Construction and beam commissioning of Hadron Experimental Hall at J-PARC

H Takahashi, K Agari, E Hirose, M Ieiri, Y Katoh, A Kiyomichi, M Minakawa, R Muto, M Naruki, H Noumi, Y Sato, S Sawada, Y Shirakabe, Y Suzuki, M Takasaki, K H Tanaka, A Toyoda, H Watanabe and Y Yamanoi

Abstract. The new facility J-PARC has been constructed in Tokai, Japan. It aims at providing intense proton beams of 750 kW for next-generation particle and nuclear physics experiments. The Hadron Experimental Hall (HD-hall) is one of the two facilities at the J-PARC Main Ring and utilizes various secondary particles produced by the slowly extracted primary proton beam. We have constructed two charged and one neutral secondary beam lines. The K1.8 beam line transports separated charged secondaries with the maximum momentum of 2 GeV/c. Secondary particles are purified by two electrostatic separators (ESSs). The K1.8BR beam line is branched from the K1.8 at the bending magnet downstream of the first ESS. The K1.8BR delivers separated charged beams with the momentum up to 1.2 GeV/c.

On January 27th, 2009, the first beam was successfully extracted to the HD-hall and transported to the beam dump. The first secondary beam extraction to the K1.8BR beam line succeeded in February 2009. The beam commissioning of the K1.8 and KL beam lines started in October 2009.

1. Introduction
The high intensity proton accelerator facility J-PARC (Japan Proton Accelerator Research Complex) has been constructed in Tokai, Japan. It consists of three accelerators: Linac, 3-GeV Rapid Cycle Synchrotron, and 50-GeV Main Ring. The Hadron Experimental Hall (HD-hall) [1] is one of the two facilities at the Main Ring. Primary proton beam with the energy of 50 GeV and the power of 750 kW is slowly extracted [2] to the hall and transported to a production target, although the energy of 30 GeV and the power of 270 kW are expected in phase 1 of the J-PARC construction. A few secondary beam lines have been completed in the hall and are currently being commissioned. Although the beam lines were optimized to provide kaons mainly, various secondary particle beams generated from the target are used for nuclear and particle physics experiments, such as hypernuclei experiments and rare-kaon-decay experiments.

3 Author to whom any correspondence should be addressed.
4 Present address: Japan Synchrotron Radiation Research Institute (JASRI/Spring-8), 1-1-1 Kouto, Sayo-cho, Sayo-gun, Hyogo, 679-5198, Japan

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Figure 1. Layout of the hadron experimental facility. Dashed lines indicate additional beam lines at future extension.

2. Primary beam line

The layout of the hadron experimental facility is illustrated in figure 1. The extracted primary beam is transported to the HD-hall through the beam switching yard (SY). The length of SY is about 200 m along the primary beam, and the size of the HD-hall is 60 m in width and 56 m in length. In future plans, a high-momentum beam line and a test beam facility can be constructed in SY. Since on-hand maintenance is expected in SY, we have developed quick disconnecting devices of water and electricity and quick alignment apparatuses for magnets to reduce the radiation exposure during the maintenance works [3].

The cross-sectional views of the primary beam line in the hall are given in figure 2. Cooling water and electric power are supplied from service space 4-m above beam level through “chimneys” mounted on magnets. The connections of water and electricity are handled on the service space, because the beam level is expected to be inaccessible due to high residual radiation dose after beam operation.

The transported proton beam is focused on the secondary-particle-production target, T1, with the spot size of $\sigma \sim 1$ mm both in the horizontal and vertical directions. The T1 target is a rotating nickel disk directly cooled by water [5, 6]. The thickness of the disk is 54 mm, which is equivalent to 30-% beam loss in interaction length. At the early stage of the beam commissioning, where the beam intensity is rather low, we also use a 60-mm-thick fixed platinum target equivalent to 50-% beam loss. Although the target releases the beam power of $750 \times 0.3 = 225$ kW, the heat deposit in the target material is only about 10 kW, and the remaining power of over 200 kW is distributed to beam line elements downstream. Beam pipes are closer to the beam than the magnet poles and hard to cool sufficiently without tritium production. The connection of the pipes is also difficult problem. Therefore, the magnets are placed in a large vacuum chamber in order to remove the beam pipes from the magnet pole gaps [7]. Figure 3 shows a schematic drawing of the target and the large vacuum chamber.

The beam dump is capable of absorbing full beam power of 750 kW. Its core is made of copper blocks and cooled by water. The total size of the core is 5 m in length and 2 m $\times$ 2 m in cross-sectional area. There is a conical hole in the core so as to distribute the heat deposit uniformly. The beam dump was designed so that it can be moved downstream remotely at the future extension of the HD-hall.

The building construction of the HD-hall was completed on July, 2007. The primary beam line and a secondary beam line (K1.8BR) in the hall were constructed in the next one and a
half years. On January 27th, 2009, the first beam was successfully extracted to the HD-hall and transported to the beam dump. The beam profiles of primary protons were measured with residual gas ionization profile monitors [8], and were in good agreement with the calculation [9].

3. Secondary beam lines
So far, two charged secondary beam lines (K1.8 and K1.8BR) and a neutral secondary beam line (KL) were constructed downstream of the T1 target. Figure 4 shows the layout of the beam lines. The K1.8 and K1.8BR beam lines are extracted beam-left from the T1 with respect to primary beam direction, while the KL beam line is placed beam-right.

The K1.8 beam line transports separated charged secondaries with the central momentum of 2 GeV/c in maximum. It was designed mainly for Ξ hypernuclear spectroscopy using the \((K^-, K^+)\) reaction. It was optimized for the momentum of 1.8 GeV/c, since the Ξ production cross section are maximum at about 1.8 GeV/c. The secondary beams produced by the T1 target are extracted to the left from the primary beam line. The production angle of secondary beams was chosen to be 6 degrees, since the \(K^-\) production cross section is maximum around 6 degrees according to an empirical formula by Sanford and Wang [10].

The most upstream magnets are operated in the large vacuum chamber as mentioned above. A water-cooled beam collimator is also placed in the chamber to protect the magnets. Indirectly cooled mineral-insulated coils were developed in order to work stably under high radiation environment [11].

Secondary particles are purified with two electrostatic separators, ESS1 and ESS2. Both of ESS1 and ESS2 have the effective length of 6 m and the electrode gap of 10 cm, and generate vertical electrostatic field of 75 kV/cm. The ESS1 was newly developed so as to achieve better radiation hardness by replacing organic materials with inorganic ones [12]. The stability against the high electric field was also improved by optimizing the shapes of the electrodes, the high-voltage feeders, and the vacuum chamber. The ESS2 had been used at KEK-PS K6 beam line and was overhauled for K1.8. Each of ESS1 and ESS2 is sandwiched by two dipole magnets, CM1/2 and CM3/4, respectively, generating horizontal magnetic fields. Unwanted secondary
beams are deflected by the combination of the electrostatic and magnetic fields and filtered by the mass slits MS1 and MS2 located downstream of ESS1 and ESS2, respectively.

Figure 5 shows the beam envelope of the K1.8 beam line calculated with TRANSPORT [13]. The total length of the beam line is 45.9 m. The extracted secondary beams are vertically focused at an intermediate focus slit (IF) in order to reduce pion contamination such as from $K^0_S$ decay or from reactions at beam-line materials. After filtered by two sets of separators and mass slits, the beams are analyzed with a beam spectrometer having a QQDQQ configuration, and finally focused on an experimental target. The beam simulation was made using the DecayTURTLE code [14]. The intensity of 1.8-GeV/$c$ $K^-$ beam was estimated to be $1.4 \times 10^6$ /spill with kaons-to-others ratio ($K/(\pi + \mu)$) of 3.5 in Phase 1 (30 GeV, 270 kW), and $6.6 \times 10^6$ /spill with $K/(\pi + \mu) = 4$ in Phase 2 (50 GeV, 750 kW).

The K1.8BR beam line is branched from K1.8 at a bending magnet downstream of the first separator ESS1. Since it shares the upstream part of the K1.8 beam line, it cannot be operated simultaneously with K1.8. However, effective sharing of beam time can be expected like preparing the next experiment at one area during the beam run at the other area. The K1.8BR beam line is designed to deliver separated charged kaons with the momentum up to 1.2 GeV/$c$. The beam envelope of the K1.8BR beam line is presented in figure 5. The length of the K1.8BR beam line is 31.5 m, which is about 15-m shorter than K1.8 and is great advantage for low-momentum kaon transportation. The intensity of 1.1-GeV/$c$ $K^-$ beam is expected to be $1.2 \times 10^6$ /spill with $K/(\pi + \mu) = 0.9$ in Phase 1, and $5.5 \times 10^6$ /spill with $K/(\pi + \mu) = 1$ in Phase 2.
The first secondary beam extractions to the K1.8BR and K1.8 beam lines succeeded in February and October 2009, respectively. Careful beam tunings of the beam lines are now in progress, and the current status are presented in detail in Ref.[15, 16].

On the right-hand side from the T1 target, the KL beam line was constructed. It consists of a sweeping magnet and collimators to produce pencil beam of neutral kaons for the search for $K^0 \rightarrow \pi^0 \nu \bar{\nu}$ decay. The beam survey of the KL beam line started in October 2009, and $K^0_L$ beam was successfully identified.

Now we are constructing another charged secondary beam line called K1.1BR. It is placed
opposite side to the K1.8 beam line and is across the KL beam line. The production angle is same as that of K1.8. Although it was originally designed by Doornbos [17] to deliver 0.8-GeV/c separated kaon beam for experiments using stopped kaons, current configuration can transport the momentum up to 1.0 GeV/c. Secondary beams are purified with a cross-field-type electrostatic separator with the gap of 15 cm and the effective length of 2 m. Careful arrangements of the most upstream magnets of K1.8 and K1.1BR enable each beam line to run independently of each other. The beam commissioning of the K1.1BR beam line will start in October 2010.

4. Summary
We have constructed hadron experimental facility which is capable of handling MW-class beams. The first beam was successfully introduced to the hall on January 27th, 2009. Secondary beam lines K1.8BR, K1.8, and KL have been constructed and beam commissioning has started. A new beam line K1.1BR is now under construction and first beam to K1.1BR is scheduled in October 2010.

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