Studies for charge symmetry breaking effect in hypernuclei with nuclear emulsion

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J-PARC E07 Collaboration

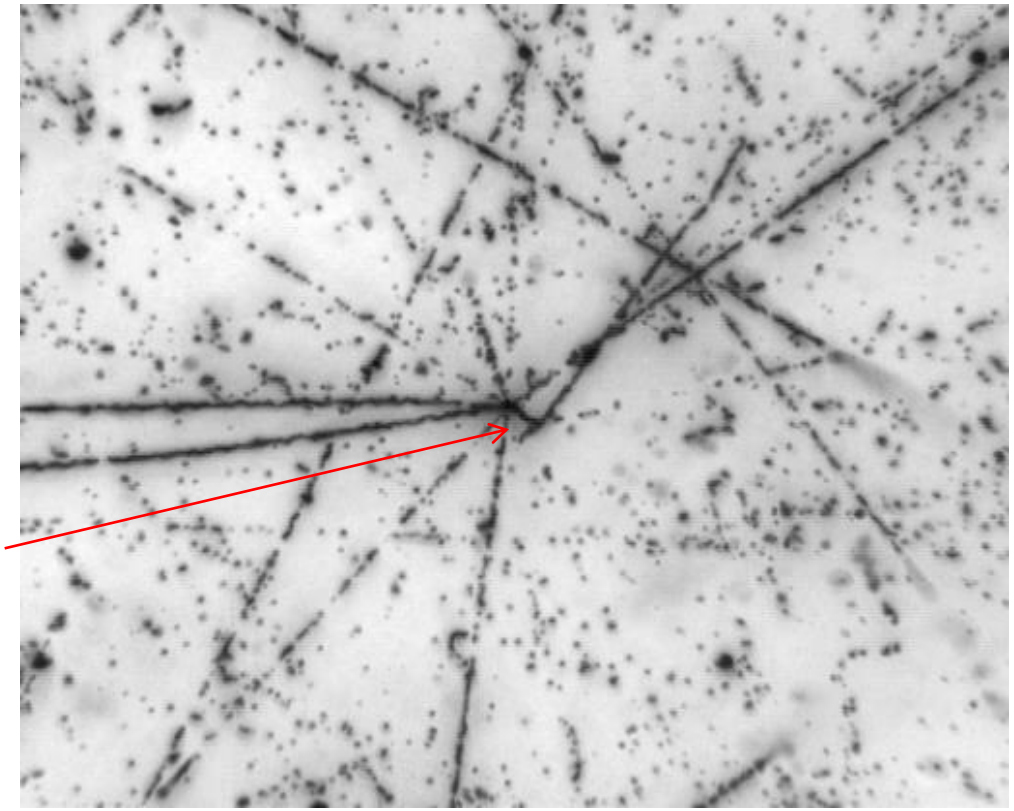
1. Gifu University

2. Advanced Science Research Center, JAEA

Revised in slide no. 5, 23 and 24.

Outlines

1. Nuclear emulsion
   - history
   - detector
   - specification
2. Past experiments
3. J-PARC E07 experiment



Very Brief History of nuclear emulsion

1910 :	S. Kinoshita	Observation of alpha particle with photographic emulsion
1947:	C. F. Pawell et al.	Discovery of π-meson in cosmic ray.
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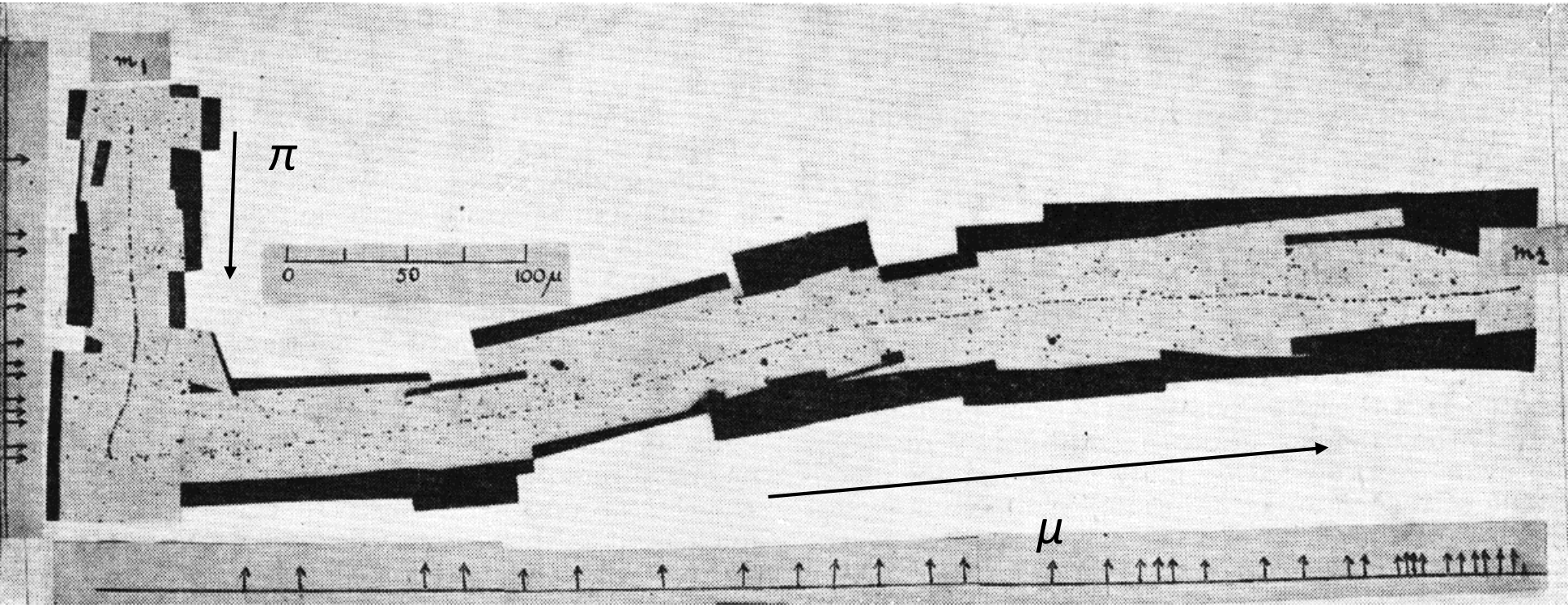
1977:	E531 experiment	First Neutrino oscillation experiment.
1985:	WA75	Detection of open bottom meson with accelerator
1988:	KEK-PS E176 exp.	Search for **double hypernuclei and H dibaryon** with counter-emulsion hybrid method
1999-:	KEK-PS E373 exp.	Search for **double hypernuclei** with the hybrid method
2000 :	DONUT experiment	Direct observation of τ neutrino.
2008- :	OPERA experiment	Discovery of τ neutrino appearance

Discovery of π-meson in cosmic ray (1947)

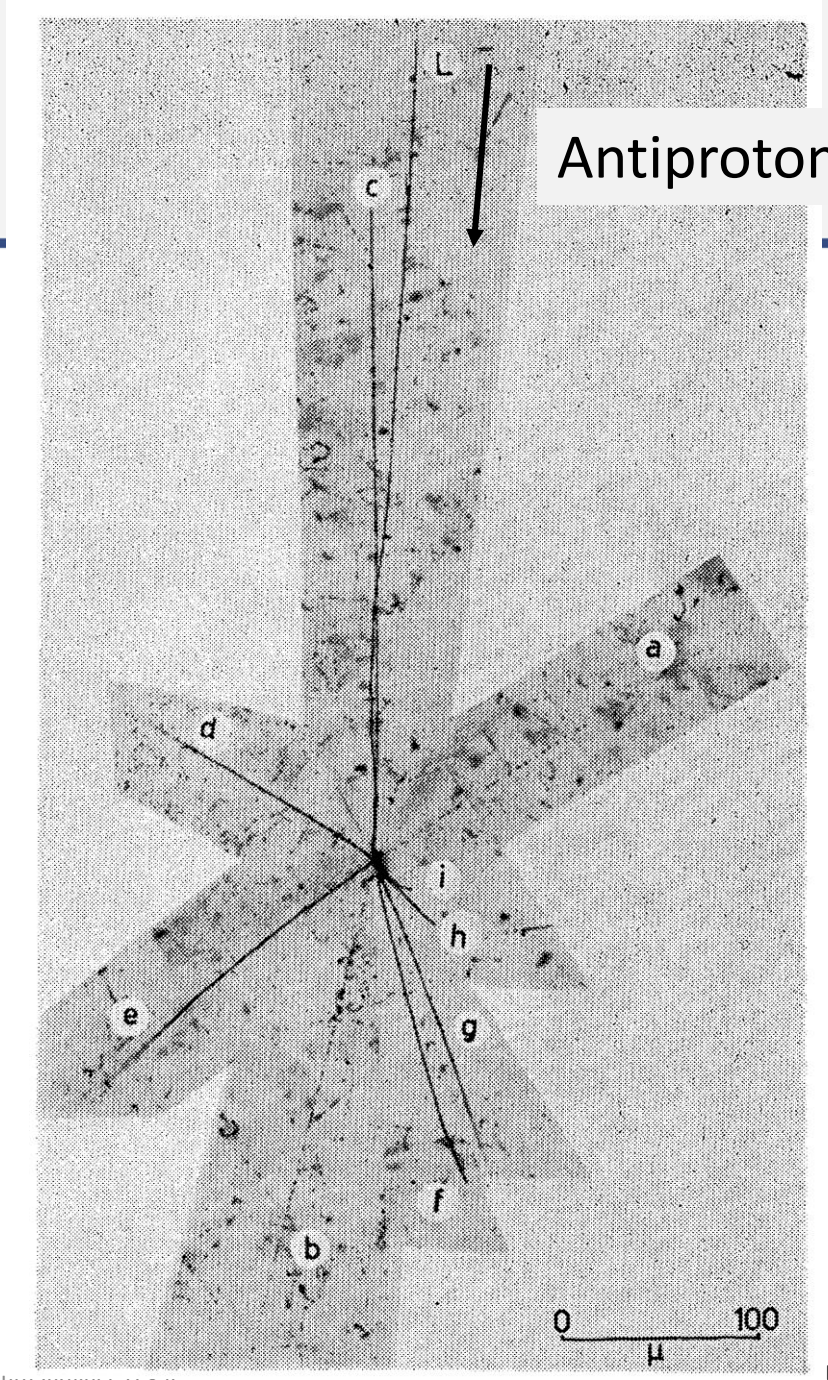
C. F. Pawell et al. Nature 159 186 (1947)
→ H. Yukawa, Nobel prize in 1949 → C. F. Pawell, Nobel prize in 1950



Detection of antiprotons in nuclear emulsion

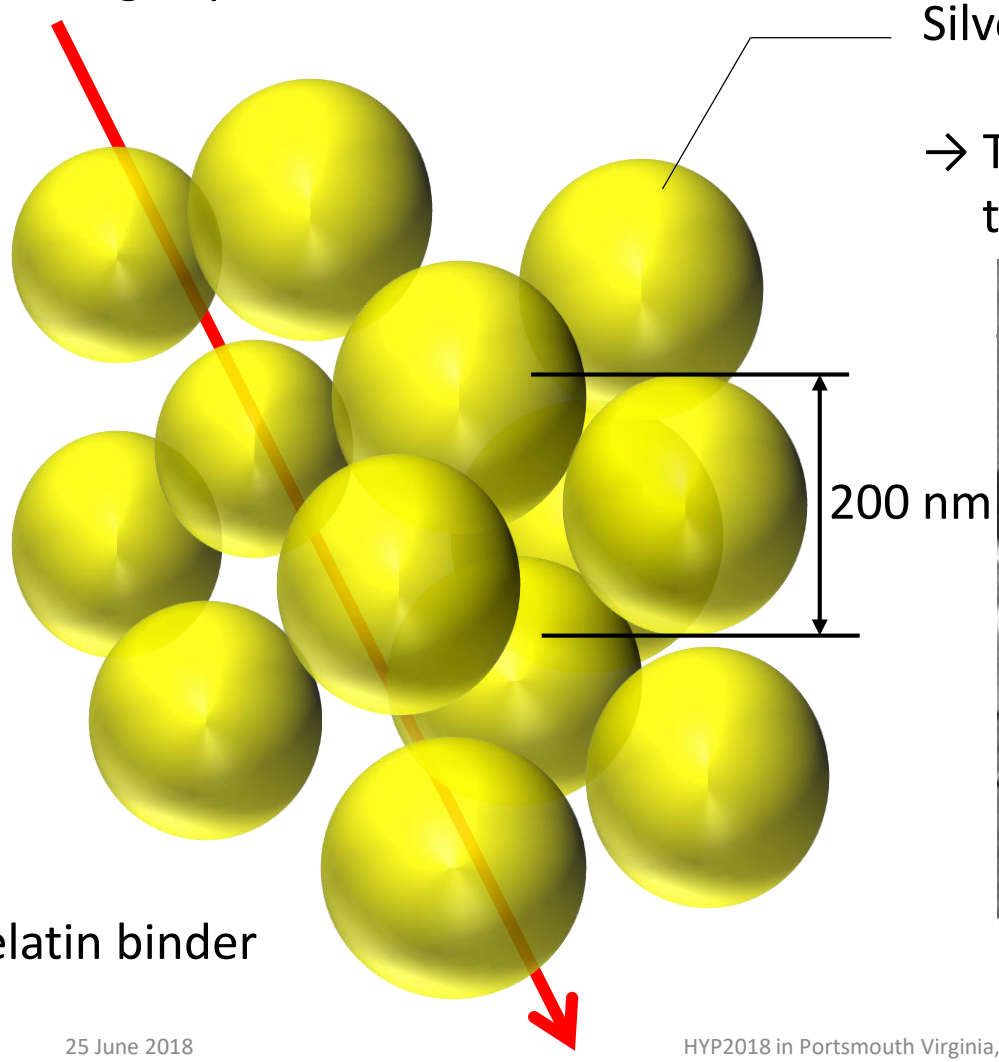
E. Segre & O. Chamberlain

Phys. Rev. 101 909-910 (1955)



Structure of nuclear emulsion plate

Charged particles



Gelatin binder

Detector elements =
Silver halide crystals 10^{14} /cm^3

→ The highest spatial resolution as tracking detector

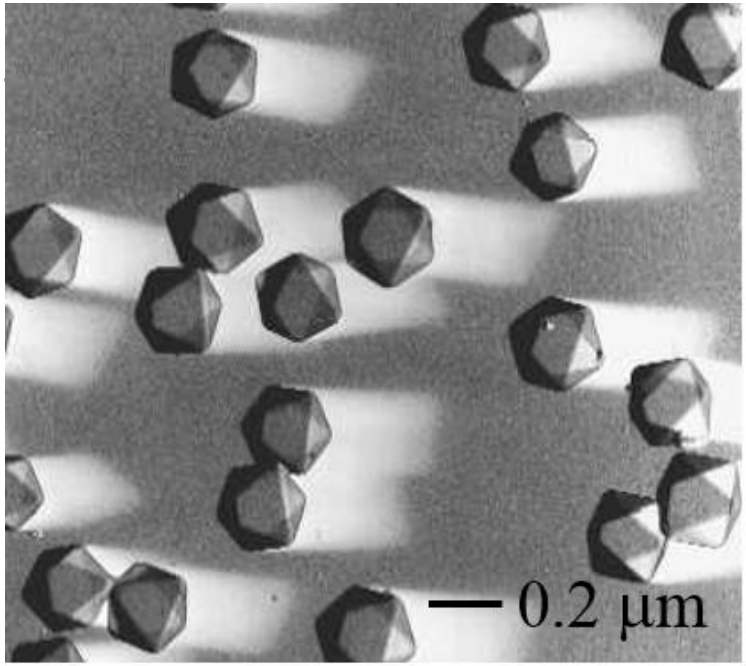
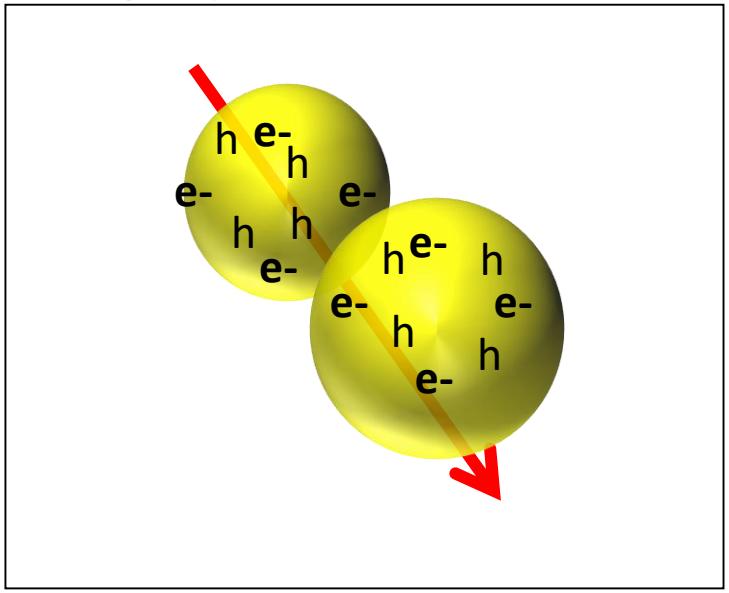
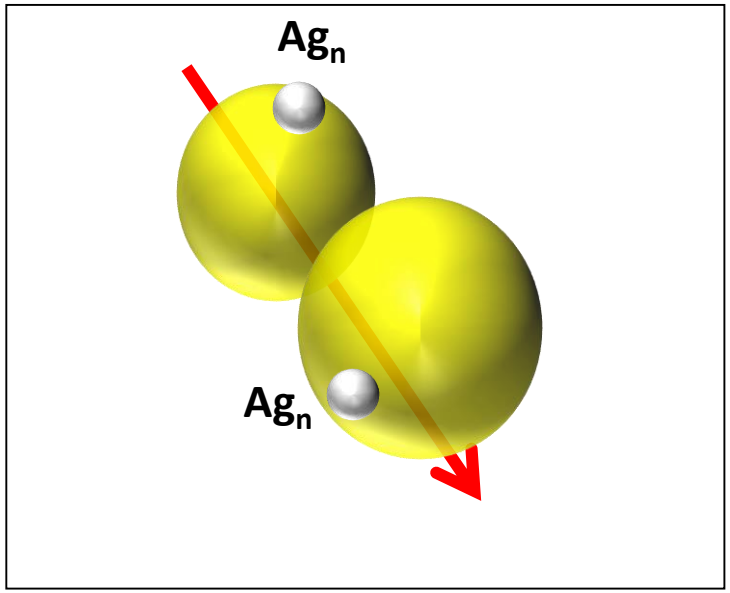


Image with electronic microscope.
developed by Fujifilm.

Charged particles





The **ionization** following the passage of the charged particles generates **electron-hole pairs** in the silver bromide crystal.

The electron reduces silver ions and makes a **latent image** (silver atoms).

$Ag^+ + e^- \rightarrow Ag$

$Ag + Ag^+ + e^- \rightarrow Ag_2$

.

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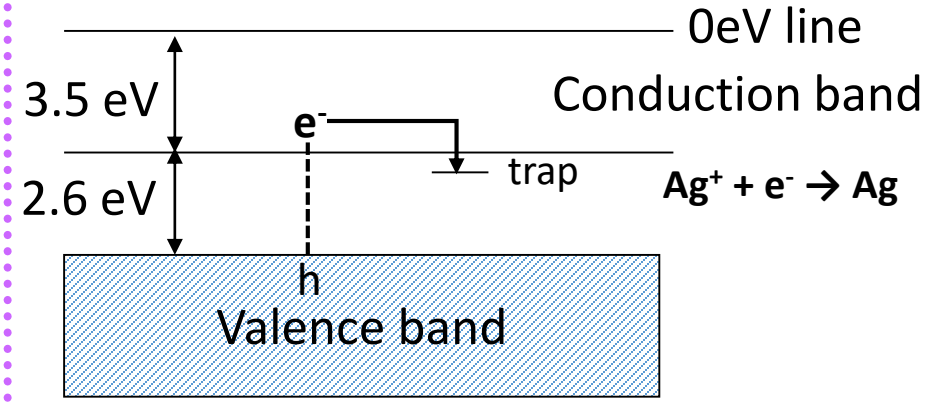
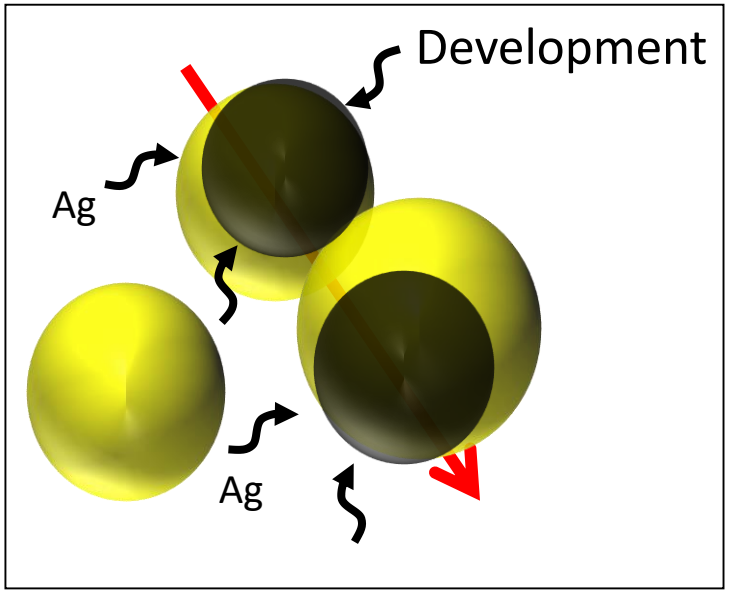
$Ag_{n-1} + Ag^+ + e^- \rightarrow Ag_n$

Energy level of AgBr



C. W. Peterson Phys. Rev. 148 335 (1966)



Chemical development:

Supply silver with reducing agent

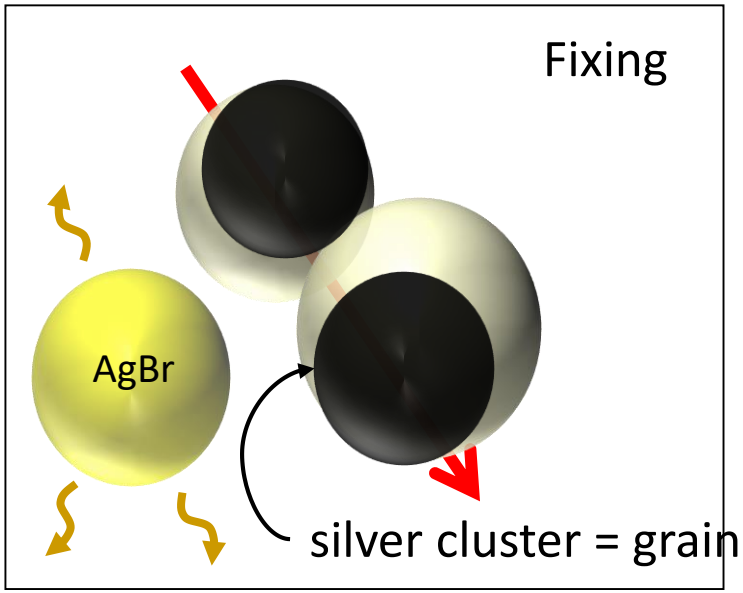
$Ag^+ + e^- \rightarrow Ag$

Grow latent images to an **observable** size

Fixing:

Remove unwanted AgBr

$2\ Na_2S_2O_3 + AgBr \rightarrow Na_3[Ag(S_2O_3)_2] + NaBr$



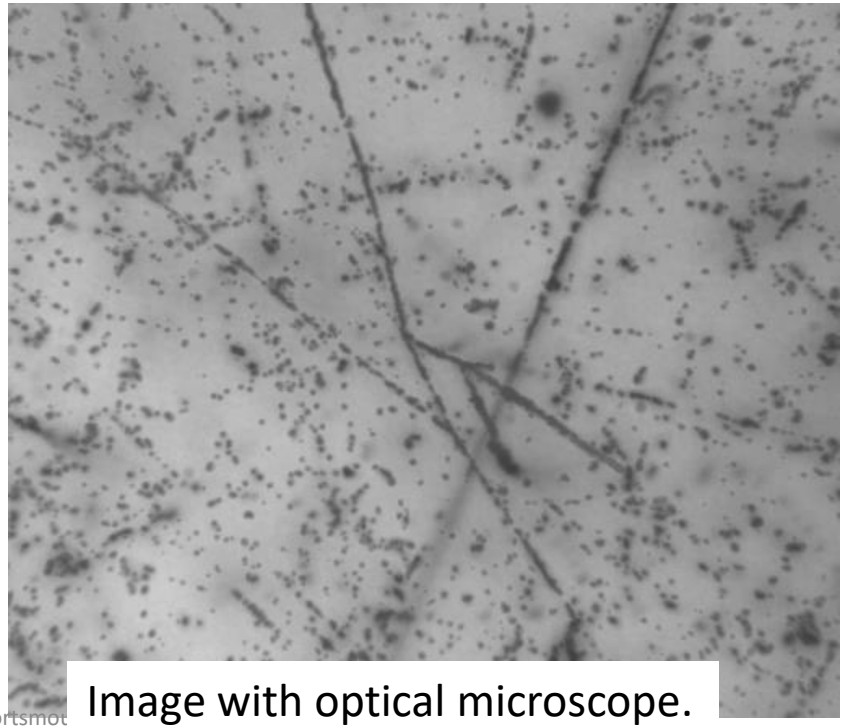


Image with optical microscope.

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Hybrid method with counter
Semi-automated stage

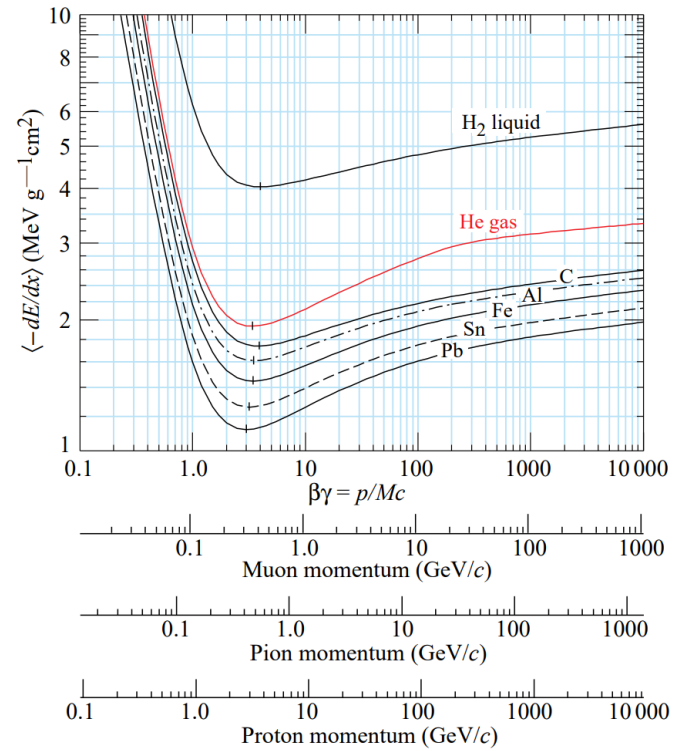
Fully automated read-out system
with a speed beyond human

How to determine the energy and identify the particles

1. Energy-loss: Bethe-Bloch equation

$$-\left\langle \frac{dE}{dx} \right\rangle = K z^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\frac{1}{2} \ln \frac{2 m_e c^2 \beta^2 \gamma^2 W_{\max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right] .$$

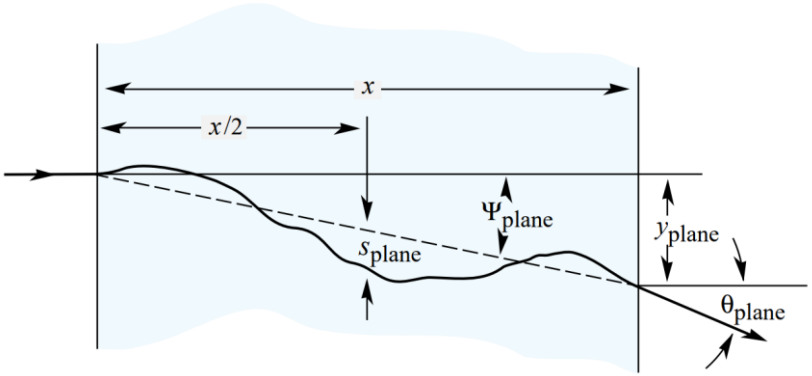
Range-Energy relation
Grain linear density measurement



PDG 2016

2. Multiple coulomb scattering

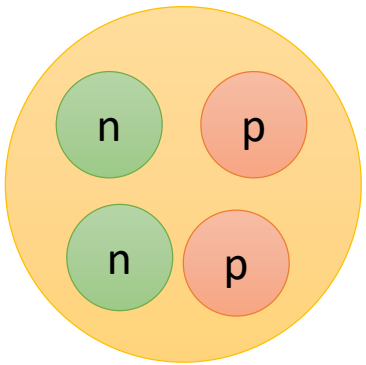
$$\theta_0 = \frac{13.6 \text{ MeV}}{\beta c p} z \sqrt{x/X_0} \left[1 + 0.038 \ln(x/X_0) \right] .$$



Mirror hypernuclei

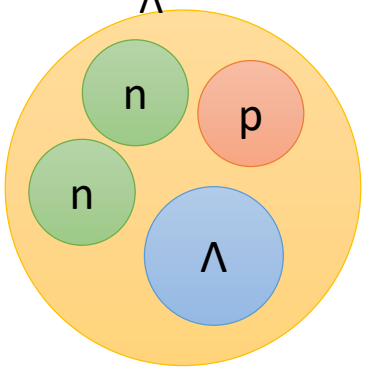
Normal nuclei

^{4}He

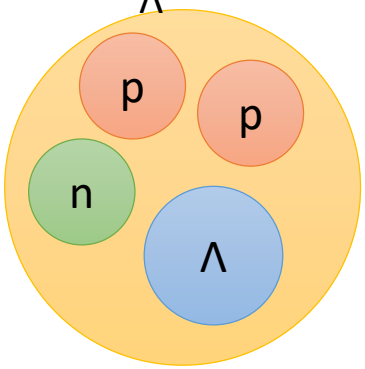


Hypernuclei

$_{\Lambda}^{4}$H



$_{\Lambda}^{4}$He



Mirror hypernuclei

$$
\begin{aligned}
{}_{\Lambda}^{4}\mathrm{H} &\rightarrow \pi^{-} + {}^{4}\mathrm{He} \\
&\rightarrow \pi^{-} + {}^{1}\mathrm{H} + {}^{3}\mathrm{H} \\
&\rightarrow \pi^{-} + {}^{2}\mathrm{H} + {}^{2}\mathrm{H} \\
{}_{\Lambda}^{4}\mathrm{He} &\rightarrow \pi^{-} + {}^{1}\mathrm{H} + {}^{3}\mathrm{He} \\
&\rightarrow \pi^{-} + {}^{1}\mathrm{H} + {}^{1}\mathrm{H} + {}^{2}\mathrm{H}
\end{aligned}
$$

Mesonic decays w/o neutron

$$\Delta B_{\Lambda} = B_{\Lambda}({}_{\Lambda}^{4}\mathrm{He}) - B_{\Lambda}({}_{\Lambda}^{4}\mathrm{H})$$

Measurement of B_Λ

$$Q_0 = M_\Lambda + M_Z^{A-1} - \sum mi$$

core decay products

$$B_\Lambda = Q_0 - Q$$

Total visible energy in emulsion

1. Range measurement error
2. Emulsion density and shrinkage factor measurement error
3. Range straggling

Emulsion can measure B_Λ of various nuclides in the same detector. Thus, the other systematic errors will be canceled.

B_Λ past results in nuclear emulsion

Table 3
Binding energies of light hypernuclei measured in emulsion. In addition to the quoted statistical errors, there are systematic errors (~ 0.04 MeV) which have been minimised by measuring M_Λ in the same emulsion stack

Hypernuclide	B_Λ/MeV		Hypernuclide	B_Λ/MeV	
${}^{3}_{\Lambda}$H	0.13 ± 0.05	[1]	${}^{9}_{\Lambda}$Li	8.50 ± 0.12	[3]
${}^{4}_{\Lambda}$H	2.04 ± 0.04	[1]	${}^{9}_{\Lambda}$Be	6.71 ± 0.04	[1]
${}^{4}_{\Lambda}$He	2.39 ± 0.03	[1]	${}^{9}_{\Lambda}$B	8.29 ± 0.18	[3]
${}^{5}_{\Lambda}$He	3.12 ± 0.02	[1]	${}^{10}_{\Lambda}$Be	9.11 ± 0.22	[2]
${}^{6}_{\Lambda}$He	4.18 ± 0.10		${}^{10}_{\Lambda}$B	8.89 ± 0.12	[1]
${}^{7}_{\Lambda}$He	not averaged		${}^{11}_{\Lambda}$B	10.24 ± 0.05	[1]
${}^{7}_{\Lambda}$Li	5.58 ± 0.03	[1]	${}^{12}_{\Lambda}$B	11.37 ± 0.06	[1]
${}^{7}_{\Lambda}$Be	5.16 ± 0.08	[1]	${}^{12}_{\Lambda}$C	10.76 ± 0.19	[4]
${}^{8}_{\Lambda}$He	7.16 ± 0.70	[1]	${}^{13}_{\Lambda}$C	11.69 ± 0.12	[2]
${}^{8}_{\Lambda}$Li	6.80 ± 0.03	[1]	${}^{14}_{\Lambda}$C	12.17 ± 0.33	[2]
${}^{8}_{\Lambda}$Be	6.84 ± 0.05	[1]	${}^{15}_{\Lambda}$N	13.59 ± 0.15	[1]

Table: D.H. Davis Nucl. Phys. A754 3 (2005)

[1] M. Juric, et al., NuclPhysB52_1 (1973)
[2] T. Cantwell, et al. NuclPhysA236_445 (1974)
[3] J. Pniewski, et al., NuclPhysA443_685 (1985)
[4] D. Dłuzewski, et al., NuclPhysA484_520 (1988)

ΔB_Λ past results in nuclear emulsion

Multiplet pair				ΔB_Λ/MeV
${}^{4}_{\Lambda}$He–${}^{4}_{\Lambda}$H	279 events [1]	VS	155 events [1]	$+0.35 \pm 0.04$
${}^{8}_{\Lambda}$Be–${}^{8}_{\Lambda}$Li	68 events [1]	VS	787 events [1]	$+0.04 \pm 0.06$
${}^{9}_{\Lambda}$B–${}^{9}_{\Lambda}$Li	**4 events [3]**	VS	13 events[3]	-0.21 ± 0.22
${}^{10}_{\Lambda}$B–${}^{10}_{\Lambda}$Be	**10 events [1]**	VS	**3 events [2]**	-0.22 ± 0.25
${}^{12}_{\Lambda}$C–${}^{12}_{\Lambda}$B	**6 events [4]**	VS	87 events[1]	-0.57 ± 0.19

The **systematics** error is dominant.

The **statistical** error is dominant.

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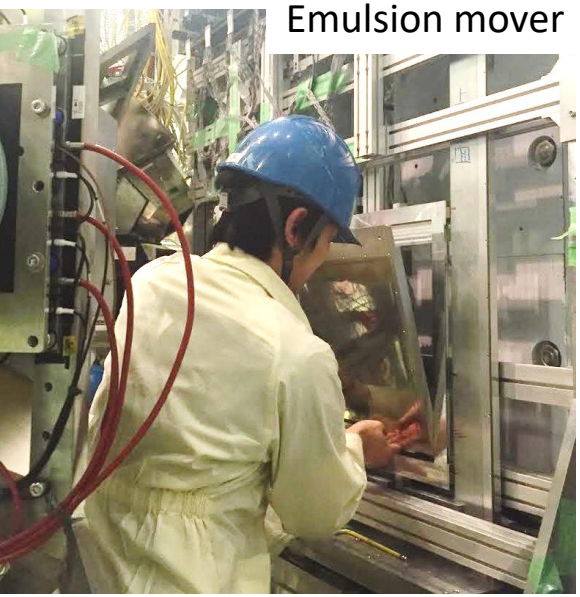
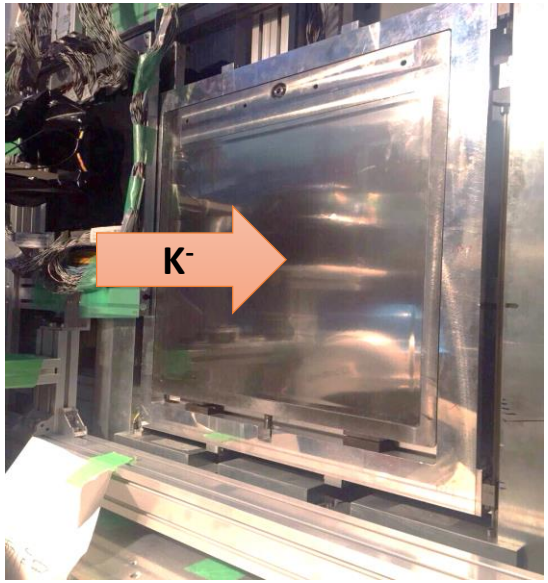
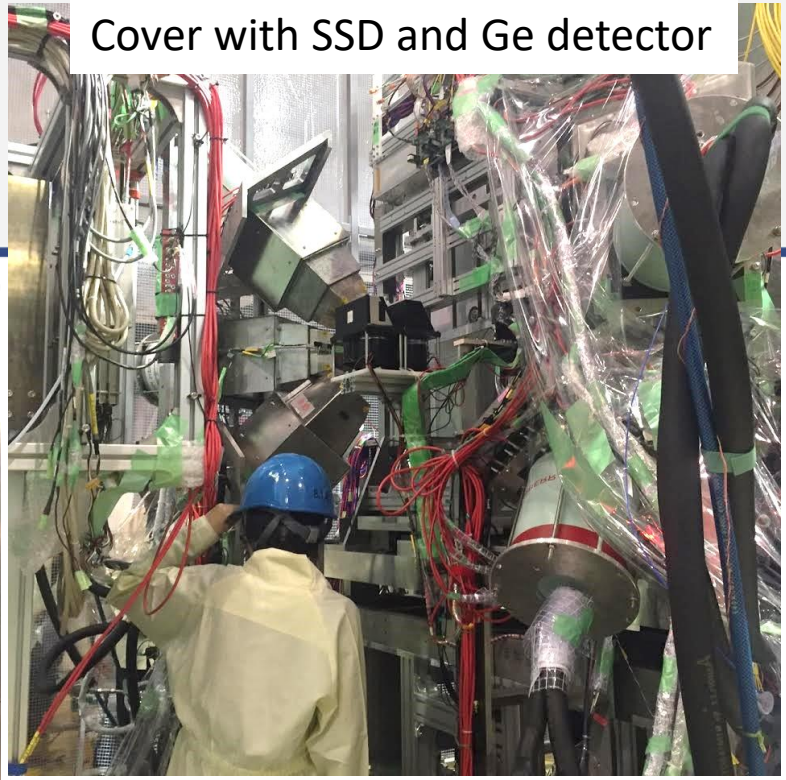
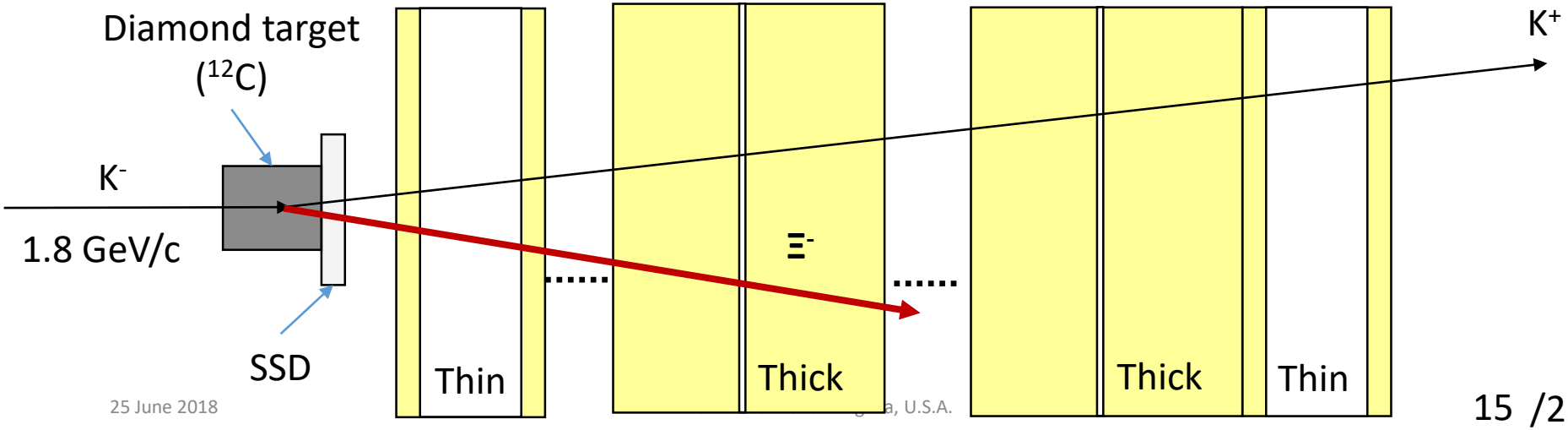
If we get **an order of magnitude higher events** and apply the latest range and emulsion calibration method, we will discuss ΔB_Λ of the multiplet pairs up to ^{12}C with **high accuracy.**

Beam exposure
J-PARC E07 in 2016 and 2017

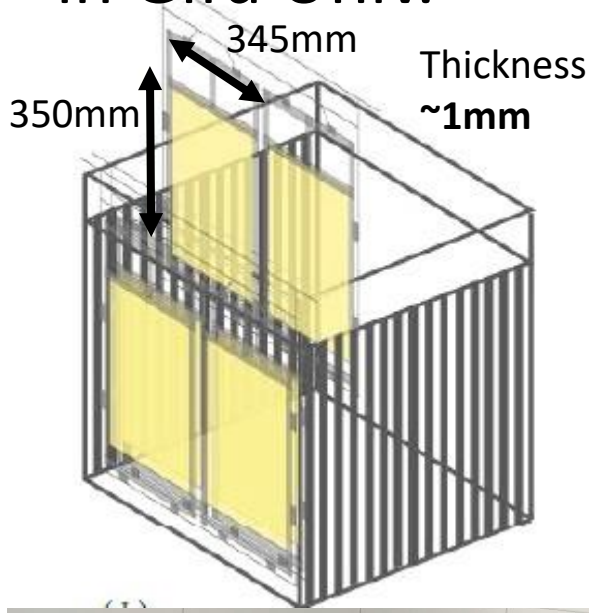


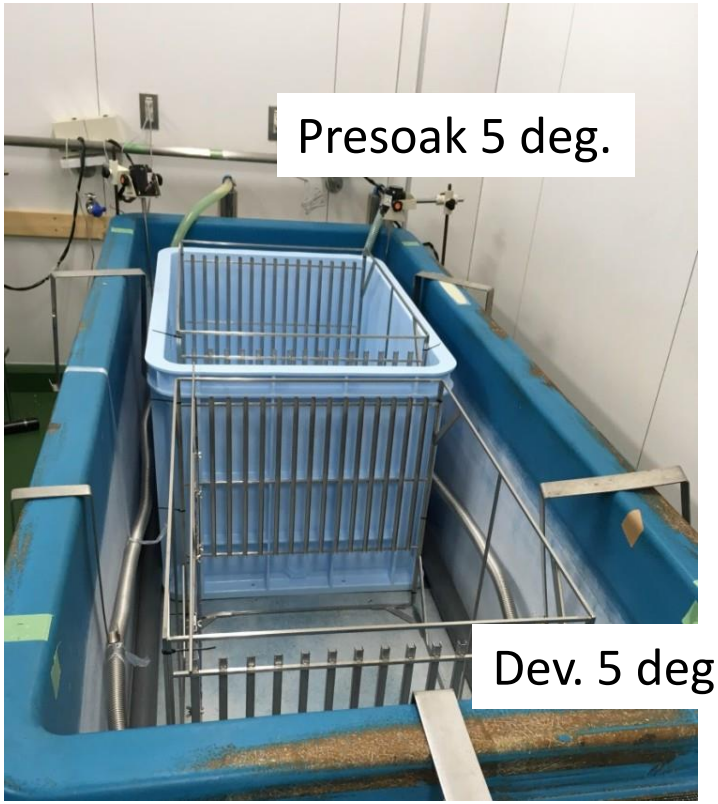


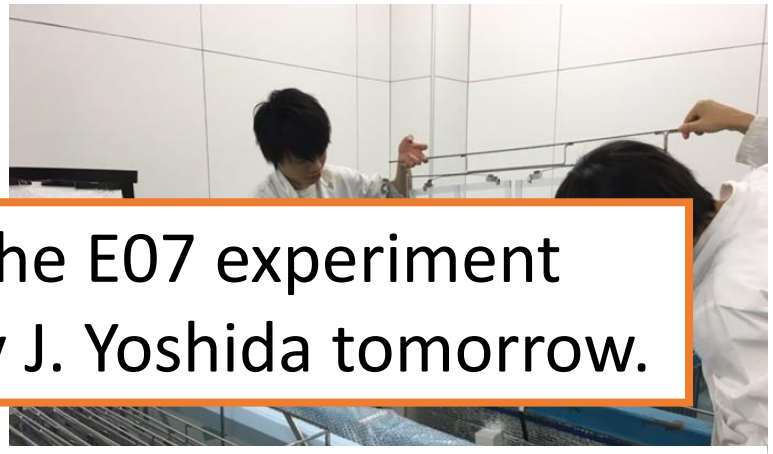




Chemical development for E07 in Gifu Univ.







Main talks on the E07 experiment will be given by J. Yoshida tomorrow.

60 plates/cycle (total 1298 plates)
~5 days/cycle from presoak to fix

J-PARC E07 Nuclear Emulsion

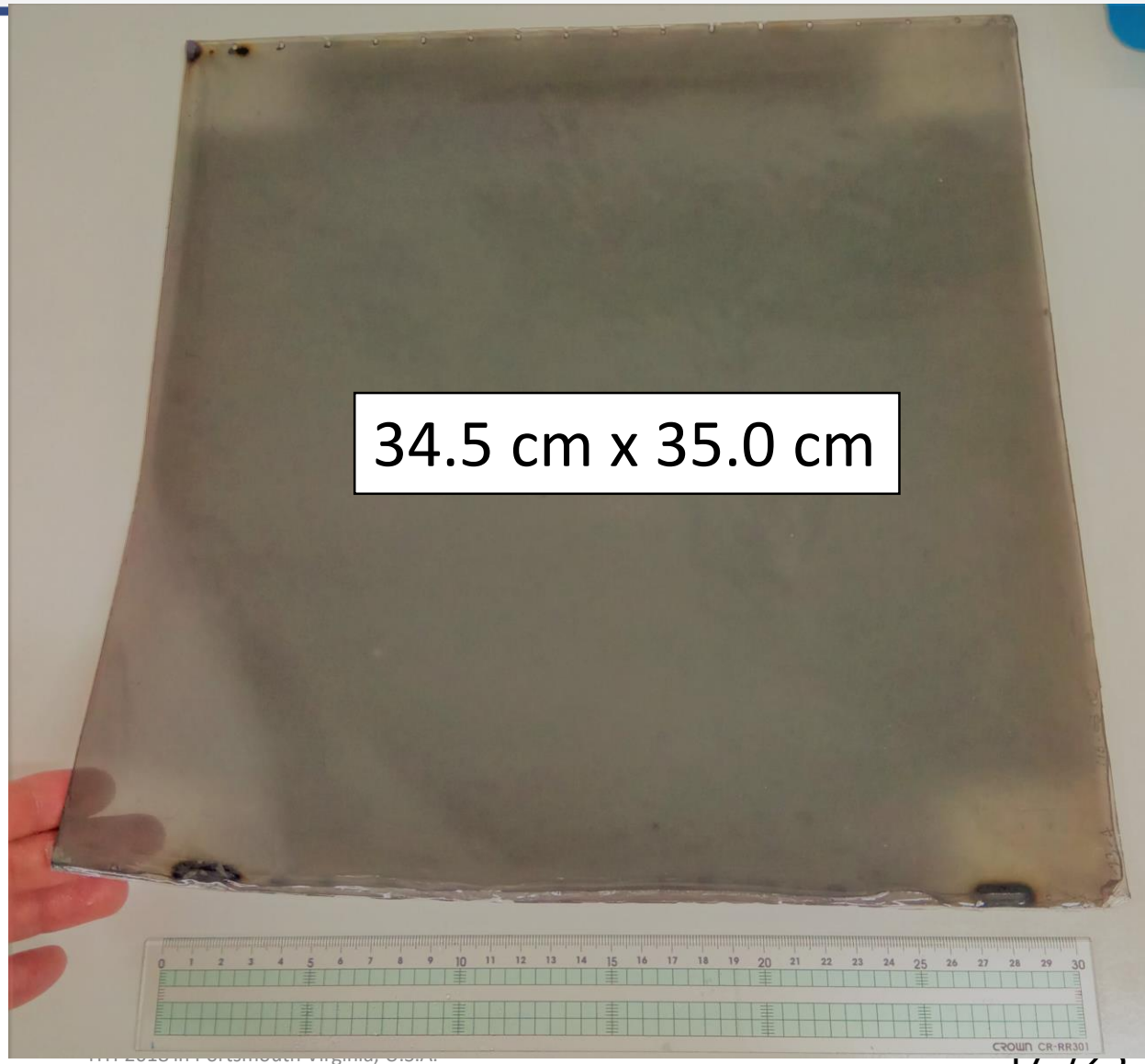
Thick emulsion plate after chemical development

Elemental composition

Element	Atomic %
H	39.6
C	20.6
N	5.9
O	11.3
Ag	11.2
Br	11.1

Density: 3.6 – 3.9 g/cm^3
Shrinkage factor: 1.6 – 1.9

Requires **calibration** using alpha decay (Z=2) and muon (Z=1) from π^+ decay



Estimation of single hypernuclei

All events **= Overall method**

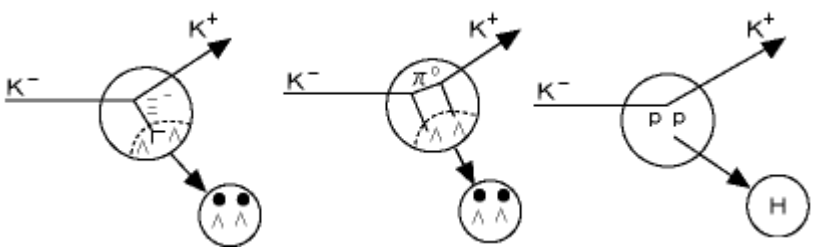
Direct process — 3 : 1 preliminary — via Ξ^- atom

$n(K^-, K^0)\,\Xi^-$ — 2 : 1 — $p(K^-, K^+)\,\Xi^-$

2 : 1

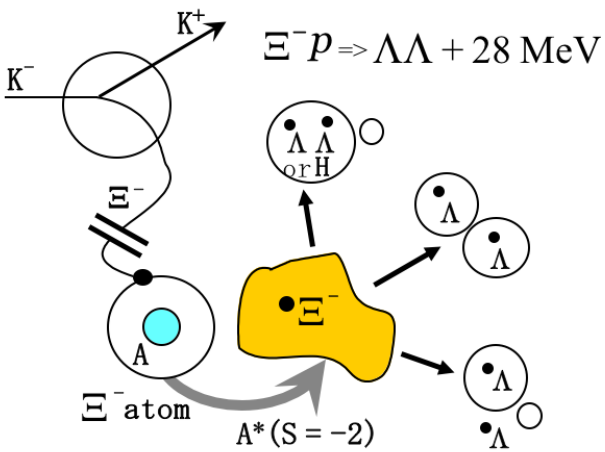
un-triggered — triggered Ξ^-

Hybrid method



K^- beam: ~10^{10} in total

	Hybrid	Overall
# of events	1	**~30**
Area to analyze	1	**~1000**



via Ξ^- atom

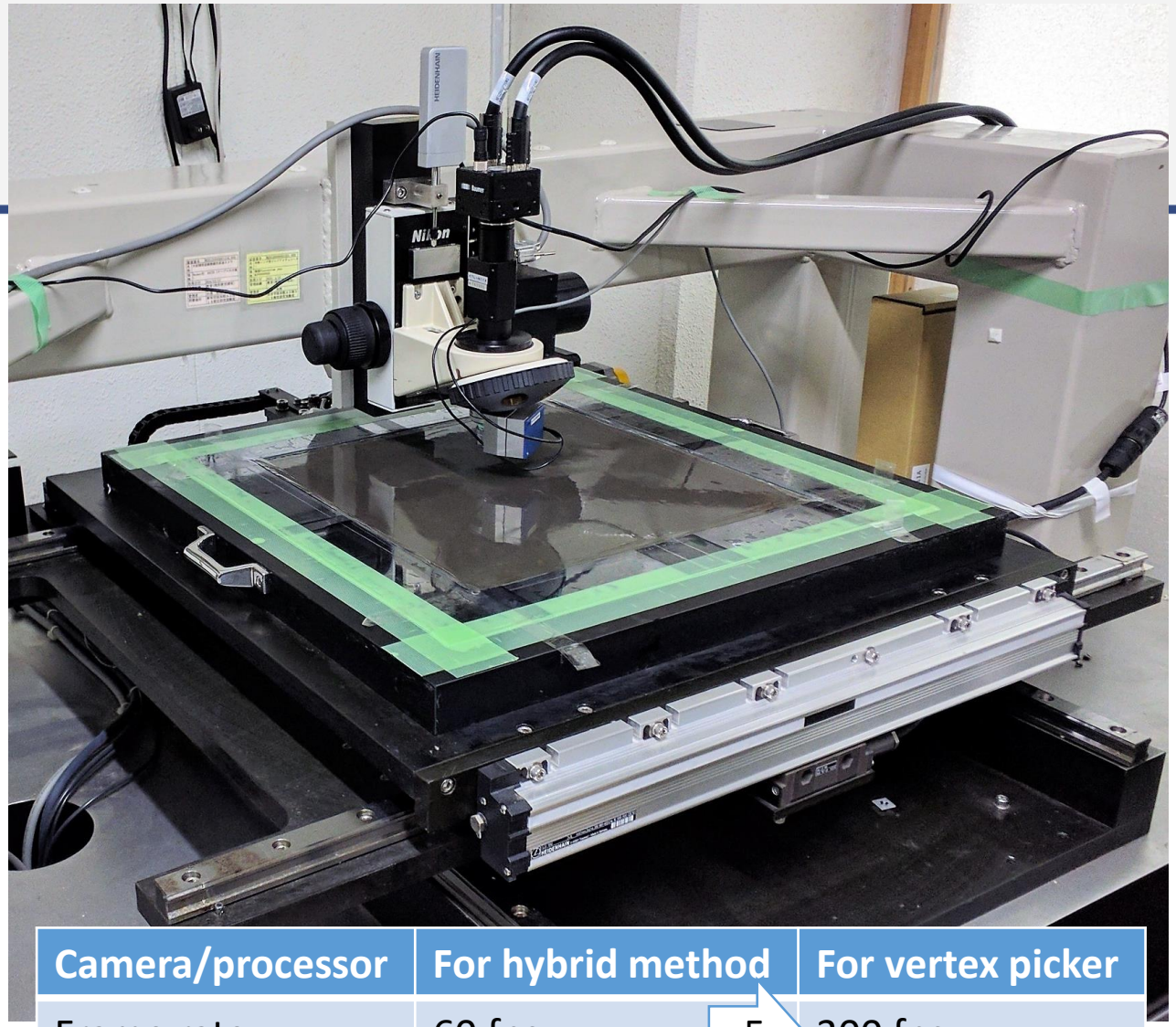
“Vertex Picker”

Fully automated microscopic stage

High resolution CMOS
2048*1088 pixels
High frame rate
300fps

Wide FOV
x20 dry lens (NA0.35)
565 × 300 μm^2

Piezoelectric drive
Stroke 200 micron
Period 1.3 Hz (current)
Picture 32picts /cycle

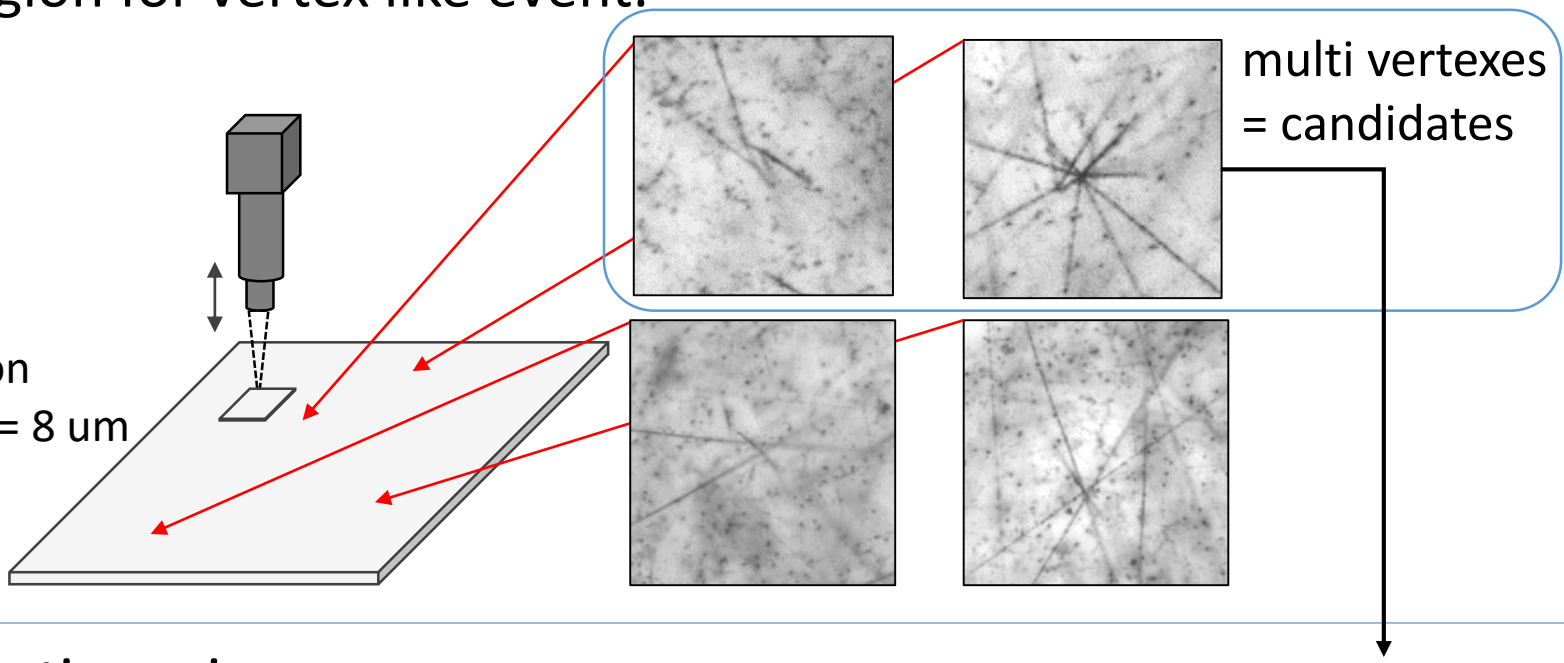


Camera/processor	For hybrid method		For vertex picker
Frame rate	60 fps	x5	300 fps
resolution	512 × 440		2048 × 1088
Field of view(μm^2)	140 × 110	x11	565 × 300
Image processing	CPU		CPU & GPU

◆ Vertex Picker

developed by J. Yoshida
NIM A847 86–92 (2017)

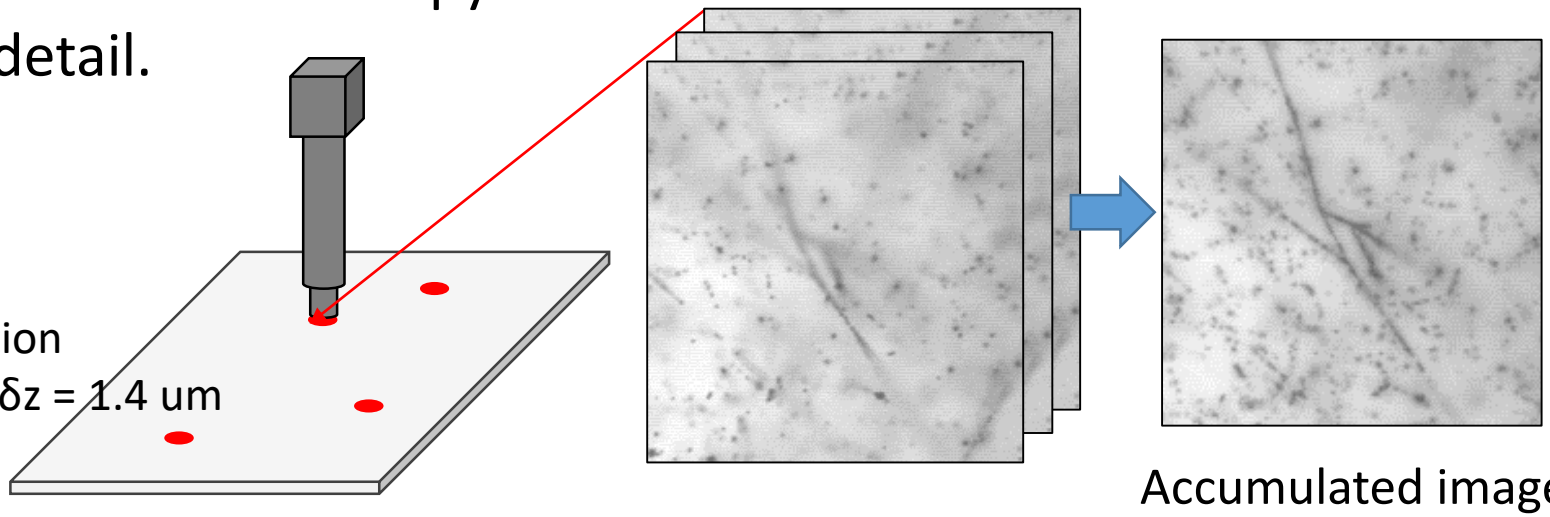
Search all region for vertex like event.



Spatial resolution
δx = 0.9 um, δz = 8 um

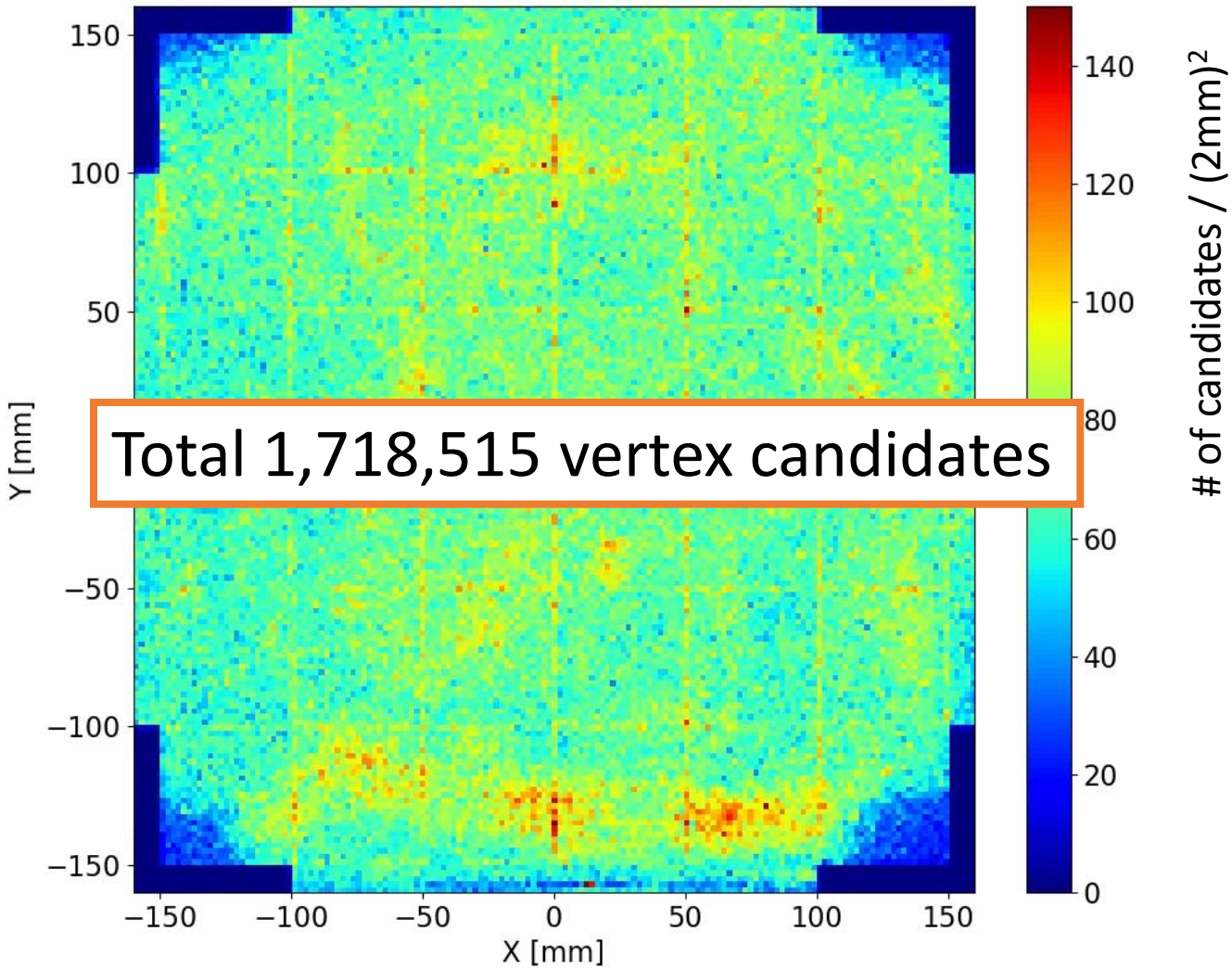
◆ High resolution microscopy

Analyze in detail.



Spatial resolution
δx = 0.36 um, δz = 1.4 um

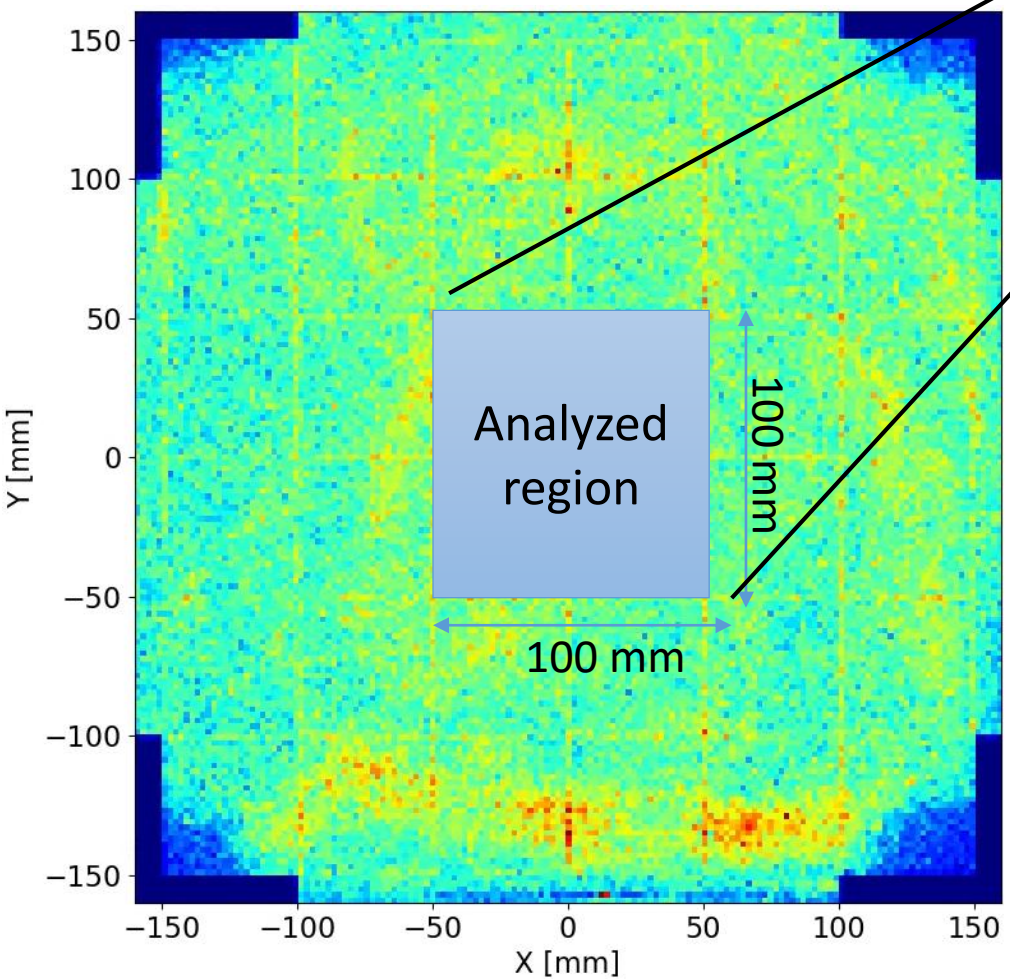
Result of vertex picker

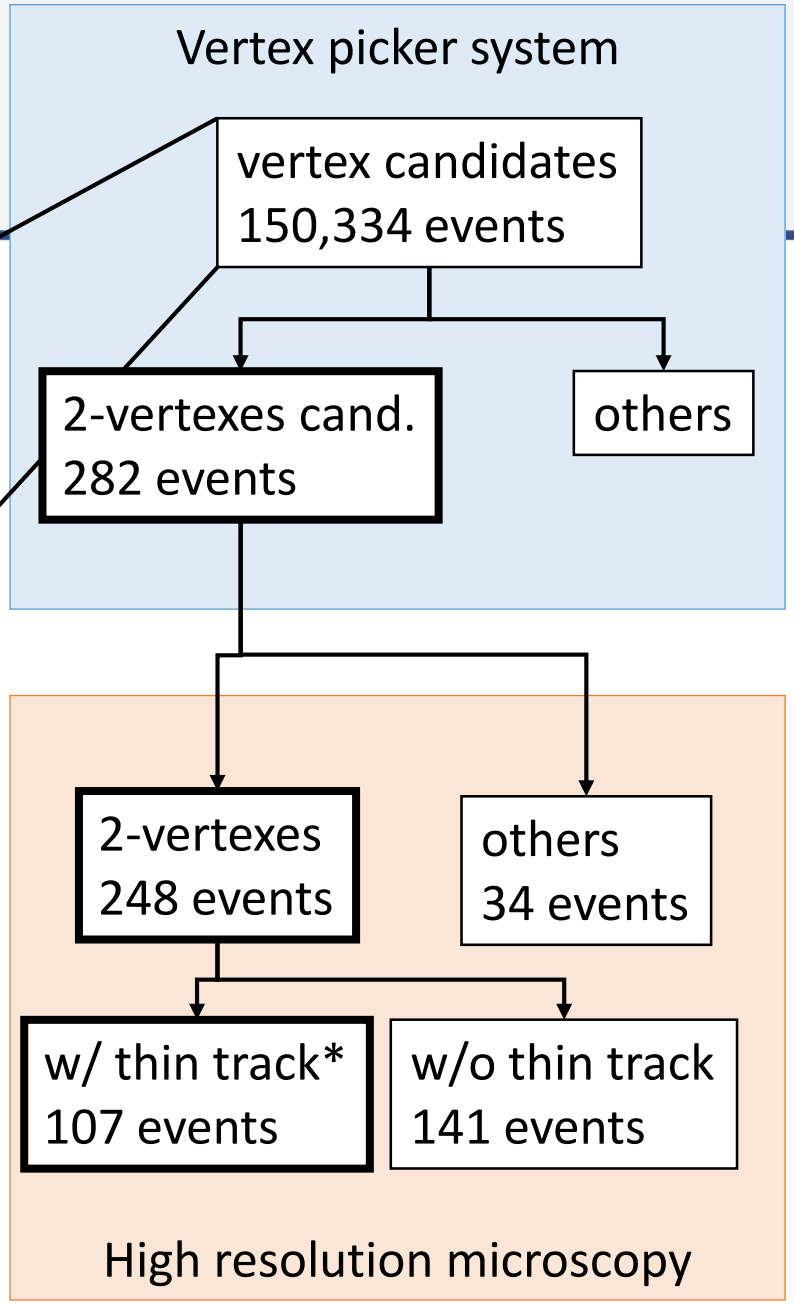


Total 1,718,515 vertex candidates

An E07 emulsion plate

Detail analysis





* The thin tracks are not identified as π-meson

Estimation with all the E07 emulsion plates

~1.7G vertex candidates

Almost all events are single vertex or fake events

~3M two vertexes

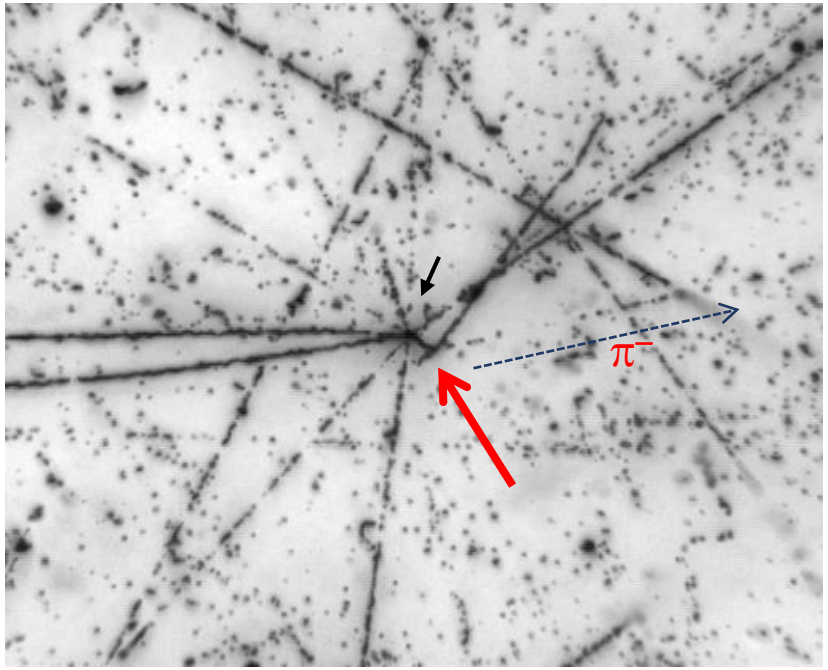
Two third will be w/o thin track

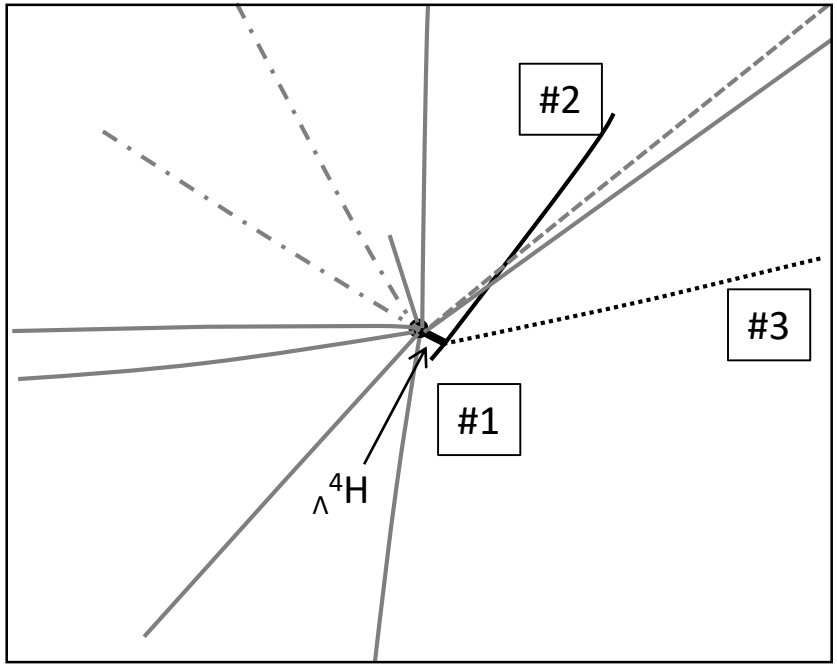
~1M two vertexes w/ thin track

It would be to obtain an order of magnitude more events approximately.

cf. 27K mesonic decay
Nuclear Physics B52 (1973) 1-30.

Mesonic decay of single hypernuclear event





Track	Range (μm)	Theta θ (deg.)	Phi ϕ (deg)
#1	5.3 ± 0.5	18.9 ± 2.1	58.2 ± 1.3
#2	29.0 ± 1.7	132.3 ± 1.8	237.3 ± 1.9
#3	12520 ± 20	125.1 ± 1.4	193.1 ± 3.3

Invariant mass [MeV/c^2]

Measured	~~3923.3±0.3*~~
~~Nuclear DB~~	~~3922.57±0.04~~

*Calibration was not finished.

This decay is only allowed by ~~kinematic analysis.~~

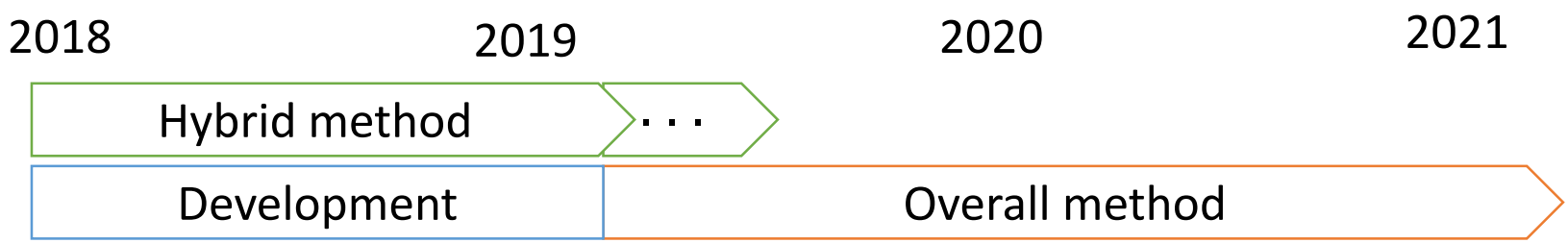
$$\cancel{{}_{\Lambda}^{4}\mathrm{H} \rightarrow \pi^{-} + \mathrm{d} + \mathrm{d}}$$

Not confirmed.

Analyzed by May Sweet

Summary and prospects

- There are many uncertainties in the past results of the emulsion experiments, and some issues can be solved by increasing events.
- Emulsions can discuss various single hypernuclei in the same detector with sub-MeV accuracy.
- Development and analysis of reading the E07 emulsion plates is ongoing.
- According to the estimate, 1,000K two vertexes w/ thin track will be acquired.



- We plan to start full-scale analysis using the overall method with vertex picker from 2019. The new results of B_Λ will be released in a few years.