# Identification of TeV hadrons: Transition Radiation Detectors (Expression of Interest: Snowmass IF02, IF09)

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**Abstract**

Identification of long-lived charged hadrons, specifically distinguishing $\pi^{\pm}, K^{\pm}, p$ and $\bar{p}$ and light nuclei such as $d, \bar{d}$ is well developed for low momenta using track ionization, Cherenkov light or time-of-flight. At collider energies most produced hadrons have higher momenta and these methods become impractical. Transition radiation detectors (TRDs) are the most promising technique for identifying hadrons in the TeV region, of increasing importance at the LHC and future colliders. We intend to further their development and invite collaborators.

At the LHC and earlier colliders after the CERN Intersecting Storage Rings the focus has been on the central region of rapidity, where most hadrons have low momenta and could be identified with established techniques such as ionization ($dE/dx$), time-of-flight (ToF) or Cherenkov radiation. Central hadrons with high momenta are mostly in jets and $\pi, K, p$ distinction has not been considered important. However most produced hadrons have $p_Z \gg p_T$ and are very forward, a region of growing importance. To understand cosmic ray showers and cosmic neutrinos (and their atmospheric neutrino background) several Monte Carlo event generators are used. These predictions diverge at high Feynman $x_F$ and would benefit from data on forward hadrons, including $\pi/K$ separation, at hadron colliders, both with proton beams and nuclear beams. This is also the dominant region of phase-space for production in high energy fixed target experiments, whether using beams from the SPS, PIP at Fermilab, extracted from the LHC (as in the AFTER proposal) or with an LHC beam on a gas target. Studies of high energy neutrinos from LHC interactions, as in the FASER$\nu$ experiment, depend for their normalization (including flavors) on the fluxes of $\pi^{\pm}, K^{\pm}, D^0$ and $\bar{D}^0$ in the very forward region.

This is likely to be even more important at the FCC, where 50 TeV hadron beams can be used as a source of neutrinos with tens of TeV in the forward direction. To know the spectra of $\nu_e, \nu_\mu, \nu_\tau$ one will need to know the spectra of their various sources. This will require hadron identification in a region where most techniques are not practical. Transition radiation detectors are presently the best known method, but we encourage other ideas.

Transition radiation, mostly in the X-ray region, occurs when a charged particle crosses an interface between two media with different dielectric constants. The probability of emission of a photon rises with $\gamma = E/m$ but is only $\sim 10^{-2}$ so many interfaces are needed for statistics. It is non-linear and saturation occurs, and the range can be tuned by choice of materials. There is information on $\gamma$ not only on the number of photons but on their energy and direction, see the test beam data in Fig.2. The emission angle decreases with increasing speed, opposite to Cherenkov photons.

TRDs are typically used to distinguish $e^{\pm}$ from hadrons, since their mass ratio is so high. In cosmic ray physics they were used from the 1970s TREE balloon experiment measuring $e^{\pm}$ with a proton rejection factor $10^2$ using a polyethylene foam radiator, to the modern AMS-02 detector.

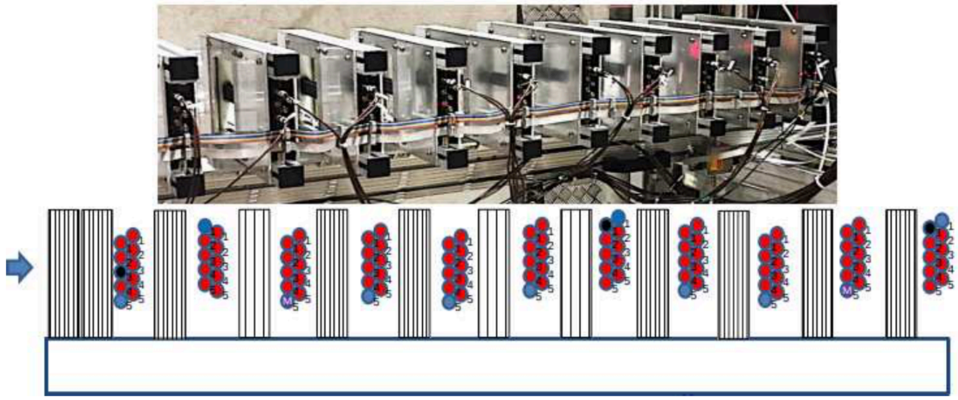

Figure 1: Straw tube with Xe TRD at a CERN test beam $(e, \pi)$ validating simulations[2].

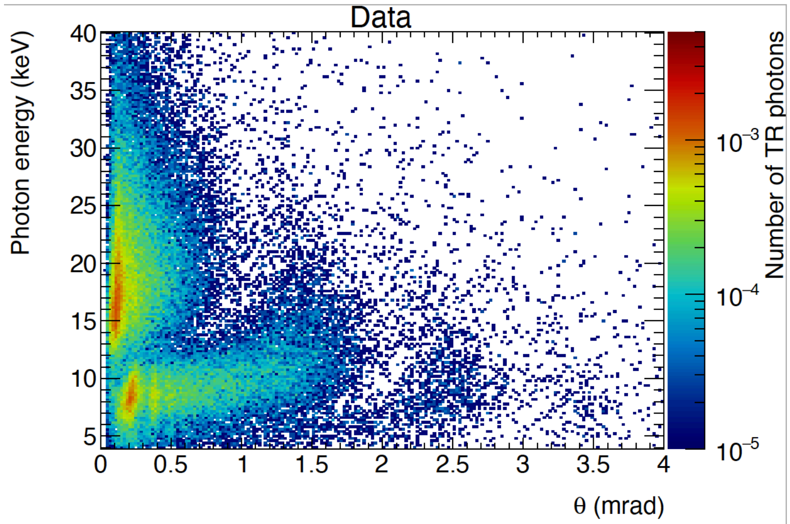


Figure 2: Correlation of TRD photon energy and production angle (20 GeV/c electrons, test beam data)[3].

They have been used in many accelerator experiments, mostly to help distinguish $e^{\pm}$ from pions, as in the ATLAS Inner Detector, but $\pi/K$ separation at 250 GeV was achieved[1]. It is much more challenging to distinguish $\pi^{\pm} - K^{\pm}$ $(K - p)$ since the mass ratio is only 3.54 (1.9), but some of us[2; 3] have been developing promising methods. Fig. 1 shows a Xe-filled straw tube TRD studied in test beams at the CERN SPS. The data have validated simulations and will enable optimisation of a design for specific applications. Solid state (e.g. GaAs) detectors are also promising.

We invite interested experimenters to participate in developing detectors for TeV hadron identification for future experiments. An early application is measuring forward hadrons, with $10^3 < \gamma < 3.5 \times 10^4$ at the LHC in special low luminosity runs. This is the subject of another Snowmass EoI[4]; we encourage you to also join that effort.

# References

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[3] J.Alozy *et al.*, Studies of the spectral and angular distributions of transition radiation using a silicon sensor on a Timepix3 chip, Nucl. Instr. Methods in Physics Research, **961** (2020) 163681.

[4] D.Cerci *et al.*, A very forward hadron spectrometer for the LHC, LoI to Snowmass EF05 and EF06.