Nuclear media effects on production and decay of vector meson studied in 12 GeV p+A interaction.

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The experiment E325 has been carried out at KEK-PS to investigate nuclear media effects on the invariant mass spectra of ρ, ω and ϕ mesons through their decays in the e^+e^- or K^+K^- channels. From the earlier data, the experiment has reported the signature of in-medium mass modification of ρ and/or ω mesons for the first time. This manuscript describes our preliminary results based on the data aquired in the allocated beam time of ~3200 hours, which ended in February 2002.

§1. INTRODUCTION

It is believed that the chiral symmetry, which is spontaneously broken in our world, should be restored in a system with a finite temperature and/or a finite density. Theoretically, it has been suggested that a signature of the chiral symmetry restoration could be seen as a possible mass shift of vector mesons in nuclear matter.[1)] Experiment E325 was proposed to measure the mass spectra of ρ, ω and ϕ mesons which are produced and decay in nuclei, through a determination of the invariant mass from the e^+-e^- pairs, or the K^+-K^- pairs following their decays.

A new spectrometer for the E325 experiment was designed and constructed at the 12-GeV proton synchrotron in the High Energy Accelerator Research Organization (KEK-PS). The experiment was successful to observe ω and ϕ mesons in the e^+-e^- invariant mass spectra, and reported the signature of an in-medium mass modification of the mesons[2)] from the earlier data (see Fig.1). This was the first observation in the leptonic in-medium decay of vector mesons at a normal nuclear matter density.

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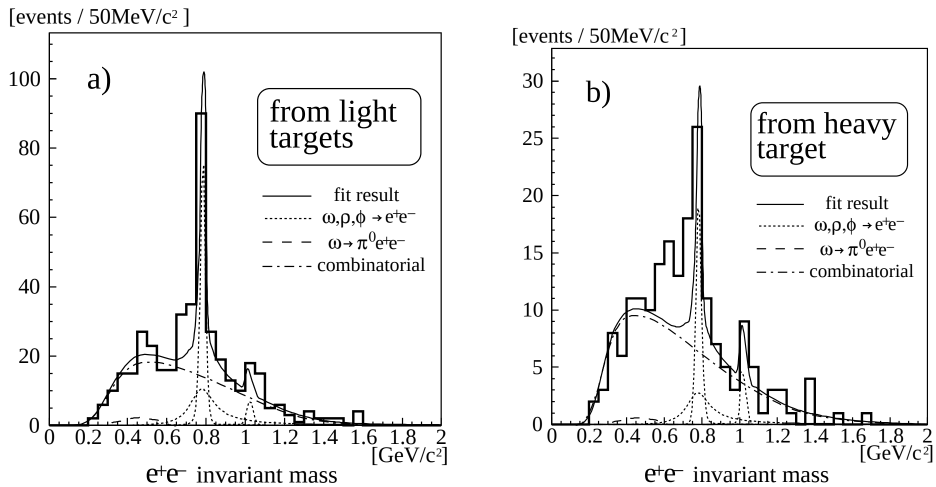

Fig. 1. Invariant mass spectra reported in our previous publication;[2)] a) is for a carbon target and b) is for a copper target. The solid lines show the best fit results of the known hadronic sources with the combinatorial background. The dotted line are the contribution from ρ, ω and ϕ meson decays. The number of excess of the carbon target is 19.6 $\pm$ 11.7 and that of the copper target is 29.5 $\pm$ 8.7.

Our observation should be compared to the results from the CERES/NA45 experiment which reported the low-mass electron pairs enhancement in Pb-Au collisions at 158 A GeV,[3)] and from the TAGX experiment which reported the signature of ρ modification in photon induced interaction on a ^3He target.[4)] Those observations including our results could be explained by a common physics behind, though the experimental verification is not sufficient yet.

The experiment E325 finished its data taking period of ∼3200 hours in five years from 1998 to 2002. We have acquired almost 100 times larger statistics compared to the previous publication,[2)] with which we will be able to provide the dispersion relation of modified ρ/ω mesons and a spectral function of ϕ mesons. In this manuscript, we introduce the experiment E325 and report our preliminary data based on the improved statistics.

§2. EXPERIMENT

The spectrometer was built at the primary beam line EP1-B of the 12-GeV proton synchrotron in KEK. This beam line was designed to transport 12-GeV protons with a maximum intensity of 4×10^9 per 2 seconds spill with a 4-second repetition cycle, and with a small beam halo. There are two key points concerning this spectrometer. The first is to detect slowly moving vector mesons which have a larger probability to decay inside a nucleus. The typical acceptance is $0.6 < y_{ee} < 2.2$ and $1 < \beta\gamma_{ee} < 4$. The second is to use a high-quality primary beam on thin targets. The combination of an intense beam with thin targets is essential to minimize the background by keeping the γ conversion rate below the Dalitz decay rate. In the typical data-taking condition the interaction rate is as high as 1 MHz using 1×10^9

beam protons per 2-sec spill on the three or five target disks with a total interaction length of 0.2∼0.4 %. We have used several nuclear targets; lead, copper, carbon and polyethylene (CH_2). Most of the statistics are acquired with a target configuration with five targets aligned in-line; four copper targets of 0.05% interaction length (0.6% radiation length) for each, and one carbon target of 0.2% interaction length (0.4% radiation length), separated each other by 23 mm typically.

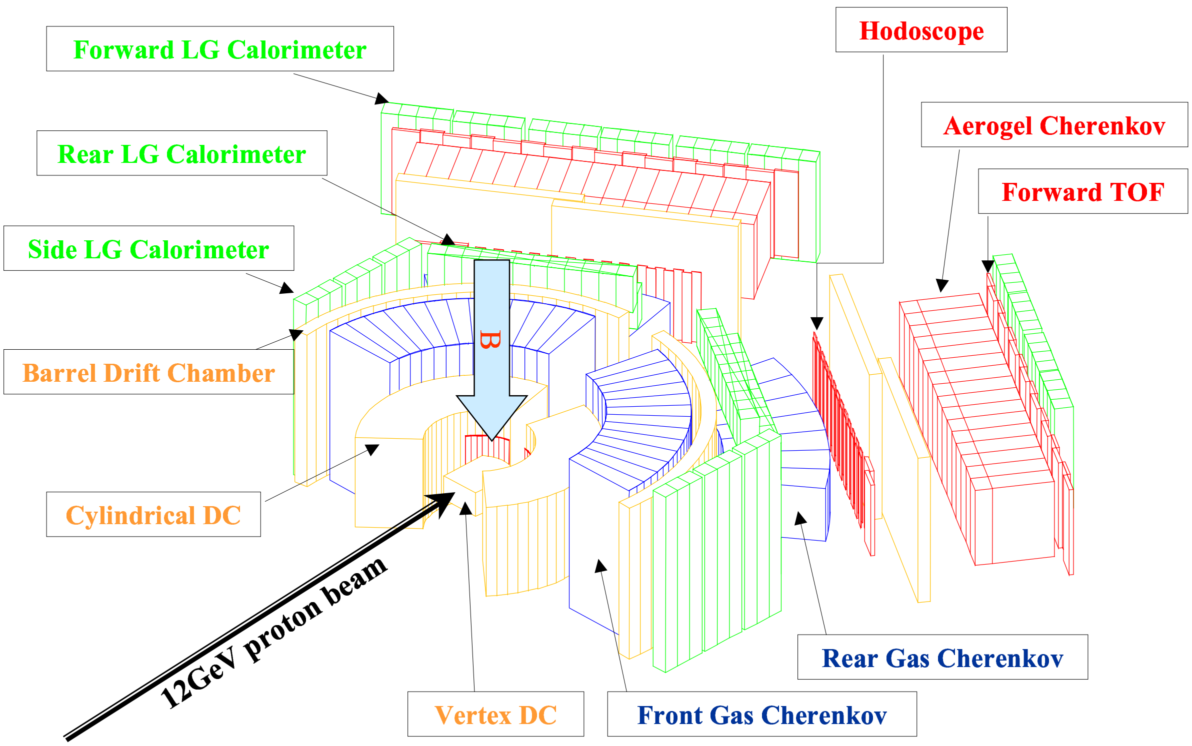

Fig. 2. Schematic view of the E325 spectrometer.

The layout of the detectors is shown in Fig. 2. The spectrometer has two electron arms and two kaon arms, which share a dipole magnet and tracking devices. The electron arms cover from ±12 degrees to ±90 degrees horizontally and ±23 degrees vertically. The kaon arms cover from ±12 degrees to ±54 degrees horizontally and ±6 degrees vertically.

Tracking has been performed with a cylindrical drift chamber (CDC) and barrel-shaped drift chambers (BDC), and with a vertex drift chamber (VTC) for a latter part of the beam time. Typical resolution of these chambers are 350 μm. The field strength at the center of the spectrometer magnet is 0.71 T and the field integral is 0.81 T·m from the center to the radius of 1600 mm, where the last tracking devices, the barrel drift chambers, are located.

For electron identification, the whole region of the electron arm is covered with two stages of electron-identification counters. The first stage of the electron identification is performed by front gas-Čerenkov counters (FGC), which cover from ±12 degrees to ±90 degrees horizontally and ±23 degrees vertically. The second stage is either gas Čerencov counters or EM calorimeters. The rear gas-Čerenkov counters (RGC) cover ±12 degrees to ±54 degrees horizontally and ±6 degrees vertically. These regions correspond to the kaon-arm acceptance. The rear lead-glass EM calorimeters (RLG) cover the same horizontal angle as RGCs, but vertically cover outside the kaon-arm acceptance, from ±6 degrees to ±23 degrees. Another set of lead glass calorimeters (forward lead-glass EM calorimeters: FLG) were recently added to improve the electron identification in the kaon arm acceptance. In the backward region, where the horizontal angle is larger than 57 degrees, second-stage electron identification is performed by side lead-glass EM calorimeters (SLG), which cover ±57 degrees to ±90 degrees horizontally and ±23 degrees vertically.

For kaon identification, segmented aerogel Čerenkov counters and time-of-flight counters are used. The aerogel Čerenkov counter (AC) is a threshold-type Čerenkov detector using aerogel, whose refractive index is 1.034, to separate kaons from pions in the momentum region of 0.53 to 1.88 GeV/c.[5),6)] Since we cannot count beam protons particle by particle, due to the high intensity, the event time-zero is given by start timing counters (STC) placed at 380 mm from the targets. The forward time-of-flight counters (FTOF) are used to measure the time of flight of particles in the kaon arm acceptance. They are also used in combination with hodoscope counters (HC) to determine the charge and the crude momentum of the particles, and to make kaon selection possible by β (v/c) measurements in the trigger.

The mass scale and the resolution were evaluated through a comparison of the observed spectra of known resonances with the Monte Carlo simulation by taking into account the chamber resolution, multiple scattering, and energy loss. The observed peak width of $\Lambda \to \mathrm{p}\pi^-$and $\mathrm{K}_s \to \pi^+\pi^-$decays were well reproduced with the simulation. The the mass resolutions for $\omega \to \mathrm{e}^+\mathrm{e}^-$, $\phi \to \mathrm{e}^+\mathrm{e}^-$and $\phi \to \mathrm{K}^+\mathrm{K}^-$were estimated to be 9.6, 12.0 MeV/c^2 and 2.4 MeV/c^2 respectively.[2)] The mass scale uncertainties are also estimated to 4, 7 and 0.3 MeV/c^2 .

The detail description of the experiment can be found elsewhere.[7)]

§3. RESULTS AND DISCUSSION

Here we only report the e^+e^- spectrum shape. The results of the K^+K^- spectrum shape and the production cross sections of measured vector mesons are reported in the references.[8)]

Figure 3 and 4 show the preliminary results for the data taken in 2002; a) is for the carbon target, and b) is for the copper targets. In the lower mass region, our acceptance is limited because we require electron pairs to be detected one in each electron arm. We have reproduced the mass shape with the combinatorial background and the known hadronic sources, $\rho \to \mathrm{e}^+\mathrm{e}^-$, $\omega \to \mathrm{e}^+\mathrm{e}^-$, $\phi \to \mathrm{e}^+\mathrm{e}^-$, $\eta \to \mathrm{e}^+\mathrm{e}^-\gamma$, and $\omega \to \mathrm{e}^+\mathrm{e}^-\pi^0$. The combinatorial background was evaluated by the event

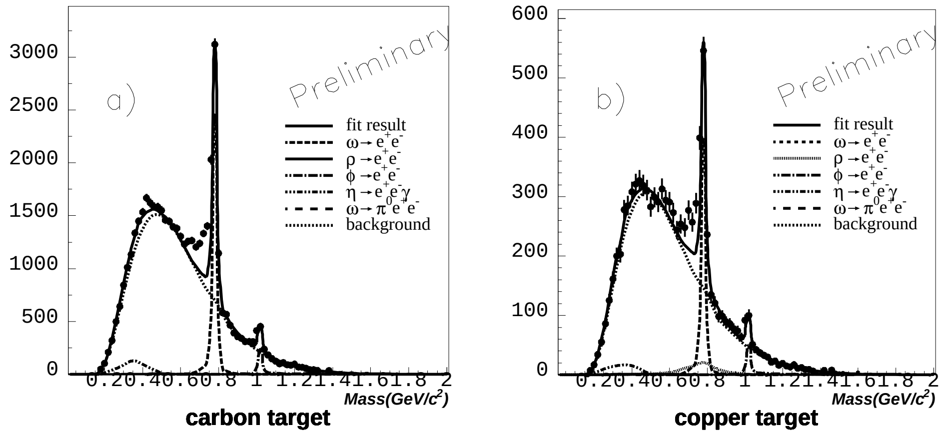

Fig. 3. Invariant mass spectra of 2002 e^+e^- data. a) is for the carbon target and b) is for the copper targets.

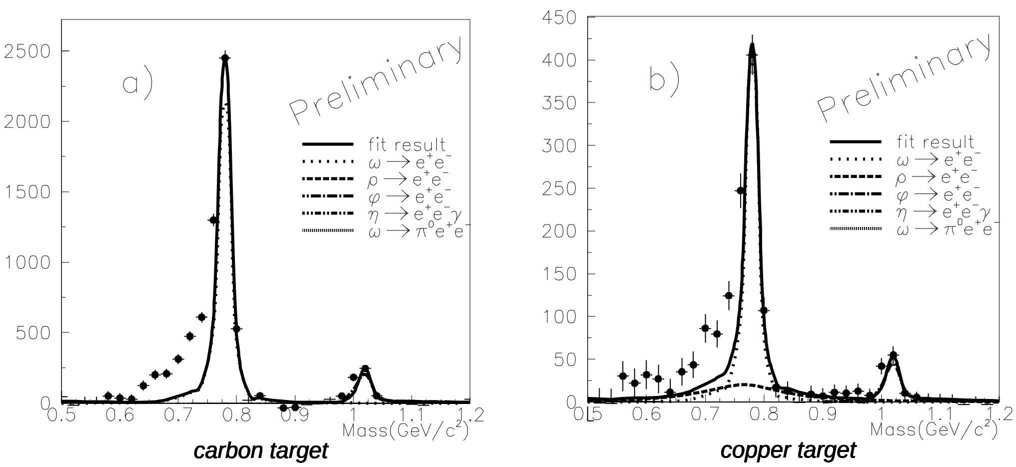

Fig. 4. Invariant mass spectra of 2002 e^+e^- data, after the subtraction of the combinatorial background; a) is for the carbon target and b) is for the copper targets.

mixing method. The mass shapes of hadrons were obtained with the nuclear cascade code, JAM,[9)] by taking the mass acceptance into account. We have convoluted the detector resolution into the spectral shapes. It should be noted that the shape change due to the radiative correction or the coulomb scattering is very small since we have employed thin targets of 0.4-0.6 % radiation length.

The relative abundances of these components were determined by the fitting. The fit results are plotted with the solid line in Fig.3. And in Fig. 4 we show the spectra after subtracting the combinatorial background. The significant excess can be seen on the low-mass side of the ω, as consistent to the previous data, and some hint below ϕ. The presented background shapes in the spectra are different from the shape in our previous paper, because the applied kinematical cut on the data is different. We are proceeding the analysis to study the momentum dependence of the spectrum change.

With these improved statistics, we are able to determine the free-decay ρ/ω ratio from the high mass tail of the spectrum. The obtained values are less than 50% for both targets, which is smaller than the known ρ/ω ratio, unity, in pp interactions.[10] Because most of ρ will be decaying inside a nucleus due to their short life time, it is natural to consider the excess is mainly dominated by the ρ meson modification.

Another important aspect of the present data is that the amount of the excess (relative to the ω peak) looks similar between the carbon and copper target data, which is at a glance inconsistent with our previous publication. It should be noted that the excess seen in our previous data is statistically significant but the shape difference is not statistically significant between the carbon and copper data. The analysis is still in progress to provide a conclusion on the nuclear size dependence of the observed mass modification.

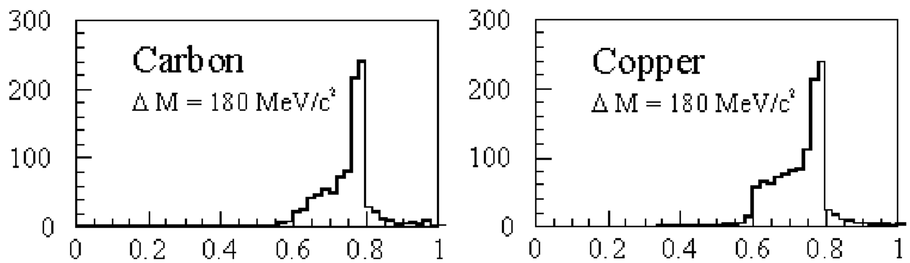

Fig. 5. Mass shape modification obtained by a Monte Carlo. See text.

We also have performed a toy model calculation for the spectral change. Figure 5 is obtained by a Monte Carlo simulation for the mesons with kinematics as we have observed, in a Wood-Saxon density distribution, with a mass shift as predicted by Hatsuda and Lee,[1] and with a in-media broadening of the widths of ρ and ω by factor 3 as suggested by Cabera *et al.*[11] At least, we can see the carbon target is big enough to have significant in-medium decays of ρ mesons, and we have a possible explanation of seeing the similar excess both in the carbon and copper data.

The key measurements is the spectral-shape modification for ϕ mesons. Answer will be obtained when we finish the analysis of all the data we have.

§4. SUMMARY

KEK-PS E325 has been performed to detect 12GeV p + A $\rightarrow$ ρ, ω and ϕ + X reactions in both $\phi \rightarrow K^+K^-$and $\phi \rightarrow e^+e^-$channels in the kinematical region where such mesons have a larger probability to decay inside a nucleus.

In the 2002 e^+e^-data, we have observed the excess over the known hadronic sources on the low-mass side of the omega peak. Obtained ρ/ω ratio for the free-space decays is significantly lower the known ρ/ω ratio in the p + p reactions. These observations support that the excess is mainly due to the modification of ρ meson.

Acknowledgements We would like to thank all the staff members of KEK-PS, especially the beam channel group for their helpful support. This work was partly supported by the Japan Society for the Promotion of Science and a Grant-in-Aid for Scientific Research from the Ministry of Education, Science, and Culture of Japan (Monbusho). We also would like to thank the computing support given from RIKEN CC-J, with which most of the present analysis was performed.

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