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

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Abstract. We report on measurements of baryon resonance and ρ meson production in the exclusive $pp \to pp\pi^+\pi^-$ channel at a beam kinetic energy of 3.5 GeV measured with the HADES experimental setup. The differential distributions are compared to Monte Carlo simulations based on a resonance model assuming an incoherent sum of contributions of various baryonic resonances with masses below 2 GeV and using inputs from one pion production measured in the same experiment. A very good description of the two pion production is achieved allowing for an estimate of the contribution of one and double baryon-resonance excitation. Using appropriate kinematical cuts the ρ meson signal could also be extracted.

1 Introduction

Pion production in nucleon-nucleon (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 GeV energy range carries information both on single and double baryon excitation and on $\pi\pi$ dynamics, which can be used for the interpretation of dielectron production. Baryonic resonances (R) indeed contribute to the dielectron spectra directly 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 with HADES simultaneously 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], $pn \to d\pi^+\pi^-$ [5] have been investigated with HADES at kinetic energies of 1.25, 2.2 and 3.5 GeV. Here we focus on the analysis of the $pp \to pp\pi^+\pi^-$ channel at 3.5 GeV, using results from $pp \to pp\pi^0$, $pp \to pn\pi^+$ [3] and $pp \to pK\Lambda$ [4] measured at the same energy by HADES.

2 $pp \to pp\pi^+\pi^-$ analysis

The $pp \to pp\pi^+\pi^-$ channel was selected using events containing $1\pi^+$, $1\pi^-$ and at least 1 proton. Particle identification (PID) was provided by the correlation between measured mo-

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mentum and particle velocity of reconstructed tracks. The distribution of the missing masses 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. Consequently an accurate extraction of the signal can be performed. 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].

3 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 ($R \to p\pi^+\pi^-$), the excitation of two resonances decaying into a proton and a pion ($R_1, R_2 \to p\pi$) and the direct ρ production followed by its decay ($\rho \to \pi^+\pi^-$).

The previous analysis of the $pp \to pp\pi^0$ and $pp \to pn\pi^+$ reactions at 3.5 GeV [1] allowed the determination of the resonance production cross sections (from $\Delta(1232)$ to $\Delta(1950)$) by simultaneous fits of the proton-pion invariant masses and angular distributions. In addition, the shape of the proton-pion angular distributions was parameterized as $t^{-\alpha_R}$ where t is the four momentum transfer t = $(p - p_R)^2$ at the resonance excitation vertex, calculated between the four-momentum vectors of the outgoing resonance (p_R) and the incoming nucleon (p) 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 for the decays into N$\pi\pi$ from the PDG [7].

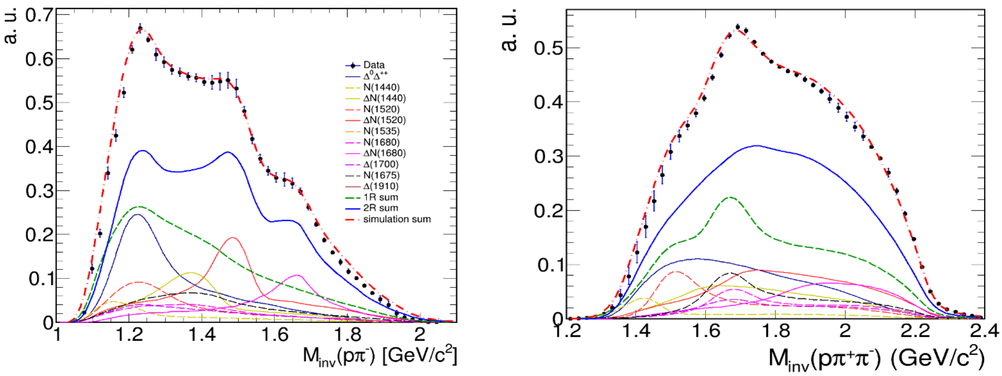
For the double resonance excitation, we use the same branching ratios into Nπ as used for the one pion analysis (i.e. PDG [7]) and adjust the cross sections to the data.

For the angular distributions we have adapted the parameterization of the one resonance excitation and used a dependence as $t_1^{-\alpha_{R1}} \times t_2^{-\alpha_{R2}}$ where t_1 and t_2 are the four momentum transfers 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 reactions based on C++. The decay channels are added incoherently and filtered with the HADES acceptance matrices deduced from GEANT simulations. Figures 1 and 2 show examples of experimental distributions compared to the simulations and displaying the different one and two resonance contributions. 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 higher 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 double resonance contribution originates from the excitation of two $\Delta(1232)$, but other channels like $\Delta(1232)N(1520)$ are also deduced.

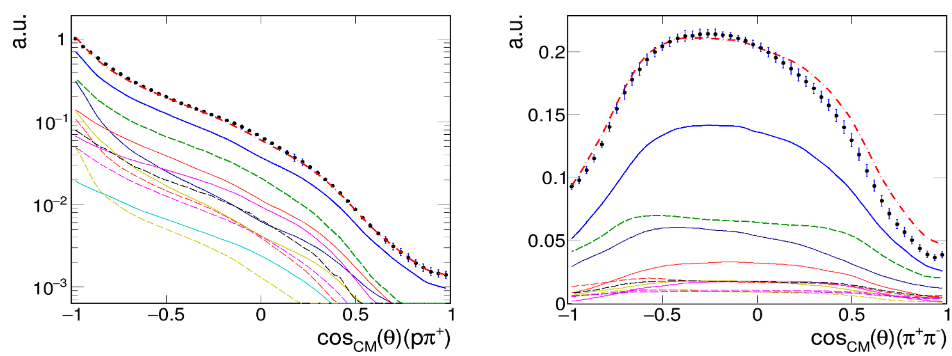
In addition to the ρ produced from the decay of the baryon resonances, a direct non-resonant production is also observed. The production of the direct ρ was highlighted after applying kinematical cuts on the ($p\pi^+$) and ($p\pi^-$) invariant masses to suppress the abundant $\Delta(1232)$ production, and on the proton polar angle to suppress the remaining heavy resonance production. The resulting $\pi^+\pi^-$ invariant mass is shown in Fig. 3. The peak at the ρ mass is clearly due to a direct ρ production which is not included in our model. In simulations it can be observed that, due to the coupling to baryonic resonances with mass lower than the ρ production threshold (e.g. N(1520), ...), the distribution of mass for the ρ meson has a large tail towards lower values.

To obtain the ρ angular distribution of the direct producyion, we evaluate the ρ cross section ($\Delta\sigma_\rho$) in bins of $\pi^+\pi^-$ angle. A significant enhancement for forward/backward emission is observed, which is consistent with the dominance of nucleon currents in the $pp \to pp\rho$ reaction as also observed by DISTO [9].



(a) (b)

Figure 1: $p\pi^-$ (a) and $p\pi^+\pi^-$ (b) invariant mass distribution, compared to simulations: Data (black dots), sum of all simulation contributions (dashed red) double resonance sum (blue), one resonance sum (dashed green).



(a) (b)

Figure 2: Distribution of center-of-mass angles of the $p\pi^+$ (a) and $\pi^+\pi^-$ (b) pairs in HADES acceptance, compared to simulations (color code same as Figure 1).

4 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 [10], [11]. The contribution of the ρ production in the $\pi^+\pi^-$ channel is small but can be extracted using kinematical cuts. These results allow for new constraints for the interpretation of the dielectron spectra measured by HADES.

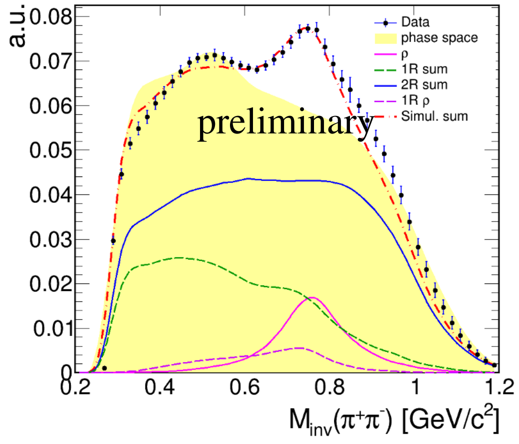


Figure 3: $(\pi^+\pi^-)$ invariant mass distribution after kinematical cuts, compared to simulations: direct ρ (pink), double resonance (blue), one resonance (dashed green). The ρ production from resonance decay (dashed purple). The phase space (yellow area).

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