First observation of ϕ-meson mass modification in nuclear medium

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We have measured e^+e^- invariant mass spectra in 12 GeV $p + A$ interactions at the KEK Proton-Synchrotron. The aim of the experiment is to detect possible in-medium modification of vector mesons at normal nuclear density. We used carbon and copper targets to study the nuclear size dependence of the e^+e^- invariant mass spectra. A significant enhancement on the low-mass side of the ϕ meson peak was observed in the low $\beta\gamma$ region ($\beta\gamma_\phi < 1.25$) in the copper data. On the other hand, in the higher $\beta\gamma$ region ($\beta\gamma_\phi > 1.25$), both the spectral shapes obtained from carbon and copper targets were consistent with the expected one from the simulation. This observation is consistent with a picture of the ϕ modification in a nucleus, i.e. normal nuclear density, because such an effect should be visible only for slowly moving mesons produced in a larger nucleus.

1. Introduction

The properties of hadrons in medium, such as mass and width, have been one of the most interesting topics in nuclear physics. It is considered that 99% of hadron mass is generated by the spontaneous breaking of the chiral symmetry in quantum chromodynamics, and various theories predict the spectral modification of hadrons even at normal nuclear density as a precursor of chiral phase transition [1–3]. The experiment, KEK-PS

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E325, performed to detect such mass modification at normal nuclear density by measuring the decays of vector mesons, $\rho, \omega, \phi \rightarrow e^+e^-$ and $\phi \rightarrow K^+K^-$ in 12 GeV $p + A$ reactions. For the detail description of our spectrometer, see [4]. The typical acceptance for e^+e^- was from 0.5 to 2.0 in rapidity and from 1 to 3 in $\beta\gamma$ of the e^+e^- pairs. The estimated mass resolutions of our spectrometer were 8.0 MeV/c^2 for $\omega \rightarrow e^+e^-$ and 10.7 MeV/c^2 for $\phi \rightarrow e^+e^-$. We used carbon and copper targets to observe nuclear size dependence of the invariant mass spectrum. In our earlier publication [5,6], we reported the mass modification of ρ and ω mesons in nuclear medium. In this paper, we present our results for ϕ mesons. Since ϕ meson has narrow decay width(4.4MeV/c^2) and there is no other resonance near ϕ meson mass region, we are able to examine possible mass modification of ϕ meson more clearly than ρ/ω meson.

2. Results and discussion

Figure 1 shows measured e^+e^- invariant mass spectra in ϕ-meson mass region. To see the $\beta\gamma$ dependence, we divided the data into three regions, low ($\beta\gamma < 1.25$), middle($1,25 < \beta\gamma < 1.75$) and high ($1.75 < \beta\gamma$). Slowly moving ϕ meson has larger probability to decay inside a nucleus, thus the mass spectral modification is expected to be more visible in the spectra of the lower $\beta\gamma$ region. We fitted the data with ϕ meson resonance shape with a quadratic background curve. The resonance shape was obtained by a detailed detector simulation including the experimental effects which affected to the shape. The solid histograms in Fig. 1 represents the fitting results. The fitting χ^2/dof are also shown in Fig. 1. In the high- and the mid- $\beta\gamma$ regions, both the carbon and the copper data are well reproduced by the fitting. However, in low- $\beta\gamma$ region, the fitting failed for the copper target data due to an excess at the low-mass side of the ϕ meson peak.

To evaluate the amount of the excess, N_{excess}, we defined the mass region from 0.95 GeV/c^2 to 1.01 GeV/c^2 as 'excess region', and fitted the data again excluding this region. Then we integrated the amount of the excess and the number of ϕ meson, N_ϕ. The obtained $N_{excess}/(N_{excess} + N_\phi)$ are plotted in Fig. 2 as a function of $\beta\gamma$. In the low- $\beta\gamma$ region, the significant amount of the excess was observed in copper target data.

To explain the data, we performed a toy model calculation including in-medium mass modification of ϕ meson. We assumed the ϕ meson mass in nuclear medium as $m_\phi(\rho)/m_\phi(0) = 1 - k_1(\rho/\rho_0)$, where ρ_0 is normal nuclear density [2]. We also assumed the width broadening of the ϕ meson in nuclear medium as $\Gamma_\phi(\rho)/\Gamma_\phi(0) = 1 + k_2(\rho/\rho_0)$. We set the parameter $k_2 = 10$. At ρ_0, this assumption is consistent with the predicted value in [3], $\Gamma_\phi(\rho_0) \sim 47$MeV/$c^2$. The branching ratio $\Gamma_{\phi\rightarrow ee}/\Gamma_\phi$ was assumed to be unchanged in nuclear medium. This assumption is needed to account for the observed excess. The decay probability of ϕ meson inside a target nucleus will increase due to the decay width broadening. We considered that ϕ mesons were generated uniformly in the target nucleus according to the nuclear density. This assumption is supported by the fact that we have measured the mass-number dependence of the ϕ meson production cross section to be $\sigma(A) \propto A^1$ [7]. Generated ϕ mesons were traced until their decay points with the modified pole mass and the decay width according to nuclear density. We used the Wood-Saxon distribution for the nuclear density distribution; $\rho/\rho_0 \propto (1 + exp((r - R)/\tau))^{-1}$, where $R = 4.1(2.3)$ fm, $\tau = 0.50(0.57)$ fm for the copper(carbon) target. From the obtained

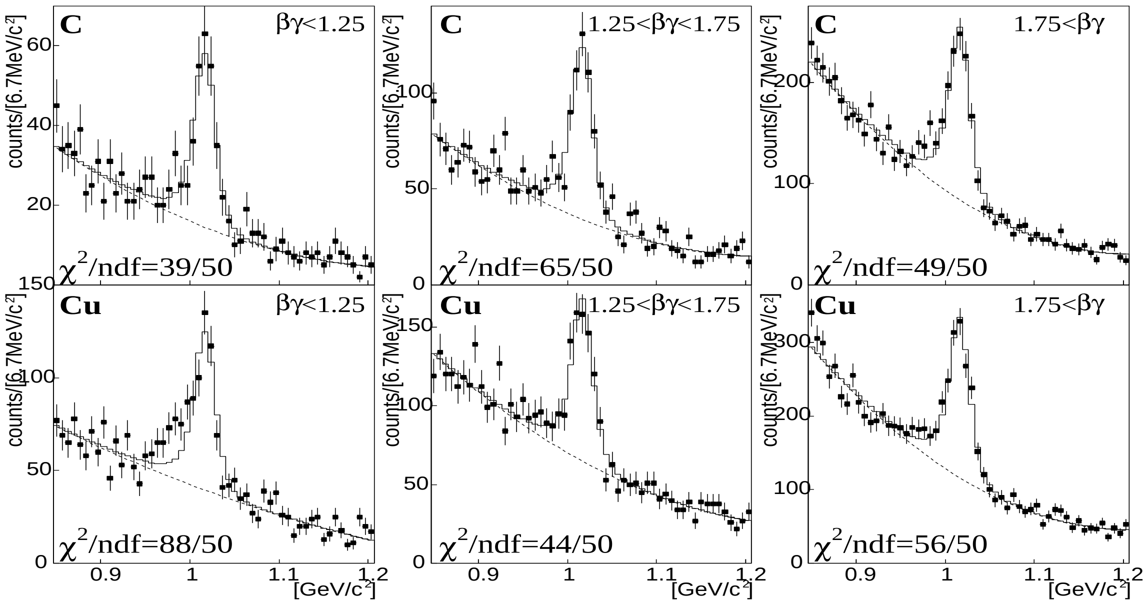

Figure 1. The e^+e^- invariant mass spectra for carbon (upper) and copper (lower) targets (preliminary results). The data are divided into three $\beta\gamma_\phi$ regions as shown in the figure. Target and $\beta\gamma$-region are shown in the each panel. The solid histograms are the fit results with expected $\phi \rightarrow e^+e^-$ shape and a quadratic background. The dotted lines represent the background.

mass spectra, we calculated the N_{excess} and N_ϕ in the same procedure as the data, except the background. The lines in Fig. 2 represent the results of the model calculations. We calculated for both case, $k_1 = 0.02$ and $k_1 = 0.04$, and the tendency of the data is reproduced by the calculation with $k_1 = 0.04$.

3. Summary

KEK-PS E325 experiment measured e^+e^- invariant mass spectra in 12 GeV $p + A \rightarrow \rho, \omega, \phi + X$ reactions. In ϕ meson mass region, we observed a significant enhancement at the low-mass side of the ϕ meson peak in the copper target data, in the $\beta\gamma_\phi < 1.25$ region. This observation is consistent with a picture of ϕ meson mass modification in nuclear medium.

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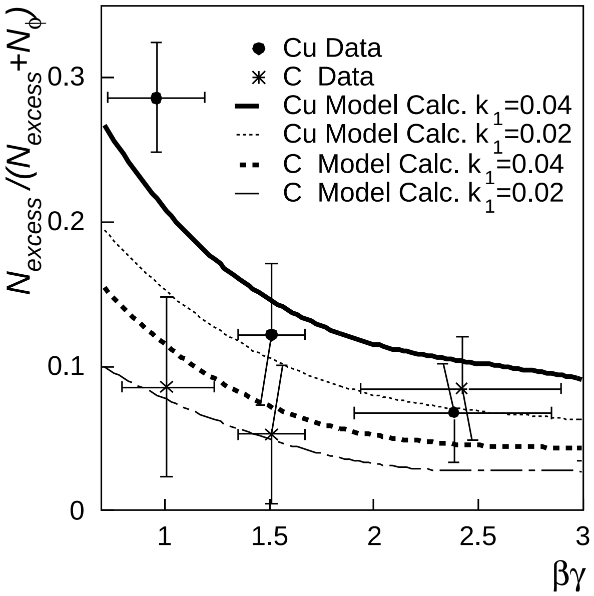

Figure 2. Obtained $N_{excess}/(N_{excess}+N_{\phi})$, bold circles are for copper targets and asterisks are for carbon target (preliminary results). The lines are the results of model calculations including in-medium mass modification as $m_{\phi}(\rho)/m_{\phi}(0) = 1 - k_1(\rho/\rho_0)$ (see text). The bold lines are for the model calculation with $k_1 = 0.04$, and the thin lines are for $k_1 = 0.02$.

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