Memorandum for the J-PARC E15 experiment

E15 first-stage plan and the current status

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Abstract

In this memorandum, we report brief summary of the E15 detector status after the disaster last year and plan to complete the E15 first-stage described in the 11th PAC meeting. We wish to have the priority to the E15 first-stage run.

1 Introduction

The J-PARC E15 experiment will investigate $\bar{K}N$ interactions around the threshold energy region via the in-flight $^3\mathrm{He}(K^-, n)$ reaction [1], and will search for the simplest kaonic nuclear bound state, a K^-pp cluster. As discussed at the 11th PAC meeting, we propose to perform E15 stepwise and to start the production run of the first stage at the present beam power of 3-10 kW.

At this beam power, we can enlarge the detector acceptance by reducing the trigger level so as to enlarge the event acceptance on the phase space of the final states. We can then study the $^3\mathrm{He}(K^-, n)$ reaction for several final states unambiguously because we can reconstruct event kinematics up to one missing particle. For example, we can study the Λpn final state by requiring a $pp\pi^-$ in the CDS and checking the kinematics using Dalitz plot analysis, if the missing mass is consistent with the neutron mass and a pair of $p\pi^-$'s invariant mass is consistent with Λ mass. In this first stage, a study of K^- multi-nucleon reaction processes is important since these were the major background in the previous kaonic nuclear bound-state search via K^- absorption at rest. To identify multi-nucleon reaction processes is not difficult when the acceptance over the possible phase space is enlarged. They are expected to form specific structures on this phase space when the number of nucleons is quite limited such as for the ^{3}He target.

Another motivation to perform the E15 first stage as soon as possible came from a recent theoretical calculation of the spectroscopic function given by Koike and Harada [2, 3]. They gave us two important hints, namely, the sub-threshold structure below the $\bar{K}N$ interaction is quite sensitive to the $\bar{K}N$ interaction, and the cross section below threshold could be very large in light nuclei such as ^{3}He. Yamagata *et. al.* also reported theoretical spectroscopic functions [4] whose sub-threshold cross sections are one order of magnitude weaker than those of Koike and Harada's calculation. The shape of the function varies - largely depending on the interaction. Therefore, the global structure of the ^{3}He(K^-, n) reaction is important, and the yield below threshold is also important in order to have a better estimation of the beam time required for the full E15 experiment.

Moreover, the DISTO group published an extremely large peak structure in a Λp invariant-mass spectrum and a K^+ missing-mass spectrum from $pp \rightarrow \Lambda p K^+$ events [5, 6]: the paper claimed such a large formation cross section gives evidence for a dense $K^- pp$ state [7]. Under such situations, new experimental data from a search for the kaonic nuclear bound state using the elementary $\bar{K}$ induced reaction is eagerly anticipated.

2 Current Status of the E15 Detector

The Japanese disaster on 3.11 in 2011 struk J-PARC, and it damaged K1.8BR experimental apparatus without exception. Fortunately, our damage is rather limited compared to the facility damage, although we found that our beam-line spectrometer system was partially destroyed. We recovered the detector system and ready to install to the area again. The current status of the E15 detector system is summarized as follows.

Beam-line Spectrometer

The D5 magnet, which is a dipole magnet located on just before the final focus point, was shook strongly and detached from the magnet holder. By the displacement of the D5, two wire drift chamber installed on fore-and-aft position of the D5 were crashed. The D5 and all beam-line detectors were un-installed in order to repair and re-alignment in May 2011. In December 2011, repair of the D5 and re-alignment of all beam-line magnets were completed. We are now installing the beam-line detectors including newly constructed a wire drift chamber toward beam-time in February 2012.

Liquid ^{3}He Target System

Fortunately the liquid ^{3}He target system was not damaged. In December 2011, we confirmed that the target system works well as before the earthquake and ^{3}He gas is quite well. Now the target system is ready for commissioning and physics run of the E15 experiment.

Cylindrical Detector System (CDS)

The CDS, consists of a solenoid magnet, a cylindrical drift chamber, and a hodoscope counter, has no damage in the earthquake. We performed conditioning run without magnetic field in December 2011, and found the system works well as before the earthquake. As reported in 12th PAC, the CDS is ready for run.

Beam Sweeping Magnet

We use the Ushiwaka dipole magnet, which is kept in KEK east counter-hall at the moment, as the beam sweeping magnet. The magnet will be tested at KEK north counter-hall in April 2012, and after that the magnet will be moved to J-PARC K1.8BR and installed before beam-time in May-June 2012

Neutron TOF Counter

For the detector, we use the neutron counter used by KEK-PS E549 experiment with a configuration optimized for the E15 experiment. An existing support frame of the new neutron counter and the scintillator array with PMTs will be transferred from KEK to J-PARC in the spring of 2012, and reconstruction will be completed before beam-time in May-June 2012

New Detectors for E15/E31

In order to upgrade the CDS for the E15 and E31 experiments, we have developed Time Projection Chamber with Thick Gas Electron Multipliers (TGEM-TPC), Backward Proton Chamber (BPC), and Backward Proton Detector (BPD). On 4-7 November 2011, we conducted test experiment using the LEPS spectrometer at SPring-8 in order to confirm these detector performances. The details of the detectors and results of test experiment are discussed below.

TGEM-TPC

Recent theoretical progresses on the K^-pp cluster indicate the importance of mesonic-decay mode, i.e., $p\pi\Sigma$, in reaching an informed conclusion about the K^-pp cluster. In order to realize an efficient measurement of the decay mode $K^-pp \to p\pi\Sigma$, we have been developing a Time Projection Chamber (TPC) with Thick Gas Electron Multiplier (TGEM) as an inner tracker for the E15 upgrade. For the TPC, the spatial resolution in the Z direction should be less than 1 mm, and the material budget for detector acceptance should be minimized as much as possible.

The TPC is cylindrical in shape with an inner diameter of 170 mm and an outer diameter of 280 mm and is filled with P-10 gas at atmospheric pressure. The drift length is 30 cm with field cages of a double-sided Flexible Printed Circuits (FPC) having staggered strip electrodes. We use a double or triple-TGEM structure for amplification, and signals are read out with 4-mm-long and 20-mm-wide pads on a standard PCB. The TGEM is economically constructed from double-clad 400-μm-thick FR4 plate using standard PCB techniques, and has mechanically drilled holes. Photographs of the TPC are shown in Fig. 1 and 2.

In the test experiment, we evaluated the spatial resolution in the Z direction using ~ 600 MeV/c positrons. Especially, the spatial resolution of drift length dependence, angular dependence, and pad dependence were examined. Although we are now performing precise analysis, we have confirmed

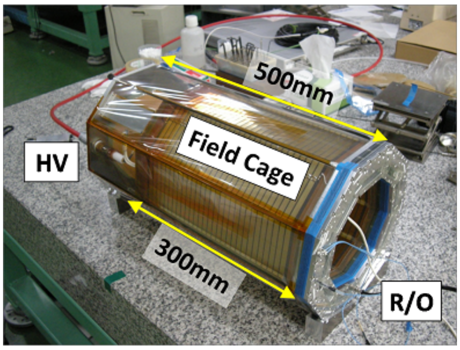

Figure 1: Photograph of the TPC.

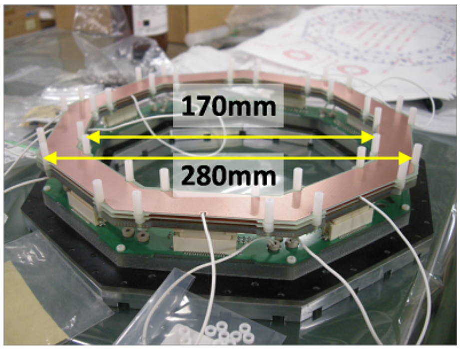

Figure 2: Photograph of the TPC readout with a double-TGEM configuration.

the spatial resolution in the Z direction to be 1 $\sim$ 2 mm as shown in Fig. 3, preliminarily.

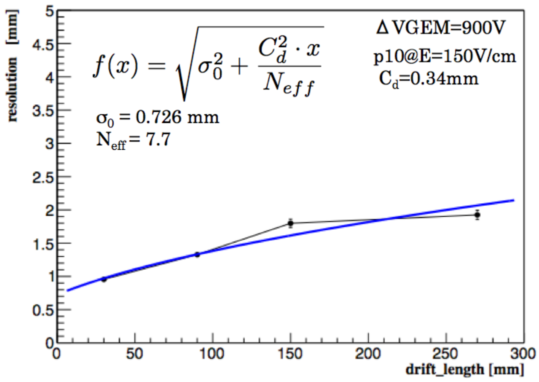

Figure 3: TPC spatial resolution in Z direction as a function of the drift length.

BPC and PBD

For the E31 experiment which aims to investigate $\Lambda(1405)$ via the in-flight (K^-, n) reaction on the deuteron target, we will add a new Backward Proton Detector (BPD) and a Backward Proton Chamber (BPC) upstream with respect of the target.

The BPC consists of 8 layers of small rectangle cells with 3.6 mm drift length, and locates just before of the target system. The number of readout channels is 120 channels. Figure 4 is a photograph of the PBC. The BPD placed about 0.5 m upstream of the target in the solenoid magnet is plastic scintillator hodoscopes array whose size of 340 mm $\times$ 340 mm. Each scintillation counter has dimensions of 5 mm $\times$ 5 mm $\times$ 340 mm as shown in Fig. 5: the BPD consists of 68 scintillators . Due to the strong magnetic field and a limited space, we employ Multi-Pixel Photon Counters (MPPC) with a 3 mm × 3 mm sensitive area. Installation of the BPC and the BPD enable to measure the time of flight of the proton emitted in the final state of the $\Lambda(1405) \to \pi^0\Sigma^0$ decay mode. A schematic illustration of the experimental set up around the target is shown in Fig. 6.

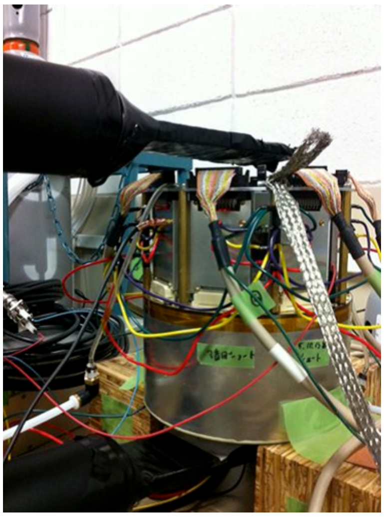

Figure 4: Photograph of the BPC.

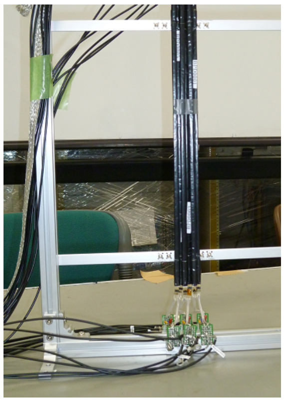

Figure 5: Photograph of the BPD.

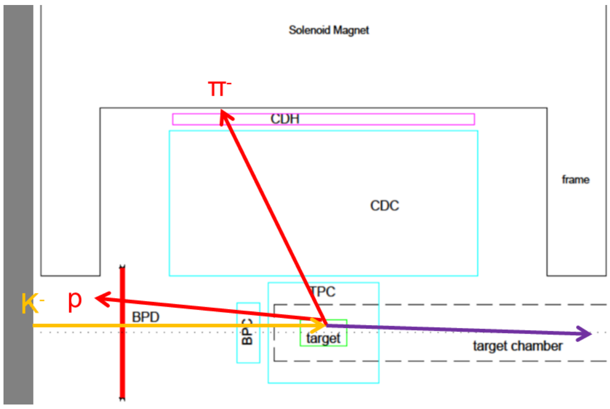

Figure 6: Schematic illustration of the experimental set up around the target with the BPC and the BPD.

The BPC and the BPD are worthwhile detectors for the E15 experiment also, because if K^- reaction produces high momentum neutron in the forward direction then the other particle should be boosted in the backward direction. This means that the requirement of a particle in backward direction, i.e., the BPC and the BPD acceptance, enable to expand the acceptance coverage in the Λpn 3-body kinematical phase-space. This is quit important to understand the nature of the possible background processes for the K^-pp bound state.

We evaluated the spatial resolution of the BPC and the time resolution of the BPD using ~600 MeV/c electrons and ~600 MeV/c positrons in the test experiment, respectively. The spatial resolution of the BPC reaches in ~100 μm as expected. As for the BPD, we confirmed the time resolution of ~150 ps which is efficient to identify a particle in backward direction.

The new CDS including above newly constructed detectors will be ready before beam-time in May-June 2012.

3 Plan to Complete the First-stage Experiment

We would like to perform first-stage production run of E15 with 30 kW·week integral proton beam on present Pt target as soon as possible. With the first-stage production run, we can study the spectral shape around $\bar{K}N$ threshold aiming at:

- to check that the in-flight K^- multi-nucleon reactions, namely background processes, are reasonably small at 1 GeV/c,
- to obtain information of the $\bar{K}N$ interaction from the spectral shape,
- to evaluate minimum beam time required to accomplish full E15 run, and
- to study whether there is any required detector upgrade to perform experiment at full intensity (cf. approved one month run at the full PS intensity of 270kW).

If the production cross section is as large as ~mb/sr at 0 degrees [2, 3], we might be able to

- observe a hint of signal in fully reconstructed $\Lambda + p + n$ final states.

In the previous 12th PAC meeting, the accelerator operation plan from JFY2010 to JFY2014 was presented including its linac upgrade. According to this slow extraction (SX) plan, long machine shutdown is scheduled from July 2014 to April 2015. Therefore, we strongly wish to accomplish E15 first-stage experiment before accelerator shutdown for the linac upgrade. To realize E15 first-stage before the shutdown, we request following beam-time:

1. **4-weeks beam-time with 3kW beam-power in May-June 2012:**
   We will carry out beam tune and full-commissioning run for the E15 experiment at first. Beam tune for 1 GeV/c K^- beam requires the Electro-Static Separator (ESS) of 275 kV (1-week). After the beam-tune, trigger tune will be performed with the full experimental apparatus (1-week). Finally, full-commissioning run will be performed (2-weeks). Using the data, we will check the detector performance and confirm calibration scheme, especially for the neutron counter.

2. **3-weeks beam-time with 10kW beam-power in October 2012 - June 2013:**
   The physics run of the E15 first-stage will be accomplished using the ^{3}He (K^-, n) reaction at 1 GeV/c.

Table. 1 shows a summary of beam-time request to complete the E15 first-stage with detector preparing schedule.

		SX power	beam-time request	subject
2012.1-5				construction of the neutron TOF counter
2012.4-5				test and installation of the beam sweeping magnet
2012.5-6		**3 kW**	**4 weeks**	**1 GeV/c K^- beam-tune full-commissioning run**
2012.7-9	shutdown			
2012.10-2013.6		**10 kW**	**3 weeks**	**physics run [^{3}He(K^-, n)]**
2013.7-2014.4	shutdown			

Table 1: Summary of beam-time request to complete the E15 first-stage with detector preparing schedule. The SX power is based on the presentation in 12th PAC meeting.

4 Conclusion

After the earthquake, apparatus of the E15 experiment and K1.8BR experimental hall are successfully recovering. No serious problem has been found to perform the E15 first-stage other than the beam assignment. The major detector components, CDS and liquid ^{3}He target system, are already completed. All other detector components, the beam-sweeping magnet, the neutron counter, *etc.* will be ready by May-June 2012. We wish to have the priority to the E15 first-stage run.

Finally, we would like to sincerely thank all the members of J-PARC for a great deal of effort to recover J-PARC.

References

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