Elementary Collisions with HADES

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Abstract

The “High Acceptance DiElectron Spectrometer” (HADES) at GSI, Darmstadt, is investigating the production of $e^+e^-$ pairs in $A + A$, $p + A$ and $N + N$ collisions. The latter program allows for the reconstruction of individual sources. This strategy will be roughly outlined in this contribution and preliminary $pp/pn$ data is shown.

1 Introduction

Recently, the HADES collaboration has reported on the production of di-leptons - unique probes to study properties of dense hadronic matter [1] - in the C+C collision at 2 AGeV [2]. In this context, the vector mesons are of particular interest as it has been proposed that their spectral functions change inside the hadronic medium [3]. On the other hand, at these energies measured di-lepton spectra do not contain the vector meson signal only, but also additional lepton pairs from other sources, like $\Delta^+ \rightarrow N \pi^0 \rightarrow N \gamma e^+e^-$ ($\pi$-Dalitz), $\Delta \rightarrow Ne^+e^-$ ($\Delta$-Dalitz), $N^*(1535) \rightarrow N\eta \rightarrow N \gamma e^+e^-$ ($\eta$-Dalitz) and the decay of baryonic $N^*$ resonances in $N(\omega, \rho)$.

This means at beam energies of 1-2 AGeV, corresponding to moderate densities (2-3 $\rho_0$) and temperatures (60-80 MeV), the production of (vector-)mesons is always accompanied by multi-step excitations of a limited number of resonances and their subsequent decays, a concept which is supported many theoretical models and also corroborated by recent HADES results [4, 5].

One of the most abundant ingredients in this cocktail, the long-lived (i.e. decaying after the freeze-out of the fireball) pseudoscalar mesons $\pi, \eta \rightarrow \gamma\gamma \rightarrow \gamma e^+e^-$, have a well described electromagnetic structure [6]. Hence, they can be regarded as “trivial” components that can be subtracted from the measured $e^+e^-$ spectrum. On the other hand, the contribution from short-lived resonances is completely unknown. For example, the Dalitz decay of the $\Delta$ resonance has not been measured. In the overall picture, these contributions are additional exchange graphs in the virtual bremsstrahlung process $NN \rightarrow NN\gamma^*$. One of the thee questions recently addressed by one-boson exchange models is how the resonance contributions have to be treated among with the bremsstrahlung in coherent calculations, but a debate on this is still ongoing [7, 8].

The general conclusion is, however, that experimentally a strong isospin dependence should be visible in the mass-dependent ratio $M_{ee}^{pp}/M_{ee}^{pn}$.

To conclude this introduction, for an understanding of di-lepton spectra and resolving medium effects from the vacuum spectral functions it is crucial to fully describe the different sources in the heavy ion cocktail. This means that branching ratios and (spin dependent) form factors have to be known a priori, as well as the features of the different production mechanisms as they serve as input for model calculations since they affect mass and momentum distributions.

2 The elementary collision program

In order to study these different processes, HADES (for a description see [4]) has started a detailed program on the di-lepton production in elementary collisions using a liquid hydrogen target and proton/deuteron beams. The first experimental run using a proton beam with a kinetic
Figure 1: The raw inclusive spectra obtained in the \textit{pp} reaction at 1.25 GeV (left) and in the \textit{np} reaction (right, tagged with a proton spectator using the \textit{dp} reaction at 1.25 AGeV). The spectra are not corrected for efficiency. In addition, for the \textit{pn} case the fermi motion has to be taken into account. Thus, the spectra cannot be compared directly.

beam energy of 2.2 GeV was successfully carried out in the year 2004 with the objective of verifying the lepton pair reconstruction efficiency using the known $\eta$ production parameters \cite{9}. Moreover, $e^+e^-$ invariant mass results can be compared to the $C+C$ experiment done at a similar kinetic energy per nucleon (2 AGeV) thus providing an important reference.

In the following, two experiments at a lower beam energy were performed: \textit{pp} at 1.25 GeV and \textit{dp} at 1.25 AGeV (N.B. the same energy per nucleon). The general idea of these consecutive measurements below the $\eta$ production threshold was to focus on the low-mass continuum of the di-lepton cocktail. By means of inclusive and exclusive analyses the $\Delta$ Dalitz decay can be studied in the \textit{pp} case, as described below, where the bremsstrahlung is negligible. The usage of iso-spin arguments allow for the subtraction of the $\Delta$ contribution in the quasi-free \textit{pn} collision of \textit{dp} data set and to study the virtual \textit{pn}-bremsstrahlung. This was made possible by the addition of a forward wall which detected the spectator proton and thus tagged the quasi-free \textit{pn} reaction. Fig. 1 shows preliminary invariant mass spectra for both the \textit{pp} as well as the \textit{pn} reaction. Here, the \textit{pp} results was obtained from $2.6 \cdot 10^9$ events, the \textit{pn} data stems from a preliminary on-line analysis ($2.4 \cdot 10^9$ events, which is 50\% of the expected statistics). Although the scales are arbitrary, isospin effects are clearly visible in the mass region above the $\pi^0$ peak, which points to additional sources like \textit{pn} bremsstrahlung and sub-threshold $\eta$ production. This has to be discussed using detailed model calculations once the data set has been finally analyzed.

It is clear that before a quantitative conclusion can be drawn a thorough understanding of
the $\Delta$ Dalitz decay (form factor and branching ratio) is mandatory. The production mechanism and decay of the $\Delta$ resonance $\Delta \rightarrow N\pi$ is already known from older measurements \[10, 11\]. This fixes the $\Delta$ and $\pi^0$ emission angle and momentum, which is modeled in the event generator Pluto \[12\]. Thus, the “trivial” $\pi^0$ component can be subtracted and the $\Delta$ decay can be studied by comparing several theoretical models with our data.

In the most recent experiment, $pp$ collisions at 3.5 GeV have been studied, where $\omega$ and $\rho$ are produced with large cross sections. Here, the focus of the analysis is to determine the contribution of vector production mechanisms (partial waves and $N^*$ resonance contributions). The inclusive $\omega$ line shape will serve as a reference for future $p + A$ reactions which will be done at the same kinetic beam energy. The preliminary analysis of on-line data suggests a yield of a few hundred $\omega$-mesons in the inclusive pair spectrum. In addition, new precise data on the vector meson production at higher beam energies are absolutely necessary, so the only data on exclusive $\rho, \omega$ production come from old bubble chamber experiments \[13\] with a yield of $\omega$ mesons of about 100 counts. No differential cross section distributions have been reported in this energy regime so far, but they are important inputs for the model calculations to be done for the upcoming $p + A$ experiment.

3 Summary and outlook

In summary, HADES has successfully initiated a detailed program using elementary collisions: The $pp$ and $pn$ reactions at 1.25 GeV to study $\Delta$ production and decay, and $pp$ collisions at 2.2 GeV and 3.5 GeV. The preliminary analysis of the data suggest a statistics large enough to clarify many open question such as the $\Delta$ Dalitz decay, the $pn$ bremsstrahlung and contributions from resonances. In particular, the preliminary analysis of the $pp$ and $pn$ reactions seems to exhibit additional sources, which supports ongoing theoretical work.

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