J-PARC E07
Systematic study of double strangeness nuclei with Hybrid emulsion method

K^-
1.8GeV/c

Target

SSD

Ξ^-

K^+

Ge detector

X-ray

Emulsion Sheets

$\Lambda\Lambda$ hypernucleus

Ξ hypernucleus

X-ray from Ξ^- atom

Ag or Br
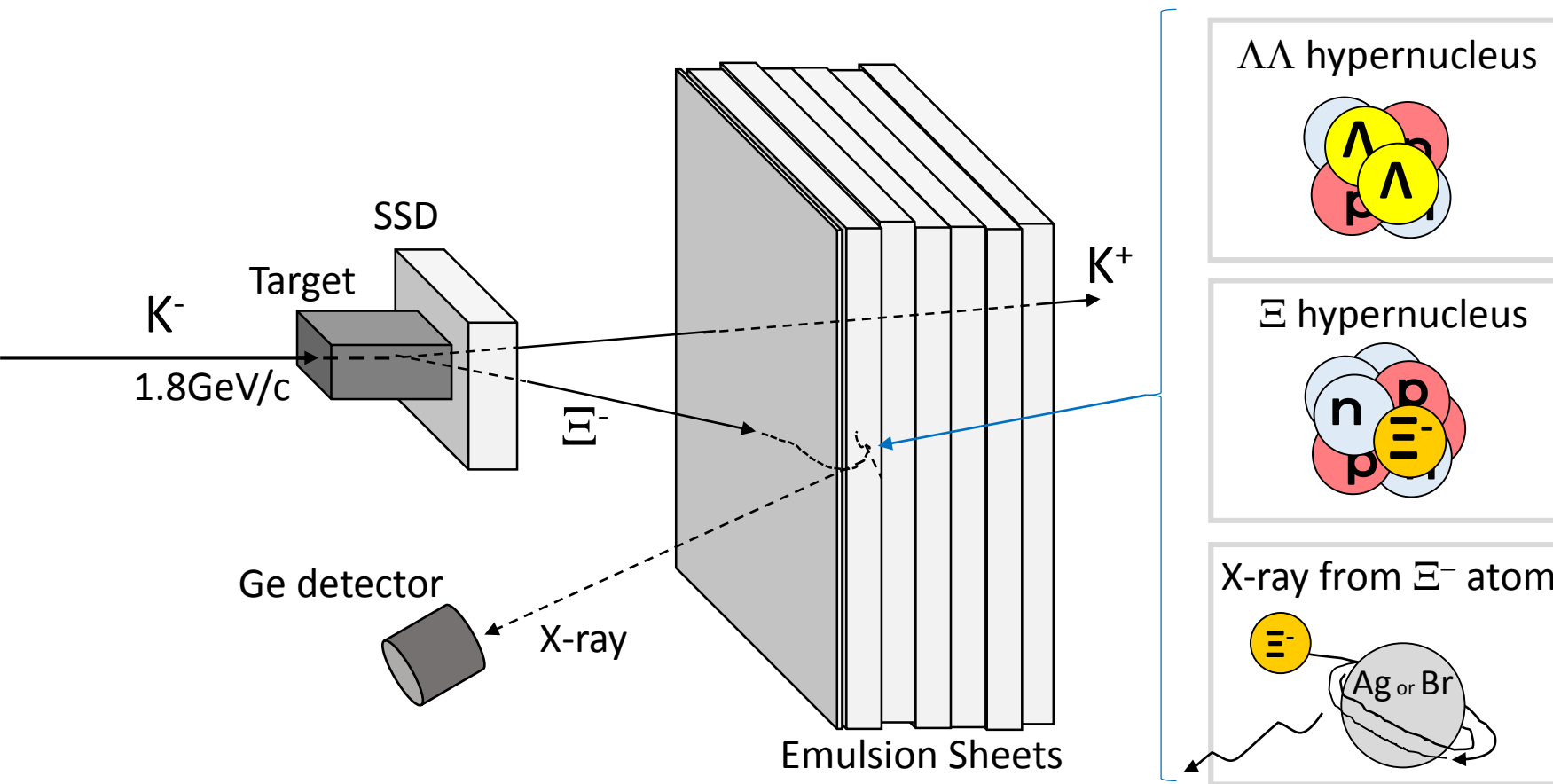
Junya Yoshida (Advanced Science Research Center, JAEA)
On behalf of J-PARC E07 Collaboration

QNP2018
8th International Conference on Quarks and Nuclear Physics

Concept: More than 10 times statistics of KEK-PS E373, 10k Ξ^- stop events

	KEK-PS E373	J-PARC E07 (in proposal)
Emulsion gel	0.8 tons	2.1 tons
Purity of K- beam	25%	~85%
Ξ^- stop yield	~650	10k
$\Lambda\Lambda$ hypernuclei	7	~10^2

about 15 times of E373

Physics motivations

Subjects: double strangeness system

Physics: baryon-baryon interaction

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

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

Ξ hypernuclei ($_\Xi^{13}$B, $_\Xi^{15}$C, and $_\Xi^{17}$N)

X-ray from Ξ-atoms (Ξ^-+Ag, or Ξ^-+Br)

$\Lambda\Lambda$ hypernuclei in excited state

$\Lambda\Lambda$ S-wave interaction

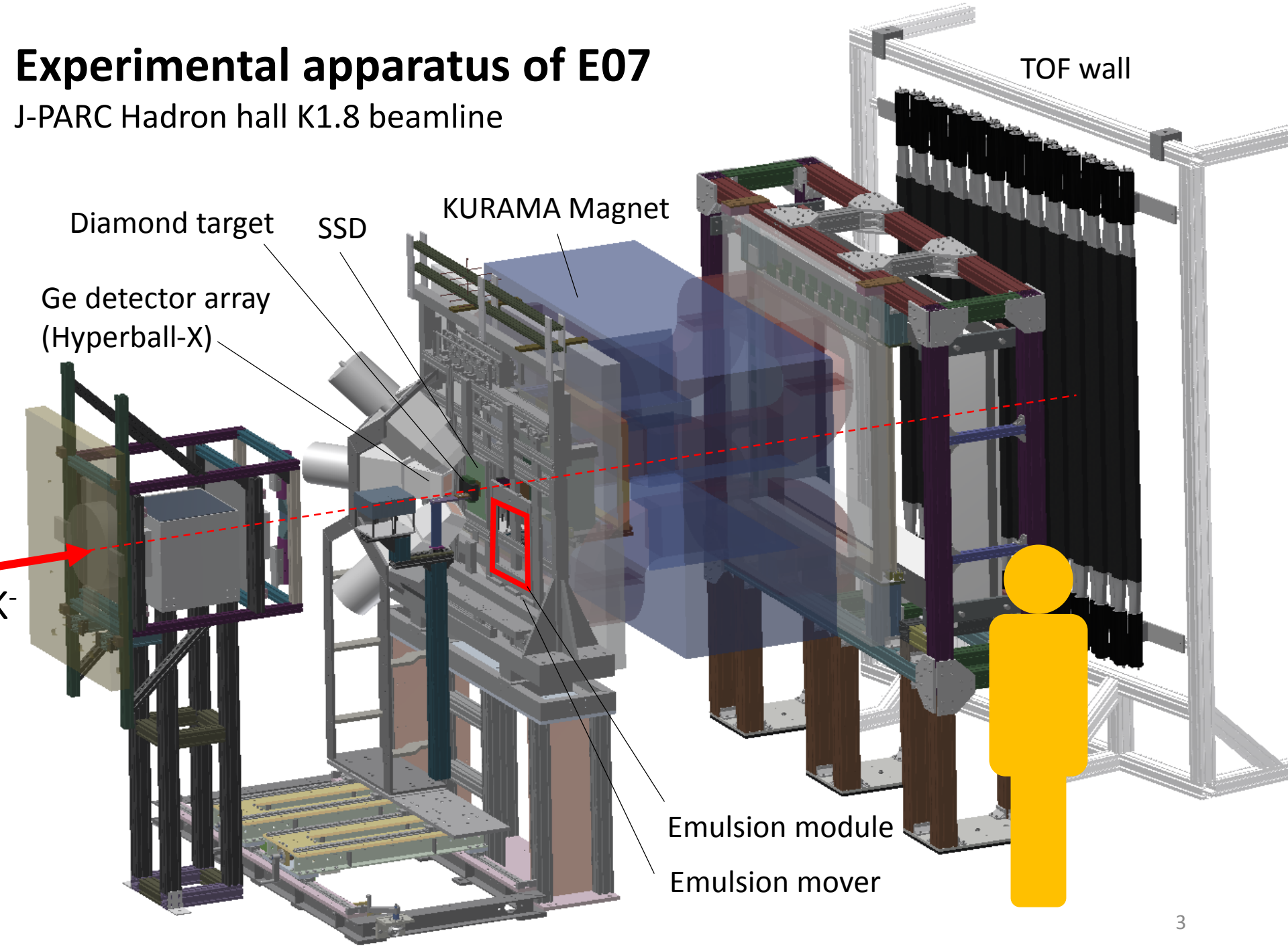$\Lambda\Lambda$ P-wave interaction

ΞN interaction

$\Lambda\Lambda$-ΞN coupling

Production, structure, and decay of double strangeness system

Experimental apparatus of E07

J-PARC Hadron hall K1.8 beamline

TOF wall

KURAMA Magnet

Diamond target

SSD

Ge detector array
(Hyperball-X)

K⁻

Emulsion module

Emulsion mover

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Beam exposure

May-Jun. 2016
  KURAMA Commissioning : 5.0 days
  Physics : 4.9 days

4/15 - 4/19, 2017 (44kW)
  Emulsion exposure : 50 h
  calibration : 19 h

5/25 - 6/29, 2017 (10 - 37.5kW)
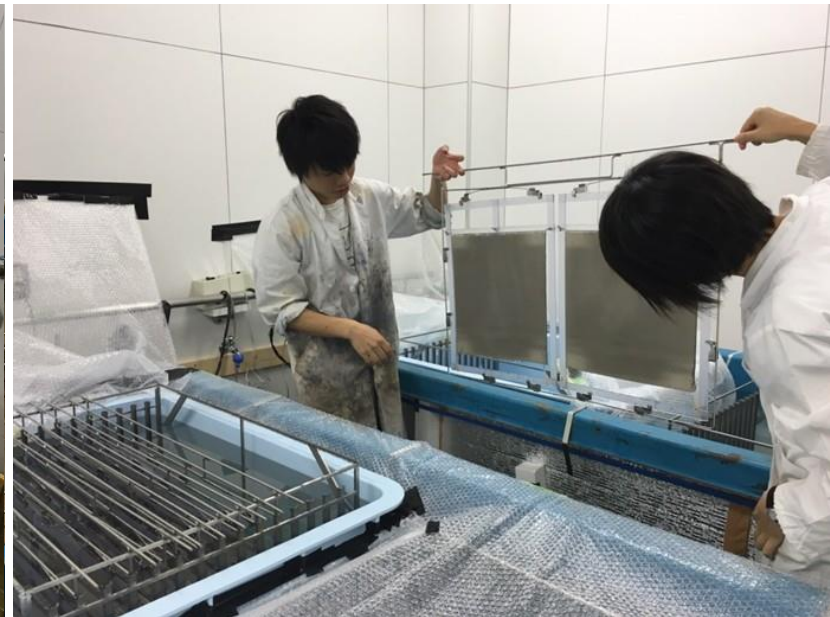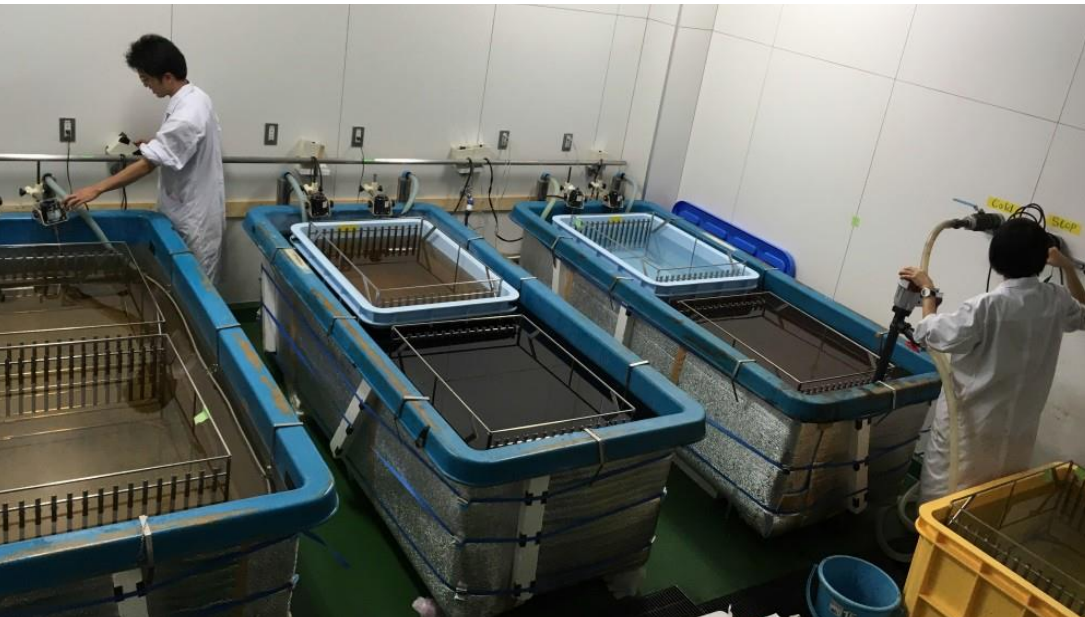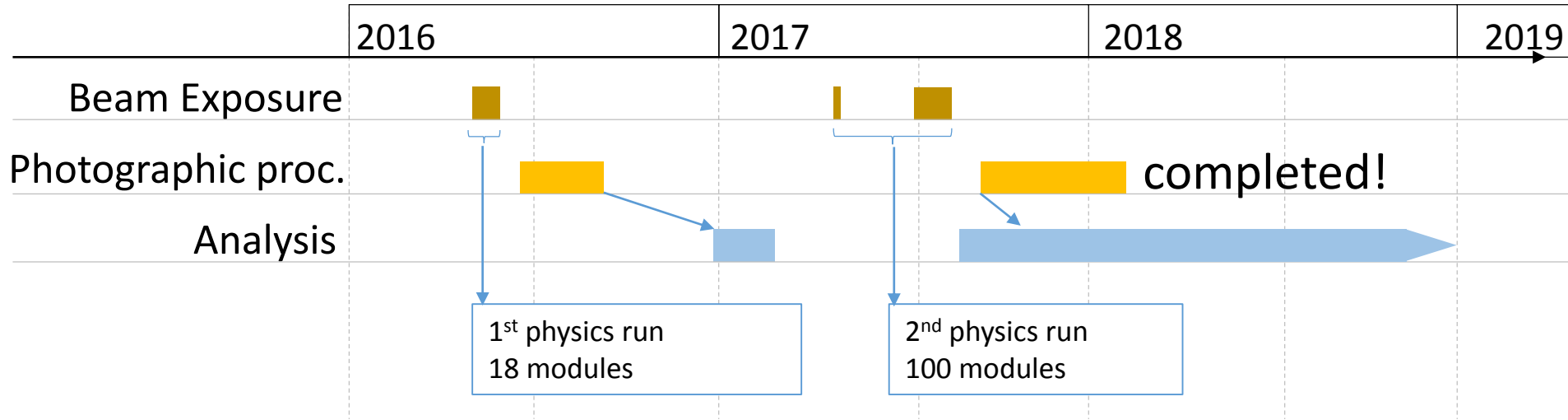 Emulsion exposure : 23.4 days
  calibration : 8.5 h
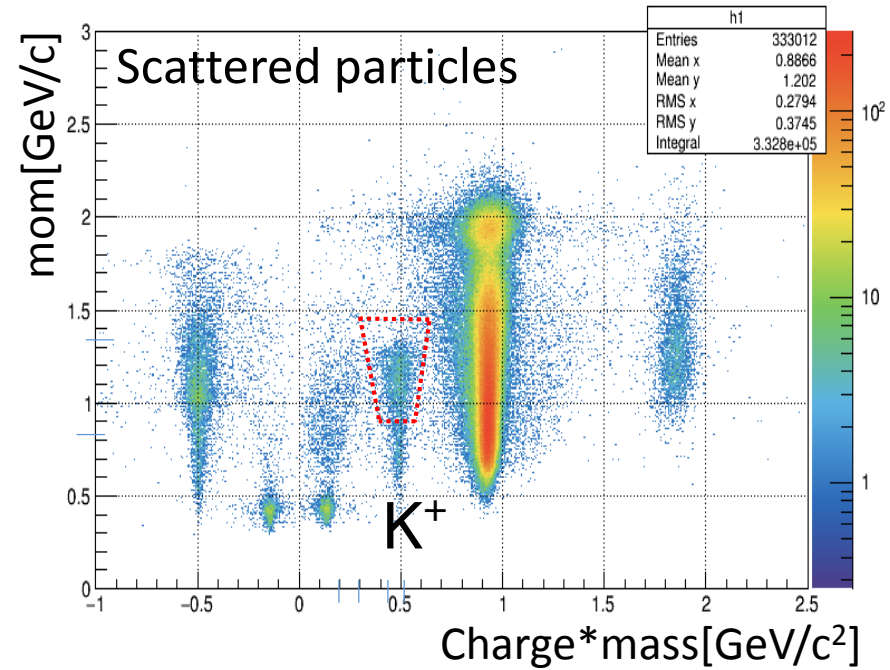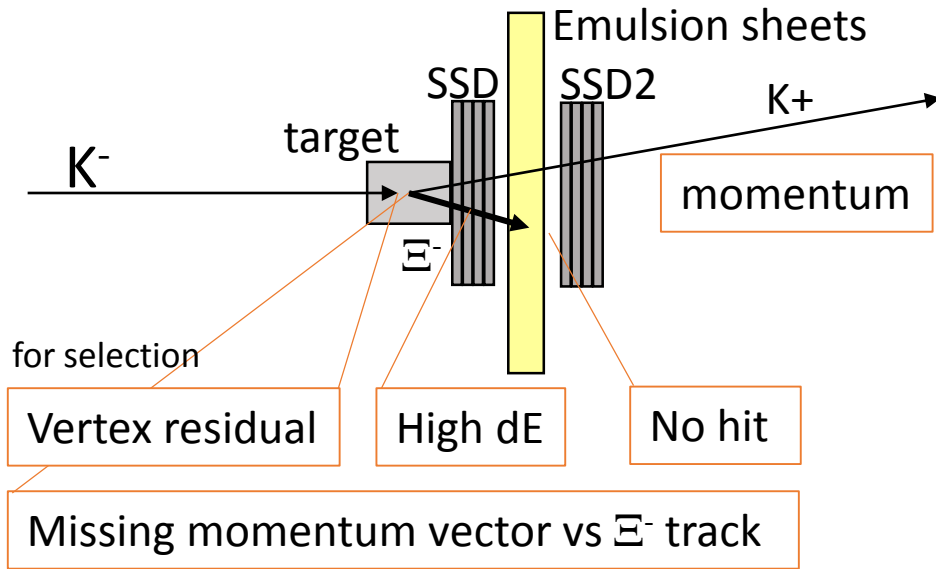

Jul. 1st 2017, Run end photo @K1.8 counting room

Year	Beam power [kW]	K⁻ intensity [/spill]	K⁻ purity	Time [h/mod.]	Integrated K⁻ [/mod.]	DAQ Eff.	Emulsion modules
2016	42	260k	81%	6.5	0.92G	83%	18
2017	44	310k	83%	5.6	1.0G	84%	8
2017	37.5	280k	82%	6.0	1.0G	89%	78
2017	10 - 35	120k – 270k	50% - 82%	6.5 – 9.0	0.52G – 1.0G	89-92%	14

Totally, 100G Kaons were exposed for 118 emulsion modules

Photographic processing: completed in Feb. 2018

	2016	2017	2018	2019

Beam Exposure

Photographic proc.   completed!

Analysis

1st physics run
18 modules

2nd physics run
100 modules

Ξ⁻ selection from the (K-, K+) reaction by off-line analysis

K⁻ → target → SSD → SSD2 → Emulsion sheets → K+

Ξ⁻

momentum

for selection

Vertex residual | High dE | No hit

Missing momentum vector vs Ξ⁻ track

			h1	
		Entries	333012	
		Mean x	0.8866	
		Mean y	1.202	
		RMS x	0.2794	
		RMS y	0.3745	
		Integral	3.328e+05	

Scattered particles

K⁺

mom[GeV/c]

Charge*mass[GeV/c²]

Criteria for Xi track selection

by simulation for 118 modules

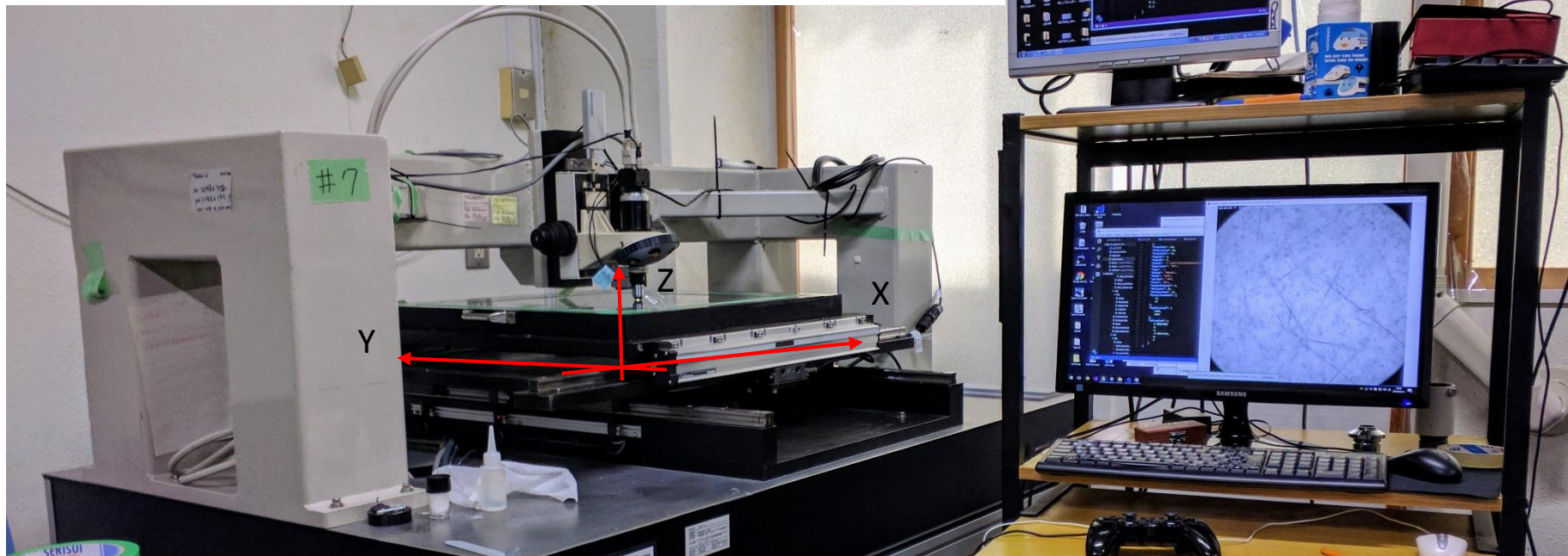| Criteria	Ξ⁻ stop	prediction/mod.		
1	10k	~440	High S/N & stop ratio	1st priority
2	2k	~850	Realistic selection	
3	1k	6.2k	All Ξ⁻ stop	
4	negligible	16k	All combination	

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Hunting Ξ⁻ stop event

* Disassembling
* Photographic developing

emulsion module

~440 predictions of Ξ⁻ tracks

🔴 p-bar tracks for SSD-emulsion alignment

🔲 volume for readout

$\sim(+\text{-}200\mu m)^2$

0.4mm Thin-type

$\sim(+\text{-}10\mu m)^2$

1.0mm Thick-type

1.0mm Thick-type

Beam direction
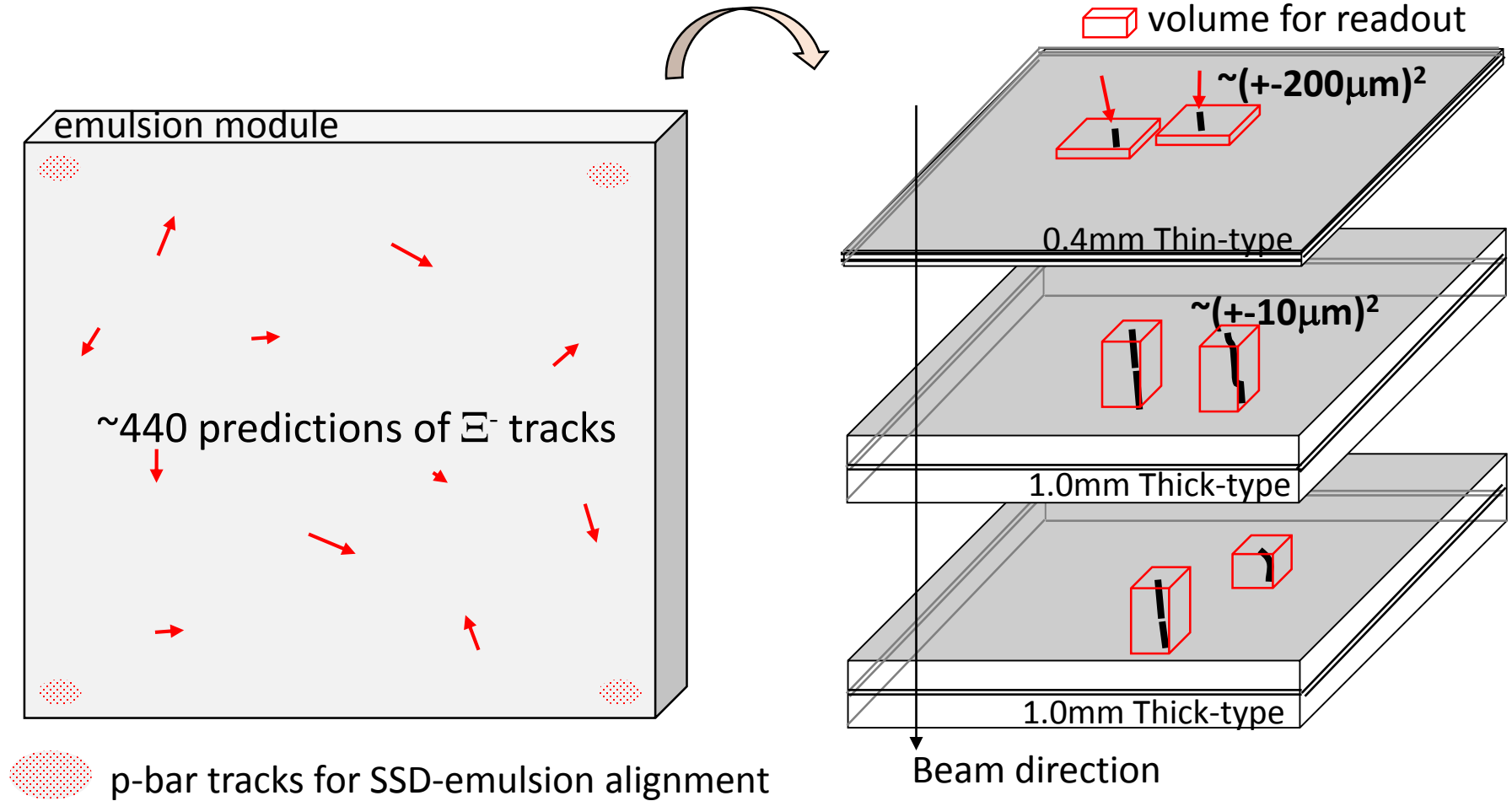
Scanning machine for pl01, scanning time: 2~3hours

#7

Z

X

Y

Tracks in X-Y space (1mm)²

track

upper layer

lower layer
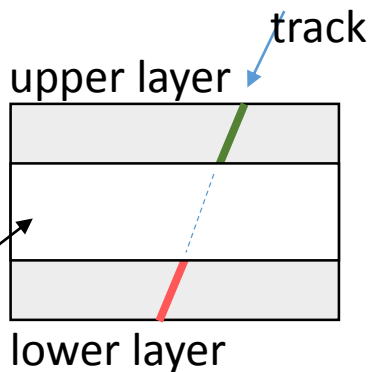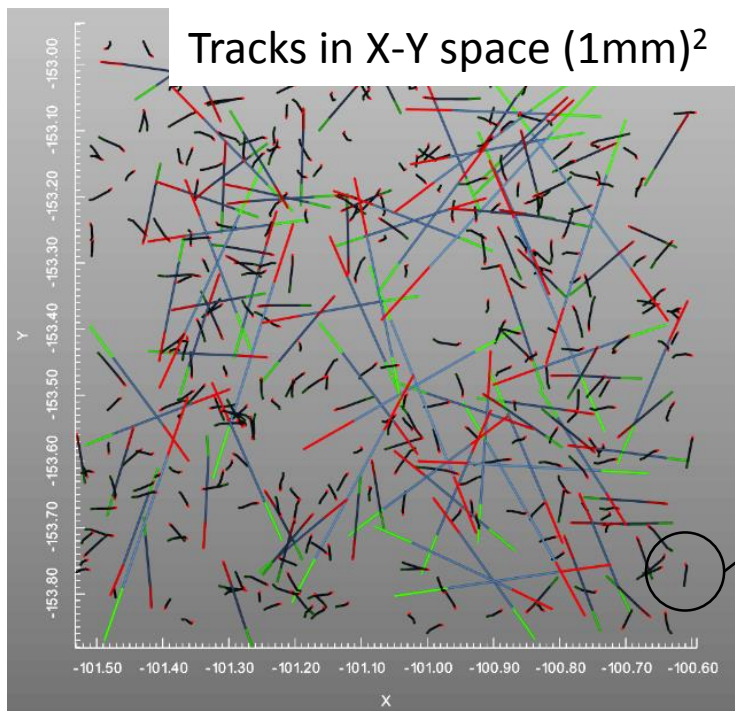
with SSD->pl01 protons
Position accuracy: reasonable

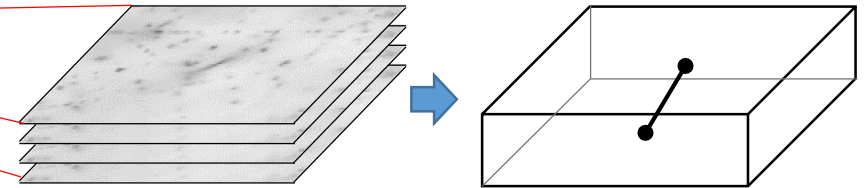
σ: 53μm

σ: 64μm
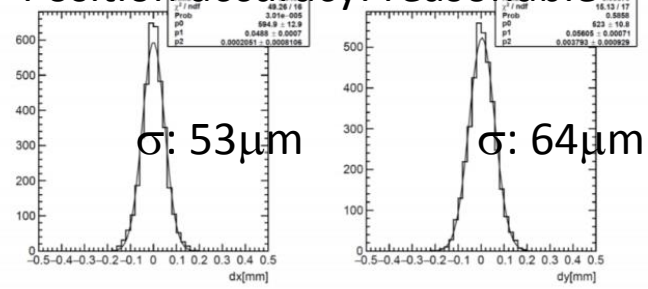
Angular accuracy: reasonable

σ: 26mrad

σ: 23mrad
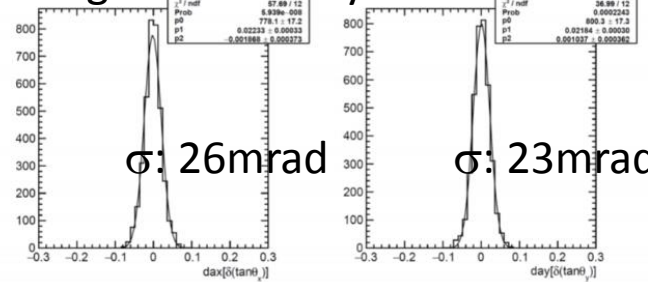
Ξ- tracking in thick-type sheet

Objective lens

Emulsion sheet (thick-type)

tracking

500 micron
emulsion layer

40 micron base

500 micron
emulsion layer
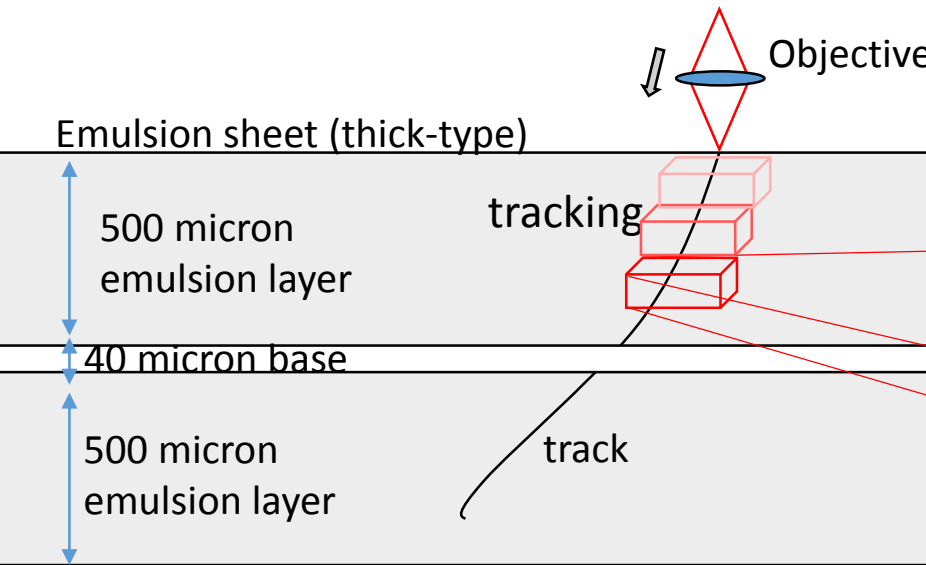
track

* Tracking with image processing

image sensor

stage

Objective lens(x50)

Optical microscope system
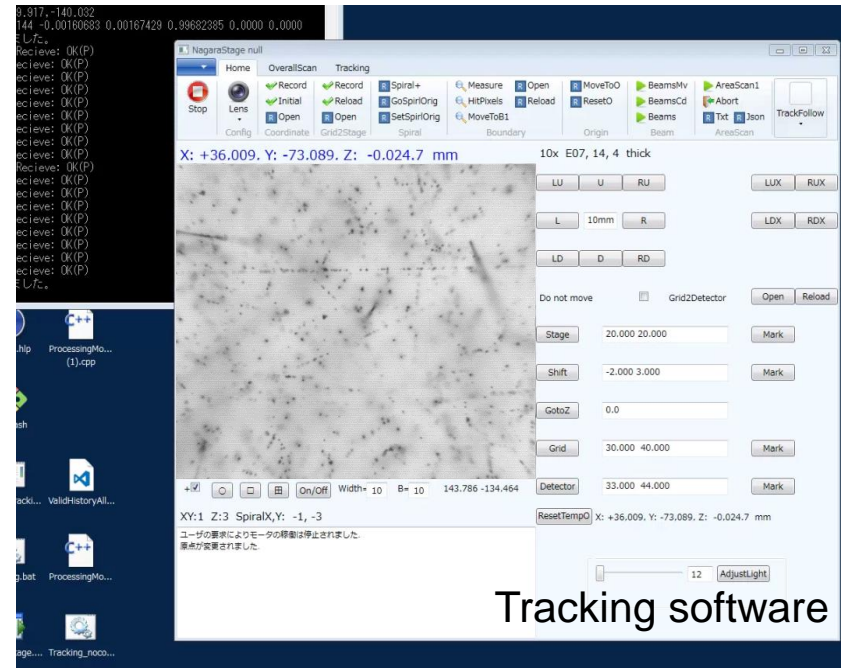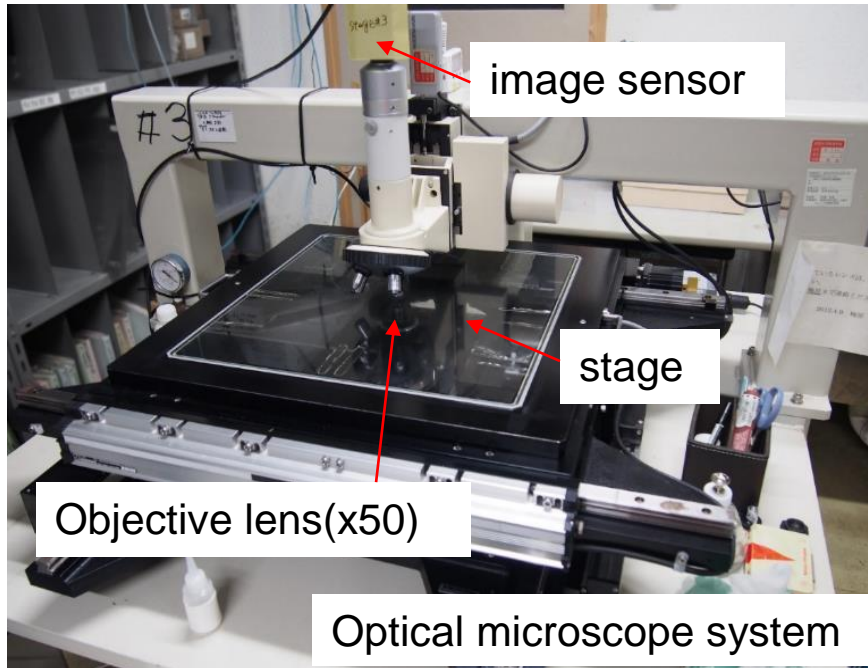
Tracking software

Observation of endpoint

Case**1**. Ξ⁻->Λπ⁻ decay
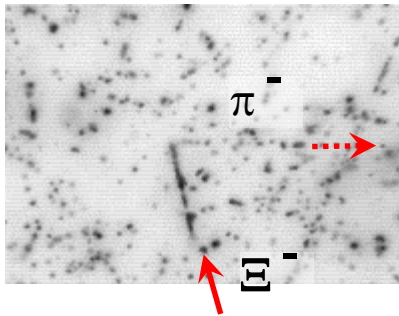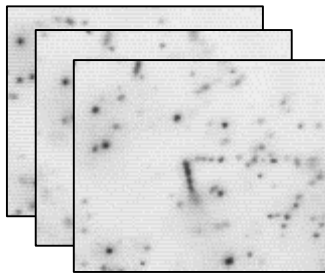
Case**2**. no visible fragment
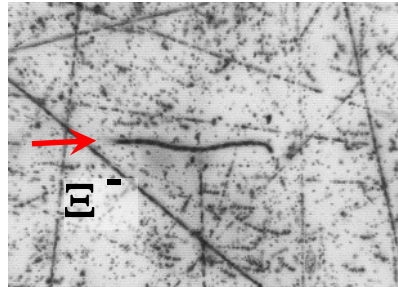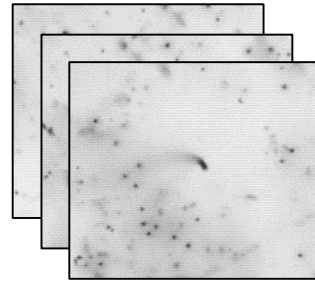
Case**3**. with hyperfragment

π⁻

Ξ⁻

Ξ⁻

Ξ⁻
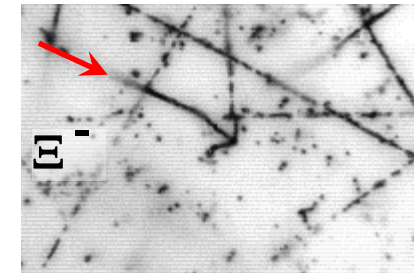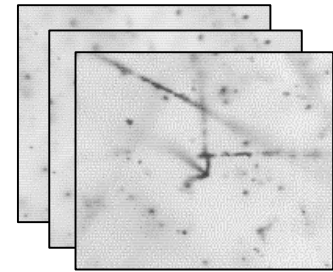
-> detail analysis

Estimation by simulation

a few % of followed track

captured by...

75%		29%				
Ξ⁻	→	stop in module	→	C, N, O	→	with hyperfragment <- case3
		50%				
		in-flight decay <- case1		Ag, Br		with nuclear fragment
25%		21%				
p		through and decay		H		no visible fragment <- case2
B.G.						

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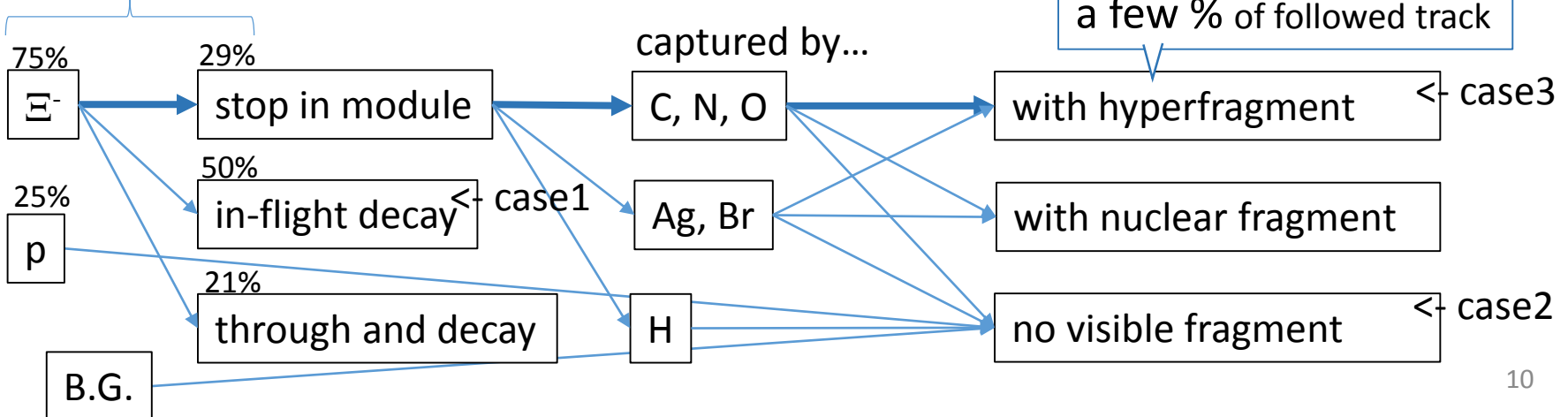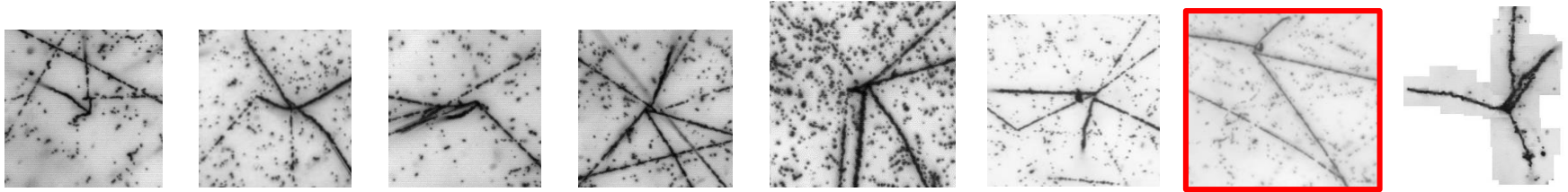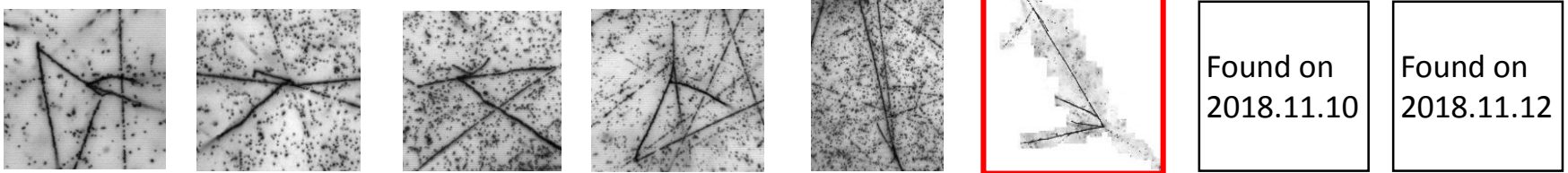
So far, 30% of the total emulsion sheets has been scanned.
Current statistics is more than twice comparable to E373

	KEK-PS E373	E07 (current)
Ξ^- stop with nuclear fragment	430	920
Double + twin	7 + 2	8 + 8?

8 double Lambda events

6 twin events + 2 more candidates?

Found on 2018.11.10

Found on 2018.11.12

MINO event

Found by Kasagi (Gifu Univ.)

10μm

$\Xi^- + X \rightarrow {}_{\Lambda\Lambda}\#1 + \#3 + \#4$

${}_{\Lambda\Lambda}\#1 \rightarrow {}_{\Lambda}\#2 + \#5 + \#6$

${}_{\Lambda}\#2 \rightarrow \#7 + \#8 + \#9$
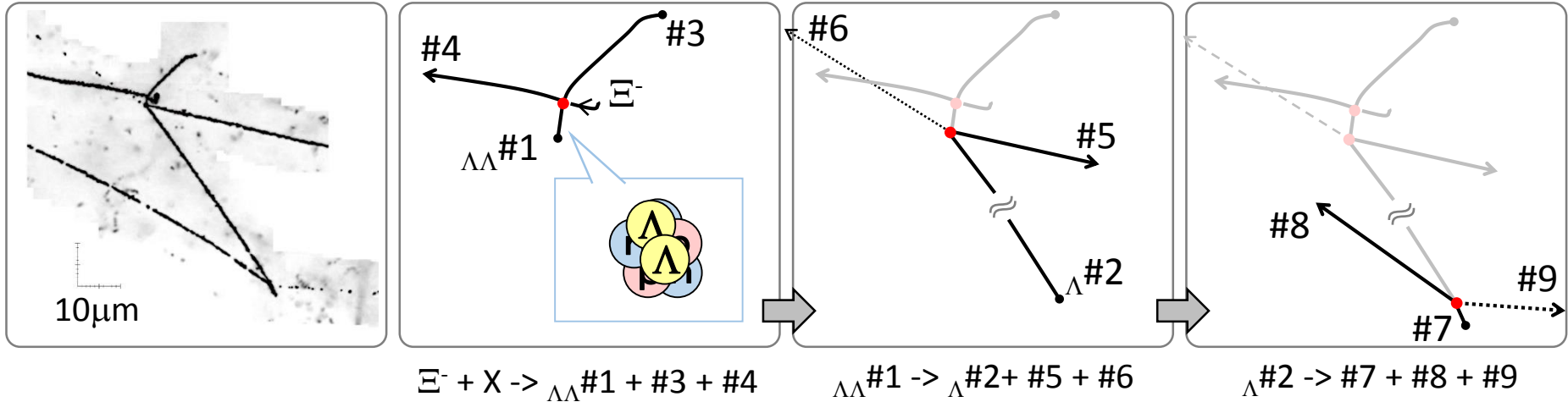
Via our analysis,

- ${}_{\Lambda}\#2$ is ${}_{\Lambda}^{5}He$
- The decay of ${}_{\Lambda\Lambda}\#1$ is non-mesonic decay (#6 is not π^-)
- The change of ${}_{\Lambda\Lambda}\#1$ is at least +4

- **${}_{\Lambda\Lambda}\#1$ is ${}_{\Lambda\Lambda}Be$** and X is ${}^{16}O$

For all combination,
- ☑ conservation laws
- ☑ geometrical consistency
- ☑ kinematic consistency, etc.

within 3σ of measurement error

Possible interpretations	$B_{\Lambda\Lambda} - B_{\Xi^-}$	$B_{\Lambda\Lambda} - B_{\Xi^-}$ [MeV]
$\Xi^- + {}^{16}O \rightarrow {}_{\Lambda\Lambda}{}^{10}Be + {}^{4}He + t$	~15	~1
$\Xi^- + {}^{16}O \rightarrow {}_{\Lambda\Lambda}{}^{11}Be + {}^{4}He + d$	~19	~2
$\Xi^- + {}^{16}O \rightarrow {}_{\Lambda\Lambda}{}^{12}Be^* + {}^{4}He + p$	~13+ E_{ex}	~-3 + E_{ex}

preliminary

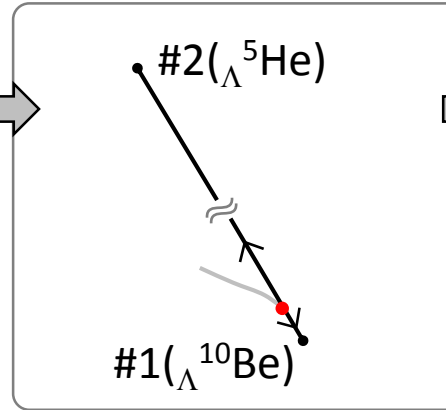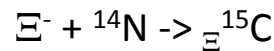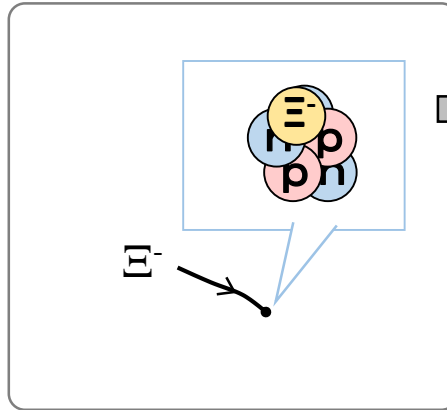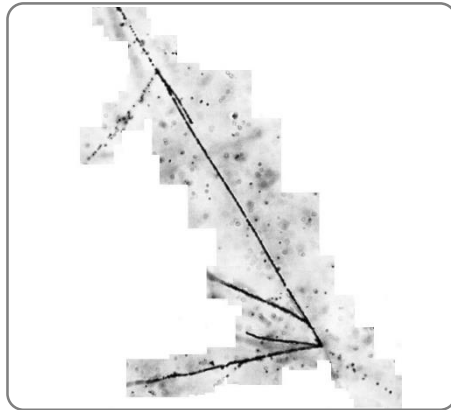${}_{\Lambda\Lambda}{}^{11}Be$ is most probable judging from the χ^2 of the "kinematic fit"

This result will be submitted to PTEP in this week.

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IBUKI event

Mod#047 pl10
ID : 20864938633496

Found by A. N. L. Nyaw (Gifu Univ.)

Ξ^-

#2($_\Lambda^5$He)

#1($_\Lambda^{10}$Be)

#9

#7

#8 (π^-)

#4

#5

#3

#6

$\Xi^- + {}^{14}N \rightarrow {}_\Xi^{15}C$

$_\Xi^{15}C \rightarrow {}_\Lambda^{10}Be + {}_\Lambda^5He$

$_\Lambda^5He \rightarrow$ #7 + #8 + #9
$_\Lambda^{10}Be \rightarrow$ #3 + #4 + #5 + #6
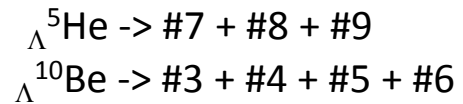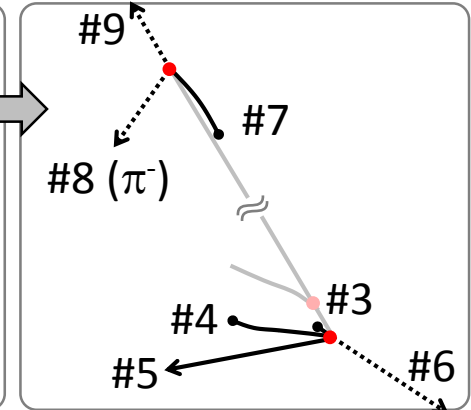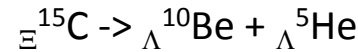
Via our analysis,

- $(\Xi^- + {}^{16}O, {}^{14}N \text{ or} {}^{12}C) \rightarrow$ 2 single Λ hypernuclei + neutrons
- Only "$_\Lambda^{10}Be + {}_\Lambda^5He$"was accepted at the 1st vertex
- #8 is π^-
- The decay of #1 and #2 are consistent with that of $_\Lambda^{10}Be$ and $_\Lambda^5He$

For all combination,
- ☑ conservation laws
- ☑ geometrical consistency
- ☑ kinematic consistency, etc.
within 3σ of measurement error
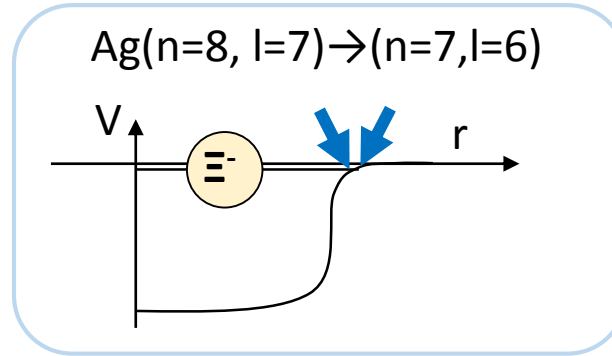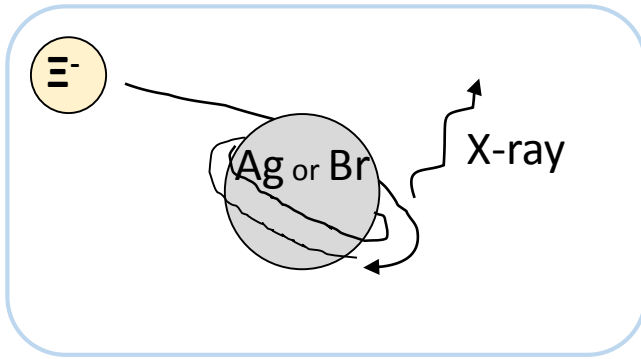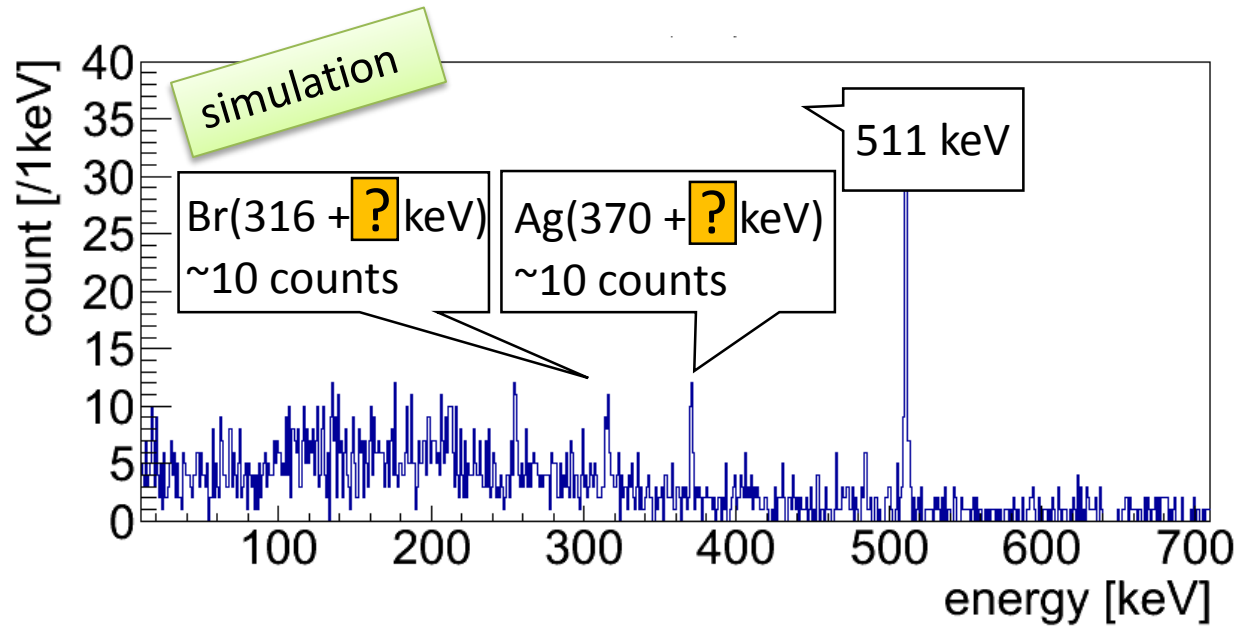
Possible interpretation	B_{Ξ^-} [MeV]
$\Xi^- + {}^{14}N \rightarrow {}_\Xi^{15}C \rightarrow {}_\Lambda^{10}Be + {}_\Lambda^5He$	~1

preliminary
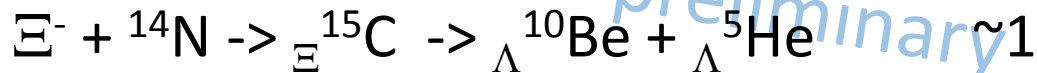
The same decay process to KISO event

To be submitted…

First measurement of X-ray from Ξ-atoms

Ag(n=8, l=7)→(n=7,l=6)

X-ray

Ge detector
Hyperball-X

simulation

Br(316 + ? keV)
~10 counts

Ag(370 + ? keV)
~10 counts

511 keV

Z(n,l)	E (keV)	Shift (keV)	Width (keV)
Ag(8,7)→(7,6)			
Case 1	370.45	0.28	0.15
Case 2		3.3	0.79
Br(7,6)→(6,5)			
Case 1	315.5	0.73	0.44
Case 2		5.5	1.74

Case 1: assuming potential shape to be the same as the nuclear density ($t\rho$ potential)
Case 2: Nijmegen D model correcting to produce the potential depth of ~ 14 MeV.

In current analysis, 900 σ stop event (15 % of total) were observed in emulsion sheets.

The detail will be introduced in

M. Fujita's poster

summary

J-PARC E07 is the most complex emulsion experiment so far to investigate double hypernuclei with Hybrid emulsion method.

Beam exposure and photographic processing has been completed successfully.

Event hunting is ongoing.
Current statistics of E07 is more than twice that of E373.
14 events of 3-vertex topology are found, so far.

Several events are identified.
These events will be published in the near future.

We will continue the event hunting.
Main search work will finished in about 1 year.