

Understanding the HADES dilepton invariant mass spectra with UrQMD simulations

C Behnke¹, Tetyana Galatyuk², Joachim Stroth¹

¹Goethe Universität Frankfurt, Max-von-Laue-Str. 1, 60438 Frankfurt am Main

²Technische Universität Darmstadt, Schlossgartenstrasse 2 64289 Darmstadt

E-mail: C.Behnke@gsi.de

Abstract. Photons and lepton pairs emerging from decays of virtual photons are the most promising probes of dense hadronic matter. In the energy domain of 1 - 2 GeV per nucleon, HADES has measured electron pairs in C+C, Ar+KCl, p+p, d+p and p+Nb collisions. An experimentally constrained N+N reference spectrum was established. Moreover, for the first time at this energy the inclusive production cross sections for light vector mesons were extracted. This result allows putting tight constraints on vector meson production in heavy-ion collisions at beam energies of a few GeV per nucleon. In this contribution I will compare the HADES data to predictions from UrQMD microscopic transport model calculations and introduce an approach which will allow to separate in a transparent way the generation of the event background from the emission pattern of a physics observable under consideration.

1. Introduction

In order to transfer nuclear matter into the deconfined phase, one has to heat the system up or increase the baryon chemical potential. Heavy ion collisions are the only way to reach these conditions in the laboratory. Photons (γ) and leptons are penetrating the dense phase without strong interactions. By the decay of virtual photons (γ^*) lepton pairs are emitted during the whole evolution of the heavy ion collision. In the first chance collision stage, at beam energies of a few GeV/u, the main source of lepton pairs is NN Bremsstrahlung. In the freeze out stage long living sources, which directly decay into lepton pairs or through Dalitz decays, are the dominant contributions. These are mainly π^0 , η and ω mesons. The short lived sources, i.e. ρ mesons and baryonic resonances like Δ_{1232} and N^* , are the best tool to access the dense stage of the heavy ion collision, because they are produced and decaying there.

1.1. Heavy ion collisions and in medium modifications

It is predicted that the hadrons, which are embedded inside nuclei, change their properties [1]. In heavy ion collisions nucleons are excited into baryonic resonance states (Δ , N^*). They decay by emitting mesons, which couple to a γ^* . The presence of baryons influences the vector meson spectral function in the medium. The ρ meson couples strongly to the 2π channel. Thus it can be seen as a broad $\pi + \pi$ resonance. Therefore, modifications of the ρ meson properties in hadronic matter can be linked to medium-dependent π propagation properties. Analog to the vacuum polarization of a photon [2] the ρ meson can create virtual π^+ and π^- pairs while propagating in the vacuum. With the presence of a medium the ρ meson self-energy becomes

much more complex. Significant modifications of the ρ meson width are expected, since π couple strongly to δ -hole states in the medium. The direct coupling of the ρ meson to the baryonic resonances is also possible. To summarize, additional contributions to the ρ meson self-energy change the width of the ρ . Therefore the broadening of the ρ meson is a hint to the existence of the medium. A lepton pair enhancement above the trivial hadronic cocktail in the invariant mass region below the ρ meson pole mass can be interpreted as a broadening of the ρ meson due to the in-medium changes of its spectral function [3].

1.2. The HADES spectrometer

To study e^+e^- pairs in cold nuclear matter in heavy ion collisions as well as in elementary collisions, the High Acceptance DiElectron Spectrometer (HADES) is installed at the SIS 18 (GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt). One of the goals was to validate the DLS pair excess and to solve the "DLS puzzle". It is build of 6 identical sectors, that covers a full azimuthal angle and polar angles from 18° to 85° . To study in a systematic way the origin of the e^+e^- pair yield and its dependence on the beam energy and system size a large amount of simulated data is needed. We have simulated C+C and Ar+KCl at beam energies already measured by HADES. In order to complete the systematics, HADES continued the investigations with larger collision systems and at the highest possible beam energies achievable at SIS18, Au+Au at 1.25 GeV/u in April 2012. This system have been simulated as well.

2. Dilepton pairs from heavy ion collisions simulated with UrQMD

Experimental results (C+C and Ar+KCl) will be compared to UrQMD transport model calculations. One would like to learn how different collision energies and different system sizes influence the distribution of invariant e^+e^- masses. The excess of electron pairs in C+C and Ar+KCl collisions was investigated by the HADES collaboration [4]. Figure 1 (a) shows the dependence of the integrated excess pair yield above the η in the invariant mass range $0.15 < M_{e^+e^-} < 0.55$ on the beam energy and on the system size. The results obtained from DLS and HADES are shown by red and black triangles (connected by dotted lines, representing arbitrary down-scaled pion excitation functions). The dilepton data is shown together with the π^0 and η multiplicities obtained with the TAPS photon calorimeter [5, 6]. Figure 1 (b) shows the excess systematics in the UrQMD simulations. The excess pairs yield was defined as a sum of all contributions (Δ_{1232} , ρ) besides the η contribution in the mass range $0.15 < M_{e^+e^-} < 0.55$ GeV/ c^2 . Please note, that the π^0 multiplicity obtained within the UrQMD model is consistent with the values measured by the TAPS collaboration. The HADES collaboration shows that the HADES and DLS excess pair yield from C+C collisions follow a remarkably similar trend with increasing beam energy like the mean π^0 multiplicity measured by TAPS. This is also the case for the UrQMD simulations. However, this is not longer true when going to the Ar+KCl system. At a given bombarding energy the excess pair yield scales with the number of participating nuclei stronger than the π^0 production. The multiplicity of the excess pair measured in C+C and Ar+KCl differs by a factor of 5, while only by factor of 2.7 for the π^0 multiplicities (see Fig. 1, a). A similar scaling is found in UrQMD, however the dependence of the excess yield on the system size is found to be not as strong as measured by HADES, i.e. just a factor of 3 (see Fig. 1, b). This might be interpreted as a fingerprint of in-medium effects related to multi-step collisions, with baryonic resonances playing an important role.

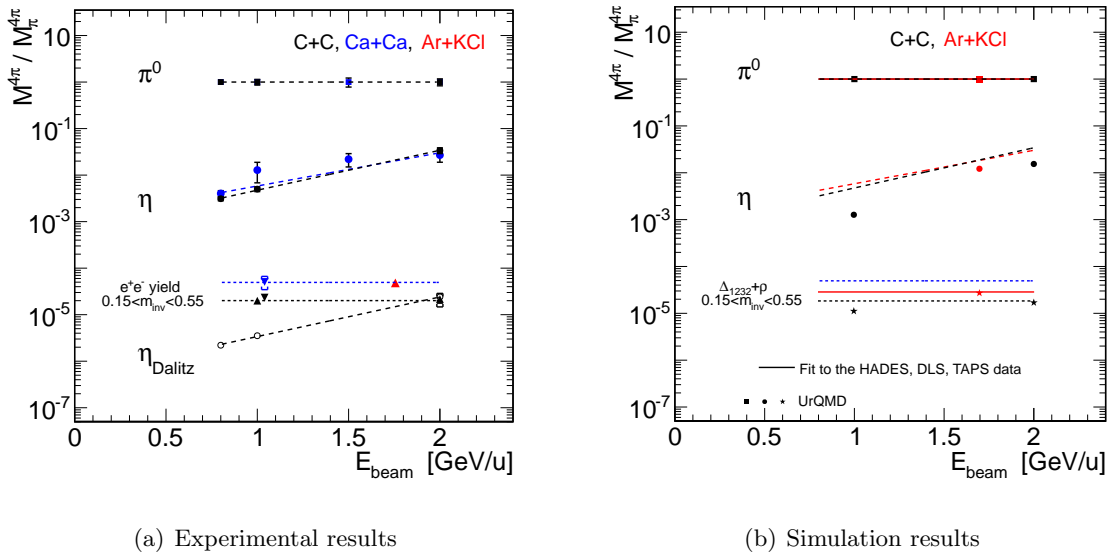


Figure 1. Multiplicity of the pair yield above the η Dalitz in the mass range $0.15 < M_{e^+e^-} < 0.55 \text{ GeV}/c^2$ as observed by DLS (open triangles) and HADES (full triangles) as function of beam energy and system size. More explanation see text.

2.1. Scaling of the dilepton pair yield with the system size

To study the scaling of the dilepton pair yield with the system size C+C, Ar+KCl, Ag+Ag, and Au+Au collisions at the same beam energy, i.e. 1.25 GeV/u have been simulated. Figure 2 shows the dependence of meson and baryon multiplicities as a function of the system size.

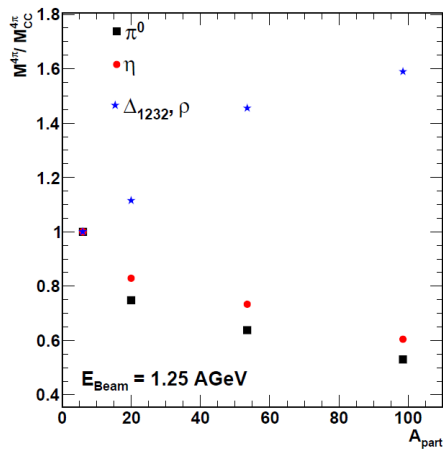


Figure 2. Dilepton multiplicities extracted from C+C, Ar+KCl, Ag+Ag and Au+Au (per A_{part}) collisions at the same beam energy simulated with UrQMD

The multiplicities of e^+e^- pairs from π^0 , η , Δ_{1232} and ρ decays were extracted for all simulated systems. Further the π^0 , η , Δ_{1232} and ρ multiplicities are normalized to the corresponding one extracted from C+C collisions and normalised to A_{part} . The multiplicities of the π^0 and η are found to be reduced when A_{part} increases. This might be explained by the time-integrated cross section for the Δ_{1232} reabsorption process ($N\Delta \rightarrow NN$), which is larger in Au+Au collisions compared to C+C collisions. Consequently, the total number of π^0 observed in the final state is up to 50% less in Au+Au collisions. The η mesons multiplicities (red dots) are decreasing with the system size by nearly 40%. In contrast, the excess pair yield, which is represented by the Δ_{1232} and the ρ in the mass region from 0.15 to 0.55 GeV/c^2 , is rising with system size. From C+C the Au+Au excess is enhanced by around 60%.

3. Modeling Au+Au collisions

The ρ and Δ_{1232} multiplicities extracted from UrQMD simulations in the M_{ee} region from 0.15 - 0.55 GeV/c^2 shows a weak dependence on the beam energy but a stronger scaling with the system size. Therefore the HADES collaboration measured Au+Au collisions at 1.23 GeV/u in

April 2012. For this system the time and the emission density evolution of the different particles is shown in Fig. 3. The figure depicts at which time and from which density of the collision the dileptons are emitted. The dileptons from π^0 meson decays (Fig. 3, (a)) are emitted at low densities and mainly at late stages of the collision. The Δ_{1232} decay (Fig. 3, (b)) is distributed over the whole time evolution and prominent at all density regions. But dileptons from this decay originate from the dense phase ($\rho/\rho_0 > 1.5$) and a certain time region from 7-14 fm. The time evolution of the ρ meson is similar to that of the Δ_{1232} [7].

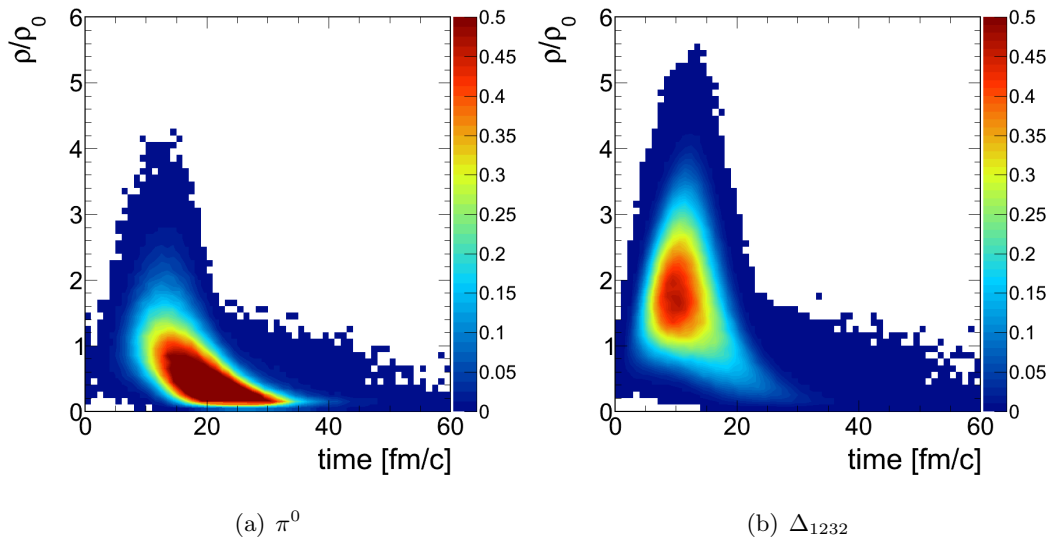


Figure 3. Emission density versus time from dilepton sources from Au+Au 1.25 GeV/u, simulated with UrQMD.

The evolution for a given meson is divided into 9 equal time steps. For each time step, the m_t spectra of the particles are analyzed with a χ^2 minimization method [7], and for each time step a density profile is extracted. This time dependence of effective slope parameters and emission density is shown in Fig. 4. For each hadron the temperature (black stars) and the density of the maximum decay probability of the dilepton sources (red squares) for the given time step is shown. Dileptons from π^0 decay (Fig. 4,(a)) are emitted at temperatures from 35 to 45 MeV for T_1 and 70 to 80 MeV for T_2 . Both temperatures show a slight rise to later stages of the collision. Note that T_1 is dominated by resonance decays, so only for T_2 the expression "temperature" is fully correct. However, the late stages suffer from statistics especially for the higher temperature (T_2). The decreasing of temperature T_2 could be a hint to freeze out effects. The dileptons from π^0 decays are emitted from dilute stages. The maximum decay rate is reached at 1.2 times normal nuclear matter density in early stages of the collision. Δ_{1232} Dalitz decays inside the dense phase, with ρ/ρ_0 up to 1.9 times normal nuclear matter density (Fig. 4,(b)). Temperatures from 48 to 78 MeV, with small errors are extracted [7].

4. Summary

In Au+Au collisions at 1.25 GeV/u a large e^+e^- pair yield comes from the emission density region which is a factor of 2 larger compared to normal nuclear matter density. Since UrQMD uses only vacuum spectral functions the predictions for e^+e^- radiation from high density stages of the heavy ion collision could be more selected. In the SPS energy regime a thermal model like from [8] is able to describe the measured NA60 data [9], which also show clear medium effects. A description of heavy ion collisions with a thermal model seems to be a good method to model

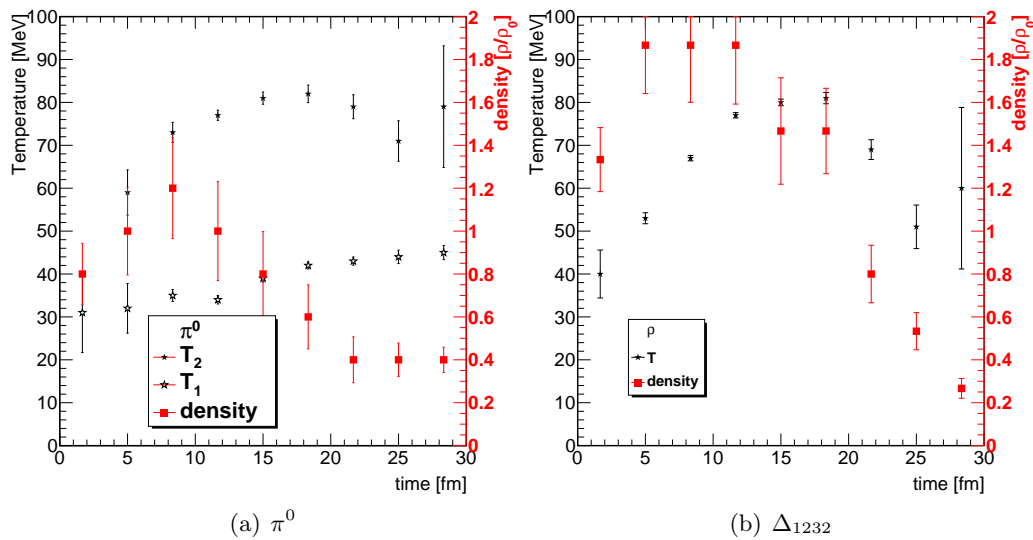


Figure 4. Emission temperature and emission density versus time from dilepton sources from Au+Au 1.25 GeV/u.

e^+e^- production from the dense stage of the heavy ion collision. The extracted temperatures and densities can be used as an input to a thermal model. The combination of UrQMD and an thermal model is expected to give a good approach for describing dilepton radiation from the dense stage of a heavy ion collision at a wide energy range.

Acknowledgments

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