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STUDY OF THE ELECTRON ENERGY LOSSES IN THE CBM TRD

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Исследование энергетических потерь электронов
в детекторе TRD эксперимента CBM

Мы исследуем распределения энергетических потерь электронов в детекторе TRD, полученные с помощью прототипа TRD на тестовом пучке в GSI (Дармштадт, Германия) и путем моделирования потерь энергии методом Монте-Карло в n-слойном TRD, выполненного в среде CBM ROOT, для импульсов в интервале от 1 до 13 ГэВ/c. Разработана процедура аппроксимации потерь энергии электронов в одном слое TRD. Эта процедура позволяет извлечь переходное излучение из реальных измерений и сравнить его с результатами моделирования методом Монте-Карло.

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Akishina T. P., Derenovskaya O. Yu., Ivanov V. V. E10-2010-73
Study of the Electron Energy Losses in the CBM TRD

We analyze the distributions of energy losses for electrons in the TRD (Transition Radiation Detector) using the energy deposits in a one-layer TRD prototype obtained during the test beam at the GSI (Darmstadt, February 2006) and Monte Carlo simulations for the n-layered TRD realized in the framework of the CBM ROOT for momenta in the range of 1 to 13 GeV/c. The procedure for approximation of the electron energy losses in one layer of the TRD is developed. This procedure permits one to extract a transition radiation part from the real measurements and compare it with the Monte Carlo simulation.

The investigation has been performed at the Laboratory of Information Technologies, JINR.

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1. INTRODUCTION

The CBM Collaboration [1, 2] builds a dedicated heavy-ion experiment to investigate the properties of highly compressed baryon matter as it is produced in nucleus–nucleus collisions in the beam energy range from about 8 up to $45A$ GeV at the Facility for Antiproton and Ion Research (FAIR) in Darmstadt, Germany.

A set of detectors and elements of the experimental setup has to fulfill the following requirements: identification of electrons which requires a pion suppression factor of the order of 10^5, identification of hadrons with large acceptance, determination of the momentum of all charged particles with $\sim 1\%$ accuracy, determination of the primary and secondary vertexes (with an accuracy of ~ 30 μm), high granularity of the detectors, fast detector response and read-out, very small detector dead time, high-speed trigger and data acquisition, radiation hard detectors and electronics, tolerance towards delta electrons.

Figure 1 depicts a general layout of the CBM experiment. Inside the dipole magnet gap, there are a target and a 7-plane Silicon Tracking System (STS) consisting of pixel and strip detectors. The STS, in conjuction with dipole magnet, is used to provide the tracking of all charged particles and their momenta. The Ring Imaging Cherenkov (RICH) detector and Transition Radiation Detector (TRD) have to identify the electrons with momentum above 1 GeV/c. The Time-of-Flight (TOF) detector based on Resistive Plate Chambers (RPC) is designed to detect the high-energy hadrons. The Electromagnetic Calorimeter (ECAL) measures electrons, photons and muons.

The measurement of charmonium is one of the key goals of the CBM experiment. For detecting J/ψ meson in its dielectron decay channel the main task is the e/π separation. One of the most effective detectors for solving this problem is a transition radiation detector.

The TRD must provide an effective electron identification, a sufficient pion suppression and tracking all charged particles. The required pion suppression is a factor of about 100 and the required position resolution is of the order of 200–300 μm.

Here we analyze and compare the e energy losses for a one-layer TRD prototype obtained during the test beam with $p = 1.5$ GeV/c in the GSI (Darmstadt, February 2006) and GEANT3 [3] Monte Carlo (MC) simulations for the n-layered

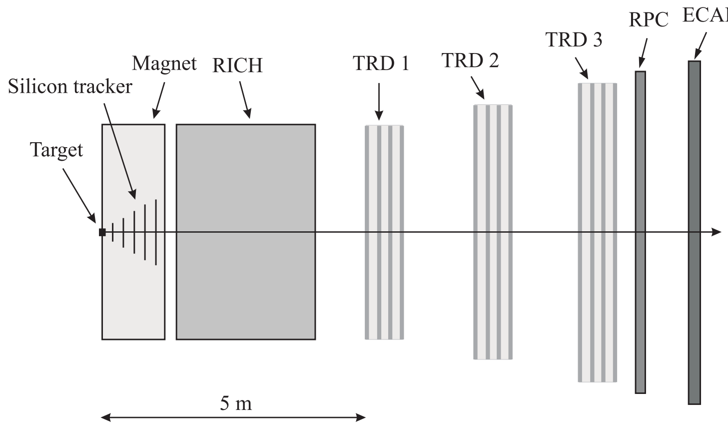

Fig. 1. Schematic view of the CBM experimental setup

TRD realized in the framework of the CBM ROOT [4, 5] for momenta in the range of 1 to 13 GeV/c. A procedure for approximation of the electron energy losses in one layer of the TRD is developed. This procedure permits one to extract the transition radiation part from the real measurements and compare it with the MC simulation.

2. MC SIMULATION OF ELECTRON ENERGY LOSSES IN THE TRD

Below we present the distributions of the electron energy losses by ionization (Fig. 2) and by transition radiation (Fig. 3) in one layer of the TRD obtained with the help of Monte Carlo simulations for electrons with $p = 1.5$ GeV/c.

The distribution of the electron ionization losses (dE/dx) is quite well approximated by a log-normal function [6] (see Fig. 2)

$$f_1(x) = \frac{A}{\sqrt{2\pi}\sigma x} \exp\left[-\frac{1}{2\sigma^2}(\ln x - \mu)^2\right], \tag{1}$$

where σ is the dispersion, μ is the mean value and A is a normalizing factor.

The correspondences between the parameters of formula (1) and Fig. 2 are as follows: $\sigma = \mathrm{P1}$, $\mu = \mathrm{P2}$, and $A = \mathrm{P3}$.

The left peak in Fig. 3 corresponds to the events with the TR (transition radiation) count equal to zero; one can clearly see that the contribution of such events is more than 1/2 of the whole statistics.

In work [7] we have shown that the distribution of the overall energy losses of electrons ($dE/dx + \mathrm{TR}$) is approximated with a high accuracy by a weighted sum of two log-normal distributions

$$f_2(x) = B\left(\frac{a}{\sqrt{2\pi}\sigma_1 x}\exp\left[-\frac{1}{2\sigma_1^2}(\ln x - \mu_1)^2\right] + \right.$$
$$\left. + \frac{b}{\sqrt{2\pi}\sigma_2 x}\exp\left[-\frac{1}{2\sigma_2^2}(\ln x - \mu_2)^2\right]\right) + c, \quad (2)$$

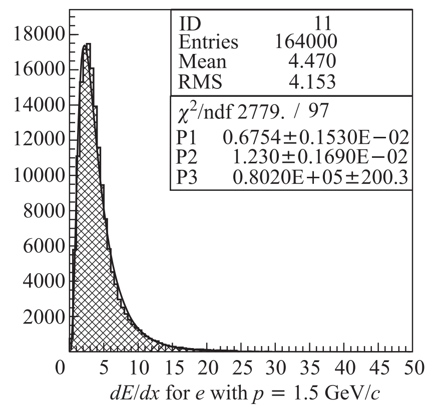

Fig. 2. Distribution of electron energy losses by ionization and its approximation by log-normal function (1)

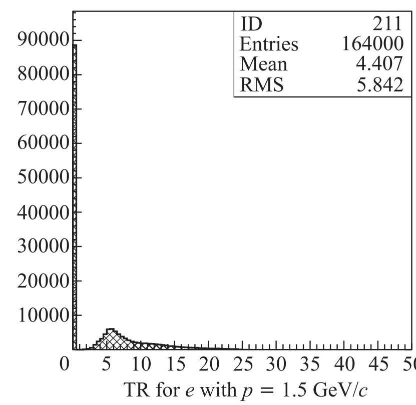

Fig. 3. Distribution of electron energy losses by transition radiation

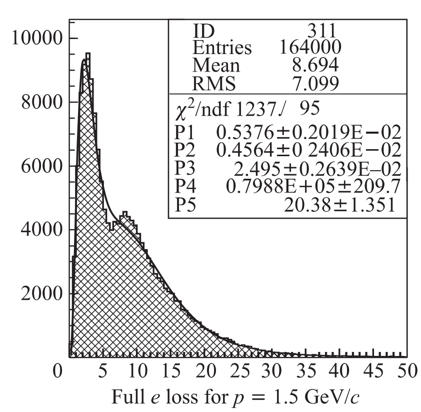

Fig. 4. Distribution of electron energy losses for MC simulation and its approximation by a weighted sum of two log-normal functions with the fixed parameters σ_1 and μ_1

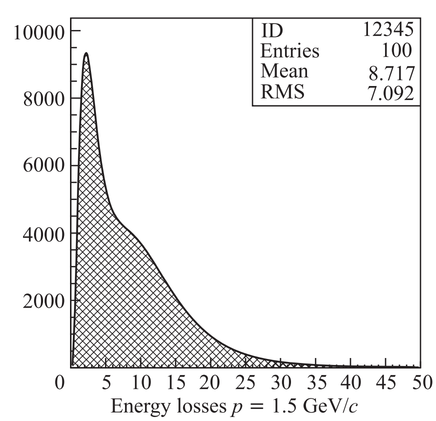

Fig. 5. Plot of a weighted sum of two log-normal distributions; all parameters are fixed

where σ_1 and σ_2 are dispersions; μ_1 and μ_2 are mean values; a and $b = 1 - a$ are contributions of the first and second log-normal distributions, correspondingly; c is a shift parameter, and B is a normalizing factor.

We know quite well the behavior of the ionization losses of charged particles in a medium, but the TR losses have a more complicated character. In order to understand the details of the TR simulation in the TRD, we performed the following study. We fixed the parameters σ and μ responsible for the ionization losses (they are obtained by fitting the dE/dx distribution: see Fig. 2) and substituted them in formula (2): $\sigma_1 = \sigma$, $\mu_1 = \mu$.

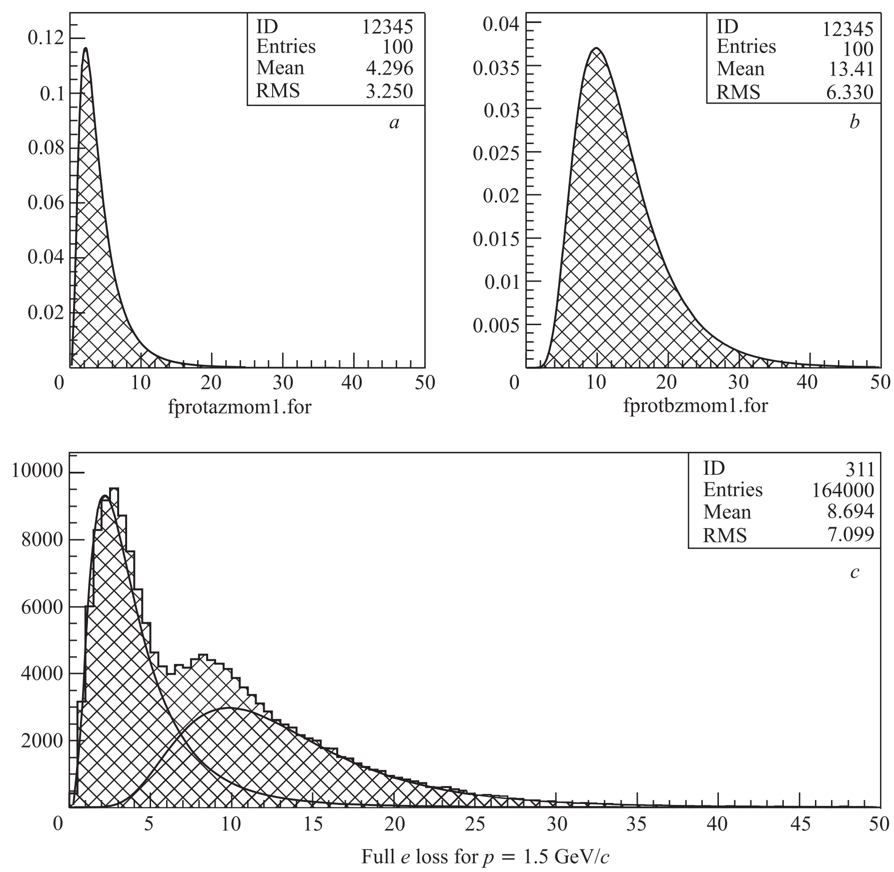

Fig. 6. Approximation of the distribution of electron energy losses by a weighted sum of two log-normal distributions (c): contributions of the ionization (a) and transition radiation (b) energy losses

Figure 4 shows the distribution of electron energy losses for the MC simulation ($p = 1.5$ GeV/c) and its approximation by a weighted sum of two log-normal functions with the fixed parameters σ_1 and μ_1.

The correspondences between the parameters of formula (2) and Fig. 4 are as follows: $a = \mathrm{P1}$, $\sigma_2 = \mathrm{P2}$, $\mu_2 = \mathrm{P3}$, $B = \mathrm{P4}$ and $c = \mathrm{P5}$.

Figure 5 shows a plot of a weighted sum of two log-normal distributions (2) with all parameters fixed.

Such an approximation of the distribution of electron energy losses by a weighted sum of two log-normal distributions permits one to extract the individual contributions of ionization energy losses and energy losses by transition radiation.

Figure 6 shows the contributions of the ionization (plot a) and the transition radiation (plot b) energy losses to the summary distribution of the electron energy losses for the MC simulation.

The table shows that the statistical characteristics for the MC simulation and for the approximation by a weighted sum of two log-normal distributions with the fixed parameters are very close. This demonstrates that our procedure for the extraction of the TR part from the distribution of the overall electron energy losses in the TRD layer is correct.

Comparison of mean value (MV) and Root Mean Square (RMS) of electron energy losses in one layer of the TRD obtained by Monte Carlo simulations and for their approximation by a weighted sum of two log-normal distributions with the fixed parameters

p, GeV/c	1.5	2	3	4	5	7	9	11
MV (MC)	8.694	9.029	9.232	9.301	9.379	9.422	9.424	9.421
MV (fit)	8.171	9.054	9.255	9.326	9.400	9.446	9.441	9.445
RMS (MC)	7.099	7.283	7.411	7.473	7.475	7.527	7.521	7.517
RMS (fit)	7.092	7.278	7.409	7.470	7.472	7.525	7.510	7.511

3. ELECTRON ENERGY LOSSES IN THE TRD PROTOTYPE

A similar procedure was applied to the measurements obtained with the help of the TRD prototype. In this case, the values of parameters σ_1 and μ_1 are taken from approximation of the ionization energy losses by electrons with $p = 1.5$ GeV/c obtained in the MC simulation (see Fig. 2).

Figure 7 shows the distribution of electron energy losses in the TRD prototype and its approximation by a weighted sum of two log-normal functions with the fixed parameters σ_1 and μ_1 (Fig. 2).

Figure 8 shows a plot of a weighted sum of two log-normal distributions (2) with the fixed parameters.

The statistical characteristics corresponding to the approximation function (see Fig. 8) coincide with real measurements (see Fig. 7).

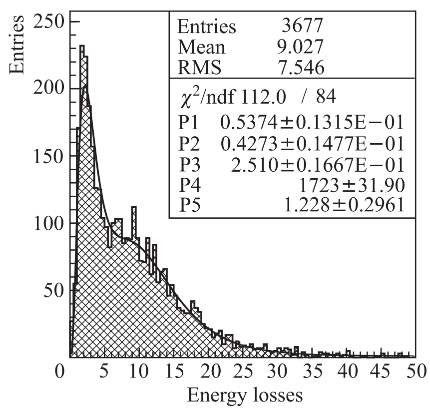

Fig. 7. Distribution of electron energy losses in the TRD prototype and its approximation by a weighted sum of two log-normal functions with the fixed parameters σ_1 and μ_1 (Fig. 2)

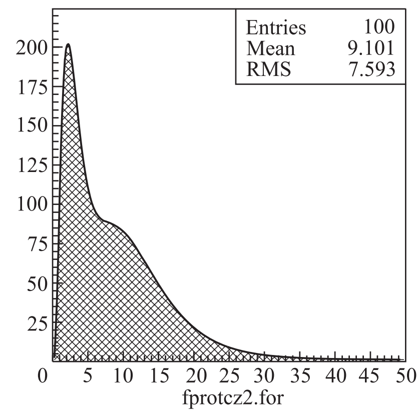

Fig. 8. Plot of a weighted sum of two log-normal distributions: all parameters are fixed

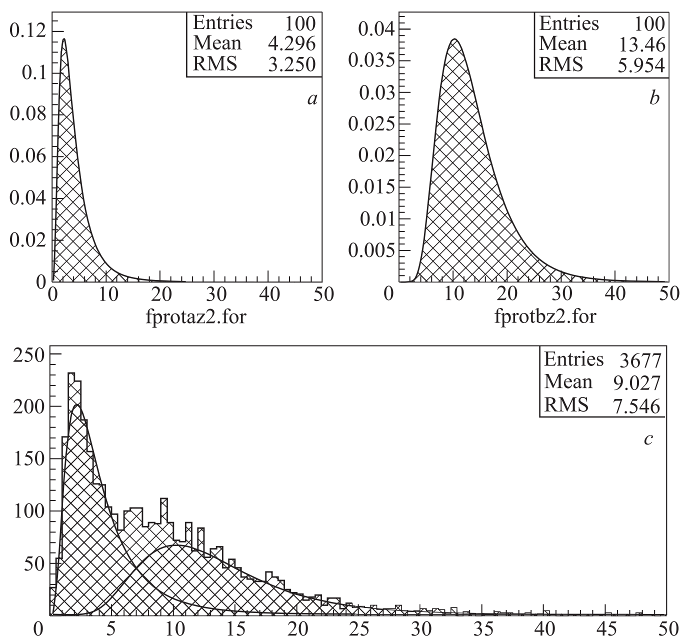

Fig. 9. Approximation of the distribution of electron energy losses by a weighted sum of two log-normal distributions (c): contributions of energy losses by ionization (a) and by transition radiation (b)

Such an accurate approximation of the distribution of electron energy losses by a weighted sum of two log-normal density functions also permits one to separate the contributions in this distribution of various physical processes: energy losses by ionization and by transition radiation (Fig. 9).

4. DISCUSSION OF RESULTS

A comparison of the distributions of the energy losses of electrons in the TRD prototype with GEANT simulations shows that the main statistical characteristics (mean value and RMS) are significantly different (Figs. 10, a and 10, b).

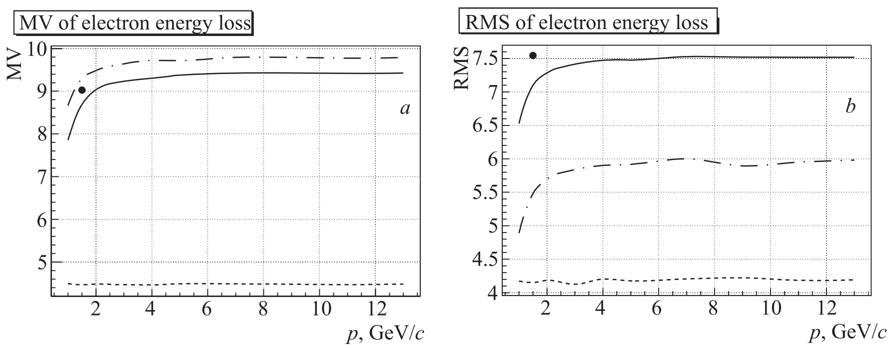

Fig. 10. MC simulation: summary plot of the mean value (a) and the root mean square (b) for different momenta: dashed line — dE/dx, dash-dotted line — TR, solid line — overall energy losses; circle — the MV and RMS for the prototype (see Figs. 2, 3, 4 and 7)

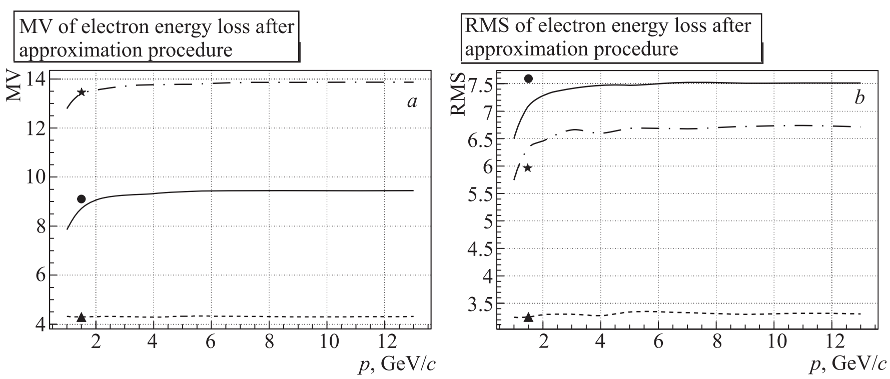

Fig. 11. Fitting by function: summary plot of the mean value (a) and the root mean square (b) for different momenta: dashed line — dE/dx, dash-dotted line — TR, solid line — overall energy losses; for the prototype: triangle — dE/dx, asterisk — TR, circle — overall energy losses (see Figs. 5, 6, 8 and 9)

We also compared the TR part for real measurements obtained with the help of the TRD prototype and the MC simulation and found that in the region of $p = 1.5$ GeV/c both the statistical characteristics (mean value and RMS) and the TR contributions to the overall energy losses for real measurements and MC simulation significantly differ (Figs. $11, a$ and $11, b$). As a result, we may lose in the pion suppression factor (around 10 times) and in the efficiency of the electron identification.

5. CONCLUSION

We have investigated the distributions of electron energy losses in the TRD detector of the CBM experiment: 1) the energy deposits in the one-layer TRD prototype obtained during the test beam at the GSI (Darmstadt, February 2006), and 2) Monte Carlo simulations of the TRD realized with the help of the GEANT in the framework of the CBM ROOT.

A procedure for approximation of the electron energy losses in one layer of the TRD has been proposed. The approximation of the distribution of electron energy losses by a weighted sum of two log-normal distributions permitted one to correctly decompose the energy losses of electrons into two independent parts: the ionization energy losses and energy losses by transition radiation.

Using this procedure, we extracted the transition radiation part from the real measurements obtained with the help of the TRD prototype and compared it with Monte Carlo simulations. We have found that in the region of $p = 1.5$ GeV/c the statistical parameters of the TR distribution (mean value and RMS) and its contribution to the distribution of the overall energy losses for real measurements and MC simulation significantly differ. As a result, we may lose in the pion suppression factor (around 10 times) and in the efficiency of the electron identification.

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