Study of Chiral Property of Nuclear Matter through Measurements of ϕ Meson Decays

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The experiment E325 being performed at KEK 12GeV-PS is to investigate the chiral property of QCD in dense matter through the measurements of vector mesons which decay inside nucleus. The status of the experiment and the preliminary mass distribution of $\phi \to K^+K^-$ decays are presented.

1. PHYSICS MOTIVATION

The chiral symmetry, broken in our world, is believed to be restored in the system at finite temperature and/or finite density. The order parameter of the chiral symmetry, $< \bar{q}q >$ which is not a measurable quantity, determines the vector-meson mass. It is hence theoretically predicted that possible mass shift of vector mesons can be considered as the partial restoration of the symmetry.

There has been no experimental input so far to determine the quark condensation in nuclear media which is schematically shown in Fig.1, even though there are many theoretical works have been made to establish the figure.

It should be noted that it is extremely difficult to know the time evolution of the temperature and density in the relativistic heavy ion collisions. The experiment E325 therefore has been planned to measure the property of ϕ mesons ($s\bar{s}$) at the normal nuclear density, aiming to provide the first experimental point on Fig.1. According to the predictions based on the QCD sum rule by Hatsuda and Lee [1], expected mass shift of the ϕ meson is 20-40 MeV at the normal nuclear density as shown in Fig.2. The decay branching ratios are also sensitive to the mass shift of ϕ mesons and kaons because of the small decay Q-value, 32MeV, in the K^+K^- channel.

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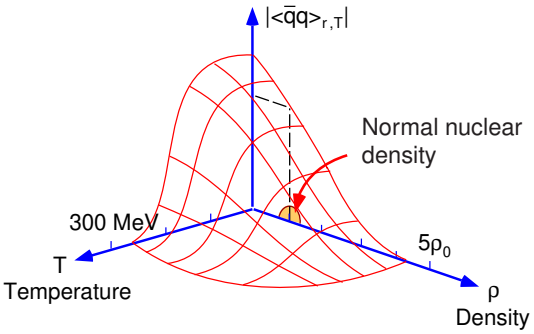

Figure 1. Schematic view of the order parameter $< \bar{q}q >$ as a function of temperature T and density ρ.

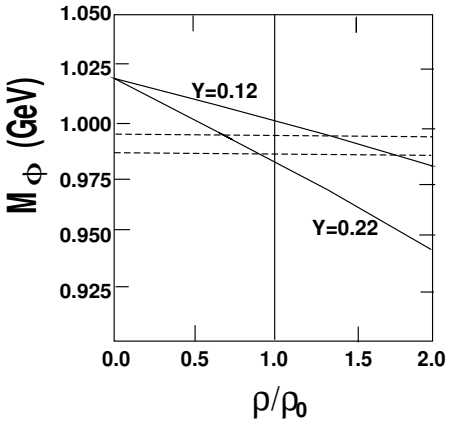

Figure 2. Hatsuda and Lee's predictions for the density dependence of the mass of ϕ meson. Dashed lines are the threshold of the $K\bar{K}$ channels. Y=$< s\bar{s} > /(< u\bar{u} > + < d\bar{d} >)$

Table 1
Experiments to study nuclear density effect on vector mesons

place	channel	status	Ref.
KEK(Tanashi)-ES	$\gamma + A \to \rho + X$ $(\rho \to \pi^+\pi^-)$	Published	[3]
KEK-PS	$p + A \to \phi + X (\phi \to K^+K^-/e^+e^-)$	Running	[2]
SPring-8	$\gamma + A \to \phi + X$ $(\phi \to K^+K^-)$	Preparation	[4]
GSI/HADES	$\pi + A \to \omega + X$ $(\omega \to e^+e^-)$	Preparation	[6]
GSI/FRS	$d + A \to^3 He + A^*(\text{bound})$	Approved	[5]

Recently many experimental efforts have started to shed the light on this subject, namely to measure the mass of vector mesons at normal nuclear density. Table 1 lists those experiments. The present work, KEK-PS E325, is characterized by the simultaneous measurements of the hadronic and the leptonic decay modes of the ϕ. The combined measurements of the mass distributions and the branching ratios are important to interpret the meaning of the signatures.

2. EXPERIMENT E325 AT KEK-PS

To achieve the physics goal described above we have built a new spectrometer as shown in the figures below. We use 12GeV $p + A \to \phi + X$ interactions to produce ϕ mesons and measure both the $\phi \to e^+e^-$ and the $\phi \to K^+K^-$ decay modes in the same apparatus. Especially we put an emphasis on the detection of slowly moving ϕ mesons. At this energy ϕ mesons produced backward in the nucleon-nucleon center of mass have the momentum $\sim$1GeV/c in the laboratory frame. About 10% of those ϕ's are to decay inside nuclei as big as copper.

The ϕ's are identified in the invariant mass spectra. Three targets in-line (Cu, CH_2 and C) are employed to deduce the nuclear size dependence of the mass shapes and the branching ratios of the two decay modes. Details of the experiment can be found elsewhere[2]. Electron are triggered by the gas Cherenkov counters and the lead-glass EM calorimeters. kaons are triggered by the aerogel Cherenkov counters and the time-of-flight counters. We use 10^9/sec primary protons on thin (0.1%) nuclear target to suppress γ conversions.

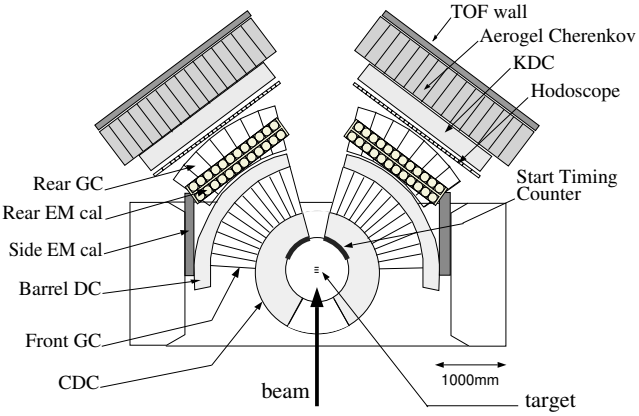

Figure 3. Top view of the E325 setup

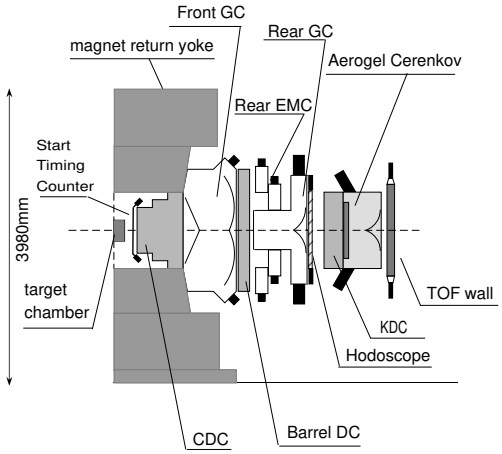

Figure 4. Side view of the E325 setup

Experimentally, to detect a meson traversing nuclear media through the invariant mass spectroscopy one has to prepare for 1) in-media broadening of the mass shape and 2) in-media dispersion of the meson mass. Although the natural width of ϕ is narrow (4.4MeV), some broadening can happen. Such broadening can be given as $\Gamma_\phi = \sigma_{\phi N} \times \beta_\phi \times \rho_0$, where $\sigma_{\phi N}$ is the total cross section of the ϕ-N interaction, $\beta_\phi = 0.7$ and $\rho_0 = 0.16/fm^3$. The upper limit of such quantity is 20 MeV deduced from available experimental data. Similar expectation can also be given by the theoretical calculation assuming the process $\phi \to K^{+*}K^{-*}(K^-N \to \Sigma X)$ in nuclei. In Figure 5 we show the expected signal in the present experiment. Here the Woods-Saxon-type density-distribution and the predictions shown in Fig.2 are employed in the Monte Carlo calculation. The main peaks at 1.02 GeV are attributed to the decays outside nuclei, and the rest are to the density effects. The possible dispersion is the one which must be determined through the measurements of the invariant mass and the momentum of the modified ϕ meson. Such an effect is not taken into account in the figure. If the mass shift took place the secondary peaks (or shoulders) would be enhanced when low β ϕ's are selected.

3. STATUS OF THE EXPERIMENT AND OUTLOOK

The first physics run of E325 has been performed in June 1997 for the $\phi \to K^+K^-$ channel. Figure 6 shows the preliminary data of the invariant mass distribution of the

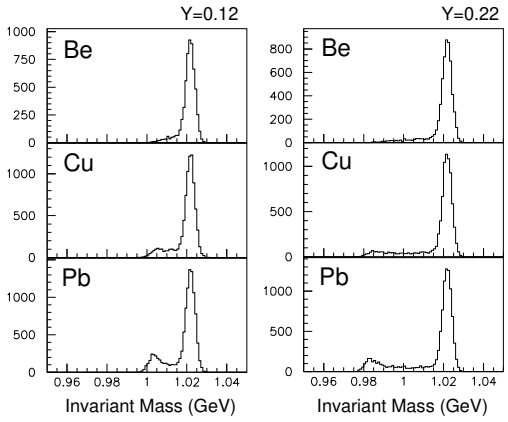

Figure 5. Expected signals for 3 different targets and for the different assumptions for the strangeness condensation.

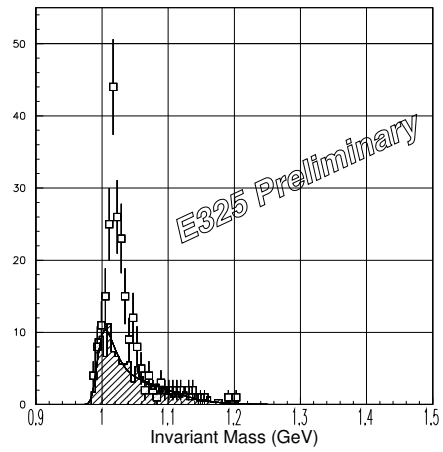

Figure 6. Invariant mass distribution of the K^+K^- channel.

K^+K^- decay channel. The hatched area represents the background estimated with the mixed events. Although the track fitting is very premature in this stage of analysis (hence the mass resolution is not optimized), $\phi \to K^+K^-$ decays are clearly identified.

Major production runs have started in April 1998 toward the collection of 10K $\phi \to e^+e^-$ decays. The statistics will enable us to compare the branching ratios with 4% accuracy between the cases of heavy nucleus and hydrogen which is obtained with CH_2-C subtraction. Further data accumulation and analyses will give an answer to the possible matter modification on the ϕ meson mass.

Besides this experiment many experimental studies on the chiral property of nuclear media are in place. For the study of high temperature media the first collision at RHIC is expected in November 1999. Many new experimental results will become available towards the 21st Century.

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