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# Di-pion and di-electron production in NN reactions with HADES at 1.25GeV incident beam energy.

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**Abstract: Significant isospin effects are observed by the HADES collaboration in inclusive dilepton production channels in the pp and quasi free np experiments at 1.25 GeV kinetic beam energy. Triggered by this observation, analyses of several exclusive channels within either dilepton or pion production have been started to shed more light on the possible explanations. Furthermore, the exclusive $\pi^+\pi^-$ production in np and pp collisions provide tests for a consistent description of double pion production in different isospin states, which is necessary to understand contributions of double Δ(1232) and N*(1440) production. This is also important in the context of the recent results from the WASA collaboration on the ABC effect with reference to a d* dibaryon resonance in the isospin 0 channel.**

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## 1. Introduction

The High Acceptance Di-Electron Spectrometer (HADES) at GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt [1] was designed to investigate dielectron emission in heavy-ion collisions in the range of kinetic beam energies 1-2 AGeV [2–4]. The main goal of the HADES experiments is to study properties of hadrons inside the hot and dense nuclear medium via their di-electron decays. One specific aspect of heavy-ion reactions in the 1-2 AGeV regime is the important role played by the baryonic resonances, which propagate and regenerate due to the long life-time of the dense hadronic matter phase. A detailed description of the resonance excitation and coupling to pseudo-scalar and vector mesons is important for the interpretation of the di-electron spectra measured by HADES.
Baryonic resonances are indeed important sources of di-electron through two mechanisms: the Dalitz decay (e.g. $\Delta/N \rightarrow Ne^+e^-$) or the mesonic decay with subsequent di-electron production ($\pi^0 \rightarrow \gamma e^+e^-$, $\eta \rightarrow \gamma e^+e^-$, $\omega/\rho \rightarrow e^+e^-$). In order to study more selectively these contributions, the HADES program also comprises elementary reactions (pp and quasi-free $np$). The possibility to measure simultaneously di-electrons and pion production with HADES is a great advantage, since pion production allows to constrain the hadronic cocktail used to describe the dilepton production. More generally, these complementary data provide quantitative information on hadronic interactions, as well as resonance excitations and resonance properties. Recently a resonant structure in the cross section of the reaction $pn \rightarrow d\pi^0\pi^0$ was observed by the WASA collaboration [5] and interpreted as a dibaryon resonance at $M = 2380$ MeV/$c^2$. It is therefore important to check that the other pion production channels in the same energy range are consistent with this interpretation.
This contribution is organized as follows. First, we describe a strong isospin dependency of $e^+e^-$ production observed in $pp$ and $np$ collisions around 1.25 GeV. In next the on-going analysis of $pp \rightarrow ppe^+e^-$, $pn \rightarrow pne^+e^-$, $pn \rightarrow de^+e^-$, $pp \rightarrow pp\pi^+\pi^-$, $pn \rightarrow pn\pi^+\pi^-$, $pn \rightarrow d\pi^+\pi^-$ exclusive channels will be discussed.

## 2. Experimental techniques

In 2006 and 2007, two dedicated experimental runs were performed with HADES [1] installed at the GSI heavy ion research facility. Proton and deuteron beams with kinetic energies of 1.25 AGeV were used together with a liquid hydrogen target. Quasi-free $n+p$ reactions were selected by detecting fast spectator protons from the deuterium break-up in a dedicated Forward hodoscope Wall (FW). The latter was placed 7m downstream the target covering polar angles between 0.3° and 7° and provided time-of-flight information. Charged particle ($p$, $d$, $\pi^\pm$, $e^\pm$) detection in HADES ($16° < \theta < 84°$) was obtained as described in [1]. Furthermore, for channels with deuteron in the final state, FW was used to increase the acceptance for deuterons at low polar angles. The identification of events with a deuteron in the final state and the rejection of background channels with an unbound $pn$ pair entails the usage of additional kinematical constraints. For example, in the case of the $d_{(n+p_s)} + p \rightarrow d'\pi^+\pi^- + (p_s)$ reaction, momentum conservation leads to the coplanarity of $\vec{p}_k = \vec{p}_d - \vec{p}_{\pi^+} - \vec{p}_{\pi^-}$, and $\vec{n} = \vec{p}_{d'} \times \vec{p}_{p_s}$, where: $\vec{p}_d$ is the momentum of the deuteron beam, $\vec{p}_{\pi^+}$ and $\vec{p}_{\pi^-}$ pion momenta, $\vec{p}_{d'}$ momentum of the deuteron detected in FW, $\vec{p}_{p_s}$ momentum of the proton spectator. The coplanarity condition can be expressed as $\theta =$

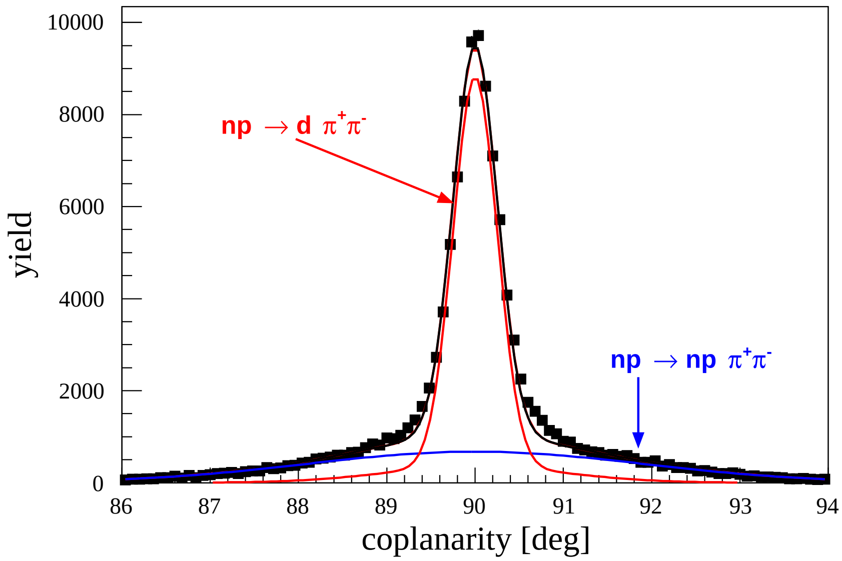


**Figure 1:** Opening angle distribution used in the coplanarity method for the quasi-free np reaction to select channels with a deuteron in final state (see text for details). Black points correspond to experimental data. The black solid line results from a fit of the data with a sum of 3 Gaussian functions and a constant. The red line is the signal contribution extracted from theoretical fit, consisting of the sum of 2 Gaussian functions. The blue line is the background contribution extracted from the theoretical fit, consisting of the sum of the third Gaussian function and constant. The signal yield is obtained by subtracting the background from the experimental points.

$\sphericalangle(\vec{p}_k, \vec{n}) = 90°$. The advantage of this method is that only the information about angles of the detected particles in the FW is used, thus it can be used as a complement to the time selection. The distribution of the coplanarity angle $\theta$ is shown in fig.1.This method can also be applied in a very similar way to the reaction $pn \to de^+e^-$. The sharp peak around 90° (fig. 1) corresponds to the channel with a deuteron in final state, while the flat background corresponds to the process with unbound neutron and proton. For each bin of di-pion invariant mass presented below, the background was fitted using the sum of a Gaussian plus a constant function and the signal was defined as the remaining yield after the background subtraction.

## 3. Dielectron production

First, we present results of the inclusive dielectron production in both $pp$ and quasi-free $np$ reactions at 1.25 GeV [7] kinetic beam energy. The data from the $pp$ experiment are well described by a simulation based on the resonance model [8, 7] with only two contributions: $\Delta$ Dalitz decay ($\Delta \to Ne^+e^-$) and $\pi^0$ Dalitz decay ( $\pi^0 \to e^+e^-\gamma$). They are also in good agreement with the predictions of the OBE model [9] (fig. 2), where the resonances give the most important contributions. In the region of the $\pi^0$ contribution (M<0.140 GeV/$c^2$), the dielectron yield obtained for the np reaction is about a factor two higher than for the pp reaction, as expected due to the isospin factors for the $\pi^0$ production from the $\Delta^+$ and $\Delta^0$ resonances. However, a much larger isospin

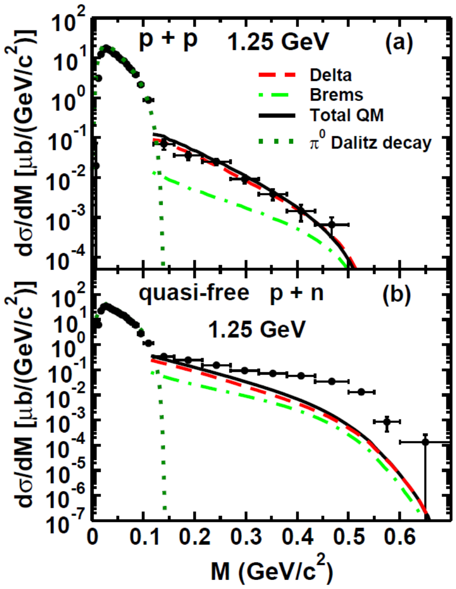


**Figure 2:** The invariant mass distribution of the dileptons produced in **(a):** $pp$ reactions; **(b):** quasi-free $np$ reactions; at 1.25AGeV kinetic beam energy compared to OBE predictions [6].

effect is seen for dilepton masses between 0.2 and 0.5 $GeV/c^2$ (fig. 2b). In the $np$ collisions, additional significant contributions arise from the non resonant nucleon-nucleon Bremsstrahlung $pn \rightarrow pne^+e^-$, which is much more important than the corresponding $pp$ process, and from the eta production, since the production threshold can be exceeded due to the neutron momentum inside the deuteron. However, even after including these contributions, the observed excess could not be fully described [10, 9, 7]. In a recent paper, Shyam and Mosel [6] showed that the inclusion of the electromagnetic form factors in the Bremsstrahlung amplitude significantly improves the description of the dilepton invariant mass spectrum for the $pn$ reaction. The most important effect is due to the electromagnetic time-like form factor of the exchanged charged pion in the in-flight production graph.

On the other hand Martemyanov and Krivoruchenko [11] developed recently a new calculation of the inclusive $e^+e^-$ production in $pp$ and $pn$ reactions. For the pp reaction, the latter is based on a incoherent sum of Delta(1232) and, to lesser extend, higher baryon resonances Dalitz decays in a 2-step resonance model. For the $pn$ reaction, the non-resonant nucleon-nucleon Bremsstrahlung from [9] is added, as well as the eta contribution. In addition, they add contribution of the $pn \rightarrow de^+e^-$ channel using estimates based on the cross-sections measured in the $\gamma d \rightarrow pn$ reaction (see [11] for details).

The preliminary analysis of the $pp \rightarrow ppe^+e^-$ and $pn \rightarrow pne^+e^-$ channels, however, show that the same excess is seen in these exclusive channels as in the inclusive channels, once the eta contribution is removed and no strong contribution from the $pn \rightarrow de^+e^-$ is visible, using the coplanarity method for the deuteron selection, the upper limit of the $pn \rightarrow de^+e^-$ yield will be extracted.

## 4. Two-pion production

Two-pion production is a very interesting source of information about NN interaction and baryonic resonances excitations in NN collisions. In this energy region, ΔΔ excitation is the leading process, but also N*(1440) should contribute. The preliminary results on $\pi^+\pi^-$ production in $pp$ and $np$ reactions are presented below.

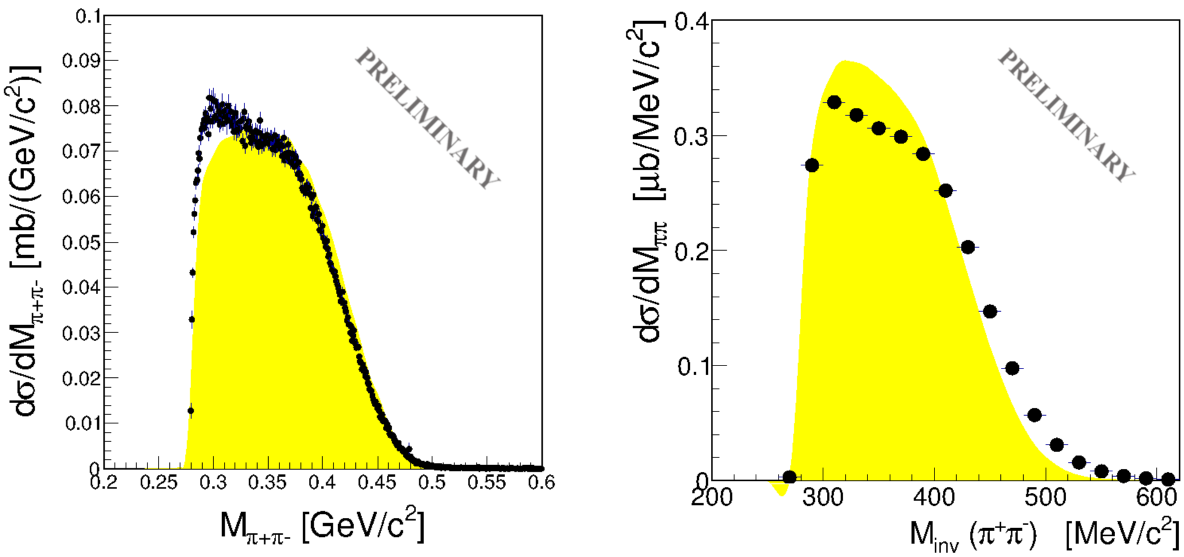


**Figure 3:** Distribution of $\pi^+\pi^-$ invariant mass from $pp \to pp\pi^+\pi^-$ (**Left**) and $pn \to pn\pi^+\pi^-$ (**Right**) exclusive channels. Black points represent experimental data with an absolute normalization and only statistical errors. The yellow region is a phase space simulation normalized to the integrated experimental yield. Presented data are inside the HADES acceptance.

### 4.1 pp $\to$ pp$\pi^+\pi^-$ and pn $\to$ pn$\pi^+\pi^-$ exclusive analysis

Figure 3 presents experimental distributions of the di-pion invariant mass from $pp$ and $np$ experiments inside HADES acceptance compared with phase-space simulations. The data have been normalized to elastic scattering. For this analysis, the detection of all charged particles in the HADES detector is requested, hence reducing the acceptance for the pp case. Different effective Lagrangian models [12 – 14] have also been investigated. A common feature of models [12, 14] is the dominance of the N*(1440) excitation close to threshold and the increase of the double Δ excitation when the incident energy increases. However, the models differ by the importance of the $\rho$-exchange contribution to the double $\Delta(1232)$ excitation and by the relative branching ratios of N*(1440) into $\Delta(1232)\pi$ and $N(\pi\pi)_S$. The $pp \to pp\pi^0\pi^0$ reaction was intensively studied by the WASA collaboration. Modifications of the [12] model have been proposed in [15], which allow for a good description of the differential spectra measured by WASA. Comparisons of the HADES data in $pp \to pp\pi^+\pi^-$ and $pn \to pn\pi^+\pi^-$ channels with this model are ongoing. The preliminary results show an improvement of the description of the existing experimental spectra.

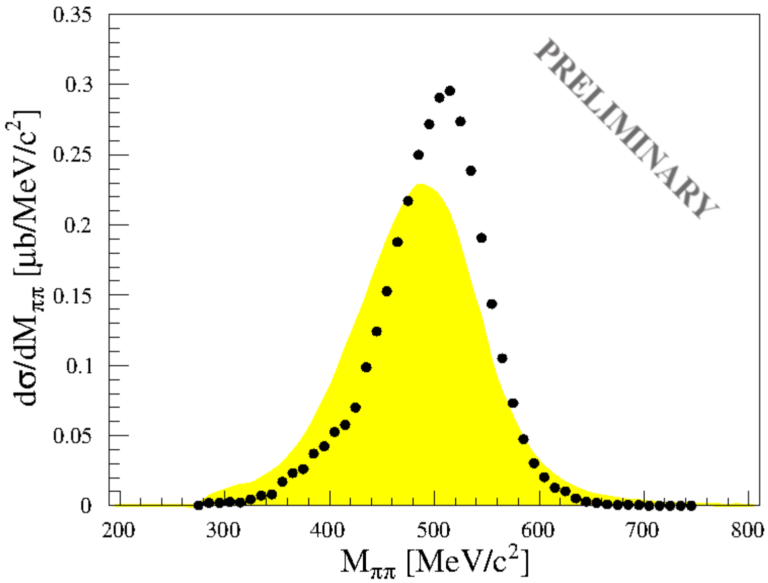


**Figure 4:** Distribution of $\pi^+\pi^-$ invariant mass from the $pn \to d\pi^+\pi^-$ exclusive channel. Black points represent experimental data with an absolute normalization. Only statistical errors are shown. The yellow region is a phase space simulation normalized to the integrated experimental yield. The data are for $\pi^+$ and $\pi^-$ detected in HADES acceptance and d detected in FW.

### 4.2 pn $\to$ d$\pi^+\pi^-$ exclusive analysis

The exclusive analysis of the two-pion production with a deuteron in final state deserves a separate discussion because of the possible manifestation of the ABC effect, in addition to the previously described channels. The systematic studies of the $\pi^0\pi^0$ production [5] by the WASA collaboration indeed revealed a resonance-like feature in the total cross section in n-p reactions at energies below the ΔΔ excitation associated with an unexpected enhancement at low $\pi\pi$ invariant mass, this is called the ABC effect. The effect appears in the di-pion isospin 0 channel and cannot be described by channels like ΔΔ or N*(1440). To explain the experimental results, a di-baryon resonance (d*) has been proposed with the width of 70 MeV and a pole mass of 2380 MeV [5]. The excitation of such a six-quark object should also be visible in the reaction $pn \to d\pi^+\pi^-$, which is an admixture of isospin 0 and 1 states. The analysis of the HADES exclusive channel $pn \to d\pi^+\pi^-$ is done in two different configurations: the first one with the deuteron detected in HADES with a good momentum resolution and particle identification capacity and the second one where the deuteron is detected in FW, where the coplanarity method has to be used to identify the deuteron. Both scenarios reveal different kinematical regions of the $d\pi^+\pi^-$ channel. Detecting the deuteron in HADES, we are limited to a very narrow $\pi\pi$ invariant mass region just above the sum of two pion masses. When the deuteron is detected in the FW, the acceptance in the low invariant mass region of the pion invariant mass, which is most sensitive to the ABC effect, is reduced (fig. 4). As it can be seen, a strong deviation from phase-space can be observed. The data are now being compared to the predictions of ref. [5], including d* dibaryon resonance, ΔΔ excitation and N*(1440). The preliminary results show a good description of the total yield. However, a significant excess is observed in the model in the low invariant mass region, where the dibaryon is contributing, while the higher invariant mass region is underestimated. The latter effect might be due to the missing contribution of the N*(1520)→ $N\rho$ process.

## 5. Conclusion

Results from inclusive $e^+e^-$ production in pp and np elementary collisions at 1.25 GeV kinetic beam energy [7] show a significant excess in dilepton masses from 0.2 to 0.5 GeV/$c^2$. This effect triggered several on-going analyses of exclusive channels with either dilepton or pion production to shed more light on possible explanations. In addition, the analysis of the $\pi^+\pi^-$ production channels will complement the extensive investigations made by the WASA collaboration in the $\pi^0\pi^0$ channel and will provide tests for a consistent description of double pion production in the different isospin states, which is necessary to understand the double Δ(1232) and N*(1440) production and the N*(1440) decay mechanisms. The study of the channels with a deuteron in the final state and $pn \to np\pi^+\pi^-$ is of special importance to understand the ABC effect and to check the contribution of the hypothetical d* dibaryon resonance, as announced by the WASA collaboration.
Finally, the dilepton and di-pion production measurement in elementary reactions with the HADES experimental set-up allow to test and improve the resonance model, which is the basis of transport models used for the description of dilepton production in heavy-ion experiments. More generally, the high statistics differential distributions provided by such measurements bring wealth of detailed information on baryonic resonance excitation and decay.

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