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

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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 ~ $2 \times 10^{34}$

### 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 $1 \times 10^{34}$ cm$^{-2}$ s$^{-1}$
EIC Detectors concepts

- EIC User Group Meeting ANL 2016. Kenneth N. Barish
- BeAST @ eRHIC
- hadronic calorimeters
- e/m calorimeters
- RICH detectors
- silicon trackers
- TPC
- GEMs
- Micromegas
- 3T solenoid cryostat

- JLEIC Design
- H-endcap
  - $Q^2 > 100 \text{GeV}^2$
  - Charged $\pi/K$
  - Scattered e
  - Secondary e
- E-endcap
  - $Q^2 < 10 \text{GeV}^2$

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**EIC: Physics motivations for electron ID**

**Hadron Endcap**
- For **rare physics**, based on electron identification
  - Charmonium, light vector mesons (\(\rho, \omega, \varphi\))
  - Tetraquarks, Pentaquarks (and other XYZ states)
  - Open Charm physics via leptonic decays
  - Di-lepton production

**Electron Endcap**
- EM calorimeter covers full range,
  - \(\pi\) background are large at small angle & low energy
    - Need a suppression at \(10^3 \sim 10^4\) level
    - EM cal alone not enough (low resolution)
  - Need additional e/\(\pi\) 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 particle when they cross the interface of two media of different dielectric constants.
- TR in X-ray photon are then emitted along with the charge particle with a forward peak within an angle of $1/\gamma$ with an energy range of 2 to 40 keV
  - With $\gamma$ the Lorentz factor of the charge particle
  - Total TR Energy $ETR$ is proportional to the $\gamma$ factor
- The probability to emit one TR photon per boundary is of order $\alpha \sim 1/137$.
- Multilayer dielectric radiators (typically few hundreds of mylar foils) are used to increase the transition radiation yield.
- Clean $e/\pi$ separation over a large energy range $>1$ to up to 100 GeV
  - No other single technique can provide a $e/\pi$ over this large range
- “Compact” detector provides with a good rejection factor (100)
- Typically TRD is either combined with tracking detector (ATLAS TRT) or provide additional tracking information

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)
Gas based Transition Radiation Detectors

ALICE MWPC-TRD


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% CF₄ + 10% CO₂ gas mixture (70% Xe + 27% CO₂ + 3%O₂ 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
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 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
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/π 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

**Xenon**
- TR photons spectrum
  - Energy vs. 
  - dNdE vs.
  - TR generated
  - TR escaped

**Argon**
- TR photons spectrum
  - Energy vs.
  - dNdE vs.
  - TR generated
  - TR escaped

**Krypton**
- TR photons spectrum
  - Energy vs.
  - dNdE vs.
  - TR generated
  - TR escaped

**Silicon**
- Energy vs.
- dNdE normalized
- incoming photons
- absorbed photons
- escaped photons

5/22/2017
TRD Drift Chamber Prototype – with Ar and Xe