Highlights from J-PARC Hadron Facility

IPNS, KEK / J-PARC Center

T. Takahashi

1. Introduction of J-PARC & Hadron Facility
2. History of J-PARC
3. E19 results
4. Other program
5. Effect of Earthquake
6. Summary
J-PARC at Tokai Village
Neutrino

MLF

RCS

181 MeV

3 GeV

Hadron

Bird’s eye photo in Feb. 2008
Hadron Experimental Hall at J-PARC

Design Beam Power: 750kW (3.4x10^{14} ppp, 50GeV-15\mu A)

270kW (2.0x10^{14} ppp, 30GeV-9\mu A)

2010 Achievement: ~5kW (~6x10^{12} ppp, 6sec. duration)

2011 Plan: ~50kW

K1.8 (2009 Oct.-)
- \( p_{\text{max}} = 2.0 \text{ GeV/c} \)
- \( I_K \approx 10^6 \text{ ppp at } 1.8 \text{ GeV/c} \)
- Double stages Electrostatic Separators
- \( K^-/(\pi^- + \mu^-) \approx 3.5@1.8 \text{ GeV/c} \)

K1.8BR (2009 Feb.-)
- \( p_{\text{max}} = 1.1 \text{ GeV/c} \)
- \( I_K \approx 10^6 \text{ ppp at } 1 \text{ GeV/c} \)

K1.1BR (2010 Oct.-)
- \( p_{\text{max}} = 1.1 \text{ GeV/c} \)
- \( I_K \approx 10^6 \text{ ppp at } 0.8 \text{ GeV/c} \)

KL (2009 Oct.-)
- \( p_{\text{mean}} \approx 2 \text{ GeV/c} \)
- \( I_{KL} = 1.8 \times 10^7 \text{ ppp} \)
- pencil-beam of 7.8\mu sr

T1-Target

K1.1BR

30GeV Proton Beam
**History of J-PARC, eps. on Hadron Facility**

- **Construction Start** (Apr. 2001)
- **181 MeV Acceleration at LINAC** (Jan. 24, 2007)
- **Complete of Civil Construction of Hadron Hall** (Jul. 2007)
- **3 GeV Acceleration at RCS** (Oct. 31, 2007)
- **3 GeV Beam Injection to MR** (May 22, 2008)
- **30 GeV Acceleration at MR** (Dec. 23, 2008)
- **Beam Extraction to Hadron Beamline** (Jan. 27, 2009)
- **Secondary Beam at K1.8BR** (Feb. 12, 2009)
Typical Beam Profiles measured with Screen Monitors

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

3 (v04in)  4 (v06in)  7 (q1Aout)  8 (T1in)

Screen Monitor Locations

January 27th, 2009
The first secondary beam at K1.8BR  Feb. 12 2009

1.1GeV/c

BHD hit pattern

BHD-T0 time difference

2cm/seg.

X-Y profile at BDC

ES-separator OFF

Feb. 15

ΔT=2.4ns
History of J-PARC, EPA. on Hadron Facility

• Construction Start
• 181 MeV Acceleration at LINAC
• Complete of Civil Construction of Hadron Hall
• 3 GeV Acceleration at RCS
• 3 GeV Beam Injection to MR
• 30 GeV Acceleration at MR
• Beam Extraction to Hadron Beamline
• Secondary Beam at K1.8BR
• The First Neutrino Beam
• The first Beam at K1.8 & KL
• The first Beam at K1.1BR
• The First Physics RUN for E19 at K1.8+SKS

Apr. 2001
Jan. 24 2007
Jul. 2007
Oct. 31 2007
May 22 2008
Dec. 23 2008
Jan. 27 2009
Feb. 12 2009
Apr. 23 2009
Oct. 22 2009
Oct. 12 2010
Oct. - Nov. 2010
We have observed charged and neutral kaons in the secondary beam lines (K1.8BR, K1.8, KL and K1.1BR) of Hadron Experimental Hall.
E19 High Resolution Search for $\Theta^+$ via the $p(\pi^-,K^-)X$ Reaction

- K.Imai, H.Sako, S.Sato, K.Shirotori (JAEA, Japan)
- K.Ikeshita, T.N.Takahashi (RIKEN, Japan)
- Y.Komatsu, S.Masumoto, K.Utsunomiya (Univ. of Tokyo, Japan)
- K.Naazawa (Gifu Univ., Japan)
- S.Adachi, H.Fujioka, Y.Ichikawa, M.Moritsu, T.Nagae, M.Niiyama, H.Sugimura, A.O.Tokiyasu, N.Tomida (Kyoto Univ., Japan)
- R.Iwasaki (Nara Women’s Univ., Japan)
- N.Ishibashi, K.Matsuoka, H.Noumi, A.Sakaguchi, T.Tanaka, K.Yoshida (Osaka Univ., Japan)
- M.J.Kim, R.Kiuchi, S.J.Kim, G.G.Joo, K.Tanida, S.B.Yang, C.J.Yoon (Seoul National Univ., Korea)
- B.Bassalleck (Univ. of New Mexico, USA)
- P.Evtoukhovitch, A.Kulikov, D.Mzhavia, V.Samoilov, Z.Tsamalaidze (JINR, Russia)
- A.Krutzenkova, V.V.Kulikov (ITEP, Russia)
- S.Bufalino, E.Botta, S.Marcello, A.Feliciello, M.Agnello (Torino, Italy)
- J.Franz (Freiburg, Germany)

71 persons, 15 Institutes
Production mechanism is a KEY

- CLAS(2006)  $\gamma d \rightarrow p K^- K^+ (n) < 0.15–3\text{nb}$
- LEPS(2009)  $\gamma C \rightarrow K^+ K^- (n) 5.1\sigma$

not inconsistent with each other due to strong angle/energy dependence

- CLAS(2006)  $\gamma p \rightarrow K^0 K^+ n < 0.8\text{nb}$
- E559(2008)  $K^+ p \rightarrow \pi^+ X < 3.5\mu\text{b/sr}$

imply a very small coupling to $K^*$ ($g_{N K^*\Theta} \sim 0$)

Pion-induced $\Theta^+$ production could be significant!

$\sigma(\pi^- p \rightarrow K^- \Theta^+) \Delta \Gamma_{KN\Theta}$
Previous Research: KEK–PS E522

Search for $\Theta^+$ via the $p(\pi^-, K^-)X$

- **K2 beamline + KURAMA**  
  at forward angle
  - Resolution of 13.4 MeV (FWHM)
- Polyethylene target (CHx)
- Beam momentum: 1.87, 1.92 GeV/c
- Intensity: $3.3 \times 10^5 \pi / \text{spill}$
- Time: $32 \times 2$ hours
  - $7 \times 10^9 \pi$
- S/N : 2.5$\sigma$
- U.L. 2.9$\mu$b/sr

A bump structure !? at 1.53 GeV/c$^2$

only at $P_{\pi} = 1.92$ GeV/c

if true, $d\sigma/d\Omega = 1.9 \mu $b/sr (lab)
KEK E522

- **K2 beamline + KURAMA**
  - at forward angle
  - Resolution of $13.4\text{MeV} (\text{FWHM})$
- Polyethylene target (CHx)
- Beam momentum: 1.87, 1.92 GeV/c
- **Intensity:** $3.3 \times 10^5 \pi / \text{spill}$
- **Time:** $32 \times 2 \text{ hours}$
  - $7 \times 10^9 \pi$

- **S/N:** $2.5\sigma$
- **U.L.** 2.9$\mu$b/sr

E19 Goal

- **K1.8 beamline + SKS**
  - $0 - 18^\circ$
  - $2.5\text{MeV} (\text{FWHM})$
- Liquid H$_2$ target
  - No quasi-free B.G.
- Beam momentum: 1.87, 1.92, and 1.97 GeV/c
  - **Energy Dependence**
- High Intensity of $\sim 10^7 / \text{spill}$
  - $4.8 \times 10^{11} \pi$ on target for each momentum

- **10^4 events (1.9\mu b/sr)**
- Sensitivity of 75nb/sr
E19 Step 1 Data-taking
Oct. 12—Nov. 16, 2010

Due to time structure of the beam (duty factor ~16%), intensity was limited to 1.1M/spill (1spill = 6 sec.)

Goal: To confirm Θ+ with 10σ at 1.92GeV/c assuming 1.9 μb/sr (E522)

RUN Summary total 272 hours (incl. down time)

• Beamline & Detector Commissioning 52 hours
• Calibration Data 64 hours
  ✓ Beam Through
  ✓ Empty target
  ✓ p(π−, K+) Σ− at 1.37 GeV/c 1.2 × 10^{10} \pi
  ✓ p(π+, K+) Σ+ at 1.37 GeV/c 3.0 × 10^{9} \pi
  ✓ p(π−, p) π− at 0.5 GeV/c 2.0 × 10^{8} \pi
• E19 Production Run 151 hours
  ✓ p(π−, K+) X at 1.92 GeV/c 7.8 × 10^{10} \pi
Setup — K1.8 Beam Spectrometer and SKS —
Setup — **K1.8 Beam Spectrometer and SKS** —

![Image of K1.8 Beam Spectrometer and SKS setup]

- **Beam momentum**: 1.92 GeV/c

Graph showing beam momentum distribution with a peak at 1.92 GeV/c.
Setup — K1.8 Beam Spectrometer and SKS —

100msr solid angle
0.7 < p < 1.0 GeV/c

M$^2$ of Particles ($\Sigma^-$ RUN)
Liquid $H_2$ target

Continuous-flow Liquid Helium Cryostat
Cell Size of 67.8 mm $\phi \times 120$mm L (PET)
Window of 0.25mm Mylar (x2)

Z-vertex distribution by $(\pi^-, \pi^-)$

Stable operation during data-taking
\[ \delta \rho / \rho \leq 10^{-5} \]

B.G. contamination < 3%
Spectrometers’ Calibration & Performance

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<td>Θ⁺ RUN</td>
<td>-1.92</td>
<td>-2.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Σ⁺ RUN</td>
<td>+1.37</td>
<td>+2.45</td>
<td>1186.2</td>
<td>1189.37 ± 0.07</td>
</tr>
<tr>
<td>Σ⁻ RUN</td>
<td>-1.37</td>
<td>+2.45</td>
<td>1196.2</td>
<td>1197.45 ± 0.03</td>
</tr>
</tbody>
</table>

Adjust offset and scale factor (B → p₀) of B.S. to reproduce PDG values

Calibration error of ±1.4 MeV/c^2

Σ⁺ Missing Mass

ΔM_{FWHM} = 1.9 ± 0.1 MeV/c^2

Σ⁻ Missing Mass

1.5 MeV/c^2 (FWHM) resolution for Θ⁺ (1530 MeV/c^2)
$p(\pi^-, K^-) X$ Missing Mass

- Expected resolution 1.5 MeV/c²
- No peak structure was observed.
  - Present upper limit $\sim 0.3 \mu b$/sr (averaged 2–15°)
  - $\sim 0.3 \mu b$ (isotopic K distribution)
Comparison with Theory

T. Hyodo, Private Communication

\(J^P = \frac{1}{2}^+\)
\(\Gamma_\Theta = 1\) MeV

\[\sqrt{s} = 2120\text{ MeV} \at 1.92\text{ GeV/c}\]
\[2160\text{ MeV} \at 2.0\text{ GeV/c}\]

\(0.3\mu b /sr \rightarrow 75\text{nb/sr}\)
\(\Gamma_\Theta = 1\) MeV \(\rightarrow 0.25\) MeV
Future Plan of E19

• New analysis is underway.
  – improve statistics by $\sim 20\%$ by adding multi-track events.

• Data-taking at 2.0 GeV/c with $\sim 0.3 \mu b/sr$
  sensitivity.
  – 6 days data-taking with $\sim 1.1M$/spill beam
  – We were planning to run in April RUN.

• Achieve the original statistics to reach
  75nb/sr with much improved beam condition.
Hypernuclear Physics

γ-ray spectroscopy of hypernuclei

(Multi-strangeness) Hypernuclei

Double-Λ Hypernuclei

K1.8

KL

K1.1

K1.1BR

T1-Target

High-p Line (Plan)
Hypernuclear Physics

γ-ray spectroscopy of hypernuclei

(Multi-strangeness) Hypernuclei

Exotic Hadrons

Double-Λ Hypernuclei

Pentaquark Θ+

K N Interaction

Kaonic atom

Kaonic nuclei
Nuclear & Hadron Physics at Hadron Hall

Hypernuclear Physics
- $\gamma$-ray spectroscopy of hypernuclei
- (Multi-strangeness) Hypernuclei

Exotic Hadrons
- Double-$\Lambda$
- Pentaquark $\Theta^+$
- Kaonic atom
- Kaonic nuclei

$\bar{K}N$ Interaction
- In-medium $\phi$ meson mass
Nuclear & Hadron Physics at Hadron Hall

**Hypernuclear Physics**
- γ-ray spectroscopy of hypernuclei
- (Multi-strangeness) Hypernuclei

**Exotic Hadrons**
- Double-Λ
- Pentaquark Θ+
- Kaon rare decay
  - $K^0 \rightarrow \pi^0 \nu \nu$

**K N Interaction**
- Kaonic atom
- Kaonic nuclei

**Origin of Hadron Mass**
- In-medium φ meson mass
  - T-violation

**Kaon rare decay**
- $K^0 \rightarrow \pi^0 \nu \nu$
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<th>Spokespersons</th>
<th>Title of the experiment</th>
<th>Approval status</th>
<th>Slow line priority</th>
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<td>E15 M.Iwasaki, T.Nagae</td>
<td>A Search for deeply-bound kaonic nuclear states by in-flight $^3$He($K^-$, $n$) reaction</td>
<td>Stage 2</td>
<td>Day1</td>
<td>K1.8BR</td>
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<td>E17 R.Hayano, H.Outa</td>
<td>Precision spectroscopy of Kaonic $^3$He $3d\rightarrow2p$ X-rays</td>
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<td>E31 H. Noumi</td>
<td>Spectroscopic study of hyperon resonances below KN threshold via the ($K^-$,$n$) reaction on Deuteron</td>
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<td>E03 K.Tanida</td>
<td>Measurement of X rays from $\Xi^-$ Atom</td>
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<td>E05 T.Nagae</td>
<td>Spectroscopic Study of $\Xi$-Hypernucleus, $^{12}\bar{\Xi}$Be, via the $^{12}$C($K^-$, $K^+$) Reaction</td>
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<td>K1.8</td>
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<td>E07 K.Imai, Nakazawa, Tamura</td>
<td>Systematic Study of Double Strangeness System with an Emulsion-counter Hybrid Method</td>
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<td>E08 A.Krutenkova</td>
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<td>K1.8</td>
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<td>E10 A. Sakaguchi, T. Fukuda</td>
<td>Production of Neutron-Rich Lambda-Hypernuclei with the Double Charge-Exchange Reaction (Revised from Initial P10)</td>
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<td>E13 T.Tamura</td>
<td>Gamma-ray spectroscopy of light hypernuclei</td>
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<td>Day1 2</td>
<td>K1.8</td>
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<td>E18 H.Bhang, H.Outa, H.Park</td>
<td>Coincidence Measurement of the Weak Decay of $^{12}$ $\Lambda$C and the three-body weak interaction process</td>
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<td>E19 M.Naruki</td>
<td>High-resolution Search for $\Theta^+$ Pentaquark in $\pi^- p \rightarrow K X$ Reactions</td>
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<td>E22 S.Ajimura, A.Sakaguchi</td>
<td>Exclusive Study on the Lambda-N Weak Interaction in A=4 Lambda-Hypernuclei</td>
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<td>E27 T. Nagae</td>
<td>Search for a nuclear $\bar{K}$ bound state $K$-$pp$ in the $d(\pi^+,K^+)$ reaction</td>
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<td>K1.8</td>
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<td>E14 K.Ozawa</td>
<td>Search for $\omega$-meson nuclear bound states in the $\pi^- + A Z \rightarrow n + (A-1)\omega(Z-1)$ reaction, and for $\omega$ mass modification in the in-medium $\omega\rightarrow \pi^0\gamma$ decay.</td>
<td>Stage 1</td>
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<td>K1.8</td>
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<tr>
<td>E06 H. Ohnishi</td>
<td>Search for $\phi$-meson nuclear bound states in the $p\bar{p} + A Z \rightarrow \phi + (A-1)\phi(Z-1)$ reaction</td>
<td>Stage 1</td>
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<tr>
<td>E16 S.Yokkaichi</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>High pt</td>
<td></td>
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</table>
Hypernuclear Physics

- Baryon-Baryon interaction through the hypernuclear structure
  - \( \Xi N \) and \( \Lambda \Lambda \) interaction
  - \( \Lambda N \) interaction in n-rich environment
- Hadron property in nuclear medium
  - g-factor of \( \Lambda \) by B(M1) measurement
- Change of nuclear property by addition of hyperon(s)
  - change of nuclear size etc..

H. Tamura Jun. 17
E05: Spectroscopy of $^{12}\Xi\text{Be}$ via the $^{12}\text{C}(K^-,K^+)$

aims to observe the $\Xi$-hypernuclear states, for the first time, with high resolution of 3MeV (FWHM)

- $S=-2$ Baryon-Baryon interaction
  - $\Xi N$ interaction
  - $\Xi N \rightarrow \Lambda \Lambda$ interaction
- Strange nuclear matter with $\Xi$
  - Core of Neutron Star
  - $\Xi$-Nucleus potential
- Strong $\Xi N - \Lambda \Lambda$ mixing effect

K1.8 BS + SksPlus
5.4g/cm$^2$ target
1.6x10$^6$ /spill $K^-$ beam
1 month data-taking

BNL-AGS E885

$V_\Xi = -20$ MeV
$V_\Xi = -14$ MeV

Expected
The Earthquake on March 11

Entrance of LINIC Building

CCR

Neutrino Beam Dump

RCS Substation

Hadron Switch Yard

Outskirt of Hadron Hall

Spring water from MR

The serious damages are

LINAC  Power lines, alignment of the elements
RCS    Power supplies, Cooling-water

In Hadron Facility, alignment of the primary & secondary beamline elements is necessary.
Summary

• J-PARC Hadron Facility has started its operational era!
  – 4 secondary beamlines, K1.8BR, K1.8, KL, and K1.1BR, are in operation.
• The first physics RUN of E19 was successfully done at K1.8.
  – No peak structure was observed in \( p(\pi^-,K^-)X \) missing mass at \( P_{\pi}=1.92 \text{ GeV}/c \), \( \frac{d\sigma}{d\Omega} < 0.3 \mu b/sr \)
• A lot of experiments on nuclear/hadron physics are planned at Hadron Facility
  – Hypernuclear physics at \( S=-1 \) and \( S=-2 \)
  – \( K^{\text{bar}} \) N Interaction by Kaonic Nuclei and Atom
  – In medium mass modification of \( \phi \) meson
• Effect of the Earthquake at March 11.
  – Beam recovery in December 2011
People at J-PARC Hadron Experimental Hall

Graduate Students, Professors, Researchers, Engineers..., all over the world

2009.1.27 First Beam to Hd Hall

2009.10.22 First beam to K1.8

KOTO (E15) Experimental Team
(KL Rare Decay Search)

Start up of K1.8 Counting Hat

Line marking at K1.8 area

Background survey before construction of KL!

Front end circuits at K1.8BR

Our TOF wall is ready!

My beautiful TOF counters!

New comers and a senior

Midnight in KL Counting Hat
Backgrounds

- $\phi$ production $30 \pm 8 \mu b$
  $\pi^- p \rightarrow \phi n, (\phi \rightarrow K^+ K^-)$

- $\Lambda(1520)$ production $20.8 \pm 5.0 \mu b$
  $\pi^- p \rightarrow \Lambda(1520) K^0, (\Lambda(1520) \rightarrow p K^-)$

- Phase space $25 \mu b$
  $\pi^- p \rightarrow K^- K^0 p$
  $\pi^- p \rightarrow K^- K^+ n$