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Some results of test beam studies of Transition Radiation Detector prototypes at CERN

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Abstract. Operating conditions and challenging demands of present and future accelerator experiments result in new requirements on detector systems. There are many ongoing activities aimed to develop new technologies and to improve the properties of detectors based on existing technologies. Our work is dedicated to development of Transition Radiation Detectors (TRD) suitable for different applications. In this paper results obtained in beam tests at SPS accelerator at CERN with the TRD prototype based on straw technology are presented. TRD performance was studied as a function of thickness of the transition radiation radiator and working gas mixture pressure.

1. Introduction

Particle identification with TRDs is based on the difference of energies deposited in detector module(s) crossed by particles with different gamma factors. Particles with high Lorentz factor, like electrons, produce photons in Transition Radiation (TR) radiator which are absorbed in the detector sensitive volume. For detectors which have small thickness like straw based detector (straw tube diameter of 4 mm) averaged energy deposition due to ionization losses of particle is significantly less than energy of TR photon which is above ∼5 keV. With some probability this allows to separate events with TR from events where TR was not absorbed. Typical resulting spectra of energy depositions for different particle types in straw detector are shown in figure 1. Figure 2 shows the same spectra in integral form: probability to exceed some energy threshold as a function of threshold. One sees large difference for pions and electrons when TR radiator

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is used. Very often for the comparison of performances of different detectors with the same structure it is better to use presentation shown in figure 3. Each point on this plot correspond to some threshold and projections on axis show probability for electron and pion to exceed this threshold. The larger electron efficiency at the same pion efficiency the better performance of the detector (better electron/pion separation). Optimal operation point of the detector (best separation) is around a "knee" of the dependence for electrons. In our case this point is around 0.05 of pion efficiency. See review in [1] for more details on principles and usage of TRDs.

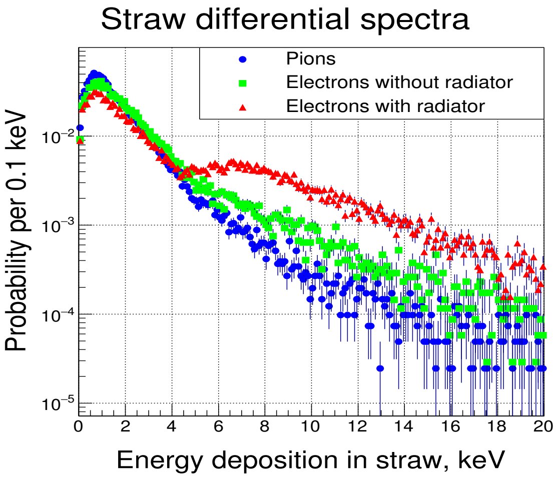

Figure 1. Examples of energy spectra in single straw chamber. Incident beam particles are 20 GeV pions or electrons.

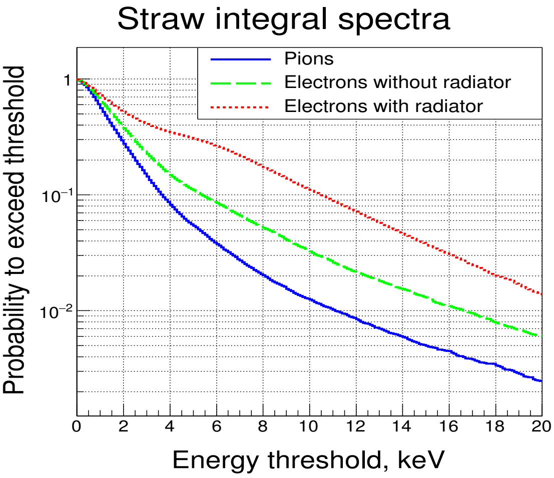

Figure 2. Integral energy spectra – probability to exceed some energy deposition in a single straw.

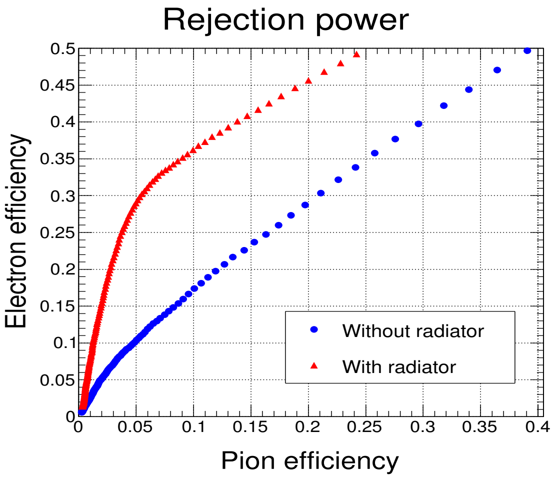

Figure 3. Efficiency of electron identification vs efficiency of pion identification.

In order to improve particle identification, several parameters of the TR radiator and detector system can be tuned depending on the desired physics task. The most important ones are radiators parameters, active gas composition and its thickness. One should also mention that the method of data analysis plays significant role in final particle separation process. This paper presents the results on the studies of detector performance with different radiator thicknesses and different working gas pressures. Some other results obtained with the TRD prototype can be also found in reports [2] and [3], presented at this Conference.

2. Test beam set-up

Schematic view of the test beam straw TRD prototype is shown in figure 4. Beam particle, triggered by 10×10 mm^2 scintillators, crosses ten straw layers. The gaps between layers are used to install different TR radiator blocks. Thin-walled proportional chambers (straws) are used to measure ionization and TR photons spectra. Straws with 4 mm diameter are made from a special conductive Kapton film. Straw wall has thickness of 70 μm. Similar chambers are used in the Transition Radiation Tracker detector [4] of the ATLAS experiment [5] at LHC. The straws in the prototype were operated with a gas mixture of 71.8% Xe, 25.6% CO$_2$ and 2.6% O$_2$. The gas gain was of about 2.5·10^4 and it was controlled with an accuracy of about 1.5% during the run using Fe^{55} source. Signals from straws were recorded using VME QDC modules. In order to separate signals from noise only energy depositions above 100 eV were considered.

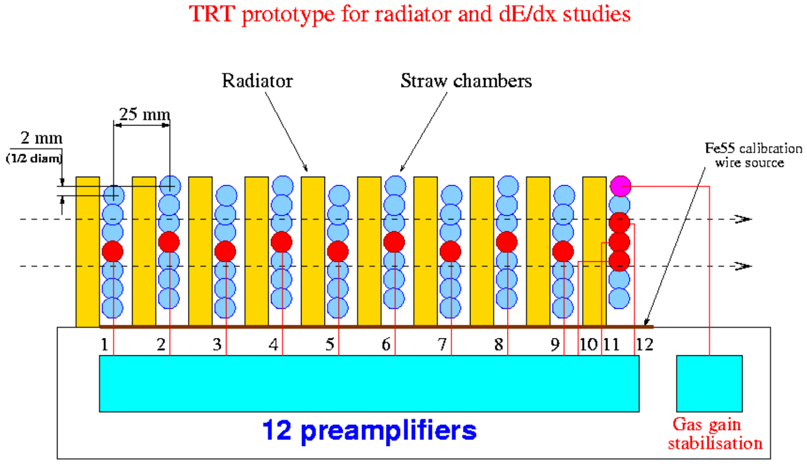

Figure 4. Schematic view of the TRD prototype exposed to the test beam.

Each radiator block contains 36 polypropylene foils of 15 μm thick spaced by 213 μm air gap. Total radiator thickness along the beam direction is 8.2 mm. Two different radiator configurations were considered. In the first case each of 10 radiators were situated in front of each of 10 straw layers. For the second setup ("double radiators") 10 radiators were grouped by two and installed in front of last five straw layers.

One should note that TR spectrum is changed with an increase of a number radiator-detector layers until it reaches saturation which is defined by equilibrium between produced and absorbed TR photons. That is why all results presented here are related to TR spectra obtained in the last straw layer where the saturation is guaranteed. Ionization spectra of pions are not affected by TR and therefore in order to increase statistics pion spectra from all 10 layer of straws were merged.

3. Results

As it was mention above energetic TR photons may cross straw layers without absorption and can be absorbed by the following radiator blocks. In order to increase a registration efficiency of the energetic photons one can increase the pressure of the working gas in the straws. It will increase a probability of TR absorption in the detector. However this would also increase ionization losses of particles. That is why the resulting effect of the pressure increase on the particle separation is not evident. Preliminary Monte Carlo simulations predict rather week dependence of probability for electron to exceed registration threshold at fixed probability for pions – figure 5 with maximum close to 1.2 bar (absolute pressure). A special test with the gas pressure of 1.5 bar (abs.) was carried out to verify this behavior.

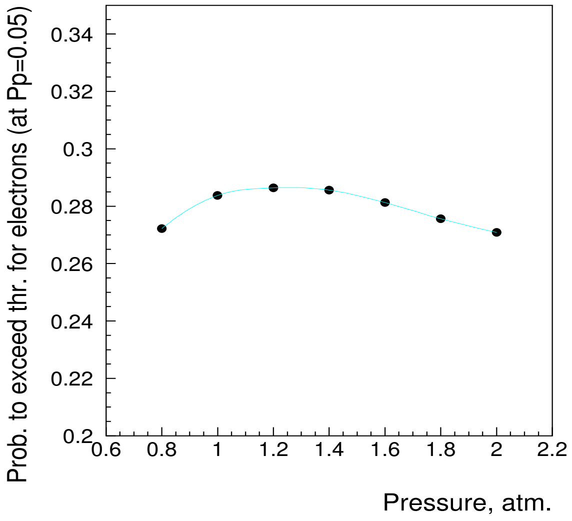

Figure 5. Monte Carlo simulation of expected electron registered efficiency at 0.05 pion efficiency as a function of working gas pressure. Line connecting points is guide to the eyes only.

Figure 6 shows comparison of probability for electrons vs probability for pions to exceed certain threshold at 1 bar (abs.) and 1.5 bar (abs.) of working gas pressure for setup with 10 single radiator blocks. The same comparison for setup with five double radiator blocks is presented on figure 7. One sees that in both cases the increase of gas pressure does not significantly change these dependencies even at rather high photon energies which correspond to low pion probabilities and this behavior is what was expected from MC simulations.

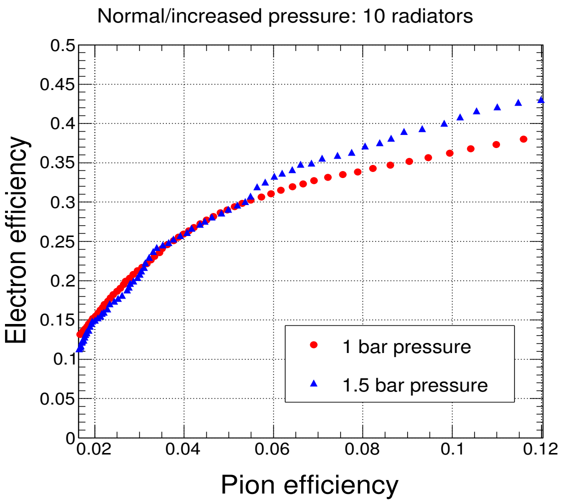

Figure 6. Comparison of electron vs pion efficiency at normal and increased gas pressure in straws. Setup with 10 single radiators.

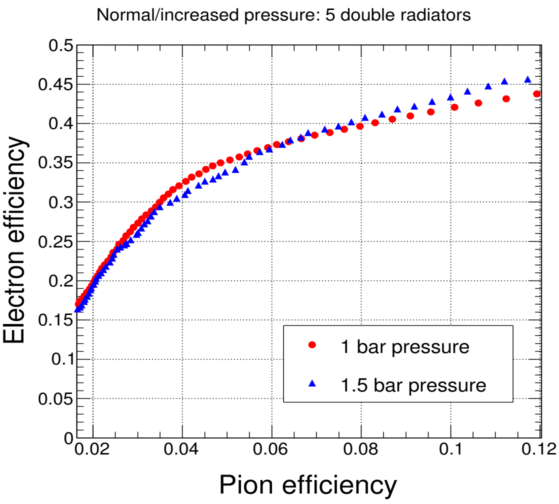

Figure 7. Comparison of electron vs pion efficiency at normal and increased gas pressure in straws. Setup with 5 double radiators.

Another way to improve particle identification power is to optimize the radiator thickness. The thicker radiator the more TR photons generated but in that case at the same number of detector modules the total detector size and material budget is increased. Figures 8 and 9 give comparison of electron vs pion efficiency dependencies for single and double layer radiator –

at 1 and 1.5 bars of the gas pressure respectively. In both cases thicker radiator can provide significantly better identification power but the length of the detector is increased by factor of 1.7. If the total detector length is fixed then the thicker radiator will produce higher number of TR photons, however the reduced number of sensitive layers will lead to larger statistical fluctuations of the registered signal thus decreasing the identification performance. In order to reach better particle identification performance the optimal configuration of radiator thickness and detector sensitive volumes can be obtained taking into consideration all external requirements such as available space and total amount of material which is crossed by particle.

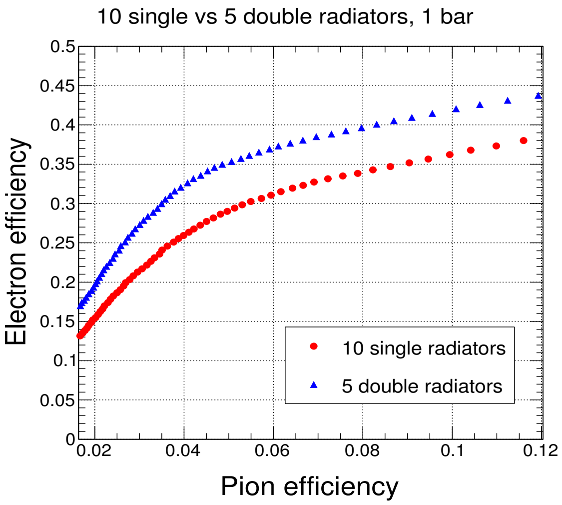

Figure 8. Comparison of electron vs pion efficiency for 10 single and 5 double radiator setups at normal gas pressure in straws.

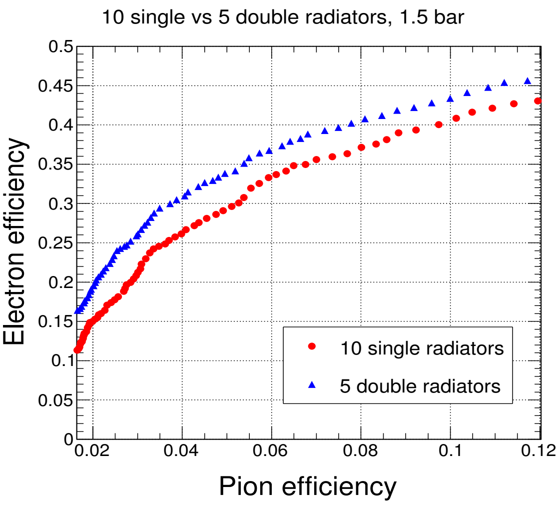

Figure 9. Comparison of electron vs pion efficiency for 10 single and 5 double radiator setups at increased gas pressure in straws.

4. Conclusion

Transition Radiation Detector prototype based on straw tubes was tested with 20 GeV pion and electron beams at CERN SPS accelerator. It was shown that an increase of the working gas pressure by 0.5 bar has no advantage for electron/pion separation with respect to normal pressure conditions. Better rejection power can be obtained by increasing radiator thickness due to larger number of generated TR photons at the cost of the increased detector length.

Acknowledgments

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