Reaffirmation of a deeply bound Ξ^{-}-^{14}N system, KISO event, with a recent experimental result

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15th Sep., 2016

Outline

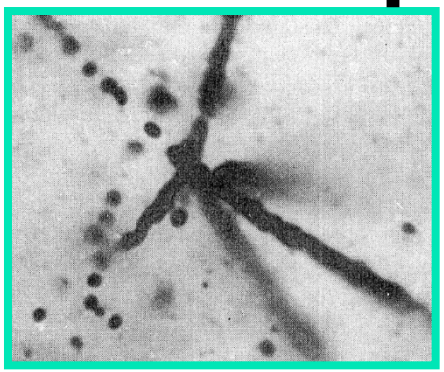
1. Information on S=-2 nuclei.
2. The KISO event and binding energy of Ξ^{-} in ^{14}N.
3. The E07 experiment @ J-PARC.
4. Summary

Double-Λ hypernuclei
[Danysz / E176 & E373@ KEK]

We have **a few x 10^2 Ξ^- captured** in light elements (C, N, O)

KEK-E176

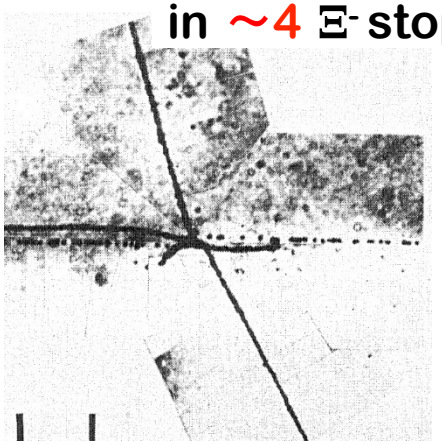
in ~80 Ξ stops



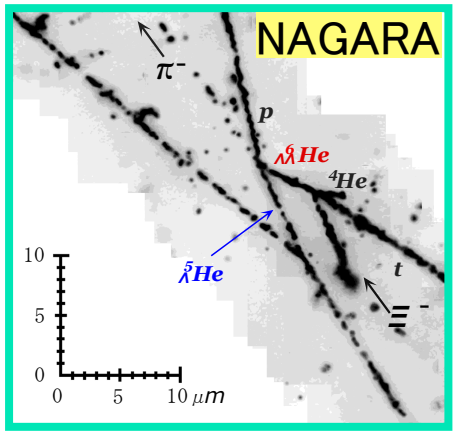
S.Aoki et al.,
NP. A828 (2009) 191-232

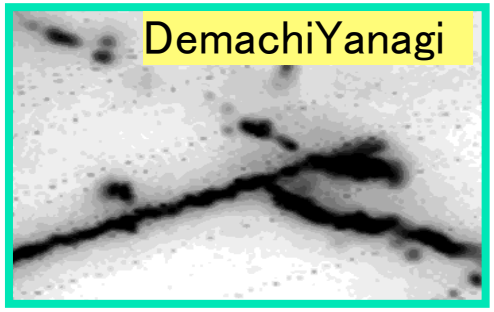
M.Danysz et al., PRL.11(1963)29;

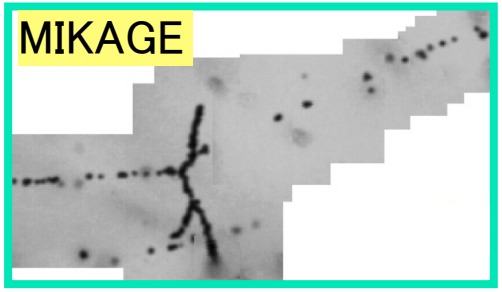
in ~4 Ξ^- stops

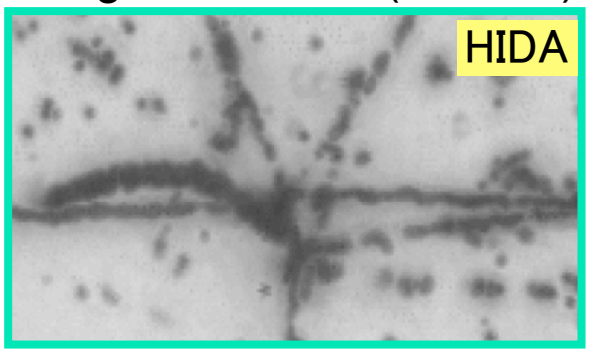


KEK-E373



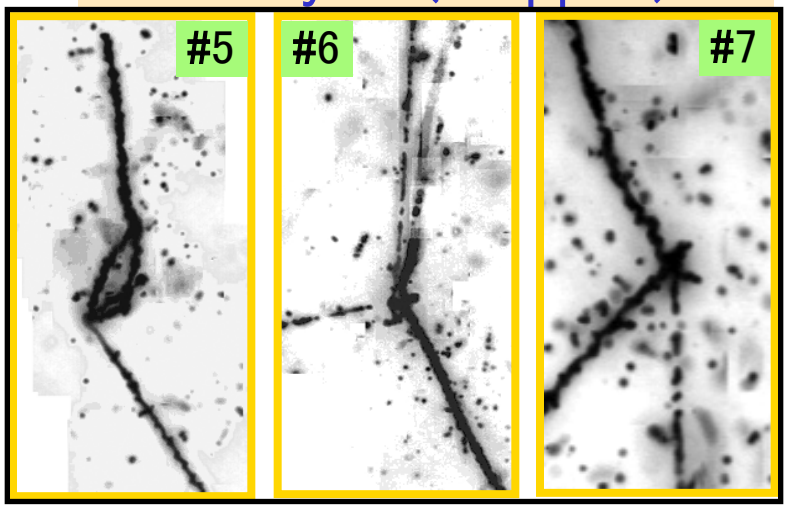






H.Takahashi et al., Phys. Rev. Lett. 87, 212502 (2001).
K.Nakazawa and H.Takahashi,
Prog. Theor. Phys. Suppl. 185, 335 (2010) .
J. K.Ahn et al., Phys. Rev. C 88, 014003 (2013).

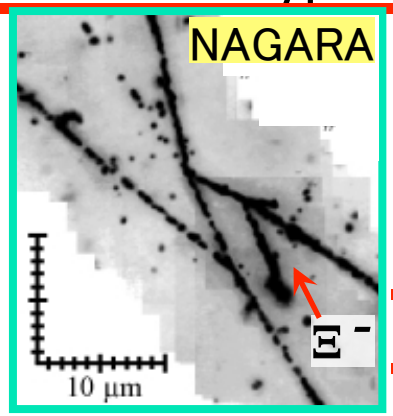
Analysis (stopped)



Nuclear Phys. with S=-2

Main subject : *Study of hadron-hadron interaction*

Double-Λ hypernucleus



$\Xi^- + {}^{12}C$

⇓

${}^{6}_{\Lambda\Lambda}He + {}^{4}He + t$

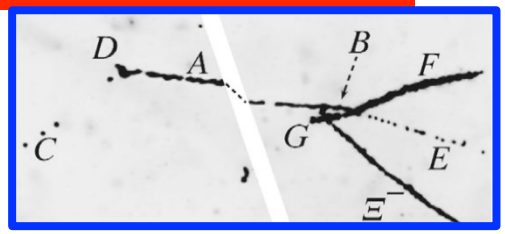
Unique identification

ΛΛ interaction energy : ${}^{6}_{\Lambda\Lambda}He$

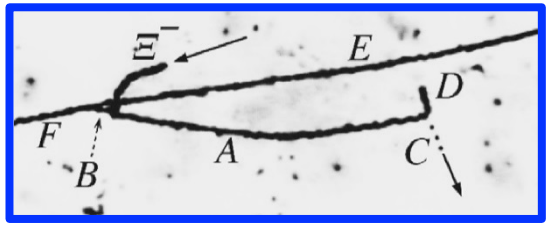
$\Delta B_{\Lambda\Lambda} \sim 1$ MeV

Constrain other events **independent of NAGARA**

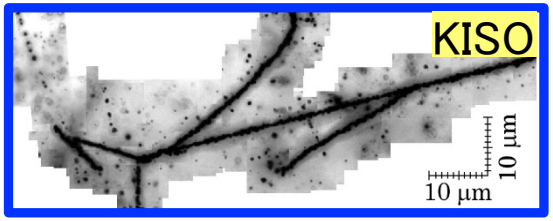
Ξ-atom, Ξ-nucleus ⇐ twin single-Λ hypernuclei



B_{Ξ^-} = 0.82±0.14 MeV
-0.19±0.15 MeV (3D)



B_{Ξ^-} = 0.82±0.17 MeV
-0.23±0.17 MeV (3D)



$\Xi^- + {}^{14}N \Rightarrow {}^{10}_{\Lambda}Be + {}^{5}_{\Lambda}He$

B_{Ξ^-} = 1.11~4.38±0.25 MeV
beyond atomic 3D (0.17MeV)

Information : *ΞN* interaction

?? ΛΛ ⇔ *ΞN* mixing

Very little is known, so far!!

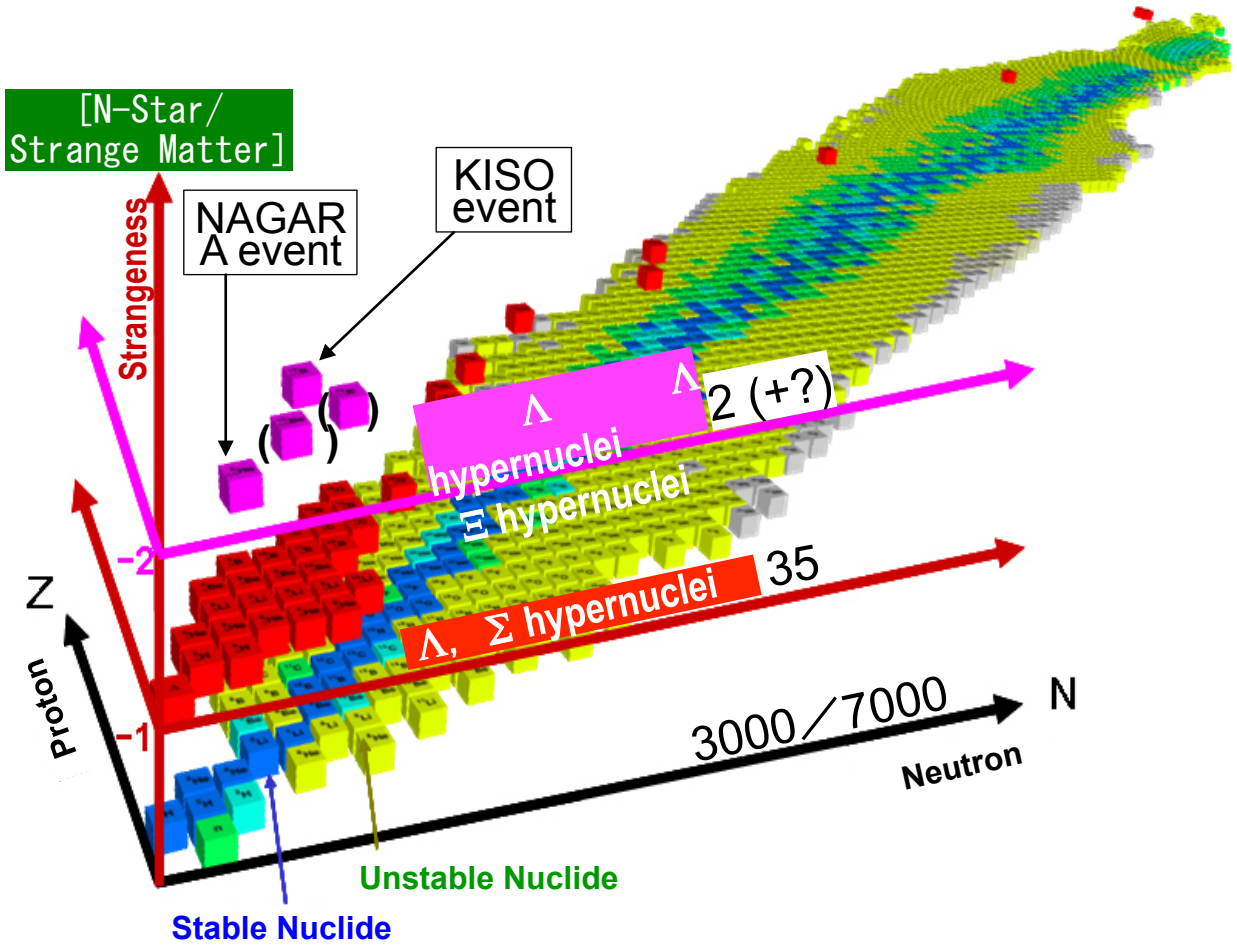
ex. ΛΛ sticking via Ξ^- *2p* absorption by ${}^{12}C$, ${}^{14}N$ or ${}^{16}O$

	Theory	Experiment
2*p* absorption	a few x 10^{-2}	
↳**ΛΛ sticking**	↳ x $10^{-(2\sim3)}$	a few x 10^{-2}

Theoretical prediction is quite different from experimental results.

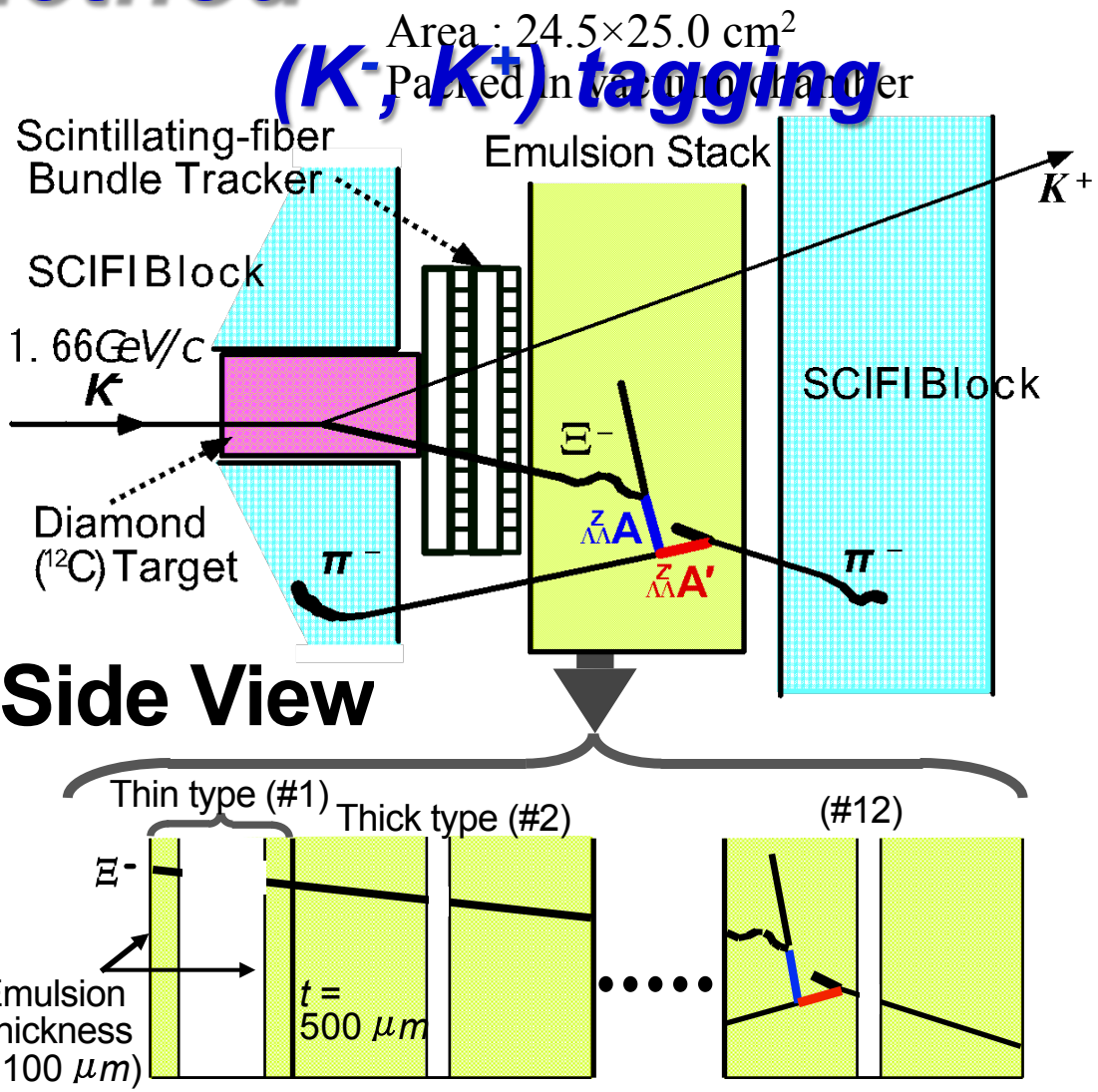
Nuclear Phys. with S=-2

* making *a nuclear chart with S=-2*



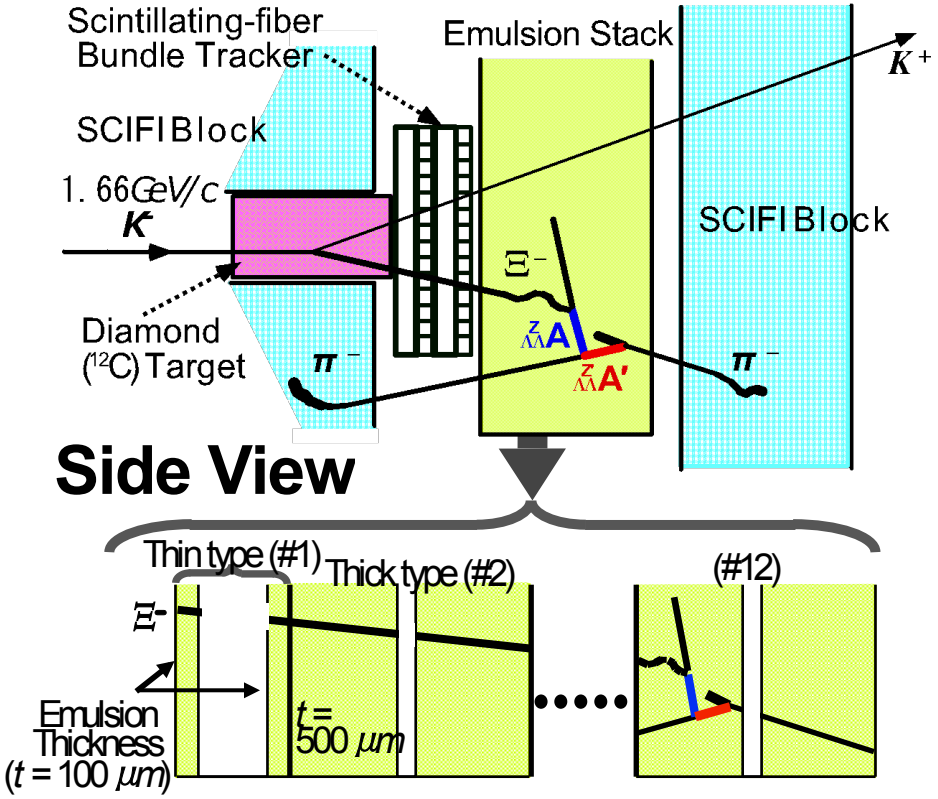
a hybrid emulsion method

(K^-, K^+) tagging



a hybrid emulsion method
(K^-, K^+) tagging

Overall-scanning



Fully automatic detection of

3 vtx. event

like **NAGARA** event, **KISO** event

in **whole area** of the Emulsion sheet

10 times statistics of that

with the hybrid method

(1/0.3): free from
X acceptance & tracking
4 :・'p'(K^-, K^+)Ξ^- in the emulsion
・'n'(K^-, K^0)Ξ^- reaction

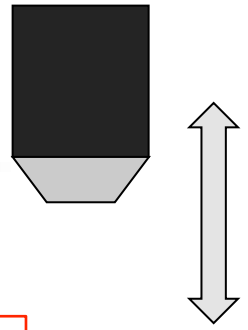
Development of "*Overall-scanning*"

n p Λ

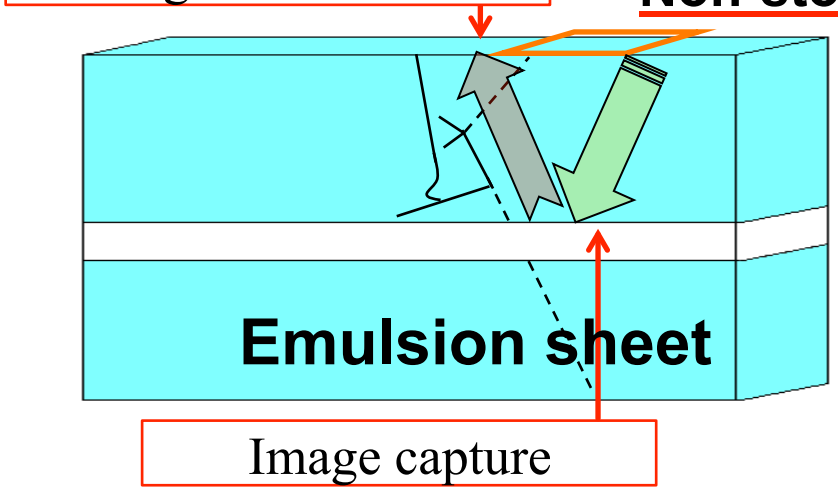
Primary motivation;

fast detection of α decay vertices of natural isotopes to calibrate range-energy relation.

1st-Generation Vertex Picker (*VP*)



Non-stop driving



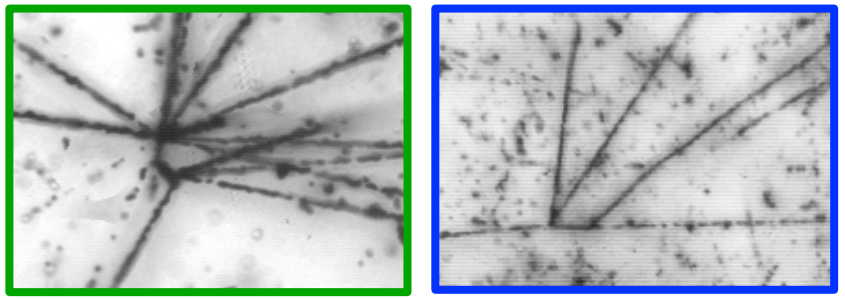
① *fast image capture*

Developed system with CCD camera

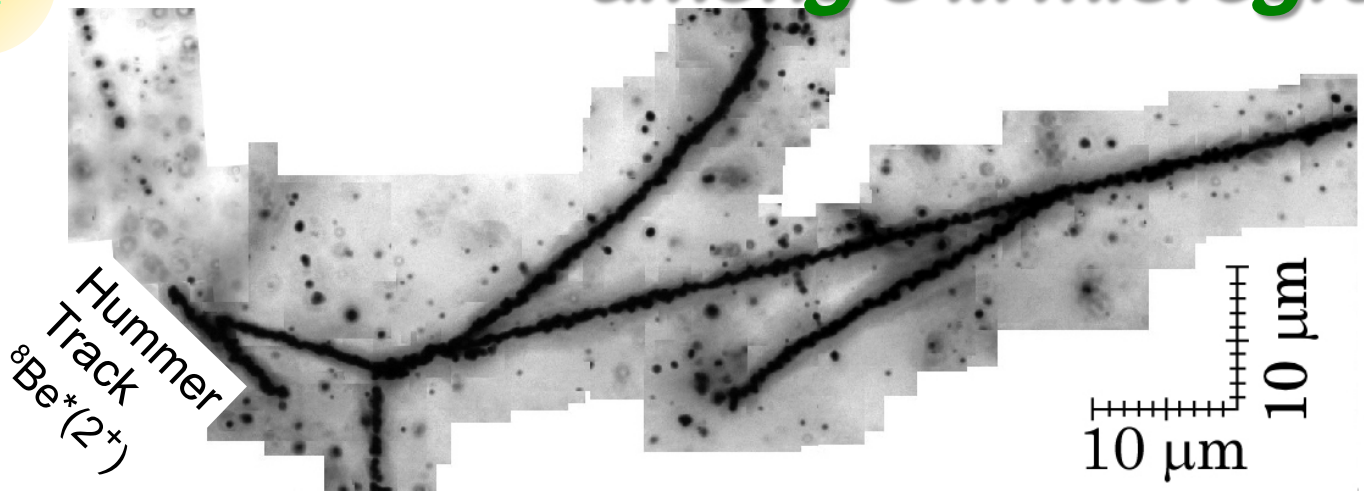
OS : Win2000 sp4
Camera : 100Hz (CCD)
Obj. lens : x 50
emulsion : 500μm
area : 0.1x0.08mm^2
# of image : ~100/cycle
Time : 5min. /cycle
➔ 3sec/cycle
[~ hard limit]

② *fast image processing*

Detected samples



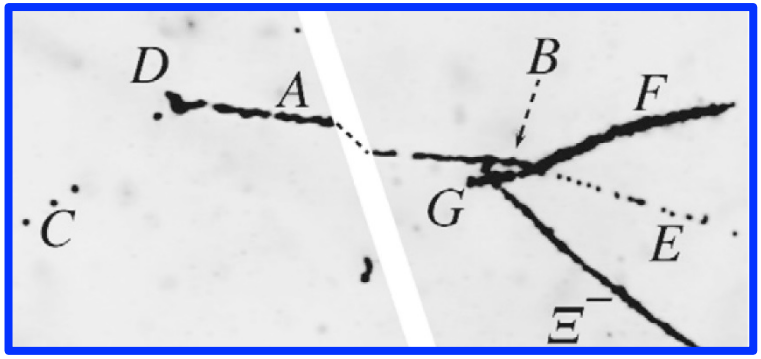
Under test operation of "Overall-scanning" among 8 M micrographs

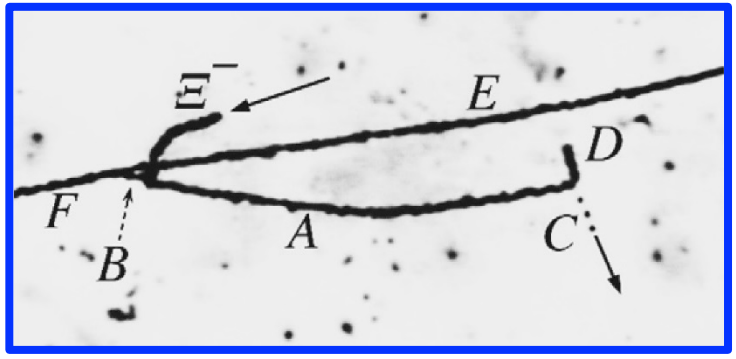


Single hypernucleus emitted back-to-back direction (**Twin** hypernuclei event)

➔ Topology seems to be consistent with the past events of twin hypernuclei (E176).

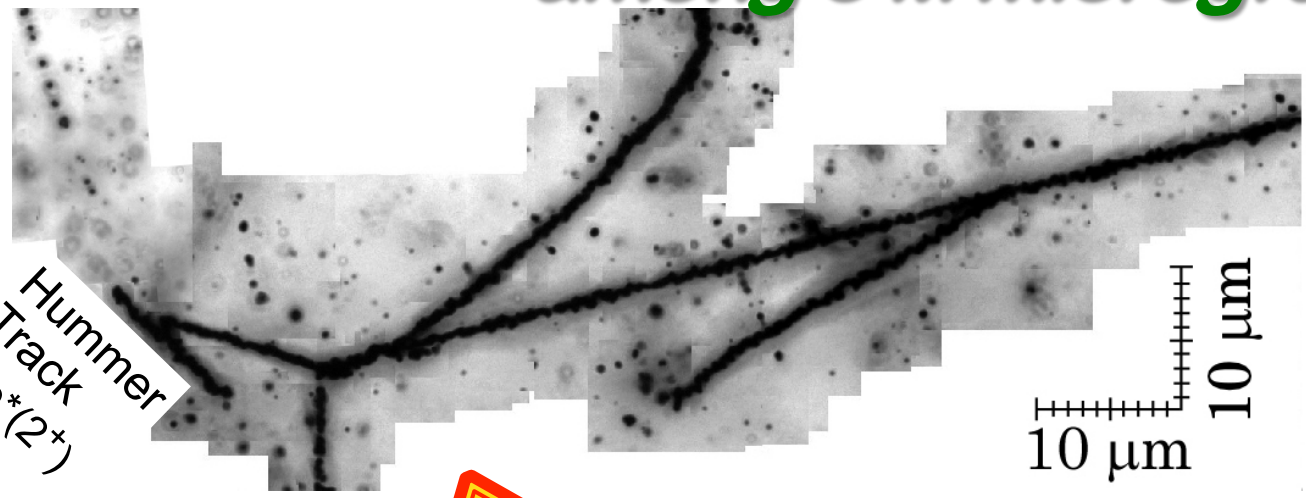
Results of KEK-E176: S.Aoki et al., NP. A828 (2009) 191-232





=> Consistent with Ξ^- capture reaction occurred on **C**, **N** or **O**.

Under test operation of "Overall-scanning" among 8 M micrographs



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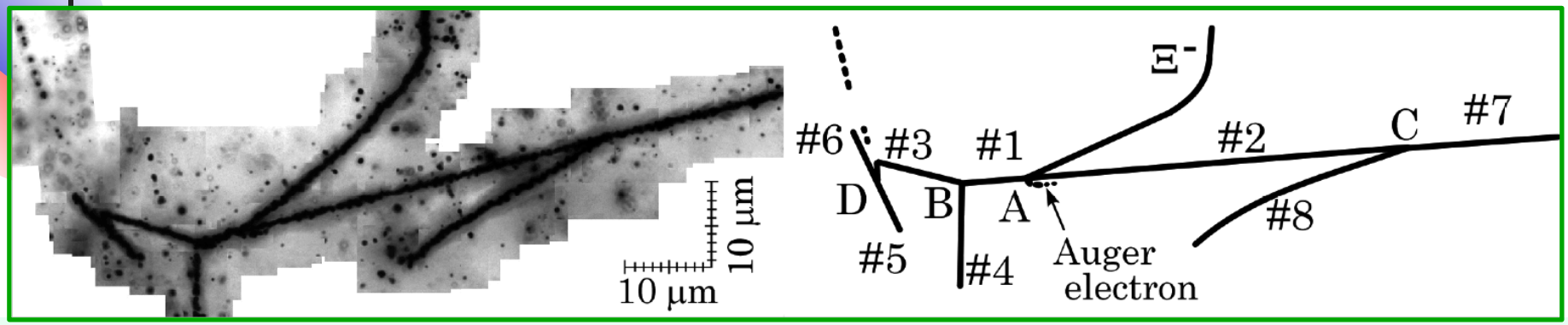
Results of KEK-E176: S.Aoki et al., NP. A828 (2009) 191-232

named

KISO event

=> Consistent with Ξ^- capture reaction occurred on **C**, **N** or **O**.

＊Event interpretation and the energy of B_{Ξ^-}



Process of the *KISO* event

$\Xi^- + {}^{14}N \rightarrow {}^{\ 0}_{\Lambda}Be$ (#1) + ${}^{\ 5}_{\Lambda}He$ (#2),

${}^{\ 0}_{\Lambda}Be \rightarrow {}^{8}Li$ (#3) + p (#4) + n, ${}^{\ 5}_{\Lambda}He \rightarrow p$(#7) + d(#8) + $2n$ (*ex.*)

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

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

B_{Ξ^-} = **4.38 +/- 0.25** MeV (by Mom. balance [#1 and #2]), if ${}^{\ 0}_{\Lambda}Be$ in **g.s.**

Measurement error : 0.09 MeV

Mass (${}^{\ 0}_{\Lambda}Be$, ${}^{\ 5}_{\Lambda}He$, Ξ^-) error : 0.23 MeV

where, $B_{\Lambda\,g.s.}({}^{\ 0}_{\Lambda}Be)$ =9.11±0.22 MeV

If ${}^{\ 0}_{\Lambda}Be$ was produced in excited states,
by using theoretical estimations → B_{Ξ^-} = **1.11 +/- 0.25** MeV,
3.7 σ far from atomic 3*D* level (**0.17 MeV** for Ξ^--${}^{14}N$)

Consistent with 2*p* state (1.14 MeV)
theoretical prediction
Yamaguchi et al,
PTP. 105 (2001) 627

K. Nakazawa et al., PTEP. 2015, 033D02 / DOI : 10.1093/ptep/ptv008

Recent exp. result for levels of $^{10}_{\Lambda}$Be

JLab E05-115

Gogami et al., Phys. Rev. C **93**, 034314 (2016)

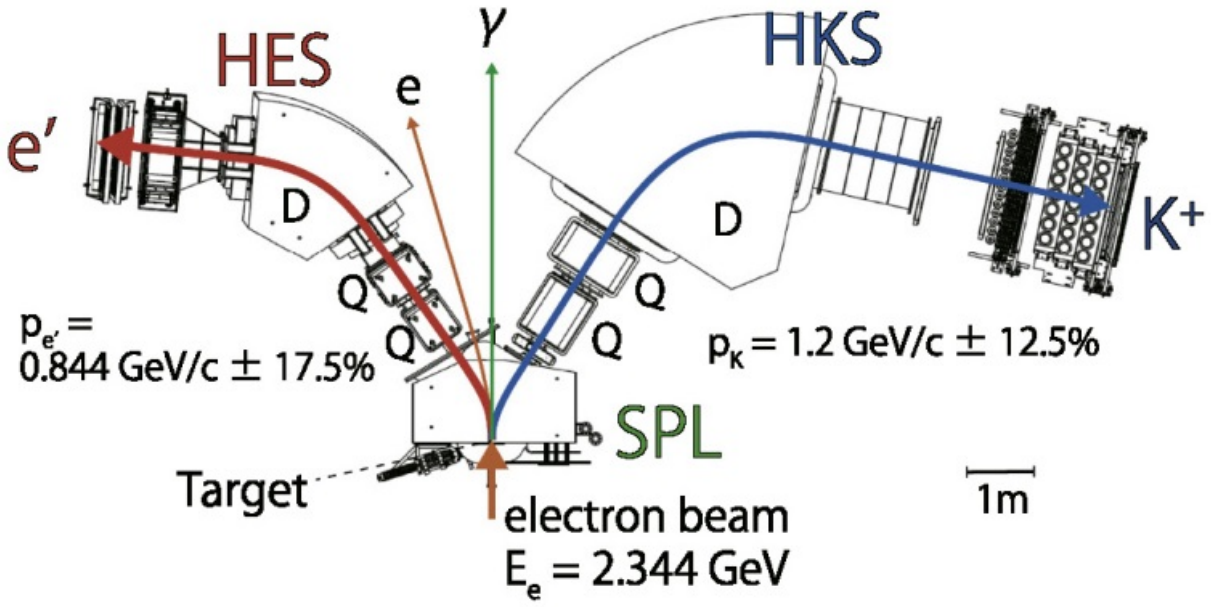


FIG. 1. A schematic drawing of the JLab E05-115 experimental geometry. The setup consists of SPL, HKS, and HES spectrometers. An electron beam with the energy of 2.344 GeV is incident on the target located at the entrance of SPL. A K^+ and an e' with the momenta of ~1 GeV/c are observed by HKS and HES, respectively.

- (e, e'K$^+$) reaction
- missing mass
- ^{10}B target
- Calibrated by
  Λ mass
  via $p(e, e'K^+)\Lambda$

Gogami et al., Phys. Rev. C **93**, 034314 (2016)

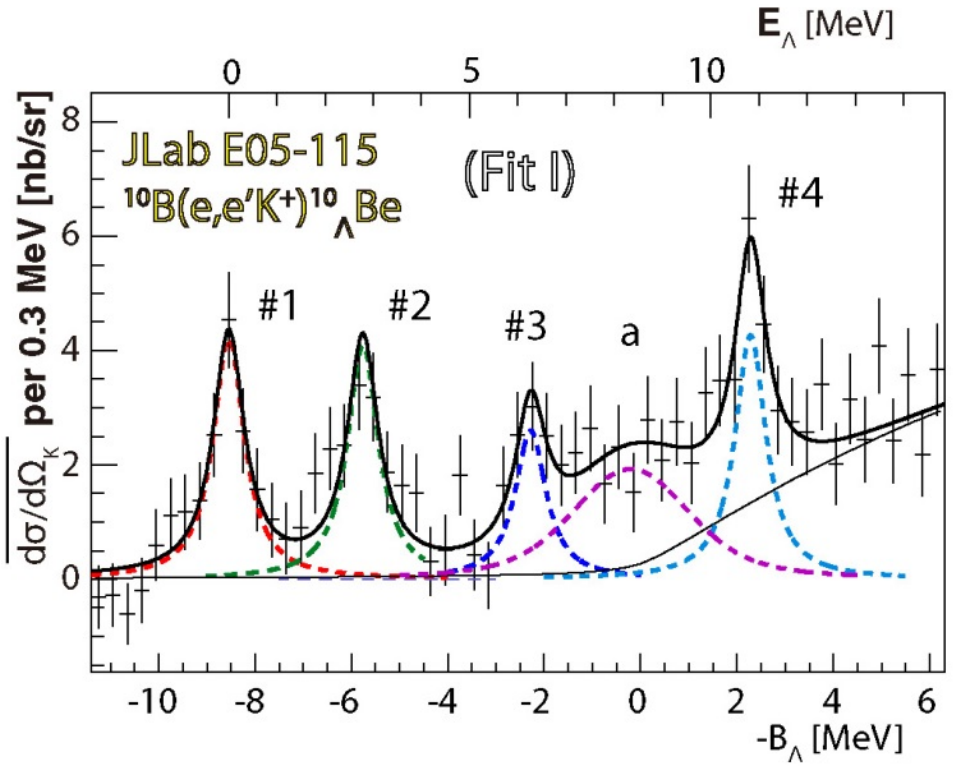


FIG. 3. Binding energy (B_Λ) and excitation energy [$E_\Lambda \equiv -(B_\Lambda - B_\Lambda(\#1))$] spectra for the $^{10}\mathrm{B}(e,e'K^+)^{10}_{\Lambda}\mathrm{Be}$ reaction with a fitting result of Fit I. The ordinate axis is $(\overline{d\sigma/d\Omega_K})$ per 0.3 MeV.

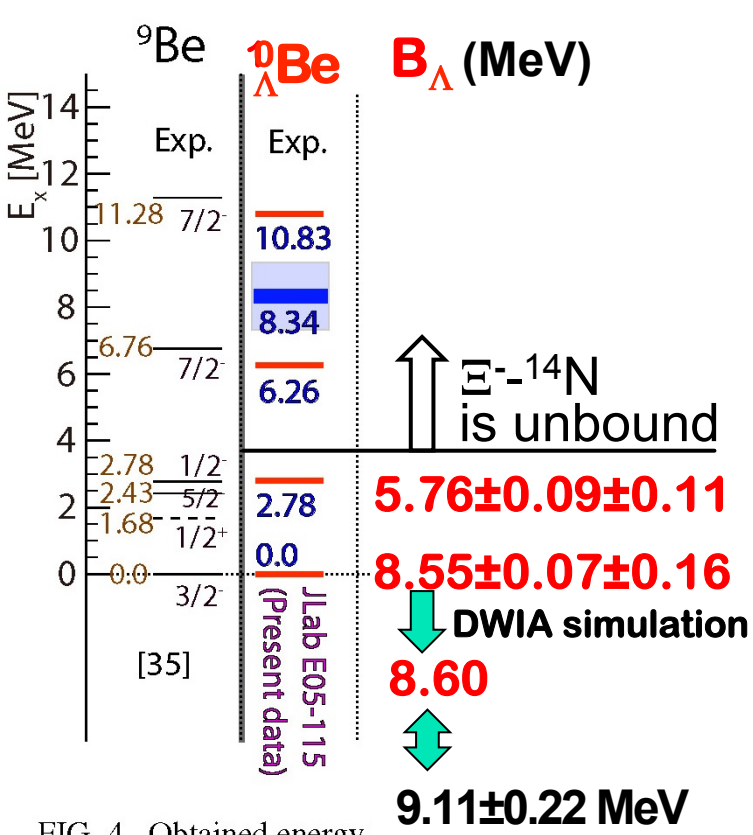


FIG. 4. Obtained energy of the theoretical calculation [35] and $^{10}_{\Lambda}\mathrm{B}$ [31] are shown

For KISO event, taking JLab data

$B_{\Xi^-}(^{10}_{\Lambda}\mathrm{Be}_{\mathrm{g.s.}})$ = **3.87 +/- 0.21 (MeV)**

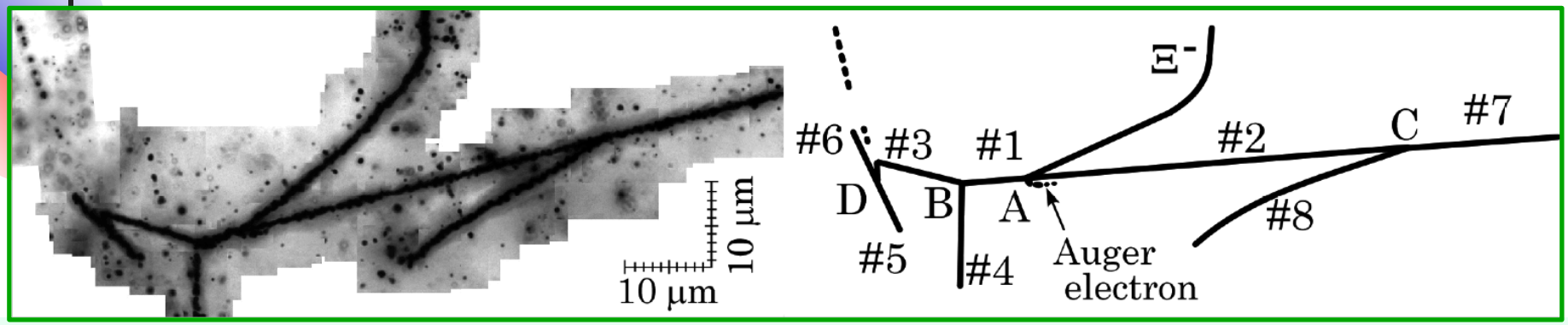
$B_{\Xi^-}(^{10}_{\Lambda}\mathrm{Be}_{\mathrm{1st\ ex.}})$ = **1.03 +/- 0.18 (MeV)**

deviation from 3*D* (0.17 MeV)

17.5 σ (mass err = 0.19 [MeV])

4.6 σ (mass err = 0.16 [MeV])

＊Event interpretation and the energy of B_{Ξ^-}



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Mass (${}^{\ 0}_{\Lambda}Be$, ${}^{\ 5}_{\Lambda}He$, Ξ^-) error : 0.23 MeV

where, $B_{\Lambda\,g.s.}({}^{\ 0}_{\Lambda}Be)$ =9.11±0.22 MeV

If ${}^{\ 0}_{\Lambda}Be$ was produced in excited states,
by using theoretical estimations ➔ B_{Ξ^-} = **1.11 +/- 0.25** MeV,
3.7 σ far from atomic 3D level (0.17 MeV)

Consistent with 2*p* state (1.14 MeV)
theoretical prediction
Yamaguchi et al.
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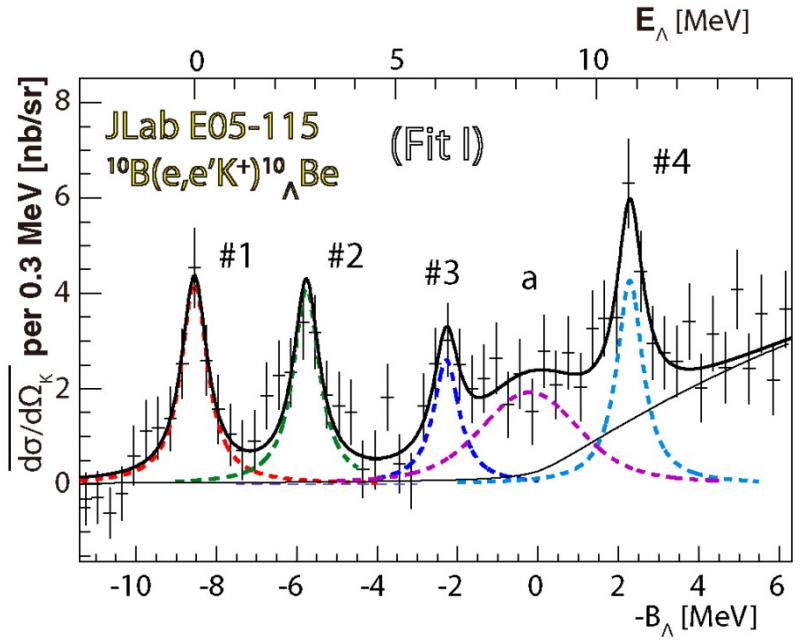

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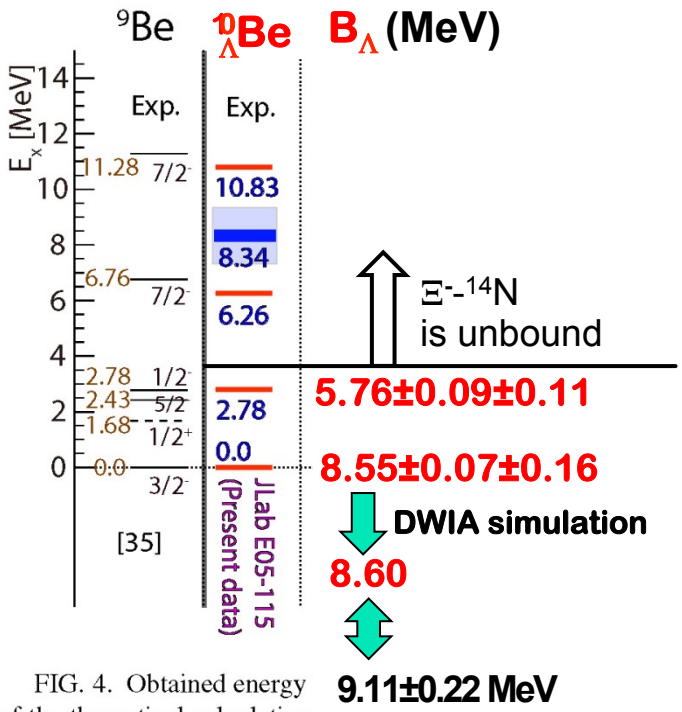

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Taking JLab data

$B_{\Xi^-}(^{10}_{\Lambda}\mathrm{Be}_{\mathrm{g.s.}})$ = **3.87 +/- 0.21 (MeV)** deviation from 3*D* (0.17 MeV) **17.5 σ** (mass err = 0.19 [MeV])

$B_{\Xi^-}(^{10}_{\Lambda}\mathrm{Be}_{\mathrm{1st\ ex.}})$ = **1.03 +/- 0.18 (MeV)** **4.6 σ** (mass err = 0.16 [MeV])

It will be almost confirmed that

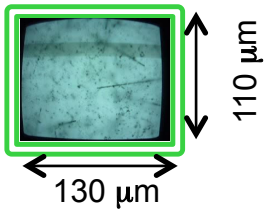
- presence of **Ξ hypernuclei**
- binding between Ξ^- and nuclei will be **weakly attractive**.

New“overall-scanning”system for the E07emulsion

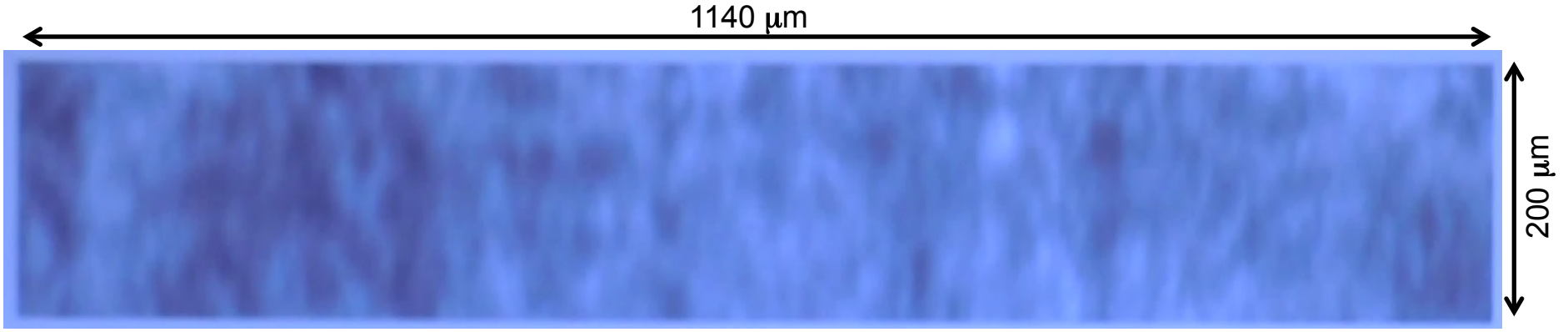
Develpping **2nd-G Vertex Picker** with piezo stage

×300 faster !!

1st-G VP

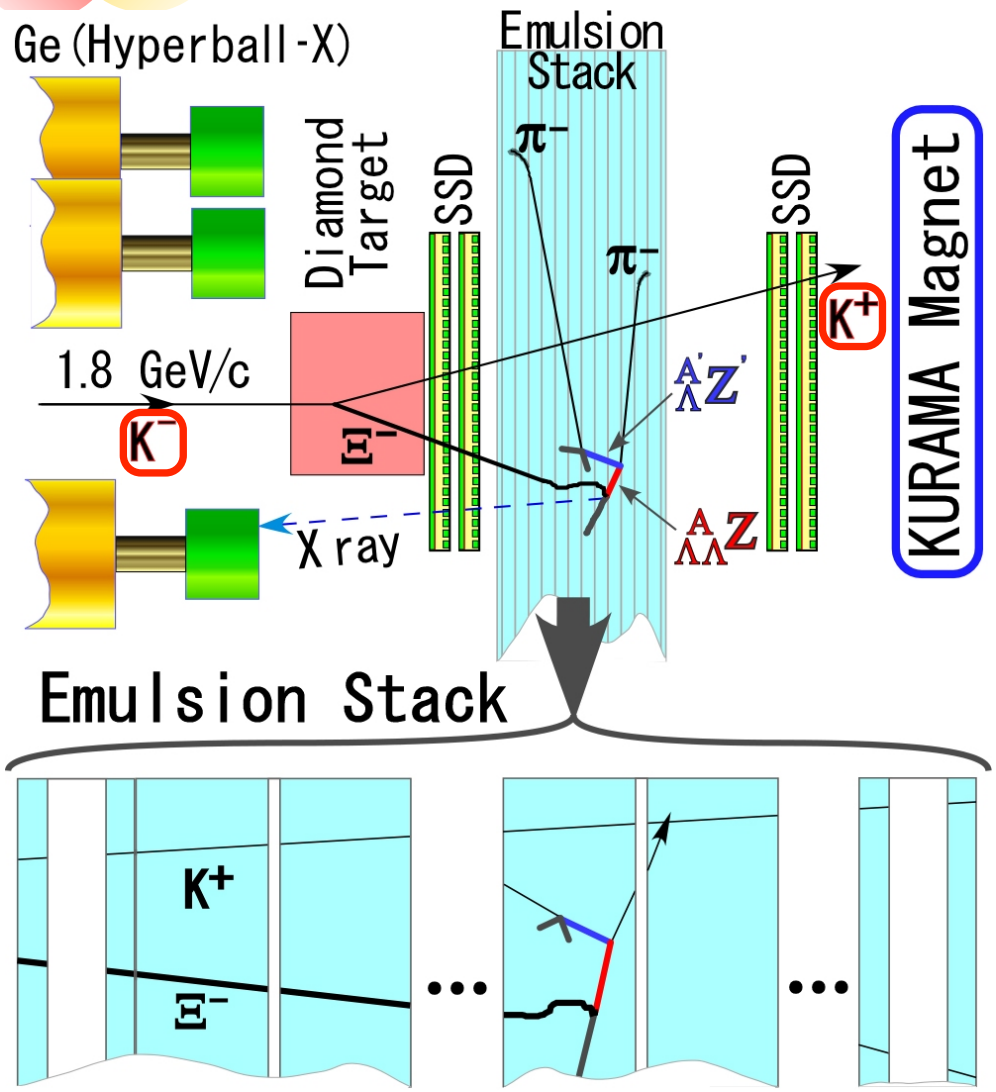


	1st-G VP	2nd-G VP
Obj. Lens	×50 (NA. 0.9)	×20 (NA. 0.35)
Camera	100Hz XC_HR300	800Hz HXC20
Pixel	512×440 pixel	2039×357 pixel
Area	130 mm×110 mm	1140 mm×200 mm
Rate(Hz)	0.3	5
	4 sets	3 sets



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

The E07 experiment with a hybrid emulsion method



1．Pure and intense K-beam
(better x 3.5 than KEK-PS)

proposal : 3x10^{5}K/*spill*, K/π≧6 (K⁻ 85%)

2．Enough emulsion volume (x 3)

Physics Goal of E07

1. **Mini-chart with S = -2**
2. **Nuclear (A) dependence of $\Delta B_{\Lambda\Lambda}$**
3. **Ξ atomic X ray with Hyperball-X**
4. **Ξ hypernuclei in twin Λ hypernuclei**
5. **H-dibaryon with Σ⁻decay (?)**

(K⁻, K⁺)tagging

10^3 Ξ- stops (E373, 7 DHN)

➔ 10^4 (E07, ~10^2 DHN)

Automatic Ξ⁻ track following

3. The E07 experiment @ J-PARC

To obtain rich information about ΛΛ & Ξ*N* interaction. !!

Collaborators

K.Imai[a], K.Nakazawa[b], H.Tamura[c], S.Ahmad[d], J.K.Ahn[e], B.Bassalleck[f], R.E.Chrien[g], H.Ekawa[i], Y.Y.Fu[j], Y.Han[f], R.Hasan[d], S.Hasegawa[a], S.Hayakawa[k], E.Hayata[i], M.Hirose[i], K.Hoshino[b], K.Hosomi[a], S.Hwang[a], M.Ieiri[l], H.Ito[b], K.Ito[m], K.Itonaga[b], T.Kawai[m], J.H.Kim[n], S.Kinbara[b], R.Kiuchi[o], T.Koike[c], H.S.Lee[e], J.Y.Lee[o], C.Li[j], Z.M.Li[j], K.Miwa[c], H.Noumi[p], S.Y.Ryu[e], A.Sakaguchi[k], H.Sako[a], S.Sato[a], T.Sato[m], M.Sekimoto[l], K.Shirotori[p], M.K.Soe[q], H.Sugimura[a], M.Sumihama[b], H.Takahashi[l], T.Takahashi[l], K.Tanida[o], A.M.M.Theint[q], K.T.Tint[r], A.Tokiyasu[p], M.Ukai[c], T.Watabe[m], T.Yamamoto[c], N.Yasuda[s], C.S.Yoon[n], J.Yoshida[b], T.Yoshida[s], D.H.Zhang[t], J.Zhou[j], S.H.Zhou[j], and L.H.Zhu[j]

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[b]*Physics Department, Gifu University, Japan,*♪
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[d]*Aligarh Muslim University, India,*♪
[e]*Korea University, Korea,*♪
[f]*Department of Physics and Astronomy, University of NewMexico, USA,*♪
[g]*Brookhaven National Laboratory, USA,*♪
[h]*University Colledge of London, UK,*♪
[i]*Department of Physics, Kyoto University, Japan,*♪
[j]*CIAE, China Institute of Atomic Energy (CIAE), China,*♪
[k]*Department of Physics, OsakaUniversity, Japan,*♪
[l]*KEK, High Energy Accelerator Research Organization, Japan,*♪
[m]*Department of Physics, Nagoya University, Japan,*♪
[n] *Gyeongsang Nat'l University, Korea,*♪
[o]*Seoul National University, Korea,*♪
[p]*Research Center for Nuclear Physics (RCNP), Japan,*♪
[q]*Mandalay University, Myanmar,*♪
[r]*Yadanabon University, Myanmar,*♪
[s]*University of Fukui, Japan,*♪
[t]*Shanxi Normal University, China.*♪

JPN：9／KOR：3／MYM：2／CHN：2／USA：2／UK：1／IND：1

・・・・・・・・20 Univ.・Inst.

The E07 experiment @ J-PARC

/Commissioning run : 3 days in Oct. 2015

The 1st Physics run in Jun. 2016

/KURAMA spectrometer

Commissioning : 6 days

/Physics : 6 days

Emulsion exposure

18 /118 stacks

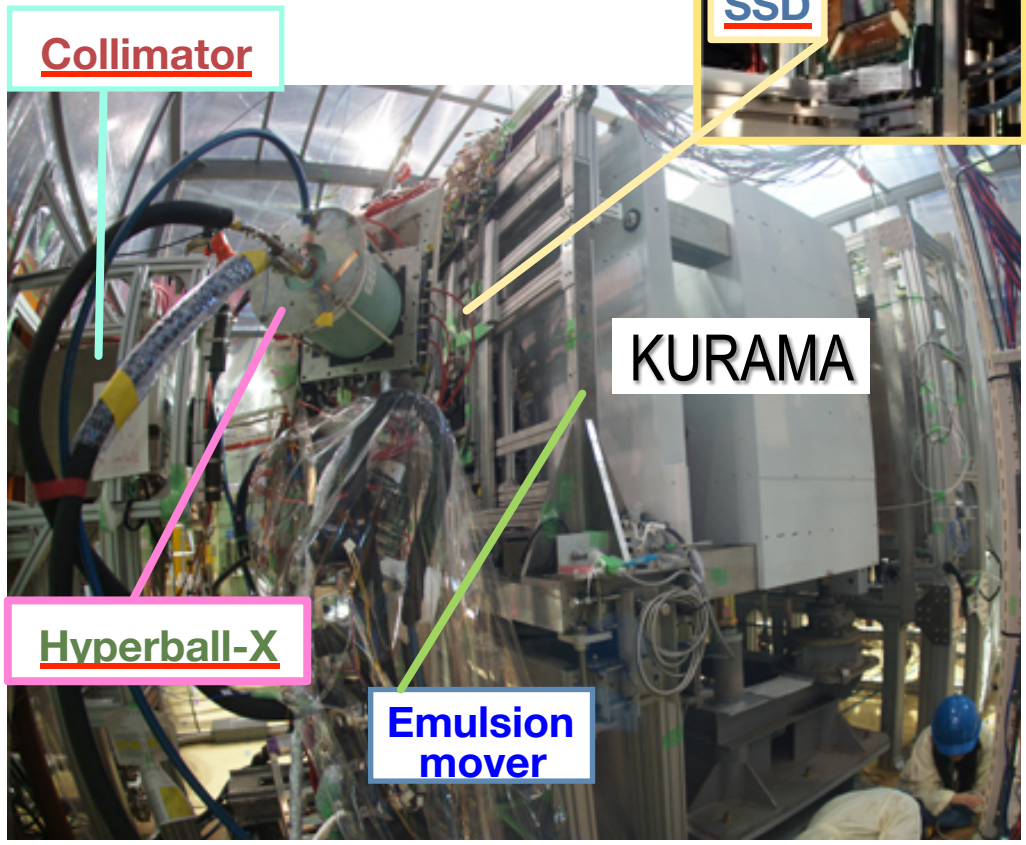
➔ yields x1.5

for the previous E373

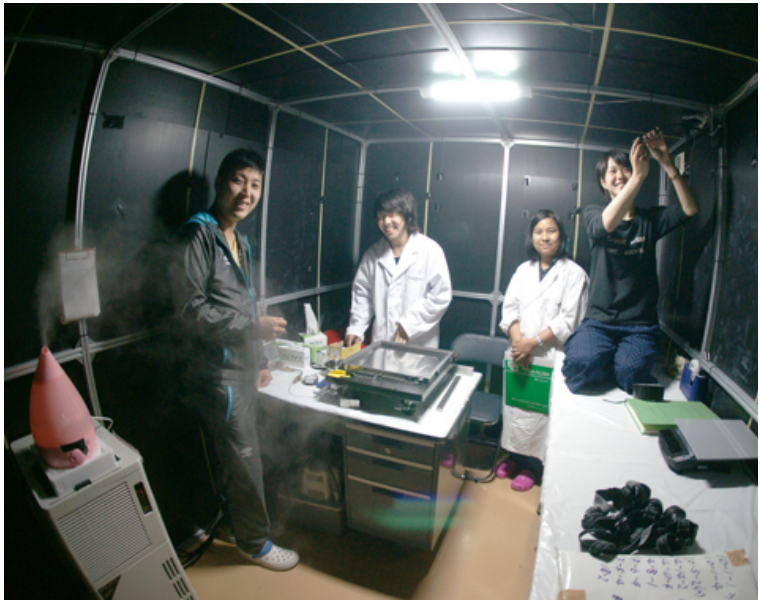
Run end photo @ K1.8 counting room
Jun. 30th, 2016
Total : 56 persons

The 1st Physics run in Jun. 2016

KURAMA spectrometer for E07

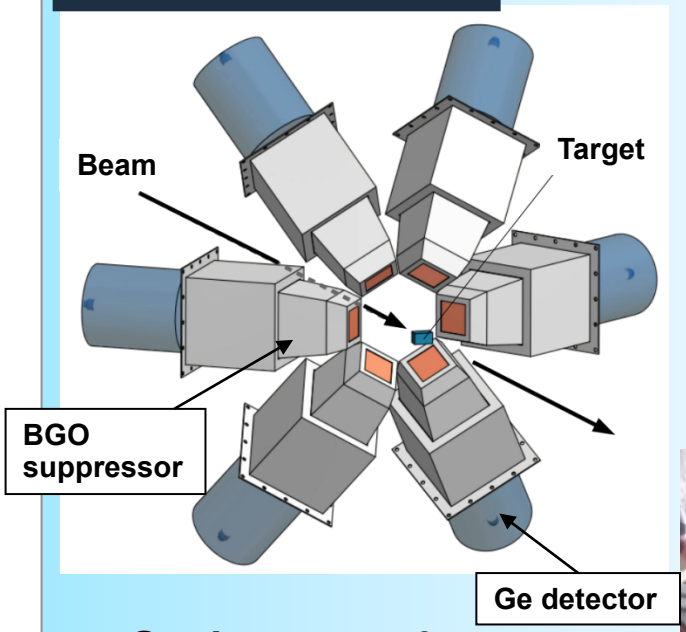


Dark room for emulsion stacking



Performance of Hyperball-X [X-ray spectroscopy of Ξ⁻ atom]

X-ray detector array "Hyperball-X"



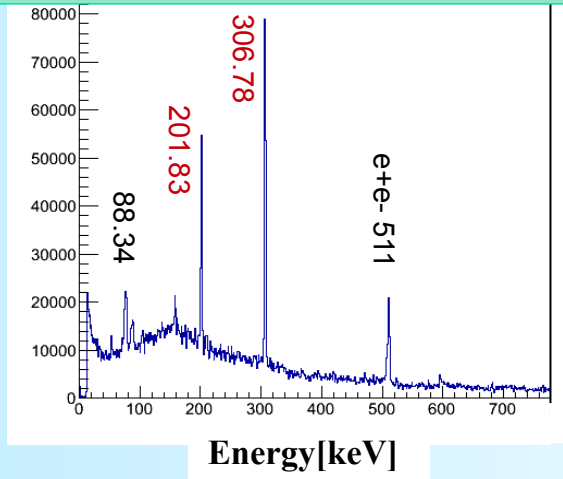
- **Ge detector x 6**
  5 clover type
  1 closed-end type
  Shaping Amp.: ORTEC 671 (shaping time 2μs)
- **BGO suppressor x 6 units**
- **LSO pulser x 2**

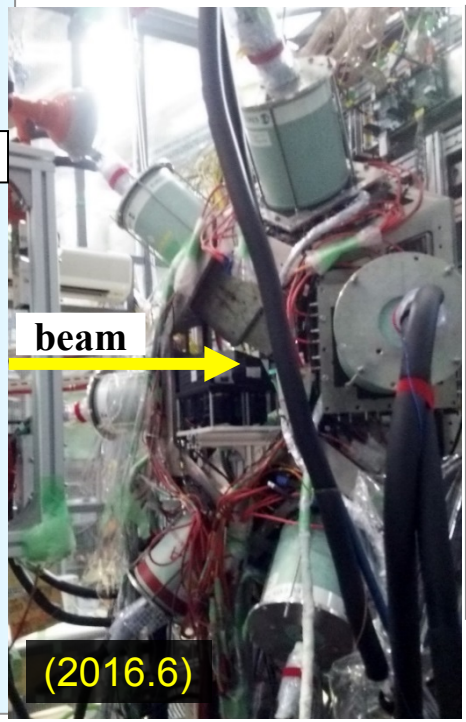
Energy calibration

Trigger-able γ-ray source **"LSO pulser"**
202, 306 keV (from ^{176}Lu)

In-beam calibration was successfully applied

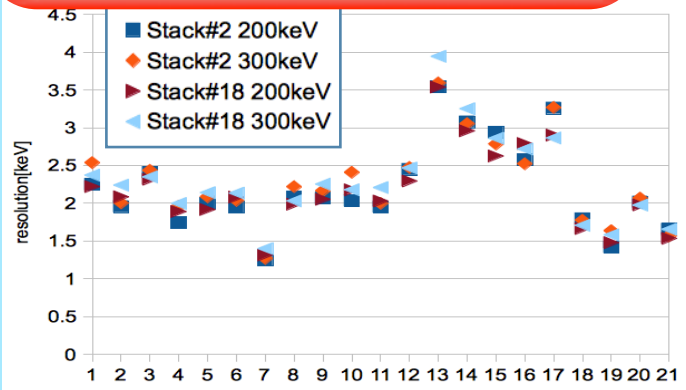
Ge energy spectrum (LSO×Ge trig.)





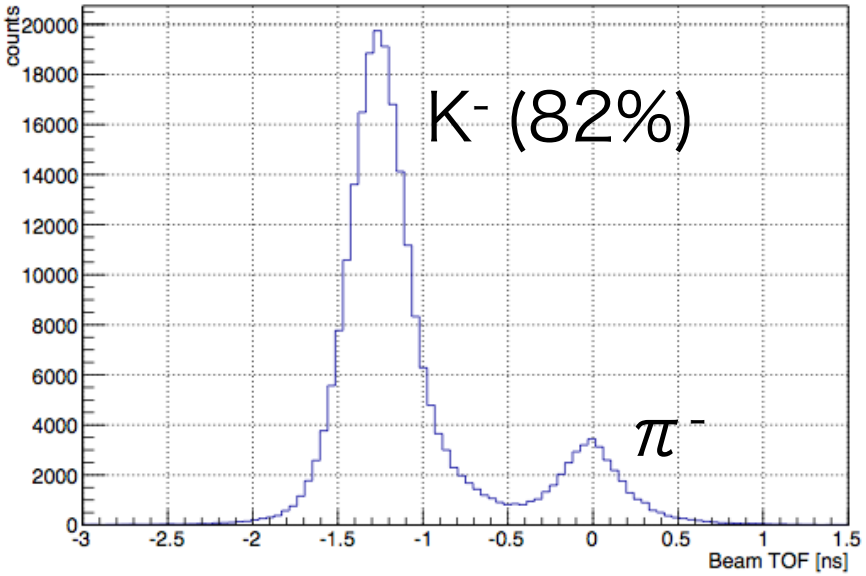
In-beam energy resolution

~2.5 keV (FWHM) @ 300 keV



Detectors were working well !

Beam condition



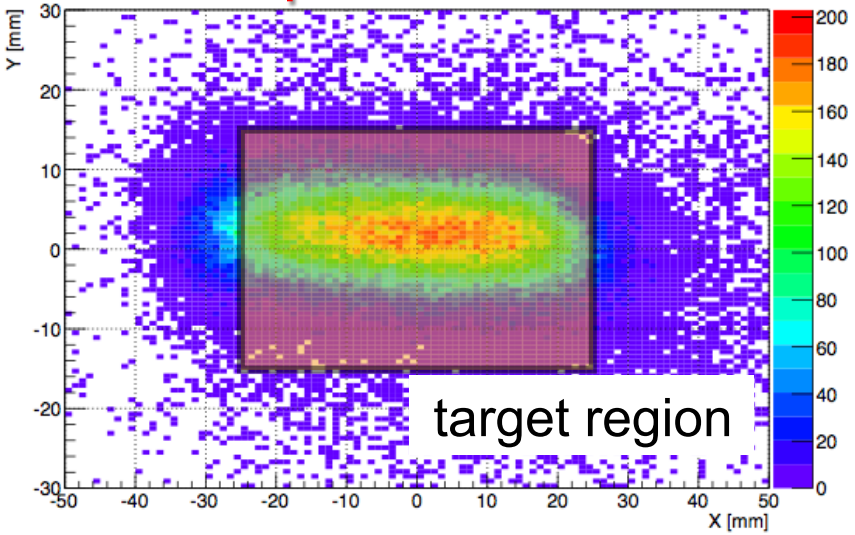
proposed

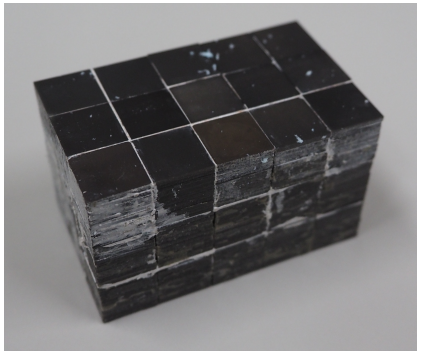
K⁻ : **260k**/spill, (300k/spill)
π⁻ : **60k**/spill, (50k/spill)
K⁻ purity : **82%** (85%)

beam size

X(σ) : 15.5mm
Y(σ) : 4.9mm

K⁻ beam profile





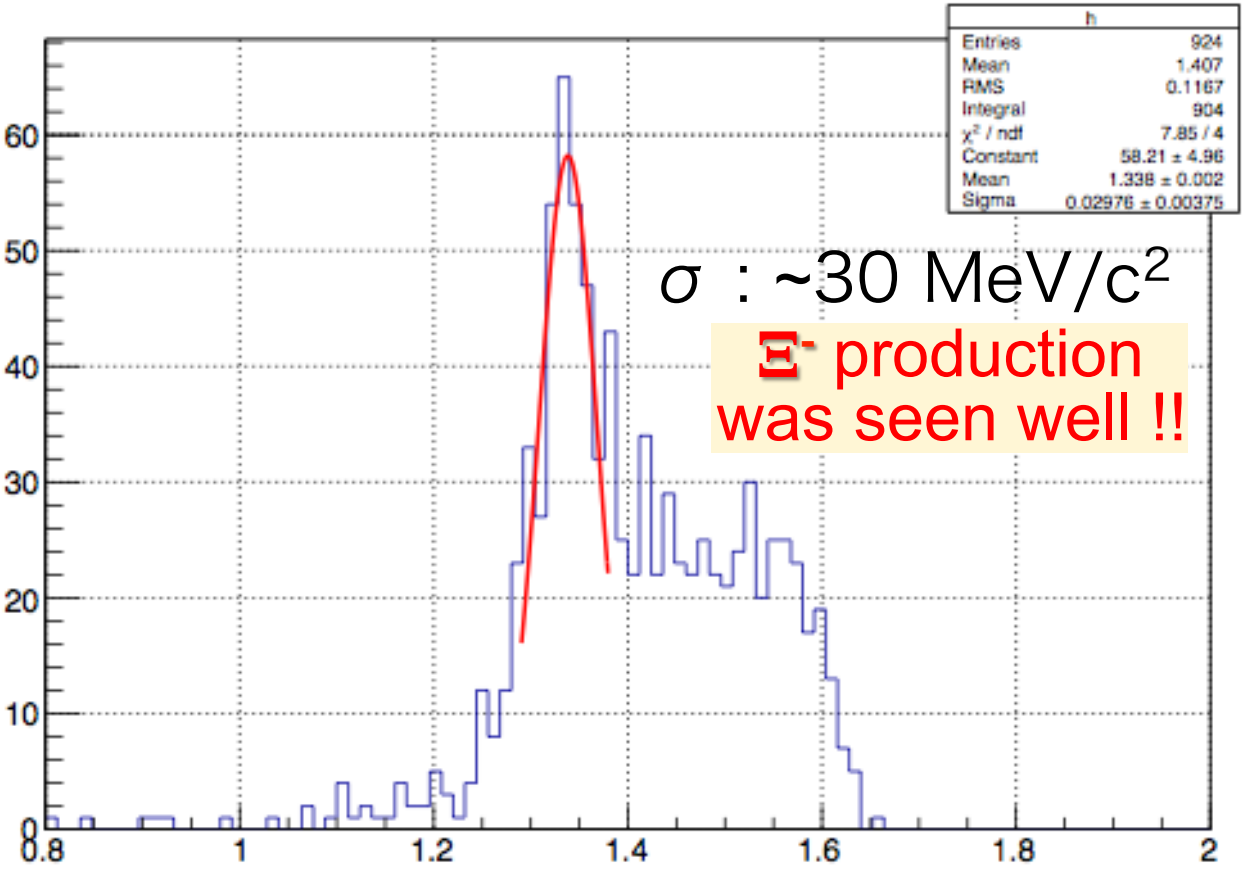
Diamond target

size : 3cm(H) x 5cm(W) x 3cm(T)
density : 3.24g/cm^3

target coverage : **90%**

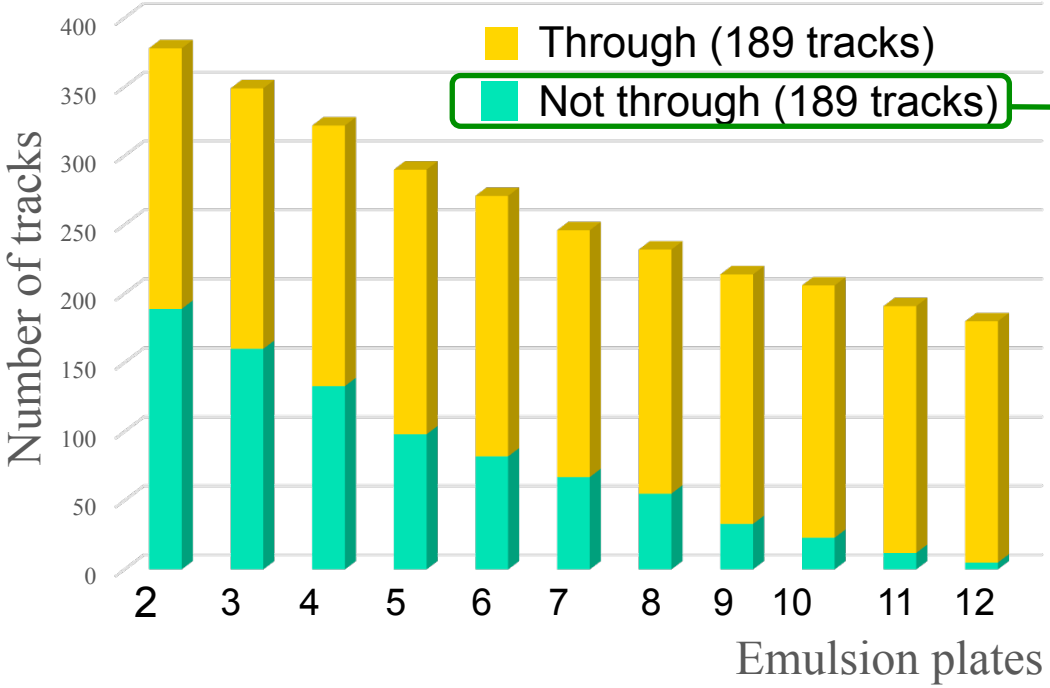
Analysis of KURAMA spectrometer

CH_2 target run

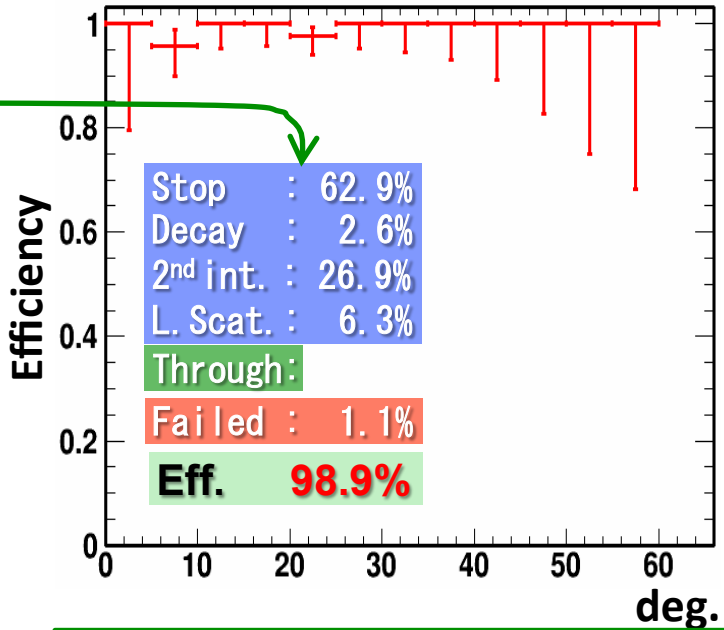


Result of R&D (using E373 Em.) of "*Full automatic Ξ⁻ tracking*"

Followed results



Efficiency of no track angle dependence



1.2 x 10^5 images (E07) will be checked by human.
➔ **~10** days' work for **ONE** person.

Tracking efficiency = ***99 %***

Scanning time estimation for E07

For ~100 candidates following,
8.0 hours / a E373 stack

If we need to follow
~10^3 candidates / a E07 stack
80 hours / a E07 stack.

For total **100** stacks (E07),
It takes **one year**
with **2** microscopes
for detection

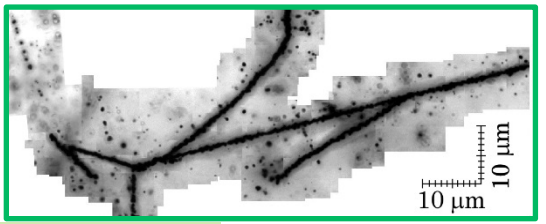
4. Summary

1. Information of S=-2 field is very limited, so far.
2. The development of "**overall-scanning**" method has been carried out for detection of typical topology relating double-Λ hypernuclei.
3. Under the test operation of it, a twin hypernucler event was detected and it was reported as **the first evidence of a deeply bound Ξ^{-14}N system, the KISO event**, with its binding energy (B_{Ξ}-) of 4.38 - 1.11 MeV, which was far from atomic 3*D* level by at least 3.7σ from 0.25 MeV error.
4. .The recent exp. data by E05-115@JLab for excited states of ${}^{9}_{\Lambda}$Be gave us **reaffirmation for the KISO event as a deeply bound system** with B_{Ξ}- = 3.87+/-0.21 or 1.03+/-0.18 MeV, where B_{Ξ}- is inconsistent with the 3*D* level by at least 4.6σ.
5. Expecting 10 times statistics than before, the 1st physics run for E07 experiment@J-PARC has been performed this June, and it may give us 1.5 times information of E373@KEK-PS. Remained 100 emulsion stacks will be exposed next year, then see you with rich data in the next INPC2019.


n
p
Λ

Range-Energy relation

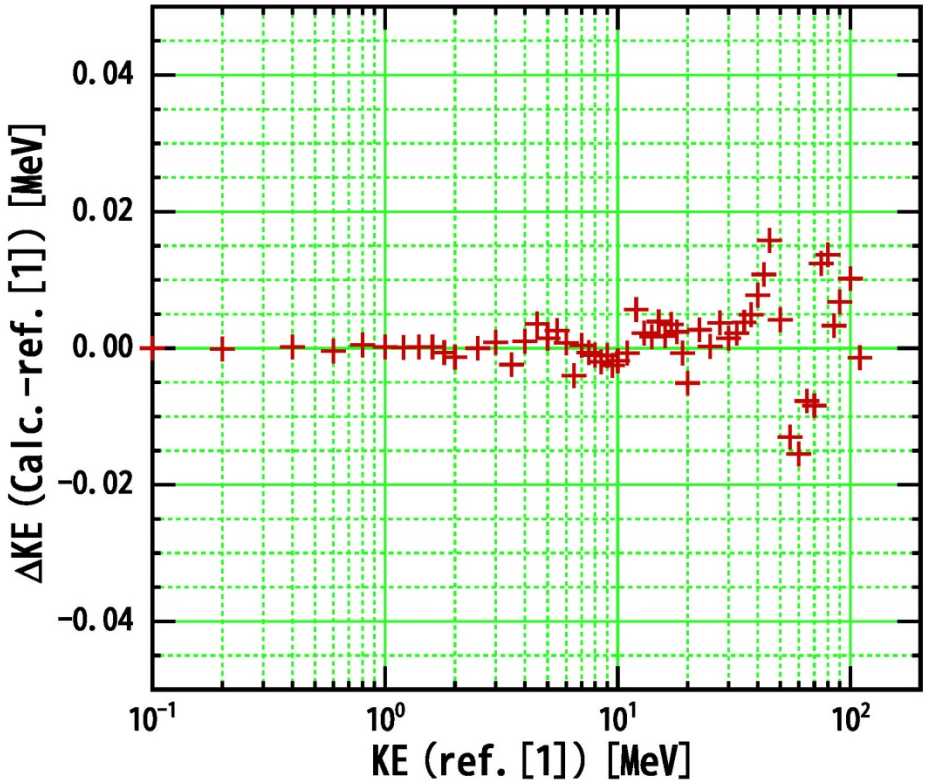
was calibrated in good accuracy



Proton for Std. emulsion
(Ilford G5 : ρ_0 = 3.815 g/cm^3);

ref.[1] **W.H.Barkas, N.C. VIII (1958) pp.201-214**
data fitted by **polynomial expression**
under the **Bethe-Bloch formula.**

Calc. **Our 7th order polynomial fitting to the ref.[1]**



Density ρ of our emulsion;

ρ = **3.621 +/- 0.105 g/cm^3**
by measurement of α **rays**
with **monochromatic K.E.**
from **^{212}Po** and **^{228}Th.**

Consistent with
ρ **= 3.667 +/- 0.066 g/cm^3**
by measurement of
its size and weight
at the E373 beam exposure.

The density error of 0.105 g/cm^3
gives rise inaccuracies,

ΔR / R : 1.1%
ΔE / E : 0.7%

for **proton** to **^{12}C**
with their energy
less than several tens' MeV