Mesons in the nuclear Medium

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Abstract. We discuss recent experimental results on the modification of hadron properties in a nuclear medium. Particular emphasis is placed on an ω production experiment performed by the CBELSA/TAPS collaboration at the ELSA accelerator. The data shows a smaller ω meson mass together with a significant increase of its width in the nuclear medium.

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INTRODUCTION

Hadrons are composite systems bound by the strong interaction. At short ranges ($r \leq$ 0.1 fm) or high energies, the theory of strong interaction, QCD, is very well tested and confirmed by perturbative methods. However, at larger distances or at energies in the range of the lowest lying hadrons (e.g. the nucleon mass $\approx$ 1 GeV), the perturbative picture breaks down and the full complexity manifests itself in a many body structure of gluons, valence quarks and sea quarks. Consequently, the mass of a hadron consisting of light quarks (u,d,s) can not be deduced from the mass of the elementary valence quarks alone. The mass balance for the proton, e. g., is 938 MeV/c^2 comparing with $\approx$ 12 MeV/c^2 for all three current quark masses. Therefore, almost the entire mass must be generated by the strongly interacting binding field or the properties of the QCD vacuum. Embedding a hadron into a nucleus, another strongly interacting environment, should necessarily affect (and alter) its mass. Moreover, chiral symmetry is another player which is at the very heart of QCD. For massless quarks, which is very close to nature in case of u, d, s quarks, right and left handed quark fields decouple. A consequence in the hadron spectrum would be the degeneracy of opposite parity states, which is neither realized for baryons nor for mesons. The reason is the spontaneous breakdown of chiral symmetry, indicated by its measure or order parameter, the non-zero vacuum expectation value of the $\bar{q}q$ operator (chiral condensate). However, model calculations suggest a significant temperature and density dependence of the chiral condensate pointing to a partial restauration of chiral symmetry. The experimental observable consequence would be a change of hadron masses towards degeneracy of opposite parity states.

The change of hadron properties when embedded in the nuclear medium is an intensively debated field in hadron physics. Today, the qualitative and quantitative behaviour of the mass of vector mesons is at hand, triggered by a few next generation experiments [1, 2, 3]. The general method to measure a modification of a hadron mass is to produce a sufficiently short lived meson in a nuclear environment either via a heavy ion collision or in an elementary reaction on a nucleus. The ρ meson is a possible probe, since its

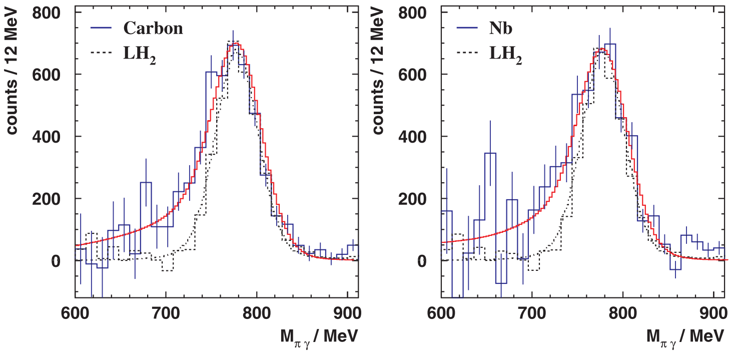

FIGURE 1. After background subtraction and for $p_\omega \leq 500$ MeV/c. Left: The ω line-shape (blue solid histogram) on C in comparison with a LH$_2$ reference signal (dashed histogram) and a Geant response simulation (dashed line). A BUU transport calculation with a 16% downward mass shift reproduces the data (red solid line) [4]. Right: The same analysis for Nb.

$c\tau = 1.3$ fm is smaller than the size of a nucleus (a few fm). Otherwise, the ρ meson is very broad (150 MeV), which makes its distinction from a $\pi\pi$ background difficult. The ω meson is an alternative probe, its $c\tau = 23$ fm is small enough to have a sufficiently high probability for a decay inside a nucleus and its vacuum width (8.5 MeV) promises a well defined signal.

THE ω MESON IN THE NUCLEAR MEDIUM

The experiment was performed at the electron stretcher accelerator (ELSA) in Bonn using the Crystal Barrel and TAPS calorimeters (see [1] for more details and [5] for a facility overview). The ω mesons were produced via the reaction $\gamma A \rightarrow \omega X$ and detected through their $\omega \rightarrow \pi^0\gamma$ decay. This channel offers a 1000 times higher branching ratio than e^+e^- measurements and a unique isolated signal since the ρ meson decay is suppressed by a factor 100, whereas di-lepton decays are of the same order for the ρ and ω. Otherwise, a distortion of the $\pi^0\gamma$ invariant mass by a possible re-scattering of the strongly interacting π^0 meson in the nucleus has to be investigated very carefully and it has been shown that the effect in the ω mass region is negligible [6, 7]. The resulting spectrum of $\pi^0\gamma$ events shows a pronounced ω peak on a smooth background, which is mainly originating from incompletely measured $\pi^0\pi^0$ events when one photon escaped detection. The background subtracted signal is shown in fig. 1 for C and Nb targets. Details of the background subtraction can be found in [1, 8]. The line-shape on the nuclear targets shows a significant tail on the low invariant mass side when compared to the reference shapes on LH$_2$ or a GEANT simulation. The extraction of an in-medium signal is less straight forward, since the decay of the ω meson occurs at different densities of the nucleus resulting in an average density of $\approx 60\%\rho_0$ for Nb and a little less for the C target. Therefore, models need to be used to separate quantitatively the integrated mass distribution m(ρ) and to unfold the spectral shape at normal nuclear matter density ρ_0. As an example, fig. 1 shows the expected line-shape within a BUU calculation with an ω mass lowered by 16% at ρ_0. Calculations with an 8% dropping

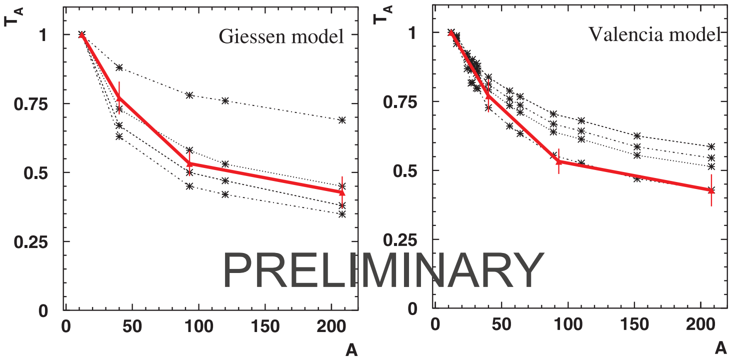

FIGURE 2. PRELIMINARY: The transparency ratio normalized on ^{12}C for the measured data (solid red line) in comparison with calculations. The best fit line corresponds to a width of $\Gamma(\rho_0, p = 0 \text{ MeV/c}) =$ 40 MeV for the Giessen model [9] and $\Gamma(\rho_0, p = 750 \text{ MeV/c}) = 95$ MeV for the Valencia model [10].

mass describe the measured data similarily well. Although, the experimental resolution of FWHM=55 MeV together with the theoretical models limit the extraction of a precise in-medium signal, a clear evidence of a dropping mass scenario for the ω meson can be concluded.

The extraction of the ω width in the nuclear medium from the measurement of the mass distribution is limited by the experimental resolution and the unfolding of the nuclear density distribution at which the ω decays. Fortunately, the measurement of the ω absorption as a function of the nuclear size allows a straight forward way to extract the (inelastic) cross section of the ω meson which can be related to its width [9, 10]. Here, the transparency ratio T_A is introduced, which is a measure of the probability for the ω meson to leave the nuclear without absorption. Fig. 2 shows T_A for the measured data in comparison to two model calculations. As a preliminary result, $\Gamma_{\text{Gi}}(\rho_0, p = 0 \text{ MeV/c}) =$ 40 MeV [9] and $\Gamma_{\text{Val}}(\rho_0, p = 750 \text{ MeV/c}) = 95$ MeV [10] can found. The width in the Giessen calculation has been computed as a function of the ω momentum and agrees at higher momenta with the Valencia value ($\Gamma_{\text{Gi}}(\rho_0, p = 750 \text{ MeV/c}) = 105$ MeV). The intuitive expectation of a significant broadening of the ω in nuclear matter as a consequence of the opening of additional partial channels (e.g. $\omega N \rightarrow NN$) can be confirmed. This topic will be elaborated in a forthcoming publication.

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