Overview of Hypernuclear Physics Program at K1.8 and K1.1 Beam lines of J-PARC

T.Takahashi (IPNS-KEK)
• Recent achievements on Hadron Facility
• Experimental plan by the next summer (2012-2013)
• Facility upgrade and experimental plan after 2014
  – K1.1 Beam line & SKS
  – High-p/COMET
  – E13/E18/E07/E05
  – New approved proposals
  – Hadron hall extension plan
• Summary
Recent Achievements on Beam & Nuclear Physics Program

before 2011-3-11
(Nov. — Dec. 2010, RUN36)
• K1.8/K1.8BR/KL/K1.1BR
• MR power 3.0kW, D.F. =~17%
  Dec.9 LINAC operation started
  Dec.24 MR beam to Neutrino

2012 Jan.28 — Feb.22 (RUN40)
• K1.8/K1.8BR/KL
• 3.3kW, D.F. =~30%

2012 Jun.9 — Jul.1 (RUN43)
• K1.8/K1.8BR/KL/K1.1BR
• 6.6kW, D.F. =~30%

E19 1st RUN@K1.8
Beam tuning etc. @ K1.8BR
Beam survey etc. @ KL

E19 2nd RUN@K1.8
Beam & detector (CDS) commissioning @K1.8BR
Detector study & commissioning@KL

E27 pilot RUN@K1.8
Detector commissioning @K1.8BR
Detector study & commissioning@KL
**E19: Search for \( \Theta^+ \) via the \( p(\pi^-,K^-)X \)**

**M. Moritsu in Parallel 2 on Oct. 1**

1\(^{st}\) RUN at 1.92 GeV/c

![Graph showing data and background](Image)

No peak structure was observed.

U.L. : 0.26 \( \mu \)b/sr

U.L. of width
- 0.72 MeV/c\(^2\) for \( \frac{1}{2}^+ \)
- 3.1 MeV/c\(^2\) for \( \frac{1}{2}^- \)


2\(^{nd}\) RUN at 2.0 GeV/c

- Max. momentum at K1.8 B.L.
- Extend mom. acceptance from 1\(^{st}\) RUN
- Same spectrometer’s performance as before the Earthquake

![Graph showing data and background](Image)
E27: Search for $K^{-}pp$ bound state via the $d(\pi^{+},K^{+})$ reaction

Y.Ichikawa Poster, H.Ekawa Poster

• “$K^{-}pp$” is produced via $\Lambda(1405)$ doorway in the $d(\pi^{+},K^{+})$ at 1.7GeV/c

- $\pi^{+} + "n" \rightarrow "\Lambda^{*}\" + K^{+}$
- “$\Lambda^{*}\" + "p" \rightarrow$ bound $K^{-}pp$ Minor
  - quasi-free $\Lambda^{*}$ Dominant


• Missing mass by Beam & SKS spectrometers
• Two protons are detected by RCA in order to suppress quasi-free B.G.
Goal & Beam Summary

- The first measurement on inclusive \(d(\pi^+, K^+)X\) spectrum at this incident momentum (1.7 GeV/c) and missing mass region (2.2 — 2.5 GeV/c\(^2\))
  - 7.6 days, 3.3\times10^{11} \pi^+ on Liq.D\(_2\) (1.7 g/cm\(^2\))
- Measurement on \(p(\pi^+, K^+)X\) spectrum to check p contribution in d.
  - 0.6 days, 7.6\times10^9 \pi^+ on Liq.H\(_2\) (0.86 g/cm\(^2\))
- Check feasibility of proton coincidence

\[
\begin{array}{c|c|c|c}
\text{a} & \text{Entries} & \text{Mean} & \text{RMS} \\
\hline
& 15220 & 1.228 & 0.07324 \\
\end{array}
\]

Very Preliminary
Experimental plan by the next summer
Hadron Hall in 2012 and 2013

K1.8BR

\( p_{\text{max}} = 1.0 \text{GeV/c} \)

K\(^-\)(1.0) 100k/spill @10kW

K1.8

\( p_{\text{max}} = 2.0 \text{GeV/c} \)

K\(^-\)(1.8) 150k/spill @10kW

K1.1BR

\( p_{\text{max}} = 1.0 \text{GeV/c} \)

Test beam line

K\(_L\) \rightarrow \pi^0 \nu \nu^\text{bar} \text{ Exp.}
Hadron Hall in 2012 and 2013

SX beam schedule (plan)
Dec. 14 — 26 2012
10kW
Jan. 7 — 16 2013
15kW
Mar. 7 — 25 2013
20kW
May 15 — Jun. 25 2013
>20kW
Aug. 2013 —
long shutdown
for LINAC 400MeV U.G.

MR operation starts
from Feb. 2014

K1.1BR
p_{max}=1.0GeV/c
Test beam line

K1.8
p_{max}=2.0GeV/c
K^-(1.8) 150k/spill
@10kW

KL
K^-(1.0) 100k/spill
@10kW

K1.8BR
p_{max}=1.0GeV/c

K\rightarrow\pi^0\nu\bar{\nu} Exp.
E10: Production of Neutron-Rich $\Lambda$ Hypernuclei,

$^6_A^\Lambda H$ and $^9_A^\Lambda He$, via the DCX ($\pi^-,K^+$) Reaction

- Change of properties on nuclei near neutron drip-line
  - Unbound $^5H$ will be bound by adding a $\Lambda$.
  - Neutron halo structure of $^8He$ may disappear by adding a $\Lambda$.

- $\Lambda N$ interaction in the extreme condition
  - $\Lambda N-\Sigma N$ mixing effect
  - EOS of neutron star matter

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2012/10/5  HYP11
Data from FINUDA/DAΦNE
- $^6\text{Li}(\pi^-,K^+)^6\Lambda\text{H}$ reaction
- 3 candidate events
  - $^5\text{H} + \Lambda$
    - 5805.44 MeV [2]
  - $^3\text{H} + 2n + \Lambda$
    - 5803.74
  - $^4\text{H} + n + n + \Lambda$
    - 5801.170
    - 5801.24
    - 5801.43 MeV

M.Agnello et al. PRL 108,042501(2012)

E.Botta Oct.3(Wed)
B.Gibson Parallel-1 on Oct.1
S.Ohnishi Parallel-1 on Oct.1

Dec., 2012 — Jan., 2013 @K1.8 Beam line

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<th>Parameters</th>
<th>Values</th>
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<tr>
<td>Pion beam momentum</td>
<td>1.2 GeV/c</td>
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<tr>
<td>Pion beam intensity</td>
<td>10M/spill</td>
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<tr>
<td>Total number of pions (6 s acc. cycle)</td>
<td>3T pions</td>
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<td>Target thickness ($^6\text{Li}$)</td>
<td>3.5 g/cm²</td>
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<td>DCX cross section (assumed)</td>
<td>10 nb/sr</td>
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<tr>
<td>Estimated $^6\Lambda\text{H}$ yield</td>
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10M/spill is very challenging.
(5M/spill is sure.)

3 weeks data-taking

2012/10/5
E13-1: γ-ray spectroscopy of $^{19}\Lambda F$ and $^4\Lambda He$

**Purpose & Goal**

- $^{19}\Lambda F$ using Liq-HF target (B.P.=20°C, ~1g/cm$^3$)
  - The first $sd$-shell hypernuclei
    - $r$-dependence of $\Lambda N$ interaction
  - $\Lambda$ spin-flip B(M1) measurement by DSAM (if enough statistics)
    - $g$-factor of $\Lambda$ in nucleus

- $^4\Lambda He$ using Liq-$^4$He target
  - CSB $^4\Lambda H$ and $^4\Lambda He$
    - $0^+ - 1^+$ level spacing

**Data-taking in May-June, 2013**

$\sim$10 + $\sim$5 days (+ commissioning) if 20kW is achieved.

*Hyperball-J was arrived at J-PARC on Aug. 30. Assembling will start after HYP11.*
Facility upgrade and experimental plan after 2014
K1.1 Beam Line & SKS 2014 Feb. ~

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<tr>
<th>IF/MS1/MS2 Opening [mm]</th>
<th>±1.5/1.0/1.0</th>
<th>±3.0/2.0/2.0</th>
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<td>@6.25E+13ppp (50kW)</td>
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<td>1.1 GeV/c</td>
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<tr>
<td>0.9 GeV/c</td>
<td>0.85</td>
<td>0.50</td>
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IF(H,V)  Mom-Slit  Beam Spectrometer  SKS

2012/10/5  HYP11
KEK is requesting to construct new primary beam lines in the south area with the highest priority.

In the earliest case, beam lines will be constructed during 2013—2015.

Experiments at K1.1 can be carried out from Feb. 2014 to June 2015 before the construction.

Experiments at K1.1 and High-p/π15 can be carried out alternatively after the construction, by switching the setup annually or bi-annually.
3 Beam lines (K1.8/K1.8BR/K1.1) will be available for Strangeness Physics from 2014

• Study on double strangeness system at K1.8
  \(\Lambda\Lambda\)-nuclei, \(\Xi\)-nuclei, \(H\) dibaryon, X-ray from \(\Xi\) atoms
  \((\Sigma^+p\) scattering \)

• Study on \(S=-1\) hypernuclei at K1.1
  \(\gamma\)-ray spectroscopy, \(\Sigma\) hypernuclei, Weak decay of \(\Lambda\) hypernuclei

• 4\(\pi\) detector (CDS) & nTOF etc. at K1.8BR
  K-nuclei, Kaonic atom, \(\Lambda(1405),...\)

  ➢ SX beam time gradually increases.
  • SX:FX = 1:1 or more (2014—)

We can carry out a lot of experiments more efficiently at 3 beam lines.
E13-2: $^{10}_\Lambda B$, $^{11}_\Lambda B$, and $^{7}_\Lambda Li$

$(K^-,\pi^-)$ reaction at 1.1GeV/c

>50kW MR power

$^{10}_\Lambda B$ and $^{11}_\Lambda B$
- Confirmation of $\Lambda N$ spin-dependent interaction
- The effect of $\Lambda N-\Sigma N$ coupling & 3-body force

$^{7}_\Lambda Li$
- g-factor of $\Lambda$ in nucleus
  - spin-flip $B(M1)$
  - $\sim 5\%$ accuracy of $B(M1)$

$\Leftrightarrow B(M1) = 0.30^{+0.4}_{-0.6} \ [\mu_N^2]$  
$- g_\Lambda = 1.1^{+0.4}_{-0.6} \mu_N$  
$- g_\Lambda$ (free) = 1.226 $\mu_N$

BNL-E930
E18: Coincidence measurement of the weak decay of $^{12}_\Lambda C$

Experimental determination of $\Lambda NN \rightarrow NNN$ weak decay process

- Recent Exp./Theory suggests $29 \pm 13\%$ of NMWD ($^{12}_\Lambda C$)

**Large Acceptance Coverage of Decay Counter (DC)**

- Measures efficiently non back-to-back nucleon pair as well as nNN final state

**Phase-1** 2M/spill beam with D.F.=30%, 3weeks
- 0.8T pions on target (5T in proposal)
E07: Study on S=−2 system by Emulsion-Counter Hybrid Method

Improvements from KEK-E373
① High purity K− beam
② KURAMA gap extension
③ Emulsion ×3
④ fiber tracker → (D)SSD
  16μm resolution for Ξ−
⑤ Position calib. of emulsion layers
  ~20μm → 1.4±0.8μm
  → Automatic scan w/ & w/o counters
⑥ Ge detectors to measure X-rays
  from Ξ−-atom
  → Ξ−-Nucleus potential (in surface region)

10 times events as those of the previous exp.!

10^4 Ξ− stopped events
10^2 double-Λ nucl. w/ counters
10^3 double-Λ nucl. w/o counters

Commissioning & physics RUN
2014～ @ K1.8
E05: Spectroscopy of $\Xi$-hypernucleus, $^{12}\Xi$Be

- First observation of $\Xi$-hypernucleus by the $(K^-,K^+)$ missing mass with good resolution and high-statistics.
- $\Xi$-Nucleus potential (inside nucleus) $\leftrightarrow$ complimentary to $\Xi$-Atom
  - Potential depth $\rightarrow$ $\Xi$-N interaction
  - Width of state(s) $\rightarrow$ $\Xi$-N$\rightarrow$ΛΛ interaction
  - EOS of high-density neutron-star matter

The original proposal using SksPlus spectrometer:

$\Delta\Omega \sim 30\text{msr}$
$\Delta M = 3\text{MeV(FWHM)}$
$1.4 \times 10^6 K^-$/spill beam
30 days

difficult to be carried out!!

2012/10/5

HYP11
E05: 2 step approach

**phase-1** with $SKS_{\text{mod}}$

- minor change from E10-1/E13-1 setup

- $\Delta \Omega = 110 \text{ msr}$
- $\Delta p/p = 0.27\% \rightarrow \Delta M = 4\text{MeV}(\text{FWHM})$

- $4.5 \times 10^5 \text{ K}^-/\text{spill} (30\text{kW})$
- $\rightarrow$ 100 events/30 days

- It may have a chance to run in **2013 June**, after E13-1, if MR power increases more rapidly than we expected.

**phase-2** with **S-2S**

- Q-Q-D spectrometer like **HKS** at JLab
  - $\Delta \Omega = \sim 50 \text{ msr}$
  - $\Delta p/p = 0.05\% \rightarrow \Delta M = 1.5\text{MeV}(\text{FWHM})$

- **Construction completed in 2014**
- **Data-taking 2015?**—
  - with $>150\text{kW}$ MR power
  - $\text{K}^-$ intensity of $\sim 1 \times 10^6/\text{spill}$
E40: $\Sigma^\pm p$ scattering

proposed by K. Miwa, Tohoku Univ. (stage-1)

$K.\text{Miwa Poster}$

$\Sigma N$ interaction is strongly related to the origin of the repulsive core of nuclear force.

$10$ ($^3S_1$) of $\Sigma N$($l=3/2$) channel is *almost Pauli-forbidden* in the quark-based picture.

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No use of imaging device.
Only counters are used.
Scattering event is kinematically identified.

high-intensity beam can be used.
$\rightarrow$ high-statistics will be achieved.

$20M/$spill $\pi^+$ beam $\rightarrow 90$ $\Sigma^+$/spill
$\rightarrow \sim 10000$ events with 20 days
E42: Search for $H$-Dibaryon with a Large Acceptance Hyperon Spectrometer

K1.8BL + KURAMA + Hyperon Spectrometer

Expected $H$ spectra with 30 days

- $\Lambda\Lambda, \Lambda \rightarrow p\pi^-$
- $\Lambda p\pi^-$
- $\Sigma^- p, \Sigma^- \rightarrow n\pi^-$

Diamond target

TPC + S.C. magnet

$K^-$

Events/2MeV/c²

2.2 2.22 2.24 2.26 2.28 2.3 2.32 2.34 2.36

$\Lambda\Lambda$ invariant mass [GeV/c²]

Events/5MeV/c²

2.2 2.25 2.3

$\Lambda p\pi^-$ invariant mass [GeV/c²]

HYP11

$\Lambda\Lambda$ invariants mass $m_H = 2250\text{MeV}/c^2 (> 2m_{\Lambda})$

$\Lambda\Lambda$ invariants mass $m_H = 2220\text{MeV}/c^2 (< 2m_{\Lambda})$
Hadron Hall Extension

HIHR
- \( \pi \) beam up to 2GeV/c
- High-intensity \( \sim 10^9/\text{spill} \)
- High-resolution \( \Delta p/p \sim 10^{-5} \)

KL
- 5° production angle

High-resolution (\( \sim 100\text{keV} \))
spectroscopy of \( \Lambda \) hypernuclei
by the \((\pi^\pm, K^+)\) reactions

medium-/heavy- \( \Lambda \) hypernuclei
neutron-rich \( \Lambda \) hypernuclei

2012/10/5

H.Takahashi, Parallel-4 on Oct.1
Summary

• E19 and E27 pilot run were successfully carried out.
• 3 beam cycles by summer 2013 with 10–20kW beam.
  – $^6$Li($\pi^-,K^+)^6\Lambda H$ (E10), $\gamma$-ray spectroscopy for $^{19}\Lambda F$ and $^4\Lambda He$ (E13)
• Facility upgrades in near future
  – New K1.1 beam line and SKS@K1.1 will be operated from 2014.
  – High-p/$\pi$15 and COMET beam lines from 2015 in the earliest case.
• Experiments
  – $^{10,11}\Lambda B$ and $^7\Lambda Li$ (E13), 2N-induced NMWD of $^{12}\Lambda C$ (E18) at K1.1
  – Emulsion exp. (E07), spectroscopy of $^{12}\Xi Be$ (E05) at K1.8
  – $\Sigma p$ scattering (E40), H-dibaryon (E42)
• Hadron hall extension under consideration
backups
Near future operation plan of MR-SX

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<tr>
<th>Periods</th>
<th>Expected beam power</th>
<th>Improvements</th>
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<td>2011. 6-11</td>
<td>shutdown</td>
<td>SX collimator</td>
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<td>2011. 12 - 2012. 6</td>
<td>3-6 kW (14 kW for study)</td>
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<td>2012. 7 – 9</td>
<td>shutdown</td>
<td>- Titanium endplate for magnetic septa</td>
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<td>- New excitor for transverse rf of 100 MHz/3kW</td>
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<td>2012. 10 – 2013. 7</td>
<td>&gt; 10 kW (50 kW for study)</td>
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<tr>
<td>2013.8 – 2014. 1</td>
<td>shutdown</td>
<td>Titanium chambers for ESS</td>
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<tr>
<td>2014. 2 – 2014. 6</td>
<td>~ 50 kW (100 kW for study)</td>
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We also started R&D of ESS with low-z material for low loss SX.

Accelerator report at 15th J-PARC PAC Meeting (July 13—15, 2012)
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<th>#</th>
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<th>Affiliation</th>
<th>Title of the agreement</th>
<th>Approval status (KEK recommendation)</th>
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Total:
- Stage-2: 12
- Stage-1: 2
- Test-Exp.: 5
- Deferred: 3

@K1.8/K1.1:
- Stage-2: 8
- Stage-1: 6
- Deferred: 1
Time structure of the SX beam

\[ \text{Duty} = \frac{\left( \int_0^T I(t) \, dt \right)^2}{\int_0^T dt \int_0^T I^2(t) \, dt} \]

- **I(t):** PM signal sampled at 100KHz through 10KHz LPF
- **t=0:** spill start
- **t=T:** spill length

Due to the large magnet current ripple (~10^-4), the duty factor of the spill is low.

- **duty 3.6%**
- **duty 17%**
- **duty 30%**

RUN in Nov. 2010

- **w/o spill FB, w/o TRF, w/ coil short**
- **w/ spill FB, w/o TRF, w/ coil short**
- **20MHz TRF ON, 5dBm, w/ spill FB, w/ coil short**
Ξ-hypernuclei: previous measurement

- Previous experiment: BNL-E885
  - not clear evidence of Ξ-hypernuclear bound state.
    - because of limited mass resolution
  - suggest weakly attractive potential of -14 MeV depth.
    - by shape analysis and counts in bound region, compared with DWIA calc.
  - 89±14 nb/sr (<8deg.); 42±5 nb/sr (<14deg.)