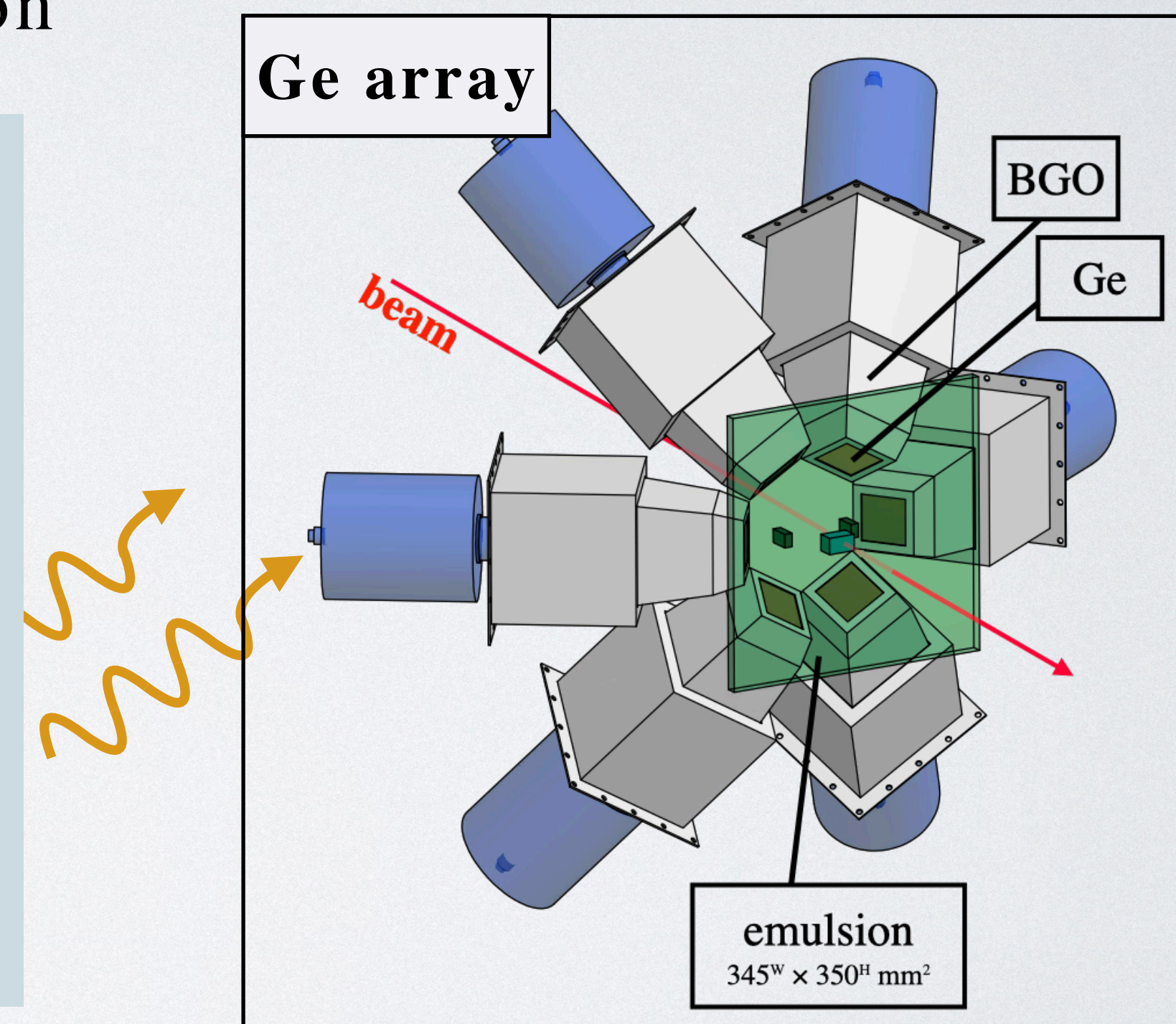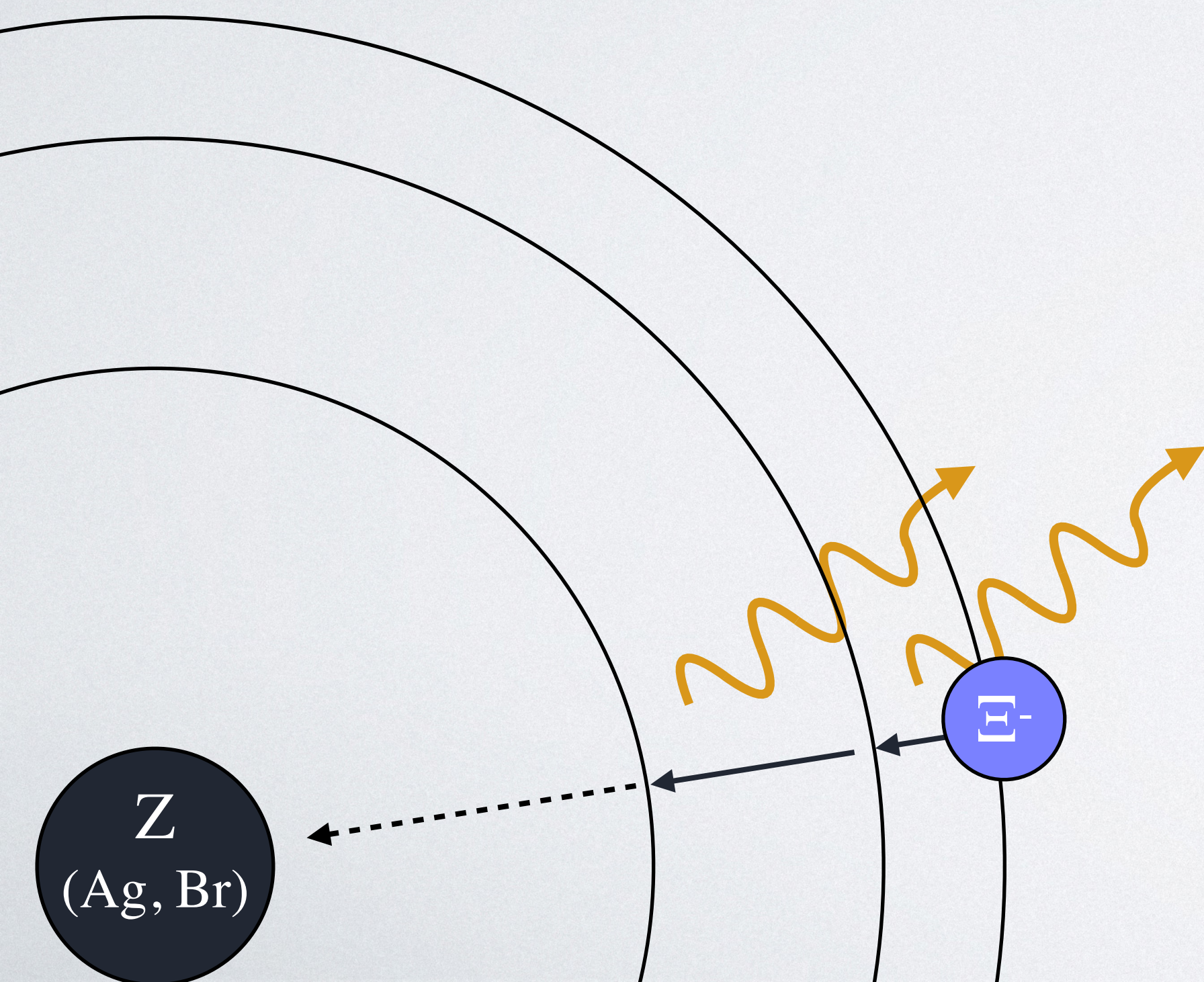# Results of Ξ atomic X-ray measurement at J-PARC E07

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on behalf of the E07 collaboration

Contents

- ❖ Introduction
- ❖ Analysis
- ❖ Result and discussion
- ❖ Summary

❖ MonIII: X-ray spectroscopy on Ξ atoms （J-PARC E03, E07 and future）by T. O. Yamamoto

❖ WedIII: X-ray spectroscopy of Ξ Fe atom in J-PARC E03 experiment by Y. Ishikawa

Introduction

❖ Physics motivation

❖ Concept of X-ray spectroscopy

❖ Experimental set up

Physics motivation

n

Ξ^-Ag atomic level

l

8J

abs.

ΔE

Γ

7I (Last orbit)

Xray

absorption
$\Xi^- p \to \Lambda\Lambda$

—— Coulomb + strong
------- Coulomb

❖ Ξ-nucleus potential : $U = V + iW$

| Energy shift (ΔE) | ⬌ | Real part (V) |
| Width (Γ) Branching ratio (BR_{abs}) | ⬌ | Imaginary part (W) |

Concept

❖ Huge backgroud photons due to in-flight Ξ⁻ decay

→ **Identify stopped Ξ⁻ events using nuclear emulsion**

(C, N, O, Br, and Ag)

J-PARC E07 : search for double Hypernuclei using emulsion

❖ MonIII: Inforamation on double hypernulcei with nuclear emulsion detector by K. Nakazawa-san

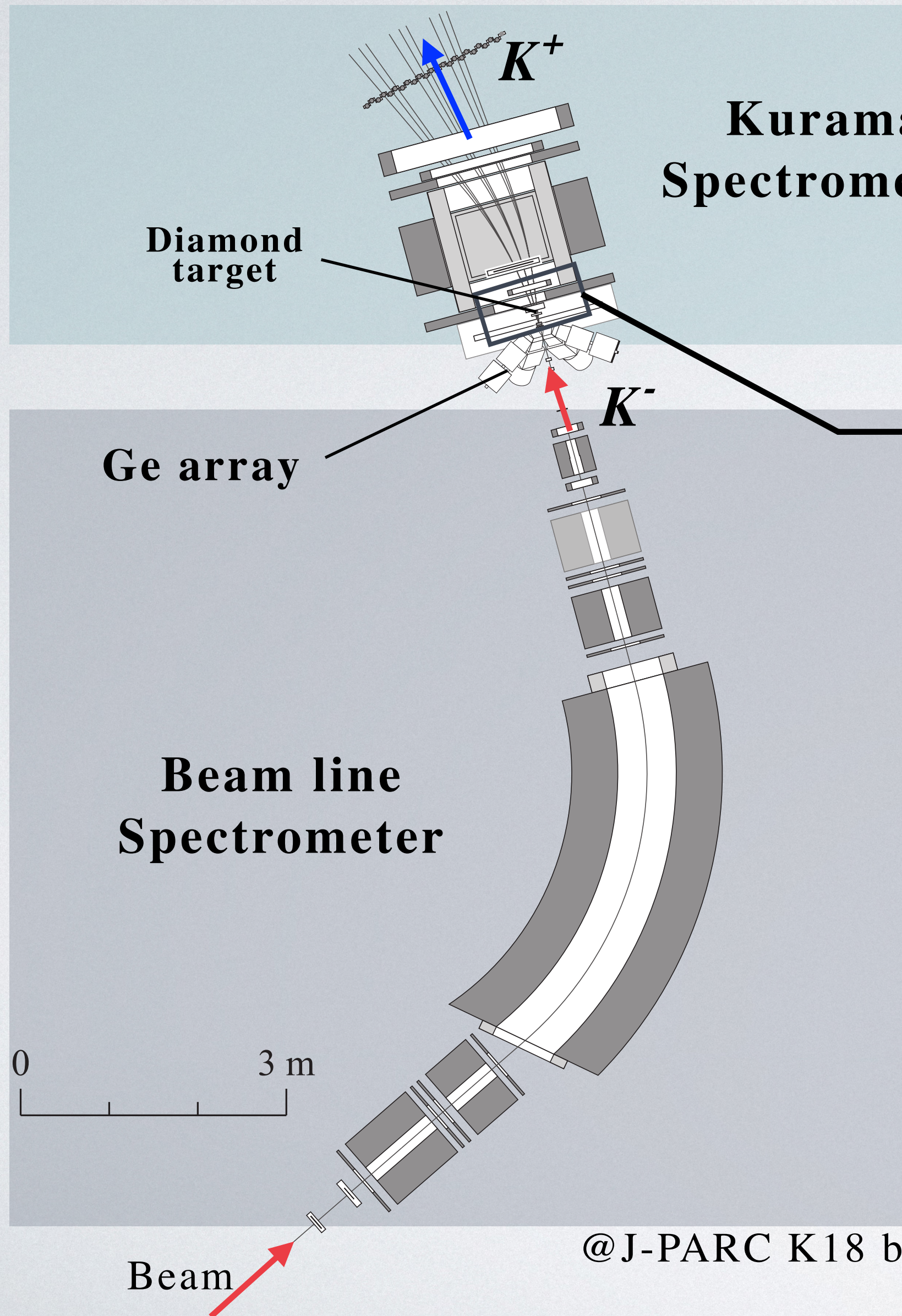❖ Theoretical expectation (E. Friedman and A. Gal, private communication 2001)

Last transition	Potential	X-ray energy [keV]	shift [keV]	Width [keV]
Ag(8J→7I)	to	370. 4	0.28	0.15
	ND		3.3	0.79
Br(7I→6H)	to	315.5	0.73	0.44
	ND		5.5	1.74

→ **Germanium(Ge) detector : measure 300-400 keV X rays**

w/ high energy resolution (σ ~ 0.8 keV)
W/ high accuracy (new in-beam calibration system)
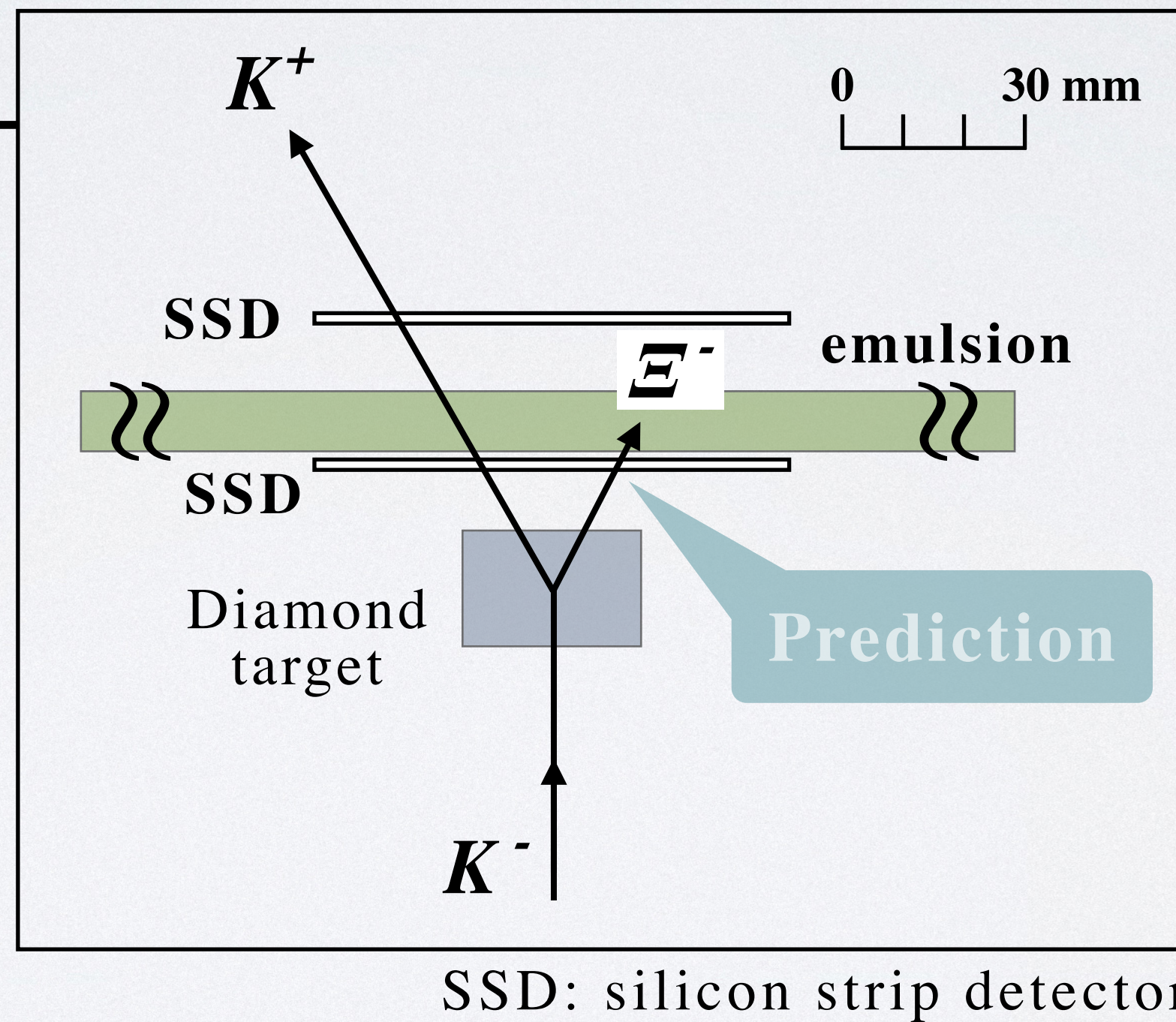
Experimental setup (J-PARC E07)

❖ (K^-, K^+) reaction spectroscopy

K^+
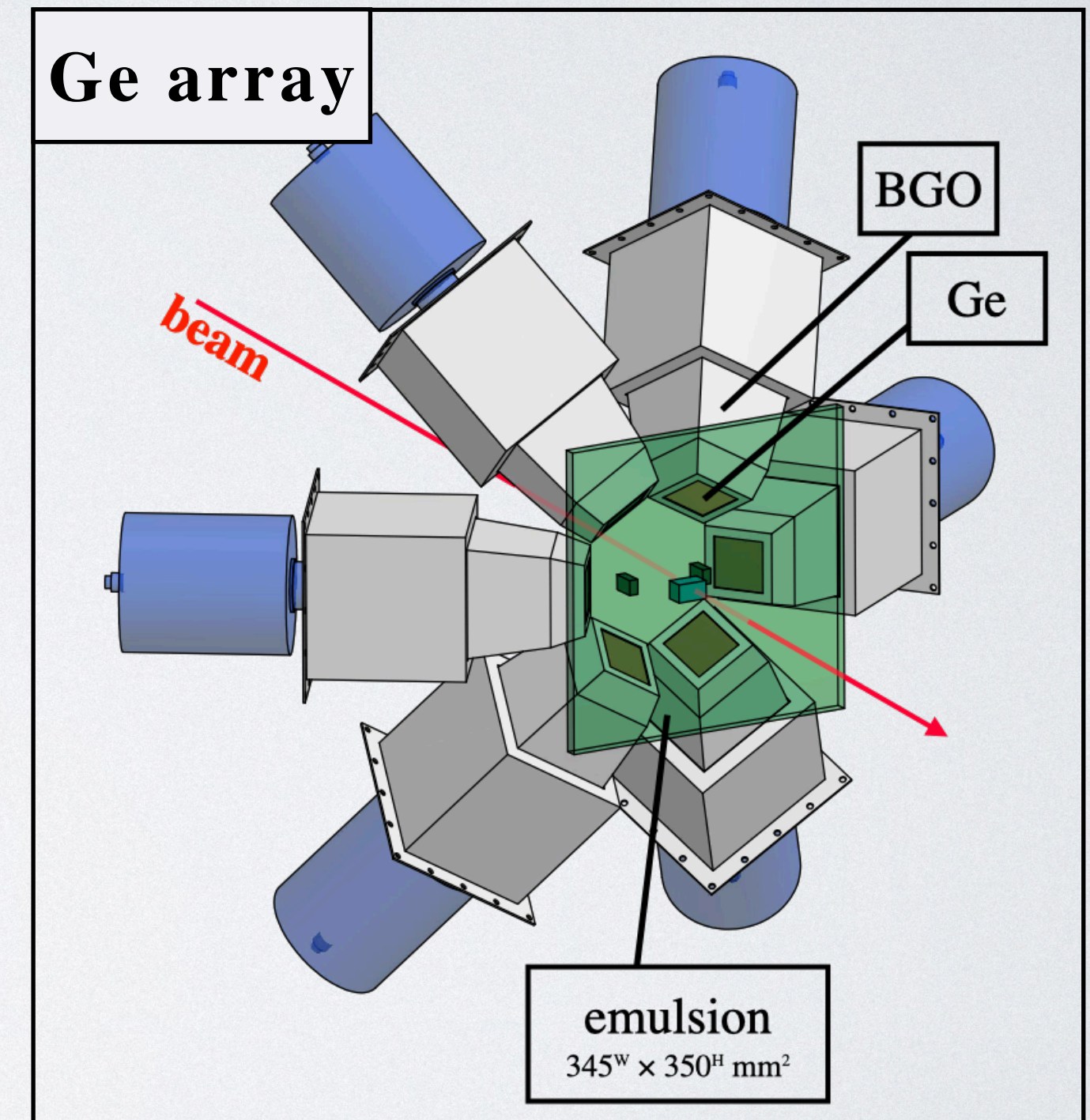
Kurama Spectrometer

Diamond target

K^-

Ge array

Beam line Spectrometer

0   3 m

Beam

@J-PARC K18 beam line

❖ Ξ tracking

K^+

0   30 mm

SSD   emulsion

Ξ^-

SSD

Diamond target

Prediction

K^-

SSD: silicon strip detector

❖ X-ray measurement

Ge array

beam

BGO

Ge

emulsion
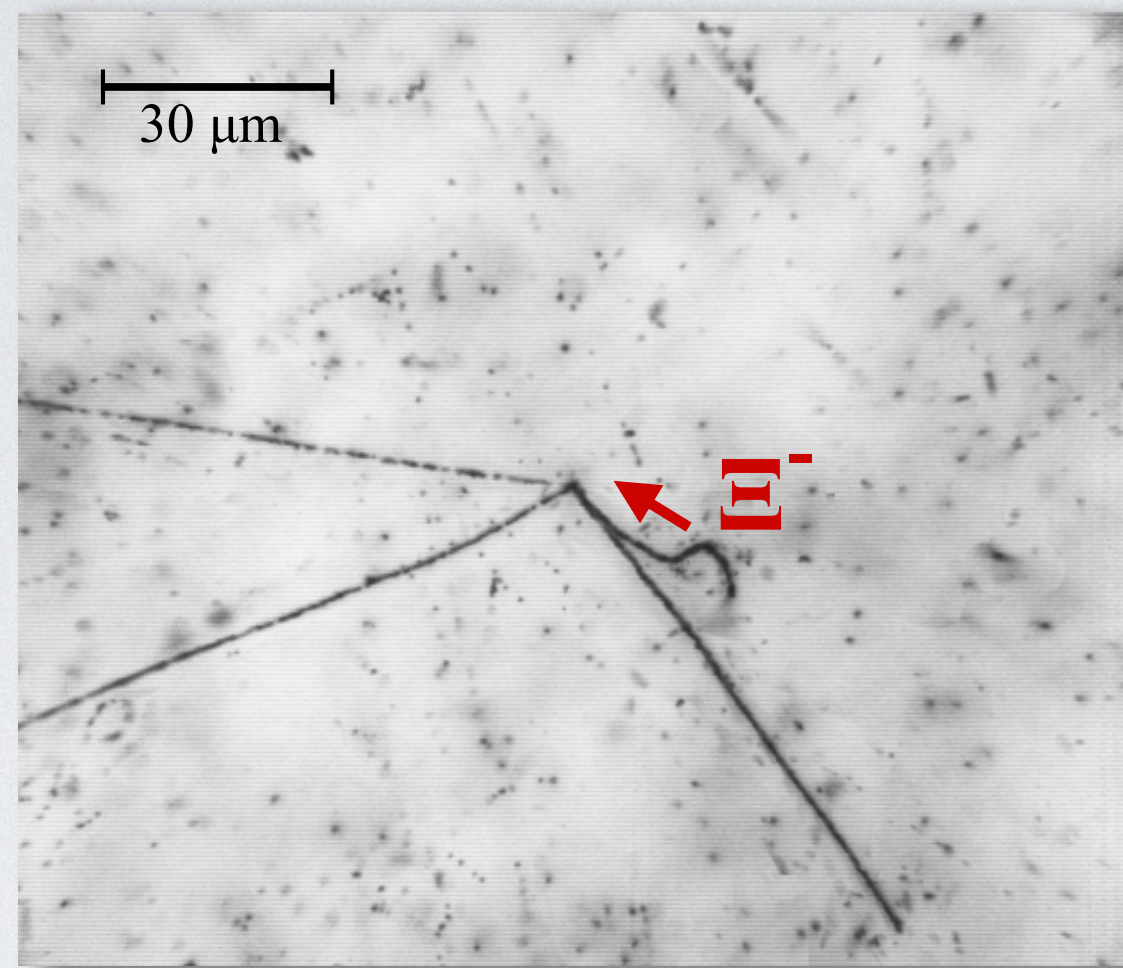$345^W \times 350^H$ mm²

Counter-emulsion hybrid method

Analysis

- ❖ (K^-, K^+) reaction analysis

- ❖ <u>Emulsion image analysis</u>

- ❖ X-ray analysis

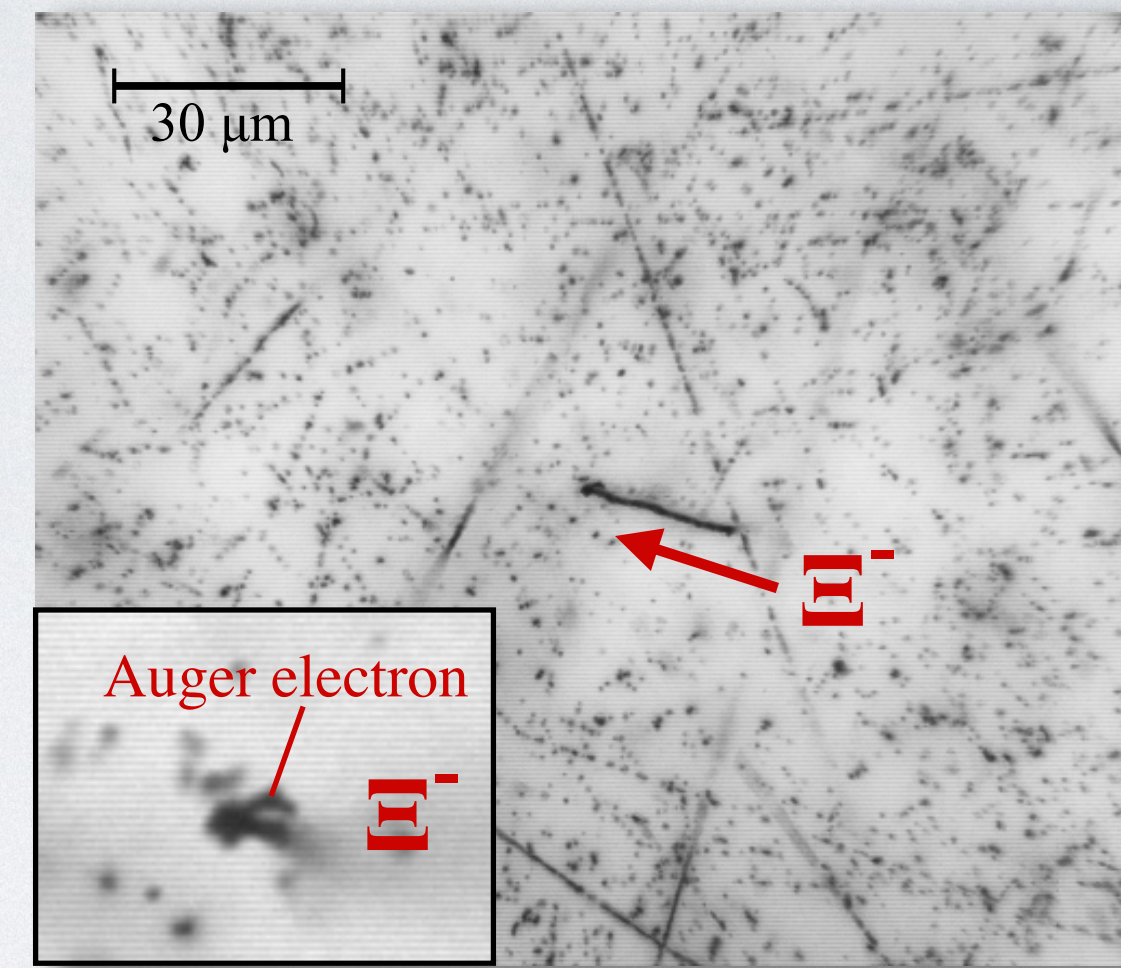# Identification of stop Ξ⁻ events

σ-stop

30 μm

Ξ⁻

One or more charged tracks are observed at the stopping point

2208 events

ρ-stop

30 μm

Ξ⁻

Auger electron

Ξ⁻

No charged track is observed except for Auger electron at the stopping point

9961 events

❖ϱ-stop w/ Auger *e* selection

The events with Auger *e* emission were selected to reject a lot of proton ϱ-stop contamination.

❖Heavy selection

The events without a short prong (~3-31 um) were selected to select the heavy (Ag, Br) Ξ atom, because emission of low-energy particles from heavy nuclei is inhibited by the Coulomb barrier.

Result

❖ X-ray spectra

❖ Peak search

❖ Branching ratio BR_{abs}, Formation probability $\mathscr{P}(nl)$

❖ Upper limit of $\mathscr{P}(nl)$
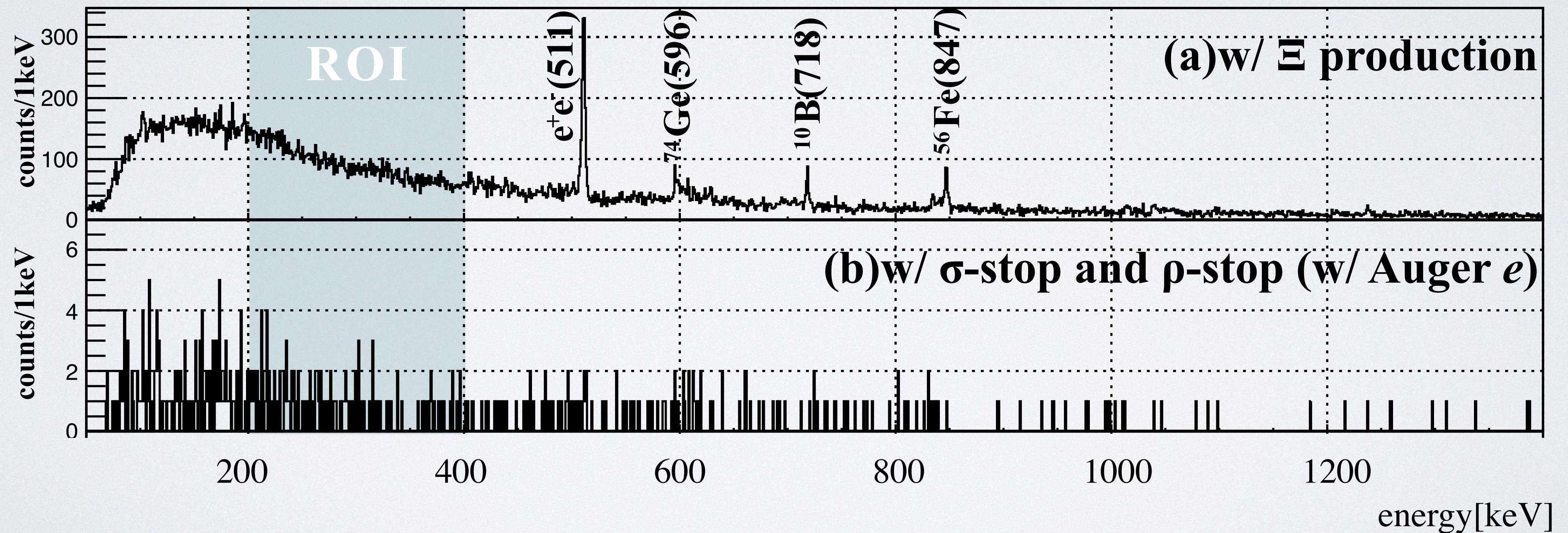
Ξ Ag, Br atomic X-ray spectra

❖(a) with Ξ production

(K⁻, K⁺) reaction analysis + Ξ tracking by SSD
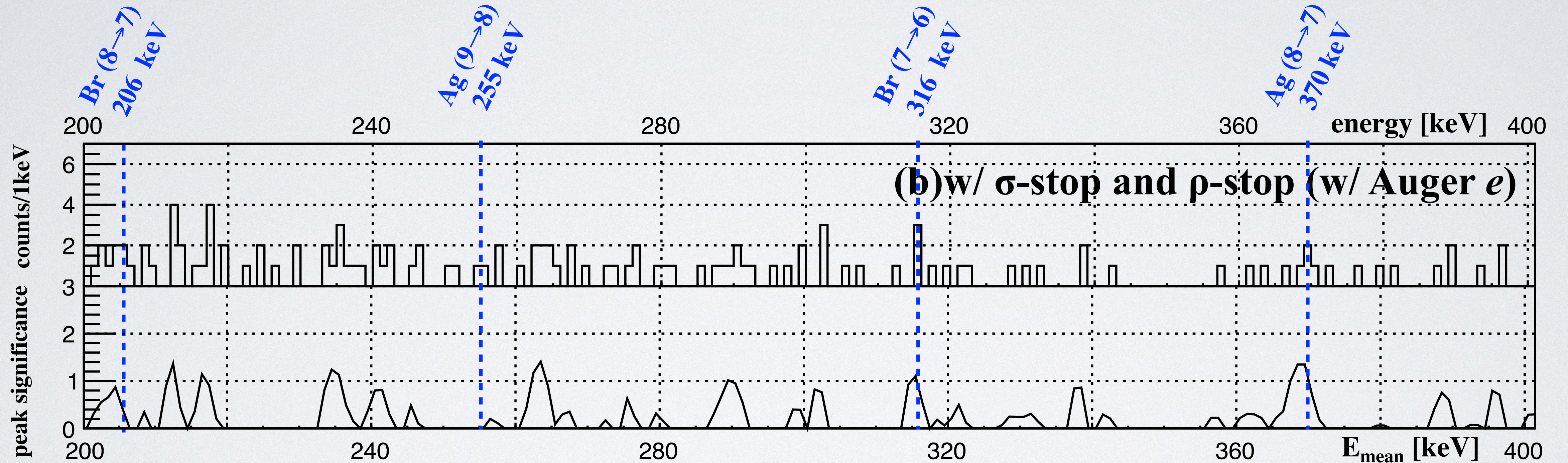
❖(b) stopped Ξ events

σ-stop + ϱ-stop(w/ Auger electron)
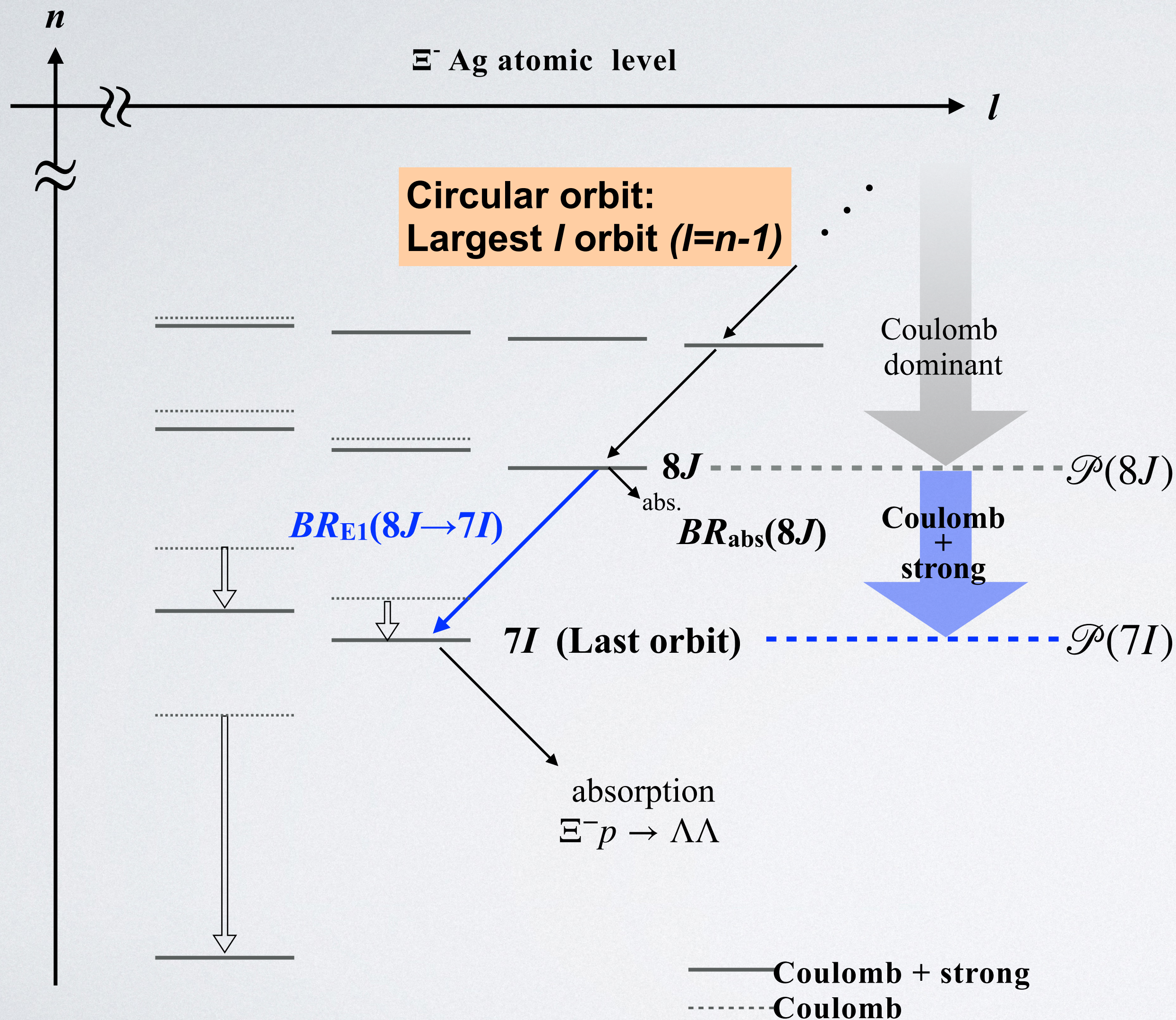
❖Total followed tracks : 35438
❖w/ BGO suppression

Peak search

(b)w/ σ-stop and ρ-stop (w/ Auger *e*)

❖ No evident peak was found.

❖ The upperlimit of X-ray yield was obtained as function of X-ray energy.

Branching ratio BR_{abs}, Formation probability $\mathscr{P}(nl)$

Circular orbit:
Largest *l* orbit *(l=n-1)*

Ξ^- Ag atomic level

$BR_{E1}(8J \rightarrow 7I)$

Coulomb dominant

8J ······· $\mathscr{P}(8J)$

abs. $BR_{abs}(8J)$

Coulomb + strong

7I (Last orbit) - - - - - - - $\mathscr{P}(7I)$

absorption
$\Xi^- p \rightarrow \Lambda\Lambda$

——— Coulomb + strong
- - - - - Coulomb

❖ $BR_{abs} \Longleftrightarrow BR_{E1}$

- $\mathscr{P}(nl)$: Probability thet the captured Ξ reaches the (n,l) state

❖ $BR_{E1}(8J \rightarrow 7I) = \dfrac{\mathscr{P}(7I)}{\mathscr{P}(8J)}$

***Assuming the Circular orbits only**

$$\mathscr{P}(7I) = \dfrac{Y_{Xray}}{Y_{\sigma\,stop} \cdot R(Z) \cdot \epsilon_{det}}$$

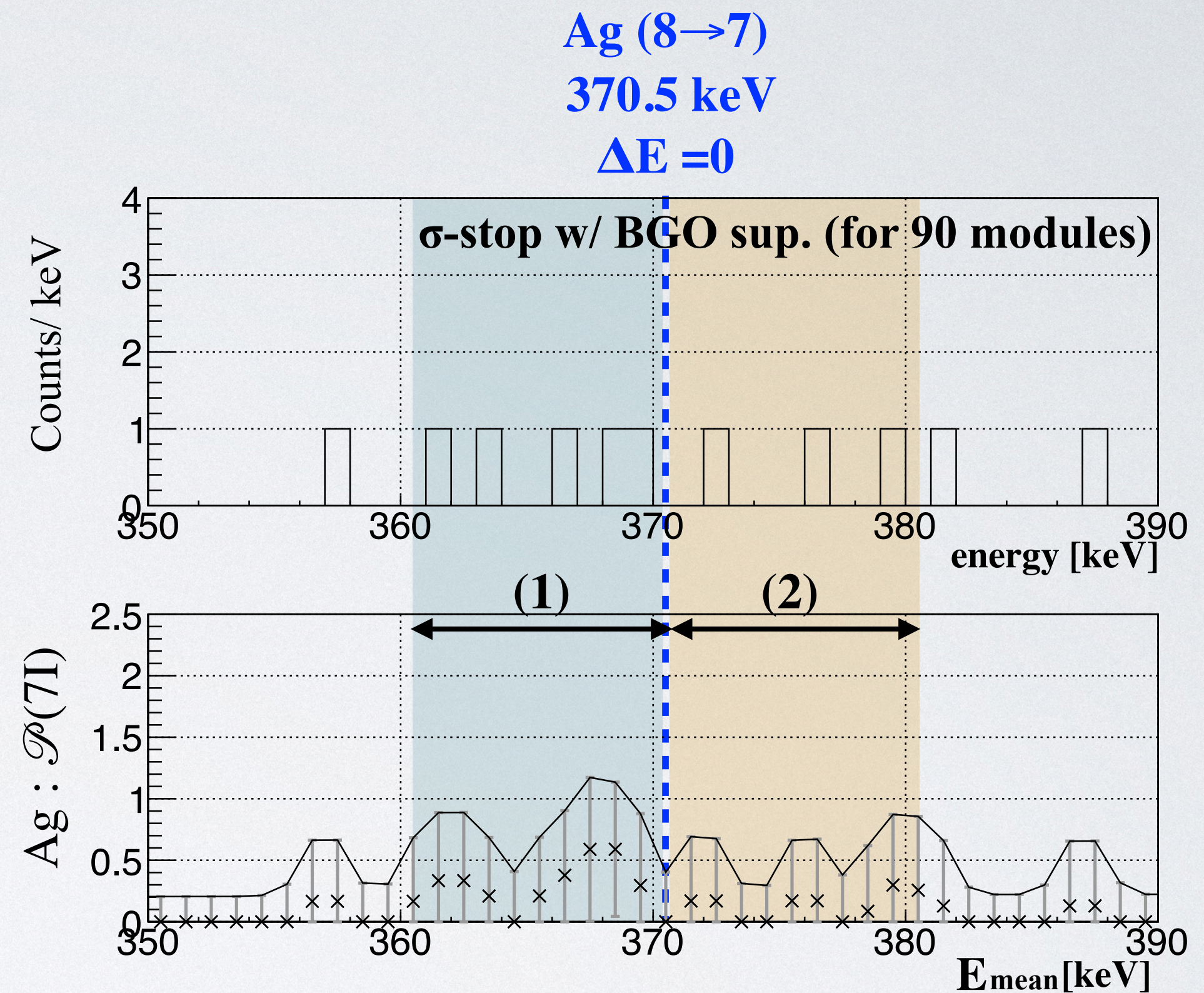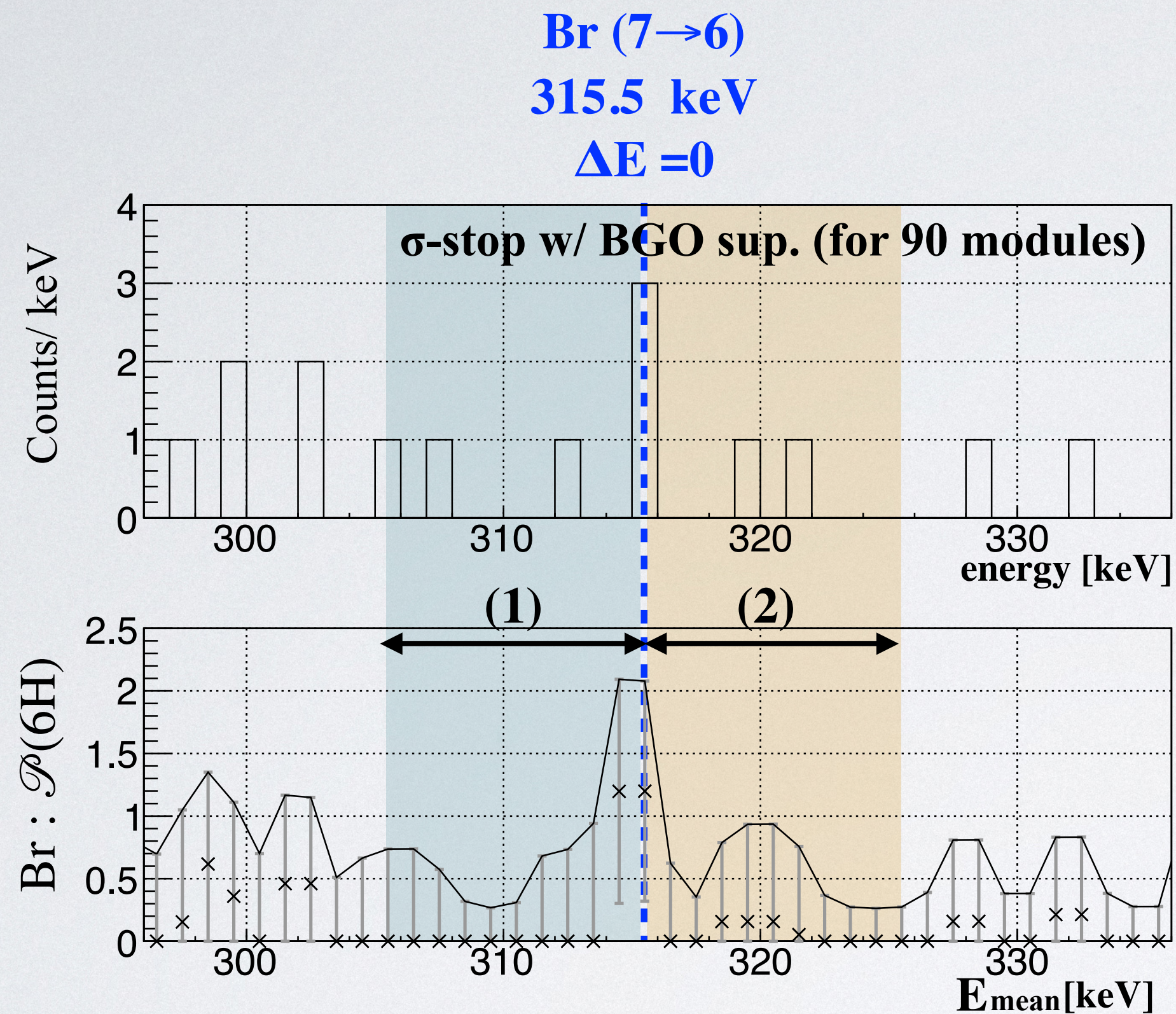**# of (8→7) X rays**

# of Ξ Ag atom

Y_{Xray} : X-ray yield
$Y_{\sigma stop}$: number of σ-stop events
$R(Z)$: probability a the Ξ is captured to a Z atom
ϵ_{det} : detector efficiency (Ge&BGO) 0.59%

Upper limit of $\mathscr{P}(n_{last})$

Br (7→6)
315.5 keV
ΔE = 0

σ-stop w/ BGO sup. (for 90 modules)

Counts/ keV

energy [keV]

(1) (2)

Br : $\mathscr{P}(6H)$

E_{mean}[keV]

Ag (8→7)
370.5 keV
ΔE = 0

σ-stop w/ BGO sup. (for 90 modules)

Counts/ keV

energy [keV]

(1) (2)

Ag : $\mathscr{P}(7I)$

E_{mean}[keV]

(1) $-10 \leq \Delta E$ [keV] ≤ 0

(2) $0 \leq \Delta E$ [keV] ≤ 10

$\mathscr{P}(6H)_{upper\ limit} > 1$

$\mathscr{P}(6H) \leq 0.94$ (C.L. 68%)

(1) $-10 \leq \Delta E$ [keV] ≤ 0

(2) $0 \leq \Delta E$ [keV] ≤ 10

$\mathscr{P}(7J)_{upper\ limit} > 1$

$\mathscr{P}(7J) \leq 0.87$ (C.L. 68%)

Summary

❖To investigate the Ξ-nucleus strong interaction, the first Ξ atomic X-ray spectroscopy was performed as J-PARC E07 experiment.

❖A novel method employing the coincidence measurement using the nuclear emulsion and the Ge detectors, was deveploped.

❖In obtained X-ray spectra, no evident peak was found. → No information on ΔE and Γ.

❖The probability that Ξ reaches the last orbit $\mathscr{P}(n_{last})$ was constrained for the first time.

Br :$\mathscr{P}(6H) \leq 0.94$, Ag :$\mathscr{P}(7I) \leq 0.87$ ($0 \leq \Delta E$ [keV] < 10)

‣ Papers

❖ "Ξ− atomic X-ray spectroscopy with a counter-emulsion hybrid method"

this results, submit to PTEP

❖ "Development of a Ge detector array and an in-beam calibration system for highly precise measurement of Ξ-atomic X-rays"

Tecnical information on Ge detectors, submit to NIM A