DILEPTON PRODUCTION STUDIED WITH
THE HADES SPECTROMETER

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With the HADES spectrometer at GSI we have studied dilepton production in various collision systems from elementary N+N, over p+p, A, up to the medium-heavy Ar+KCl system. We have confirmed the puzzling results of the former DLS collaboration at the Bevalac. While we have traced the origin of the excess pair yield in C+C collisions to elementary p+p and n+n processes, we find a significant contribution from the dense phase of the collision in larger Ar+KCl system. From recently obtained e+e− pair spectra in p+p and p+NB interactions at 3.5 GeV kinetic energy the inclusive production cross sections for neutral pions, ω and p mesons are extracted for the first time at this beam energy. Furthermore, the production mechanisms of the vector mesons, which are not well known at these energies, are investigated. The direct comparison of p+p and p+Nb data allows us to investigate in-medium mass modifications of vector mesons at nuclear ground state density.

On the other hand, exclusive production of ω and η mesons in p+p reactions at 3.5 GeV were studied via their e+e− decay channel. Production cross sections and angular distributions for both states were determined.

Keywords: Dilepton spectroscopy; meson production; nucleus-nucleus collisions.


1. Introduction

The study of hot and dense nuclear matter by means of relativistic nucleus-nucleus collisions is one of the main topics of high energy heavy-ion physics. Changes of vector meson (ρ, ω, φ) masses and decay widths in such matter are often discussed in the context of the restoration of the broken chiral symmetry. On the other hand hadronic models also predict significant meson mass changes due to strong meson-hadron couplings but there is no clear connection between these two scenarios. The QCD sum rules relate only the integrals over the meson spectral functions with the QCD condensates. From the experimental point of view the most promising meson to look at in this context is the ρ. Because of its short life time (2τ ~ 1.3 fm/c) it decays inside the created volume, and the original information about this state can be obtained only through its decay products. In a similar way also ω and φ mesons can be explored, but due to their longer live time, they decay only partially inside collision zone. Unfortunately, the preferential hadronic decay channels of these mesons are not well suited for such investigations, because the final products strongly interact with the nuclear matter. Therefore, it is preferable to study electromagnetic decays of the hadrons into lepton pairs, as leptons do not undergo strong final state interactions. However, the finally observed dileptons originate from different sources and phases of the collision process. In general, besides vector meson decays, dileptons are produced through N+N bremsstrahlung and Dalitz decays of π0, η mesons and of baryon resonances. In particular, at low energies (1-2 AGeV) bremsstrahlung and Dalitz decays of baryons are important,
but poorly known sources and must be determined from p+p and n+p interactions. Indeed, according to the model calculations N+N bremsstrahlung plays important role for the n+p reactions, while for the p+p reactions the contribution from Δ isobar dominates the spectra. This implies the importance of experimental study of n+p reactions. These sources are in particular important in the first stage of collisions. At further course of reaction dileptons are emitted from the hot and dense phase of the collision process and finally from the freeze-out part (long lived components) when particles do not interact any longer. The latter is known in a model independent way by hadron (π±, η) yield measurements from other experiments. In order to reveal the contribution from the hot and dense phase, it is important to subtract the dilepton yield emitted after the freeze-out stage as well as properly take into account the contribution from first-chance elementary reactions.

The DLS collaboration at the Bevalac has formerly reported an enhancement over known hadronic sources in C+C and Ca+Ca reactions at 1 AGeV. In contrast to the high energy regime, these results could not be explained by theoretical calculations, leaving the question, whether the observed enhancement is related to the properties of the created medium or to contributions from elementary collisions which, at this stage were not known with sufficient precision.

Fig. 1. (Color online) Efficiency corrected and background subtracted invariant mass distribution of e+e− pairs (full circles), compared to the thermal dilepton cocktail of long-lived components (π±, η, ω). A clear enhancement over the long-lived components in the intermediate mass region is observed.

Fig. 2. (Color online) Comparison of the reference spectrum (defined as the average of p+p and n+p data at 1.25 AGeV) with the C+C data at 1 (full circles) and 2 AGeV (open circles). All spectra are normalized to respective pion multiplicities. From C+C and n+p data the corresponding η components are subtracted. In the inset the ratio to the reference spectrum in the excess range is shown.

Fig. 3. (Color online) Comparison of the reference spectrum (defined as the average of p+p and n+p data at 1.25 AGeV) with the Ar+KCl data at 1.76 AGeV. All spectra are normalized to respective pion multiplicities. From Ar+KCl and n+p data the corresponding η components are subtracted.

2. Dilepton Study with HADES

The High Acceptance Di-Electron Spectrometer (HADES) operates at the Helmholtzzentrum für Schwerionenforschung (GSI) in Darmstadt, Germany. As a result of several experimental campaigns HADES has established the dilepton excess, i.e. the enhancement in the dilepton spectra over the long-lived components coming from the freeze-out phase in C+C collisions at 1 and 2 AGeV, as well as in the medium-heavy Ar+KCl system at 1.76 AGeV. This is demonstrated in Figure 1 by comparing C+C data at 1 AGeV to the freeze-out components (π±, η → e+e−, ω → e+e−). Furthermore, the HADES C+C data agree with the corresponding DLS measurements remarkably well. Moreover, comparing our C+C data taken at two different beam energies, the energy dependance of the excess yield has been established. This comparison reveals that the excess scales with beam energy like pion production. It is well known that at these beam energies pion production is mediated by the Δ resonance. Therefore, it is then suggestive to link the observed excess to the baryon resonance decay and/or N+N bremsstrahlung processes during the early stages of the collision (first-chance collisions). To verify this, we have measured p+p and quasi-free n+p reactions at 1.25 AGeV, i.e. just below the η production threshold in p+p. The quasi-free n+p reactions were selected by triggering on the forward-going spectator proton in d+p reactions.

The comparison of the obtained reference N+N spectra (defined as average of the p+p and the quasi-free n+p data) with the C+C data at 1 and 2 AGeV, after
subtraction of the \( \eta \) yield (representing a long-lived contribution from the freeze-out) and normalization to the pion multiplicities, is shown in Figure 2. For the C+C case, the \( \eta \) contribution was determined from the measured multiplicities by the TAPS collaboration,\(^{15}\) whereas for the n+p case it was taken from data on the \( pn \rightarrow p\eta \) and \( pn \rightarrow d\eta \) reactions.\(^{16}\) As it is seen from this figure, in the mass range of \( 0.15<\text{GeV}/c^2<0.5 \), where the excess is defined, both C+C data sets are overlapping within experimental errors. This, as was mentioned above, points to a similar energy scaling of the excess and pion yields. Moreover, within 30% (experimental errors), the C+C data are described by an incoherent sum of the n+p and p+p data. This observation indeed underlines the importance of the dilepton contributions from the early stages of the collision process. It is then obvious that, the long standing puzzle of the \( e^+e^- \) excess is related to the dilepton emission mechanisms in elementary p+p and n+p reactions.

As it was already mentioned in 1-2 AGeV energy regime the dileptons originating from intermediate nucleon lines (known as N+N bremsstrahlung \( \gamma \) and from Dalitz decays of \( \Delta \) isobar state (excitation of an intermediate \( \Delta \) state followed by its decay through \( \Delta \rightarrow Ne^+e^- \)) are very important pair sources. It is not so trivial to separate these two contributions because of the interference effects between different Feynman diagrams describing this process. However, the contrast between these contributions can be obtained by a simultaneous investigation of the p+p and n+p reactions. Two model calculations, both using the effective Lagrangian approach,\(^{4,5} \) were performed in order to describe the p+p as well as n+p data measured by HADES. While our p+p data is quite reasonably described by [5], both calculations were failing in describing the n+p data. By including in the model electromagnetic form-factors at the pion and nucleon vertices, the authors of [5] improved substantially the description of n+p data.\(^{17} \)

Next, in order to investigate the system size dependence of the excess, we have studied dilepton production in the Ar++KCl system. In contrast to the C+C case, the normalized Ar++KCl data are no longer described by the N+N reference spectrum (see Figure 3). This result can be interpreted as the onset of contributions from the dense phase of the collision. Indeed, we find that the excess shows a non-linear scaling with the number of participants (\( A_{\text{part}} \)), which can be attributed to the importance of multi-step processes in the dense phase of the collision process. Furthermore, around \( M=0.78 \text{ GeV}/c^2 \) a clear \( \omega \) signal could be reconstructed for the first time at SIS energies in nucleus-nucleus interactions.

The \( \omega \) meson production was also investigated in p+p, p+Nb collisions at 3.5 GeV. In p+p collisions the inclusive production cross sections for the \( \pi^+ \), \( \eta \), \( \omega \) and \( \rho \) mesons were extracted for the first time at this energy.\(^{18} \) The exclusive reaction channels \( pp \rightarrow pp\pi^+ \), \( pp \rightarrow pp\eta \) have also been studied via their hadronic decay channels \( (\pi^+\pi^-\pi^0) \) and is presented in [19]. However, the main purpose of these measurements is to learn about the properties of vector mesons in cold nuclear matter by directly comparing the corresponding \( e^+e^- \) invariance mass distributions. Preliminary results are presented at this conference by M. Weber.\(^{20} \)

### 3. Conclusion

We reported on dilepton studies performed by the HADES collaboration in different collision systems. It was established that the inability of transport models to describe the old DLS data is connected to an insufficient treatment of radiations coming from the early stages of the collision process, which can be traced back to the elementary n+p reaction channel. Furthermore, in the medium-heavy Ar++KCl system the intermediate-mass yield was found to be even stronger, indicating that contributions from the dense phase of the collision set in. By direct comparison of \( e^+e^- \) invariant mass distributions from p+p and p+Nb collisions, measured at the same kinetic energy of protons, the properties of vector mesons in cold nuclear matter were investigated.

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