Double pion production in np and pp collisions at 1.25 GeV with HADES

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The results of double pion production in np and pp collisions at an incident beam energy of 1.25 GeV with the HADES spectrometer at GSI are presented. The $np-$ reactions were studied in dp collisions at 1.25 GeV/u using Forward Wall hodoscope aimed at registering spectator protons. High statistic invariant mass and angular distributions are obtained within the HADES acceptance which are compared with phase-space distributions.

XXI International Baldin Seminar on High Energy Physics Problems,
September 10-15, 2012
JINR, Dubna, Russia

*Speaker.

1. Introduction

Double-pion production in nucleon-nucleon (NN) collisions is of particular interest in view of studying the simultaneous excitation of the baryons and their subsequent decays. A number of low statistic experiments on pion productions in NN interactions have been performed in the past spanning the energy region from threshold to many GeV's by using bubble chamber techniques [1]-[2]. The bulk of the experimental data has come from pp collision. In contrast the data on np interaction in the low and medium energy regions are scare. Recently, double-pion production in NN collisions has been accurately measured at CELSIUS [3], COSY [4], KEK [5], and PNPI-Gatchina [6] facilities. The differential cross section for $pp \to pp\pi^+\pi^-$ and $pp \to pp\pi^0\pi^0$ reactions have been obtained at CELSIUS and COSY for the beam energies from the threshold up to 1.4 GeV[3, 4]. The total cross section of $pn \to pn\pi^+\pi^-$ and $pn \to pp\pi^-\pi^0$ channels have been measured at KEK in the beam energy range from 698 MeV up to 1172 MeV.

On the theoretical side, the double pion production in NN collisions has been the subject of many investigations. The effective Lagrangian models (Valencia[8], XuCao[9] and modified Valencia[10]) predict that at energies near threshold the $\pi\pi$ production is dominated by the excitation of one of the nucleons into the Roper resonance $N^*(1440)P_{11}$ via σ-exchange. At higher energies the double $\Delta(1232)$ excitation is expected to be the dominant reaction mechanism for $\pi\pi$ production. The OPER model [11] based on the exchange of reggeized π have been successfully used to describe bubble chamber data[1] on $np \to np\pi^+\pi^-$ reaction at the momenta above 3 GeV/c. This model can be applied for description of $np \to np\pi^+\pi^-$ reaction at the momenta below 3 GeV/c by taking into account the mechanism of one baryon exchange(OBE).

New experimental data on double-pion production are needed to provide quantitative information on hadronic interactions, resonance excitations and resonance properties. In this work we present high statistic invariant mass and angular distributions on double pion production in np and pp collisions at an incident beam energy of 1.25 GeV obtained with the HADES spectrometer.

2. Experiment

The experimental data were collected using the High Acceptance Di-Electron Spectrometer(HADES) installed at the heavy-ion synchrotron SIS-18 at GSI in Darmstadt, Germany. The HADES is a modern multi-purpose detector currently operating in the region of kinetic beam energies of up to 2A GeV. The schematic view of the HADES spectrometer is presented in Fig. 1. Geometrically the spectrometer is divided into 6 identical sectors covering the full azimuthal angle and polar angles from 18° to 85° measured relative to the beam direction. Each sector of the spectrometer contains a Ring Imaging Cerenkov detector (RICH) operating in a magnetic field-free region, inner multi-wire drift chambers (MDCs) in front of the magnetic field, outer MDCs behind the magnetic field, TOF and TOFino time-of-flight detectors and a electromagnetic cascade detector (Pre-Shower). In order to investigate the np interaction using deuteron beam the HADES setup was upgraded with a Forward Wall (FWall) scintillator hodoscope covering the polar angles between 1° and 7°. While a detailed description of the setup can be found in [12], we summarize here only the features relevant for the present analysis.

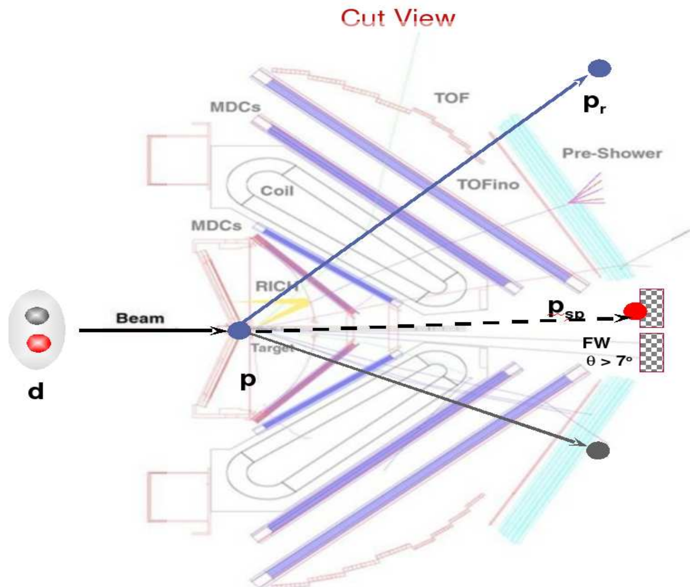

Figure 1: Cut through two sectors of the HADES spectrometer. The magnet coils are projected onto the cut plane to visualize the toroidal magnetic field. A schematic view of the quasi-free $n+p$ reaction is shown.

In the presented experiments the proton and deutron beams with intensities up to 10^7 particles/s and 1.25 GeV/c kinetic energy were directed to a 5 cm long liquid-hydrogen target of 1% interaction probability. The momenta of the produced particles were deduced from the hits in the four drift chamber planes (two before and two after the magnetic field zone) using a Runge-Kutta algorithm [12]. The momentum resolution was 2-3% for protons and pions and 1-2% for electrons, depending on momentum and angle [12]. The start signal for the time measurements was taken from the fastest signal from the scintillator wall. To reconstruct the time-of-flight for each particle, a dedicated method was developed [12], using the identification of one reference particle, the time-of-flight of which can be calculated. The time-of-flight reconstruction algorithm was checked in a dedicated experiment with a low beam intensity using a START detector [12]. The charge hadrons were selected from leptons by using RICH detector, together with TOF/TOFINO and Pre-Shower detectors. The selection of np collisions from dp and pp one was performed by using criteria on the momentum of the proton-spectator in FWall detector. The selection of the $pp \to pp\pi^+\pi^-$ and $np \to np\pi^+\pi^-$ reactions were performed by using event hypothesis. For each hypothesis, any one of the hadrons was considered as reference particle and time-of-flight was calculated. The velocities of all the other products were then deduced, using only the time-of-flight differences to the reference particle. The correlations between velocity and momentum of all particles were then used to reject the wrong hypotheses and to assign the final PID of all particles.

3. Results

The experimental results on double pion production in np and pp collisions at incident beam energy 1.25 GeV are presented in Fig. 2 and Fig. 3 together with the phase-space distribution(PS) in the HADES acceptance. Panels a), b), c) and d) in the Fig. 2 and Fig. 3 correspond to the invariant mass of $\pi^+\pi^-$, $p\pi^-$, $p\pi^+$ and angular distributions of the opening angle for $\pi^+\pi^-$ in the c.m. The experimental data are presented by the black points and include the statistical errors only. The systematic errors are about of 10% due to the correction on the efficiency and normalization on pp elastic scattering. Phase-space distributions(PS) in Fig. 2 and Fig. 3 are normalized on the area of experimental data.

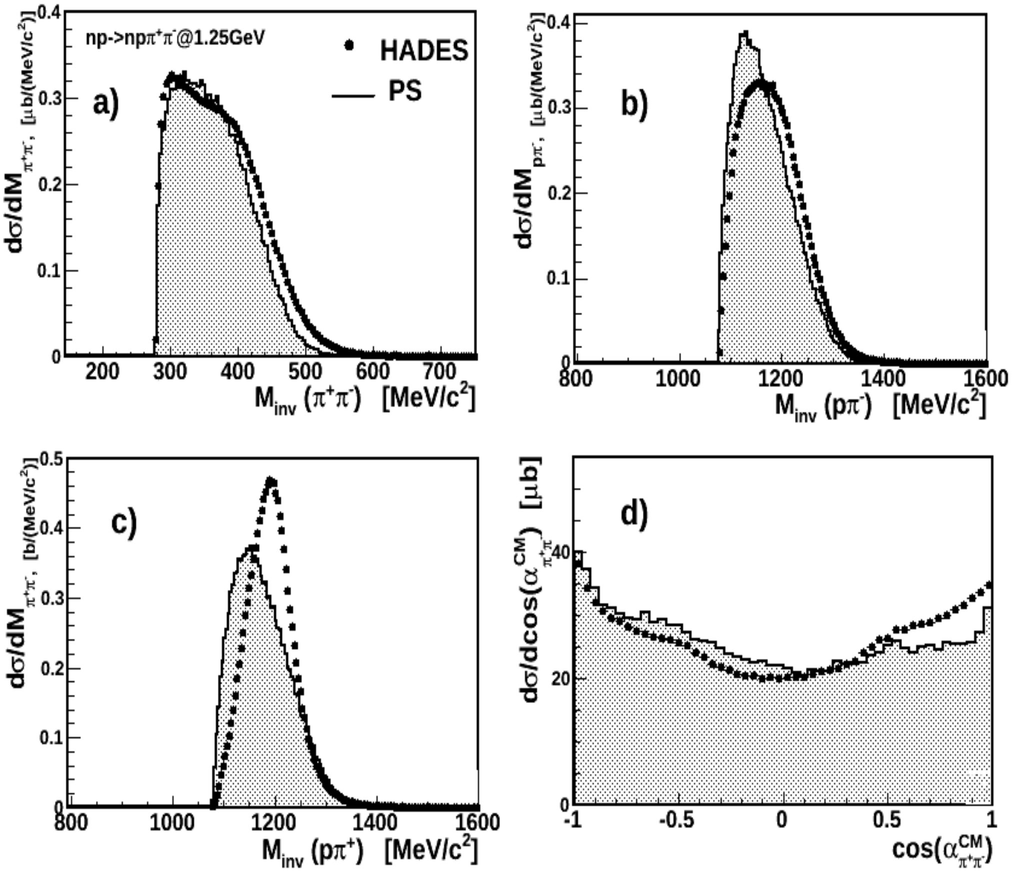

Figure 2: The invariant mass spectra and angular distributions of the opening angle for $\pi^+\pi^-$ in the c.m.s. for the $np \to np\pi^+\pi^-$ reaction at incident beam energy 1.25 GeV. Black points and filled histogram are experimental data and phase-space(PS) distribution in the HADES acceptance, respectively.

The large discrepancies between the experimental data and phase-space distributions are observed at small angles in forward semisphere for angular distributions and in the $p\pi^+$ and $p\pi^-$ invariant mass distributions. M_{inv} of $\pi^+\pi^-$ demonstrate phase-space like behavior except the low mass region, where experimental results for np and pp reactions show clearly an enhancement in the invariant mass distributions. The similar effect was observed in the CELSIUS data on $\pi^0\pi^0$ production in pp collisions at the beam energies above 1.0 GeV [3]. Different models give the different possible interpretations of the low mass enhancement in $\pi\pi$ mass spectra for the $NN \to NN\pi\pi$ reaction[10]-[11]. CELSIUS data have been described by using the modified Valencia model[10]. This model gives reasonable agreement both for invariant mass spectra and angular distributions of

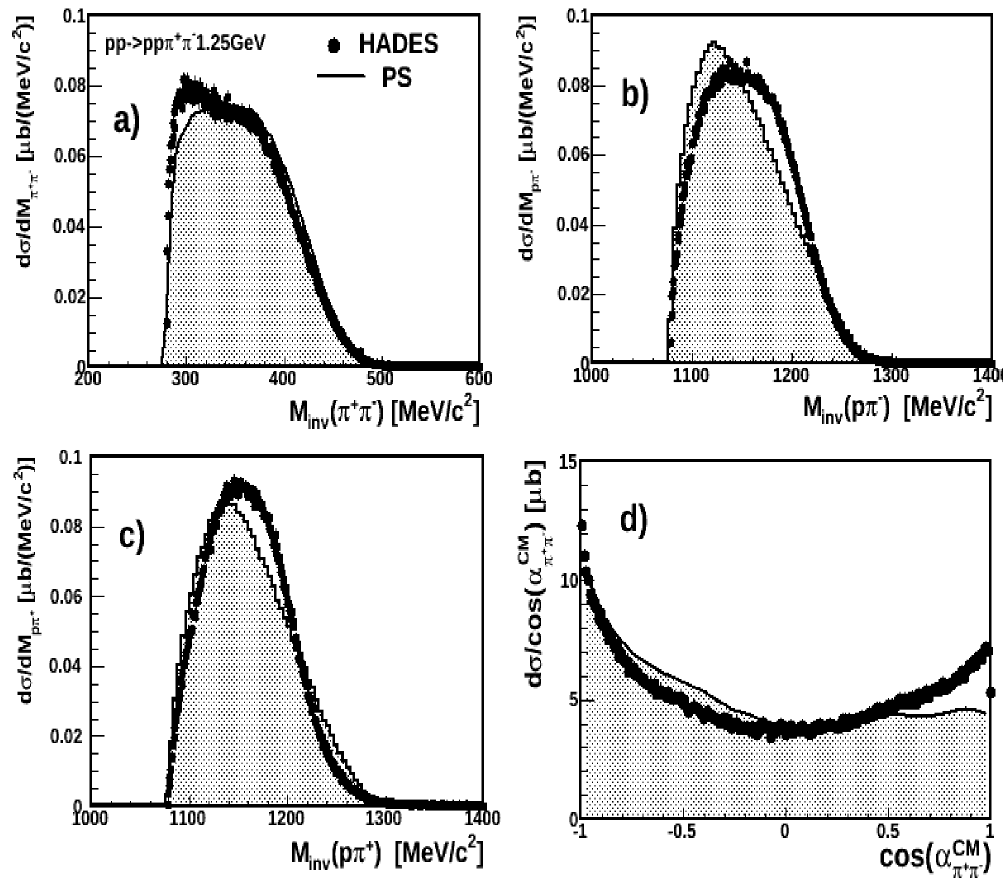

Figure 3: The invariant mass spectra and angular distributions of the opening angle for $\pi^+\pi^-$ in the c.m.s. for the $pp \to pp\pi^+\pi^-$ reaction at incident beam energy 1.25 GeV. Black points and filled histogram are experimental data and phase-space(PS) distribution in the HADES acceptance, respectively.

the opening angle in the c.m. for the $pp \to pp\pi^0\pi^0$ reactions. The ratio between decay of $N^* \to \Delta\pi$ and $N^* \to N\sigma$ was changed from 4 to 1 and ρ-exchange in the $\Delta\Delta$ excitation was suppressed by factor of 12 in this model[10]. On the other hand the OPER model, which successfully used to describe the bubble chamber data in $np \to np\pi^+\pi^-$ reactions shows the importance of the so called "hanged" diagrams[13]. The inclusion of these diagrams significantly improves the description of $\pi\pi$ invariant mass spectra in the low mass region.

4. Conclusion

The experimental results on double pion production in *np* and *pp* collisions at incident beam energy 1.25 GeV are obtained with the HADES spectrometer at GSI. The new high statistic HADES data provide precise results for mesons production measured in hadronic channels, paving the way for further theoretical or experimental studies of hadronic channels in elementary reactions.

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