Transition Radiation Detector as EIC Detector 1 Tracking Improvement

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Transition Radiation Detectors

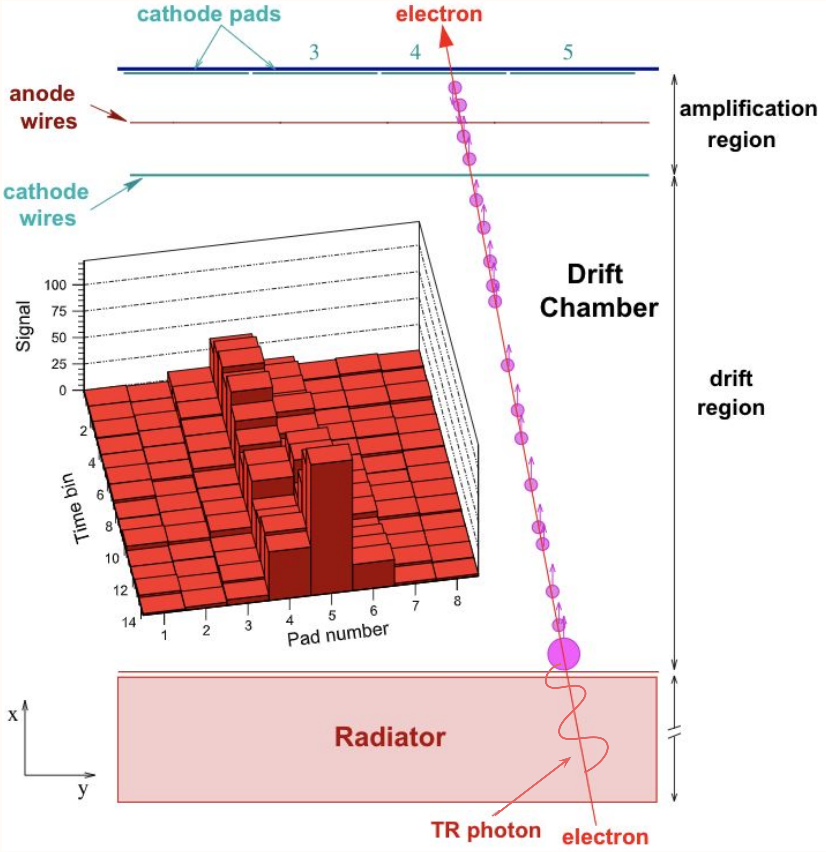
TR (~2-40 keV) produced by charged particles crossing boundary between two media of different refractive indices

Probability to emit 1 photon per crossing: $\alpha \sim 1/137$

Total TR energy emitted $\propto \gamma$-factor of charged particle; detect both X-rays & dE/dx losses by a proportional chamber behind TR radiator[1]

PID → Based on threshold properties of TR

Ideal discrimination of e's & h's in 1 GeV/c < p < 100 GeV/c



Source: Paolo Spinelli Università di Bari and INFN Sezione di Bari. 42 nd INFN ELOISATRON Workshop

TRDs at Work

Typically for *e* ID & *e*/*h* separation

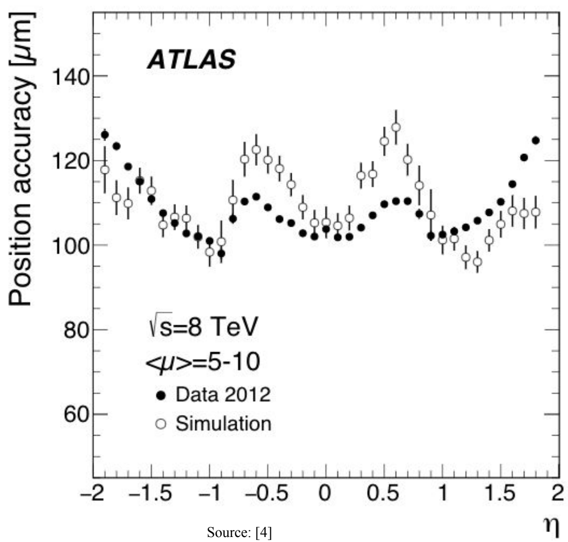
Understanding separation capability relies on understanding details in specific energy deposit of the particles

ATLAS: Straw based (thin design) tracking chamber for *e* ID, ~2x10^4 gas gain, drift time ~40 ns, counting rate ~6-18 MHz

ALICE: e/π ID p > 1 GeV/c, fast (6μs) high-p_T trigger. $\varepsilon_\pi \sim 10^{-3}$ @ ε_e ~90%

PHENIX: e/π ID, tracking, & mom. reconstruction with dE/dx utilizing 24 chambers[2]

Others: UA2, NA34, DØ, HERMES, CBM, ZEUS, NA31, HELIOS, kTeV, H1, WA89, NOMAD, HERA-B…



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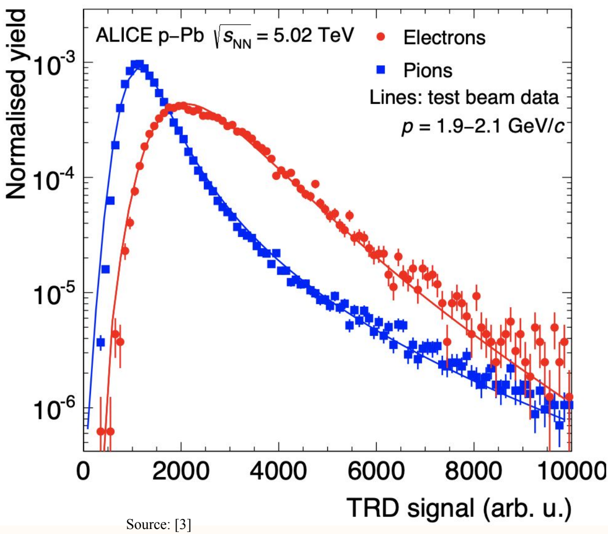

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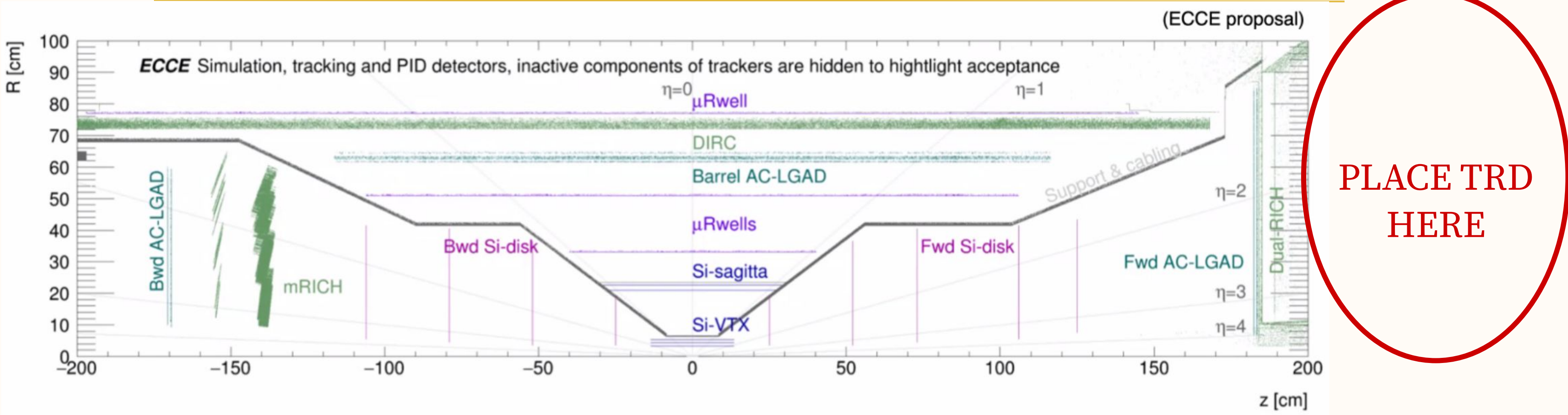
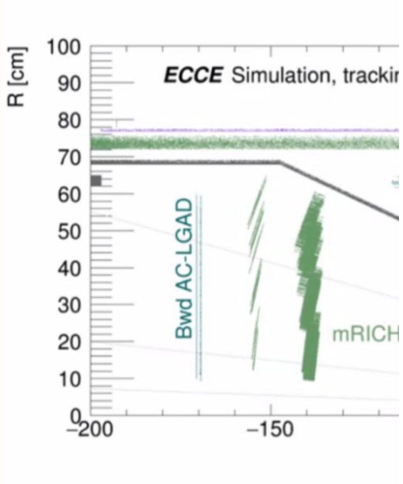
Proposed TRD Studies



Physics motivation in hadron endcap:

- provide additional *e/π* separation
- measure track angular resolution → improve RICH performance
- correct for multiple scattering before EMCAL, improve charged particle tracking
- improve pointing track res. & position measurements for EMCAL
- could use as seed element for track-finding algorithms



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Physics motivatio

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- measure trac ... e
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- could use as

Friday, June 24th: EIC General Meeting

Also PID for high mom. range

Kick-Off Meeting - Synergies between the Electron-Ion Collider and the Large Hadron Collider

- CERN, 6/20-21/2022, https://indico.ph.tum.de/event/7014/
- Main focus of the kick-off meeting: **the physics**
  - More about detector R&D synergies at future meetings
- Here, a selection of items pointing to suggestions for the DETECTOR-1 community (obvious matter is omitted)
- Selection prepared with the advice of Charlotte Van Hulse and Abhay Despande
  - several and strong comments pointing to the **relevance of muon identification** for:
    - cleaner (= less background affected) channels for quarkonia invariant mass reconstruction (talk by JP Lansberg);
    - access to BSM channels (talk by S. Forte)
    - **Muon detectors: really a continuous leitmotif during the whole meeting**
  - request of **deeper exploration of BSM opportunities** at EIC (talk by S. Forte)
  - keyrole of the **differential diffractive cross-section** of J/Ps for **gluon saturation** studies (talk by H. Mäntysaari)
  - request of more attention to **spectroscopy** within the Physics programm at the EIC, with needs for optimal vertex reconstruction and PID (talk by L. An)

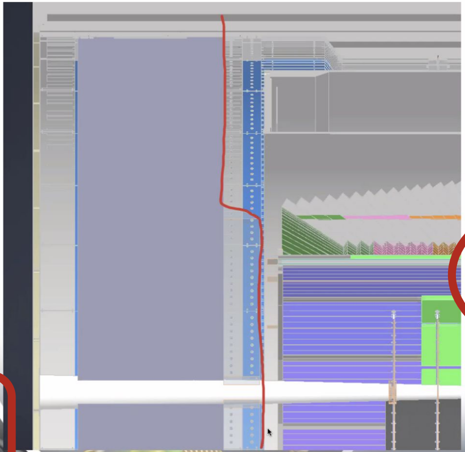
Integration Progress

To solve dRICH – Barrel ECal conflict that we illustrated at the earlier 06/09/22 meeting:

→ bECal projectivity changed: New model has 50cm "focal length" Sci-Glass variant blocks.

Details: The central region of focus is 50 cm long currently with 27.cm on one side of the centerline and 22.5 cm on the other side, respectively to the long and short sides of the detector.

→ Need to implement in simulation to see impact on physics – if any



dRICH implementation equal to recent presentations in WGs

https://indico.bnl.gov/event/16208/contributions/64912/attachments/41520/69576/%5BEIC%5D%5BDetector1%5D%5BIntegration%5D%20Constrains%20and%20needs%20for%20the%20dRICH%20envelope.pdf

→ to have space for services dRICH shifted by 15 cm away from IP along z

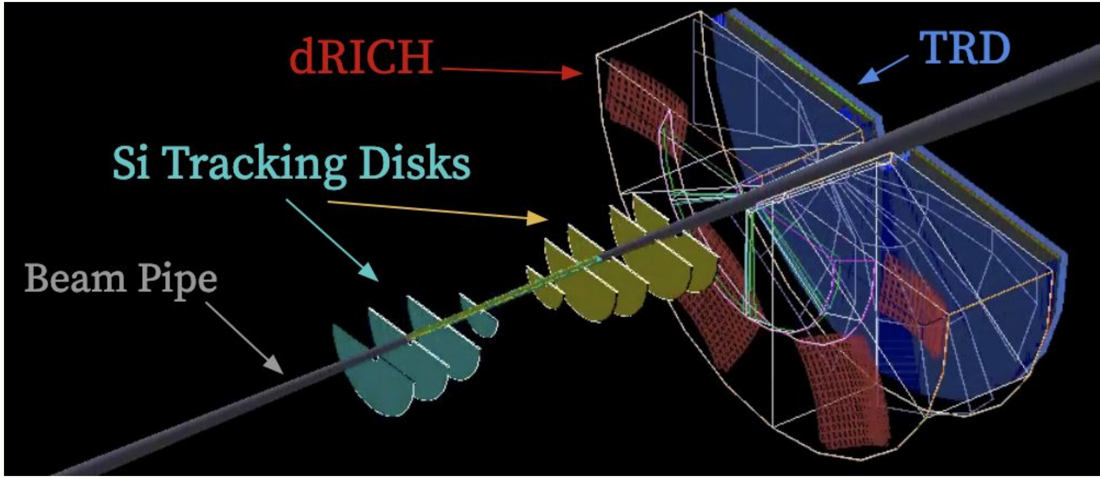
→ there is now an additional 20 cm for extending the dRICH
or
extending the dRICH and adding a tracker behind the dRICH

Question: why is the aerogel box so big?

Electron-Ion Collider

TRD Simulation

Geometry implemented in Fun4All → Transition to DD4HEP in coming months



Intend to simulate:

- Detector performance in Geant4
  - Mom. resolution
  - e/π efficiency & rejection factors
  - Angular res. when combined w dRICH
- Detector hardware parameters (gas, gaps, radiators), finite element analysis (ANSYS)
- Data analysis with ROOT-based TMVA (Deep Neural Network)

GEM TRD Tracking Prototype (JLab)

High resolution tracker w low material budget

- Gas for efficient absorption → $XeCO_2$ 70:30
- Fleece radiator (to produce more energetic TR photons)
- Drift region ~21 mm
- 3 GEM foils for signal amplification
- Gas gap ~400 µm, E-field ~3 kV/cm

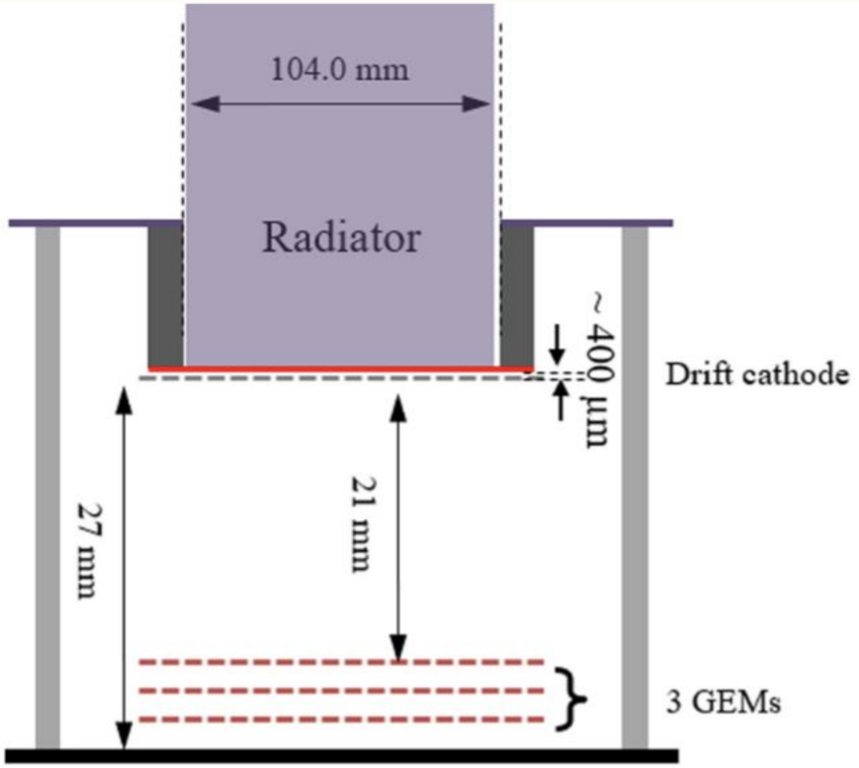


Fig. 2. Schematic of GEM-TRD/T prototype.

Source: [5]

GEM TRD Tracking Prototype (JLab)

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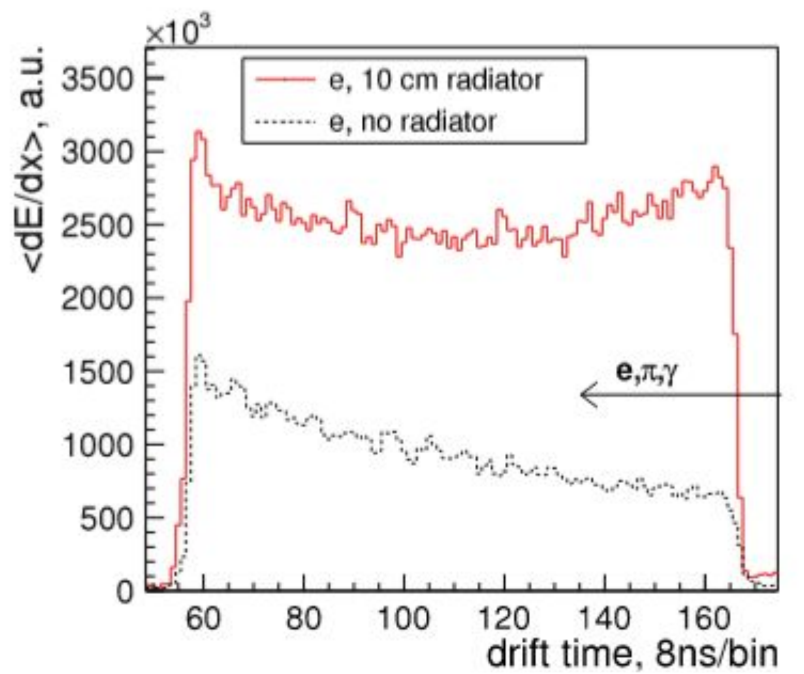


Fig. 8. The measured dE/dx vs. drift time for 3 GeV electrons with (red) and without (black) radiator, drift distance is 21 mm.

Source: [5]

Reference

[1] - B. Dolgoshein, “Transition Radiation Detectors”, NIM A326 (1993), p. 434-469

[2] - P. Spinelli, “Transition Radiation Detectors: recent developments and outlooks”, 42nd Eloisatron INFN Workshop (2003), Erice

[3] - The ALICE Collaboration, “The ALICE Transition Radiation Detector: construction, operation, and performance”, Nucl. Instrum. Meth. A 881 (2018) 88, arXiv 1709.02743

[4] - J. Adelman; The ATLAS Collaboration, “Performance of the ATLAS Transition Radiation Tracker”, Nuclear Inst. and Methods A 706 (2013), p. 33–38

[5] - F. Barbosa *et al*, “A new Transition Radiation detector based on GEM technology”, Nuclear Inst. and Methods A 942 (2019) 162356

Questions?

Backup

- Operational gas mixture changed from Ar-based mixture to Xe-based → Heavy gases required for efficient X-ray absorption
- Compare various noble gases & silicon in terms of absorption power for 20 mm gas thickness. Best gas is Xe
- Xe-based mixture requires higher fields (~2000 V/cm) for a similar drift velocity as Ar (~1000 V/cm). High cost of Xe means closed loop gas system necessary. Xe-CO2 70:30 mixture used

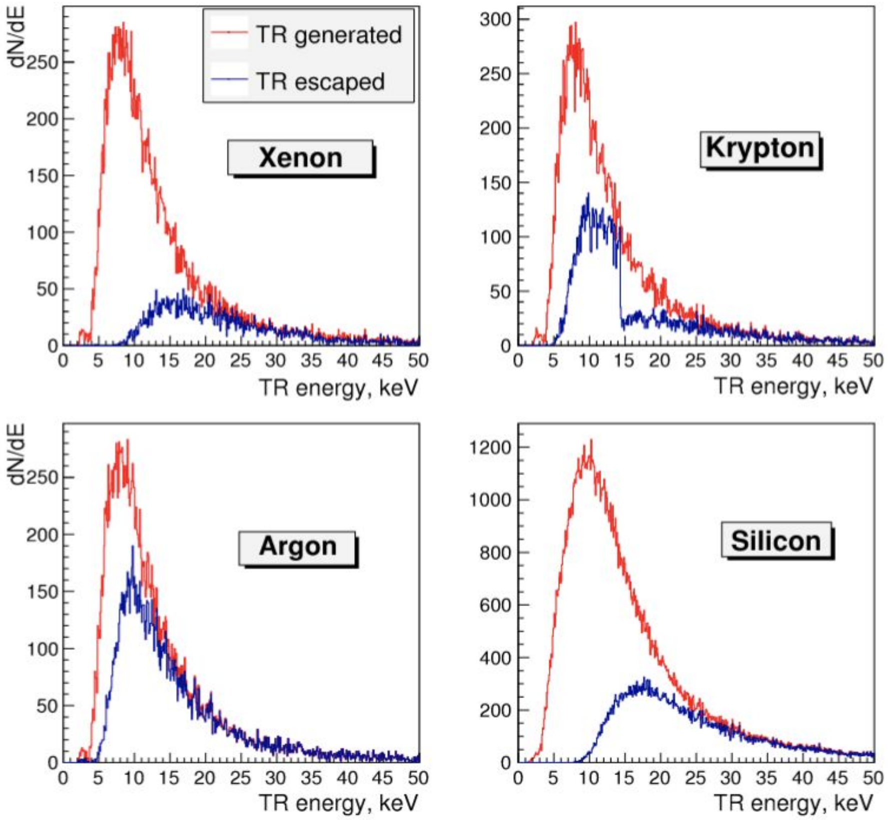
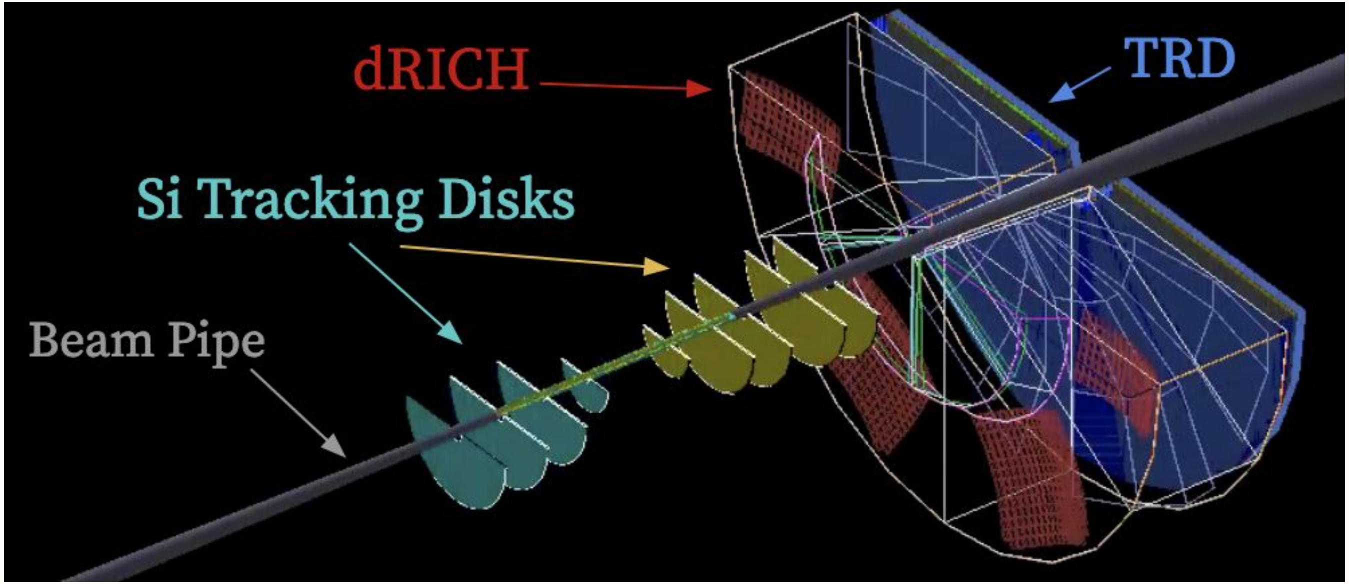


Fig. 3. TR absorption efficiency for different gas mixtures and silicon.

TRD Geometry in Fun4All



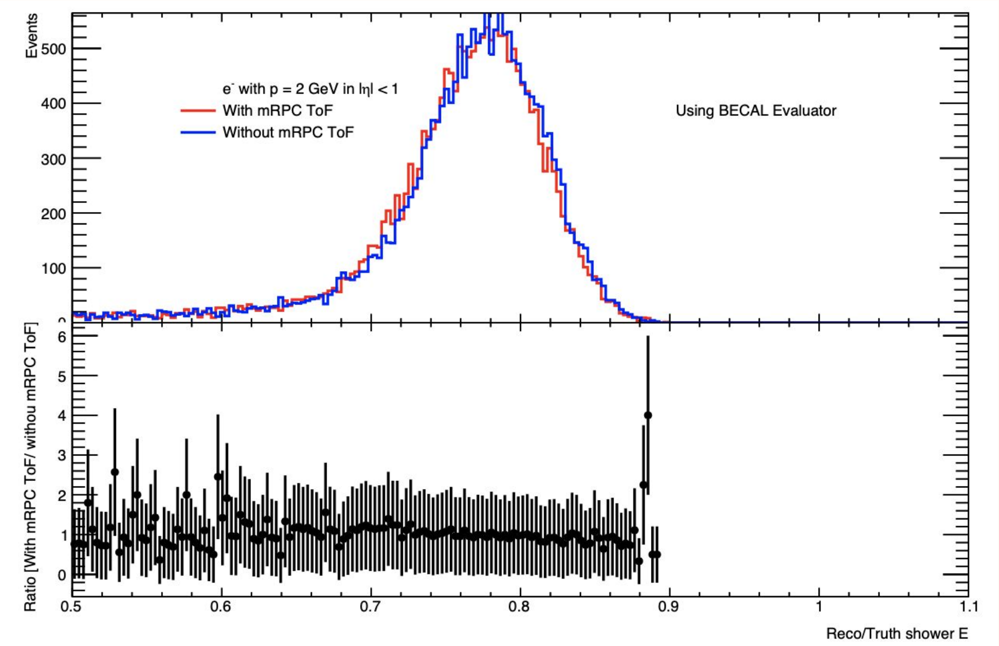
Gas gap ~2 cm

Total length ~18 cm

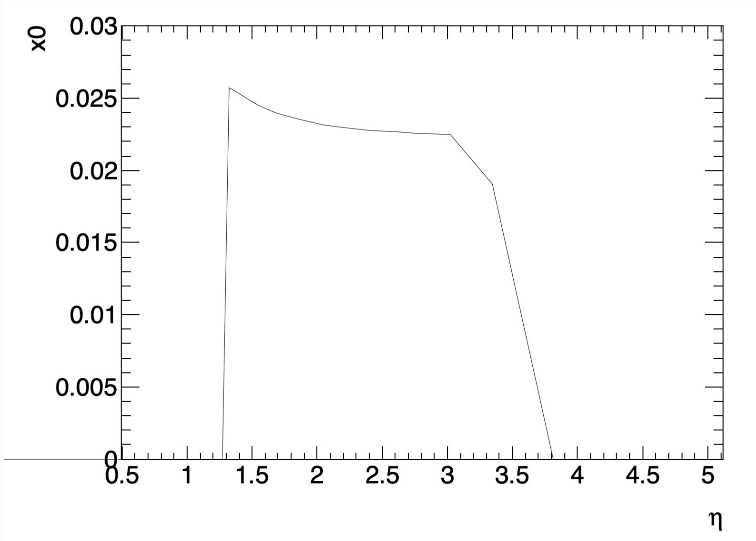
Radiator material: mylar. In Geant4, radiator length default → 10 cm

Material Budget

No effect on *e*- shape in Barrel EMCAL from mRPC ToF of ~10% RL



Measured ~2.5% RL for 18 cm TRD implemented in Fun4All



JETSCAPE

Jets provide powerful tools to study internal structure of QGP (tomography)

Interpretation of jet measurements requires sophisticated modeling/simulation, and comparison of theory calculations with experimental data requires advanced statistical tools

JETSCAPE Collaboration → interdisciplinary group developing comprehensive software framework to do this; generators, emulation, validation…

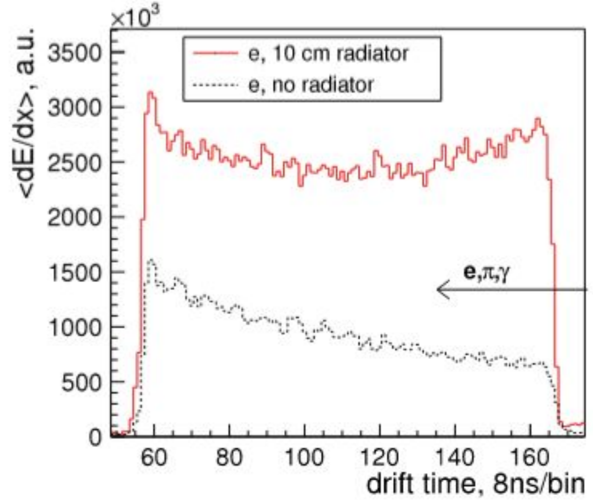


Fig. 8. The measured dE/dx vs. drift time for 3 GeV electrons with (red) and without (black) radiator, drift distance is 21 mm.

Presence of additional ionization from TR photons along the particle trajectory used for TR-identification. Measured dE/dx profile in good agreement with MC simulation. Ionization of 3 GeV pions is less than that for 3 GeV electrons due to a relativistic rise

Readout

- Standard GEM readout measures peak amplitude - TRD needs additional info about ionization along the track
- GEM-TRD/T prototype modified to use 125 MHz FADC with VME-based readout. Readout window of up to 8 μs → covers entire drift time of the prototype
- Able to provide ~ 60–200 energy measurements along each particle trajectory
- 3–6 GeV *e*'s produced in photon converter of a pair spectrometer - precise determination of incident photon spectrum and hence e^-/e^+ energies

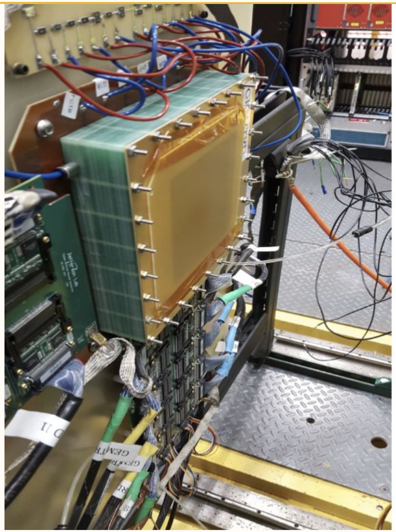
Beam Test

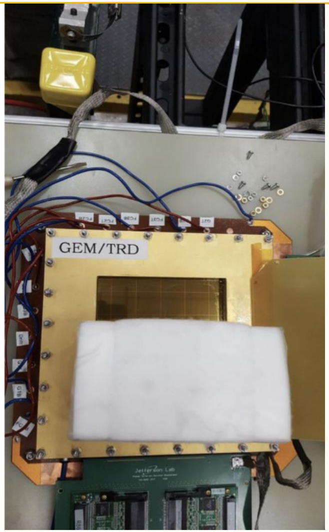
- TR photons emitted at very small angles within $1/\gamma$ and detected on top of ionization energy loss of the particle. To discriminate:

- Cluster counting method - One threshold on signal amplitude assuming energy deposition from TR photons is point-like, produces clusters with large amplitudes
- Separation in space - Requires high position resolution detectors to see natural angular distribution of TR photons
- Strong magnetic field for deflecting charged particle from TR photon

In the case of measurements along a track, a neural network method may be used for *e*/h separation ← used here

Prototype Data to be Analyzed





- Various readout structures to minimize
- Modifications to test on new prototypes: radiators, MPGD technology (GEMs, MicroMegas, μRWELL…)
- Investigate faster front-end electronics and readout systems, alter readout strip configurations
- Test different Xe-gas mixtures: drift time, voltages / gas-gain, adjustments…