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Towards $J/\psi \to e^+e^-$ Decays Triggering with TRD in CBM Experiment

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Abstract. The paper presents an efficient Cellular Automaton based algorithm for trajectory reconstruction in the Transition Radiation Detector of the CBM experiment. The comparison of the different electron identification methods is also given.

1 Introduction

The Compressed Baryonic Matter (CBM) collaboration [1] conducts dedicated heavy-ion experiments to investigate the properties of highly compressed baryonic matter as it is expected to be produced in nucleus–nucleus collisions at the Facility for Antiproton and Ion Research (FAIR) in Darmstadt, Germany.

The CBM experimental setup for studying dielectron decays is shown in Fig. 1. Behind the target between the poles of the superconducting dipole magnet there is a Silicon Tracking System (STS). The STS detectors are intended to reconstruct trajectories and momenta of charged particles, as well as to reconstruct primary and secondary vertices. The electron–positron identification system includes the Ring Imaging CHerenkov (RICH) and Transition Radiation Detectors (TRD). The TRD is also used to reconstruct the trajectories of charged particles registered by the detector. The detector for particle Time-Of-Flight (TOF) measurement is intended for hadron identification. The Electromagnetic CALorimeter (ECAL) serves to identify photons. The Projectile Spectator Detector (PSD) calorimeter serves to the determination of the reaction plane.

The study of the charmonium production is one of the key objectives of the CBM experiment. To register them via the dielectron decay channel, one needs a reliable electron–positron identification in the conditions of a dominant hadronic background, primarily from pions. The TRD is the most suitable for solving the above-mentioned task. TRD should yield reliable electron identification, a high pion suppression level, a reconstruction of trajectories of charged particles passing through the detector in the condition of intense fluxes (up to 10^7 collisions per second), and a high multiplicity of secondary particles (from 100 to 1000 particles per nucleus–nucleus collision).

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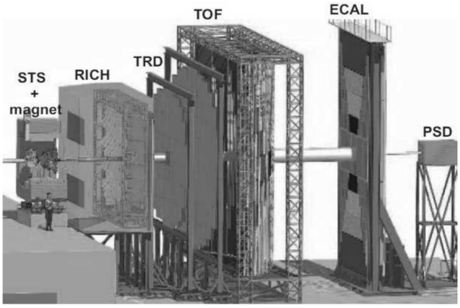

Figure 1. General view of the CBM setup

2 Track reconstruction algorithm

First step towards the $J/\psi \to e^+e^-$ decays triggering is trajectories reconstruction in TRD. The cellular automaton (CA) based algorithm was developed for TRD. The following assumptions have been made to simplify and accelerate the algorithm [2]:

1. Because of secondaries from the J/ψ decay have high momenta and the influence of the magnetic field on the area of the TRD stations is negligible, the particle trajectories can be approximated by segments of straight lines.

2. Only those tracks are considered which have hits in all TRD stations.

The track reconstruction algorithm includes two main stages: a) segment set formation, b) segments binding and track construction.

The segments are fragments of straight lines connecting the neighbouring points of the consecutive TRD stations (Fig. 2(a)). These lines do not differ much from the lines connecting one of the segment ends and the target center. Limits for the segment inclinations have been determined by Monte Carlo (MC) simulation. After the segments are built, consecutive segments are bound if they have a common

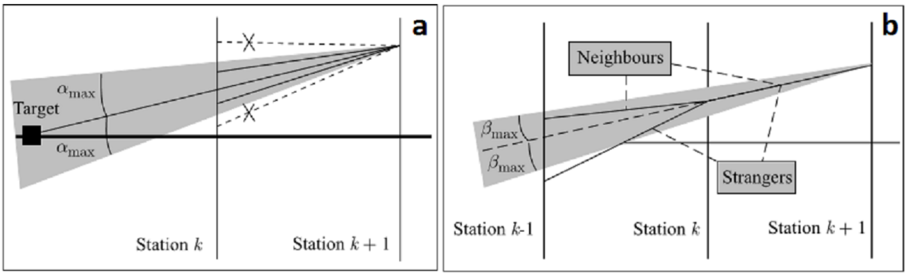

Figure 2. (a) Segment set formation and (b) segments binding procedure

point and the angle between them does not exceed the limit found by simulation (Fig. 2(b)). If two segments are bound, they are referred as "neighbours", if not – as "strangers".

A track candidate is formed from the segment sequence from right to left (upstream the beam direction) by joining neighbouring segments. The first segment is taken on the last TRD station and the last must end on the first station. If during the track candidate building several alternatives appear, the one with minimum χ^2 is chosen.

3 Electron identification

Each track is associated with a set of measurements of the particle energy losses (see Fig. 3(a)).

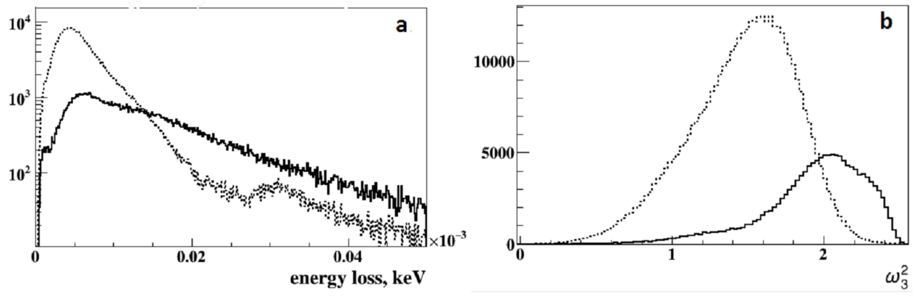

Figure 3. Distributions of the energy losses (a) and ω_3^2 values (b) for $\pi^{+/-}$ (dash line) and $e^{+/-}$ (solid line)

With the help of various mathematical methods, it is possible to determine to which distribution (electrons or pions) these losses are related.

3.1 Goodness-of-fit ω_n^k-criterion

To apply the goodness-of-fit ω_n^k-criterion [3], one needs to calculate the formula:

$$\omega_n^k = -\frac{n^{\frac{k}{2}}}{k+1}\sum_{j=1}^{n}\left\{\left[\frac{j-1}{n} - \phi(\lambda_j)\right]^{k+1} - \left[\frac{j}{n} - \phi(\lambda_j)\right]^{k+1}\right\}, \tag{1}$$

where k is the criterion degree, $\phi(\lambda)$ is the Landau distribution function (which describes the pion energy losses) in terms of the station dependent values of the variable λ_j:

$$\lambda_j = \frac{\Delta E_j - \Delta E_{\text{mp}}^j}{\xi_j} - 0.225, \qquad j = 1, 2, \ldots, n, \tag{2}$$

ΔE_j is the energy loss in the j-th TRD layer, ΔE_{mp}^j is the value of most probable energy loss, $\xi_j = \frac{1}{4.02}$ FWHM of distribution of the energy losses for pions, and n is the number of TRD layers.

Fig. 3(b) shows the distributions of ω_3^2 values for pions (dash line) and electrons (solid line).

3.2 Artificial neuron network (ANN)

In [3], the possibility of electron identification using an artificial neural network has been investigated. A three-layered perceptron from the ROOT package is currently used in the CBM experiment. Fig. 4(a) shows the distributions of the ANN output signals.

3.3 Likelihood function ratio method

While applying the likelihood test[4] to the problem considered, the value

$$L = \frac{P_e}{P_e + P_\pi}, \qquad P_e = \prod_{i=1}^{n} p_e(\Delta E_i), \qquad P_\pi = \prod_{i=1}^{n} p_\pi(\Delta E_i), \tag{3}$$

is calculated for each event (see Fig. 4(b)), where $p_\pi(\Delta E_i)$ is the value of the density function p_π in the case when the pion loses the energy ΔE_i in the i-th station, and $p_e(\Delta E_i)$ is a similar value for the electron.

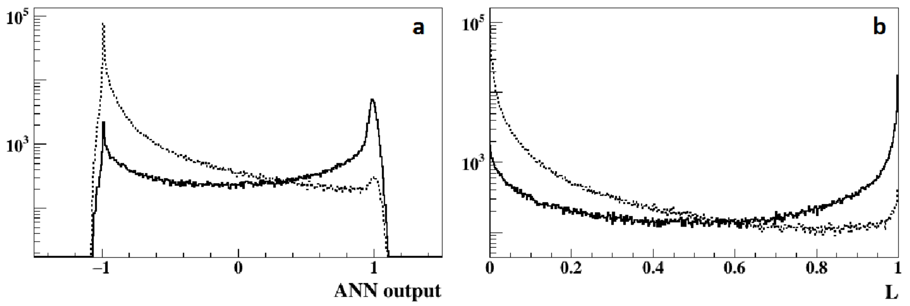

Figure 4. Distributions of the ANN output (a) and the variable L (b) for $\pi^{+/-}$ (dash line) and $e^{+/-}$ (solid line)

4 Conclusion

An algorithm for the trajectory reconstruction in the TRD based on the CA has been developed. The efficiency of the signal track reconstruction calculated by the formula

$$\mathrm{Eff} = \frac{N_{\mathrm{rec}}}{N_{\mathrm{ref}}} \times 100\% \tag{4}$$

is about 92%. Here N_{ref} is the number of reference tracks corresponding to the electron or the positron from the J/ψ decay and which have hits in all layers of the TRD. N_{rec} is the number of reference tracks that have been matched to the reconstructed track. The track is matched if at least three hits of the track coincide with three points of the reference track.

Table 1 shows the results of comparison of the given methods: background suppression factor corresponding to 11% of electron/positron losses. The best pion suppression level is achieved using the

Table 1. Background suppression factor corresponding to 11% of electron/positron losses

method	ω_n^k	ANN	LFR
suppression factor	5.4	9	9

LFR method and ANN with transformation (2) of energy losses in the TRD stations. The bottleneck of these methods is the requirement to know the density functions of energy losses for both pions and electrons. The distribution of pion ionization losses in a material is well studied, whereas the energy losses of electrons/positrons in the TRD staions are complex by nature. For ω_n^k application one should only know the parameters of the pion losses distribution.

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