J-PARC
JAPAN PROTON ACCELERATOR RESEARCH COMPLEX

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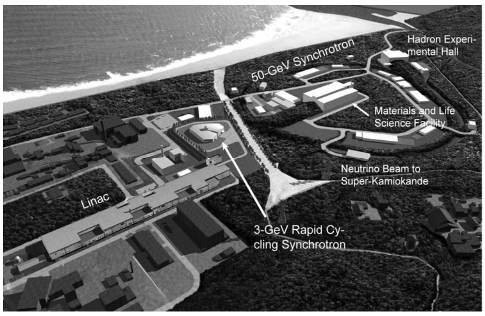
J-PARC, Japan Proton Accelerator Research Complex, is now under construction at Tokai, Japan. It consists of a linear accelerator, a 3-GeV synchrotron, a .50-GeV synchrotron, and experimental facilities. The construction began 2001, and will be completed in 2008. At the 50-GeV synchrotron, wide variety of possibilities in nuclear and particle physics can be expected.

1. Overview

1.1. *Accelerator Complex*



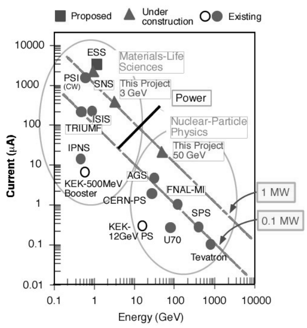


Fig. 1 (Left) Conceptual view of J-PARC at Phase 1. The site is located along the pacific coast. (Right) Beam power of world proton accelerators.

J-PARC, Japan Proton Accelerator Research Complex, is a cascade accelerator complex with experimental facilities (Fig. 1). There are three accelerators: a linear accelerator as an injector, a 3-GeV rapid cycling synchrotron, and a 50-GeV synchrotron. There are major facilities for experiments, such as the Materials and Life Science Facility (MLF) using the 3-GeV beams, the Hadron Hall, which utilizes slow-extracted beams from the 50-GeV synchrotron, and the Neutrino Beamline. Most of the protons accelerated up to 3 GeV go to the MLF where muons and neutrons are utilized. The rest of the protons are accelerated more by the 50-GeV accelerator and led to the Hadron Hall with slow extraction mainly for secondary beams, and to the Neutrino Beamline.

J-PARC has three major goals: materials and life sciences using muons and neutron at the MLF, nuclear and particle physics using secondary beams (kaons, pions, neutrinos, etc.) as well as primary proton beams at the 50-GeV facility, and R&D for nuclear transmutation using beams from the linear accelerator.

J-PARC aims to be the high-intensity frontier. As seen from Fig. 1, all the existing proton accelerator facilities for materials and life sciences and nuclear and particle physics have their beam power of about 0.1 MW or less, except for one at Paul Scherrer Institute which is a continuous beam facility, not pulsed. J-PARC will have the proton beam power of 1 MW with its 3-GeV accelerator for the materials and life science facility, and 0.75 MW with its 50-GeV accelerator for the nuclear and particle physics facilities.

J-PARC is a joint project between KEK, High Energy Accelerator Research Organization, and JAEA, Japan Atomic Energy Agency, and located at Tokai Village, about 70 km north east of KEK with about 1hour and 10 minutes drive.

In 2001, a part of the budget for the entire project of J-PARC was approved by the Japanese government as Phase 1. The Phase 1 includes the linear accelerator up to 180 MeV, the 3-GeV synchrotron, the 50-GeV synchrotron, the building of the MLF, about a half of the building of the Hadron Hall, and the Neutrino Beamline. The total budget size of Phase 1 is about US$ 1.5 billion if we assume 100 Yen correspond to US$1.

2. Nuclear and Particle Physics

2.1. *Performance of the 50-GeV synchrotron*

The design goal and the expected performance of the Phase-1 era of the 50-GeV synchrotron are tabulated in Tab. 1. In the design performance, the proton beam energy is 50 GeV, the intensity is 3.3 x 10^{14} particles per pulse (ppp), which corresponds to 15 μA when the repetition rate is around 3.5 sec., and the resulting beam power is 750 kW. In the Phase-1 era, there are two limitations; the linac energy is not 400 MeV but 180 MeV, and the beam energy of the 50-GeV accelerator is 30 GeV for slow extraction and 40 GeV for fast extraction. The energy reduction in the linac leads to reduction in the beam intensity at the 3-GeV synchrotron and thus that of the 50-GeV synchrotron. The limitation in the beam energy at the 50-GeV synchrotron leads to reduction in the beam power. As a result, the beam power at the Hadron Hall (slow extraction beams) will be 270 kW, and that at the Neutrino Beamline (fast extraction beams) will be 360 kW. The linac energy is planned to be recovered to 400 MeV (design energy) soon after the completion of the Phase-1 construction. In order to achieve 50-GeV beams at the 50-GeV synchrotron, installation of electric power utilities is necessary. Especially at the Neutrino Beamline, a fast extraction facility, gaining the beam power may be possible by using faster repetition rate of the synchrotron. Realistic and detailed numbers on the beam intensity and beam power will become clearer after beam acceleration is started in 2008. For the slow extracted beams, the flat top is assumed to be 0.7 sec., and a longer flat top up to 2 or 3 sec. may be possible. The beam power in the Tab. 1 is calculated assuming the design repetition rate of about 3.5 sec.

Table 1 Design performance and performance of the Phase-1 era of the 50-GeV synchrotron.

	Energy	Linac Energy	Intensity	Current	Power
Design Goal	50 GeV	400 MeV	3.3×10^{14} ppp	15 μA	750 kW
Phase 1 Slow	30 GeV	180 MeV	2×10^{14} ppp	9 μA	270 kW
Phase 1 Fast	40 GeV	180 MeV	2×10^{14} ppp	> 9 μA	> 360 kW

2.2. *Letters of Intent and Proposals*

Discussions on the physics possibilities at the 50-GeV facility have been intensively initiated through various workshops. As a result o these discussions, 30 Letters of Intent [1] had been collected by early 2003. An international committee evaluated these Letters of Intent and the resulting recommendations were taken into account for the facility design.

Full proposals were called in November, 2005, and the 1st deadline was set to be April 28, 2006. The Program Advisory Committee (PAC) for experiments at the 50-GeV facility is formed under the Director of Institute of Particle and Nuclear Study, KEK, to discuss and evaluate the proposals.

2.3. *Hadron Hall*

The Hadron Hall utilizes a slowly extracted proton beam from the 50-GeV synchrotron. As shown in Fig. 3, there are secondary beamlines originating from the production target which allows 30% loss of the primary proton beam. The K1.8 beam line is designed especially for high quality (good K/π ratio) kaon beams with the momentum around 1.8 GeV/c. The K1.1/0.8 beam line is also for high quality kaon beams but around 1.1/0.8 GeV/c. The KL beamline is for an experiment of neutral kaon decays. The high-momentum beam line branches off from a splitting point upstream which allows 2% loss of the primary beam, and it aims at primary proton beams with the intensity of 10^9 – 10^{12} per sec., as well as high momentum secondary pions and kaons. In addition, temporary test beam line may be constructed.

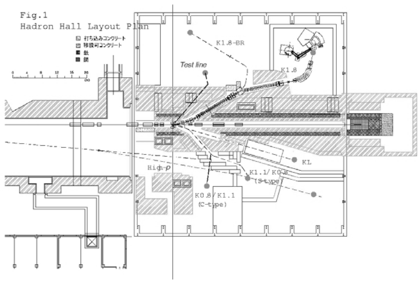


Fig. 2 Phase-1 layout of Hadron Hall. The K1.8 beamline is likely to be ready at the beginning of the operation of the 50-GeV facility.

2.4. *Physics Possibilities at Hadron Hall*

While there are many possibilities on experiments at Hadron Hall and the program will be discussed and evaluated at the PAC of J-PARC, some of the examples are introduced below.

2.4.1. *Flavor Asymmetry in Sea Quark Distribution at Large x*

The most relevant topic to the DIS2006 conference may be an experiment of measuring muon pairs via the Drell-Yan process to deduce $\bar{d}/\bar{u}$ asymmetry at large Bjorken-x. A primary proton beam with an intensity of about 10^{12}/sec. is used to produce muon pairs from a liquid hydrogen target, a deuterium target, and nuclear targets. By taking a ratio of the di-muon cross sections p + d and p + p reactions, one can get a ratio of the distribution of $\bar{d}$ quarks to that of $\bar{u}$ quarks ($\bar{d}/\bar{u}$) as a function of Bjorken x. While perturbative production of quark and anti-quark pairs ($g \rightarrow q\bar{q}$) should give symmetric $\bar{u}$ and $\bar{d}$, a series of previous experiments at Fermilab [2] suggests the $\bar{d}/\bar{u}$ ratio may be different from unity (Fig. 3). Meson cloud may have significant contributions to the sea-quark structure at large x, and a dimuon experiment at J-PARC can measure the $\bar{d}/\bar{u}$ ratio at larger Bjorken x up to about 0.6, making a clear sign of the structure. In addition, this experiment can extract quark energy loss in a cold nuclear matter, and basic information on J/Ψ production.

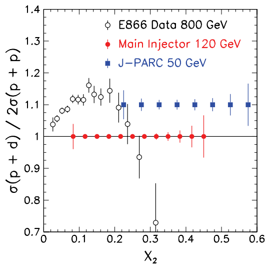


Fig. 3 $\bar{d}/\bar{u}$ ratio as a function of Bjorken x. White circles are results from a Fermilab experiment, and the blue boxes show expected statistics for an experiment at J-PARC.

2.4.2. *Hypernuclear Spectroscopy*

Hypernuclear spectroscopy is one of the major themes. The high-intensity K^- beam with a momentum around 1.8 GeV/c is best suitable for production of Ξ hyperons, and thus Ξ-hypernuclei and double-Λ hypernuclei. By utilizing existing Superconducting Kaon Spectrometer (SKS) at KEK-PS to be moved to J-PARC with improvements, as well as high intensity kaon beams, one can get precise spectroscopic data. The energy resolution of the SKS system is expected to be 2 MeV (FWHM) and the K^- intensity to be 2×10^6 /sec. even at Phase 1. This opens a precise spectroscopic study of the Strangeness = -2 world, which is indispensable, for example, to explore high density matter in the universe.

2.4.3. *CP Violation in* $K_L \to \pi^0 \nu\bar{\nu}$

Kaon rare decay experiments are also suitable to utilize the high intensity kaon beams. Especially $K_L \to \pi^0 \nu\bar{\nu}$ is a direct CP violating process and a clear test for the Standard Model. As the first stage of the experiment, existing KEK-PS E391a apparatus will be moved to the KL beam line of the Hadron Hall with modifications. Even with this apparatus, the experimental group expects to achieve a precision almost similar to the Standard Model prediction, whose branching ratio is about 10^{-11}.

2.5. *Long-Baseline Neutrino-Oscillation Experiment and Neutrino Beamline*

The T2K experiment, a long baseline neutrino oscillation experiment, is another major topic of J-PARC. The muon neutrinos produced at J-PARC are led to the Super-Kamiokande detector 295 km west of J-PARC. The major motivation at

Phase 1 is to measure the last unknown mixing parameter between mass eigenstates and weak eigenstates, θ_{13}, through the measurement of appearance of the electron neutrinos at the Super-Kamiokande detector.

The protons are fast extracted from the 50-GeV synchrotron inward at a extraction point. Protons incident on the graphite target produce pions, which are focused to a forward direction by a set of horns. In order to produce neutrinos with the momentum around 1 GeV/c efficiently, the so-called off-axis beam is used, where the direction of the proton beam is slightly (a few degrees) different from that of the Super-Kamiokande. A near detector, measuring neutrinos at the source, is located at 280 m downstream of the production target. Another detector at 2 km is planned.

3. Construction Schedule and Status

The construction started in the year of 2001. The Phase-1 construction completes in 2008. Beam commissioning at the linac is anticipated later this year. In the late 2008, a proton beam is expected to go to the Hadron Hall, and in the spring of 2009, the first beam to the neutrino beam line is planned. In Fig. 4, an aerographic view of the J-PARC site, taken in February, 2006, is shown.

Fig.4 Aerographic view of the J-PARC site taken in February, 2006.

4. Summary

J-PARC will be the highest intensity accelerator complex in the GeV and ten-GeV energy regions in the world. The major aims are materials and life sciences, nuclear and particle physics, and R&D for nuclear transmutation technology. The Phase-1 construction is from 2001 until 2008. Variety of physics possibilities can be foreseen.

References

1. Letters of Intent are listed at http://www-ps.kek.jp/jhf-np/LOIlist/LOIlist.html .
2. R. Towell *et al.*, *Phys. Rev.* **D 64**, 052002 (2001), and references therein.