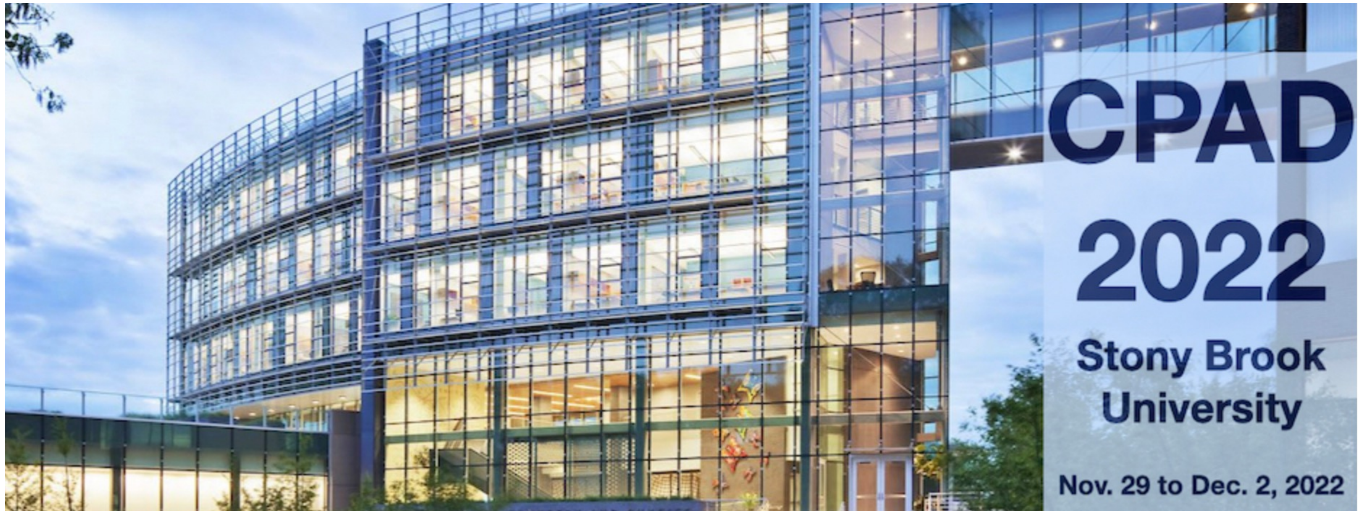


Particle Identification using GEM based TRD/T

Sourav Tarafdar

Vanderbilt University

MPGD-TRD/T consortium

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

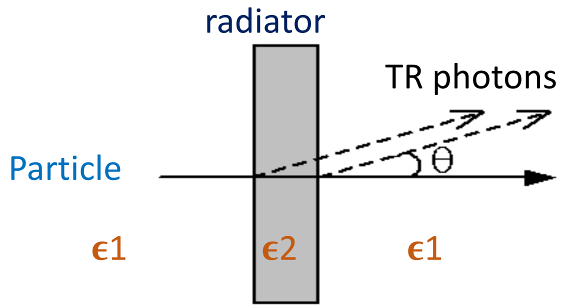
- Temple University
  - ✓ Matt Posik
  - ✓ Bernd Surrow

- Old Dominion University
  - ✓ Lee Belfore

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

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

Transition Radiation



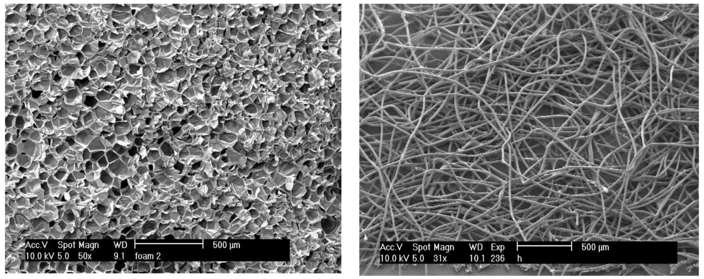
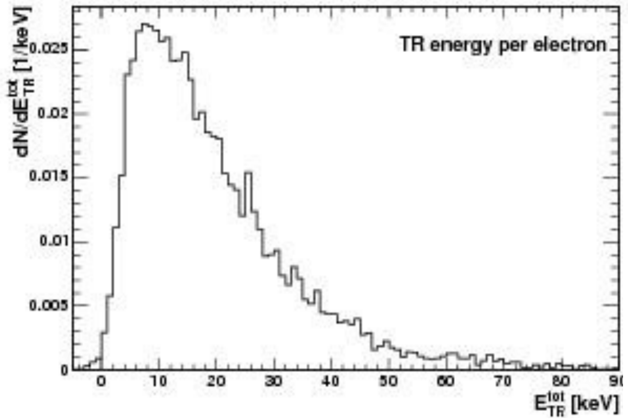
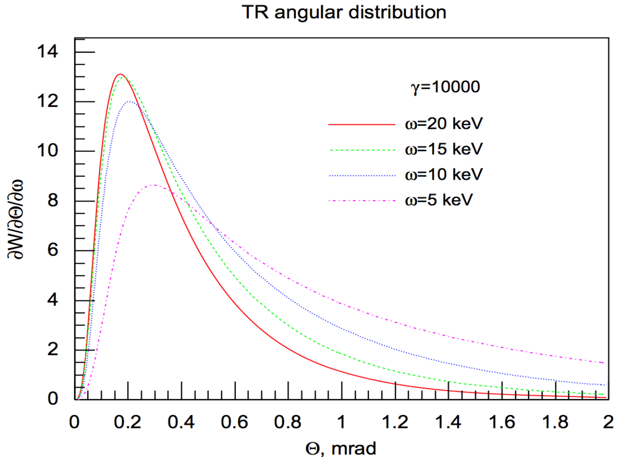
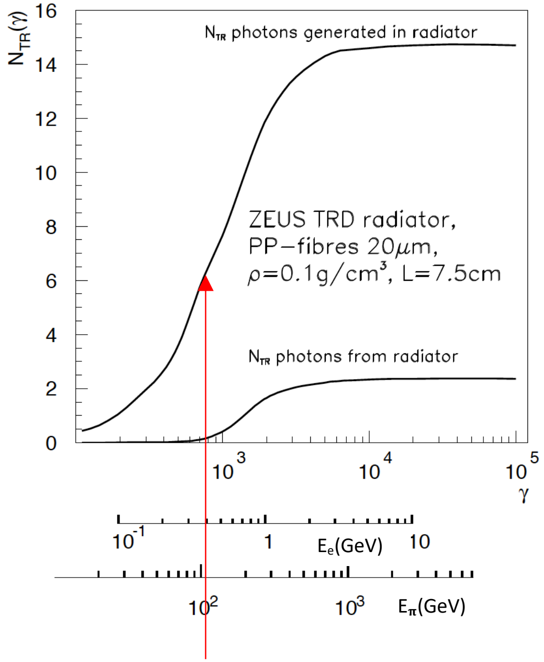


Figure 2: Electron microscope images of a polymethacrylimide foam (Rohacell HF71)(left) and a typical polypropylene fiber radiator (average diameter ≈ 25 μm) (right) [52].

- 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 α~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





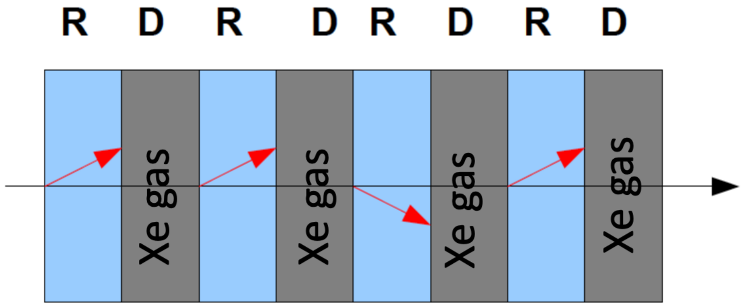


Only e produce TR photons (E > 1 GeV)

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

Detecting Transition Radiation

- Stack of radiators and absorbers (sandwich)



- Both gaseous detectors with high Z (preferably Xenon) and Si detectors are excellent candidates.

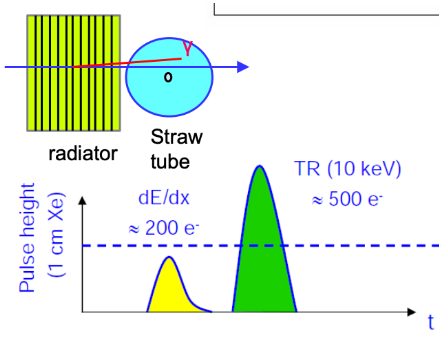
- Gas based TRD are being used by many accelerator based High Energy Physics.

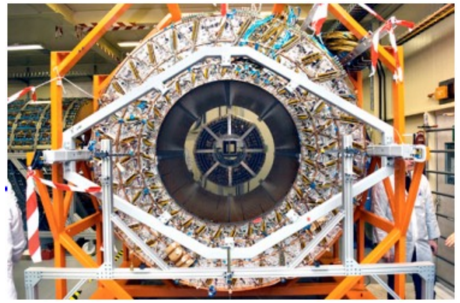
Experiment	Radiator (x, cm)	Detector (x, cm)	Area (m^2)/N	L (cm)	No. of chan.	Method	π_{rej}
HELIOS	Foils (7)	Xe–C_4H_{10} (1.8)	4/8	70	1744	N	2000
H1	Foils (9.6)	Xe–He–C_2H_6 (6)	5.3/3	60	1728	FADC	10
NA31	Foils (21.7)	Xe–He–CH_4 (5)	18/4	96	384	Q	70
ZEUS	Fibers (7)	Xe–He–CH_4 (2.2)	12/4	40	2112	FADC	100
D0	Foils (6.5)	Xe–CH_4 (2.3)	11/3	33	1536	FADC	50
NOMAD	Foils (8.3)	Xe–CO_2 (1.6)	73/9	150	1584	Q	1000
HERMES	Fibers (6.4)	Xe–CH_4 (2.54)	28/6	60	3072	Q	1400
kTeV	Fibers (12)	Xe–CO_2 (2.9)	39/8	144	~ 10 k	Q	250
PHENIX	Fibers (5)	Xe–CH_4 (1.8)	300/6	4	43 k	FADC	~ 300
PAMELA	Fibers (1.5)	Xe–CO_2 (0.4)	0.7/9	28	964	Q,N	50
AMS	Fibers (2)	Xe–CO_2 (0.6)	30/20	55	5248	Q	1000
ATLAS	Fo/fi (0.8)	Xe–CO_2–O_2 (0.4)	1130/36	40–80	351 k	N,ToT	100
ALICE	Fi/foam (4.8)	Xe–CO_2(3.7)	716/6	52	1.2 mil.	FADC	200

- TRDs can see all charged particles based on dE/dx.

- Different experiments uses various methods to distinguish TR γ from charged hadrons

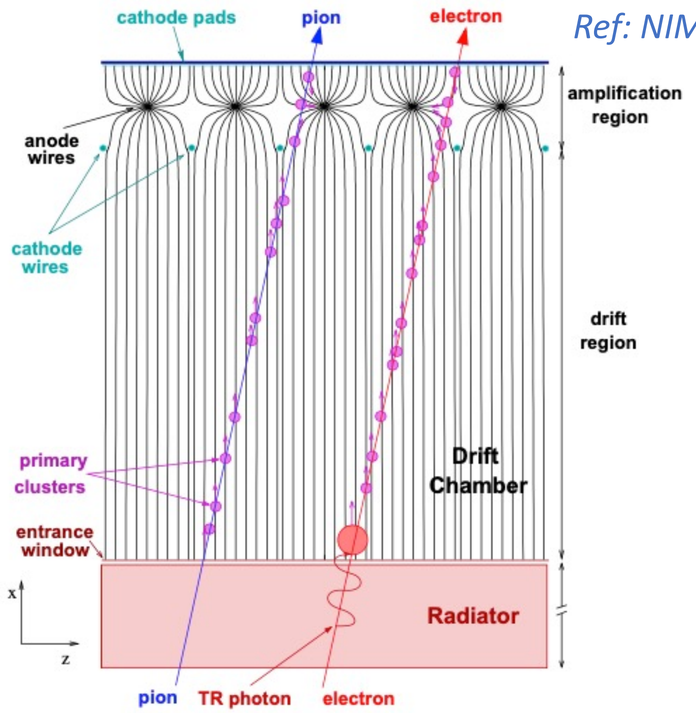
- Discrimination by threshold (ATLAS)
- Average pulse height along adjacent pads (or along a track) (ALICE)



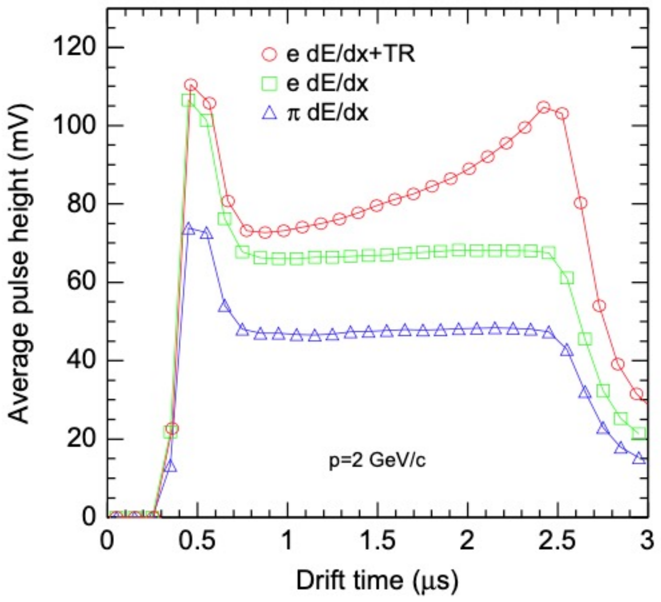


Detecting Transition Radiation (MWPC, Silicon)

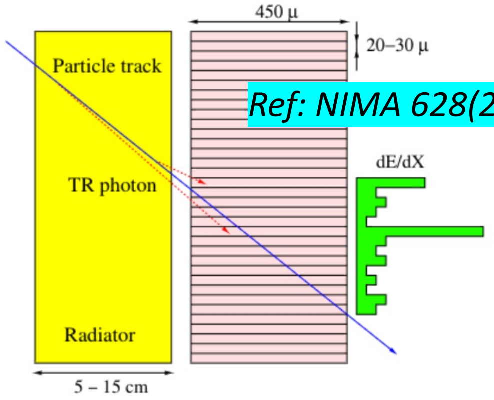
- With MWPC (e.g. ALICE TRD) : Significant increase in the average pulse height for electrons at later drift times due to absorption of the transition radiation near the entrance of the drift chamber.



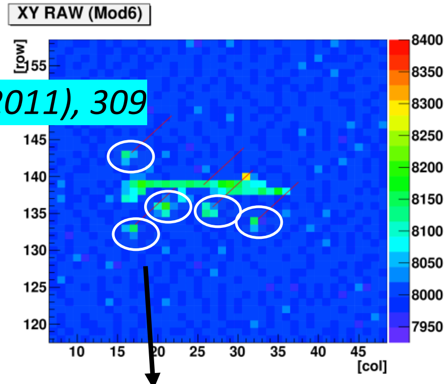
Ref: NIMA 666(2012), 130



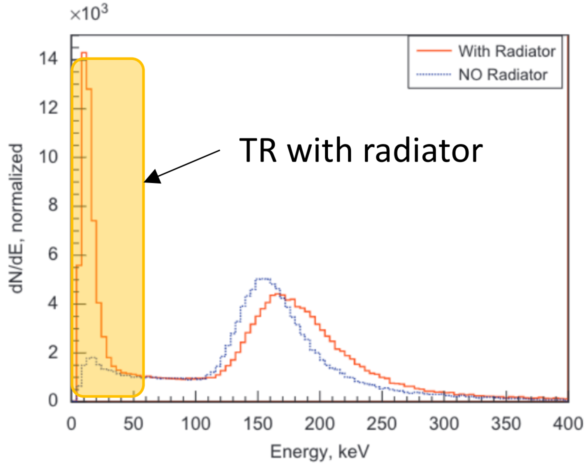
- Similar effect with a silicon (DEPFET pixel) where TR clusters could be seen as separate clusters.



Ref: NIMA 628(2011), 309



White circles TR dE/dx



TR with radiator

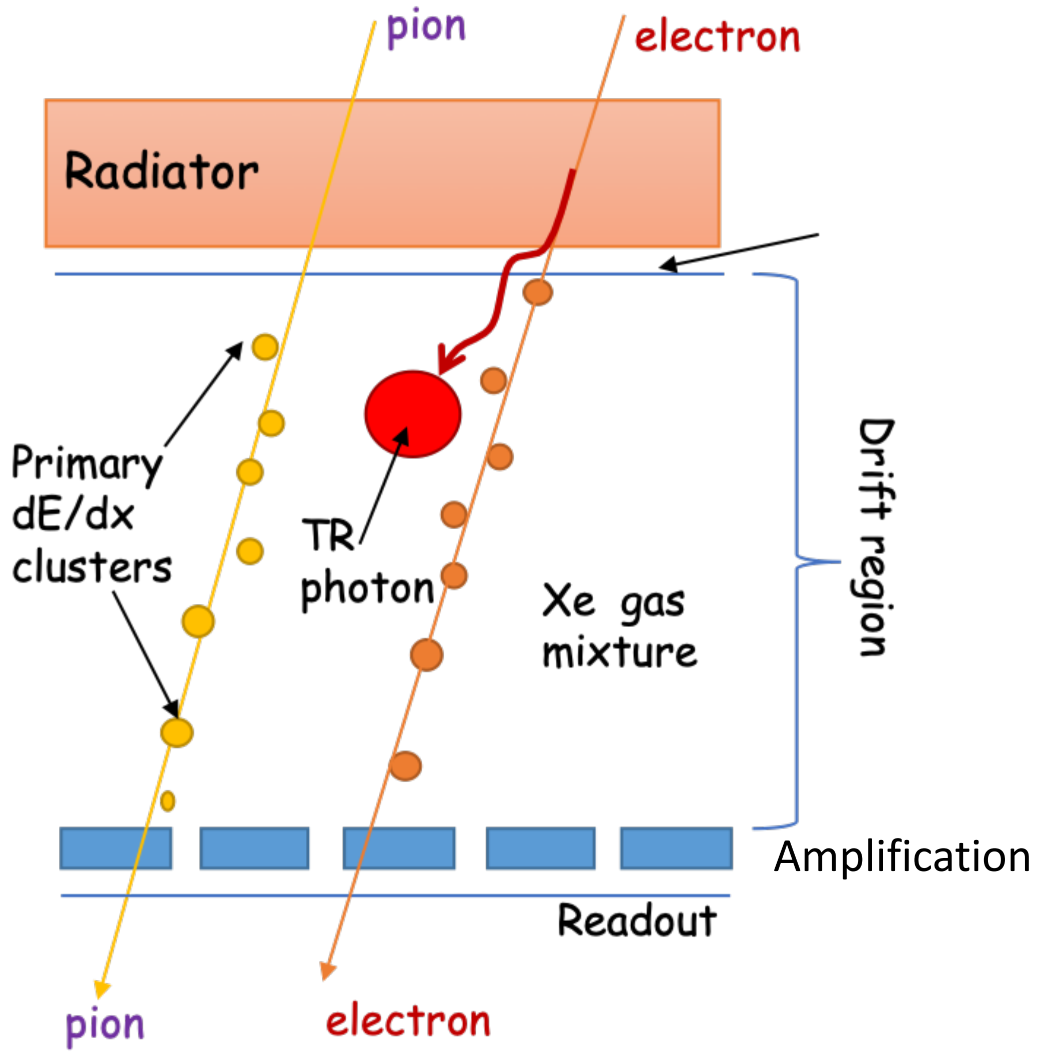
GEM based Transition Radiation Detector/Tracker

Why GEMs /MPGD ?

- High resolution tracker.
- Good energy resolution and high rate capability.
- Less affected by space charge accumulation

Convert GEM/MPGD tracker to TRD

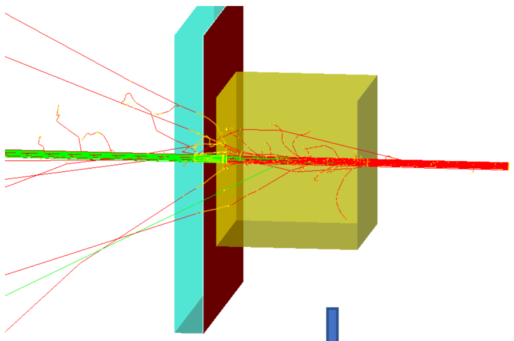
- Increase drift gap (~2-3 cm)
- Use heavier gas mixture (Xe or Kr)
- Implement radiator at entrance (~5-15 cm, depending on multi layered thin TRDs or single layer thick TRD)
- Implementing suitable readout electronics



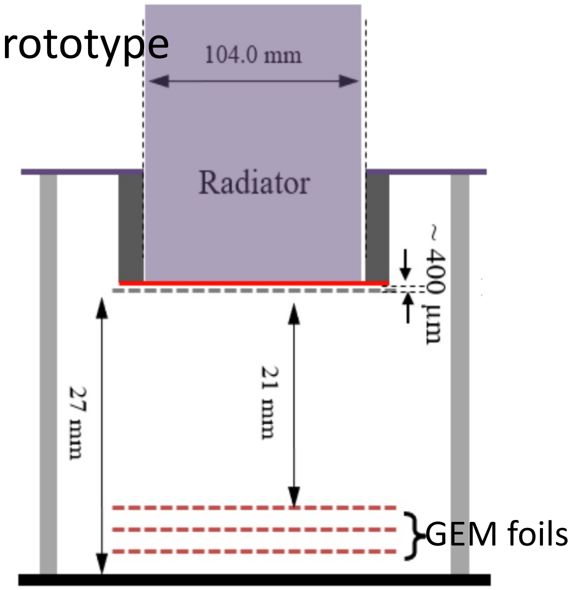
GEM based Transition Radiation Detector/Tracker

- First prototype based on triple GEM assembled at UVA.
- Drift gap was chosen as ~ 2.0 cm based on standalone Geant4 simulation.
  - ✓ Drift gap > 2 cm do not provide additional advantage in terms of TR yield
- Fleece Radiator length of 10 cm was used.
- Xenon gas was chosen.
- Two individual HVPS channels were used for biasing triple GEM via voltage divider and for independent biasing of drift cathode

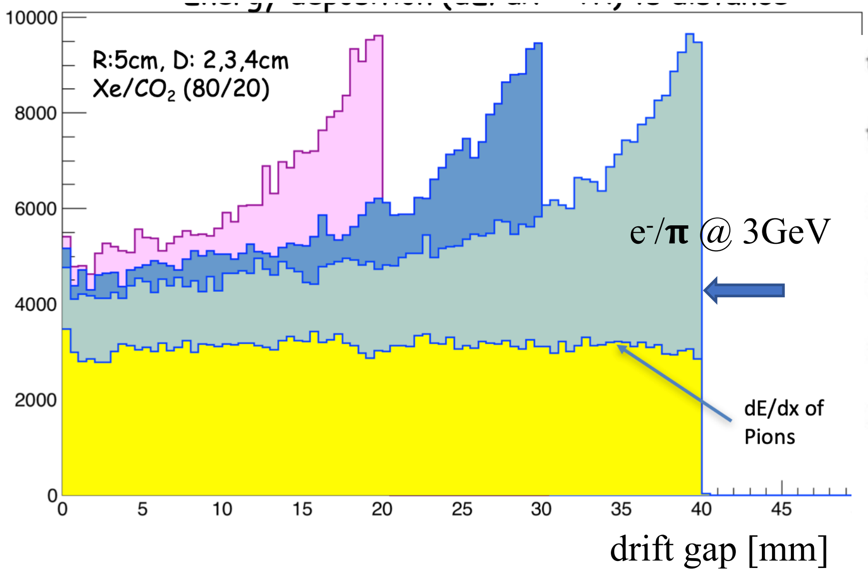
Geant4 model

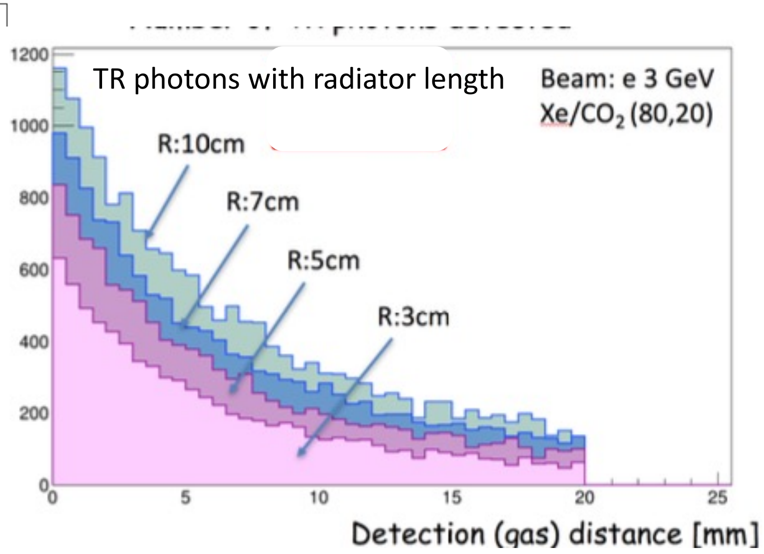


GEM-TRD prototype



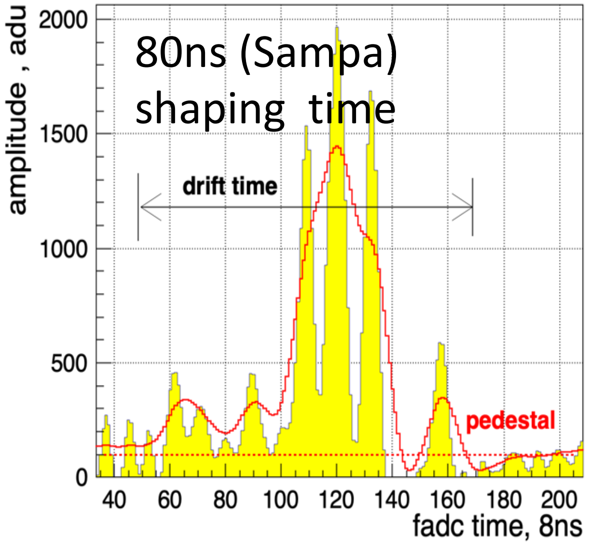
Energy deposition (dE/dx+TR) vs drift gap



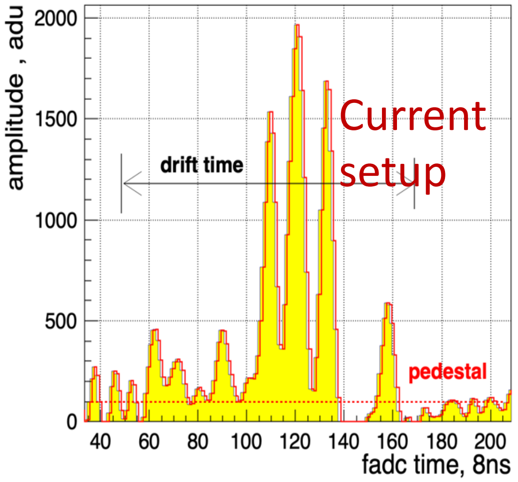


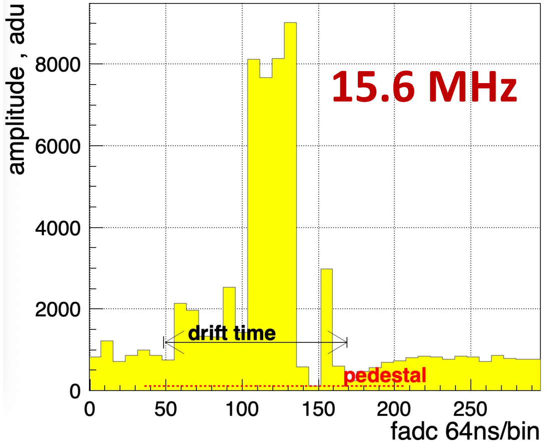
GEM TRD/T Electronics

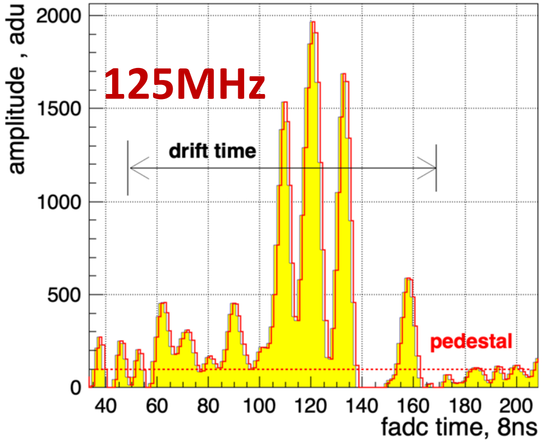
- Requirement :
  - ➢ Large readout window due to long drift distance (>1 µs).
  - ➢ Excellent timing resolution for cluster counting along drift direction
  - ➢ Good ADC resolution to detect dE/dx for TR photons.
  - ➢ Standard electronics for GEMs/MPGD do not meet the requirement.
    - APV25 : too few bins,coverage (~600 ns)
    - VMM3 : 200 ns/bin (not optimal timing resolution)
    - SAMPA : 10-20 MHz only and >60 ns/bin
- Solutions :
  - ➢ Pre-amplifier cards with charge sensitivity of **2.6mV/fc and 10 ns** peaking time
  - ➢ JLab custom Flash ADC with readout window upto **8 ms @ 125 MHz** (upto 1K time samples)



~ 20ns shaping time with FADC

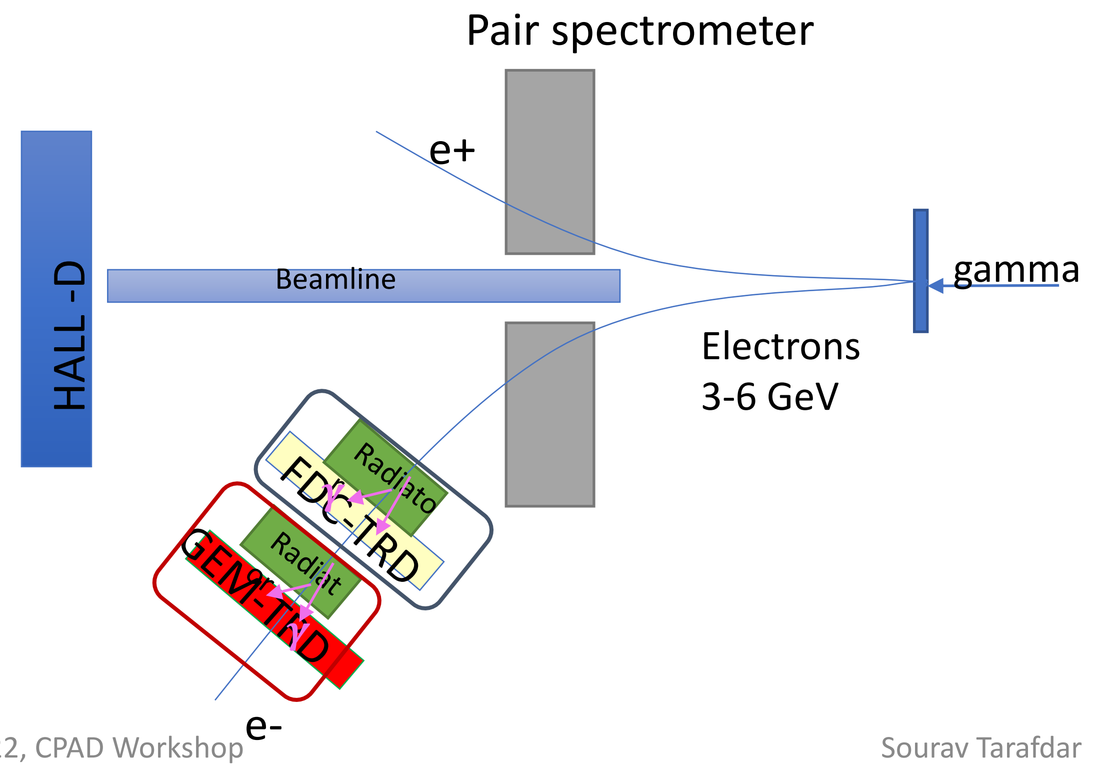


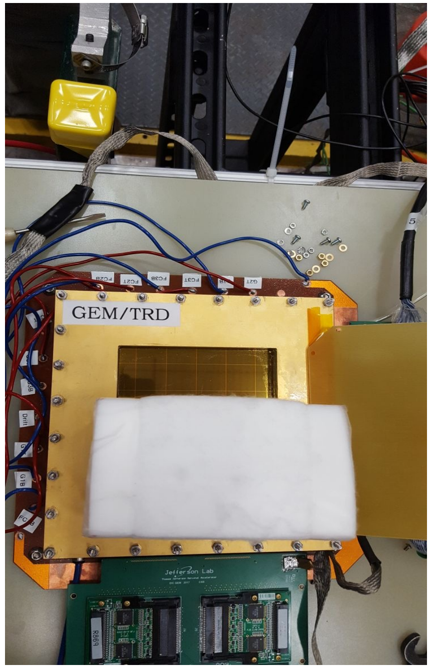


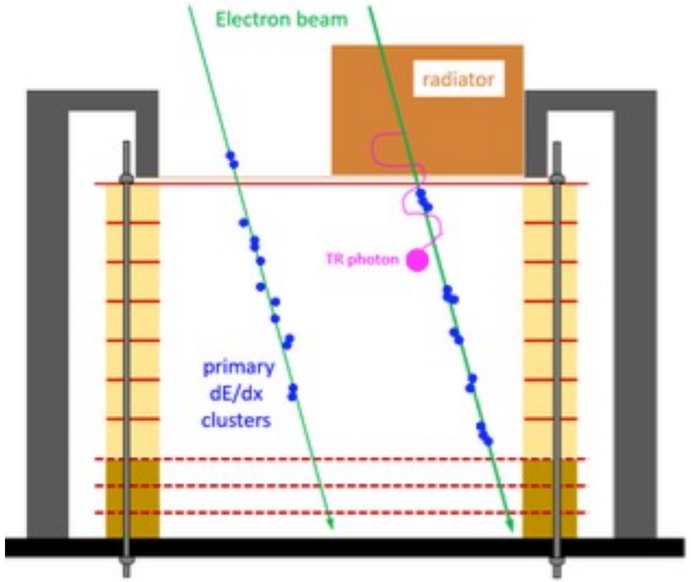


1st Test Beam studies

- First tested the proof of principle in JLab Hall-D using 3-6 GeV electrons from pair spectrometer **during fall 2018 and spring 2019 run.**
- Comparison of performance was done between GEM-TRD and Forward Drift Chamber (FDC)-TRD.



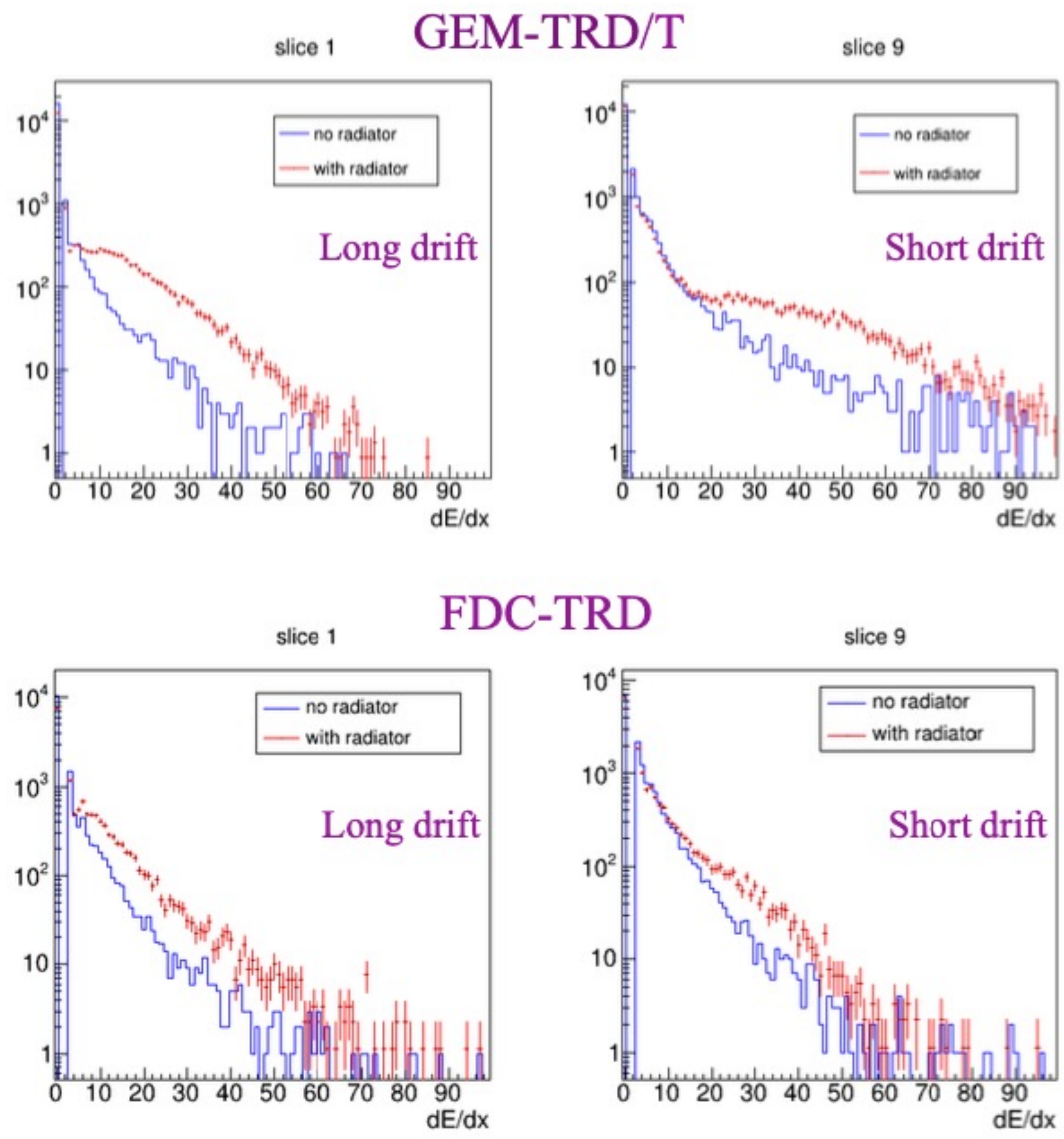


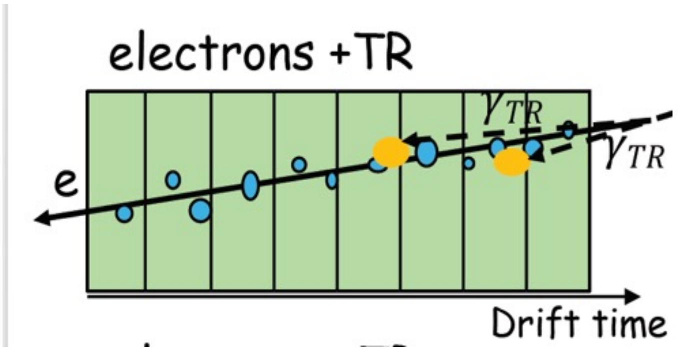


- Flat beam : x/y spread ~ 5 mm , 10 kHz rate
- No pion beam
- Covered half of the active area of detector with radiator.
  - ➢ Just comparing energy deposited in drift volume by electrons with and without radiator can show the detector performance.

GEM-TRD/T *vs* FDC-TRD performance

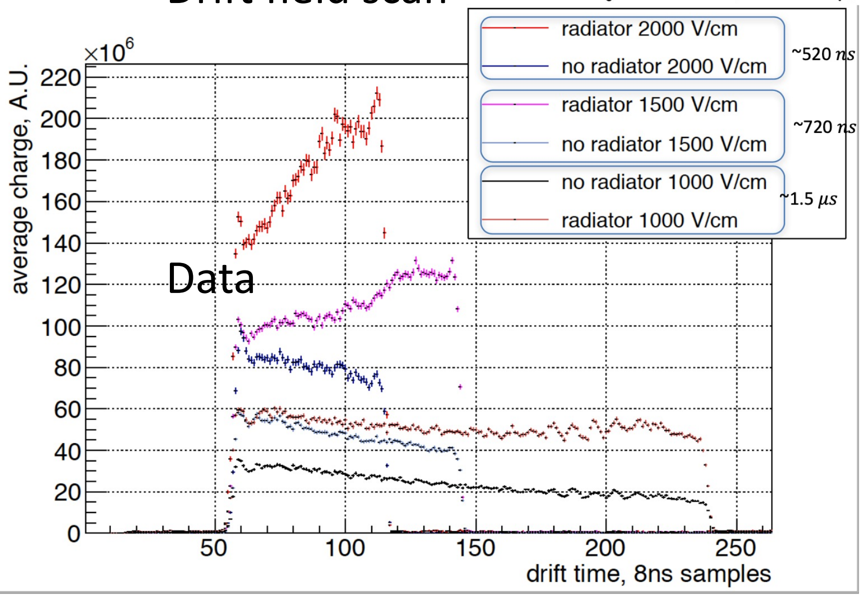
- Drift gap was divided into 10 slices and integrated ADC distribution was calculated with and w/o radiator for both GEM-TRD/T and FDC-TRD
- Slice 1 corresponds to the region close to drift cathode having maximum TRD effect.
- Slice 9 is close to amplification.
- Data from GEM-TRD shows better performance as compared to FDC-TRD in terms of detection efficiency of TR photons
- Poor performance of FDC-TRD was probably because of space charge accumulation near drift wires.
- MPGDs better alternative for gaseous drift chamber TRD



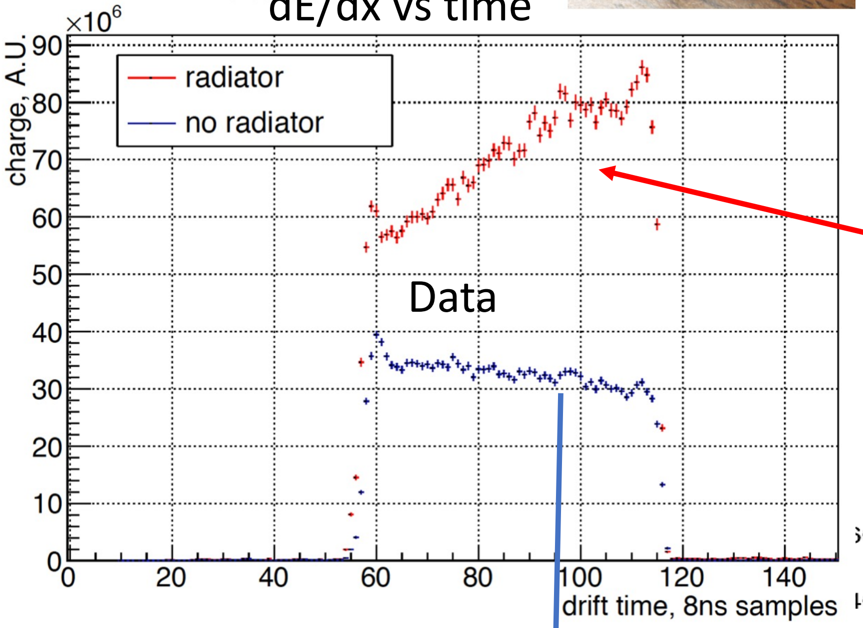


GEM-TRD 1st testbeam results as PID

Drift field scan

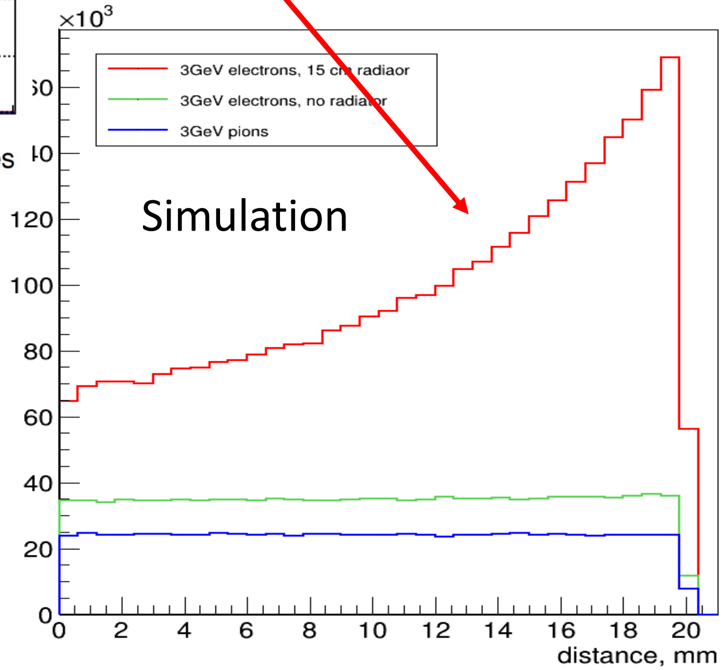


dE/dx vs time



Clear visibility of TR spectra from the prototype and it matches well with simulation

dE/dx vs distance



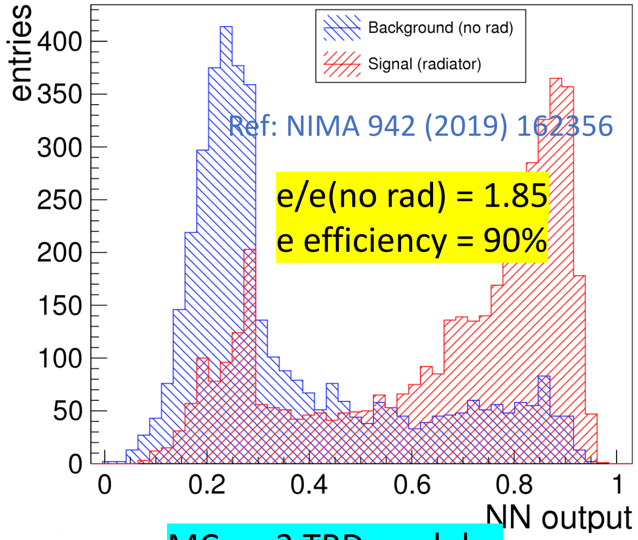
- Drift field scan was performed to test the TR yield.
- High drift field gives better yield
- Also increases transverse diffusion of electrons.

Slope in dE/dx not yet clear.

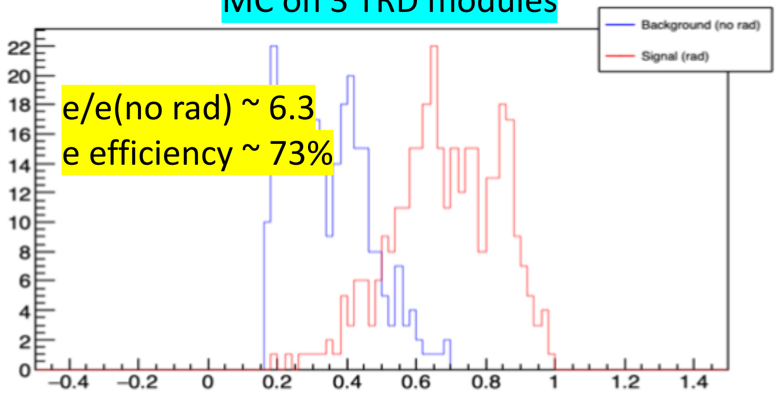
Neural Network based TR identification

- The ionization along the track was used as input to a neural network program
- The particle track drift time was divided into 10 slices
- Energy deposited from each slices was used as input to NN
- NN was trained on signal and background using two different MC samples
  1. electrons with radiator (signal) and electrons without radiator (background)
  2. electrons (signal) and pions (background) with radiator
- Output from training was applied on data to extract relevant information
- Same algorithm used for both MC and test beam data along with using JETNET and ROOT-based TMVA NN program as cross-check

NN output from test beam 1 data for single GEM-TRD module



MC on 3 TRD modules

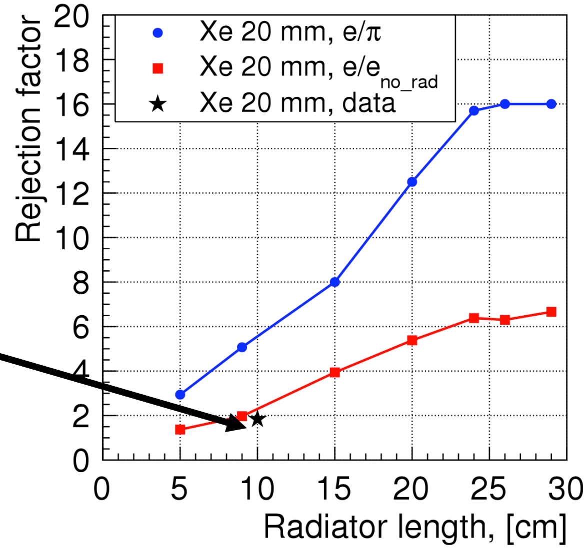


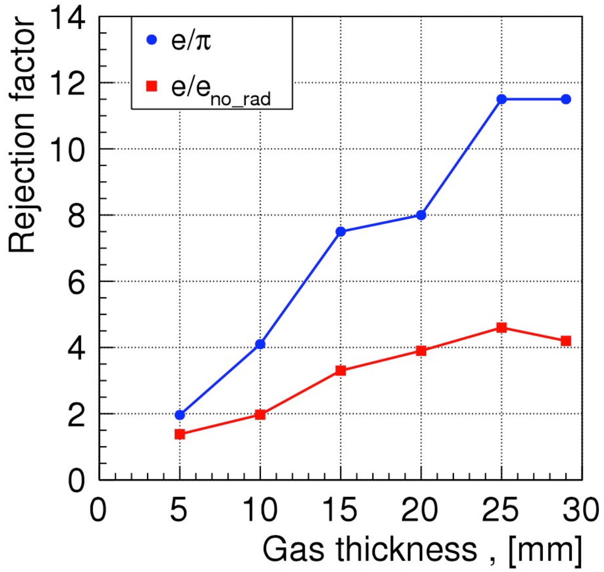
Multi layered modules look attractive but reduces e- detection efficiency

e/π rejection and track reconstruction

- MC scanning on
  i. Fixed gas thickness with 5 cm < radiator < 30 cm
  ii. Fixed radiator of 15 cm with 5 mm < gas < 30 mm

- Test beam data with ~ 10 cm radiator and 21 mm gas absorber was in good agreement with MC having rejection with and without radiator of ~ 1.85





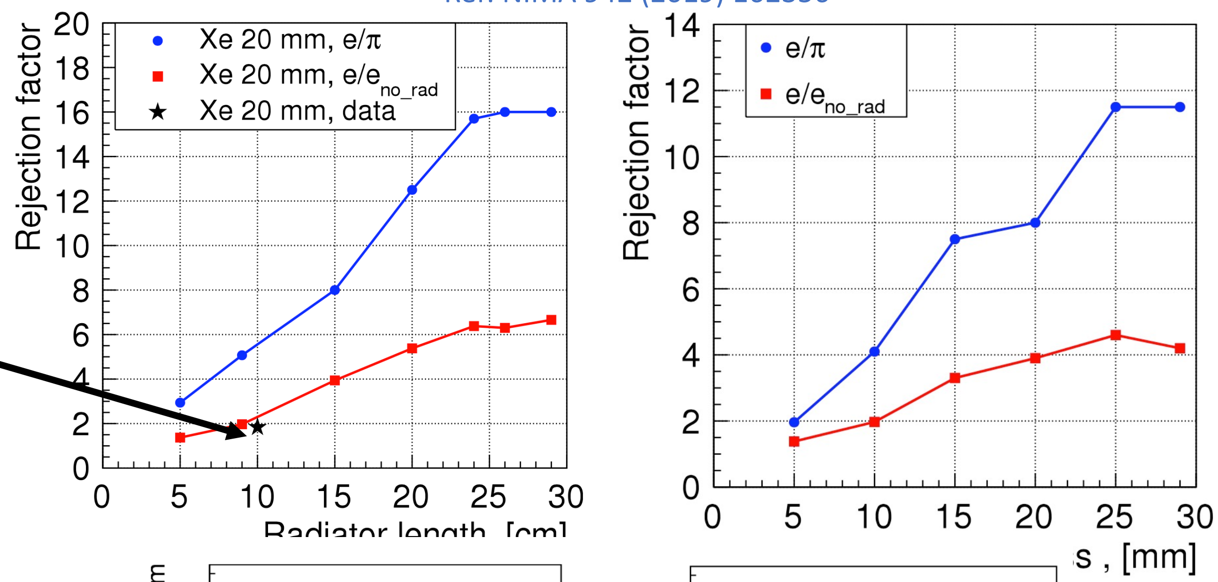
- From MC scan one can predict the current set up providing e/**π** rejection ~ 5.5 → Need to be validated

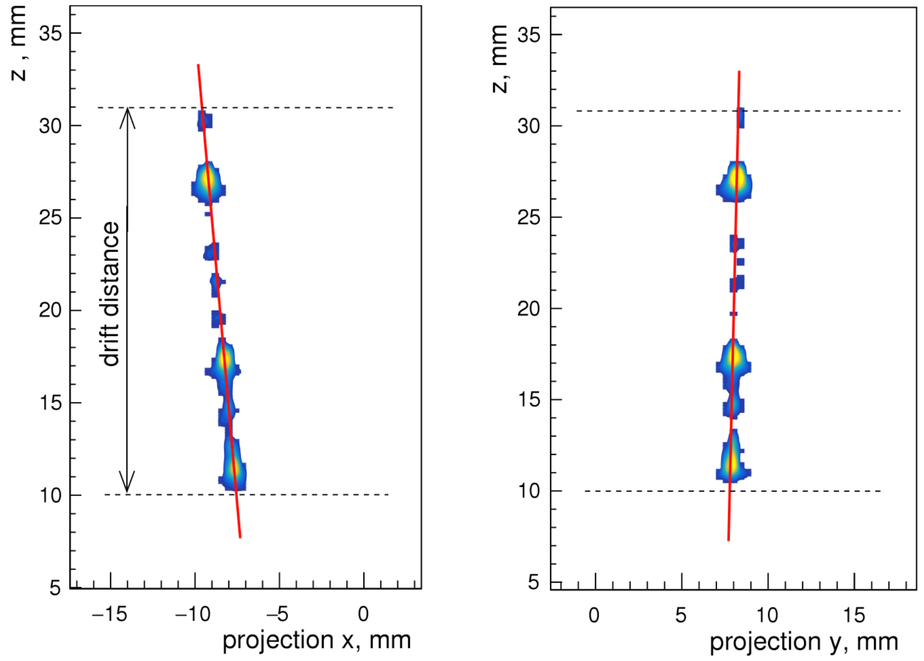
- An e/**π** rejection of ~ 16 with radiator of 25 cm and gas absorber of 21 mm is achievable.

e/π rejection and track reconstruction

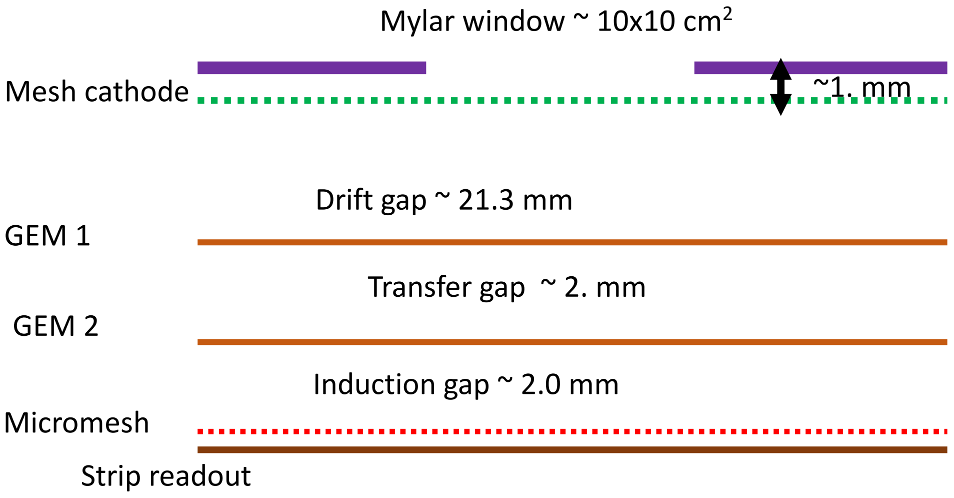
Ref: NIMA 942 (2019) 162356

- MC scanning on
  - i. Fixed gas thickness with 5 cm < radiator < 30 cm
  - ii. Fixed radiator of 15 cm with 5 mm < gas < 30 mm
- Test beam data with ~ 10 cm radiator and 21 mm gas absorber was in good agreement with MC having rejection with and without radiator of ~ 1.85
- From MC scan one can predict the current set up providing e/**π** rejection ~ 5.5 → Need to be validated
- An e/**π** rejection of ~ 16 with radiator of 25 cm and gas absorber of 21 mm is achievable.
- Standard GEM plane is known to provide 2D X-Y position.
- GEM-TRD/T with 21 mm drift path and FADC readout allows 3D track segments reconstructed similar to **μ**TPC



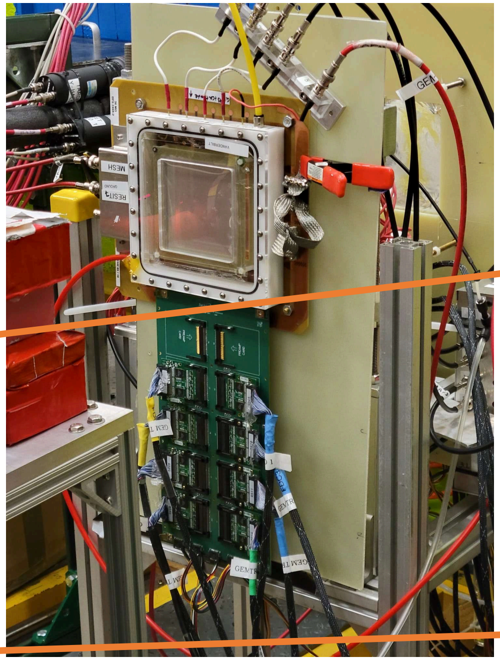


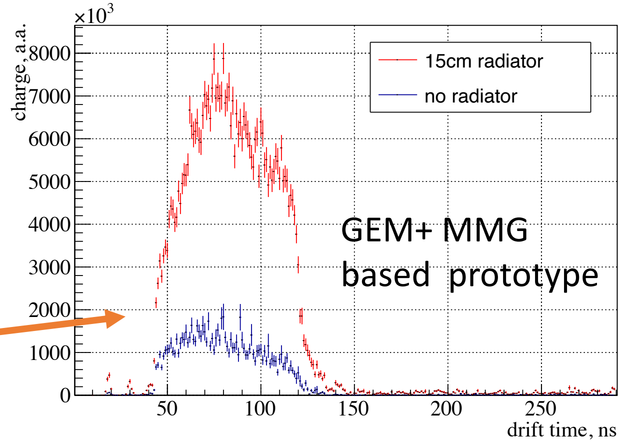
Hybrid GEM+MicroMegas based TRD

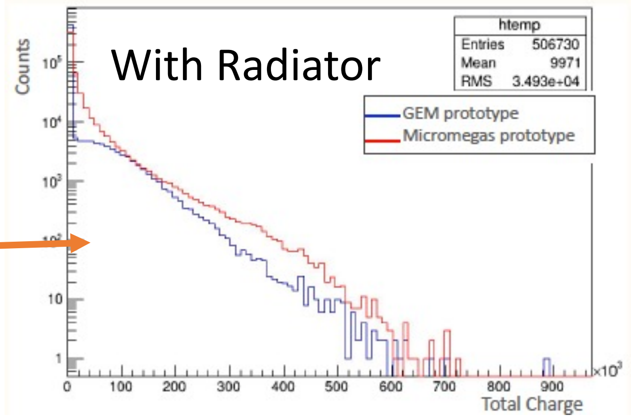


- Intended to move towards single amplification unit
- Signal profiles from MMG and GEMs are different , ions contribute a long tail (~100 ns) in MMG signal
- GEM layers were used mostly for spreading of electron charge.
- Most of the gain was provided by MMG layer
- Compare detection of TR yield from triple GEM and hybrid MPGD based TRD

- Tested during winter 2021 JLab Hall-D 3 GeV e- test beam along with new triple GEM TRD prototype.
- Initial study showed clear distinction between yield with and without radiator => Different signal profile of MMG and GEM seems to be not an issue
- Charge collection efficiency at par with GEM based TRD

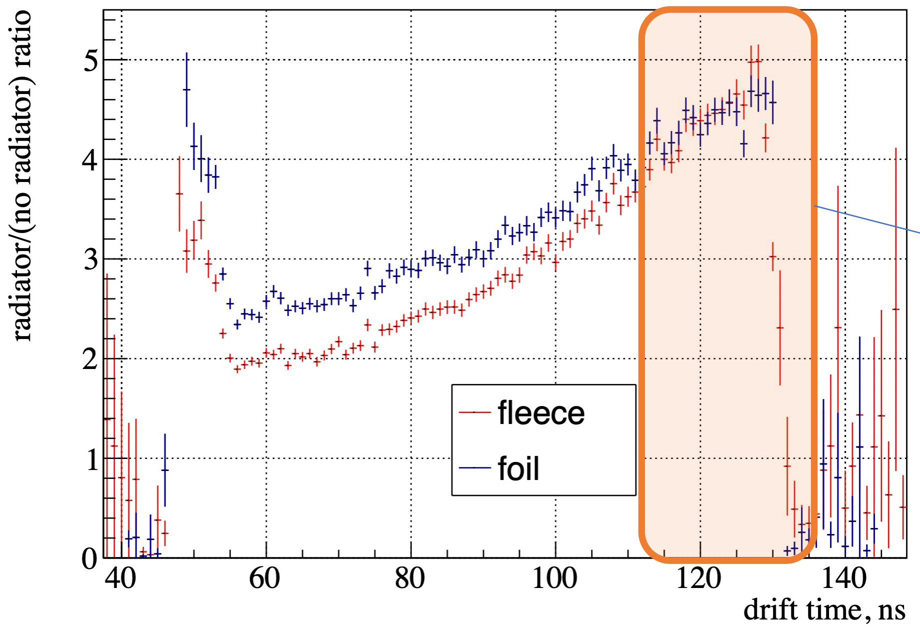


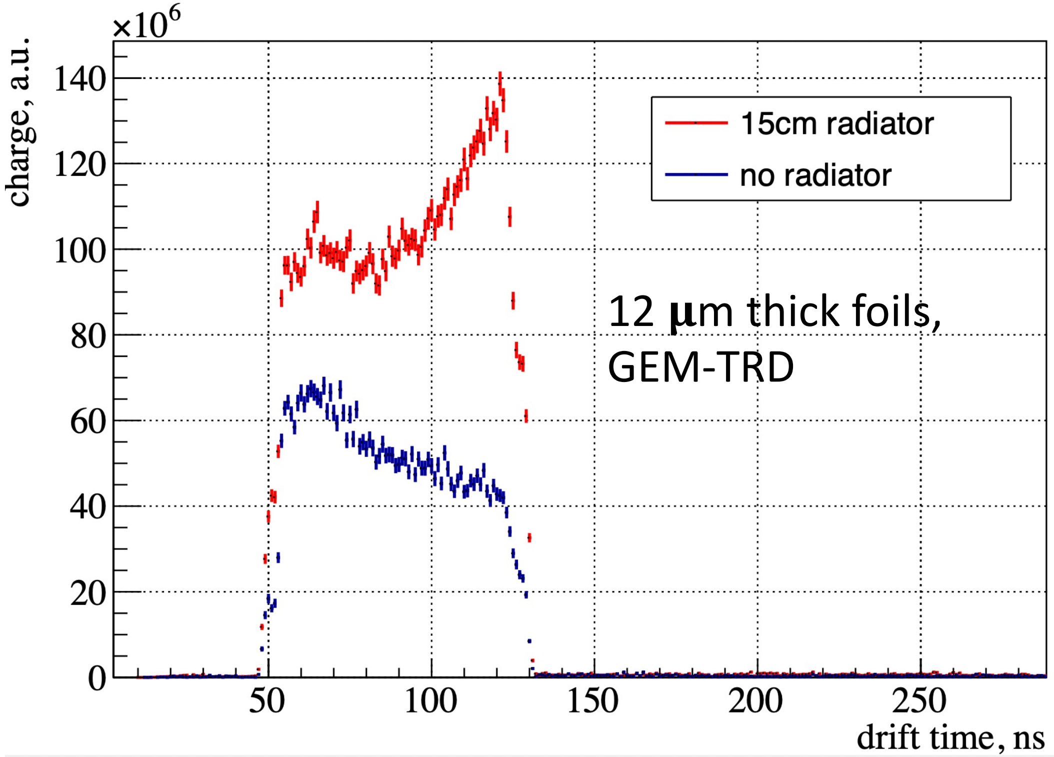




2nd Test beam @ Jlab during winter 2021

- Testing various radiators
  - Fleece
  - 25 um Mylar foils
  - 12 um Mylar foils
- GEM-TRD with capacitive sharing R/O and hybrid MPGD-TRD study

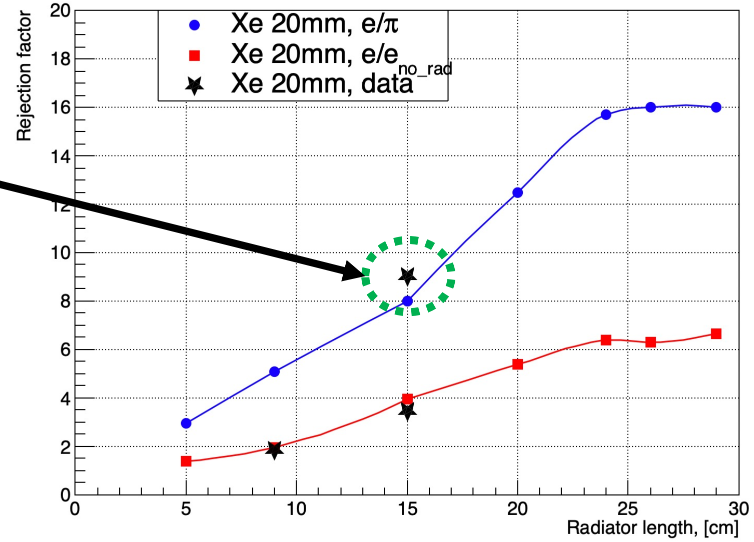




- Foils can be good replacement for fleece : Low radiation length
- Detailed analysis of data ongoing .

Plans for the future

- Study of various R/O pattern with larger pitch to reduce electronics channel and hence reduce the electronics cost.
    1. Capacitive sharing R/O (Developed at Jlab)
    2. 2D zigzag (Developed at BNL).
- Use single amplification unit as MMG and **μ**Rwell with the above two different R/O patterns.
- Test these different prototypes in Fermilab pion beam to test the e/**π** rejection under same experimental condition.
    - ✓ Previously this has been tested @ different locations (e- beam @ Jlab hallD pair spectrometer and mainly hadrons in Glue-X set up
- Recently submitted EIC-generic R& D proposal got accepted



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]

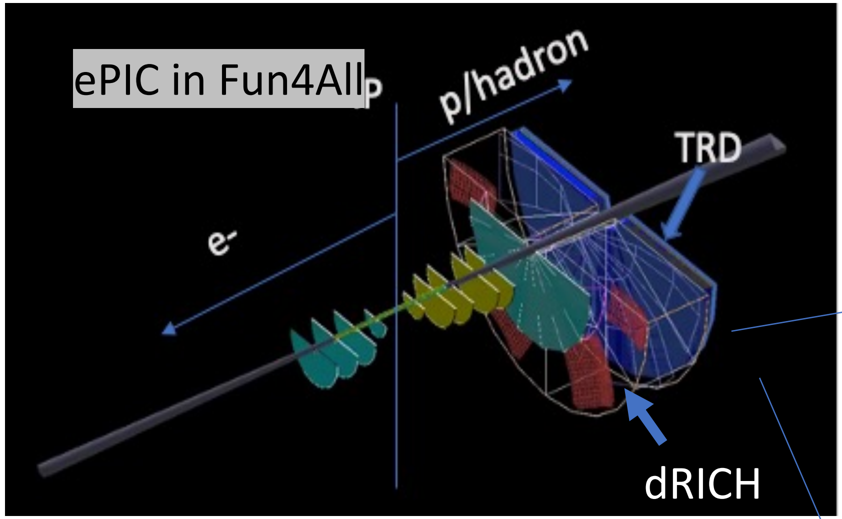
[1]Jefferson Lab
[2]Old Dominion University
[3]Vanderbilt University
[4]University of Virginia
[5]Temple University

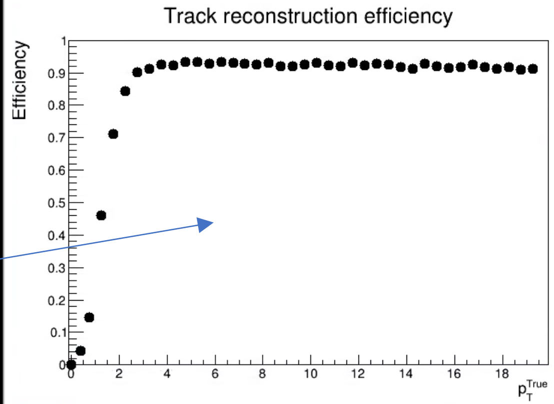
July 25, 2022

EICGENR&D Proposal Number (1 thru 27)	Title	PI(s)	Institution(s) (abbreviated and only includes PI's)
	PID (non-TOF):		
2	A proposal for MPGD-based transition radiation detector/tracker	Y. Furletova, J. Velkovska	Jlab, and Vanderbilt U., USA

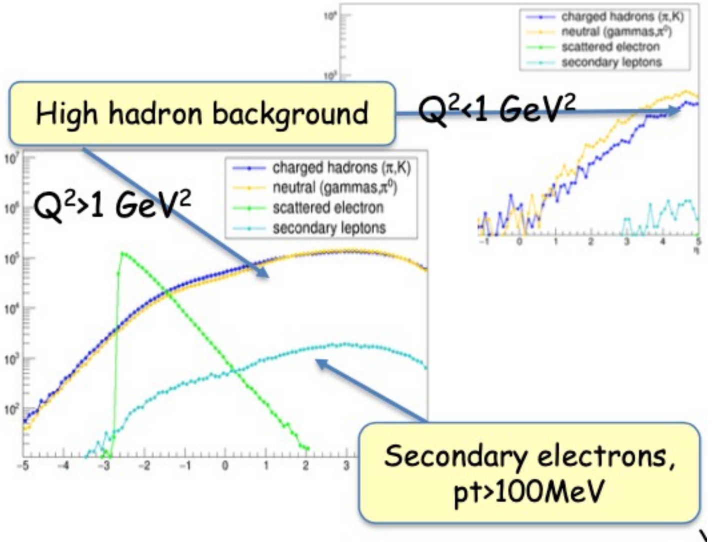
Role in EIC

- The main detectors for $e/h^{\pm}$ separation is calorimeter . Also Cherenkov in limited momentum range.
- TRD offers high e/h rejection for electrons in 1-100 GeV range
- Hadron end cap in EIC can gain by additional $e/h^{\pm}$ separation at high momentum regime.
- Several Physics processes J/ψ production , D and B-mesons production, resonant searches of X.Y.Z etc in EIC will get benefit from additional $e/h^{\pm}$ separation .

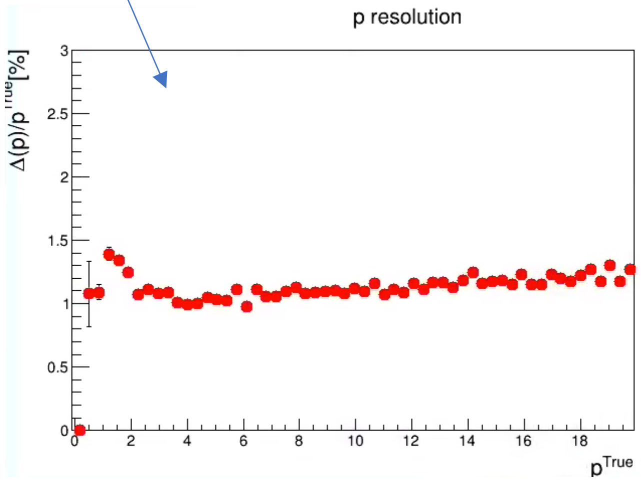




Ongoing studies in simulation integrated within ePIC detector



- Additional tracking point after dRICH will increase angular resolution and also dRICH performance. (path for upgrade of ePIC)
- Possible to use in EIC detector2 barrel region with other tracking detectors to provide both tracking and PID (eg. in ALICE and ATLAS detectors).

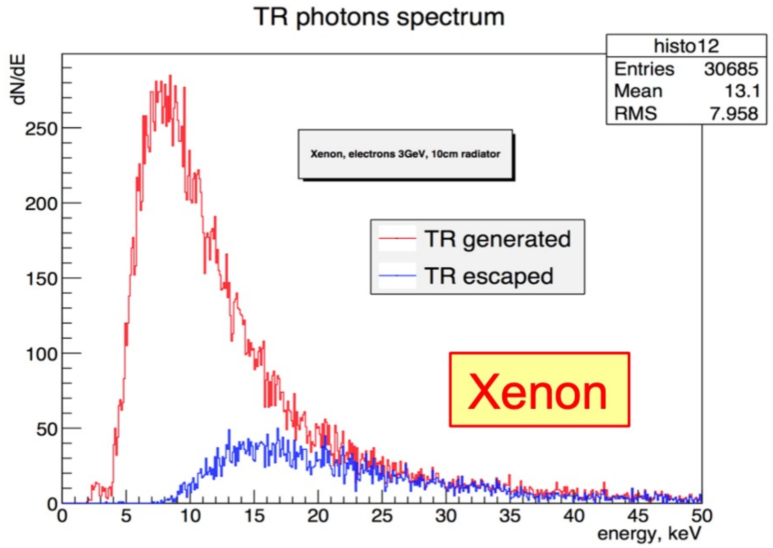


Conclusions and Outlook

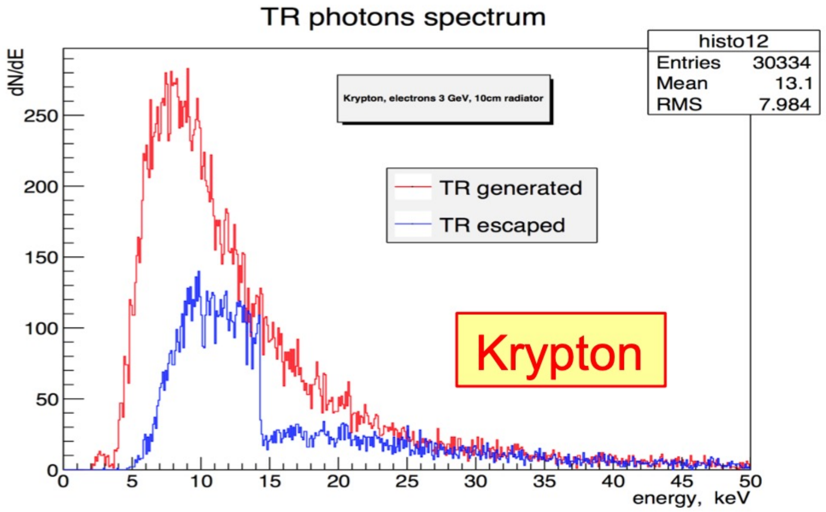
- Electron identification is very important for both hot and cold QCD.
- MPGD based TRD performance has been shown.
- Implementing MPGD based TRD in upcoming EIC experiment ePIC not only can improve pion rejection factor with calorimeter at high background hadron end cap but can also improve dRICH performance by providing good resolution track point.
- MPGD based TRD can be a good candidate for barrel tracking and PID for detector 2 in EIC.
- Approved EIC generic R&D funding for MPGD-TRD will focus on development of low channel count single amplification unit MPGD-TRD along with estimating pion rejection factor under same test beam condition.

Backup

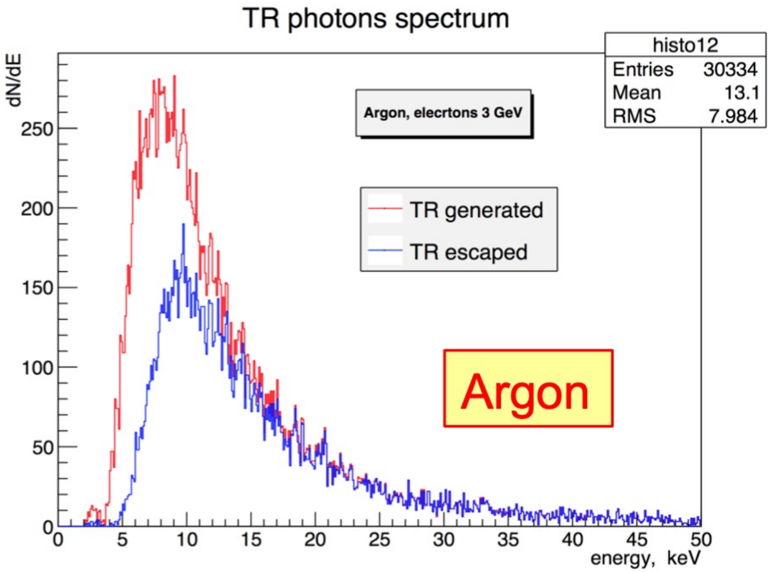
Backup



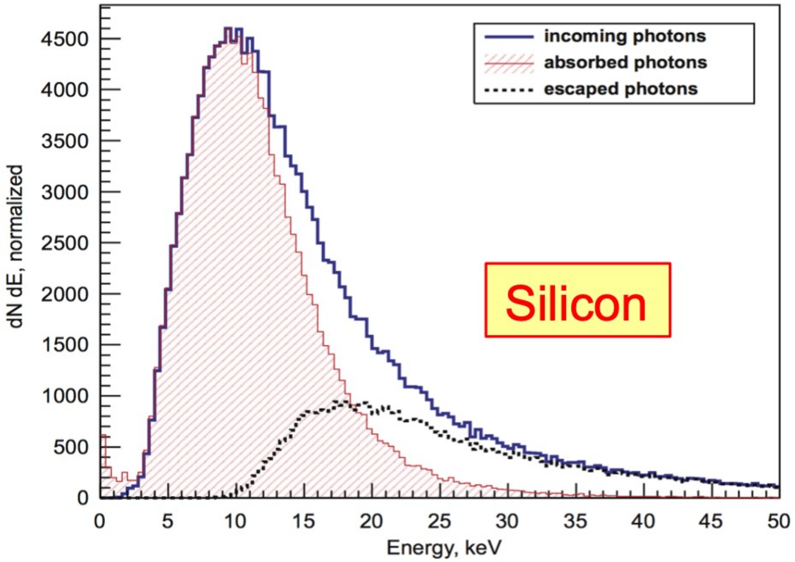
TR photons spectrum
histo12
Entries 30685
Mean 13.1
RMS 7.958
Xenon, electrons 3GeV, 10cm radiator
TR generated
TR escaped
Xenon
dN/dE
energy, keV



TR photons spectrum
histo12
Entries 30334
Mean 13.1
RMS 7.984
Krypton, electrons 3 GeV, 10cm radiator
TR generated
TR escaped
Krypton
dN/dE
energy, keV

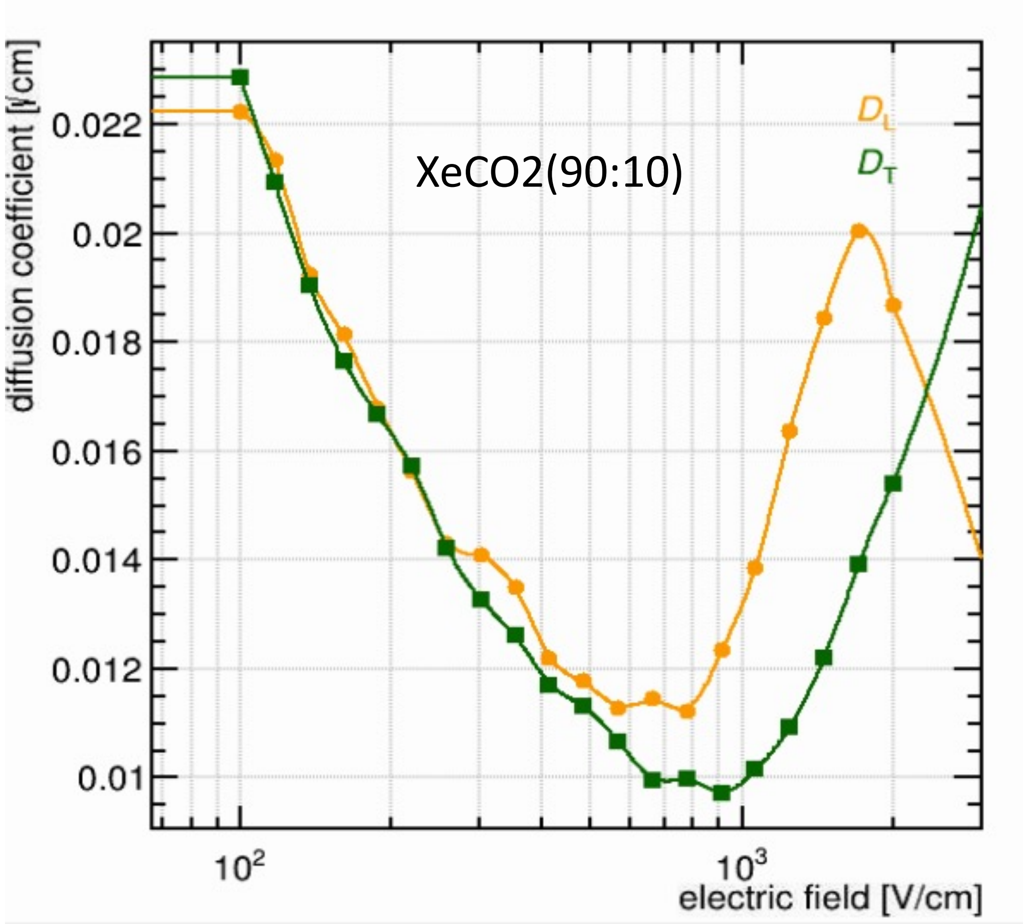


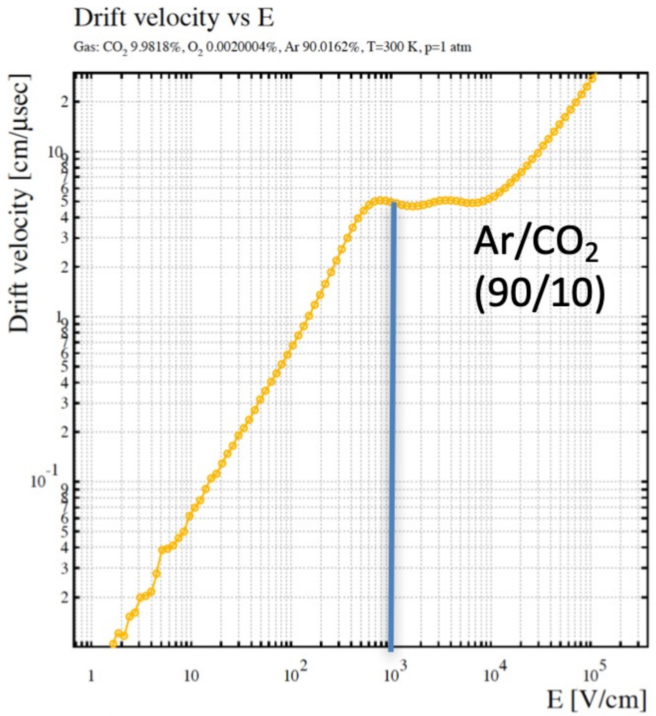
TR photons spectrum
histo12
Entries 30334
Mean 13.1
RMS 7.984
Argon, elecrtons 3 GeV
TR generated
TR escaped
Argon
dN/dE
energy, keV

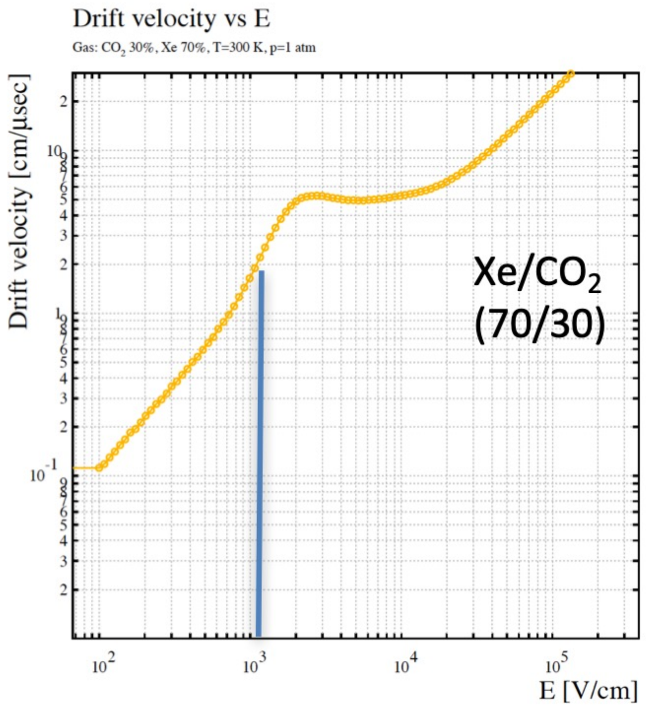


incoming photons
absorbed photons
escaped photons
Silicon
dN dE, normalized
Energy, keV

Backup


diffusion coefficient [√cm]
0.022
0.02
0.018
0.016
0.014
0.012
0.01
10^2
10^3
electric field [V/cm]
XeCO2(90:10)
D_L
D_T


Drift velocity vs E
Gas: CO_2 9.9818%, O_2 0.0020004%, Ar 90.0162%, T=300 K, p=1 atm
Drift velocity [cm/µsec]
E [V/cm]
Ar/CO_2
(90/10)


Drift velocity vs E
Gas: CO_2 30%, Xe 70%, T=300 K, p=1 atm
Drift velocity [cm/µsec]
E [V/cm]
Xe/CO_2
(70/30)