J-PARC 50 GeV Proton Synchrotron

J-PARC E15
January 07, 2008

MEMORANDUM

J-PARC E15 status report

The J-PARC E15 collaboration

Abstract

This memorandum provides a status report on J-PARC E15, with particular emphasis on the evolution of the experiment over the last year.

There have been no problems related to construction delays in construction of the E15 detector. The construction work for the E15 major detector components, Cylindrical Detector System (CDS) and the liquid ^{3}He target will be completed by August 2008. Detector commissioning is planned during early 2008 and we expect all detector components will be ready by December 2008.

However, beam dump requirements for K1.8BR which were recently discussed show that we will not be able to place our neutron counter at the proposed position which has a major impact on the experimental resolution of the E15 detector complex. Because of this problem on the space limitation at K1.8BR beam line together with low beam intensity expected for first 2-3 years, we would like to start with the physics program using stopped K^-, which dose not required large space behind the target for neutron ToF measurement. It should be note that stopped K^- will also be a good calibration method of CDS, because monochromatic pion or muon will be emitted from stopped Kaons in target. Therefore, we would like to propose following strategy to complete our physics program. The E17 experiment, which is the experimental program for precise measurement of the X-ray from Kaonic-^{3}He, is using the same setup with E15 experiment apart of neutron counter. Therefore, we think that will start with E17 experiment as a first step of our physics program. After completion of E17, it is expected after JFY2010, we will move to the data taking for the E15 experiment. According to the construction plan for the beam in the hadron hall, the K1.1 beam line will be available when we are ready to taking data for the E15 experiment. For the E15 experiment, K1.1 beam line will be the best experimental area, because we will be able to keep flight distance for E15 neutron counter up to the value in the proposal of E15 experiment.

1 Introduction

The J-PARC E15 collaboration is preparing an experiment to search for the simplest deeply bound kaonic nuclear state, *i.e.* K^-pp clusters, via direct production mode of the in-flight (K^-, n) reaction on the ^{3}He target. The detector construction has been in progress since the proposal was accepted, therefore, in this memorandum, we would like to summarize recent progress on the experiment in detail.

On the other hand, based on the new information available from J-PARC, we realized that the experimental area at the K1.8RB beam line where we are planing to place our detectors is much smaller than expected due to the beam dump which will be placed in the K1.8BR area, especially the length of the experimental area along the beamline. This information was not available when we were laying out the E15 experiment. Also, expected beam intensity is recently presented for first a couple of years. As we described in the proposal, the E15 experiment requires one month at full beam intensity, *i.e.* 9 uA at 30 GeV, to obtain the desired statistics. Therefore, in the last section of this memorandum, we would like to present our strategy over the next few years for completion of both the E15 and the E17 experimental programs.

2 Design of the E15 detector

The E15 experiment consists of a complex of four major detectors, a beam line spectrometer, forward neutron spectrometer, Cylindrical detector system (CDS) around liquid ^{3}He target and the liquid ^{3}He target itself. A schematic view of the detector setting is shown in Figure 1. The beam line spectrometer identifies incoming Kaons hitting the liquid 3He target and analyzes their momenta. The momentum of of outgoing neutrons is measured by the neutron counter which is limited by available space to being placed only 12 m from the target. Around the target, a cylindrical detector system will be installed consisting of a cylindrical drift chamber(CDC) as a charged particle tracker and a trigger scintillator forming a detector hodoscope (CDH) which is placed around the CDC. To analyze momentum of the charged particle from target region, CDC will be installed in side solenoid magnet.

In the following sections, we will discuss recent progress on the E15 detector components and present milestones for the next years to complete the E15 experimental program.

2.1 Cylindrical detector system(CDS)

The reconstruction of K$^-$pp clusters via invariant mass from the expected decay particles, a Λ and a proton, is the most important role for the CDS. To achieve such a measurement, we are considering a general purpose detector that allows precision tracking in a solenoid field. For the trigger, a segmented scintillation counter will be installed around the tracking detector. The conceptual design for the CDS is shown in Figure 2.

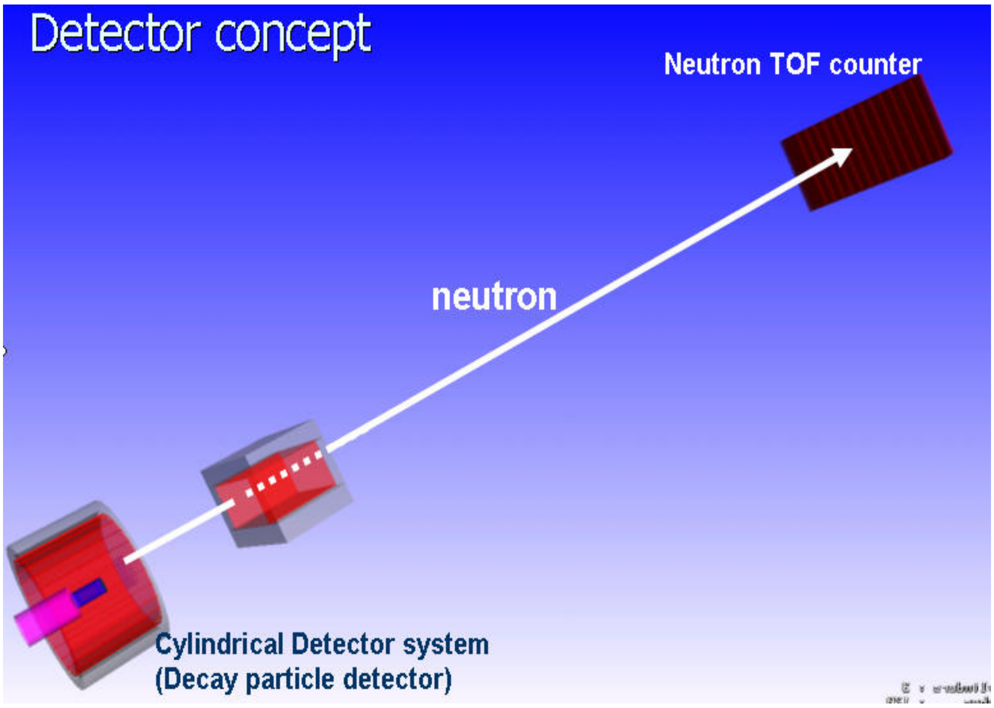

Figure 1: Conceptual design for the E15 experiment

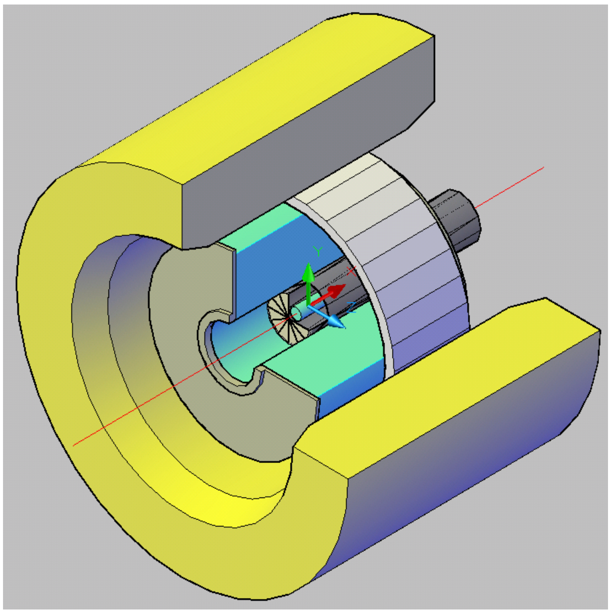

Figure 2: Conceptual design for the CDS

2.1.1 Solenoid magnet

The charged particle tracker inside the solenoid magnet is designed to have an invariant mass resolution of ∼20 MeV/c for the K-pp cluster using its' decay mode into a lambda and a proton. To satisfy the requirement, the field strength of the solenoid is required to be 0.5 Tesla in the central tracking region and the bore diameter of the solenoid magnet is 1.2 m to have an adequate lever arm for the tracking detector. The overall length is 1.2 m which is budget limited. The design of the solenoid magnet is shown in Figure 3.

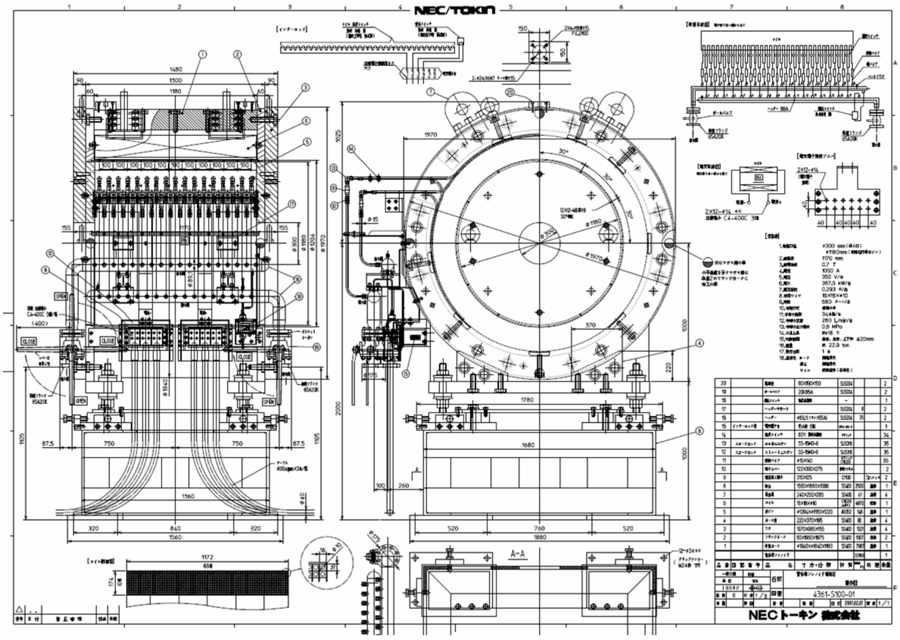

Figure 3: Design for solenoid magnet

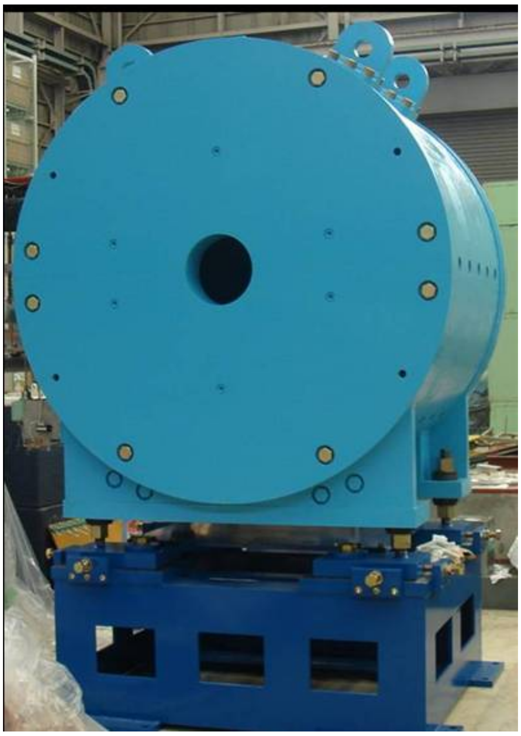

Figure 4: E15 solenoid magnet

The construction of the solenoid magnet was completed during JFY 2007. Figure 4 shows the E15 solenoid magnet. The solenoid magnet has been energized at the factory to test internal field uniformity. The results are shown in Figure 5. From the measurement, we confirmed that uniformity of the field strength inside the detector volume is comparable with the design value. At this moment, the magnet is stored in the East experimental hall at KEK. We will move the magnet once once the Hadron hall at J-PARC is ready for installation of our detectors.

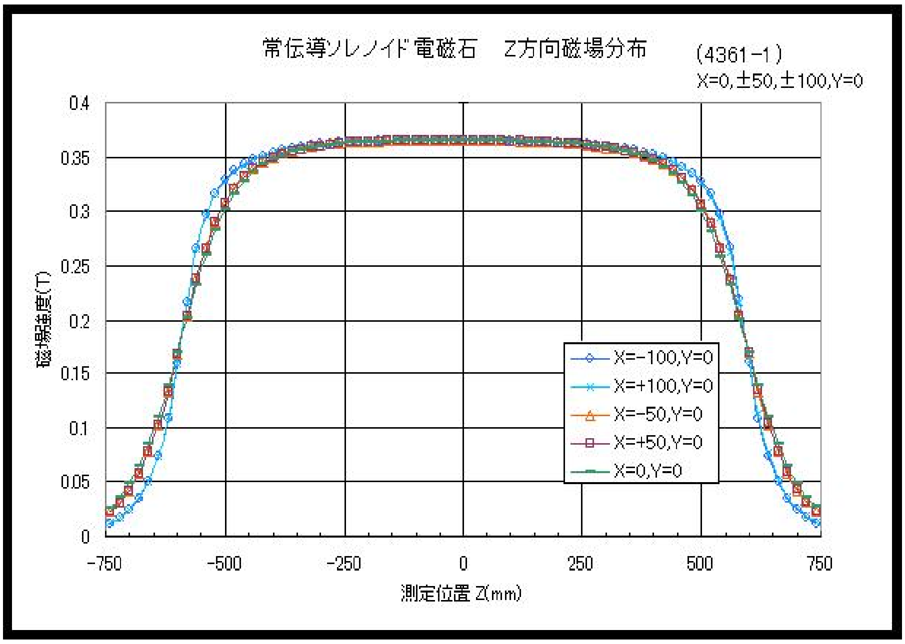

Figure 5: Measured field strength inside the solenoid magnet along the beam direction.

2.1.2 Cylindrical Drift Chamber(CDC)

A conventional charged particle tracker, the cylindrical drift chamber(CDC) has been chosen for the main tracker inside solenoid magnet. The CDC will occupy most of the region inside the solenoid magnet starting at a radial distance of 150 mm from the beam axis up to 500 mm. The total length of the CDC is designed to be 800 mm. The CDC consists of 15 layers of small hexagonal cells which provide up to 15 spatial measurements for charged particles. Longitudinal position information is obtained from 8 stereo layers which have a small angle with respect to the z-axis. A part of the cell structure inside the CDC is shown in Figure 6. For this design, the number of the readout channel is 1816 channels and total number of wires in the CDC is 8064. To reduce the material budget, aluminum wire with 100 μm will be used for the field and guard wires. For the sense wires, wires, 30 μm diameter tungsten wire will be used. The design for the CDC has been completed. The end plates, which carry an axial load of $\sim$ 8000 N, made of 20 mm aluminum plates. To withstand the axial load created by the wires, a 1mm thick CFRP cylinder was installed as the inner wall of the CDC, and six aluminum posts were placed outside the tracking volume. The outside of the CDC will be covered by special plastic film to define gas volume of CDC. During 2007, we build CDC prototype which has

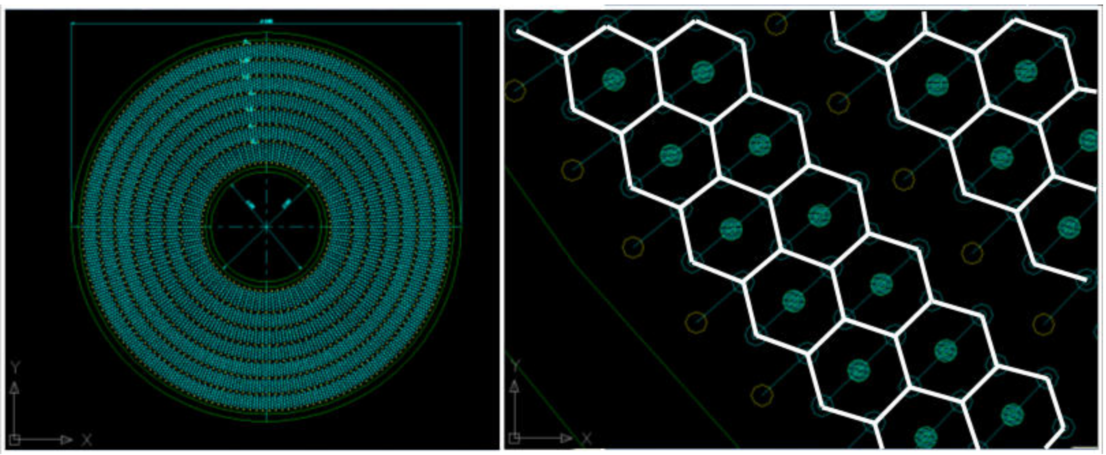

Figure 6: Design of cell structure of CDC

same cell structure and wire length as the real CDC. Figure 7 shows the CDC prototype. Normally, H.V. for a CDC will be supplied by daisy chain from the feedthrough connector

Figure 7: CDC prototype

using wires. However, for this CDC, we are testing the use of a printed circuit board (PCB) for the H.V. feed. Figure 8 shows the 1st prototype HV distribution board. One of the problems we found in producing this prototype is the lack of a commercially made socket for the pins used for the CDC through hole. Finally, we decided to produce custom made sockets and made this prototype. Presently, all problems associated with this HV distribution board have been solved and the final design shown in Figure 9 was chosen. Mechanical construction of the CDC has been completed in November 2007. The picture of the CDC before installing wires is shown in Figure 10. The inner cylinder made with CFRP and the 6 posts around the CDC are clearly seen in the picture. The expected

Figure 8: H.V. distribution board prototype connected on CDC prototype for test

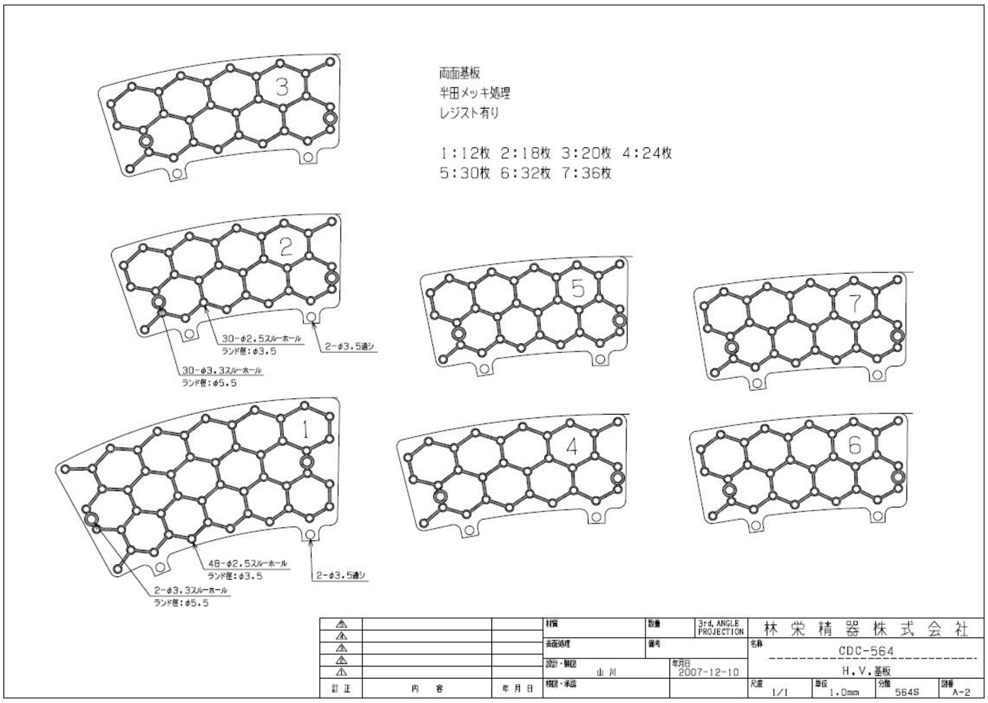

Figure 9: Design of H.V. distribution board

deformation of the end-plates due to wire tension for this configuration is an order of 20μm in maximum. Construction of the CDC is in progress. The Figure 11 shows the CDC assembly at the factory. Almost 1/3 of the wires will be installed by end of December 2007. Assembly of the CDC will be completed by the end of February 2008.

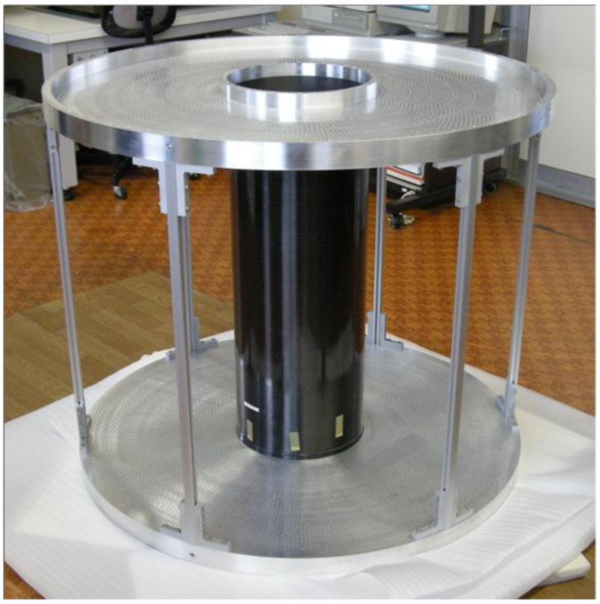

Figure 10: Structure of the CDC

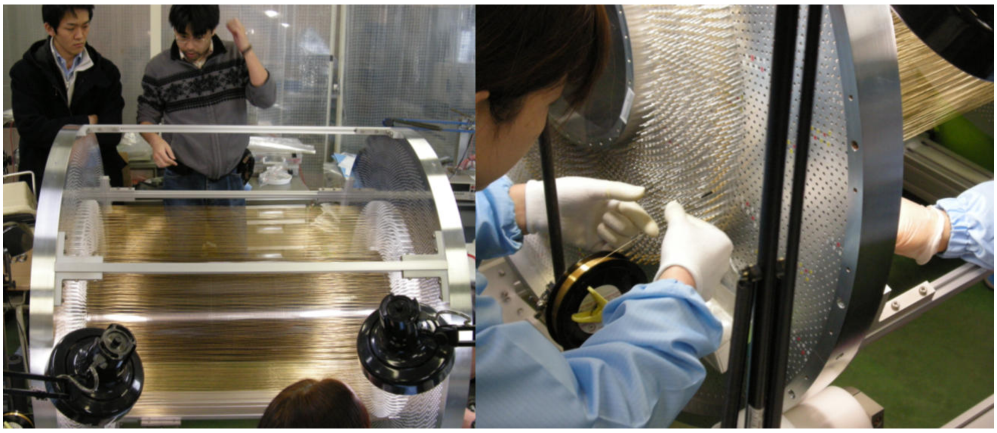

Figure 11: Constraction of the CDC at factory

2.1.3 Cylindrical Detector Hodoscope(CDH)

The Cylindrical Detector Hodoscope (CDH) sof plastic scintillation counters is used for the charged particle trigger. In offline analysis, the CDH system will be used to measure the time of flight (TOF) of charged particles together with the Start Counter system. Particle identification will be performed with the TOF information together with a flight length and a momentum given by the track fitting from the Cylindrical Drift Chamber (CDC). The minimum transverse momentum to reach the CDH counters is about 50 MeV/c, and the expected K and p separations with 200ps TOF resolution are up to 400MeV/c and 800MeV/c, respectively. The CDH system is located at a radius of 544mm from the target system covering a polar angle range from 54 to 126 degrees. The CDH system consists of 36 modules, and these modules are individually mounted on the inner wall of the solenoid magnet Figure 12. The scintillators are made of Bicron BC408, whose dimensions are

790mm in length, 99mm in width and 30mm in thickness. Hamamatsu type R7761 fine-mesh photomultipliers, with a 1.5 inch diameter and 19 dynode stages, were selected. They are operated under the magnetic field of 0.5T, with a typical gain of 3×10^6. The design of the CDH system is substantially complete, and we have made test modules to check performance of the CDH system and matching between the CDH modules and other detectors, at RIKEN Wako campus as shown in Figure 13.

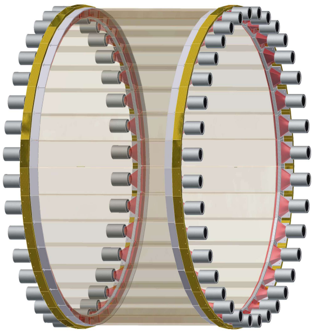

Figure 12: conceptual design of CDH

Figure 13: test modules of CDH with dummy solenoid magnet

2.2 Liquid ^{3}He target

2.2.1 Design

Development of the liquid ^{3}He target is the joint project between KEK and RIKEN. Figure 14 shows the design of the liquid ^{3}He target which is now under construction. Basic design for the target system is is based on the techniques developed for the ^{4}He target used by KEK-PS E471, E549 and E570. Liquid ^{4}He will be supplied from a dewar placed outside to the separator inside the target system. From the separator, only liquid helium will be dropped into the Evaporator which is placed under under the Separator, then decompressed down to 1 Torr, where the temperature inside will be kept ~ 1.3 K. The chamber for the ^{3}He is placed under the Evapotator, in contact with the heat exchanger. The ^{3}He gas will be cooled down and liquefied in the heat exchanger and target cell will be filled with liquid ^{3}He, which is almost 1 m away from the ^{3}He heat exchanger.

2.2.2 Gas handling system

Because ^{3}He gas is very expensive, the gas system must be operated very carefully. Since typically the experiment will run for the order of two months, careful operation alone is inadequate, so we are now developing and constructing a safe and efficient "automatic" gas handling system. The schematic diagram of the gas handling system is shown in Figure 15 and photograph of the system is shown in Figure 16. This system has been developed based on an exist ^{3}He circulatory system at KEK with the following major upgrades:. (a) the new system itself is oil-free, therefore impurities in the target due to

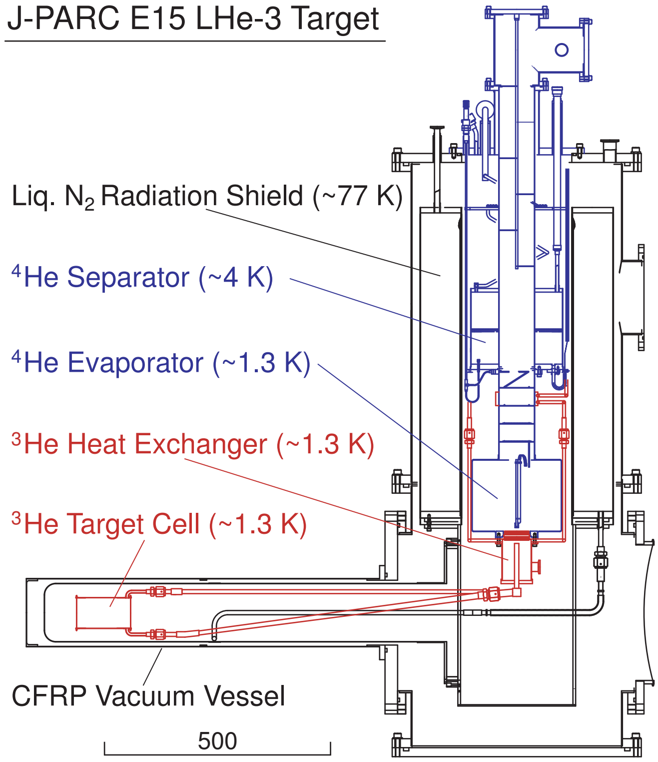

Figure 14: Design of ^{3}He target cell

the oil from pumps will be eliminated. This improvement allows us to make long stable operation of the target system. (b) The gas tank can be easily dismount from the system to improve maintenance capability of the system. (c) A safety valve has been connected to the gas tank to collect 3He gas if the internal pressure exceeds a limit. This system has been tested using ^{4}He gas, and and the leak rate of the system is $\sim 10^{-10} Pa \cdot m^3/\text{sec}$.

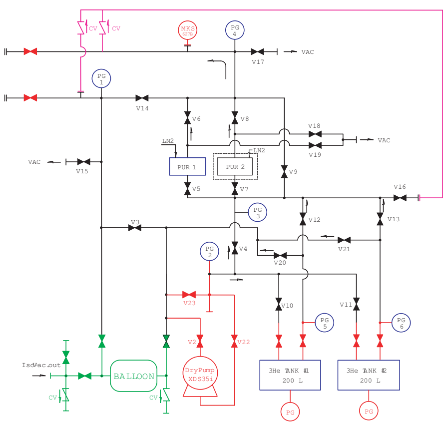

Figure 15: Schematic view of gas handling system

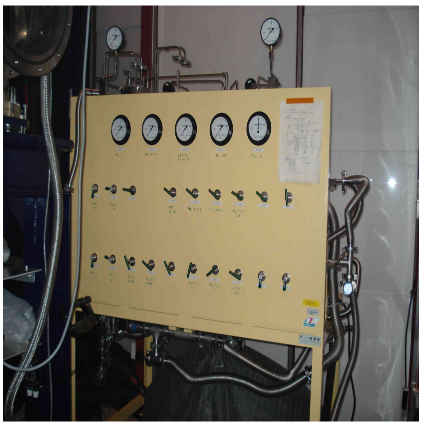

Figure 16: photograph of gas handring system

2.3 Beamline drift chamber for vertex reconstruction

To reconstruct vertices of the in-flight K^- reactions, trajectories of the incident kaon beam will be tracked with a multiwire planer drift chamber (Vertex Beamline Chamber, VBLC) located upstream of the experimental target on the beamline. The VBLC must be installed in as close contact as possible with the target, despite the limitation that the target is surrounded by the cylindrical detector system (CDS).

The VBLC system was designed to be installable within the 30 cm inner diameter of the CDS, and to ensure a large sensitive area of 8×8 cm^2 so as to cover the kaon beam size ($\sim$3 cm for X and $\sim$1 cm for Y at 20-cm upstream of the final-focus point). A design drawing of the VBLC is shown in Fig. 17. It is composed of nine cathode planes and eight sensitive planes, XX'-YY'-XX'-YY', where X and Y planes are for vertical and horizontal wires, and the prime means the half-cell-shifted sense-wire plane used for resolving the left-right ambiguity. A sensitive plane has 16 sense wires and 17 potential wires with 5-mm spacing for each wire. A schematic of a cross section of the VBLC is illustrated in Fig. 18. The sense and potential wires are made of gold-plated tungsten ($\phi 12.5 \mu$m) and gold-plated copper-beryllium ($\phi 75 \mu$m), respectively. The cathode planes are made of 7.5 μm-thick Kapton, of which both sides are coated by 0.1 μm aluminum with a layer of 0.0025 μm chromium as protection against oxidization.

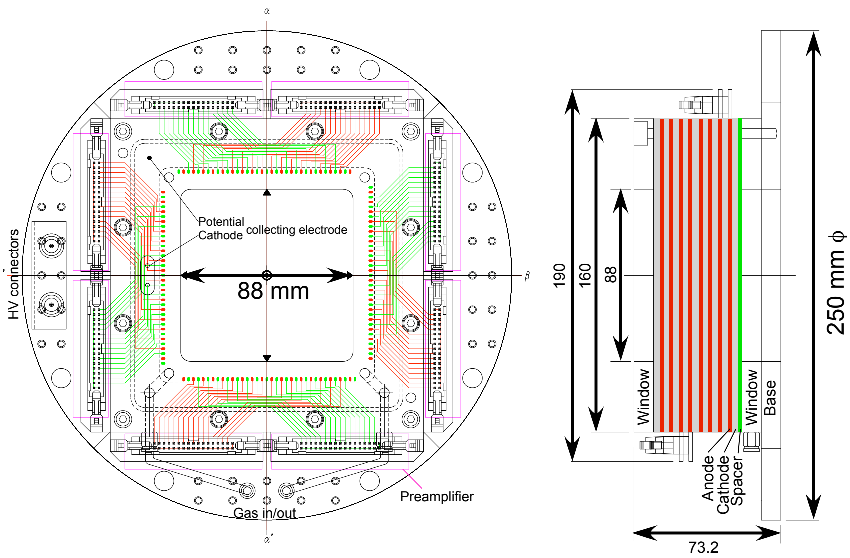

Figure 17: A design drawing of VBLC

To avoid over concentration of the beam on a wire, the VBLC will be rotated at 45 degrees since the beam shape is extended transversely. The beam hit rate per wire is therefore estimated to be $\sim$ 0.3 MHz assuming full intensity with 30GeV/9μA primary beam for K1.8 beamline.

The VBLC will be operated in the magnetic field applied in a direction perpendicular to the chamber plane. Almost all of the components were therefore made of non-magnetic materials (e.g. aluminum for the chamber frames). According to a simulation with GARFIELD, the distortion of the isochrones due to the magnetic field of 0.7 tesla (maximum applied magnetic field) is subtle as shown in Fig. 19; and the difference of the drift time for 0 and 0.7 tesla was only 5 %.

We are in the process of the production. The winding operation of the VBLC has been finished as of end of December 2007. The scheduled completion date is mid January 2008. Photos of a wire plane and a tentative assembly of the VBLC respectively are shown in Figs. 20 and 21.

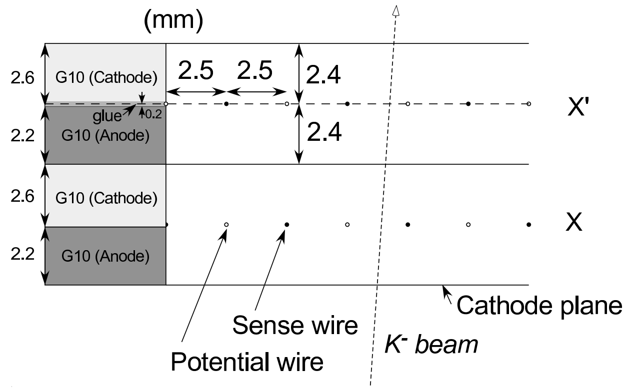

Figure 18: A schematic illustration of a cross section of the VBLC

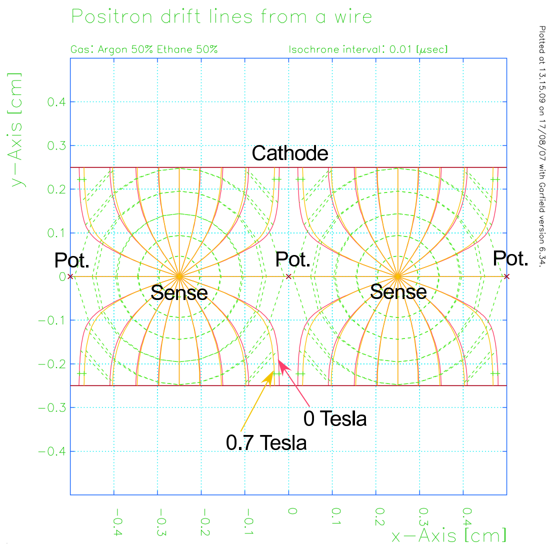

Figure 19: Drift lines from a wire (calculated with GARFIELD)

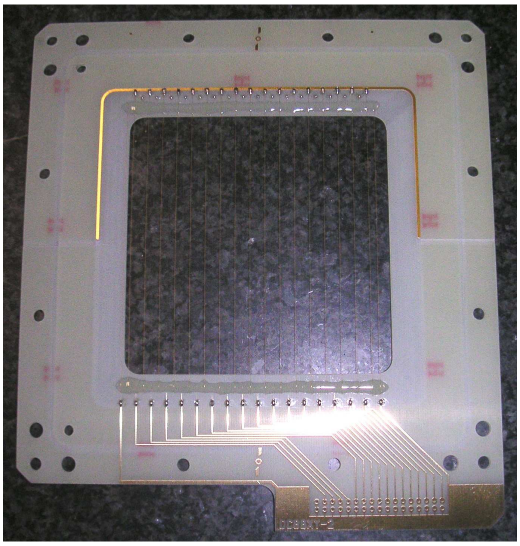

Figure 20: A wire plane of the VBLC

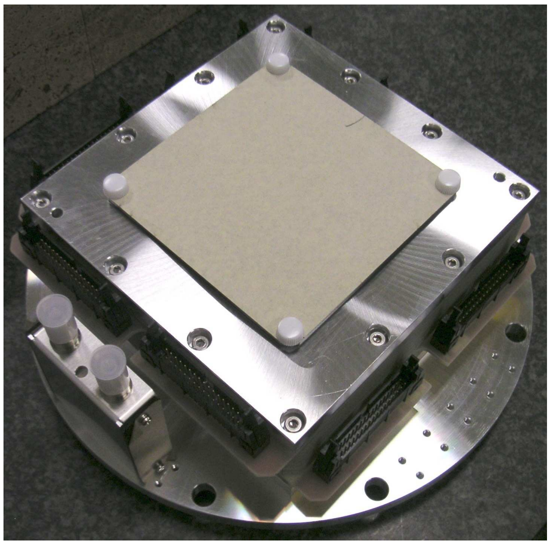

Figure 21: A tentative assembly of the VBLC

2.4 Neutron Counter

For the detector itself, we are planning to use the neutron counter used by KEK-PS E549 experiment with a configuration optimized for the E15 experiment. The neutron counter consists of an array of of scintillator counters. Each scintillation counter has dimensions of 20cm x 5cm x 150 cm with two Photo Multipliers (PMT) attached to both long side of scintillator. Figure 22 shows the recently designed support structure of the Neutron counter for the E15 experiment. Design has been completed and construction has begun

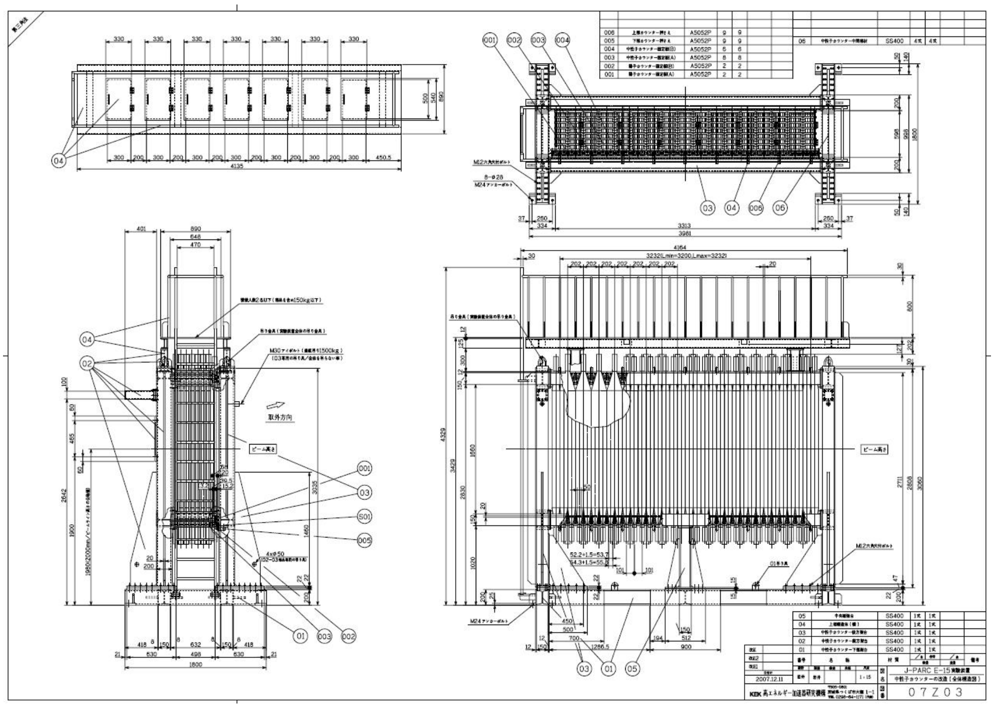

Figure 22: The configuration of the neutron counter.

3 Plan to complete E15 experiment

One of the key measurements for E15 experiment is the missing mass spectroscopy using outgoing neutron from the primary (K^-, n) reaction. The resolution of the missing mass is strongly dependent on the flight path length of the neutron, i.e. distance between target and the neutron counter. In the proposal, we requested a 15 m flight path length for the measurement to achieve missing mass resolution of $\sim$ 20 MeV/c^2 (FWHM). At that time we stated that we would like to perform this experiment at either K1.1 or K1.8BR beam line. However, when preparing the report for FIFC, we are focusing on the K1.8BR because it will be the first beam line constructed in the hadron hall. The expected flight path available for the K1.8BR beam line we reported to FIFC was 12 m, which was the maximum available flight length based on all available information. However, in recent discussions, at least a 1 m shielding wall must be installed at the end of the beam line even with only 1% of the beam intensity in the 50 GeV PS. It should be much thicker when the 50 GeV PS reaches its design luminosity. Based on this new information, flight path length will be reduced again. The best realistic estimate of neutron flight path length is now down to 10 m. As a result of the reduced neutron flight path, the missing mass resolution for the measurement is now down to be ~ 34 MeV/c^2 (FWHM). In addition to the length of the flight path, we are also concerned with the background from the beam dump on the neutron counters when placed in front of the dump.

Recently, the construction plan for the beam line in the Hadron hall has been presented. The plan shows that the low momentum Kaon beam line, K1.1, will be competed during JFY2010. Based on its intensity, it was proposed to be used for E15 and, as a consequence of the beam dump limitation at K1.8BR, it may now be the best location for E15.

On the other hand, the E17 experiment, which is also accepted as a DAY-1 experiment, is planing to use almost the same setup as E15 with the exception of the neutron counter. One advantage for E17 is that it will be able to obtain significant physics results with lower beam intensity and relatively short running time. Therefore we are now considering the following stepped strateygy to complete both the E15 and E17 experiment.

1. JFY 2008 : First beam available at K1.8BR, 50 GeV PS 1.0 kW operation
   E15 beam line spectrometer and Cylindrical detector system (CDS) will be installed in the K1.8BR beam line. Commissioning of the detectors will be performed using first beam available at K1.8BR beam line.
2. JFY 2009 : 50 GeV PS 100kW operation
   Installation of the liquid ^{3}He target together with E17 setup will be installed inside CDS. The physics run of E17 experiment will be performed.
3. JFY 2010 and after :
   If K1.1 beam line is available by then, we will install neutron counter in K1.1 beam line. Once data taking for the E17 experiment have been completed, CDS and ^{3}He target system will be moved to K1.1 beam line. First data taking for E15 will begin during this fiscal year.

4 Conclusion

No major delays or problems have have occurred on the construction of the E15 experiment. The major detector components, CDS and liquid ^{3}He target will be complete by August 2008. All detector components will be ready by December 2008.

However, the beam dump required at K1.8BR beam line which recently discussed precludes placing our neutron counter at the proposed position, which makes a major impact on the experimental resolution of the E15 detector complex.

Based on the problem with the space limitation at the K1.8BR beam line together with low beam intensity expected for first 2-3 years, we would like to start with the stopped K$^-$ experiment, *i.e.* E17 experiment, which does not require high intensity.

After completion of E17, it is expected after JFY2010, we will move the complete setup to the K1.1 beam line to take data for the E15 experiment, if K1.1 beam line is in operational condition.