Development of GEM-based Transition Radiation Detector (GEM-TRD/T)

Kondo Gnanvo

University of Virginia, Charlottesville, VA, USA

On behalf of the eRD22 – EIC Detector R&D Program

May 07, 2019

Electron Ion Collider (EIC)

EIC is a proposed QCD facility to study the structure and dynamics of matter (our world):

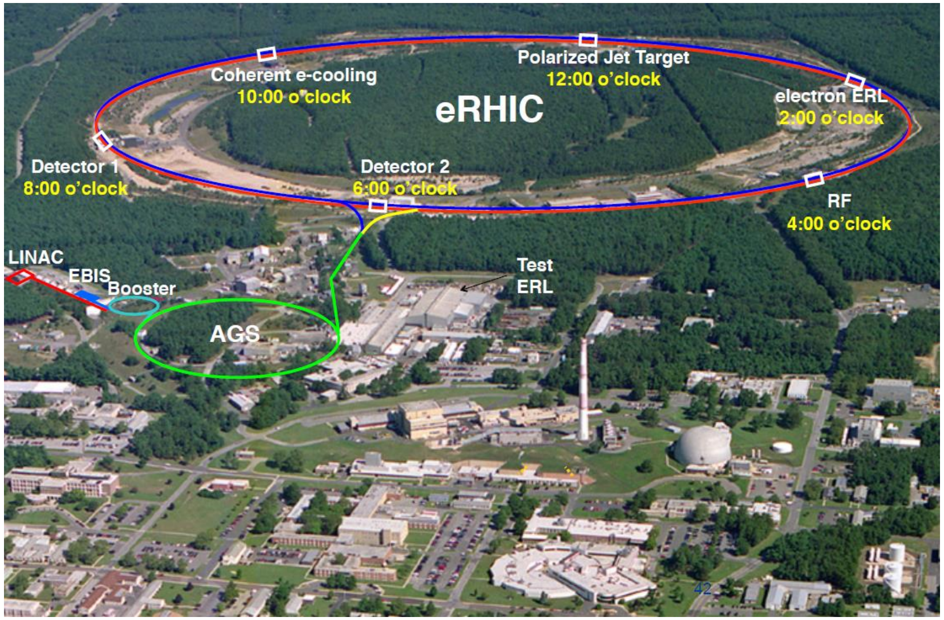
- Property of Hadrons (Mass, Spin …)
- Structure and Imaging of Hadrons (PDF, TMD, GDP …)
- QCD at Extreme Parton Densities

EIC Characteristics

- Wide range of nuclei
- CM energy $\sqrt{s}(eN) \sim 20$–140 GeV
- Luminosity $L \sim 10^{34}\ cm^{-2}\ s^{-1}$
- Polarized beams (both)
- Next generation of detectors

Two sites proposed their design

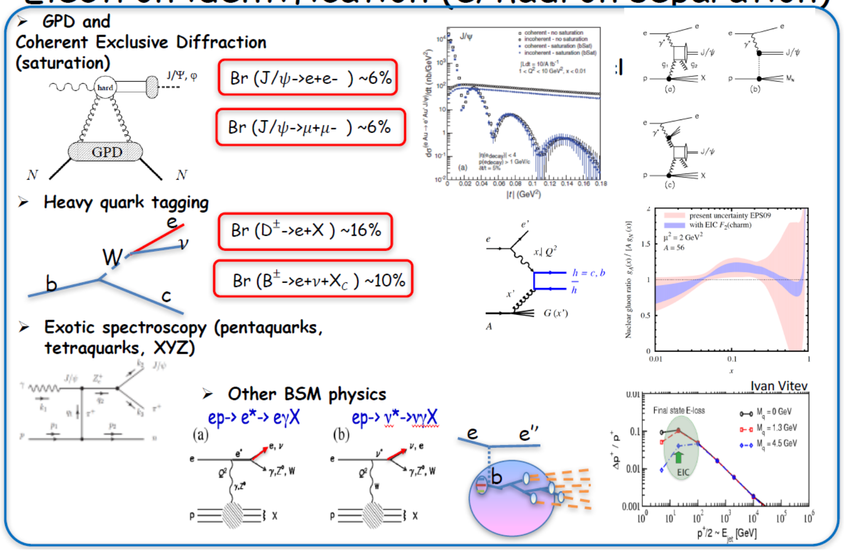
Brookhaven Nat. Lab, Long Island, NY



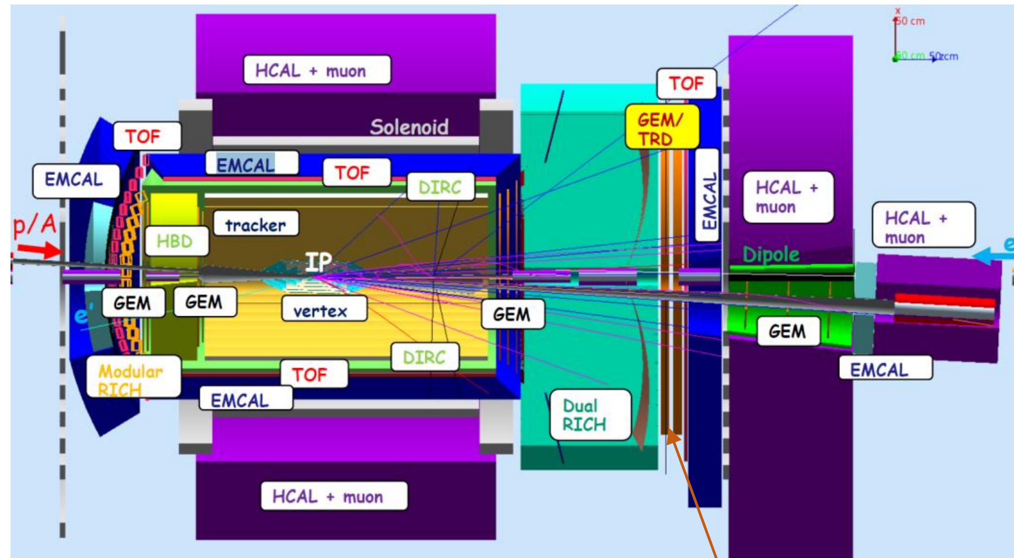
Jefferson Lab, Newport News, VA

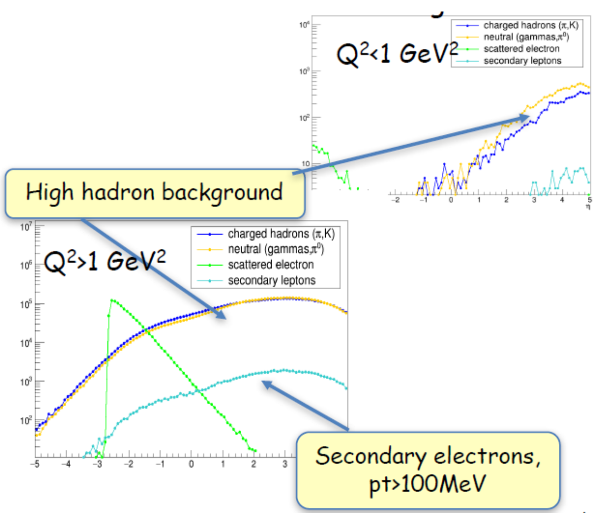
Electron ID in Hadron End-Cap

Electron identification (e/hadron separation)



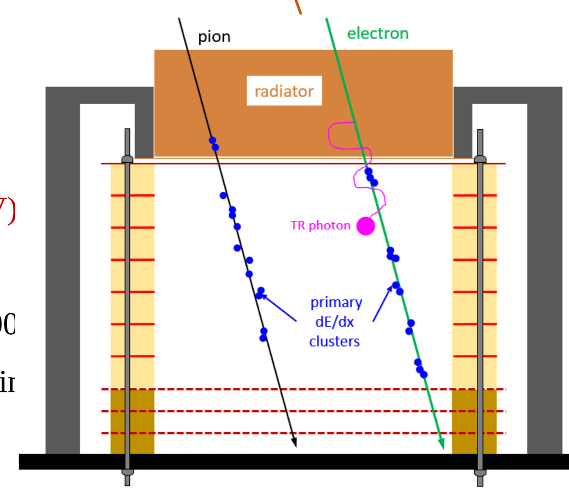
EIC Detector Concept (JLEIC) Design





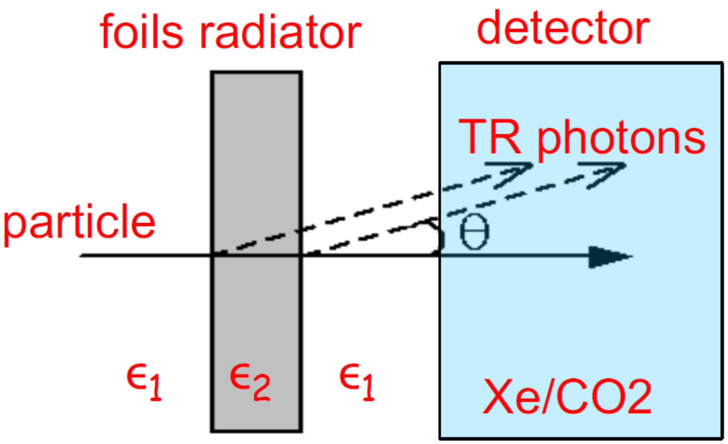
Electron/hadron separation

- e/h separation in the hadron end-cap: calorimeters
- dE/dx and RICH: PID in limited momentum range
- TRD: high e/h rejection in large range (1 – 100 GeV)
- Two or three GEM-TRD layers between the RICH and EMCAL provide additional pion rejection (1/10
- Additional tracking in μTPC (mini-drift) mode poi and reference point for the RICH ring center



Introduction to Transition Radiation

- Transition radiation is produced by a charged particles when they cross the interface of two media of different dielectric constants ε_1 and ε_2



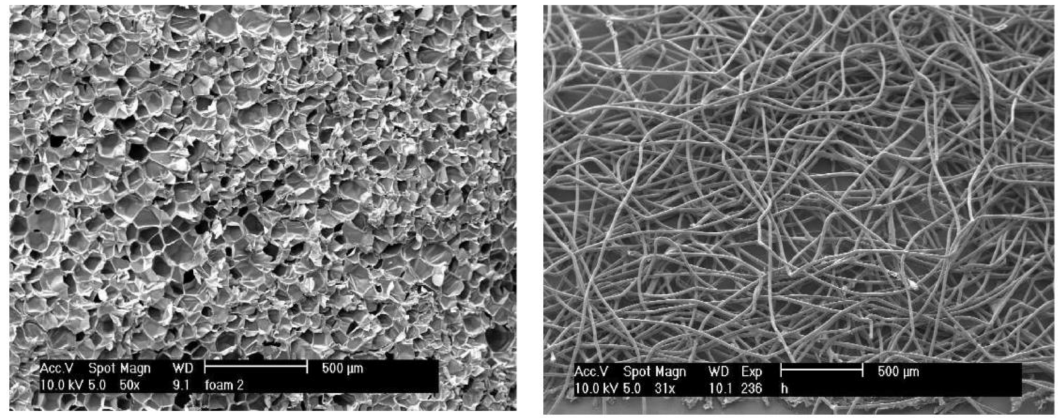


Figure 2: Electron microscope images of a polymethacrylimide foam (Rohacell HF71)(left) and a typical polypropylene fiber radiator (average diameter ≈ 25 μm) (right) [52].

[52] A. Andronic et al. (ALICE collaboration), Nucl. Instr. and Meth. in Phys. Res. A **558**, 516 (2006).

- 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 a stack of few hundreds of foils with air gaps.
- TR in X-ray region is emitted within an angle $\theta \sim 1/\gamma$ in extremely forward direction w.r.t the incoming particle
- TR photon energy is in the range of 2 to 40 keV and total energy proportional to the γ factor of the charged particle.

⇨ TRD can separate charged particles by their gamma-factor

More details about TRD: B. Dolgoshein, Transition radiation detectors, 1993 Nucl. Instr. and Meth. A 326 434-469.

eRD22 - Development of GEM-TRD/T

- BNL, in association with Jefferson Laboratory and the DOE Office of Nuclear Physics, has established a **generic detector R&D program** to address the requirements for measurements at a future Electron Ion Collider (EIC).

- eRD22 is an one of the Working Group of this R&D program, dedicated to the development of **MPGD based Transition Radiation Detector for electron ID** in the hadron endcap of a future EIC detector

eRD22 Working Group Team:

- **Jefferson Lab (JLab)**

  People: Y. Furletova, S. Furletov, L. Pentchev, H. Fenker, B. Zihlmann, C. Stanislas, F. Barbosa.

  Expertise and R&D: Transition Radiation Detectors, Fast Readout Electronics, Beam Test Facility …

- **University Of Virginia (UVa)**

  People: K. Gnanvo, N. Liyanage

  Expertise and R&D: Prototyping of the GEM based Transition Radiation Detectors (GEM-TRD/T)

- **Temple University (TU)**

  People: M. Posik, B. Surrow

  Expertise and R&D: GEM detector development and Gas Mixture System

GEM-TRD/T Prototype

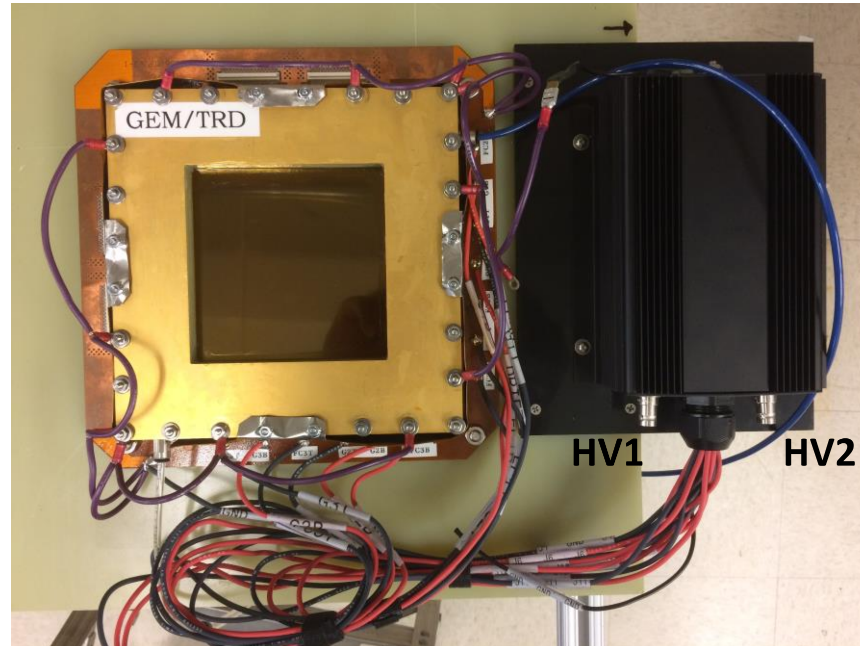
GEM-TRD/T Prototype:

- Refurbishment of standard 10 cm × 10 cm CERN Triple-GEM detector
- 21 mm drift volume with field cage system ⇨ 7 electrodes to the r/o board
- Minimization of the gap b/w drift cathode and the entrance window
- Chromium foil for the cathode to minimize material
- Operate with Xe-based mixture instead of Ar-CO_2

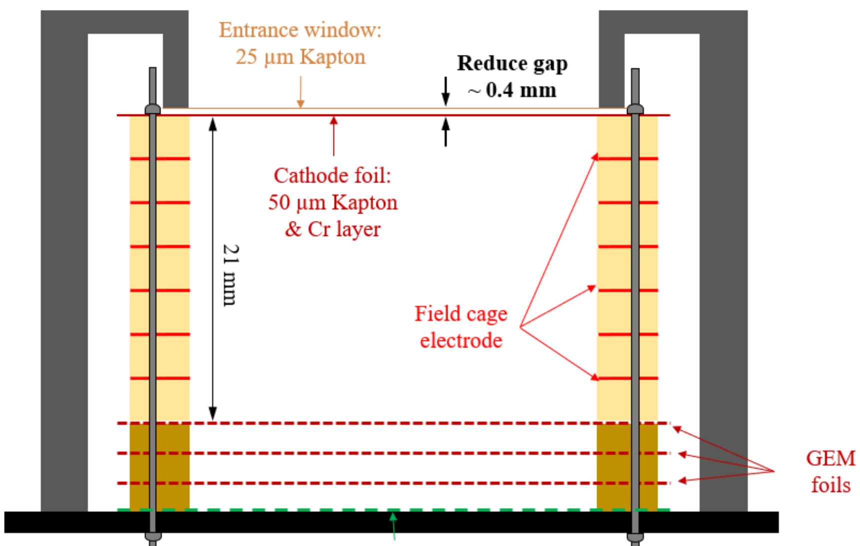
Development of new HV divider for the GEM-TRD-T prototype

- Designed at JLab Electronics Group
- 2 HV independent inputs: HV1 for amplification and HV2 for cathode
- Independent control of E-field in the drift and amplification in the GEMs

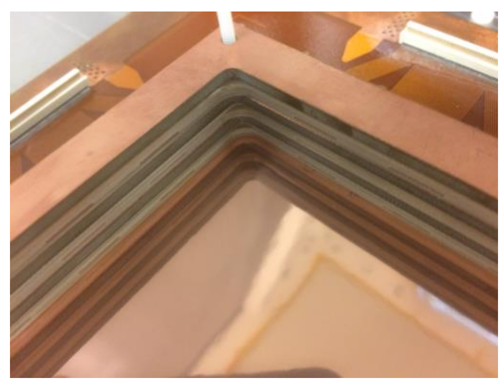
GEM-TRD/T Prototype



Cross section of GEM-TRD/T



Field cage for 21 mm drift



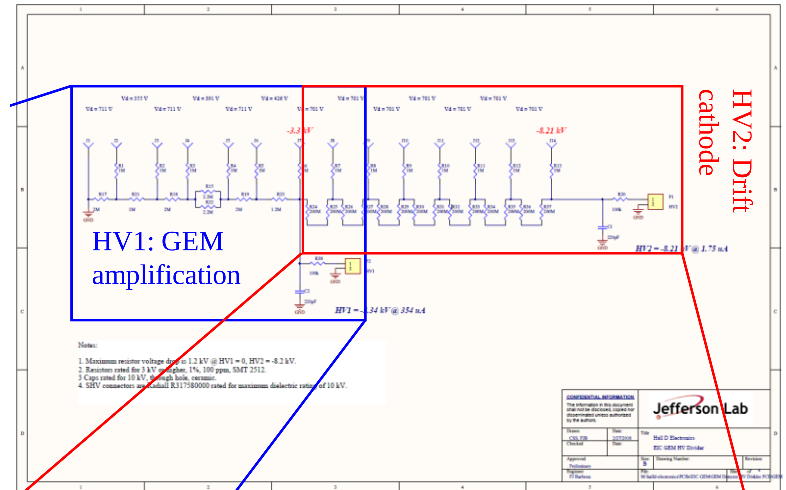
New HV divider board

GEM-TRD/T HV Resistive Divider

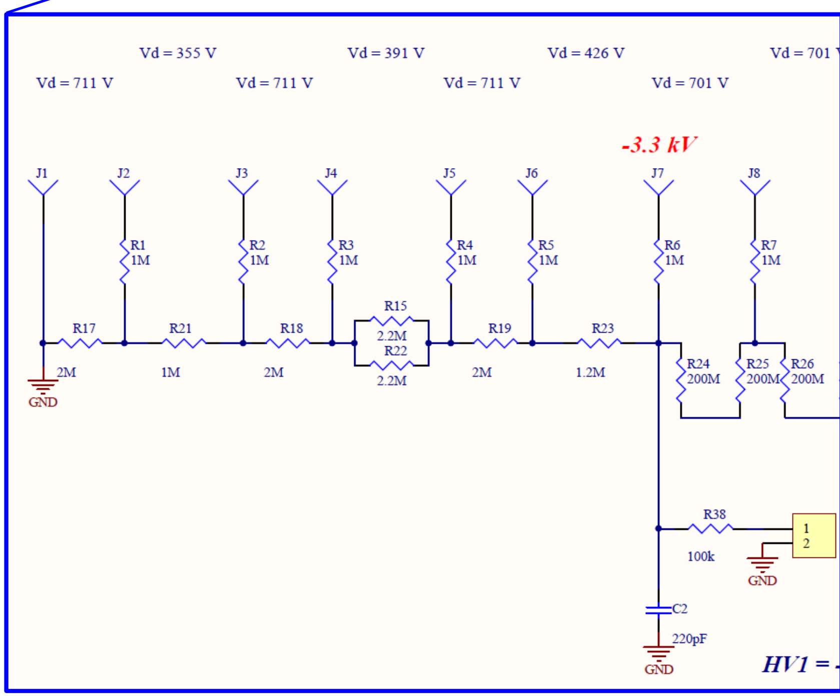
Specification and characteristics of the new divider

- Resistors rated for 3 kV or higher, 1%, 100 ppm, SMT 2512.
- Caps rated for 10 kV, through hole, ceramic.
- SHV connectors are Radiall R317580000, maximum dielectric rating of 10 kV
- Maximum resistor voltage drop is 1.2 kV @ HV1 = 0, HV2 = -8.2 kV.
- HV filters to HV1 & HV2 and multiple ground connections and 1 MΩ spark protection resistors in series with each electrode.

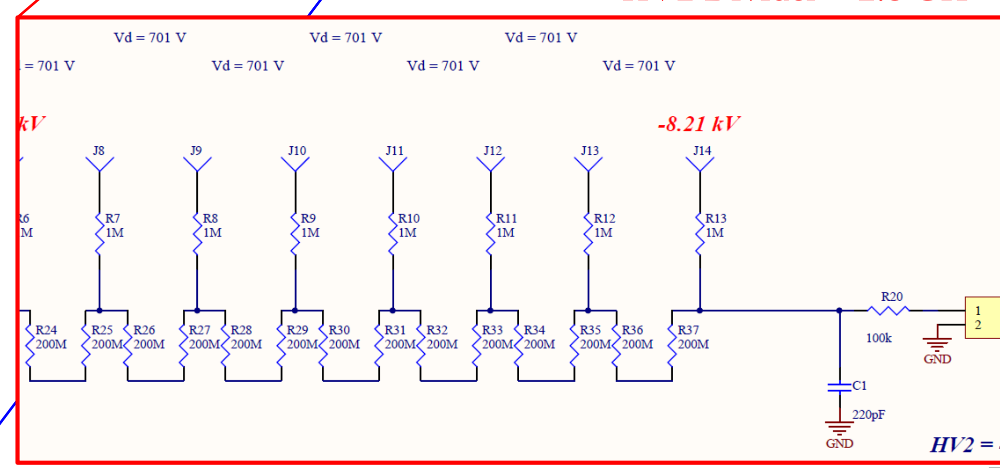
Schematics of the GEM-TRD/T HV divider



HV1 Divider = 9.3MΩ



HV2 Divider = 2.8 GΩ



Readout Electronics for GEM-TRD/T

Basic requirements for GEM-TRD/T:

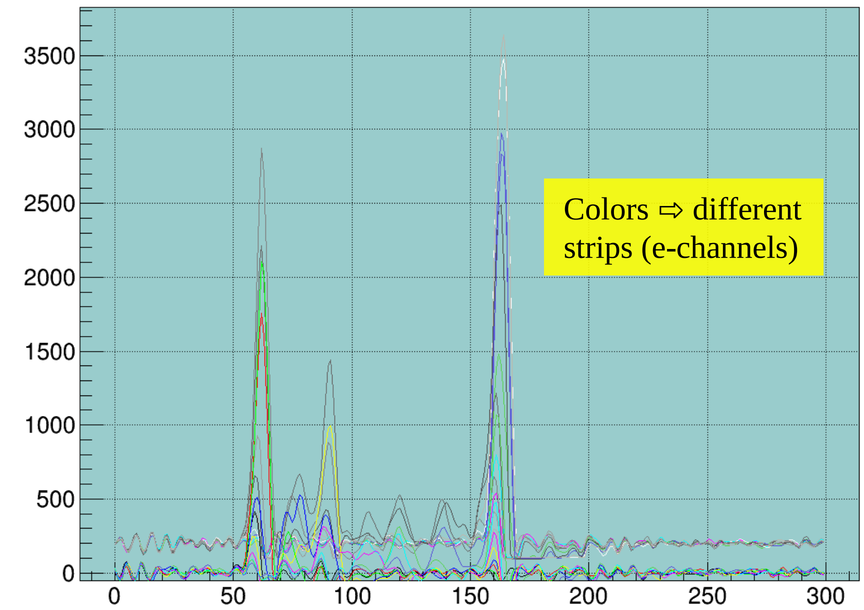
- Long drift distance ⇨ large readout window (pipeline electronics)
- Cluster counting along the drift ⇨ Excellent timing resolution
- dE/dx energy loss vs. TR photons ⇨ Good ADC resolution

⇨ Standard chips such as APV25 or DREAM or SAMPA are not the answers

For the GEM-TRD/T prototype we used:

- Pre-amplifier cards with 24 channels GAS-II ASIC (JLab GlueX Wire Chambers) with a charge sensitivity of 2.6 mV/fc and 10 ns peaking time
- JLab custom 125 MHz, 14 bits Flash ADC with VME readout developed
- FADC readout window up to 8 ms @ 125 MHz (up to 1000 time samples)
- Adapter board with Panasonic connectors to interface with the prototype

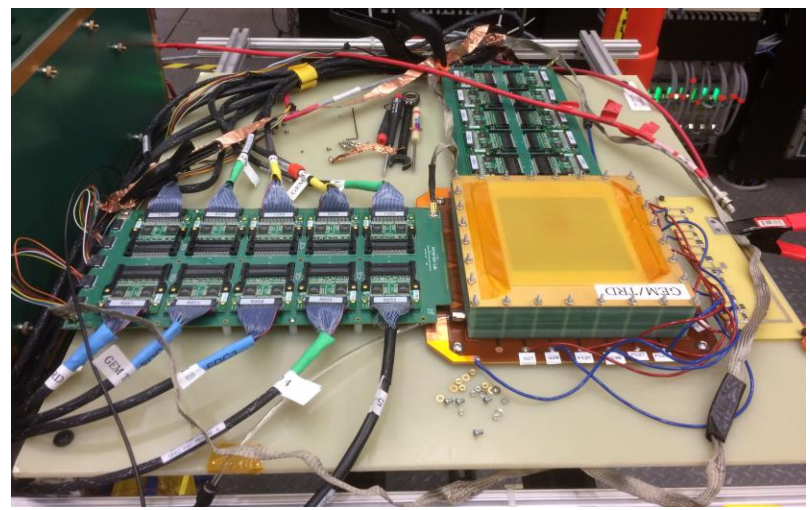
Fast signal samples from F125



Pre-amp card

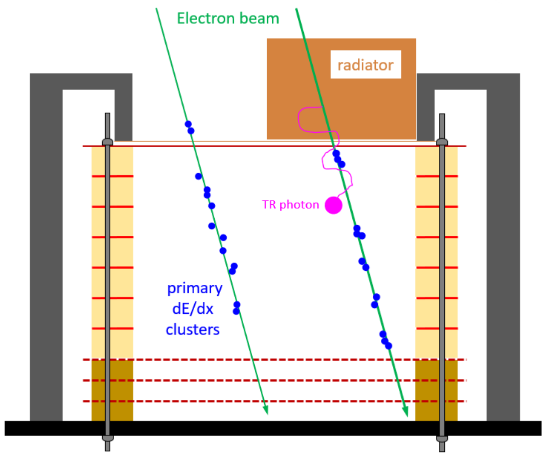
VME based Flash ADC boards (F125)

Adapter board with the pre-amps on GEM-TRD

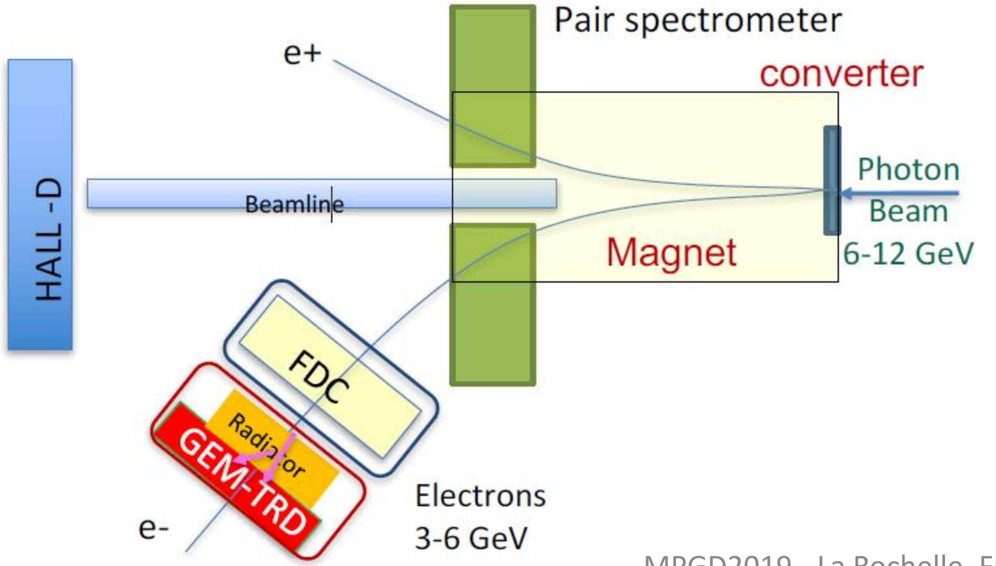


Test Beam Setup in Hall D @ JLab

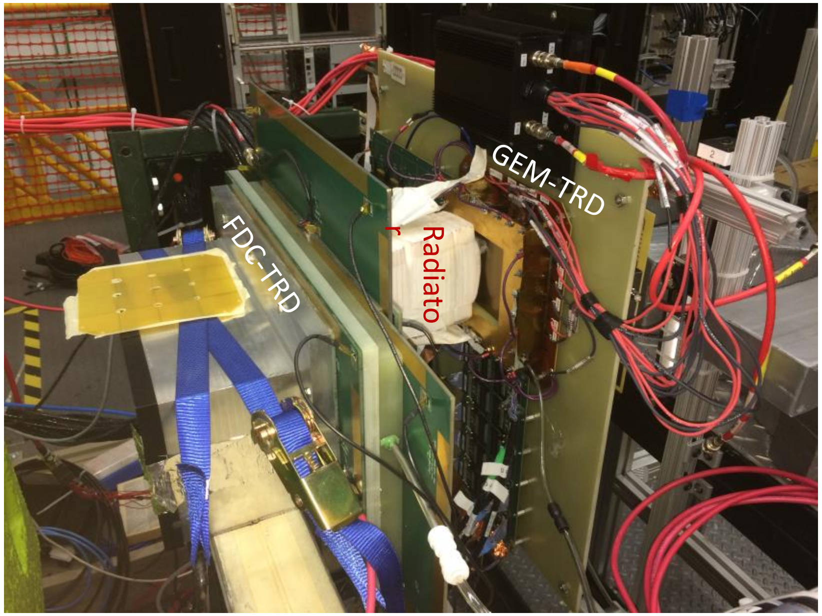
- Test beam campaign during JLab spring, fall run 2018 and spring Run 2019
- Tests carried out with GEM-TRD and FDC-TRD (Forward Drift Chambers)
- 3 to 6 GeV electrons are produced in the converter of a pair spectrometer
- No pion beam for direct comparison of the TR effect for JLab beam tests
- The radiators and covers about half of the sensitive area of the GEM-TRD
- Analysis is done by comparing the energy deposited in the drift volume covered with and without radiator



Hall D beam Line



GEM-TRD setup @ JLab Hall D



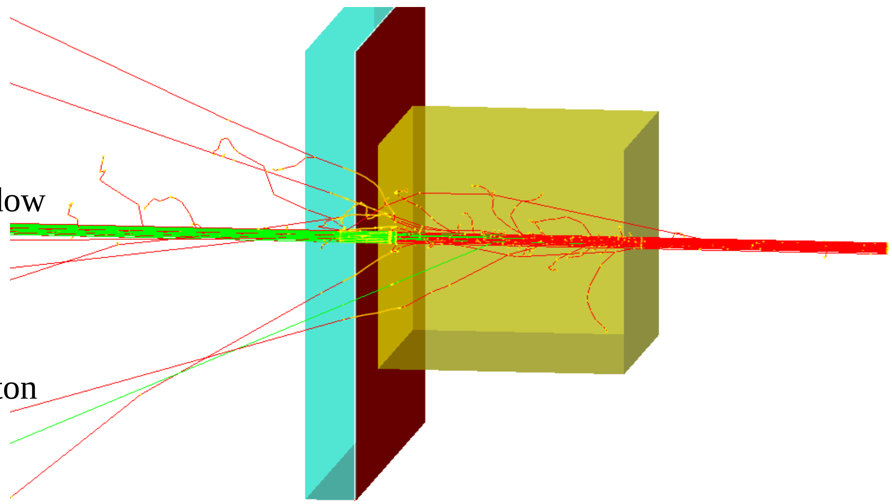
GEANT4 Simulation

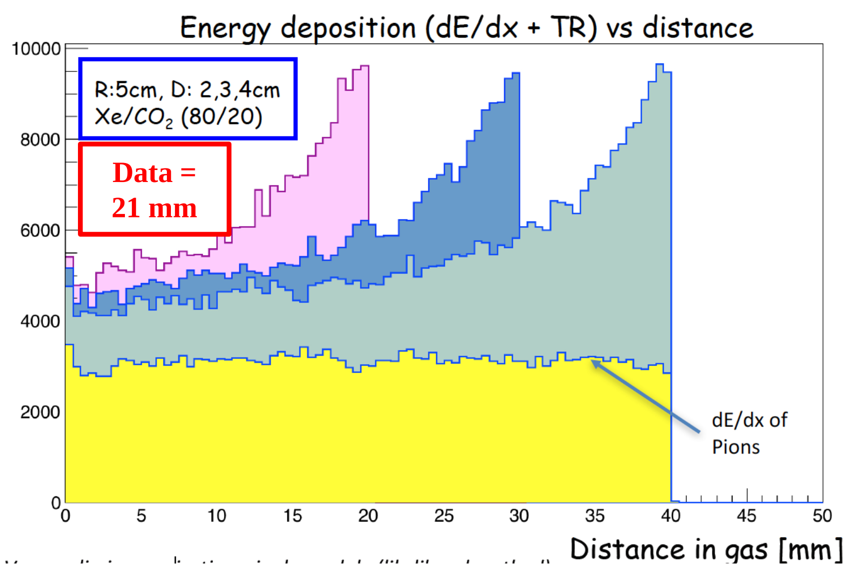
Soft TR-photons

- Absorbed near the entrance window ⇨ have the largest drift time
- Sensitive to material between the radiator and drift
- Insensitive to drift length as they are absorbed near the entrance window
- Number of soft TR photons increase with radiator thickness

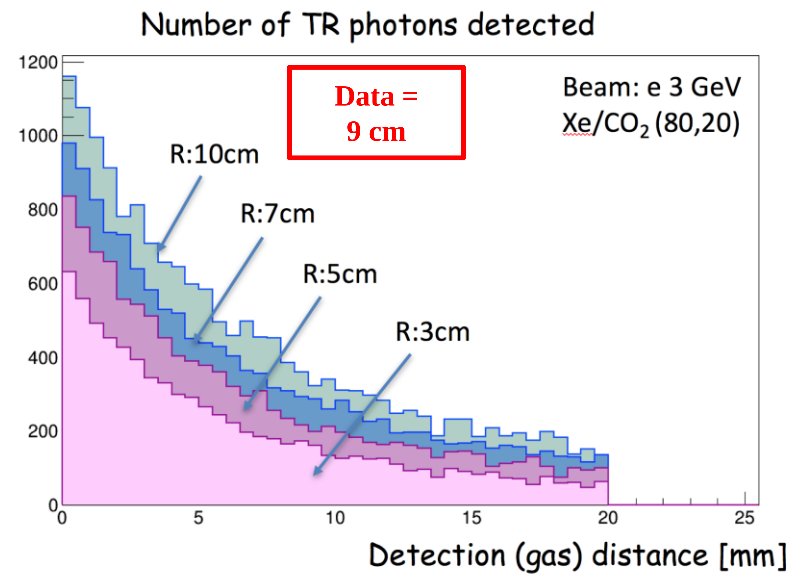
Hard TR-photons

- Can escape the detection volume depending of the energy of TR-photon
- Detection efficiency increases with drift volume
- Increasing radiator length extends hard TR spectrum





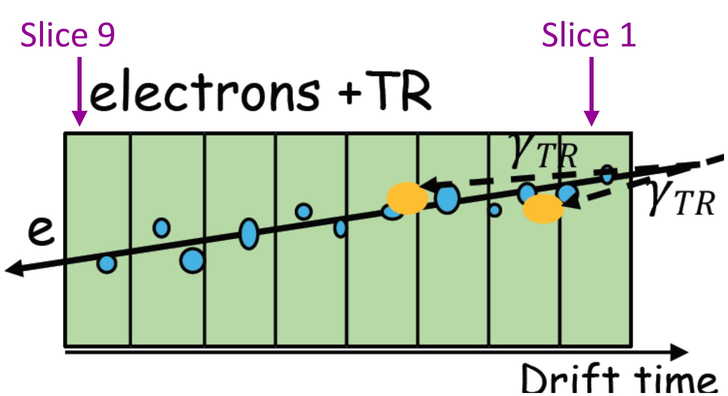
e,π ~3 GeV



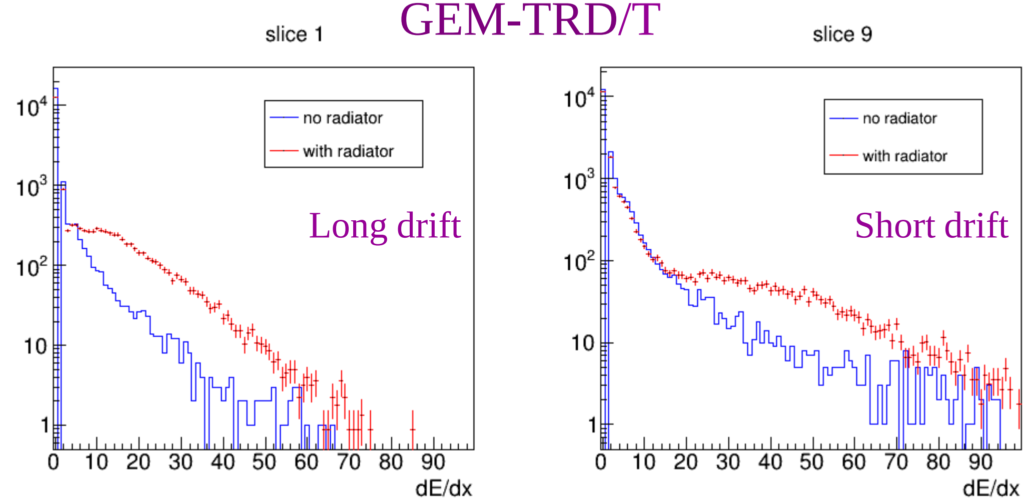
Performance of GEM-TRD/T & FDC-TRD

Comparison between GEM-TRD/T and FDC-TRD

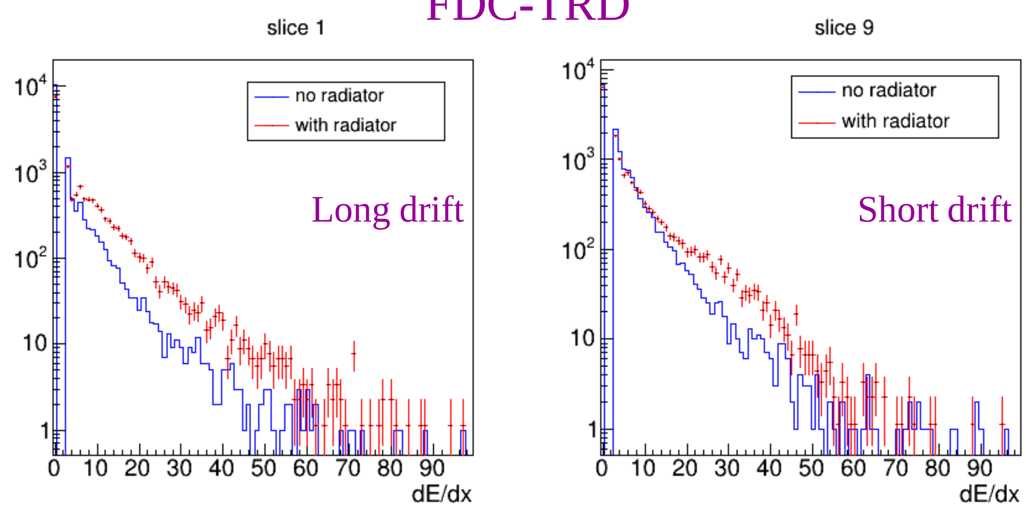
- Drift distance is divided in 10 slices and we compute the integrated ADC distribution in the area with and w/o radiator for both the GEM-TRD-T and FDC-TRD
- Slice 1 (close to the drift cathode) ⇨ where we expect the highest TRD effect, slice 9 (close the amplification)
- Data with GEM-TRD/T shows better performance than FDC (bigger difference between red and blue curve) in all slices
- Poor performances of FDC-TRD might be due to space charge effect that affect the charge collection at the sensing wire
- Similar space charge effect were observed with ALICE TRD
- MPGD can be a strong alternative to wire chambers based TRD detectors



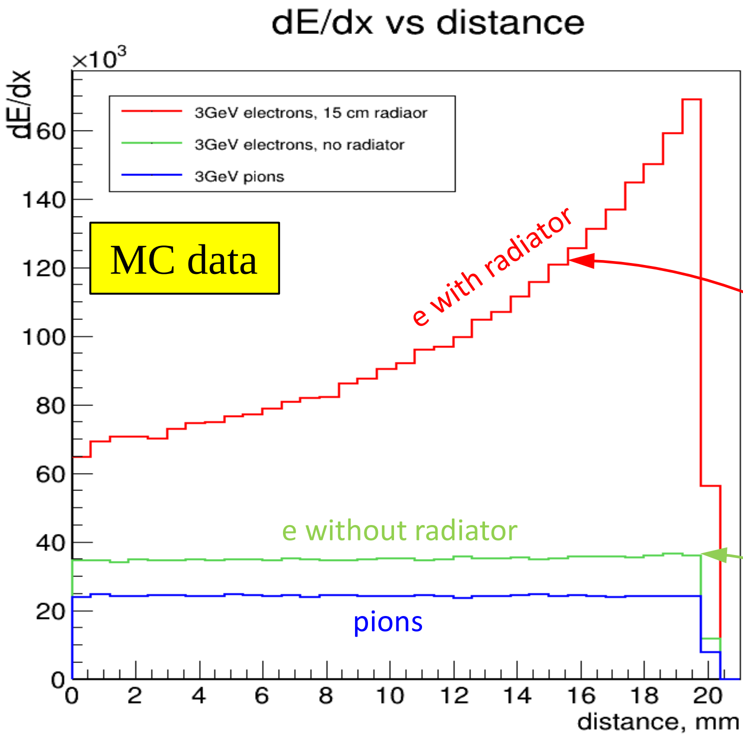
GEM-TRD/T



FDC-TRD

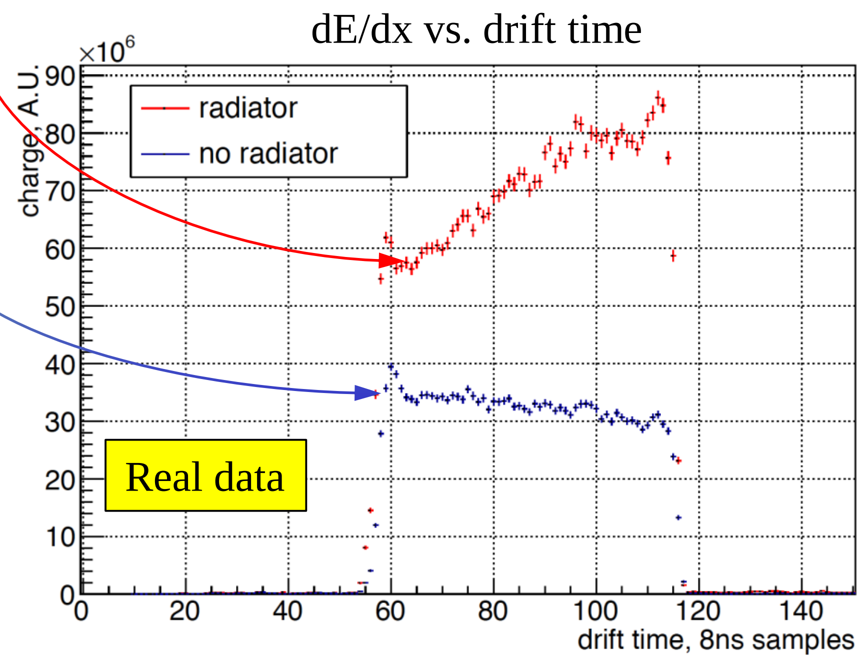


Ionization along the particle track



MC data:

- The ionization from 3 GeV electrons is about 40% higher than from 3 GeV pions
- In fact, the effective pion rejection factor will be better than results from test beam data where the pions mimicked by electron in area with no radiator

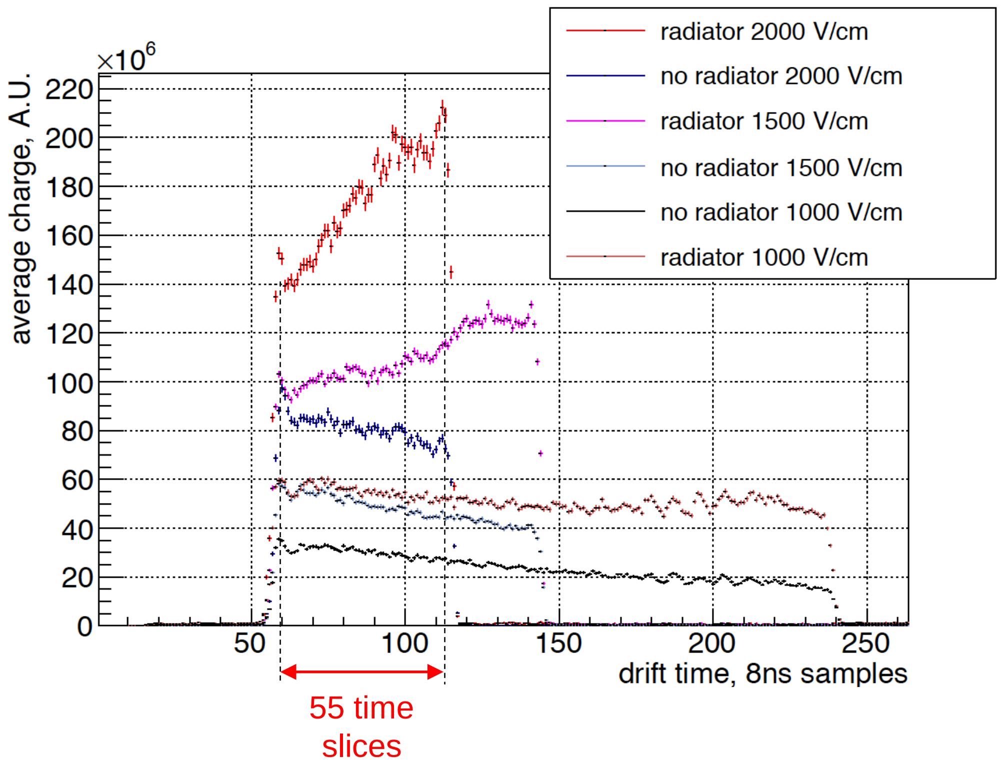


Test beam data:

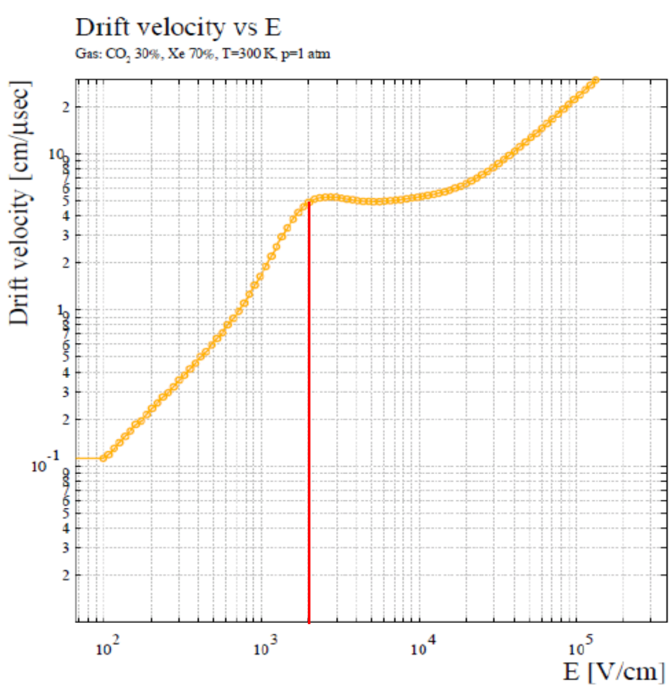
- Signal from ionization (dE/dx & photon conversion): very good agreement with MC results
- TR-photon spectrum is clearly observed in the data in the region of the detector covered by the radiator

HV scan in the drift (E-field)

Drift Field Scan



Garfield simulation of drift field

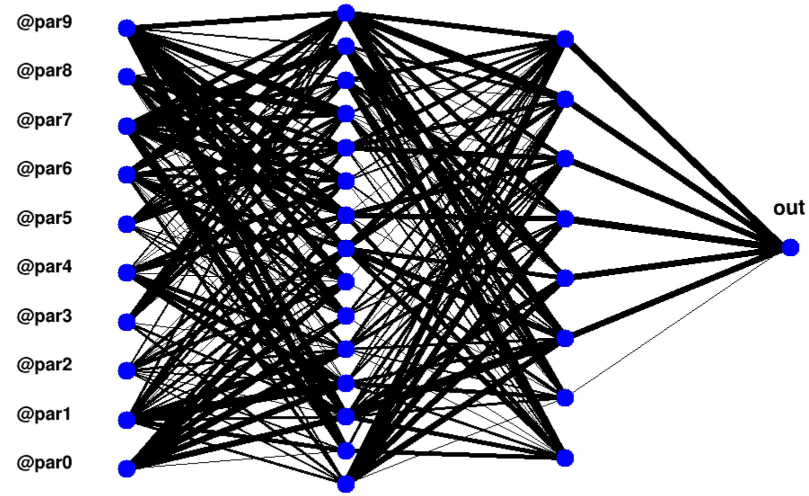


- Optimized E-field for the drift > 2 kV / cm ⇨ plateau for the drift velocity
- From Garfield simulation: drift velocity at **2 kV = 5 cm / μs** ⇨ 420 ns for 2.1 cm drift
- Good agreement with real data ⇨ about 55 time slices x 8 ns = 440 ns

Machine learning for the data analysis

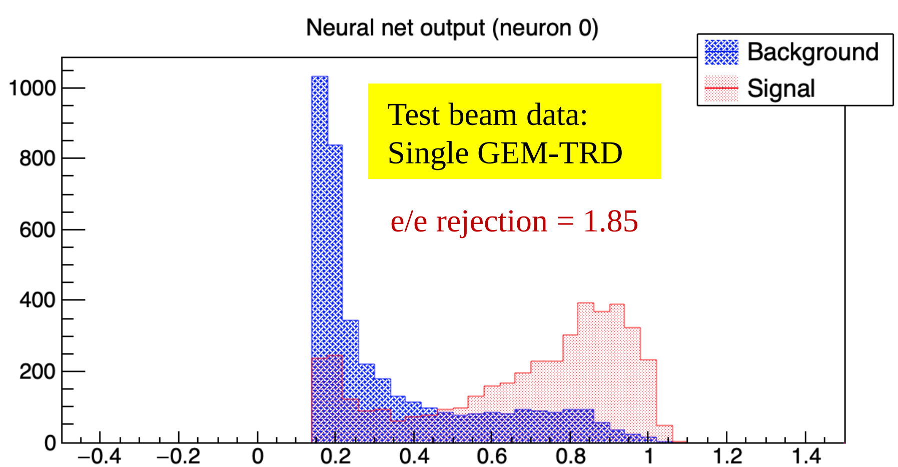
Neural network (NN) algorithm tested on MC data:

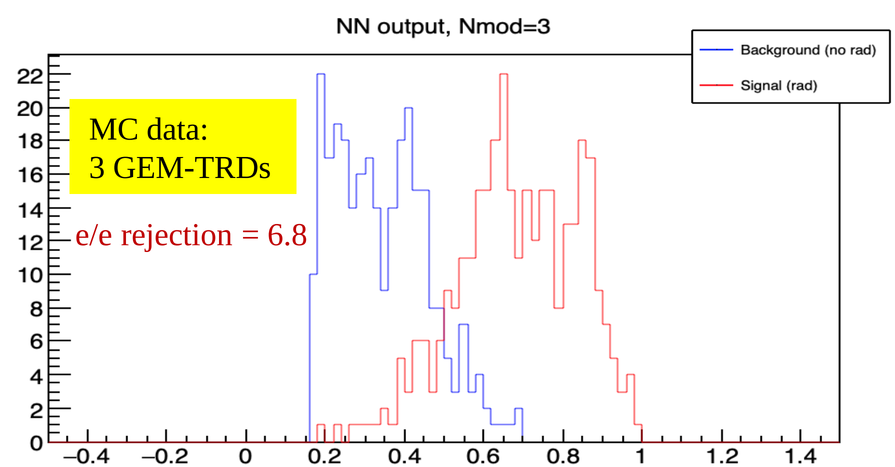
- Drift distance divided into 10 slices
- Energy deposited in each slice used as input for the NN
- 2 different programs used for cross check (JETNET and ROOT-based TMVA)
- Training on MC data: e/e with and without (signal / background) and on e/π (signal / background) with radiator.
- NN output for one GEM-TRD gives a rejection of 1.97 for e/e and 5.1 for e/π



NN on the test beam data: Used the same method as for MC data

- All data divided into 2 samples: training and test samples
- Output of the NN on the test data samples: blue / red (w/o or with radiator)
- NN output for real data for single GEM-TRD layer gives a rejection of 1.85





e/π rejection (MC vs data)

MC scan was performed with:

1. Fixed gas thickness at 20 mm and radiator length varied from 5 mm to 29 mm
2. Fixed radiator length at 15cm and gas thickness varied from 5 mm to 29 mm

GEM-TRD/T with 21 mm drift gap was tested with ~9 cm radiator

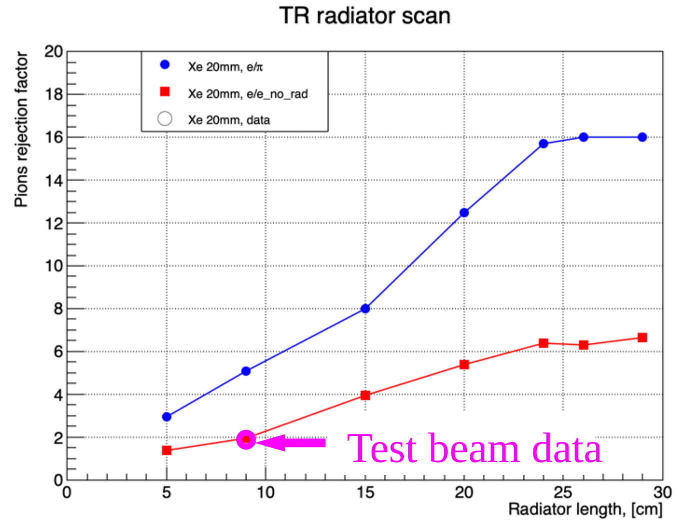
- The test beam data point (magenta) was found to be in a very good agreement with MC predictions yielding a rejection with and w/o radiation of about 1.85

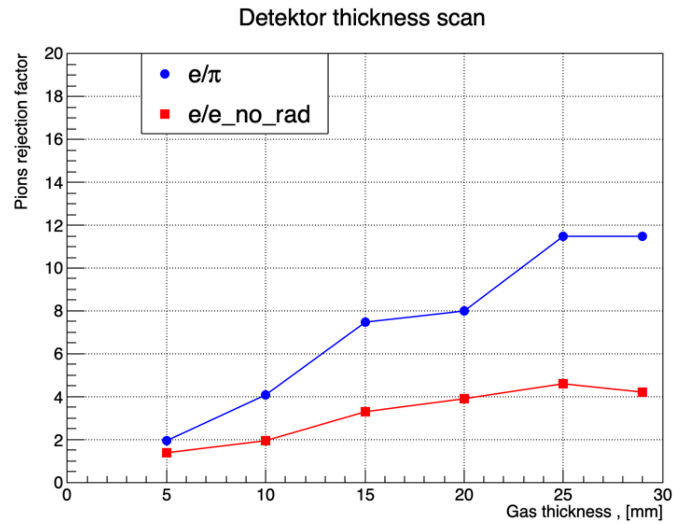
From MC scans one can predict:

- an e/π separation with **pion rejection factor of about 5.07** with the current setup
- Gas thickness 20 mm and 26 mm radiator yield an e/π rejection factor of 16
- Single GEM-TRD/T with **25 mm gas with 25 mm radiator** yields $e/\pi > 20$

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	

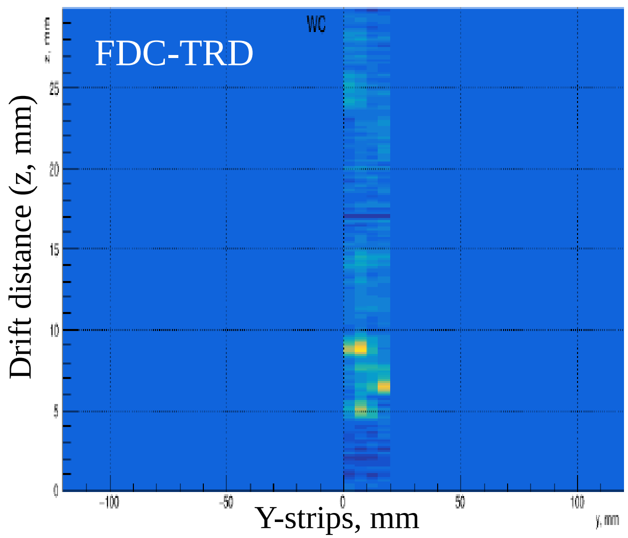
Table 1: Rejection factor corresponding to 90% of electron efficiency

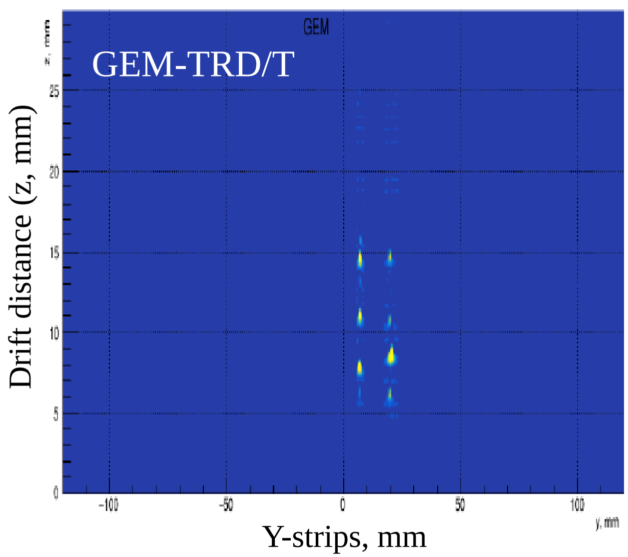




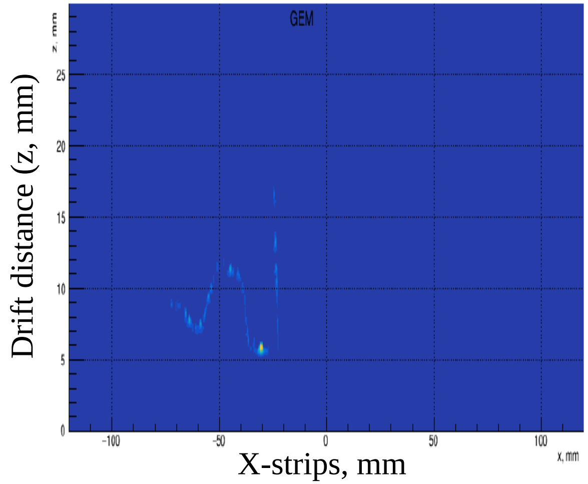
Tracking with GEM-TRD/T

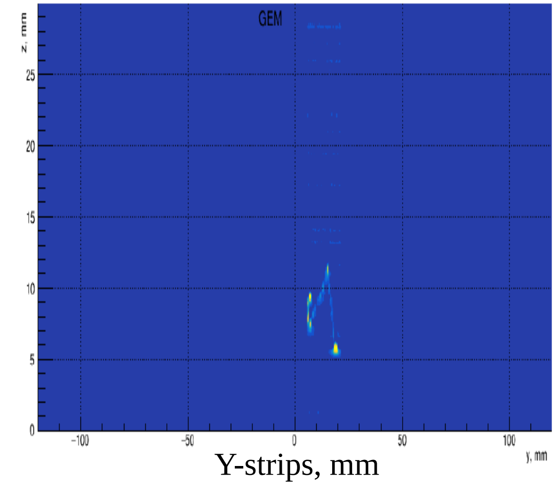
Two tracks event



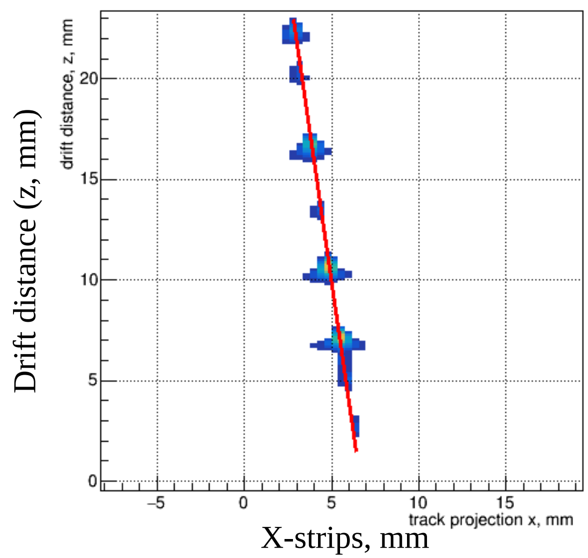


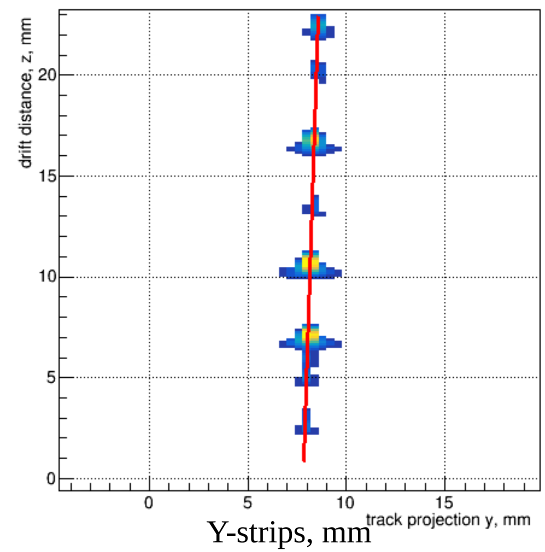
Event with delta electron track in GEM-TRD/T





Tracks from clusters separation (µTPC mode)





Summary and Outlook

Development of GEM based Transition Radiation Detector

- GEM-TRD/T for electron ID in Hadron End Cap of an EIC detector
- Additional tracking capability in µTPC mode

Preliminary beam test in the electron beam @ JLab show promising results

- TRD / dE/dx signal ratio for GEM-TRD, wire based TRD
- Good agreement with MC simulation for predicted e / π rejection
- Optimized single GEM-TRD/T layer would provide an e / π rejection higher than 20

Challenges and lessons learned from the current R&D and test beam campaign

- We observe non uniform distribution of the charge along the drift volume in no radiator area
- One of the causes might be an O_2 contamination of the Xe-CO_2 gas mixture
- Need gas mixture system and analyzer to control Xe and CO_2 concentration and O_2 contamination

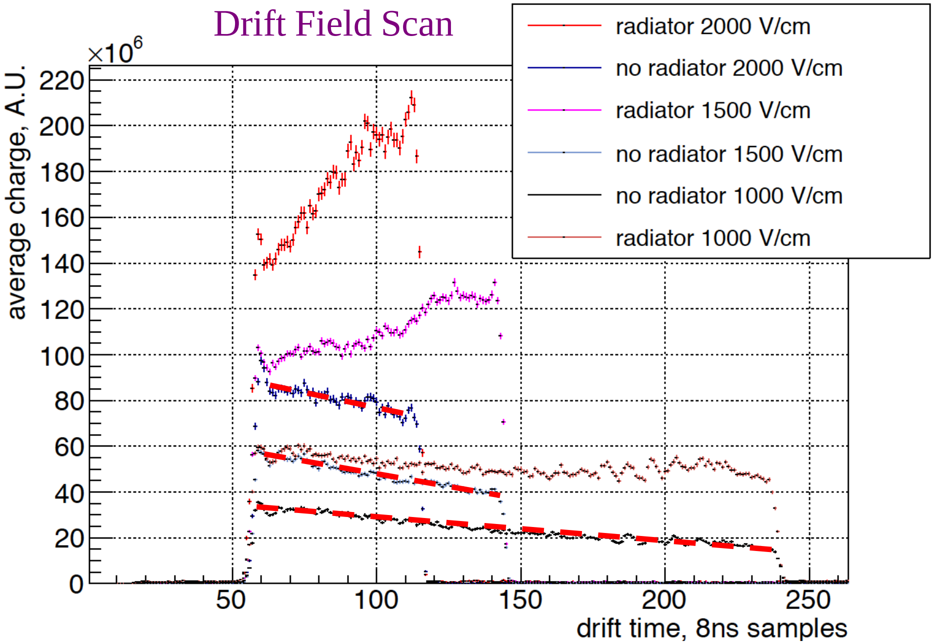
Explore alternative amplification device for TRD detectors

- µRWELL can be a good candidate for TRD application
- We want to explore this alternative in the future

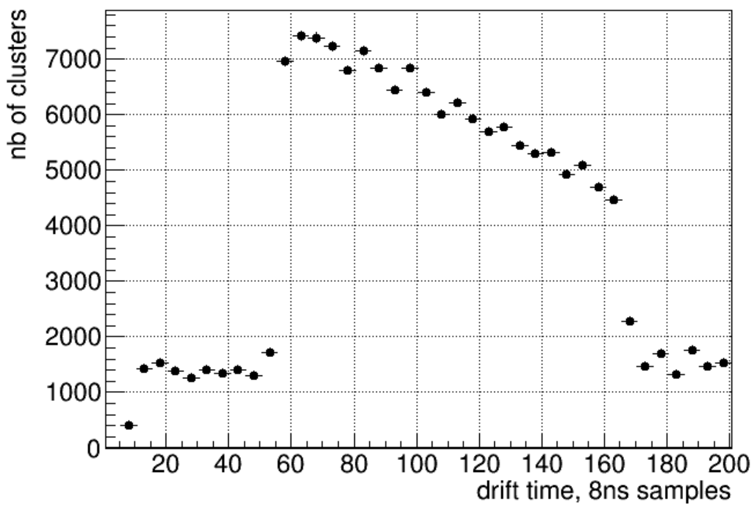
Back up

Charge collection issues in the drift

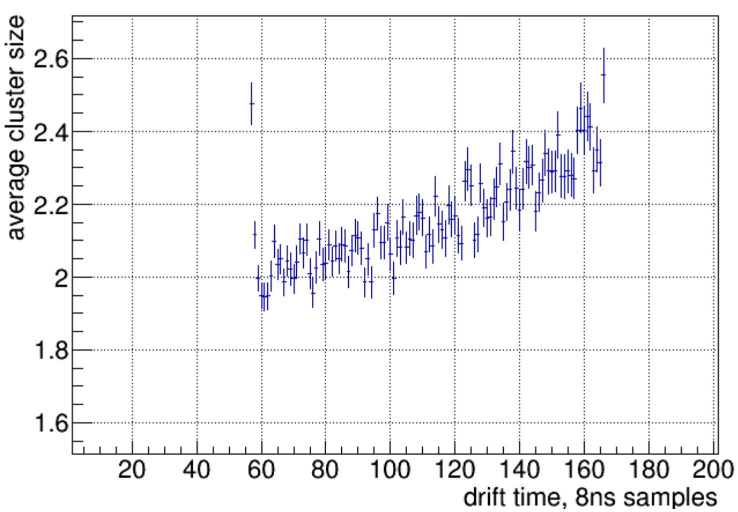
Drift Field Scan



Integrated # of clusters vs. drift distance



# of strips per cluster vs. drift distance



- We are losing clusters (charges) along the drift length
- Can be seen in the area without radiator with the decrease of average dE/dx (red lines) w.r.t drift distance where we normally expect a flat distribution
- Confirmed by the steady drop of number of clusters (expected fat distr.) and slow rise of average number of strips per cluster as a function of the drift time
- Can be explained by O_2 contamination of the Xe-CO_2 gas mixture or alternatively that we set threshold on the readout electronics too high (noisy electronics) and are cutting out clusters along drift

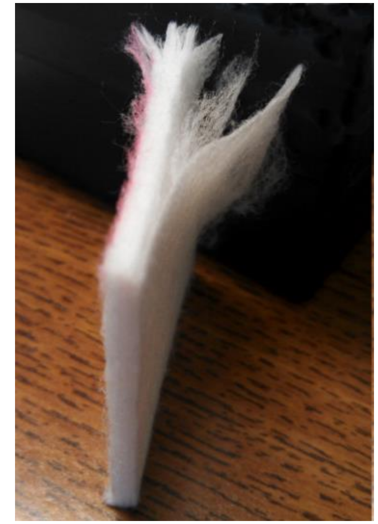
The issue is under investigation

Comparing different radiators

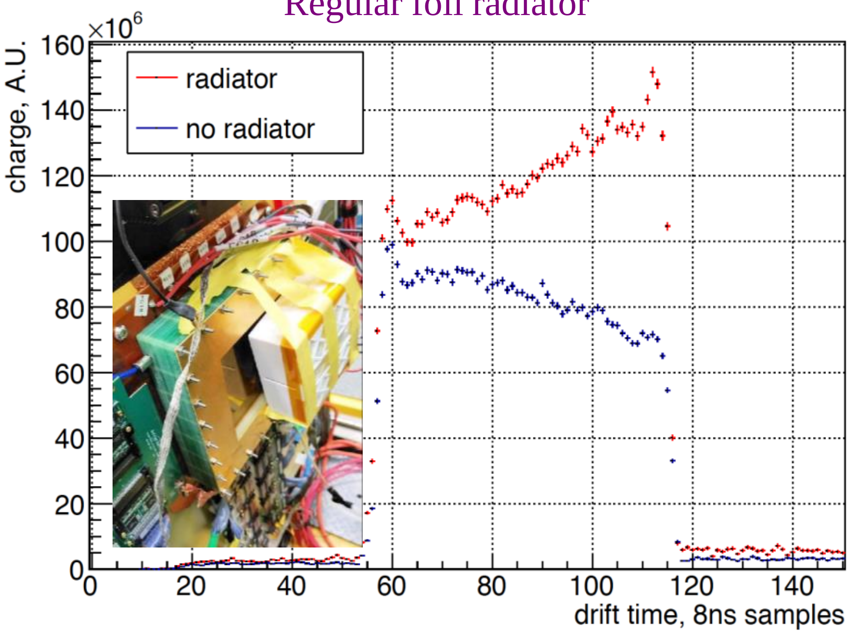
Fleece radiator:
Random oriented
Polypropylene fivers (20μm)

Regular foils:
~200 polypropylene foils (~13 μm thick) with spacers (~180μm) made from nylon net

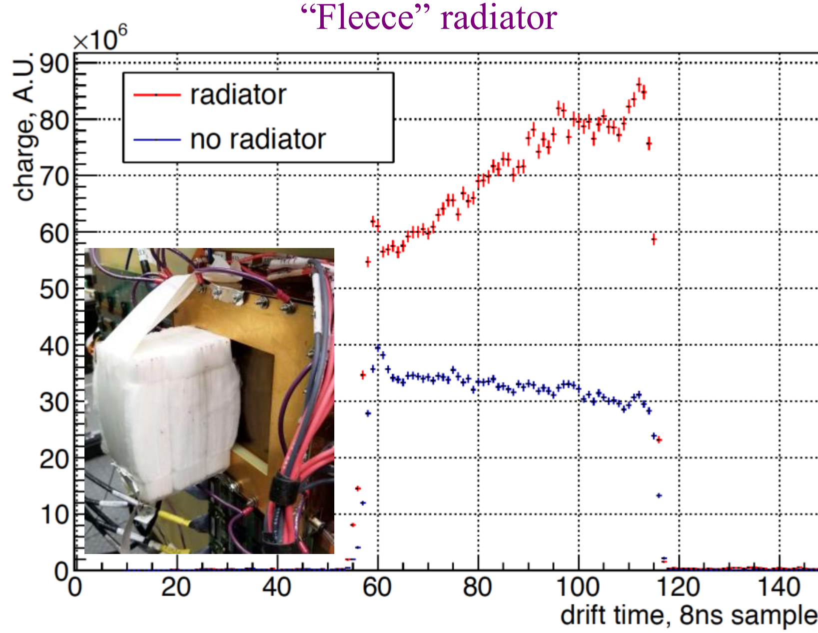
“Fleece” radiator



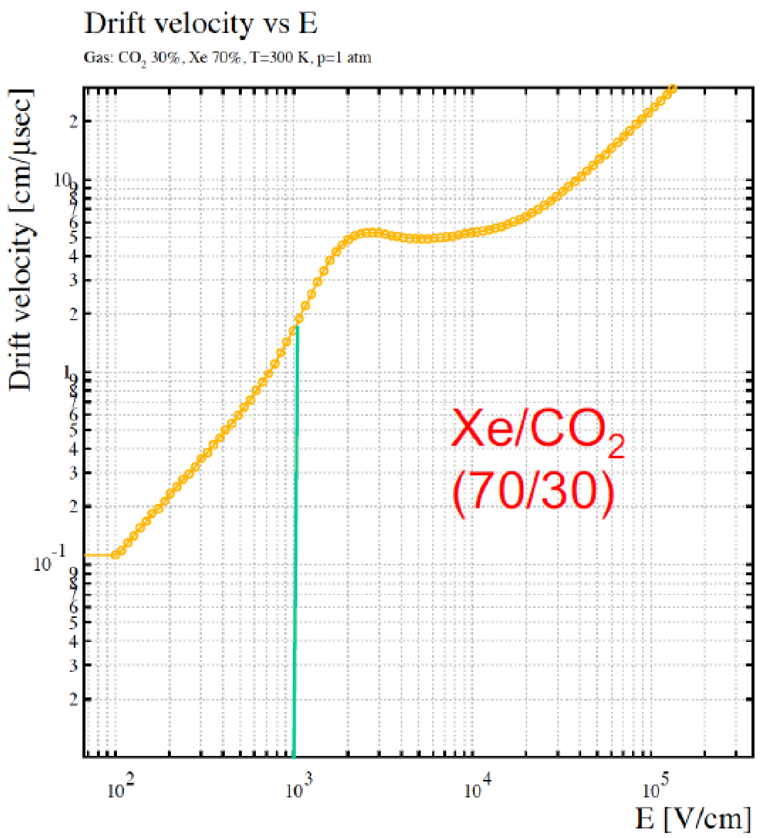
Regular foil radiator

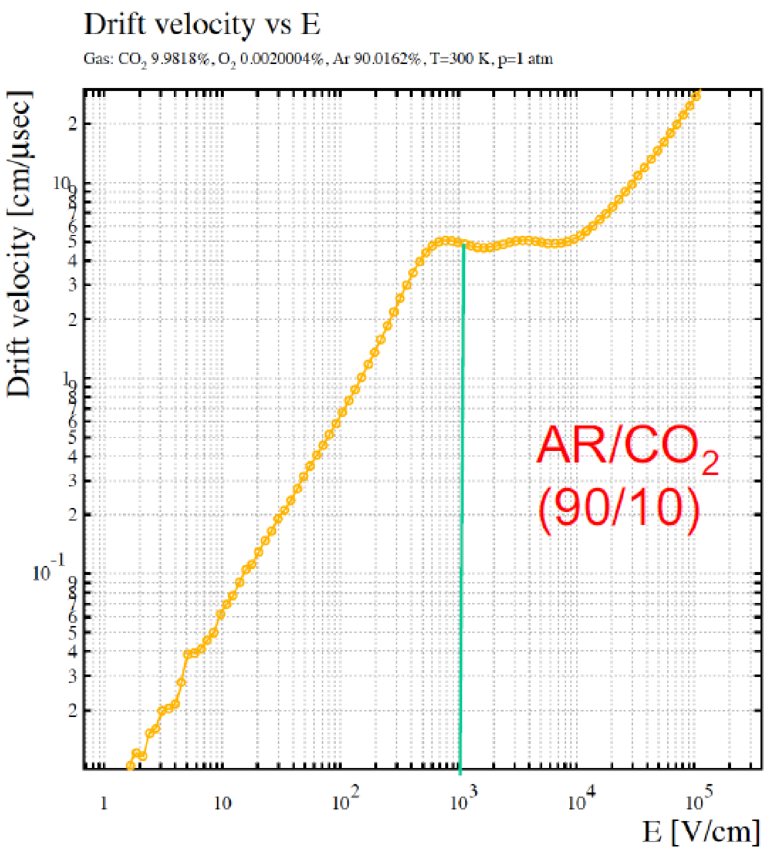


“Fleece” radiator



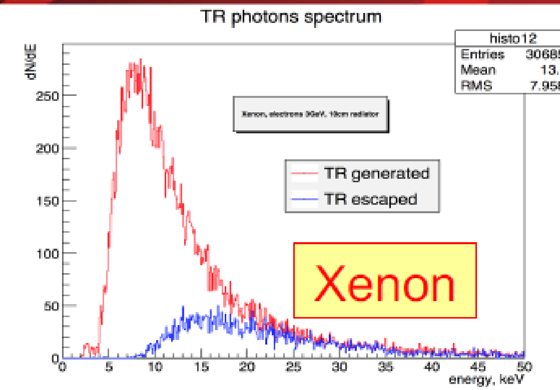
MC Simulation: Gas Mixture

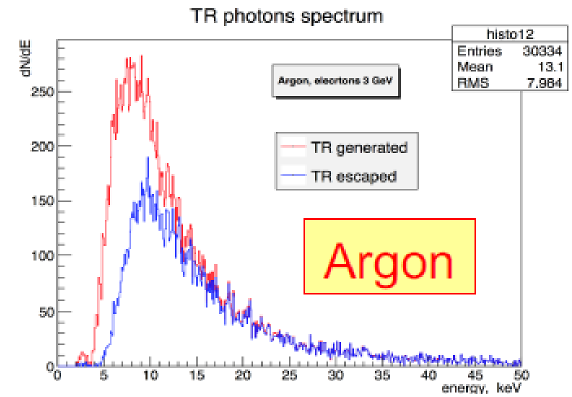




Select working gas

- GEM tracker uses Argon mixture, while TRD needs heavy gas to efficiently absorb X-rays (TR photons), typically Xenon based mixture.
- Plots on the right compare noble gases and silicon in terms of efficient absorption of TR photons : red – incoming (incident photon spectrum), blue – escaped TR-photons.
  - Gas thickness 20mm, silicon thickness 500 um
- The bottom left plot represents absorption length versus photons energy, and reflects a shell structure of atoms.





in Physics Research A 666 (2012) 130–147