X-ray spectroscopy of Ξ^-Fe atom in the J-PARC E03 experiment

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for J-PARC E03 collaboration

HYP2022, 6/29/2022

Outline

- Introduction
  - X-ray spectroscopy of Ξ^- atom
  - X-ray spectroscopy of Fe-Ξ^- atom [J-PARC E03]
  - Experimental setup

- Analysis
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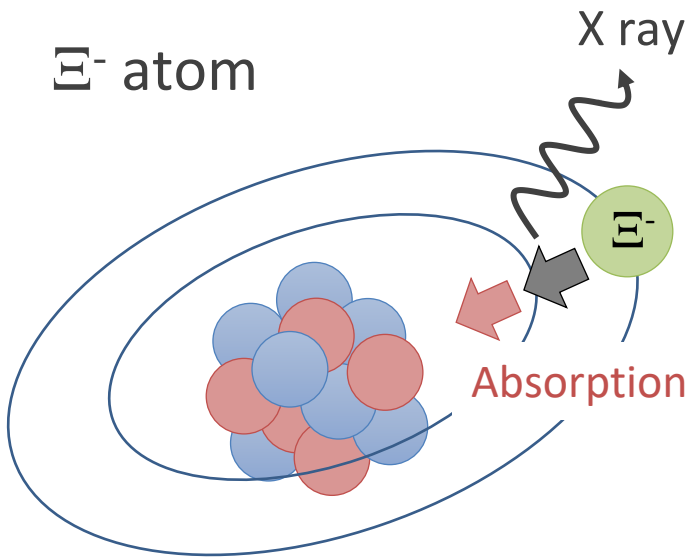
  - Ge detector array [Hypreball-X’]
  - X-ray spectrum [(K^-, K^+) reaction]
  - Analysis plan

Introduction

X-ray spectroscopy of Ξ^- atom

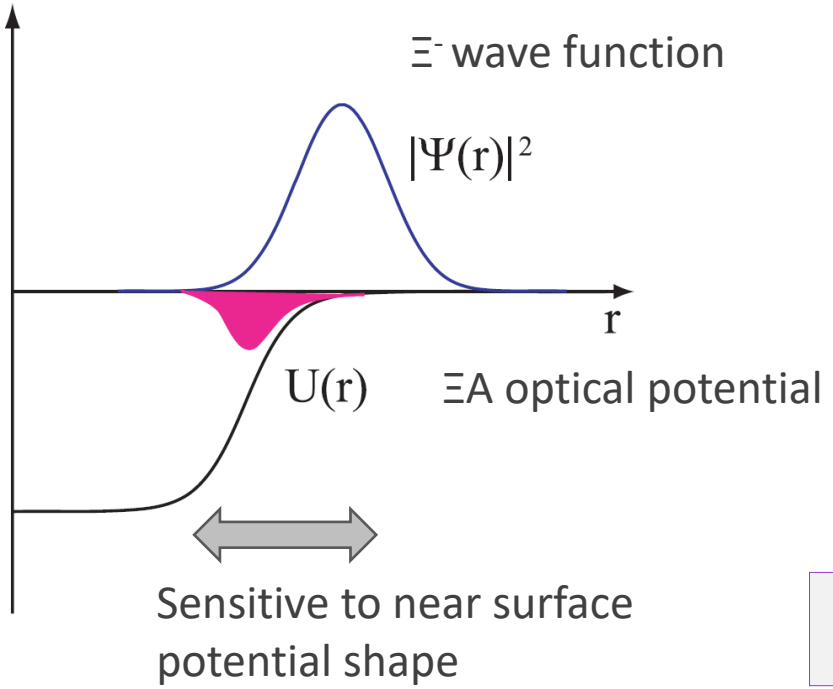
Measurement of X-ray energy shift and width
→ Real and imaginary term of ΞA optical potential

- S = -2 Baryon – Baryon effective interaction
- Role of Ξ^- in neutron star

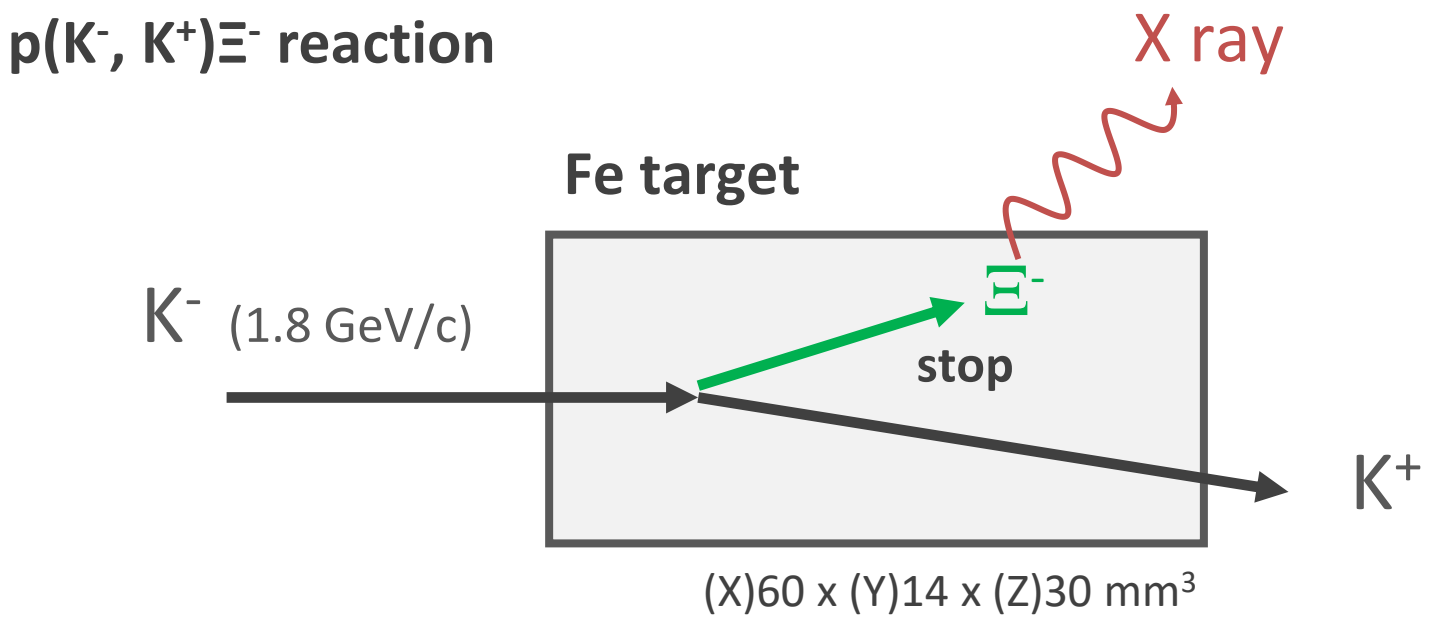


We are aiming for
world first measurement of X ray from Ξ^- atom

- J-PARC E07 [-2017] C (Z=6), Br (Z=35), Ag (Z=47)
  Talk by M. Fujita (6/30)
- **J-PARC E03 [-2021] Fe (Z=26)**



X-ray spectroscopy of Ξ⁻-Fe atom [J-PARC E03]



Advantage of Fe target

- Enough dense (~7.9 g/cm³) for higher stopping probability of Ξ⁻

- Theoretical case study: 5G state: ΔE ~ Γ ~ 4 keV
  (W.S. shape potential of -24-3i MeV)

Calculated by T. Koike

Recent Lattice & Chiral EFT calc.
shows <1/10 smaller imaginary strength

X-ray spectroscopy of Ξ⁻-Fe atom [J-PARC E03]

We performed run with 10% statistics [1st phase]

<1st phase> 10% statistics [2020.12 – 2021.4]

- (7I → 6H) transition
  → World first measurement of X ray from Ξ atom
- (6H → 5G) → finite shift & width (if Γ < 1 keV)
- Absorption strength from N_X (6H → 5G) / N_X (7I → 6H)

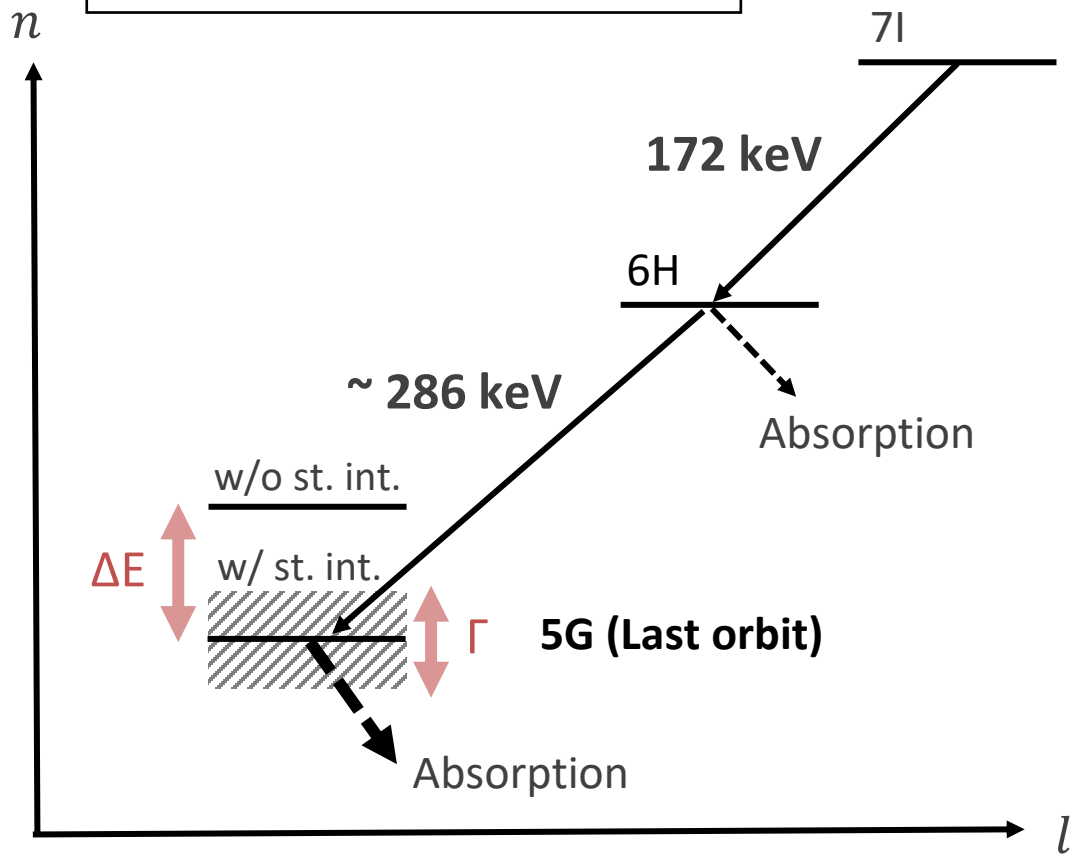
Expected X-ray yield (Γ = 1 keV)

- N_X(7I → 6H) : 600
- N_X(6H → 5G) : 200

<2nd phase> Full statistics

- (6H → 5G) → finite shift & width (if Γ ~ 4 keV)

Level scheme of Ξ⁻-Fe atom



Rx : Intensity of X ray per stopped Ξ⁻

- Rx (7I → 6H) : 0.3
- Rx (6H → 5G) : 0.1

Experimental Setup [J-PARC E03]

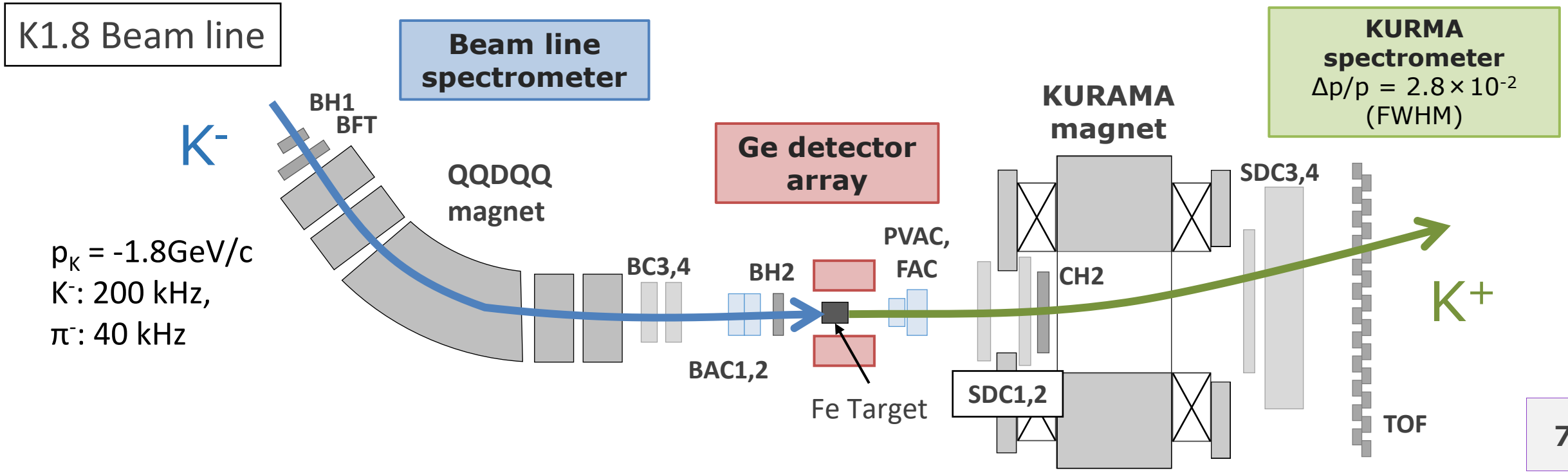
Tagging $(K^-, K^+)\Xi^-$ production

- Beam line spectrometer for beam K^-
- KURAMA spectrometer for scattered K^+

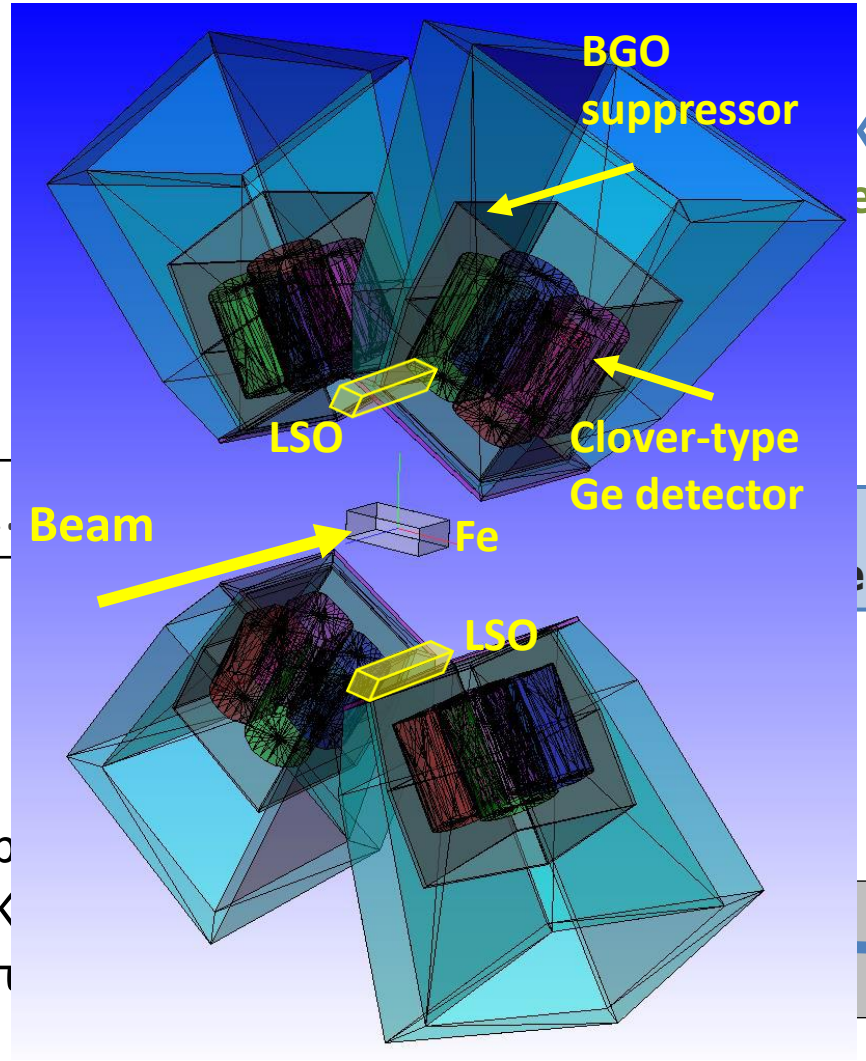
Energy measurement of X ray from Ξ^- - Fe atom

- Ge detector array [Hyperball-X']
  - Clover-type Ge detector
  - BGO Compton suppressor
  - LSO pulser for energy calibration (202, 307 keV)

Energy resolution: 2 keV (FWHM) for 300 keV



Experimental Setup [J-PARC E03]



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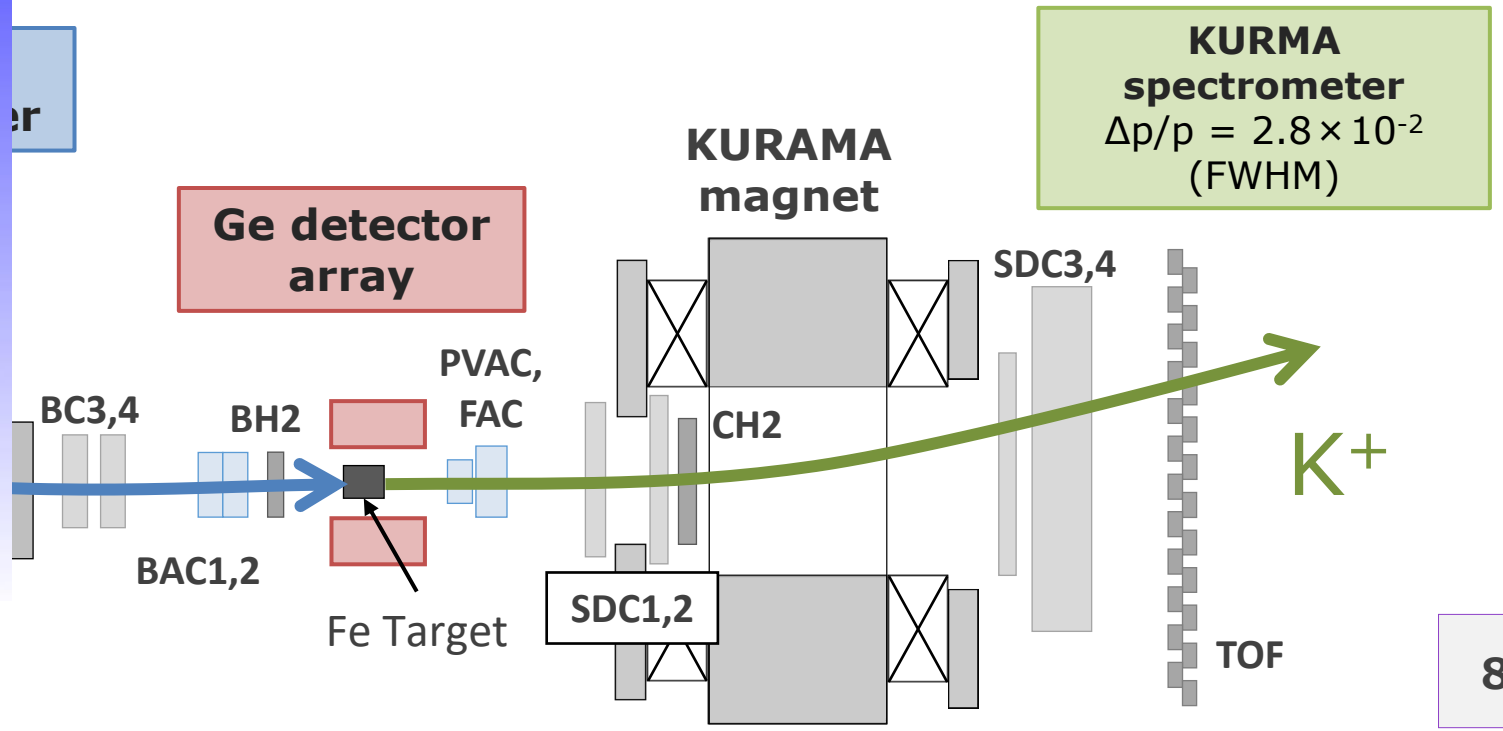
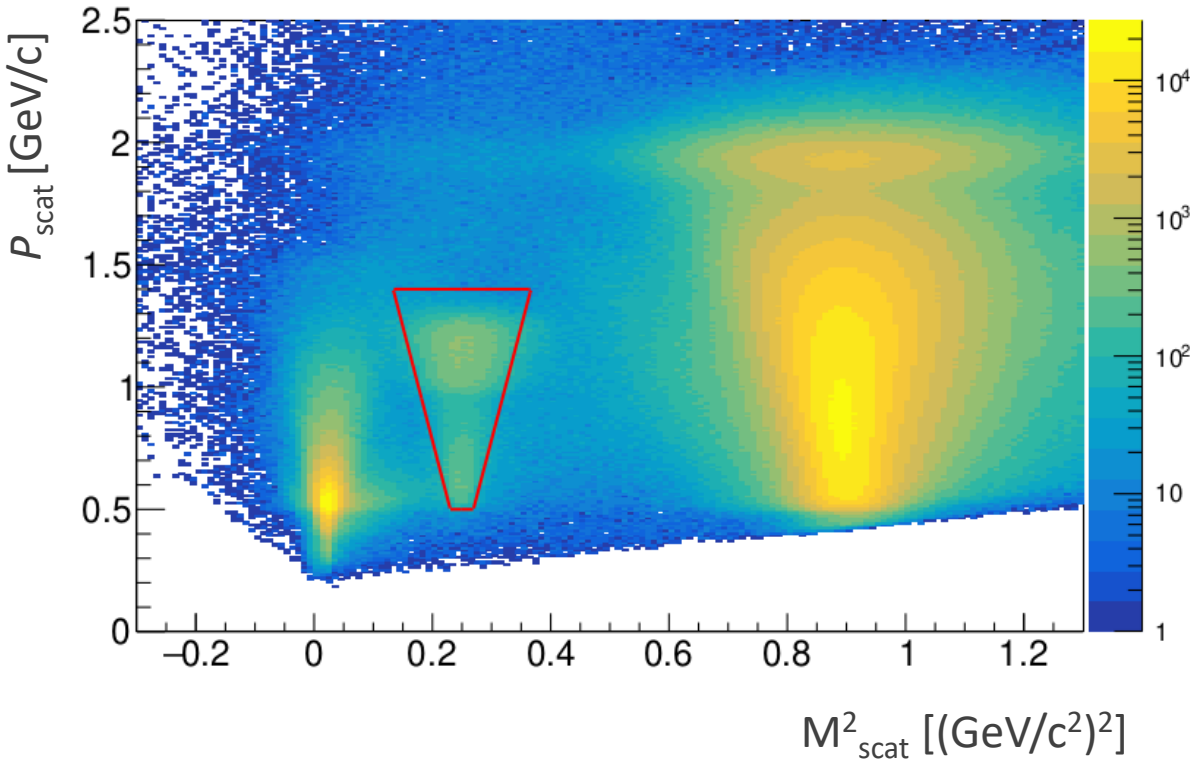


Analysis status

Tagging Ξ^- production

Identification of scattered particles [Fe target]

- Selecting positive charge particle

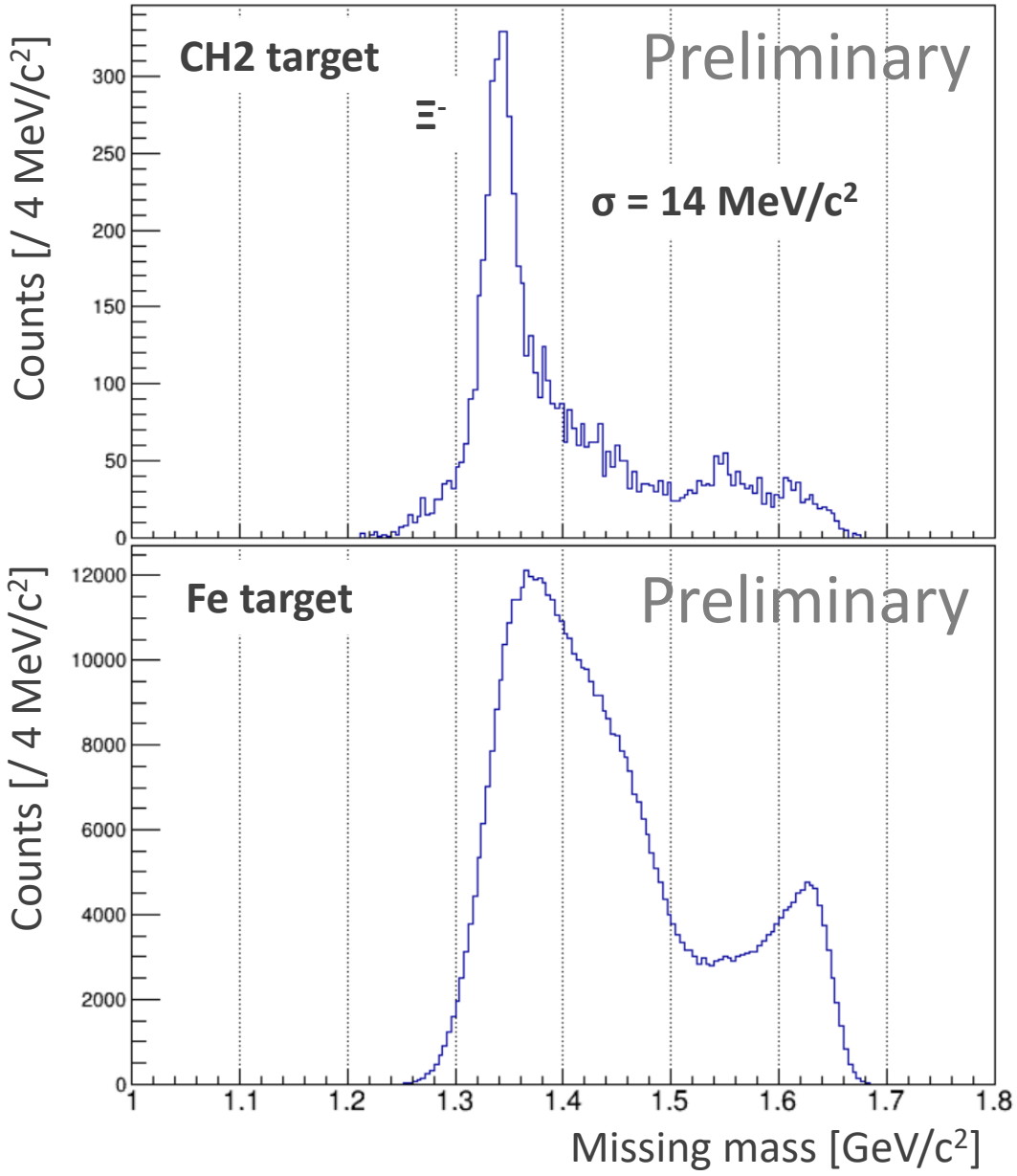


K^+ yield : 3.9 x 10^5

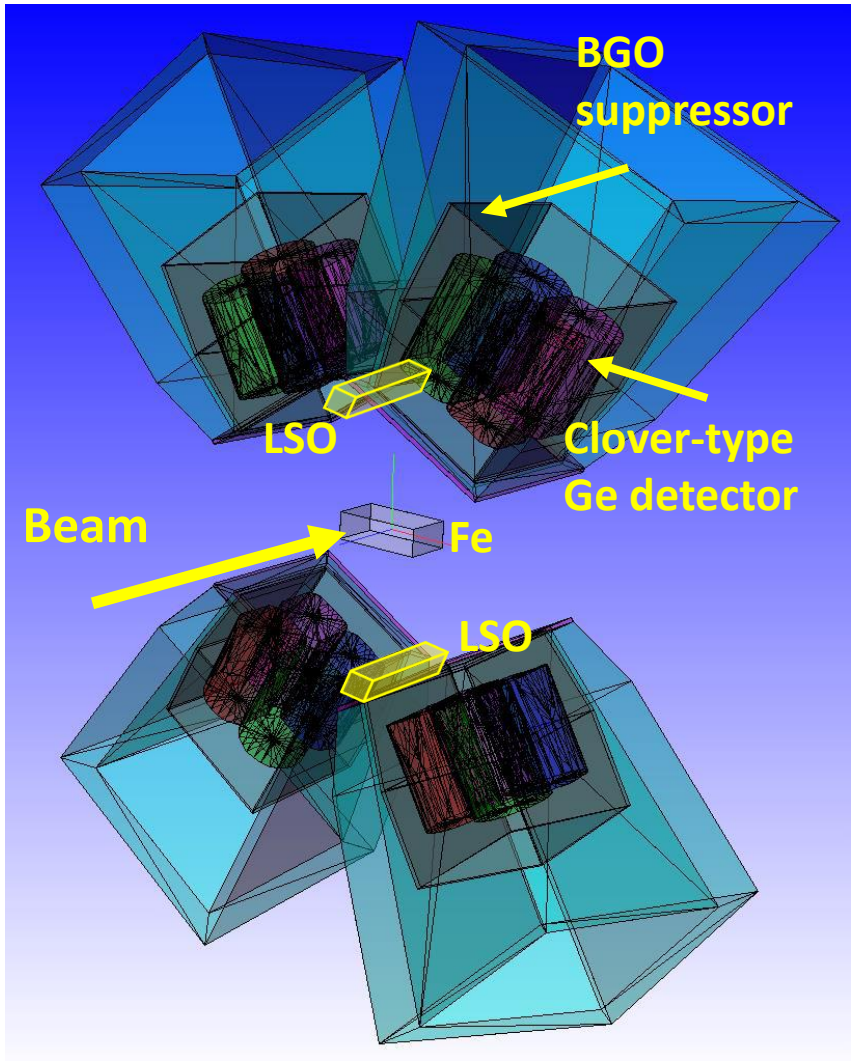
Background: 22%

for Ξ^- production region ($0.9 < p_{scat} < 1.3$ GeV/c)

Missing mass spectrum [$p(K^-, K^+)X$]



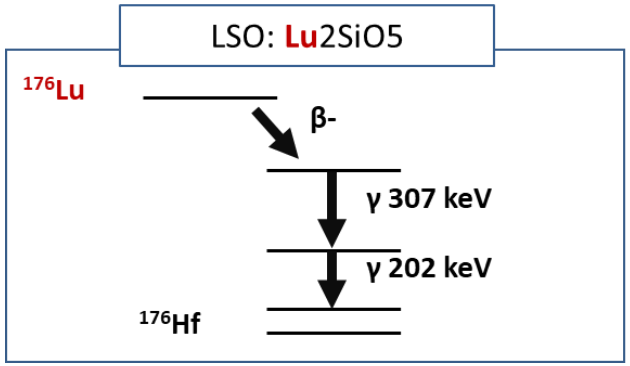
Hyperball-X'



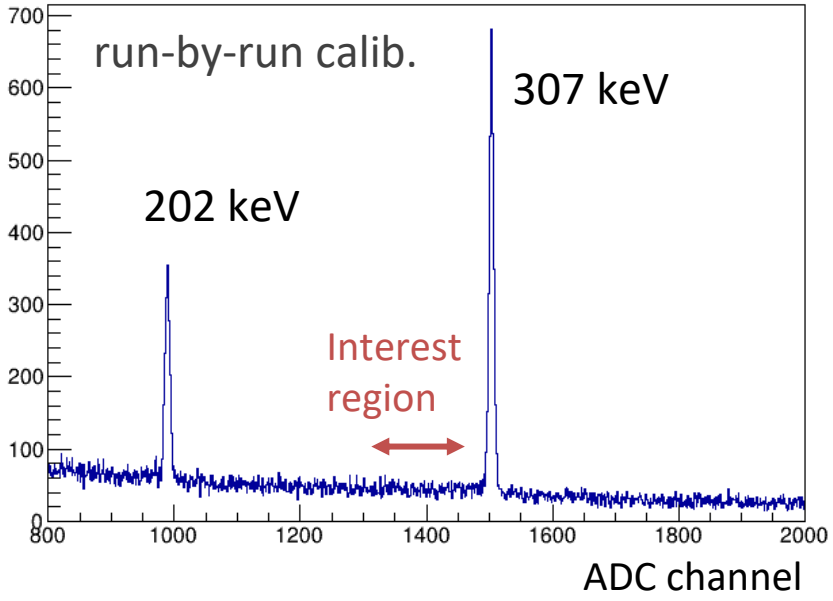
■ Energy calibration

LSO pulser (scintillator)

- ✓ β-γ coincidence trigger
- ✓ In-beam energy calibration



Spectrum for in-beam energy calib.

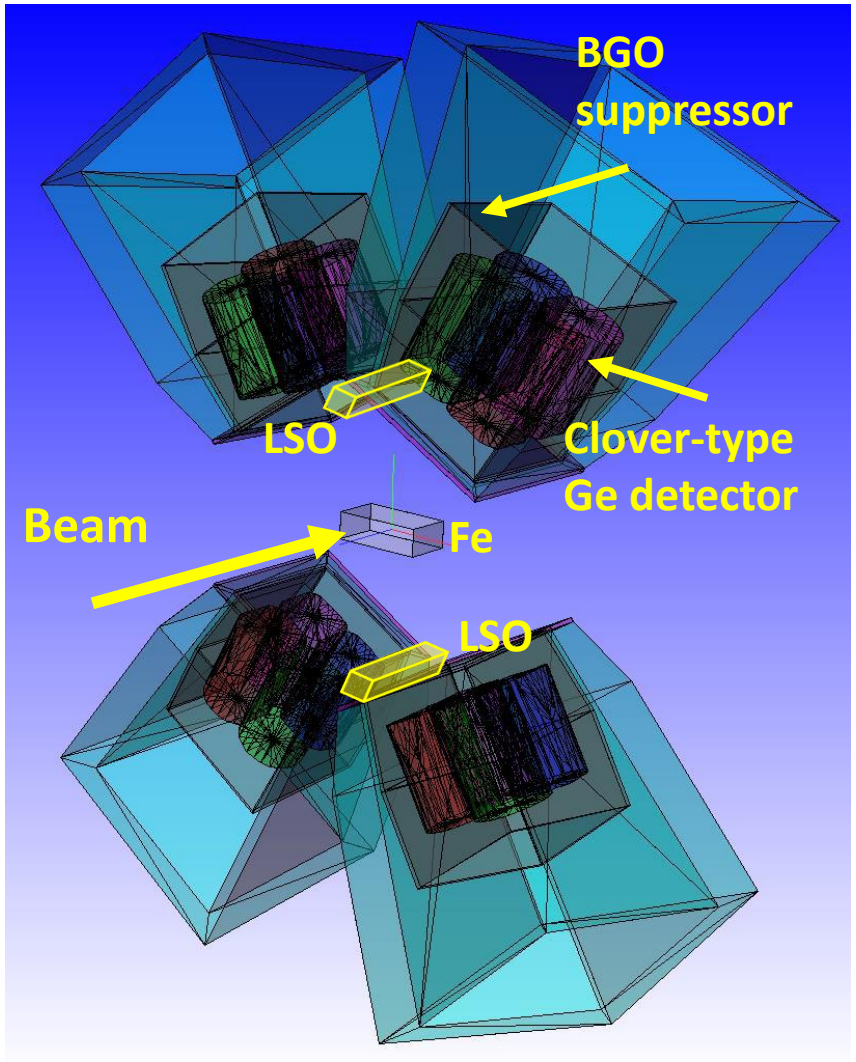


Energy resolution : 2 keV (FWHM) @ 307 keV
Calibration accuracy : < 0.3 keV

■ Detection efficiency

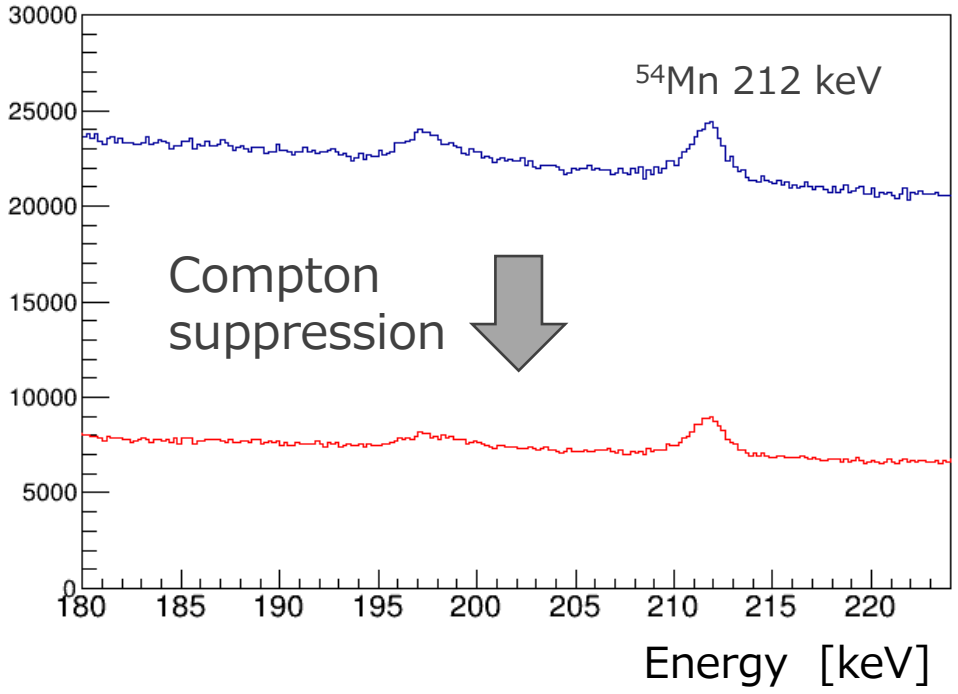
- Photopeak efficiency : 5.4% for 254 keV
- Throughput (live time) : 80%

Hyperball-X’



■ BGO Compton suppressor

Reaction-γ coin. spectrum [(K^-, p) reaction]

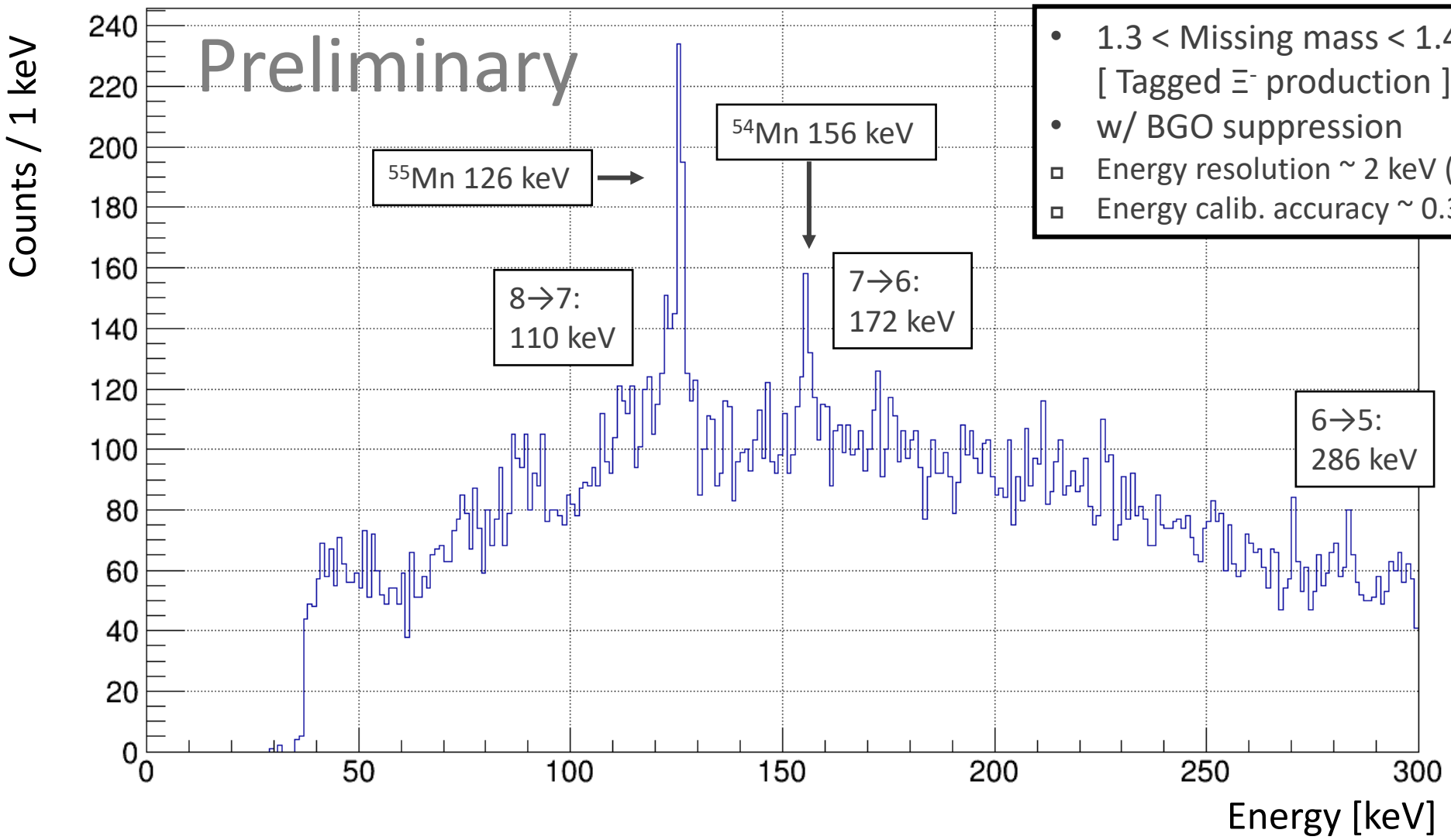


B.G. suppression [200 – 300 keV]: 69%

Over kill ratio [212 keV]: 27%

Hyperball-X’ system worked well

X-ray spectrum [(K^-, K^+) reaction]



Expected X-ray yield

- N_X (7 → 6) : 600
- N_X (6 → 5) : 200

In the current analysis, no clear X-ray peak has been observed.

For more background reduction, analysis to select the events with high stopping probability of Ξ^-.

Selecting Ξ^- with high stopping probability in the target

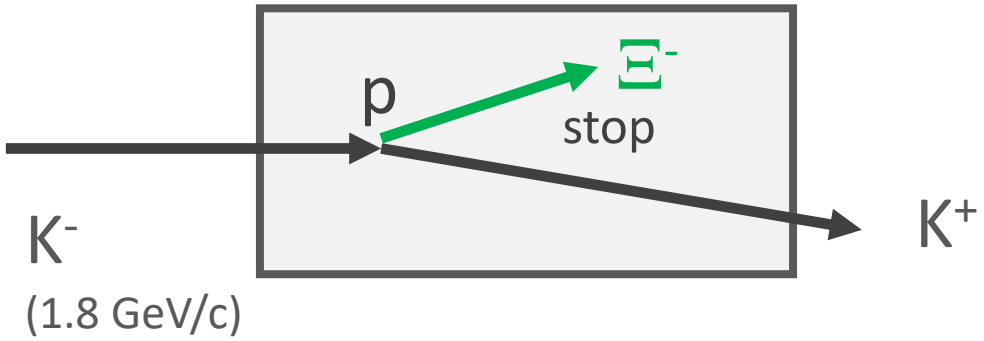
Estimating stopping probability using Geant4 simulation

Missing momentum

$$\overrightarrow{p_X} = \overrightarrow{p_{K^-}} + \overrightarrow{p_p} - \overrightarrow{p_{K^+}}$$

$\overrightarrow{p_p}$: Fermi motion of proton

Fe target (X)60 x (Y)14 x (Z)30 mm^3



- For $\overrightarrow{p_{K^-}}$, $\overrightarrow{p_{K^+}}$ and vertex point, obtained data is used
- Z position of vertex and missing momentum have uncertainties due to vertex resolution (σ_z ~ 20 mm) and Fermi motion (0 – 0.3 GeV/c)

Simulating many times under different assumption of the generation point and the Fermi motion for each event

$$P_{\Xi\ stop} = \frac{\#\ \text{of}\ \Xi\ \text{stop event}}{\#\ \text{of simulation}}$$

Summary

- Ξ^- atomic X-ray spectroscopy → Information on ΞA optical potential

- Ξ^--Fe atomic X-ray spectroscopy [J-PARC E03]
  - 1st phase data taking was finished [2020.12 ~ 2021.4]
  - Output
    - (7I → 6H) → world first measurement of X ray from Ξ^- atom
    - (6H → 5G) → finite shift & width (if $\Gamma < 1$ keV)
    - Absorption strength from N_X(6H → 5G) / N_X(7I → 6H)

- Spectrometers and Ge detectors worked well

- In the current analysis, no clear X-ray peak has been observed
  - ➢ Select the events with high stopping probability of Ξ^- for background reduction