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Measurement of the quasi free $np \rightarrow np\pi^+\pi^-$ and $np \rightarrow pp\pi^-\pi^0$ reactions at 1.25 GeV with HADES

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Abstract. We present the results of two-pion production in tagged quasi-free np collisions at a deutron incident beam energy of 1.25 GeV/c measured with the High-Acceptance Di-Electron Spectrometer (HADES) installed at GSI. The specific acceptance of HADES allowed for the first time to obtain high-precision data on $\pi^+\pi^-$ and $\pi^-\pi^0$ production in np collisions in a region corresponding to large transverse momenta of the secondary particles. The obtained differential cross section data provide strong constraints on the production mechanisms and on the various baryon resonance contributions ($\Delta\Delta$, $N(1440)$, $N(1520)$, $\Delta(1600)$). The invariant mass and angular distributions from the $np \to np\pi^+\pi^-$ and $np \to pp\pi^-\pi^0$ reactions are compared with different theoretical model predictions.

1 Introduction

The two-pion production in nucleon-nucleon (NN) collisions is a very rich source of information about the baryon excitation spectrum and the baryon-baryon interaction properties. In addition to the excitation of a resonance decaying into two pions, which can also be studied in the $\pi N \to \pi\pi N$ and $\gamma N \to \pi\pi N$ reactions, the simultaneous excitation of two baryons can be investigated in the NN reactions. Since baryon excitation processes contribute significantly to meson and dilepton production, the two-pion production appears as a key process towards a better understanding of hadronic interactions. The $\pi\pi$ production in NN collision has been a subject of many experimental and theoretical investigations. The intriguing results, recently obtained by the WASA collaboration [1–4] renewed the interest for the study of the two-pion production in NN collisions, in order to check the possible contribution of a dibaryon resonance [5, 6]. In comparison to the one pion mode, two pion production mode presents a different selectivity with respect to the various resonances. In particular, with the two pions in the isospin 1 channel, the excitation of baryonic resonances coupled to the ρ meson can be studied. It is of high interest for a better understanding of the dilepton production in nucleon-nucleon reactions and also in nucleon matter due to the expected modifications of the ρ meson spectral functions [7]. Finally, the comparison of two-pion production in pp and np channels could shed some light on the origin of the very large isospin dependence of the dilepton emission observed by the HADES experiment [8]. In this work we present high statistics invariant mass and angular distributions on $\pi^+\pi^-$ and $\pi^-\pi^0$ production in quasi-free np collisions at an incident deutron beam energy of 1.25 GeV/c obtained with the HADES spectrometer.

2 Experimental procedure

The experimental data have been obtained using the High Acceptance Di-Electron Spectrometer (HADES) [9] located at the GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt, Germany. HADES is a modern multi-purpose detector currently operating in the region of kinetic beam energies of up to 2 A·GeV for nucleus-nucleus collisions. HADES is geometrically divided into identical sectors defined by the superconducting coils producing toroidal geometry magnetic field. The spectrometer has 85% of azimuthal acceptance and covers polar angles from 18° to 85° measured relatively to the beam direction. Each sector of the spectrometer contains a Ring Imaging Cherenkov detector (RICH), 4 planes of the Multi-wire Drift Chambers (MDC), two plastic scintillator walls for the polar angles larger (TOF) and smaller (TOFINO) than 45°, respectively, and an electromagnetic cascade detector (Pre-Shower) behind TOFINO for particle identification. The investigation of the quasi-free np reactions with the deuteron beam is performed by using a Forward Wall (FW) scintillator hodoscope by registering spectator protons [8].

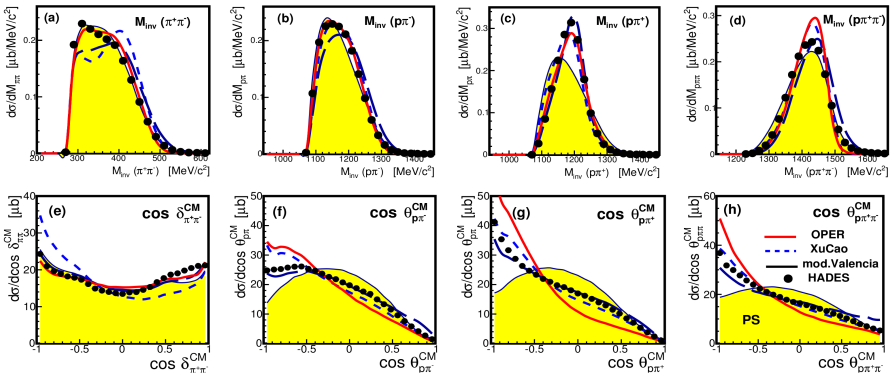

Figure 1. Distributions of the $\pi^+\pi^-$, $p\pi^-$, $p\pi^+$ and $p\pi^+\pi^-$ invariant masses for the $np \to np\pi^+\pi^-$ reaction at 1.25 GeV are presented in *a*), *b*), *c*) and *d*) panels, respectively. e) - opening angle of $\pi^+\pi^-$ in the np rest frame, f), g), h) - polar angles of $p\pi^-$, $p\pi^+$, $p\pi^+\pi^-$ in the np rest frame, respectively. The experimental data are shown with solid symbols. The theoretical predictions within HADES acceptance from Refs. [11], [12], [3] are given by the solid, dashed and long-dashed lines, respectively. The shaded areas show the phase-space distributions.

3 Results

The data on the differential cross section and angular distributions for the $np \to np\pi^+\pi^-$ reaction at 1.25 GeV corrected for the reconstruction efficiency are presented by the solid circles in Fig. 1. The data error bars include the statistical errors only. The normalization of the experimental yield has been performed using the simultaneously measured quasi-elastic pp- scattering yield [10]. The experimental data are compared with OPER model [11] based on the reggeized π exchange and with effective Lagrangian models (modified Valencia [3] and Cao et al. [12]). The theoretical predictions of modified Valencia [3], Cao et al. [12] and OPER [11] models inside HADES acceptance are presented in Fig. 1 and Fig. 2 by the long-dashed, dashed and solid lines, respectively. All the calculations are normalized to the number of the events in the experimental spectra. The shaded areas show the phase-space distributions. The models differ a lot in number of resonances taken into account, the interaction mechanism of interactions and the role of interference between different contributions. The calculations [3] and [12] predict that the $\pi\pi$ production for the $np \to np\pi^+\pi^-$ reaction at 1.25 GeV is mainly caused by the $\Delta\Delta$ excitation, while according to the OPER model [11] the $\Delta\Delta$ and OBE gives commensurable contributions. The comparison of experimental data with theoretical predictions in Fig. 1 and Fig. 2 show that none of the models can describe all distributions, simultaneously. The most significant difference between the obtained data and theoretical predictions is observed for the $\pi^+\pi^-$ invariant mass distribution, where enhancement is present at low $M_{\pi^+\pi^-}$ values. Similar enhancement has been observed earlier for the $\pi^0\pi^0$ system in the $pp \to pp\pi^0\pi^0$ reaction at the energies above 1.0 GeV [2, 4]. The modified Valencia model [3], which was successfully used to describe $\pi\pi$ production in pp collision [2, 4] and Cao et al. [12] calculations don't reproduce the $\pi^+\pi^-$ in np collision. The OPER [11] model predicts some enhancement at low $\pi^+\pi^-$ masses, but it fails in reproducing the angular distributions (see Fig. 1 f),g),h)). The Fig. 2 presents preliminary results for the $np \to pp\pi^-\pi^0$ reaction at 1.25 GeV. Experimental data showed by solid circles are compared with OPER [11] and modified Valencia model with taking into account s-channel d^* resonance amplitude [13]. The modified Valencia model inside HADES acceptance [13] gives a good description of pp and $pp\pi^-$ invariant mass spectra, but it fails in reproducing the polar angle of $pp\pi^-$ in the np rest

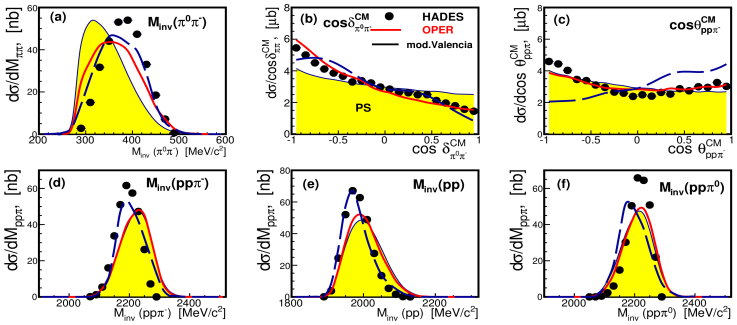

Figure 2. Distributions of the $\pi^-\pi^0$, $pp\pi^-$, pp and $pp\pi^0$ invariant masses for the $np \to pp\pi^-\pi^0$ reaction at 1.25 GeV are presented in *a*), *d*), *e*) and *f*) panels, respectively. b) - opening angle of $\pi^-\pi^0$ in the np rest frame, c) - polar angle of $pp\pi^-$ in the np rest frame. The experimental data are shown with the solid symbols. The theoretical predictions within HADES acceptance from Refs. [11], [13] are given by the solid and long-dashed lines, respectively. The shaded areas show the phase-space distributions.

frame. The OPER model [11] well describes the angular distributions, while the invariant masses show deviations from experimental data.

In the summary, we have presented high precision exclusive measurements of the $np \to np\pi^+\pi^-$ and $np \to pp\pi^-\pi^0$ reactions at 1.25 GeV with the HADES spectrometer. The specific acceptance of HADES favors to the non-peripheral region of this reaction corresponding to the intermediate and large squared momentum transfer. It allows one to test and specify various models of double-pion production in NN-interactions. The deviations for the shapes of some differential distributions still leave an opportunity for further optimization of the existing models.

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