Hadron Physics at J-PARC

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Abstract. The Japan Proton Accelerator Research Complex, J-PARC, has just finished its phase-1 construction, and the proton beams have been delivered to the experimental facilities. The hadron experimental hall (Hadron Hall) is one of the experimental facilities at J-PARC, where secondary beams such as pions and kaons, as well as the primary proton beams, will be used for fixed target experiments. The first proton beam to the Hadron Hall was delivered in January and February, 2009, and the beam was resumed from October. The first experiments at the Hadron Hall are just being started, at a low-momentum beam lines for charged particle beams (K1.8BR and K1.8) and at a neutral kaon beam line. Other beam lines, such as K1.1 and high momentum beam lines, are planned. In this talk, physics topics to be conducted at the Hadron Hall will be introduced as well as the status and plan of the facility.

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OVERVIEW OF J-PARC

The Japan Proton Accelerator Research Complex [1], J-PARC, is a high-intensity, multipurpose proton accelerator facility with experimental facilities for hadron beam sciences. The accelerator complex consists of a linac (linear accelerator), a 3-GeV rapid cycling synchrotron (RCS), and a 50-GeV proton synchrotron (the main ring, MR) (Fig. 1). The linac is the injector to the RCS and will be used for R&D of nuclear transmutation systems in the future. The 3-GeV RCS delivers beams to the Materials and Life Science Facility (MLF), and works as an injector to the MR. The MR delivers beams to the Hadron experimental facility (Hadron Hall) and to the neutrino beam line. The first beams were delivered up to the RCS in Japanese fiscal year (JFY) 2007, to the MLF and the Hadron Hall in JFY2008, and to the neutrino beam line at the beginning of JFY2009. With these accomplishments, the phase-1 construction of J-PARC, which started in JFY2001, completed. Now J-PARC enters its operational era.

HADRON EXPERIMENTAL FACILITY (HADRON HALL)

The beams from the MR are used for particle and nuclear physics experiments by means of secondary as well as primary beams. There will be two extracted beams from the MR: one is the slow extracted beam used for fixed target experiments at the Hadron Hall and the other is the fast extracted beam for the neutrino beams.

The proton beams slowly extracted from the MR are conducted to the primary beam line of the Hadron Hall (Fig. 2). Currently one primary beam line has been prepared, but in the future, a branch of the primary beam line, designated as “High Momentum Beam Line” in Fig. 2, will be constructed. The design beam power of the primary beam is 750 kW (50 GeV, 15 μA), while the MR is operated with 30 GeV of the beam energy and the maximum beam power expected with the 30-GeV beams and the current linac (180 MeV) is 270 kW. The current maximum beam power to the Hadron Hall under the radiation license is 5 kW, which will be increased based on the progress of the accelerator commissioning.

The main primary proton beams hit the production target, T1. A charged secondary beam line, K1.8, its branch K1.8BR, and a neutral kaon beam line, KL, use secondary beams produced at the T1 target. The K1.8 beam line is designed to accept charged particles up to around 1.8 GeV/c. It has double electrostatic separators and a good K/π...
ratio is expected. The maximum momentum of the K1.8 was chosen so that the production cross section of the cascade baryons with the \((K^-, K^+)\) reaction is around the maximum. The maximum momentum of the K1.8BR, which uses the first half of the K1.8, is about 1.1 GeV/c. The KL beam line is dedicated for a rare decay experiment of neutral kaons (E14, the KOTO experiment). In addition, the K1.1BR beam line, whose maximum momentum is about 1.1 GeV/c, will become available in 2010.

The first beam to the Hadron Hall was injected for the first time on January 27th, 2009. Though the accelerator commissioning was the major goal during 2009 and the beam delivery to the Hadron Hall was very limited, we have already started commissioning of the beam lines and observed pion and kaon beams at K1.8, K1.8BR, and KL beam lines. The properties of the secondary beams agree well with the design.

As was mentioned above, the high momentum beam line will be constructed in the future. The high momentum beam line can transport a part of the primary proton beam up to around \(10^{12}/\text{sec}\) and also produce unseparated secondary beams if we install a thin target in the main stream of the primary proton beam at the most upstream of the branch.

**HADRON PHYSICS EXPERIMENTS**

The Program Advisory Committee, PAC, has discussed the proposals on the experiments at the Hadron Hall. The information of the PAC and the proposal can be seen at a web site [2]. The already approved experiments on hadron physics include hadron spectroscopy (E19, E15, E17), hypernuclear physics (E03, E05, E07, E08, E10, E13, E18, E22, E27), and origin of the QCD mass (E16). In addition, there are other experiments proposed such as high-mass dimuon measurement (P04), etc.

One of the major physics topics at J-PARC is hypernuclear physics, which utilizes the high intensity secondary (pion and kaon) beams. While nuclear physics has a long history of the research on “normal” nuclei of protons and neutrons and a lot of information has been accumulated, only the small number of hypernuclei, which contain strangeness flavor, has been found and investigated. While materials around us on the earth consist of normal nuclei,
hypermultiplets are considered to play an important role in the universe. The high-intensity $K^-$ beam at around 1.8 GeV/c available at the K1.8 beam line is quite unique to open a new frontier of hadronic physics in the spectroscopic studies of $S$ (strangeness) = -2 systems, such as $\Xi$ hypernuclei (note that no $\Xi$ hypernuclei has been found yet). With the knowledge of the $\Xi$ single particle potential and $\Xi N$ and $\Lambda \Lambda$ interactions from the spectroscopic date to be taken at J-PARC, we can obtain the equation of states of hadronic matter in high density, say in a neutron star, for example. Note that the knowledge of the depth of the $\Xi$-nucleus potential is important for estimating the existence of strange hadronic matter in the universe. An experiment on $\Xi$ hypernuclei is planned at the K1.8 beam line as E05.

The E05 experiment uses the Superconducting Kaon Spectrometer, which has a large acceptance (about 30 msr with the so-called SksPlus configuration) and a good momentum resolution ($\Delta p/p \sim 3.3 \times 10^{-4}$).

A search for a pentaquark system, $\Theta^+$, with $H(\pi^-, K^-)$ reactions was chosen as the first experiment at the K1.8 beam line since enough intensity for $\pi$ beams can be obtained even with the low intensity proton beams at the beginning of the accelerator operation. This experiment, E19, aims to seeing the $\Theta^+$ peak in the $H(\pi^-, K^-)$ spectrum, which is the case if one of the production mechanisms of $\Theta^+$ works.

A series of experiments, E17 and E15, is being conducted at the K1.8BR also. The E17 experiment is to measure the X rays from a kaonic $^3$He, which corresponds to the 3d-to-2p transition of the kaon captured by the $^3$He. The 2p orbit might be affected by the strong interaction and its energy and width might be changed as a result. The next experiment to the E17 is the E15 experiment, which looks for a bound state of the $K\Lambda$ system.

One of hadron physics experiments is at the high-momentum beam line. The E16 experiment, “Electron pair spectrometer to explore the chiral symmetry in QCD”, will measure electron-positron pairs from a vector meson ($\phi$), to see a change in the mass and/or the width as a result of the partial chiral symmetry restoration in the nuclear matter. The predecessor of the E16 experiment was the KEK-PS E325 experiment, which suggested a shift of the mass of the $\phi$ meson. As the statistics of the E325 experiment was not enough, the E16 experiment aims at collecting 100 times more statistics than the E325, which enables systematic study of the mass and its width such as the velocity dependence, nuclear number dependence, and centrality dependence. The E16 experiment will use $10^{10}$/sec proton beams at the high-momentum beam line. Though the beam line is yet to be constructed, the large spectrometer magnet, used for the KEK-PS E325 experiment, has already been moved to the Hadron Hall to be used for the J-PARC E16 experiment.
Another example of the experiments at the high-momentum beam line is dimuon measurement, P04. This experiment will measure the muon pairs from the p+p, p+d, and p+A reactions. The major goal is to see the flavor asymmetry (d-bar/u-bar) at a large Bjorken-x region (x > 0.3) with the Drell-Yan muon pairs. While a series of the experiments has been done at Fermilab using the 800-GeV protons, lower energy protons are necessary to go to the larger x region. A similar experiment is now prepared at the Main Injector of Fermilab with the 120-GeV protons as the E906/SeaQuest experiment. The experimental apparatus for the E906/SeaQuest is planned to move to J-PARC after the E906/SeaQuest experiment.

SUMMARY

J-PARC has entered its operational era. The first hadron physics experiments at the Hadron Hall have already been started, such as the E17 experiment (kaonic X ray) at the K1.8BR beam line, and the E19 experiment (Θ⁺) at the K1.8 beam line. Hypernuclear spectroscopy is one of the major direction, and the experiments are soon to be started. Chiral symmetry and hadron mass are another direction. The E16 experiment is being prepared. Exotic hadrons, hadron spectroscopy, and hadron structure are also another direction. Experiments for these topics have been and will be proposed. Ideas on proposal are always welcome.

REFERENCES