Overview of Hadron Facilities

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Abstract. Hadron facilities in the world are reviewed, in particular, under the emphasis of recently completed J-PARC. The J-PARC consists of three experimental facilities: materials and life experimental facility, neutrino experimental facility and hadron experimental facility. In this talk the first one is skipped and the second one is described only briefly. Described in detail is the third hadron experimental facility. Other world hadron facilities including COSY, GSI, COMPASS, DAΦNE, and FNAL are also briefly reviewed. Electron facilities are not described in this talk, although the facility at JLab is pursuing hadron physics.

1. J-PARC

J-PARC consists of three accelerators and three experimental facilities.
In calendar year of 2007 the linac and the 3 GeV synchrotron were completed. Then, in fiscal year of 2008 the 50 GeV synchrotron and two experimental facilities, the materials and life experimental facility with neutron and muon beams, and the hadron experimental facility with primarily kaon beams were completed. Finally, in fiscal year of 2009, which is the last year, the neutrino facility to send the neutrino beams to Superkamiokande was completed. The entire facility is shown in Figure 1.

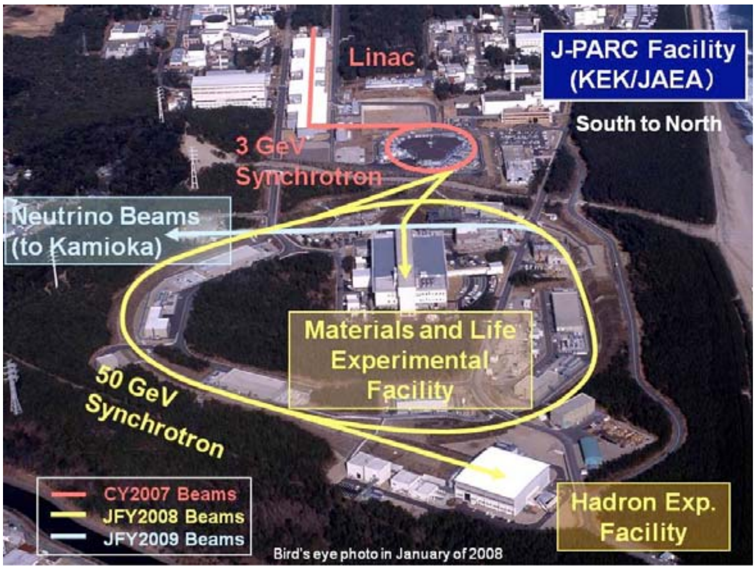


Figure 1. J-PARC Facility as viewed from sky.

Let me explain the goal of the J-PARC. When a high-energy proton hits the nucleus, many particles are emitted: pions, kaons, neutrons, etc. The pion decays into muon and neutrino. The entire purpose of the J-PARC is to use these secondary particles as "beams". Muons and neutrons will be used for materials and life sciences and neutrinos and kaons will be used for nuclear and particle physics. Later, neutrons will be used for nuclear transmutation. For this purpose, we need high power proton beams and, therefore, MW class proton accelerator is needed.

When we proposed this facility the entire cost was about 2 billion dollars. Therefore, the government asked us to cut down to about 1.5 billion dollars, for the construction period of 8 years. In particular, the hadron facility is still too small in Phase 1. We are now considering the expansion of this hall.

In regard to the share of the construction cost, JAEA covered 56% of the budget and KEK covered 44%. JAEA covered upstream portion of the project and KEK covered the downstream portion of the project.

2. Status of J-PARC

The entire accelerators started to run last year. All experimental facilities are now in operation. I would like to briefly describe accelerator status and progress in experimental facilities.

2.1. Power for J-PARC

Figure 2 explains power capability for J-PARC. Many different expectations are written here. At the beginning we had, for a short time period, about 200 kW. Therefore, we were very excited about it. Subsequently, however, we encountered a trouble on RFQ in Linac, but this problem was fixed during the summer shutdown 2009. In November of 2009 we reached a very stable operation of 120 kW at 3 GeV. We also achieved 300 kW for a short period. Since then, we have been running 120 kW at 3 GeV at a very stable mode (90-95% availability).

At the main ring of 50 GeV, 30 GeV is currently in operation, and we recently achieved 100 kW, for a short time, to a neutrino beamline. Slow extraction to hadron hall is still very low, to the level of 5 kW. Soon we will go up to 30 kW operations in this slow extraction mode.

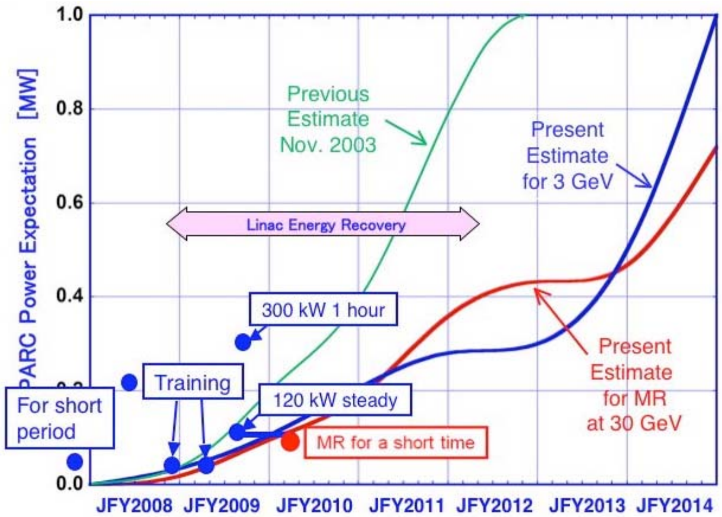


Figure 2. Power capabilities from 3 GeV RCS and 50 GeV MR at J-PARC.

2.2. Neutrino Experiment

We have two major programs in particle and nuclear physics programs at the main ring, one for fast extracted beams on neutrinos and the other for slow extracted beams on hadrons.

For neutrino program, as shown in Figure 3, the muon neutrino beams are being created at J-PARC. First, disappearance experiment will be done, which was already confirmed at KEK-PS [1]. High statistics run is planned here. Second, electron neutrino will be measured to measure θ_{13}, a missing angle between the 1st and the 3rd neutrinos. This is a brand new approach for this parameter. Later, if θ_{13} is significantly large, then a CP violation experiment is planned, using neutrino beams and anti-neutrino beams. Clearly, there is strong competition with other facilities such as DayaBay and Fermilab in regard to the determination of θ_{13}.

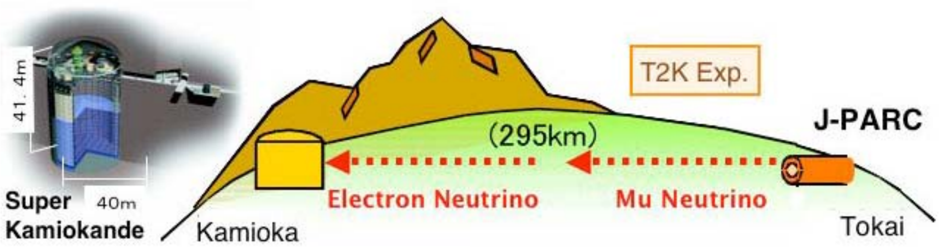


Figure 3. T2K (Tokai to Kamioka neutrino experiment).

For a disappearance experiment of muon neutrinos, the ultimate goal is to detect θ_{23} to the level of 0.01 and mass-square to the level of 10^{-4}. For an appearance experiment of electron neutrinos, the goal is to improve the current limit of θ_{13} to the level of 0.01 (current upper limit is 0.2).
The neutrino beam is created like in what follows. First, proton beams were bent by a superconducting magnet to the target area. Then, pions are produced at the target, focused through electromagnetic horn, and finally, sent to the decay volume to produce neutrinos. Once neutrino beams were produced, they are sent to the "On-Site" detector to confirm the neutrino production. On February 24 the first neutrino event was detected at Super Kamiokande. By the middle of May, they already collected 22 events.

2.3. Hadron Experiments
On the other hand, the hadron experimental hall has many experiments, as shown in Figure 4. Proton beam produces various kaon beam lines. Indicated in Figure 4 as K=1.8 means kaon beam line with

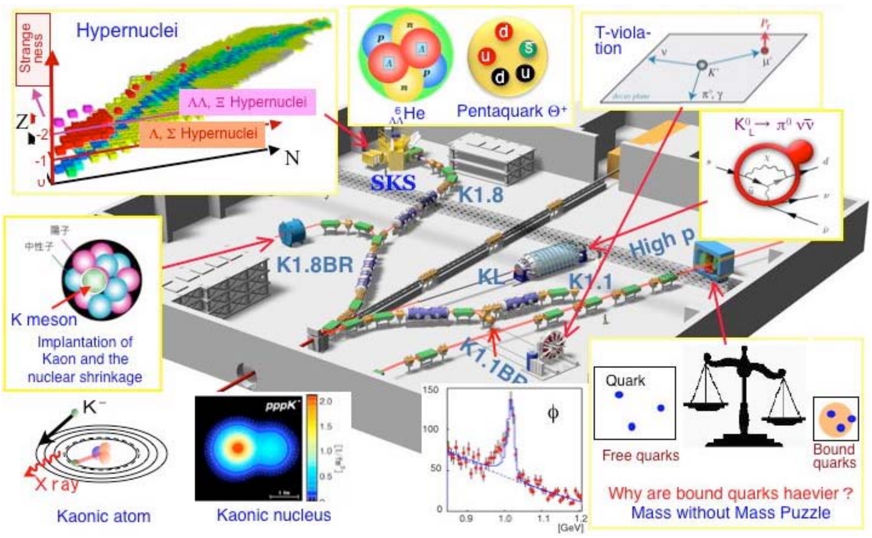


Figure 4. Hadron experimental facility at J-PARC.

momentum of 1.8 GeV/c. At the 1.8 line a spectrometer called SKS is prepared and, there, hypernuclear spectroscopy will be performed for a variety of nuclei. In particular, searches for double hypernucleus and pentaquark are the highlights in this spectrometer. In K=1.8BR, kaon implantation is planned. When kaon is implanted inside the nucleus, there is a possibility that high density matter is created. Kaonic atom and kaonic nucleus will therefore be studied. On the right-hand side, a neutral kaon line is being prepared to study CP violation. Another beam line (K=1.1BR) is for T-violation experiment. Finally, the high-momentum primary beamline, which is not yet completed, is dedicated to the study of chiral symmetry measurement, namely, the mass generation mechanism of bound quarks.
The first beam test was performed. By using the kaon separator the kaon is clearly separated. All experiments are now waiting for beams in the fall of 2011. Therefore, unfortunately, I cannot show any data at this conference.

2.3.1. The SKS Spectrometer. In the SKS Spectrometer, hypernuclear studies will be done, under the emphasis of studying spin dependent interaction. In the past, from a γ-ray Doppler shift attenuation method it was demonstrated [2] that implantation of single Λ already induces a shrinkage of the nucleus by 20% in radius. We would like to extend the measurement not only to Λ-N but Λ-Λ interaction. Also, baryon chemical potential will be studied. Furthermore, nuclear shrinkage will be studied extensively from the measurement of high-resolution γ-rays.
Studies of double strange nuclei are of another interest at J-PARC through K^- to K^+ reactions. In here, Σ-N interactions as well as Λ-Λ interactions will be studied. Since it was expected that rich strangeness content be predicted in a neutron star, it is of particular interest in studying these interactions. I shall describe this point later.
A search of pentaquark is planned also at J-PARC in pion proton interactions. Since this channel is two body decay channel, a sharp peak is expected if a pentaquark exists.

2.3.2. A Deeply Bound Kaonic State. Another experiment, which is in progress, is a kaon implantation inside the nucleus. There is a theoretical prediction that a deeply bound kaonic state induces a strong shrinkage of the nucleus [3] and, as a result, the density up to 10 times normal matter density could be produced. Whether this deeply bound state exists or not is a question. Two methods will be utilized. One is to measure missing mass of neutron, and the other is to measure an invariant mass of decay particles. We will try both approaches to pin down if this state exists.
So far, experimentalists have searched for such an exotic state. Some experiment claims the existence of a bound state [4]. However, no experiments confirmed the existence of kaonic nuclei, so that a new experiment is necessary.

2.3.3. Vector Meson Mass. A planned experiment is to measure vector meson mass, in particular, ϕ-meson mass inside the nucleus. The measurement will be done through di-electron detection. This experiment is similar to the HADES experiment at GSI. From a previous data in proton-nucleus collisions, a tail toward low-mass region was observed at the KEK-PS, indicating a hint of ρ/ω mass modification inside the nucleus [5]. Therefore, the experimental group would like to reconfirm it with much higher statistics at the J-PARC.

2.3.4. Particle Physics Experiments. The approved experiment is $K_0 \rightarrow \pi^0\nu\bar{\nu}$ experiment to study CP violation. This experimental group anticipates obtaining 30 kW beam soon, and later higher. The other experiment is Time reversal test experiment from the measurement of muon polarization. Recently, Comet expt. to measure μ-e conversion was proposed. Here, lepton flavor violation will be tested. Other proposals like neutron EDM and g-2 measurements are also proposed.

2.3.5. Hadron Hall Expansion. Finally, concerning hadron hall expansion, we are eager to have it. For example, RIKEN is considering a possibility of funding it, since RIKEN is a major component for J-PARC hadron facilities.

3. Other World Hadron Facilities

Figure 5 shows world map for hadron facilities.

Figure 5. Hadron experimental facilities in the world.

3.1. COSY at Juelich

Juelich has COSY (Figure 6). It is a very unique polarized proton and deuteron facility with momentum up to 3.7 GeV/c. Three experimental programs are currently running in this facility: WASA, ANKE and TOF. There are a number of devices to provide polarization, including polarized source, low energy polarimeter, high-energy polarimeter, and so on.

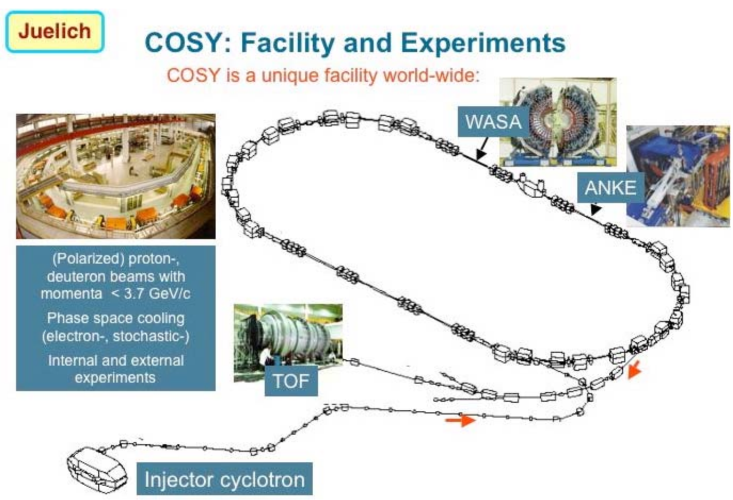


Figure 6. COSY at Juelich.

3.2. GSI and FAIR

GSI has a running machine called SIS. There are a lot of experiments in progress with heavy ion beams. However, proton and pion runs are also available here. HADES to measure di-electrons and FOPI to measure KN interactions are two representative cases at the present GSI –SIS.

Of course, the famous one and the largest one is the FAIR project (Figure 7). SIS-18 beams will be extracted into a new ring called SIS-100/300 and, then, rare isotope beams and antiproton beams will be extracted. Of course, this is a hybrid machine for both heavy-ions and hadron physics.

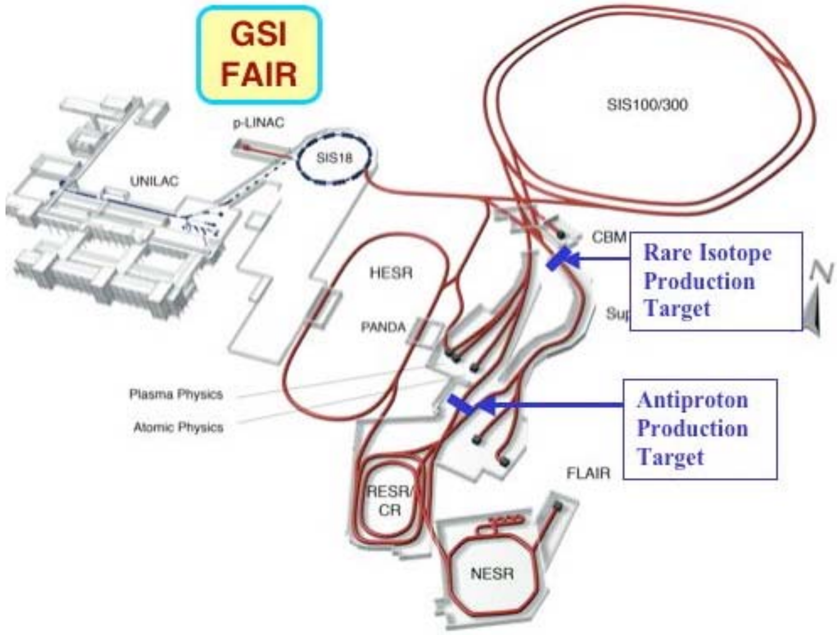


Figure 7. FAIR at GSI.

Detailed view of the FAIR facility, as shown in Figure 7, is as follows.
-- In the first, antiproton beams up to 15 GeV will be accumulated in this ring.
-- Secondly, nuclear matter physics will be done with 35 to 45 GeV per nucleon heavy ion beams, to study high density matter physics.
-- In the third, rare isotope beams will be studied.
-- Other sciences such as plasma science will be done.

The anticipated first beam from the FAIR is around 2017, seven years from now. This is, of course, the largest facility in Europe.

3.3. COMPASS at CERN

Most famous experiment at CERN is COMPASS, which intends to measure light meson spectrum, gluon excitations, and polarizabilities of pion and kaon. COMPASS collected peta byte events since 2002. Previously, they measured deep inelastic scattering with muon beams, to measure spin contribution to protons, and concluded that quark spin contribution is 0.3, the strangeness -0.1, and gluon contribution is 0 to 0.35. Some pion experiment was also done, and recently, a spectroscopy with hadron beams is the major focus of the group, to measure diffractive reactions.

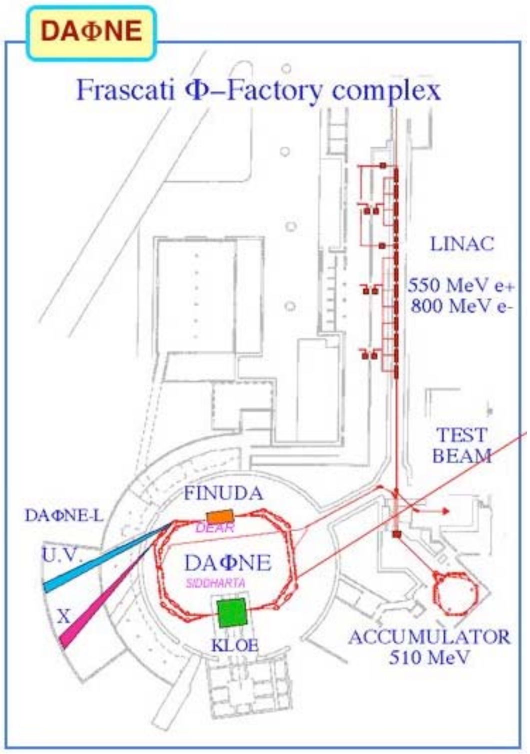
3.4. DAΦNE in Italy

There are two intersections, one called KLOE and the other called FINUDA, as shown in Figure 8. The data from FINUDA shows a peak-like spectrum, which is a hint of K^- bound state inside the nucleus, as discussed before in the J-PARC experiment. Many other experiments are in progress here.

3.5 FNAL

Final example is Fermilab (Figure 9). It has a booster ring and Tevatron. Fermilab has a very broad program. MINOS experiment for neutrino oscillation. NOVA experiment, again, for neutrino oscillation, where NOVA intends to measure θ_{13}, so this experiment is under direct competition with J-

PARC. Other program called "Project X" contains not only neutrino programs but also muon, kaon and nuclear physics experiments. μ−e conversion and g-2 are also included in here.
There are two major nuclear physics experiments here. One is to measure precisely the structure function with much higher statistics, and the other is to measure neutrino nucleus interactions. This is a brand new experiment and would be very interesting.



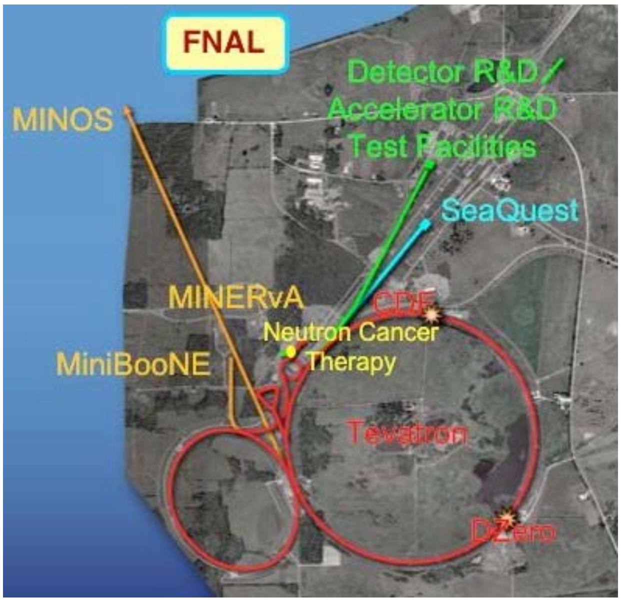


Figure 8. DAFNE in Italy (left).
Figure 9. FNAL (right).

4. Summary

Let me summarize my talk.
Concerning J-PARC, the facility was completed in JFY2009, the last year. Hadron facility is about ready to run many experiments. Neutrino facility started to take data at Superkamiokande. Concerning Materials and Life Facility, neutron and muons beams already started to produce many data and results are being published. In all the areas, we are waiting for more international users to come and use it.
In regard to other hadron facilities in the world, the construction of FAIR is in progress smoothly and the first beam is expected in 2017. COSY, DAΦNE, COMPASS are running well. Fermilab neutrino program is running, and Project X is in progress.
Although I have not discussed electron machine, hadron physics is in progress with electron beams as well.

References

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