Fifth International Conference on
PERSPECTIVES IN HADRONIC PHYSICS
Particle-Nucleus and Nucleus-Nucleus Scattering at Relativistic Energies

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J-PARC
Japan Proton Accelerator Research Complex

Shin'ya SAWADA
High Energy Accelerator Research Organization (KEK)
Institute of Particle and Nuclear Studies
Theory Group
1-1-Oho, Ibaraki
Tsukuba 305-0801
JAPAN

These are preliminary lecture notes, intended only for distribution to participants
J-PARC
Japan Proton Accelerator Research Complex

Shin'ya Sawada
KEK
(High Energy Accelerator Research Organization, Japan)
Overview
  - Uniqueness of our accelerator complex.

Nuclear and Particle Physics Facility at J-PARC

Construction Schedule and Status
Overview
  - Uniqueness of our accelerator complex.

Nuclear and Particle Physics Facility at J-PARC
Construction Schedule and Status
Cascaded Accelerator Complex:

- 3GeV Rapid Cycling (25Hz) Synchrotron
- Linac
- Hadron Hall (Slow Extracted Beams)
- Neutrino Beamline to Super-Kamiokande
- Materials and Life Science Facility
- 50GeV Synchrotron
J-PARC: the High Intensity Frontier

- J-PARC aims for the high intensity frontier for
  - materials/life sciences (3GeV), and
  - nuclear/particle physics (50GeV)
- High intensity proton beam leads to high intensity secondary (neutron, meson, …) beam.
  - The power (= Energy x Current) is a good measure.
- Neutron: from 0.16MW (ISIS) to 1MW
- K meson: 5 to 10 times more intense than existing BNL-AGS.
Phase 1 & 2

- The budget for about 2/3 of the entire project has been approved by the Japanese government from JFY2001 as Phase 1.
- Phase 1 (~151 billion Yen) consists of major accelerator components and a part of experimental facilities.
Organization and Location

- J-PARC is a joint project between KEK and JAEA (Japan Atomic Energy Agency).
- J-PARC will be located at the Tokai campus of JAEA.
Three Goals of J-PARC

- Materials & Life Sciences at 3 GeV
- Nuclear & Particle Physics at 50 GeV
- R&D toward Transmutation at Linac
Overview
  - Uniqueness of our accelerator complex.

Nuclear and Particle Physics Facility at J-PARC

Construction Schedule and Status
**Performance of the 50-GeV PS**

Numbers in red are design values.

Numbers in parentheses are ones for the beginning of Phase 1. Energy recovery of the linac to 400 MeV is planned just after the completion of the Phase-1 construction in 2009.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Beam Energy</td>
<td>$50 \text{ GeV}$</td>
</tr>
<tr>
<td>$E_{\text{Linac}}$</td>
<td>$400 \text{ MeV}$</td>
</tr>
<tr>
<td></td>
<td>($30 \text{ GeV}$ for <strong>Slow Beam</strong>)</td>
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<tr>
<td></td>
<td>($40 \text{ GeV}$ for <strong>Fast Beam</strong>)</td>
</tr>
<tr>
<td>Repetition</td>
<td>$3.4 \sim 5-6\text{s}$</td>
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<tr>
<td>Flat Top Width</td>
<td>$0.7 \sim 2-3\text{s}$</td>
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<tr>
<td>Beam Intensity</td>
<td>$3.3 \times 10^{14} \text{ppp}, 15\mu\text{A}$</td>
</tr>
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<td></td>
<td>($2 \times 10^{14} \text{ppp}, 9\mu\text{A}$)</td>
</tr>
<tr>
<td>Beam Power</td>
<td>$750\text{kW}$</td>
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<td></td>
<td>($270\text{kW}$)</td>
</tr>
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</table>
Discussions on Physics at the 50-GeV PS

- **Workshops**
  - NP01: December 2001
  - NP02: October 2002 – Discussions for Letters of Intent
  - NP04: August 2004 – Discussions for full proposals
    - Neutrino oscillation physics
    - Kaon decay physics
    - Strangeness nuclear physics
    - Hadron physics
    - Muon physics


- **Letters of Intent**

  [http://www-ps.kek.jp/jhf-np/LOIlist/LOIlist.html](http://www-ps.kek.jp/jhf-np/LOIlist/LOIlist.html)
Letters of Intent for 50 GeV

- Announce of LoI call: July 2002
- Thirty LoI’s were submitted by early 2003
  - Strangeness nuclear physics: 6
  - Nuclear/hadron physics: 7
  - Kaon decay physics: 4
  - Muon physics: 3
  - Neutrino physics: 1
  - Future facilities: 9
- 478 physicists with 2/3 from outside Japan.
- Committee meetings to evaluate the LoI’s:
  ➔ Feedback to the facility design
- The full proposals:
  - The first deadline was April 28, 2006!
  - 16 proposals and 4 Lols were submitted.
  - The first PAC meeting will be held from June 30 through July 2.
Slow Extraction Beamline (Phase 1)

NP-HALL
56m(L)×60m(W)

50-GeV PS

Switch Yard

A-Line

T0 Target 0.5% Loss

T1 Target 30% Loss

Beam Dump 750kW

Plan to extend the hall downstream (~50m) in the Phase 2.

May 26, 2006 Shin'ya Sawada @ ICTP, Trieste
Slow Extracted Beams at the Hadron Hall
The building is being constructed so that phase-1 experiments (LoIs) can be accommodated.

K1.8 (and K1.1) has a higher priority for the day-1 exps.
- much higher K intensity than existing facilities.

Major physics topics:
- Kaon decays
- Hypernuclear physics
- Hadron physics

- $K^- (1.8 \text{ GeV/c})$
  - $(K, K^+)$, $S=-2$
  - $K^+ (0.8 \text{ GeV/c})$
  - $K^+ \text{ rare decay}$
- $K^- (1.1 \text{ GeV/c})$
  - $(K^-, \pi^-)$, $S=-1$
K1.8 beamline

- Most probable at Day-1 (the first day of the Phase 1)
- High quality kaon beamline.
  - Best suitable for hypernuclear study, especially of S=-2 systems, using (π, K), (K, π), and (K, K) reactions.
Spectroscopy with $(K^-, K^+)$

$\Xi$ Spectroscopy with $(K^-, K^+)$

KEK-SKS (Superconducting Kaon Spectrometer)

$\Delta E \sim 2 \text{ MeV (FWHM)}$

$BL = 6 \text{ Tm}$

$\sim 6 \text{ events/day/MeV for 50 msr, 2g/cm}^2\text{-thick Pb} \Rightarrow \sim 20 \text{ days}$

May 26, 2006

Shin'ya Sawada @ ICTP, Trieste
Another probable beamline at Day-1 (the first day of the Phase 1)

People are trying to get funding also from agencies other than KEK (RIKEN, Korea, …)

High quality kaon beamline with lower momenta.
  – Suitable for stopped kaon experiments as well as $K^+$ decay experiments etc.
Hadron Physics: Strange Meson Implantation

$K^- + ^4\text{He} \rightarrow \text{"K}^-\text{pnn/p"} + \text{p/n} \quad @ \text{KEK-PS}$

Theory by Y. Akaishi, et al.

$\rho_{\text{center}} = \sim \rho_0$

$\rho_{\text{center}} = \sim 10 \rho_0$

$\rho_{\text{center}} = \sim 20 \rho_0$

Production of dense nuclear matter which can correspond to neutron starts. Study of dense matter will be continued to J-PARC

Beamline specifically designed for $K^0 \rightarrow \pi^0 \nu \bar{\nu}$.

Shielding is designed so that this experiment can be accommodated.

A prototype experiment has been done at KEK-PS.
Most important rare decay channel in the J-PARC era

- Direct CP violation in FCNC process
- Clean measurement of $\text{Im}(V_{td}) \sim \eta$
- Clear test of the Standard Model
- Clue for new physics in comparison with $B$ physics

Unitarity relation

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

Standard Model prediction

$$\text{BR}(K_L \to \pi^0 \nu \bar{\nu}) = 6 \kappa_1 \cdot \text{Im}(V_{td}V_{ts})^2 X^2(\chi_t)$$

$$= 1.94 \cdot 10^{-10} \eta^2 A^4 X^2$$

$$\sim 3 \times 10^{-11}$$

Determination of $\eta$ 10% precision
Not day-1, but I (we) expect early realization.
Primary protons and high mom. 2ndary beams.
Foreign colleagues are interested in experiments at this beamline.

Issues:
- Budget.
- Development of equipments at the separation point.
- Utilities (electric power and cooling water).
Hadron Physics: Sea Quark at Large $x_{Bj}$

- Direct investigation of quark-gluon multibody system
- Proton beams (50 GeV) +hydrogen/deuterium target+dimuon (↔ Drell-Yan process) spectrometer
  - $dar{b}/uar{b}$ (flavor asymmetry) at large $x$
  - Anti quark PDF in A
  - Quark energy loss in A
  - PDF in large $x$
  - Future: Drell-Yan and J/$\psi$ with polarized beam

May 26, 2006 Shin'ya Sawada @ ICTP, Trieste
Vector Meson Modification in Nuclear Matter

**KEK-PS E325:**

PRL 96 (2006) 092301

- Improve KEK-PS E325
  - thin target / primary beam ($10^9 \sim 10^{10}$ ppp) / slowly moving mesons
- Main goal: collect $10^4 \sim 10^5 \phi \rightarrow ee$ for each target in 100 shifts
  - 10-100 times as large as E325
    - velocity dependence of 'modified' component
    - new nuclear targets: proton (CH$_2$ - C subtract), Pb
  - narrow width -> sensitive to modification
  - free from $\omega$-$\rho$ interference
- $\omega, \rho$ and $J/\psi$ can be collected at the same time
  - higher statistics of $\omega, \rho$ than E325 with different A targets
  - 100-1000 $J/\psi$ are expected in 50GeV operation
- Normal nuclear density (p+A)
  - but also high matter density (A+A, ~20GeV/u) in the future
- Tracking Device
  - Drift Chamber
  - GEM (Gas electron multiplier): strip readout
- Two-stage Electron ID
  - Gas Cherenkov:
    - PMT+2 mirrors
    - GEM+CsI photocathode: pad readout
  - Leadglass EMC
- ~30K Readout Channels (in 20 units)
  - E325: 3.6K, PHENIX:~300K
- Cost: ~$5M (including $2M electronics)
Neutrino Facility

- inward beam extraction
- proton line with SC combined-function magnets
- variable off-axis angle between 2-3 degrees
- 130m long decay section
- a near detector at 280 m
- another detector planned at 2km
Status of $\nu$ oscillation and neutrino mass:
- Atmospheric $\nu$ experiments (SK…) discovered neutrino oscillation and thus finite masses of neutrinos.
- K2K $\nu_\mu$ disappearance experiment confirmed the existence of the neutrino oscillation with “man-made” neutrinos.

Motivations of T2K (Tokai to Kamioka):
- Precise measurement of disappearance $\nu_\mu$ to $\nu_x$.
- Discovery of $\nu_e$ appearance: High flux of $\nu_\mu$ enables us to observe it.
  - Flux ($\nu_\mu$) at the 50 GeV PS $> 100 \times$ Flux ($\nu_\mu$) at KEK 12 GeV PS

Future upgrade … towards CP violation in the lepton sector
Many of the issues can be studied at J-PARC if once the facility is well prepared through the plan.

- Drell-Yan, J/Psi production
- Structure at large $x$
- Neutrino scattering
- The Quest of QCD
- Quark confinement and chiral symmetry breaking
- The foundation for nuclear physics

- Hadron Physics
- The Weisskopf barrier
- Chiral symmetry breaking
- From where we are now to the early universe

- Hadron Spectroscopy
- Heavy quark hadrons
- Heavy quark baryons
- Multiquark states
- Glueballs

- Scattering
- Heavy-ion collisions
- Deep-inelastic scatterings
- Chiral perturbation theory

- Spin structure
- EMC effects
- Sečmen structure

- Equation of states
- Compact stars
- Compact supernovae
- Nuclear phase transitions
- QCD phases at finite temperature and density

- Drell-Yan, J/Psi production
- Structure at large $x$
- Neutrino scattering

- Chiral perturbation theory via K decays
- Spectroscopy with $\pi$ and K beams
- Overview
  - Uniqueness of our accelerator complex.

- Nuclear and Particle Physics at J-PARC

- Construction Schedule and Status
Construction Schedule & Commissioning (Phase-1)

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</tbody>
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- Bldg. construction
- Equip. construction
- Beam test
- User access
- Archiological studies
- Study report

Construction Start

Beam
Scenes of Construction
Scenes of Construction
Neutrino Tunnel Tour

Shin'ya Sawada @ ICTP, Trieste
Scenes of Construction
Scenes of Construction

- Linac Area
- 3 GeV Area
Scenes of Construction

- Neutron source being prepared
Scenes of Construction
Scenes of Construction

- 50 GeV Area
Scenes of Construction
Scenes of Construction
Scenes of Construction

- Hadron Experimental Hall
Scenes of Construction

- Hadron Experimental Hall
Summary

- J-PARC will be the highest intensity accelerator complex of the GeV and ten-GeV energy regions in the world.
- The major aims are materials and life sciences by the 3-GeV synchrotron, nuclear and particle physics by the 50-GeV synchrotron, and R&D for nuclear transmutation technology by the linear accelerator.
- The phase-1 construction began 2001, and will be completed in 2008.
- There is a wide variety of physics possibilities.
  - Hadron physics, including Drell-Yan and quarkonium production, vector mesons etc. at the slow extracted facility.
  - Neutrino beam
  - Etc. etc.