J-PARC Facilities in Tokai

- 3 GeV Synchrotron (350m)
- LINAC (330m)
- Neutrino Beam line
- Hadron Exp. Facility
- Material and Life Science Facility
- 50 GeV Synchrotron (1600m)

Feb., 2006
## J-PARC Schedule

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<th>Facility</th>
<th>2001</th>
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- **Construction:** Civil Engineering and Equipment
- **Test:** Beam
- **Operation:** Beam Operation
- **Users:**

- **Dec. 2006 → LINAC**
- **Sep. 2007 → 3 GeV**
- **May 2008 → 50 GeV**
- **Dec. 2008, First beam from 50GeV**
Hadron Exp. Hall

60m x 56m
Compl. in March, 2008
Layout Option - K1.8+K1.1BR

\[ \sim 10^7 \, \text{K}^{-\text{sec}}, \, K/\pi > 1 \]
Proposals at J-PARC

- Proposal Call: Nov., 2005 - Apr., 2006
- 20 proposals including 4 Lols
  - ~10 proposals in Strangeness Nuclear Physics
- First PAC Meeting: June 30 - July 2
  - Five Day-1 Experiments
  - Stage-2 Approval: (Full Approval)
    - E05: Ξ hypernuclei Spectroscopy (Nagae) [1st priority]
    - E13: Hypernuclear γ-ray Spectroscopy (Tamura) [2nd priority]
Stage-1 Approval: (Scientific Approval)

- E15: Search for $K \cdot pp$ bound state (Iwasaki, Nagae)
- E17: Kaonic $^3$He $3d \rightarrow 2p$ X-ray (Hayano, Outa)
- E19: Search for Penta-quark in $\pi p \rightarrow K \cdot X$ reaction (Naruki)

† Day-1 experiments --

- E03: $\Xi$-atom X rays (Tanida)
- E07: Hybrid-Emulsion for Double-$\Lambda$ (Imai, Nakazawa, Tamura)
New Hypernuclear Spectroscopy at J-PARC

- Spectroscopic studies on S=-2 systems; E05
  - Ξ hypernuclei with (K⁻,K⁺) reaction
  - Excited states of double-Λ hypernuclei
- Extensive study of hypernuclear γ spectroscopy; E13
  - Table of Hyper-isotopes
- Deeply-bound Kaonic Nuclei; E15
  - High-density matter
Spectroscopic Study of $\Xi$-Hypernucleus, $^{12}\Xi$Be, via the $^{12}$C(K$^-$,K$^+$) Reaction

- Discovery of $\Xi$-hypernuclei
- Measurement of $\Xi$-nucleus potential depth and width of $^{12}\Xi$Be
- Beam: $K^- @ 1.8$ GeV/c, $1.4 \times 10^6$/spill
- $CH_2 \sim 2 \text{ g/cm}^2$: 2 weeks for tuning and calibrations
- $^{12}$C 5.4 g/cm$^2$: 4 weeks
- Setup: K1.8 & SKS+

Unique experiment at J-PARC: No other place can do this experiment!
Purpose of the experiment

- First Spectroscopic Study of $S=-2$ systems in $(K^-,K^+)$ reaction
  - $\Xi$-hypernuclei → double-$\Lambda$ hypernuclei
  - $\Xi p$-$\Lambda \Lambda$ mixing
  - First step for multi-strangeness baryon systems

- $\Xi N$ Interactions: almost no information
  - Attractive or repulsive? → potential depth
  - $\Xi p$→$\Lambda \Lambda$ conversion? → conversion width
  - Isospin dependence? → Lane term($\tau_\Xi \cdot \tau_C / A$)
Strangeness Nuclear Physics

(K⁻, K⁺) Spectroscopy

Three-Dimensional Nuclear Chart

Double-Λ Hypernuclei
Ξ Hypernuclei
Λ, Σ Hypernuclei
Λ ~35
Σ 1

Ordinary nuclei

stable ~300
unstable > 3000
First Spectroscopic Study of $S=-2$ systems in $(K^-,K^+)$ reaction

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$S=-2$ Baryon Systems

Energy Spectrum of $S=-2$ systems

$\Xi^{-}$-hypernucleus

$\Xi^{-}$-$N$ Interaction

$\Xi N \quad \sim 28$ MeV

$\Lambda \Lambda \quad \sim 75$ MeV

$\Lambda$ - Large Mixing ?

$\Lambda \Sigma$ mix. $\sim$ a few %

$\sim 300$ MeV

$N$ - H?

$\Lambda$ - Large 3-body force ?

$\Delta$

$\Lambda$ - $\Lambda$ Interaction

$\Delta B_{\Lambda \Lambda} > 0$ ? $\Delta B_{\Lambda \Lambda} < 0$ ?

$M_H > 2xM_\Lambda - B_{\Lambda \Lambda}$

Weak Decays

$M_H < 2xM_\Lambda - B_{\Lambda \Lambda}$

H particle mass

H + (A-2)

S=0

S=-1

S=-2
Purpose of the experiment - cont.

- First Spectroscopic Study of $S=-2$ systems in $(K^-,K^+)$ reaction
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  - $\Xi p$-$\Lambda\Lambda$ mixing
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- $\Xi N$ Interactions: almost no information
  - Attractive or repulsive? $\rightarrow$ potential depth
  - $\Xi p$ $\rightarrow$ $\Lambda\Lambda$ conversion? $\rightarrow$ conversion width
  - Isospin dependence? $\rightarrow$ Lane term ($\tau_\Xi \tau_C / A$)
Chemical Potential: \[ \mu_B = m_B + \frac{k_F^2}{2m_B} + U(k_F) \]

- \[ U_{\Sigma} < 0, \ U_{\Xi} < 0 \]
- \[ U_{\Sigma} > 0, \ U_{\Xi} < 0 \]
- \[ U_{\Sigma} > 0, \ U_{\Xi} > 0 \]
First Spectroscopic Study of $S=-2$ systems in $(K^-,K^+)$ reaction

- $\Xi$-hypernuclei $\rightarrow$ double-$\Lambda$ hypernuclei
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- First step for multi-strangeness baryon systems

$\Xi N$ Interactions: almost no information

- Attractive or repulsive? $\rightarrow$ potential depth
- $\Xi p \rightarrow \Lambda\Lambda$ conversion? $\rightarrow$ conversion width
- Isospin dependence? $\rightarrow$ Lane term($\tau_{\Xi}\cdot\tau_C/A$)
Evidence for \( p(K^-K^+) \) production on \( ^{12}\text{C}(K^-K^+) \)

Previous Measurements on \( ^{12}\text{C}(K^-K^+) \)

PKhaustov et al., PRC61(2000)0546

\( P_K = 1.8 \text{ GeV/c} \)
\( \Delta M = 9.9 \text{ MeV/c}^2 \; (\text{FWHM}) \) for \( p(K^-K^+\Xi^-) \)

-20 < \( E_\Xi^- \) < 0 MeV
89+14 nb/sr \( \theta < 8^\circ \)
42+5 nb/sr \( \theta < 14^\circ \)

FIG. 6. Excitation-energy spectra from E885 for \( p(K^-K^+)X \)

\( K^+ < 14 \) (top figure) and \( K^+ < 8 \) (bottom figure) along with 11B production theoretical curves for \( T_V \) equal to 20, 18, 16, 14, and 12 MeV. The results of a quasifission calculation and 12B production are indicated with arrows.

The expected location of the ground state of \( ^{11}\text{Be} \) and the thresholds for \( ^{11}\text{Be} \) and 12B production are indicated with arrows.

\( ^{11}\text{Be} \) and the thresholds for \( ^{11}\text{Be} \) and 12B production are indicated with arrows.
SKS+ Spectrometer

- 95° total bend
- ~7m flight path
- Δx=0.3 mm (RMS)
\[ V_{\Xi} = -20 \text{ MeV} \]

\[ V_{\Xi} = -14 \text{ MeV} \]

\[ \Delta E_{\text{meas.}} = 3 \text{ MeV}_{\text{FWHM}} \]

Precision:
- Peak Position: 0.1 - 0.3 MeV
- Width: 0.2 - 1 MeV
Gamma-ray Spectroscopy of Light Hypernuclei

- Spin-flip $B(M1)$ measurement for $g_\Lambda$ in nuclei
  - $^7\text{Li}(K^-\pi^-\gamma)^7\Lambda\text{Li}$ at 1.5 GeV/c: $M1:3/2^+\rightarrow 1/2^+$

- $\Lambda N$ interaction in p-shell hypernuclei
  - $^{10}_\Lambda\text{B}$ and $^{11}_\Lambda\text{B}$

- Radial dependence of $\Lambda N$ interaction in sd-shell hypernuclei
  - $^{19}_\Lambda\text{F}$: easiest in sd-shell

- Charge-Symmetry Breaking in $\Lambda N$ interaction, and Spin-flip excitation in $(K^-\pi^-)$ reaction
  - $^4\Lambda\text{He}(M1:1^+\rightarrow 0^+)$
1. Beam and Setup

- **Beamline:** K1.8
  - 0.5x10^6 K^-/spill at 1.5 GeV/c (9µA)
  - K/π >> 1

- **Spectrometer:** SKS (modified)
  - Δp ~ 4 MeV (FWHM)
  - Ω ~ 110 msr

- Hyperball-J
  - ε ~ 7% at 1 MeV

- **K^- + n → Λ + π^-**

- Lab Cross Sections
  - Lab Momentum: pK^- (GeV/c)
  - Spin-Nonflip: |f|^2
  - Spin-Flip: |g|^2

- Diagram:
  - SMF (iron)
  - STOF
  - SDC1,2
  - SAC
  - BAC
  - Target
  - Spin Filter (SFV)
  - Hyperball-J
  - 2.7T

- K1.8
Hyperball-J

- Single (r.e.~70%) x 30-40
  ➔ peak efficiency ~ 7% at 1MeV
  (x3 of Hyperball)

- Mechanical cooling (under development)
  -- Lower temp. for less radiation damage
  -- save space for flexible arrangement

- PWO background suppression counters replaced from BGO for higher rate

Grant: ~ 3.3M$, 2005-2009
“Gamma spectroscopy of strange baryon multi-body systems”

+ Waveform readout (under development)
  ➔ Rate limit ~2x10^7 particles /s
  (x5 of Hyperball)
  ➔ Yield: x 15 for single γ
            x 45 for γγ
### Summary of the beam time request

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<th>Target</th>
<th>(g/cm²)</th>
<th>Beam time</th>
<th>Main objective</th>
<th>Purposes</th>
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<tr>
<td>tuning</td>
<td>300 hrs</td>
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<tr>
<td>$^{7}\text{Li}$</td>
<td>17.2 for $^7\text{Li}$</td>
<td>500 hrs</td>
<td>$^{7}\text{Li}: \ B(M1:3/2^+\rightarrow1/2^+)$</td>
<td>$g_A$ in nucleus</td>
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<tr>
<td>$^{10}\text{B}$ metal</td>
<td>(20)</td>
<td>100 hrs</td>
<td>$^{10}\text{B}: \ E(2^-,1^-)$</td>
<td>$\Lambda N$ spin dependence, $\Sigma A$ coupling</td>
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<tr>
<td>$^{11}\text{B}$ metal</td>
<td>(20)</td>
<td>200 hrs</td>
<td>$^{11}\text{B}: \text{level scheme}$</td>
<td>$\Lambda N$ spin dependence, $\Sigma A$ coupling</td>
</tr>
<tr>
<td>(CF$_2$)$_n$ teflon</td>
<td>(15.2 for $^{19}\text{F}$)</td>
<td>100 hrs</td>
<td>$^{19}\text{F}: \ E(3/2^+,1/2^+)$</td>
<td>$\Lambda N$ spin-spin int. in sd shell</td>
</tr>
<tr>
<td>He liquid</td>
<td>(3.13)</td>
<td>100 hrs</td>
<td>$^4\text{He}: \ E(1^+,0^+)$</td>
<td>$\Lambda N$ CSB, ($K^-,\pi^-$) reaction test</td>
</tr>
</tbody>
</table>

Beam time is calculated for the $K^-$ beam intensity of $0.5 \times 10^6$ $K^-$ (1.5 GeV/e) per spill, which corresponds to 30 GeV, 9 $\mu$A proton beam.

When beam intensity is weak (1~2$\mu$A), we can run one or two targets first after tuning.

Ready to run at the end of 2008.
A Search for deeply-bound kaonic nuclear states by in-flight $^3$He(K$^-$,n) reaction

Evidence for K$^-$pp in FINUDA

$K^- + \text{“pp”} \rightarrow \Lambda + p$

- A bridge from K$^-p(\Lambda(1405))$ to K-Nucleus
quasi-free process (80–85\%) 
\[ K^- + \text{"N"} \rightarrow \Lambda + \pi, \Sigma + \pi \]
\[ p_\Lambda \lesssim 400 \text{ MeV}/c \]

two-nucleon absorption:
\[ K^- + \text{"NN"} \rightarrow \Lambda + N, \Sigma + N \]
\[ p_\Lambda: 400 - 700 \text{ MeV}/c \]

\[ 1\% \text{ on } d \text{ (T=0)}, \text{ but } 15\text{-}20\% \text{ on } ^4\text{He} \sim \text{heavier} \]

\[ K^-\text{"d"} \rightarrow \Sigma - p; \text{ no need for binding} \]

*Contributions of NN pairs in T=1*
Angular correlation of $\Lambda$-p

$^6$Li, $^7$Li, $^{12}$C

$^{27}$Al, $^{51}$V

First experimental evidence for Two-Nucleon Absorption
In-flight ($K^-, n$) reaction on $^3\text{He}$

$K^- + ^3\text{He} \rightarrow \langle K^- pp \rangle + n$

$\langle K^- pp \rangle \rightarrow \Lambda + p \rightarrow p\pi^- + p$

$\sigma_M = 9 \text{ MeV}$

$\sigma_M = 15 \text{ MeV}$

Cylindrical detector system (around target)
Summary

- J-PARC Construction: 2001 ~
  - ~70% completed
  - Beam commissioning: LINAC (Dec., 06), RCS (Sep., 07), MR (May, 08)
  - Beam from MR: ~ end of 2008
- Day-1 Experiments in preparation with ~10 M$
  - hypernuclei
  - Hypernuclear gamma-ray spectroscopy
  - Deeply-bound Kaonic nuclei
  - etc.

See you at J-PARC in HYP2009
J-PARC E05/E13 collaboration meeting

E05: Ξ-hypernuclear spectroscopy
E13: γ spectroscopy

Date/Time: October 14th (Sat.) 13:00-15:00

Place: Room A9 in the HYP2006 site

Everyone is welcome.