COMMISSIONING RUNS OF J-PARC E16 EXPERIMENT*

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The J-PARC E16 experiment focuses on a measurement of the spectral modification of vector mesons at nuclear density. In the experiment,

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30-GeV primary proton beam is irradiated on targets to produce vector mesons, ρ, ω, and ϕ. The medium mass modifications of the vector mesons are investigated using their decay into e^+e^-. The experiment has been successfully launched at J-PARC high momentum beamline in 2020, and three commissioning runs have been carried out in 2020–2021. The first physics run is planned in 2023. In this article, preliminary results of the commissioning runs are presented.

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1. Introduction

The quark condensate, which is the order parameter of the chiral symmetry breaking, is suggested to decrease at finite density or high temperature. In contrast to the behavior around the critical temperature, the decrease according to the density is linear and significant even at the normal nuclear density. The vector meson mass can be directly connected to the quark condensate based on the QCD sum rule [1, 2]. Therefore, measurement of the vector meson mass at the normal nuclear density does give us critical information on the symmetry breaking. The previous experiment, KEK-PS E325, observed the spectral modification of vector mesons [3–5]. As discussed in Ref. [6], it is important to establish it with enough high statistics and give a solid statement through systematic study.

2. J-PARC E16 experiment

The J-PARC E16 experiment [7] is carried out at the high-momentum beamline at J-PARC hadron experimental facility. The construction of the beamline was completed in 2020 and it is the first experiment using the beamline. The 30-GeV primary proton beam with an intensity of 1.0×10^{10} per spill (2-s duration, 5.2-s cycle) is irradiated to C, Cu, Pb, and CH_2 thin targets at an interaction rate of 10 MHz to produce vector mesons which are measured via the di-electron decay. In the static system, nuclei are used to examine medium modification of the vector meson mass at finite density. The expected yield of ϕ mesons is larger by two orders of magnitude compared with the previous result [4].

Figure 1 (a) shows the spectrometer. It consists of detectors surrounding the targets which are placed at the center of the dipole magnet. The detectors are divided into 26 modules, one module is shown in Fig. 1 (b). There are nine or eight modules in the horizontal direction and three modules in the vertical direction. The most inner part consists of silicon strip detectors (SSD) and GEM trackers (GTR) for tracking, and the outer region is covered with hadron blind detectors (HBD) and lead glass calorimeters

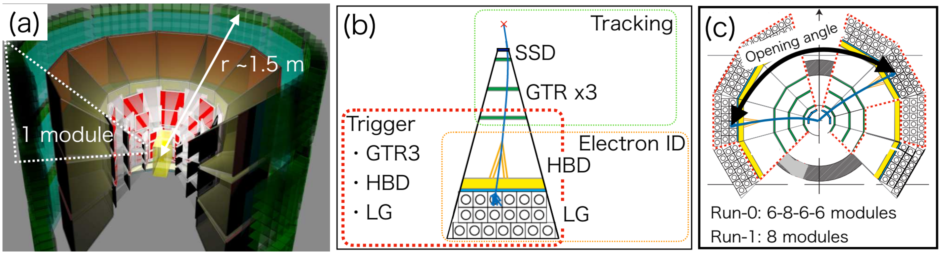

Fig. 1. (Color online) (a) Spectrometer with full 26 modules. (b) Top view of one module. (c) Module configuration at Run 0 (surrounded by the red dotted line) and Run 1.

(LG) which are used for electron identification [6, 8, 9]. The total number of detector channels is 148,740. The mass resolution for the slow ϕ meson is estimated to be 5.8 MeV, and the electron efficiency and pion rejection power are estimated to be 57 % and 99.97 %, respectively.

The branching ratio of di-electron decay of vector mesons is very small, for example, it is only 3×10^{-4} in the case of ϕ meson. The main backgrounds are e^+ and e^- from π^0 Dalitz decays, γ-conversions in the target together with detector materials and misidentified pions. Pions generated from the p-nucleus interaction are more than 100 times larger than electrons, therefore, it is a key to suppress pions using a trigger. In the trigger, two-electron candidates are required. As shown in Fig. 1 (b), the candidate is selected by the coincidence of the third layer of GTR, HBD, and LG. A large opening angle between tracks is required to reject electrons from π^0 (see Fig. 1 (c)). The number of trigger channels is 2,620 and the single rate of the trigger channel is up to 1 MHz [10, 11]. The trigger rate is expected to be 1 kHz, while surviving ratio of ϕ meson is 74 %.

We take a staging approach of the spectrometer construction, named as Run 0, Run 1, and Run 2. Run 0 is planned as beamline and detector commissionings. The result of the commissioning is described in Sec. 3. Run 1 is the first physics run planned for the beginning of 2023. Eight modules will be installed and 15,000 ϕ mesons will be accumulated, which is six times larger than the previous experiment. By studying the $\beta\gamma$ and target dependences of the modification probability, the medium modification will be established experimentally through systematic measurement [6]. Figure 1 (c) shows the detector configuration in Run 0 and Run 1. For Run 1, two new LG modules were installed in autumn 2021, to enlarge the geometrical acceptance (see Fig. 2 (a)). Two new HBD modules are under construction and will be installed in Nov. 2022. As shown in Fig. 2 (b) and (c), a double-sided SSD, which has X and U (stereo angle 7.5°) strips on each side, is developed in cooperation with the CBM group at FAIR [13]. Run 2 is the main physics

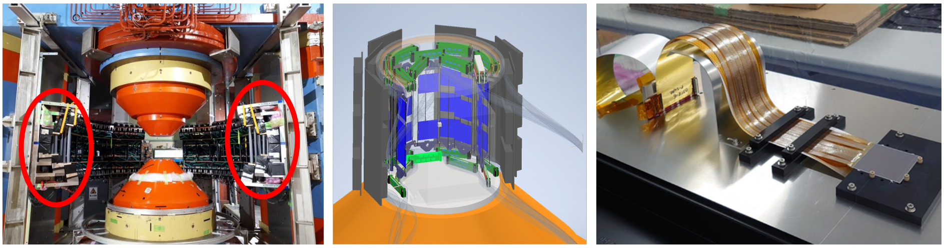

Fig. 2. (a) Newly installed two LG modules. (b) Layout plan of new SSD. (c) A picture of new SSD sensor.

run with full acceptance. Pb and CH_2 targets will be added and ϕ mesons will be produced with a beam time of 2,560 hours. Dispersion relation of ϕ meson in nuclei with four points can be obtained. It enables us to discuss the momentum dependence of mass modification [6, 14, 15].

3. Result of commissioning run

Three commissioning runs were carried out in 2020–2021. Three target foils, Cu and C, were used (see Table 1). The total beam time is 403 hours with an intensity up to 1.2×10^{10} per spill. An unexpected microtime structure of the beam was observed and the DAQ performance was hence deteriorated; the DAQ live time, which was expected to be 75 %, was deteriorated to 15 %. It will be improved in the next beam time by an upgrade of power supplies of accelerator magnets and beamline optics. Track reconstruction was performed using SSD and three layers of GTR. Figure 3 (a) and (b) shows residuals between a track projection and the hit position of HBD and LG, respectively. The pion rejection power of the trigger system is realized to be 97.6 ± 0.6 % for HBD and 91.2 ± 0.7 % for LG [12]. Their performances are consistent with the expectations. Figure 3 (c) and (d) shows photoelectrons measured by HBD and energy deposit measured by LG, respectively.

Table 1. Target material summary. The thicknesses of foils in the table were measured by weight scale.

	Quantity	Nominal thickness [μm]	Thickness [mg/cm^2]	Interaction length	Radiation length	Width [mm]
Cu	2	80	70.8	0.052 %	0.55 %	10
C	1	500	89.6	0.102 %	0.21 %	10

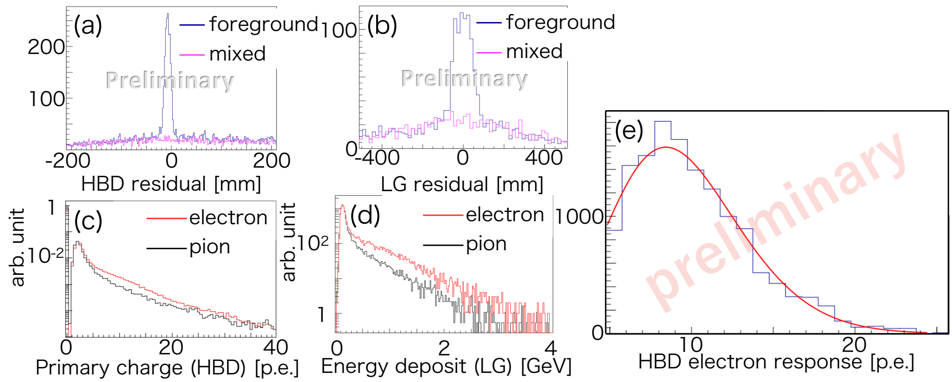

Fig. 3. (Color online) (a) and (b) HBD and LG horizontal residual of hit position from track projections. (c) and (d) HBD and LG response to electrons (red upper lines) and pions (black lines). (e) Fit result (red curve) of HBD response to electrons (blue, step-like line). The fit function is a Poisson distribution convoluted with a Polya distribution.

Both detectors show the electron enhancement successfully. Figure 3 (e) shows HBD photoelectron distribution. The photoelectrons of HBD for electrons are obtained as 10 ± 2 photoelectrons which is consistent with the design value of 11 photoelectrons. In conclusion, the good tracking performances are realized and the online pion rejection and electron identification performances are enough to separate electrons from pions.

4. Summary

The J-PARC E16 experiment measures the vector mesons in nuclei using the 30-GeV primary proton beam at the newly-built high-momentum beamline. Three commissioning runs were carried out in 2020–2021. The unexpected beam microstructure was found and it will be improved by the next beam time. The performances of tracking, online pion rejection, and electron identification were evaluated and found to be consistent with the expectations. The first physics run, Run 1 is planned for 2023 with full-eight-detector modules, including the newly developed SSD.

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