Electron identification with the electromagnetic calorimeter and its application for charmonia studies in the experiment ALICE3 at the LHC

Идентификация электронов с помощью электромагнитного калориметра и ее применение в исследованиях чармония в эксперименте ALICE3 на БАК

Y. Hambardzumyan [a,1], *Y. Kharlov* [a,b]

Е.В. Амбарцумян [a,1] *Ю.В. Харлов* [a,b]

[a] Moscow Institute of Physics and Technology, Dolgoprodny, Moscow Oblast, 141701 Russia

[a] Московский физико-технический институт, г. Долгопрудный, Московская область, 141701 Россия

[b] NRC "Kurchatov Institute"—IHEP, Protvino, Moscow Oblast, 142281 Russia

[b] НИЦ «Курчатовский институт» – ИФВЭ, г. Протвино, Московская область, 142281 Россия

ALICE3 - эксперимент нового поколения на Большом адронном коллайдере по изучению столкновения тяжелых ионов, преемник эксперимента ALICE. Он открывает область исследований сильновзаимодействующей материи высокой точности. Ряд измерений ALICE3 требует идентификации электронов с высокой эффективностью и чистотой, которая будет выполняться с использованием нескольких дополняющих друг друга экспериментальных методов. Возможность идентификации электронов с использованием кластеров электромагнитных калориметров, сопоставленных с треками, восстановленными в центральном трекере, изучается с помощью системы моделирования и анализа ALICE3. Критерии идентификации электронов оптимизированы для эффективности и подавления адронного фона и применяются для восстановления чармония (1P) в pp-столкновениях через канал распада $\chi_{cJ} \to J/\psi + \gamma$. Обсуждается возможность восстановления состояний чармония в pp-столкновениях на ALICE3.

ALICE3 is a next-generation heavy-ion experiment at the LHC, a successor of the ALICE experiment. It opens a high-precision domain to the strongly interacting matter studies. A set of ALICE3 measurements requires electron identification with high efficiency and purity, which will be performed using several complementing experimental techniques. Feasibility of electron identification using electromagnetic calorimeter clusters matched with tracks reconstructed in the central tracker is studied withing the ALICE3 simulation and analysis framework. Electron identification criteria are optimized against efficiency and hadron contamination suppression and applied to charmonium (1P) reconstruction in pp collisions via the $\chi_{cJ} \to J/\psi + \gamma$ decay channel. Feasibility to reconstruct the charmonium states in pp collisions at the ALICE3 is discussed.

PACS: 29.40.Vj; 29.85.Fj; 13.20.Gd

---

[1] E-mail: yeghishe.hambardzumyan@cern.ch

[1] E-mail: ambartsumian.ev@phystech.edu

Introduction

ALICE3 is a next-generation heavy-ion detector [1] at the Large Hadron Collider and is a successor to the present ALICE experiment [2]. During the last decade of LHC operation with colliding heavy-ion beams at TeV-energies, a big progress was achieved in understanding the key properties of the hot quark-gluon matter, answering the questions of the nature of interactions between quarks and gluons in the deconfined state, transport properties and evolution of the quark-gluon plasma. However, the present detectors at the LHC reached their limits, and a number of key measurements will remain missing after the next 10 years of their operation. The new experiment ALICE3 aims to fill the gap in understanding the quark-gluon studies via new precision measurements of charm and beauty hadrons to explore the transport properties of heavy quarks in the hot QCD medium, measurements of multiple heavy-flavored hadrons, production of exotic charmed states from the quark-gluon plasma, multi-differential measurements of electromagnetic radiation. One of the physics tasks of ALICE3 is to perform precision measurements of quarkonia production in S- and P-states in pp and AA collisions [3]. To achieve the goals of this physics programme, the ALICE3 experiment will be equipped by novel detectors with high readout rate, excellent tracking, and particle identification over a wide rapidity range. The plan is to start the ALICE3 operation at the LHC Run 5 in 2035.

A set of measurements pursued by the ALICE3 experiment requires electron identification. The ALICE3 detectors will provide various complementary methods of electron track identification covering different momentum ranges. The ALICE3 electromagnetic calorimeter (ECAL) is capable to contribute to electron identification at high momenta, together with the time-of-flight and Cherenkov ring detectors, extending the overall kinematic range of electron measurements.

In this paper, the performance of the calorimeter in electron identification is studied within the ALICE fast Monte Carlo framework DelphesO2 [4] that describes the calorimeter response to different particle species and provides reconstruction and particle identification. The performance of the electron ideitification method is studied using the PYTHIA8 event generator [5] with pp collisions at $\sqrt{s} = 14$ TeV. For analysis, the ALICE O2 software suite [6] is used.

Electron Identification and Track Matching

The key ALICE3 detectors for electron identification and charmonium reconstruction are the outer tracker (OT) and the electromagnetic calorimeter (ECAL). The OT is used to reconstruct charged particle tracks in the full azimuth and pseudorapidity range $|\eta| < 4$. The ECAL is used for electron identification and photon reconstruction and consists of the barrel divided into two segments; the high-resolution segment covers pseudorapidities

$|\eta| < 0.53$, and the coarse segment is located at $0.53 < |\eta| < 1.6$. Small material budget of the detectors in front of ECAL is essential to minimize bremsstrahlung of electrons.

For distinct particle species, the calorimeter response for photons (γ), leptons ($e^{\pm}, \mu^{\pm}$) and charged hadrons ($\pi^{\pm}, K^{\pm}, p^{+}$) was implemented in DelphesO2. Electrons and photons deposit their full energy in the ECAL cells. Muons deposit mininum ionization energy loss (MIP), a randomized ionization loss energy with a Landau distribution. Charged hadrons feature MIP in 50% cases and hadronic strong interaction otherwise. Eventually, all deposited energies get smeared with a Gaussian function according to finite photostatistics to reproduce the photon energy resolution parameters derived from the ALICE3 Letter of Intent [1].

Electron identification is based on the equality of energy E deposited in the ECAL and the momentum p measured in the OT. Under assumption of negligible bremsstrahlung, simulations confirm $E/p \approx 1$ for electrons (Fig. 1) with the distribution width being dependent on the ECAL resolution and mostly $E/p < 1$ for other tracks. The resulting Gaussian standard deviations σ define criteria for the selection of electron candidates $|E/p - 1| < 2\sigma$.

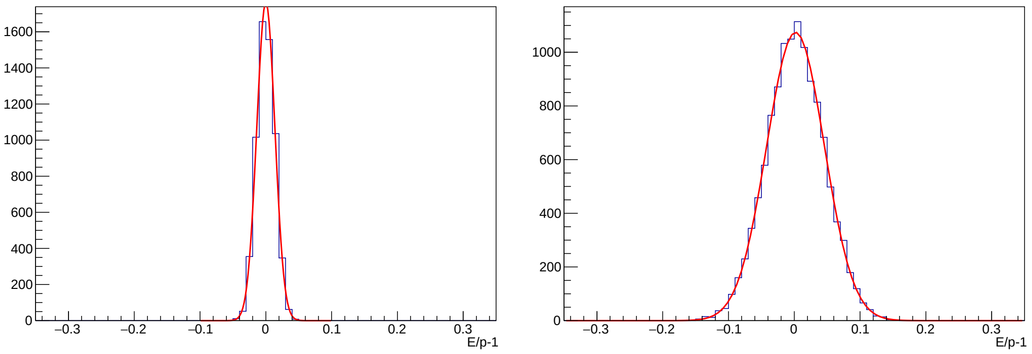

Fig. 1. Example of fitting the $E/p - 1$ distribution for the electrons with the Gaussian distribution function at $E = [5.0, 5.2]$ GeV for high-resolution segment (left) and coarse (right)

Another prerequisite for electron identification is the track propagation matching with the reconstructed point in the ECAL. Track propagation to ECAL surface is smeared due to multiple scattering and tracking resolutions, and ECAL reconstructed point is smeared according to shower development in the ECAL medium. Track matching residuals ΔZ in the coordinates along the beam axis are shown in Fig. 2 for low- and high-energy electrons. Similar distributions can be seen for azimuth angle residuals $\Delta\varphi$. These distributions are fitted by the Gaussian function to obtain a $\pm 2\sigma$ corridor of tracks acceptance as matched with ECAL signals. An electron is identified when $|\Delta Z| < 2\sigma_Z$, $|\Delta\varphi| < 2\sigma_\varphi$ and the E/p criterion is satisfied. The ECAL signals without matched tracks are identified as neutral particles.

Charmonia reconstruction

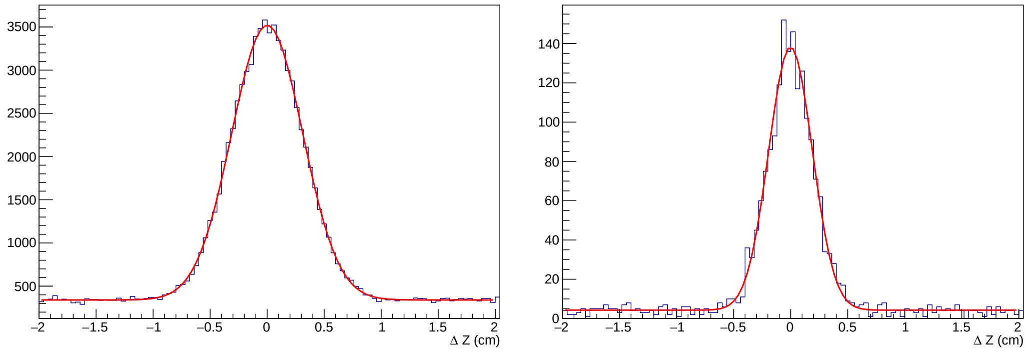

Fig. 2. Examples of fitting the for variable ΔZ with Gauss plus a constant at $E = [1.0, 1.5]$ GeV (left) and $E = [5.0, 5.5]$ GeV (right)

To evaluate the efficiency and contamination of the electron identification algorithm, the electron candidate energy spectrum is compared with the true electron energy spectrum. The ratio of these spectra is obtained in simulations of 10^5 pp collision events in PYTHIA8 with the process of inelastic pp interactions (`SoftQCD:inelastic`) (Fig 3). The deployed method of electron identification has a high purity in the high-resolution ECAL segment at $E > 2$ GeV, though hadron contamination for electron candidates remain high in the coarse ECAL segment in a wide E range.

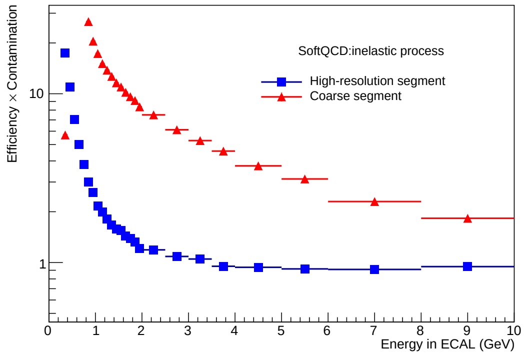

Fig. 3. Calorimeter hadron contamination in PYTHIA8 pp inelastic processes (high-resolution segment drawn in blue, coarse segment drawn in red)

Charmonium reconstruction was studied in simulation of PYTHIA8 processes enhanced by quarkonium production `Onia:all`. The J/ψ is reconstructed via the invariant-mass spectra of electron-positron candidate pairs. Electrons and positrons can hit one of the two ECAL segments, or different segments ("mixed"). The χ_{cJ} $(J = 0, 1, 2)$ is further reconstructed using the invariant-mass spectra of the J/ψ candidates and photon candidates using the decay channel

$$\chi_c \to J/\psi\gamma \to e^+e^-\gamma \tag{1}$$

Figure 4 shows that the peaks of χ_{c1} and χ_{c2} can only be seen when the photon candidates are from the high-resolution segment. The χ_{c0} is heavily suppressed by its branching ratio. Developed electron identification indicates that χ_{c1}, χ_{c2} detection is feasible in pp collisions in ALICE3 provided the photon is detected in the high-resolution ECAL segment.

Conclusion

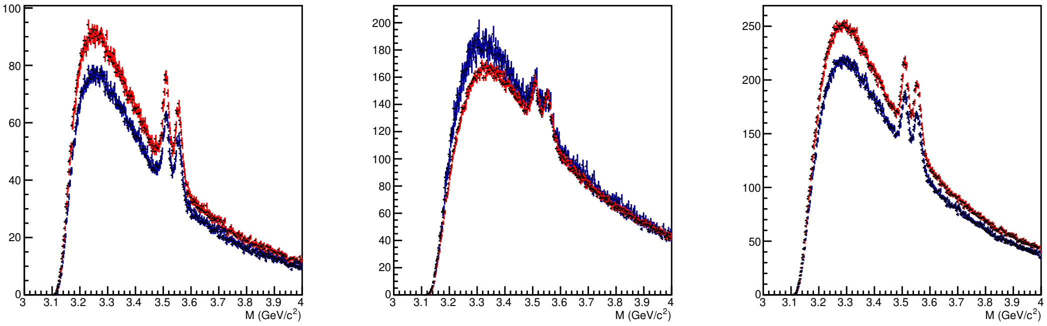

Fig. 4. $e^+e^-\gamma$ mass spectra in 3 different scenarios. Photons are detected in the high-resolution calorimeter segment only. Electron pair detection from left to right: high-resolution scenario, coarse scenario, mixed scenario (histograms in red show reconstruction using Monte-Carlo data, blue histograms show reconstruction from derived candidates for particles)

Electron identification algorithm in the ALICE3 ECAL and the tracker was elaborated in pp inelastic events. Hadron contamination vanishes at high momenta, though complementary electron identification methods are necessary for moderately soft electrons. The algorithms developed demonstrate satisfactory performance for χ_c reconstruction via radiative decay with a photon detected in the high-resolutiuon ECAL segment and electrons reconstructed in the tracker and identified in the whole ECAL acceptance.

This research is supported by the RSF grant 22-42-04405.

REFERENCES

1. *Acharya S. et al.* [ALICE collaboration] Letter of intent for ALICE 3: A next-generation heavy-ion experiment at the LHC arXiv:2211.02491 [physics.ins-det].

2. [ALICE Collaboration], The ALICE experiment – A journey through QCD, arXiv:2211.04384 [nucl-ex].

3. *Kharlov Y.V., Hambardzumyan Y.V., Varlamov A.M.* Probing the Hot QCD Matter via Quarkonia at the Next-Generation Heavy-Ion Experiment at LHC Particles 6 (2023) no.2 — P. 546–555

4. ALICE fast simulation DelphesO2, `https://github.com/AliceO2Group/DelphesO2`

5. *Bierlich C., Chakraborty S., Desai N., Gellersen L., Helenius I., Ilten P., Lönnblad L., Mrenna S., Prestel S. and Preuss C.T. et al.* A comprehensive guide to the physics and usage of PYTHIA 8.3, arXiv:2203.11601 [hep-ph]; `https://pythia.org/`

6. *Alkin A., Eulisse G., Grosse-Oetringhaus J. F., Hristov P. and Kabus M.*, ALICE Run 3 Analysis Framework, EPJ Web Conf. **251** (2021), 03063, `https://aliceo2group.github.io/analysis-framework/`