MESON–NUCLEON SCATTERING AND VECTOR MESONS IN NUCLEAR MATTER*

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The properties of vector mesons in nuclear matter are discussed. I examine the constraints imposed by elementary processes on the widths of ρ and ω mesons in nuclear matter. Furthermore, results for the ρ- and ω-nucleon scattering amplitudes obtained by fitting meson-nucleon scattering data in a coupled-channel approach are presented.

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1. Introduction

The electromagnetic decay of the vector mesons into e^+e^- and $\mu^+\mu^-$ pairs makes them particularly well suited for exploring the conditions in dense and hot matter in nuclear collisions. The lepton pairs provide virtually undistorted information on the mass distribution of the vector mesons in the medium.

The lepton-pair spectrum in nucleus-nucleus collisions at SPS energies exhibits a low-mass enhancement compared to proton-proton and proton-nucleus collisions [2]. A quantitative interpretation of the lepton-pair data can be obtained within a scenario, where the effective vector-meson masses are reduced in a hadronic environment [3–6]. On the other hand, attempts to interpret the low-mass enhancement of lepton pairs in terms of many-body effects also yield good agreement with the data [7, 8]. In these calculations the broadening of the ρ meson in nuclear matter due to the interactions of its pion cloud with the medium [9–12] and the momentum dependence of the

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ρ-meson self energy due to the coupling with baryon-resonance–nucleon-hole states [13, 14] are taken into account.

Through the low-density theorem hadron-nucleon scattering data can be used to determine the self-energies of hadrons in nuclear matter at low densities. In this talk I discuss the the constraints on the imaginary part of the vector-meson self energy in nuclear matter that can be derived from elementary reactions, and present results of a coupled channel calculation of meson-nucleon scattering. The latter provides a model for the vector-meson–nucleon scattering amplitude.

2. Constraints from elementary processes

The low-density theorem states that the self energy of *e.g.* a vector meson V in nuclear matter is given by [15]

$$\Sigma_V(\rho_N) = -4\pi(1 + \frac{m_V}{m_N})\langle f_{VN}\rangle \ \rho_N + \ldots, \tag{1}$$

where m_V is the mass of the vector meson, m_N that of the nucleon, ρ_N the nucleon density and $\langle f_{VN}\rangle$ denotes the VN forward scattering amplitude f_{VN}, appropriately averaged over the nucleon Fermi sea. For the vector mesons ρ, ω and ϕ the elastic scattering amplitudes have to be extracted indirectly, *e.g.* in a coupled channel approach, which I will discuss in Section 3.

In order to avoid an extrapolation over a wide range in mass, which would introduce a strong model dependence [16], I will use only data in the relevant kinematic range to constrain the VN scattering amplitudes. As an example, I shall first discuss the implications of the data on pion-induced vector-meson production for the in-medium width of ω mesons.

Using detailed balance and unitarity one can relate the cross section for the reaction $\pi^- p \to \omega n$ to the imaginary part of the ω-nucleon scattering amplitude due to the $\pi^- p$ channel [16]

$$\sigma_{\pi^- p\to\omega n} = 12\pi \frac{k_\omega}{k_\pi^2} \,\mathrm{Im}\, \bar{f}^{(\pi^- p)}_{\omega n\to\omega n}(\theta = 0), \tag{2}$$

where $\bar{f}$ denotes the spin-averaged scattering amplitude. Close to the ωn threshold, the scattering amplitude can be expanded in powers of the relative momentum in the ωn channel q_ω. An excellent fit to the data from threshold up to $q = 120$ MeV/c^2 is obtained with $\mathrm{Im}\, \bar{f}^{(\pi^- p)}_{\omega n\to\omega n} = a + bq_\omega^2 + cq_\omega^4$, where $a = 0.013$ fm, $b = 0.10$ fm^3 and $c = -0.08$ fm^5 (see Fig. 1). The coefficient a is the imaginary part of the scattering length.

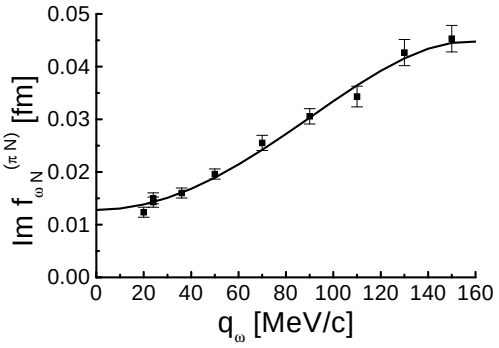


Fig. 1. The $\pi^- p$ contribution to the imaginary part of the $\omega - n$ forward-scattering amplitude obtained by a fit to the $\pi^- p \to \omega n$ data (Ref. [17]) near threshold.

The corresponding contribution of the π-nucleon channel to the width of the ω meson at rest in nuclear matter can now be obtained by using the low-density theorem (1)

$$\Delta\Gamma_\omega = 4\pi(1 + \frac{m_\omega}{m_N})\frac{3}{2}\frac{\langle \mathrm{Im}\, f^{(\pi^- p)}_{\omega n \to \omega n}\rangle\, \rho_N}{m_\omega}. \tag{3}$$

This implies that at nuclear-matter density the width of the ω meson in nuclear matter is increased by 9 MeV due to the π-nucleon channel. Other channels, like the $\pi\pi N$ channel leads to a further enhancement of the ω width in matter.

For the ρ meson the situation is more complicated. First of all the experimentally accessible πN channel is subdominant. Second, both isospin $1/2$ and $3/2$ are allowed. Thus, three independent reactions are needed to pin down the amplitudes of the two isospin channels and their relative phase. The data [18, 19] on the reactions $\pi^- p \to \rho^0 n$, $\pi^+ p \to \rho^+ p$ and $\pi^- p \to \rho^- p$ would, if measured down to threshold, be sufficient to determine the amplitudes. Unfortunately the large width of the ρ meson makes its identification close to threshold very difficult. Thus, the data even in the one channel, which is measured close to threshold $\pi^- p \to \rho^0 n$, is afflicted with a large uncertainty [20]. Clearly new data on ρ production close to threshold would be very useful.

3. Meson-nucleon scattering

In this section I describe a coupled channel approach to meson-nucleon scattering [21]. The following channels are included: πN, ρN, ωN, $\pi\Delta$ and ηN. Our goal is to determine the vector-meson–nucleon scattering amplitude

close to threshold, which in turn determines the self energy of a vector-meson at rest in nuclear matter to leading order in density.

Since we are interested in the vector-meson scattering amplitude close to threshold, it is sufficient to consider only s-wave scattering in the ρN and ωN channels. This implies that in the πN and $\pi\Delta$ channels we need only s- and d-waves. In particular, we consider the S_{11}, S_{31}, D_{13} and D_{33} partial waves of πN scattering. Furthermore, we consider the pion-induced production of η, ω and ρ mesons off nucleons. In order to learn something about the momentum dependence of the vector-meson self energy, vector-meson–nucleon scattering also in higher partial waves would have to be considered.

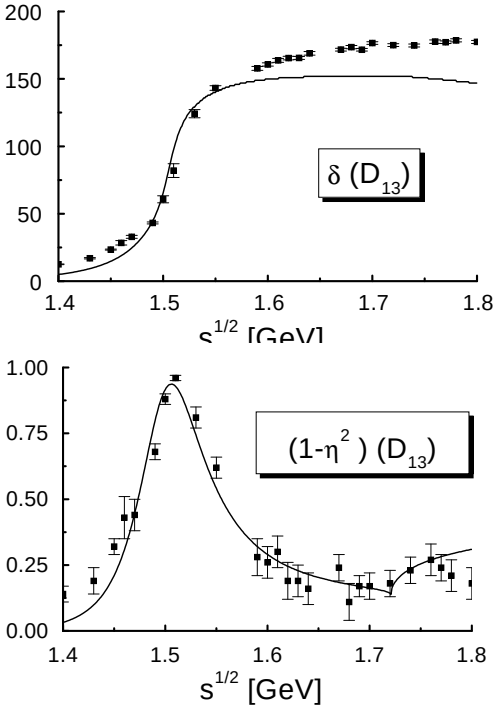


Fig. 2. The πN scattering phase shifts and inelasticity. The line shows the best fit, while the data points are those of the analysis of Arndt *et al.* [22].

In accordance with the approach outlined above only data in the relevant kinematical range will be used in the analysis. The threshold for vector-meson production off a nucleon is at $\sqrt{s} \simeq 1.7$ GeV. We fit the data in the energy range 1.45 GeV $\leq \sqrt{s} \leq 1.8$ GeV, with an effective Lagrangian with 4-point meson-meson–baryon-baryon interactions. For details the reader is referred to Ref. [21]. In Fig. 2 our fit to the πN scattering data is illustrated by the D_{13} channel. In the remaining channels the quality of the fit is in general better.

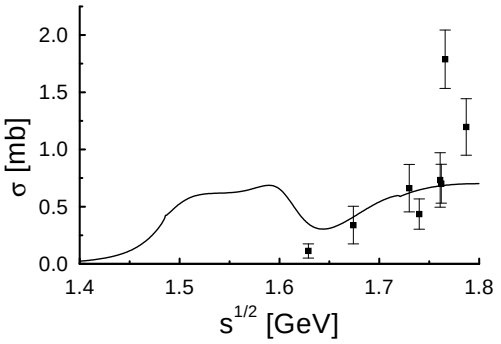


Fig. 3. The cross section for the reaction $\pi^- p \to \rho^0 n$. The data points are from Ref. [18], as given in Ref. [19]

Furthermore, in Fig. 3 the cross section for the reaction $\pi^- p \to \rho^0 n$ is shown. The bumps at $s^{1/2}$ below 1.6 GeV are due to the coupling to resonances below the threshold, like the $N^\star(1520)$. This indicates that these resonances may play an important role in the ρ-nucleon dynamics, in agreement with the results of Manley and Saleski [20]. However, the strength of the coupling is uncetrain, due to the ambiguity in the ρ-production cross section close to threshold mentioned above. We find that also the ω meson couples strongly to these resonances.

The pion-induced η-production cross section is well described up to $s^{1/2} \simeq 1.65$ GeV. At higher energies presumably higher partial waves, not included in our model, become important. Similarly, the pion-induced production of ω mesons is reasonably well represented close to threshold, although the strong energy dependence of the amplitude shown in Fig. 1 is not reproduced by the model. This may be due to the coupling to channels not included at present, like the $K - \Sigma$ channel.

The resulting ρ- and ω-nucleon scattering amplitudes are shown in Fig. 4. The $\rho - N$ and $\omega - N$ scattering lengths are (-0.2+0.7i) fm and (-0.5+0.1i) fm respectively. To lowest order in the density, this corresponds to the following in-medium modifications of masses and widths at nuclear matter density: $\Delta m_\rho \simeq 20$ MeV, $\Delta m_\omega \simeq 50$ MeV, $\Delta \Gamma_\rho \simeq 140$ MeV and $\Delta \Gamma_\omega \simeq 20$ MeV. However, the coupling of the vector mesons to baryon resonances below threshold, which is reflected in the strong energy dependence of the amplitudes, implies that in medium the vector-meson strength will be split into a meson like mode, which is pushed up in energy, and a resonance-hole like mode, which is pushed down in energy. The downward shift of vector-meson strength would contribute to the low-mass enhancement in the lepton-pair spectra. Thus, our results support the dynamical scenario discussed in Ref. [23].

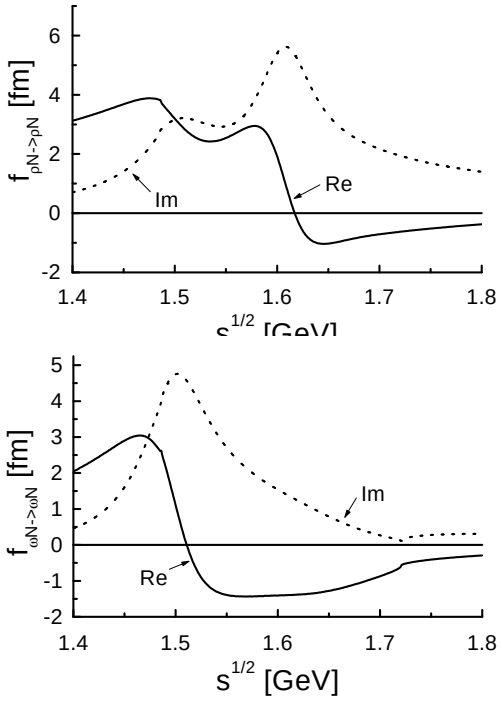


Fig. 4. The ρN and ωN scattering scattering amplitudes, averaged over spin and isospin.

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