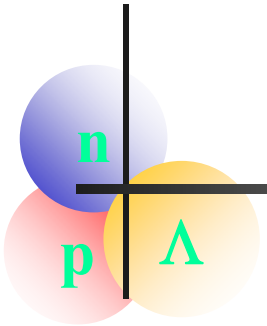


Double-Λ hypernuclei at J-PARC

E07 experiment

Systematic Study of Double Strangeness System with the Emulsion-counter Hybrid Method

Kazuma Nakazawa
Phys. Dept., Gifu Univ., JAPAN

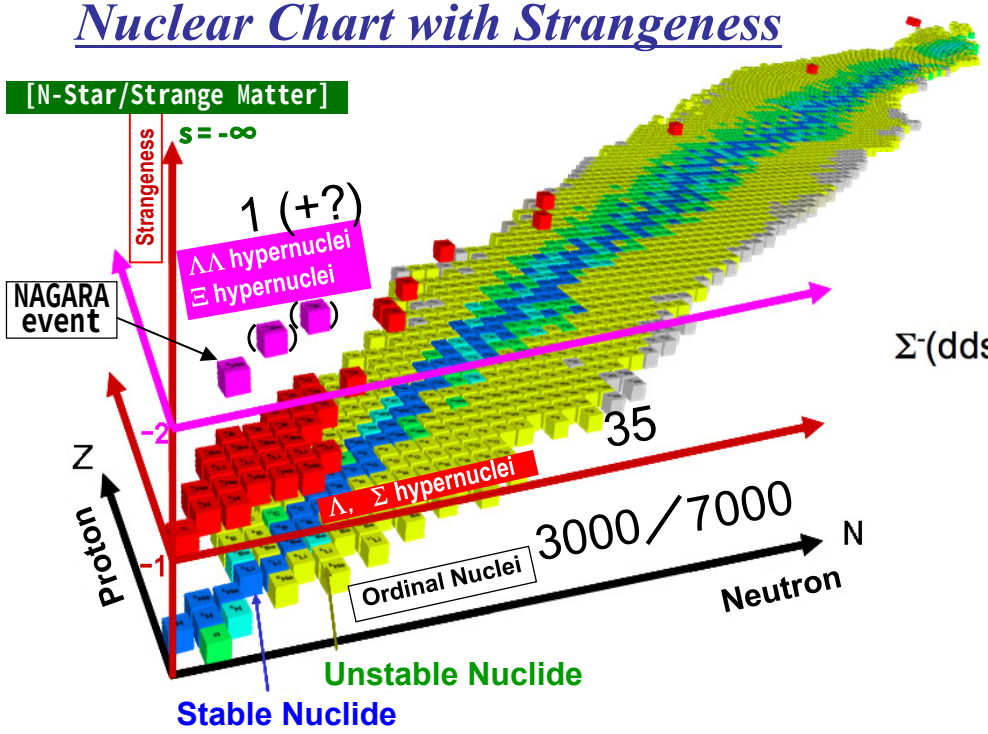
Outline

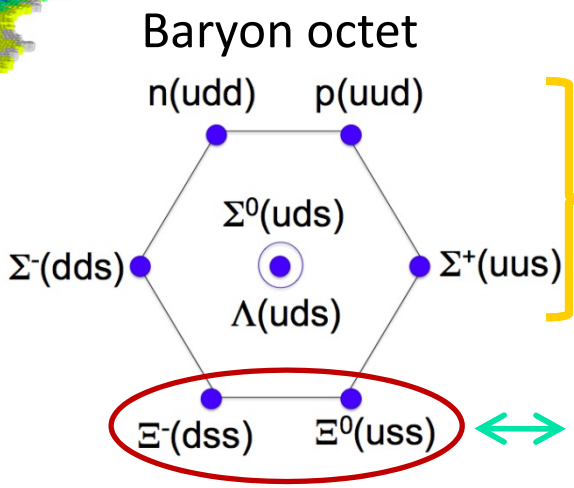
1. Experimental motivation for double-Λ hypernuclei
2. Strategy of the E07 experiment
   - ***2-1 Collaborators***
   - ***2-2 Experimental setup***
   - ***2-3 New developed hybrid-emulsion method***
   - ***2-4 Overall detection method***
   - ***2-5 Sample events by Overall method***
3. Summary

1. Experimental motivation for study of double-Λ hypernuclei

Study of hadron-hadron interaction

Nuclear Chart with Strangeness





·N-N interaction

Continuous research in experiment and theory for more than 50 years

· Y-N interaction where Y = (Σ, Λ)

Steadily Progressing

↔ Next subject

Study of

- **Λ-Λ interaction**
- **Ξ-N interaction**

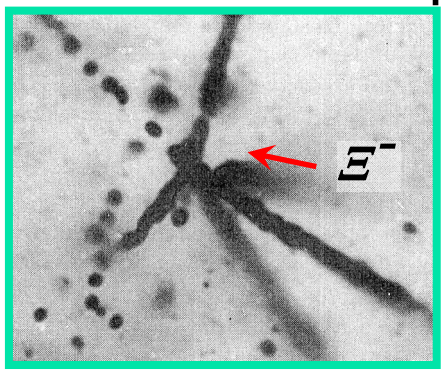
One of the most powerful methods for the detection of DHN

→ Emulsion experiment !!

List of double-Λ hypernuclei

KEK-E176

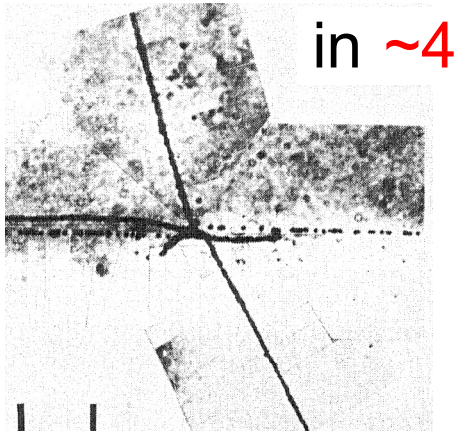
in ~80 Ξ⁻ stops



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

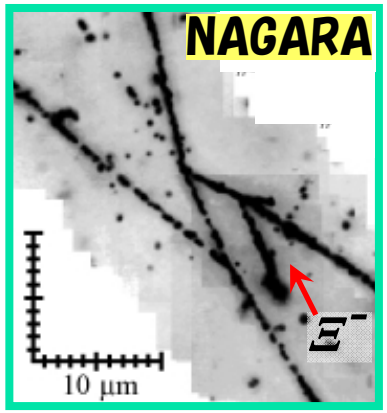
M.Danysz et al., PRL.11(1963)29;
R.H.Dalitz et al., Proc. R.S.Lond.A436(1989)1

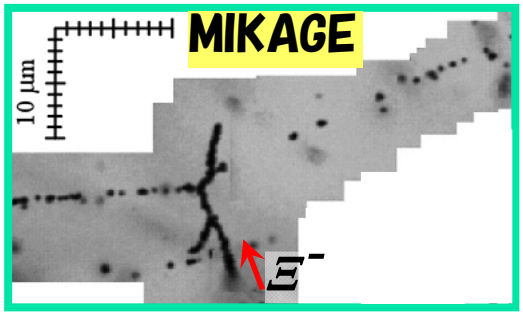
in ~4 Ξ⁻ stops

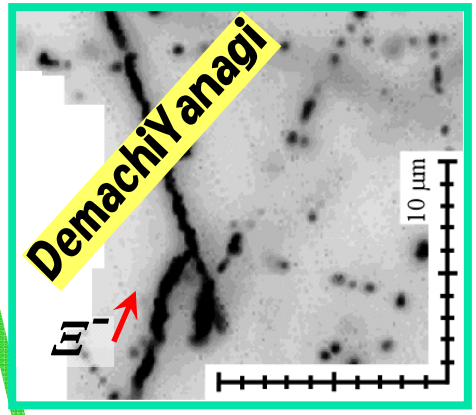


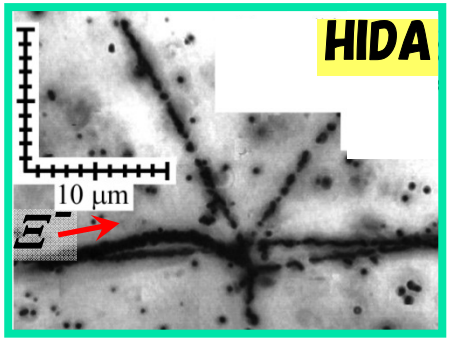
KEK-E373

~ 2×10^4 Ξ⁻ tracks (followed) ➡ ~ 10^3 Ξ⁻ stops





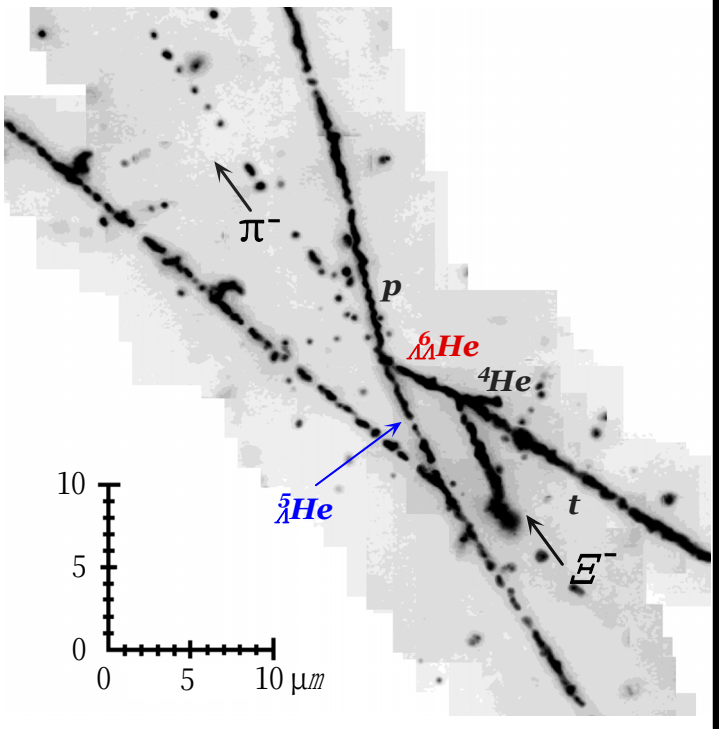




4 D.H.N in 7 samples by E373

summarized in
PHYSICAL REVIEW **C88**, 014003(2013) J.K.Ahn *et al.*

NAGARA event



J.K.Ahn, et al, Phys. Rev. C88 (2013) 014003

Double-Λ hypernuclei in the world

By checking consistency of $\Delta B_{\Lambda\Lambda}$ (NAGARA) within 3 STD. errors,

Most likely assignment

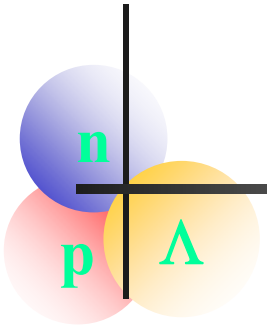
	${}^{A}_{\Lambda\Lambda}Z$	Ξ^- Captured	$B_{\Lambda\Lambda}$ - B_{Ξ^-} [MeV]	$\Delta B_{\Lambda\Lambda}$ - B_{Ξ^-} [MeV]	Assumed level	$B_{\Lambda\Lambda}$ [MeV]	$\Delta B_{\Lambda\Lambda}$ [MeV]
NAGARA	${}^{6}_{\Lambda\Lambda}$He	^{12}C	$B_{\Lambda\Lambda}$ = 6.79 + 0.91B_{Ξ^-} (+/- 0.16) $\Delta B_{\Lambda\Lambda}$ = 0.55 + 0.91B_{Ξ^-} (+/- 0.17) B_{Ξ^-} < 1.86		3D	6.91 +/- 0.16	0.67 +/- 0.17
MIKAGE	${}^{6}_{\Lambda\Lambda}$He	^{12}C	9.88 +/- 1.71	3.64 +/- 1.71	3D	10.01 +/- 1.71	3.77 +/- 1.71
DEMACHI-YANAGI	${}^{10}_{\Lambda\Lambda}$Be*	^{12}C	11.77 +/- 0.13	-1.65 +/- 0.15 *cf.* Ex = 2.8	3D	11.90 +/- 0.13	-1.52 +/- 0.15 *cf.* Ex = 2.8
HIDA	${}^{11}_{\Lambda\Lambda}$Be	^{16}O	20.60 +/- 1.27	2.38 +/- 1.34	3D	20.83 +/- 1.27	2.61 +/- 1.34
	${}^{12}_{\Lambda\Lambda}$Be	^{14}N	22.31 +/- 1.21	------	3D	22.48 +/- 1.21	------
E176	${}^{13}_{\Lambda\Lambda}$B -> ${}^{13}_{\Lambda}$C*		------ Ex = 4.9	-------	3D	23.3 +/- 0.7	0.6 +/- 0.8
	${}^{10}_{\Lambda\Lambda}$Be -> ${}^{9}_{\Lambda}$Be*		------ Ex = 3.0	-------	------ (from decay)	14.7 +/- 0.4	1.3 +/- 0.4

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

Theoretical calculations:

4-body Cluster …A=7-10 DoubleΛ. Hiyama *et al.*, PRC66 (2002) 024007

5-body Cluster Structure…${}^{11}_{\Lambda\Lambda}$Be. Hiyama *et al.*, PRL104 (2010) 212502



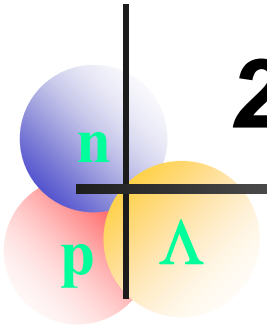
Experimental motivation

∗Detection of double hypernuclei

- 10 times' statistics of E373 (KEK-PS) ⇔ **10^4** Ξ-stop
  - ➔ **~10^2** double hypernuclei,
    ~10 identification of nuclide.
- **Nuclear (A) dependence** of Λ-Λ binding energy.
- Making **S = -2 nuclear chart**.
- **H-dibaryon**.
- **Ξ-N interaction** via twin hypernuclei.

∗Measurement of X ray from Ξ-atom

- **Ξ-N interaction**.



2. Strategy of the E07 experiment

2-1 E07 collaborators

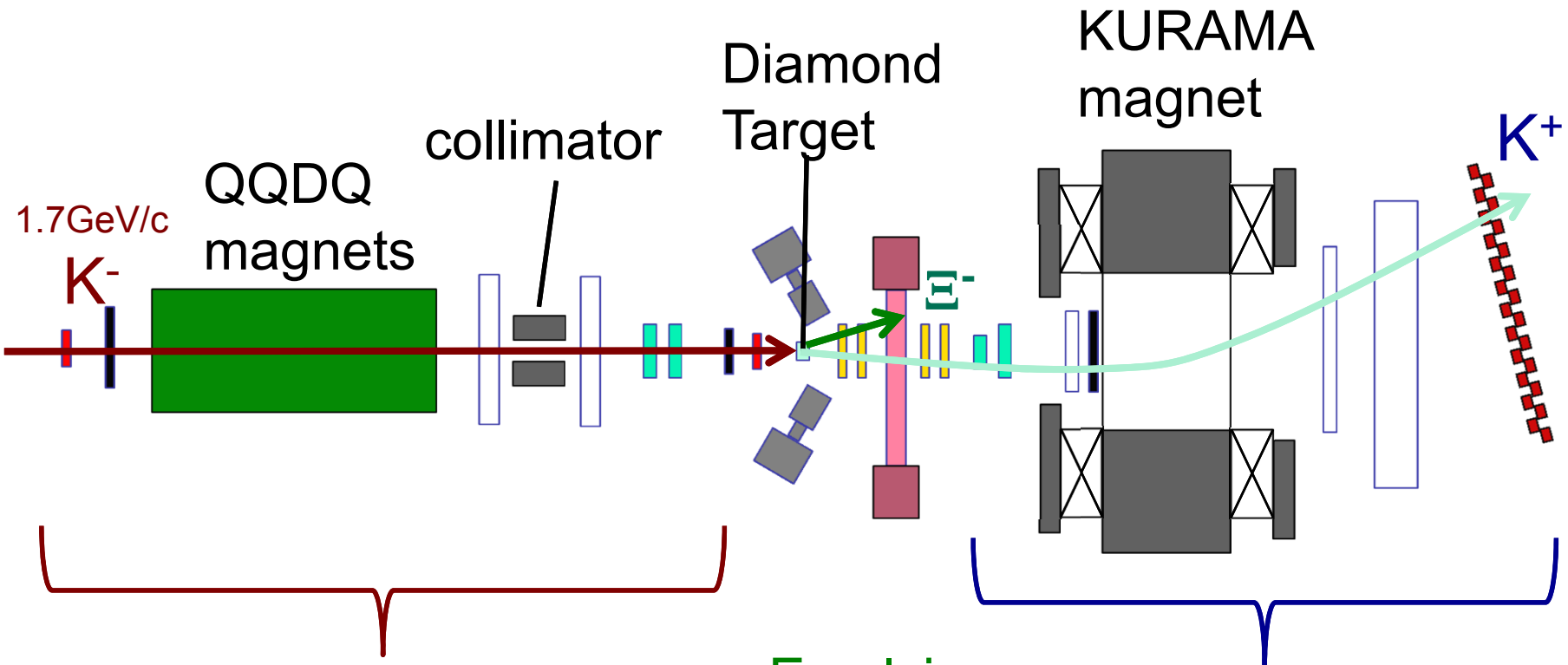
K.Imai[a], K.Nakazawa[b], H.Tamura[c], S.Ahmad[d], J.K.Ahn[e], B.Bassalleck[f], R.E.Chrien[g], D.H.Davis[h], H.Ekawa[i], Y.Y.Fu[j], S.Fukunaga[k], Y.Han[f], R.Hasan[d], S.Hasegawa[a], E.Hayata[i], M.Hirose[i], K.Hoshino[b], K.Hosomi[a], S.Hwang[a], M.Ieiri[l], K.Ito[m], K.Itonaga[b], T.Kawai[m], J.H.Kim[n], S.Kinbara[b], R.Kiuchi[o], T.Koike[c], H.S.Lee[e], J.Y.Lee[o], C.Li[j], Z.M.Li[j], A.Mishina[b], K.Miwa[c], H.Noumi[p], S.Ogawa[k], S.Y.Ryu[e], H.Sako[a], S.Sato[a], T.Sato[m], M.Sekimoto[l], H.Shibuya[k], K.Shirotori[p], M.K.Soe[q], H.Sugimura[a], M.Sumihama[b], H.Takahashi[l], T.Takahashi[l], K.Tanida[o], K.T.Tint[r], A.Tokiyasu[p], D.Tovee[h], M.Ukai[c], K.Umehara[b], 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]

[a]Japan Atomic Energy Agency (JAEA), Japan,
[b]Physics Department, Gifu University, Japan,
[c]Department of Physics, Tohoku University, Japan,
[d]Aligarh Muslim University, India,
[e]Pusan National 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, Toho University, 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]Adanabon University, Myanmar,
[s]University of Fukui, Japan,
[t]Shanxi Normal University, China.

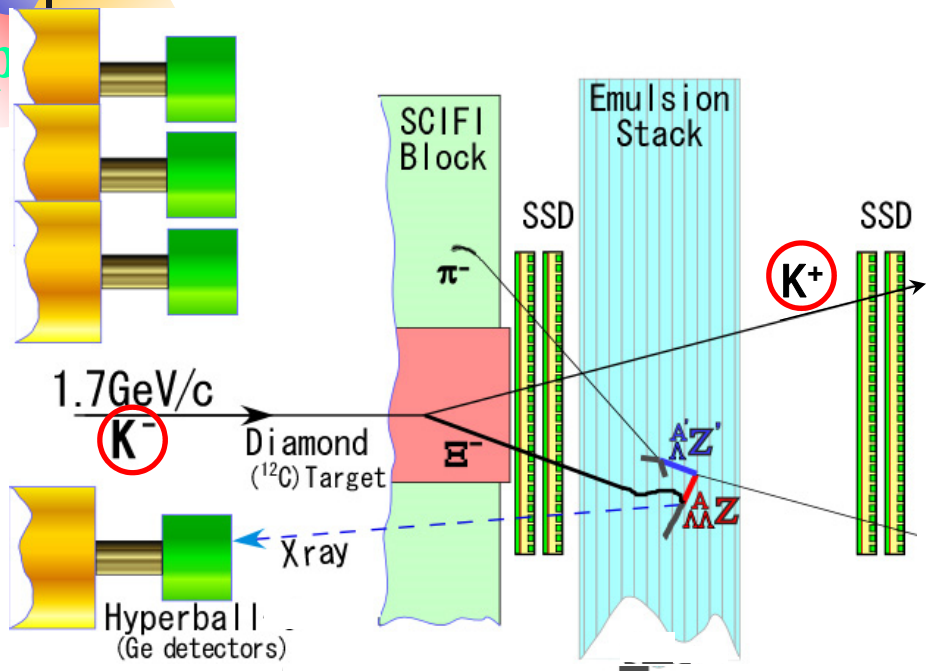
2-2 Experimental setup

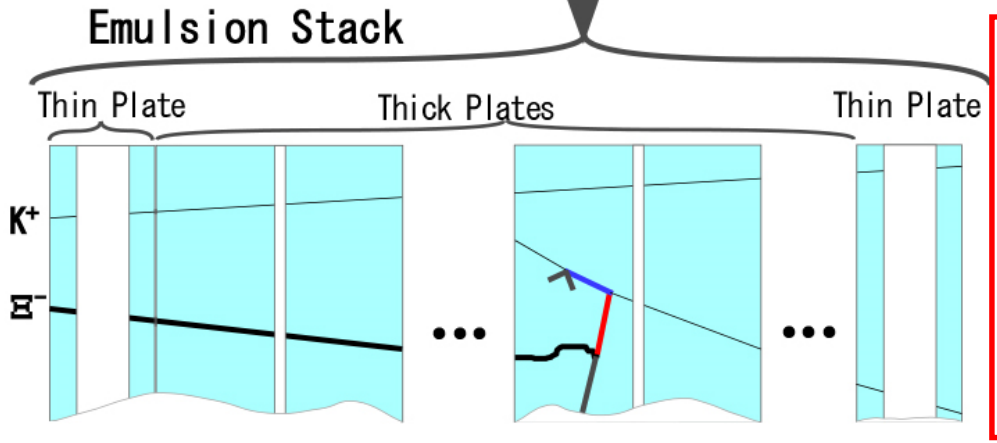
K1.8 Beam Line @J-PARC

➔ Q.F. (K-,K+) tagging



2-3 Newly developed hybrid-emulsion method





J-PARC

1. Pure K-beam (>70%)
   (better 3.5 times than KEK-PS)
2. More volume of emulsion (x 3)
   than previous E373 experiment

What is "hybrid"

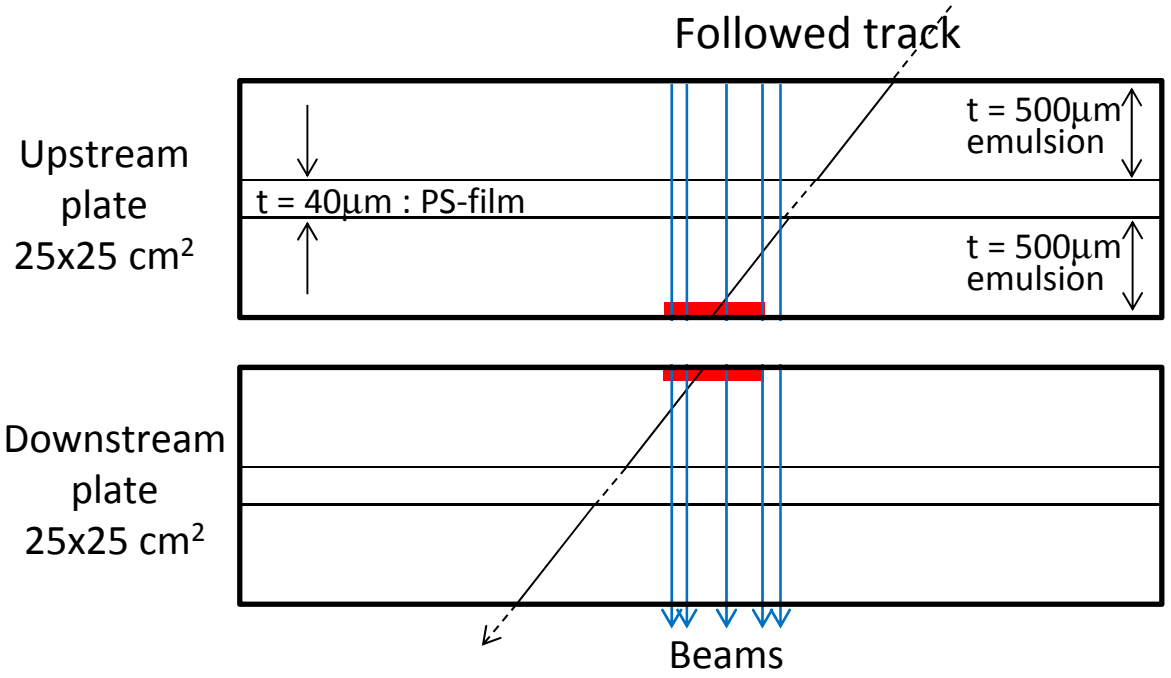
1. **Emulsion ⇔ SSD**
   unique detection of Ξ⁻ hyperon
   ➔ fast Ξ⁻ track following
2. **Emulsion ⇔ Hyperball (Ge)**
   Low noise detection of X-ray
   from Ξ atoms with stop info. by Em.

10^3 Ξ⁻ stop events (E373)
➔ 10^4 events (E07)

1. ~10^2 **double hypernuclei**
   => uniquely identification of
   DHN independent on NAGARA.
2. ~10^2 **X-rays**
   => study of Ξ-N interaction

2-3 Newly developed hybrid-emulsion method

Fully automated track-following system



1. **Beams** (~10^2 in one view of microscope) penetrate perpendicular to the plate.
2. **Image taking** can be done near the both surfaces (—).
3. Getting beam positions by **image processing**, and **position matching**.
4. We succeeded to align position in plate by plate with **1.2 +/- 0.7 μm** accuracy.

➔ **Track following of all Ξ^- hyperons (~ several × 10^4) can be done in one year.**

2-4 Overall detection method

Yield of the hybrid method

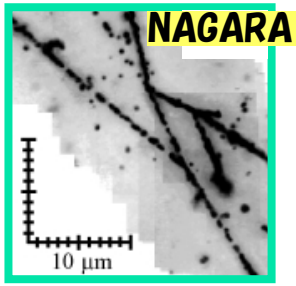
- Tagging yield is ~30%
  due to detector acceptance & tracking efficiency.

➔
- ~70% $\bar{p}$ $(K^-,K^+)\Xi^-$ events
- Ξ^- hyperons from $\bar{n}$ $(K^-,K^0)\Xi^-$ reaction

10 times higher statistics than that with the hybrid method

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

If Fully automatic detection of
3 vtx. event
like "NAGARA event"
with graphic processing,



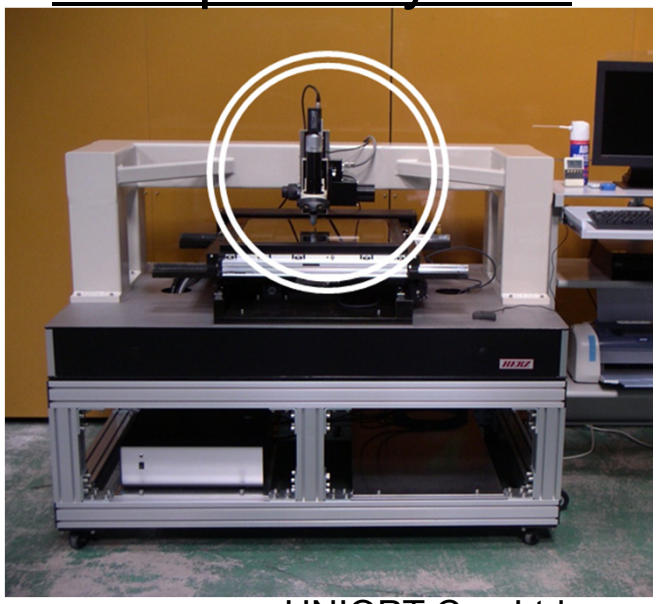
Overall detection method

➔ knowledge for
A-dependence
on ΛΛ interaction !!

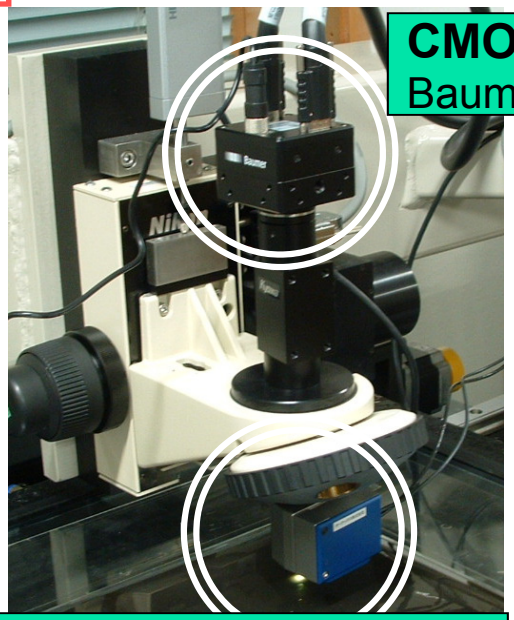
2-4 Overall detection method

Scanning systems

New piezo system

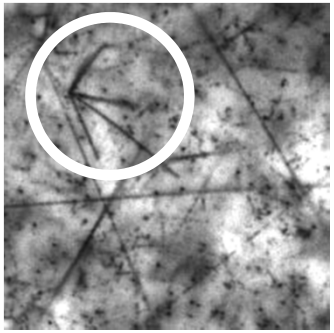


UNIOPT Co., Ltd.

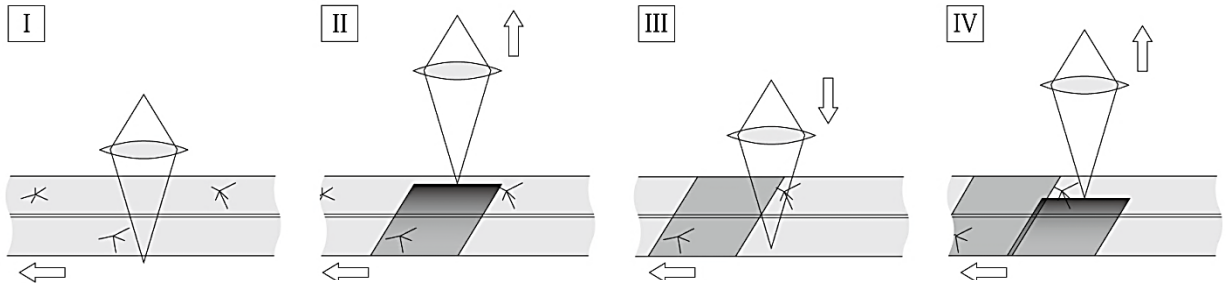


CMOS Camera
Baumer HXC20

Piezo Actuator
MIPOS600GD w/ Obj. lenz



Alpha decay in the emulsion (up); its detection by Image recognition (down).

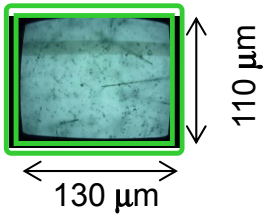


3-dimensional image taking with NON-stop stage driving.

2-4 Overall detection method

Scanning systems --2

Present system

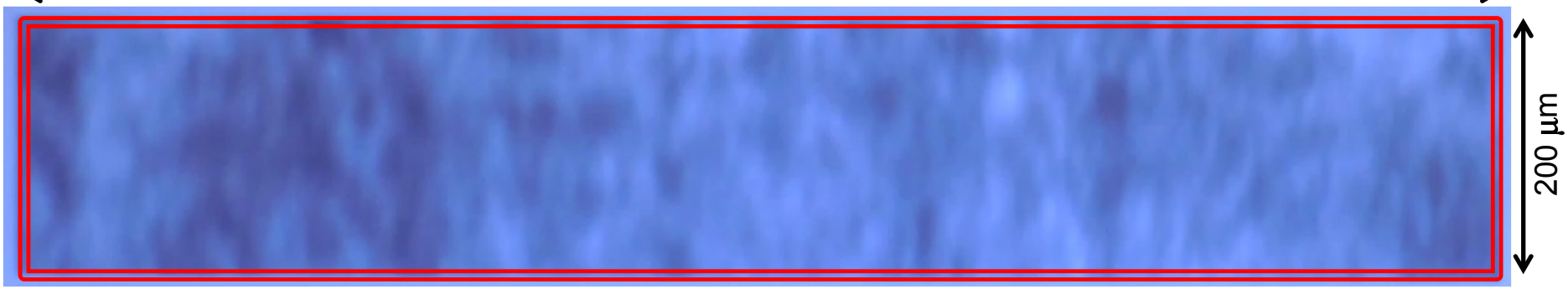


	Present	Overall method
Obj. Lens	× 50 (NA. 0.9)	× 20 (NA. 0.35)
Camera	100Hz XC_HR300	800Hz HXC20
Pixel	512 × 440 pixel	2039 × 357 pixel
Area	130 mm × 110 mm	1140 mm × 200 mm
Rate(Hz)	0.3	5

5 sets
1 set

2 sets in Gifu
in Korea and Toho

New system with piezo stage



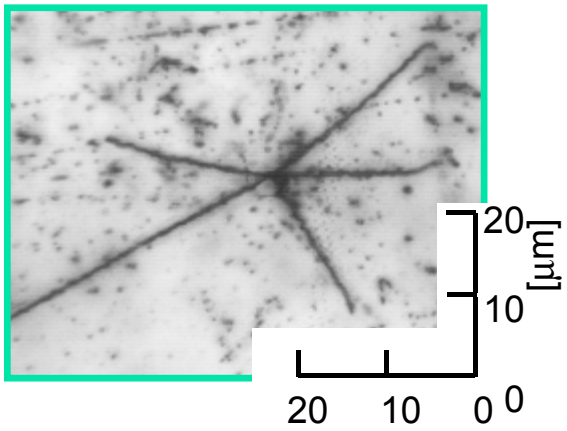
Images of all of the emulsion plates can be obtained in a few years.

2-5 Sample events by Overall method

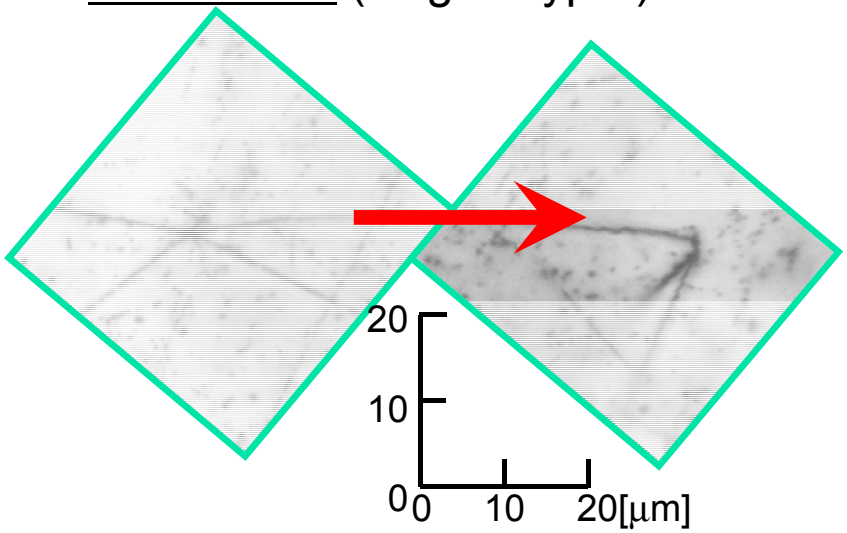
Results of test operation of overall system

Process	input	output
Image taking	Emulsion 81.3cm^2 × 1.0mm	2.5 × 10^6 pictures
Graphic processing	2.5 × 10^6 pictures	3.0 × 10^5 reaction vertices
Human's check	2.2 × 10^5 reaction vertices	~4 × 10^2 HY (11events:3-VTX?)
	3.0 × 10^4 reaction vertices	~2 × 10^2 Alpha decay

α decay (Thorium series)



Mult. vertex (single-Hyper)

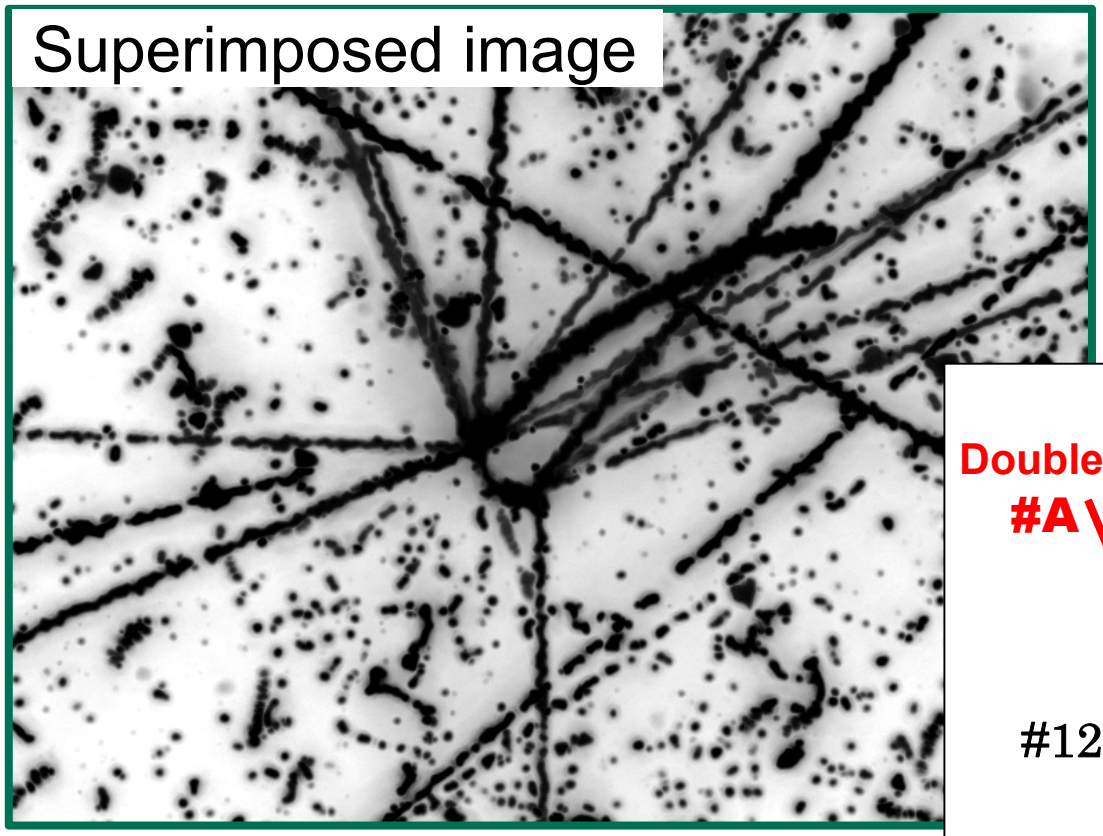


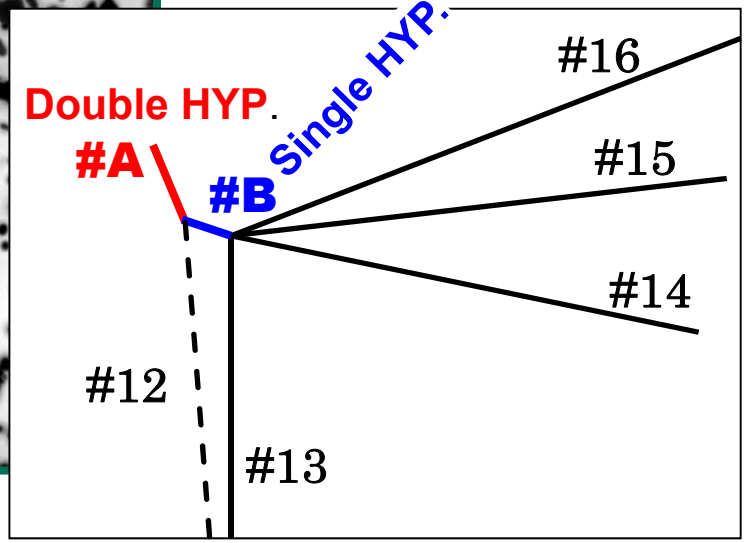
2-5 Sample events by Overall method

Beam Interaction :
beam + 11fragments + DoubleHyper?

Double Hyper. cand. (Track **#A**) from 10^6 pictures

	range (μm)
#A	4.2 ± 0.1
#12	>11.3mm
#B	2.9 ± 0.1
#13	370.5 ± 2.8
#14	1452.7 ± 6.4
#15	1029.7 ± 1.9
#16	107.5 ± 2.7





3. Summary

E07 Yield expected from the knowledge (E176 & E373) at KEK-PS

at Ξ^- capture point	Hybrid		Overall
• X-ray	~ 10^2	→	----
• single-Λ	~ $10^{3\text{-}4}$	→	~ $10^{4\sim5}$
• twin single-Λ	~ 10^2	→	~ 10^3
• Light double-Λ	~ 10^2	→	~ 10^3
• Heavy double-Λ	~ 10^3	→	~ 10^4
at (K-, K+) reaction point in the emulsion			
• single-Λ	----	→	~ $10^{6\sim7}$(?)
• Heavy (?) double-Λ	----	→	~ 10^5(?)

The E07 experiment will be ready
in April, 2014 (by using present systems)
or in Aug., 2014 (by upgrading present systems)