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Measurement of Vector Meson Mass in Nuclear Matter at J-PARC

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An experiment at J-PARC, E16 experiment, which aims to measure the spectral modification of vector meson in nuclear matter is planned. The experiment will measure light vector mesons ($\rho/\omega/\phi$ mesons) generated in nuclear target through the 30 GeV p+A reactions. The mass spectra can be reconstructed with e^+e^- pairs originating from their decays. The spectral modification in finite baryon density is studied systematically. The detail of the experimental plan and expected results are presented with a particular focus on first physics run.

KEYWORDS: vector meson, medium modification, di-lepton, J-PARC

1. Introduction

Since hadrons can be considered as elementary excitation in QCD vacuum, their mass reflect the vacuum structure of QCD. Especially, the modification of vector meson spectra can be a good probe for medium property. The observables such as spectral moments can be related to the QCD condensates [1, 2].

Experimentally, the medium modification can be directly observed with vector mesons through lepton pairs. This is because vector mesons can decay via electro-magnetic interaction thus almost free from the final-state interaction. Light vector meson's spectra in nuclear medium have been measured and significant spectral modification has been observed in several experiments [3–7]. However, a solid interpretation of spectral modification is still not established. This is mainly because experimental resolution and statistics are not enough to discuss the spectral modification. It should be noted that the spectral change of ϕ meson is observed only in the KEK-PS E325 experiment [5].

In order to settle this situation, an experiment dedicated for the di-lepton measurement with a higher resolution with enough statistics has been desired. The new di-lepton experiment is proposed at J-PARC as the E16 experiment [8] and will start in January 2020.

2. J-PARC E16 experiment

2.1 Overview

The J-PARC E16 experiment aims at performing systematic studies on meson's spectral change in nuclear medium. With 30 GeV proton beam, light vector mesons ($\rho/\omega/\phi$ mesons) are produced in nuclear target and these spectra are measured by using meson's decay into e^+e^- pair. Because the branching ratios of their di-lepton decays are in the order of 10^{-4} and the target thickness should be less than 0.5% radiation length to reduce the background electrons, the experiment requires high intensity beam to get enough statistics in reasonably short time. Such a high-intensity-proton beam can be realised at J-PARC.

The J-PARC E16 experiment will be performed at a new beam line called as a high-momentum beam line in the J-PARC hadron experimental faculty. The beam line is now under construction, and will be completed by the end of 2019. The beam line provides 30 GeV proton beams whose intensity is 1×10^{10} protons per beam pulse of 2-sec duration. The key features of the experiment are two kinds of systematic studies on spectral change in nuclear medium. One is the nuclear size dependence. Various sizes of nucleus from H to Pb are used as meson production targets. The other is meson's velocity dependence. From these studies, spectral information of mesons in medium can be extracted. Mesons are generated in nucleus, then some of them pass through the nuclear and decay in vacuum and some decay in nuclear medium according to their lifetime. Experimentally, a superposition of both spectra is obtained and the ratio of them depends on target nuclear size and meson's velocity. Therefore, to study the dependencies of nuclear size and velocity is important to extract in-medium information of vector mesons. The another important information is dispersion relation, namely, momentum dependence of the meson mass which can be expected to be extracted from the research. From the relation, the mass at zero momentum can be extrapolated. The dispersion relation will be measured with high statistics for the first time. Especially it is important to evaluate the meson mass at zero momentum which enable us to relate measured properties with theoretical calculations.

The J-PARC E16 experiment can achieve these results with state-of-the-art experimental techniques, in particular, high statistics and the best mass resolution in the world.

2.2 Experimental setup

Fig. 1 shows the schematic view of the E16 spectrometer. It is expected to achieve the high mass resolution of 5.8 MeV for slowly moving mesons ($\beta\gamma$ <1.25). Three thin nuclear targets whose interaction length is 0.2% in total, namely, one 400 μm carbon and two 80 μm copper in thickness, are located at centre of the spectrometer. In the inner part of the spectrometer, a combination of SSDs and GEM trackers [10] are installed under the magnetic field for a precise track measurement. GEM trackers which employ the Gas Electron Multiplier (GEM) [9] with Ar+CO_2 (70:30) gas as amplification gas. This tracker successfully achieves a high position resolution less than 100 μm.

Outside of the tracking detectors, there are two stages of electron identification counters such as the Hadron Blind Detector [11] [12] and Lead-glass calorimeter. They provide us 99.97% pion rejection power keeping at least the 57% electron efficiency. In Hadron Blind Detector, GEM is also employed to amplify electrons. CF_4 gas is used as a Cherenkov radiator and Cherenkov photons are converted into electrons on the CsI cathode evaporated on top of the GEM. The Hadron Blind detector has achieved high pion rejection factor of 99.4% with electron efficiency 63%. The Lead-glass electro-magnetic calorimeter for the electron identification is placed the outermost part of the spectrometer. The calorimeter consists of fragmented lead glass blocks in order to achieve high rate resistance and achieves 92% pion rejection power with 90% efficiency for electrons. Since the experiment will be done with high intensity beam, all detectors have high rate resistance and will be operated under 10M /s interaction rate at the target. All detectors 'performance evaluations are almost done, and mass production is on-going now.

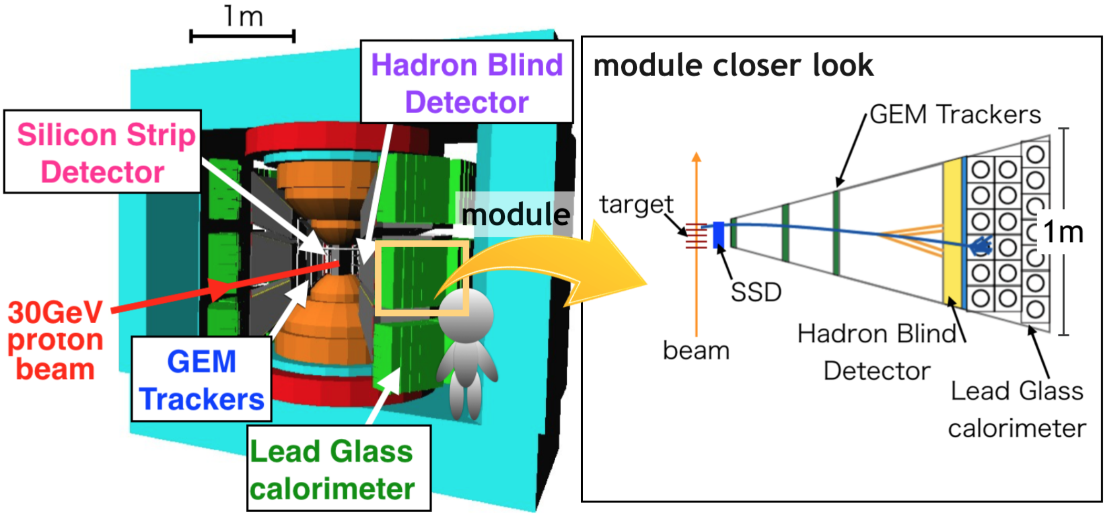

Fig. 1. The schematic view of E16 spectrometer.

Staged approach is taken to reach the final goal of the experiment as follows. By the end of 2019, the new beam line will be completed, and the beam line and also a detector commissioning will start in January 2020. After that, first physics run is planned with with C, Cu target and with the smaller acceptance detector configuration. After first physics run, more data will be taken with H, Pb target and with full detector acceptance.

2.3 *Expected result*

The expected result of the first physics run is evaluated. 30 GeV p+A event is generated based on JAM [13] assuming the same mass modification observed in the KEK-PS E325. Then, full detector simulation based on GEANT4 [14] packages is performed in order to evaluate the mass resolution and sensitivity for the possible spectral modification under the expected background. Fig.2 shows velocity dependence of the ϕ meson's spectrum simulated over 15k events in total with the copper target. This statistics corresponds to first physics run. In the slower ϕ velocity region, the spectral modification can be enhanced. The excess from normal shape should be originated from the spectral change in medium. More clarified view of the modification can be seen in Fig.3. The vertical axis

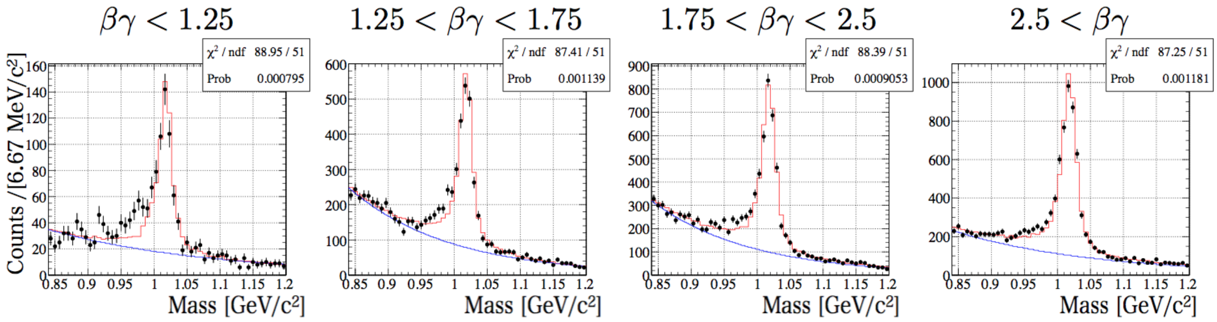

Fig. 2. Expected velocity dependence of ϕ meson's spectrum simulated over 15k events in total with the copper target. The red line shows fit result assuming normal shape and background shown with blue line.

is the expected ratio of the amount of excess from normal shape to the amount of total event, and the horizontal axis is the ϕ meson's velocity. At first physics run in the E16 experiment, green points will be obtained, which show significant spectral change in all velocity regions. The error bar at each point is improved in every velocity region, while only the slowest Cu data is significant in the E325 data. From these data, we can extract the meson mass at zero momentum by using a theoretical curve. For example, a dispersion curve calculated by Lee [15] is assumed in Fig.4. In previous research, the KEK-PS E325 were able to put only one point in the figure. From systemic study in the E16 experiment, four points expected to be added on the plot and the mass at zero meson's momentum can be extrapolated. The rest meson mass could be compared with some theoretical works.

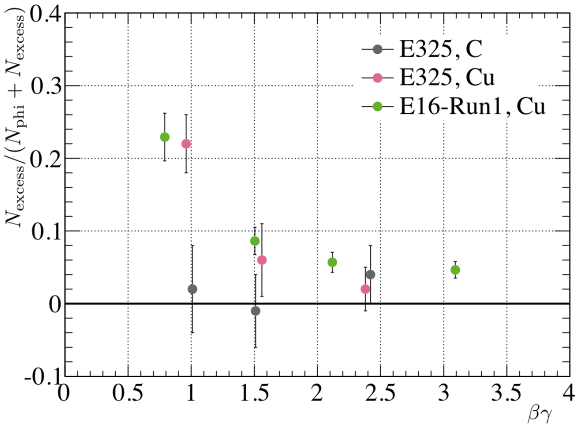

Fig. 3. Expected velocity dependence of the excess ratio for the ϕ mesons. The vertical axis is the expected ratio of the amount of excess from normal shape to the amount of total event, and the horizontal axis is the ϕ meson's velocity. Green points are expected result in the E16 experiment and the others are from the KEK-PS E325 [5].

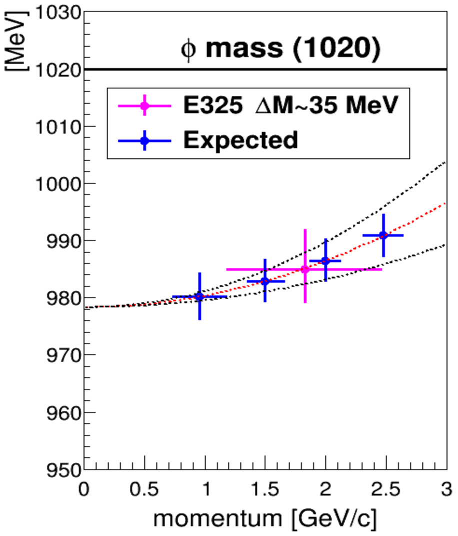

Fig. 4. The rest meson mass could be extracted from experimental data by assuming the theoreteical dispersion curve [15] and it's extrapolation to higher momentum region (dotted line).

Acknowledgments

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