Hadronic Physics at the J-PARC Facility

Shin’ya Sawada

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KEK

(High Energy Accelerator Research Organization, Japan)
Contents

- Overview of J-PARC
- Current Hadron Experimental Facility (Hadron Hall) and the 1st Experiments
- Coming Experiments and Facility
- Summary
Nuclear Transmutation (Phase 2)

Materials and Life Science Experimental Facility

Joint Project between KEK and JAEA

J-PARC = Japan Proton Accelerator Research Complex

GeV = $10^9$ electron volt

Hadron Experimental Facility

Neutrino to Kamiokande

500m

Linac (330m)

3 GeV Synchrotron (25 Hz, 1MW)

50 GeV Synchrotron (0.75 MW)
Location of J-PARC at Tokai

295 km

1 hour

KAMIOKA

TOKAI

J-PARC

KEK

TOKYO

JAEA

NARITA

TSUKUBA
Neutrino Beams (to Kamioka)

JFY2009 Beams

3 GeV Synchrotron

JFY2007 Beams

Linac

JFY2008 Beams

J–PARC Facility (KEK/JAEA)

South to North

Materials and Life Experimental Facility

50 GeV Synchrotron

Hadron Exp. Facility

Bird's eye photo in January of 2009
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Construction of Hadron Experimental Hall
Typical Beam Profiles measured with Screen Monitors

January 27th, 2009

Screen Monitor Locations

1 (q01in)  
2 (q02in)  
5 (q11in)  
6 (T0in)  
9 (Dump in)  

3 (v04in)  
4 (v06in)  
7 (q1Aout)  
8 (T1in)
Current Accelerator Status

- 30-GeV protons with slow and fast extraction
- Fast extracted protons are used for the neutrino experiment (T2K).
  - Beam power ~ 40 kW.
  - 100 kW is an immediate goal.
- Slow extracted protons are used at Hadron Hall.
  - Beam power ~ 1 – 2 kW, almost similar to KEK-PS.
  - 5 kW in this fall (October 12 - ), and 20 – 30 kW is a goal in a couple of years.
  - Current accelerator cycle is 6 sec with 1.5-2 sec beam spill.
  - Accelerator people, collaborating with our hadron group, work to improve the beam structure for higher duties. It might take a bit time to get a pure “DC” beam.
  - About 10+ days of total beam time to Hadron Hall between October, 2009, and February, 2010.
  - The next beam time at Hadron Hall is from October 12, 2010.
Current Hadron Hall at February, 2010

K1.1

K1.8 & SKS

KL
$P_{\text{max}} = 2.0$ GeV/c

Double stages of E.S. Separators

High-resolution beam spectrometer

Suitable for $S=-2$ Spectroscopy

<table>
<thead>
<tr>
<th>K1.8 Beamline</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>750kW</strong></td>
</tr>
<tr>
<td><strong>270kW</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Primary proton beam</strong></th>
<th><strong>50 GeV-15\mu A</strong></th>
<th><strong>30 GeV-9\mu A</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length (m)</strong></td>
<td></td>
<td>45.853</td>
</tr>
<tr>
<td><strong>Acceptance (msr.%)</strong></td>
<td></td>
<td>1.4</td>
</tr>
<tr>
<td><strong>$K^- (\pi^-)$ intensity (ppp) @ 1.8 GeV/c</strong></td>
<td>6.6E+06</td>
<td>1.4E+06</td>
</tr>
<tr>
<td></td>
<td>@ 1.5 GeV/c</td>
<td>2.7E+06</td>
</tr>
<tr>
<td></td>
<td>@ 1.1 GeV/c</td>
<td>0.38E+06</td>
</tr>
<tr>
<td><strong>Electrostatic separators</strong></td>
<td>750kV/10cm, 6m×2</td>
<td></td>
</tr>
<tr>
<td><strong>Single rate @ MS2 @ 1.8 GeV/c</strong></td>
<td>&gt; 33E+06</td>
<td>&gt; 8E+06</td>
</tr>
<tr>
<td><strong>$K^-/ (\pi^- + \mu^-)$ @ FF @ 1.8 GeV/c</strong></td>
<td>4</td>
<td>3.5</td>
</tr>
<tr>
<td><strong>X/Y (rms) size @ FF (mm)</strong></td>
<td>19.8/3.2</td>
<td></td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>+1.8 GeV/c</th>
</tr>
</thead>
<tbody>
<tr>
<td>K⁺</td>
</tr>
<tr>
<td>K⁻</td>
</tr>
<tr>
<td>⨿</td>
</tr>
<tr>
<td>⨿</td>
</tr>
<tr>
<td>$P^-$</td>
</tr>
</tbody>
</table>

13
1st experiment at K1.8

- E19 at K1.8/SKS: $\Theta^+$ pentaquark in $\pi$-p -> K-X

Flat distribution

Precise measurement
E19 @ J-PARC

From E559 result
(K+, $\pi^+$) experiment

Backward peak
E19 at K1.8/SKS: $\Theta^+$ pentaquark in $\pi^-p \rightarrow K^-X$

K1.8 beam line + SKS

2GeV/c $\pi^- + p \rightarrow K^- + \Theta^+$

target : liquid $H_2$, reuse E559’s

$K^-$: scattered angle $\leq 40^\circ$
momentum $< 0.9$ GeV/c

SKS : momentum coverage : 0.7–0.95GeV/c
angle coverage $\leq 20^\circ$
$p_{\text{scattered}}$ up to $\sim 1.1$ GeV/c
d$p/p \sim 0.2\%$ @ 1GeV/c
($\sim$5 times better than KURAMA)

Even with the initial beam intensity, this experiment will take enough data in a short period.
K1.8BR Beam Line

K1.1

K1.8BR and E17/15 setup

June 1, 2010
Shin'ya Sawada
Beam line commissioning has been almost done.

K1.8BRのrun#27のビーム利用(11/14、11/15、11/19)

By E17/E15 team, T. Suzuki et al.
1st Experiments at K1.8BR

- E17 at K1.8BR: Precision spectroscopy of Kaonic 3He atomic 3d->2p X-rays
- E15 at K1.8BR: Next to E17, with almost the same apparatus: Search for K-pp kaonic nuclear bound state

T. Suzuki (2B)
R. Hayano (2B)
M. Sato (3B)
E17: Strong-interaction Shift and Width of Kaonic Helium 3

Last orbit of Kaonic atoms is sensitive to $K^-$-nucleus strong-interaction.

$$ \Delta E_{2p} = E_{2p}^{\text{exp}} - E_{2p}^{\text{EM}} $$

Atomic orbits of Kaonic Helium 3

3d → 2p X-rays

(Coulomb-only) 2p

(Strong-interaction) 2p

Nucleus

Slide by Dr. M. Iio
$K^- + ^3\text{He} \rightarrow K^-\text{pp}$ search with TOF measurement of neutron

$K^-\text{pp}$ state is investigated in $K^- + ^3\text{He} \rightarrow \Lambda p + n$ well distinguished final state. $\Lambda$ is always attributed to $K^-$ in the initial state.
Beam line is ready for KL → π^0νν experiment (KOTO)
The area is being extended.

June 1, 2010
Shin'ya Sawada
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Coming Hadron Physics Experiments: PAC approved experiments

**Hadron Spectroscopy**
- Theta+ via (pi-, K-): E19
- Xrays from Kaonic Atom: E17
- K-pp bound State: E15

**Hypernuclear Physics**
- \(\gamma\) ray spectroscopy for \(S=-1\) systems
- \(\Xi\) hypernuclei
- weak decay etc.
- E03, E05, E07, E08, E10, E13, E18, E22, E27
Three Dimensional Nuclear Chart

Nu ~ Nd ~ Ns

"Stable"

Higher density

Strangeness in neutron stars (\( \rho > 3 - 4 \rho_0 \))

Strange hadronic matter (\( A \rightarrow \infty \))

\( \Lambda\Lambda, \Xi \) Hypernuclei

\( \Lambda, \Sigma \) Hypernuclei

Shin'ya Sawada

1, 2010

Shin'ya Sawada
Coming Hadron Physics Experiments: PAC approved experiments

**Hadron Spectroscopy**
- Theta+ via (pi-, K-): E19
- Xrays from Kaonic Atom: E17
- K-pp bound State: E15

**Hypernuclear Physics**
- $\gamma$ ray spectroscopy for $S=-1$ systems
- $\Xi$ hypernuclei
- weak decay etc.
  E03, E05, E07, E08, E10, E13, E18, E22, E27

**Origin of QCD Mass**
- Modification of vector meson mass in nuclear medium
  E16
Mass modification of vector meson

QCD Vacuum

Spontaneous Breaking of Chiral Symmetry

Restoration

Hot/Dense Matter

Vector meson mass at normal nuclear density

\[ \frac{m^*}{m} = 1 - k \frac{\rho}{\rho_0} \]

(Hatsuda & Lee PRC 46(92) R34)

\( \rho/\omega : \Delta m = 130 \text{ MeV at } \rho_0 \)

\( \phi : \Delta m = 20-40 \text{ MeV at } \rho_0 \)
E16: Results of a previous experiment (KEK-PS E325):
Invariant mass spectra of $\phi \rightarrow e^+e^-$

- $\beta\gamma < 1.25$ (Slow)
- $1.25 < \beta\gamma < 1.75$
- $1.75 < \beta\gamma$ (Fast)

Small Nucleus

Large Nucleus

\[
\chi^2/\text{ndf} = 36/50
\]

\[
\chi^2/\text{ndf} = 63/50
\]

\[
\chi^2/\text{ndf} = 43/50
\]

\[
\chi^2/\text{ndf} = 46/50
\]

\[
\chi^2/\text{ndf} = 56/50
\]

PRL 98(2007)042501
J-PARC E16: Electron pair spectrometer to explore the chiral symmetry in QCD

primary proton beam at high momentum beam line + large acceptance electron spectrometer

$10^7$ interaction (10 X E325)

$10^{10}$ protons/spill

with 0.1% interaction length target

→ GEM Tracker
eID: Gas Cherenkov

+ Lead Glass

Large Acceptance (5 X E325)

→ $x100$ statistics

velocity dependence

nuclear number dependence ($p \rightarrow Pb$)

centrality dependence

→ systematic study of mass modification
Location of E16: High-momentum beam line

SM1: branched by 5°
2% beam loss is allowed

Vertical Bend

3.9°  5.8° x3

Already the spectrometer magnet has been moved to Hadron Hall.

Budget being requested.

R&D for the actual beam line is underway.
Construction during shutdown from March to September, 2010

KL area extension

K1.1BR construction
• K1.1BR Beam Line will be available by the end of summer, 2010.
• Area extension of KL will be completed by the end of summer, 2010.
• Budget Request of the High Momentum Beam Line started in JFY2009.
J-PARC has started its operational era!
- E17/E15 (X rays from kaonic atom/kaon-nucleus bound states), and E19 (pentaquark) are being started.

The hadron physics programs;
- Hypernuclear spectroscopy is one of the major direction. Experiments are soon to be started.
- Chiral symmetry and hadron mass are another direction. An experiment (E16) is being prepared, and others will come.
- Exotic hadrons, spectroscopy, and hadron structure are also another direction.
- Physics with hard processes, such as nucleon structure and short range correlation, is also under consideration.
Hadron Hall Extension

- Recently RIKEN expressed interest of contributing to the Hadron Hall extension.
- The Hadron Hall extension was considered as the Phase 2 of the J-PARC, where the Hadron Hall will be extended 50m downstream so that the 2\textsuperscript{nd} target and beam lines from it can be accommodated.
- Hadron Hall Users’ Association plays a leading role for the discussion on physics and beam lines at the extended Hadron Hall.
Tentative Plan for Hadron Hall Phase-II

J-PARC

Extension

Di-Lepton Spectrometer

Nucleon quark structure

Plan of the extended hall (beam lines, detectors, etc.) is completely open at this time.

June 1, 2010

Shin'ya Sawada
Summary

- **J-PARC** has started its operational era!
  - E17/E15 (X rays from kaonic atom/kaon-nucleus bound states), and E19 (pentaquark) are being started.

- **The hadron physics programs**;
  - Hypernuclear spectroscopy is one of the major direction. Experiments are soon to be started.
  - Chiral symmetry and hadron mass are another direction. An experiment (E16) is being prepared, and others will come.
  - Exotic hadrons, spectroscopy, and hadron structure are also another direction.
  - Physics with hard processes, such as nucleon structure and short range correlation, is also under consideration.

- We need your input and even collaboration to realize more hadron physics at J-PARC, including the Hadron Hall extension.
Backups
P04: High mass dimuon measurement

- dimuons from p+p, p+d, p+A
- dbar/ubar asymmetry at large x with Drell-Yan process

- J-PARC can measure d-bar/u-bar at larger x.

- Experiment at Fermilab (=E906) at 120GeV is first.
Directions of hadron physics at J-PARC

Hypernuclear Spectroscopy
- A major direction.
- Precise $S=-1$ measurement
- $1^{st}$ measurement for $S=-2$

Chiral Phase Transition and Origin of Hadron Mass
- Vector meson in nuclear medium

Exotic Hadrons, Spectroscopy, Hadron Structure
- Tetraquark, pentaquark, molecular resonance, ...
- K-nucleus

Hard Processes
- Nucleon structure
- Short range correlation

Others?
Civil engineering of the Hall was finished in July, 2007.
# Already Approved Experiments

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Co-Spokespersons</th>
<th>Affiliation</th>
<th>Title of the Experiment</th>
<th>Approval status</th>
<th>Day1? / priority</th>
<th>Beamline</th>
<th># of participants, (Domestic/Foreign)</th>
</tr>
</thead>
<tbody>
<tr>
<td>E03</td>
<td>K. Tanida</td>
<td>Kyoto U.</td>
<td>Measurement of X rays from Ξ- Atom</td>
<td>Stage 2</td>
<td></td>
<td>K1.8</td>
<td>35 (22/13)</td>
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<tr>
<td>E05</td>
<td>T. Nagae</td>
<td>Kyoto U.</td>
<td>Spectroscopic Study of Ξ-Hypernucleus, 12ΞBe, via the 12C(K-, K+) Reaction</td>
<td>Stage 2</td>
<td>Y / 1</td>
<td>K1.8</td>
<td>76 (46/30)</td>
</tr>
<tr>
<td>E06</td>
<td>J. Imazato</td>
<td>KEK</td>
<td>Measurement of T-violating Transverse Muon Polarization in K+ -&gt; π0μν Decays</td>
<td>Stage 1</td>
<td></td>
<td>K1.1BR</td>
<td>45 (15/30)</td>
</tr>
<tr>
<td>E08</td>
<td>A. Krutenkova</td>
<td>ITEP</td>
<td>Pion double charge exchange on oxygen at J-PARC</td>
<td>Stage 1</td>
<td></td>
<td>K1.8</td>
<td>7 (4/3)</td>
</tr>
<tr>
<td>E10</td>
<td>A. Sakaguchi, T. Fukuda</td>
<td>Osaka U., Osaka EC U.</td>
<td>Production of Neutron-Rich Lambda-Hypernuclei with the Double Charge-Exchange Reaction (Revised from initial P10)</td>
<td>Stage 2</td>
<td></td>
<td>K1.8</td>
<td>18 (13/5)</td>
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<tr>
<td>E11</td>
<td>K. Nishikawa</td>
<td>KEK</td>
<td>Toka-to-Kamioka (T2K) Long Baseline Neutrino Oscillation Experimental Proposal</td>
<td>Stage 2</td>
<td></td>
<td>Neutrino</td>
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<tr>
<td>E13</td>
<td>T. Tamura</td>
<td>Tohoku U.</td>
<td>Gamma-ray spectroscopy of light hypernuclei</td>
<td>Stage 2</td>
<td>Y / 2</td>
<td>K1.8</td>
<td>93 (59/43)</td>
</tr>
<tr>
<td>E14</td>
<td>T. Yamanaka</td>
<td>Osaka U.</td>
<td>Proposal for KL -&gt; π0νν-bar Experiment at J-PARC</td>
<td>Stage 2</td>
<td></td>
<td>K0</td>
<td>66 (34/32)</td>
</tr>
<tr>
<td>E15</td>
<td>M. Iwasaki, T. Nagae</td>
<td>RIKEN, Kyoto U.</td>
<td>A Search for deeply-bound kaonic nuclear states by in-flight 3He(K-, n) reaction</td>
<td>Stage 2</td>
<td>Y</td>
<td>K1.8BR</td>
<td>55 (32/23)</td>
</tr>
<tr>
<td>E16</td>
<td>S. Yokkaichi</td>
<td>RIKEN</td>
<td>Electron pair spectrometer at the J-PARC 50-GeV PS to explore the chiral symmetry in QCD</td>
<td>Stage 1</td>
<td></td>
<td>High p</td>
<td>16 (16/0)</td>
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## Already Approved Experiments (cont’d)

<table>
<thead>
<tr>
<th>(Co-)&lt;br/&gt;Spokesperson&lt;br/&gt;s</th>
<th>Affiliation</th>
<th>Title of the experiment</th>
<th>Approval&lt;br/&gt;status (PAC&lt;br/&gt;recommendation)</th>
<th>Day1? /&lt;br/&gt;priority</th>
<th>Beamline</th>
<th># of&lt;br/&gt;participants,&lt;br/&gt;(Domestic/Foreign)</th>
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<tbody>
<tr>
<td>E17</td>
<td>R. Hayano, H.&lt;br/&gt;Outa</td>
<td>U. Tokyo, RIKEN</td>
<td>Precision spectroscopy of Kaonic $^3\text{He}$ 3d -&gt; 2p X-rays</td>
<td>Stage 2</td>
<td>Y</td>
<td>K1.8BR</td>
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<tr>
<td>E18</td>
<td>H. Bhang, H.&lt;br/&gt;Outa, H. Park</td>
<td>SMU, RIKEN, KRISS</td>
<td>Coincidence Measurement of the Weak Decay of $^{12}\text{C}$ and&lt;br/&gt;the three-body weak interaction process</td>
<td>Stage 1</td>
<td></td>
<td>K1.8</td>
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<tr>
<td>E19</td>
<td>M. Naruki</td>
<td>KEK</td>
<td>High-resolution Search for $\theta$+ pentaquark in $\pi$-p -&gt; K-X&lt;br/&gt;Reactions</td>
<td>Stage 2</td>
<td>Y</td>
<td>K1.8</td>
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<tr>
<td>E21</td>
<td>Y. Kuno</td>
<td>Osaka U.</td>
<td>An Experimental Search for $\mu$-e conversion at a Sensitivity&lt;br/&gt;of $10^{-16}$ with a Slow-extracted Bunched Beam</td>
<td>Stage 1</td>
<td></td>
<td>New&lt;br/&gt;beam&lt;br/&gt;line</td>
</tr>
<tr>
<td>E22</td>
<td>S. Ajimura, A.&lt;br/&gt;Sakaguchi</td>
<td>Osaka U.</td>
<td>Exclusive Study on the Lambda-N Weak Interaction in $A=4$&lt;br/&gt;Lambda-Hypernuclei (Revised from Initial P10)</td>
<td>Stage 1</td>
<td></td>
<td>K1.8</td>
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<tr>
<td>T25</td>
<td>S. Mihara</td>
<td>KEK</td>
<td>Extinction Measurement of J-PARC Proton Beam at K1.8BR</td>
<td>Test&lt;br/&gt;experiment</td>
<td></td>
<td>K1.8BR</td>
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<tr>
<td>P26</td>
<td>K. Ozawa</td>
<td>U. Tokyo</td>
<td>Direct Measurement of omega mass modification in $A(\pi^- n)omega$ reaction and omega -&gt; pi0 gamma decays</td>
<td>Deferred</td>
<td></td>
<td>K1.8</td>
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<tr>
<td>E27</td>
<td>T. Nagae</td>
<td>Kyoto U.</td>
<td>Search for a nuclear Kbar bound state K-pp in the d($\pi^+, K^+$)&lt;br/&gt;reaction</td>
<td>Stage 1</td>
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<td>K1.8</td>
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<tr>
<td>P28</td>
<td>H. Fujioka</td>
<td>Kyoto U.</td>
<td>Study of isospin dependence of kaon-nucleus interaction&lt;br/&gt;by in-flight $^3\text{He}(\text{K}^-, n/p)$ reactions</td>
<td>Approved as&lt;br/&gt;a part of E15</td>
<td></td>
<td>K1.8BR</td>
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<tr>
<td>P29</td>
<td>H. Ohnishi</td>
<td>RIKEN</td>
<td>Study of in medium mass modification for phi meson using&lt;br/&gt;phi meson bound state in nucleus</td>
<td>Deferred</td>
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<td>K1.1</td>
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<tr>
<td>P31</td>
<td>H. Noumi</td>
<td>Osaka U.</td>
<td>Spectroscopic study of hyperon resonances below KN&lt;br/&gt;threshold via the (K-, n) reaction on Deuteron</td>
<td>Deferred</td>
<td></td>
<td>K1.8</td>
</tr>
</tbody>
</table>

Total # (D/F): 348 (180/168)
Proposals/LoI’s

- **Already submitted Proposals**
  - P04: dimuon from p+p, p+d, p+A; flavor asymmetry in sea quark, etc.
  - P26: omega mass modification via A(pi-, n)omega
  - P29: phi mass modification by phi bound states with p-bar beam
  - P31: hyperon resonance below KN threshold via d(K-, n)

- **LoI’s**
  - P09: S=+1 spectroscopy and K+ rare decay with low momentum K+ beams
  - PDF of mesons via Drell-Yan
  - eta mesic nuclei via (pi-, n)
  - hyperon-nucleon scattering with SCIFI-MPPC
  - gamma-ray spectroscopy of hypernuclei at K1.1
  - Sigma-N interaction
  - Theta+ via (K+, p)
  - Double anti-kaon production via p-bar annihilation