

Production and Dalitz decays of baryon resonances in proton-proton interaction at $\sqrt{s} = 3.16 \text{ GeV}$ with HADES

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Abstract. One of the physics goals of HADES is to investigate spectral modifications of light vector mesons in strongly interacting matter via their dielectron (e^+e^-) decay channel. Theoretical models predict such modifications due to strong meson-baryon resonance coupling which can be also probed in elementary collisions. In 2007 electron-positron pair production has been measured in p+p reactions at a beam kinetic energy of 3.5 GeV. We present analysis results of the exclusive channels $pp\pi^0$, $pn\pi^+$, ppe^+e^- , which indicate contributions of higher resonances. In order to estimate production cross sections of the baryonic resonances, the results have been compared to Monte Carlo calculations based on a resonance model assuming an incoherent sum of various four-star resonances. To obtain the corresponding e^+e^- yields, two models of the width parametrization are applied in the simulation.

1. Introduction

The High Acceptance Di-Electron Spectrometer (HADES) [1] operates at the GSI Helmholtzzentrum für Schwerionenforschung in Darmstadt, Germany. One of the physics goals of HADES is to investigate spectral modifications of light vector mesons in strongly interacting matter via the dilepton (e^+e^-) decay channel. The HADES collaboration has set up an experimental program to measure dilepton spectra in p+p and p+n collisions [2]. In 2007, electron-positron pair production has been measured in elementary collisions of two protons with 3.5 GeV projectile kinetic energy. One of the basic observables in this measurement is the inclusive e^+e^- mass distribution, shown in Fig.1 after Combinatorial Background (CB) subtraction. The expected e^+e^- production channels are Dalitz decays of π^0 , η , ω mesons and of the $\Delta(1232)$ resonance. In the high-mass region, two-body decays of ρ/ω play a role. Indeed, the experimental data can be described by PLUTO [3] simulations (see Fig. 1) assuming the aforementioned components, except the mass region below the vector meson pole $M_{inv}^{e^+e^-} \in (0.5 - 0.7) \text{ MeV}/c^2$. However, the Dalitz decay channel of baryonic resonances is included only for $\Delta(1232)$ here. In order to study the contributions of higher lying baryonic resonances the ppe^+e^- , $pp\pi^0$, $pn\pi^+$ and $pp\omega(\eta) \rightarrow \pi^+\pi^-\pi^0$ exclusive channels have been analysed. The ppe^+e^- channel has been selected by a condition on the pe^+e^- missing mass $\sim 0.938 \text{ MeV}/c^2$. The respective e^+e^- invariant mass spectrum is shown in Fig. 2. The mass region below the vector meson pole is not described by a simulation including only ω and η channels, with production cross sections constrained by the hadronic channels mentioned above (see [7]). In this region, the contribution of baryonic resonances is expected to be enhanced due

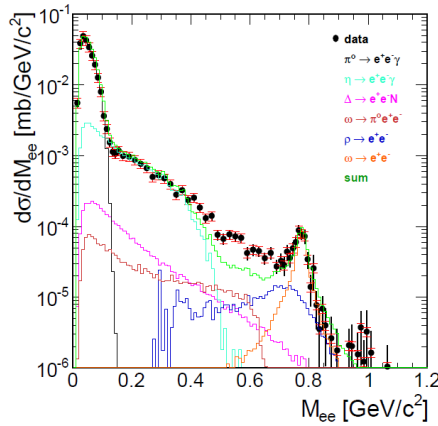


Figure 1. Efficiency corrected inclusive invariant mass distribution of dielectrons inside the geometrical acceptance of HADES. e^+e^- - signal pairs (black dots), after combinatorial background subtraction for $p(3.5\text{GeV})+p$ collisions with corresponding simulation cocktail components. The data are normalized to the measured $p+p$ elastic events.

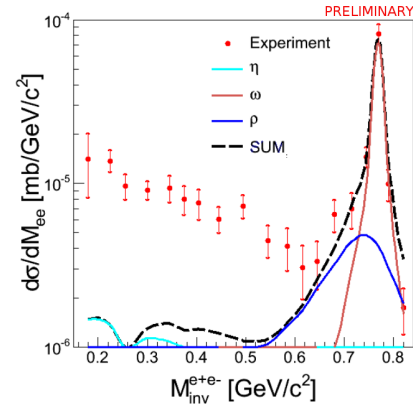


Figure 2. Efficiency corrected invariant mass distribution of dielectrons for exclusive ppe^+e^- channel inside the geometrical acceptance of HADES after combinatorial background subtraction. The data are normalized to $p+p$ elastic events and compared to simulation cocktail which includes the sources given in the legend.

to the coupling to the ρ meson. In order to estimate production cross sections of the resonances which decay in the $pn\pi^+$ and $pp\pi^0$ final states, the results have been compared to Monte Carlo calculations based on the resonance model [4] assuming an incoherent sum of various resonances. The differential Dalitz decay width is calculated for each resonance as a function of the dielectron invariant mass, using different electromagnetic transition form factor models.

2. Analysis of $pp \rightarrow pn\pi^+$ and $pp \rightarrow pp\pi^0$ final states

In both final states only events with two positive tracks were selected. Protons and positive pions were distinguished using measured momentum and particle velocity of reconstructed tracks. The channels were selected via a condition on missing mass of neutral particles (n and π^0 , respectively). The signal was obtained as the number of counts above the fitted continuous background. In the case of $pp\pi^0$, the elastic scattering and multi-pion contribution was first subtracted to enhance the purity of the signal. The resonance cross sections were estimated by simultaneous fits of invariant masses ($M_{inv}^{p\pi^+}$, $M_{inv}^{n\pi^+}$, $M_{inv}^{p\pi^0}$) and of angular distributions ($\cos\theta_{CM}^{p\pi^+}$, $\cos\theta_{CM}^{n\pi^+}$, $\cos\theta_{CM}^{p\pi^0}$) in several bins of the $N - \pi$ invariant mass. An iterative procedure was applied: in the first step, an isotropic angular distribution has been assumed for resonance production. Since experimental distributions show a clear forward-backward peaking, in the next step a modified distribution of the form $d\sigma/dt \sim A/t^\alpha$ has been used. The quantity t is Mandelstam variable and A , α are fit parameters depending on resonance mass, respectively. Furthermore, the isospin relations connecting the contributions of a given resonance in $pn\pi^+$ and $pp\pi^0$ channels have been preserved. In Figs. 3a, 3b, 4a and 4b the results obtained after acceptance/efficiency corrections assuming the above model are presented. The $pn\pi^+$ channel allows to distinguish doubly and singly charged resonances.

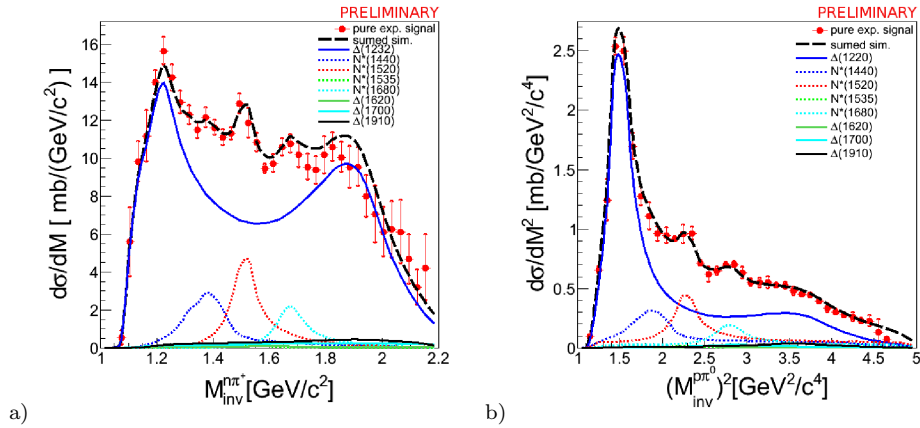


Figure 3. Acceptance and efficiency corrected cross sections as a function of $n\pi^+$ (a) and $p\pi^0$ (b) invariant mass. Simulation components are depicted by curves.

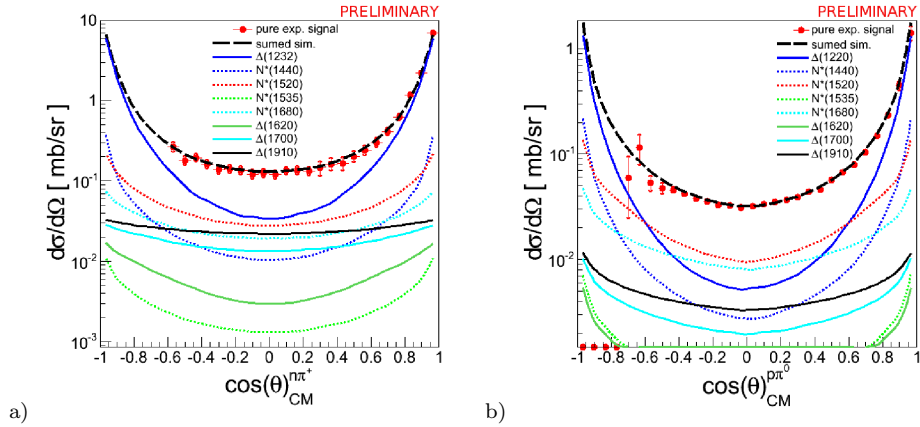


Figure 4. Acceptance and efficiency corrected spectra of $p\pi^+$ (a) and $p\pi^0$ (b) angular distribution in the centre of mass. Simulation components are depicted by curves.

3. Analysis of $pp \rightarrow ppe^+e^-$ final state

Five different models have been compared to the data inside the HADES acceptance including momentum resolution in reconstruction process. Three models ("QED", "Wan/Iachello", "eVMD") are compared to the data with the following assumptions:

- Cross sections for resonances production have been obtained from the analysis of $pp\pi^0/pn\pi^+$ final states presented above.
- Two parametrizations of e^+e^- mass dependent width of decay in Dalitz mode has been used in "QED" ("Wan/Iachello") and "eVMD" models.
- Cross sections for η , ω , ρ production have been obtained from an independent analysis of $pp \rightarrow pp\pi^+\pi^-\pi^0$ final state (see [7]).
- The grey band shows the uncertainty of mesonic and baryonic resonances cross sections estimates.

In Figs. 5a and 5b, the result of e^+e^- production obtained from "QED" model [5] has been compared to the data. This model does not have an electromagnetic form factor for different baryonic resonances which decay in the Dalitz mode $R \rightarrow pe^+e^-$.

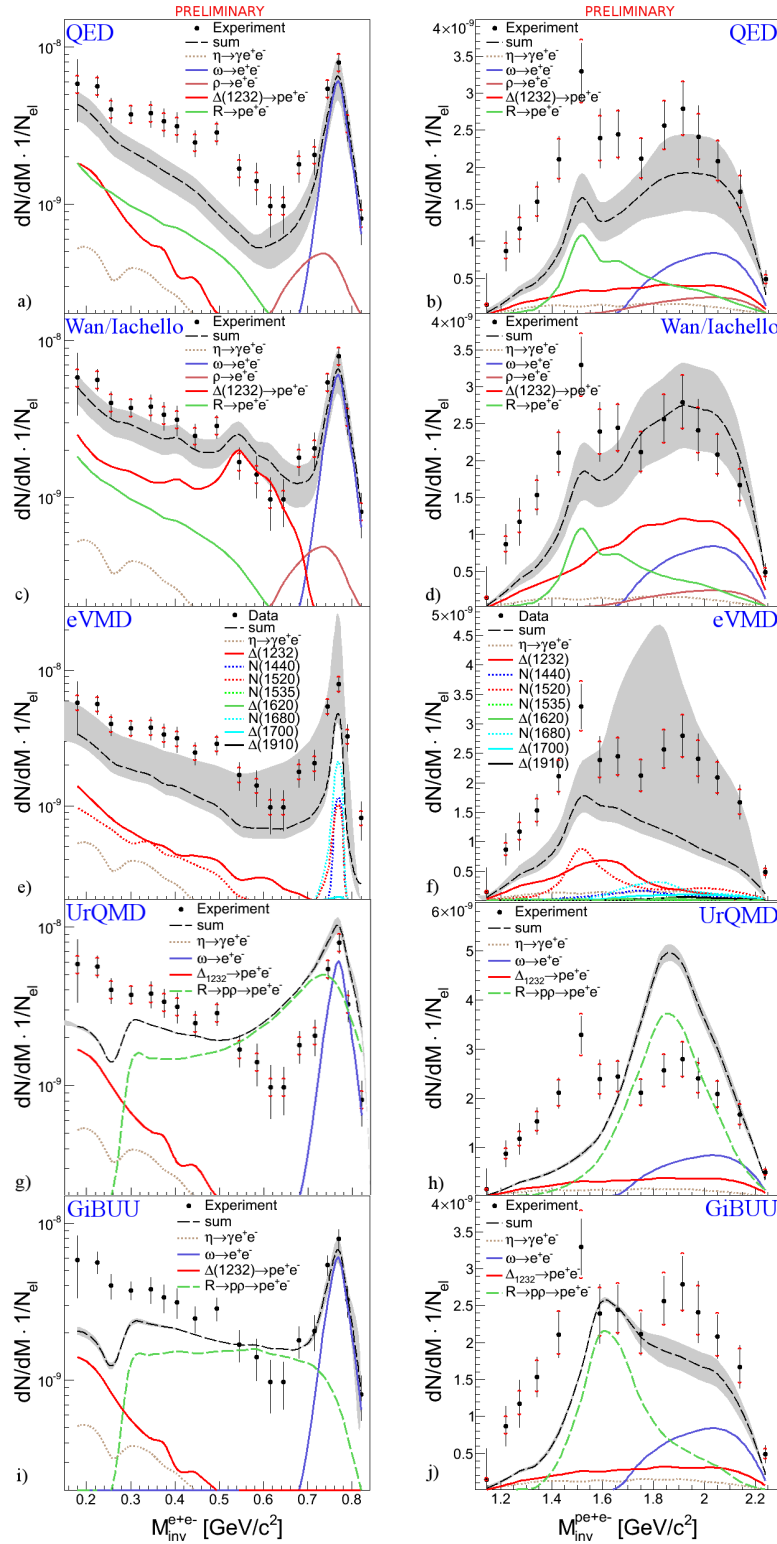


Figure 5. Invariant mass spectrum of e^+e^- and pe^+e^- inside the HADES acceptance. Simulations are based on models "QED" (a,b), "eVMD" (c,d), "Wan/Iachello" (e,f), "UrQMD" (g,h), "GiBUU" (i,j).

"Wan/Iachello" model is a modification of "QED" which assumes a non-constant electromagnetic form factor for the $\Delta(1232)$ resonance Dalitz decay. It causes an enhancement in the range $M_{e^+e^-} \in (0.3 - 0.6) \text{ GeV}/c^2$ (see Fig. 5c) which leads to a better description of data. In addition, $M_{inv}^{pe^+e^-}$ spectrum is not overestimated by this calculation (see Fig. 5d).

Figures 5e and 5f show a comparison of data with predictions of the "eVMD" model [6] where the transition form factors take into account the interferences between the coupling of the baryonic resonance to different vector meson excited states (ρ' , ρ'' , ω' , ...). Even considering the large uncertainty, this model cannot describe the data, in particular data are underestimated below and overestimated above the region $M_{inv}^{pe^+e^-} = 1.6 \text{ GeV}/c^2$.

Transport models calculations like UrQMD [8] and GiBUU [9] models are compared to the data with the following assumptions:

- Only $\Delta(1232)$ decays in a Dalitz mode; the rest of baryonic resonances decay in the channel $R \rightarrow N\rho$.
- Cross sections for resonance production are taken from model calculations.
- Cross sections for η , ω production have been obtained from an independent analysis of $pp \rightarrow pp\pi^+\pi^-\pi^0$ final state (see [7]).
- The grey band shows uncertainty of η and ω cross sections estimations.

"UrQMD" model [8] favors higher lying resonances which populates high values of $N\rho$ masses leading to an overestimate of the data (see Figs. 5g and 5h). In addition, the $M_{inv}^{pe^+e^-}$ spectrum cannot be described at $M_{inv}^{pe^+e^-} < 1.7 \text{ GeV}/c^2$.

The composition of baryonic resonance production in "GiBUU" model (see [9]) based on aforementioned resonance model [4] where the dominant contribution is due to the coupling of the ρ meson to the $N(1520)$ resonance, gives a better description of both the $M_{inv}^{pe^+e^-}$ and $M_{inv}^{e^+e^-}$ invariant mass spectra (see Fig. 5i). However, like in the UrQMD model, the yield is underestimated for $M_{inv}^{e^+e^-} < 0.25 \text{ GeV}/c^2$, due to the cut at $2M_\pi$ in the ρ mass distribution (see Figs. 5h and 5j).

4. Conclusions and outlook

The applied resonance model of baryon resonance production describes the production of pions in the $pp\pi^0$ and $pn\pi^+$ channels. The obtained cross sections for the various resonances fulfill all isospin relations. The estimated cross section for the $\Delta(1232)$ production is in a good agreement with observations of other experiments. The obtained cross sections for the total π^0 and π^+ yields are also in a agreement with previous measurements.

The best descriptions of the experimentally measured invariant mass spectrum inside HADES acceptance without overshooting other observables, are obtained by "Wan/Iachello" and "GiBUU" models. The Wan/Iachello model, where a form factor is applied only in the case of the $N - \Delta(1232)$ transition is just an attempt to test the sensitivity of the data to the electromagnetic transition form factor models. Agreement with "GiBUU" model points to the importance of the coupling of the ρ meson to the baryonic resonances.

References

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