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Algorithms for Selection of $J/\psi \to e^+e^-$ Decays Registered in the CBM Experiment

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A procedure for selection of $J/\psi \to e^+e^-$ decays registered by the CBM set-up is presented. The key problem is a fast and reliable electron/positron identification using the energy losses of charged particles in the Transition Radiation Detector. An analysis of the application features and a comparison of power of two methods to solve this task are given: an artificial neuron network (ANN) and a ω_n^k goodness-of-fit criterion. The choice of the approach based on the ω_n^k goodness-of-fit criterion is explained.

Key words and phrases: multivariate analysis, pattern recognition, CBM experiment, transition radiation detector TRD, selection of $J/\psi \to e^+e^-$ decays.

1. Introduction

The Compressed Baryonic Matter (CBM) Experiment [1] is designed to investigate high-energy heavy ion collisions at the future international Facility for Antiproton and Ion Research (FAIR) in Darmstadt, Germany.

The proposed detector system is schematically shown in Fig. 1. Inside the dipole magnet there is a silicon tracking system STS which provides track and vertex reconstruction and track momentum determination. The ring imaging cherenkov RICH and the transition radiation detectors TRD have to detect electrons. TOF provides time-of-flight measurements needed for hadrons identification. The electromagnetic calorimeter ECAL measures electrons and photons. A projectile spectator detector PSD determines the centrality of the collision.

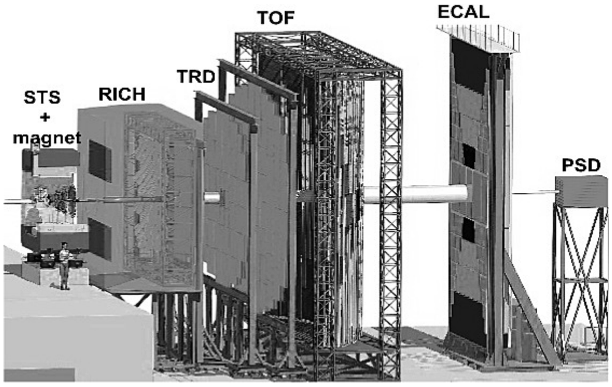

Figure 1. CBM experimental setup

The measurements of the process of $J/\psi \to e^+ + e^-$ in the predominant background (mostly pions) are one of the key tasks of the CBM. The reconstruction of the events of interest should be realized in a real-time experiment. This imposes high requirements as to the efficiency and speed of processing algorithms.

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2. The J/ψ reconstruction procedure

The J/ψ reconstruction is based on the registration of its decay products in the STS, RICH, TRD and TOF detectors. The procedure includes several steps [2]:

1) track and momentum reconstruction of charged particles with STS;
2) electron/positron identification; the RICH and TRD are applied to solve this task; TOF is also used to separate hadrons from electrons via their time of flight from the target to RPC;
3) only electrons and positrons emitted from the target (χ_{prim} ¡ 3,5) and with a transverse momentum more than 1 GeV/c are selected;
4) combination of electrons and positrons to construct a J/ψ — candidate; the KF-Particle [3] package is used;
5) the construction of the invariant mass spectrum.

3. Electron identification in the TRD

The main step in the J/ψ reconstruction procedure is an electron/positron identification using the energy losses of charged particles in the TRD. In paper [4], a comparative analysis of different methods, including those based on ANN [5] and ω_n^k goodness-of-fit criterion, have been realized.

It is noted that, in order to correctly apply ANN, one should have an adequate information about the energy loss distributions for both particles, namely pions and electrons [4]. The distribution of the ionization losses of pions in a substance has been well studied. The distributions of electron energy losses in radiators are of a complex character so that no correctness of the results obtained with the help of the ANN is guaranteed.

In addition, in order to carry out identification of particles with different momenta and/or tracks that contain different numbers of hits in the TRD (from 9 to 12), a corresponding adjustment of ANN is required.

That is why we suggest a method based on the ω_n^k goodness-of-fit criterion [4]:

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

where k is the criterion degree, $\varphi(\lambda)$ is Landau distribution function (which describes pion energy losses) with a new variable λ:

$$\lambda_i = \frac{\Delta E_i - \Delta E_{mp}^i}{\xi_i} - 0.225, \quad i = 1, 2, \dots, n,$$

ΔE_i — the energy loss in the i-th TRD layer, ΔE_{mp}^i — the value of most probable energy loss, $\xi_i = \dfrac{1}{4.02}$ FWHM of distribution of the energy losses for pions, and n — number of TRD layers.

In paper [4], the ω_n^k criterion was modified with respect to the most probable value of the transition radiation counting in the TRD layers – about half cases. So that one should calculate ω_5^k or ω_6^k statistics for track with number of hits from 9 to 12, respectively. However, our study has shown that one can use the ω_6^k statistic with no efficiency loss for all cases. The criterion degree was chosen 4. It should be noted that this modification significantly increases the power of the test [4].

4. J/ψ invariant-mass spectrum

Selected opposite charged tracks emerging from the target and identified as e^- or e^+ by the RICH, TRD and TOF were combined with help the KFParticle to construct a J/ψ — candidate. In order to suppress the physical electron-positron background, a transverse momentum cut at 1 GeV/c was applied.

The resulting invariant-mass spectrum of J/ψ mesons in 10^{11} central Au+Au collisions at 25 AGeV is shown in Fig. 2: a) ANN and b) mod. ω_n^k is used for e/π — identification in the TRD. The event mixing technique was applied to get a proper shape of the background. The expected number of signal events can be estimated taking into account the number of central collisions, the multiplicity $M = 1.92 \cdot 10^{-5}$ [2], the decay branching ratio 6% and the J/ψ reconstruction efficiency.

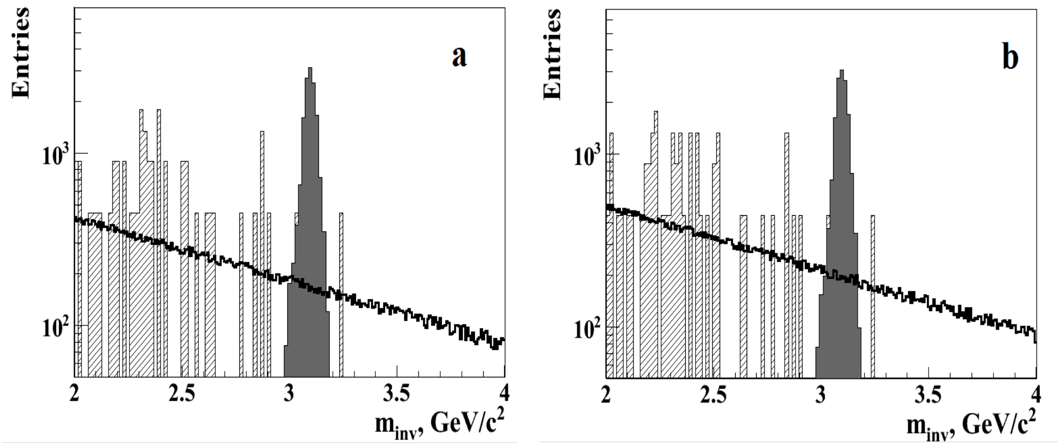

Figure 2. The reconstructed invariant-mass spectrum of J/ψ: a) ANN and b) mod. ω_n^k is used for e/π — identification in the TRD

The signal is clearly visible above the background; the signal-to-background ratio is 7.5 and reconstrucion efficiency is about 13.5% for both cases.

5. Conclusion

Our study for the problem of reconstruction of the $J/\psi \to e^+ + e^-$ decays, has shown that the modified criterion ω_n^k is not inferior in power to ANN. The CBM detector allows one to collect about 530 J/ψ per hour at 1 MHz interaction rate.

With this in mind and taking into consideration a very simple software implementation of the modified ω_n^k criterion, it can be used, in particular, for a real-time J/ψ mesons selection.

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Алгоритмы отбора распадов $J/\psi \to e^+e^-$, регистрируемых в эксперименте CBM

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В работе представлена процедура отбора распадов $J/\psi \to e^+e^-$, регистрируемых установкой CBM. Ключевая проблема — быстрая и надёжная идентификация электронов/позитронов на основе потерь энергии заряженных частиц в детекторе переходного излучения. Проведён анализ особенностей применения и сравнение мощностей двух методов решения данной задачи: искусственная нейронная сеть (ИНС) и критерий согласия ω_n^k. Обосновывается выбор в пользу подхода на основе критерия согласия ω_n^k.

Ключевые слова: многомерные методы анализа данных, методы распознавания образов, эксперимент CBM, отбор распадов $J/\psi \to e^+e^-$.