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

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Abstract. 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, heavy-ions, and nuceous 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 will 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.

1. Introduction

Nuclear matter under extreme conditions can be created via heavy-ion collisions in the laboratory. At SIS 18 energies three possible stages of such a collision (see Fig. (1)), the first chance collisions, the hot and dense stage and the freeze-out, are assumed. Direct photons (γ) and dileptons (e^+e^-) are penetrating all these stages without strong interactions. Therefore lepton pairs, are an ideal probe to test the properties of the hot and dense stage of the collision. Furthermore it is necessary to understand the lepton pair production mechanisms in the other stages. Measurements of reference spectrum 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 understanding the π^0 is crucial. The cross section of the η is essential to determine the non trivial enhancement of low-mass ($M_{e^+e^-}$ between 0.15 GeV/c^2 and 0.55 GeV/c^2) lepton pairs, 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 in Au+Au at 1.23 GeV/u.

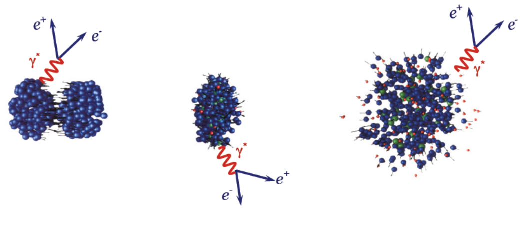


Figure 1: Scematical view of a 3 possible stages of a heavy-ion collision. Dileptons are indicated in all stages.

2. Analysis strategy

The contribution of the neutral mesons to the dilepton spectra is given by their Dalitz decays (meson $\rightarrow \gamma e^+ e^-$). The detection of the γ from Dalitz decay would give opportunity to fully reconstruct the meson yield. Besides the Dalitz decay, π^0 and η mesons have dominant decay channel into two photons (meson $\rightarrow \gamma\gamma$), that also could be studied.

2.1. HADES spectrometer

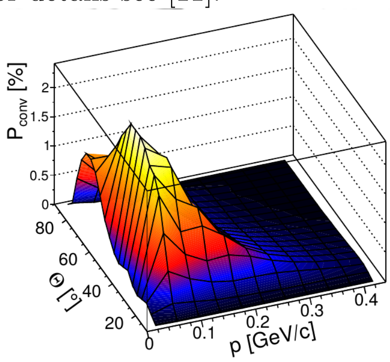
The High Acceptance DiElectron Spectrometer (HADES) is installed at the SIS 18 (GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt)[10] . It consists of 6 identical sectors that cover a full azimuthal angle and polar angle from 18° to 85°. The tracking is performed with 4 x 6 Multiwire Drift Chambers and a superconducting toroidal magnet. For the time-of-flight measurement the ToF detector and Resistive Plate Chamber walls are used. HADES measured the collision system Au+Au at the highest (achievable at SIS 18) beam energies, E_{kin} = 1.23 GeV/u in April/May 2012. In total 7.3 x 10^9 events, that corresponds to 140 TByte of data have been collected. The trigger on hit multiplicity in ToF_{Mult} =>20 (PT3) corresponds an impact parameter $b_{max} \approx 10$ fm.

2.2. Conversion Probability

Since HADES has no photon detector yet, the measurement of the electromagnetic decays of π^0 and η is only possible via external conversion of photons in detector material. The conversion probability can be extracted with the help of the simulation tool GEANT3. In this work the conversion probability is defined as a reconstructible (which means traversing the HADES acceptance) dilepton coming from a γ which originate from a π^0. The differential cross section for such 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:

$$Prob(Z_i, E_\gamma) = \frac{n_{ati}\sigma(Z_i, E_\gamma)}{\sum_i [n_{ati} \cdot \sigma_i(E_\gamma)]}, \quad (1)$$

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 Θ angle 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 flightpath trough target material. The dependence of Eq. 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)

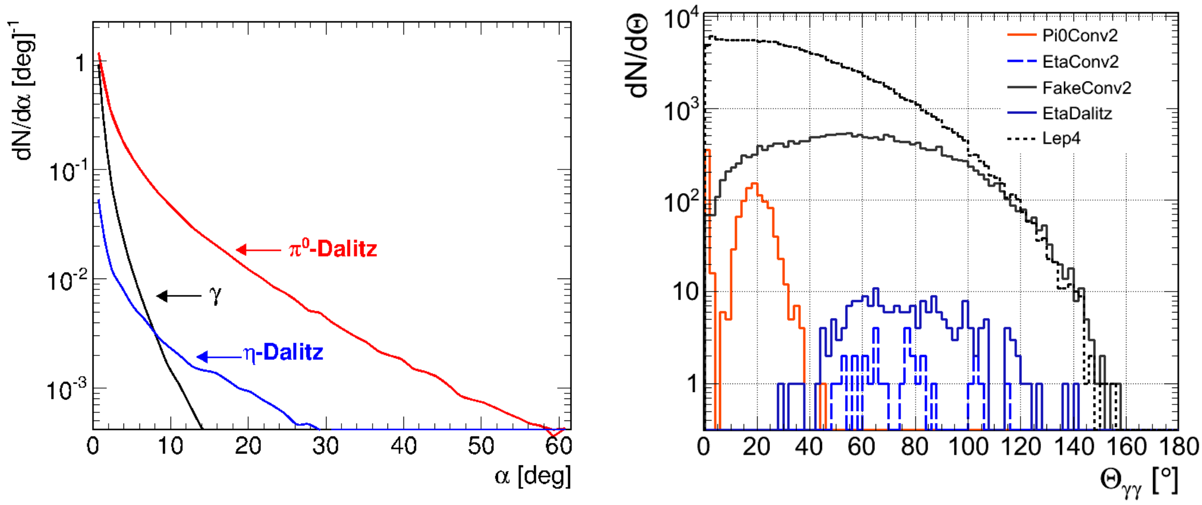
Detector component	Material	% (π^0)
Target	Gold	0.05
δ-shield	PE	0.05
Beam pipe	Carbon	0.04
Radiator gas	C4F10	0.11
Mirror	Carbon	0.08
Sum		0.36

(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. Lepton pairs coming from conversion are characterized by a very small opening angle and a low momentum. Pairs with this small opening angles will be identified as a single ring in the RICH detector. Algorithms to reconstruct close pairs are under development. Furthermore conversion in 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. This leptons are combined into opposite charge pairs. At least two pairs are reqired in one event. To identify neutral mesons, topological cuts on the opening angles between the leptons and the reconstructed γs are applied. In Fig. 3a 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 need to come from a real photon. Therefore one of the lepton pairs need 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. 3b the $\Theta_{\gamma\gamma}$ from different sources can be seen. Uncorrelated leptons (black dashed curve, labled with Lep4) and photons (black solid curve, labled with Fake2Conv) reslut 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°.



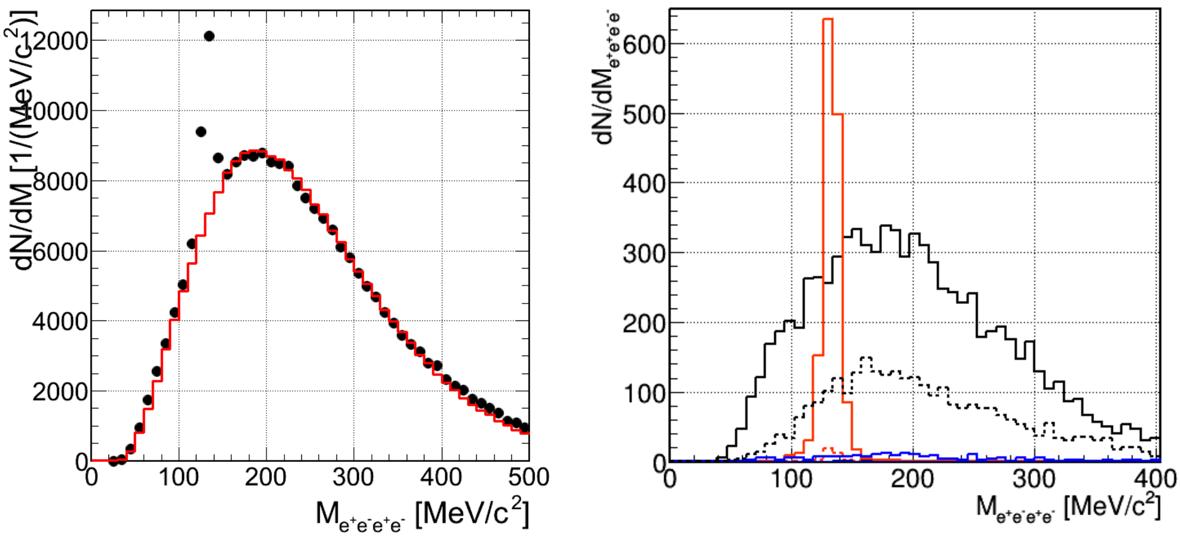
(a) (b)

Figure 3: (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 γ originating from π^0 and η decays in comparison to uncorrelated γ.

3. Results

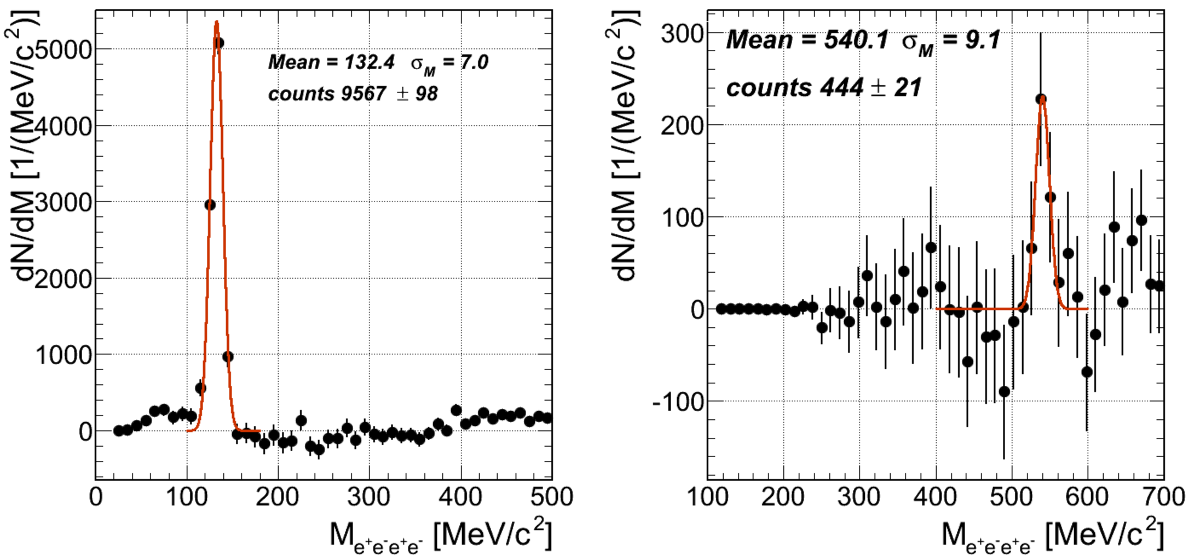
After applying topological cuts to identify π^0 the resulting four lepton invariant mass spectrum is shown in Fig. 4a (black circles) together with the event-mixed background (red curve). At 130 MeV/c^2 a clear π^0 peak is visible. In Fig. 4b UrQMD simulations show the different contributions to the 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. 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 where mixed.

The event-mixing background was normalized to the integral of events used for the like sign analysis. In Fig. (5a) and Fig. (5b) the four lepton mass spectra after subtraction of the event-mixed background are shown. In both cases the event-mixed 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 4: (a) Four lepton invariant mass spectrum (black circles) after applying topological cuts for π^0 reconstruction, together with the event-mixed background (red curve). (b) Four lepton invariant mass spectrum from UrQMD simulation. For details see text.



(a) (b)

Figure 5: 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 optimised for (a) π^0 and (b) η

4. Summary and Outlook

In this work we study 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 decay. Lepton candidates were identified using velocity and momentum and combined to 4 lepton invariant mass spectrum. Both mesons were found and the yield was estimated to be $N_{\pi^0} \approx 9600$ counts and $N_\eta \approx 450$. 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 a cross section will be extracted. In future an electromagnetic calorimeter will be installed at HADES and it will support the reconstruction of photons and neutral mesons.

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