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Abstract. Measurements of hadron production in the TeV energy range are one of the tasks of the future studies at the Large Hadron Collider (LHC). The main goal of these experiments is a study of the fundamental QCD processes at this energy range, which is very important not only for probing of the Standard Model but also for ultrahigh-energy cosmic particle physics. One of the key elements of these experiments measurements are hadron identification. The only detector technology which has a potential ability to separate hadrons in this energy range is Transition Radiation Detector (TRD) technology. TRD prototype based on straw proportional chambers combined with a specially assembled radiator has been tested at the CERN SPS accelerator beam. The test beam results and comparison with detailed Monte Carlo simulations are presented here.

1. Introduction

Study of hadron production at the Large Hadron Collider (LHC) at small angles with respect to the beam is being actively discussed now (see, for example, [1]). Apart from a better understanding of the fundamental QCD processes, the study of high energy particle production in the forward direction is an extremely important topic for cosmic ray physics. Such measurements could remove uncertainties in physics models explaining particle production with energies up to 10^{17} eV in the Universe (the problem of so-called knee of the cosmic ray spectrum at these

energies). The proposed experiment at the LHC is aimed at measurement of the secondary particle composition (protons, kaons, pions, muons and electrons) in the rapidity range of $\sim 5 < |\ \eta\ | < 9$ produced in proton collisions. The energy range of the particles extends from 1 TeV to 6 TeV that corresponds to Lorentz factor value from $\approx 1 \times 10^3$ to $\approx 4 \times 10^4$ for protons, kaons and pions. The only particle identification technique able to effectively separate hadrons with these γ-factors is based on the properties of the X-ray transition radiation (TR) production. Transition radiation detectors (TRD) have been used for accelerator experiments and cosmic ray experiments on the ground, at balloon altitudes, and in space (see reviews, [2, 3, 4]). Most of the transition radiation detectors are designed to separate electrons and pions and they use the threshold effect of the TR production. In these detectors the TR yield starts to be significant at γ-factor of $\sim 5 \times 10^2$ and saturates already at $\sim 2 \times 10^3$. There exist cosmic ray experiments and developments [5] with TRDs for large γ-factor range. They use the fact that TR production is proportional to Z^2 and are aimed to separate nuclei with charges $Z > 1$. Separation technique for single-charged particles with γ-factors up to $\approx 4 \times 10^4$ does not exist yet.

The TRD operation range is defined by the radiator and the detector properties: material, thickness and number of radiator foils, the gap between the foils, detector material and its thickness. For efficient particle separation it is important to exploit all features of the TR. The probability density of TR exiting from the radiators is a complex function of the particle's γ-factor, the radiator parameters, photon emission angle and photon energy. Integrating over the angle, one obtains the TR spectrum with many maxima. TR production at each maximum has its own γ-factor dependence. This feature can be used to develop a single detector with responses to a few γ-factor regions, which could significantly enhance its performance.

In order to study this possibility, a dedicated setups based on straw proportional tube arrays were built and tested at the CERN SPS accelerator [6, 7]. The straw layers are interleaved with blocks of radiator material. Dedicated Monte Carlo (MC) simulations were performed and compared with the experimental data. The results of these measurements with a Mylar radiator and comparison with MC predictions are presented in this paper.

2. Test beam setup

The experimental set-up and schematic view of the TRD prototype are shown in Figure 1. Beam particles, triggered by 8×20 mm^2 scintillators, cross 22 layers of thin-walled proportional chambers (straws) which detect ionization losses and TR photons. The straws have 4 mm diameter and are spaced by 5 mm within one layer. Four layers of straws are grouped together and the gaps between the groups are used to install the TR radiator blocks. The layers within one group are shifted with respect to each other in the vertical direction to minimize fluctuations of the active gas thickness crossed by the particles. The straws are made from a special conductive polyimide (Kapton) film of 70 μm thickness and are filled with gas mixture of 71.8% Xe, 25.6% CO_2 and 2.6% O_2. The anode wire has a diameter of 30 μm. Similar straw chambers are used in the Transition Radiation Tracker detector [8] of the ATLAS experiment [9] at the LHC. The gas gain is about $2.5 \cdot 10^4$ and is controlled with an accuracy of about 1.5%. An energy calibration using an Fe^{55} source was done for each straw to convert QDC channel counts to energy. In order to separate signals from noise, only energy depositions above 300 eV were considered. Each radiator block contains 30 Mylar foils of 50 μm thick spaced by 3 mm. The first radiator, installed in front of the first straw layer, contains 55 foils.

A few types of the beams were used for tests: 20 GeV mixed beam containing electrons and pions as well as muon beams with energies of 120, 180 or 300 GeV. These beams allows to cover the range of γ-factors from 140 to 3.9×10^4. Tests with and without radiators were performed at all beam energies.

Figure 2 shows the energy spectra obtained with a 20 GeV electron beam with and without radiators. The spectra are presented in two forms: differential – an energy registered in straws,
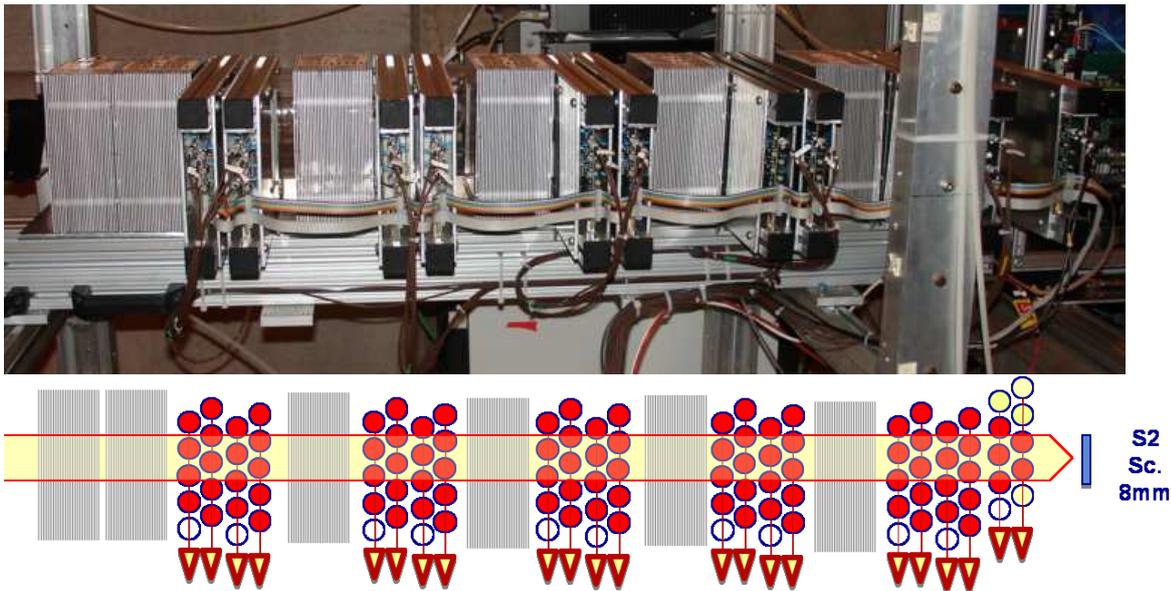
Figure 1. Top: side view of the TRD straw layers interchanged with radiator blocks in the H8 beam line at the CERN SPS. Bottom: schematic view of the straw TRD.

and integral – probability to exceed some threshold of registered energy. For the configuration with radiators, energy depositions above ∼6 keV are defined mainly by absorbed TR photons. At an energy above 6 keV, one distinguishes two peak structures – one peak occupies the energy range of 6-14 keV and another one – above 14 keV.
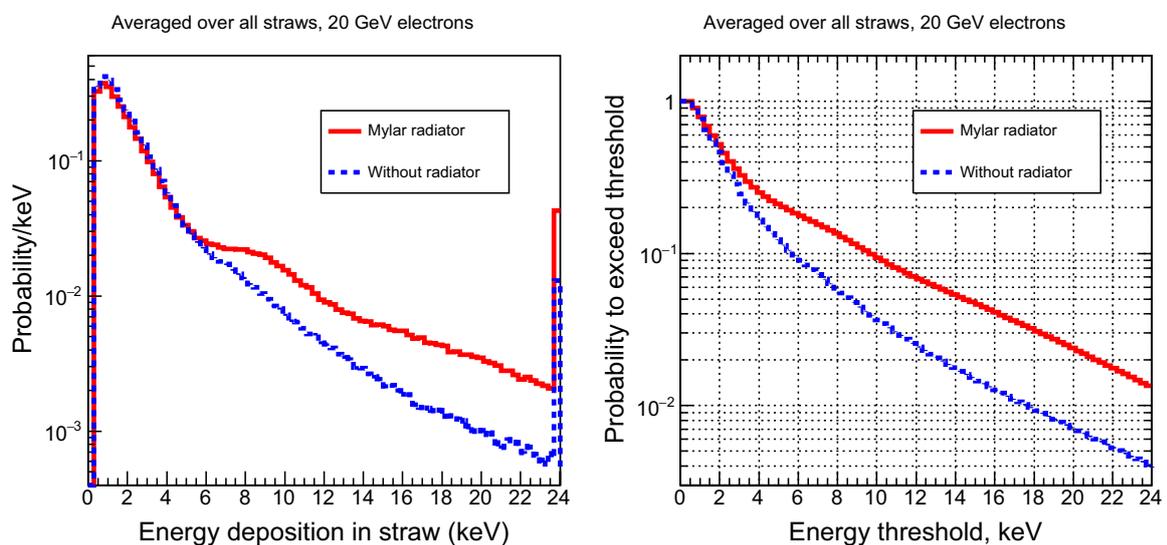
Figure 2. Experimental spectra of the energy registered in the straws by a 20 GeV electron beam with and without radiators. Left: differential spectra, right: integral. The rightmost bin on the differential spectrum includes the overflows. The spectra are averaged over all TRD straws.

## 3. Monte Carlo simulations and comparison with data

In order to understand in detail the measured spectra, dedicated Monte Carlo simulations were performed. The MC software is based on the TRT simulation code [10] and includes detailed descriptions of the detector geometry and the materials (radiator blocks and straw tubes, including straw walls and anode wires).

The simulation also takes into account:

- An energy loss in the straw gas of a charged particle according to the Photo-Absorption Ionization (PAI) model [11].
- Production and absorption of transition radiation photons.
- Response of the straws to the energy deposited by ionizing particles and photons.
- Convolution of the straw output signal with the model of the front-end electronics.

Some additional factors, such as space charge effect, photo electron path in the active gas and TR generation on the straw walls, were also included in the Monte Carlo model.

A comparison of the simulation results and data was done for all particle energies. As an example, spectra averaged over all straw layers for 20 GeV electron beam are shown in Figure 3. A good agreement between data and MC can be seen. The two peak structures in the same energy ranges as in data are clearly seen. The fact that they are more pronounced in MC than in the data might be explained by the simplified model of the photoelectron path in the gas volume used in MC.
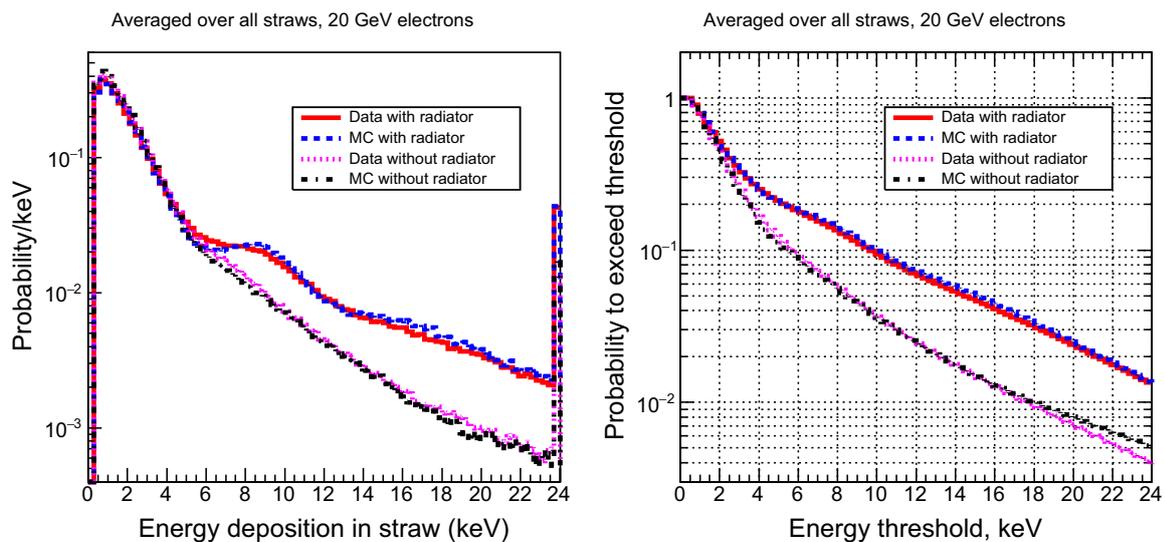
Figure 3. Comparison of experimental and simulated spectra of energy registered in the straws, averaged over all straw layers. Left: differential spectra, right: integral. The rightmost bin on the left plot includes overflow values. Results are shown for 20 GeV electron beam, and using Mylar radiators.

The comparison of data and MC for probabilities to exceed a certain energy deposition threshold as a function of straw layer number is shown in Figure 4. As the TR photons generated in radiators are absorbed in the active gas, it is not surprising that the probability to detect TR photon drops with increasing straw layer number with respect to radiator. On the other hand, high energy TR photons have a relatively low absorption efficiency and can be accumulated along the beam. This TR accumulation effect is clearly observed in the data and MC. In

general, the agreement between data and MC is very good but some difference still exists. This difference can be explained by the beam structure (beam profile) which is not exactly known. In MC the beam profile is considered to be flat, with a width of 8 mm. For data, the 8 mm scintillation counter defines the beam limits, however the beam profile within the 8 mm still has some structure.
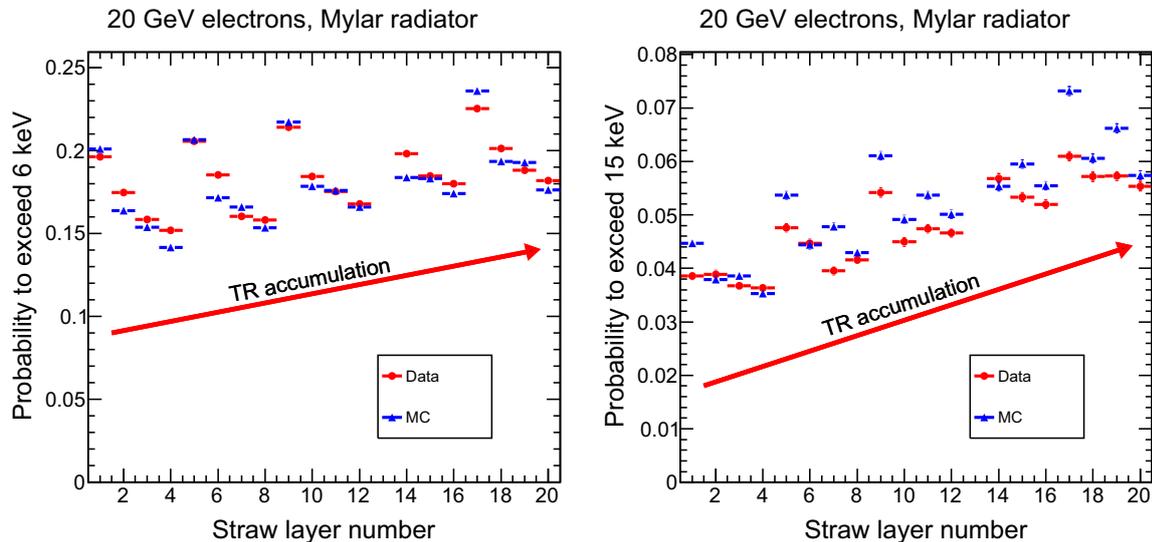
Figure 4. The measured and simulated probabilities to exceed an energy threshold depend on straw layer number along the beam. Left: for 6 keV threshold, right: for 15 keV threshold. Results are shown for a 20 GeV electron beam, TRD with Mylar radiators.

4. Lorentz factor dependence

As it was mentioned in section 1, different parts of the TR spectrum have different γ-factor dependencies. Figure 5 shows the averaged probability to have an energy deposition in one straw layer in different energy intervals as a function of γ-factor. Both, data and MC simulation results are presented.

This figure clearly shows a different γ-factor response for the soft TR energy range (6-14 keV) and for the TR energy range above 14 keV. The soft TR range is better suitable for particle separation with γ-factors from $\sim 1 \times 10^3$ to $\sim 8 \times 10^3$. The high energy range allows to move the TR production threshold to $\sim 3 \times 10^3$ and it can be effectively used for particle separation with close mass values in the γ-factor range from $\sim 3 \times 10^3$ to $\sim 2 \times 10^4$.

In general, a very good data/MC agreement is obtained. These studies confirm that two energy intervals have significantly different gamma dependencies, which allows to obtain responses on two γ-factor regions in a single detector.

5. Conclusions

A transition radiation detector with a specially designed radiator was tested in CERN SPS beam line with different particle types and energies. Predictions by a dedicated Monte Carlo simulations program, which was developed to describe the particular TRD, show good agreement with the data obtained. The possibility to use different energy intervals to obtain a different detector response as a function of the particle's γ-factor was demonstrated. These studies give
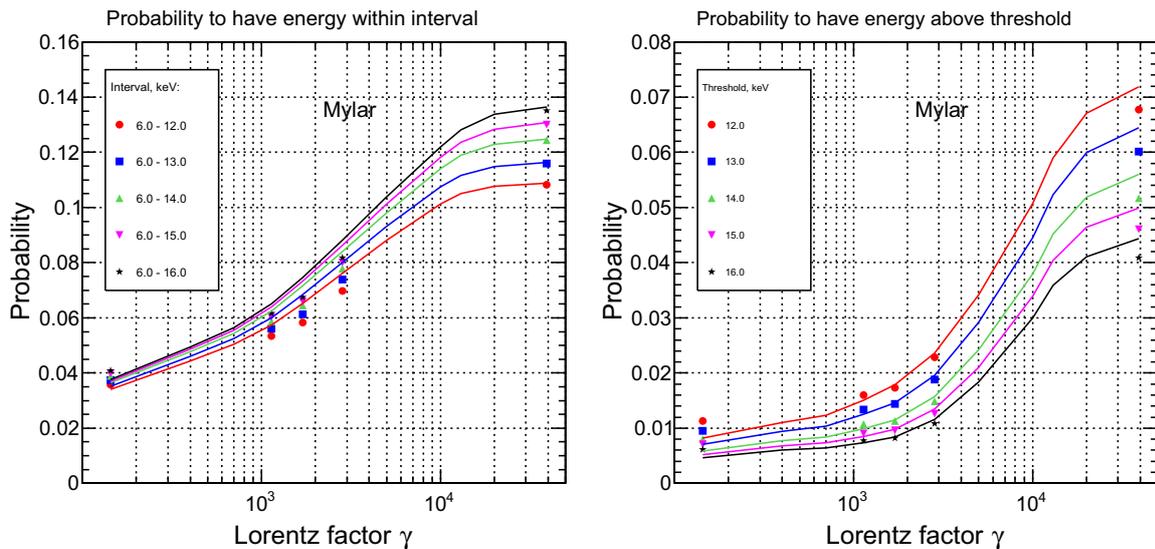
Figure 5. Averaged probabilities per straw layer to have an energy deposition in the low energy interval (left) and above a high energy threshold (right) as a function of the particle's γ-factor. Data (markers) and MC (points, connected by lines) are presented.

a solid basis for an optimization of the detector configuration which would allow to separate particles with γ-factors in the range of $\sim 10^3$-4×10^4.

Acknowledgments

References
[1] https://indico.cern.ch/event/379705/contributions/1806467
     https://indico.cern.ch/event/563277/contributions/2488034
[2] Dolgoshein B 1993 *Nucl. Instr. and Meth.* A **326** 434-469
[3] Andronic A, Wessels J P 2012 *Nucl. Instr. and Meth.* A **666** 130-174
[4] Patrignani C *et al.* 2016 (Particle Data Group) *Chin. Phys.* C **40** 100001, chapter "Transition radiation detectors"
[5] Cherry M L 2013 Measuring the Lorentz factors of energetic particles with transition radiation. *Nucl. Instr. and Meth.* A **710** 39-42
[6] Celebi E. *et al.* 2017 *Journal of Physics Conference Series* **798** 012172
[7] Tikhomirov V.O. *et al.* 2017 *Journal of Physics Conference Series* **798** 012183
[8] Abat E *et al.* 2008 The ATLAS Transition Radiation Tracker (TRT) proportional drift tube: design and performance *JINST* **3** P02013
[9] Aad G *et al.* 2008 The ATLAS Collaboration, The ATLAS Experiment at the CERN Large Hadron Collider. *JINST* **3** S08003
[10] Nevski P 2004 *Nucl. Instr. and Meth.* A **522** 116
[11] Grishin V M, Ermilova V K and Kotelnikov S K 1991 *Nucl. Instr. and Meth.* A **307** 273