Study of medium effect on the ρ meson in the γ nucleus reaction

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The ρ meson production in the nuclear reaction has been drawn considerable attention since the CERES and HELIOS experiments [1] on the ultra-relativistic heavy ion collision at CERN indicated drastic medium modification of the ρ meson produced in this collision. This meson had been probed by its decay products, i.e., dilepton, in the final state. Because of poor resolution and statistics of the data, it was not possible to estimate quantitatively the change in mass and width of the ρ meson. To be mentioned, the upgraded CERES and NA60 experiments [2] reported the enhancement in the ρ meson width, where as the mass-shift for this meson was found insignificant. The ultra-relativistic heavy ion collision occurs far from the equilibrium at high temperature and density. Many channels contribute to the dilepton production channel. Therefore, it is very difficult to make correct interpretation of the data.

To avoid the above stated complicacies, the medium modification of the ρ meson should be searched in the normal nucleus. In view of this, the KEK-PS collaboration measured the e^+e^- invariant mass distribution spectrum in the proton nucleus reaction [3] and they have shown the reduction of ρ meson mass by ~9%. This data could be affected by the initial state interaction. The background subtraction in the analysis of this data has been criticized. The TAGX collaboration [4] has found a large decrease in ρ meson mass in the $^3He(\gamma,\pi^+\pi^-)X$ reaction at the subthreshold region. This result is questionable because of the low density of target nucleus and pion nucleus final state interaction.

The medium modification of the ρ meson can be investigated undoubtedly by the electromagnetic probe. In this context, the experiment on the ρ meson photoproduction was carried out recently at TJNAF and the broadening of the rho meson has been reported. In this experiment, the ρ meson was produced in a nucleus by the γ beam and it was detected through the e^+e^- invariant mass m distribution. The electromagnetic probe provides undistorted signal for the hadronic properties of ρ meson produced in the nucleus. To segregate out the dielectron signal from the ω meson, the data for high momentum e^+e^- pair were taken.

We are developing the formalism for the $\rho(\to e^+e^-)$ meson production in the γ nucleus reaction. According to our formalism, the elementary reaction for the ρ meson photoproduction in the nucleus is $\gamma N\to\rho N$. This meson propagates certain distance from the production point, and finally it (because of its small life-time, i.e., $\sim 10^{-23}$ sec) decays into e^+e^-. The ρ meson (during its propagation through the nucleus) interacts with the nuclear particles which can modify the hadron parameters for it in the nucleus.

The ρ meson photoproduction can be described by the generalized potential:

$$\Pi(\vec{r}) = -4\pi f_{\gamma N\to\rho N}\,\rho(\vec{r}), \qquad (1)$$

where $\rho(\mathbf{r})$ represents the density distribution of the nucleus. It is approximated by the density distribution obtained from the electron scattering data. $f_{\gamma N\to\rho N}$ denotes the amplitude for the $\gamma N\to\rho N$ reaction. The energy dependent values for it can be extracted from the measured cross section of the $\gamma N\to\rho N$ reaction.

The propagation of the ρ meson through the nucleus is described by the eikonal form. This form consists of (i) free-space propagator, and (ii) ρ meson nucleus interaction. The free-space ρ meson propagator $G_{0\rho}(m)$ is given by

$$G^{-1}_{0\rho}(m) = m^2 - m^2_\rho + i m_\rho \Gamma_\rho(m), \qquad (2)$$

where m_ρ (~770 MeV) and $\Gamma_\rho(m)$ denote the resonant mass and free-space width for the ρ meson. The later is composed of widths due to ρ meson decay into hadronic, semi-hadronic and leptonic channels [5].

The dominant decay channel for the ρ meson is hadronic, i.e., $\rho\to\pi^+\pi^-$ (~100%). The width for this channel is given by

$$\Gamma_{\rho\to\pi^+\pi^-}(m)=\Gamma_{\rho\to\pi^+\pi^-}(m_\rho)\frac{m_\rho}{m}\left[\frac{k(m)}{k(m_\rho)}\right]^3. \quad (3)$$

The value for $\Gamma_{\rho\to\pi^+\pi^-}(m_\rho)$ is ~151 MeV [5].

The contributions of the ρ meson semi-hadronic and leptonic decay widths to its total decay width are very small. Since we are studying the e^+e^- invariant mass distribution spectrum due to $\rho\to e^+e^-$, the width $\Gamma_{\rho\to e^+e^-}$ must be concerned:

$$\Gamma_{\rho\to e^+e^-}(m)\approx\frac{\alpha^2}{3}\frac{4\pi}{f_\rho^2}m, \quad (4)$$

where α is the fine structure constant. f_ρ can be obtained from the measured $\Gamma_{\rho\to e^+e^-}(m_\rho)$ [5]. It is found equal to 5.03.

The ρ meson nucleus interaction (which appears in the ρ meson propagator) is addressed by the corresponding optical potential $V_{o\rho}$. In fact, this potential causes the medium modification for the ρ meson. According to ``$t\rho$'' approximation, $V_{o\rho}$ can be written as

$$V_{O\rho}(\vec{r})=-\frac{1}{2}v_\rho[i+\beta]\sigma_t\rho(\vec{r}). \quad (5)$$

$\rho(\mathbf{r})$ appearing in this equation is discussed below Eq. (1). v_ρ represents the velocity of ρ meson. β is the ratio of the real to imaginary part of the amplitude for the rho meson nucleon (ρ*N*) scattering. σ_t denotes the corresponding total cross section. Since the ρ meson beam is not possible, the experimentally determined ρ*N* scattering parameters (i.e., β and σ_t) can't be available. But, they can be estimated from the couple channel analysis of the pion nucleon scattering in the lower and subthreshold energy regions. At higher energies, β and σ_t can be evaluated from the photoproduction data using the Vector Meson Dominance model.

We will calculate the differential cross section $d\sigma/dm$ for the e^+e^- invariant mass distribution spectrum due to $\rho\to e^+e^-$ in the photonuclear reaction. It can be written as

$$\frac{d\sigma}{dm}=\int d\Omega_\rho[KF]<|T_{fi}|^2>, \quad (6)$$

where [*KF*] stands for the kinematical factor for this reaction. $<|T_{fi}|^2>$ contains the informations about the ρ meson photoproduction (given in Eq. (1)), the propagation of ρ meson (described in Eqs. (2) & (5)), and the decay $\rho\to e^+e^-$ (see in Eq. (4)). Some results of this work may be expected in near future.

References

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