Journal of Physics: Conference Series **503** (2014) 012015 doi:10.1088/1742-6596/503/1/012015

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

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Abstract. Lepton pairs emerging from decays of virtual photons are one of the most promising probes of dense hadronic matter. The HADES experiment at GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt studies dielectron radiation as well as strangeness production in various reactions, i.e. proton, deuteron and heavy-ion. The understanding of the corresponding experimental results calls for supporting studies from various model calculations. For a more model independent understanding of the dilepton cocktail the production cross sections of particles created during the freeze-out is crucial. In this contribution we will present results from a two photon analysis of Au+Au in 1.23 GeV/u collisions providing information on π^0 and η mesons. Therefore the capability of HADES to detect e^+e^- pairs from external conversion of real photons will be explained and first results will be shown.

1. Introduction

Heavy-ion collisions provide a unique possibility to study nuclear matter under extreme conditions in the laboratory. The most abundantly produced and recostructed particles are pions, kaons, protons and light fragments. But the most promising tool to probe the microscopic properties of strongly interacting matter under extreme temperatures and densities is electromagnetic radiation. Photons (γ) and dileptons (e^+e^-) are penetrating all stages of a heavy-ion collision without strong interactions. Lepton pairs, emerging from decays of virtual photons (γ^*) are emitted during the whole evolution of the fireball. On the other hand they will not only probe the hot and dense stage but also the first chance collisions and the freeze-out of the collision. To estimate the contribution of the first chance collisions one can measure so called reference spectrum from elementary reactions, i.e. pp and np. These reactions have been successfully measured by the HADES Collaboration [1, 2, 3].

The contribution to the dilepton invariant mass spectra from the freeze-out stage is dominated by mesons with a long lifetime (long compared to the lifetime of the fireball), i.e. the neutral π^0, η and the ω meson. It is crucial to understand the contribution of the π^0 for the normalization of dilepton invariant mass spectra. The cross section of the η is essential to determine the non trivial enhancement of low mass (M_{ee} between 0.15 and 0.55 GeV/c^2) lepton pairs, that was found by DLS [4] and HADES [5] at Bevalc/SIS, CERES [6] and NA60 [7] at CERN, and STAR[8] and Phenix [9] at RHIC. The detection of the γ from Dalitz decays (meson $\rightarrow \gamma e^+e^-$) would give opportunity to fully reconstruct the meson yield. Besides the Dalitz decays π^0 and η mesons have dominant decay into two photons (meson $\rightarrow \gamma\gamma$). The Two Arm Photon Spectrometer (TAPS) Collaboration provided a large set of measurements for this decay channel [10].

In Fig. 1 the multiplicities of the π^0 and η mesons, as functions of beam energy and system size are shown. The data were obtained with TAPS [10], the π^+ data as shown in Fig. 1 was measured by KaoS Collaboration [11]. Curves are log-log polynomial fits to the data in lighter systems. The curves for the Au+Au data points are from extrapolation of the light systems (C+C, Ca+Ca). The the Au+Au data sets were measured with much less accuracy compared to the light systems. The estimated multiplicities of the π^0 and η mesons in Au+Au at 1.23 GeV/u are indicated with red stars on a dashed line and extracted values are 6.4 $\pm$ 15% for the π^0 and 0.09 $\pm$ 50% for the η. To make a solid statement on a possible e^+e^- enhancement, one has to minimize the uncertainties on the trivial sources, in particular on η. The HADES experiment has no dedicated detector system to measure photons. Therefore photons are detected via conversion into e^+e^- pairs. Such analysis has been already preformed at the beam times Ar+KCl at 1.76 GeV/u [12] and p+Nb at 3.5 GeV/u [13] with HADES. This procedure was successfully used by other experiments [14, 15].

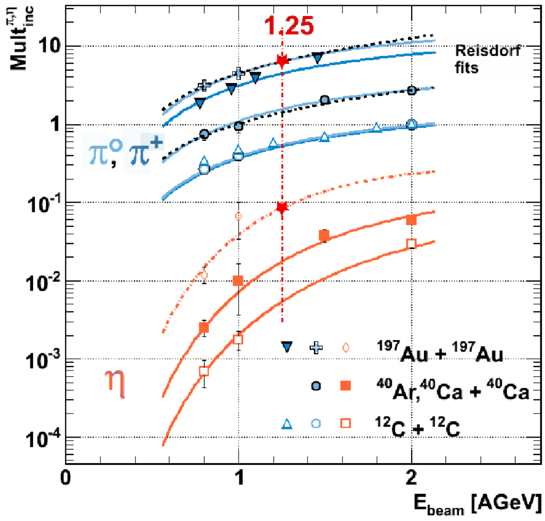


Figure 1: Excitation functions of inclusive π and η production in the C+C, Ca+Ca and Au+Au systems by TAPS Collaboration [10] and KaoS Collaboration [11]

1.1. The HADES spectrometer

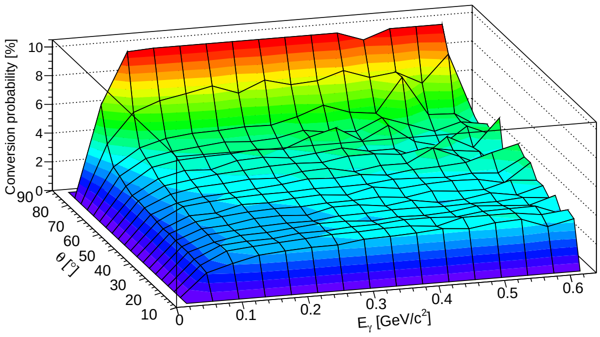
To study e^+e^- pairs radiated from cold nuclear matter, hot and dense nuclear matter as well as in elementary collisions, the High Acceptance DiElectron Spectrometer (HADES) is installed at the SIS 18 (GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt). It consists of 6 identical sectors that covers 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 a Resistive Plate Chamber (RPC) walls are used. HADES measured the collision system Au+Au at the highest (achievable at SIS18) 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 $b_{max} \approx 9$ fm.

2. Conversion in the HADES spectrometer

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. Therefore the knowledge of the conversion probability is needed. The conversion probability can be extracted with the help of the simulation tool GEANT3. Lepton pair production of a γ can only occur when the photon passes near a massive particle such as an atomic nucleus. The recoil of the massive particle satisfies momentum conservation without carrying off a significant amount of energy, so the assumption that all of the energy of the photon goes into the electron-positron pair is a good approximation. 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 in which the photon will convert 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 vertical aligned gold discs (r =1.2 mm, thickness = 0.25mm), a lager 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 are is presented. The systematic errors are in the order of 5% due to uncertainties in the material budget, for details see [13].



(a)

Detector component	Material	% (π^0)	% (η)
Target	Gold	0.32	0.54
Target holder	Carbon	0.026	0.045
Beam pipe	Carbon	0.26	0.48
Radiator gas	C4F10	0.59	0.91
Sum		1.2	2.0

(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 and η decay

3. Estimations of π^0 and η multiplicities

To validate the feasibility of the two photon and photon e^+e^- analysis the expected multiplicities of the neutral mesons reconstructed from 4 leptons in finale state need to be estimated. To do that one can use the following equation:

$$N_{AuAu} = Mult_{TAPS} \cdot N_{events} \cdot BR \cdot P_{Conv} \cdot \epsilon_{reconstruction} \cdot \epsilon_{acceptance}, \quad (2)$$

where N_{AuAu} is the expected multiplicity for 4 leptons in final state for Au+Au at 1.23 GeV/u, $Mult_{TAPS}$ is the multiplicity of the mesons (as estimated from Fig. 1) , N_{events} the total number of events, BR is the decay branching ratio [16], P_{Conv} the conversion probability and $\epsilon_{reconstruction} \cdot \epsilon_{acceptance}$ the assumed efficiencies for reconstruction and geometrical acceptance. In Table 1 BR, and P_{Conv} for these channels are summed up. Note that the product of the BR and P_{Conv} is on the same order of magnitude for the Dalitz and the 2γ decay channels.

Channel	BR	P_{Conv}	Total
$\pi^0 \to \gamma\gamma \xrightarrow{conv} e^+e^-e^+e^-$	$98.8 \cdot 10^{-2}$	1.44%	$1.4 \cdot 10^{-7}$
$\pi^0 \to \gamma e^+e^- \xrightarrow{conv} e^+e^-e^+e^-$	$1.17 \cdot 10^{-2}$	1.2%	$1.4 \cdot 10^{-7}$
$\pi^0 \to e^+e^-e^+e^-$	$3.34 \cdot 10^{-5}$		$0.3 \cdot 10^{-7}$
$\eta \to \gamma\gamma \xrightarrow{conv} e^+e^-e^+e^-$	$39.3 \cdot 10^{-2}$	4%	$4.7 \cdot 10^{-7}$
$\eta \to \gamma e^+e^- \xrightarrow{conv} e^+e^-e^+e^-$	$7.0 \cdot 10^{-3}$	2%	$4.2 \cdot 10^{-7}$
$\eta \to e^+e^-e^+e^-$	$<6.9 \cdot 10^{-5}$		$2.1 \cdot 10^{-7}$

Table 1: Branching ratios and conversion probabilities into various decay channels

Based on [12, 13] reconstruction efficiency for π^0 and η has been estimated to be 10% and acceptance 1% and 2%, respectively. Summing up all 4 lepton final state decay channels the expected yield will be around $1.5 \cdot 10^4$ entries for the π^0 and 750 for the η meson.

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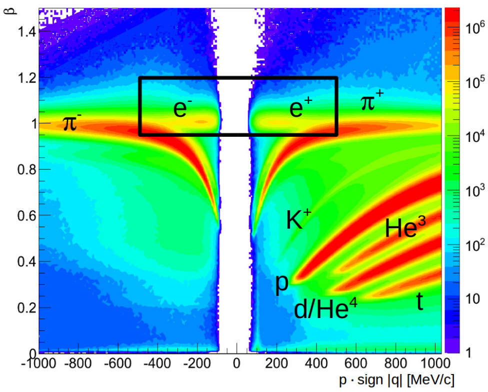
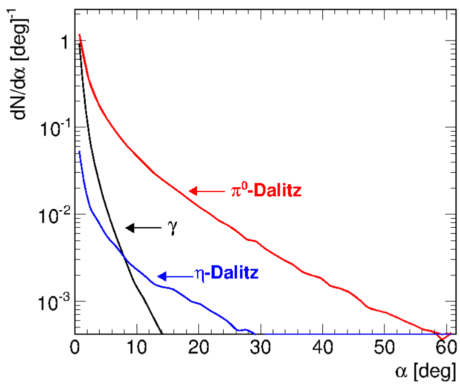
4. Analysis of Real Data

HADES provides possibility to identify electrons using various detector observables, i.e. RICH ring properties, particle velocity, energy loss in ToF (Time of Flight) detector and MDC chambers (Multiwire Drift Chambers), etc. Leptons from γ conversion can be characterized by a small momenta and e^+e^- has small opening angles (α <2°), see Fig 3b. Due to the small opening angles they will be identified as a single ring in the RICH. Therefore for the lepton identification currently only the velocity versus momentum dependence for the particle identification is used. Algorithms to reconstruct close pairs are under development. In Fig. 3a the distribution, as reconstructed with the RPC detector (Θ <45°), is shown. Different particles can be seen clearly. The lepton selection criteria are velocity (β) between 0.97 and 1.1 and a momentum smaller than 500 MeV/c. The black box in Fig 3a indicates the identification criteria. After such selection all



(a) Velocity versus momentum · sign$|q|$ in the RPC region of the HADES spectrometer.



(b) Opening angle distribution for different dilepton sources.

Figure 3: Velocity versus momentum · sign$|q|$ and opening angle for different dilepton sources.

surviving lepton candidates are combined to pairs to reconstruct photons or pairs form Dalitz decay. In this first analysis topological selection criteria on opening angle are used to identify leptons from conversion
(α <2.5°) and from the Dalitz decay (α <20°) at the same time. Those cuts are based on former analysis as discussed in Ref. [12]. As it has been mentioned before, the angle between the e^+e^- pairs from conversion is small. To avoid correlation between random photons the angle between the photons (photons originating from various sources) is required to be at least 5°. In Fig. 4 the preliminary invariant mass distribution of the 4 lepton candidates is shown. At an invariant mass of 140 MeV/c^2 a clear π^0 peak is visible. The background was simulated with a 4th order polynomial function. The extracted π^0 counts on the order of 8000 counts. This result demonstrates that the π^0 can be reconstructed in Au+Au collisions via conversion method.

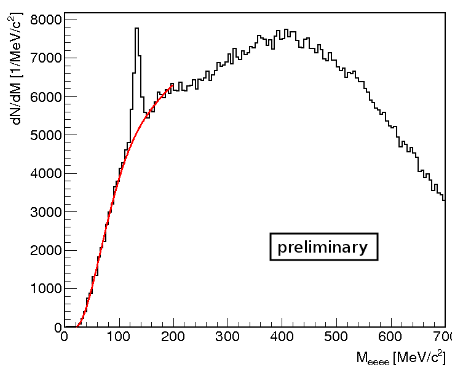


Figure 4: 4 lepton invariant mass spectrum after the topological cuts.

5. Summary and Outlook

In this work a feasibility study of the reconstruction of neutral mesons π^0 and η via photon conversion was studied. The conversion probability in the inner parts of the HADES detector was calculated. The π^0 and η multiplicities were estimated. Lepton candidates were identified using velocity and momentum and combined to 4 lepton invariant mass spectrum. The π^0 peak is visible and is about 8000 signal entries. The reconstruction of the η is ongoing.

Electron identification and topological cuts are still an issue for optimizations. Later acceptance and efficiency corrections will be extracted and in the final step the multiplicities for both mesons will be determined for Au+Au at 1.23 GeV/u.

Acknowledgments
The collaboration gratefully acknowledges the following funding: INFN-LNS Catania (Italy); LIP Coimbra (Portugal): PTDC/FIS/113339/2009; SIP JUC Cracow (Poland): NN202198639; GSI Darmstadt (Germany): Helmholtz Alliance HA216/EMMI; TU Darmstadt (Germany): VH-NG-823, Helmholtz Alliance HA216/EMMI; HZDR, Dresden (Germany): 283286, 05P12CRGHE; Goethe-University, Frankfurt (Germany): Helmholtz Alliance HA216/EMMI, HIC for FAIR (LOEWE), GSI F&E, BMBF 06FY9100I, HGS-Hire, H-QM research school TU München, Garching (Germany): BMBF 06MT7180; JLU Giessen (Germany): BMBF:05P12RGGHM; University Cyprus, Nicosia (Cyprus): UCY/3411-23100; IPN Orsay, Orsay Cedex (France): CNRS/IN2P3; NPI AS CR, Rez, (Czech Republic): MSMT LG 12007, GACR 13-06759S.

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