Modification of Vector Mesons in Nuclear Matter measured in 12GeV p+A reactions at KEK-PS

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We have measured invariant mass spectra of electron-positron pairs and K^+ K^- pairs in 12GeV p+A interactions at KEK Proton-Synchrotron. The aim of the experiment is to detect in-medium modification of vector mesons, which is theoretically predicted as a consequence of partially-restored chiral symmetry. We have observed clear peaks of $\phi \to K^+K^-$ and $\omega \to e^+e^-$. The invariant mass spectra of $\phi \to K^+K^-$ have been well described with known physical processes. In the e^+e^- invariant-mass spectra, we have observed a statistically significant excess for the copper target below the ω peak over the known physical processes, which indicates that the spectral shape of meson is modified at normal nuclear-matter density.

1. INTRODUCTION

The origin of mass of hadrons have been drawing strong interest of nuclear and particle physicists. In QCD the mass of hadrons is composed of a sum of the effective mass of valence quarks, known as constituent quark mass, and their interaction term. The effective mass of valence quarks is determined by the chiral property of the QCD vacuum. This mechanism is understood as a consequence of the dynamical breaking of chiral symmetry. In hot and/or dense matter, this broken symmetry will be restored either partially or completely and, hence, the properties of hadrons can be modified. Therefore we can study the property of the QCD vacuum by measurements of the in-medium decay of vector mesons. Although, there are several theoretical approaches to the investigation of the meson modification and its density dependence [1,2], only one experimental data has addressed such a modification in dense matter [3] and further experimental data are awaited. The present experiment, KEK-PS E325, focuses on measurements of vector mesons at normal nuclear density.

The experiment, KEK-PS E325, was designed to measure the decays of the vector mesons, $\phi \to e^+e^-$, $\rho/\omega \to e^+e^-$ and $\phi \to K^+K^-$, in the kinematical region where the decay probability inside a target nucleus was enhanced ($0.6 <$ rapidity < 2.2, $0.0 < P_T < 1.5$

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GeV/c). We measured invariant mass spectra both in the e^+e^- channel and in the K^+K^- channel. The spectrometer is a double-arm type and was built at the primary beam line EP1B at 12GeV-PS in KEK.

2. RESULTS and DISCUSSION

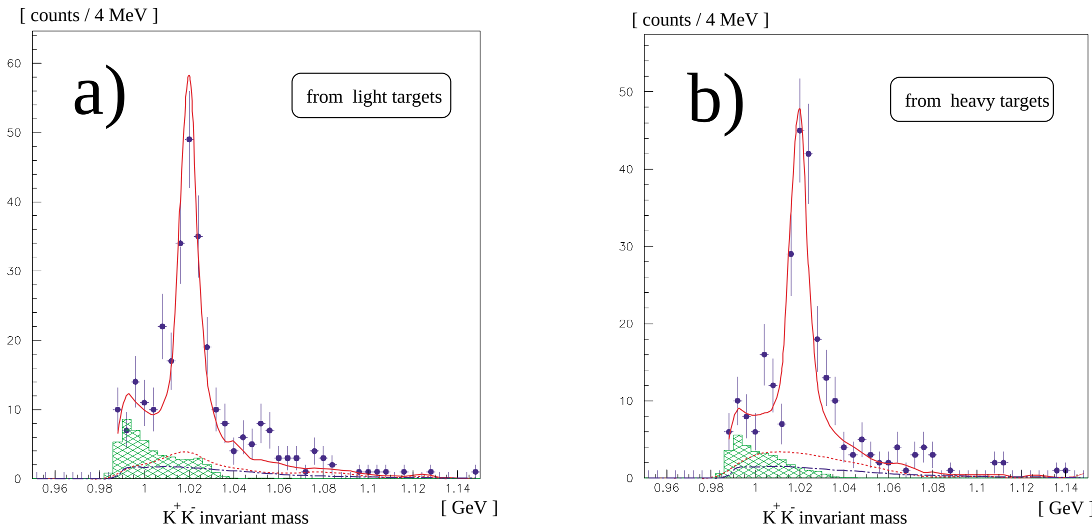

Figure 1. Invariant mass spectrum of e^+e^- pair: (a) for the light nuclear targets (C and CH_2) and (b) for the heavy nuclear targets (Cu and Gd). The full line is the fit result. The hatched histogram represents the $a_0/f_0 \rightarrow K^+K^-$ decays. The dotted line corresponds to the non-resonant K^+K^- pairs. The dot-dashed line is a background due to the particle miss-identification.

The invariant mass spectra of the K^+K^- pairs detected in a single arm are shown in Figure 1 [4]. Clear peaks corresponding to the $\phi \rightarrow K^+K^-$ decays are observed. We have reproduced the invariant mass spectra with outputs of the nuclear cascade code, JAM [5], as described below.

First of all, to verify the JAM result, obtained kinematic distributions of the ϕ mesons were compared to the output of JAM. We found that the obtained distributions were well reproduced by JAM. The mass number dependence of the ϕ production was analyzed using the standard parameterization as $\sigma(A) = \sigma(A{=}1)\times A^{\alpha}$, where A is the atomic mass number of the target nucleus. The parameter α was obtained as 1.01 ± 0.09 and 1.08 ± 0.01 from the data and JAM, respectively [4,6]. They are statistically consistent each other.

Next, we determined the relative abundance of the known sources and background. The cocktail plots in Figure 1(a) and 1(b) were obtained as the best fit results taking the followings into account; $\phi \rightarrow K^+K^-$ decays, non-resonant K^+K^-, $a_0/f_0 \rightarrow K^+K^-$ and the background component due to the particle miss identification. The mass distribution of the last item was estimated by the event mixing method. For other sources the mass distributions were obtained from the JAM outputs and smeared with the achieved mass resolution. The ratio of the abundance of non-resonant K^+K^- pairs to that of $\phi \rightarrow K^+K^-$ was fixed by the JAM results. The contribution of the miss identification was determined experimentally and was about 10% of the total number of K^+K^- pairs. Thus free parameters in the fit are only the overall normalization and the relative strength of a_0/f_0 to ϕ.

The observed spectra were well reproduced both in the light nuclear targets and the heavy nuclear targets with these four components by scaling down the yields of a_0/f_0 mesons from the JAM prediction. The ratios of a_0/f_0 to ϕ were statistically the same for both the light and heavy target samples, meaning that the two spectra are statistically identical. We thus did not observed a signature of in-medium modification of ϕ meson mass, which should appears as a significant mass number dependence of the spectrum.

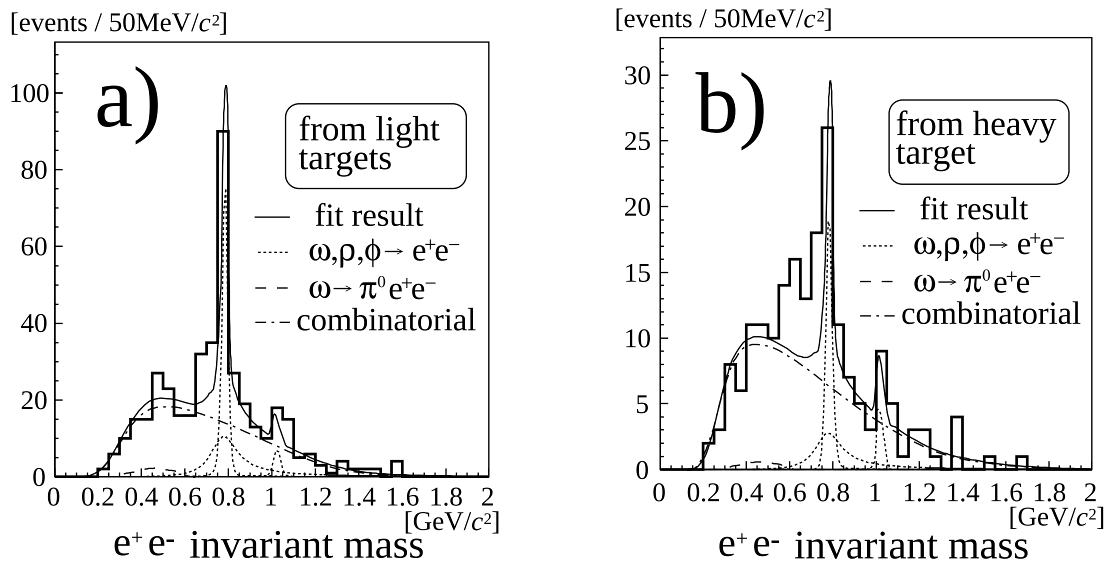

Figure 2. Invariant mass spectrum of e^+e^- pair: (a) for the light nuclear targets (C and CH_2) and (b) for the heavy nuclear target (Cu). The solid lines show the best-fit results obtained as a cocktail of the known hadronic sources and the combinatorial background. The dotted lines indicate the contributions from free decays of ρ, ω, and ϕ. The dashed lines are the $\omega \to \pi^0$ e^+e^- decays and the dot-dashed lines the combinatorial background.

Figure 2 show the obtained e^+e^- invariant mass spectra: (a) for the light nuclear targets and (b) for the heavy nuclear target [7]. Clear peaks corresponding to the $\omega \to e^+e^-$ decays are observed. These histograms depict the events when the electron and the positron are detected in the different arms, so that the low-mass part of the spectra is largely suppressed. We tried to reproduce the mass shape of the obtained histograms taking into account the combinatorial background and the known hadronic sources. As known hadronic sources, $\rho \to e^+e^-$, $\omega \to e^+e^-$, $\phi \to e^+e^-$, $\eta \to e^+e^-\gamma$, and $\omega \to e^+e^-\pi^0$ were considered. The mass shape of the ρ, ω and ϕ mesons was given as the Breit-Wigner function with the natural width, which were smeared with the estimated mass resolution. The shapes of the e^+e^- invariant mass spectra from the Dalitz decays were taken from reference [8]. To obtain the mass shape of the known sources in the observed spectra, we evaluated the experimentally mass acceptance using the JAM outputs. The distribution of the combinatorial background was obtained using the event-mixing method. The relative abundances of the known sources and the combinatorial background were obtained through fitting. We assumed that the production cross section of ρ is equal to that of ω following the data obtained at the same energy [9]. As can be seen in Figure 2, the fit results show some excess below the ω peak. We repeated the same fit procedure excluding the mass region from 550 MeV/c^2 to 750 MeV/c^2. The excess was estimated by subtracting the amplitude of the fit function from the data. As a result of the fits, the contribution of $\eta \rightarrow \gamma e^+e^-$ turned out to be negligible, and we found 75.5 $\pm$ 9.0 ω mesons and 7.4 $\pm$ 5.8 ϕ mesons from the light target and 20.0 $\pm$ 4.8 ω mesons and 5.2 $\pm$ 2.7 ϕ mesons from the copper target. The amount of the excess of the light target was 19.6 $\pm$ 11.7 and that of the copper target was 29.5 $\pm$ 8.7. The excess is statistically significant for the copper target data.

The natural explanation of the shape change is that the mass modification of ρ/ω mesons takes place inside a nucleus. Although the mass shape of the modified meson is difficult to be predicted and the trivial effect like a collisional broadening was not perfectly ruled out, it should be noted that the excess in the copper target data is visible in the mass range about 200 MeV below the ω peak, being consistent with the expected shift predicted by Hatsuda and Lee [1] or Brown and Rho[2].

In summary we have observed a clear resonance peak of $\phi \rightarrow K^+K^-$ and $\omega \rightarrow e^+e^-$ for both light and heavy nuclear targets. The invariant mass spectra of K^+K^- pairs were well described with three physical processes of $\phi \rightarrow K^+K^-$, $a_0/f_0 \rightarrow K^+K^-$ and non-resonant K^+K^- pairs given by JAM by scaling down the production yields of a_0/f_0 mesons. We have observed a statistically significant excess in the e^+e^- invariant-mass spectra at the mass region from 550 MeV/c^2 to 750 MeV/c^2 for the copper target. This excess indicates that the spectral shape of mesons are modified at normal nuclear-density matter. The data taken in 1999 and 2000 is currently being analyzed and further data accumulation is scheduled in 2001 and later. Data with larger statistics will be reported in near future.

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