PRAMANA
— journal of
physics

Vol. 66, No. 5
May 2006
pp. 947–952

$(\gamma, \pi^0\gamma)$ reaction on a nucleus in the GeV region

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Abstract. $\pi^0\gamma$ invariant mass distribution spectrum has been calculated for the $(\gamma, \pi^0\gamma)$ reaction on ^{12}C nucleus at 2.5 GeV beam energy. These π^0 and γ are assumed to originate due to the decay of vector mesons produced in the photonuclear reaction. The nuclear medium effect on vector mesons and the effect of π^0 rescattering on the $\pi^0\gamma$ invariant mass spectrum have been investigated.

Keywords. Vector meson photoproduction; medium effect; pion rescattering.

PACS No. 25.20.Ly

1. Introduction

Medium modification on the vector meson has drawn considerable attention in recent times. Experimentally, large medium effect is believed to have been seen in the enhanced dilepton yields in CERES and HELIOS relativistic heavy-ion reaction data [1]. This observation has prompted one to look for the hadron parameters of vector mesons in a normal nucleus. Intensive experimental programmes are there at various centers to push forward this issue [2]. Since, ω meson has relatively large decay width in the $\pi^0\gamma$ channel, the experiment on the $(\gamma, \pi^0\gamma)$ reaction had been done recently at ELSA, Germany, to explore the medium effect on the ω meson [3]. Calculations have also been performed [4] showing large medium effect on omega meson in the nucleus.

As shown in ref. [5], widths for ρ^0, ω and ϕ mesons decaying to $\pi^0\gamma$ channel are 0.12, 0.72 and 0.006 MeV respectively. The photoproduction data [6] shows $\sigma_t(\gamma p \to \rho^0 p) \approx 17$ μb, $\sigma_t(\gamma p \to \omega p) \approx 4.8$ μb, and $\sigma_t(\gamma p \to \phi p) \approx 0.3$ μb. These data show that both the production of ϕ meson, and its decay to $\pi^0\gamma$ channel could be insignificant in comparison to those due to ρ^0 and ω mesons. In addition, the mass of ϕ meson does not lie in the domain of present interest. Therefore, the present calculation for the $\pi^0\gamma$ invariant mass distribution spectrum incorporates the coherent contributions from ρ^0 and ω mesons only.

2. Formalism

As discussed above, the $\pi^0\gamma$ (seen in the photonuclear reaction) can arise due to the decay of ρ^0 and ω mesons. The coherent contribution from these mesons to the $\pi^0\gamma$ invariant mass distribution spectrum can be expressed as

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}m\mathrm{d}\Omega} = \mathrm{KF}[\Gamma(m)_{\rho^0\to\pi^0\gamma}|F_{\rho^0}|^2 + \Gamma(m)_{\omega\to\pi^0\gamma}|F_\omega|^2 + \{\Gamma(m)_{\rho^0\to\pi^0\gamma}\Gamma(m)_{\omega\to\pi^0\gamma}\}^{\frac{1}{2}}|F^*_{\rho^0}F_\omega + F_{\rho^0}F^*_\omega|], \tag{1}$$

where KF is the kinematical factor for the $(\gamma,\pi^0\gamma)$ reaction on a nucleus. $\Gamma(m)_{V\to\pi^0\gamma}$ denotes the vector meson ($V\equiv\rho^0,\omega$) decay width to the $\pi^0\gamma$ channel.

F_V, appearing in the above equation, describes the production, propagation and decay of a vector meson in the nucleus. It is given by

$$F_V = \iint \mathrm{d}\mathbf{r}\mathrm{d}\mathbf{r}'\chi^{(-)*}(\mathbf{k}_{\pi^0},\mathbf{r}')\phi^*(\mathbf{k}_{\gamma'},\mathbf{r}')G_V(\mathbf{r}'-\mathbf{r})\Pi_{\gamma N\to VN}(\mathbf{r})\phi(\mathbf{k}_\gamma,\mathbf{r}), \tag{2}$$

where $\phi(\mathbf{k}_\gamma,\mathbf{r})$ is the wave function for photon. $\chi^{(-)*}(\mathbf{k}_{\pi^0},\mathbf{r}')$ denotes the eikonally distorted wave function for the pion: $\chi^{(-)*}(\mathbf{k}_{\pi^0},\mathbf{r}) = \mathrm{e}^{-i\mathbf{k}_{\pi^0}\cdot\mathbf{r}}\times \exp[-\frac{i}{v_\pi}\int_z^\infty \mathrm{d}z' V_{O\pi^0}(\mathbf{b},z')]$. Here, $V_{O\pi^0}(\mathbf{b},z')$ is the optical potential for the π^0 nucleus scattering. $\Pi_{\gamma N\to VN}(\mathbf{r})$ describes the generalized optical potential for the vector meson photoproduction.

The vector meson propagator in a nucleus $G_V(\mathbf{r}'-\mathbf{r})$ in eq. (2) carries information about the nuclear medium effect on it. In this work, it is described by the eikonal form:

$$G_V(\mathbf{r}'-\mathbf{r}) = -\frac{i}{2k_V}\delta(\mathbf{b}'-\mathbf{b})\theta(z'-z)\mathrm{e}^{i\mathbf{k_V}\cdot(\mathbf{r}'-\mathbf{r})} \times \exp\left[\frac{i}{2k_V}\int_z^{z'}\mathrm{d}z''\tilde{G}_V^{-1}(m;\mathbf{b},z'')\right], \tag{3}$$

with $\tilde{G}_V^{-1}(m;\mathbf{r}) = m^2 - m_V^2 + im_V\Gamma_V(m) - 2E_V V_{OV}(\mathbf{r})$. Here, $\Gamma_V(m)$ and $V_{OV}(\mathbf{r})$ denote the total width and optical potential respectively for the vector meson.

The optical potential describes the medium effect on a vector meson in the nucleus. Using '$t\varrho$' approximation, the meson nucleus optical potential can be written as

$$V_{OM}(\mathbf{r}) = -(\beta_{MN}+i)\frac{\tilde{k}}{2\tilde{E}}\sigma_t^{MN}\varrho(\mathbf{r}), \tag{4}$$

where $\tilde{k}$ is the momentum in the meson nucleon cm system. $\tilde{E}$ denotes the corresponding reduced energy. σ_t^{MN} is the meson nucleon scattering cross-section, and β_{MN} is the ratio of the real to the imaginary part of the meson nucleon scattering amplitude. $\varrho(\mathbf{r})$ represents the density distribution for a nucleus, normalized to mass number of the nucleus.

3. Results and discussion

To evaluate the meson nucleus optical potential $V_{OM}(\mathbf{r})$ (see eq. (4)), it is required to use the meson nucleon scattering amplitude. Since the vector meson is an unstable particle, its scattering amplitude cannot be obtained directly from measurements. Therefore, this amplitude extracted from the vector meson photoproduction data [7] has been used in this calculation. For π^0 meson, its scattering amplitude is extracted from the available $\pi^\pm$ scattering data on a nucleon [5,8]. In this work, the $\pi^0\gamma$ invariant mass distribution spectra have been calculated for the $(\gamma, \pi^0\gamma)$ reaction on ^{12}C nucleus at 2.5 GeV beam energy. Here, it is also explored to which extent both ρ^0 and ω mesons can contribute to the $\pi^0\gamma$ invariant mass spectrum in the presence as well as in the absence of the nuclear medium. In addition to this, the effect of pion distortion on the $\pi^0\gamma$ invariant mass distribution spectrum has been investigated.

In figure 1, the calculated $\pi^0\gamma$ invariant mass distribution spectrum is shown for vector mesons and pion not interacting with the nuclear medium. In this spectrum, contribution from ω meson dominates over that for ρ^0 meson by a factor of about 400. This happens because of the rho meson getting lost due to its large decay width.

The medium interaction for a meson is described by its optical potential. In figure 2, the energy dependence of the optical potential for both ρ^0 and ω mesons is plotted. The optical potential for ω meson is larger than that for ρ^0 meson, since the latter has smaller scattering amplitude [7].

The optical potential reduces the decay length for an unstable particle: $\lambda^* = v/\Gamma^*$. Here, v and Γ^* denote the velocity and the effective width respectively for a vector meson in the nucleus. Therefore, the medium of interaction increases the decay probability. The vector meson can decay inside as well as outside the nucleus. Due to the preliminary nature of this work, the vector meson propagation only up to its effective decay length (λ^*) has been considered. In figure 3, the effect

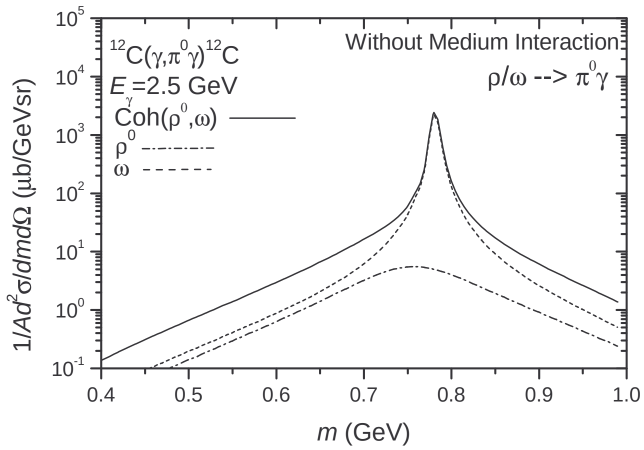

Figure 1. The $\pi^0\gamma$ invariant mass (m) distribution spectrum for both vector mesons and pion not interacting with the medium.

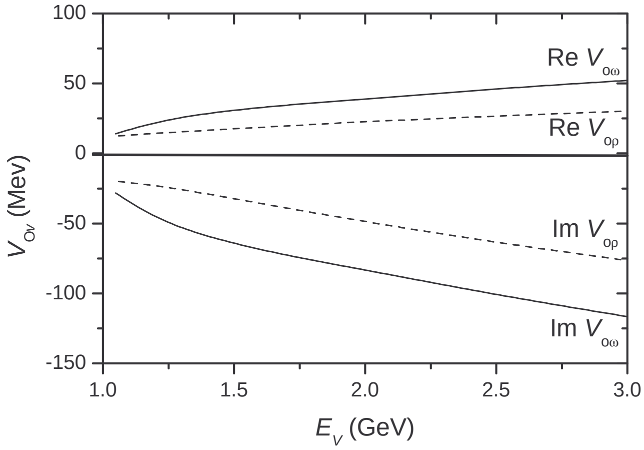

Figure 2. The energy dependence for ρ^0 and ω optical potentials.

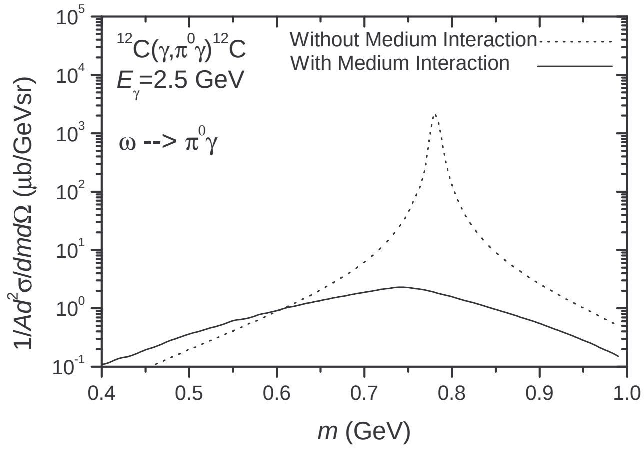

Figure 3. The effect of nuclear medium on the $\pi^0\gamma$ (due to $\omega \rightarrow \pi^0\gamma$) invariant mass ($m$) distribution spectrum.

of nuclear medium on ω meson decaying to $\pi^0\gamma$ is presented. The medium effect reduces the peak cross-section drastically, and enhances the width significantly for the $\pi^0\gamma$ invariant mass distribution spectrum. In this calculation, similar effect has been seen on ρ^0 decaying to $\pi^0\gamma$, which is not shown here. Figure 4 shows that π^0 scattering only attenuates the plane wave results by a factor of about 1.24.

In figure 5, the in-medium contributions from both ρ^0 and ω mesons to the $\pi^0\gamma$ invariant mass distribution spectrum have been compared. This figure shows that ω meson contributes five times more than ρ^0 meson. The importance of ρ^0 meson appears through the interference term, which itself, as shown in this figure, contributes almost equally as ω meson alone does.

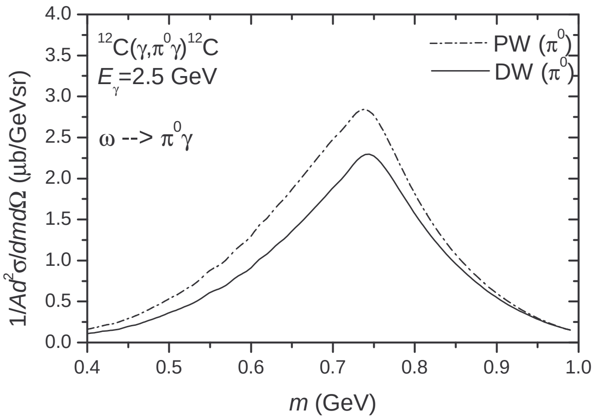

Figure 4. The effect of pion distortion on the $\pi^0\gamma$ (due to $\omega \to \pi^0\gamma$) invariant mass (m) distribution spectrum.

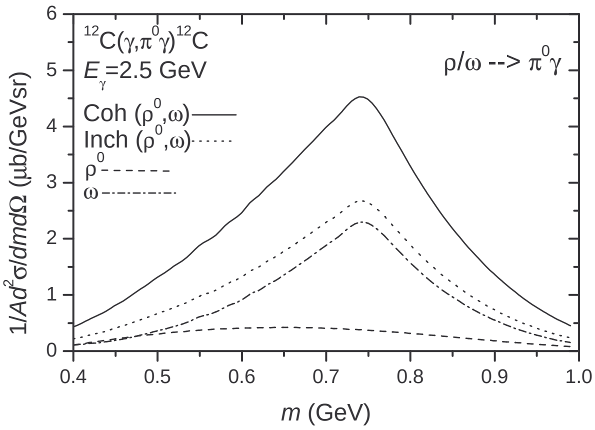

Figure 5. The coherent contribution from ρ^0 and ω mesons to the $\pi^0\gamma$ invariant mass (m) distribution spectrum.

4. Conclusion

In this study, the dynamics for vector mesons in the $\pi^0\gamma$ invariant mass distribution spectrum have been investigated. This spectrum, in the absence of medium interaction, mainly arises due to the ω decay. On the other hand, the rho meson could be important in the in-medium decay.

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