e^+e^- pair production from nucleon targets in the resonance region

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Abstract

We present consistent theoretical descriptions of the $\pi N \to e^+e^-N$ and $\gamma N \to e^+e^-N$ reactions on proton and neutron targets for total center of mass energies $\sqrt{s}$ ranging between 1.50 GeV and 1.75 GeV. These reactions are complementary to study the coupling of low-lying baryon resonances to vector meson-nucleon channels. We show in particular how the resonant structure of the amplitudes for both processes generates specific and large quantum interferences between ρ- and ω-meson decays into e^+e^- pairs. Data on the $\pi N \to e^+e^-N$ and $\gamma N \to e^+e^-N$ reactions are expected in the near future from the HADES program at GSI and from dilepton studies with CLAS at JLab.

1 Introduction

Low-lying resonances of masses $\lesssim 1.7$ GeV do not decay into a vector meson ($V = \rho, \omega$) and a nucleon because there is no phase space for such decays (except far on the resonance tails). The effective transition couplings of the lowest-lying baryon excitations to vector field-nucleon final states are nevertheless quantities of much significance to characterize the structure of baryons and the propagation of vector mesons in the nuclear medium [1, 2]. These couplings can be best accessed through studies of reactions in which baryon resonances are excited and decay into a time-like photon (materializing subsequently into an e^+e^- pair) and a nucleon. We consider two such processes, $\pi N \to e^+e^-N$ and $\gamma N \to e^+e^-N$. The model [2] underlying the description of these reactions makes use of the information available on pion-nucleon and photonucleon processes in the kinematic range where their dynamics is largely determined by the excitation of s-channel baryon resonances.

We discuss the processes building up the amplitudes for the $\pi N \to e^+e^-N$ and $\gamma N \to e^+e^-N$ reactions and the way they are calculated in Section 2. A few numerical results are displayed in Section 3 and a brief conclusion is given in Section 4. The work outlined in this talk relies on a published article [3] and on a forthcoming paper [4].

2 The $\pi N \to e^+e^-N$ and $\gamma N \to e^+e^-N$ amplitudes

The graphs entering the calculation of the $\pi N \to e^+e^-N$ and $\gamma N \to e^+e^-N$ amplitudes are displayed in Figs. 1 and 2.

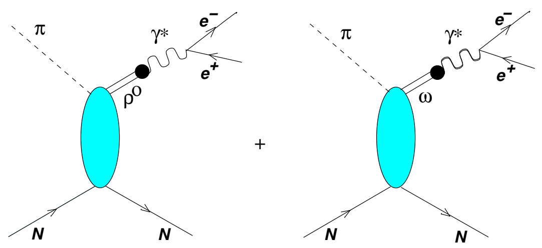

Fig. 1: Diagrams contributing to the amplitude for the $\pi N \to e^+e^-N$ reaction.

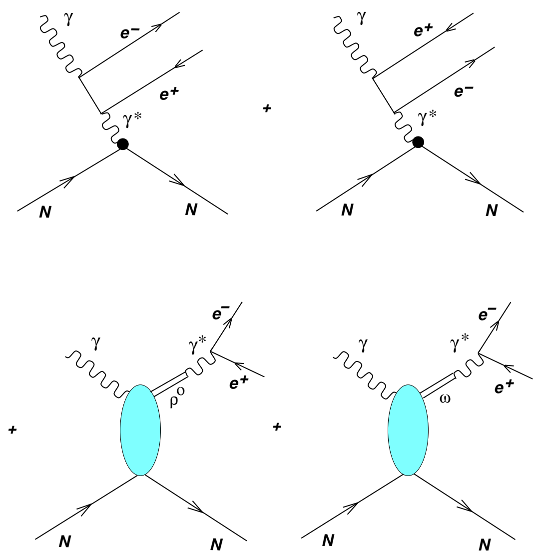

Fig. 2: Diagrams contributing to the amplitude for the $\gamma N \to e^+e^-N$ reaction.

For the $\pi N \to e^+e^-N$ reaction, the amplitude consists of two terms representing the production of a massive photon of isovector and isoscalar character respectively. Using the Vector Meson Dominance assumption, these massive photons can be related to the ρ^0- and ω-meson fields [5]. For the $\gamma N \to e^+e^-N$ reaction, there are four terms. The first two diagrams are associated with the electromagnetic production of e^+e^- pairs (Bethe-Heitler processes). They depend on the (well-known) nucleon electromagnetic form factors at low momentum transfers. The last two diagrams represent the photoproduction of isovector and isoscalar massive photons in the Vector Meson Dominance model.

The main dynamical quantities entering the calculation of the $\pi N \to e^+e^-N$ and $\gamma N \to e^+e^-N$ cross sections are therefore the (off-shell) $\pi N \to \rho N$, $\pi N \to \omega N$, $\gamma N \to \rho N$ and $\gamma N \to \omega N$ amplitudes. They are computed using the relativistic, chiral coupled-channel approach of Ref. [2]. This model offers a consistent picture of the πN and γN reactions and involves the πN, $\pi\Delta$, ρN, ωN, $K\Lambda$, $K\Sigma$ and ηN hadronic channels. It is restricted to center of mass energies ranging between 1.40 GeV and 1.75 GeV and describes vector meson-nucleon channels below and very close to the vector meson threshold ($\sqrt{s}$ $\simeq$1.72 GeV). The vector meson and the nucleon in the final state are assumed to be in relative S-wave. The Bethe-Salpeter kernel for the coupled-channel system is constructed from an effective quasi-local meson-meson-baryon-baryon Lagrangian. The fundamental fields are the photon, the mesons, the nucleon and the Δ(1232). The baryon resonances which do not belong to the large N_c groundstate multiplets are generated dynamically. They are the N(1520), N(1535), N(1650), Δ(1620) and Δ(1700) resonances. A generalized Vector Meson Dominance assumption is used to relate amplitudes involving photons to amplitudes involving vector mesons. The effective Lagrangian parameters are fitted using all available data, such as phase shifts, inelasticity parameters, pion photoproduction multipole amplitudes, inelastic pion-nucleon cross sections. The quality of the fit is quite satisfactory for all these quantities in the interval 1.40 GeV $\leq \sqrt{s} \leq$ 1.75 GeV [2].

The presence of baryon resonances in this energy energy range is reflected in the structure of the scattering amplitudes for vector meson production. It is this particular structure that we are interested in unravelling in e^+e^- pair production processes. We illustrate the resonant behavior of the vector meson production amplitudes by showing in Fig. 3 the (projected) amplitudes for the $\pi N \to \omega N$ process in the S11 and D13 partial waves [3]. In the S11 channel, the N(1535) and the N(1650) resonances lead to peak structures in the imaginary parts of the amplitudes. The pion-induced ω production amplitudes in the D13 channel reflect the strong coupling of the N(1520) resonance to the ωN channel [2]. The $\pi N \to \omega N$ amplitudes contain also significant contributions from non-resonant, background terms.

The $\pi N \to e^+e^-N$ and $\gamma N \to e^+e^-N$ amplitudes involving intermediate vector mesons are calculated assuming the specific Vector Meson Dominance form given by the meson-photon interaction terms,

$$\mathcal{L}_{\gamma V}^{int} = \frac{f_\rho}{2M_\rho^2} F^{\mu\nu}\,\rho^0_{\mu\nu} + \frac{f_\omega}{2M_\omega^2} F^{\mu\nu}\,\omega_{\mu\nu}, \tag{1}$$

where the photon and vector meson field tensors are defined by $F^{\mu\nu} = \partial^\mu A^\nu - \partial^\nu A^\mu$ and $V^{\mu\nu} = \partial^\mu V^\nu - \partial^\nu V^\mu$. The Bethe-Heitler terms are computed with phenomenological electromagnetic form factors [4].

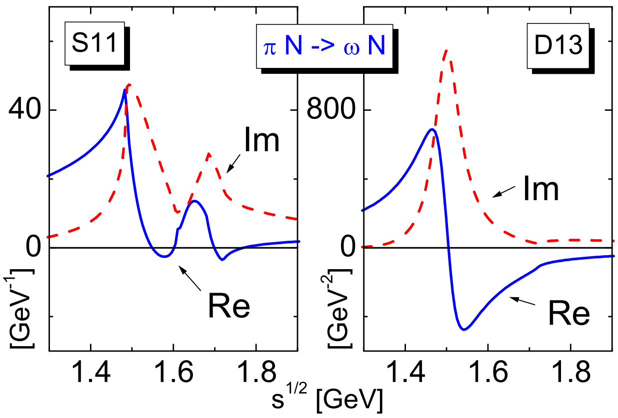

Fig. 3: Amplitudes for the $\pi N \to \omega N$ process in the S11 and D13 partial waves [3].

3 Numerical results

A large set of numerical results for the $\pi N \to e^+e^-N$ and $\gamma N \to e^+e^-N$ reactions is presented in Refs. [3, 4]. We display only a couple of illustrative figures in this paper.

Figs. 4 and 5 exhibit a very large quantum interference effect obtained for the $\pi N \to e^+e^-N$ reaction in the lowest-lying resonance region (N(1520), N(1535)) for $\sqrt{s}$=1.5 GeV. The ρ^0-ω interference is destructive for the $\pi^-p \to e^+e^-n$ reaction and constructive for the $\pi^+n \to e^+e^-p$ process. The $\pi^-p \to e^+e^-n$ differential cross section is extremely small in the range of invariant masses considered in this calculation (less than 10 nb GeV^{-2}). In contrast, the constructive ρ^0-ω interference for the $\pi^+n \to e^+e^-p$ reaction leads to a sizeable differential cross section (of the order of 0.15 μb GeV^{-2}). This prediction is closely linked to the resonant nature of the amplitudes and reflects the couplings of both the N(1520) and N(1535) baryon resonances to the vector meson-nucleon channels. Data on these differential cross sections would provide strong constraints on these couplings.

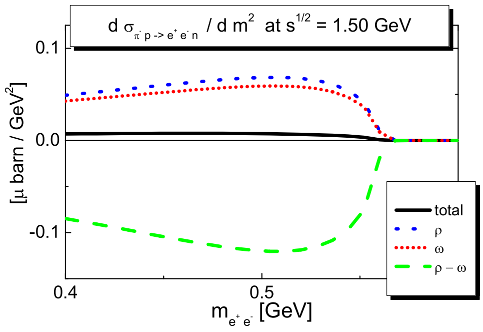

Fig. 4: Differential cross section for the $\pi^- p \rightarrow e^+ e^- n$ reaction at $\sqrt{s}$=1.5 GeV as function of the invariant mass of the e^+e^- pair [3].

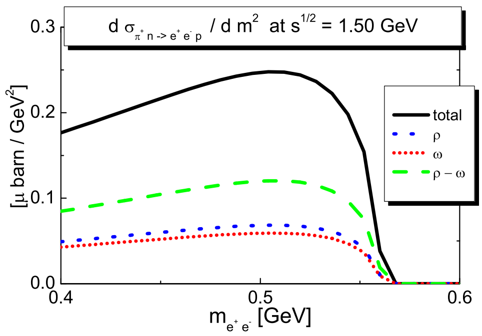

Fig. 5: Same as Fig. 4 for the $\pi^+ n \rightarrow e^+ e^- p$ reaction [3].

Fig. 6 illustrates the relative importance of e^+e^- pair production through Bethe-Heitler and vector meson production processes in the $\gamma p \rightarrow e^+ e^- p$ reaction. The cross sections displayed are fully integrated over both lepton three-momenta. There is no quantum interference between Bethe-Heitler pairs and vector meson e^+e^- decays in this case. The right-hand side of Fig. 6 shows the e^+e^- spectra produced in the $\gamma p \rightarrow e^+ e^- p$ reaction at $\sqrt{s}$=1.65 GeV. For large e^+e^- pair invariant masses, vector meson decays dominate over Bethe-Heitler pair production. Computations of lepton pair angular distributions [4] indicate that Bethe-Heitler cross sections are strongly peaked at forward angles while vector meson decays are much more isotropic. The latter can be best studied at backward angles. The $\rho - \omega$ interference in the $\gamma p \rightarrow e^+ e^- p$ reaction is constructive in both spin channels and dominated by ρ-meson production. This property is related in particular to the coupling of the $\Delta(1620)$ and $\Delta(1700)$ resonances to the ρN channel. The $\gamma p \rightarrow e^+ e^- p$ reaction appears as a much cleaner process to study ρ-meson photoproduction than $\gamma p \rightarrow \pi^- \pi^+ p$, whose cross section involves a large $\Delta\pi$ component in these kinematics. The left-hand side of Fig. 6 shows that the $\gamma p \to e^+e^-p$ cross section increases very much above threshold and displays a very characteristic $\rho - \omega$ interference pattern, while Bethe-Heitler processes represent only a small background.

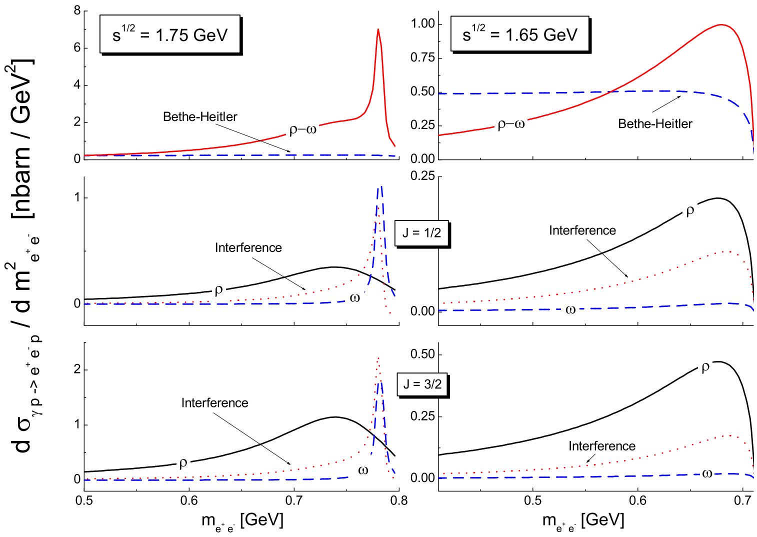

Fig. 6: Differential cross section for the $\gamma p \to e^+e^-p$ reaction at $\sqrt{s}$=1.75 GeV and $\sqrt{s}$=1.65 GeV as function of the invariant mass of the e^+e^- pair (preliminary result) [4].

4 Conclusion

We have presented fragmentary results of an extensive theoretical study [3, 4] of the $\pi\, N \to e^+e^-N$ and $\gamma\, N \to e^+e^-N$ reactions in the resonance region. These reactions are sensitive to the coupling of low-lying baryon resonances to vector meson-nucleon channels. These couplings imply specific quantum interference patterns in the e^+e^- decays of the virtual ρ- and ω-mesons produced in these reactions. Data on these interferences would be extremely useful.

References

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