新学術領域研究会「中性子星核物質」

The first evidence of a deeply bound Ξ^{-}-^{14}N system

(detected in nuclear emulsion)

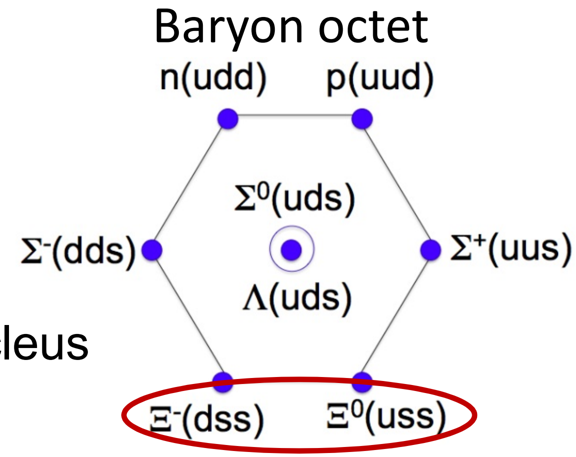
Kazuma Nakazawa
for the E07 (J-PARC) collaboration
Phys. Dept., Gifu Univ., JAPAN
13th Mar., 2015

Outline

1. Ξ-*N* interaction
2. Strategy of our experiment
3. The ***KISO*** ***event*** showing
 a deeply-bound Ξ-*N* system
4. Summary

1. Ξ-N interaction

Study of hadron-hadron interaction,



In S=-2 sector,

➔ YY-mixing [ΛΛ⇔ΞN⇔ΣΣ(⇔H)]

- m(ΞN) – m(ΛΛ) = (23~28) MeV
  <= m(ΣN) – m(ΛN) = 80 MeV

➔ Uniquely available source of information;
H-dibaryon, double-Λ hypernucleus, Ξ hypernucleus

ΞN interaction,

➔ can be studied a Ξ-nucleus potential via Ξ hypernucleus and Ξ atoms
However non conclusive measurement has been made, so far.

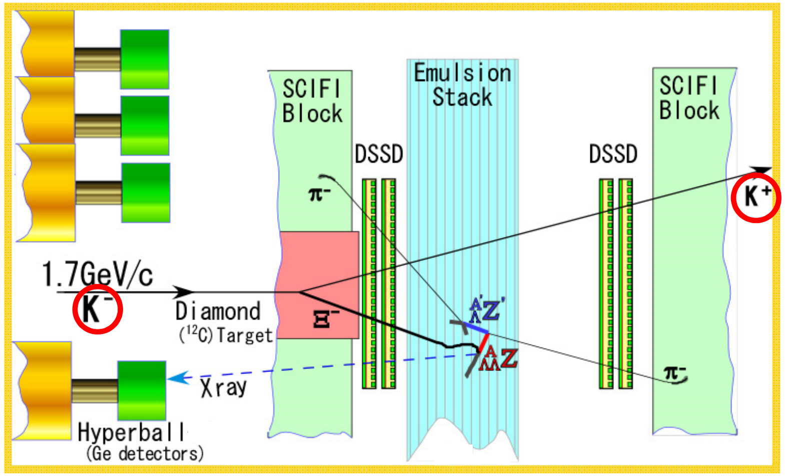
@ BNL, KEK
- Any peak structures for Ξ-nuclear state were not observed.
- Attractive potential on ${}^{12}_{\Xi}$Be was suggested to be 14 MeV.
- Two events (E176) … 3D atomic or nuclear *p* bound state?
  one event (E373) … consistent with the Ξ^- capture in 3D orbit.

@ J-PARC (coming soon)
- E03 & E07 … X-ray measurement from Ξ atoms.
- E05 ………… High reso. spectr. of Ξ hypernuclei.

For the emulsion experiment,
it has been a key point to develop **fully automated** and **fast *scanning system***.

Strategy of E07@J-PARC

2-1.New Hybrid method



J-PARC

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

10^3 (E373) ➔ 10^4 Ξ- stop events

1. X ray measurement from Ξ **atom** with **Hyperball-X**
   ➔ study of **Ξ-N interaction**
2. ~10^2 double hypernuclei

Automated track-following

2-2. *Overall-scanning*

Fully automatic detection of
3 vtx. event
like "NAGARA event"

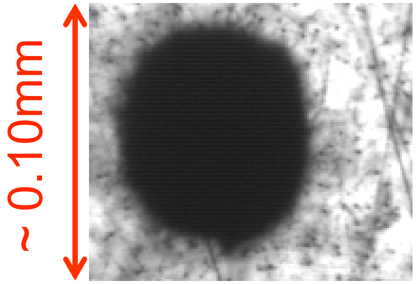
10 times statistics of that
with the hybrid method

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

Measurement of the mass of
~10^3 double hypernuclei
with A<16

2-1. Development of "*Automated track-following*"

E373 : alignment of plate by plate

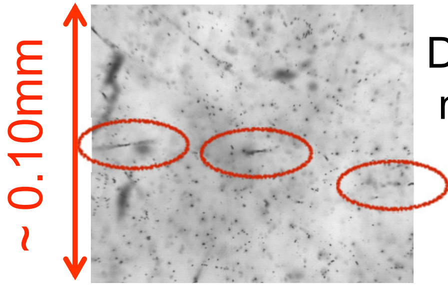


[Grid Mark]

Accuracy :

~ 17+/- 9μm

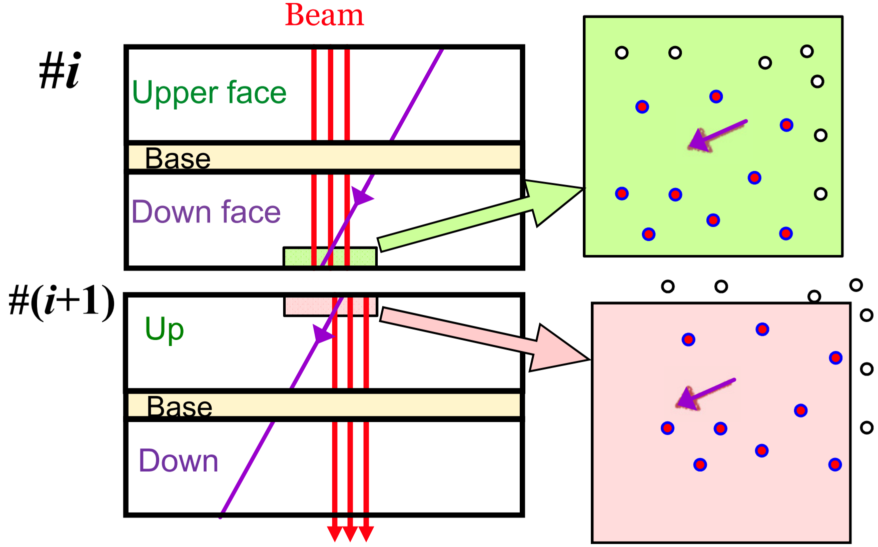
/ 24.5 × 25 cm^2



Detected multi-candidates

Automated track-following

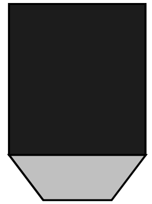
~ 90 s, Now



Alignment accuracy has achieved:

1.1 +/- 0.1 μm / 24.5 × 25 cm^2

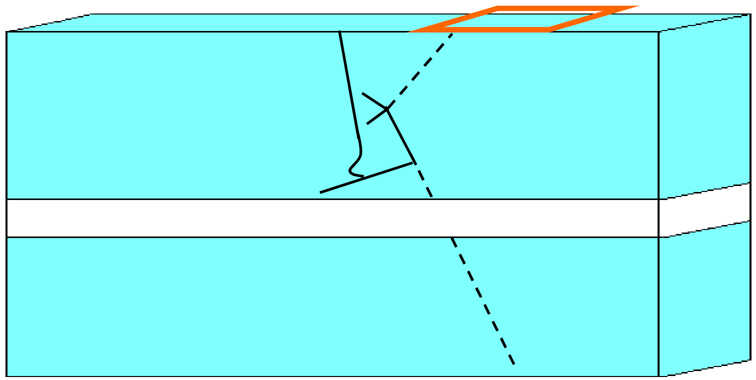
2-2. Development of "*Overall-scanning*"



Primary motivation;

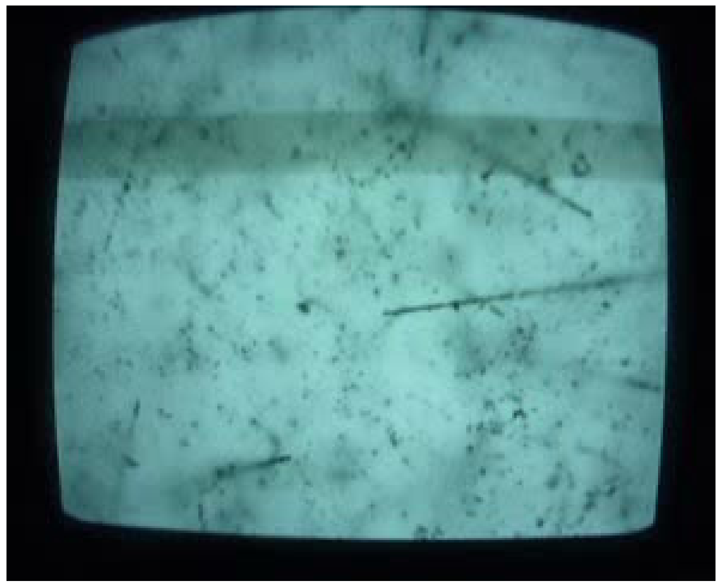
fast detection of α decay vertices of natural isotopes to calibrate range-energy relation.

① *fast image capture*



Developed system with CCD camera

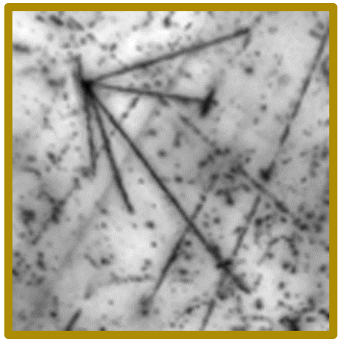
OS : Win2000 sp4
CPU : 3.0 GHz
1.57GB RAM
Camera : 100Hz (CCD)
Obj. lens : x 50
emulsion : 500μm
area : 0.1x0.08mm^2
# of image : ~100/cycle
Time : 5min. /cycle
➔ 3sec/cycle
[~ hard limit]



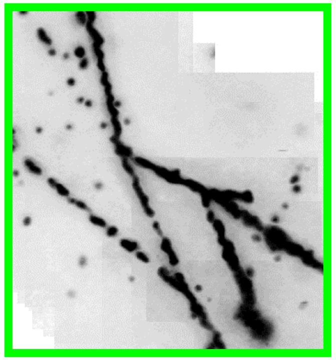
2-2. Development of "*Overall-scanning*"

② *fast image processing* for event detection

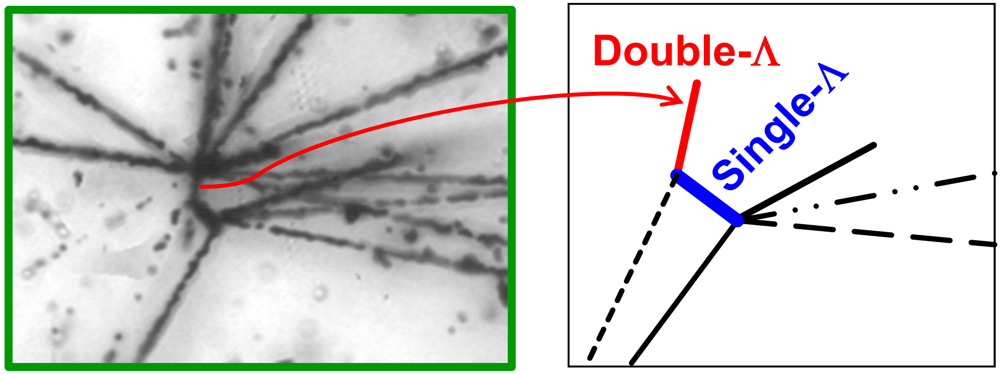
α decay **VTX**



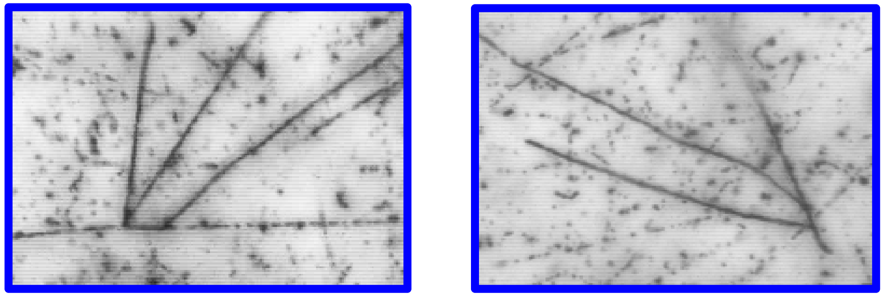
3 vertices



NAGARA event
was detected by this method



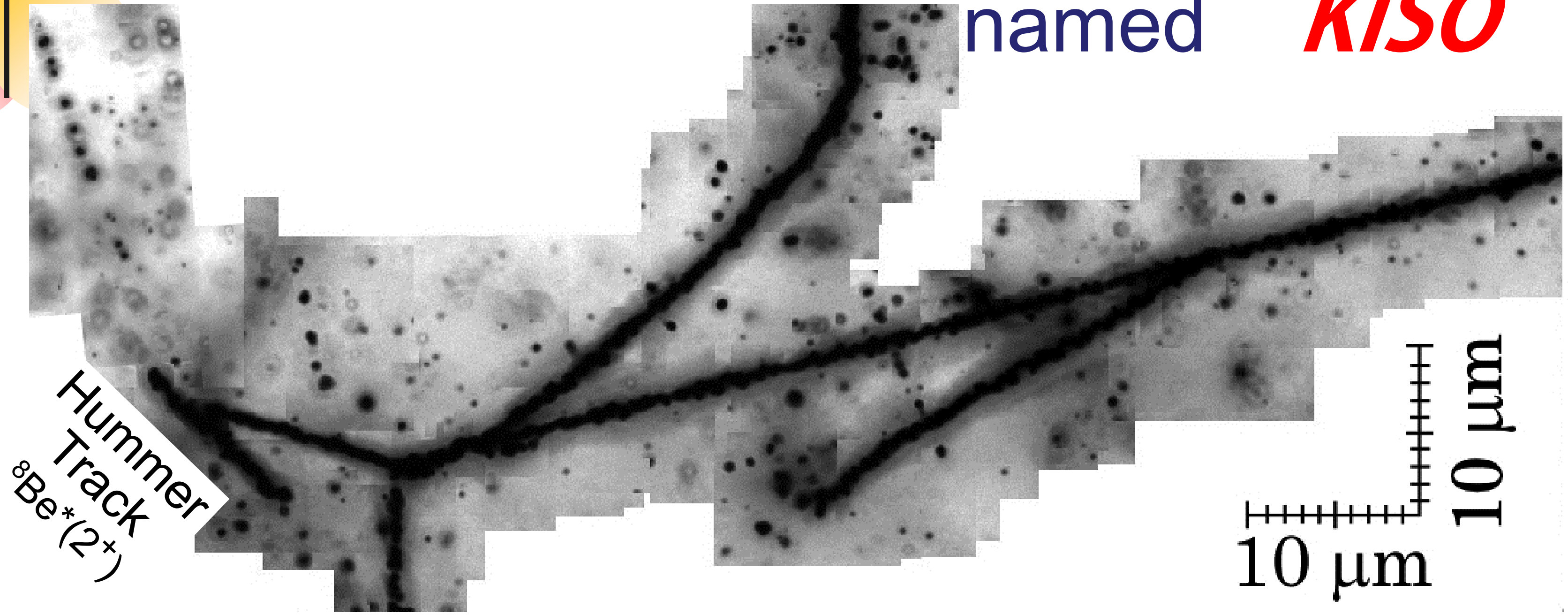
2 vertices (single-Λ cand.)



●●●●●● more

Until April. 2013,
***8 M* images under test operation** (1.46 cm³)
using E373 emulsion (**55 liters**)

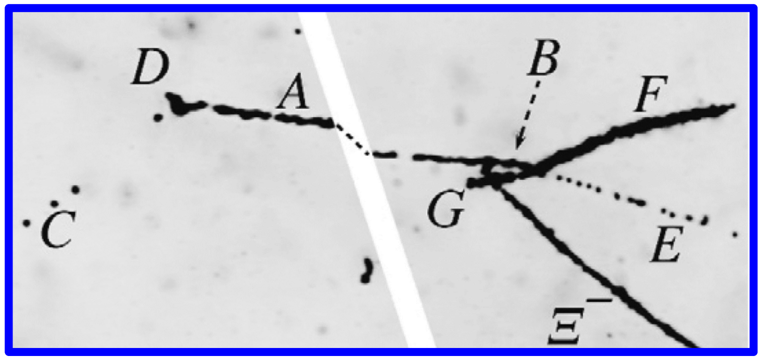
3. An event by the "*Overall-scanning*", named "*KISO*"

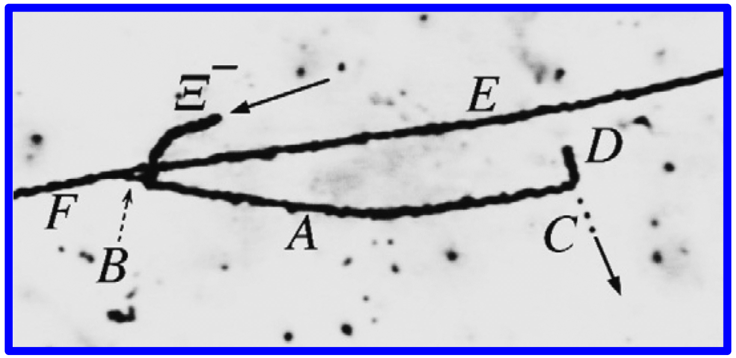


Emitted back-to-back direction

➔ 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



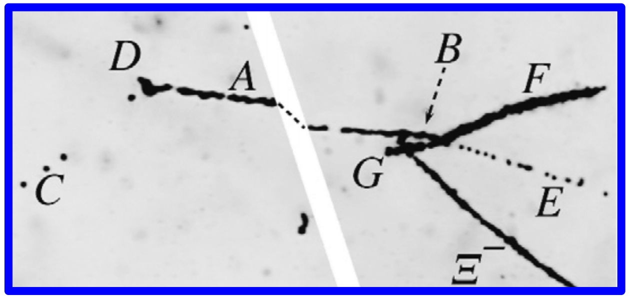


An event by the "*Overall-scanning*", named "***KISO***"

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

Ξ^- binding energy (MeV) in nucleus : ^{12}C [**most probable**]

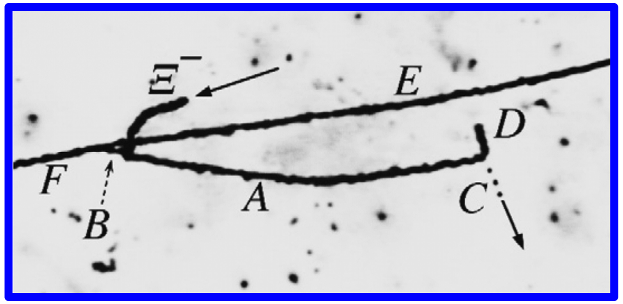
Event	${}^{4}_{\Lambda}\mathrm{H} + {}^{9}_{\Lambda}\mathrm{Be}$



0.82 ± 0.17 → Coulomb assisted **nuclear *p*** bound state. ==> V_{Ξ^-} = 18 MeV **Y. Yamamoto, Few-Body Syst. Suppl. 9 (1995) 145**

-0.23 ± 0.17 $({}^{4}_{\Lambda}\mathrm{H}^* + {}^{9}_{\Lambda}\mathrm{Be})$

$(\chi^2 = 0.4)$



3.89 ± 0.14 → B_{Ξ^-} = 3.75 MeV (Γ = 2.7 MeV) for **nuclear *p* state** **Y. Akaishi, Nucl. Phys. A 547 (1992) 217c**

0.82 ± 0.14 $({}^{4}_{\Lambda}\mathrm{H} + {}^{9}_{\Lambda}\mathrm{Be}^*)$

2.84 ± 0.15 $({}^{4}_{\Lambda}\mathrm{H}^* + {}^{9}_{\Lambda}\mathrm{Be})$

-0.19 ± 0.15 $({}^{4}_{\Lambda}\mathrm{H}^* + {}^{9}_{\Lambda}\mathrm{Be}^*)$

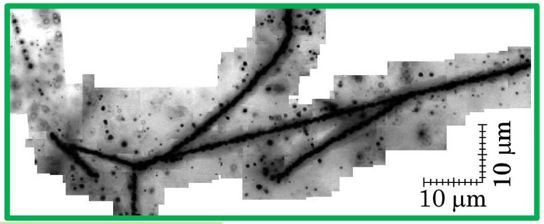
$(\chi^2 = 1.3)$

B_{Ξ^-}(3D) = 0.13 MeV for ^{12}C ➔ not inconsistent***!!***

(= 0.17 MeV for ^{14}N)

Range-Energy relation

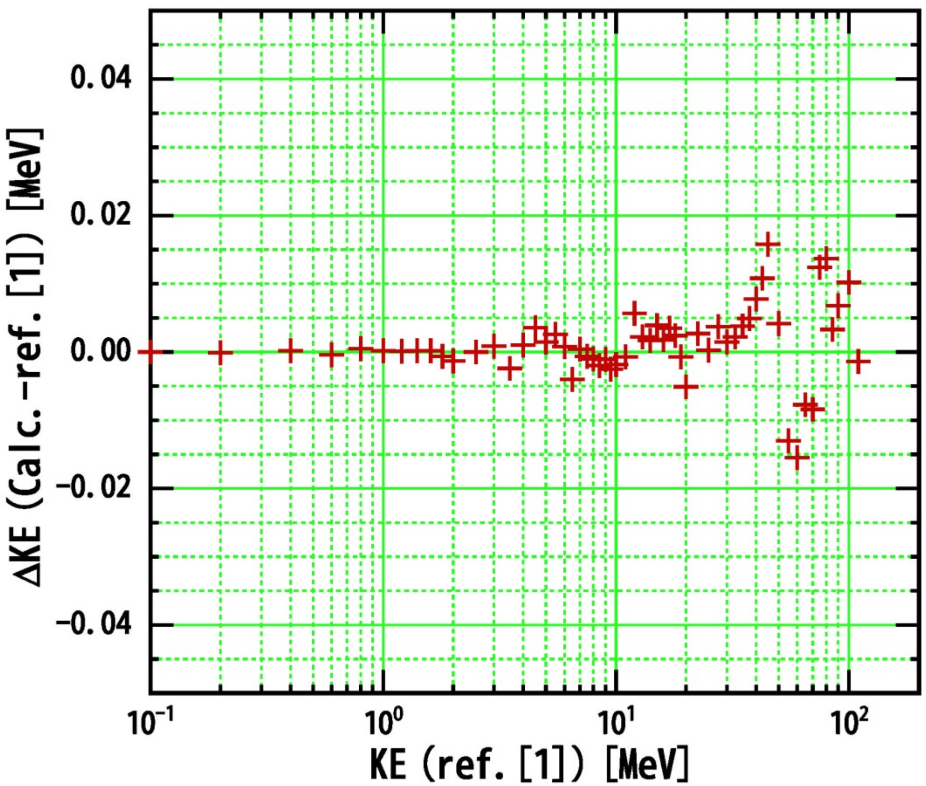
was calibrated in good accuracy



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.

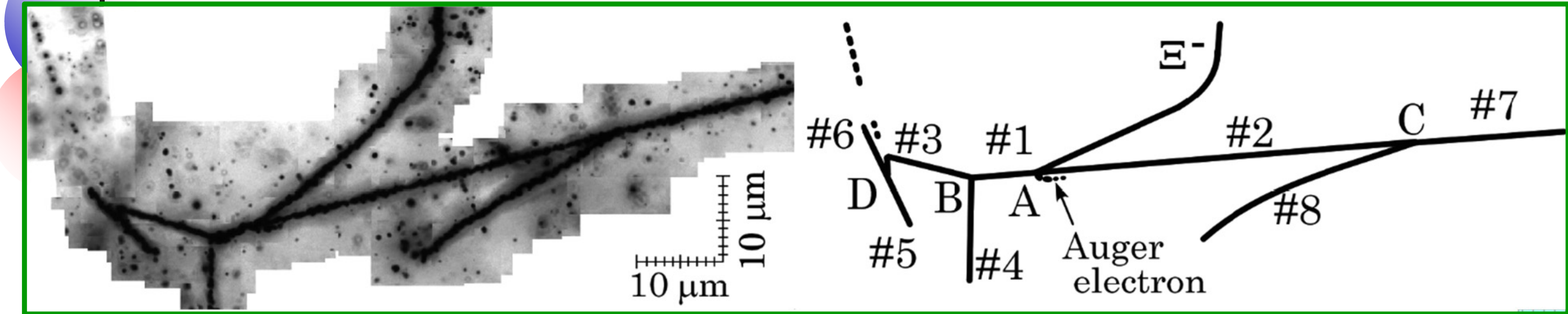
The density error of 0.105 g/cm^3
gives rise inaccuracies,

ΔR / R : 1.1%

ΔE / E : 0.7%

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

Outline of the *KISO* event



1) Ξ- hyperon can be produced in the target (8 mm from top the Em.)

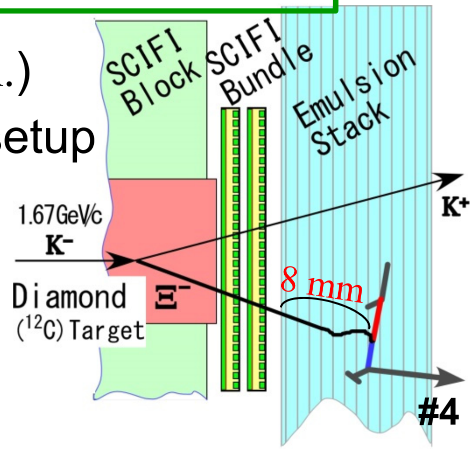
2) **Auger electron** ➔ make the capture point clear.

3) MIPS track from the decay point **D**.

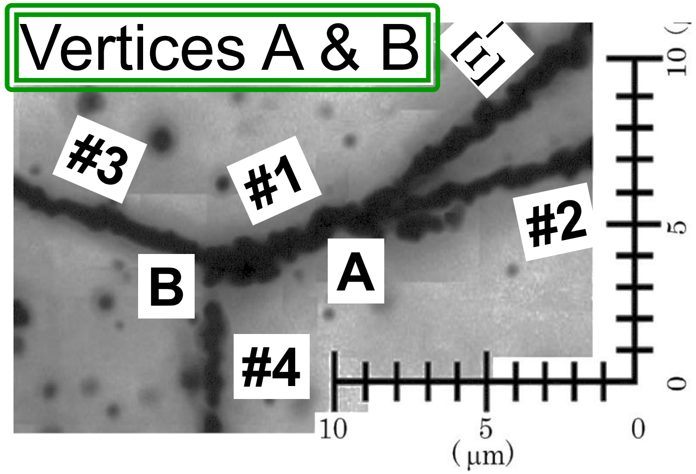
4) TK #4 ➔ went out of the emulsion stack.

5) Consistent with Ξ- capture reaction occurred on **C**, **N** or **O**.

E373 setup



Vertices A & B

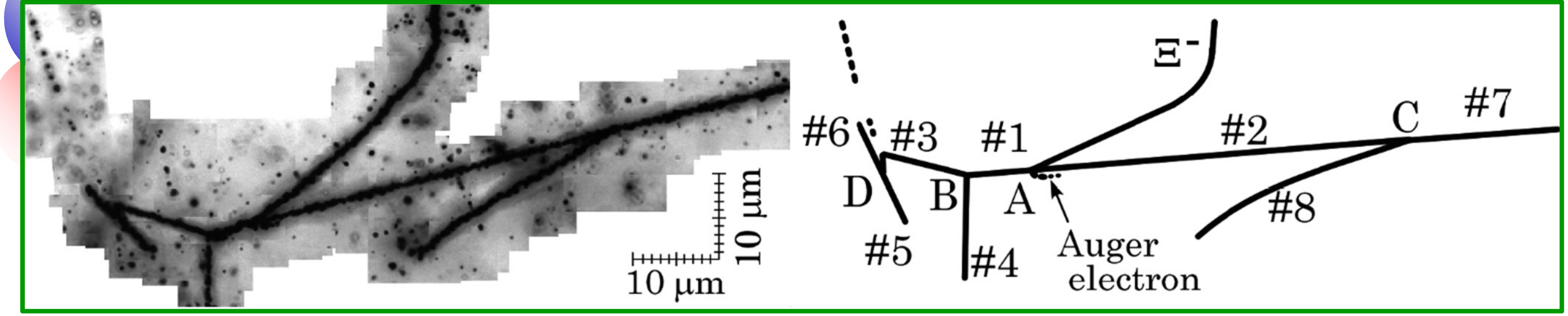


[1] The charge of #2 should be 2 or more.

[2] The charge of #1 should be ≦ 5.

[3] Hummer track : ^{8}He, ^{8}Li or ^{8}B ➔ ^{8}Be*(2$^+$).

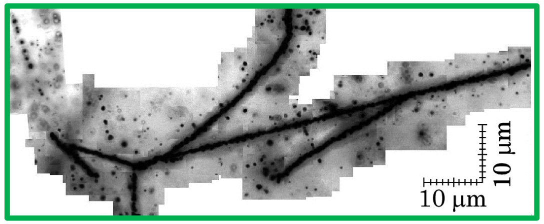
Outline of the *KISO* event



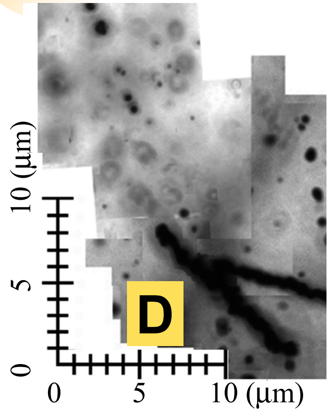
Ranges and angles

vtx	track	range (μm)	theta (deg.)	phi (deg.)	comments
A	#1	8.0 ± 0.3	133.0 ± 3.0	13.2 ± 3.2	Single-hypernucleus 77.1 ± 0.3 μm : B ~ C
	#2	69.1 ± 0.5	40.4 ± 0.9	193.1 ± 1.2	
B	#3	13.3 ± 0.4	102.3 ± 2.3	340.4 ± 1.6	
	#4	> 4990.7	145.0 ± 0.9	85.4 ± 1.3	Out of the emulsion stack
D	#5	6.7 ± 0.3	49.6 ± 4.2	132.6 ± 4.3	α from ^{8}Be
	#6	5.8 ± 0.3	131.0 ± 4.5	318.9 ± 4.7	α from ^{8}Be
C	#7	2492.0 ± 3.9	43.1 ± 1.3	191.8 ± 1.5	
	#8	37.3 ± 0.7	131.9 ± 1.3	29.2 ± 1.3	

Analysis of the *KISO* event



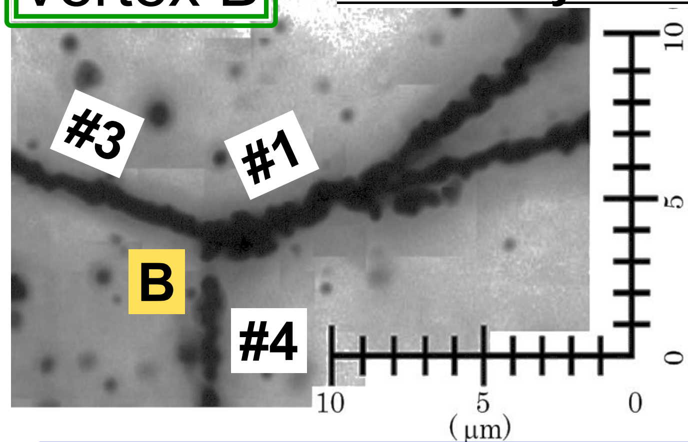
Vertex D



	Mass of ^{8}Be*(2^{+}) (MeV/c^{2})	Reconstructed mass (MeV/c^{2})	
(a)	**7457.890**	7458.531 ± 0.307	← Using measured data
(b)	**(Γ = 1.5 MeV)**	7458.540 ± 0.308	← Under the momentum balance

^{8}Be*(2^{+}) → 2α at VTX. D

Vertex B



Non-mesonic decay at VTX. B

Possibility of mesonic decay of #1

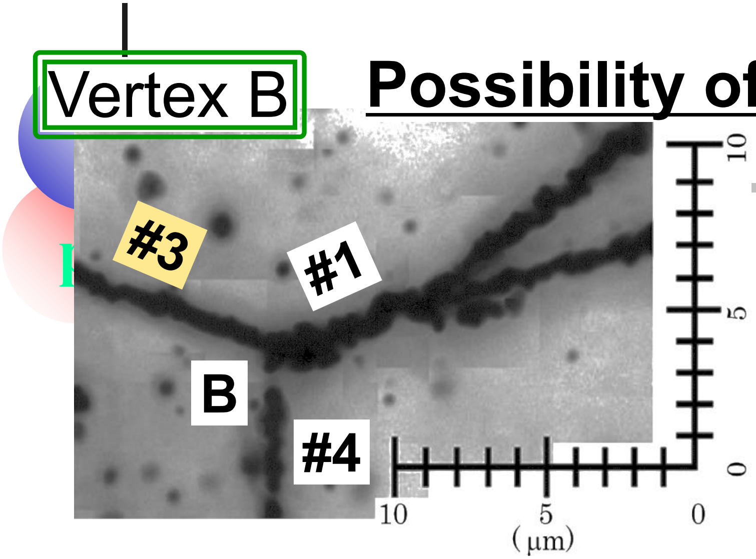
π- possibility (#4) is nothing in comparison with Energy-loss (Grain density ~ x1.41[+/- 0.08]) of **π-** in the NAGARA event.

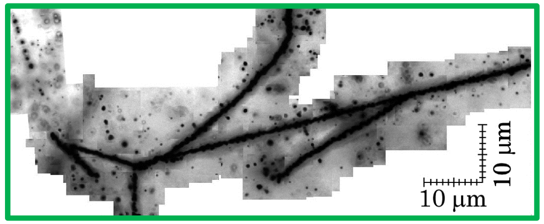
K.E. of #4 (34.8MeV, if it's a proton) was too large to understand the decay mode with a π^0 meson at the decay point of #1.

Table 3 Calculated Q-values for several processes in the assumption of the daughter particle of track #1 to be ^{8}He or ^{8}Li.

Reaction		#1 #2	Decay Process			Q-value (MeV)
$\Xi^- + {}^{12}$C	→	${}^{9}_{\Lambda}$Li + ${}^{4}_{\Lambda}$He	${}^{9}_{\Lambda}$Li	→	^{8}He + p + π^0	23.06 ± 0.12
$\Xi^- + {}^{14}$N	→	${}^{9}_{\Lambda}$Be + ${}^{6}_{\Lambda}$He	${}^{9}_{\Lambda}$Be	→	^{8}Li + p + π^0	19.21 ± 0.04
	→	${}^{10}_{\Lambda}$Be + ${}^{5}_{\Lambda}$He	${}^{10}_{\Lambda}$Be	→	^{8}Li + p + π^0 + n	15.15 ± 0.22
	→	${}^{11}_{\Lambda}$Be + ${}^{4}_{\Lambda}$He	${}^{11}_{\Lambda}$Be	→	^{8}Li + p + π^0 + $2n$	9.25 ± 0.87
$\Xi^- + {}^{16}$O	→	${}^{9}_{\Lambda}$Be + ${}^{8}_{\Lambda}$Li	${}^{9}_{\Lambda}$Be	→	^{8}Li + p + π^0	19.21 ± 0.04
	→	${}^{10}_{\Lambda}$Be + ${}^{7}_{\Lambda}$Li	${}^{10}_{\Lambda}$Be	→	^{8}Li + p + π^0 + n	15.15 ± 0.22

Possibility of ^{8}He or ^{8}B for TK #3





The case of ^{8}B : denied under **charge conservation**

Total A ≦ 17, total Z ≦ 7 (even for Ξ^{-} + ^{16}O)

・TK #2 … must be non-mesonic … Z(≧2)

⇔ TK #1 (Z≦5) ➔ if TK #4 Z=1, TK #3(Z≦4) ➔ ~~^{8}B~~

The case of ^{8}He : denied **momentum imbalance** at VTX.A

Assuming ^{8}He (#3) / *p* or *d* (#4) ➔ $_{\Lambda}$Li (#1),

only the process is considered;

Ξ^{-} + ^{16}O => $^{10}_{\Lambda}$Li (#1) + $^{7}_{\Lambda}$Be(#2), $^{10}_{\Lambda}$Li => ^{8}He (#3) + *p* (#4) + n

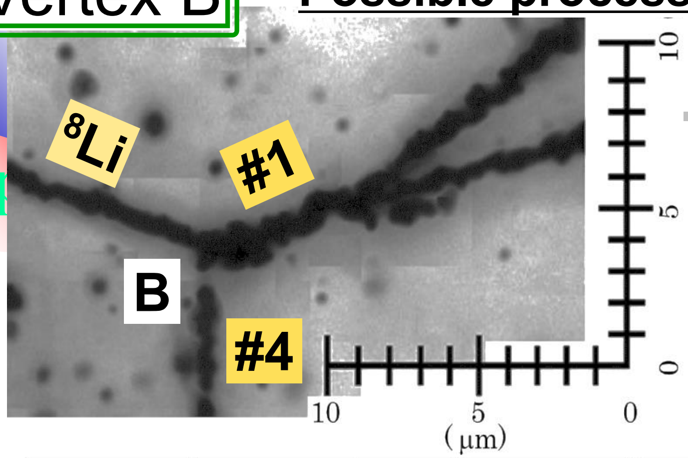
Momentum imbalance (373.1 +/- 13.4 MeV/c) at point A

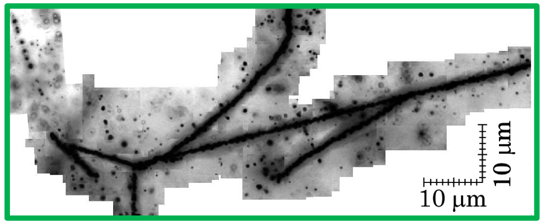
The particle (#3) should be ^{8}Li

Consistent with an association of a MIPS from VTX. D.

Vertex B

Possible process at VTX. B





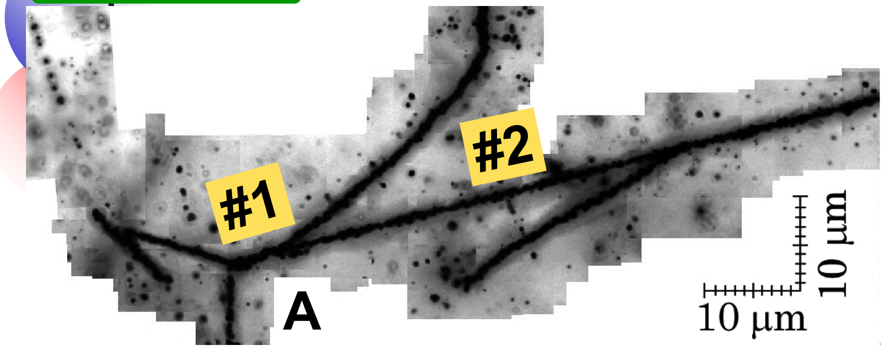
Mc : Mass of a core nucleus + M(Λ)
Mr : reconstructed minimum mass
Mc - *Mr* : $B_\Lambda$max. should be plus value.

Track #3	Track #4		Track #1	Mc (MeV/c^2)	Mr (MeV/c^2)	$Mc - Mr$ (MeV/c^2)	Comment
^{8}Li	p	n	$^{10}_{\Lambda}$Be	9508.43	9478.60 ± 4.07	29.83	**acceptable**
^{8}Li	p	$2n$	$^{11}_{\Lambda}$Be	10441.19	10375.74 ± 3.40	65.45	**acceptable**
	d	n			10482.27 ± 5.76	−41.08	rejected
^{8}Li	p	$3n$	$^{12}_{\Lambda}$Be	11380.25	11300.37 ± 3.07	79.88	**acceptable**
	d	$2n$			11354.65 ± 4.92	25.60	**acceptable**
	t	n			11487.43 ± 7.16	−107.18	rejected
^{8}Li	^{3}He	n	$^{12}_{\Lambda}$B	11368.23	11714.51 ± 10.06	−346.28	rejected
^{8}Li	^{3}He	$2n$	$^{13}_{\Lambda}$B	12304.42	12495.38 ± 9.42	−190.96	rejected
	^{4}He	n			12777.93 ± 11.89	−473.51	rejected

→ There is no bound hyperfragment for track #2

The particle (#1) can be $^{10}_{\Lambda}$Be or $^{11}_{\Lambda}$Be.

Vertex A **Possible process at VTX. A**



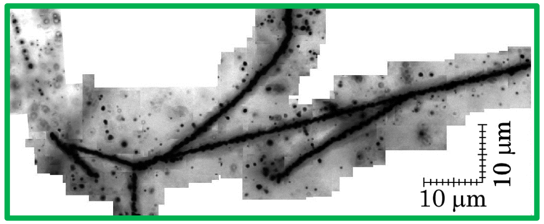


Table 5 Ξ^- binding energies are listed for the cases without any neutron emission at point A. The values of B_{Ξ^-} were calculated using the observed range for each track

Absorption	Track #1	Track #2	B_{Ξ^-} (MeV)	Comment
$\Xi^- + {}^{14}\mathrm{N}$	${}^{10}_{\Lambda}\mathrm{Be}$	${}^{5}_{\Lambda}\mathrm{He}$	4.43 ± 0.34	**acceptable**
	${}^{11}_{\Lambda}\mathrm{Be}$	${}^{4}_{\Lambda}\mathrm{He}$	-10.08 ± 0.90	rejected
$\Xi^- + {}^{16}\mathrm{O}$	${}^{10}_{\Lambda}\mathrm{Be}$	${}^{7}_{\Lambda}\mathrm{Li}$	-22.65 ± 0.34	rejected

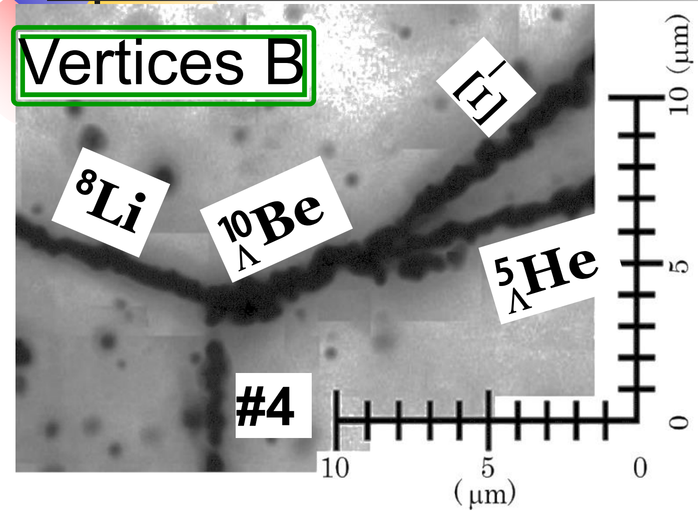
Table 6 Ξ^- binding energy is listed for the case with neutron(s) emission at point A. The value of B_{Ξ^-} was obtained so as to balance momentum by tracks #1, #2 and a neutron using the observed ranges for #1 and #2.

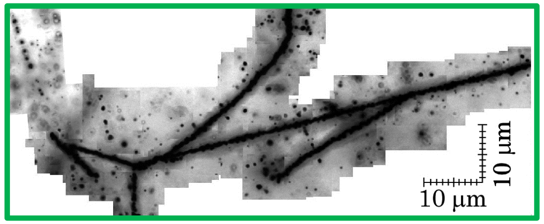
Absorption	Track #1	Track #2		B_{Ξ^-} (MeV)	Comment
$\Xi^- + {}^{14}\mathrm{N}$	${}^{10}_{\Lambda}\mathrm{Be}$	${}^{4}_{\Lambda}\mathrm{He}$	n	-17.73 ± 0.89	rejected

The mode : $\Xi^- + {}^{14}\mathrm{N} \rightarrow {}^{10}_{\Lambda}\mathrm{Be} + {}^{5}_{\Lambda}\mathrm{He}$

was uniquely identified

＊Regarding decay of $^{10}_{\Lambda}$Be





$^{10}_{\Lambda}$Be ➔ ^{8}Li(#3) + #4 + *n*

Track range (#4 if a proton) to give the known mass ($^{10}_{\Lambda}$Be) ➔ ~8 mm

We measured the energy loss of a fast proton (a decay daughter of Heavy Double-HY) around 8mm before stopping.

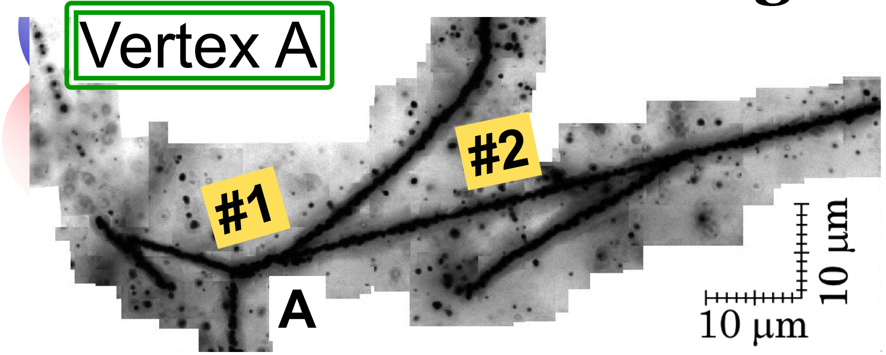
$$\text{Energy-loss ratio} = \frac{\text{-dE/dx (The KISO event)}}{\text{-dE/dx (Fast proton)}} = 1.06 \pm 0.06$$

PID(#4) ➔"*p*"

c.f. 1.35 for ^{2}H, 1.61 for ^{3}H

$$^{10}_{\Lambda}\text{Be} \rightarrow {}^{8}\text{Li} + p + n$$

∗Possibilities of in-flight decays on both hypernuclei



$B_{\Xi^-} = M(\Xi^- + ^{14}\mathrm{N}) - E(^{10}_{\Lambda}\mathrm{Be}) - E(^{5}_{\Lambda}\mathrm{He})$
$\qquad - \Delta \mathrm{K.E.}(^{10}_{\Lambda}\mathrm{Be} + ^{5}_{\Lambda}\mathrm{He})$

ΔK.E. = 4.43 MeV (assumed B_{Ξ^-} = 0.00 MeV)

Table 7. Momenta, kinetic energies and ranges for $^{10}_{\Lambda}$Be and $^{5}_{\Lambda}$He in the cases of $B_{\Xi^-} = 4.43$ and 0.00 MeV. Ranges for the case of $B_{\Xi^-} = 0.00$ MeV were estimated by kinetic energies using the range–energy relation. Errors were obtained by ranges, their straggling and the density error of the emulsion and mass errors.

	$^{10}_{\Lambda}$Be (Track #1)			$^{5}_{\Lambda}$He (Track #2)		
B_{Ξ^-} (MeV)	range (μm)	kinetic energy (MeV)	momentum (MeV/c)	range (μm)	kinetic energy (MeV)	momentum (MeV/c)
4.43	8.0 ±0.3	6.09 ±0.23	340.76 ±6.40	69.1 ±0.5	12.11 ±0.10	342.56 ±1.41
0.00	10.1	7.65	381.31	96.7	15.00	381.31

Decay rates $\boldsymbol{R}$ were estimated,

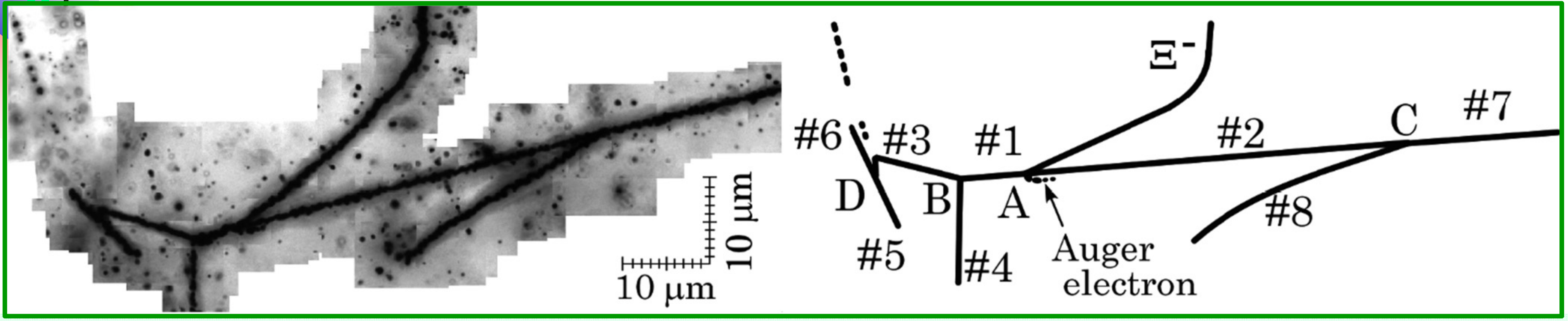
$\boldsymbol{R}\,(^{10}_{\Lambda}\mathrm{Be}) = 0.6\%,\ \boldsymbol{R}\,(^{5}_{\Lambda}\mathrm{He}) = 2.9\%$

It is very unlikely for decays in flight on both nuclei.

Also unlikely for decay in flight of one of bouth due to well mom. balance.

➔ **$^{10}_{\Lambda}$Be and $^{5}_{\Lambda}$He decayed after stopping.**

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



Process of the *KISO* event

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

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

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

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

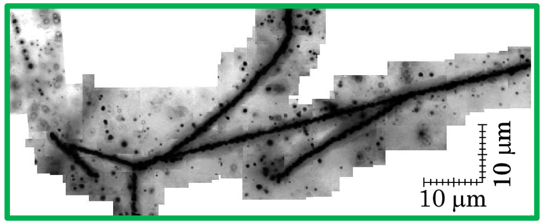
ex.

${}^{5}_{\Lambda}He \rightarrow p$(#7) $+ d$(#8) $+ 2n$

B_{Ξ^-} = **4.38 +/- 0.25** MeV (by Mom. balance [#1 and #2])

- Measurement error : 0.09 MeV
- Mass (${}^{10}_{\Lambda}Be$, ${}^{5}_{\Lambda}He$, Ξ^-) error : 0.23 MeV

The case of production of $^{10}_{\Lambda}$Be in excited state



$$B_{\Xi^-} = M(\Xi^- + {}^{14}\mathrm{N}) - E({}^{10}_{\Lambda}\mathrm{Be}) - E({}^{5}_{\Lambda}\mathrm{He})$$

Table 8. Excitation energies of $^{10}_{\Lambda}$Be calculated by cluster (Hiyama & Yamamoto) and shell (Millener) models. The B_{Ξ^-} value for the ground state, g.s., is 4.378 ± 0.250 MeV, determined by our experiment.

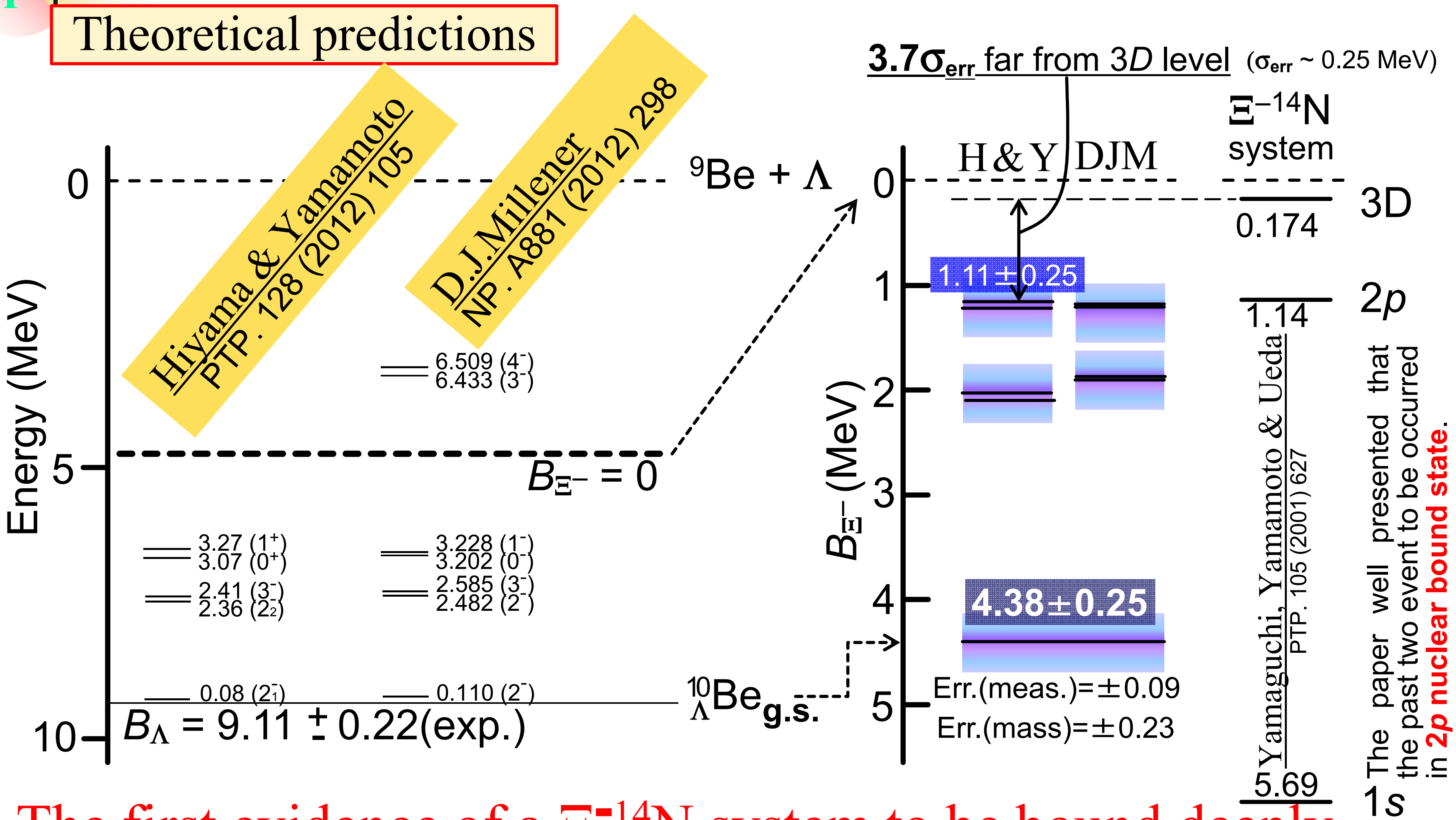
State	Hiyama & Yamamoto (cluster model) [28] (MeV)	Expected B_{Ξ^-} (MeV)	Millener (shell model) [29] (MeV)	Expected B_{Ξ^-} (MeV)
g.s.	0 (1^-)	4.38	0 (1^-)	4.378
	0.08 (2^-_1)	4.30	0.110 (2^-)	4.268
1st	2.36 (2^-_2)	2.02	2.482 (2^-)	1.896
	2.41 (3^-)	1.97	2.585 (3^-)	1.793
2nd	3.07 (0^+)	1.31	3.202 (0^-)	1.176
	3.27 (1^+)	1.11	3.228 (1^-)	1.150
3rd	–	–	6.433 (3^-)	Ξ^- unbound
			6.509 (4^-)	

[28] E. Hiyama and Y. Yamamoto, PTP **128**, 105 (2012)
[29] D. J. Millener, Nucl. Phys. A **881**, 298 (2012)

the *KISO* event

$\Xi^- + {}^{14}N \rightarrow {}^{10}_{\Lambda}Be + {}^{5}_{\Lambda}He$ uniquely identified*!!*

B_{Ξ^-} = **4.38 +/- 0.25** MeV (by Mom. balance for ${}^{10}_{\Lambda}Be$ and ${}^{5}_{\Lambda}He$)



The first evidence of a Ξ^--^{14}N system to be bound deeply.

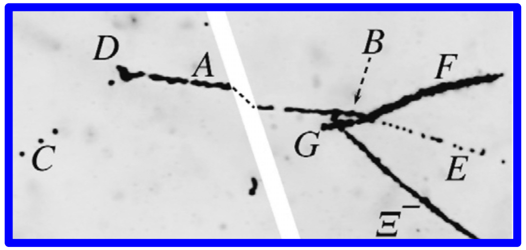
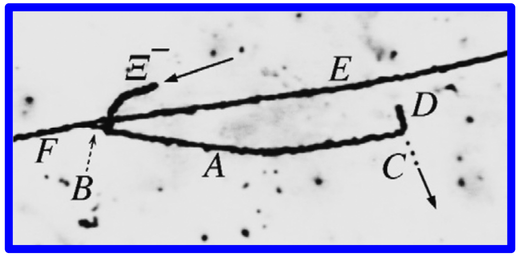
Comarison of E176 events with theoretical prediction

Table 9. **Theoretical prediction** of B_{Ξ^-} values for the Ξ^--^{12}C and Ξ^--^{14}N systems using **Coulomb and Ehime potentials**.

State	$B_{\Xi^-}[\Xi^- - ^{12}\mathrm{C}]$ (MeV)	$B_{\Xi^-}[\Xi^- - ^{14}\mathrm{N}]$ (MeV)
1s	4.77	5.93
2p	0.58	1.14
3D	0.126	0.174
2s	0.40	0.54
3p	0.19	0.28

M.Yamaguchi, K. Tominaga, Y. Yamamoto, and T. Ueda, PTP **105**, 627 (2001)

E176 results; S.Aoki et al., NP. A828 (2009) 191-232
Ξ^- binding energy (MeV) in nucleus : ^{12}C [**most probable**]

Event	${}^{4}_{\Lambda}\mathrm{H} + {}^{9}_{\Lambda}\mathrm{Be}$
	0.82 ± 0.17 -0.23 ± 0.17 (${}^{4}_{\Lambda}\mathrm{H}^* + {}^{9}_{\Lambda}\mathrm{Be}$) ($\chi^2 = 0.4$)
	3.89 ± 0.14 0.82 ± 0.14 (${}^{4}_{\Lambda}\mathrm{H} + {}^{9}_{\Lambda}\mathrm{Be}^*$) 2.84 ± 0.15 (${}^{4}_{\Lambda}\mathrm{H}^* + {}^{9}_{\Lambda}\mathrm{Be}$) -0.19 ± 0.15 (${}^{4}_{\Lambda}\mathrm{H}^* + {}^{9}_{\Lambda}\mathrm{Be}^*$) ($\chi^2 = 1.3$)

Good agreement
with
a theoretical prediction
in the case of

Ξ^- - ^{12}C system

Published at PTEP

PTEP

Prog. Theor. Exp. Phys. **2015**, 033D02 (11 pages)
DOI: 10.1093/ptep/ptv008

The first evidence of a deeply bound state of Xi$^-$–^{14}N system

K. Nakazawa[1,*], Y. Endo[1], S. Fukunaga[2], K. Hoshino[1], S. H. Hwang[3], K. Imai[3], H. Ito[1], K. Itonaga[1], T. Kanda[1], M. Kawasaki[1], J. H. Kim[4], S. Kinbara[1], H. Kobayashi[1], A. Mishina[1], S. Ogawa[2], H. Shibuya[2], T. Sugimura[1], M. K. Soe[1], H. Takahashi[5], T. Takahashi[5], K. T. Tint[1], K. Umehara[1], C. S. Yoon[4], and J. Yoshida[1]

[1] *Physics Department, Gifu University, 1-1 Yanagido, Gifu 501-1193, Japan*
[2] *Department of Physics, Toho University, Funabashi 274-8510, Japan*
[3] *Advanced Science Research Center, JAEA, Tokai 319-1195, Japan*
[4] *Department of Physics, Gyeongsang National University, Jinju 660-701, Korea*
[5] *Institute of Particle and Nuclear Studies, KEK, Tsukuba 305-0801, Japan*
*E-mail: nakazawa@gifu-u.ac.jp

Received October 27, 2014; Revised December 25, 2014; Accepted January 9, 2015; Published March 5, 2015

4. Summary

1. We have performed experiments to study S=-2 systems with the nuclear emulsion at KEK.

2. To get more rich information about S=-2 systems, we are developing fully automated and fast scanning system, "***Overall scanning***" for the emulsion.

3. During test operation of the system, a clear evidence of a deeply bound Ξ-^{14}N system has been detected and uniquely identified, **$\Xi^- + {}^{14}N \rightarrow {}^{10}_{\Lambda}Be + {}^{5}_{\Lambda}He$**, in the emulsion of 1.46 cm^3 volume among 55 liters.

4. The detected event, named "***KISO***", presents a deeply bound Ξ-^{14}N system with **Ξ^- binding energy of 4.38 +/- 0.25 MeV**, which is no longer the atomic 3D state (0.17 MeV for Ξ- atom on ^{14}N). Even if the **${}^{10}_{\Lambda}Be$** nucleus was produced in excited state, **Ξ^- binding energy** is far from 3D atomic state by more than **3.7 standard deviations**. Theoretical predictions for Coulomb-assisted nuclear bound state for **Ξ^--^{12}C** and **Ξ^--^{14}N** agree the results of not only KISO, but also two events presented by the E176 experiment.

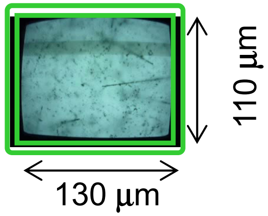
5. It was understood that **ΞN interaction** will be **attractive*!!*** To understand **A-dependence of $\Lambda\Lambda$ int.** and **ΞN interaction more in detail**, we will continue development of "***overall scanning***" method to be applied in the E07 experiment, of which beam exposure can be carried out in Early 2016 (?).

New scanning system for the E07emulsion

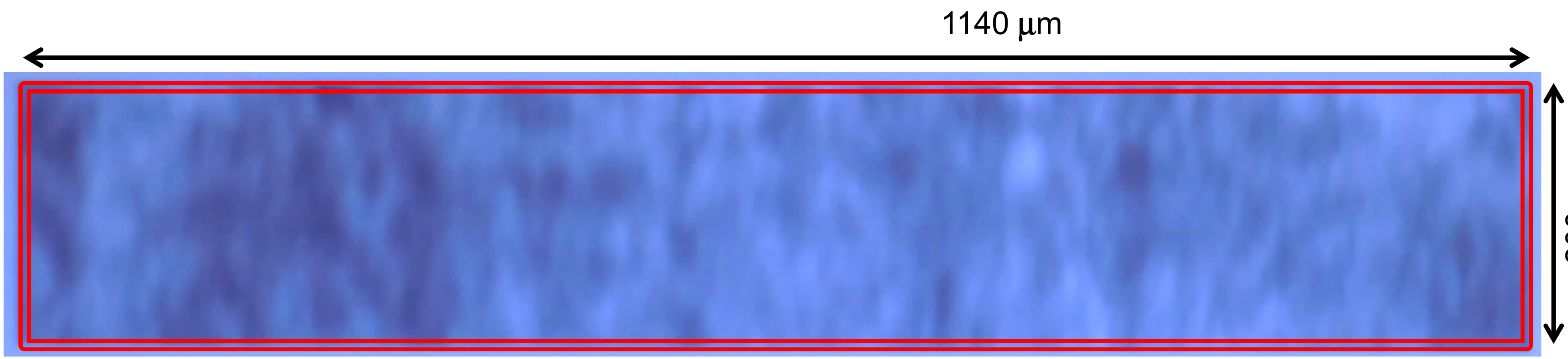
with piezo stage

×300 faster !!

Present system



	Present	New
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 plates can be obtained in a few years.