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Study of baryonic resonances in the reaction $pp \to pp\pi^+\pi^-$ at 3.5 GeV with HADES

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Report on baryon resonance production and decay in the exclusive $pp \to pp\pi^+\pi^-$ channel at a kinetic energy of 3.5 GeV based on data measured with HADES. The invariant masses and angular distributions of the pion-nucleon systems were compared to simulations based on a resonance model assuming an incoherent sum of contributions from baryonic resonances with masses < 2 GeV and using inputs from one pion measured in the same experiment. A very good description of the two pion production is achieved allowing for an estimate of one and double baryon-resonance as well as ρ meson production cross sections.

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1. Introduction

Pion production in NN collisions is one of the sources of information on the NN interaction and on the contribution of nucleon resonances. In particular, two-pion production in the few energy range, carries information both on single and double baryon excitation and on $\pi\pi$ dynamics, which are also useful for the interpretation of dielectron production. Baryonic resonances indeed contribute to the dielectron spectra via their Dalitz decay ($R \to Ne^+e^-$) and indirectly as intermediate states for neutral meson Dalitz decays. In addition, the $\pi^+\pi^-$ production channel gives access to the ρ contribution, which, due to its coupling to the baryonic resonances, is a crucial ingredient of calculations of the e^+e^- emissivity in hadronic matter. The possibility to measure simultaneously with HADES pion and e^+e^- production is therefore a great advantage.
Recently, differential and integrated cross sections for the reactions $pp \to pp\pi^0$, $pp \to pn\pi^+$ [1], [2], $pp \to pp\pi^+\pi^-$, $pn \to pn\pi^+\pi^-$ [3], $pn \to d\pi^+\pi^-$ [4] have been investigated with HADES at kinetic energies 1.25, 2.2 and 3.5 GeV. We focus here on the analysis of the $pp \to pp\pi^+\pi^-$ channel at 3,5 GeV, using results from $pp \to pp\pi^0$, $pp \to pn\pi^+$ and $pp \to pK\Lambda$ [3] measured at the same energy by HADES.

2. The HADES detector

HADES (High Acceptance Di-Electron Spectrometer) is a fixed target experiment placed in GSI, Darmstadt, designed for the detection of leptons and charged hadrons in elementary and heavy-ion collisions.
It consists of six identical sectors covering polar angles 18°- 85° with respect to the beam axis. The momentum vectors of produced particles are reconstructed by means of the four drift chambers (MDC) placed before (two) and behind (two) the magnetic field region provided by six coils of a super-conducting toroid. Particle identification (electron/pion/proton) was provided in this experiment by a hadron blind Ring Imaging Cherenkov (RICH) detector, centered around the target, two time-of-flight walls based on plastic scintillators covering polar angles larger (TOF) and smaller (TOFINO) than 45°, respectively, and a Pre-Shower detector placed behind TOFINO. A detailed description of the spectrometer, track reconstruction and particle identification methods can be found in [5].

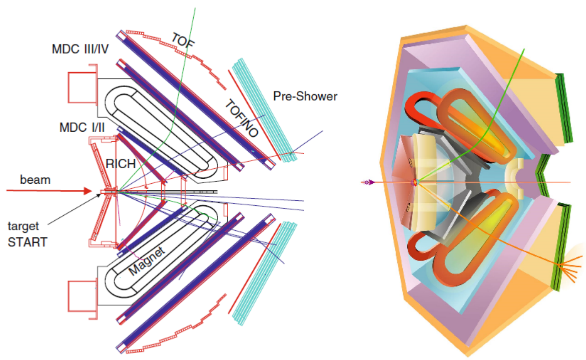

Figure 1: Schematic layout of the HADES detector.

3. $pp \to pp\pi^+\pi^-$ analysis

The channel was selected using events containing $1\pi^+$, $1\pi^-$ and at least 1 proton. Particle identification (PID) of the tracks was provided by the correlation between velocity (β=v/c) and momentum. The distribution of the missing mass of the reaction $pp \to p\pi^+\pi^-X$ can be described by the sum of three contributions: a constant background, the two pion production signal, and

the three pion production, which allow for an accurate extraction of the signal (fig.2). Efficiency corrections are calculated for each particle using GEANT simulations of the detector response. The normalization of the experimental yield is obtained using the analysis of events produced in elastic scattering, as described in [1].
The correlation between (p$\pi^+\pi^-$) and (pπ^+) invariant masses (fig.3 left) shows the dominance of the resonances decaying to p$\pi^+\pi^-$ via $\Delta^{++}(1232)\pi^-$, on the other hand the correlation between (pπ^+) and (pπ^-) invariant masses (fig.3 right) indicates double resonance excitation with a clear dominance of the $\Delta^{++}(1232)\Delta^0(1232)$.

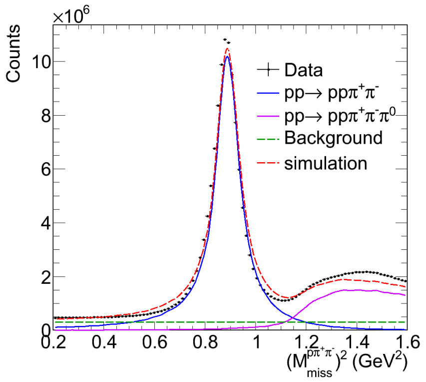

Figure 2: Missing mass squared of the reaction $pp \to p\pi^+\pi^- X$. Data are compared to the sum (red) of three contributions: 2π (blue) and 3π (purple) production from simulations and a constant background (green).

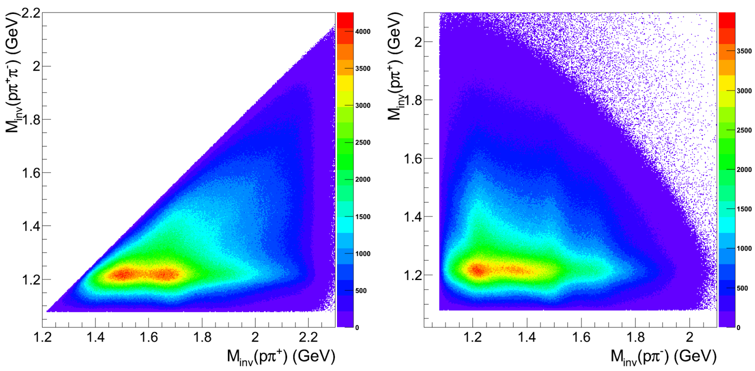

Figure 3: Correlation between pπ^+ and p$\pi^+\pi^-$ invariant masses (left) and between pπ^+ and pπ^- invariant masses (right).

4. HADES resonance model

To describe our data, we developed a model for the $pp \to pp\pi^+\pi^-$ reaction based on three different processes: the excitation of one resonance, with subsequent decay into a proton and two pions ($R \to p\pi^+\pi^-$) (fig.4 left), the excitation of two resonances decaying into a proton and a pion ($R_1, R_2 \to p\pi$) (fig.4 right) and the direct ρ production $\rho \to \pi^+\pi^-$.

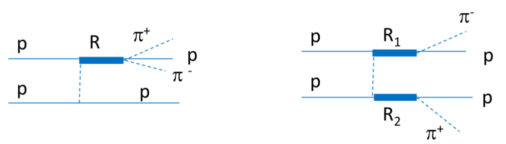

Figure 4: Feynman diagrams of the one resonance excitation (left) and the double resonance excitation (right).

For the analysis of the $pp \to pp\pi^0$ and $pp \to pn\pi^+$ at 3.5 GeV [1], a resonance model was built by fitting the cross sections for the excitation of the different resonances to the experimental distributions. In addition, the shape of the angular distributions could be parameterized as $t^{-\alpha_R}$

where t is the four momentum transfer t = $(p - p_R)^2$ at the resonance excitation vertex and α_R is a parameter fitted to the data and depending on the mass of the resonance. For the excitation of a single resonance decaying to the 2 π channel, we use the cross sections and angular distributions deduced from the one pion analysis and take the branching ratios into N$\pi\pi$ from the PDG [7].
For the double resonance excitation, we use the same branching ratios into Nπ as used for the one pion analysis (i.e. PDG[7]) and adjust the cross sections to the data. For the angular distributions we have adapted the parameterization of the one resonance excitation and used a dependence on $t_1^{-\alpha_{R1}} \times t_2^{-\alpha_{R2}}$ where t_1 and t_2 are the four momentum transfer for the first resonance and the second resonance excitation respectively.
The simulations of the resonance production and decay were performed with PLUTO++ [8], a simulation framework for heavy ion and hadronic-physics reactions based on C++. The decay channels are added incoherently and filtered with the HADES acceptance matrices deduced from GEANT simulations. For the excitation of a single resonance, a good consistency is found with the one pion production analysis. Moreover, the 2π analysis allows for a better precision on some contributions, in particular for the heavier resonances which have a larger branching ratio into the N$\pi\pi$ channel like N(1680) and N(1720) where only an upper limit was determined previously. The dominant contribution originate from the excitation of two $\Delta(1232)$, but other channels like $\Delta(1232)N(1520)$ are also observed.

5. Conclusion

We have presented an analysis of the reaction $pp \to pp\pi^+\pi^-$ measured with HADES at 3.5 GeV. Combining these results with the ones obtained before for one pion production channels, allows for an extension of the model to two resonance excitation and decay. The differential spectra will also be compared to theoretical models [9], [10]. The contribution of the ρ production in the $\pi^+\pi^-$ channel is small but can be extracted using kinematical cuts. This work is on-going.
These results bring new constraints for the interpretation of the dielectron spectra measured by HADES.

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