Outline

1. Introduction…..old samples (HN), Motivation
2. Strangeness (S) = -1 sector [1980~]
   • KEK-PS, J-PARC, (BNL, Mainz, JLAB)
3. S = -2 sector [1990~]
   • KEK-PS, BNL-AGS
     \[\Lambda\Lambda\] bound energy
     \[\Xi^-\]Nucleus potential (\[\Xi^-\] binding energy),
4. Summary
Single-Λ hypernucleus

Λ° as a component of the nuclear fragment

Danysz and Pniewski Phil. Mag. 44 (1953) 348

Cosmic ray ~30GeV

Delayed disintegration of a nucleus at the end of its range

C. F. Powell
Photographic emulsion

PERGAMON PRESS 1959
Systematical meas.
Binding energy, $B_\Lambda$, 
\[ ^3_\Lambda H \sim ^{15}_\Lambda N \]

**Physics Motivations**
- spin-dependence of the $\Lambda N$ interaction
- Checking the existence of
  - strong three-body $\Lambda NN$ forces
  - non-central $\Lambda N$ forces from $p$-shell hypernuclei

Data, with nuclear emulsion, from,
2) Unpublished data of European K- Collaboration.
Double-$\Lambda$ hypernucleus

$\Lambda\Lambda$ bound energy: $\Delta B_{\Lambda\Lambda}(A_{\Lambda\Lambda}Z) = B_{\Lambda\Lambda}(A_{\Lambda\Lambda}Z) - 2 B_\Lambda(A_{\Lambda}Z)$

M. Danysz et al.,
Nucl. Phys. 49 (1963) 121

$^{10}\text{Be}$

$\Delta B_{\Lambda\Lambda} = 4.6 \pm 0.5$ MeV

D.J. Prowse,
PRL.17 (1966) 782

$^{6}\text{He}$

$\Delta B_{\Lambda\Lambda} = 4.6 \pm 0.5$ MeV

Just a schematic drawing was given w/o angle data.
Main subject: Study of hadron-hadron interaction

1. Strangeness is a probe to search for deep part of nucleus
   / Hyperon(Y)s are free from Pauli Exclusion Principal.

2. Impurity physics
   / Glue role of hyperons inside nuclei.
   / Changing structure of nuclei.

3. Bryon-Baryon interaction
   / YN, YY interaction based on SU(3)\textsubscript{f}.
   / Unified understanding of nuclear force
     .... origin of repulsive core.

4. Structure and evolution of Neutron Stars
   / High density nuclear matter, EoS, Max. mass, Cooling,,,“
   ➔ Serious problems hyperon-mixing (Takatsuka)
In S=-2 sector,

\[ \text{YY-mixing } [\Lambda\Lambda \Leftrightarrow \Xi N \Leftrightarrow \Sigma \Sigma (\Leftrightarrow H)] \]

\[ \cdot m(\Xi N) - m(\Lambda\Lambda) = (23\sim 28) \text{ MeV} \]

\[ \cdot m(\Sigma N) - m(\Lambda N) = 80 \text{ MeV} \]

* For those information;
uniquely available source is
double-\( \Lambda \) hypernucleus,
\( \Xi \) hypernucleus, \( H \)-dibaryon

\( \frac{306}{30} \)
$S=-1$ sector
Systematic $\gamma$-ray measurement with Ge detector (Hyper-ball)

by H. Tamura, at HYP2015, Sep. 7-12 Tohoku Univ. Japan

Ge ADC

Calibration (off beam spill) using Th-series gamma rays

- **$^{208}$Tl (583)**
- **$^{228}$Ac (911)**
- **$^{208}$Tl SE (2103)**

Resolution (off spill) :
4.5 ~ 5.5 keV (FWHM)
@ 1~2 MeV
after summing all Ge’s

On beam spill:
- CF$_2$ target
- $^{19}$F (197.1 keV)
- $^{10}$B (718.4 keV)
- $^{17}$O (870.7 keV)
- $^{18}$F (937 keV)

$\gamma$-rays from beam reaction on target nuclei

$e^-(511$ keV)
**Hypernuclear γ-ray data**

@ KEK-PS & BNL-AGS

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**12C (π⁺, K⁺γ)** KEK E566

- 11B (π⁺, K⁺γ) KEK E518

- 11B (π⁺, K⁺γ) KEK E518

- 12C (π⁺, K⁺γ) KEK E566

- 13C (K⁺, π⁺γ) BNL E929 (Nal)

- 16O (K⁺, π⁺γ) BNL E930(’01)

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*PRL 84 (2000) 5963*  
*PRL 86 (2001) 1982*  
*PLB 579 (2004) 259*  
*PRC 73 (2006) 012501*

*PRL 88 (2002) 082501*  
*NPA 754 (2005) 58c*

*EPJ A33 (2007) 243*  
*PTEP (2015) 081D01*

*PRL 86 (2001) 4255*  
*PRC 65 (2002) 034607*  
*PRC 77 (2008) 054315*  
*PRL 93 (2004) 232501*  
*EPJ A33 (2007) 247*
### S=-1 sector

**Table 1.** Present status of our knowledge on $YN$ and $YY$ interactions obtained from experimental data. $U_\Lambda$ and $U_\Sigma$ stand for the nuclear potential depth for a $\Lambda$ and a $\Sigma$ hyperon, respectively. Definitions of $\Delta$ and $T$ are given in Sect. 4.1. $\Delta B_{\Lambda\Lambda}$ is the $\Lambda$–$\Lambda$ bond energy in the double $\Lambda$ hypernucleus.

<table>
<thead>
<tr>
<th>Knowledge</th>
<th>Experimental data</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Lambda N$</td>
<td>$\Lambda N$ scattering data [5–9]</td>
</tr>
<tr>
<td>Attractive ($U_\Lambda = -30$ MeV)</td>
<td>$B_\Lambda$ of $A = 3 - 208$ $\Lambda$ hypernuclei [11–13]</td>
</tr>
<tr>
<td>Very small LS force ($\sim 1/50$ of $NN$)</td>
<td>$^9_\Lambda$ Be and $^{13}_\Lambda$ C $\gamma$-rays [14–17]</td>
</tr>
<tr>
<td>Small spin–spin force ($\Delta \sim 0.4$ MeV)</td>
<td>$^7_\Lambda$ Li $\gamma$-ray [18]</td>
</tr>
<tr>
<td>Small tensor force ($T \sim 0.03$ MeV)</td>
<td>$^{16}_\Lambda$ O $\gamma$-rays [19,20]</td>
</tr>
<tr>
<td>$\Sigma N$</td>
<td>$\Sigma N$ scattering data [5–9,21–23]</td>
</tr>
<tr>
<td>Strong spin/isospin dependence</td>
<td>$^4_\Sigma$ He($0^+$) bound state [24]</td>
</tr>
<tr>
<td>(attractive for $(I, J) = (\frac{3}{2}, 0), (\frac{1}{2}, 1)$)</td>
<td>$^{28}_\pi$ Si($\pi^-, K^+$) spectrum [25]</td>
</tr>
<tr>
<td>Repulsive ($U_\Sigma &gt; 0$)</td>
<td></td>
</tr>
<tr>
<td>$\Lambda N$–$\Sigma N$</td>
<td>$B_\Lambda$ of $A = 3 - 5$ $\Lambda$ hypernuclei [26]</td>
</tr>
</tbody>
</table>

The potential of the two-body $\Lambda N$ effective interaction can be written as;

$$V_{\Lambda N}(r) = V_0(r) + V_\sigma(r) \frac{\sigma_\Lambda \sigma_N}{\Delta}: \text{spin-spin term} + V_{\Lambda}(r) \frac{1_{\Lambda N} \sigma_\Lambda}{\Delta}: \Lambda \text{ spin-orbit} + V_{N}(r) \frac{1_{\Lambda N} \sigma_N}{\Delta}: N \text{ spin-orbit}$$

$$+ V_T(r) \left[ 3 \frac{\sigma_\Lambda \hat{\mathbf{r}}}{\Delta} (\sigma_N \hat{\mathbf{r}}) - \frac{\sigma_\Lambda \sigma_N}{\Delta} \right]$$

$$T: \text{tensor term} \tag{4.1}$$
HyperN experiment program
History @ J-PARC Hadron

- 2011 : Mar.  
  * Big earthquake

- 2012 : Dec.  
  * 3.3 $\rightarrow$ 15 kW
    - E19 : $(\pi^-, K^-) \Theta^+ \rightarrow$ no peak structure
    - E10 : $(\pi^-, K^+) \Lambda H$

- 2013 : Mar. - May  
  * 20 kW
    * Radiation Leak Accident

- 2015 : May  
  * 30 kW
    - E13 : $\gamma$-ray spectroscopy, $^4\Lambda$He & $^{19}\Lambda F$

- 2016 : Mar.  
  * 40 kW(?)
    - E07 : $S=-2$ physics (June?)
2011 Mar. Earthquake

- Serious cracks on the road in front of Linac
- Water level is 10 cm in Linac Tunnel
- Air conditioning for Neutrino Hall
HyperN experiment program
History @ J-PARC Hadron

- 2011 : Mar.  
  Big earthquake
- 2012 : Dec.  
  3.3 $\Rightarrow$ 15 kW
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- 2013 : Mar. - May  
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- 2015 : May  
  30 kW
  - E13 : $\gamma$-ray spectroscopy, $^4\Lambda He$ & $^{19}\Lambda F$
- 2016 : Mar.  
  40 kW(?)
  - E07 : $S=-2$ physics (June?)
Neutron-rich $\Lambda$ hypernuclei close to drip-line

**FINUDA:**
- Study of the $^6\text{Li}(K^-\text{stop},\pi^+\pi^-)$ reaction

$^6\text{Li}(K^-\text{stop},\pi^+)\Lambda\text{H}, \Lambda\text{H} \rightarrow ^6\text{He} + \pi^-$

Reported 3 candidate events of $^6\Lambda\text{H}$ production
M. Agnello et al. PRL 108 (2012) 042501

**J-PARC-E10:**
- Missing-mass spectrum of the $^6\text{Li}(\pi^-,K^+)X$ reaction

No clear peak was observed in thres. region.
H. Sugimura et al., PLB 729 (2014) 39

Cross section can be extremely smaller than expected (?)
HyperN experiment program
History @ J-PARC Hadron

- 2011 : Mar.  \textit{Big earthquake}
- 2012 : Dec. 3.3 $\Rightarrow$ 15 kW
  - E19 : $(\pi^-, K^-) \Theta^+ \rightarrow$ no peak structure
  - E10 : $(\pi^-, K^+) \Lambda H$
- 2013 : Mar. - May 20 kW
  - May \textit{Radiation Leak Accident}
- 2015 : May 30 kW
  - E13 : $\gamma$-ray spectroscopy, $^4\Lambda$He & $^{19}\Lambda$F
- 2016 : Mar. 40 kW(?)
  - E07 : S=$-2$ physics (June?)
2013 May *Radiation leak accident*
By 1ry beam-control problem, etc.

30T protons / 2 sec $\Rightarrow$ 20T protons / 0.5 msec
- Au target was melt
- RI was diffused into 1ry line $\Rightarrow$ 2ndry line $\Rightarrow$ HD hall $\Rightarrow$ Outside

Safety Division set up.
- Sealing up shielding blocks,
- Completely isolation of 1ry target.
- RI removal devices for air fan,
- Safety training,
- Evacuation method,
HyperN experiment program
History @ J-PARC Hadron

- 2011 : Mar.  Big earthquake
- 2012 : Dec.  3.3 $\Rightarrow$ 15 kW
  - E19 : $(\pi^-, K^-) \Theta^+ \rightarrow$ no peak structure
  - E10 : $(\pi^-, K^+) \Lambda H$
- 2013 : Mar. - May  20 kW
  - May Radiation Leak Accident
- 2015 : May  30 kW
  - E13 : $\gamma$-ray spectroscopy, $^4\Lambda$He & $^{19}\Lambda$F
- 2016 : Mar.  40 kW(?)
  - E07 : S=−2 physics (June?)
The CSB effect using a central-force $\Lambda N-\Sigma N$ interaction is estimated using D2 potential by A. Gal. Estimated $\Delta B_\Lambda(1^+)$ value (by A. Gal) is in agreement with the present observation.
The first study of sd-shell hypernucleus

**Mass-gated γ-ray spectrum**

Target: thick CF$_4$

- 315 keV
- 578 keV
- 895 keV

- **Very preliminary**
- **Most likely**, the 315 keV peak is assigned as the g.s. doublet M1 transition, $^{19}_ΛF(3/2^+ \rightarrow 1/2^+)$
- Several other peaks are also seen.
A-dependence of $\Lambda N$ interaction strength

=> Information on wave functions and interaction range
=> confirm short-range nature of $\Lambda N$ int.

Systematic Understanding
$S=-2$ sector
How to input double strangeness into nucleus

- Direct process

- via $\Xi$ atom

KEK-PS(E176); 1988~
KEK-PS(E373); 1995~
The E373 experiment @ KEK
(K-,K+) reaction

E373 setup

1.67 GeV/c

followed $\Xi^{-}$ cand. track,

$\Rightarrow \sim 10^3 \Xi^{-}$ stops.

captured by light elem. (C,N,O) :

300~400 events

(estimated)
The authenticity of Prowse paper (1966 / $\Delta B_{\Lambda\Lambda} = 4.6 \pm 0.5$ MeV) was considered quite doubtful.


if we take into account $B_{\Xi^-} = 0.13$ MeV [atomic 3D : $^{12}$C- $\Xi^-$]

$^{6}_{\Lambda\Lambda}$He $B_{\Lambda\Lambda} = 6.91 +/- 0.16$ MeV, $\Delta B_{\Lambda\Lambda} = 0.67 +/- 0.17$ MeV

Cf. a previous paper ; H. Takahashi et al., PRL(2001) $B_{\Lambda\Lambda} = 7.25 +/- 0.19$ MeV, $\Delta B_{\Lambda\Lambda} = 1.01 +/- 0.20$ MeV
**Observed \(\Lambda\Lambda\) Hypernuclei in E176/E373 Hybrid Emulsion experiments**

**KEK-E176**
- in \(\sim 80\ \Xi^-\) stops

**KEK-E373**
- \(\sim 10^3\ \Xi^-\) stops

4 D.H.N in 7 samples by E373

\[\Lambda\Lambda\text{ bound energies}\]

<table>
<thead>
<tr>
<th>Event</th>
<th>(\Lambda\Lambda Z)</th>
<th>Target</th>
<th>(B_{\Lambda\Lambda}) [MeV]</th>
<th>(\Delta B_{\Lambda\Lambda}) [MeV]</th>
<th>Cluster [1]</th>
<th>Shell [2]</th>
</tr>
</thead>
<tbody>
<tr>
<td>NAGARA</td>
<td>(^6\Lambda\Lambda He)</td>
<td>(^{12}\text{C})</td>
<td>6.91 ± 0.16</td>
<td>0.67 ± 0.17</td>
<td>(6.91)</td>
<td>(6.91)</td>
</tr>
<tr>
<td>DEMACHIYANAGI</td>
<td>(^{10}\Lambda\Lambda Be) ((\Lambda\Lambda^{10}\text{Be})*)</td>
<td>(^{12}\text{C})</td>
<td>11.90 ± 0.13</td>
<td>-1.52 ± 0.15</td>
<td>11.88</td>
<td></td>
</tr>
<tr>
<td>HIDA</td>
<td>(^{11}\Lambda\Lambda Be)</td>
<td>(^{16}\text{O})</td>
<td>20.83 ± 1.27</td>
<td>2.61 ± 1.34</td>
<td>18.23</td>
<td>18.40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(^{12}\text{Be})</td>
<td>22.48 ± 1.21</td>
<td>-</td>
<td>20.27</td>
<td></td>
</tr>
<tr>
<td>MIKAGE</td>
<td>(^{6}\Lambda\Lambda He)</td>
<td>(^{12}\text{C})</td>
<td>10.01 ± 1.71</td>
<td>3.77 ± 1.71</td>
<td>23.21</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(^{11}\Lambda\Lambda Be)</td>
<td>23.05 ± 2.59</td>
<td>4.85 ± 2.63</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E176</td>
<td>(^{13}\Lambda\Lambda B) ((\Lambda\Lambda^{13}\text{C})*)</td>
<td>(^{14}\text{N})</td>
<td>23.3 ± 0.7</td>
<td>0.6 ± 0.8</td>
<td>23.21</td>
<td></td>
</tr>
<tr>
<td>Danysz et al.</td>
<td>(^{10}\Lambda\Lambda Be) ((\Lambda\Lambda^{10}\text{Be})*)</td>
<td>(^{14}\text{N})</td>
<td>14.7 ± 0.4</td>
<td>1.3 ± 0.4</td>
<td>14.74 (g.s.)</td>
<td>14.97 (g.s.)</td>
</tr>
</tbody>
</table>

\(\Delta B_{\Lambda\Lambda}(\Lambda\Lambda^{6}\text{He}) \sim 4.6 \rightarrow 0.67\ \text{MeV}\)

**2\(M_{\Lambda} - B_{\Lambda\Lambda}\) < \(M_{H}\): H-dibaryon, Jaffe PRL38(1977) 195**
$\Xi^-$ hyperons surely bound to nucleus

$\Xi^-$ binding energies are obtained

$$B_{\Xi^-} = \text{[Q-value]} - \text{[released energy]}$$

**E176 results:** S.Aoki et al., NP. A828 (2009) 191-232

$\Xi^-$ binding energy (MeV) in nucleus: $^{12}\text{C}$ [most probable]

<table>
<thead>
<tr>
<th>Event</th>
<th>$^4\text{H} + ^9\text{Be}$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$0.82 \pm 0.17$ $^4\text{H}^* + ^9\text{Be}$</td>
</tr>
<tr>
<td></td>
<td>$-0.23 \pm 0.17$ $(^4\text{H} + ^9\text{Be})$</td>
</tr>
<tr>
<td></td>
<td>($\chi^2 = 0.4$)</td>
</tr>
<tr>
<td></td>
<td>S. Aoki, et al., PTP 89 (1993) 493,</td>
</tr>
</tbody>
</table>

Coulomb assisted

**nuclear p bound state.**

$\Xi^- = - (16\sim 17)$ MeV


$B_{\Xi^-} = 3.75$ MeV ($\Gamma = 2.7$ MeV)

for **nuclear p state**

Y. Akaishi,

$B_{\Xi^-}(3D) = 0.13$ MeV for $^{12}\text{C}$ ➔ **not inconsistent!!** (0.17 MeV for $^{14}\text{N}$)
Woods-Saxon well depth of Xi-Nucleus potential


E176 (KEK-PS) \(\Xi^{-}\) stopping at rest \(\rightarrow\) Twin \(^{\Lambda\Lambda}Z\) pair prod.
The first observations of clearly identified \(\Xi^{-}\) bound systems.

Based on the Two events

1994 \(\sim\) -16 MeV[2] \(\Xi^{-}\) bound system (\(\Xi^{-}^{12}\)C)
1995 -(16~17) MeV[3-1] Same as above Nijimegen D
-16 MeV[3-2] Same as above Green function

Missing mass spectrum of (K\(^{-}\), K\(^{+}\)) reaction

2000 \(\sim\) -14 MeV [?][5] \(\Xi^{-}\) bound state E885 (BNL-AGS)
2001 Well reproduce \(\Xi^{-}\) bound state

E176 Ehime potential[6]

HyperN experiment program

History @ J-PARC Hadron

- 2011 : Mar.  Big earthquake
- 2012 : Dec.  3.3  $\rightarrow$  15 kW
  - E19 : $(\pi^-, K^-) \Theta^+ \rightarrow$ no peak structure
  - E10 : $(\pi^-, K^+) \Lambda H$
- 2013 : Mar. - May  20 kW
  - May  Radiation Leak Accident
- 2015 : May  30 kW
  - E13 : $\gamma$-ray spectroscopy, $^4\Lambda$He & $^{19}\Lambda$F
- 2016 : Mar.  40 kW(?)
  - E07 : S=$-2$ physics (June?)
1. New Hybrid method

- Pure K-beam (better 3.5 times than KEK-PS)
- More emulsion volume (E373 x 3)

- $10^3$ (E373) $\rightarrow$ $10^4$ Ξ- stop events
  1. X ray measurement from Ξ atom with Hyperball-X
     $\Rightarrow$ study of Ξ-N interaction
  2. $\sim 10^2$ double hypernuclei

2. Overall-scanning

- Fully automatic detection of 3 vtx. event like NAGARA event, KISO event
- $10$ times statistics of that with the hybrid method

J-PARC

- X-ray measurement from Ξ atom
- Study of Ξ-N interaction
- $\sim 10^3$ double-$\Lambda$ hypernuclei
- $\sim 10^2$ Ξ hypernuclei with $A<16$

Automated track-following
Concept of “Overall-scanning”

1. **fast image capture**
   Developed system with CCD camera

2. **fast image processing**
   for vertex detection
   - 3 vertices
   - NAGARA event was detected by this method

---

8 M images
under test operation using E373 emulsion
An event by the "Overall-scanning", named "KISO"

Single hypernucleus emitted back-to-back direction (Twin hypernuclei event) ➞ Topology seems to be consistent with the past events of twin hypernuclei (E176).


=> Consistent with $\Xi^-$ capture reaction occurred on C, N or O.
Image of the *KISO* event
* Event interpretation and the energy of $B_{\Xi^-}$

**Process of the KISO event**

\[ \Xi^- + ^{14}\text{N} \rightarrow ^{10}_{\Lambda}\text{Be} (#1) + ^5_{\Lambda}\text{He} (#2), \]

\[ ^{10}_{\Lambda}\text{Be} \rightarrow ^8\text{Li} (#3) + p (#4) + n, \]

\[ ^8\text{Li} \rightarrow ^8\text{Be}^*(2^+) + e^- (+ \bar{\nu}_e) \]

\[ ^8\text{Be}^*(2^+) \rightarrow 2\alpha (#5 \& #6) \]

\[ ^5_{\Lambda}\text{He} \rightarrow \rho(#7) + d(#8) + 2n \]

\[ B_{\Xi^-} = 4.38 \pm 0.25 \text{ MeV (by Mom. balance [#1 and #2])} \]

Measurement error: 0.09 MeV

Mass ($^{10}_{\Lambda}\text{Be}, ^5_{\Lambda}\text{He}, \Xi^-$) error: 0.23 MeV

Where we took $B_{\text{gs.}}(^{10}_{\Lambda}\text{Be}) = 9.11 \pm 0.22 \text{ MeV}$
The first evidence of a $\Xi^-$-$^{14}$N system to be bound deeply.

K. Nakazawa et al., PTEP. 2015, 033D02 / DOI: 10.1093/ptep/ptv008
New scanning system for the E07 emulsion

**Vertex Picker (VP)**

for Overall scanning in full volume of EM

Fast image capture by Obj. x20 ➔ image processing ➔

Picked up vertices are checked by Obj. x50

with piezo stage

- 300 faster !!

Images of all of the emulsion can be obtained in a few years.

<table>
<thead>
<tr>
<th></th>
<th>Old</th>
<th>VP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obj. Lens</td>
<td>× 50 (NA. 0.9)</td>
<td>× 20 (NA. 0.35) ➔ × 50</td>
</tr>
<tr>
<td>Camera</td>
<td>100Hz XC_HR300</td>
<td>800Hz HXC20</td>
</tr>
<tr>
<td>Pixel</td>
<td>512 × 440 pixel</td>
<td>2039 × 357 pixel</td>
</tr>
<tr>
<td>Area</td>
<td>130 mm × 110 mm</td>
<td>1.1 mm × 0.20 mm</td>
</tr>
<tr>
<td>Rate(Hz)</td>
<td>0.3</td>
<td>5</td>
</tr>
</tbody>
</table>

4 sets 3 sets

Human check 3 VTX. in well contrasted images

In Myanmar Univ.:
by more than 10 Graduate Stu.

Images with 3 VTX. are taken by bj. × 100

Event analyses by the image

Physics by,

~10^3 D.H.N
~several × 10^2 Twin

~1.1 mm

0.2 mm

0.1 mm

0.13 mm

Fast image capture by Obj. x20 ➔ image processing ➔

Picked up vertices are checked by Obj. x50

with piezo stage

- 300 faster !!

Images of all of the emulsion can be obtained in a few years.
3. Summary

1. We have performed experiments to study **S=-1, -2 systems** at KEK, BNL (J-Lab and MAINZ).

2. J-PARC provides high intense and pure K- beam to get more rich information about S= -1 and -2 systems, which is quite important to understand the **EOS of neutron stars** and **YN & YY interaction in baryon octet scheme**.

3. Regarding S=-2, the information of interaction are given by NAGARA and KISO events, however they are very limited, so far. Thus, the following experiments are waiting for the beams.
   - **E07 exp.**: Huge amount (~10^3) ........ Double & Ξ Hyper
   - **E03 exp.**: X atomic X-ray ............... Ξ–N interaction.
   - **E05 exp.**: Missing mass ¹²C(K-, K+) ...... Ξ Hyper
   - **E42 exp.**: Mass meas. ¹²C(K-, K+)ΛΛX .... H dibaryon

4. To speed up for getting fruitful experimental results, the extension of Hadron hall at J-PARC are planned, now.
Extension of HD-hall @ J-PARC

@ present

K1.8

π exp. ⇒ K exp.
S = -1 ⇒ S = -2

Primary beam (2018?~)

HIP

High intensity. & High res. π beam

S = -1

K1.1

2020?~

High mom. p, K beam

KL

CP violation

Extension