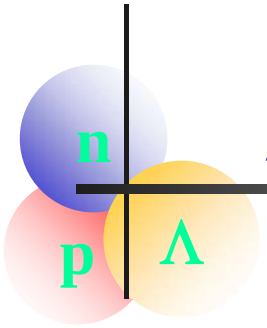


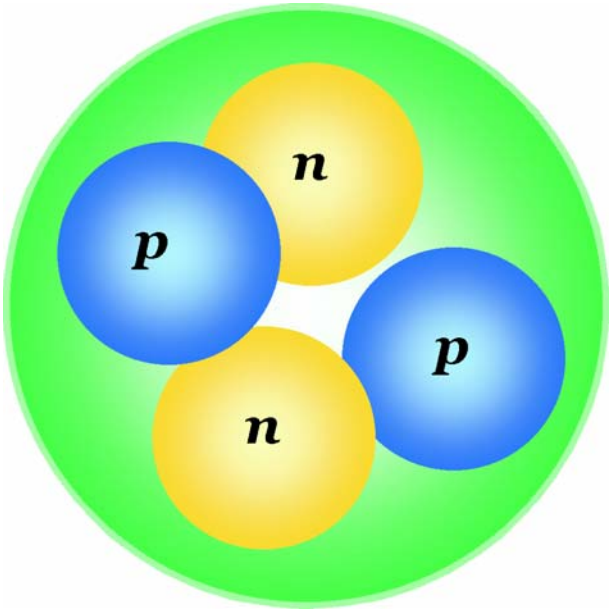
Reaearch on Double Hypernucleus

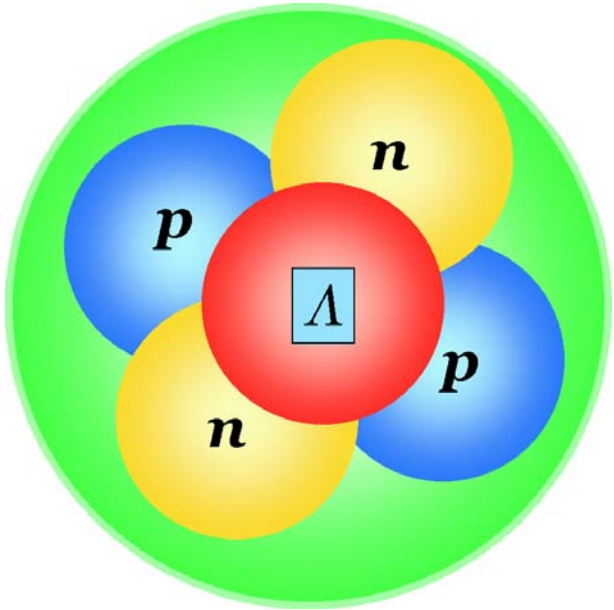
K.NAKAZAWA
(Gifu Univ.)

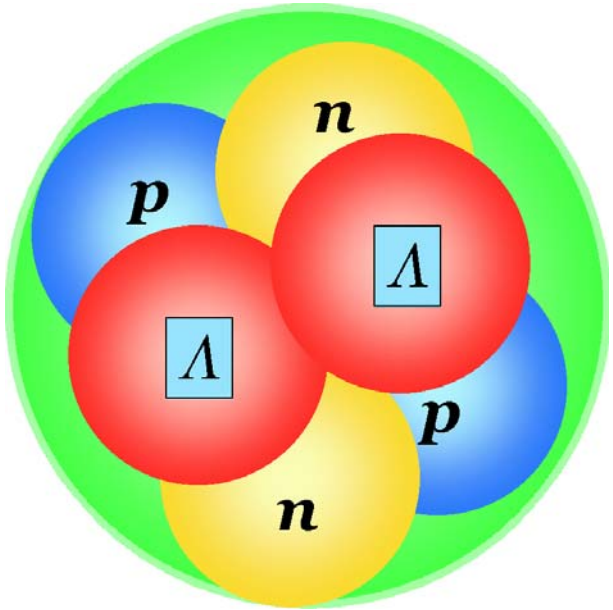
Normal nucleus
^{4}He

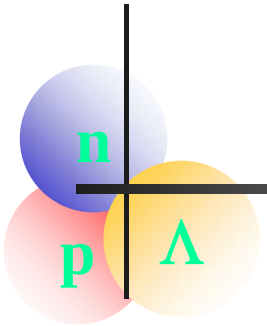
Single–Λ nucleus
$^{5}_{\Lambda}$He

Double–Λ nucleus
$^{\Lambda}_{\Lambda}{}^{6}$He





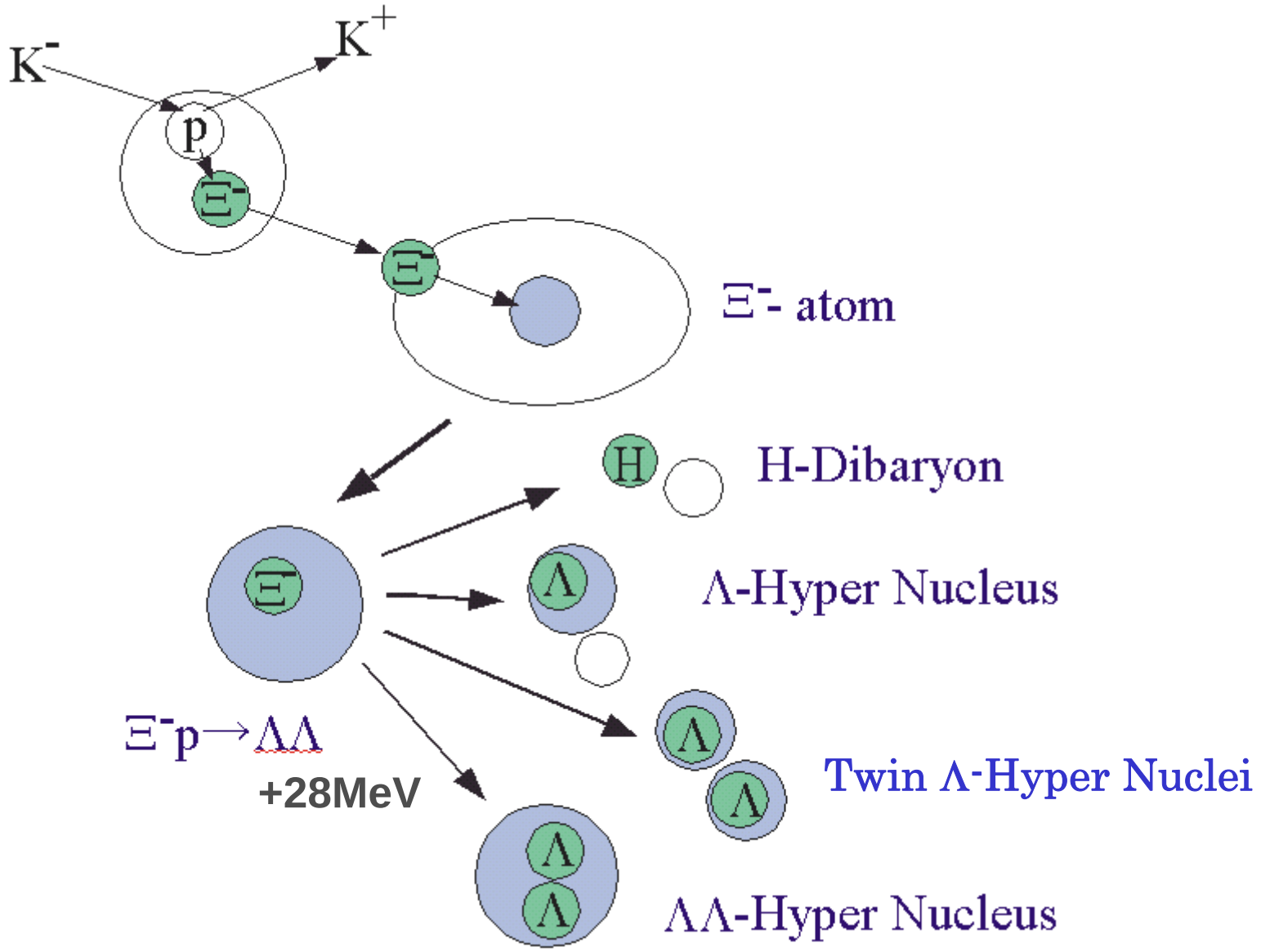




Outline

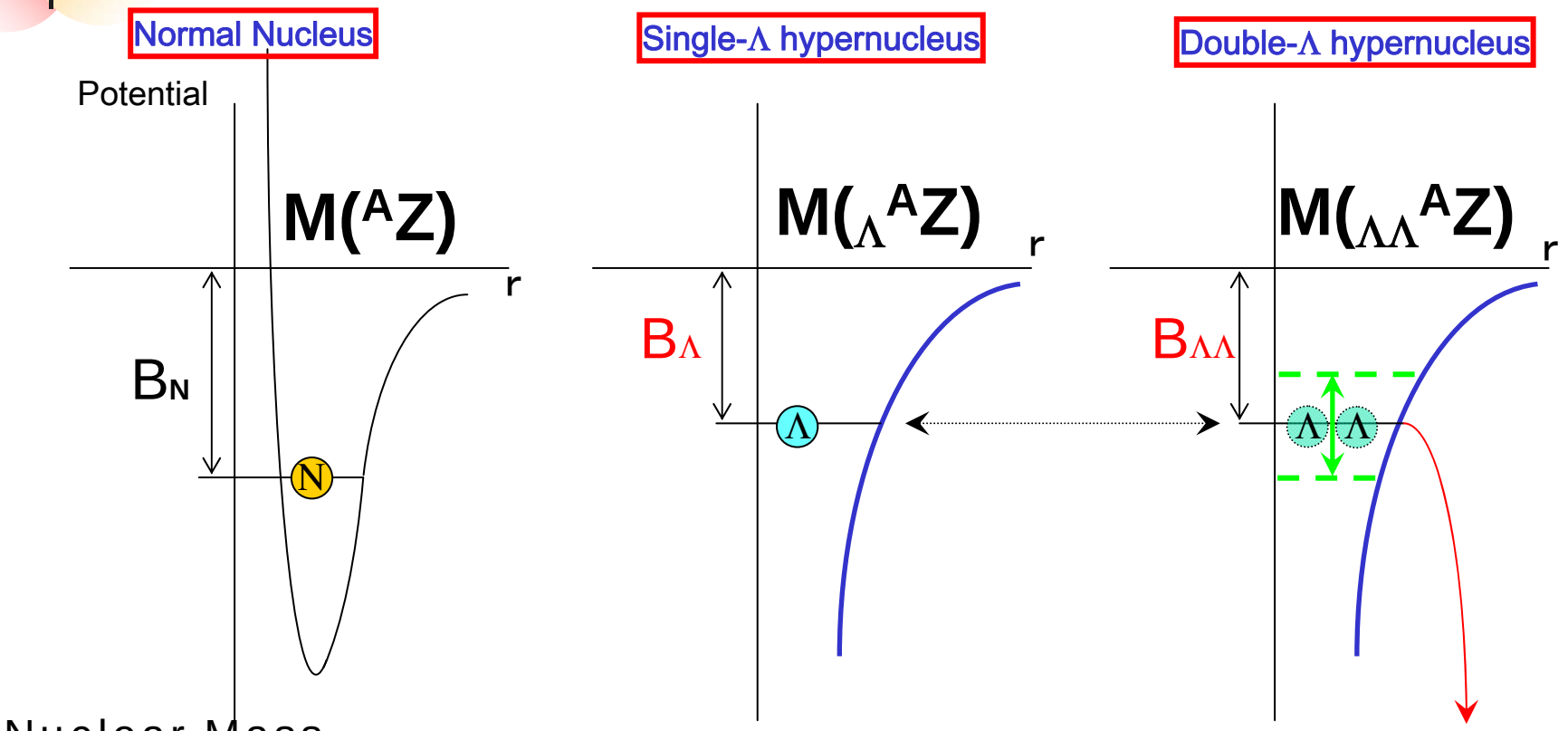
- **Nuclei with double strangeness (S=-2)**
  - Double hypernucleus
  - typical events
- **Experimental Plan near future**
- **Summary**

How we produce S=-2 Systems ?



What can be measured in S=-2 Systems ?

Λ-Λ interaction energy ($\Delta B_{\Lambda\Lambda}$)



Nuclear Mass

$M(^{A}Z) \equiv M(N) - B_N \times A$

$M(_{\Lambda}{}^{A}Z) = M(^{A-1}Z) + M(\Lambda) - B_\Lambda$

$M(_{\Lambda\Lambda}{}^{A}Z) = M(^{A-2}Z) + M(\Lambda)\ x2 - B_{\Lambda\Lambda}$

Λ-Λ interaction energy

$\Delta B_{\Lambda\Lambda} = B_{\Lambda\Lambda} - 2\,B_\Lambda$

?

$B_{\Lambda\Lambda} > 2xB_\Lambda$: attractive ΛΛ–int.

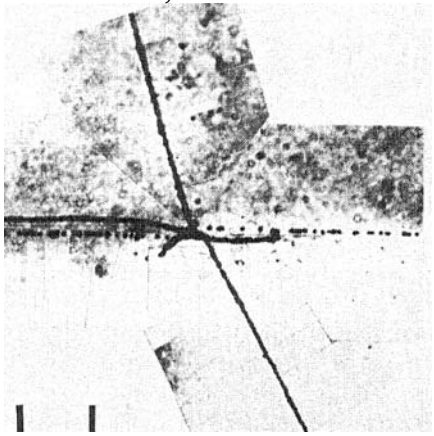
$B_{\Lambda\Lambda} < 2xB_\Lambda$: repulsive ΛΛ–int.

Double Strangeness Systems

Experimental status

Only **3** candidate events 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

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

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

$\Delta B_{\Lambda\Lambda} => \sim \mathbf{1.3}$ MeV

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

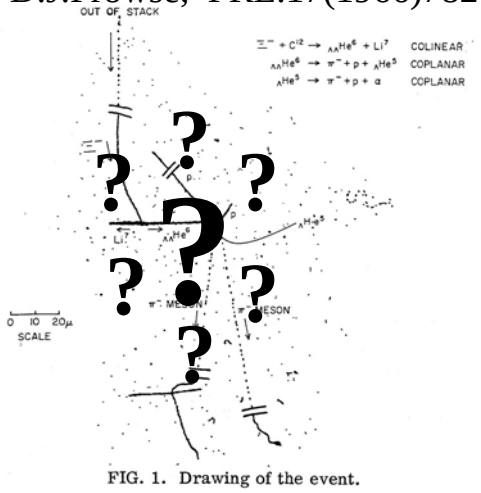
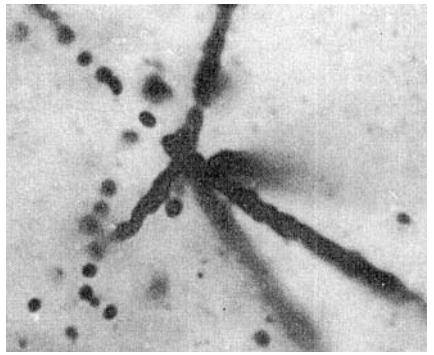


FIG. 1. Drawing of the event.

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

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

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



KEK-E176

in ~80 Ξstops

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

$\Delta B_{\Lambda\Lambda} = \mathbf{4.9}^{+0.7}_{-0.8}$ MeV

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

$\Delta B_{\Lambda\Lambda} => \sim \mathbf{0}$ MeV

or

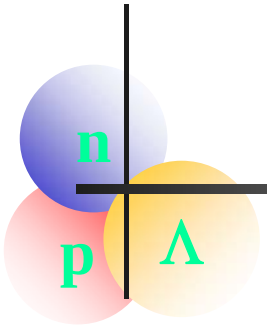
$^{10}_{\Lambda\Lambda}$**Be**

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

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

"interesting theoretical problem"

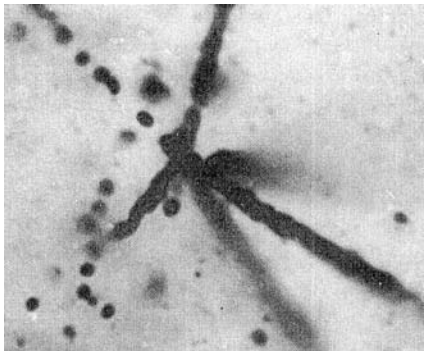
C.B.Dover, Proc. HYP91, NP.A547(1992)27c



in this 10 years

PS-E176 (KEK)

in ~80 Ξ^- stops



Double-Hypernucleus with sequential decay surely exists.

PS-E373 (KEK)

in ~700 Ξ^- stops

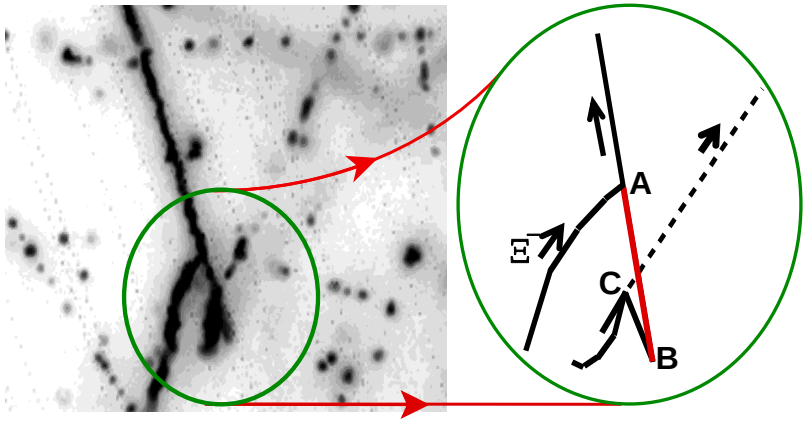
- **7: double-hypernuclei**
- **3: twin-hypernuclei**
- **1: Σ^-emission at Xi-stopping point**

Double-Hypernuclei found by KEK-E373

Demachi-yanagi event

* two body case at point A
$\Xi^- + {}^{12}C \rightarrow {}^{10}_{\Lambda\Lambda}Be + t$ or ${}^{10}_{\Lambda\Lambda}Be^* + t$

* three body case at point A
$\Xi^- + {}^{14}N \rightarrow {}^{13}_{\Lambda\Lambda}B + p + n$



NAGARA event

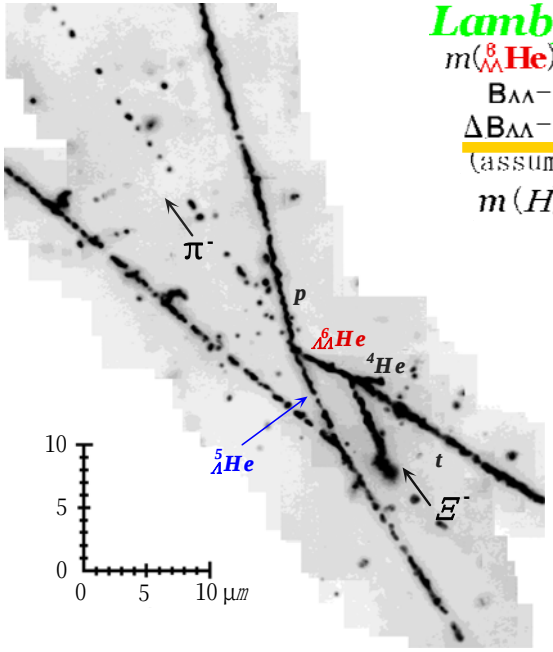
${}^{6}_{\Lambda\Lambda}He$ double-hypernucleus

Unique interpretation!!

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

${}^{6}_{\Lambda\Lambda}He \rightarrow {}^{5}_{\Lambda}He + p + \pi^-$

P. R. L. 87, 212502(2001)



Lambpha

$m({}^{8}_{\Lambda\Lambda}He) = 5951.82 \pm 0.54$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)

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

$\Delta B_{\Lambda\Lambda}$: $\Lambda\Lambda$ Interaction Energy

$\Delta B\Lambda\Lambda = B_{\Lambda\Lambda}({}_{\Lambda\Lambda}{}^{A}Z) - 2B_{\Lambda}({}^{A-1}_{\Lambda}Z)$

Found

Weakly attractive $\Lambda\Lambda$ Interaction !

Hybrid Method ==> Reliable

Events of double-hypernucleus from KEK-E373

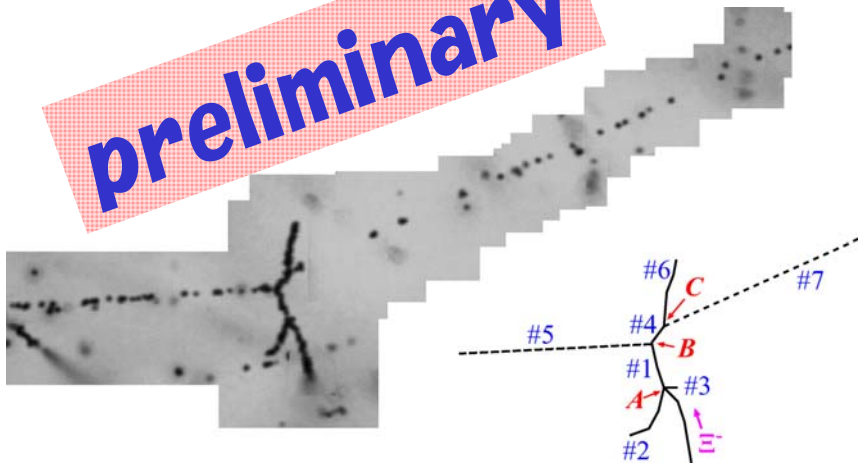
Analysis in progress

2002 **#3**

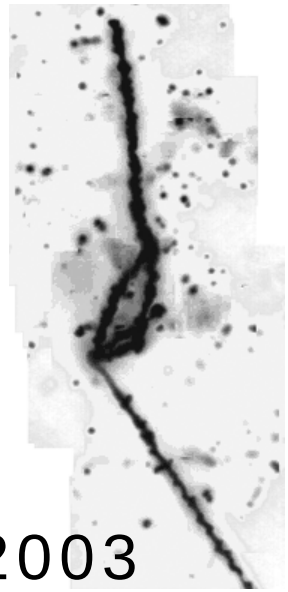
3rd double-Λ hypernucleus

Nuclear species of the double-Λ can be ${}^{6}_{\Lambda\Lambda}\mathrm{He}$, ${}^{7}_{\Lambda\Lambda}\mathrm{He}$ or ${}^{11}_{\Lambda\Lambda}\mathrm{Be}$.

preliminary

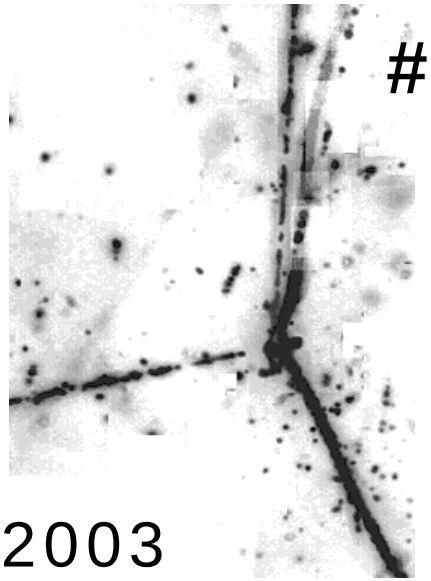


#4



2003

#5



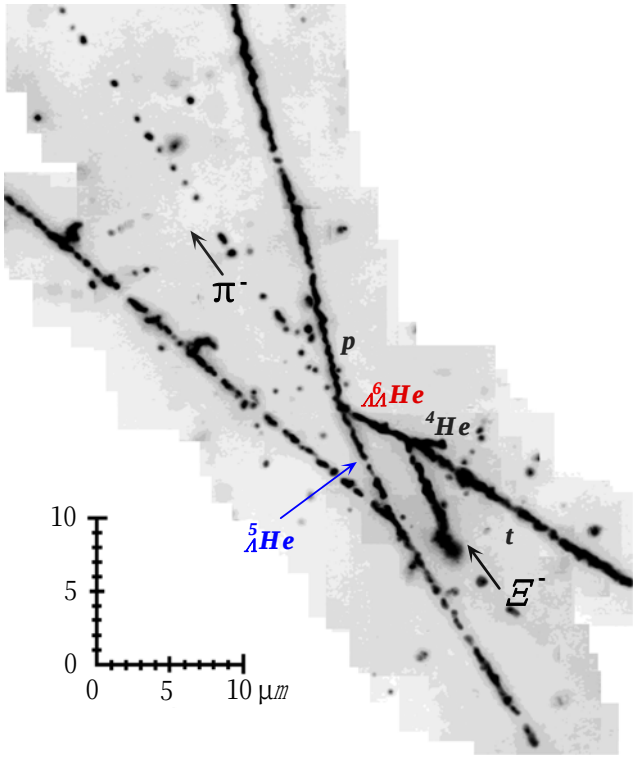
2003

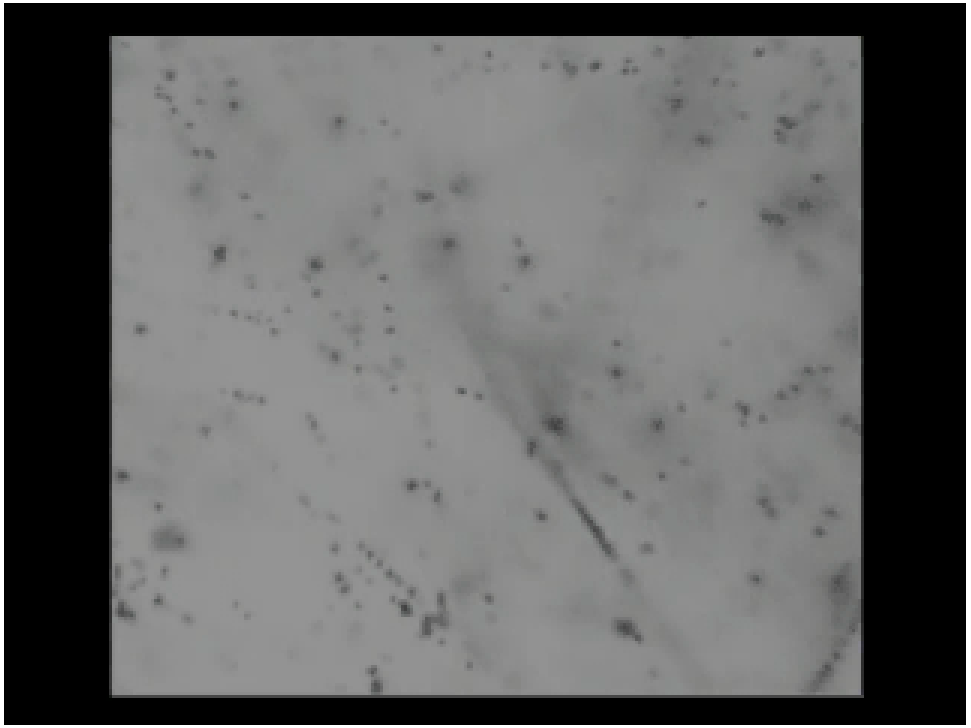
2004 **#6 (still candidate)**

NAGARA event

Observation of a Lambpha

Success of Emulsion detector with micro-meter accuracy



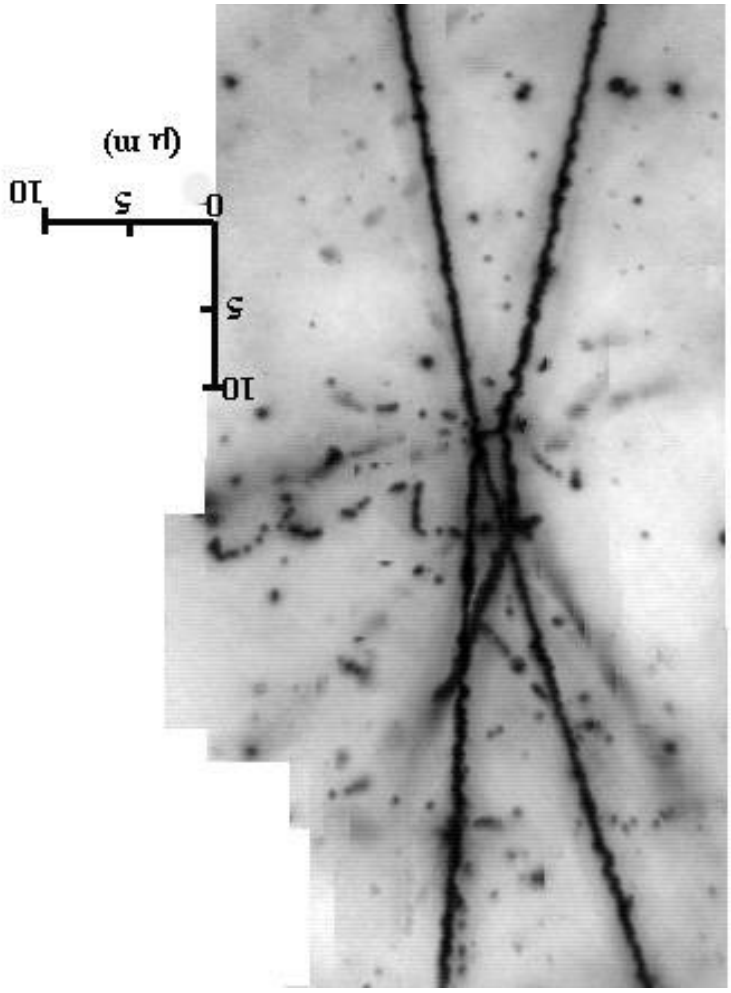


“ the most significant result of the past 5 years in hypernuclear physics. ”

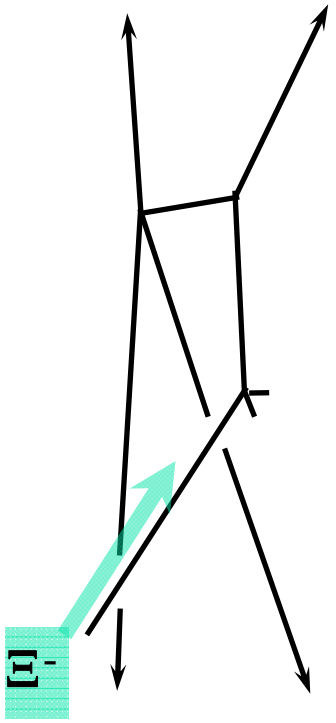
Final Report of the 2004 KEK PS

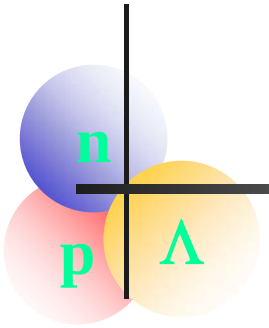
External Review Committee (August 30, 2004),p5.

7th Double Hypernucleus event



Mod#91
Pl#8
Event#3101-1
Double Hyper!

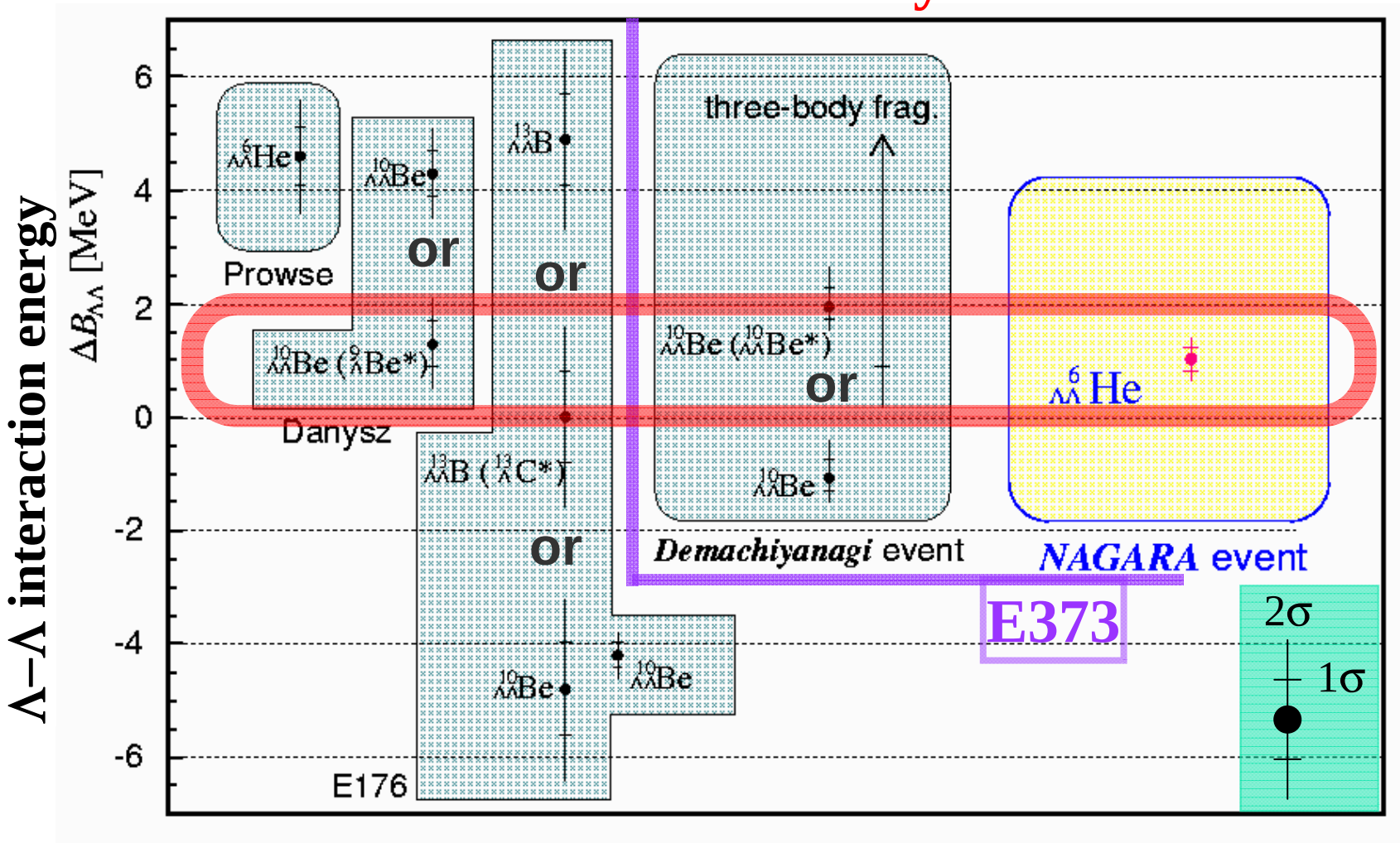


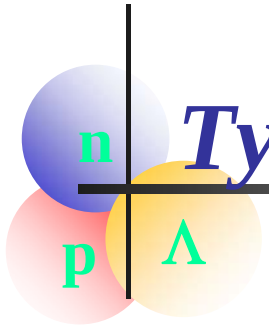


Comparison with past results

Our knowledge for ΛΛ int. until now.

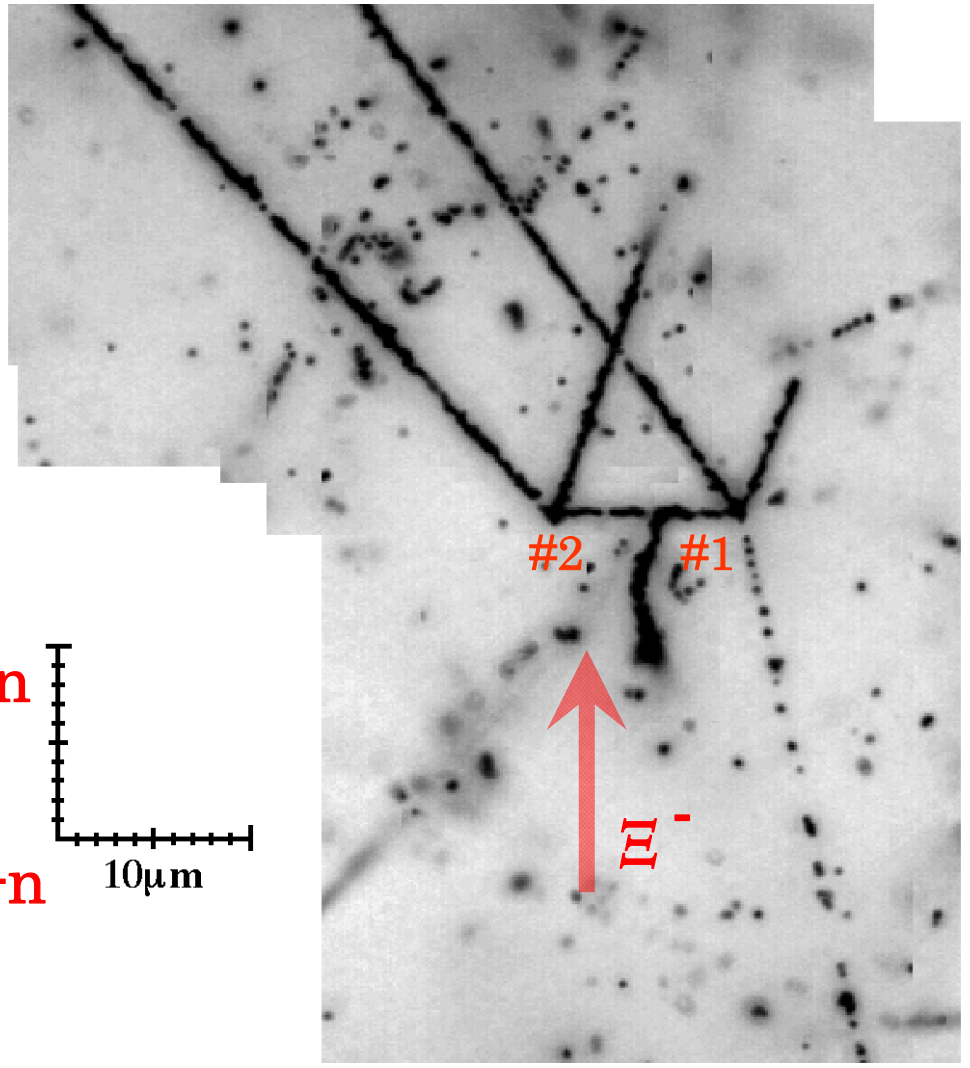
ΛΛ interaction is weakly attractive.





Typical Twin single-Λ hypernucleus

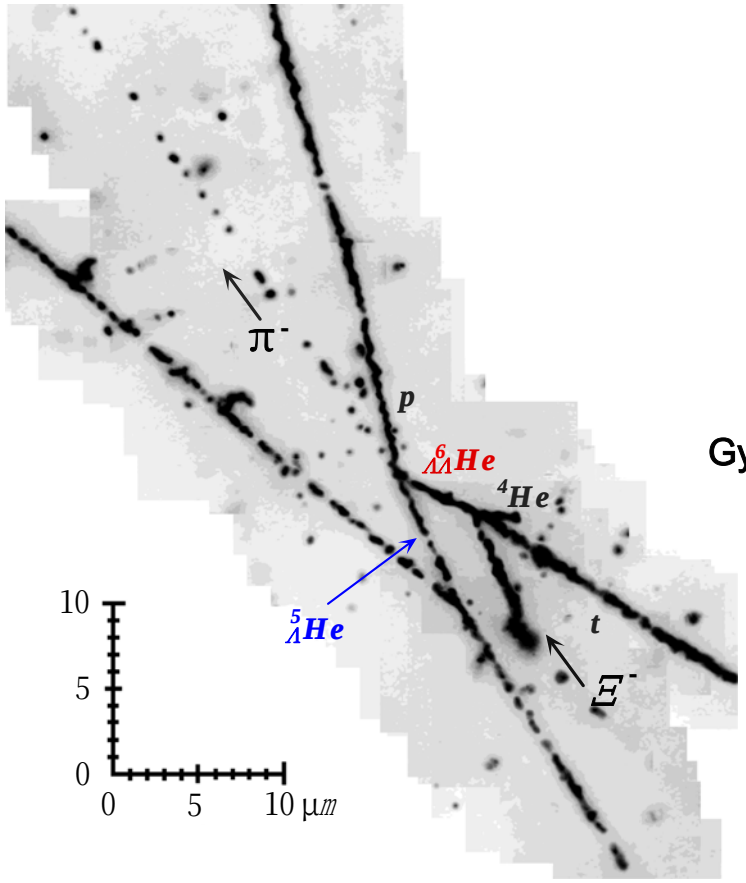
- $\Xi^- + {}^{12}C$
  - $\rightarrow {}^{6}_{\Lambda}He + {}^{7}_{\Lambda}Li$
  - $\rightarrow {}^{5}_{\Lambda}He + {}^{7}_{\Lambda}Li + n$
- $\Xi^- + {}^{14}N$
  - $\rightarrow {}^{5}_{\Lambda}He + {}^{9}_{\Lambda}Be + n$



the E07 experiment at J-PARC

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

NAGARA event (KEK-E373)



Kyoto: E.Hayata, M.Hayata, M.Hirose, K.Imai, S.Kamigaito, A.Okamura, K.Tanida, M.Togawa, T.Tsunemi

Gifu: M.Kawasaki, Y.Nakanishi, K.Nakazawa, K.T.Tint, M.Ukai

Tohoku: K.Hosomi, T.Koike, Y.Ma, K.Shirotori, H.Tamura

AMU: R.Hasan

BNL: R.E.Chrien

CIAE: Y.Y.Fu, C.P.Li, Z.M.Li, J.Zhou, S.H.Zhou, L.H.Zhu

Chonnam: J.Y.Kim

Dongshin: M.Y.Pac

Fukui: T.Yoshida

Gyeongsang: K.S.Chung, S.H.Kim, J.S.Song, C.S.Yoon

KEK: M.Ieiri, H.Noumi, N.Saito, M.Sekimoto, H.Takahashi

Nagoya: K.Hoshino, T.Kawai, B.D.Park, T.Sato, T.Watabe

NIRS: N.Yasuda

OsakaCity: K.Yamamoto

Pusan: J.K.Ahn, S.Y.Ryu

Shanxi: D.H.Zhang

Toho: C.Fukushima, M.Kimura, S.Ogawa, H.Shibuya

UCL: D.H.Davis, D.Tovee

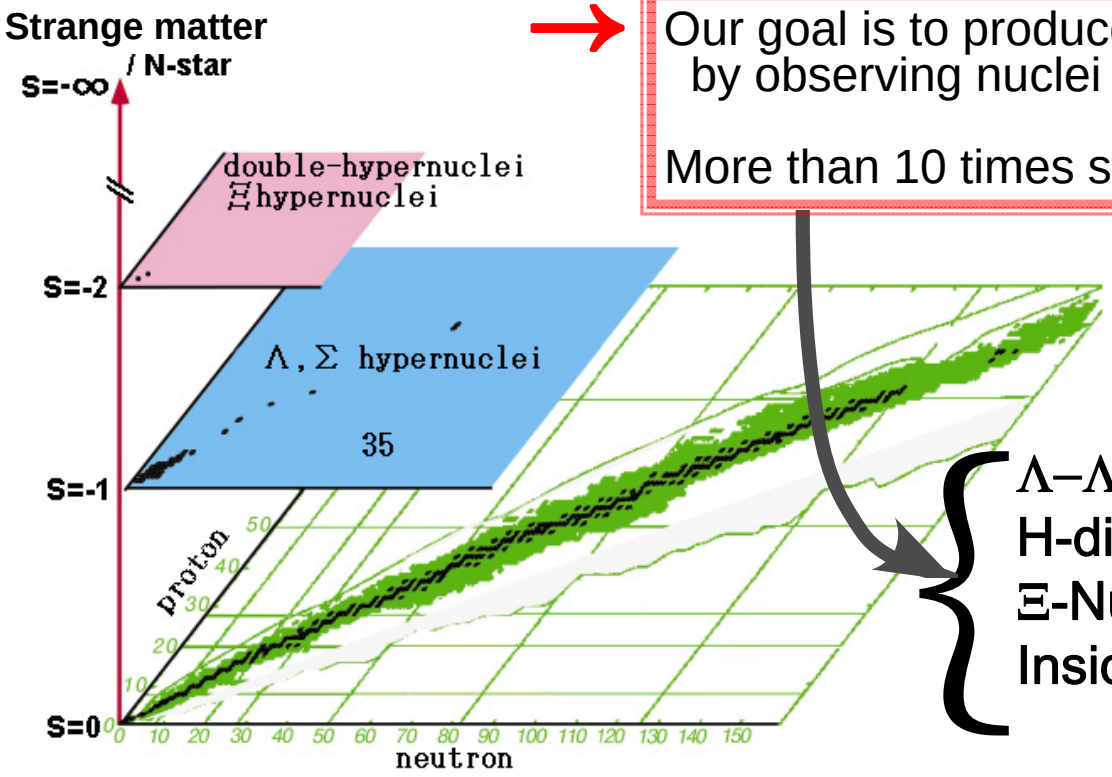
U.Houston: Ed.Hungerfold

U.New-Mexico: B.Bassalleck

Physics Motivation of the Planning Exp.

n p Λ

✱ detection of 10^2 or more candidate events with S = –2,
→ Discovery of 10 or more nuclear species.



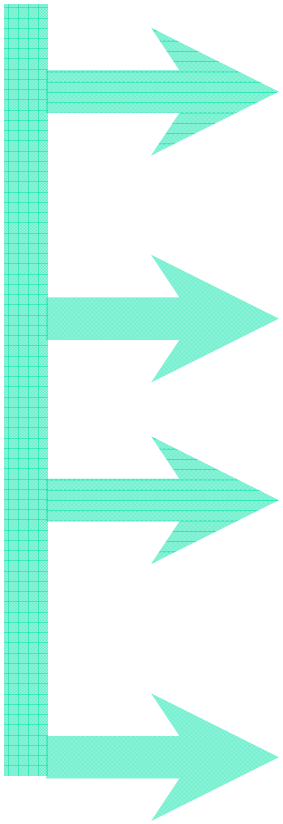
Our goal is to produce a S=-2 nuclear chart,
by observing nuclei with S=-2 as many as possible.

More than 10 times statistics than previous E373.

Λ–Λ Interaction,
H-dibaryon,
Ξ-Nucleus Interaction,
Inside Neutron Stars (Quark-star?)

Outlook for E07

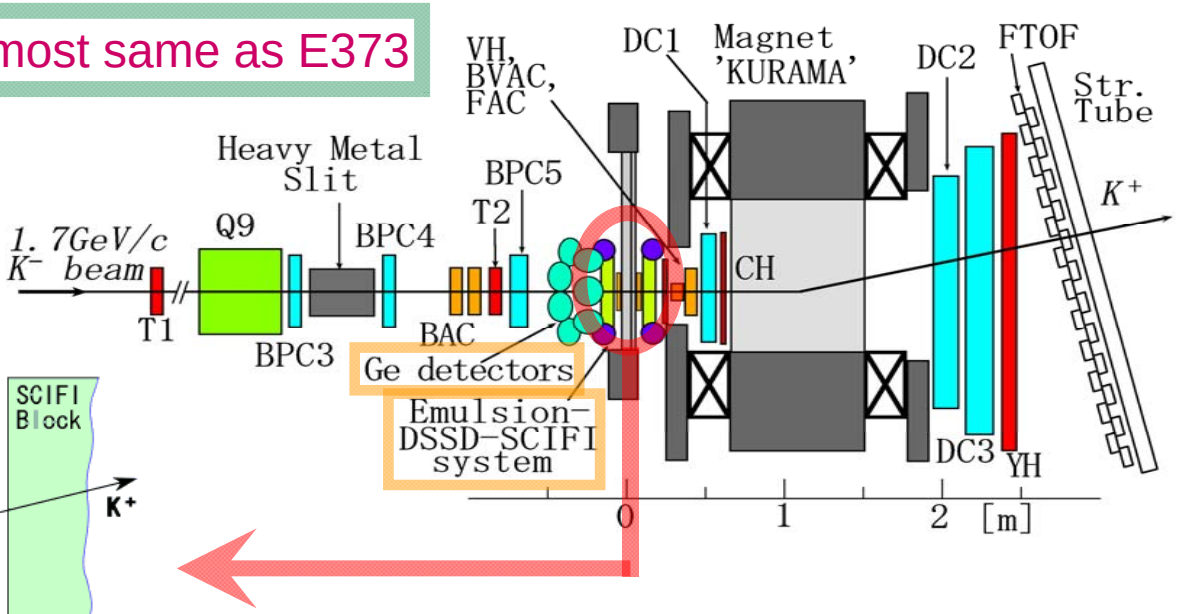
~10^4 Ξ^-stops

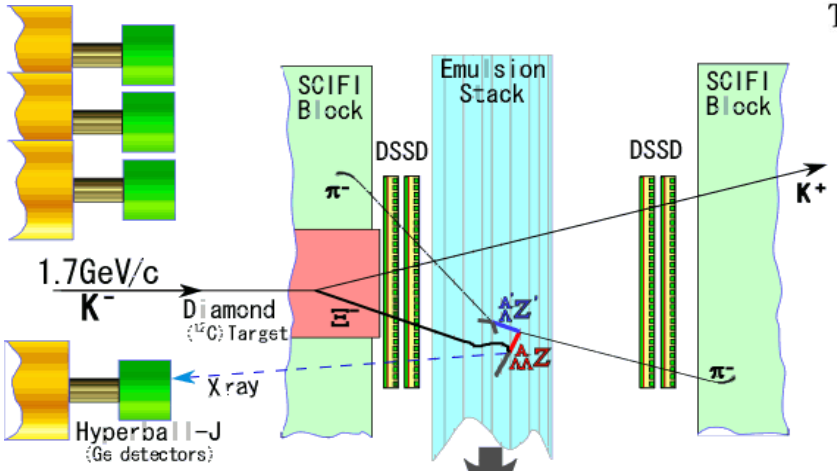


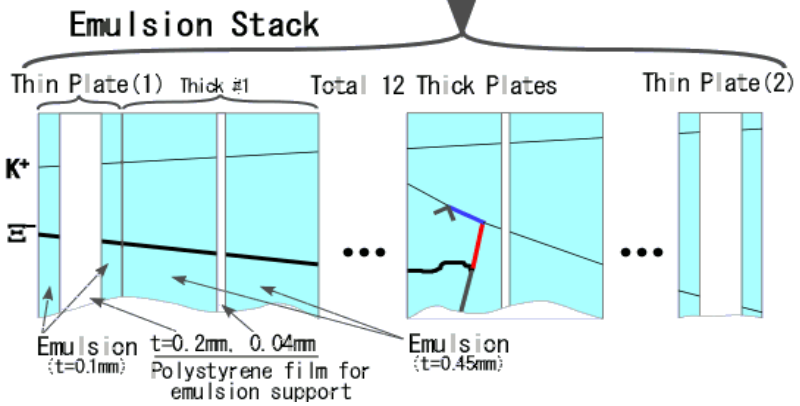
1. ~10^2 S=-2 nuclei
   - => S= -2 nucl. chart
   - => Int. energy mass number dep.
2. Σ^- decay events
   - => S= -2 mixing and/or H-state
3. Ξ-nucleus int.
   - <= Ξ atomic X-ray
   - <= Twin Hypernuclei
4. new phenomena ?

Setup of the E07 experiment

Almost same as E373







Beam : K⁻ (1.7GeV/c),

3 x 10⁵ K⁻/spill with **K⁻/π⁻ > 6**

at **K1.8 beam-line** **(~20% of 9μA)**

Trigger : **(K-, K+)**

=> 10⁴ Ξ⁻ stopping events

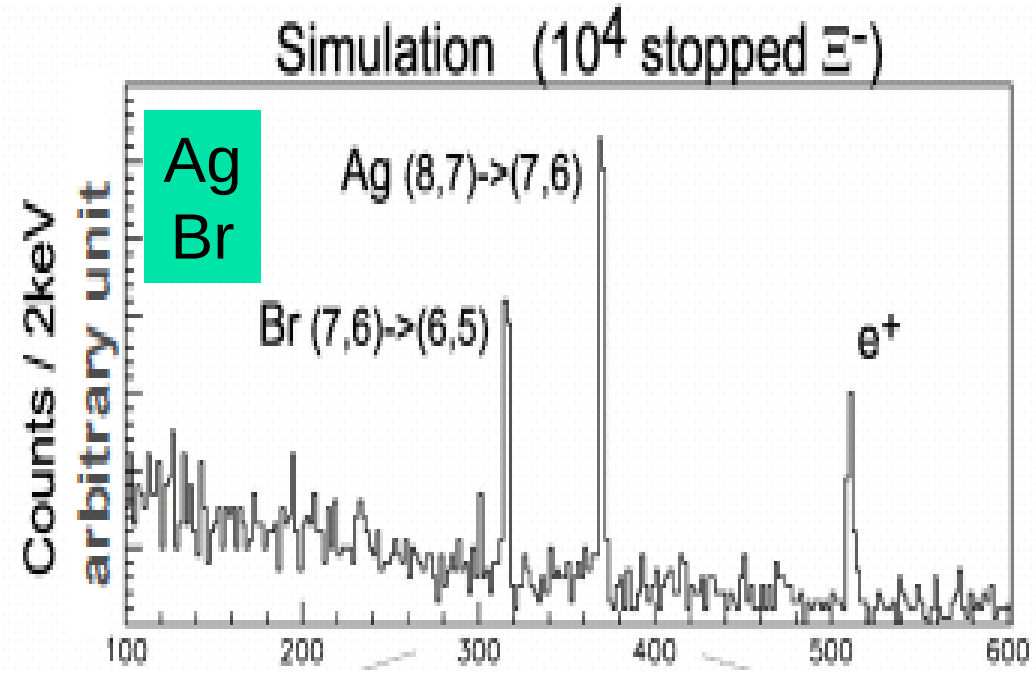
(more than 10 times higher stat. than E373)

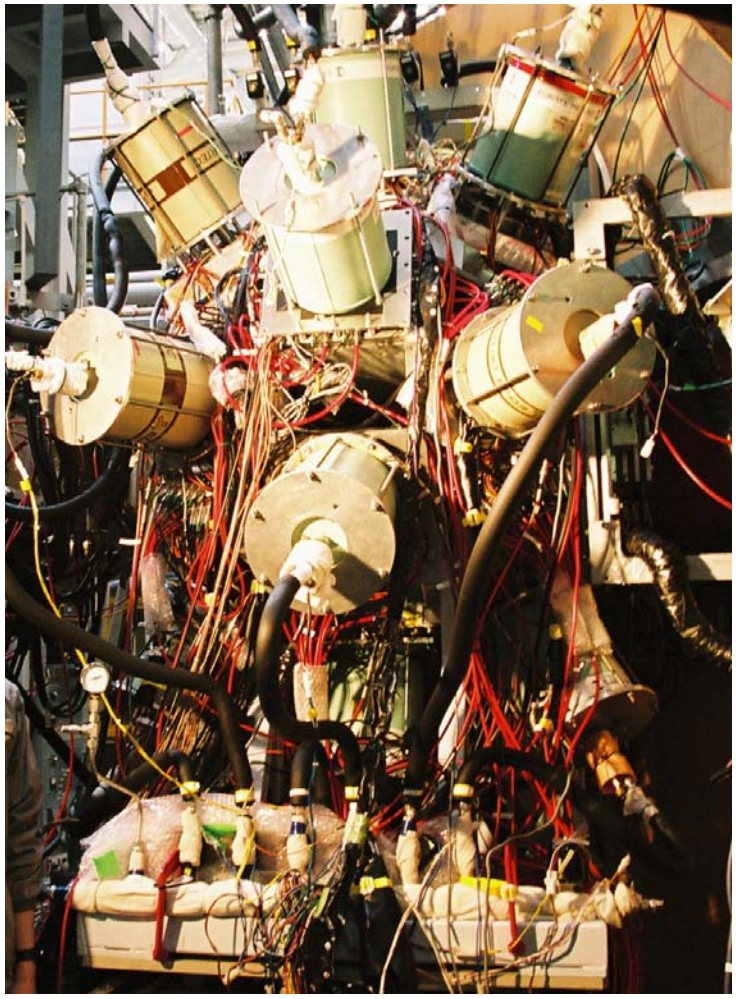
X-ray measurement of Ξ atom

HYPERBALL

==> **HYPERBALL-J**

J-PARC E07

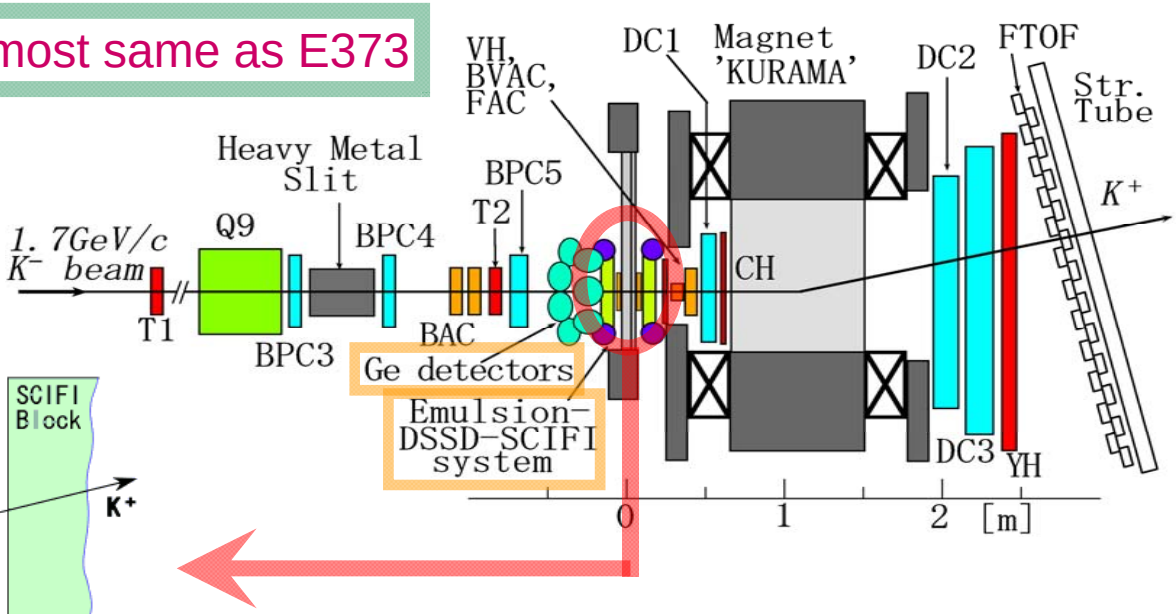


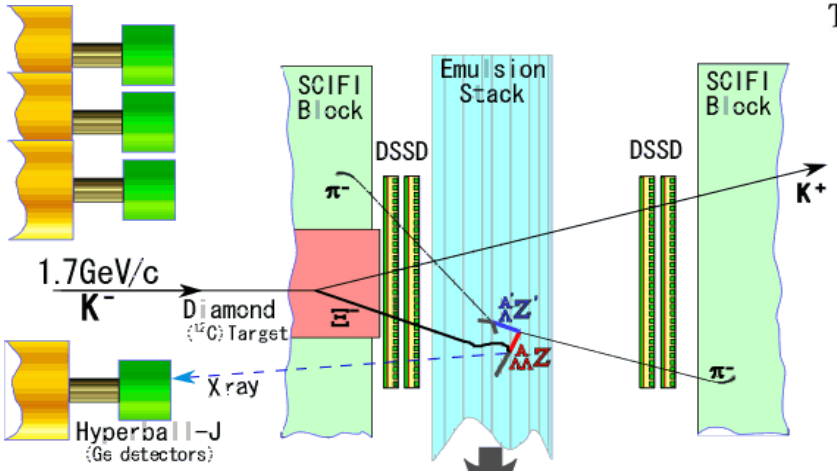


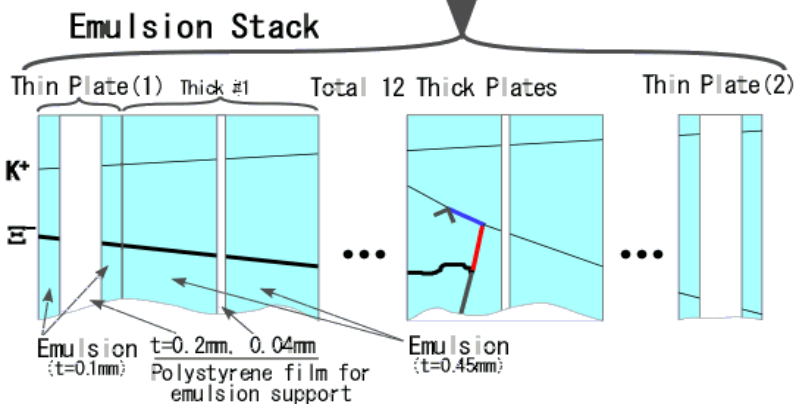
precisely measurement of Xi-Nucleus int.

Setup of the E07 experiment

Almost same as E373







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3 x 10⁵ K⁻/spill with **K⁻/π⁻ > 6**

at **K1.8 beam-line** **(~20% of 9μA)**

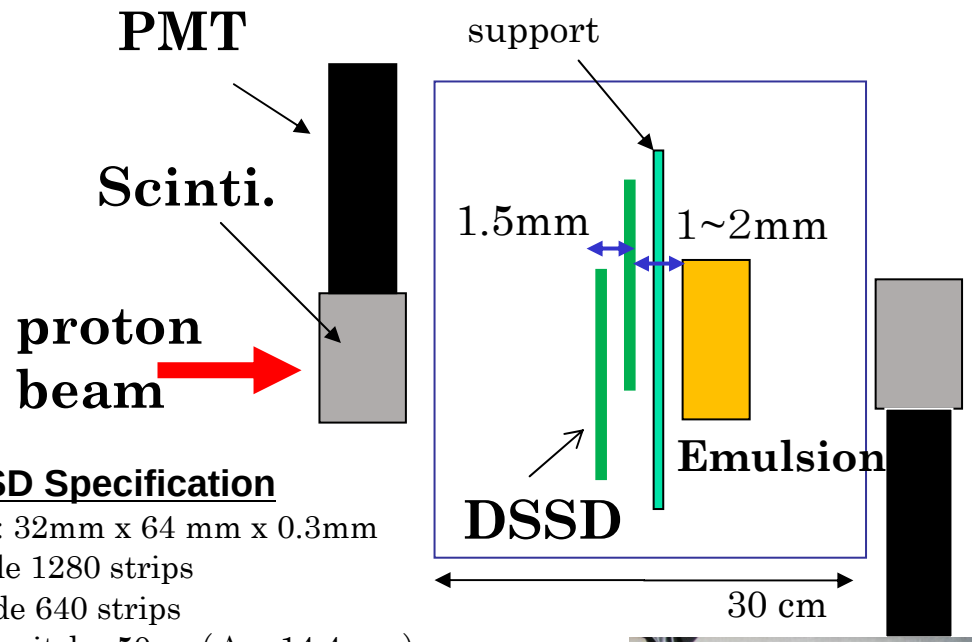
Trigger : **(K-, K+)**

=> 10⁴ Ξ⁻ stopping events

(more than 10 times higher stat. than E373)

performance of developed DSSD

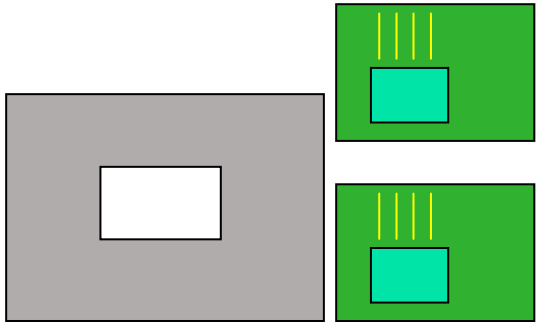
Test exp. of DSSD at RCNP- R78 (Dec.,2006)

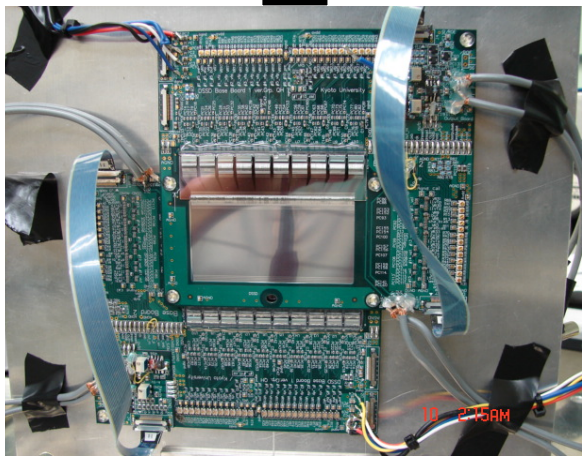


- Beam **Proton**(136.2 MeV)
- Incident angle
  0°, 15°, 20°, 30°, 45°, 50°
- Track density in the Emulsion
  3 protons/[mm²]
- Gap [DSSD <=> DSSD]
  1.5mm
- Gap [DSSD <=> emulsion]
  1~2mm

DSSD Specification

size : 32mm x 64 mm x 0.3mm
P-side 1280 strips
N-side 640 strips
Strip pitch : 50μm (Δr=14.4μm)
S/N ration : p-side 31.03±0.16
n-side 24.46±0.13





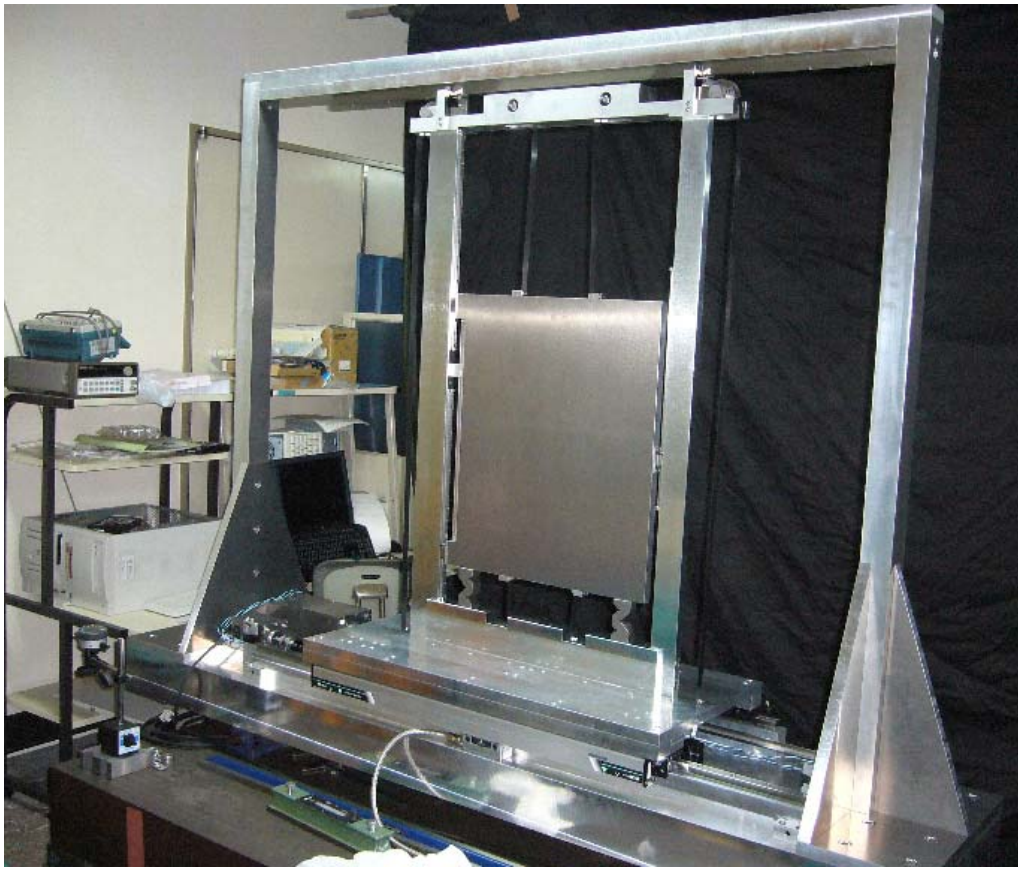
Result

Δposition : 20~45 um

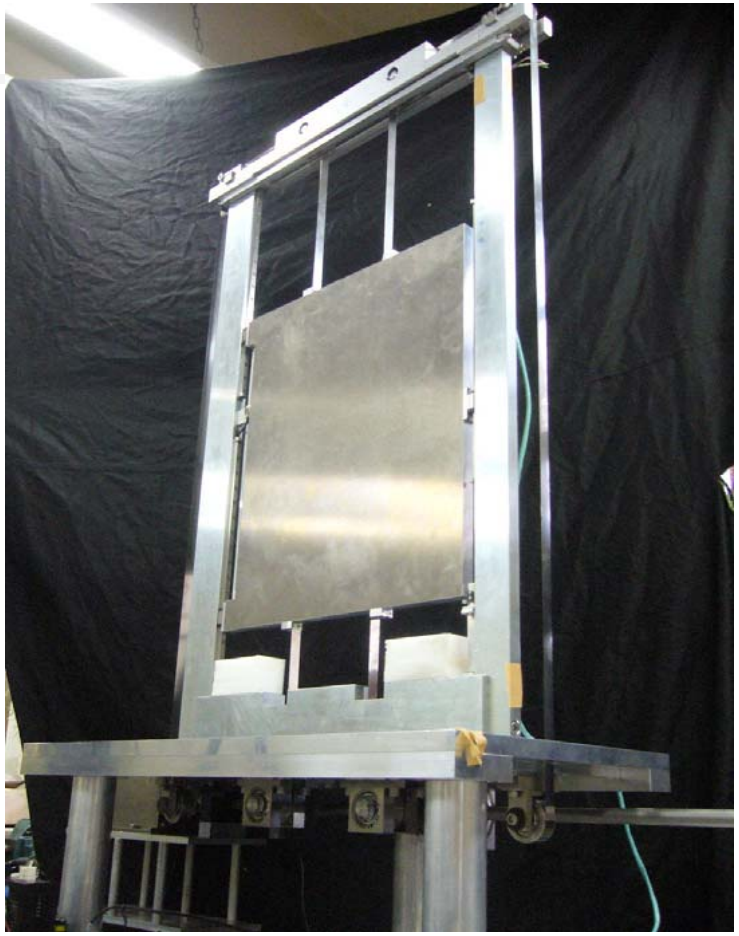
Δangle : 10~20 mrad

good enough!!
S/N ~ 10times
than E373

Emulsion mover



by Kyoto & Nagoya



position accuracy
<10μm
steal belt
max. speed
x : 25mm/sec
y : ~5mm/sec

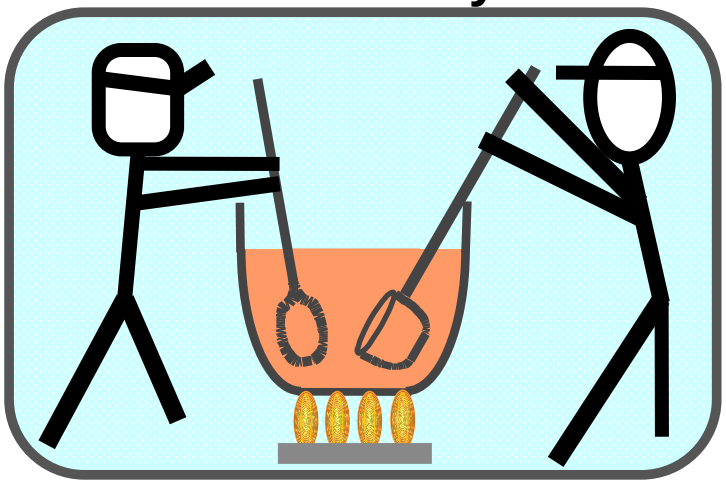
Production method of emulsion

New method of Emulsion gel. production

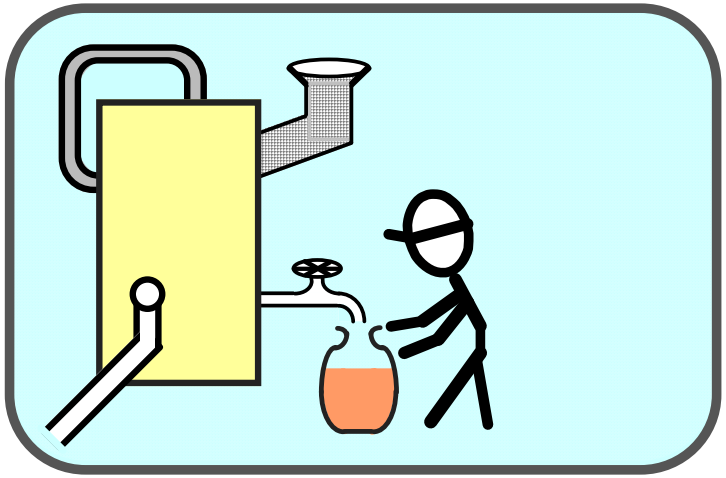
For the proposed exp., amount of emulsion gel => 2.6 tons

Fuji-film needs one year or more by conventional way.

Conventional way by hand



Using the production lines for commercial films



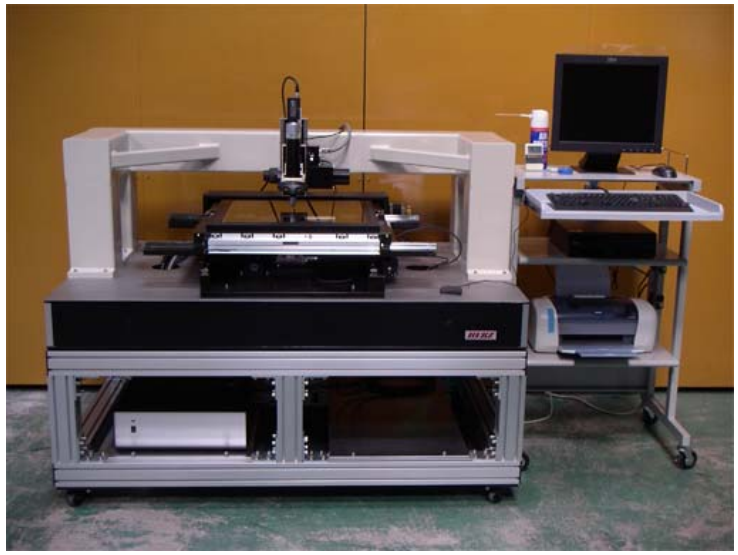
Tested by particle beams with good results.
Half of necessary emulsion has been made!

Emulsion cost will be saved

50%

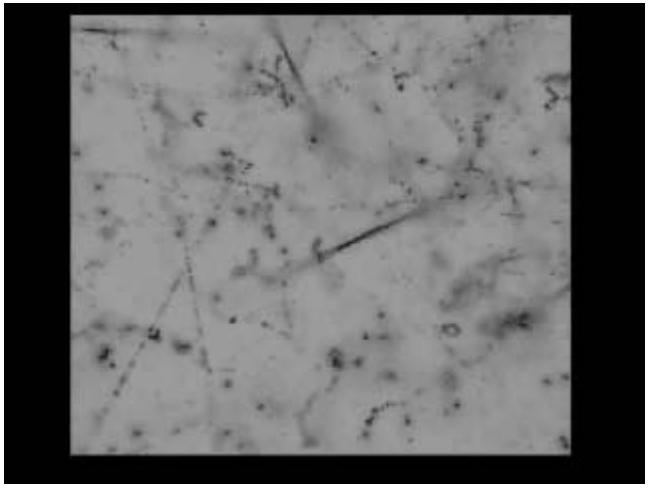
Emulsion scanning system

Area : **35×35** cm^2 ➔ **40×40** cm^2
Light : Halogen Lamp ➔Ultra High-bright **LED**
speed : × 2
tracking eff. : × 1.5
# of System : **6** (old, E373) ➔**7** (new) + **3** (old)

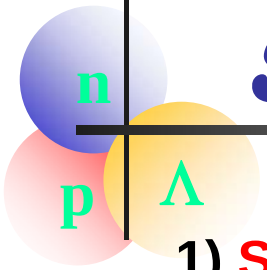


Old system

New system



Scanning for this experiment : **more speed-up** [× **6** than old system]
(1) Develop scanning algorism (2) **Optimize the area for scanning**



Summary

1) **S=-2 nuclear chart** by **~10^2 $_{\Lambda\Lambda}^{\ \ A}Z$** via **$10^4$ Ξ^--stopping events**.

=> **$\Delta B_{\Lambda\Lambda}$ of several nuclides** will provide definitive information on ΛΛ interaction and structure of S=-2 nuclei.

2) **H-dibaryon state** in S=-2 system ?

=> measure **A-dependence of $\Delta B_{\Lambda\Lambda}$** & **$\Sigma^-$decay mode of $_{\Lambda\Lambda}^{\ \ A}Z$**.

3) **Ξ^--nucleus potential**

=> detection of **twin hypernuclei**
=> First measurement of **X-ray** of **Ξ^-atom**

<== E07 (J-PARC)

We will handle 2.6t emulsion gel, soon (? Dec.2009)