Input from J-PARC
to the update of the European Strategy for Particle Physics

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Abstract

Current research activities of Japan Proton Accelerator Research Complex (J-PARC) and the future prospects are summarized with emphasis on the particle physics experiments.

1 Introduction

J-PARC (Fig. 1), located at Tokai, Ibaraki, Japan and operated under the agreement between High Energy Accelerator Research Organization (KEK) and Japan Atomic Energy Agency (JAEA), is a multi-purpose and multi-disciplinary facility open to users from around the world. High-intensity proton accelerators produce intense secondary beams of neutrino, kaon, muon, neutron, etc to study rare processes and do precise measurements. The accelerator complex consists of Linac, Rapid Cycle Synchrotron (RCS), and Main Ring (MR). There are three experimental facilities: Materials and Life Science Experimental Facility (MLF), Neutrino Experimental Facility (NEF), and Hadron Experimental facility (HEF). Muon and neutron beams are available at MLF, and kaon and other hadron beams are available at HEF. The MR accelerator, NEF, HEF, and the muon beam lines and several neutron beam lines of MLF are operated by KEK.

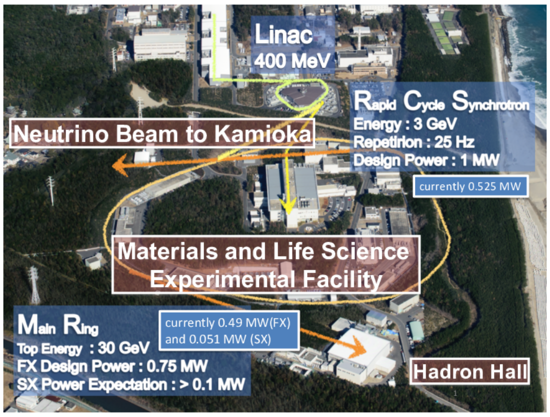

Figure 1: J-PARC site view.

1.1 scientific mission and research programs

J-PARC covers a broad range of scientific research from particle and nuclear physics, materials and life science, to nuclear technology. The main subjects in particle physics are “Neutrino physics” at NEF and “Flavour physics and CP violation” with kaon and muon at HEF.

NEF provides the intense muon-neutrino and anti muon-neutrino beams to Super-Kamiokande, which is located 295 km away from J-PARC. The T2K (Tokai-to-Kamioka) experiment, in Fig. 2, measures the neutrino oscillations and searches for the CP violation in the neutrino sector.

At HEF, various particle and nuclear physics experiments are carried out with a variety of intense hadron beams (Fig. 3). Using secondary kaon beams from the primary proton beam hitting the target in the hall, kaon-decay experiments and strangeness nuclear-physics experiments are being performed. The KOTO (K0 at TOkai) experiment studies the rare neutral-kaon decay $K_L \to \pi^0 \nu \overline{\nu}$ at the KL beam line. A new primary beam line for high-momentum (High-p) and muon beams are in preparation to perform hadron-physics experiments and a muon-to-electron conversion experiment named COMET.

Some particle-physics experiments are carried out at MLF with pulsed muon and neutron beams.

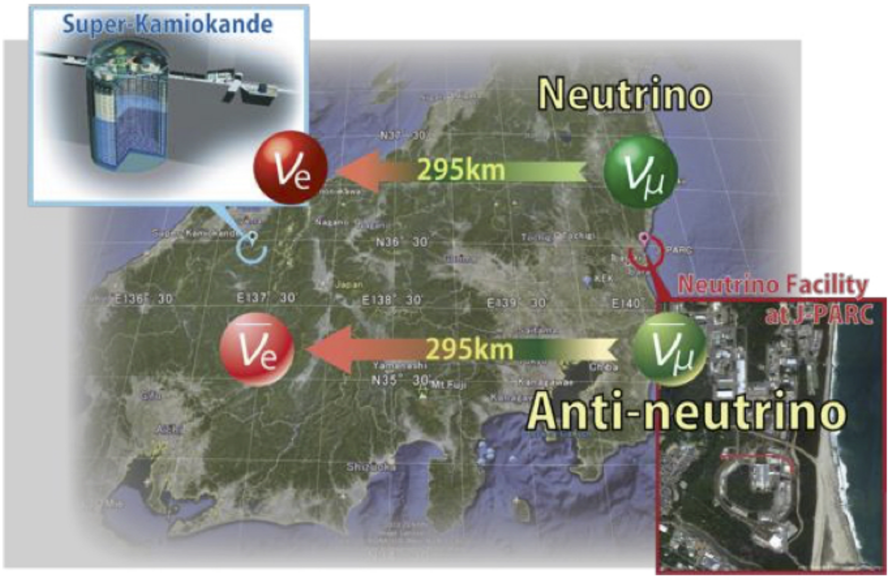

Figure 2: T2K experiment.

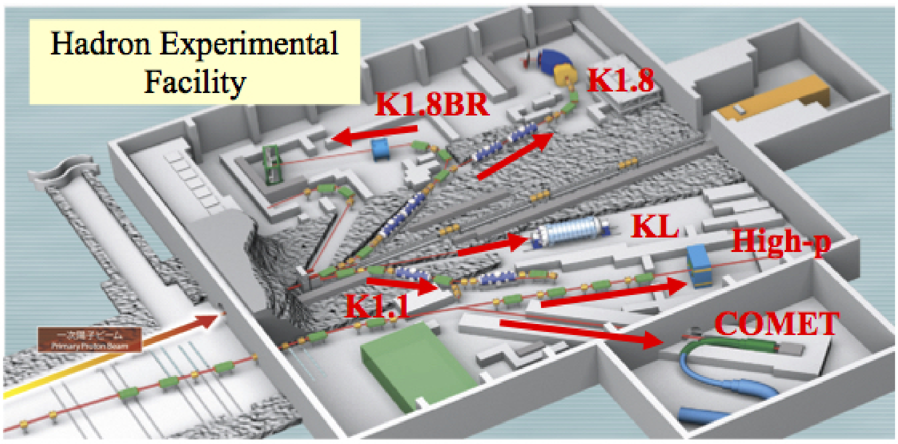

Figure 3: Hall of Hadron Experimental Facility.

1.2 accelerators and beam lines

RCS provides the 3 GeV pulsed proton beam for MLF, and MR provides the 30 GeV proton beam for NEF with fast extraction (FX) and for HEF with slow extraction (SX). FX and SX cannot be operated in the same time. The parameters of RCS and MR are summarized in Table 1.

Table 1: Parameters of RCS and MR.

Accelerator Name	**Energy**	**Current (Design) Power**	**Cycle**	**Extraction**
RCS	3 GeV	500 kW (1 MW)	40 msec	pulsed
MR	30 GeV	485 kW (750 kW) (1.3 MW)	2.48 sec (1.32 sec) (1.16 sec)	fast eight bunches, beam on for 4.2 μsec
MR	30 GeV	51 kW (100 kW)	5.20 sec	slow beam on for 2 sec

Table 2 summarizes the beam lines that are in operation or under construction for particle and nuclear physics experiments. The neutrino beam is delivered from NEF to Super-Kamiokande, and other beams are available at HEF. Note that 1) K1.8 and K1.8BR at HEF share beam-line magnets in their upstream part and the beam can be delivered only one of them at a time, and 2) COMET will use a dedicated 8 GeV proton beam from MR and cannot be conducted with other HEF experiments.

Table 2: Parameters of beam lines at NEF and HEF.

Name	**Species**	**Energy, Momentum**	**Intensity**
ν	ν	0.7 GeV (average)	$1.2 \times 10^7 \nu/\mathrm{cm}^2/10^{21}$ pot at SK
KL	K_L	2.1 GeV/c (average)	10^7 Hz
K1.8	$K^\pm$, $\pi^\pm$	< 2.0 GeV/c	10^6 Hz for K^-
K1.8BR	$K^\pm$, $\pi^\pm$	< 1.1 GeV/c	10^5 Hz for K^-
K1.1	$K^\pm$, $\pi^\pm$	< 1.1 GeV/c	10^5 Hz for K^-
High-p	proton un-separated	30 GeV < 20 GeV/c	10^{10} Hz 10^7 Hz
COMET	μ^-	20-60 MeV/c	3×10^{11} Hz

At MLF a new beam line, named the H-line, is planned for doing more muon experiments.

2 Experiments

Particle and nuclear physics experiments at J-PARC are conducted by international collaborations.

2.1 neutrino physics

T2K is the long-baseline neutrino oscillation experiment of J-PARC, and is running by using Super-Kamiokande as the far detector. The near detector complex has been build and maintained by international collaboration, and its upgrade is being planed with large initiative by European collaboration. Following T2K, the Hyper-Kamiokande project together with the J-PARC beam power upgrade, presented in Section 4, is being proposed. The Hyper-Kamiokande and T2K collaborations have their own input to the update of the European Strategy for Particle Physics (ESPP) [1] to describe the opportunities in accelerator-based neutrino physics in Japan.

At MLF, with the anti muon-neutrinos from the spallation neutron source, a new experiment to search for a sterile neutrino (E56, JSNS^2) is being prepared.

2.2 kaon decay physics

At the KL beam line of HEF, the KOTO experiment is being conducted to study the directly CP-violating rare decay $K_L \to \pi^0\nu\overline{\nu}$. No other $K_L \to \pi^0\nu\overline{\nu}$ experiment is present as of 2018. KOTO has just announced the first major results [2] with the upper limit of 3.0×10^{-9} for the branching ratio of the $K_L \to \pi^0\nu\overline{\nu}$ decay. KOTO continues to take data to reach the Standard Model sensitivity and cover a wide unexplored region predicted by various New Physics scenarios. For the measurement of the $K_L \to \pi^0\nu\overline{\nu}$ branching ratio, a new beam line and a new detector will be constructed as the KOTO step-2 experiment (KOTO-II) at the extended experimental hall of HEF described in Section 4.

At the K1.1BR beam line of HEF, a measurement of $\Gamma(K^+ \to e^+\nu)/\Gamma(K^+ \to \mu^+\nu)$ with K^+ decays at rest (E36) was performed in 2015. The K1.1BR beam line was dismantled after the experiment.

2.3 muon physics

At the South Experimental Building of HEF, a dedicated beam line and a target facility are being prepared to perform the COMET experiment to search for the rare muon-to-electron conversion. The COMET collaboration has its own input to the update of ESPP [3].

At the H-line of MLF, another muon-electron conversion experiment (DeeMe) and a new muon g-2/EDM experiment (E34, g-2/EDM) with an ultra-cold muon beam, which is completely different from those used in previous g-2 experiments, are being planned.

2.4 strangeness nuclear physics

At the K1.8 and K1.8BR beam lines of HEF the following experiments have been performed: search for the Θ^+ pentaquark [4] (E19), observation of the “ K^-pp ”-like structure [5] (E27), missing-mass spectroscopy to search for ${}^{6}_{\Lambda}$H [6] (E10), γ-ray spectroscopy of ${}^{4}_{\Lambda}$He [7], in which a large charge symmetry breaking was observed, and ${}^{19}_{\Lambda}$F [8] with a Ge-detector array (E13), observation of ${}^{12}_{\Xi}$Be bound states [9] (E05), search for the deeply bound K^-pp state [10] (E15), counter-emulsion hybrid experiment to study double strangeness nuclei [11] (E07), spectroscopic study of hyperon resonances below $\overline{K}N$ threshold (E31), and precision spectroscopy of kaonic ^{3}He $3d \to 2p$ X rays (E62). The following experiments will be performed: measurement of the cross sections of Σp scatterings (E40), measurement of X rays from Ξ^- atom (E03), search for H-dibaryon (E42), and coincidence measurement of the weak decay of ${}^{12}_{\Lambda}$C and the three-body weak interaction process (E18). In future, at the K1.1 beam line, γ-ray spectroscopy of ${}^{4}_{\Lambda}$H and ${}^{7}_{\Lambda}$Li (E63) will be made.

2.5 hadron physics

At the K1.8 beam line of HEF, study of baryon resonances in the $\pi N \to \pi\pi N$ reactions (E45) will be performed.

At the High-p beam line of HEF, with 30 GeV primary protons, measurement of the vector meson decays in nuclei to investigate the spctral change of mesons and the chiral symmetry restoration in dense nuclear matter (E16) will be performed. A plan to locate a production target in the Switchyard, far upstream of the hall, to produce charged pions up to 20 GeV/c, transport them through the High-p beam line, and perform charmed baryon spectroscopy is being planned.

2.6 neutron physics

At the BL05, or Neutron Optics and Physics (NOP), beam line of MLF, a series of experiments to study fundamental physics and neutron optics using pulsed neutrons are being performed, including a measurement of neutron lifetime and a search for deviations from the inverse square law of gravity at nm range [12].

3 Program Advisory Committee for proposals

New proposals should be submitted to the Program Advisory Committee (PAC) [1] under the KEK Institute of Particle and Nuclear Studies (IPNS) and J-PARC Center.

PAC consists of fifteen members, most of which are from institutes out of KEK and more than half of which are from abroad. The PAC meeting is held twice a year, usually in January and July, in Tokai and all the presentations and discussions are made in English. PAC evaluates the new proposals to give recommendation to the IPNS and J-PARC directors on their approval or rejection as well as the progress in the approved experiments. PAC also recommends the guide line on beam time allocation in the next six to twelve months, and advises on the middle and long term plans and any other issues.

PAC adopts two-stage approval.

- Stage-1 status will be given by the IPNS director based on the recommendation of PAC, if the scientific merit of the proposal is high and the experimental methods are sound.
- After the stage-1 status is given, the PAC will judge the feasibility of the experiment and gives a recommendation for a stage-2 approval to the IPNS director. The feasibility

[1] Program Advisory Committee for the Nuclear and Particle Physics Experiments at the J-PARC Main Ring, `http://j-parc.jp/researcher/Hadron/en/PAC_for_NuclPart_e.html` .

judgment will be based on the technical achievability, the reliability of the cost estimate, and the manpower allocations.

- If necessary, after the stage-1 status, the IPNS director can ask the Facilities Impact and Finance Committee (FIFC), which is under the IPNS director, to evaluate the various aspects of the feasibility with respect to the Laboratories program.

Based on this information, a stage-2 approval may be given by the IPNS director through the J-PARC center to the proponents, based on the recommendation of the PAC and consideration of the financial situation.

The second stage approval is a green light for the experiment to proceed. Instrumentations in the experimental areas should be constructed and operated by the proponents.

J-PARC has its own International Advisory Committee [2], whose meeting is held once a year, usually in early March, in Tokai.

4 Future prospects

The prospects for the MR beam power is shown in Fig. 4.

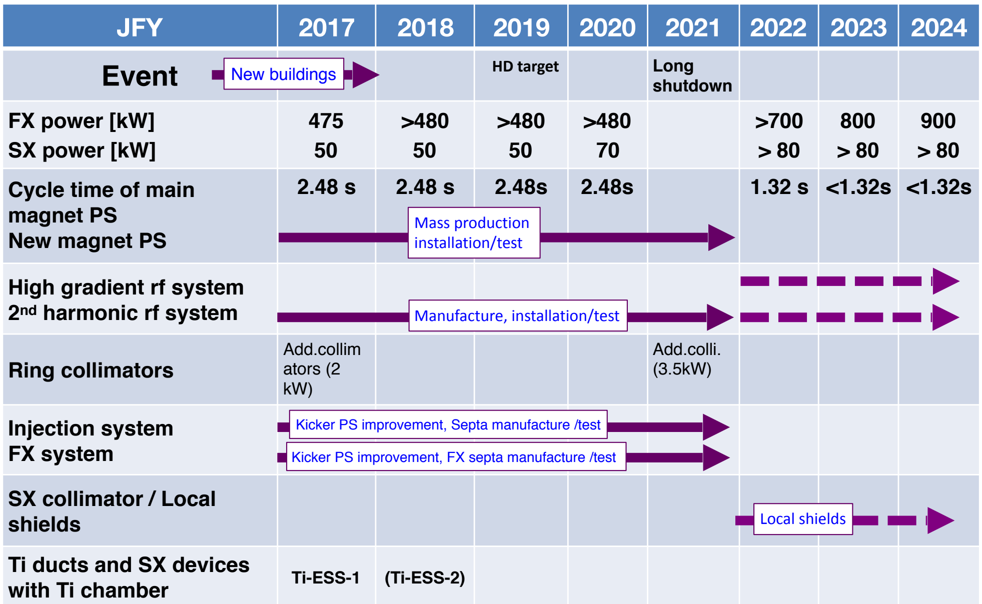

Figure 4: Mid-term plan of the MR beam power as of 2018.

For future plans, KEK has the five-year Roadmap and the Project Implementation Plan (KEK-PIP) [3]. In KEK-PIP on June 30, 2016 [13], as for J-PARC, within the scope of the project funding the priority will be given to obtaining sufficient running time along with maintenance and improvement of the accelerator and experimental facilities. The budget also covers computer costs required in data analyses. In addition to these, the following five experimental apparatus will be covered within the J-PARC project budget: the COMET Phase-I experiment, reinforcement of the facilities for T2K experiment, a neutron polarization analysis system, the

[2] International Advisory Committee, `http://j-parc.jp/committee/en/iac.html` .

[3] KEK Roadmap·KEK-PIP, `https://www.kek.jp/en/About/Roadmap/` .

central portion of the MLF muon beam H-line, and a High-p beam line at HEF. Prioritization of KEK's future projects which require extra funding resources is:

1. Upgrading J-PARC for the Hyper-Kamiokande project,
2. Particle physics in high-luminosity LHC/ATLAS,
3. MLF muon beam H-line and g-2/EDM experiment, and
4. Extension of the J-PARC Hadron Experimental Facility,

three of these are on J-PARC. Note that this does not mean these projects have been approved; PAC's assessment and recommendation are needed.

KEK's participation in the national road maps for large-scale projects for academic research: Master Plan of Japan Science Council and Road Map of Ministry of Education, Culture, Sports, Science and Technology will be base on the above.

In the plan of the extension of HEF [14], the following new secondary beam lines will be constructed for new experiments in order to expand the potential for particle and nuclear physics: new KL beam line for high-intensity K_L, HIHR beam line for high-intensity and high-resolution $\pi^{\pm}$, K10 beam line for high-momentum (2 to 10 GeV/c) $K^{\pm}$, $\pi^{\pm}$ and anti-proton, and K1.1 beam line for low-momentum ($<$ 1.2 GeV/c) $K^{\pm}$. The hall, whose size is 58 m in width and 56 m in length at present, is extended to the downstream by 105 m (Fig. 5). The existing primary beam line is extended, and two new production targets (T2 and T3) are installed. The K1.1 and K10 beam lines are extracted from the T2 target station, and the HIHR and new KL beam lines are extracted from the T3 target station. The beam dump to absorb primary protons is located downstream of the T3 target. The detector for the new K_L experiment KOTO-II will be installed downstream of the beam dump, so that the experimental area will be extended by 48 m. The K1.8, High-p, and COMET beam lines that already exist in the hall continue to be operated.

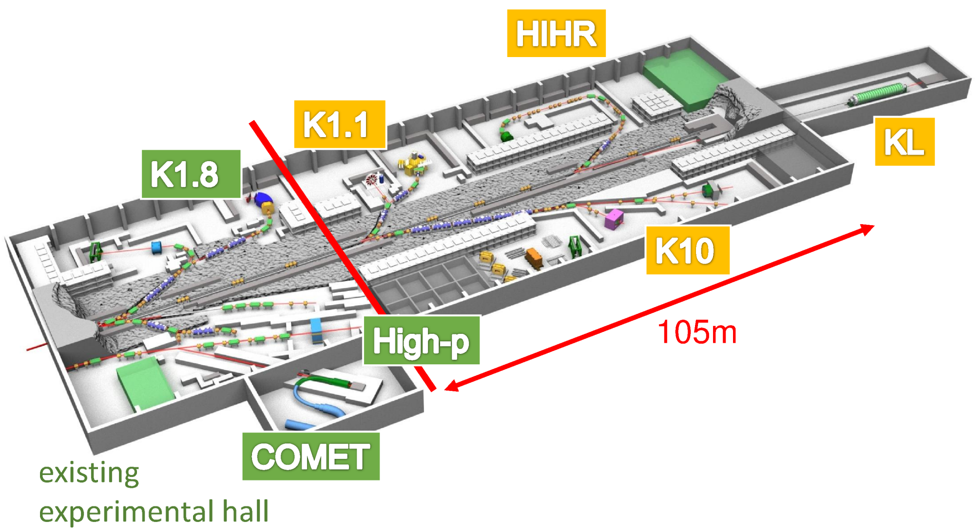

Figure 5: Layout plan of the extended experimental hall of HEF.

References

[1] Hyper-Kamiokande and T2K Collaborations, Opportunities in Accelerator-based Neutrino Physics in Japan, European PP strategy update, 2018.

[2] KOTO Collaboration, J.K. Ahn *et al.*, *arXiv:1810.09655*.

[3] COMET Collaboration, COMET, European PP strategy update, 2018.

[4] J-PARC E19 Collaboration, M. Moritsu *et al.*, Phys. Rev. **C 90**, 035205 (2014).

[5] Y. Ichikawa *et al.*, PTEP **2015** 021D01 (2015).

[6] J-PARC E10 Collaboration, R. Honda *et al.*, Phys. Rev. **C 96**, 014005 (2017).

[7] J-PARC E13 Collaboration, T.O. Yamamoto *et al.*, Phys. Rev. Lett. **115**, 222501 (2015).

[8] J-PARC E13 Collaboration, S.B. Yang *et al.*, Phys. Rev. Lett. **120**, 132505 (2018).

[9] T. Nagae *et al.*, *PoS(INPC2016)038*.

[10] J-PARC E15 Collaboration, T. Hashimoto *et al.*, PTEP **2015** 061D01 (2015); see also J-PARC E15 Collaboration, S. Ajimura *et al.*, *arXiv:1805.12275*.

[11] H. Ekawa *et al.*, *arXiv:1811.07726*.

[12] C.C. Haddock *et al.*, Phys. Rev. **D 97**, 062002 (2018).

[13] "KEK Project Implementation Plan (KEK-PIP)", `http://wwwcms1.kek.jp/en/About/Roadmap/2016/08/03/KEK-PIP.pdf` .

[14] Committee for the study of the extension of the Hadron Experimental Facility, H. Fujioka *et al.*, *arXiv:1706.07916*.