In-medium properties of the ω meson near the production threshold

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Using the CrystalBall/TAPS photon spectrometer at MAMI Mainz the ω photoproduction off nuclei (C, Nb) and off the proton (LH_2) were studied via the hadronic decay channel $\omega \to \pi^0\gamma$. The aim of this work is to investigate whether the properties of the ω meson are modified within normal nuclear matter. Two different experimental approaches have been used: the measurement of the ω lineshape and of the ω momentum distribution. Differences are expected to be most pronounced close to the production threshold ($E_{\gamma,thresh} = 1108$ MeV). Thus, the analyses were performed in the energy range 900 to 1300 MeV. Here we present the experimental results in comparison to GiBUU transport code calculations [1].

1 Introduction

The aim of this experiment is to study whether the well known vacuum mass and width of the ω meson changes in a strongly interacting environment. Possible modifications of these properties can help to understand the strong interaction in the non-perturbative sector of QCD. Hence, considerable attention has been given to this field in the last years, both from the theoretical and experimental side (e.g. [2]). The focus of this analysis is on the sector of light vector mesons where different model calculations predict relatively large changes in the mass or width. Due to the strong broadening of the ω meson in a nuclear medium [3] the sensitivity of the lineshape to in-medium modifications is reduced [4]. Whereas GiBUU calculations predict only small differences in the ω lineshape, the analysis of the momentum distribution is predicted to be more sensitive to in-medium modifications.

2 Experimental Setup

The data have been taken at the Mainz Mikrotron MAMI, using the combined detector system Crystal Ball [5] and TAPS [6]. When electrons from the accelerator with a maximum energy of $E_{e-} = 1508$ MeV hit a radiation target of 10 μm copper Bremsstrahlung photons are produced. For these anaysis energy marked photons in the range of 900 to 1300 MeV

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have been used. The Crystal Ball calorimeter comprises 672 NaI(Tl) crystals with 15.7 radiation lengths. The detector covers polar angles from 20° to 160° and the full azimuthal angle. The polar angle up to 20° in forward direction is covered by the TAPS calorimeter in a forward wall configuration. It consists of 378 BaF_2 ($\approx$ 12 X_0) and 24 $PbWO_4$ ($\approx$ 12 X_0) crystals, covering the full azimuthal angle. For charged particle identification the PID, consisting of 24 plastic scintillator bars, in the center of the Crystal Ball as well as the 5 mm thick Veto plastic scintillators, placed in front of each TAPS crystal, have been used. The three different targets LH_2, C, Nb with 30 mm in diameter and 49 mm, 15 mm, 1 mm in length, respectively, were placed directly in the center of the Crystal Ball.

3 Experimental Approach

The channel of interest is the hadronic decay mode of the ω meson into three photons in the final state:

$$\gamma A \rightarrow (A-1)\omega p \rightarrow (A-1)\pi^0\gamma p \rightarrow (A-1)\gamma\gamma\gamma p \tag{1}$$

The invariant mass of the ω meson is reconstructed using the three photon final state invariant mass, where two of the photons have to come from a π^0 decay. Since the π^0 meson can rescatter in the nuclear medium its 4-momentum can change, leading to a distortion of the ω invariant mass. To suppress these final state interactions down to the percent level a cut on the kinetic energy $T_{\pi^0} > 150$ MeV is applied (for details see [7]).
For the analyses strict time cuts ($\pm 3\sigma$) have been applied to the detector systems (CB, TAPS, Tagger) and only events are used where exactly three photons are detected within the prompt peak. A cluster threshold of 50 MeV is required to reduce the amount of split-offs. For the lineshape analysis the proton is identified using time of flight and $\Delta E/E$ techniques. For this proton a cut on the missing mass between 800 and 950 MeV is applied.
Because of the relatively long lifetime of the omega meson ($\tau = 22$ fm/c), the lineshape of the resulting $\pi^0\gamma$ invariant mass spectrum is always a superposition of vacuum and in-medium decays. Thus, to increase the amount of decays inside the nuclear medium the data have been taken close to the ω production threshold $E_{\gamma,thresh} = 1108$ MeV in the energy range 900 to 1300 MeV.

3.1 Lineshape Analysis

To extract the ω meson lineshape, the shape of the background has to be determined and subtracted. In Figure 1 (left) the $\pi^0\gamma$ invariant mass spectrum is shown. The background can be parametrized (dashed blue line) using the following equation:

$$b(x) = exp(p_0 + p_1 \cdot x + p_2 \cdot x^2 + p_3 \cdot x^3 + p_4 \cdot x^4). \tag{2}$$

In a second independent method the background is directly determined from the data. One of the main background sources comes from events with four photons in the final state ($\pi^0\pi^0$ or $\pi^0\eta$ events) where one photon is lost due to cluster overlapping or detection inefficiencies. Details can be found in [4]. Figure 1 (middle) shows the background determined from the data in magenta together with a fit through this contribution (dashed line). The good agreement of both methods can be seen in the right panel of Figure 1.

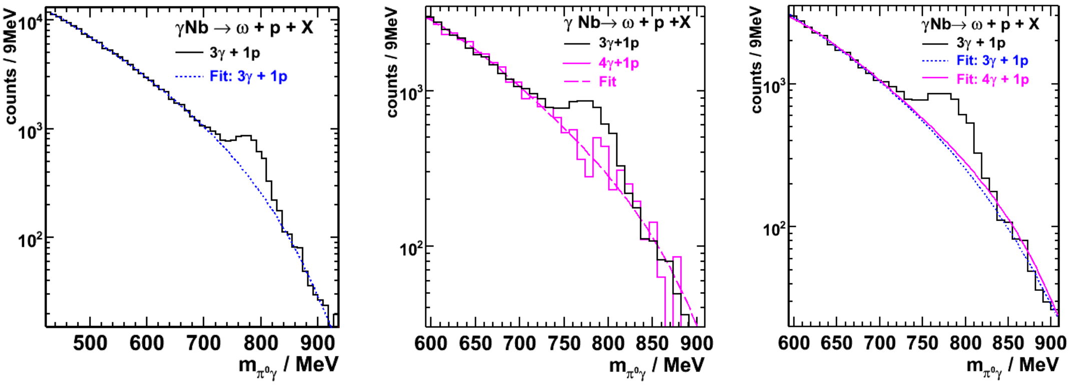

Figure 1: $\pi^0\gamma$ invariant mass spectrum for the Nb target (black). Left: The dashed blue line shows a fit of the background. Middle: The background determined directly from data (magenta) and a fit to the background contribution (dashed magenta). Right: Comparison of both background determination.

This can be verified by looking at the obtained lineshapes in Figure 2 (left). For the Nb data the background determined with the different methods is subtracted and within the error bars no significant deviations are observed.
The lineshape comparison of the three different targets provides good agreement between niobium and carbon, with a width slightly broader compared to LH_2 (see Figure 2 (middle)). In Figure 2 (right) the $\pi^0\gamma$ invariant mass spectrum is compared to different in-medium scenarios calculated with the GiBUU transport code [8]. Here the in-medium ω pole mass is modified as a function of the probed density according to:

$$m_\omega = m_\omega^0 \cdot \left(1 - 0.16 \cdot \frac{\rho_N}{\rho_0}\right) \tag{3}$$

For the scenarios including collisional broadening an in-medium width of $\Gamma_{med} = 150$ MeV has been assumed. Only small differences in the four scenarios are observed. The limited sensitivity arises from the strong broadening of the ω meson, resulting in a suppression of contributions from higher densities by order $1/\rho^2$ near the peak.

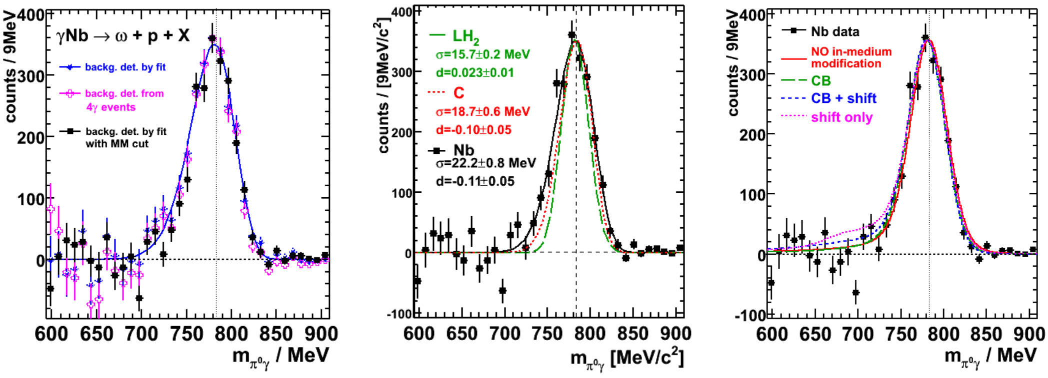

Figure 2: Left: Preliminary background subtracted $\pi^0\gamma$ invariant mass spectrum for the Nb target, applying the different background determination methods. Middle: Lineshape comparison for the three targets LH_2 (green), C (red) and Nb (black). The distortion of the lineshape due to different target thicknesses has been corrected for. Right: Background subtracted $\pi^0\gamma$ invariant mass spectrum on Nb target compared to GiBUU calculations: no modification (solid red line), collisional broadening (dashed green line), collisional broadening plus mass shift (dashed blue line) and mass shift only (dotted magenta line).

3.2 Momentum Distribution

The analysis of the momentum distribution implies information on in-medium properties at the nuclear density of the production point. Here the advantage is to be independent of any meson lifetime. For this analysis the ω yield is determined in different 50 MeV wide momentum bins from 150 MeV/c up to 1000 MeV/c. To have sufficient statistics over the full momentum range, the analysis is performed semi-exclusively without requiring the proton. In Figure 3 the experimentally observed momentum distributions (acceptance corrected) for C and Nb are compared to recent GiBUU transport calculations [9]. For comparison, the data points and the theory curves are normalized to the same area.

4 Conclusion

Although the statistics is good and improved to former experiments in this energy regime by a factor 3 (see [8]) only the "mass shift only" scenario seems to be disfavoured by the lineshape analysis. This result is confirmed by the analysis of the momentum distribution of the ω meson, which also disfavours the scenarios including a mass shift.

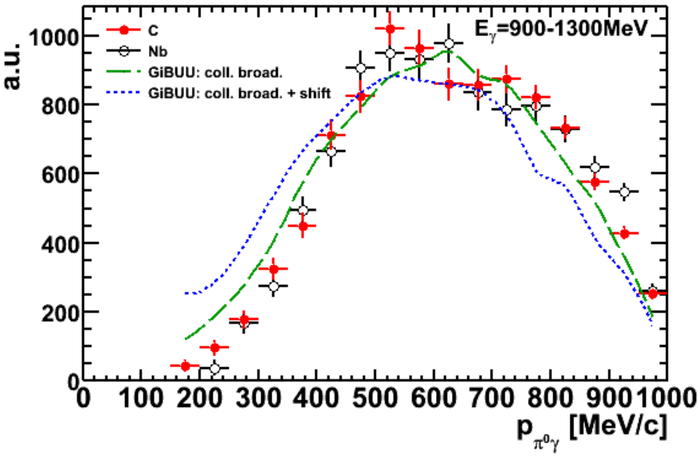

Figure 3: Momentum distribution for the two targets carbon (red points) and niobium (open circles), compared to GiBUU calculations: collisional broadening (dashed green line) and collisional broadening plus mass shift (dashed blue line).

Acknowledgments

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