Medium effects in the production and $\pi^0\gamma$ decay of ω-mesons in pA collisions in the GeV region*

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The question about modifications of the ω-meson properties in the nuclear medium has received a vivid attention during the last years (see [1, 2]). A meson or baryon resonance produced in hA or AA collisions can decay outside or inside the target nucleus. Correspondingly, the invariant-mass distribution of the decay products for each resonance contains two components. The first component is described by a Breit-Wigner resonance with vacuum values for the mass M_0 and width Γ_0. The second component is strongly distorted by the nuclear medium due to collisional broadening $\Delta\Gamma$ and a possible mass shift ΔM, where, in first approximation, $\Delta\Gamma$ and ΔM are proportional to the nuclear density. In principle, medium modifications of ω mesons can be detected directly measuring the dilepton invariant mass spectra in hA and AA collisions. The advantages of this method are related to the fact that the dilepton mass spectra are almost undistorted by the final state interaction. However the ω-signal in the dilepton mode is weak ($BR(\omega \to e^+e^-) \simeq 7.1 \times 10^{-5}$ and is always accompanied by a comparatively large background from ρ^0 decays. From this point of view it is useful to consider also the $\omega \to \pi^0\gamma$ decay which has a branching ratio of about 3 orders of magnitude higher (see [3, 4]). As it was shown in Ref. [4] the effect of the ω mass shift in $\pi^0\gamma$ invariant mass distribution can be separated from the background which is related to π^0N rescattering. Here we consider additional criteria which might help to separate the $\omega \to \pi^0\gamma$ signal in pA collisions at GeV energies from other sources of background.

The yields of ω-mesons in the reaction $pA \to \omega X$ at 2.4 GeV were calculated within the framework of the Intranuclear Cascade Model (INC). The propagation of the ω-resonance in nuclear medium (as well as its mass shift and collisional broadening) is described here in the same way as in Ref. [2] where the INC model was used for the analysis of medium effects in the production of ω's in pion-nucleus reactions.

In Figs. 1 and 2 we present the $\pi^0\gamma$ invariant mass distributions for p+Pb and p+C, respectively. Fig. 1a) and 2a) show the invariant mass distributions when medium effects are not taken into account and all the distortion of the $M(\pi^0\gamma)$ spectrum from ω decay is caused by π^0 rescattering. Figs. 1b)-1c) and 2b)-2c) demonstrate the $\pi^0\gamma$ invariant mass spectrum when only collisional broadening $\Delta\Gamma$ (b) and both medium effects $\Delta\Gamma + \Delta M$ (c) are taken into account. The hatched areas in Figs. 1a)-1c)and 2a)-2c) show the events with rescattered pions. The dotted histograms in Figs. 1a)-1c) and 2a)-2c) describe the events with ω's decaying outside, while the dashed ones correspond to ω's decaying inside nucleus with their rescattering switched off. The different contributions are compared in Figs. 1d) and 2d) where the histograms correspond to the calculations without

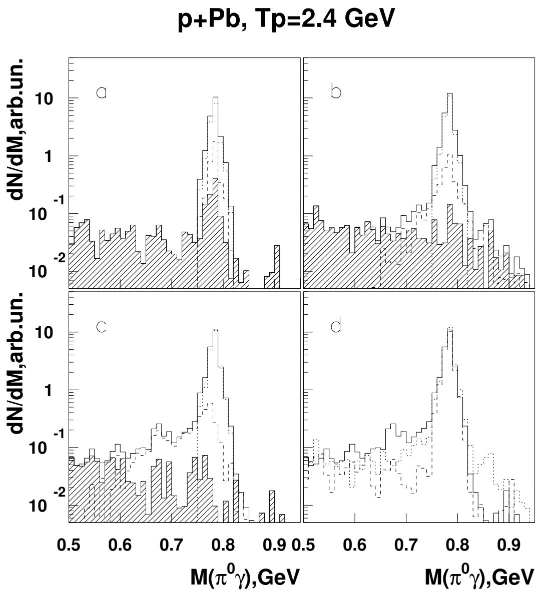

Figure 1: The $\pi^0\gamma$ invariant mass distriutions in $p + Pb$ collisions at 2.4 GeV. The meanings of the curves on the diagrams a),b),c) and d) are explained in the main text.

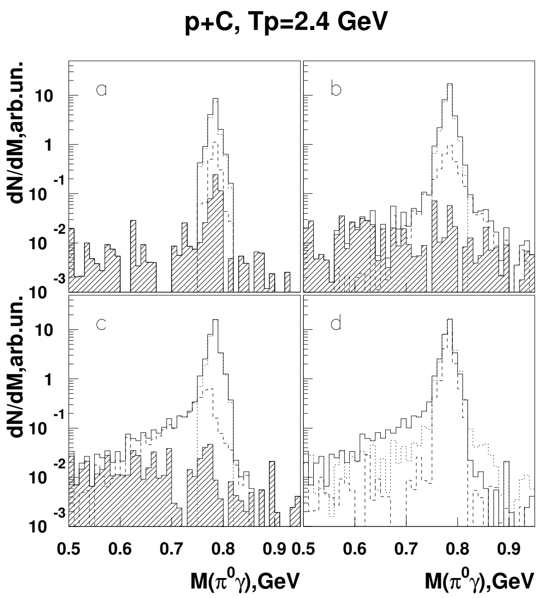

Figure 2: Same as in Fig. 1 for $p + C$ collisions at 2.4 GeV.

medium effects (dashed), with collisional broadening $\Delta\Gamma \neq 0$ but wihout mass shift $\Delta M = 0$ (dotted) and with collisional broadening $\Delta\Gamma \neq 0$ and mass shift $\Delta M \neq 0$ (solid) (treated in the same way as in Ref. [2]). In the region $M(\pi^0\gamma) = 0.65$-0.75 GeV there is a significant enhancement in the spectrum due to medium effects (solid histograms) relative to the vacuum ω decays (dashed histogram). This is in agreement with the results of previous calculations [2]- [4].

Such an experiment might be carried out at COSY proton accelerator (Jülich) using a photon detector to look for the 3γ invariant mass distribution and selecting 2γ in the mass region of π^0. However in the mass region $M(\pi^0\gamma) = 0.65$-0.75 GeV there might also be essential 'background' from four photon final states (e.g. decay products from $2\pi^0$, $\eta\pi^0$ etc.) when one photon is missing due to the finite geometrical acceptance of the detector. There are also other sources of background: One of the most important source of three photons may be related to the reactions $\mathrm{pp} \to \mathrm{p}\Delta^+(\mathrm{p}\gamma)\pi^0(2\gamma)$ and $\mathrm{pN} \to \mathrm{p}\Delta^0(\mathrm{n}\gamma)\pi^0(2\gamma)$. This means that an additional criterion how to select the events which correspond to ω decay inside the nucleus from background is quite important.

It is possible to exploit, for example, kinematical conditions. If an ω-meson is produced not far from the threshold it should have comparatively small transverse momentum P_{T} in the lab. system. In this case we would expect that the π^0 and γ from ω decay will be strongly correlated in their transverse momenta while $\pi^0\gamma$ from the background will not have such a correlation.

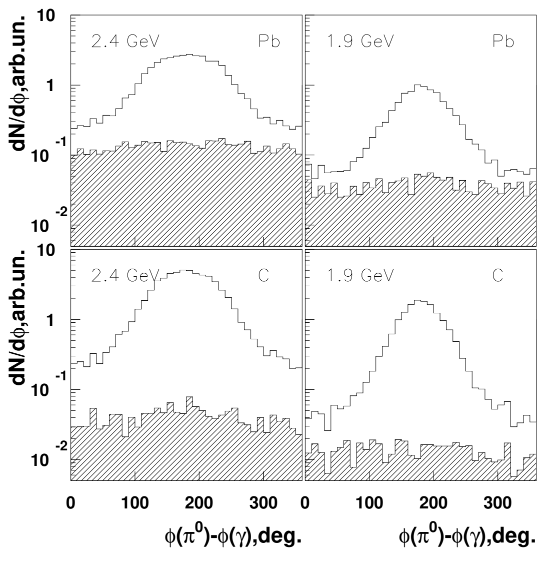

Figure 3: The distributions in azimuthal angle $\phi = \phi_{\pi^0} - \phi_\gamma$. The meanings of the histograms are explained in the main text.

To show this correlation in the case of ω decay inside nucleus we present in Fig. 3 the distributions of the azimuthal angle between two planes $\phi = \phi_{\pi^0} - \phi_\gamma$, where one plane is formed by the initial proton momentum and the π^0 momentum ($\mathbf{p}_0 \wedge \mathbf{p}_{\pi^0}$) and the second one is formed by the initial proton momentum and the γ momentum ($\mathbf{p}_0 \wedge \mathbf{p}_\gamma$). The solid histograms in Fig. 3 describe the distributions $dN/d\phi$ from p+Pb (upper) and p+C (lower) collisions at $T_{\mathrm{p}} = 2.4$ GeV (left) and 1.9 GeV (right)for ω decaying inside. The hatched histograms which describe the events with rescattered pions are completely flat and do not show any correlation between π^0 and γ. At the same time the solid histograms have distinctive maxima at $\phi = 180°$ which correspond to correlated π^0 and γ from ω decay. The width of the distribution dN/dϕ depends on the ω-meson transverse momentum P_{T}. Therefore it becomes narrower with decreasing initial energy and very close to the threshold it would depend mainly on the Fermi motion of target nucleons and effects of ω rescattering. Those effects are smaller for carbon than for lead (compare upper and lower solid histograms in Fig. 3). Nevertheless the azimuthal correlation remains quite pronounced also in Pb even at 2.4 GeV.

We also investigated how different kinematical cuts can increase the signal-to-background ratio. The in-medium modifications are found to be most pronounced for the cuts

n the total and transversal momentum of $\pi^0\gamma$ system $P_{\mathrm{tot}} \leq 0.5$ GeV/c, $P_{\mathrm{T}} \leq 0.2$ GeV/c and the azimuthal angle $\phi = \phi_{\pi^0} - \phi_\gamma = 180 \pm 30°$. For example the ratio

$$R = \frac{N(M(\pi^0,\gamma) = 0.6 - 0.75\ GeV)}{N(M(\pi^0,\gamma) \geq 0.75\ GeV)} \tag{1}$$

calculated for Pb (C) without cuts changes from 0.029 (0.008) when medium effects are absent to 0.128 (0.059) when both medium effects, collisional broadening and mass shift, are included. The calculations with cuts yield, respectively, the ratio $R =$ 0.033 (0.020) whithout medium effects and 0.401 (0.183) with collisional broadening $\Delta\Gamma \neq 0$ and mass shift $\Delta M \neq 0$ included. We thus conclude that the study of medium effects for ω in $\pi^0\gamma$ decay mode in pA collisions in the near threshold region looks to be quite promising.

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