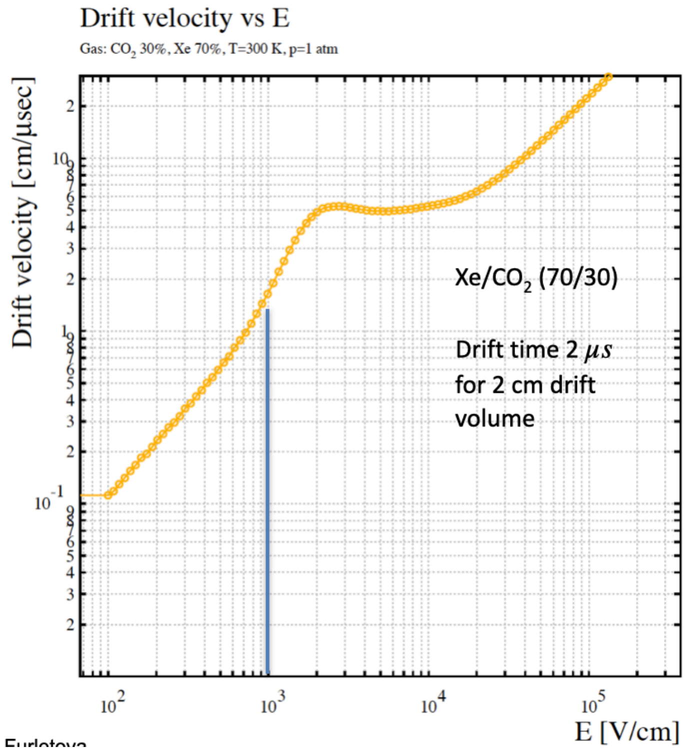


Drift velocity vs E

Gas: CO_2 9.9818%, O_2 0.0020004%, Ar 90.0162%, T=300 K, p=1 atm

Ar/CO_2 (90/10)

Drift time 0.5μs for 2cm drift volume



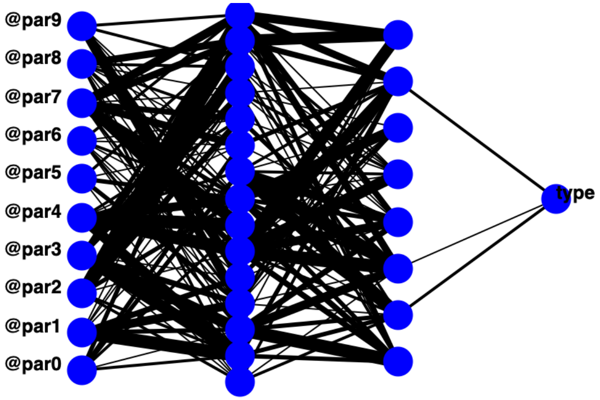
Drift velocity vs E

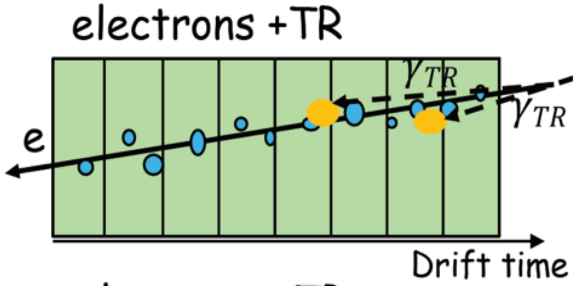
Gas: CO_2 30%, Xe 70%, T=300 K, p=1 atm

Xe/CO_2 (70/30)

Drift time 2 μs for 2 cm drift volume

Simulation: Data analysis using various Machine Learning algorithms/tools





Nowdays many other new AI tools are available, such as **Keras and Tensorflow** for different types on neural networks: **Graph Neural Network** (GARNET) or **Recurrent Neural Network** (LSTM), etc. We will addopt the use of these AI tools for TRD applications.

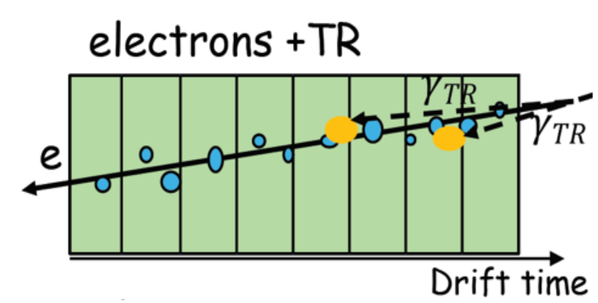
during the eRD22 project (GEMTRD) we used likelihood and artificial neural network (ANN) programs, such as JETNET or ROOT-based (Multi-layer Perceptron).

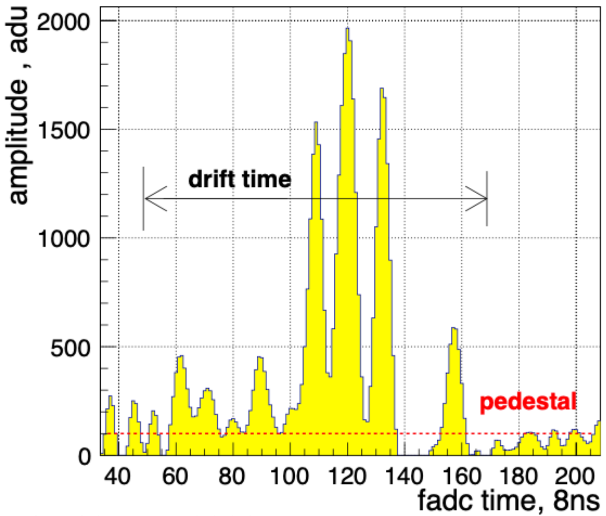
We compared cluster counting method and integrated charge within a bin (drift slice).

Cluster counting method (Time, Amplitude, number of clusters)

Machine Learning on FPGA

For OFF-line data analysis we are using neural network library provided by root /TMVA package : MultiLayerPerceptron (MLP)





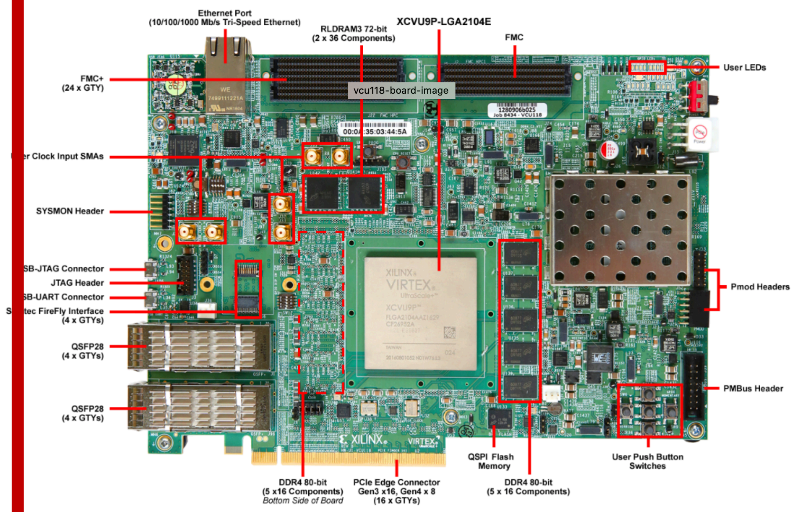
Moving towards ON-line data processing

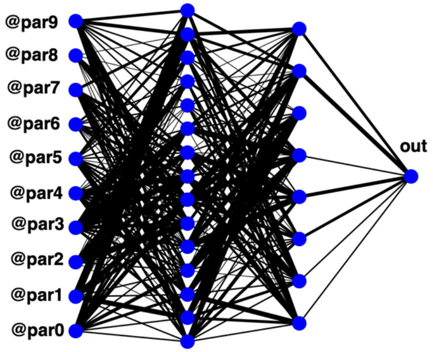
In a collaboration with GlueX, PANDA and ODU

ML FPGA Core for TRD

Xilinx Virtex® UltraScale+™

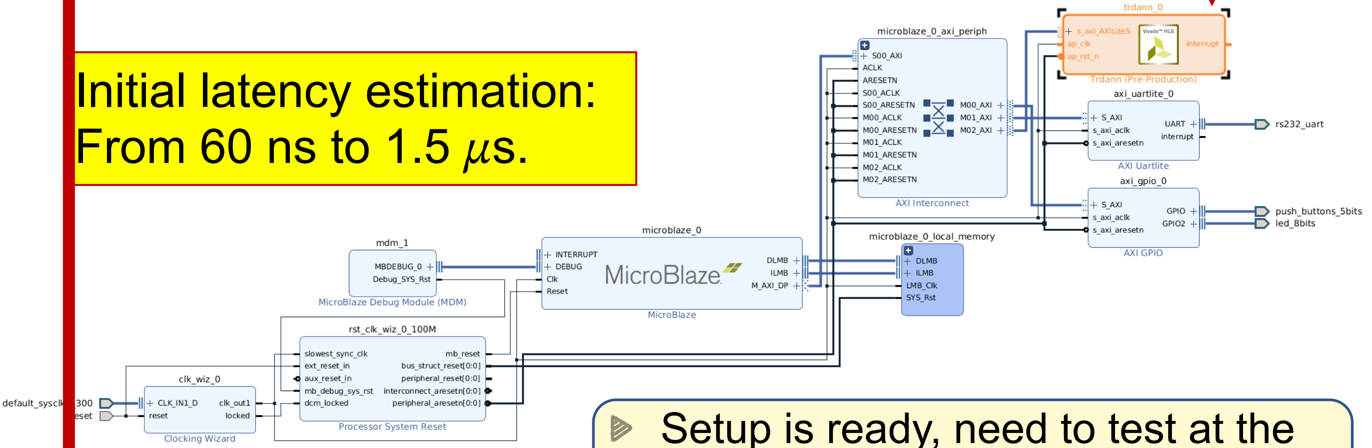
Featuring t e Virtex® UltraScale+™ XCVU9P-L2FLGA2104E FPGA





TRD
ML Core

Initial latency estimation:
From 60 ns to 1.5 μs.



- Setup is ready, need to test at the testbeam
- synergy with proposal #15

2. Can you detail the prototype of the field cage that is planned?

See slide on page 10.

- While the gas properties will be studied in Magbohtlz and Heed, the design and the need of a field cage will be studied in ANSYS. The study of the properties of the gas mixture will be helpful in optimizing the drift field.
- Modeling and designing a filed cage to provide a **uniform electric field in the drift region** and for the **optimization of HV** for the use of different gas mixtures.
- entrance window/ no gap optimization for TR-photons

3. Why not buy the gain mapping device from a private company? (A lot of X-rays guns are available.)

➢ Description of device

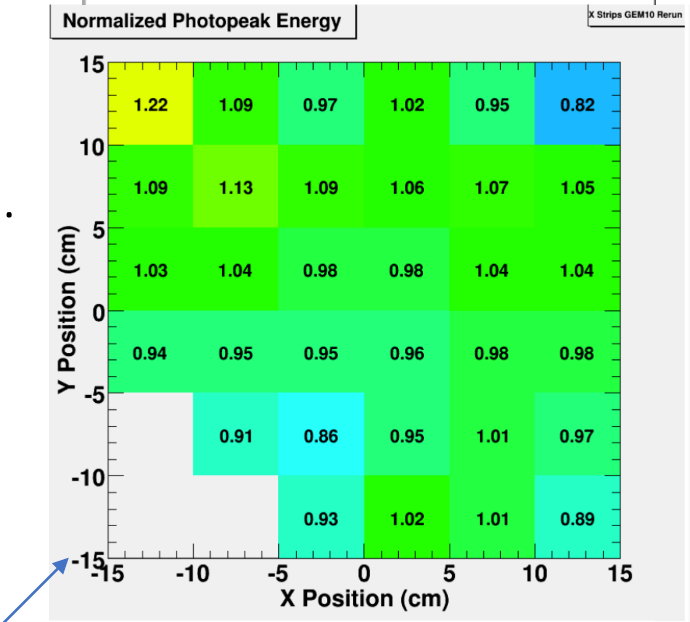
- The proposed mapping device **will act as scanner** to have fine mapping of gain uniformity .
- The X-ray gun to be mounted on the scanner has already been procured.
- The scanner comprises the following
  - ○ Bislide with span of 40” in X and Y
  - ○ Step motors with controllers to control X and Y movement
  - ○ Encoders along with digital readout .

➢ Requirement of device

- **Fluctuation in MPGD gain** can be caused by nonuniformity either in the amplification unit or in the readout board.
- Precise mapping of gain is possible by controlled movement of X-ray device with collimation to map the gain in the form of small grid.

➢ Example measurement of gain uniformity of a GEM foil with X-Y strip R/o

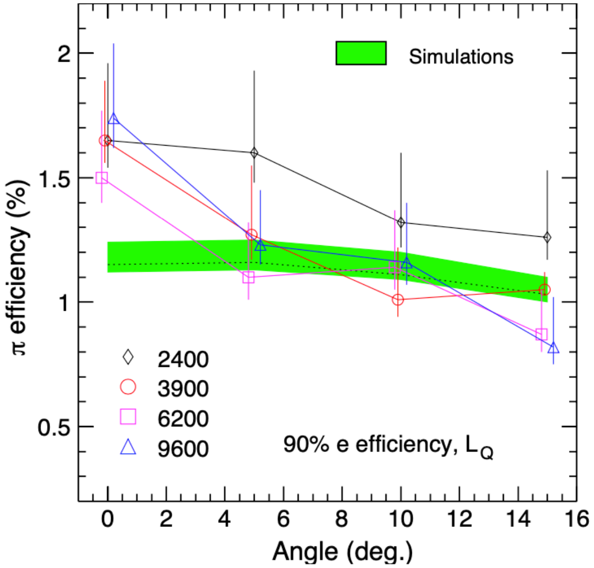
A. Andronic et al. / NIMA 525 (2004) 447–457



Normalized Photopeak Energy

1.22	1.09	0.97	1.02	0.95	0.82
1.09	1.13	1.09	1.06	1.07	1.05
1.03	1.04	0.98	0.98	1.04	1.04
0.94	0.95	0.95	0.96	0.98	0.98
	0.91	0.86	0.95	1.01	0.97
		0.93	1.02	1.01	0.89

➢ ALICE TRD has shown variation in pion rejection efficiency with change in gain of detector as shown below.



4. There appears to be non-zero overlap in detector R&D prototypes with proposal #23: Development of Thin Gap MPGDs for EIC Trackers . (All received proposals can be found at https://www.jlab.org/research/eic_rd_prgm/receivedproposals .) If this is correct, and both proposals are funded, how would you exploit this potential synergy?

Synergy & overlap between proposal #2-MPGD-TRD and proposal #23-thin gap-MPGD

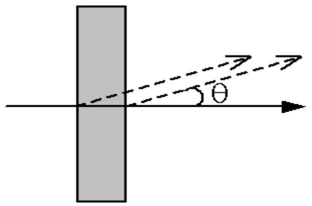
1. **Technologies:**
   - uRWELL, Micromegas, GEM
   - Development of Low channel count high-performance anode readout structures (zigzag / capacitive-sharing ..)
   - Same interest for exploring different gas mixtures (Xe. Kr mixtures …) ➔ cost saving
2. **Application / detectors:**
   - **High- performance tracking** for tg-MPGD proposal#23 vs. **PID + tracking f**or MPGD-TRD proposal#2
   - Slightly different R&D effort ➔ Prototypes are different and not interchangeable
   - Different readout electronics.
3. **Same expertise:**
   - Demonstrated expertise and experience for all 3 MPGD technologies ➔ critical for both proposals
   - Improve chances of the successful outcome of the R&D effort ➔ share experience and knowledge
4. **Share tg-MPGD / MPGD-TRD test beam time and resources:**
   - Only one week slot available at Fermilab in 2023 for beam test ➔ Combined beam test
   - Will also save a lot in travel cost to Fermilab
   - Share gas during beam test ➔ Xe / Kr –based gas mixture are expensive and procurement is a concern

5. Travel costs are roughly ¼ of the budget request. Are all 6 people necessary for the tests at Fermilab?

- Most of the travel cost is assigned to the test beams. We have 5 institutions participating in the proposal: 1-2 people per institution.
- Only 1 week for beam test. Shifts: 2 people per shift on a 24h beam use => min 6 people.
- During the testbeam operation we need experts on detector, electronics, DAQ
- Testbeams provide a hands-on expertise for students.
- We plan to minimize travel cost by combining beam test effort with the thin gap MPGD members (proposal #23) and ML on FPGA members(proposal #15).

Backup

Transition Radiation



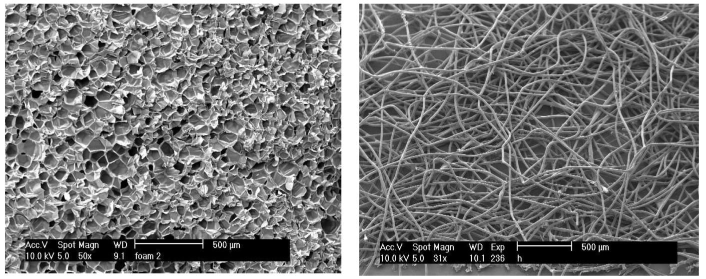
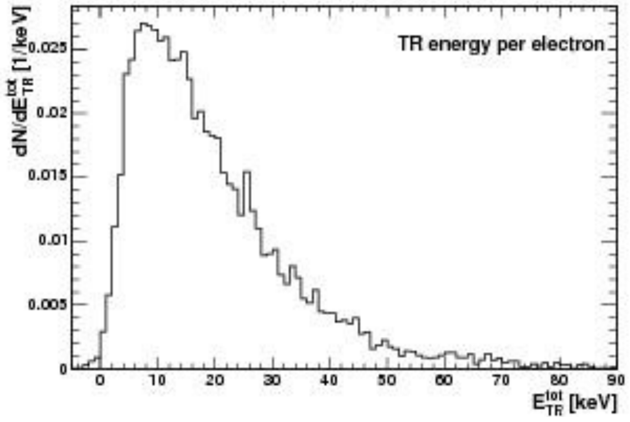
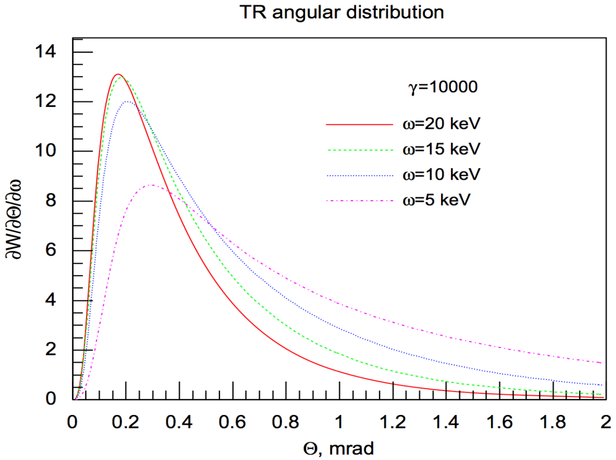
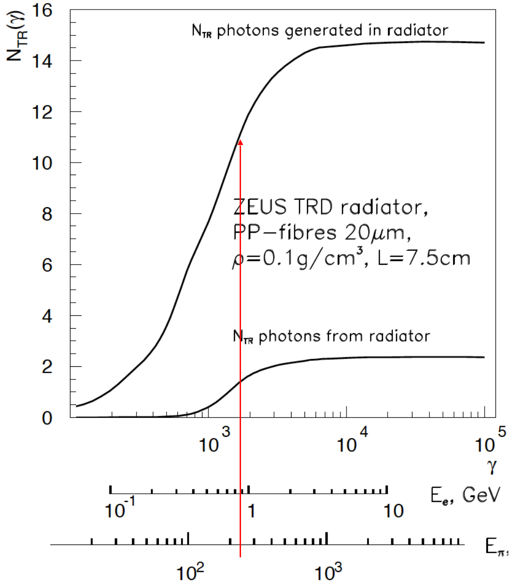


Figure 2: Electron microscope images of a polymethacrylimide foam (Rohacell HF71)(left) and a typical polypropylene fiber radiator (average diameter ≈ 25 μm) (right) [52].

- Transition radiation is produced by a charged particles when they cross the interface of two media of different dielectric constants
- the probability to emit one TR photon per boundary is of order $\alpha \sim 1/137$. Therefore multilayer dielectric radiators are used to increase the transition radiation yield, typically few hundreds of mylar foils.
- TR in X-ray region is extremely forward peaked within an angle of $1/\gamma$
- Energy of TR photons are in X-ray region (2 - 40 keV)
- Total TR Energy ETR is proportional to the γ factor of the charged particle







Only e produce TR photons (E>1GeV)

Pions only start to produce TR at E > 100-150 GeV

GEM as Transition Radiation detector and tracker for EIC (eRD22)

- ➢ High resolution tracker (based on GEM)
- ➢ Low material budget detector
- ➢ And provides PID (electron / pion separation)
- ➢ How to convert GEM tracker to TRD:

✓ Increase drift region up to 2-3 cm (for the same reason).

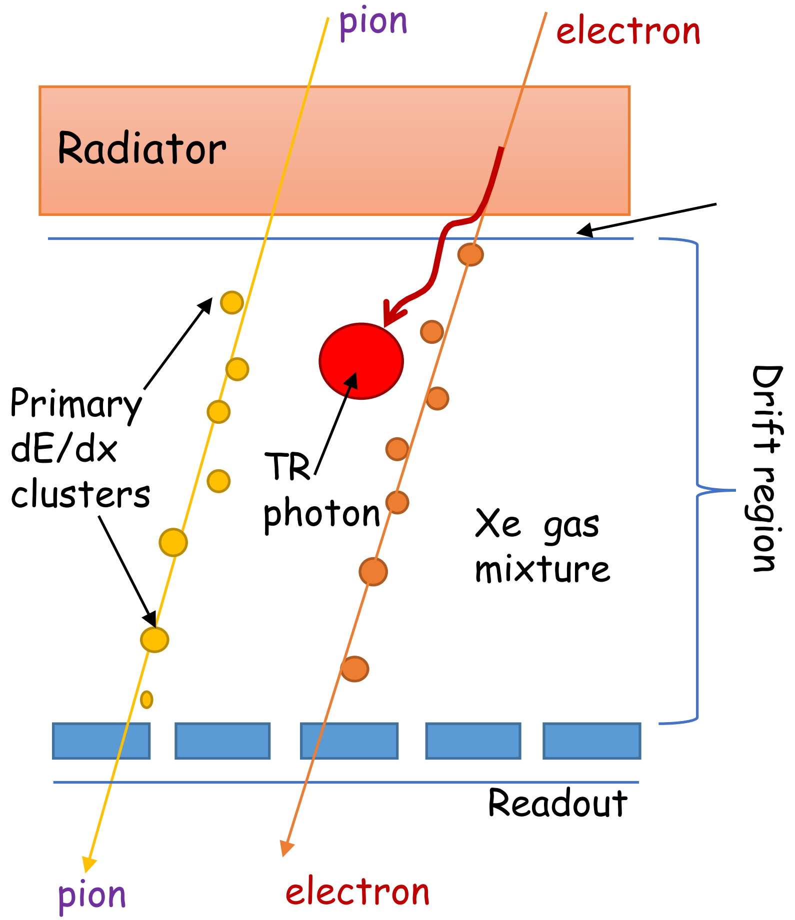
=> higher HV, and field uniformity

✓ Change gas mixture from Argon to Xenon
(TRD uses a heavy gas for efficient absorption of X-rays)

=> higher HV (Xe - slow gas)

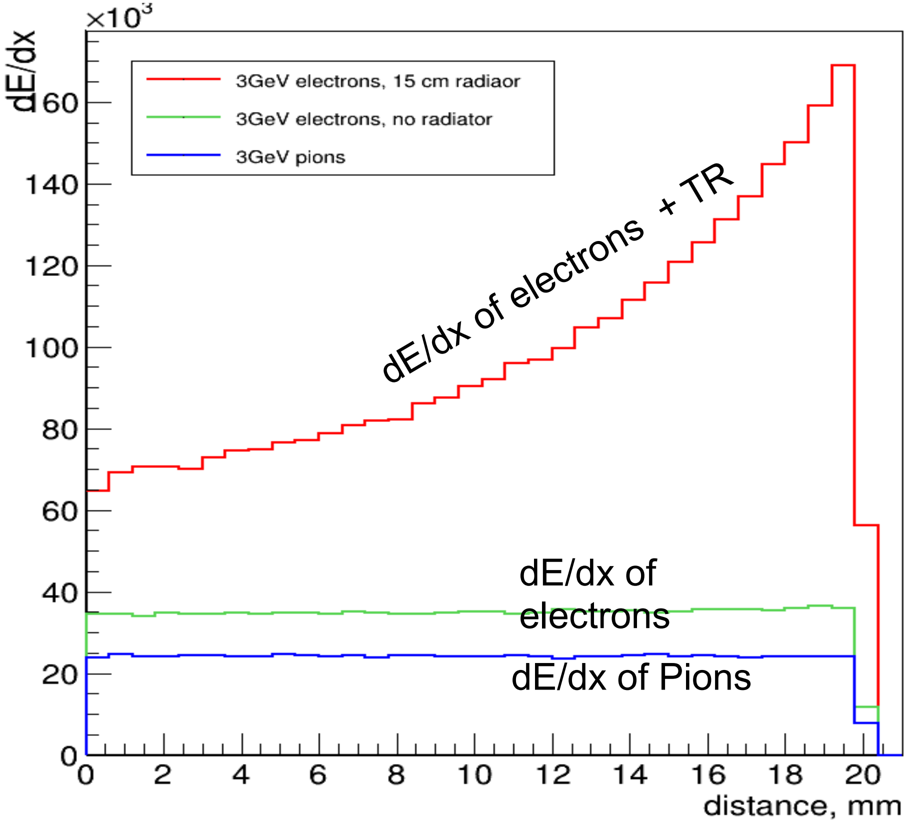
✓ Add a TR radiator in the front of each chamber (radiator thickness ~5-15cm)

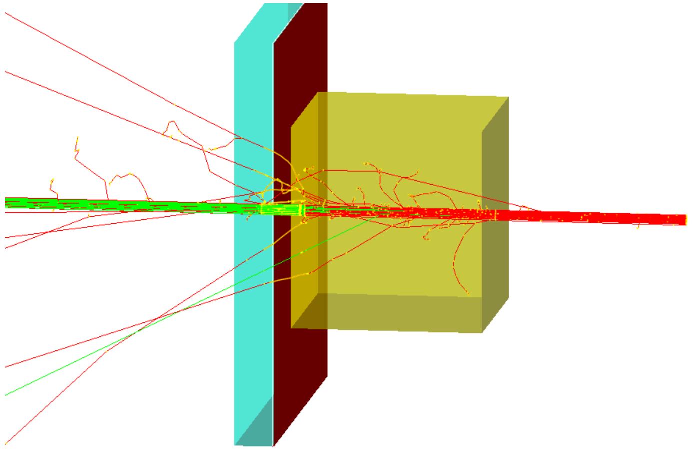
=> minimize material at entrance window



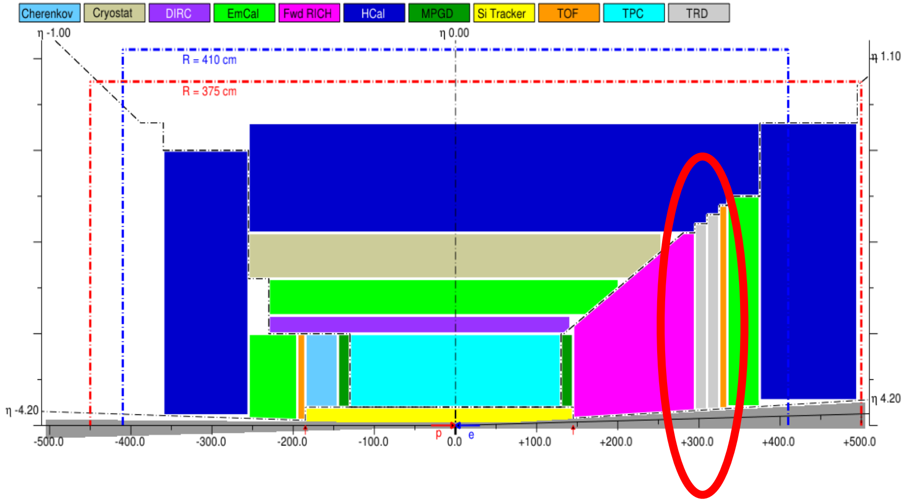
GEANT4: electron and pion comparison

Energy deposition (dE/dx + TR) vs drift distance





e,π ~3 GeV



Implemented in g4e

Parameters:

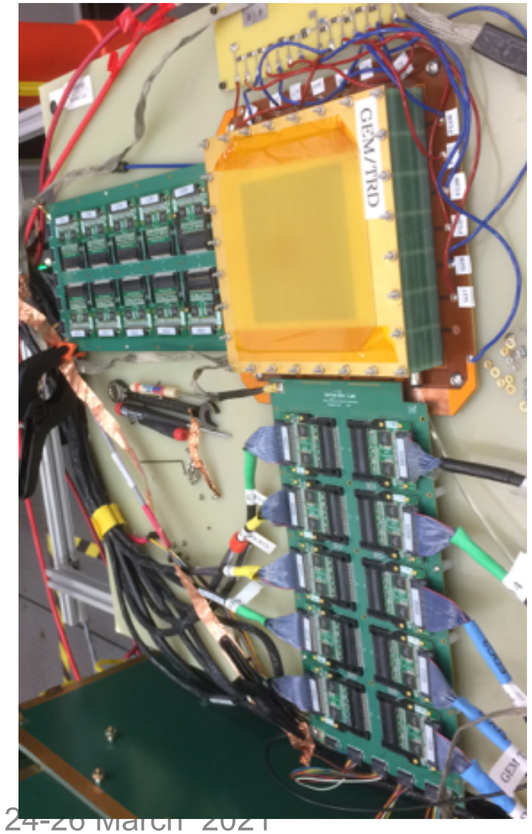
- ✓ Detector Gas Thickness (D) : 1 – 4 cm
- ✓ Radiator Thickness (R): 3-10 cm
- ✓ "Dead region":
  - ✓ cathode material(Al, Cu, Cr)
  - ✓ gap (Xe filled) 400um
- ✓ Gas mixture: Xe/CO_2 , Ar/CO_2 …
- ✓ # layers:1,2,3 …

Prototypes

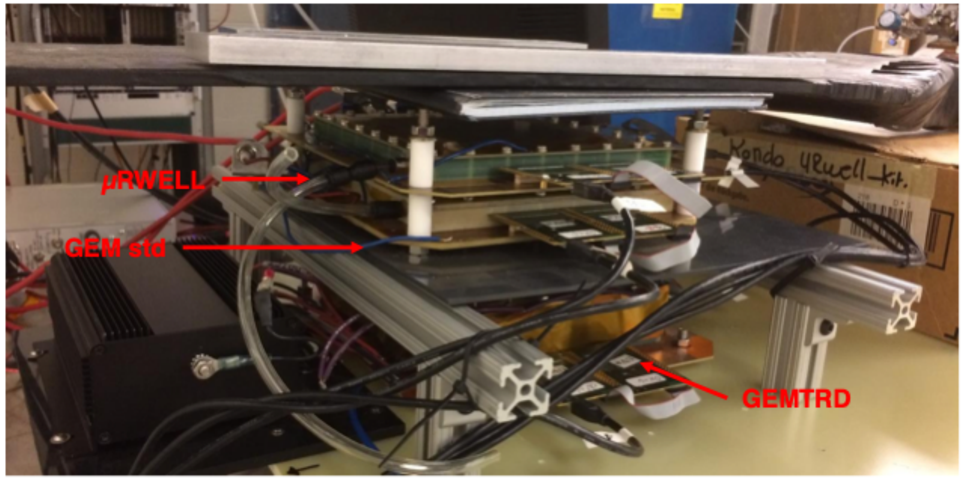
-10x10cm² prototypes assembled at Uva

-Assembly and X-ray/cosmic tests of each prototype

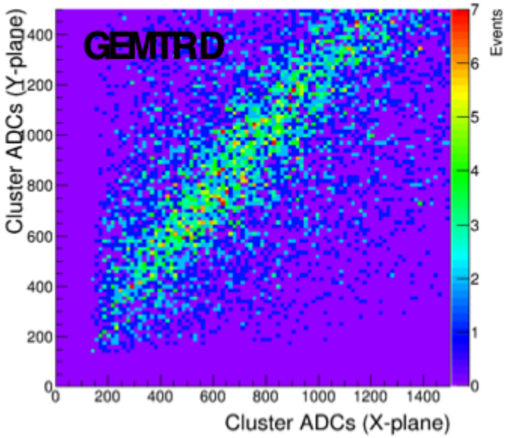
-Noise, pedestal tests



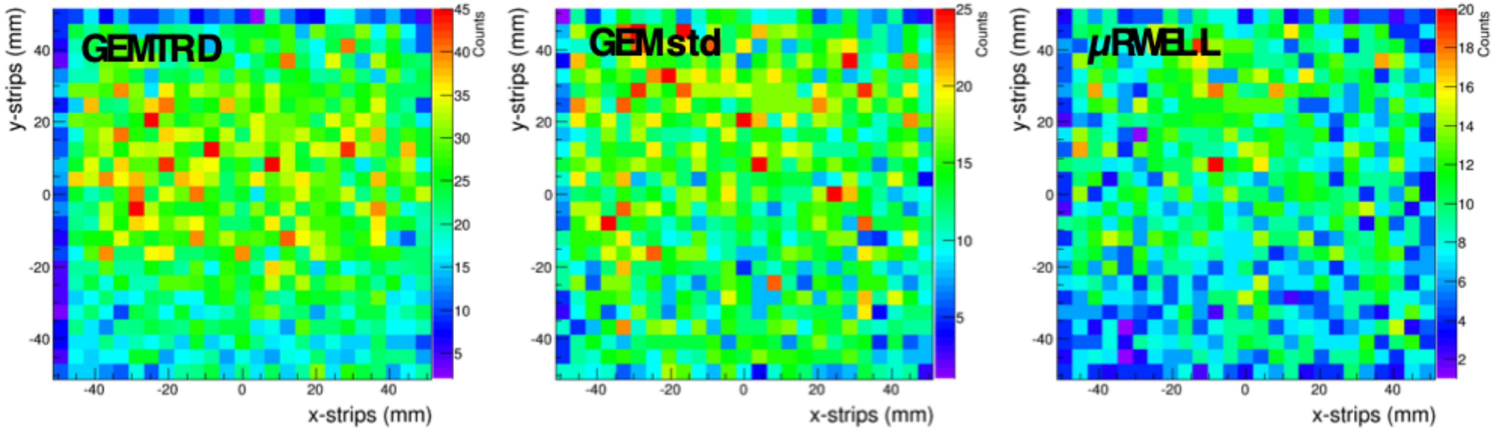
GEMTRD Test in cosmic setup @ UVa



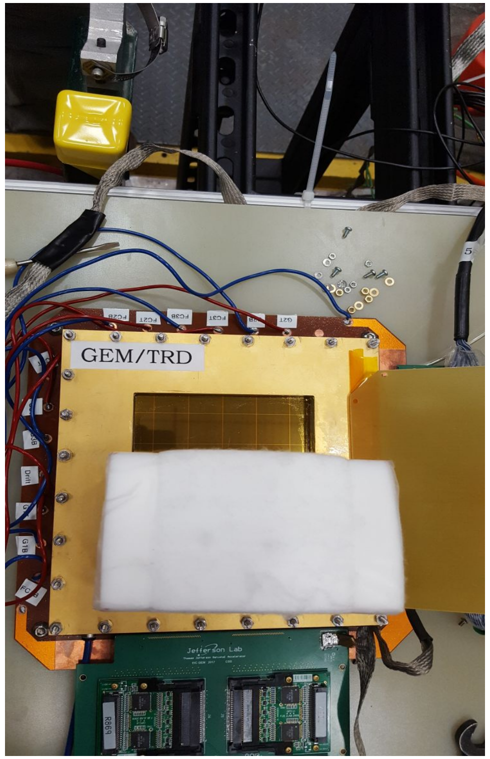
X-Y charge sharing

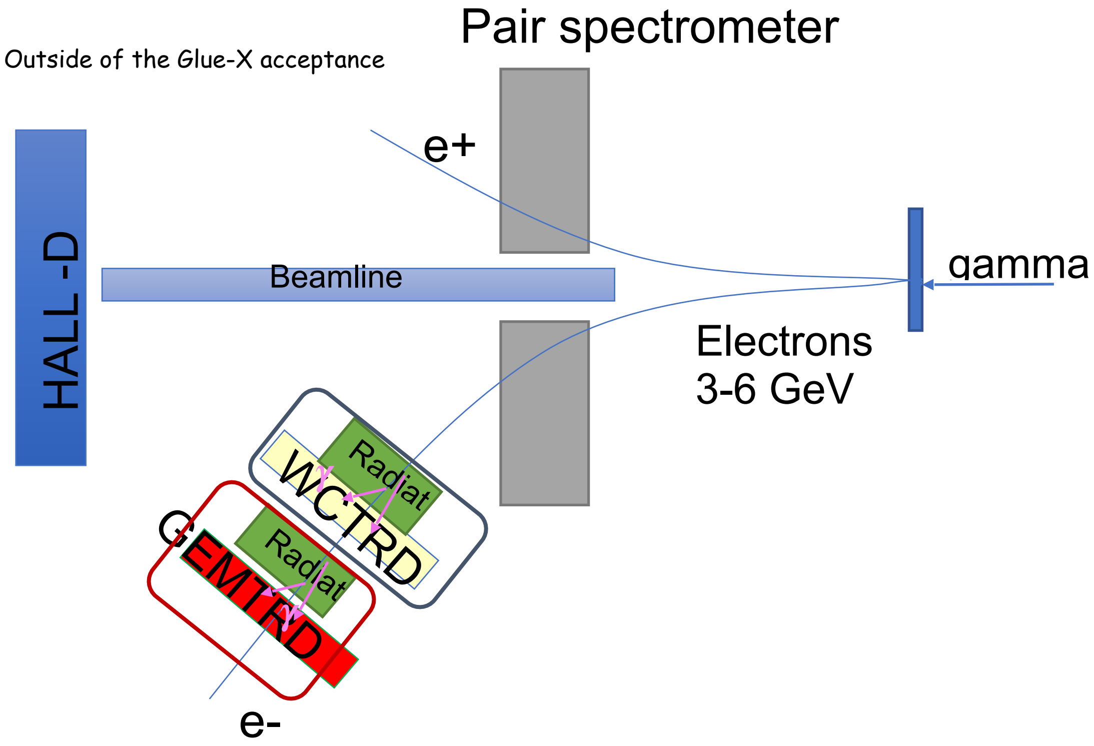


Reconstructed position hit map

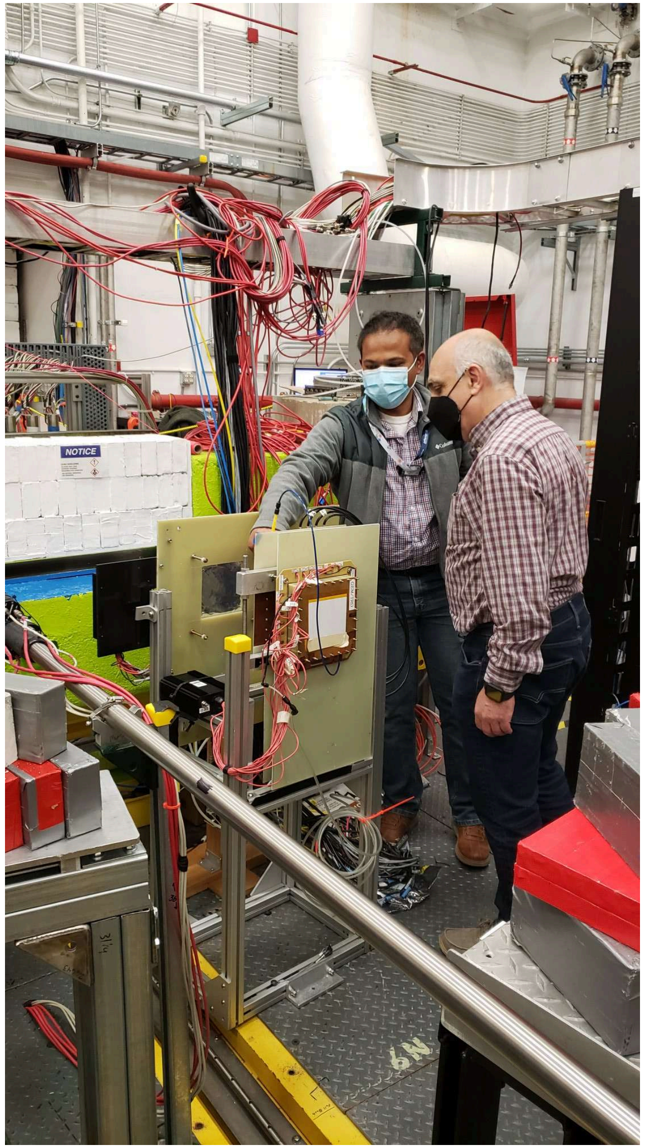


Beam test using Hall-D pair spectrometer



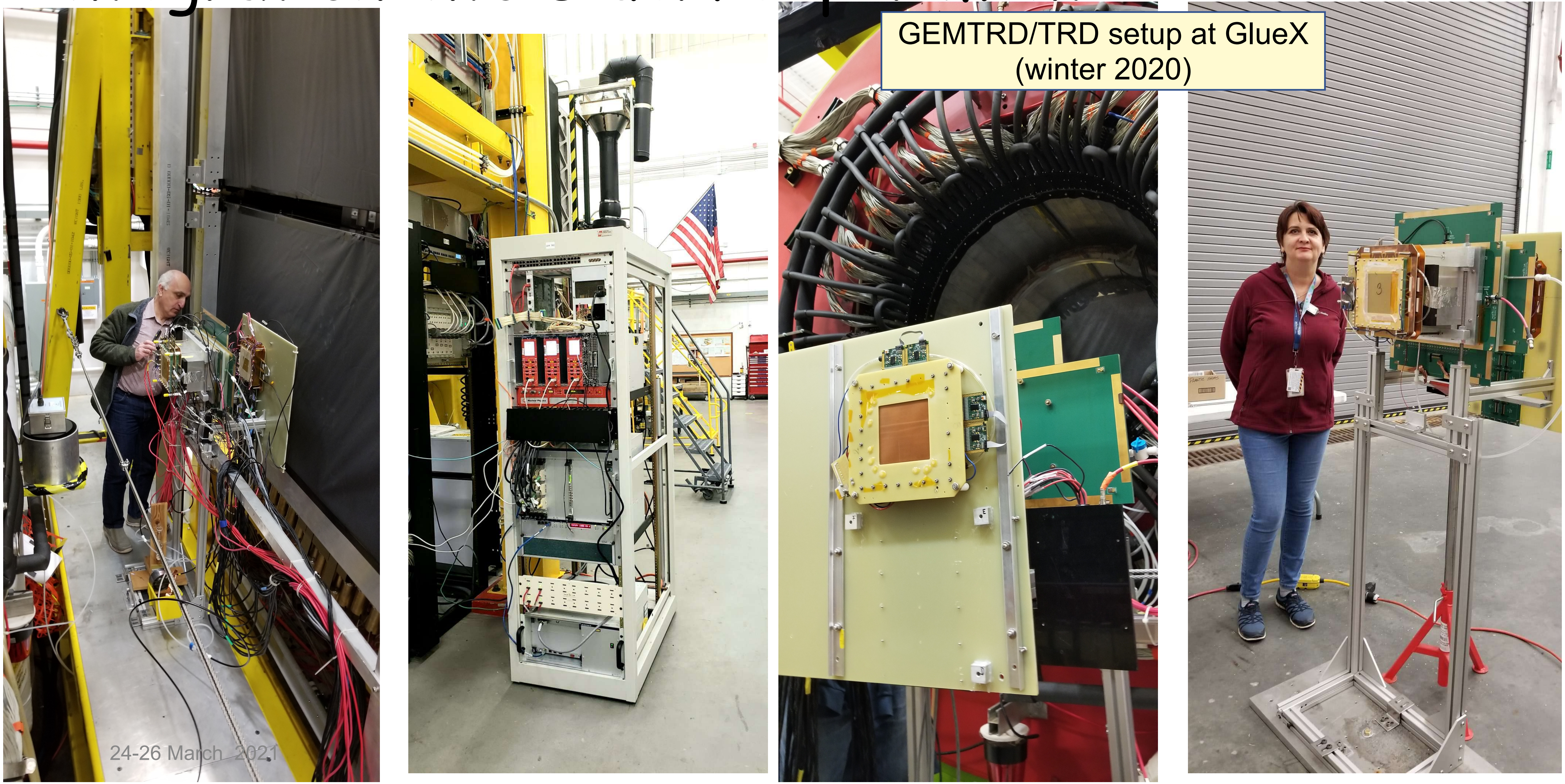

Outside of the Glue-X acceptance

Pair spectrometer



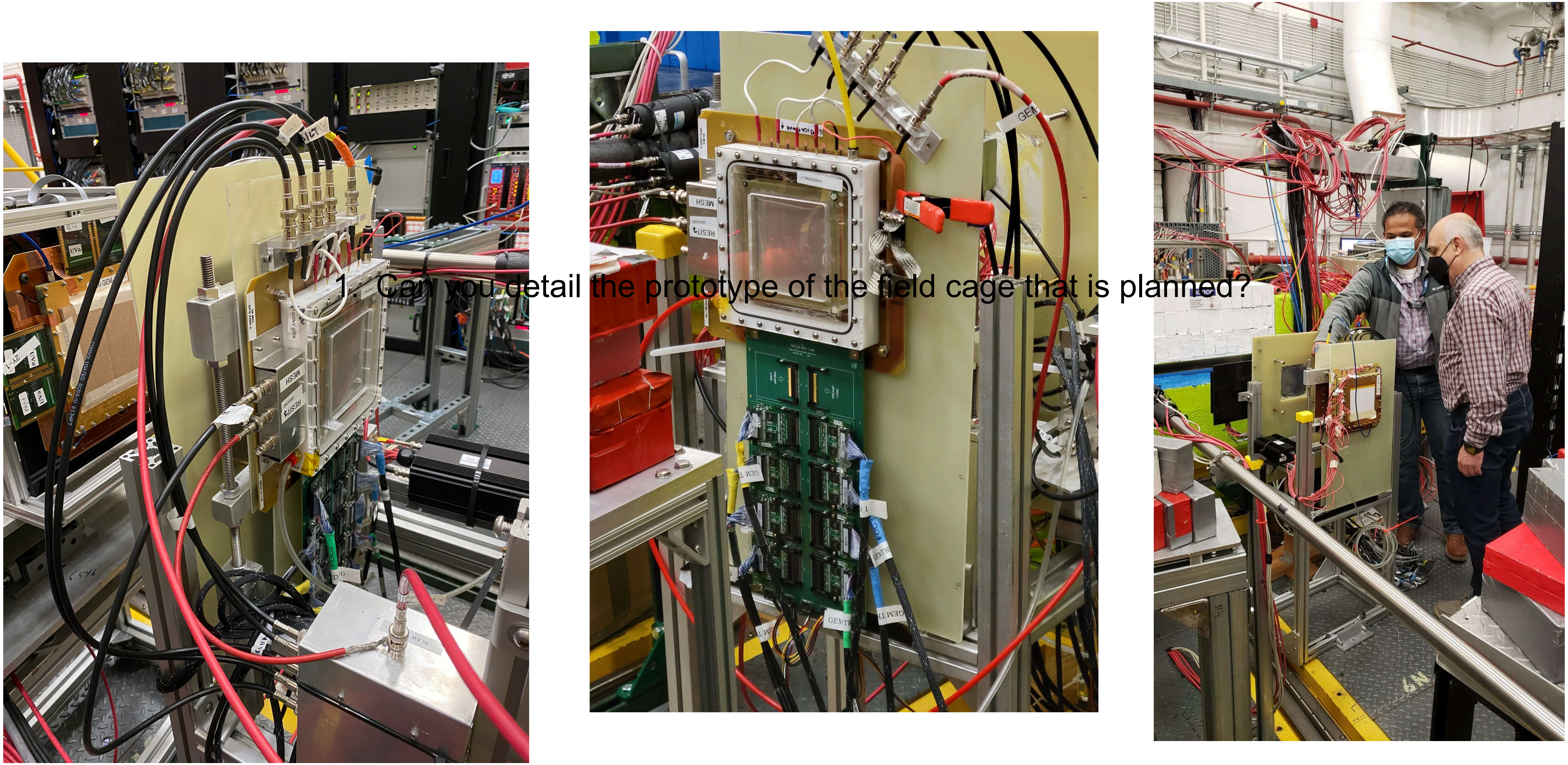
- ➢ 3-6 GeV electrons in Hall-D from pair spectrometer
- ➢ Flat beam: in-plane(y spread ~ 5mm) 10kHz rate
- ➢ In parallel with other tracking detectors.
- ➢ covered ½ of the sensitive area with radiator (to compare with and without radiator)

Integration into GlueX experiment



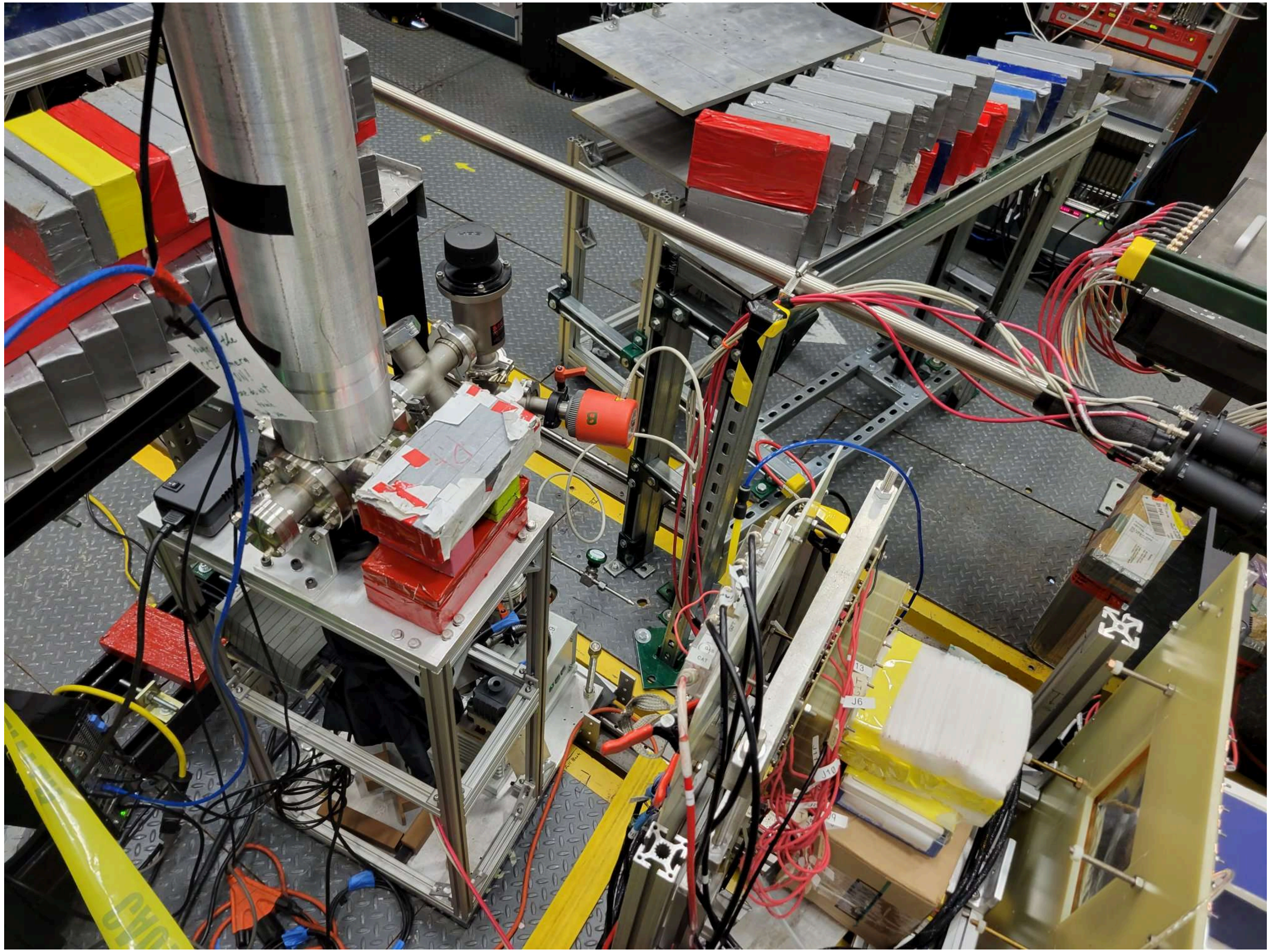
GEMTRD/TRD setup at GlueX
(winter 2020)

New prototype from Vanderbilt Uni @ JLAB test beam

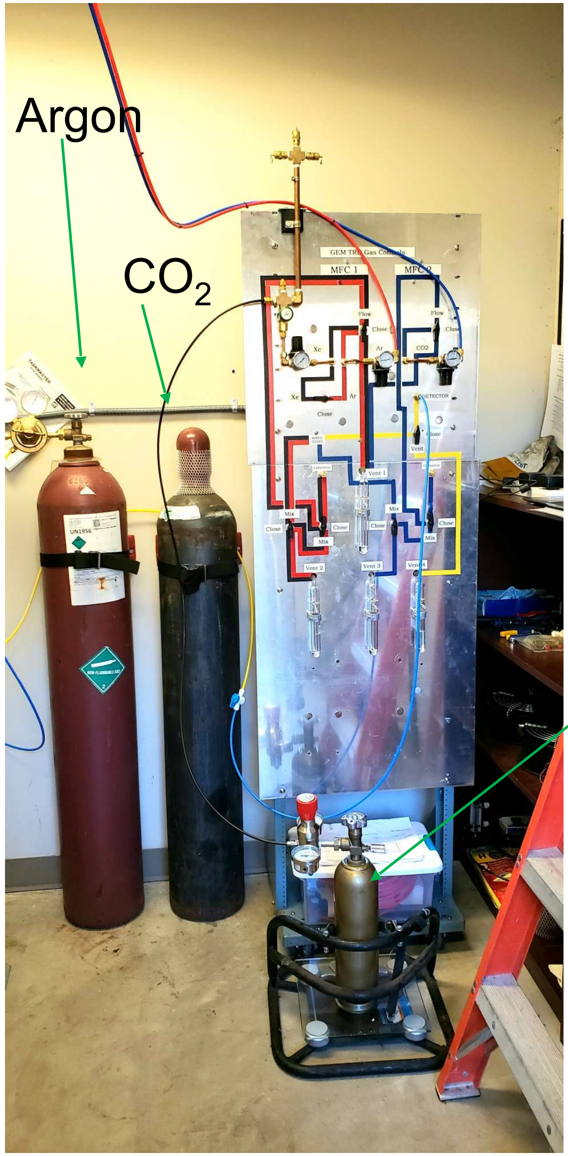


1. Can you detail the prototype of the field cage that is planned?

Setup



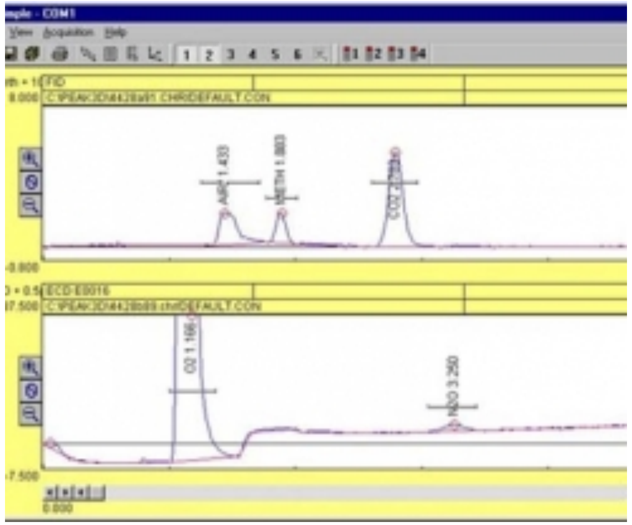
Gas system



Gas system (assembled at Temple U.):

- Without a re-circulation and a purification system (too early stage of R&D)
- But with gas mixing system and Flow controller, CO_2 controller
- We purchased gas analyzer to begin quantifying and monitoring contaminations and to measure the concentrations of the Xe and CO_2 gasses.

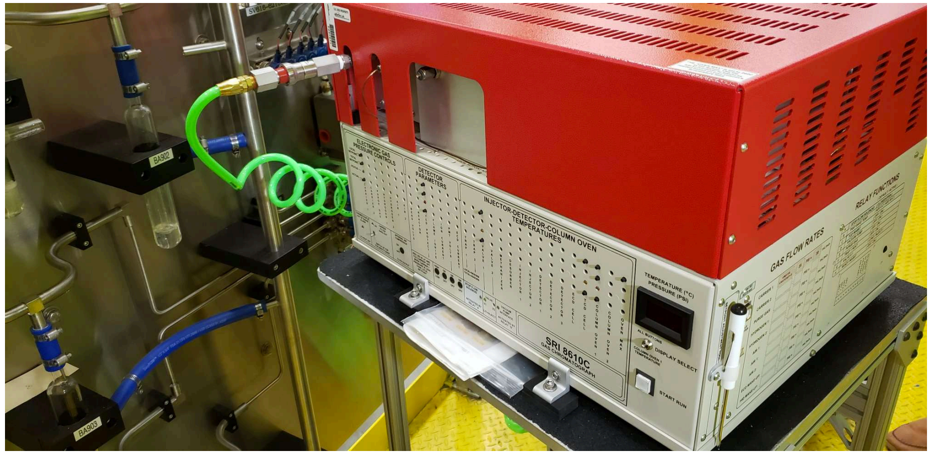
-> split a cost with Hall-D : our contribution $7k (40%) to extend up to Xe



- Small Xe-gas bottle : $8k !

(need a good program planning!!!)

Gas mixing setup:
Xenon/CO2: 80/20 percent.



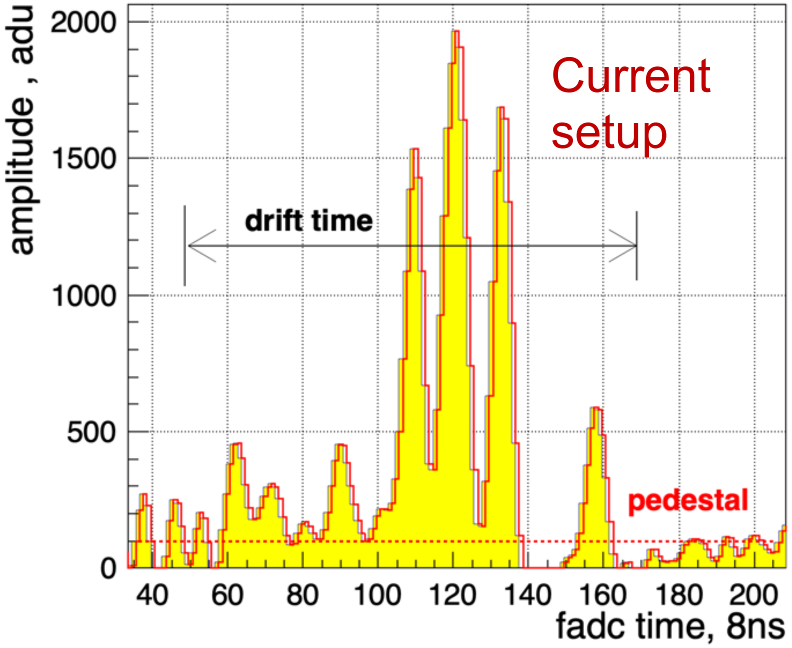
SRI 8610C

Readout

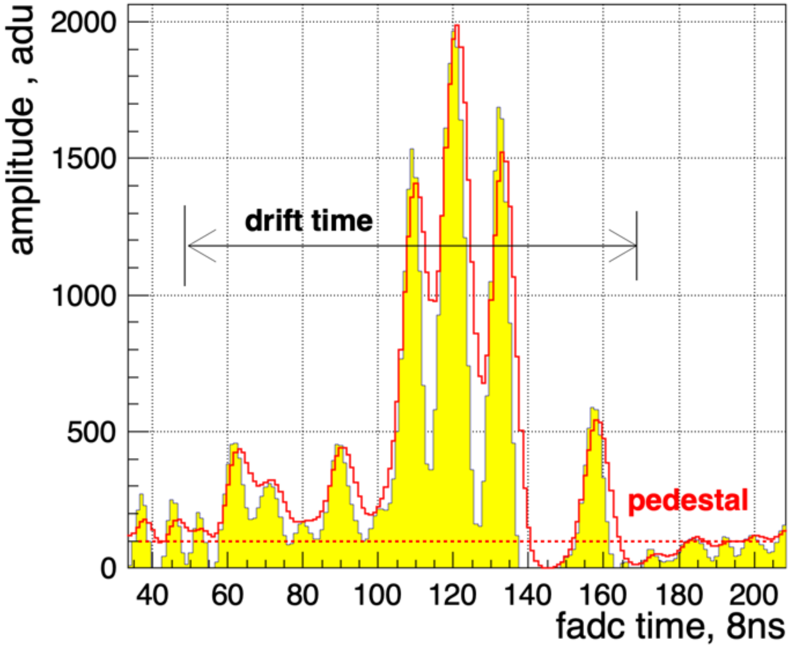
Current setup: preamplifiers (GAS2 ASIC chip) with shaping times of~10-12ns.
The flash ADC has a sampling rate of 125 MHz and 12 bit resolution but provides only pipe-lined triggered readout (price ~50$/channel)

Shaping time:
For TRD applications not only raising time is important, but also full width (tails, return to baseline)
In Xe – high density clusters
(ionization density)

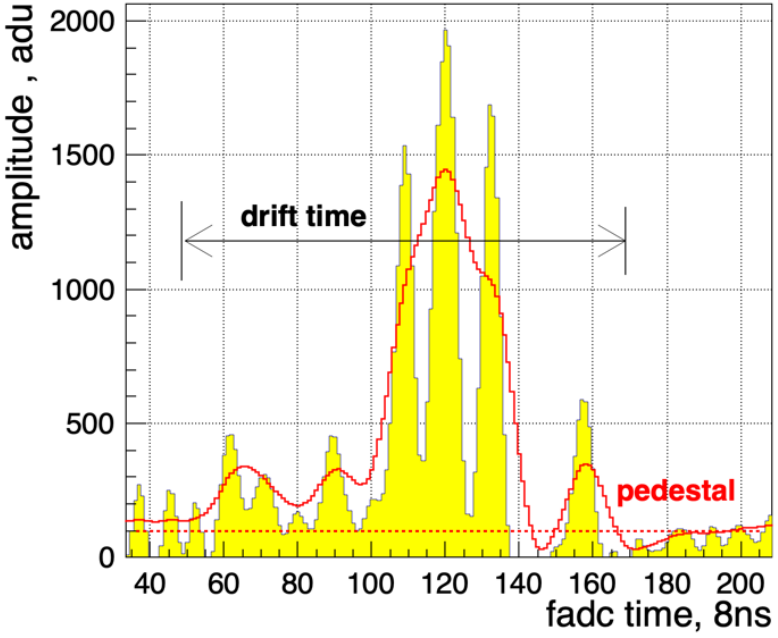
~ 20ns shaping time



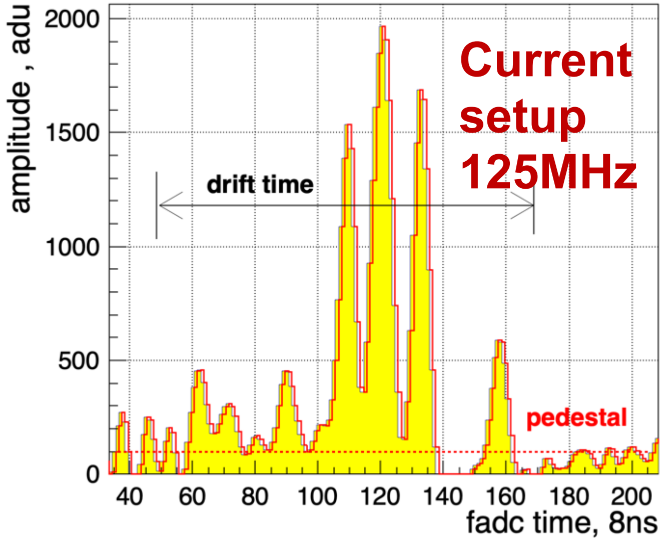
~ 40ns shaping time



80ns (Sampa) shaping time

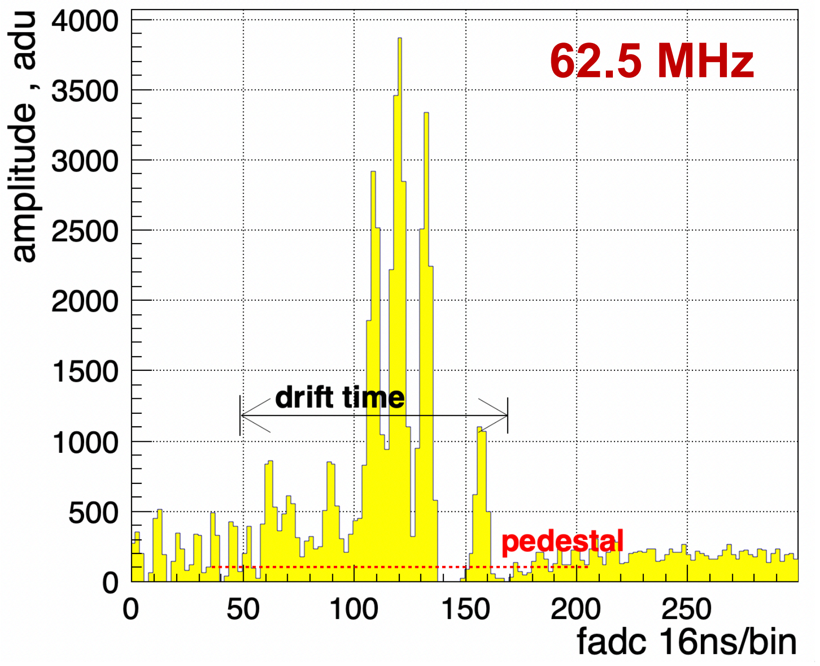


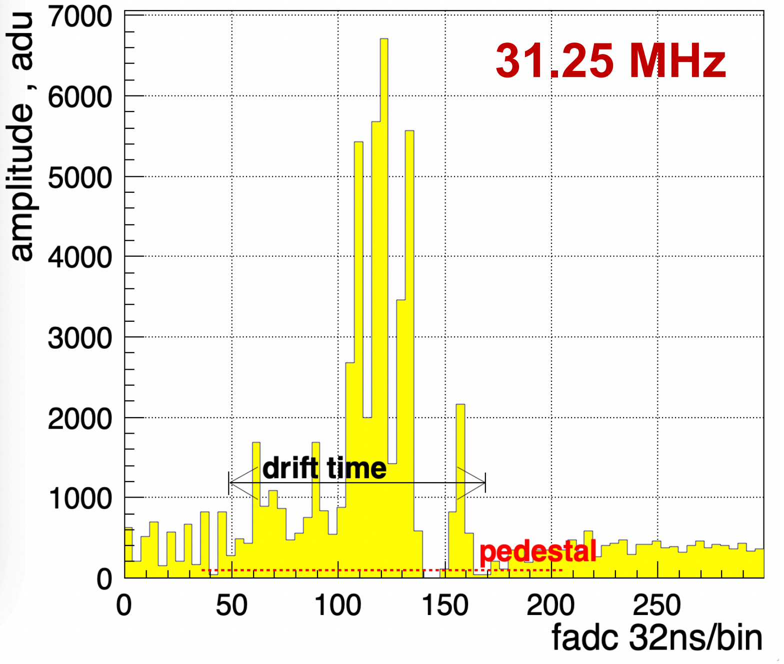
Readout

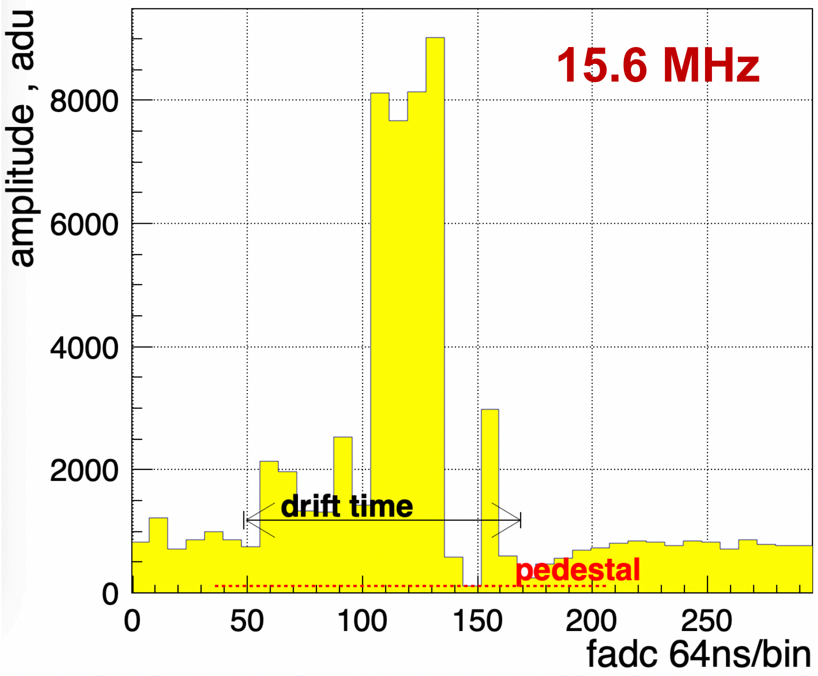


a preamplifier (GAS2 ASIC chip) with shaping times of~10-12ns. The flash ADC has a sampling rate of 125 MHz and 12 bit resolution but provides only pipe-lined triggered readout (price ~50$/channel)

Sampling frequency:

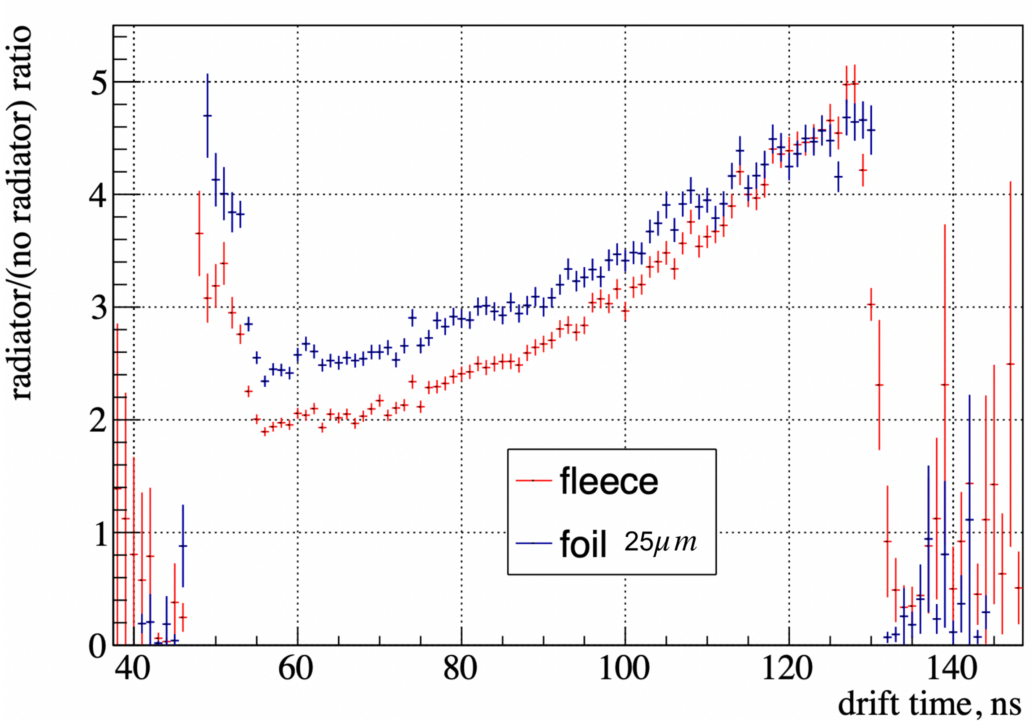


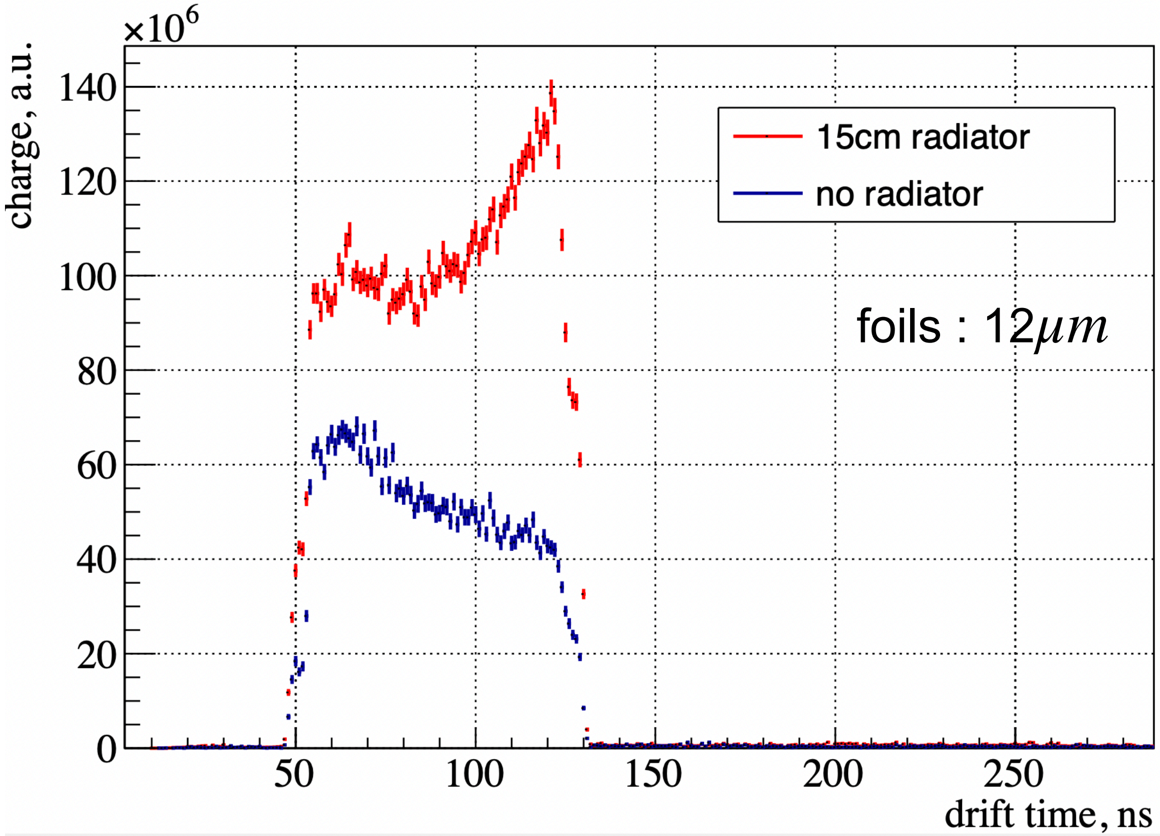




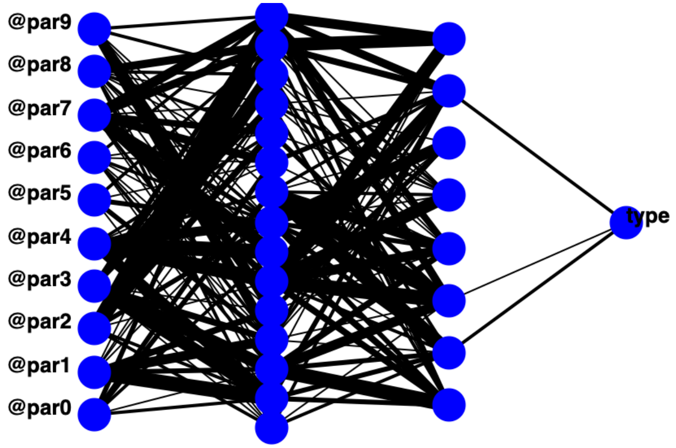
New Results (very preliminary)

Radiator comparison
fleece,
ca 500 foils of different thickness 25μm ,
12 μm (0.0005 inch)





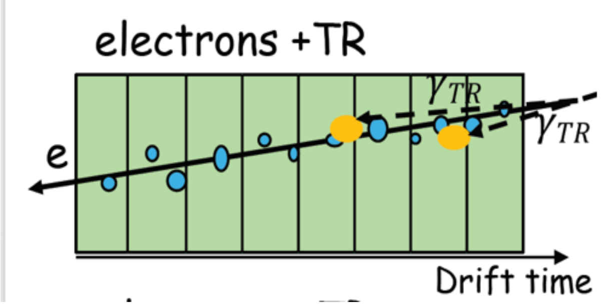
Machine learning technique

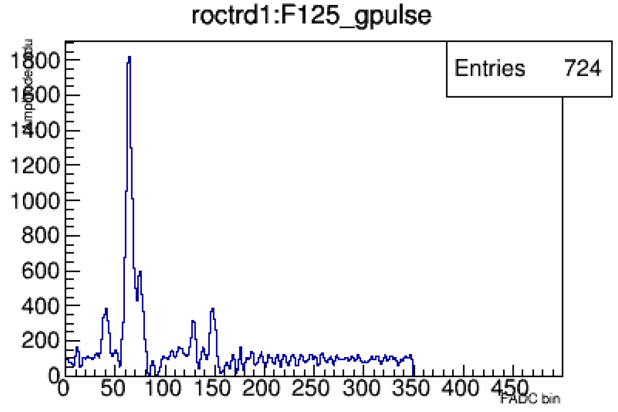


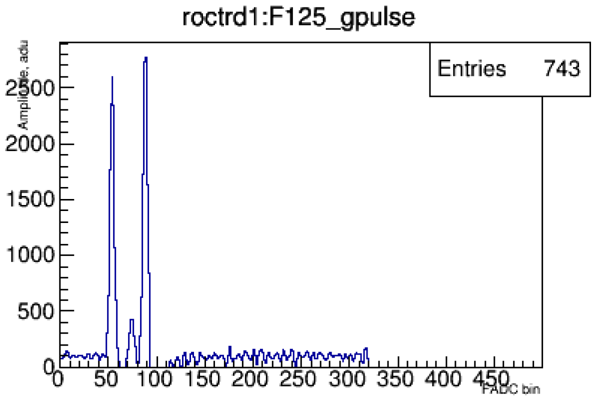
Upto 20 variables were used as input for likelihood and artificial neural network (ANN) programs, such as JETNET or ROOT-based (Multi-layer Perceptron).

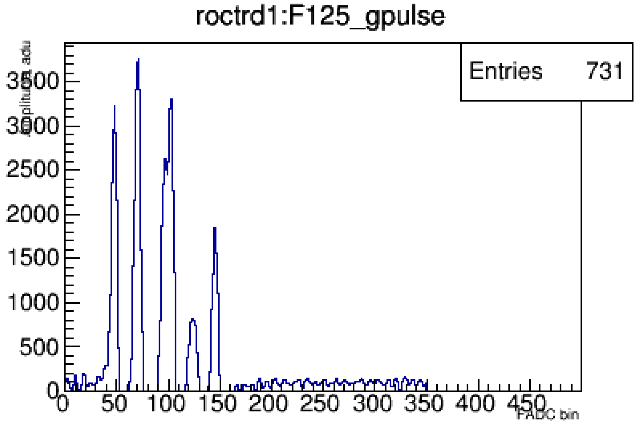
We compared cluster counting method and integrated charge within a bin (drift slice).

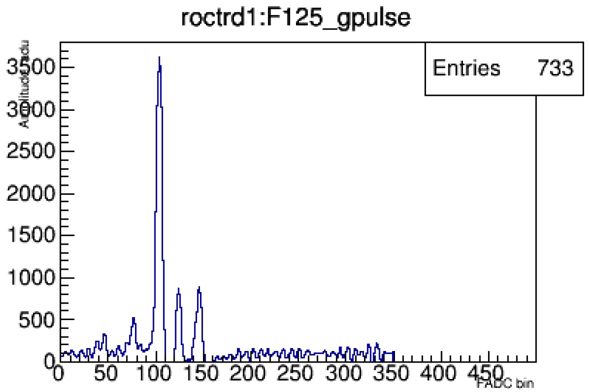
Cluster counting method (Time, Amplitude, number of clusters)

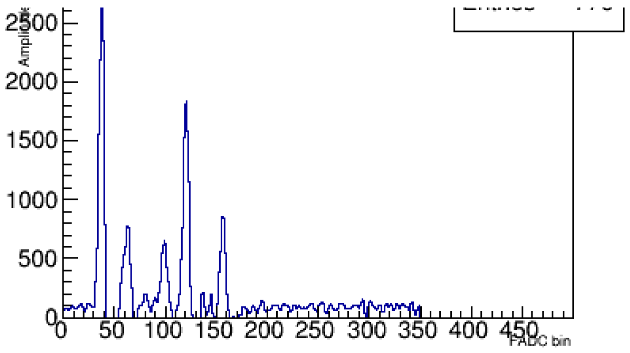






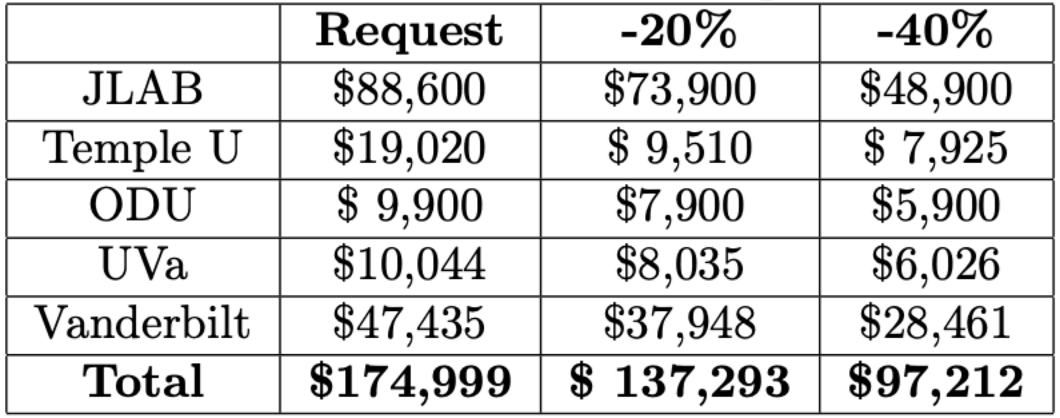






Budget

Table 7: **A total** FY23 request.



	Request	**-20%**	**-40%**
JLAB	$88,600	$73,900	$48,900
Temple U	$19,020	$ 9,510	$ 7,925
ODU	$ 9,900	$7,900	$5,900
UVa	$10,044	$8,035	$6,026
Vanderbilt	$47,435	$37,948	$28,461
Total	**$174,999**	**$ 137,293**	**$97,212**

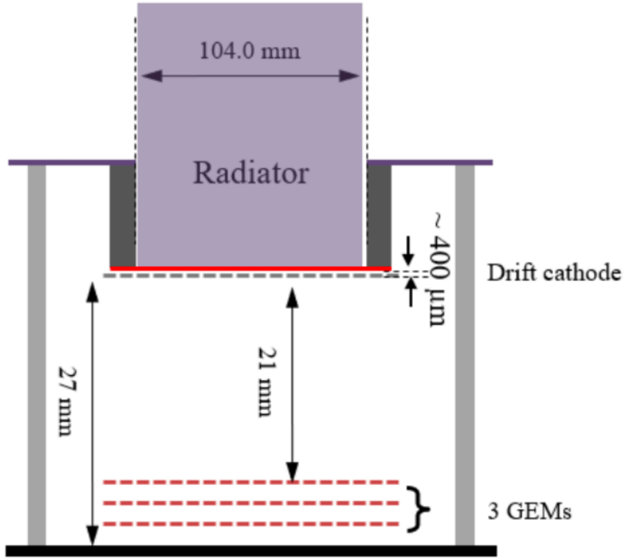
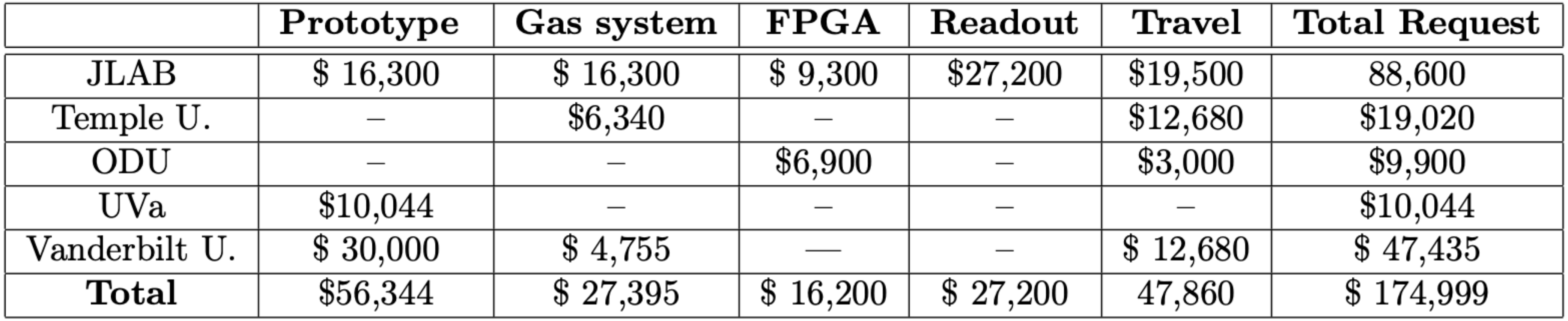


Table 6: **Total Budget (includes overheads and IDCs).**



	Prototype	**Gas system**	**FPGA**	**Readout**	**Travel**	**Total Request**
JLAB	$ 16,300	$ 16,300	$ 9,300	$27,200	$19,500	88,600
Temple U.	–	$6,340	–	–	$12,680	$19,020
ODU	–	–	$6,900	–	$3,000	$9,900
UVa	$10,044	–	–	–	–	$10,044
Vanderbilt U.	$ 30,000	$ 4,755	—	–	$ 12,680	$ 47,435
Total	$56,344	$ 27,395	$ 16,200	$ 27,200	47,860	$ 174,999