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# Search for H-dibaryon at J-PARC with a Large Acceptance TPC

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**Abstract.** H-dibaryon has been predicted as a stable 6-quark color-singlet state. It has been searched for by many experiments but has never been discovered. Recent lattice QCD calculations predict H-dibaryon as a weakly bound or a resonant state close to the $\Lambda\Lambda$ threshold. E224 and E522 experiments at KEK observed peaks in $\Lambda\Lambda$ invariant mass spectra near the threshold in ($K^-$, $K^+$) reactions, which were statistically not significant. Therefore, we proposed a new experiment E42 at J-PARC. It will measure decay products of $\Lambda\Lambda$ and $\Lambda\pi^-p$ in a ($K^-$, $K^+$) reaction. We design a large acceptance spectrometer based on a Time Projection Chamber (TPC) immersed in a dipole magnetic field. The TPC surrounds a target to cover nearly $4\pi$ acceptance, and accepts $K^-$ beams up to $10^6$ counts per second. To suppress drift field distortion at high beam rates, we adopt Gas Electron Multipliers (GEMs) for electron amplification and a gating grid. We show an overview of the experiment, the design of the spectrometer, and the R&D status of the TPC prototype.

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# 1 Introduction

The H-dibaryon has been predicted as the most stable color and SU(3)$_f$ single 6-quark state (*uuddss*) in 1977 [1]. Since then, it has been searched for in many reaction channels and decay modes, but it has never been discovered. In addition, the observation of the double-Λ hypernucleus, ${}_{\Lambda\Lambda}{}^{6}$He seemed to have ruled out the H-dibaryon existence [2]. On the other hand, there were some indications of H-dibaryons in two experiments, E224 [3] and E522 [4] at KEK Proton Synchrotron. They observed peaks near the ΛΛ threshold in ΛΛ invariant mass spectra. However, their statistics was too low to draw definite conclusions whether they are due to H-dibaryons or not.

Recent Lattice QCD calculations succeeded in reproducing properties of nucleon-nucleon interactions [5]. HAL QCD [6] and NPLQCD [7] collaborations extended these Lattice QCD calculations to the H-dibaryon studies. They calculated binding energies of H-dibaryon turned out to be $7.4 \pm 2.1 \pm 5.8$ MeV (the errors are statistical and systematic) and $-13 \pm 14$ MeV (the error is statistical only) [6-8], respectively. Since the binding energy is close to 0, H-dibaryon may be either a weakly bound state or an unbound resonance state.

The current status of experimental and theoretical studies of H-dibaryon is summarized as follows. The H-dibaryon in the mass region $m_{\Lambda\Lambda}<2224$ MeV/c$^2$ is excluded by the observation of ${}_{\Lambda\Lambda}{}^{6}$He. KEK E224 and E522 experiments observed peaks around 2235 MeV/c$^2$. Lattice QCD calculations of the binding energies point to $m_{\Lambda\Lambda}$ =2224-2244 MeV/c$^2$.

Therefore, we proposed a new experiment E42 at J-PARC [9] to have a two-order of magnitude higher statistics data sample than the KEK experiments.

# 2 J-PARC E42 Experiment

Fig. 1 shows the proposed experimental setup of J-PARC E42. It is conceived to search for $H \rightarrow \Lambda\Lambda$ or $\Lambda\pi^- p$ events in ($K^-$, $K^+$) reaction. It consists of a Time Projection Chamber (TPC), named HypTPC, as a central tracker. It is immersed in a vertical dipole magnetic field of ~1 T, provided by a superconducting Helmholtz magnet. A diamond ($^{12}$C) target is embedded in the TPC and a $K^-$ beam of $10^6$ cps/cm$^2$ is injected directly into the TPC. $K^+$ is tagged with downstream Kurama spectrometer consisting of a dipole magnet, some tracking chambers and a Time-of-Flight counter.

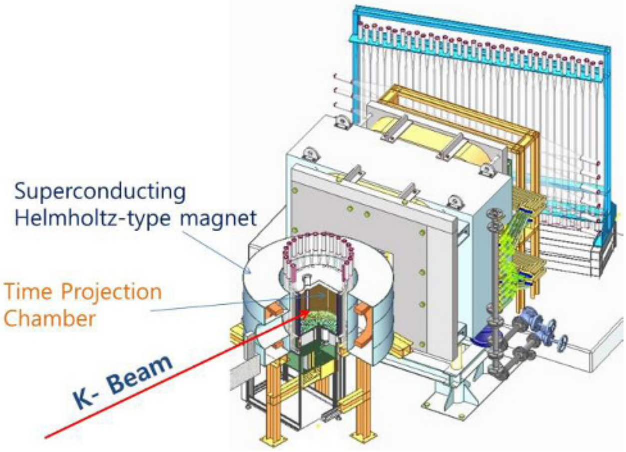

**Figure 1.** Experimental setup of J-PARC E42.

## 2.1 HypTPC design

Fig. 2 shows the schematic view of HypTPC. It has an octagonal prism shape with the field cage (sensitive area) of 500 mm diameter and 550 mm drift length. P-10 gas (Ar-CH$_4$ 90:10) is adopted. A vertical drift electric field of 180 V/cm is applied, resulting in an electron drift velocity of ~ 5 cm/μsec. A magnetic field of ~1 T is applied in parallel to the electric field in order to achieve good horizontal position resolutions. The target is installed in the middle of the drift volume, by inserting it from the top of the TPC into the vertical cylindrical target holder as shown in Fig. 2. A uniform electric field is generated by the field strips on the walls of the target folder and the field cage. Ionization electrons drift downwards to the bottom amplification section, which consists of a gating grid plane, GEMs (Gas Electron Multipliers), and a pad plane. In order to achieve a high gain of ~$10^4$, we combine three GEM sheets of 50 μm, 50 μm, and 100 μm thickness. Since the largest GEM in Japan is limited to 300 mm x 300 mm, we use 4 GEM sheets per layer to cover the entire area.

Fig. 3 shows the pad arrangements. The pad dimensions are designed to be 2.1-2.7 x 9 mm$^2$ in the inner rings (yellow area) and 2.3-2.4 x 12.5 mm$^2$ in the outer rings to achieve the horizontal position resolution better than 300 μm for the drift length larger than 10 cm. The simulated momentum resolution is 0.8-2.3 % for $\pi^-$ and 2.2-4.0 % for p. The expected $\Lambda\Lambda$ invariant mass resolution is ~1.5 MeV/$c^2$ at the $\Xi N$ mass threshold. A simulated invariant mass spectrum in E42 experiment, corresponding to a 33 day period, is shown in Fig. 4. We assume a zero H dibaryon mass width and a production cross section of 1.0 μb/sr. The spectrum includes 11000 $\Lambda\Lambda$ events with 1440 H-dibaryon signals. This statistics is 120 times as high as that in the KEK E522.

We have adopted GET (General Electronics for TPC) [10] for readout electronics. The system is designed for various kinds of TPCs with thousands of channels. It performs signal amplification, pulse shape digitization, and zero suppression. The data acquisition rate is expected to be ~ 1 kHz.

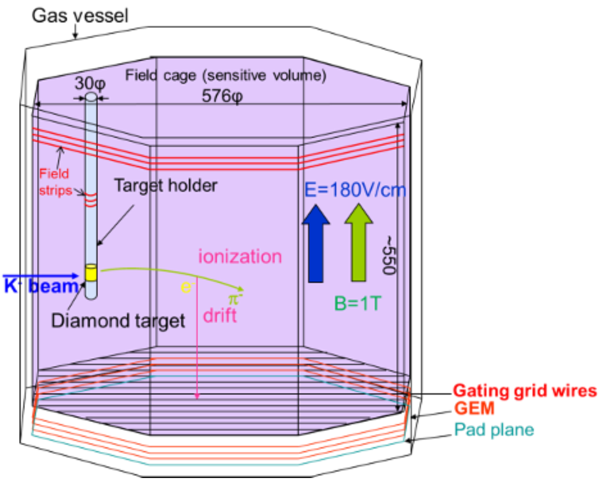

**Figure 2.** Schematic view of HypTPC.

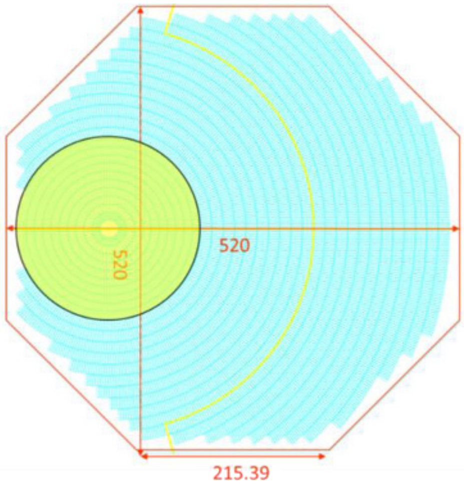

**Figure 3.** Geometry of the pad plane.

## 3 TPC prototype tests

We built a TPC prototype with a drift volume of 10x10x20 cm$^3$, with 10x10 cm$^2$ GEMs (50 μm + 50 μm + 100 μm), gating grid wires, and 4 kinds of pads with width of 2, 3, 4 and 6 mm and 10 mm length. We have measured a gain of $10^4$ at the GEM voltage of 325 V for 50 μm thick GEM and 488 V at 100 μm thick GEM. We have also performed a long term operation test of GEMs with 1 MBq $^{90}$Sr and 1 MBq $^{55}$Fe sources for 1 month without any damage.

### 3.1 High rate beam test at RCNP

A test with 400 MeV protons beams was performed at Research Center for Nuclear Physics, in Nov. 2011. The horizontal position resolution with 4 mm width pads without magnetic field was 400 μm. Detection efficiency per pad was better than 95% at beam rates up to $10^6$ cps/cm$^2$. The horizontal hit position shifts due to positive-ion feedback measured with reference silicon strip detectors in the gating grid operation were reduced to less than 0.1 mm at the beam rate up to $10^6$ cps/cm$^2$, while ~1 mm shifts are observed with the gating grid open even at the low beam rate of $10^4$ cps/cm$^2$.

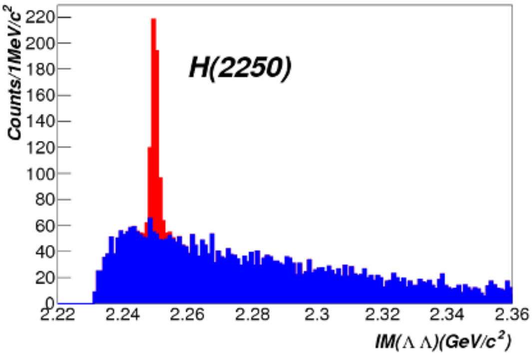

**Figure 4.** Simulated ΛΛ invariant mass spectrum (GeV/c$^2$) at J-PARC E42.

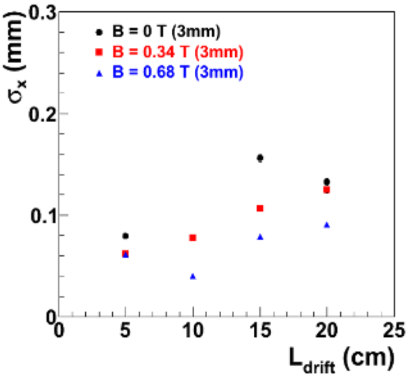

**Figure 5.** Horizontal position resolutions (mm) as a function of the drift length (cm).

### 3.2 Laser test under magnetic field

We have performed a TPC test with a YAG laser in magnetic field at J-PARC in Apr. 2013. We injected laser beam of 266 nm wave length horizontally in parallel to the pad length direction into the TPC drift volume through quartz windows. We applied vertical magnetic field, parallel to the drift electric field. As shown in Fig. 5, horizontal position resolution improved by 50-70% by increasing the magnetic field from 0 to 0.7 T. The resolution, however, is much better, namely only 60% compared to that for minimum ionizing particles. It turned out due to times more ionization electrons.

## 3 Conclusions

We have designed a TPC for H-dibaryon search experiment E42 at J-PARC. It has the unique feature that the target is enclosed inside the drift volume to maximize the H-decay event acceptance, while an extremely high-rate $K^-$ beam must be directly injected to the drift volume. In order to cope with the high-rate beam, we adopted GEMs and a gating grid. We tested a TPC prototype with and without magnetic field and good performance on the spatial resolution, efficiency and reduction of position shifts were obtained.

We have started the construction of the final TPC. We are going to perform GEM tests in this fall. In parallel, we will construct the field cage and the target holder. Production of readout boards will be completed by this year. We expect the completion of the TPC by the end of 2014.

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