Quantum interference in the e^+e^- decays of ρ^0- and ω-mesons produced in π^-p reactions

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Abstract

The study of the $\pi^- p \to \rho^0 n$ and $\pi^- p \to \omega n$ amplitudes close and below the vector meson production threshold ($1.2 < \sqrt{s} < 1.8$ GeV) reveals a rich dynamics arising from the presence of specific baryon resonances in this energy range. The interference pattern of the e^+e^- decays of the ρ^0- and ω-mesons produced in π^-p reactions reflects directly this dynamics. We discuss this interference pattern in the $\pi^- p \to e^+e^- n$ reaction as function of the total center of mass energy $\sqrt{s}$. We emphasize the importance of an experimental study of this reaction, which could be made with the HADES detector and the available pion beam at GSI.

1 Introduction

The coupling of light vector mesons [$\rho(770)$ and $\omega(782)$] to low-lying baryon resonances is still to a large extent unknown. This lack of information is a particularly important source of uncertainties in the theoretical description of the propagation of vector mesons in a nuclear medium, where resonance-hole states are expected to contribute largely to the dynamics.

The $\pi^- p \to \rho^0 n$ and $\pi^- p \to \omega n$ processes have been described recently in the framework of a relativistic coupled-channel model [1]. They are particular processes included in a broader scheme aiming at reproducing data on pion-nucleon elastic scattering and pion-induced production reactions involving the $\pi\Delta$, ρN, ωN, KΛ, KΣ and ηN channels. The model is restricted to s-wave scattering in the ρN and ωN channels. The corresponding s- and d-wave resonances in the πN channel are generated dynamically. The meson-baryon coupling strengths are determined from the fit to the available data on the channels included in the calculation.

The $\pi^- p \to \rho^0 n$ and $\pi^- p \to \omega n$ amplitudes are very sensitive to the presence of the s- and d-wave pion-nucleon resonances lying below the vector meson production threshold ($1.3 < \sqrt{s} < 1.7$ GeV). This point is discussed and illustrated in Section 2. Data that directly reflect these amplitudes would provide very useful constraints on the underlying dynamics. The $\pi^- p \to e^+ e^- n$ reaction appears as a particularly relevant process to study the $\pi^- p \to \rho^0 n$ and $\pi^- p \to \omega n$ amplitudes. This reaction offers the possibility to test experimentally the ρ^0 and ω strengths below threshold and the quantum interference in the $e^+ e^-$ decays of the ρ^0- and ω-mesons is very sensitive to the magnitudes and the relative phase of the production amplitudes. In Section 3 we present briefly the formalism and preliminary numerical results. The perspectives of this work are discussed in Section 4.

2 The $\pi^- p \to \rho^0 n$ and $\pi^- p \to \omega n$ amplitudes close to the vector meson production threshold

The $\pi^- p \to \rho^0 n$ and $\pi^- p \to \omega n$ amplitudes of Ref. [1] entering our calculation of the $\pi^- p \to e^+ e^- n$ reaction are displayed in Fig. 1. We shall restrict our discussion to $e^+ e^-$ pairs of invariant masses ranging from 0.5 to 0.8 GeV. The exclusive measurement of the $e^+ e^- n$ outgoing channel ensures that the $e^+ e^-$ pairs come from vector meson decays (pseudoscalar mesons decay into an $e^+ e^-$ pair and an additional photon). We recall however that only s- and d-wave pion-nucleon resonances are at present included in the model of Ref. [1]. To be complete, the description of the $\pi^- p \to e^+ e^- n$ reaction in the energy range discussed in this work ($1.2 < \sqrt{s} < 1.8$ GeV) should include also the effect of other partial waves. We will return to this question in Section 4.

The $\pi^- p \to \rho^0 n$ and $\pi^- p \to \omega n$ scattering amplitudes of Fig. 1 illustrate the importance of baryon resonances in vector meson production below threshold. These resonances induce a rich structure in both the real and imaginary parts of the amplitudes. In particular, the presence of the d-wave N*(1520) resonance is clearly reflected in the J=3/2 amplitudes for ρ^0 and ω production. This is an immediate consequence of the strong coupling of the N*(1520) to both the $\rho^0 n$ and ωn channels [1]. The strong couplings imply that there is considerable vector-meson strength in the N*-hole modes in the nuclear medium.

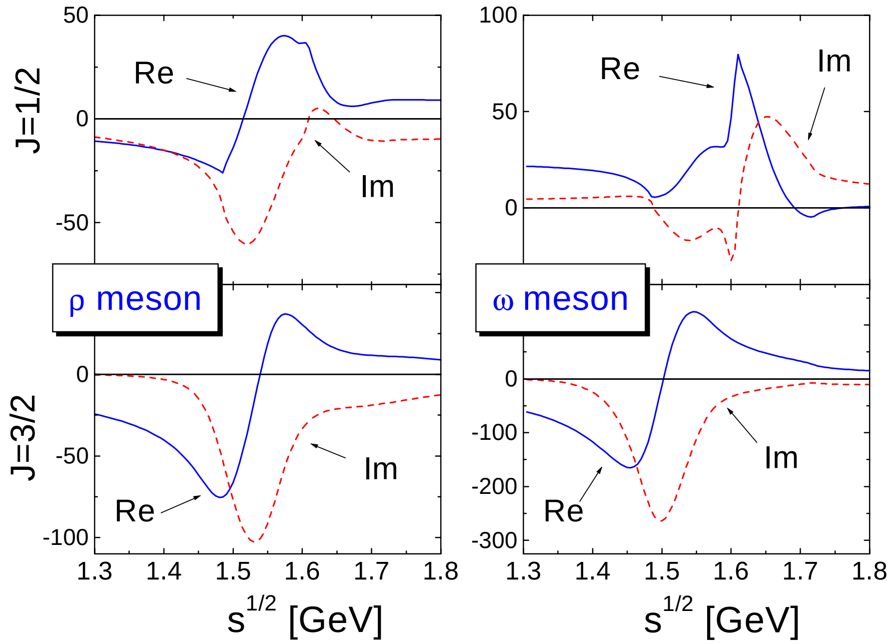

Fig. 1. Amplitudes in GeV^{-1} for the $\pi^- p \to \rho^0 n$ and $\pi^- p \to \omega n$ processes obtained in Ref. [1]. The amplitudes are averaged over isospin and shown for the two spin channels.

An experimental test of the $\mathrm{N^*N}\rho^0$ and $\mathrm{N^*N}\omega$ vertices through the $\pi^- p \to e^+e^- n$ reaction below the vector meson production threshold would be a most valuable constraint on the in-medium propagation of ρ^0- and ω-mesons.

3 The $\pi^- p \to e^+e^- n$ reaction

The $\pi^- p \to \rho^0 n$ and $\pi^- p \to \omega n$ amplitudes are simply related to the $\pi^- p \to e^+e^- n$ amplitudes through the Vector Dominance assumption [2, 3]. In this picture, the e^+e^- decay of vector mesons is described by their conversion into time-like photons which subsequently materialize into e^+e^- pairs. The magnitude of the coupling constants f_ρ and f_ω, which characterize the conversion of ρ- and ω-mesons into photons, is determined from the measured partial widths of ρ^0- and ω-mesons into e^+e^- pairs [4]. The relative phase of the ρ and ω amplitudes is not determined by hadronic observables. We determine this phase in each channel by comparing with the photon-decay helicity amplitudes of the corresponding resonance [4], assuming Vector Meson Dominance. We use f_ρ=0.036 GeV^2 and f_ω=0.011 GeV^2 [5].

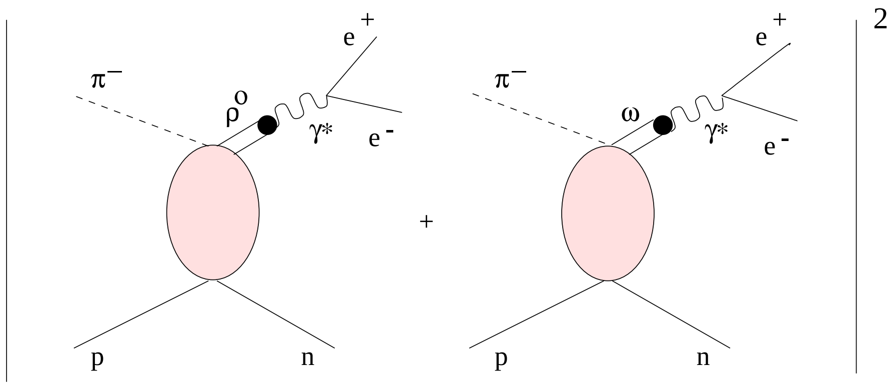

Fig. 2. Squared amplitude for the $\pi^- p \to e^+e^-n$ reaction with intermediate ρ^0- and ω-mesons.

The squared amplitude for the $\pi^- p \to e^+e^-n$ reaction with intermediate ρ^0- and ω-mesons in the Vector Dominance Model is illustrated in Fig. 2. Schematically, this quantity can be written as

$$\left|< ne^+e^-|\pi^- p >\right|^2 = \frac{\left|< e^+e^-|\gamma * >\right|^2}{m^4} \mid \frac{f_\rho \; \mathcal{M}_{\pi^- p \to \rho^0 n}}{m^2 - m_\rho^2 + i m_\rho \Gamma_\rho(m)} + \frac{f_\omega \; \mathcal{M}_{\pi^- p \to \omega n}}{m^2 - m_\omega^2 + i m_\omega \Gamma_\omega(m)} \mid^2, \quad (1)$$

where the first term of the right-hand side describes the propagation of the time-like photon and its decay into an e^+e^- pair of invariant mass m and the second term contains the vector meson production dynamics. The vector mesons are characterized by their mass m$_V$ and energy-dependent width $\Gamma_V(m)$. The interference of the complex $\mathcal{M}_{\pi^- p \to \rho^0 n}$ and $\mathcal{M}_{\pi^- p \to \omega n}$ amplitudes (Fig. 1) in the $\pi^- p \to e^+e^-n$ cross section is sensitive to their relative phase. The importance of measuring such a phase in the e^+e^- or $\pi^+\pi^-$ decays of ρ^0- and ω-mesons has been evidenced by the contribution of such data to the understanding of other processes, like the photoproduction of ρ^0- and ω-mesons in the diffractive regime ($\gamma Be \to e^+e^-Be$) [6] and the $e^+e^- \to \pi^+\pi^-$ reaction [7, 8].

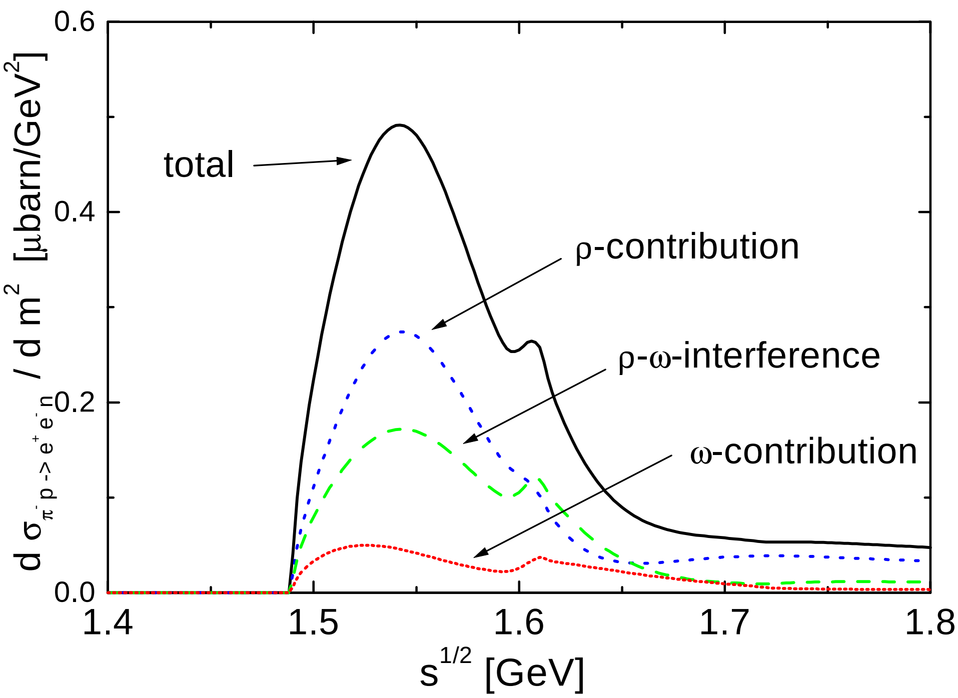

Fig. 3. Differential cross section $d\sigma/dm^2$ for the $\pi^- p \to e^+e^-n$ reaction as function of $\sqrt{s}$ for a fixed e^+e^- pair invariant mass m=0.55 GeV.

We indicate the magnitude of the $\rho^0 - \omega$ interference in the $\pi^- p \to e^+e^-n$ reaction as function of the total center of mass energy in Fig. 3. We have selected e^+e^- pairs of invariant mass m=0.55 GeV. This figure illustrates the role of baryon resonances with masses in the range of 1.5 to 1.6 GeV in generating strong interference effects.

Above the vector meson threshold, the $\rho^0 - \omega$ interference in the $\pi^- p \to e^+e^-n$ cross section is particularly interesting for e^+e^- pair invariant masses close to the ω mass. This effect is manifested in the invariant mass spectrum displayed in Fig. 4 ($\sqrt{s}$=1.8 GeV). The model of Ref. [1] for the $\mathcal{M}_{\pi^- p\to\rho^0 n}$ and $\mathcal{M}_{\pi^- p\to\omega n}$ amplitudes predicts a constructive interference at this energy. This feature appears to be a very sensitive test of the model.

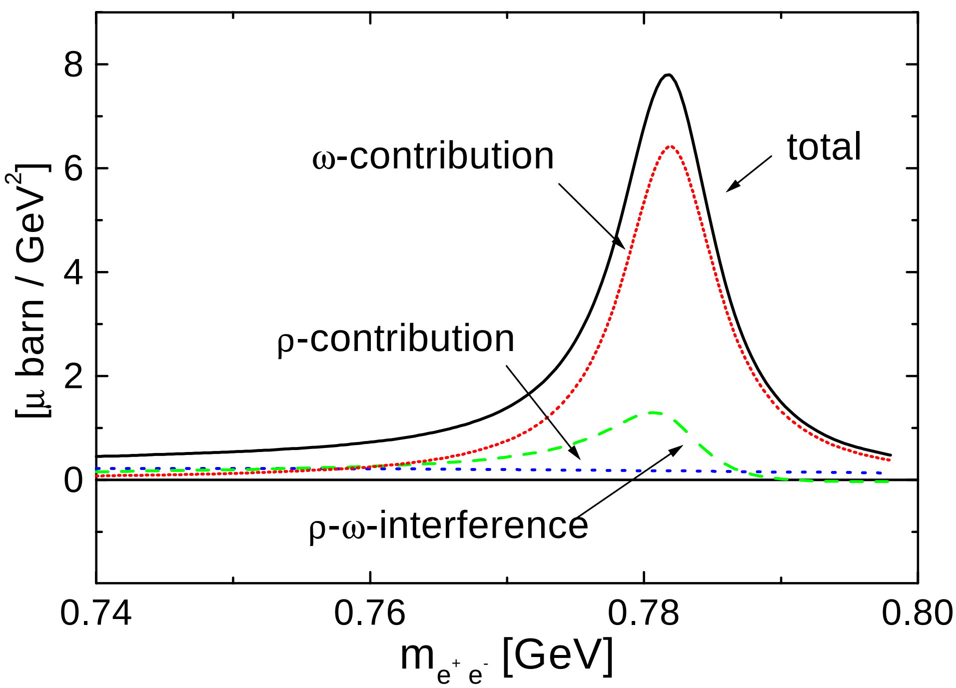

Fig. 4. Differential cross section $d\sigma/dm^2$ for the $\pi^- p \to e^+e^- n$ reaction as function of the e^+e^- pair invariant mass for a fixed total center of mass energy $\sqrt{s}$=1.8 GeV.

A detailed discussion of these interference patterns will be presented in a forthcoming publication [9].

4 Perspectives

The study of the $\pi^- p \to e^+e^- n$ reaction provides a particularly stringent test of the $\pi^- p \to \rho^0 n$ and $\pi^- p \to \omega n$ amplitudes close and below the vector meson production threshold ($1.2 < \sqrt{s} < 1.8$ GeV).

We have computed the cross section of the $\pi^- p \to e^+e^- n$ reaction using the model of Ref. [1] for the vector meson production amplitude and indicated its main features as function of the total center of mass energy.

A natural extension of the present work would be to include the p-wave pion-nucleon resonances in the coupled channel scheme of Ref. [1], thereby increasing the expected domain of validity of the $\pi^- p \to \rho^0 n$ and $\pi^- p \to \omega n$ amplitudes. Projecting the coupled-channel amplitudes on specific s- and t-channel exchanges could be a useful step in providing a simple interpretation of our numerical results.

We note that the study of the quantum interference of ρ^0- and ω-mesons produced in the $\pi^- p \to \rho^0 n$ and $\pi^- p \to \omega n$ reactions in other channels than the e^+e^- decay ($\pi^0\gamma$ for example) may also be of interest.

Data on the $\pi^- p \to e^+e^- n$ cross section in the energy range considered in this work are at present not available. Such measurements would provide an important test of the dynamics in a reaction which is crucial for the understanding of the in-medium propagation of vector mesons.

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