Development of overall emulsion scanning method with high efficiency and speed for large-scale analyses of few-body hypernuclei

This work is supported by MEXT KAKENHI Grant Number JP19H05147
& JSPS KAKENHI Grant Number JP16H02180

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18th May, 2020

On behalf of E07(J-PARC) collaborations

Outline

1. The E07 experiment at J-PARC & Recent results (＊Ξ hypernuclei)

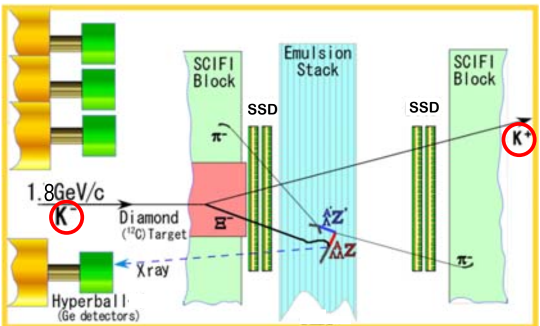
2. Issues to be solved for discovery of new hypernuclei

- 2-1. Speeding up for scanning of E07 emulsion
- 2-2. Automated tracking of charged particles in 3-dimension
- 2-3. Machine learning to recognize 3 vertices of double hypernuclei

3. Summary and prospect for FY2020

The E07 experiment @ J-PARC [2016-] (K-,K+) reaction

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. *Overall-scanning*

VP : Vertex Picker

Fully automatic detection of
3 vtx. event
like NAGARA event, KISO event

10 times statistics of that with the hybrid method

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

➔ 10^5 Ξ- stop events
Measurement of the mass of
~10^3 double hypernuclei
~10^2 Xi hypernuclei
with A<16

Topics with 100 times statistics of E373

1) s-shell DBL. hypernuclei : ${}^{4}_{\Lambda\Lambda}$H, ${}^{5}_{\Lambda\Lambda}$He and ${}^{5}_{\Lambda\Lambda}$H

$\Lambda\Lambda$-ΞN-H coupling interaction affects mass, since s-shell nucleons are not fully occupied. Thus, it can be determined.

2) A = 6~17 $\Lambda\Lambda$ hypernuclei (spectroscopy)

Confirmation of $\Lambda\Lambda$ interaction strength and nuclear structure effects such as shrinkage due to Λ, independent information of NAGARA event, ${}^{6}_{\Lambda\Lambda}$He.

3) Ξ-hypernuclei : Ξ^{-16}O, Ξ^{-14}N(KISO event), Ξ^{-12}C

From multiple events of Ξ-hypernucleus, we can determine the (natural) width of Ξ-hypernucleus, which is related to $\Lambda\Lambda$-ΞN coupling interaction.

4) ΞN interaction with X-ray from Ξ-atoms

Expected yields for X-rays from Br and Ag are so small. To observe the shifts, it is necessary for detecting peak shapes with 10 times statistics.

5) Λ-Λ P-wave interaction (?)

If $\Lambda\Lambda$ hypernuclei can be detected in excited states with **one Λ-hyperon in p-orbit**, it may present information on $\Lambda\Lambda$ p-wave interaction, where that will be recognized via the spectroscopy of $\Lambda\Lambda$ hypernuclei. The interaction might change max. mass of n-star.

2. Recent Results from E07 (J-PARC)

At present, Hybrid Method (starting in Apr., 2018)

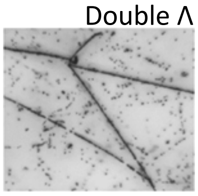
- M. Danysz et al. [1963] ….. 1event
- E176 (KEK) [1991] ……… 1 (DBL-Λ) + 2 (Twin)

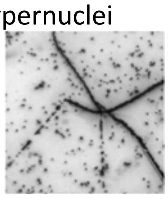
	KEK-PS E373	E07 (current*)	E07 (estimated)
Ξ^- stop w/ fragment(s)	430	~2.5 x 10^3	5100
All Ξ^- stop	~650	~4.0 x 10^3	7800
Double Λ + twin + confused	9	34	~100

x4

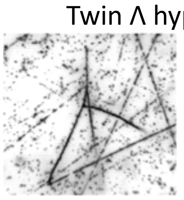
* Apr. 2020

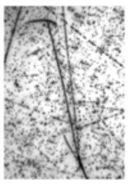
Double Λ hypernuclei





Twin Λ hypernuclei

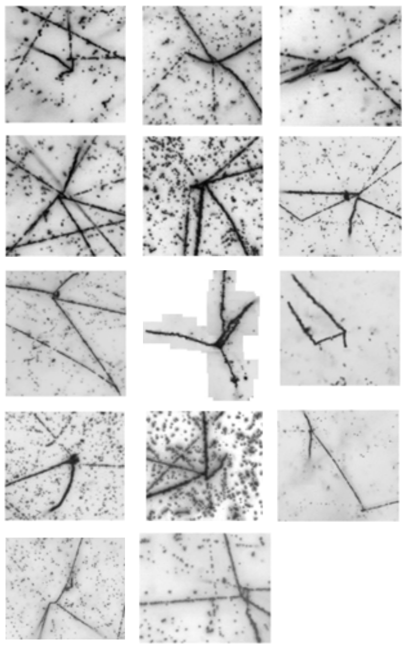




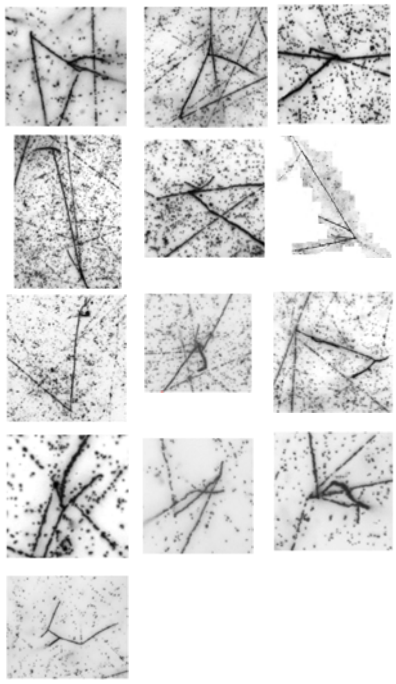
List of detected events in E07 (Apr., 2020)

	KEK-PS E373	J-PARC E07
Searching period	~7 years	2 years (Apr., 2018 ~)
S=-2 system	9	34

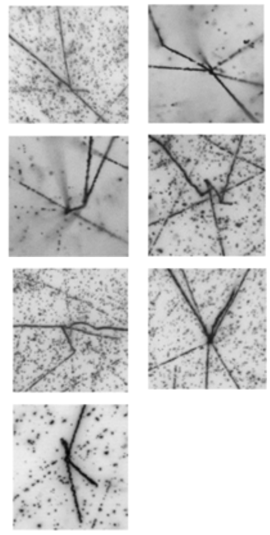
14 double-Λ events



13 twin-hyper events



7 confused



X-ray microscope to be developed

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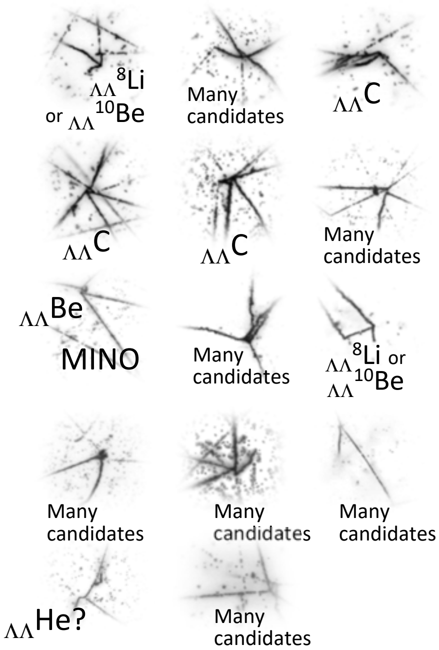
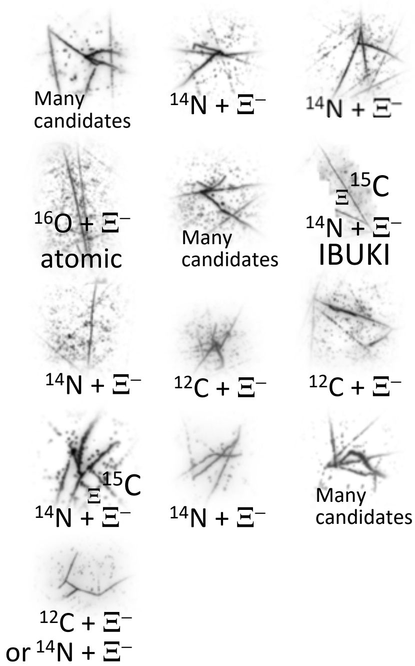
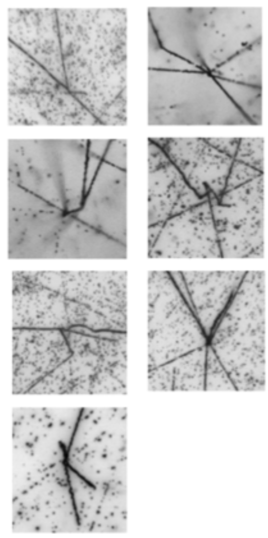


13 twin-hyper events



7 confused



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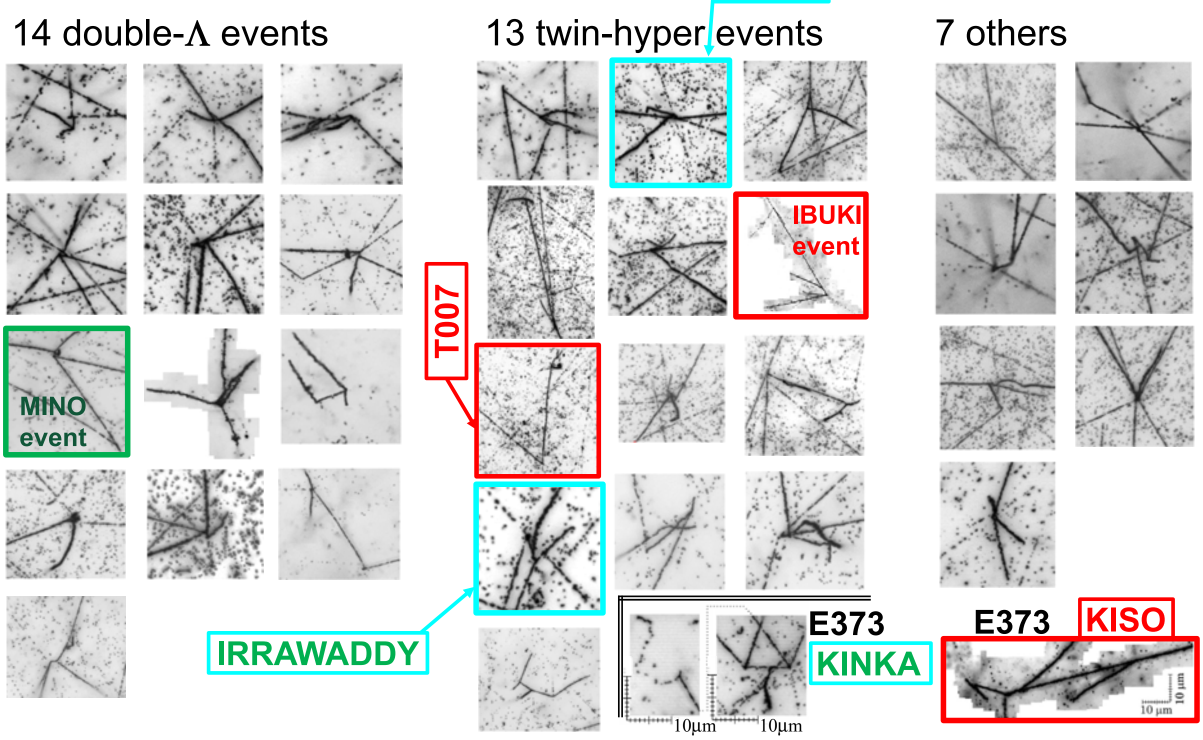


Ξ hypernuclei (List of nuclides)

Atomic state

[Ξ] hypernuclei

	Ξ⁻ captured by…			daughter						
	^{12}C	^{14}N	^{16}O	H	He	Li	Be	B	C	n
E176 #10-9-6 (2*p*?)	●			1			1			
E176 #13-11-14 (2*p*?)	●			1			1			
T008, atomic	●			1	2					
T009, atomic	●				1	1				
T004, atomic			●		1			1		
E373 Ichikawa's		●			3					1
T002 (2*p*?)		●			1		1			1
E373 : **KISO**		●			1		1			
T006 : **IBUKI**		●			1		1			
T003		●			1		1			1
E373 : **KINKA**		●			1		1			1
T007		●			1		1			1
T010 : **IRRAWADDY**		●			3					1
T011		●			3					1
E176 #14-03-35		○	○							

●: Uniquely identified,
○: Multiple interpretations

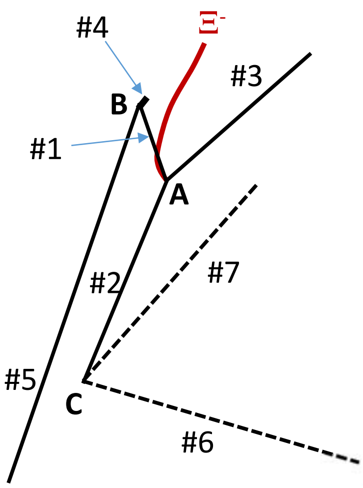
Several events are identified as ($\Xi^- + {}^{14}N \rightarrow {}_{\Xi}^{15}C \rightarrow {}_{\Lambda}Be + {}_{\Lambda}He$) although ^{14}N is the most dominant element in emulsion layer.

Irrawaddy event (twin single-Λ hypernucleus)

Detected on 2019/06/05 by Mr. Aung Nay Lin Nyaw (D2:Gifu Univ.)

Microscopic image

Event Topology



@ vtx. A

#1 #2 #3

1. Ξ^- & ^{12}C -> $\boxed{^{4}_{\Lambda}H}$ + $^{5}_{\Lambda}He$ + ^{4}He
2. Ξ^- & ^{14}N -> $^{5}_{\Lambda}He$ + $^{5}_{\Lambda}He$ + ^{4}He + n

@ vtx. B

$\boxed{^{4}_{\Lambda}H \quad : \quad \text{no solution}}$

$^{5}_{\Lambda}He$ -> p + p + 3n
$^{5}_{\Lambda}He$ -> p + d + 2n
$^{5}_{\Lambda}He$ -> d + p + 2n
$^{5}_{\Lambda}He$ -> d + p + π^0 + 2n
$^{5}_{\Lambda}He$ -> d + p + π^0 + 2n

@ vtx. C

$^{5}_{\Lambda}He$ -> p + p + 3n
$^{5}_{\Lambda}He$ -> p + d + 2n
$^{5}_{\Lambda}He$ -> d + p + 2n

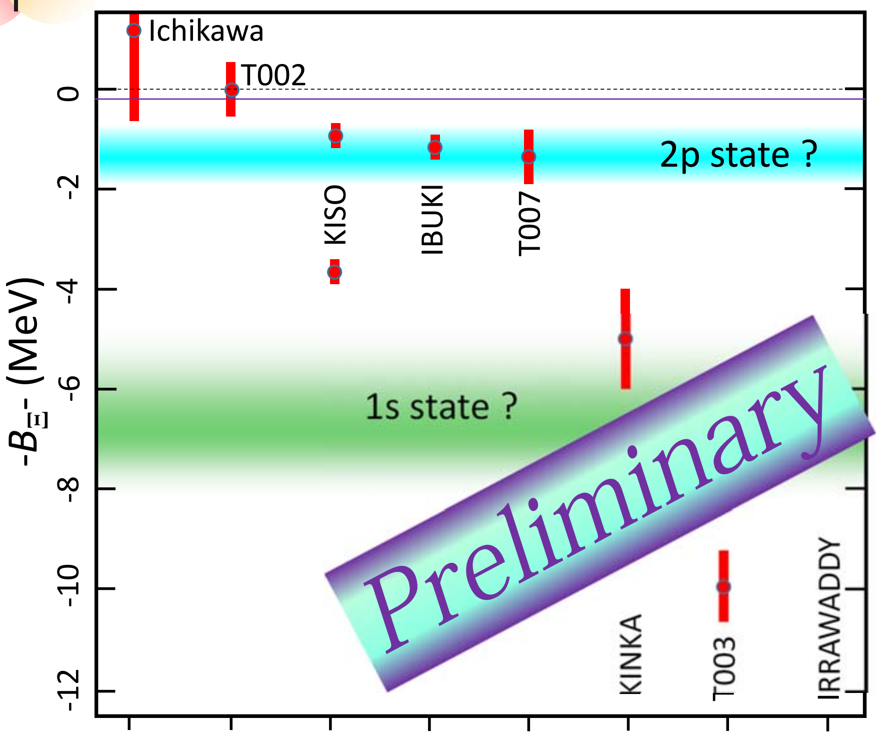
Only the case 2. was accepted.

Ξ^- + ^{14}N → $^{15}_{\Xi}C$ → $^{5}_{\Lambda}He$ Preliminary MeV

No excited state for $^{5}_{\Lambda}He$, thus the B_{Ξ^-} value is ***Unique!!***

Level scheme of Ξ hypernuclei ($^{15}_{\Xi}C$ [Ξ^--^{14}N])

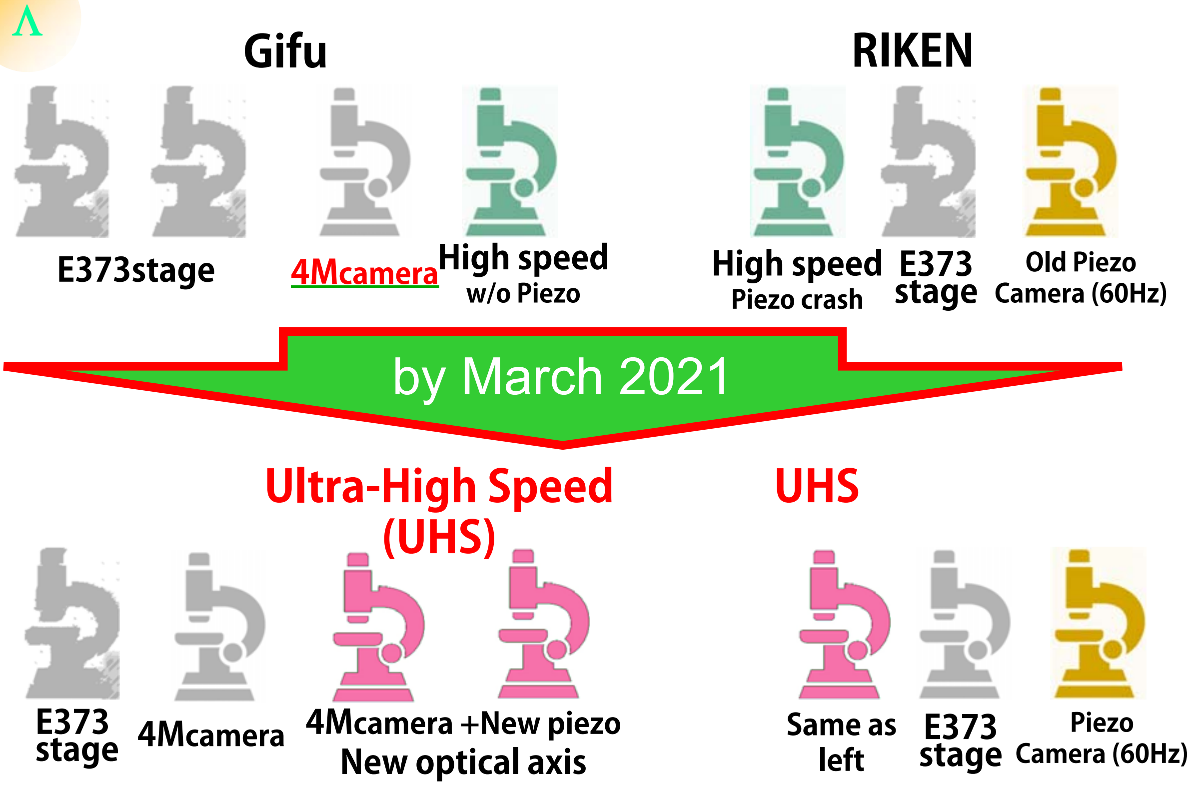
Experimental data



-0.17 : atomic 3D

ΛΛ–Ξ*N* coupling can be weak*!!*

2-1. 高速化 (Speeding up for scanning of E07 emulsion)



2-1. 高速化 (Speeding up for scanning of E07 emulsion)

SPEC	E373	4MCamera	Piezo(x20)Old	Ultra-High Speed (x20)
Visual field size (μm × μm)	140×120	270×270	560×280	560×560
Effective field size	110×90	240×240	530×250	530×530
Pixel size (μm)	0.28	0.11	0.275	0.275
Frame rate (Hz)	60	160	300	160
Depth of field (μm)	3	3	6	6
# of picture in half side	80	80	40	40
Dead time (s)	(0.2)	(0.2)	0.2	0.2
Scanning area(cm^2/day)	5.5	71	380	540
For all E07 Emulsions (yr)	1500	110	21	15
				~ 5years/ 3 Mic.

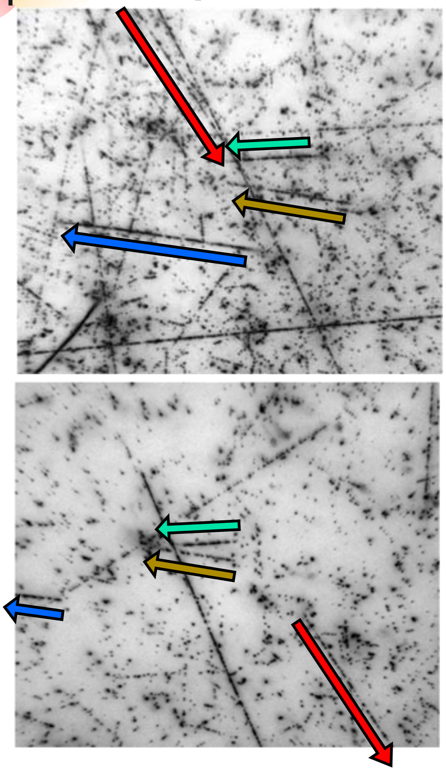
Condition
area : 1000 cm^2/Em_sheet
working : 250 days/year

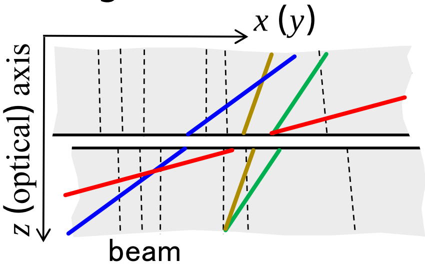
×10
×100

2-2. 3次元飛跡自動追跡

(Automated tracking of charged particles in 3-dimension)

Purpose (precise positioning of followed track in sheet by sheet)

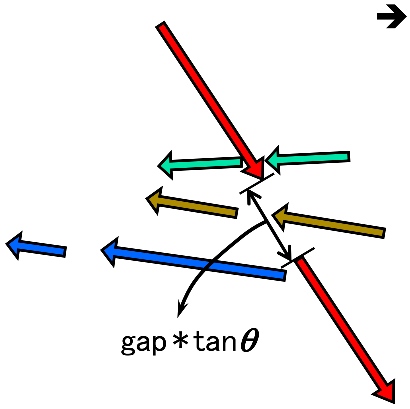




(Now) beam−position pattern matching ➔ x (y) offsets

(Dev.) thick tracks should stay on each line

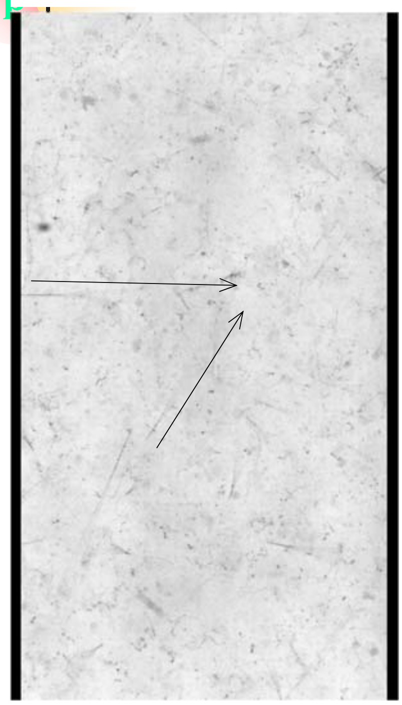
➔ x (y) offsets + gap



2-2. 3次元飛跡自動追跡

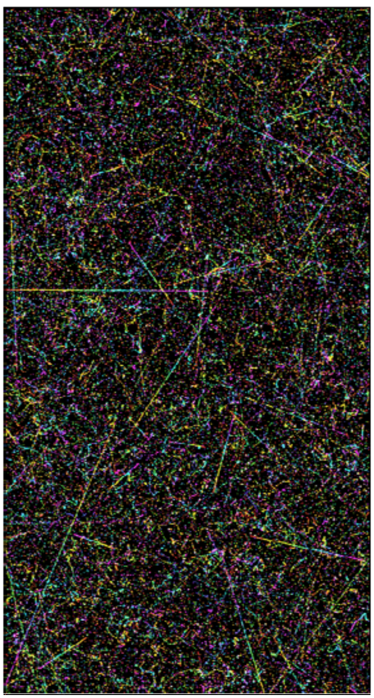
(Automated tracking of charged particles in 3-dimension)

Emulsion image w/ Piezo



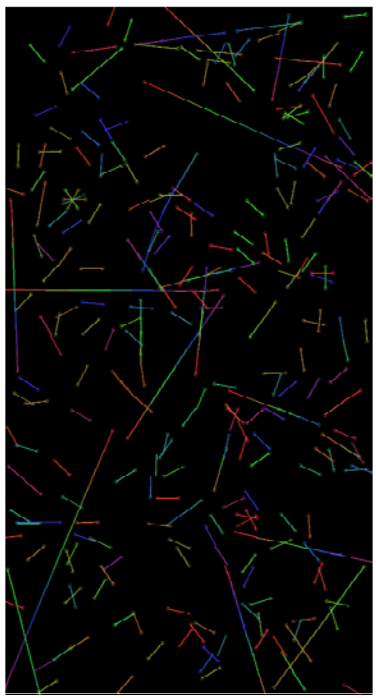
# of layers : 16 / 40
Speed : 1/150 for Piezo dr.

Grain detection



Colors show depth difference

Auto tracking



# of tracks can be 2.5 times for 40 layers.

2-3. 機械学習

(Machine learning to recognize 3 vertices of double hypernuclei)

Strategy (due to very little samples for HY)

Many Images of Hypernuclei simulated by **Geant4**

Simulated image

Image-to-Image translation [Pix2Pix]
条件付き敵対的生成ネットワーク(CGAN)
Conditional Generative Adversarial Net.

Translated Emulsion Images of Hypernuclei

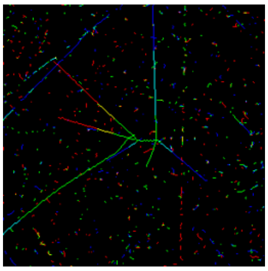
CNN Machine Learning
Convolutional Neural Network

Best selection eff.

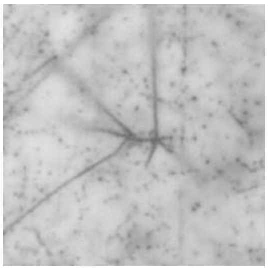
application to

Overall Scanning

~10^3 Double HY
~10^6 light single HY



Double HY
Simulated Image
(test)



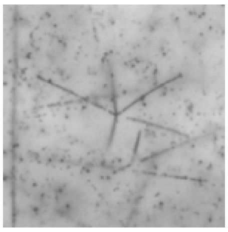
Translated Image
(test)

2-3. 機械学習

(Machine learning to recognize 3 vertices of double hypernuclei)

Present test studies

1. α decay (Real)



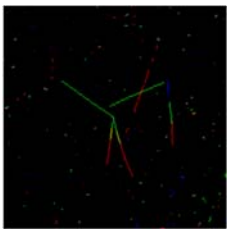
CNN

Other α decay (Real)

CNN

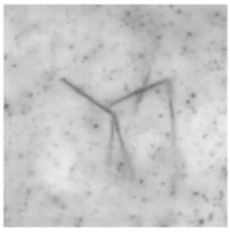
α Selection (~90%)

2. α decay (Geant4)



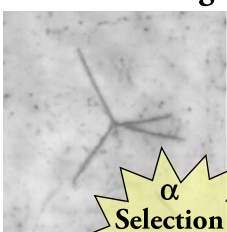
CGAN

Simulated images



CNN

Other Simulated images



CNN

α Selection (~70%)

Other α decay (Real)

CNN

α Selection (40~50%)

Not catch characteristics for both images, yet.

3. Summary and Prospect for FY2020

1. Under the few results for DBL hypernuclei by previous experiments, we have challenged E07 experiment. Detection with Hybrid-emulsion method has been finished in this April, and then we got 34 samples of DBL HY.

2. At present, it is not so easy to say $B_{\Lambda\Lambda}$ for DBL-Λ HY, however ΞN interaction is cleared to be attractive without any theoretical aspects. By the detected level scheme in $^{15}_{\Xi}C$ hypernucleus, $\Lambda\Lambda \Leftrightarrow \Xi N$ coupling effect can be small.

3. To realize Overall Scanning for expected ~ 1×10^{3} DBL HY and ~ 1×10^{6} SGL HY, developments has been started for
   - ➔ Speeding up for scanning of E07 emulsion,
   - ➔ Automated tracking of charged particles in 3-dimension,
   - ➔ Machine learning to recognize 3 vertices of DBL HY.

4. In FY 2020,
   Microscope ➔ Ultra High speed (w/ Piezo, Focusing Mod., Camera)
   Tracking ➔ High efficiency (optimization)
   Machine L. ➔ High efficiency (Alpha detection => HY VTX detection)