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π^0 production in $Ag + Ag$ collisions at 1.23 A GeV beam energy measured with HADES

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One of the major goals of the HADES experiment is the measurements of spectra of dileptons originating from dense nuclear matter. The normalization of these spectra is given by the π^0 yield dominating the low mass region (M<0.14 GeV/c^2). Another reason to study yield of π^0-mesons is a unique possibility to measure and compare all three isospin components of pion triplet in the same experiment. In this work the preliminary results of measurements of π^0 production at $\sqrt{s_{NN}} = 2.42$ GeV energy are presented. The results are obtained for the reaction Ag+Ag in the HADES experiment at 1.23 A GeV beam energy. The yields of π^0 were measured via $\pi^0 \to \gamma\gamma$ decay in the acceptance of the ECal detector. The ECal covers the π^0 acceptance range $0 < p_t < 1$ GeV/c and $0.16 < y_{cm} < 1.16$. The acceptance and efficiency corrections are applied. Preliminary results on inclusive π^0 multiplicity per participant is compared with the available world data.

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1. Introduction

Pions are the most abundantly produced mesons in heavy-ion collisions. Their momentum and angular distributions provide information about thermodynamic properties of the hadronic matter. The ratio of yields of π^- / π^+ is sensitive to the Coulomb field of the fireball [1]. However, in addition to the initial differences in spectra, charged pions are affected by the long-range Coulomb forces, which also change their spectra. In order to separate these two effects, it would be interesting to measure the intact momentum spectra. It can be done using the neutral component of the isospin triplet. The measurement of π^0 allows to obtain the information about the initial distributions of pions right after the chemical and kinetic freeze-out. The HADES upgraded with the ECal has unique possibility to study all three isospin components of the pion within the same setup.

Measurement of the yield of the π^0-mesons plays an important role in reducing the systematic uncertainties in study of dileptons because it allows to normalize the spectra by the low mass region (M<0.14 GeV/c^2), where the Dalitz decay $\pi^0 \to \gamma e^+ e^-$ dominates the spectrum.

2. The HADES experiment

HADES (High Acceptance DiElectron Spectrometer)[2] is a fixed-target experiment which explores the properties of dense hadronic matter in heavy-ion collisions at 1-2 A GeV beam energies. It has several subsystems. Four sets of Mini-Drift Chambers (MDC) provide tracking and determination of momenta of particles. Time of flight measurements are carried by diamond Start detector, scintillation detector TOF and resistive plate chambers RPC. The ring imaging Cherenkov detector RICH allows to identify electrons and positrons. The forward scintillation hodoscope (Forward Wall) is used to determine the geometry of the collision. The newly built electromagnetic calorimeter ECal is added to the setup in 2019 in order to measure photons. The schematic view of the HADES is shown in Fig. 1.

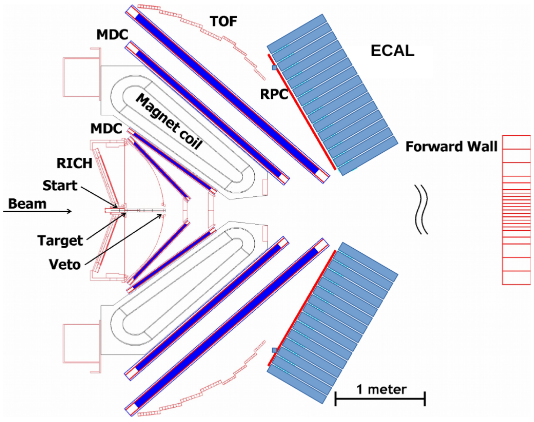

Figure 1: Schematic view of the HADES experiment.

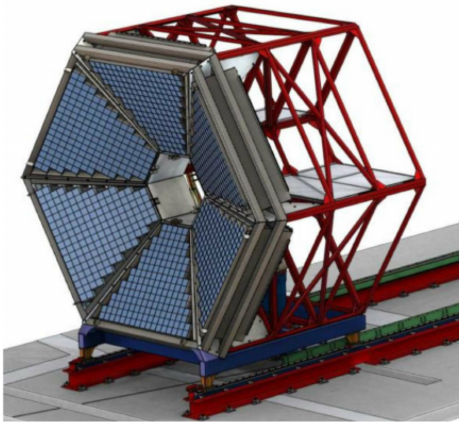

Figure 2: Electromagnetic calorimeter ECal.

The ECal detector (see Fig. 2) is composed of 978 modules combined into six sectors with 163 modules each. The energy resolution of the ECal is found to be $6\%/\sqrt{E[GeV]}$. Time resolution is $\simeq$ 300 ps. Its detailed description can be found in [3]. It covers almost full azimutal angle and polar angles of $12^\circ < \theta < 45^\circ$. Each module has a homogeneous lead glass Cherenkov radiator and a photomultiplier. If a particle hit the ECal detector, one or several modules can fire. Thus several neighbouring modules fired at the same time are combined into clusters in the analysis. Most of clusters have one or two fired modules.

3. Reconstruction of diphoton spectra

About 700 millions $Ag + Ag$ events were taken for the analysis. The most central events (0 - 30%) were selected by the number of hits of charged particles in RPC and TOF detectors. Selection of photons were done using several criteria. First of all, there must be no coincidence between the cluster of fired ECal modules and any tracks of charged particles. Second, there must be no hit in RPC detector near the fired cluster of ECal. RPC is the closest detector to ECal, so this criterion allows to provide more precise matching with the tracks of charged particles. After application of these criteria only clusters corresponding to uncharged particles are left. In order to reject neutrons, it is required that $0.9 < \beta < 1.1$ and $E_{cluster} > 0.1$ GeV.

All selected photons in the event are combined into pairs. Taking into account the angular size of each ECal module, the angle between detected photons is required to be greater than 10°. Supposing both photons come from the decay of a particle, its mass m, transverse momentum p_t and rapidity y are calculated. For each $p_t - y$ bin the diphoton mass spectrum is drawn. Uncorrelated combinatorial background is subtracted using mixed-event technique. The amount of produced neutral pions is estimated as the integral of mass spectrum around π^0 peak within two standart deviations bounds (see Fig. 3).

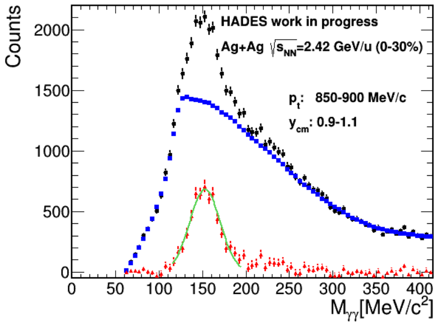

Figure 3: Example of diphoton mass spectra. **Black** line corresponds to pairs combined within one event. **Blue** is combinatorial background. **Red** is the resulting signal. The π^0 peak is approximated with gauss distribution.

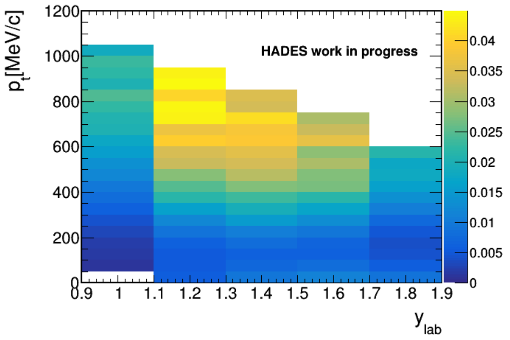

Figure 4: Acceptance * efficiency of registration of π^0.

4. Acceptance and efficiency corrections

Efficiency corrections were determined using both experimental data and simulation. The ECal is the only detector able to register photons in HADES, so the efficiency of γ detection can be obtained only from simulation. However, calculated efficiency can differ from the real one because of instabilities of ECal performance during the beamtime. Fortunately, positrons and electrons produce the same electromagnetic shower as photons while crossing the calorimeter. This makes it possible to get the experimental efficiency of $e^{+/-}$ detection $\mathrm{eff}^e_{\mathrm{exp}}$ and compare this efficiency with the efficiency $\mathrm{eff}^e_{\mathrm{sim}}$ of $e^{+/-}$ detection obtained from Monte-Carlo simulation. This procedure was done for every module of the ECal at all available momenta. The ratio of $\mathrm{eff}^e_{\mathrm{exp}}/\mathrm{eff}^e_{\mathrm{sim}}$ was found to be $\simeq 0.85$. This factor is multiplied by the simulated efficiency of γ detection in order to get its realistic value.

Acceptance corrections were estimated from Monte-Carlo simulation. The UrQMD generator [4] was used to produce π^0-mesons with realistic angular and momentum distribution. Each π^0 meson with branching ratio 99% decayed to two photons. After full Geant transportation of the photons through the HADES, the ECal response was obtained. The data was analyzed in exactly the same way as the experimental one. The acceptance correction factor in each $p_t - y$ bin was obtained as a result of division of the reconstructed number of pions by the produced one. This factor includes the efficiency of γ detection, because the possibility to incorrectly reconstruct the energy of a photon is taken into account. The acceptance · efficiency values can be seen in Fig. 4.

5. Preliminary results

The measured yields of π^0-mesons depending on transverse momentum and rapidity (in the fireball centre-of-mass system) are shown in Fig. 5. In each rapidity bin the p_t dependence can be approximated [5] with Boltzmann fit function.

$$\frac{dN}{dp_t} = C \cdot p_t \cdot m_t \exp^{-\frac{m_t}{T}}, \tag{1}$$

$$\text{where } m_t = \sqrt{p_t^2 + m^2}, \text{ T - inverse slope parameter} \tag{2}$$

This approximation allows to extrapolate the results of measurements to the p_t region, which is not covered by the acceptance of the ECal detector. Integration of the obtained dependences gives the total amount of pions emitted within each of five available rapidity intervals. Taking into account symmetry of the collision we can reflect the dN/dy measurements with respect to the midrapidity.

In order to find the π^0 yield into the full solid angle, the $1/N_{\mathrm{events}} \cdot dN/dy$ was approximated with a Gauss fitting function.

$$\frac{dN_{\pi^0}}{N_{\mathrm{events}} dy} = A \cdot \exp^{-y_{cm}^2/\sigma^2} \tag{3}$$

Its integration gives the avarage number of neutral pions emitted per event in the centrality range 0-30%. Thus, inclusive π^0 multiplicity per participant was found to be $(41 \pm 10) \cdot 10^{-3}$ (see Fig. 6). Data is taken for comparison from [6]. The polynomial fit lines are drawn to mark the area between CC and AuAu data. The error is caused by the systematic uncertainty, while the statistical one is negligible. The source of uncertainties is mostly the efficiency corrections.

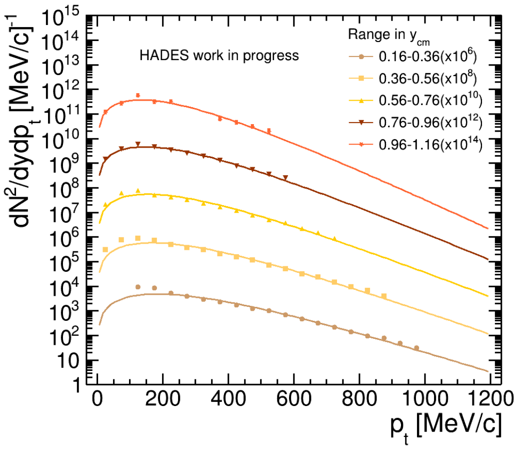

Figure 5: $dN^2_{\pi^0}/dp_t dy$ as a function of p_t.

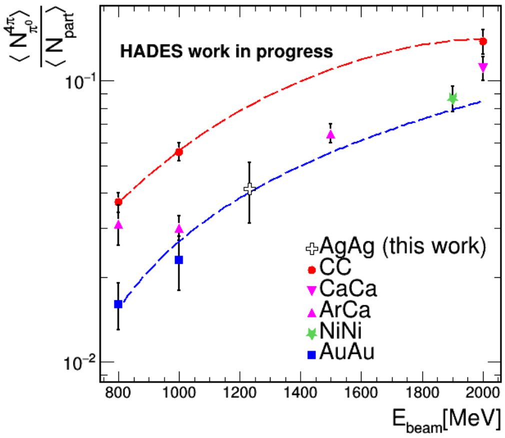

Figure 6: Inclusive π^0 multiplicity per participant as a function of beam energy.

6. Summary and outlook

The yield of π^0-mesons have been measured in $Ag + Ag$ collisions at $\sqrt{s_{NN}}$ = 2.42 GeV via its $\pi^0 \to \gamma\gamma$ decay. The resulting value is comparable with the world data within errors. Further studies of efficiency and systematic uncertainties are needed in order to optimize the signal extraction and improve the quality of extrapolation.

References

[1] M. Gyulassy and S.K. Kauffmann, *Coulomb effects in relativistic nuclear collisions*, *Nucl. Phys. A* **362** (1981) 503.

[2] HADES collaboration, *The High-Acceptance Dielectron Spectrometer HADES*, *Eur. Phys. J.* **A41** (2009) 243 [`(arXiv:0902.3478[nucl-ex])`].

[3] W. Czyzycki et al., *Electromagnetic Calorimeter for HADES*, `arXiv:1109.5550[nucl-ex]`.

[4] S. Bass, M. Belkacem, M. Bleicher, M. Brandstetter, L. Bravina, C. Ernst et al., *Microscopic models for ultrarelativistic heavy ion collisions*, *Progress in Particle and Nuclear Physics* **41** (1998) 255.

[5] R. Hagedorn, *Multiplicities, p_T Distributions and the Expected Hadron → Quark - Gluon Phase Transition*, *Riv. Nuovo Cim.* **6N10** (1983) 1.

[6] R. Averbeck, R. Holzmann, V. Metag and R.S. Simon, *Neutral pions and eta mesons as probes of the hadronic fireball in nucleus-nucleus collisions around 1-A-GeV*, *Phys. Rev. C* **67** (2003) 024903 [`nucl-ex/0012007`].