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Reconstruction of neutral mesons via photon conversion method in Ag-Ag collisions at 1.58 AGeV with HADES

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The physics program of the HADES (High Acceptance DiElectron Spectrometer) experiment is focused on investigating properties of strongly interacting matter at moderate temperatures and large baryo-chemical potential. Amongst the most important observables to be studied are virtual photons and their decays into electron pairs ($e^- + e^+$) in hadron and heavy-ion collisions. As electrons are not affected by final-state interactions, the electrons and positrons offer the possibility to look into the dense nuclear medium in the first stage of collisions. The major background in the dielectron spectrum at low invariant masses are Dalitz-decays of light neutral mesons. Hence, the precise knowledge of neutral meson production is mandatory for the dielectron analyses. In HADES, these mesons can be reconstructed via their dominant $\gamma\gamma$ decays utilizing double photon detection in the electromagnetic calorimeter (ECAL) or via double photon conversion $\gamma + X \rightarrow e^+ + e^-$ in target or detector material with subsequent electron/positron identification. In this contribution, emphasis will be put on recent analysis results for π^0 and η-reconstruction via the double conversion method (DCM) in Ag+Ag collisions at 1.58A GeV.

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1. Introduction

The conversion method for reconstruction of photons has already been successfully applied in earlier HADES experiments and has shown a good performance for neutral meson reconstruction [1]. This method is used as an alternative approach to the direct measurement of photons with an electromagnetic calorimeter (ECAL). Particularly, the photon energy reconstruction from e^+e^--pairs is more precise than its measurement in calorimeter scintillators, due to the very precise charged particle momentum reconstruction. This helps significantly in discriminating the meson signal from the combinatorial background. However, the method typically suffers from lower event statistics due to low (double) conversion probability. In the HADES Ag+Ag beam time, the ECAL detector was only partly assembled. Therefore, the reconstruction of converted photons is a helpful additional instrument in determining the neutral meson production yield.

This work will present preliminary results of π^0- and η-production yields in Ag+Ag collisions measured with HADES via the photon conversion method at 1.58 AGeV incident beam energy. The detector acceptance and photon conversion probability is accounted for.

2. Reconstruction algorithm and invariant mass spectrum of 4-leptons

The reconstruction procedure applied in double photon conversion analysis consists of four main steps: electron identification, $e^+e^- \to \gamma$ pairing, $\gamma\gamma \to \pi/\eta$ pairing, and subtraction of combinatorial background. In this analysis, electron candidates have to be detected in the inner and outer MDC (Multiwire Drift Chambers) and need a valid TOF (Time of Flight) reconstruction. Moreover, each electron candidate is required to have a high track fit quality, a momentum smaller than 1000 MeV/c and a deduced velocity in the range $0.9 \leq \beta \leq 1.2$. In addition, the particle mass reconstructed from momentum and velocity is limited to values smaller than 100 MeV/c^2.

The selected leptons are then combined to photon candidates, where two cases are distinguished: photons with conversion vertices inside and outside the target region. In HADES, the target region extends over $\simeq$ 120 mm and contains a segmented stack of 15 Au foils (D = 1.6 mm, L = 51 mm) housed in carbon fibre beam tube. With the RICH detector enclosing the target region, most detected electron candidates stem from conversion outside this target region, i.e. inside the RICH radiator vessel, in the RICH mirror shell, or beyond. Hence, differentiation is based on the reconstructed z coordinate of the pair vertex inside the target region and up to 800 mm downstream of the target. A matching ring in the RICH photon detector is required only for candidates from conversion vertices inside the target region. In addition, for all photon candidates the pair opening angle is limited to measured opening angle $\theta_{e^-e^+} < 9^\circ$, and the pair invariant mass to $M_{inv} < 100\,\mathrm{MeV}/c^2$. Finally, an upper limit is applied on the minimum distance of approach between the two fitted particle trajectories, thus suppressing combinations of leptons being unlikely to stem from a common conversion vertex. This distance must be smaller than 4 mm.

In the $\gamma\gamma$ pairing step, 2 intervals of photon-pair opening angles are selected such as to analyze π^0 and η meson production separately. The respective opening angle regions are $10^\circ < \measuredangle_{\gamma\gamma} < 40^\circ$ for π^0 and $40^\circ < \measuredangle_{\gamma\gamma} < 110^\circ$ for η candidates. These regions are expected to contain more than 90% of the respective mesons produced in the given collision system and CM energy.

Finally, an invariant mass spectrum $m_{e^+e^-e^+e^-}$ is filled for each meson mass region separately. Results of this reconstruction are presented in Fig. 1. The main background contribution beneath the meson peaks comes from combinatorial background (CB) which refers to photons emitted in uncorrelated processes. One method to subtract this uncorrelated background is the event mixing technique. This technique is based on combining truly uncorrelated photon candidates (from 2 $e^- + e^+$ pairs) originating from different events. Agreement of the spectral CB shapes from mixed event and same event (signal) pairs is further improved by implying that mixed electrons stem from events of similar centrality and with the global event vertex in the same target segment. Finally, the event mixing background is scaled to and subtracted from the signal spectrum. The scaling factor is calculated using side band regions left and right of the π^0/η-signal peak. The remaining signal is fitted using a Gaussian function and an additional constant offset which takes into account minor background remnants on the high mass side of the η- peak. The structures visible in the spectrum are currently being investigated. Both meson yields were determined inside a $\pm 3\sigma$ region of the respective invariant mass peak. The raw yield are $15657 \pm 194\, \pi^0$ and $1920 \pm 239\, \eta$ candidates in a data set of $1.09 \cdot 10^8$ semi-central events.

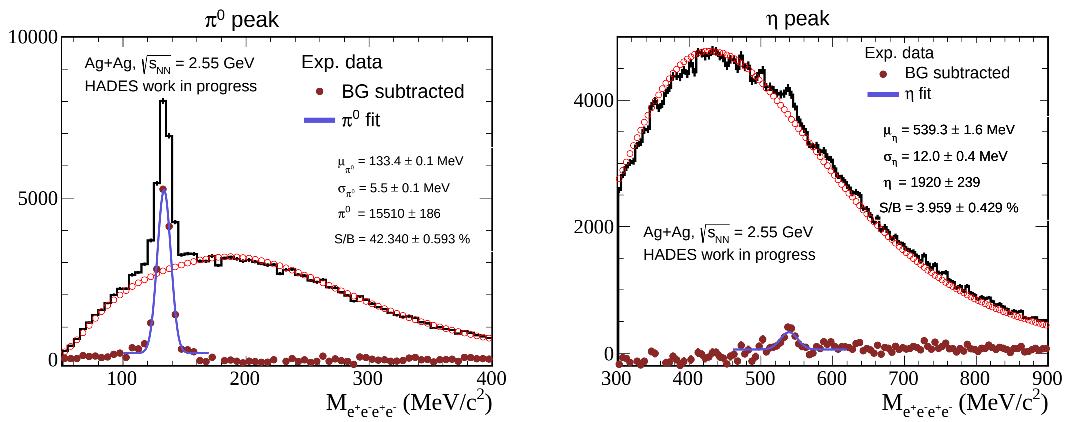

Figure 1: Invariant mass $e^+e^-e^+e^-$ distributions in the π^0- (left) and η-meson (right) mass range. Both spectra depict the measured signal distribution and the scaled background estimated using the event mixing technique. Raw meson yields are given for a $\pm 3\sigma$ window around the signal peak.

3. Acceptance and efficiency correction

In order to extract production cross sections and compare the results with theory and other experiments, the yields need to be corrected for geometrical acceptance, single photon conversion probability inside the acceptance, $e^- + e^+$ detection efficiency and meson reconstruction efficiency.

In this context the level of reconstruction is important for the acceptance definition. An acceptance can be derived at three different stages along the analysis chain: acceptance Acc_γ for individual photons combined with the respective conversion probability, $Acc_{e^\pm}$ at each photon energy for individual conversion electrons/positrons, and $Acc_{\gamma\gamma}$ for photon pair decays of π^0/η mesons in their given kinematics. In a first step and for the analysis presented here, the combined acceptance $\epsilon_{Acc} = Acc_\gamma \cdot Acc_{e^\pm}$ is calculated on single photon level. The $e^+ + e^-$ detection efficiencies, the photon pair acceptance $Acc_{\gamma\gamma}$ and the meson reconstruction efficiency are then combined to an overall efficiency ϵ_{rec}.

For this purpose, 10^7 simulated photons have been emitted from the target point homogeneously distributed in space (polar and azimuthal angles θ and ϕ) and momentum $p = 0$ - $2000\,\mathrm{MeV}/c$ and were propagated through a GEANT3 based description of the full HADES detector. The corresponding acceptance probability is then calculated in each phase space bin as a ratio of the number N_{Acc} of e^+e^- pairs registered in the active parts of the relevant detectors to the number $N_{Photons}$ of all produced photons (eq. (1)).

$$\epsilon_{Acc}(p,\theta,\phi) = \frac{N_{Acc}(p,\Theta,\Phi)}{N_{All}} \tag{1}$$

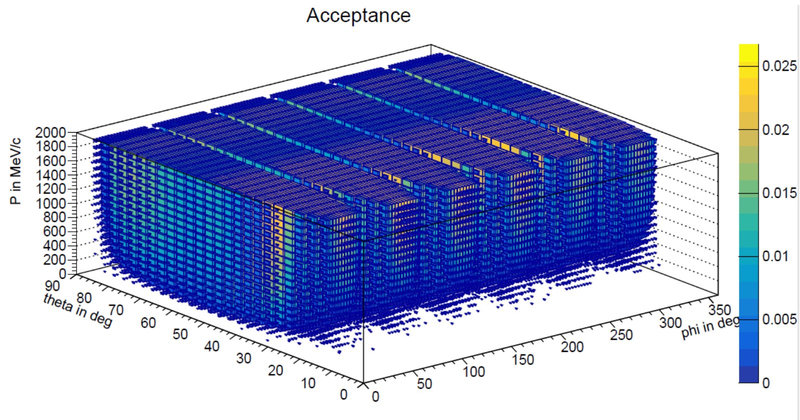

Figure 2: Acceptance of reconstructed photon conversion pairs.

The acceptance on the photon level already includes the photon conversion probability and the combined acceptance probability of both, electron and positron. Hence it is independent of the type of meson under reconstruction. A photon is deemed "accepted", if it underwent conversion inside target or detector material, and if both resulting electrons were emitted into the geometrical acceptance of all (two inner and two outer) MDC tracking layers. The resulting multi differential acceptance matrix on photon level is shown in Fig. 2. The low acceptance values of ≈ 0.5–1.0% are essentially determined by the small conversion probability and reflect the low material budget of the HADES detector.

The reconstruction efficiency, on the other hand, is a measure of the probability, that any particle fulfilling the acceptance conditions is indeed reconstructed based on a realistic description of all detector responses and taking into account all analysis cuts and conditions. In the present case, the efficiency ϵ_{rec} can then be calculated as a ratio of the number of reconstructed particles N_{Reco} to the number of all accepted particles N_{Acc} (eq. (2))

$$\epsilon_{rec} = \frac{N_{Reco}}{N_{Acc}}. \tag{2}$$

For this analysis, the determination of the reconstruction efficiency is based on a complete UrQMD (Ultra-relativistic quantum molecular dynamics) simulation providing realistic particle multiplicities and particle interactions for each simulated event [4],[5]. This is important, as the

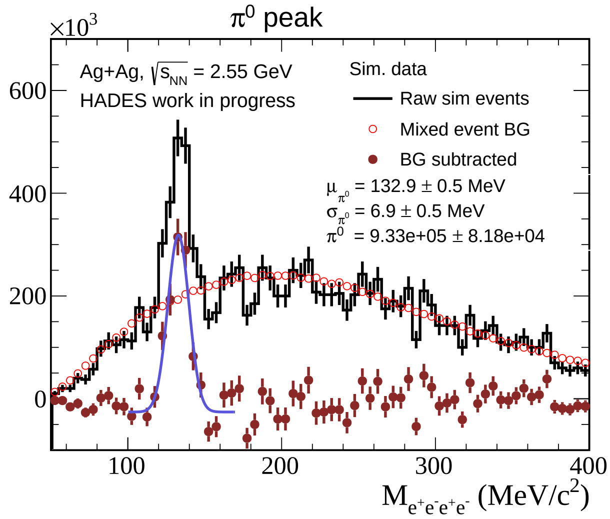

Figure 3: Simulated invariant mass spectrum of double conversion pairs in the π^0 mass region after acceptance correction.

reconstruction probability depends on the precise track environment and detector hit densities as encountered in the experimental data. Moreover, the meson kinematics impose particular limits on the photon pair acceptances. The full reconstruction chain used for the experimental data, including the subtraction of the combinatorial background, was applied on this UrQMD / GEANT data set.

Based on the single photon acceptance, the invariant mass spectrum of two conversion pairs was then built in each of 10×10 bins for transverse momentum p_t and rapidity y. The combinatorial background was derived from mixed events (1 photon in each event), properly scaled and subtracted. However, due to the requirement of twofold conversion probability, the simulation suffered from limited statistics of reconstructed double pairs with obvious π^0 / η signature in many bins. Therefore, in a first step, the determination of ϵ_{rec} was done for the π^0 mass region by averaging over the accepted phase-space region. Consequently, extrapolation to full solid angle (4π) is rather uncertain. In the η mass region, statistical limitations did not allow to derive any efficiency correction factor. New simulation approaches are currently being investigated to overcome these limitations. The averaged efficiency factor for the π^0 region was derived to be $\epsilon_{\text{rec}} \approx (1.57 \pm 0.14)\cdot 10^{-3}$. The full π^0 meson yield in simulation is $5.93 \cdot 10^8$.

The resulting experimental invariant mass spectrum corrected for acceptance and efficiency is depicted in Fig. 4. The experimental π^0 meson yield is estimated by a fit of the integrated corrected signal spectrum to $2.61\cdot 10^{10}$. This results in 5.43 ± 0.06 π^0 mesons emitted per semi-central Ag+Ag collision. It has to be noted, however, that the error does not yet include systematic uncertainties due to the small phase space coverage of the measured data.

4. Conclusion

A preliminary analysis of the HADES data of Ag+Ag collisions at a beam energy of 1.58 AGeV is presented. Applying the double photon conversion method allows to obtain a clear π^0- and η-meson identification in the data. A raw yield for π^0 of 15657 ± 194 is extracted after subtracting

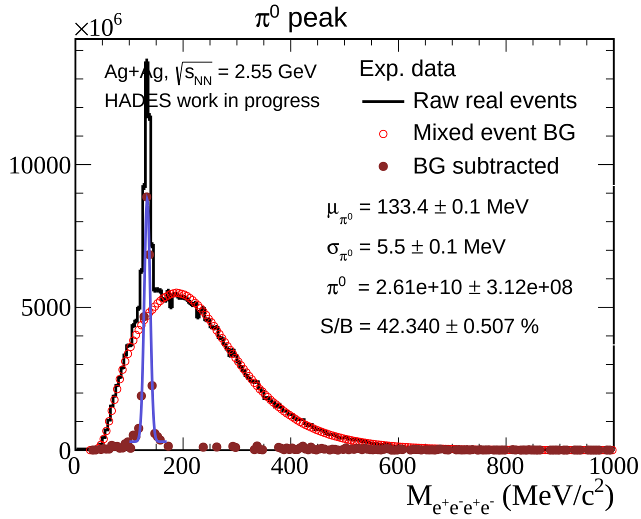

Figure 4: Experimental invariant mass spectrum of double converted photon pairs after correction for acceptance and reconstruction efficiency.

the background contribution through the event mixing technique. In the η-meson mass region a raw signal yield of 1920 ± 239 was extracted a slight discrepancy between background from mixed and same event data remains. The differential acceptance on photon level as function of p, θ and ϕ was determined and found to be in the order of 10^{-2} per photon and correspondingly $\approx 10^{-4}$ for mesons. Statistical limitations were encountered in the Monte Carlo simulations needed to derive efficiency correction factors. This is true in particular in the case of the η-meson, where Monte Carlo statistics are presently not sufficient to obtain even a non-differential spectrum needed for efficiency determination. For the π^0-meson, non-differential efficiency factors could be obtained, allowing to derive an acceptance and efficiency corrected yield. Around 5.43 ± 0.06 π^0 per event are obtained in this analysis. This number is considerably smaller than the expectation from theory ($\approx 8\pi^0$ per event). Due to the low statistics in simulation data the efficiency correction needs further study.

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