A TRANSITION RADIATION DETECTOR WHICH FEATURES ACCURATE TRACKING AND dE/dx PARTICLE IDENTIFICATION*

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Abstract

We describe the results of a test run involving a Transition Radiation Detector that can both distinguish electrons from pions with momenta greater than 0.7 GeV/c and simultaneously track particles passing through the detector. The particle identification is accomplished through a combination of the detection of Transition Radiation from the electron and the differences in electron and pion energy loss (dE/dx) in the detector. The dE/dx particle separation is most efficient below 2 GeV/c while particle ID utilizing Transition Radiation is effective above 1.5 GeV/c. Combined, the electron-pion separation is better than $5x10^2$. The single-wire, track-position resolution for the TRD is $\sim 230\mu$m.

Introduction

Experiments being designed for the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory will need to distinguish electrons from pions to better than 0.1% over a momentum range of 0.1 GeV/c to 8.0 GeV/c. The particle multiplicity will be high (dN/dy$\geq$1000) but the event rate for central Au-Au collisions will be relatively modest (1-10 kHz). Transition Radiation Detectors (TRD's) are well suited for separating electrons from pions in a high multiplicity environment within a colliding beam geometry. By conducting a test run with a TRD prototype we have been able to quantify many of the RHIC TRD performance parameters.

We have designed a TRD for inclusion in a RHIC experiment that allows electron-pion separation utilizing both TR and dE/dx information, while simultaneously tracking charged particles with good position accuracy[1]. A prototype of this detector has been tested in a secondary beam of the Alternate Gradient Synchrotron at Brookhaven National Laboratory. In this test run we have determined the e/π separation of our prototype over a momentum range of 0.7 GeV/c - 4.0 GeV/c, evaluated a variety of potential radiator materials for the TRD and measured the TRD tracking resolution.

The Test Run

The TRD used in our test run was a modified version of the NA34 TRD[2]. It consisted of four wire chambers interleaved with radiator material. Each wire chamber was a xenon-filled Time-Expansion Chamber with a 1 cm drift space and a proportional region of 8 mm x 2.5 mm per anode wire (Fig. 1). A single wire chamber consisted of a 10μm aluminized mylar front entrance window that served as both a cathode to the chamber's drift section and a gas barrier, a plane of vertical cathode wires located at the beginning of the chamber's proportional region, a plane of horizontal, 25μm, Au-W anode wires spaced $\sim$2.5 mm apart and cathode strips etched into a rear aluminized mylar window. Each of the four wire chambers was separated from the next by 16.8 cm in the z-direction (beam direction). The radiator material of the TRD consisted of either 10 cm thick blocks of polyethylene foam or 120 layers of 12μm polypropylene foils spaced by 800μm. Several radiator materials were tested. The RHIC TRD and prototype differ in the length of the drift region, cathode orientation and number of detector planes. The prototype contains 4 planes of radiator-detector, a 1 cm drift space and cathode strips perpendicular to the anode wires, while the RHIC TRD will have 8 detector planes, a 3 cm drift space, and cathode strips oriented for stereo readout.

The electronics chain on each anode wire or cathode strip consisted of a preamplifier, a shaping amplifier and a 6-bit Flash ADC clocked at 24.5 nsec. The FADC had a memory depth of 256 bins or 6.25 μsec. The digitized

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Figure 1: Schematic of Test TRD

FADC signal was read through a VME DR11W into a VME crate that also received CAMAC data from detector elements in the beamline (Fig. 2). The whole data aquisition system was controlled by a Macintosh running Mac-UA1 software from CERN.

The test run took place at the A2 beamline of the AGS at BNL and used a secondary beam containing e^-'s, π^-'s and K^-'s. The beamline was instrumented with two beam defining scintillators S1 and S2, a veto counter S3, two Cerenkov counters C1 and C2, and a block of Pb-glass 10 radiation lengths deep (Fig. 3). The data were taken either with a minimum bias trigger ($S1{\cdot}S2$), or an electron trigger ($S1{\cdot}S2{\cdot}C1{\cdot}C2$), where both the Cerenkov counters were set for e/π discrimination. The e/π ratio in the beam ranged from 0.5% to 20% depending on the beam momentum.

Radiator Tests

The number of transition radiation photons produced for 6 different polyethylene foam radiators, and a polypropylene foil radiator, was measured. Each radiator was 10 cm thick. Our goal was to determine the absolute transition radiation production of each radiator *and* the production of TR photons per radiation length of material. The cell sizes and densities of our test radiators are listed in the following table.

Figure 2: Test run electronics chain

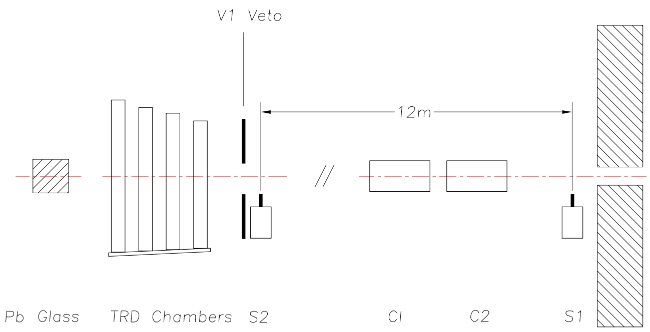

Figure 3: Overview of Test Beamline Set-up

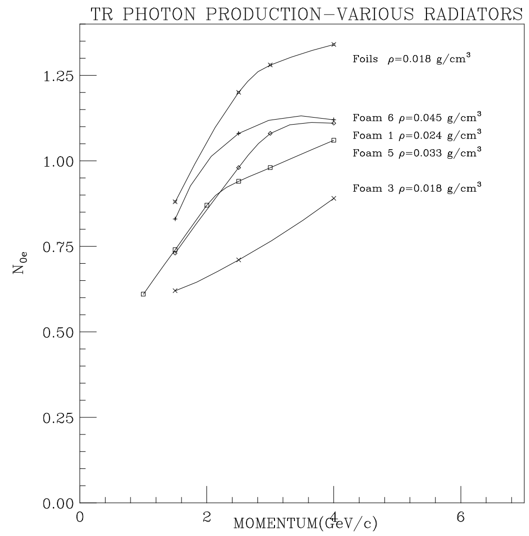

Figure 4: Number of photon clusters over threshold per 10 cm layer of radiator. The data is from electrons at different momenta.

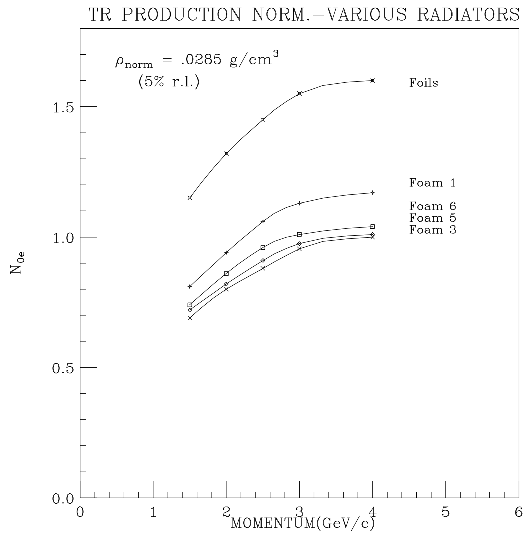

Figure 5: Number of photon clusters produced by electrons in 1 layer of radiator normalized where 8 layers of radiator= 5% radiation length.

Radiator Type	Density	Cell Size or Foil Gap
Foil	0.018 gm/cm^3	800μm
Foam 1	0.024 gm/cm^3	800μm
Foam 2	0.044 gm/cm^3	1000μm
Foam 3	0.018 gm/cm^3	600μm
Foam 4	0.024 gm/cm^3	200μm
Foam 5	0.033 gm/cm^3	$600 - 700\mu$m
Foam 6	0.045 gm/cm^3	$200 - 250\mu$m

Both electron and pion data were taken for each radiator at three or more momentum settings. The FADC data from each event was scanned for photon clusters. A photon cluster was defined as $E \geq 4.5$ keV deposited inside the xenon gas chamber in a volume 0.5 to 1.5 mm in diameter. We called this an identified TR photon. The size of the cluster seen in our detector is determined by a combination of the initial electron cluster size due to the absorption of the X-ray, the gas diffusion over the drift distance, and the rise time of our shaping amplifier. The energy scale of the clusters were set by normalizing the FADC pulse heights to an ^{55}Fe source. The relative normalization of each wire was obtained with pulser calibration runs that involved injecting a known amount of charge into the input of each preamplifier. The ^{55}Fe normalization was performed at least once every eight hour running period. The pulser calibration was found to be consistent over many days.

The mean numbers of TR photons, as defined above, were calculated for each radiator at each beam momentum and are shown in figure 4. We can normalize the mean number of TR photons produced per radiation length of the radiator material (Fig. 5) and see that on average the foil radiator produces 50% more TR photons than the foam radiators. It should be noted that pure pion data also show pions producing what are apparently TR photons, although at a much lower rate than electrons. Large energy clusters in pion data come from δ-rays, and it is this background that ultimately limits the ability of a TRD to separate electrons from pions.

Transition Radiation e/π Separation

Once transition radiation can be identified in our detector the e/π rejection can be determined by histogramming the TR photon cluster distributions for electrons and pions traveling through many layers of the TRD. The TRD that we have designed for RHIC experiments will include 8 layers of radiator and gas detector, so to calculate e/π separation with data from our 4 layer test detector we have paired consecutive electron or pion events. We believe that summing pairs of tracks is an accurate method because backgrounds that degrade pion rejection, such as δ-rays accompanying pions through 8 planes of the TRD, are either rare or readily identified by the tracking features of the detector.

Large statistical samples of both electrons and pions were accumulated at a few momenta for one particular foam radiator. Additional data were taken with the foil radiator for normalization purposes. Large statistics are required to determine e/π separation to the 10^{-3} level and beyond.

In the analysis we accepted events that contained only single tracks, summed charge from neighboring wires to reduce diffusion effects, and employed threshold cuts as outlined in the previous section. We also utilized a cut called the intelligent threshold, which applies a sliding ADC threshold that moves from low to high as the clus-

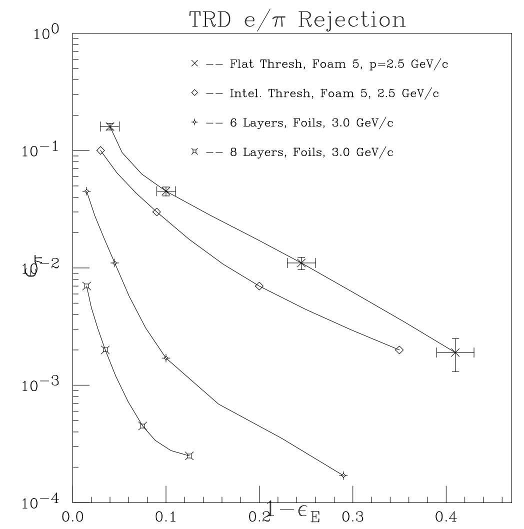

Figure 6: Pion rejection vs. electron efficiency for 2.5 and 3.0 GeV/c particles. Curves shown are for 8-layer foam radiators with simple threshold, 8 layer foam and intelligent threshold, 6 layer foils and 8 layer foils each with intelligent threshold

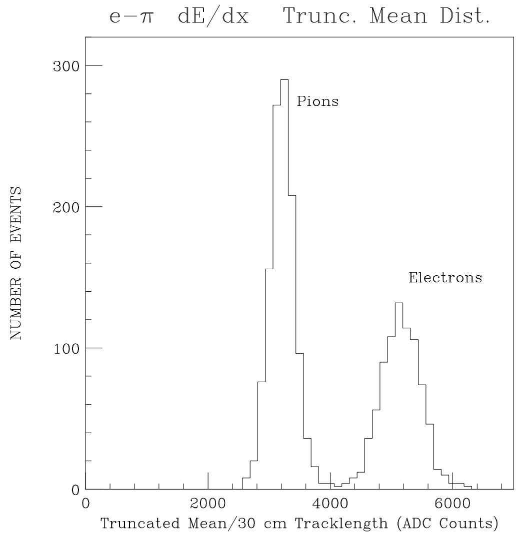

Figure 7: Electron, pion dE/dx distribution for 30 cm track length and 60% truncated mean. The data is for particles with momenta 1.0 GeV/c and 35° incident angle.

ter location moves away from the radiator. The intelligent threshold is effective because δ-rays from pions are evenly distributed in the z direction (beam direction) inside the drift volume while transition radiation photons are not. Lower energy TR photons tend to be absorbed earlier in the Xe gas, that is closer to the radiator, whereas higher energy TR photons penetrate farther into the gas detector before being absorbed.

Results of the analysis of data taken at both 2.5 and 3.0 GeV/c can be seen in figure 6. This figure shows four curves:(a) e/π rejection for 8 TRD planes using foam radiator and a simple threshold cut,(b) the same detector-radiator combination and an intelligent threshold,(c) 6 TRD planes using foil radiator and the intelligent threshold, and (d) 8 TRD foil radiator planes and the intelligent threshold. One sees that with 8 layers of foam radiator and 90% electron efficiency one retains 3×10^{-2} pions. Likewise, 90% electron efficiency and 6 or 8 planes of foil radiator retain 2×10^{-3} and 3×10^{-4} pions respectively. We conclude that the foil radiators will easily provide us with the desired e/π rejection above 2.0 GeV/c, but that the foam radiators needs further study if they are to be used in a RHIC experiment. Mechanical construction of the TRD would be considerably easier if one used foam radiators rather than foil radiators, but it is still possible to construct a large area TRD with foil radiators.

dE/dx e/π Separation

Below a momentum of 2.5 GeV/c the effectiveness of e/π separation using TR photons starts to diminish because as the electron becomes less relativistic, the probability of a TR photon being emitted by the radiator decreases. Since it is desirable to have good e/π separation below this momentum, other methods must be considered. Particle ID using dE/dx in the Time-Expansion Chamber can be used to achieve good e/π separation below 2.5 GeV/c.

In the momentum region 200 MeV/c to 3.0 GeV/c, an electron loses more energy through dE/dx than a pion due to its position on the relativistic rise of the dE/dx curve as described by the Bethe-Bloch formula. Energy losses in xenon gas are large, so a low momentum track traveling through a sufficient path length of xenon can be identified as either an electron or a less relativistic particle by evaluating the truncated means of the dE/dx distributions. The average charged track moving through the RHIC TRD passes through 30 cm of xenon gas as it crosses the eight layers of the detector. In our analysis of the test data we have combined multiple pion or electron events to obtain the equivalent 30 cm track length in the xenon gas to evaluate the dE/dx e/π rejection. The dE/dx data have been taken at three angles $(0°, 20°, 35°)$ and with two different gas mixtures (95%Xe+5%C_4H_{10}, 50%Xe+45%He+5%C_4H_{10}).

The drift velocity in the test TRD is ∼20 mm/μsec which translates to a drift distance of 0.5 mm per 24.5 nsec FADC time bins. If one takes each FADC time bin as an independent measurement, one obtains 600 ADC data samples for each 30 cm charged track. We combined events containing either electrons or pions until we obtained data equivalent to a 30 cm track length. We created a pulse area(PA) distribution of the 600 FADC values/track, eliminated the highest 40% of the FADC values and calculated the mean PA value of the remainder. This is the standard

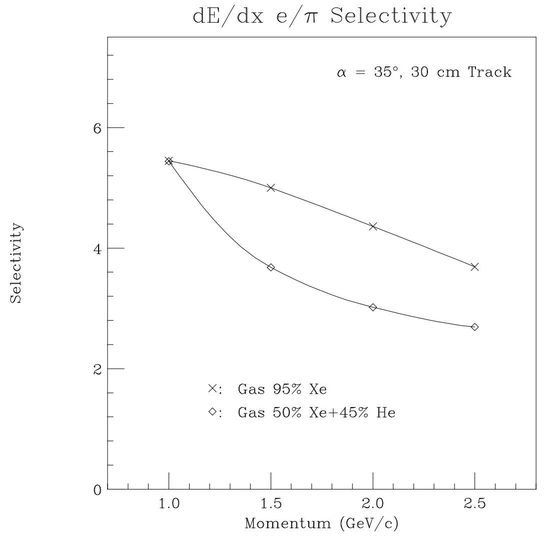

Figure 8: S-value for 2 different gas mixtures. 95% Xe + 5% C_4H_{10} and 50 % Xe + 45% He + 5% C_4H_{10}. The data is for 30 cm track length and 35° incident angle.

truncated-mean technique. A distribution of these mean PA values shows a large separation between the mean PA of electrons and pions (Figure 7). The electron-pion separation shown in figure 7 can be described by the selectivity value (S-value) where:

$$S = \frac{(E_e - E_\pi) - 2\sigma_e(E_\pi/E_e)}{\sigma_\pi}$$

E_e and E_π represent the means of the dE/dx truncated mean distribution for electrons and pions.

Figure 8 shows the S-value plotted versus momentum as obtained from our 35° dE/dx data. Our results agree with that of previous studies [3, 4]. The S-value is larger for data taken with the TRD filled with a higher percentage of xenon, which is expected since a larger percentage of xenon yields larger dE/dx losses.

The e/π separation in figure 9 shows that for 35° tracks at 1.5 GeV/c, one has 97% electron efficiency while keeping only 1.5×10^{-3} pions. The average track angle in the RHIC TRD is predicted to be $35^\circ - 40^\circ$. The e/π separation in our data has a strong dependance on track angle. The dependance is understood to be due to space charge building up along the anode wires, which effectively reduces the chamber gas gain for the electron clusters drifting in at times later in the avalanche process. One expects that this effect could be ameliorated with a careful optimization of the gas mixture and detector gain.

It is important to understand how the ADC resolution effects the dE/dx e/π separation so that the minimum number of ADC bits required to do the job can be determined. The resolution of our 6-bit FADC was artificially reduced in our analysis to make the data appear as if it had come from an ADC with a fewer number of bits. The

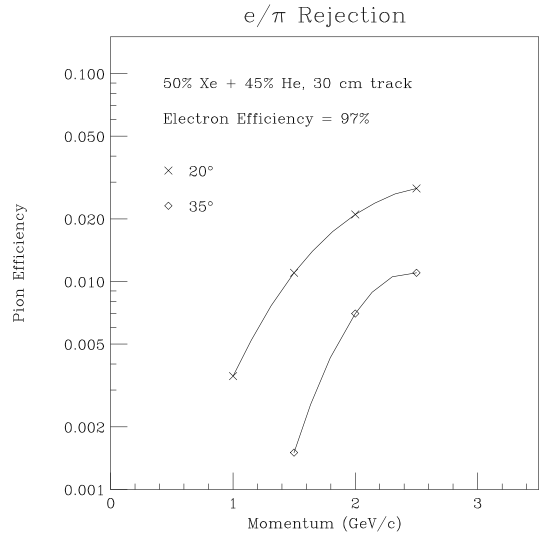

Figure 9: dE/dx e/π rejection for 97% electron efficiency and 50% Xe + 45% He + 5% C_4H_{10} gas. The track length is 30 cm and the incident angles are 20° and 35°.

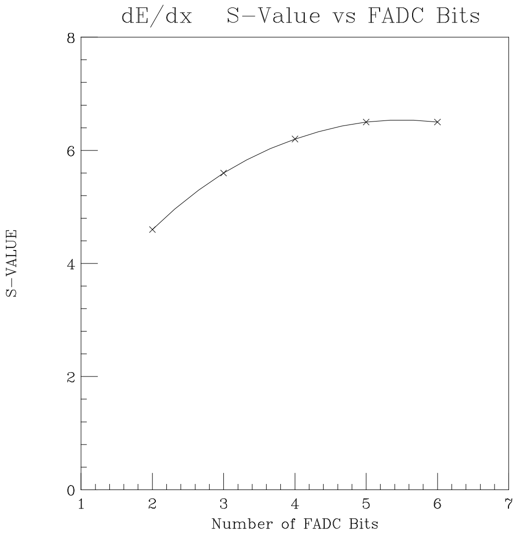

Figure 10: S-value for dE/dx e/π rejection vs. effective number of FADC bits

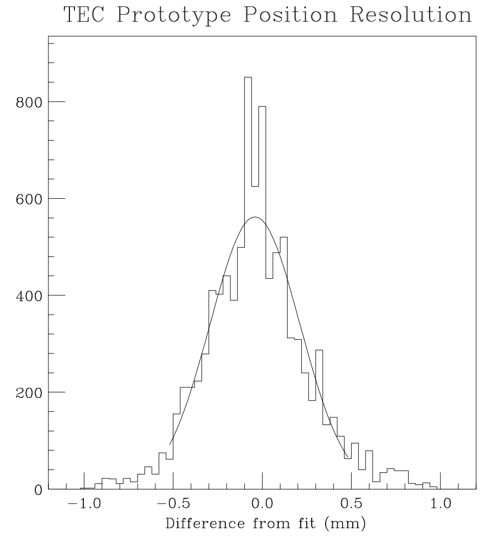

Figure 11: Single point, single plane track resolution of 230μm RMS using TRD anode wires, $0°$ track angle.

result of this procedure shows that the S-value improves with ADC resolution until one reaches 4-bits, after which the S-value increases only marginally (Figure 10).

Track Reconstruction

Instrumenting the TRD with FADC electronics allows one to not only do e/π separation using dE/dx techniques but to also track all charged particles through the detector. Our RHIC experiment requires the momentum of each charged track in the detector to be reconstructed with a $\Delta p/p = 0.2\%$ at 1.0 GeV/c. GEANT calculations show that to achieve this one requires a single point resolution of $\sim 250\mu$m RMS. Reconstructing 4-plane detector tracks in our test data using a simple χ^2 algorithm yields a single point resolution of $230\mu m$ RMS for $0°$ tracks and $200\mu m$ RMS for $35°$ tracks (Fig. 11). Since the geometry and FADC clock cycle for both the prototype and our RHIC TRD are quite similar, we expect the position resolution for the test TRD to be about the same as that of the final TRD.

Summary

We have conducted a test run with a TRD that has the ability to do particle ID using both transition radiation and dE/dx measurements, while also tracking all charged particles through the detector with a single point resolution better than 250μm RMS. We have tested a variety of polyethylene foam radiators and found that, when normalized to a constant thickness in radiation lengths, they produce on average 50% less TR photons than polypropylene foil radiators. Results from foam radiator tests show that we can expect an e/π rejection of 3×10^{-2} for 8 planes of TRD and $p \geq 2.5 GeV/c$, while the equivalent foil radiator would yield a rejection of 3×10^{-4}. The e/π rejection using dE/dx run from 1.5×10^{-3} for $35°$ tracks at 1.5 GeV/c to 1×10^{-2} at 2.5 GeV/c. The dE/dx rejection is a function of both xenon content in the gas and track angle, however the dependance on track angle may be reduced with optimization of the gas mixture. The particle ID and tracking ability of the TRD we have tested is well matched to the performance requirements for detectors at RHIC.

Acknowledgments

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