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Reconstruction of π^0 and η mesons via photon conversion in Au+Au at 1.23 GeV/u with HADES

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Lepton pairs emerging from decays of virtual photons represent promising probes of matter under extreme conditions. In the energy domain of 1 - 2 GeV per nucleon, the HADES experiment at GSI Helmholtzzentrum fuer Schwerionenforschung in Darmstadt studies di-electrons and strangeness production in various reactions, i.e. collisions of pions, protons, deuterons,and heavy-ions with nuclei. An accurate determination of the medium radiation depends on a precise knowledge of the underlying hadronic cocktail composed of various sources contributing to the net spectra. Therefore, a measurement of the neutral meson yields together with the dileptons is crucial. In this contribution, the capability of HADES to detect e^+e^- pairs from conversion of real photons will be demonstrated. We present results from a two-photon analysis of Au+Au collisions at 1.23 GeV/u providing information on neutral π^0 and η mesons.

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1. Introduction

The degrees of freedom for nuclear matter strongly depend on its temperature and its baryochemical potential. At very high temperatures and low baryochemical potentials a deconfined phase called the quark-gluon plasma has been measured. At lower temperatures and higher baryochemical potentials models predict even more exotic states. At SIS18 nuclei are shot with energies between 1 -2 GeV/u on fixed target to probe nuclear matter at those conditions. One of the latest measurements has been performed by the HADES collaboration in April 2012, with the collision system gold on gold with a beam energy of 1.23 GeV/u.

1.1 Heavy-Ion Collisions

At SIS18 energies three possible stages of such a collision are assumed. Fig. 1 shows the first chance collisions, the hot and dense stage and the freeze-out. Direct photons (γ) and dileptons (e^+e^-) are penetrating all these stages without interacting strongly. Therefore lepton pairs are an ideal probe to understand the properties of the hot and dense stage of the collision. Since the lifetime of a collision is much shorter than the read-out time of detectors the different stages are indistinguishable. It is necessary to understand the lepton pair contributions from the other stages. Measurements of a reference spectra from elementary reactions, i.e. pp and np, are used to estimate the contribution of the first chance collisions [1, 2, 3]. Mesons with a long lifetime (long compared to the lifetime of the fireball), i.e. the neutral π^0 and η, are the dominant contribution to the dilepton invariant mass spectra from the freeze-out stage. For the normalization of dilepton invariant mass spectra, the measuring of the π^0 contribution is crucial. The cross section of the η is essential to determine the non-trivial enhancement of low-mass dileptons ($M_{e^+e^-}$ between 0.15 GeV/c^2 and 0.55 GeV/c^2), that was found by DLS [4] and HADES [5] at Bevalac/SIS18, CERES [6] and NA60 [7] at CERN, and STAR[8] and Phenix [9] at RHIC. This contribution will focus on the reconstruction of neutral π^0 and η with the HADES detector via conversion method.

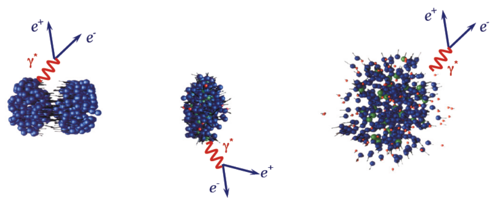


Figure 1: Schematical view of 3 possible stages of a heavy-ion collision. Dileptons are produced in all stages.

2. Analysis strategy

The contribution of the neutral mesons to the dilepton spectra is given by their Dalitz decays (meson $\to \gamma e^+e^-$). The full reconstruction of the meson yield can be achieved by measuring the γ from Dalitz decays. Furthermore, π^0 and η mesons decay dominantly into two photons (meson $\to \gamma\gamma$), this channel could also be studied. Since HADES has no photon detector yet, the measurement of the photons is only possible via external conversion of photons in detector material.

2.1 HADES

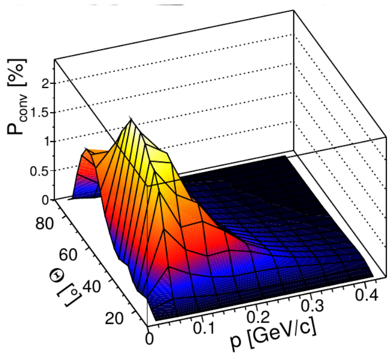
The High Acceptance DiElectron Spectrometer (HADES) is installed at the SIS18 (GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt) [10] . It consists of six identical sectors that cover the full azimuthal angle and polar angle from 18° to 85°. Particle tracking is performed with 4 x 6 Multiwire Drift Chambers and a superconducting toroidal magnet. For the time-of-flight measurement the ToF detector and Resistive Plate Chamber walls are used. HADES measured in April 2012 the collision system Au+Au at the highest beam energy achievable at SIS18, namely at Ekin = 1.23 GeV/u. The trigger on hit multiplicity in ToF_{Mult} >= 20 (PT3) corresponds to an impact parameter $b_{max} \approx 10$ fm which is equivalent to 35% most central events.

2.2 Conversion Probability

The photon conversion probability was calculated with the help of the simulation tool GEANT3. In this work the conversion probability is defined as the probability to find a reconstructible dilepton pair (which means traversing the HADES acceptance) originating from a γ which comes from a π^0. The differential cross section for this process depends on the atomic number Z of the material in which the interaction occurs. In a compound material the element i in which the interaction occurs is chosen randomly according to the probability:

$$Prob(Z_i, E_\gamma) = \frac{n_{ati}\sigma(Z_i, E_\gamma)}{\sum_i [n_{ati} \cdot \sigma_i(E_\gamma)]}, \tag{2.1}$$

where Z_i stands for the atomic number of the material, n_{ati} is the number of atoms per volume of the i^{th} element and E_γ the energy of the photon. In Fig. 2a the conversion probability inside the HADES as a function of the photon energy and the polar angle theta Θ is shown. Since the target is segmented into 15 vertically aligned gold discs (r =1.2 mm, thickness = 0.25mm), a larger polar angle corresponds to a longer flight path through target material. The dependence of Eq. 2.1 is reflected here. In Fig. 2b the conversion probability for the main inner detector parts is presented. The systematic errors are in the order of 5% due to uncertainties in the material budget, for details see [11].



(a)

Detector component	Material	% (π^0)
Target	Gold	0.05
δ-shield	PE	0.05
Beam pipe	Carbon	0.04
Radiator gas	C4F10	0.11
Mirror	Carbon	0.08
Sum		0.36

(b)

Figure 2: (a) Conversion probability (in %) as function of the γ energy and the Θ angle. (b) Conversion probability (in %) for different material in the center of the spectrometer for γ coming from π^0 decays

2.3 Reconstruction of Neutral Mesons

Leptons can be identified within the HADES spectrometer by various observables, i.e. RICH ring properties, particle velocity, energy loss in ToF detector and MDC chambers, etc. In Fig. 3 the velocity as a function of momentum and charge can be seen. At velocity $\beta \approx 1$ and momentum smaller than 750 MeV/c leptons can be identified. Lepton pairs coming from conversion are characterized by a very small opening angle and a low momentum. Pairs with such small opening angles will be identified as a single ring in the RICH detector. Backtracking algorithms to reconstruct close pairs are under development. Furthermore conversion in the radiator gas and the mirror will not be taken into account if a ring would be required. Therefore the identification of leptons is realized using momentum versus velocity information in the RPC and ToF detectors (See Fig. 3). Identified leptons are combined as opposite charged pairs. At least two pairs are required in one event. To identify neutral mesons, topological cuts on the opening angles between the leptons and the reconstructed pairs (photons) are applied. In Fig. 4a the opening angle α distribution for dilepton-pairs coming from γ, π^0-Dalitz and η-Dalitz decays is shown. For identification with the full conversion method at least one of the reconstructed pairs needs to come from a real photon. Therefore one of the lepton pairs needs to have an opening angle α_1 <2.5°. Since the second pair could origin from a virtual photon of a Dalitz decay the cut is less strict : α_2 <20°. Another cut is applied on an opening angle between the two reconstructed photons $\Theta_{\gamma\gamma}$. In Fig. 4b the $\Theta_{\gamma\gamma}$ from different sources can be seen. Uncorrelated leptons (black dashed curve, labeled with Lep4) and photons (black solid curve, labeled with Fake2Conv) result in a wide distribution, where photons coming from π^0 and η decays appear in certain opening angle regions. For π^0 the used topological cut is 10° <$\Theta_{\gamma\gamma}$<40°, for η 40° <$\Theta_{\gamma\gamma}$<140°.

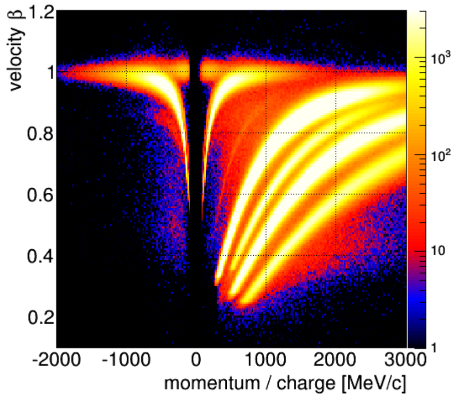
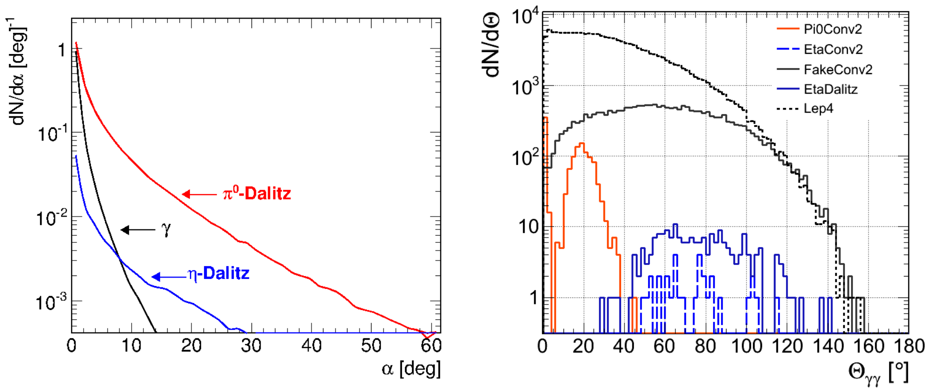


Figure 3: Velocity vs momentum times charge measured with the HADES detector. Velocity is measured by RPC

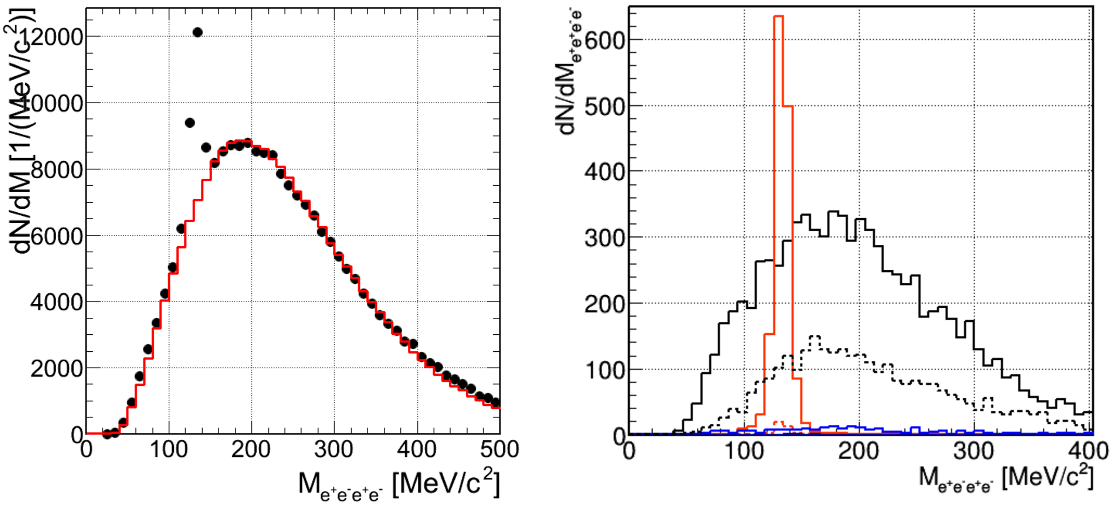


(a) (b)

Figure 4: (a) Opening angle (α) distribution for dilepton-pairs coming from γ, π^0-Dalitz and η-Dalitz decays. (b) Opening angle ($\Theta_{\gamma\gamma}$) distribution for photon pairs originating from π^0 and η decays in comparison to uncorrelated γ.

3. Results

After applying topological cuts to identify π^0 the resulting four lepton invariant mass spectrum is shown in Fig. 5a (black circles) together with the mixed-event background (red curve). Close to 130 MeV/c^2 a clear π^0 peak is visible. In Fig. 5b UrQMD simulations show the different contributions to the invariant mass spectrum. Real π^0 are shown with the orange curve. Uncorrelated real ($\gamma\gamma$ black curve) and virtual photons ($\gamma\gamma^*$ black dashed line) are the main background sources. The contribution from misidentified particles (blue curve) is minor. To subtract the combinatorial background the event-mixing technique was used. Here photons and virtual photons from different events were mixed.

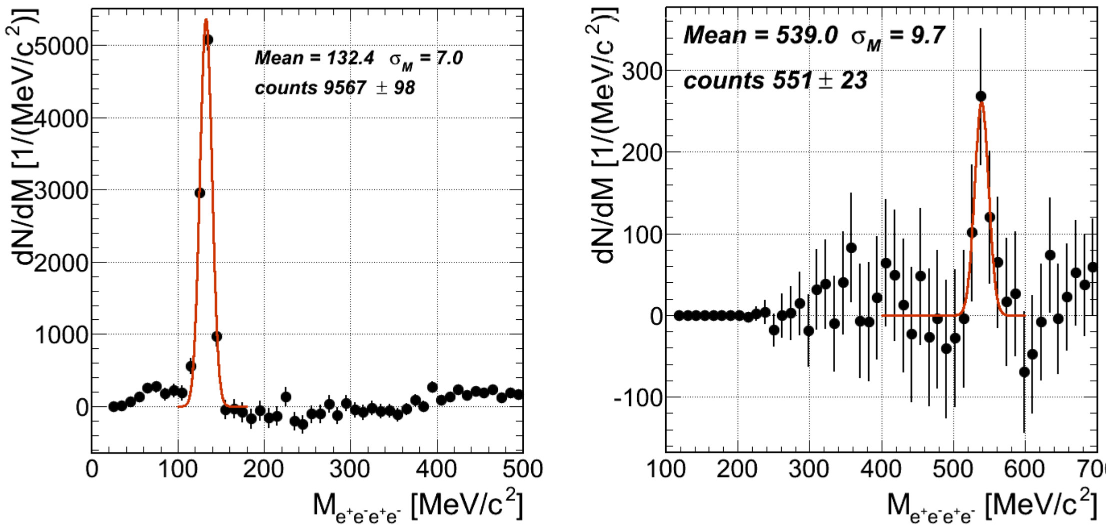


(a) (b)

Figure 5: (a) Four-lepton invariant-mass spectrum (black circles) after applying topological cuts for π^0 reconstruction, together with the mixed-event background (red curve). (b) Four-lepton invariant-mass spectrum from a UrQMD simulation. For details see text.

3.1 Integrated Yield

The event-mixing background was normalized to the integral of events used for the like sign analysis. In Fig. (6a) and Fig. (6b) the four lepton mass spectra after subtraction of the mixed-event background are shown. The π^0 peak is clearly visible at 132.4 MeV/c^2 and a width of 7 MeV/c^2. The shift of 3 MeV/c^2 compared to the the nominal mass of 135.0 MeV/c^2 can be explained with missing energy loss corrections of the leptons that will be included in future analysis. The 4 lepton invariant mass spectrum shows a second signal (not shown here) at 539.0 MeV/c^2 with a width of 9.7 MeV/c^2 that was identified as η meson. The shift compared to the nominal mass has the same reasons as for the π^0. In both cases the mixed-event technique was able to describe the background. Integration of the spectrum in the 2σ region around the peak gives $\approx$ 9600 counts for π^0 and $\approx$ 450 counts for η. This amount of signal will allow for a multi-differential analysis.

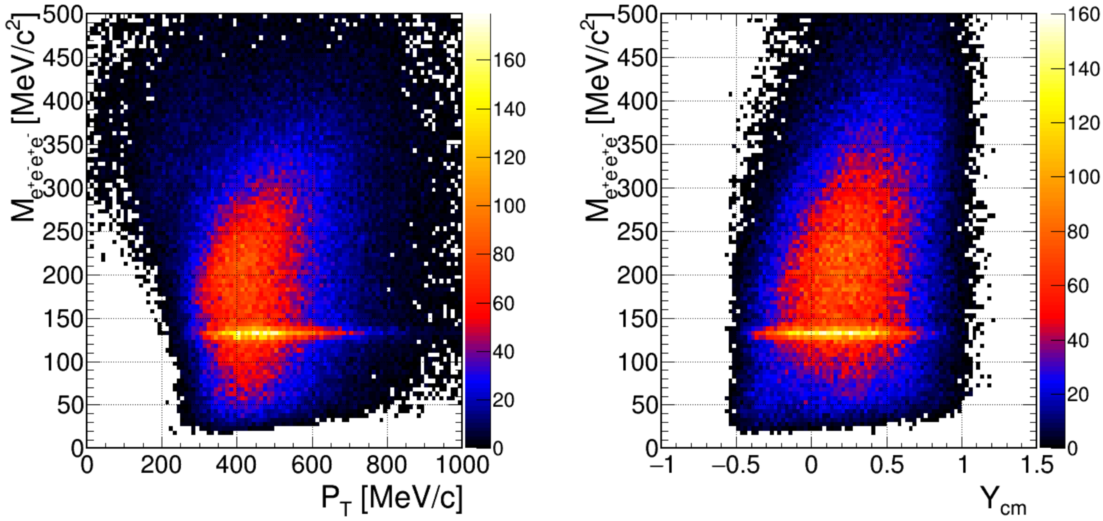


(a) (b)

Figure 6: Four-lepton invariant-mass spectrum (black circles) after subtraction of event-mixed background. Gaussian functions (red curve) are fitted to estimate the yields. Topological cuts are optimized for (a) π^0 and (b) η.

3.2 Phase Space Coverage

In Fig. 7a and 7b invariant mass as a function of transverse momentum (a) and rapidity (b) is shown. The transverse momentum at π^0 mass can be measured from 200 MeV/c to 900 MeV/c. The very low momentum region ($p_\perp$ < 200 MeV/c) cannot be covered due to the bending of low momentum leptons out of the HADES acceptance by the magnetic field. The rapidity (y) is covered around mid-rapidity and furthermore in the back and forward rapidity region.



(a) (b)

Figure 7: Four-lepton invariant-mass as a function of transverse momentum (a) and rapidity (b).

4. Summary and Outlook

In this work we studied the reconstruction of neutral mesons π^0 and η via photon conversion. The conversion probability in the inner parts of the HADES detector was calculated using simulated photons coming from π^0 decays. Lepton candidates were identified using velocity and momentum and combined to 4 lepton invariant mass spectrum. Both mesons were found and the raw yield was estimated to be $N_{\pi^0} \approx 9600$ counts and $N_\eta \approx 550$. Acceptance and efficiency corrections will be extracted in the next step. The multiplicities, y and $p_\perp$ for both mesons will be reconstructed for Au+Au at 1.23 GeV/u and the cross section will be extracted. In the future an electromagnetic calorimeter (See Fig. 8) will be installed at HADES and it will support the reconstruction of photons and neutral mesons.

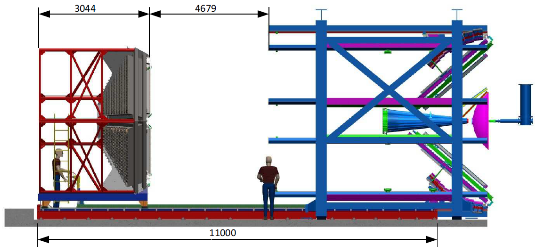


Figure 8: Technical drawing of the future HADES electromagnetic calorimeter.

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