In-medium $\omega$ mass from the $\gamma + Nb \rightarrow \pi^0 \gamma + X$ reaction

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(Dated: May 25, 2010)

Data on the photoproduction of $\omega$ mesons on nuclei have been re-analyzed in a search for in-medium modifications. The data were taken with the Crystal Barrel(CB)/TAPS detector system at the ELSA accelerator facility in Bonn. First results from the analysis of the data set were published by D. Trnka et al. in Phys. Rev. Lett 94 (2005) 192303 \cite{1}, claiming a lowering of the $\omega$ mass in the nuclear medium by 14\% at normal nuclear matter density. The extracted $\omega$ line shape was found to be sensitive to the background subtraction. For this reason a re-analysis of the same data set has been initiated and a new method has been developed to reduce the background and to determine the sum and of the background magnitude are described. The $\omega$ signal on the Nb target, extracted in the re-analysis, does not show a deviation from the corresponding line shape on a $LH_2$ target, measured as reference. The earlier claim of an in-medium mass shift is thus not confirmed. The sensitivity of the $\omega$ line shape to different in-medium modification scenarios is discussed.

PACS numbers: 14.40.Be, 21.65.-f, 25.20.-x

I. INTRODUCTION

Quantum Chromodynamics (QCD) has been remarkably successful in describing strong interactions at high energies ($\approx 10$ GeV) and short distances ($\approx 10^{-2}$ fm) where quarks and gluons are the relevant degrees of freedom. At these scales the strong coupling is so small ($\alpha_s \approx 0.1$) that perturbative treatments provide a first order description of the phenomena \cite{2-4}. Applying QCD at lower energies is a major challenge. In the GeV energy range the coupling strength among quarks and gluons becomes very large and hadrons - composite objects made of quarks and gluons - emerge as the relevant degrees of freedom. A rigorous way to solve QCD in this energy regime is lattice QCD. With the advent of high speed supercomputers remarkable progress has been achieved in lattice QCD simulations with dynamical $u, d,$ and $s$ quarks. Dürr et al \cite{5} have recently succeeded in reproducing masses of mesons and baryons within 3\% of the experimental values. While the properties of free hadrons are in most cases experimentally known with reasonable accuracy a possible modification of these properties in a strongly interacting medium is a much debated issue. In fact, in-medium changes of hadron properties have been identified as one of the key problems in understanding the non-
perturbative sector of QCD. Fundamental symmetries in QCD provide guidance in dealing with strong interaction phenomena in the non-perturbative domain. Furthermore, QCD sum rules have been applied to connect the quark-gluon sector to hadronic descriptions. Along these lines, QCD inspired hadronic models have been developed to calculate the in-medium self-energies of hadrons and their spectral functions. Mass shifts and/or in-medium broadening as well as more complex structures in the spectral function due to the coupling of vector mesons to nucleon resonances have been predicted. A recent overview is given in [6]. These studies have motivated widespread experimental attempts to confirm or refute these theoretical predictions.

Heavy-ion collisions and reactions with photons and protons have been used to extract experimental information on in-medium properties of hadrons. The experiments have focused on the light vector mesons and their spectral functions. Mass shifts and/or in-medium broadening as well as more complex structures in the spectral function due to the coupling of vector mesons to nucleon resonances have been predicted. A recent overview is given in [6]. These studies have motivated widespread experimental attempts to confirm or refute these theoretical predictions.

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A full consensus has not yet been reached among the different experiments. A detailed account of the current status of the field is given in comprehensive reviews [7, 8]. An in-medium broadening of the vector mesons is reported by almost all experiments and the majority of experiments does not find evidence for a mass shift. Apart from [1] only one other experiment at KEK [9] reports a drop of the $\rho$ and $\omega$ mass by 9% at normal nuclear matter density. Studying $\omega$ meson production in ultra-relativistic heavy-ion collisions, the NA60 collaboration observes a suppression of the meson yield for $\omega$ momenta below 1 GeV/c which is even more pronounced for more central collisions [10]. This is interpreted as evidence for in-medium modifications of slow $\omega$ mesons but it cannot be concluded whether this is due to a mass shift, a broadening, or both.

It should be noted that a search for mass shifts has turned out to be much more complicated than initially thought for those cases where a strong broadening of the meson is observed as for the $\omega$ [11] and $\phi$ meson [12]. In the $\omega \rightarrow \pi^0\gamma$ decay mode the increase in the total width of the $\omega$ drastically lowers the branching ratio for in-medium decays into this channel and thereby reduces the sensitivity of the observed $\omega$ signal to in-medium modifications. In this paper data on the photoproduction of $\omega$ mesons on Nb and $LH_2$ are re-analyzed which were taken with the CB/TAPS detector system at the ELSA accelerator facility in Bonn. First results from an analysis of these data were published by D. Trnka et al. [1], claiming a mass shift of the $\omega$ meson by -14% at normal nuclear matter density. This information was extracted from a comparison of the $\omega$ signals on Nb and $LH_2$, reconstructed in the $\pi^0\gamma$ channel. As pointed out in the literature [13] the deduced line shapes are very sensitive to the background subtraction. While in the initial work the background was determined by fitting the $\pi^0\gamma$ invariant mass spectrum a much more refined background determination is used in the current analysis. The paper gives a full account of the experiment and details of the analysis steps.

II. EXPERIMENTAL SETUP

A. CB/TAPS detector system at ELSA

Data on $LH_2$, C, and $Nb$ have been taken with the detector system Crystal Barrel (CB) [14] and TAPS [15, 16] at the electron stretcher facility ELSA [17, 18]. The detector setup is shown schematically in Fig. 1. Electrons extracted from ELSA with energy $E_0$ hit a primary radiation target, a thin copper or diamond crystal, and produce bremsstrahlung [19]. The energy of the bremsstrahlung photons is determined eventwise from the deflection of the scattered electrons in a magnetic field. The detector system in the focal plane of the magnet consists of 480 scintillating fibers and 14 partly overlapping scintillator bars. From the energy of the scattered electron $E_\gamma$ the energy of the photon impinging on the nuclear target is given by $E_\gamma = E_0 - E_\gamma$. Photons were tagged in the energy range from 0.5 GeV up to 2.6 GeV for an incoming electron energy of 2.8 GeV. The total tagged photon intensity was about 10$^7$ s$^{-1}$ in this energy range. The energy resolution varied between 2 MeV for the high photon energies and 25 MeV for the low photon energies, respectively. The part of the beam that did not produce any bremsstrahlung photons was deflected by the magnet as well. Since these electrons retained their full energy the curvature of their track is smaller and they passed over the tagger into a beam dump.

The Crystal Barrel (CB) detector, a photon calorimeter consisting of 1290 CsI(Tl) crystals (≈16 radiation lengths), covered the complete azimuthal angle and the polar angle from 30° to 168°. The $LH_2$, C and $Nb$ targets (30 mm in diameter, 53 mm, 20 mm and 1 mm thick, respectively) were mounted in the center of the CB, surrounded by a scintillating fibre-detector to register charged particles [20]. The CB was combined with a forward detector - the TAPS calorimeter - consisting of 528 hexagonal BaF$_2$ crystals (≈12 $X_0$), covering polar angles between 5° and 30° and the complete azimuthal angle. In front of each BaF$_2$ module a 5 mm thick plastic scintillator was mounted for the identification of charged particles. The combined CB/TAPS detector covered 99% of the full 4$\pi$ solid angle. The high granularity of this system makes it very well suited for the detection of multi-photon final states.
B. The trigger

ω mesons produced by photons on a nuclear target were identified via their ω → π0γ → γγγ decay. Events with ω candidates (3 photons in the final state) were selected with suitable trigger conditions: the first level trigger was derived from TAPS, requiring either ≥2 hits above a low threshold (A) or, alternatively, ≥1 hit above a high threshold (B). The second level trigger (C) was based on a fast cluster recognition (FACE) logic, providing the number n of clusters in the Crystal Barrel within ≈10 μs. For the data on the solid target the total trigger condition required \([A \lor (B \land C)]\), with n = 2 clusters identified on the second level (C).

C. Detector acceptance

Although the CB/TAPS detector system covers almost the full solid angle it is nevertheless very important to study the acceptance for reconstructing the reaction of interest. Monte Carlo (MC) simulations of the reaction γA → Xπn0γ have been performed for solid targets using the GEANT3 package, assuming a phase space distribution of the final state particles and taking the Fermi motion of nucleons in the target nucleus into account. The reconstruction of simulated π0γ data is done for the same trigger conditions as in the experiment and for the incident photon energy range from 900 to 2200 MeV. The acceptance as a function of the invariant mass and the momentum of the π0γ final state is shown in Fig. 1 right. In the ω mass range the acceptance is rather flat as a function of momentum and amounts to ≈ 35%.

III. ANALYSIS

A. Calibration

Since the experiment searches for possibly small mass shifts it is absolutely mandatory to verify the accuracy and stability of the photon energy calibration. The accurately known masses of the π0 and η mesons are used as calibration fix points. The invariant masses of the mesons were calculated from the measured 4 momenta of the decay photons. To ensure the stability of the photon energy calibration the invariant mass of π0- and η-mesons is checked for different momentum bins. For this check a 2-dimensional plot of the π0(η) invariant mass against the momentum \(|P|_{π(η)}\) of the π0(η) is filled and projected onto the π0(η) invariant mass axis for different slices in the momentum of the γγ pair. Changes in the π0 and η meson invariant mass with momentum are found to be less than ≤ 1.9 % and 1.3%, respectively (Fig. 2 b). The peak position of π0 at 135 MeV and of η at 547 MeV is stable for different cuts on the momentum like > 500 MeV or < 500 MeV (Fig. 2 c,d). In addition, it has been verified that the energy calibrations for the runs with different targets are in agreement. This is demonstrated in Fig. 3 which shows the signal link shapes for the π0 and η meson measured via their two photon decays for the LH2, C and Nb targets.

B. Event Selection

ω mesons were reconstructed in the reaction γA → (A − 1)πω → (A − 1)πn0γ from events with 3 photons and one proton in the final state in contrast...
FIG. 2. (Color online) a) Invariant mass of two γ's ($\pi^0 \rightarrow \gamma\gamma$ and $\eta \rightarrow \gamma\gamma$) as a function of the momentum of the 2γ pair for the Nb target. The vertical lines show the slices for the projections on the y-axis. b) The peak position of the π$^0$ and $\eta$ invariant mass in 8 slices of the momentum. The horizontal lines show the tolerance of ±2.5 MeV of the π$^0$ mass (135 MeV/c$^2$) and of ±7 MeV of the $\eta$ mass (547 MeV/c$^2$). c) The π$^0$ invariant mass for low and high momenta. d) The $\eta$ invariant mass for low and high momenta.

FIG. 3. (Color online) $\pi^0$ (a) and $\eta$ (b) invariant mass distributions reconstructed from the $\pi^0(\eta) \rightarrow \gamma\gamma$ decay for the LH$_2$, C and Nb targets.
FIG. 4. (Color online) TAPS-tagger coincidence time spectra without (a) and with (b) requiring the hit in TAPS to be due to a photon (no response in plastic scintillator in front of TAPS). The shaded areas represent the applied cuts. The peaks reside on an uniformly distributed background stemming from random coincidences.

to the analysis by D. Trnka et al. [1] where the fourth particle was not further identified. In a first step only those events were selected which had 4 hits, so called PED (particle energy deposit), in the detector system. In order to reconstruct the reaction for $\omega$ photoproduction 1 charged particle was required in coincidence with 3 neutral hits (from 4 PED data set) in the CB/TAPS detector system. The selection of the charged particles was done by using either the information from the fiber detector in the CB or the information from the plastic scintillators in front of the TAPS detector. Requesting a charged particle in addition to 3 neutral hits leads to a loss in statistics, but is essential for the background determination described in section III D.

The possible background contributions were investigated via Monte Carlo simulations. The reactions $\gamma A \rightarrow (A - 1)p\pi^0\pi^0 \rightarrow (A - 1)p4\gamma$ and $\gamma A \rightarrow (A - 1)p\pi^0\eta \rightarrow (A - 1)p4\gamma$, where one of the photons in the final state escaped detection, were found to be the dominant background sources. Furthermore the reaction $\gamma A \rightarrow (A - 1)n\pi^+\pi^0$ where the neutron and the $\pi^+$ are misidentified as a photon and a proton, respectively, also contribute to the background. For the analysis which is presented here the background was reconstructed from 5 PED events with 4 neutral and 1 charged particle (see section III D).

C. Reconstruction of the $\omega$ meson

1. Incident photon energy range

The analysis was performed for incident photon energies from 900 to 2200 MeV, i.e. starting about 200 MeV below the $\omega$ production threshold off the free nucleon $E^N_{\gamma,thresh} = 1109$ MeV. The threshold for $\omega$ production on nuclei is given by the threshold for coherent production

$$E^A_{\gamma,thresh} = m_\omega + \frac{m_\omega^2}{2m_A}$$

where the recoil momentum of the produced meson is taken up by the whole nucleus. For a Nb target Eq. 1 yields a coherent threshold energy of $E^N_{\gamma,thresh} = 786$ MeV, i.e. the threshold is even lower than 900 MeV. The choice of the incident energy interval represents a compromise between sufficiently low energies for $\omega$ production off a nuclear target and sufficient discrimination of background sources, which strongly increase with decreasing photon energies.

2. Time coincidence

For reconstructing the reaction $\gamma A \rightarrow (A - 1)p\omega \rightarrow (A - 1)p\gamma\gamma\gamma$ a prompt coincidence between a particle in TAPS and an electron in the tagger was required to eliminate time accidental background. Random time coincidences were subtracted using events outside the prompt time coincidence window. For this analysis the prompt
4. ω reconstruction

The ω meson was reconstructed and identified via the three photon final state invariant mass. According to the relation

\[ E^2 = m^2 + p^2 \]  \hspace{1cm} (2)

it is given by:

\[ m_\omega = \sqrt{(E_{\gamma 1} + E_{\gamma 2} + E_{\gamma 3})^2 - (\mathbf{p}_{\gamma 1} + \mathbf{p}_{\gamma 2} + \mathbf{p}_{\gamma 3})^2} \]  \hspace{1cm} (3)

Since the ω meson sequentially decays according to \( \omega \rightarrow \pi^0 \gamma \rightarrow \gamma \gamma \), the reconstructed particle can only be a ω meson if two of the three photons stem from a \( \pi^0 \) decay. Thus in a two-dimensional plot, plotting the two photon invariant mass (all 3 combinations) against the \( \pi^0 \gamma \) invariant mass, the ω meson must appear in this plane at the \( \pi^0 \) mass (2γ axis) and the ω mass (3γ axis). Such a plot is shown in Fig. 5 left, where all cuts described so far have been applied.

5. Sideband subtraction technique

As mentioned above, one of the channels which contribute to the background is \( \pi^0 \eta \) photoproduction with 4 photons in the final state when one of the photons escapes detection. In order to suppress this background in the \( \pi^0 \gamma \) spectrum the technique of side band subtraction was used. Monte Carlo simulations (Fig. 5 right) show that...
combining 2 $\gamma$'s from an $\eta$ decay with a $\gamma$ coming from a $\pi^0$ decay, an almost vertical band can be seen around 600 MeV on the x-axis, which appears like a bump in the $M(\pi^0\gamma)$ projection. The same is seen in the experimental data (Fig. 5 left).

To reduce this bump and to suppress the combinatorial background, side band subtraction has been applied. Fig. 6 a shows the projection on the y-axis $M(\gamma\gamma)$ for the mass range $570 \leq M(\gamma\gamma) \leq 630$ MeV. Projections on the x-axis $M(\pi^0\gamma)$ are shown in Fig. 6 b for cuts close to the pion mass: 110 to 160 MeV and left (75 to 100 MeV) and right (170 to 195 MeV) from the peak. The sum of both sideband spectra (Fig. 6 c) was normalized to the background counts under the pion peak and fitted with an exponential and Gaussian function. In the next step this curve was subtracted from the $M(\pi^0\gamma)$ spectrum over the full mass range. Fig. 6 d shows the resulting spectrum after the sideband subtraction. The bump around 600 MeV can no more be seen in the final spectrum. The background in the spectrum for masses of 400 MeV to 700 MeV is 37% lower compared to the spectrum without sideband subtraction, but the difference in the region of the $\omega$ signal from 700 MeV to 820 MeV is only 14% (Fig. 6 d). It is essential to remove this structure arising from the $\pi^0\eta$ channel as it extends towards higher masses where it may distort the $\omega$ line shape.

FIG. 6. (Color online) a) Invariant mass of two $\gamma$'s; y-projection of Fig. 5 left for a cut of $M(\pi^0\gamma)$ between 570 and 630 MeV. The shaded areas show the cuts for sideband subtraction. b) The $M(\pi^0\gamma)$ invariant mass distribution for the $\pi^0$ peak (black) and left (blue) and right (red) from the peak position as shown in a). c) The $\pi^0\gamma$ invariant mass in the $\pi^0$ peak (black) and the sum of the $M(\pi^0\gamma)$ projections left and right from the peak. The solid curve is a fit to the summed background spectrum. d) The $\pi^0\gamma$ invariant mass distribution after side band subtraction (solid curve) compared to the spectrum without sideband subtraction (dashed curve). All spectra refer to the Nb target.
6. Momentum cut

Only $\omega$ mesons decaying inside the nucleus carry information on the in-medium properties which are to be studied. To enhance the in-medium decay probability, the vector meson decay length should be comparable to nuclear dimensions. This was achieved in the analysis by applying a kinematic cut on the three momentum of the $\omega$ meson \( |p_\omega| \leq 500 \text{ MeV/c} \). But still, only a fraction of the $\omega$ mesons will decay inside the nucleus. Thus, one expects the $\pi^0\gamma$ invariant mass spectrum to show a superposition of decays outside of the nucleus at the vacuum mass with a peak position at 782 MeV/c² and of possibly modified decays inside the nucleus [21].

7. Cut on the kinetic energy of the $\pi^0$ in the final state

The disadvantage of reconstructing the $\omega$ meson in the decay mode $\omega \rightarrow \pi^0\gamma$ is a possible rescattering of the $\pi^0$ meson which was studied in [21]. The authors have demonstrated that the constraint on the pion kinetic energy $T_{\pi^0} > 150$ MeV suppresses the final state interaction down to the percent level in the invariant mass range of interest ($650 \text{ MeV} \leq M(\pi^0\gamma) \leq 850$ MeV). This result has been confirmed in transport calculations [13], [22].
D. Background Analysis

The next main step in the analysis was the determination of the background directly from the data and its absolute normalization.

1. Background reconstruction

As mentioned before, the most probable sources of background come from the reactions $\gamma A \rightarrow (A-1)p\pi^0\pi^0$ and $\gamma A \rightarrow (A-1)p\eta\eta$ with 4 $\gamma$ and one proton in the final state. Due to photon cluster overlap or detection inefficiencies one of the four photons may not be registered, thereby giving rise to a $\pi^0\gamma$ final state, which is exactly identical and therefore not distinguishable from the $\omega$ meson final state. To study this background, 5 PED events were selected with 4 neutral and 1 charged hit. One of the four neutral particles was randomly omitted and from the remaining photons a $\pi^0$ was identified and combined with the 3rd photon. The 2-dimensional plot of mass $M_{\omega\gamma}$ versus the $\pi^0\gamma$ invariant mass is similar to the plot from 4 PED events for the $\omega$ reconstruction (see Fig. 5 left). This is filled four times for all combinations with 4 photons. The side band subtraction technique was applied as described in sec. III C 5. The applied cuts on the $\pi^0\gamma$ momentum, on the kinetic energy of the pion and on the prompt peak were the same as for the $\omega$ meson reconstruction.

2. Lost photons

The slopes in the signal and background (BG) spectra shown in Fig. 7 a are different due to the different kinematics in detecting events with 4 neutral and 1 charged particle with respect to events with 3 neutral and 1 charged hits, reflecting the energy dependence of the probability that only 3 out of 4 photons are detected. The ratio of both spectra is shown in Fig. 7 b for the $C$ target. A procedure has been developed to correct the background slope in the $Nb$ spectrum using the data obtained on the carbon target which is such a light nucleus that strong in-medium effects are not expected. The correction function is derived by fitting the ratio of the spectra for the carbon data excluding the peak region, as it is shown in Fig. 7 b. The dependence of this correction on the $\pi^0\gamma$ invariant mass is confirmed by simulations (dashed curve in Fig. 7 b) studying the energy dependence of the probability to register only 3 out of 4 photons for the dominating $2\pi^0$ background channel. The $\pi^0\gamma$ background for $Nb$ from events with 4 neutral and 1 charged particles is multiplied with this correction function. As a result, the background for the $Nb$ data changes its slope.

3. Background normalization

The absolute height of the background is determined by requesting the same number of counts for the signal and background spectra in the mass range from 400 to 960 MeV, excluding the counts in the $\omega$ peak which account for only 2% of the total yield in the given mass range. Thereby, the background level is fixed without paying any attention to the $\omega$ signal region. Fig. 7 c shows the $\pi^0\gamma$ and the corrected and normalized background spectra. The ratio of these two spectra given in Fig. 7 d demonstrates that the background in the $\omega$ signal region. Fig. 7 c is properly reproduced by the background spectrum generated from the events with 4 neutral and 1 charged hits after applying the required corrections. In the invariant mass range from 400 to 700 MeV the average deviation from 1.0 is 4%. For higher invariant masses fluctuations become stronger because of the poorer statistics.

E. Results and Discussion

The $\omega$ signal shown in Fig. 8 is obtained by subtraction of the background from the signal spectrum. For comparison the $\omega$ line shape deduced in the previous analysis [1] is overlayed. Only slight differences are observed which, however, become more apparent when the signals are fitted individually. The following function [23] has been used for the fits:

$$f(x) = A \cdot \exp(-0.5(\frac{\log q_x}{d}) + d^2)$$

(4)
FIG. 9. (Color online) a) $\omega$ signal for $\pi^0 \gamma$ momenta below 500 MeV/c and kinetic energy $T_{\pi^0} > 150$ MeV (Nb target). The solid curve represents a fit with the function of Eq. 4. b) $\omega$ signal (Nb target) from the previous analysis [1] and fit with the same function. c) $\omega$ signal for a LH$_2$ target and d) $\omega$ signal from MC simulation.

where

$$q_x = 1 + \frac{(x - E_p)}{\sigma} \cdot \frac{\sinh(d)}{\sqrt{\log 4}}$$  \hspace{1cm} (5)$$

Here $A$ is the amplitude of the signal, $E_p$ is the peak energy, $\sigma$ is FWHM/2.35 and $d$ is the asymmetry parameter. This function takes into account the tail in the region of lower invariant masses resulting from the energy response of the calorimeters. Fig. 9 compares fits to the $\omega$ signal obtained in this work (Fig. 9 a) with fits to the $\omega$ signal published in [1] (Fig. 9 b), to the $\omega$ signal obtained for the LH$_2$ target (Fig. 9 c) and for a GEANT3 simulation of the $\omega$ signal (Fig. 9 d).

The fit to the $\omega$ signal from the previous analysis (Fig. 9 b) yields a width parameter $\sigma=37.2\pm2.3$ MeV which differs from the $\sigma$ values for the LH$_2$ and MC signals while the current analysis yields $\sigma=24.4\pm2.5$ MeV, consistent within errors with the LH$_2$ and MC signals which serve as a reference. The deviation from the reference signals claimed in [1] and interpreted as evidence for an in-medium mass shift of the $\omega$ meson is not confirmed in the re-analysis of the data described in this paper. The current analysis does not yield any evidence for an in-medium lowering of the $\omega$ mass. This does not necessarily mean that there is no mass shift because the $\omega$ line shape may be insensitive to in-medium modifications as pointed out in [13].

This problem is illustrated in Fig. 10 which compares the $\omega$ line shape of the present analysis to the line shape for the LH$_2$ target as well as to a prediction of the $\omega$ line
this broadening is very large as observed for the lifetime and correspondingly increasing their width. If in the nuclear medium thereby reducing their effective mass so strongly that it becomes difficult to distinguish [11] the in-medium decay contribution is spread out in 20% of all momentum to be lower than 500 MeV/c only about ρ/ρ0 to BUU simulations [25]. In addition, due to inelastic ω reactions Γmed ≫ Γvac, as in case of the ω meson [11], then Γtot ∼ ρ/ρ0. This implies that the second factor in Eq. 8 is proportional to 1/ρ and for masses ρ near the pole mass mV, also the first factor is proportional to 1/ρ, leading to a suppression of contributions from higher densities by 1/(ρ/ρ0). The sensibility of a meson production experiment is thereby shifted to the nuclear surface. In case of a strong in-medium broadening of a meson it is thus in principle difficult to detect in-medium modifications by an analysis of the signal shape since contributions from higher densities are suppressed. As a consequence the experiment becomes less sensitive to a possible mass shift. Requesting a proton in coincidence with 3 photons does not shift the sensitivity to higher densities than 2% for the kinematic conditions of the current analysis [27].

IV. SUMMARY AND CONCLUSIONS

Data on the photoproduction of ω mesons on LH2, C, and Nb have been re-analyzed, applying an improved

\[
\Gamma_{\text{med}}(\rho(r)) = \Gamma_{\text{med}}(\rho_0) \frac{\rho(r)}{\rho_0}. \tag{10}
\]

in the low density approximation. If the meson is strongly broadened in the nuclear medium due to inelastic reactions Γmed ≫ Γvac, as in case of the ω meson [11], then Γtot ∼ ρ/ρ0. This implies that the second factor in Eq. 8 is proportional to 1/ρ and for masses ρ near the pole mass mV, also the first factor is proportional to 1/ρ, leading to a suppression of contributions from higher densities by 1/(ρ/ρ0). The sensibility of a meson production experiment is thereby shifted to the nuclear surface. In case of a strong in-medium broadening of a meson it is thus in principle difficult to detect in-medium modifications by an analysis of the signal shape since contributions from higher densities are suppressed. As a consequence the experiment becomes less sensitive to a possible mass shift. Requesting a proton in coincidence with 3 photons does not shift the sensitivity to even smaller densities. According to GiBUU simulations the fraction of ω → πN decays at densities larger than 0.1ρ0 is thereby changed only by less than 2% for the kinematic conditions of the current analysis [27].

It should be pointed out, however, that a significant effect close to the production threshold of the ω meson, Eγ = 1109 MeV, was nevertheless predicted by the GiBUU model [28]. A data analysis confined to this energy regime is under way and will be published separately.
background determination and subtraction method. An earlier claim of an in-medium lowering of the $\omega$ mass is not confirmed. The strong broadening of the $\omega$ meson in the nuclear medium due to inelastic processes - as determined in a transparency ratio measurement - suppresses contributions to the observed $\omega$ signal from the interior of the nucleus. The branching ratio for in-medium decays into the channel of interest is drastically reduced. Thereby, the sensitivity is shifted to the nuclear surface, making the line shape analysis less sensitive to a direct observation of in-medium modifications. Data with much higher statistics will be needed to gain further insight. A corresponding experiment has been performed at the MAMI C electron accelerator using the Crystal Ball/TAPS detector setup. The analysis is ongoing.

ACKNOWLEDGMENTS

We thank the scientific and technical staff at ELSA and the collaborating institutions for their important contribution to the success of the experiment. We acknowledge detailed discussions with M. Kaskulov, U. Mosel, P. Mühlisch, E. Oset and J. Weil. This work was supported financially by the Deutsche Forschungs Gemeinschaft through SFB/TR16. The Basel group acknowledges support from the Schweizerischer Nationalfond and the KVI group from the Stichting voor Fundamenteel Onderzoek der Materie (FOM) and the Nederlandse Organisatie voor Wetenschappelijk Onderzoek (NWO).