R&D for GEM based Transition Radiation Detector (GEM-TRD)

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MPGD2017, Temple University, Philadelphia PA 2017

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GEM experts:

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Outline

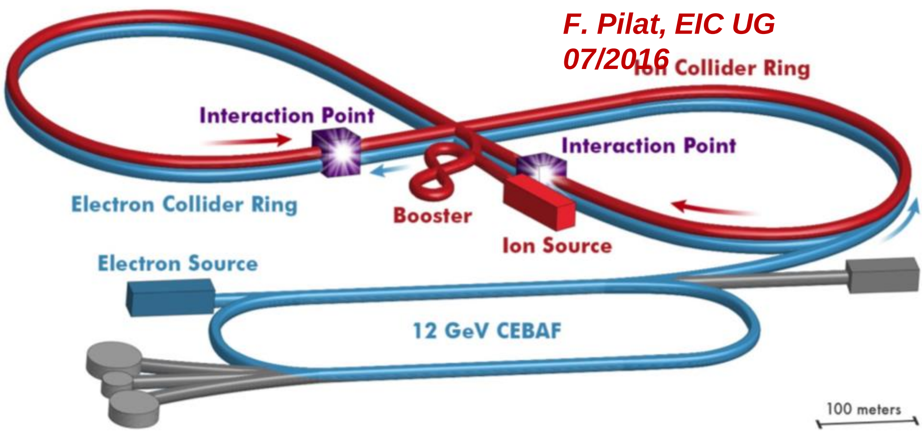
- Electron Ion Collider (EIC)
- Basics on Transition Radiation
- GEM-based Transition Radiation Detectors
- Proof of principle and preliminary test beam results

Electron Ion Collider (EIC)

- ✓ Explore the next QCD frontiers: Gluons and sea quarks and their spins distributed in position space and momentum space inside a nucleon
- ✓ High-energy high-luminosity polarized EIC was highly recommended as the highest priority for the next new facility construction by **the 2015 Long Range Plan for Nuclear Physics**

JLEIC @ Jefferson Lab (Jlab)

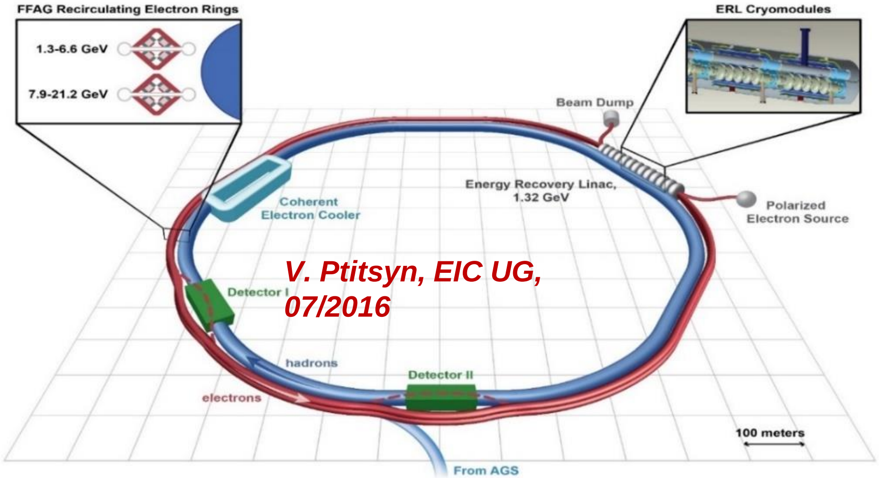
F. Pilat, EIC UG 07/2016



JLEIC energy range:
- electrons: 3-10 GeV
- protons : 20-100 GeV
- Luminosity ~ 2 × 10^{34}

eRHIC @ Brookhaven Lab (BNL)

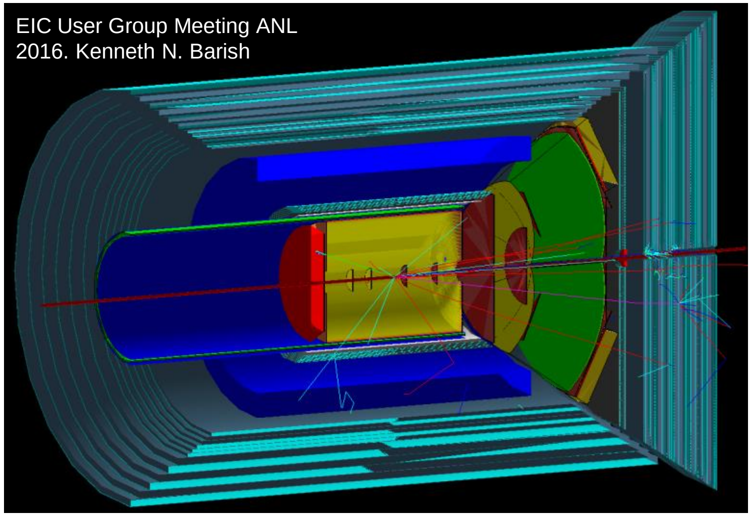
V. Ptitsyn, EIC UG, 07/2016



eRHIC energy range:
- electrons: 10 GeV
- protons : 250 GeV
- CM: 100 GeV
- Luminosity ~0.1 to 1 × 10^{34} cm^{-2} s^{-1}

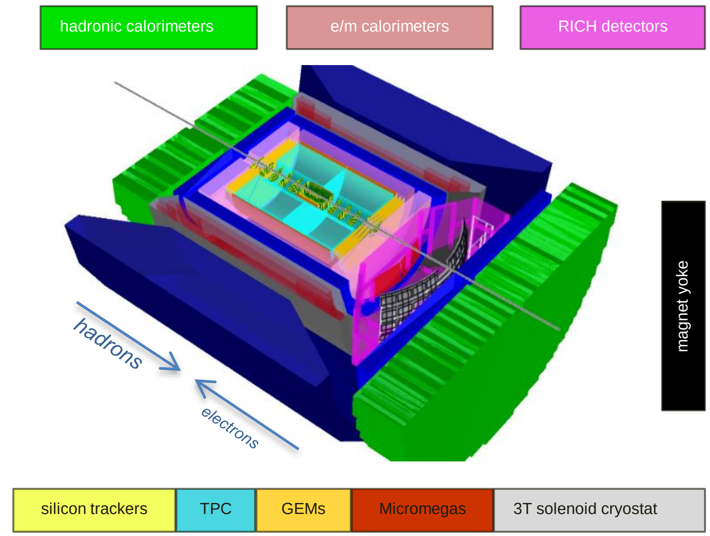
EIC Detectors concepts

ePHENIX @ eRHIC



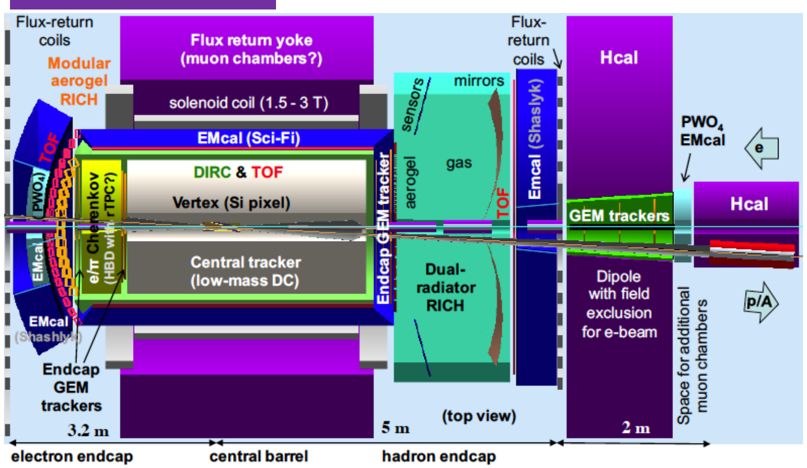
EIC User Group Meeting ANL 2016. A. Kiselev

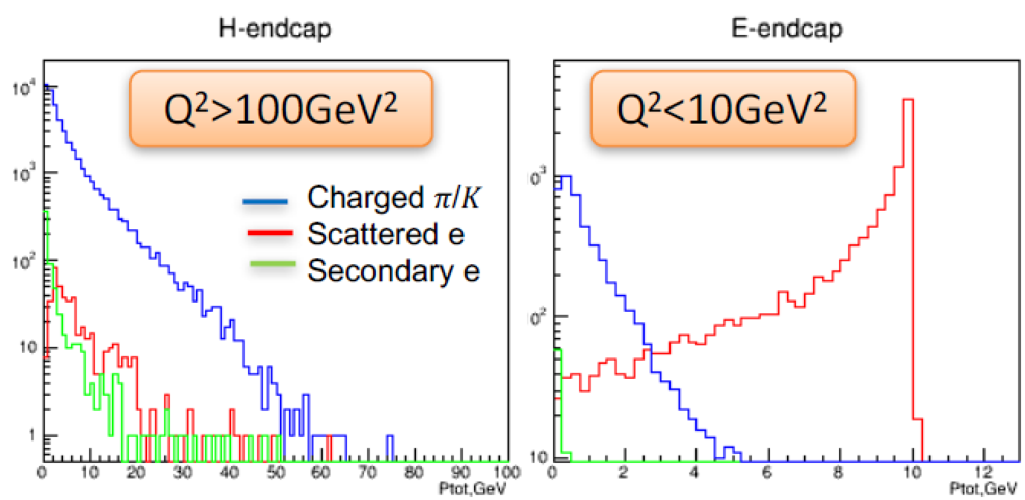
BeAST @ eRHIC



EIC User Group Meeting ANL 2016 Rik Yoshida

JLEIC Design





EIC: Physics motivations for electron ID

Hadron Endcap

- For rare physics, based on electron identification
- Charmonium, light vector mesons (ρ,ω,φ)
- Tetraquarks, Pentaquarks (and other XYZ states)
- Open Charm physics via leptonic decays
- Di-lepton production

Environment:

- Background: High multiplicity heavy Ion collisions, large number of pions and Kaons in forward region.
- Large π^0 background.

Needs:

- 10^3-10^4 e/π rejection factor required over wide (1-100GeV) energy range in the forward region (EMCAL e/π rejection 50-100)
- High granularity tracker with low material budget, not very expensive=> GEM

Proposal:

- Tracker combined with TRD/PID function: which could provide additional e/hadron rejection 10-100 and will cover energy range 1-100 GeV =>

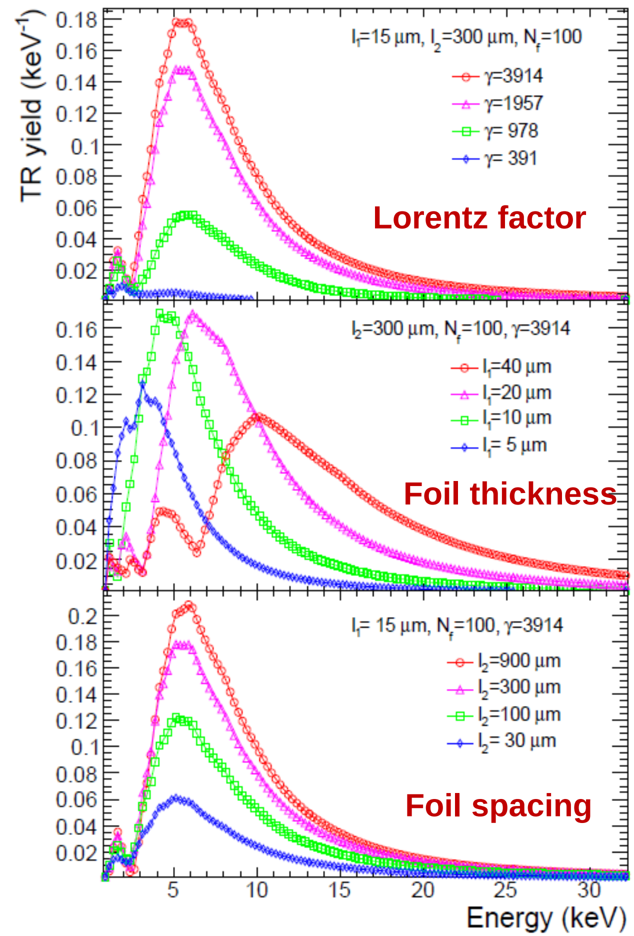
GEM based transition radiation detector/tracker
GEM-TRD/T

Electron Endcap

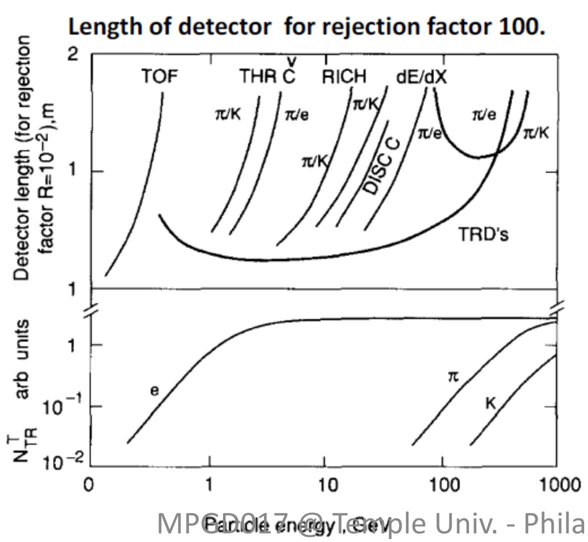
- EM calorimeter covers full range,
- π background are large at small angle & low energy
  - ⇨ Need a suppression at 10^3 – 10^4 level
  - ⇨ EM cal alone not enough (low resolution)
- Need additional e/π ID up to 4 GeV
  - ⇨ Hadron Blind Detector or RICH or DIRC or TRD?

Introduction to Transition Radiation

- Transition radiation (TR) is produced by a charged particles when they cross the interface of two media of different dielectrics constants.
- TR in X-ray photon are then emitted along with the charge particle with a forward peak within an angle of 1/γ with an energy range of 2 to 40 keV
  - ⇨ With γ the Lorentz factor of the charge particle
  - ⇨ Total TR Energy ETR is proportional to the γ factor
- The probability to emit one TR photon per boundary is of order α~1/137.
- Multilayer dielectric radiators (typically few hundreds of mylar foils) are used to increase the transition radiation yield.
- Clean e / π separation over a large energy range > 1 to up to 100 GeV
  - ⇨ No other single technique can provide a e / π over this large range
- “Compact” detector Provide with a good rejection factor (100)
- Typically TRD is either combined with tracking detector (ATLAS TRT) or provide additional tracking information

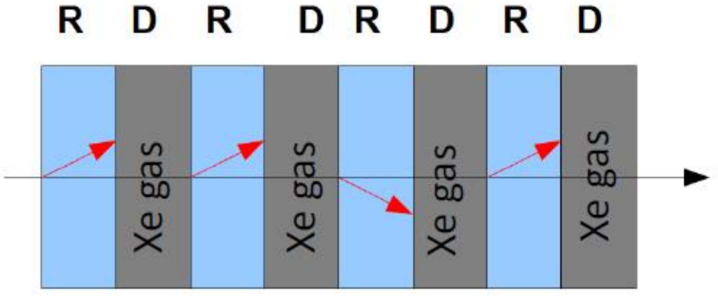


ALICE MWPC-TRD: https://arxiv.org/pdf/1111.4188.pdf



Gas based Transition Radiation Detectors

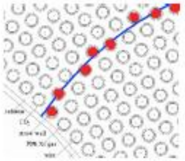
How easy to detect Transition Radiation ?

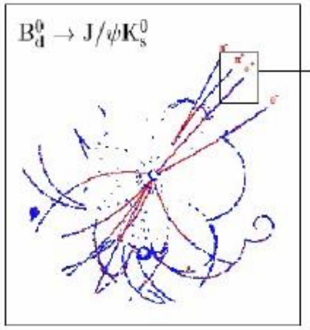


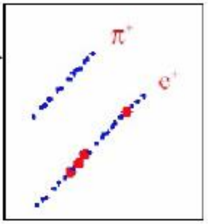
- Stack of radiators and detectors (sandwich)
- For "classical" TRD (straws, MWPC) gas is needed for better absorption of TR photons: high Z required => Xenon gas (Z=54)
- TRDs are not "hadron-blind" ! they see all charged particles dE/dx
- Several methods exist to identify TR photons on the top of dE/dx:
  (TR photons (5-30 keV) over a dE/dX background in Xe gas (2-3 keV)).

- **Discrimination by threshold** (ATLAS)
- **Average pulse height along adjacent pads (or along a track)** (ALICE) => (next slide)

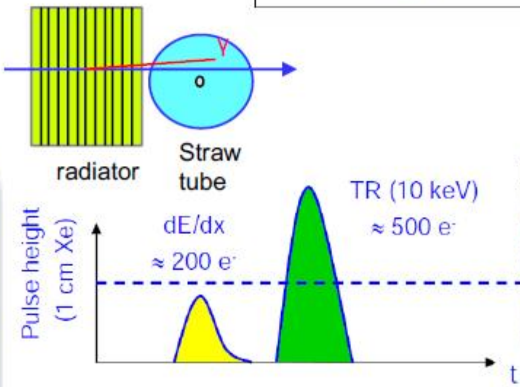
ATLAS TRT







Simulated event, illustration of clusters from eletron/positron and pion hits – small blue dots are ionizing hits, large red dots are TR hits



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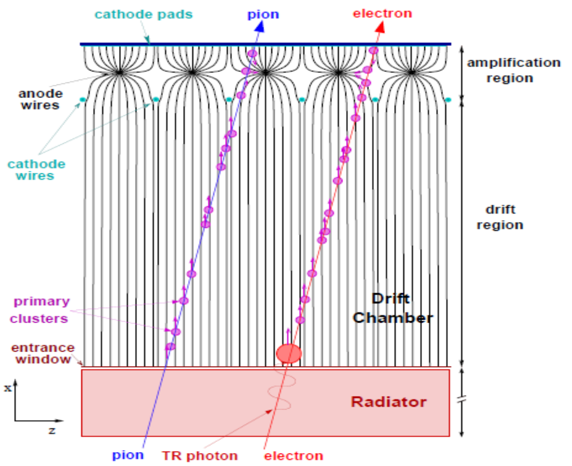
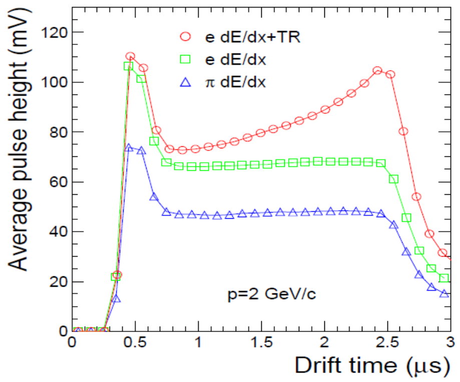
Gas based Transition Radiation Detectors

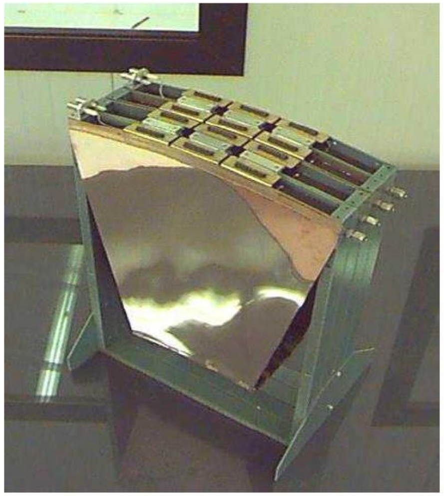
ALICE MWPC-TRD





https://arxiv.org/pdf/1111.4188.pdf

ATLAS Straw tube TRT



- Sector of ATLAS TRT end cap
- 384 straws, 16 layers on beam direction
- 4 mm straw diameter
- Regular radiator: 15 μm polyethylene foils with 200 μm spacing
- 70% Xe + 20% CF_4 + 10% CO_2 gas mixture (70% Xe + 27% CO_2 + 3%O_2 since 2002)
- 2.5 $\cdot 10^4$ nominal gas gain
- LHC type electronics

(V.Tikhomirov. ATLAS TRT test beam results. 4 September 2003, Bari, Italy.)

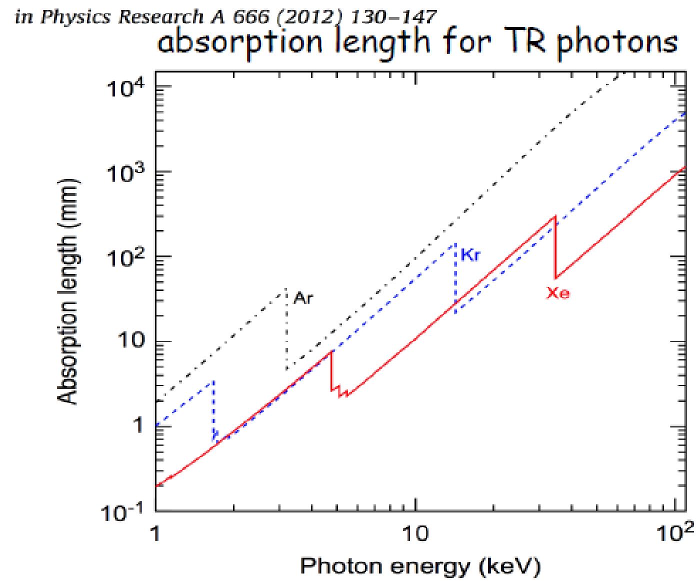
GEM based Transition Radiation Detectors (GEM-TRD)

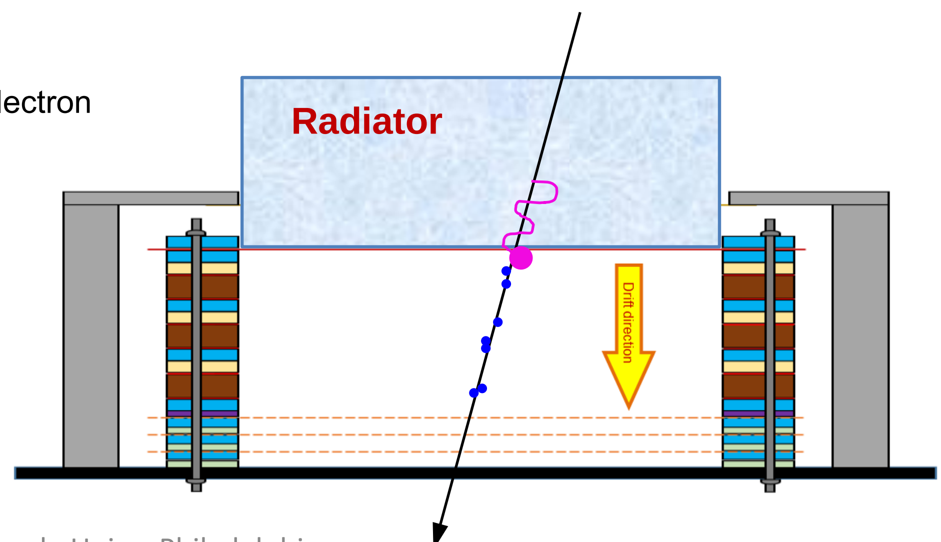
- **High resolution tracker**
- **Low material budget detector**
- Gas TRD needs a heavy gas for efficient absorption of X-rays

⇨ Xe based mixture used instead of Ar based mixture

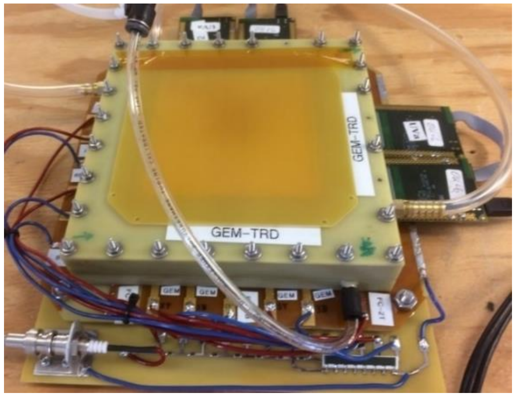
- Drift region up to 20 - 30 mm ⇨ Good detection efficiency with Xe
- Radiator in the front of each chamber (radiator thickness ~5-10cm)
- Number of layers of TRD detectors depends on needs:

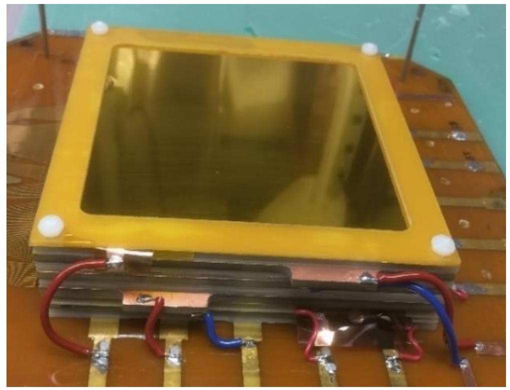
⇨ Single layer provide e/π rejection at level of 10 with 90% electron efficiency





Small GEM-TRD prototype





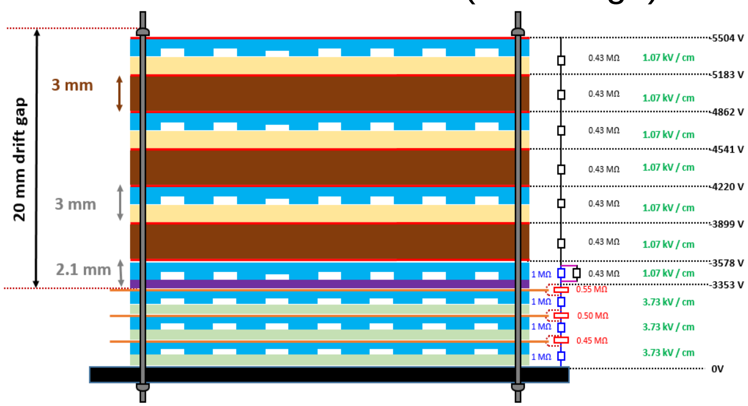
GEM TRD Chamber

- Modified standard CERN 10 cm × 10 cm triple-GEM with a **21 mm drift gap**
- Electric field for the drift = 1.07 kV

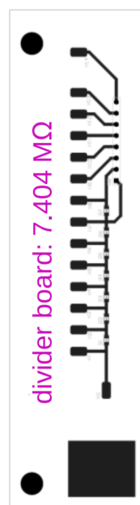
Field cage

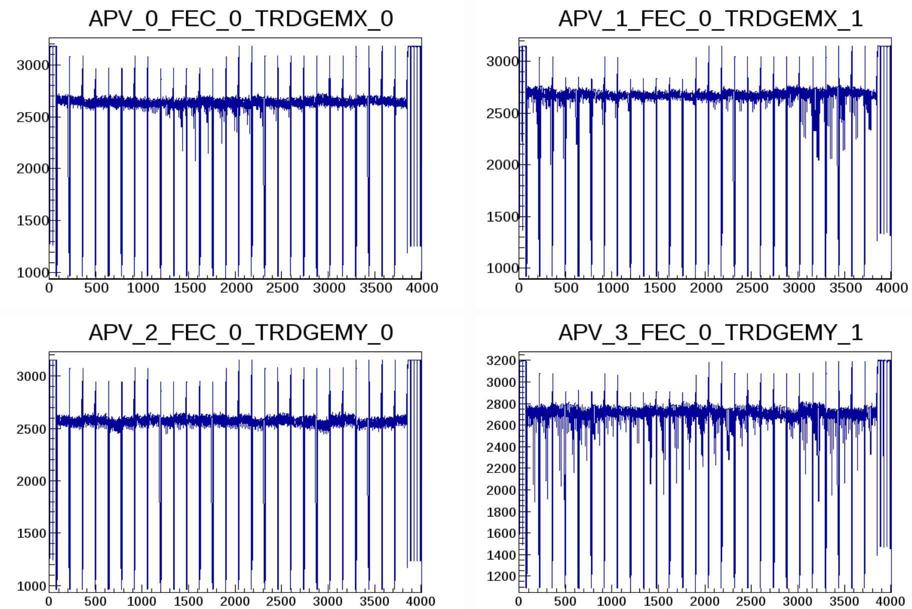
- 3 mm thick and double sided copper-clad G10 frames spaced with 3 mm gap in between
- Standard HV divider modified for the field cage

Wall cross section (Field cage)



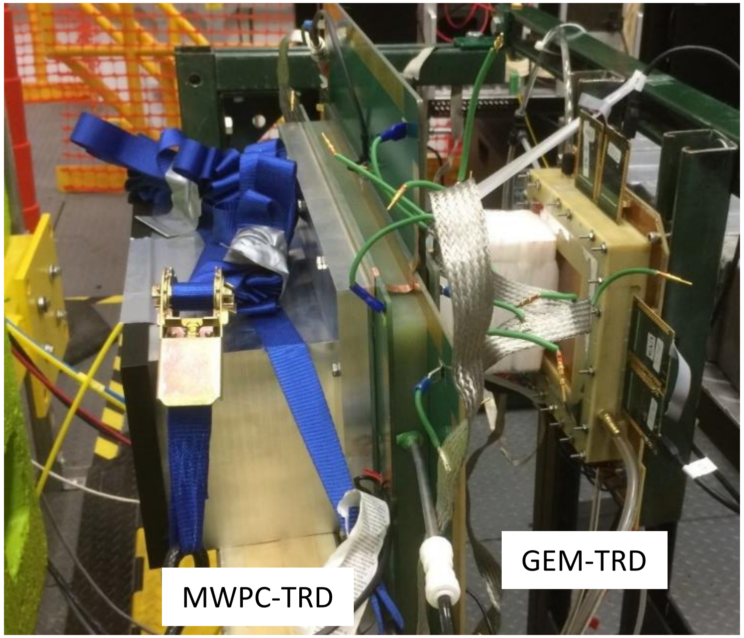
ArCO2 (70/30), HV = 5.5 kV, I = 747 µA

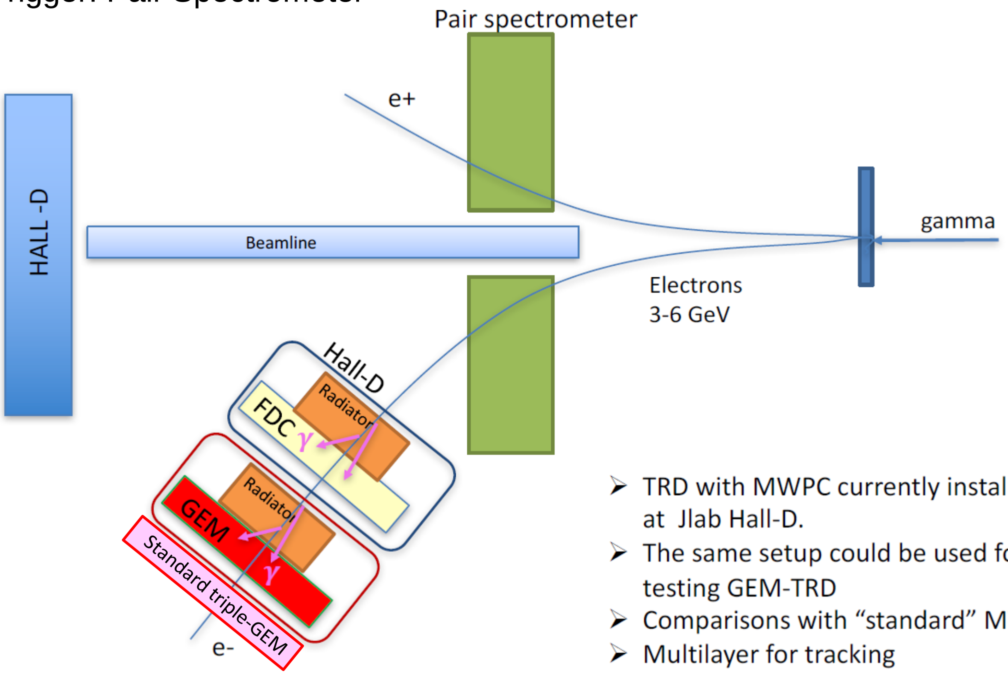




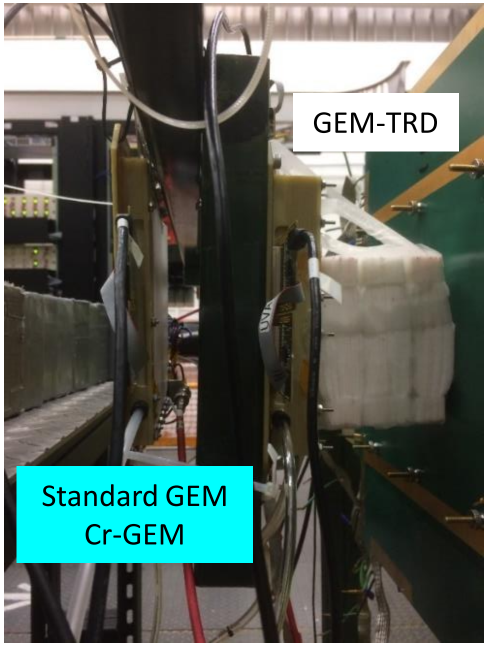
GEM-TRD Test Beam @ JLab Hall D: setup

- Installation in Feb. 2017 as parasitic test beam in Hall D @ JLab
- One 10 cm x 10 cm GEM-TRD prototype (20 mm drift)
  - ⇨ **Half active area cover by 15 cm radiator (fleece)**
  - ⇨ **Test with Ar-CO2 (90/10) gas mixture**
- One 10 cm x 10 cm standard Triple-GEM (3 mm drift)
- 1 MWPC-TRD prototype, Half active area cover by radiator
- APV25 + SRS readout + CODA (JLab DAQ)
- 3-6 GeV Electron beam (conversion from Hall D photon beam)
- Trigger: Pair Spectrometer

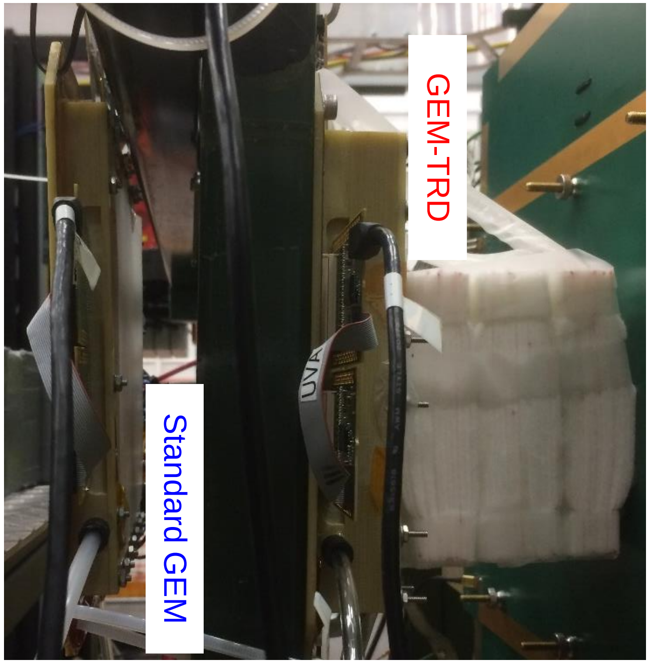


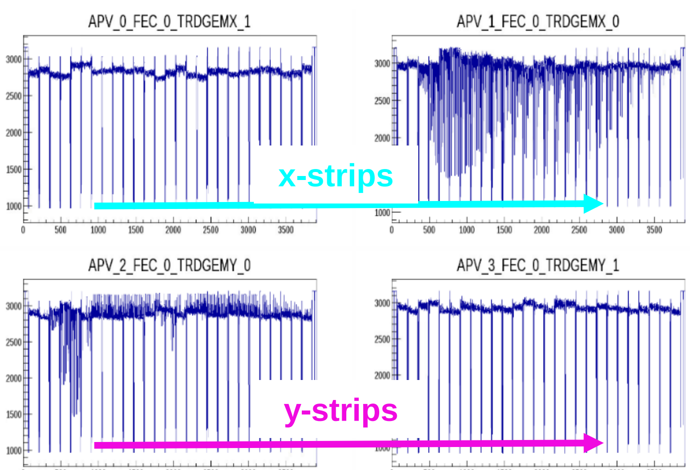


- TRD with MWPC currently installed at Jlab Hall-D.
- The same setup could be used for testing GEM-TRD
- Comparisons with “standard” MWPC
- Multilayer for tracking



Test Beam @ JLab Hall D: Preliminary results with Ar / CO2





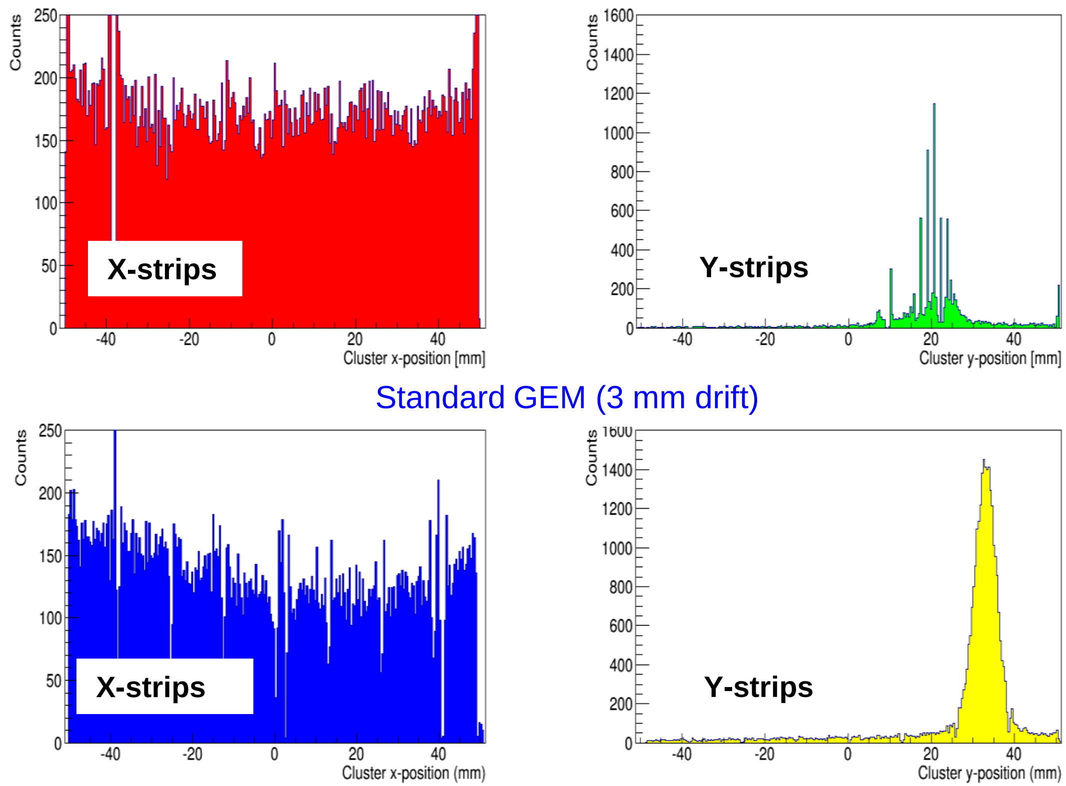
Issues we face during the test beam

- Y-Strips connectors for GEM-TRD broken during installation at the test beam
- HV divider was not optimized for **Ar-CO2 (90/10)**
- Data only with **Ar-CO2 (90/10)** gas mixture ⇨ **No time for data with Xe**

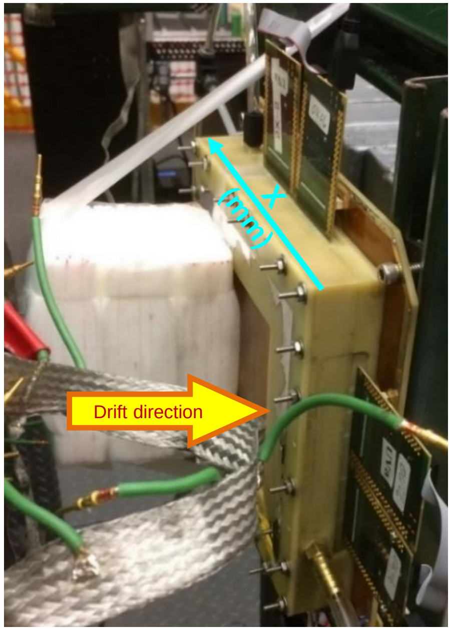
Hit distribution for GEM-TRD (top) and standard GEM (bottom)

GEM-TRD (20 mm drift)

Standard GEM (3 mm drift)

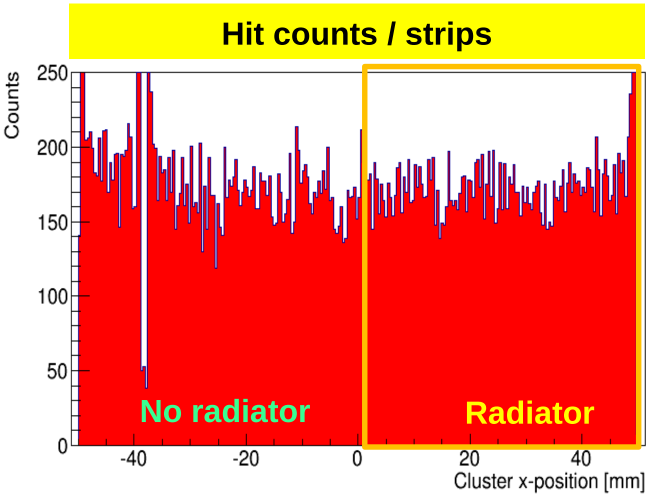


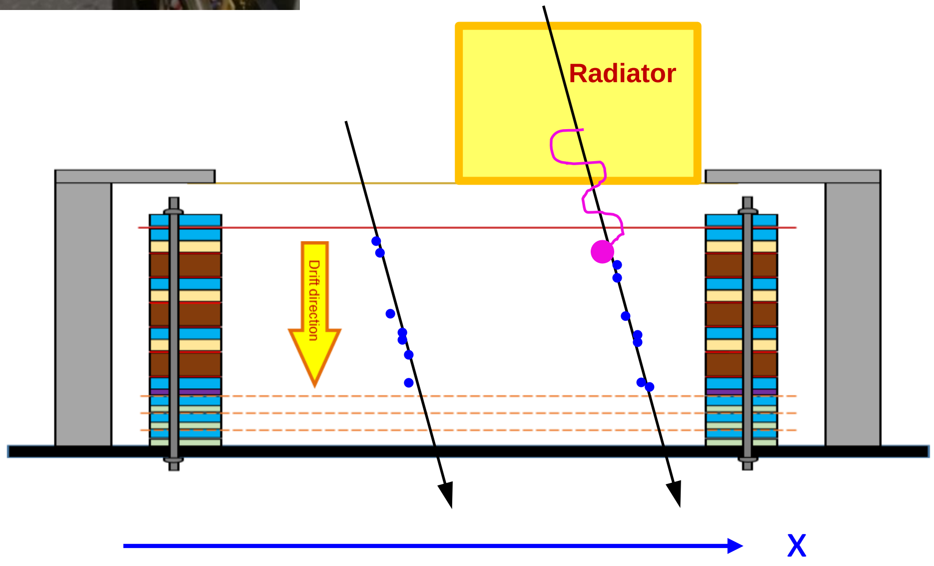
Test Beam @ JLab Hall D: Preliminary results with Ar / CO_2

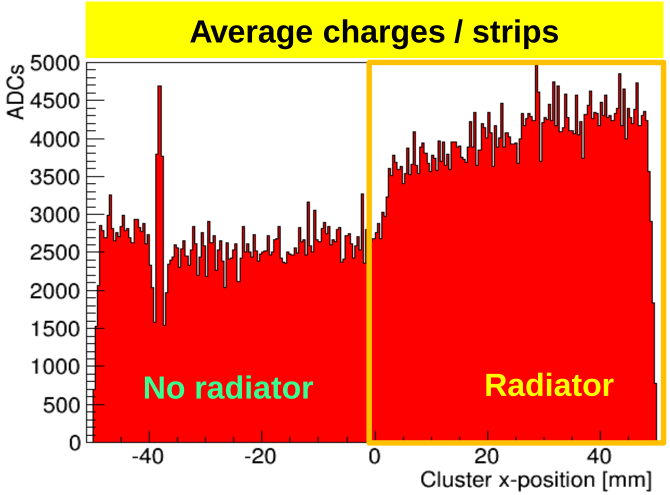


GEM-TRD prototype

- Hit distribution uniform along the x-axis (Top plot)
- No cluster counting
  - ⇨ Analysis does not separate TR cluster from the charge particle
- Average accumulated charges per strips show the TR effect (bottom plot)
  - Average charge 60% higher with radiator than without







Test Beam @ JLab Hall D: Preliminary results with Ar / CO2

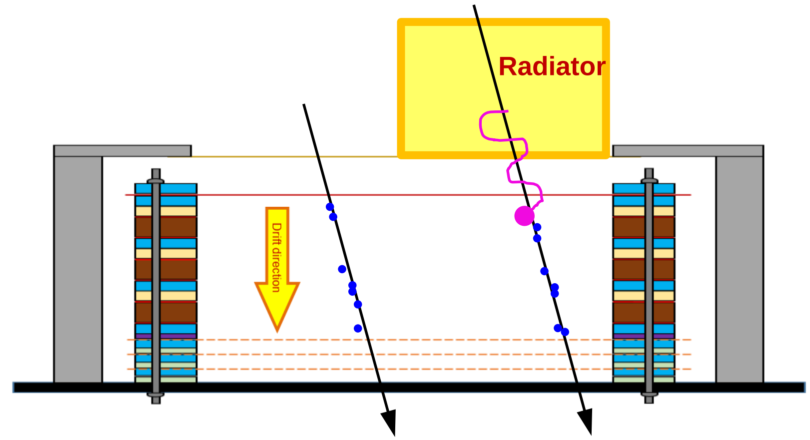
GEM-TRD Performances: Average deposited charges vs. drift time

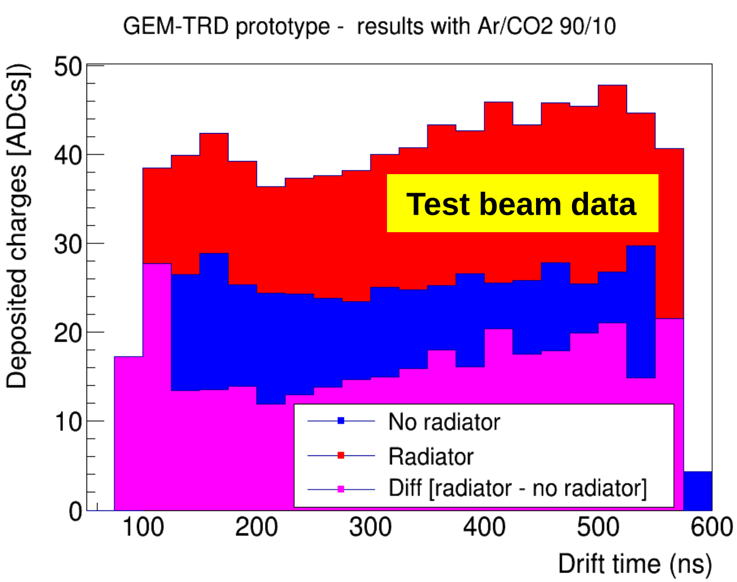
⇨ **Radiator area**: Expected exponential drop due to photon attenuation in the gas (red plot)

⇨ **Non radiator area:** Average ionization density is uniform with drift time (blue plot)

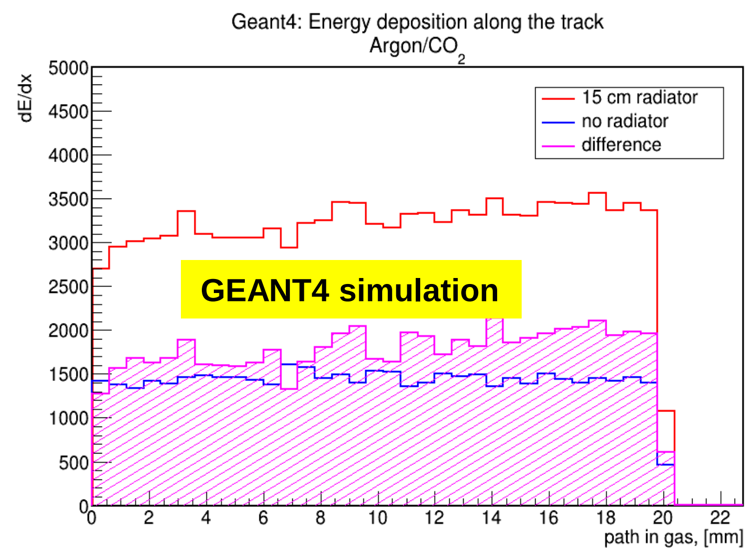
⇨ Results in full agreement with the simulation data:

⇨ Difference radiator / non radiator is higher for simulation data (magenta) ⇨ TRD effect is more pronounced





Drift direction



Ionization density in the chamber

Plan for GEM-TRD R&D

Proposal to be submitted EIC Detector R&D Advisory Committee (July 2017)

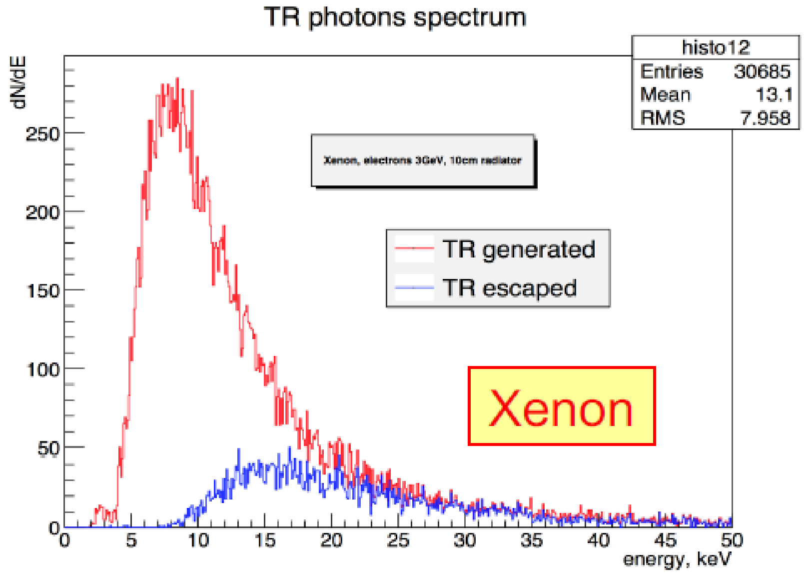
- GEANT4 simulation of TRD setup with GEM detector
  - ⇨ Estimate e/pi rejection factor for different configurations: layers, gases, electron efficiencies…
- Basic Transition Radiation features
  - ⇨ Using the existing facility at JLAB Hall-D perform a test with “known” radiators (ATLAS, ZEUS, etc.)
  - ⇨ R&D on other TR-radiators: Nano-technological radiators from BNNT
- Second GEM-TRD prototype
  - ⇨ Modifications to implement lessons learnt from the first prototype
  - ⇨ Investigate faster (than APV25) front-end electronics and readout system for GEM-TRD purpose.
  - ⇨ Test different Xe-gas mixtures: drift time, voltages and gas-gain, adjustments.

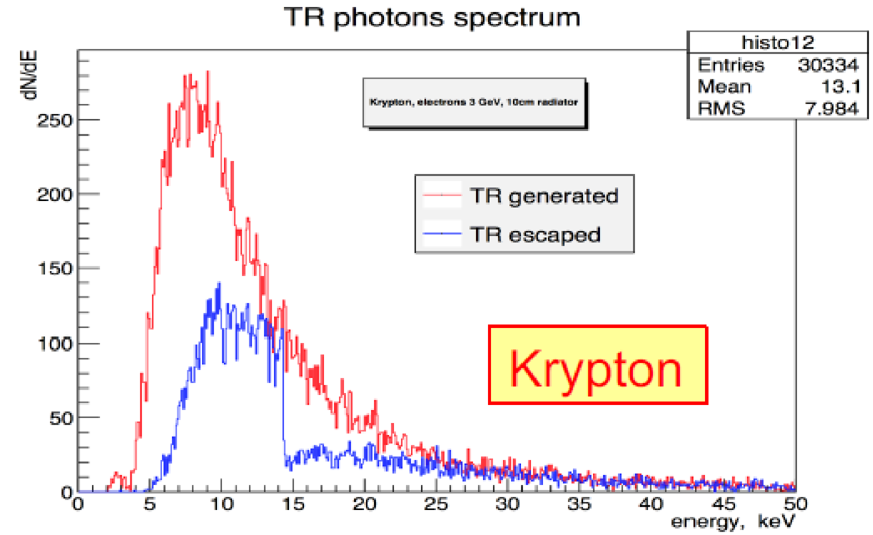
Summary

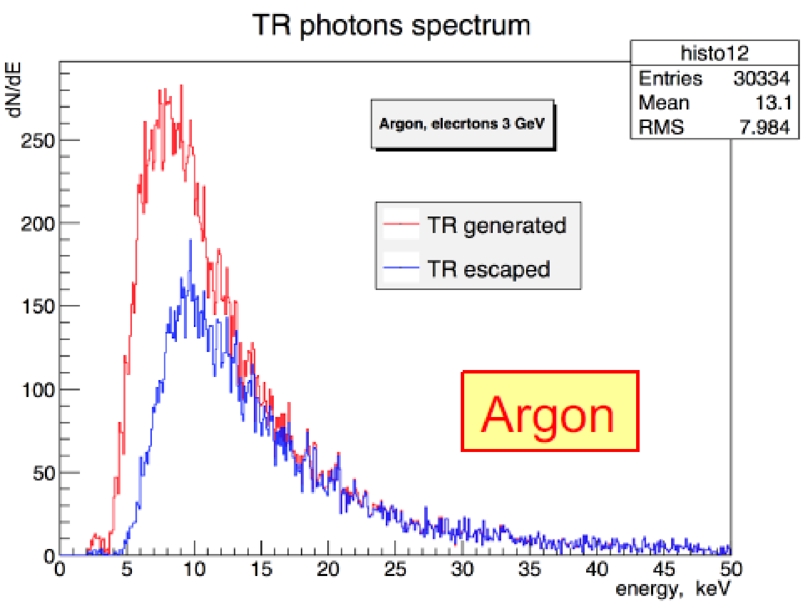
- R&D of GEM-TRD as an option for electron ID for EIC Forward Regions
- Small GEM-TRD was built prototype to demonstrate the proof of principle
- Preliminary test beam results are promising
- Proposal to the EIC Detector R&D for more detailed studies

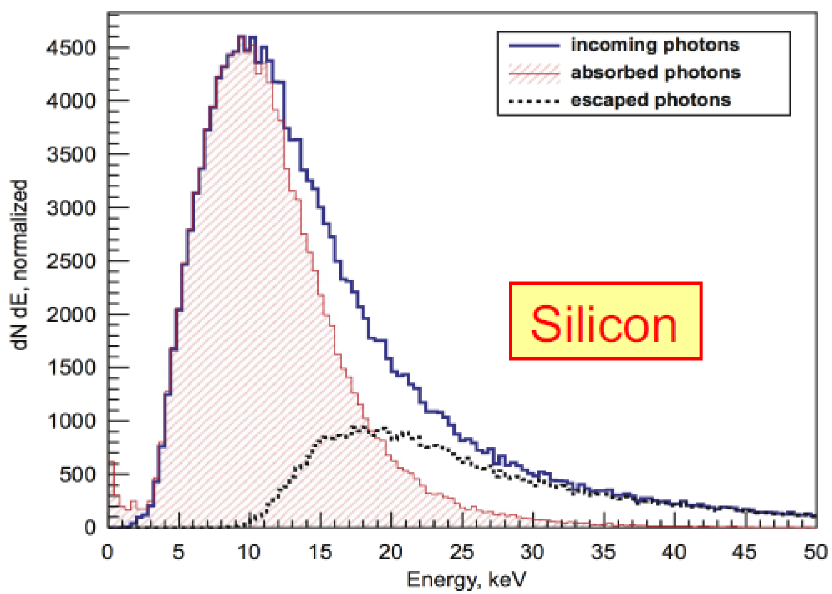
Backup

Transition Radiation Absorption









TRD Drift Chamber Prototype – with Ar and Xe