E373 / E522

Study of Double Strangeness Systems

- **Experimental motivation**

Quit limited experimental information

=> Information Λ-Λ force,

for understanding B-B int. in SU(3)*f*

investigating Multi-strangeness system, “strange matter”

$$\begin{aligned}\Delta B_{\Lambda\Lambda}({}^{A}_{\Lambda\Lambda}Z) &= B_{\Lambda\Lambda}({}^{A}_{\Lambda\Lambda}Z) - 2B_{\Lambda}({}^{A-1}_{\Lambda}Z) \\ &= 2M({}^{A-1}_{\Lambda}Z) - M({}^{A-2}Z) - M({}^{A}_{\Lambda\Lambda}Z)\end{aligned}$$

Existence of the H-dibaryon

$$M_H \geq 2m_\Lambda - B_{\Lambda\Lambda}$$

Coupling effect

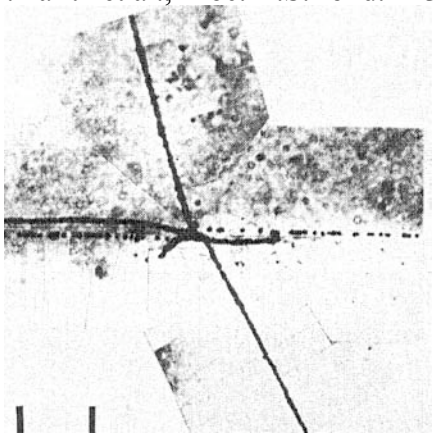
$$|H> = \sqrt{\frac{1}{8}}|\Lambda\Lambda> + \sqrt{\frac{4}{8}}|N\Xi> - \sqrt{\frac{3}{8}}|\Sigma\Sigma>$$

Double Strangeness Systems

Experimental status before E373

3 candidate events (Double-Λ) in the 20th century.

M.Danysz et al., PRL.11(1963)29;
R.H.Dalitz et al., Proc. R.S.Lond.A436(1989)1



$^{10}_{\Lambda\Lambda}$**Be** in ~4 Ξstops

$\Delta B_{\Lambda\Lambda} = 4.3 \pm 0.4$ MeV

if a doughter $^{9}_{\Lambda}$Be is in excited

$\Delta B_{\Lambda\Lambda} \sim 1.3$ MeV

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

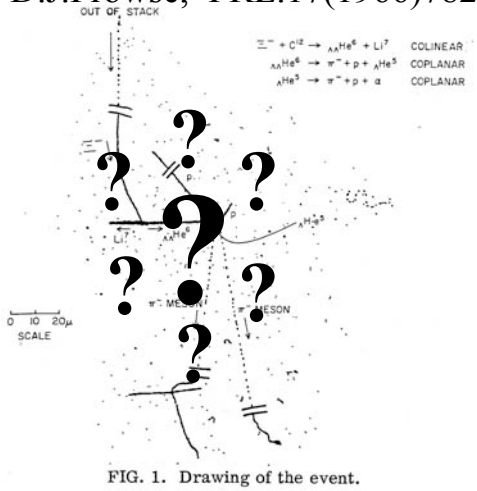
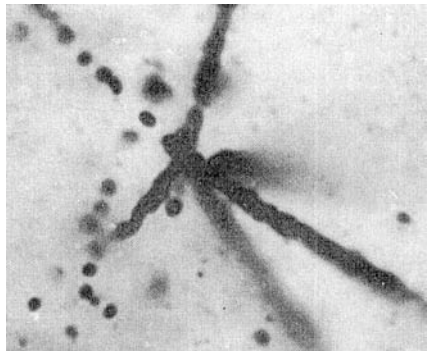


FIG. 1. Drawing of the event.

$^{6}_{\Lambda\Lambda}$**He**

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

S.Aoki et al, PTP.85(1991)1287



KEK-E176

in ~80 Ξstops

$^{13}_{\Lambda\Lambda}$**B**

$\Delta B_{\Lambda\Lambda} = 4.9 \pm^{0.7}_{0.8}$ MeV

if a doughter $^{13}_{\Lambda}$C is in excited

$\Delta B_{\Lambda\Lambda} \sim 0$ MeV

or

$^{10}_{\Lambda\Lambda}$**Be**

$\Delta B_{\Lambda\Lambda} = -4.8 \pm^{0.7}_{0.8}$ MeV

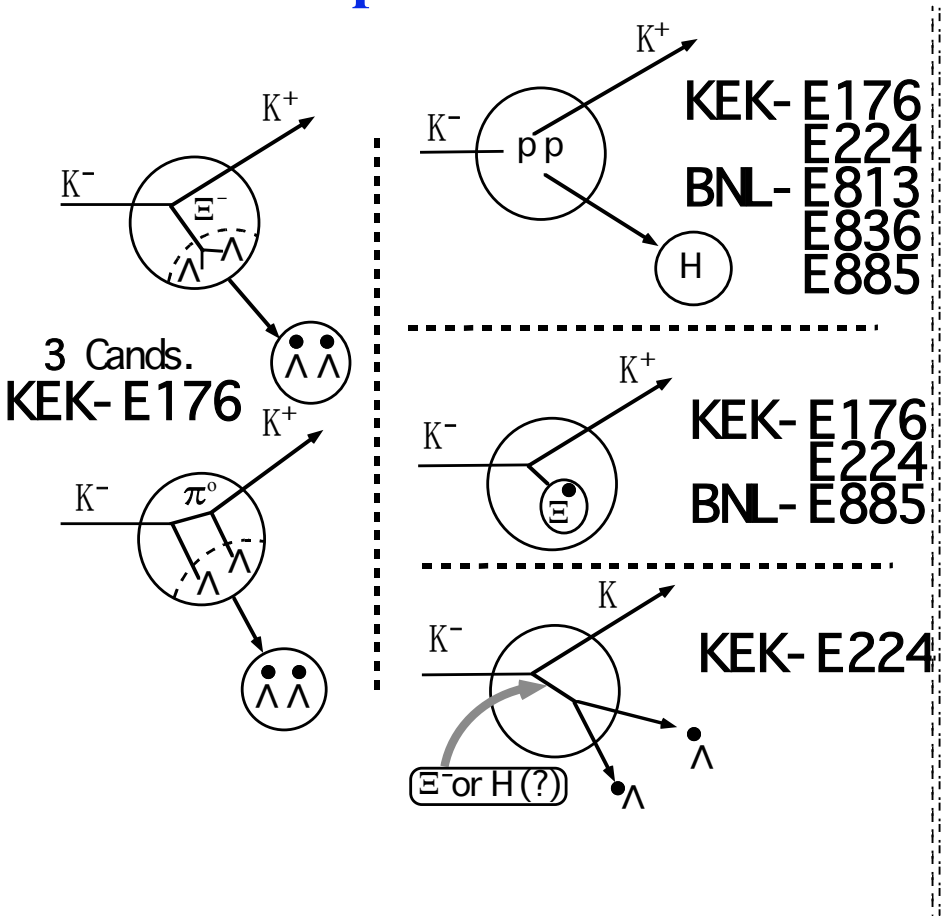
Why $V_{\Lambda\Lambda}$ so strong?

"interesting theoretical problem"

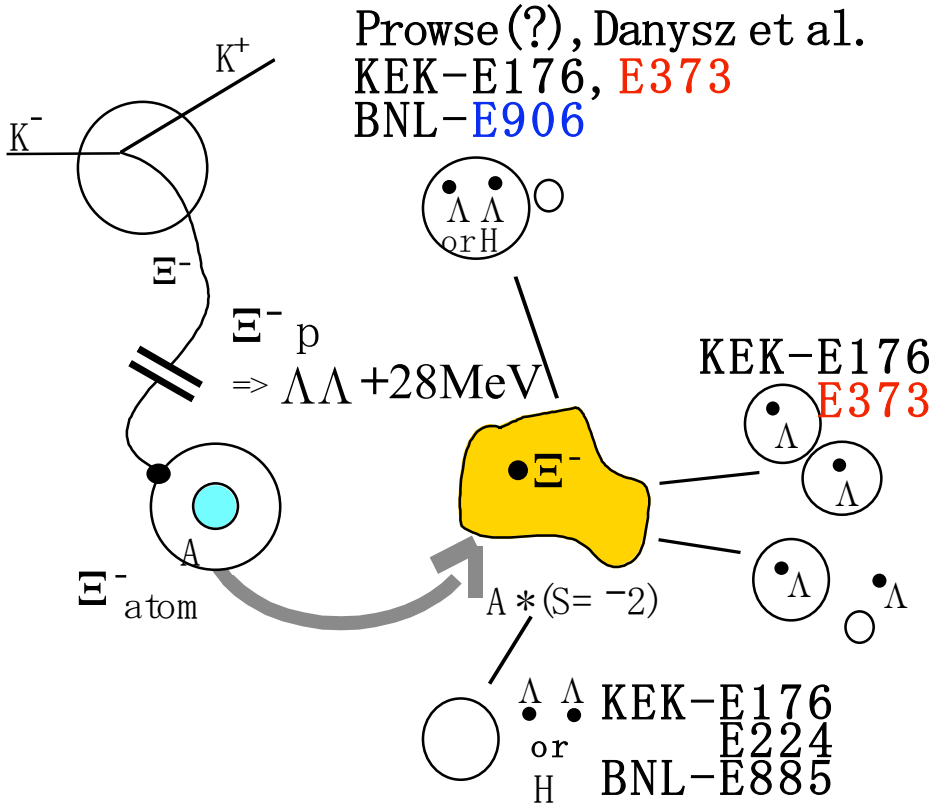
C.B.Dover, Proc. HYP91, NP.A547(1992)27c

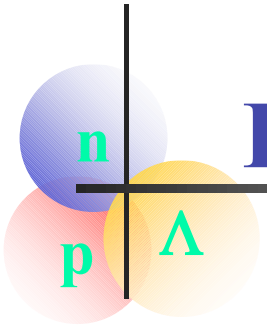
How to produce S=-2 Systems

- **Direct process**



- **via Ξ atom**





KEK-E373

PS-Review2004
Jun.07
K.Nakazawa

Study of *S*=-2 Nuclear System by an Emulsion-Counter Hybrid Method

KEK-E373 **collaborators**

Japan(16 Univ.・Inst.)
Aichi-edu, Gifu, Higashi-Nippon-Kokusai, KEK, Kobe, Kyoto,
Kyoto-Sangyo, Nagoya, Nat. Inst. Rad. Sci., Osaka-city, Osaka-ele.-comm.,
Science-center Osaka pref., Toho, Tohoku, Tokyo, Tsuru

Korea(4 Univ.)
Gyeonsang National Univ., Chonnam National Univ.,
Wonkwang Univ., Konkuk Univ., Korea Univ.

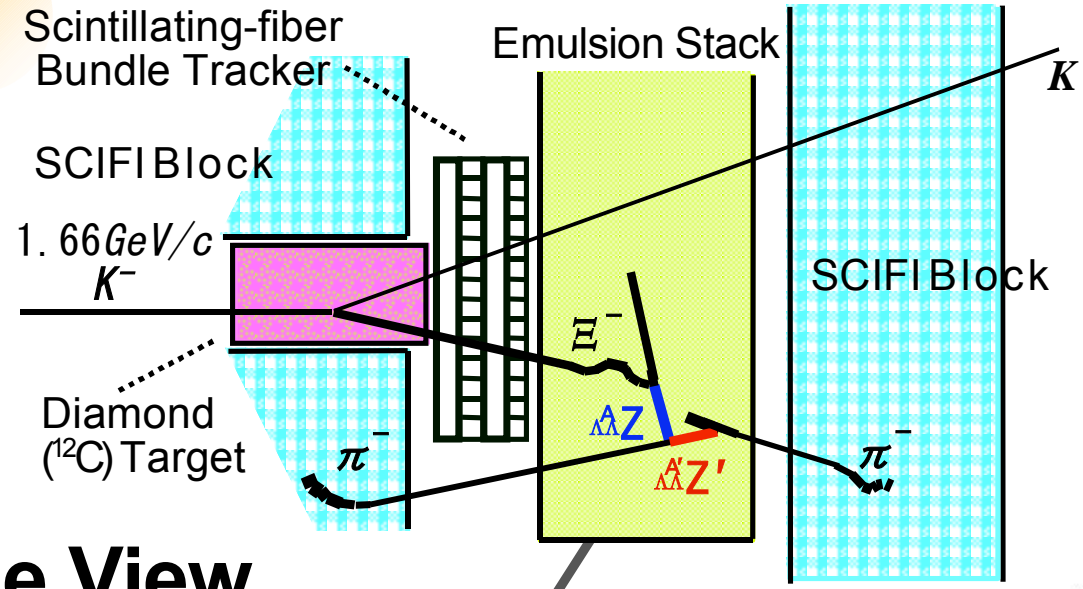
USA(3Univ.・Inst.)
BNL, Univ. New Mexico,
Carnegie Mellon Univ.

UK(1Univ.)
Univ. College London

Analysis for 10^3 stopped Ξ^- events (statistics **10 times** more than KEK-E176)

- Λ-Λ interaction energy
- existence of *H* dibaryon
- $\Lambda\Lambda$ weak interaction ($\Lambda\Lambda$ => Λn, ΣN)
- level energy of Ξ in nucleus

Experimental Method (KEK-E373)

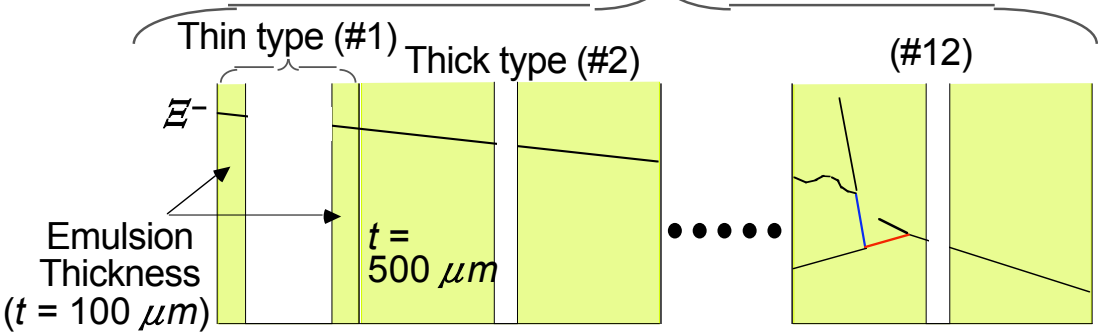


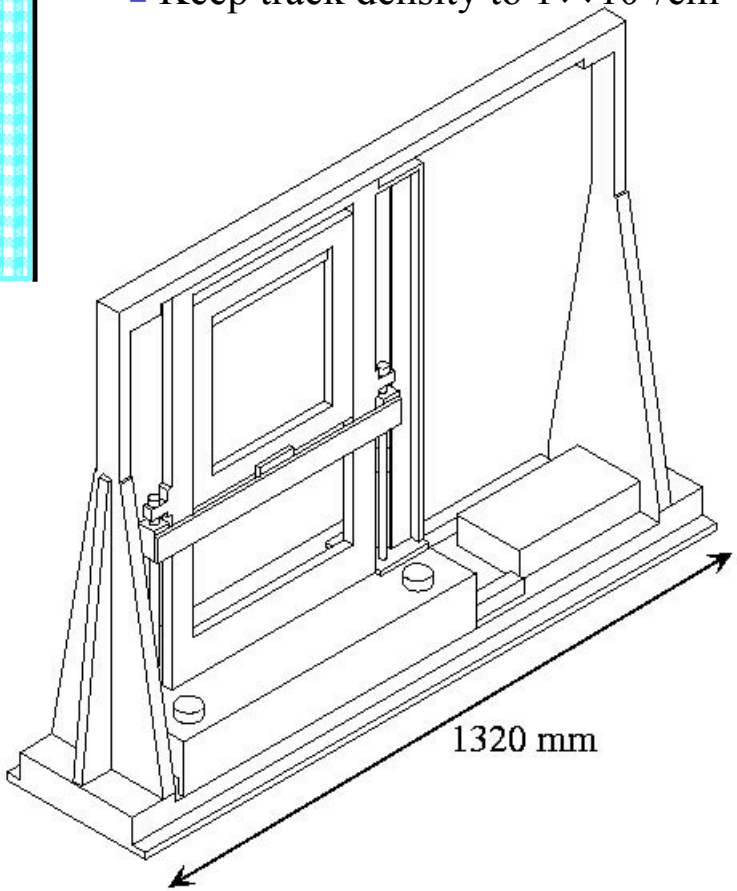
Area : 24.5×25.0 cm²
Packed in vacuum chamber

Emulsion Mover

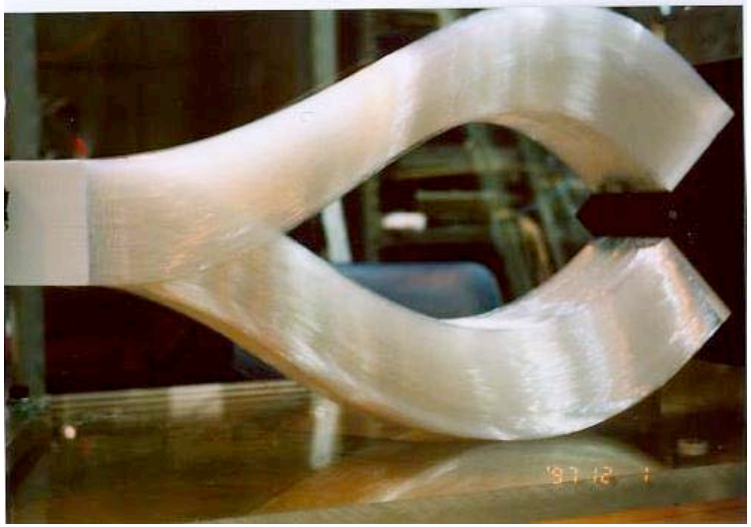
- Controlled with PC
- Move emulsion during spills
- Keep track density to $1\times10^6/cm^2$

Side View





Scintillating-fiber blocks (KEK-E373)



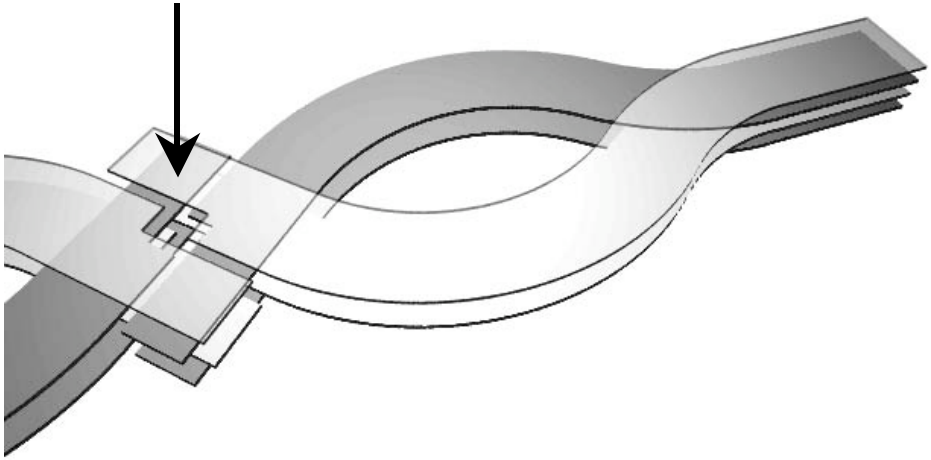
Readout with Image Intensifier Tube and CCD

Cross section of a fiber : 0.3 x 0.3 mm^2

Cross section of a block : 10 x 10 x 10 cm^3

There is almost NOT dead area.

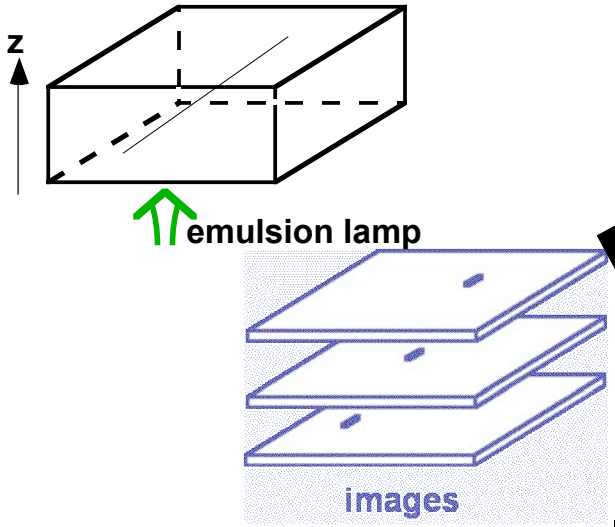
Diamond Target (2 x 2 x 3 cm^3)



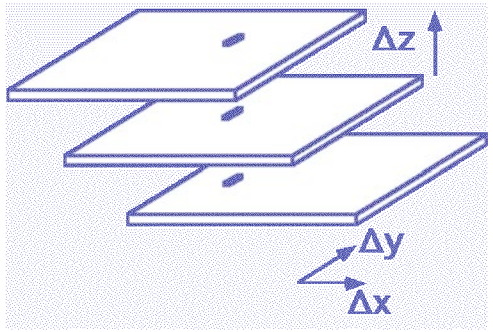
KEK-E373: *Automatic track finding*

Algorism

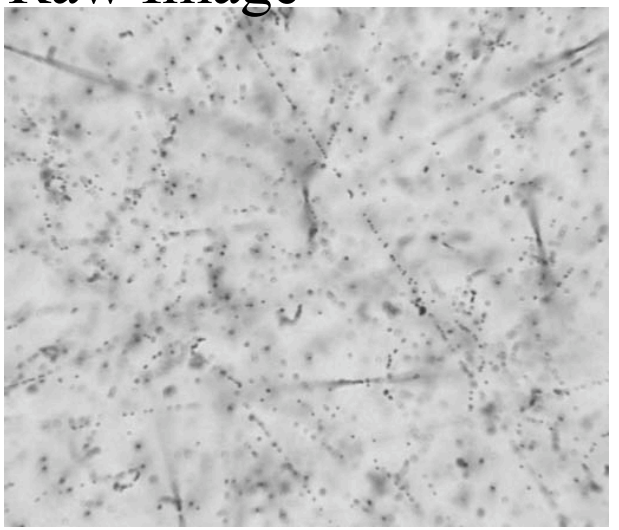
1) Take pictures at different *z*(focusing)position.



2) Make overllapped image shift each image by (-Δx,-Δy)

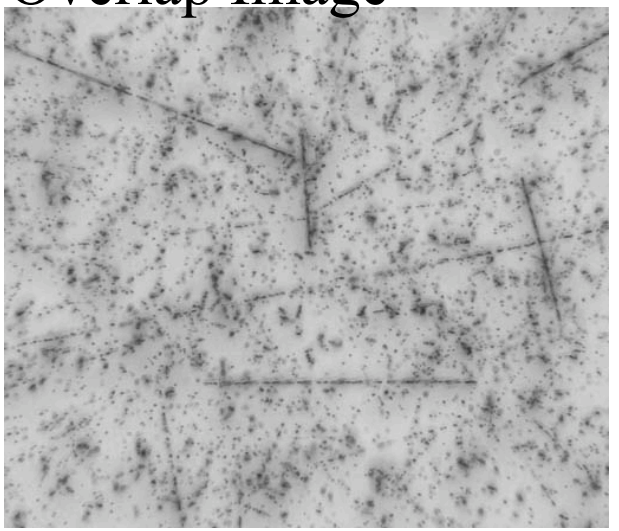


Raw Image

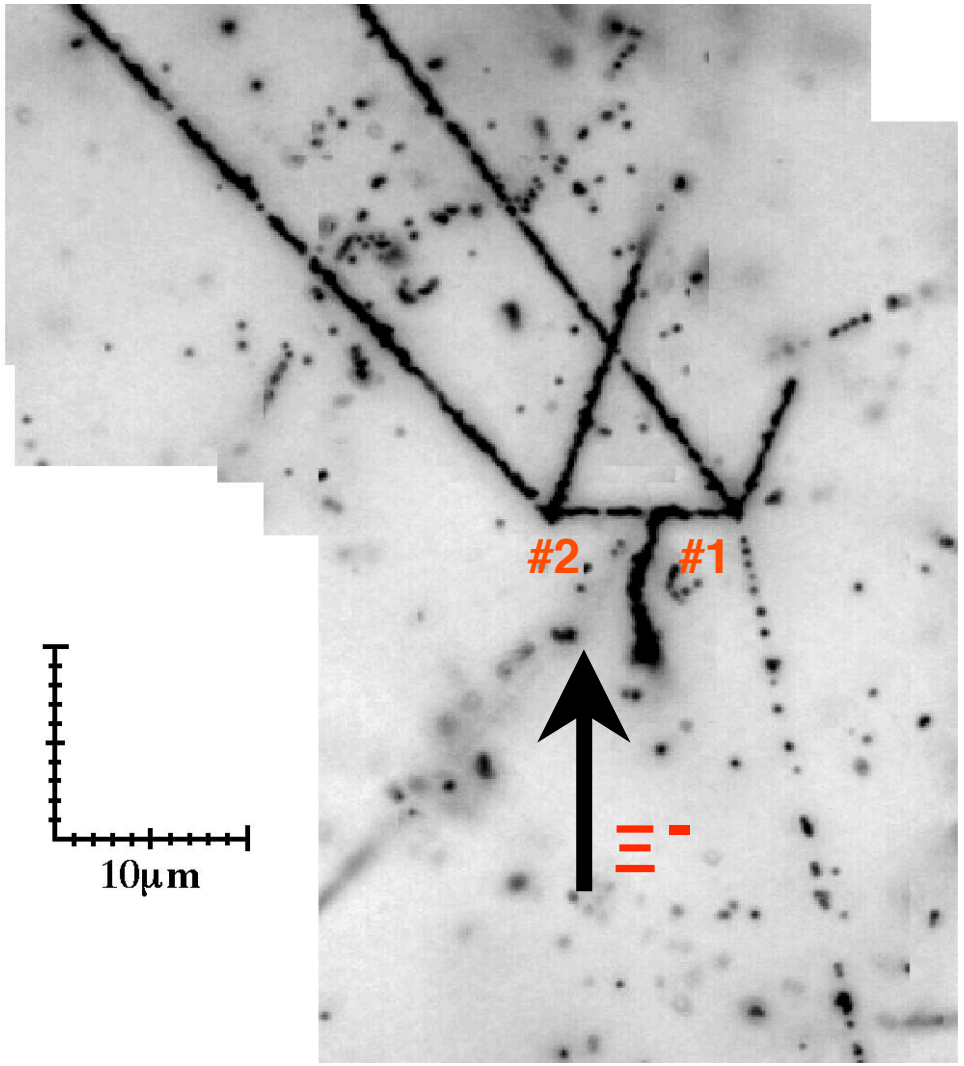


~100μm

Overlap Image



Typical Twin single-Λ hypernucleus



Preliminary

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

  → ${}^{6}_{\Lambda}He(\#2) + {}^{7}_{\Lambda}Li(\#1)$

  B_{Ξ^-} =1.6MeV(${}^{7}_{\Lambda}Li^*$:0.9±0.3MeV) 2P

  → ${}^{5}_{\Lambda}He + {}^{7}_{\Lambda}Li + n$

  B_{Ξ^-} =1.1MeV(${}^{7}_{\Lambda}Li^*$:0.4 ±0.4MeV) 3D

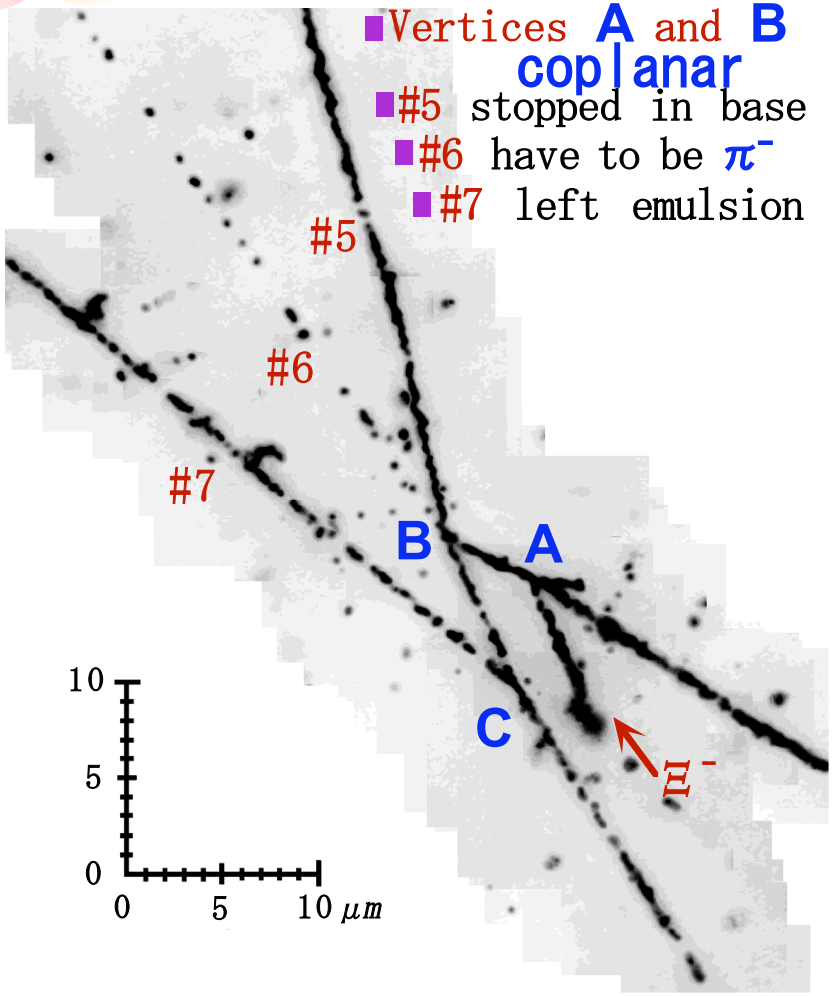
- $\Xi^- + {}^{14}N$

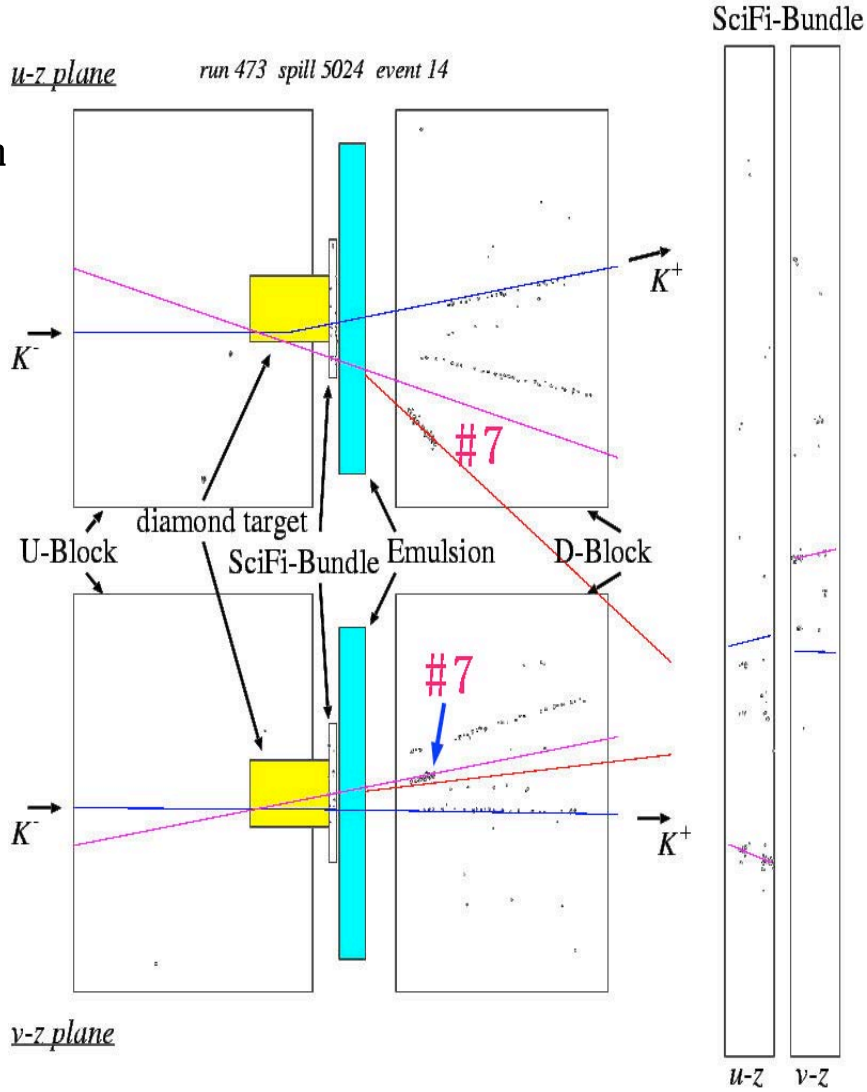
  → ${}^{5}_{\Lambda}He + {}^{9}_{\Lambda}Be + n$

  B_{Ξ^-} =10MeV(${}^{9}_{\Lambda}Be^*$:6.9 ±1.0MeV) 0s

Double hypernucleus #2

- Vertices A and B coplanar
- #5 stopped in base film
- #6 have to be π^-
- #7 left emulsion





Reconstruction and $\Delta B_{\Lambda\Lambda}$

by Y.S. Iwata & H. Takahashi

Production

Target	#1	#3	#4		$B_{\Lambda\Lambda}$ [MeV]	$\Delta B_{\Lambda\Lambda}$ [MeV]
^{12}C	$^{\ 6}_{\Lambda\Lambda}$He	^{4}He	p	$2n$	> 16.9	> 10.6
^{12}C	$^{\ 6}_{\Lambda\Lambda}$He	^{4}He	d	$1n$	14.5 ± 0.7	8.2 ± 0.7
^{12}C	$^{\ 6}_{\Lambda\Lambda}$He	^{4}He	t		7.3 ± 0.2	1.1 ± 0.2
^{12}C	$^{\ 7}_{\Lambda\Lambda}$He	^{4}He	p	$1n$	21.6 ± 1.3	13.3 ± 1.3
^{14}N	$^{\ 6}_{\Lambda\Lambda}$He	^{7}Li	p	$1n$	24.4 ± 2.1	18.2 ± 2.1
^{14}N	$^{\ 6}_{\Lambda\Lambda}$He	^{6}Li	d	$1n$	25.8 ± 1.3	19.6 ± 1.3
^{14}N	$^{\ 6}_{\Lambda\Lambda}$He	^{4}He	^{4}He	$1n$	17.9 ± 1.5	11.7 ± 1.5
^{14}N	$^{\ 7}_{\Lambda\Lambda}$Li	^{4}He	t	$1n$	26.2 ± 0.9	17.2 ± 0.9
^{14}N	$^{\ 9}_{\Lambda\Lambda}$Li	p	^{4}He	$1n$	31.5 ± 1.8	17.9 ± 1.8
^{16}O	$^{\ 8}_{\Lambda\Lambda}$Li	^{4}He	^{4}He	$1n$	31.1 ± 0.9	19.9 ± 0.9

($\Delta B_{\Lambda\Lambda}$<20MeV)

Decay

double-hyp.	#2	#5	#6		$B_{\Lambda\Lambda}$ [MeV]	$\Delta B_{\Lambda\Lambda}$ [MeV]
$^{\ 5}_{\Lambda\Lambda}$He	$^4_\Lambda$He	p	π^-		7.1 ± 0.5	2.4 ± 0.5
$^{\ 6}_{\Lambda\Lambda}$He	$^5_\Lambda$He	p	π^-		6.9 ± 0.6	0.6 ± 0.6
$^{\ 7}_{\Lambda\Lambda}$He	$^5_\Lambda$He	p	π^-	$1n$	< 8.6	< 0.3
$^{\ 7}_{\Lambda\Lambda}$He	$^6_\Lambda$He	p	π^-		6.3 ± 0.7	-2.0 ± 0.7
$^{\ 8}_{\Lambda\Lambda}$He	$^5_\Lambda$He	p	π^-	$2n$	< 6.8	< -7.2
$^{\ 8}_{\Lambda\Lambda}$He	$^5_\Lambda$He	d	π^-	$1n$	< 7.4	< -6.6
$^{\ 8}_{\Lambda\Lambda}$He	$^6_\Lambda$He	p	π^-	$1n$	< 6.6	< -7.4
$^{\ 8}_{\Lambda\Lambda}$He	$^7_\Lambda$He^a	p	π^-		7.7 ± 0.8	-6.3 ± 0.8
$^{\ 9}_{\Lambda\Lambda}$He	$^5_\Lambda$He	p	π^-	$3n$	< 7.2	< -7.1
$^{\ 9}_{\Lambda\Lambda}$He	$^5_\Lambda$He	d	π^-	$2n$	< 8.2	< -6.1
$^{\ 9}_{\Lambda\Lambda}$He	$^5_\Lambda$He	t	π^-	$1n$	< 11.2	< -3.1
$^{\ 9}_{\Lambda\Lambda}$He	$^6_\Lambda$He	p	π^-	$2n$	< 7.2	< -7.1
$^{\ 9}_{\Lambda\Lambda}$He	$^6_\Lambda$He	d	π^-	$1n$	< 8.4	< -5.9
$^{\ 9}_{\Lambda\Lambda}$He	$^7_\Lambda$He^a	p	π^-	$1n$	< 11.2	< -3.1
$^{\ 9}_{\Lambda\Lambda}$He	$^7_\Lambda$He^a	d	π^-		13.4 ± 0.5	-0.9 ± 0.5
$^{\ 9}_{\Lambda\Lambda}$He	$^8_\Lambda$He	p	π^-		6.4 ± 0.8	-7.9 ± 0.8

($\Delta B_{\Lambda\Lambda}$>−20MeV)

Nuclear Physics with double strangeness (S=−2)

KEK-E373 => AGS-E964 ……> J-PARC

Λ Observation of a $^{\Lambda\Lambda}_{\ \ 6}$He (KEK-E373)

Success of Emulsion detector with micro-meter accuracy

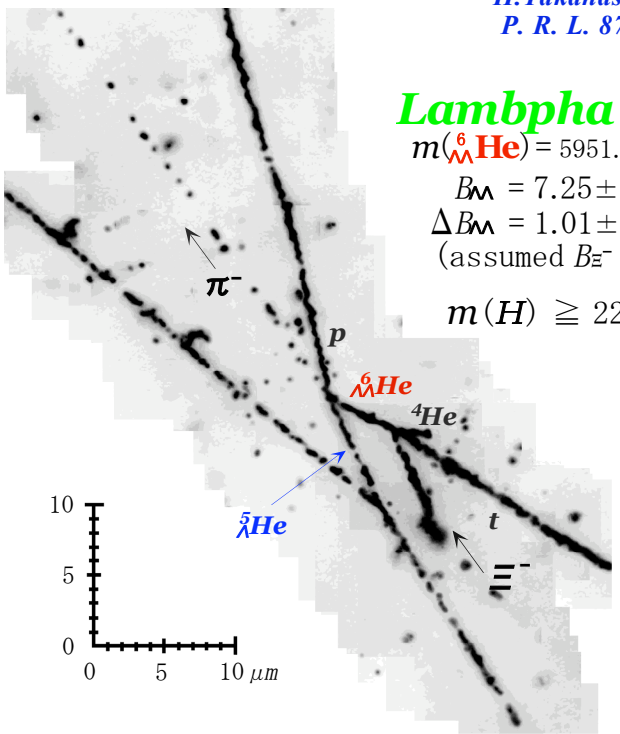
NAGARA event

$^{\Lambda\Lambda}_{\ \ 6}$He double-hypernucleus

Unique interpretation!!

$$\Xi^- + {}^{12}\mathrm{C} \rightarrow {}^{\Lambda\Lambda}_{\ \ 6}\mathrm{He} + {}^{4}\mathrm{He} + t$$
$$^{\Lambda\Lambda}_{\ \ 6}\mathrm{He} \rightarrow {}^{\ 5}_{\Lambda}\mathrm{He} + p + \pi^-$$

H.Takahashi et al.,
P. R. L. 87, 212502(2001)



Lambpha

$m(^{\Lambda\Lambda}_{\ \ 6}\mathrm{He}) = 5951.82 \pm 0.54$ MeV

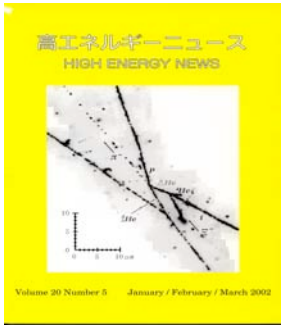
$B_{\Lambda\Lambda} = 7.25 \pm 0.19^{+0.18}_{-0.11}$ MeV

$\Delta B_{\Lambda\Lambda} = 1.01 \pm 0.20^{+0.18}_{-0.11}$ MeV

(assumed $B_{\Xi^-} = 0.13$ MeV)

$m(H) \geqq 2223.7$ MeV/c^2 (90% C.L.)

http://www.phys.ed.gifu-u.ac.jp/Topics/NAGARA-e.htm



High Energy News
Vol.20 No.5 (2002)
KEK

Demachi-yanagi event

✻ **two body** case at point A

$\Xi^- + {}^{12}\mathrm{C} \rightarrow {}^{10}_{\Lambda\Lambda}\mathrm{Be} + t$ or ${}^{10}_{\Lambda\Lambda}\mathrm{Be}^* + t$

$\Delta B_{\Lambda\Lambda}$: -1.14±0.19 or +1.86±0.19MeV

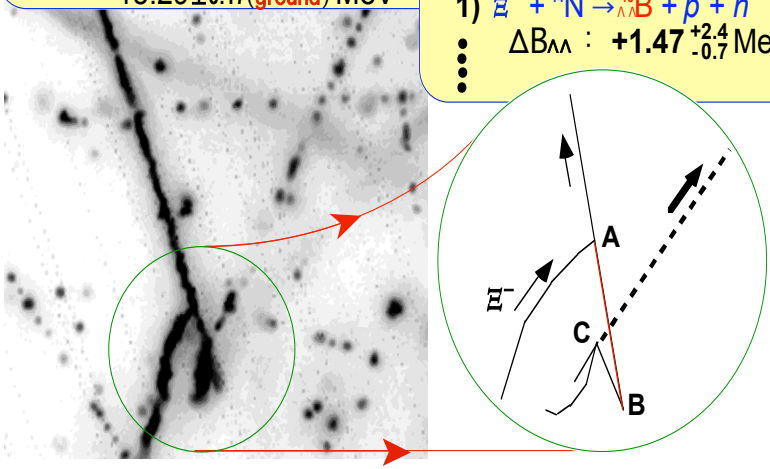
$B_{\Lambda\Lambda}$: 12.29±0.17(excited) MeV

15.29±0.17(ground) MeV

✻ **three body** case at point A

1) $\Xi^- + {}^{14}\mathrm{N} \rightarrow {}^{13}_{\Lambda\Lambda}\mathrm{B} + p + n$

$\Delta B_{\Lambda\Lambda}$: $+1.47^{+2.4}_{-0.7}$ MeV

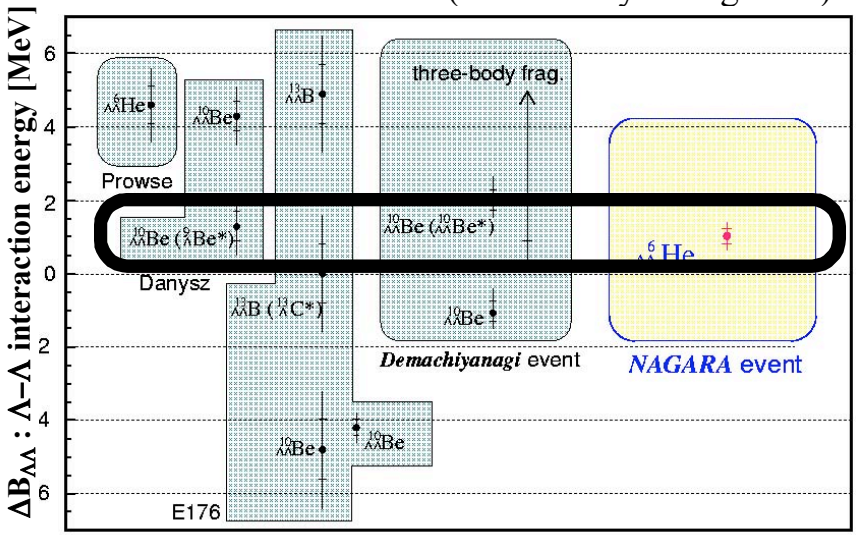


KEK-E373 → AGS-E964

KEK-E373 (Preliminary results)

*) **~10^3 Ξ⁻** stopping events in nuclear emulsion.

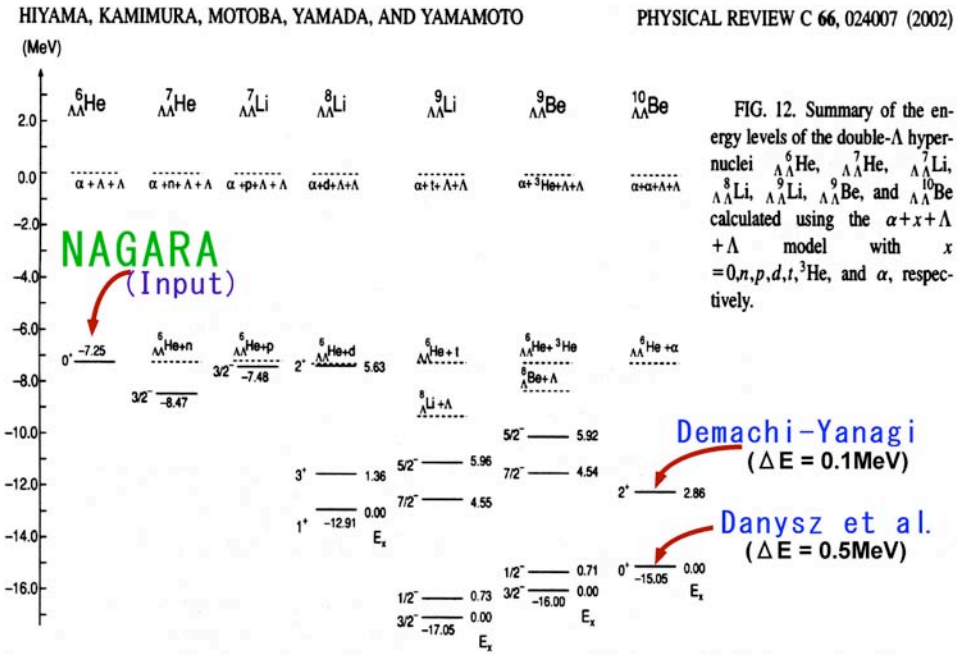
*) Observation of several double-Λ hypernuclei
=> **NAGARA event** (without any ambiguities).



ΛΛ interaction is attractive but weak

- 7th publication award (JPS) ➔ E176
- Gifu Univ. Award ➔ Iwata (MS)
- Young scientist Award ➔ Ichikawa(DC)
  ➔ Takahashi (DC)
- Three DC students

Theoretical calculation for light double hypernuclei



AGS-E964 (statistics x 10)

*) **~10^4 Ξ⁻ stopping events** in nuclear emulsion.

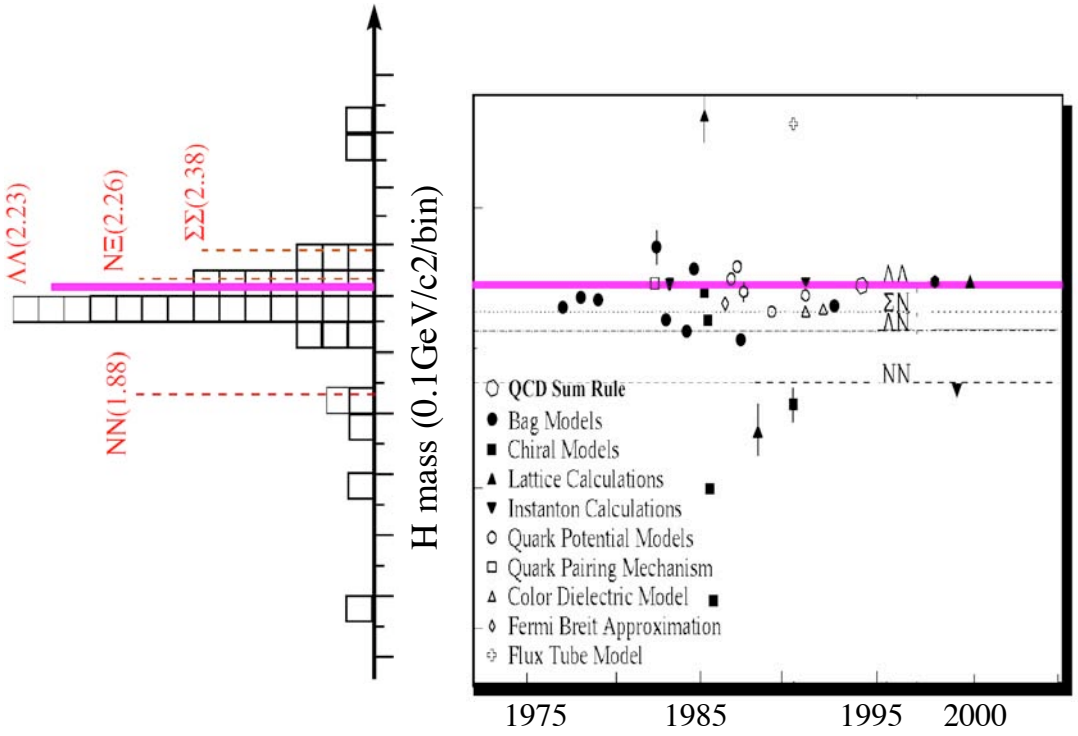
*) **~10** double-Λ hypernuclei (**without any ambiguities**).
=> making a **nuclear chart with S=-2**.
A-dependence of **$\Delta B_{\Lambda\Lambda}$** in several nuclides.

*) **X-ray measurement** from Ξ⁻-atom, for the first time.
=> information of Ξ-N interaction.

*) **funded** by JPN. Gov., already. (2003~2007)

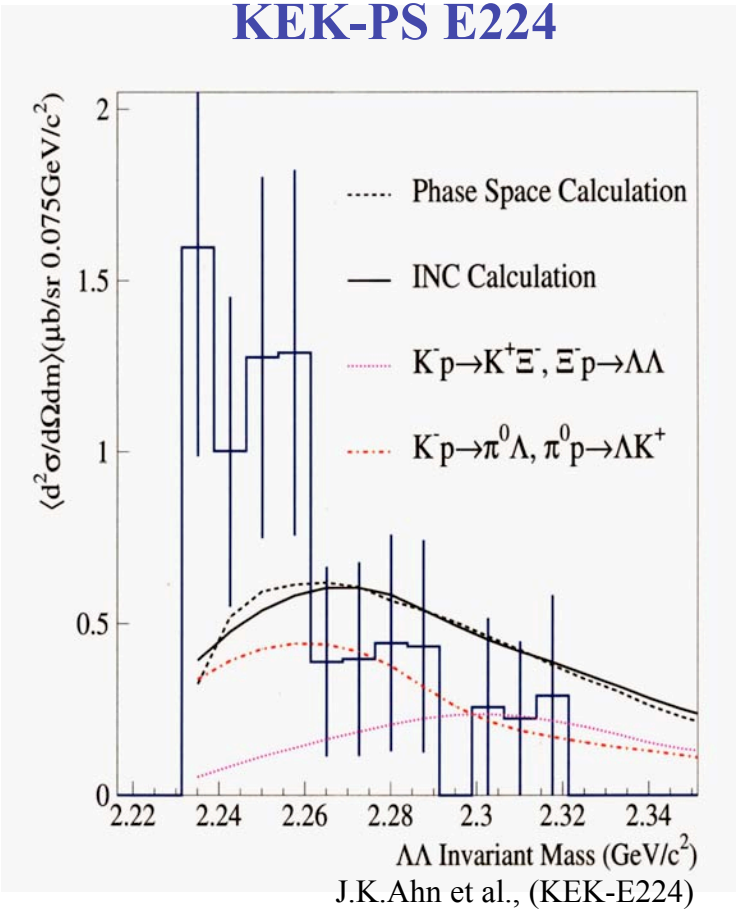
H-Dibaryon resonance search

Predicted masses



Updated from the year 1995, referred on
S.V.Bashinsky, R.L.Jaffe, Nucl. Phys. A625(1997)167,
and W.J.Lope, talk given at '12th Winter Workshop on Nuclear Dynamics'

ΛΛ Invariant mass spectrum
KEK-PS E224



J.K.Ahn et al., (KEK-E224)
Phys. Lett. B444 (98) 267

H-dibaryon resonance : KEK-E522

Search for H–dibaryon Resonance via $^{12}C(K^-, K^+\Lambda\Lambda)$ and Study of $\Xi^- N$ interaction

KEK E522

Participants

K.Aoki, Y.Fukao, H.Funahashi,H.Okada
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H.N.Kyaw,K. Nakazawa,M.Okuda, T.Wint d)
T.Hayakawa, T.Kishimoto, A.Sato, Y.Shimizu e)
K.Yamamoto, T.Yoshida f)
J.K.Ahn, S.J.Kim g)
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f) Dept. Phys. Osaka City Univ.
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h) Dept. Phys. Gyeongsang Nat'l Univ.
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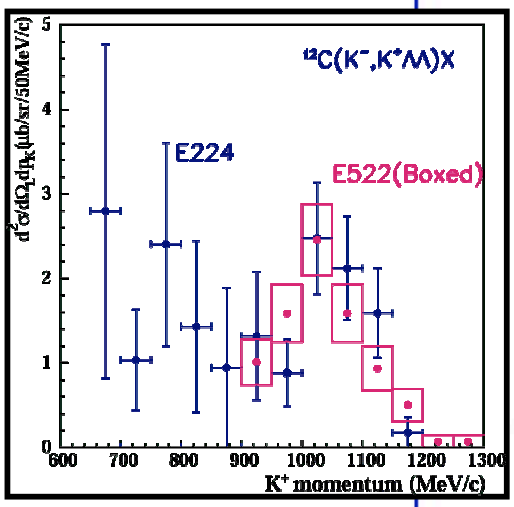
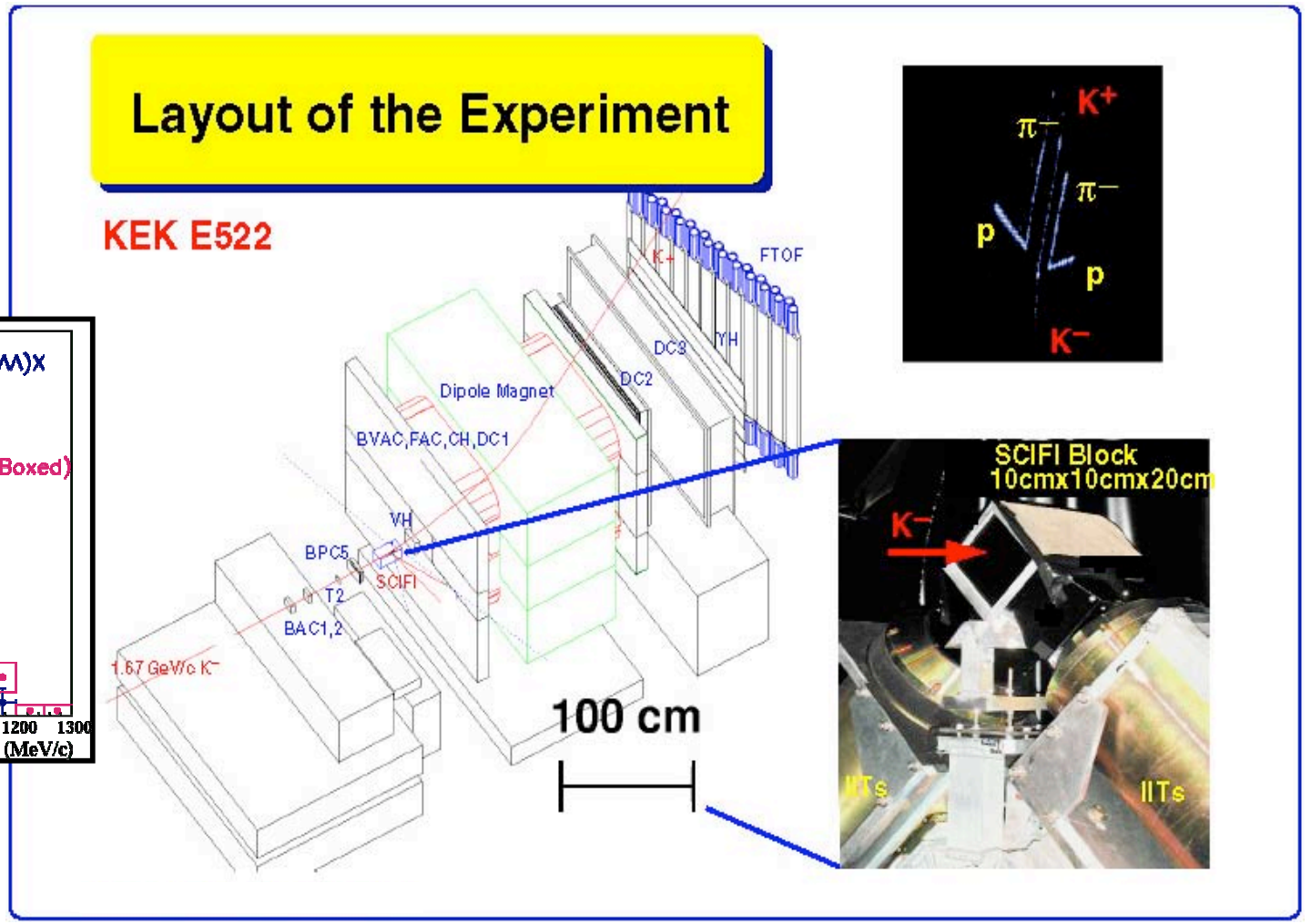
k) RIKEN, l) Dept. Phys. Tohoku Univ.
*) spokes person

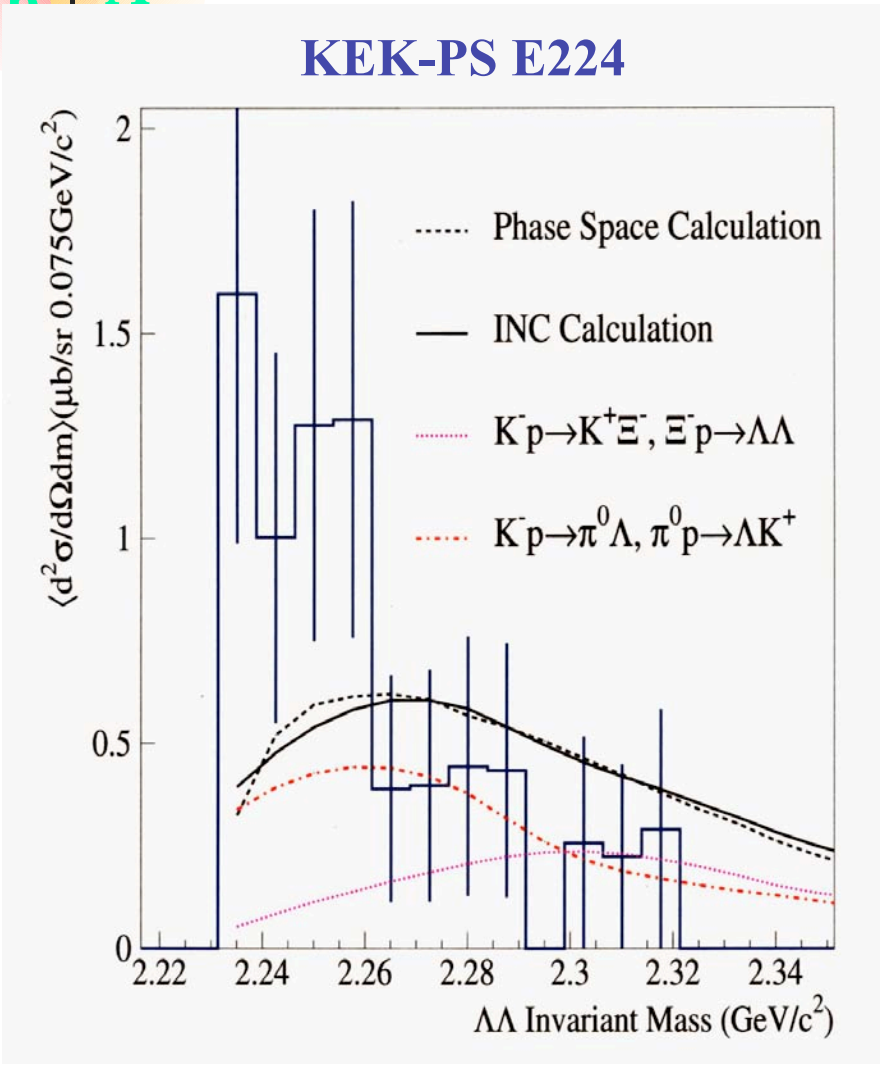
H-Dibaryon resonance : KEK-E522





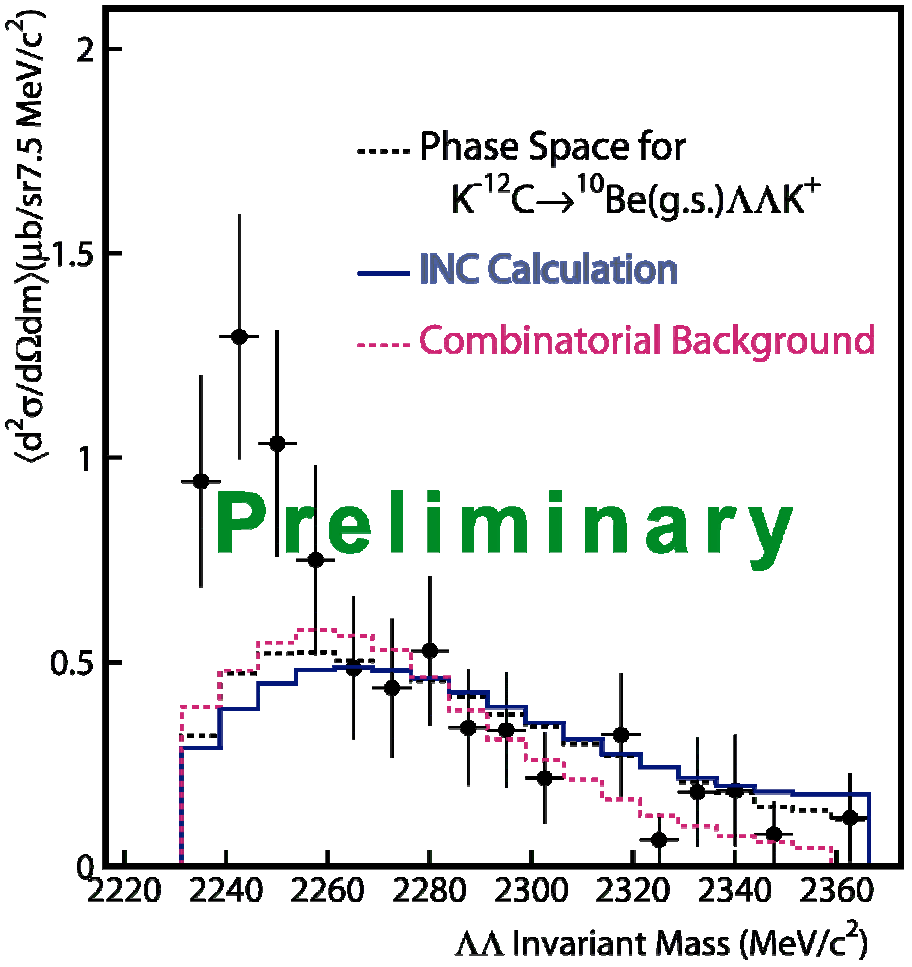
H-Dibaryon near the ΛΛ threshold

KEK-PS E224



J.K.Ahn et al., (KEK-E224)
Phys. Lett. B444 (98) 267

KEK-PS E522



Future plan

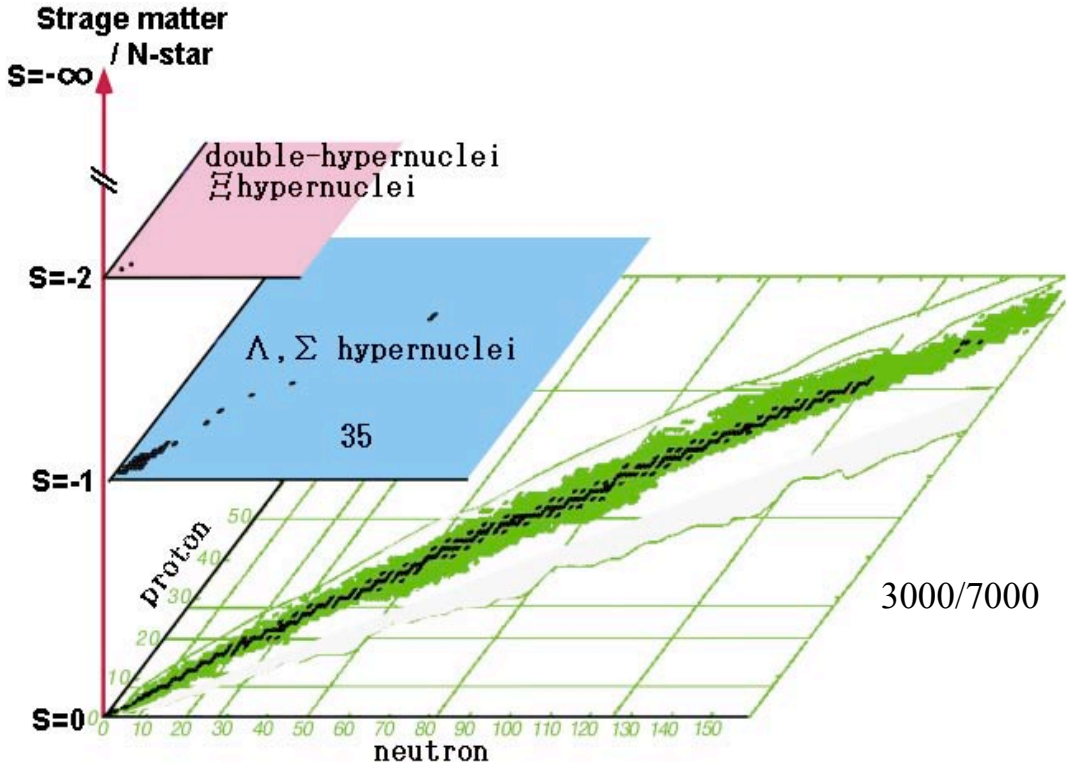
- PS-E559(**High Resolution Spectroscopy of Pentaquark Θ⁺**)

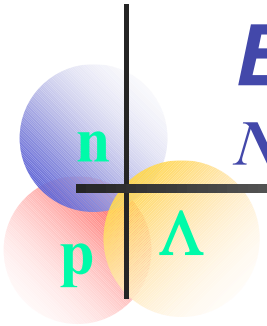
PS-Shutdown

- AGS-E964
  (2006?)
  [Spring8/RHIC]

↓ ↓ ↓ ↓ ↓ ↓

- J-PARC





E964 experiment

Nuclear Physics with double strangeness (S=−2)

KEK-E373 => AGS-E964 ……> J-PARC

PS-Review2004
Jun.07
K.Nakazawa

Title : Systematic Study of Double Strangeness System with an Emulsion-Counter Hybrid Method.

Beam : K^- (1.7GeV/c),
2 x 10^5 K^-/spill (4.1sec)
with K^-/π^->9 at D6-line

Detectors : Nuclear Emulsion,
Double-sided Si strip Detector,
Ge-Detector (Hyperball),
KURAMA magnet

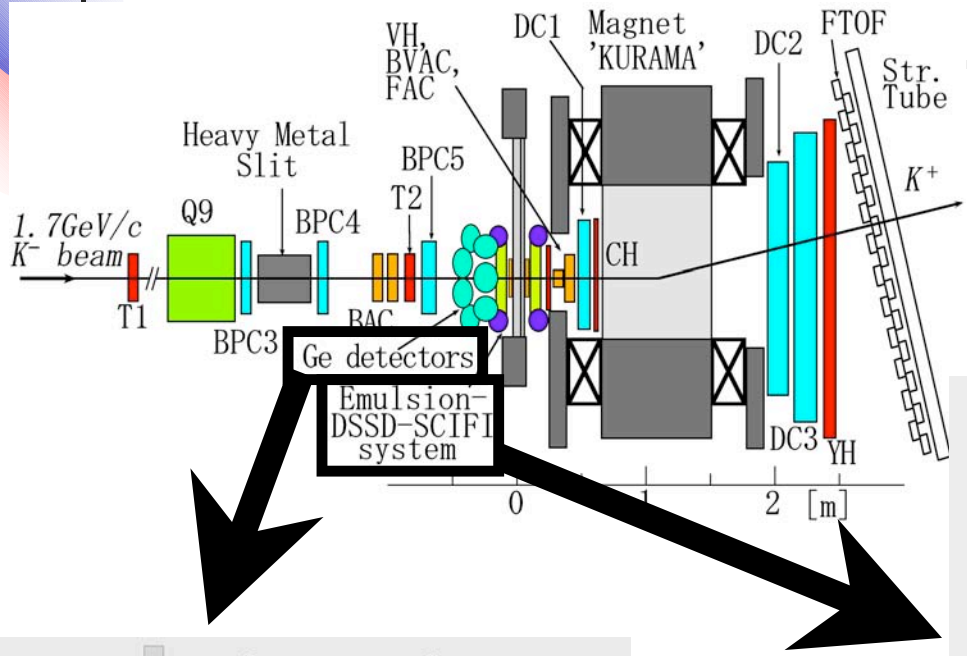
Time requested :
100 hours for detector tune
100 hours for beam tune
1100 hours for beam exposure

AGS-E964 (statistics X10 of the past experiments)

*) **International collaboration**
(USA/China/India/JPN/Korea/Myanmar/UK)
*) ~10^4 Ξ^- **stopping events** in nuclear emulsion.
*) ~10 double-Λ hypernuclei
(**without any ambiguities**).
=> making **nuclear chart with S=-2**.
A-dependence of $\Delta B_{\Lambda\Lambda}$ in several nuclides.
*) **X-ray measurement** from Ξ^--atom,
for the first time.
=> information of Ξ-N interaction.
*) **funded** by JPN. Gov., already.
(2003~2007)

E964 leads the community of hypernuclear physics to significant activities at J-PARC.

Setup around the target (E964)

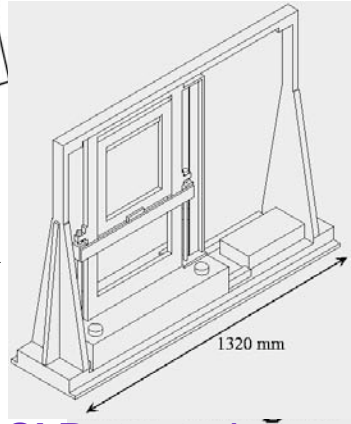


Volume of nuclear emulsion

70 *liters* (E373) => **210 *liters***

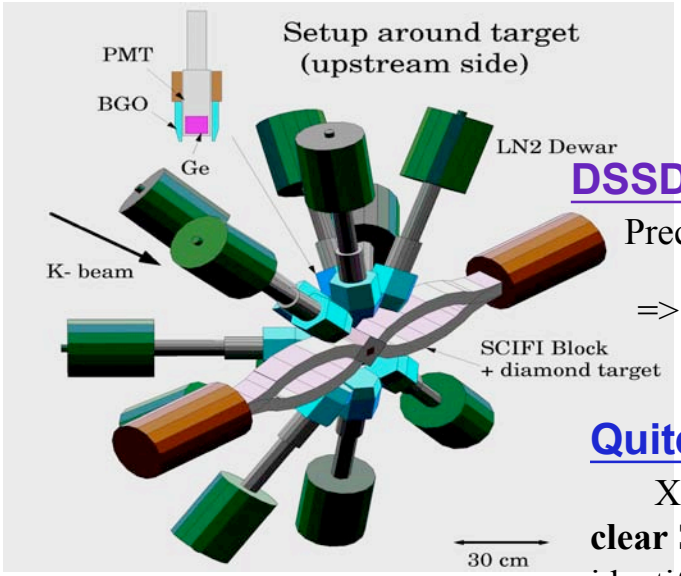
Track scanning method

Automated + Interactive (E373)
=> **Fully Automated (speed x 4)**



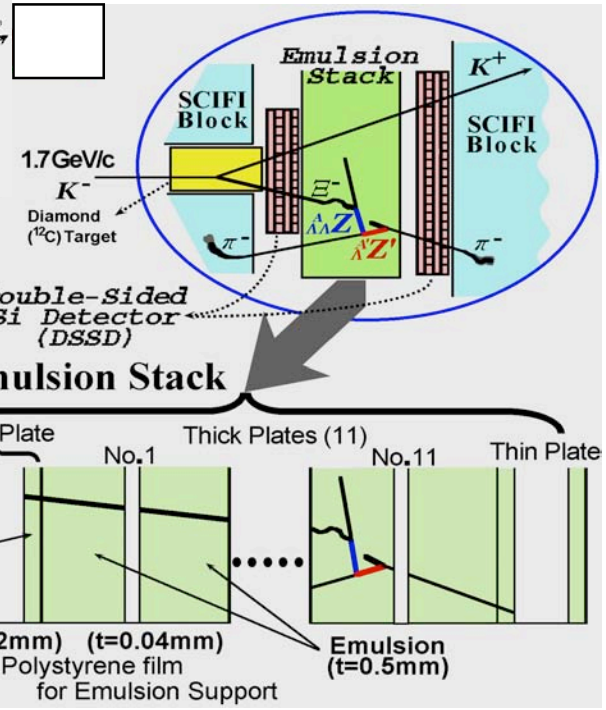
Emulsion Mover

- Controlled with PC
- Move emulsion during spills
- Keep track density to $1 \times 10^6/cm^2$



DSSD(Double-Sided Si Detector)

Precise prediction of Ξ⁻ tracks
on the first emulsion plate.
=> Reduction in background tracks
which are picked up in the first plate.



Quite low background

X-ray data are only analyzed for **clear Ξ⁻ stopping events** which are identified by nuclear emulsion.

Development of Automatic Scanning

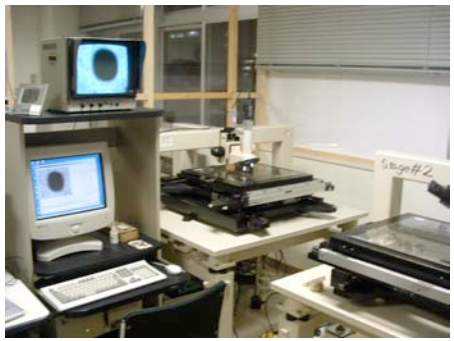
○KEK-E373

- stage drive : step-by-step
- image capture : 30Hz

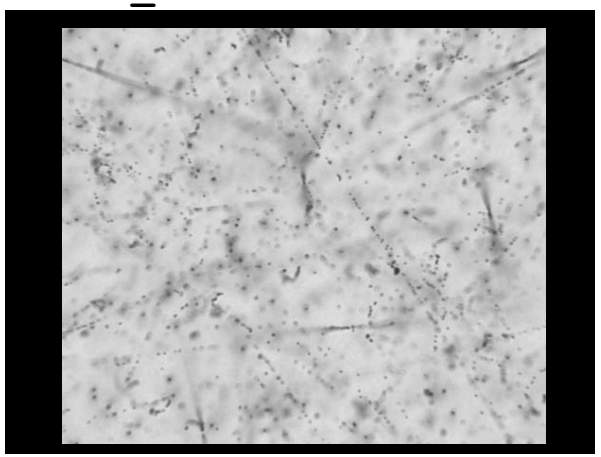
⇨ **1.5~2.0 sec / one view**

Images are shown:

1. **Surface** detection
   => **Grid** measurement
   for position calib.
2. **Track scanning**



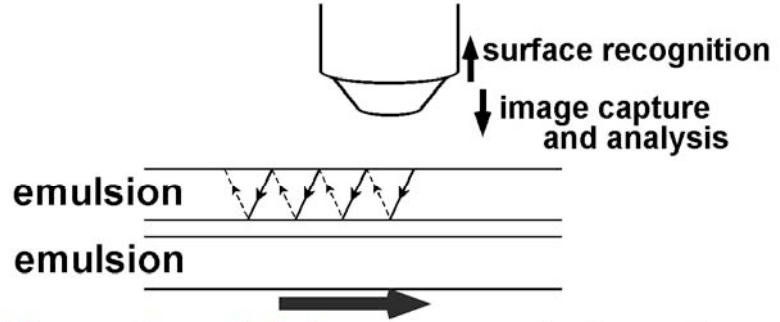
Current system
Surface & Grid : 22 sec.
Track_scan : 15 sec.



◎AGS-E964(BNL)

- stage drive : Non-Stop
- image capture : 100Hz

⇨ **~0.2 sec / one view**
(designed value)



Non-stop driving : speed~1mm/sec

Developing system
Surface & Grid : 9 sec.
Track_Scan : 6 sec.