HYP2022, Prague, 27/06/2022

X-ray spectroscopy on Ξ^- atoms (J-PARC E03, E07 and future)

T. O. Yamamoto (JAEA ASRC [Japan])

for the E07/E03 collaboration

Contents

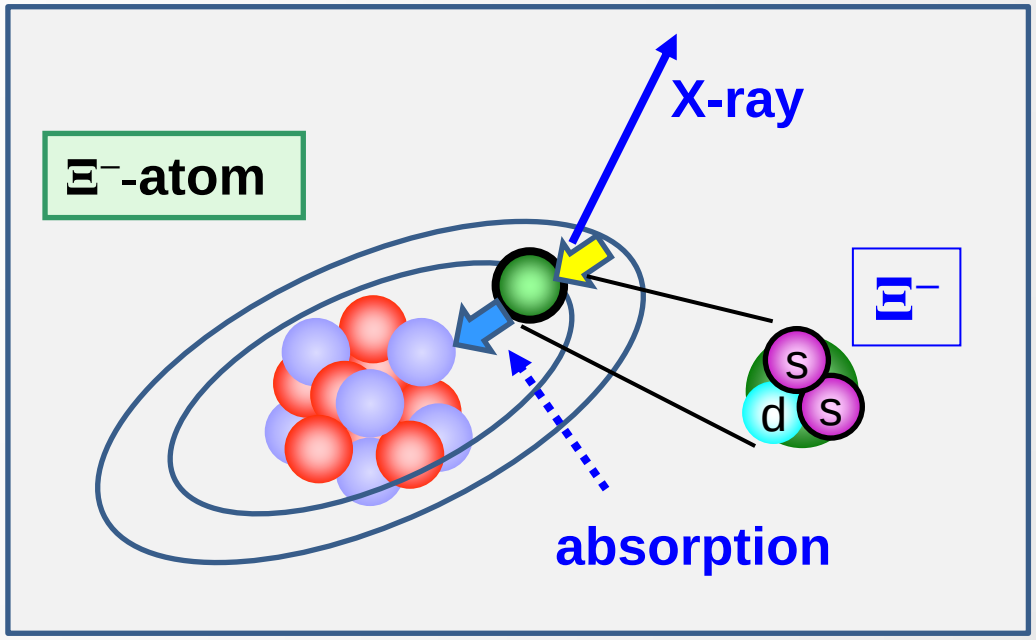
- X-ray spectroscopy of Ξ^- atom
- Our first try [J-PARC E07]
- Fe Ξ^- atom measurement [J-PARC E03]
  - 1st-phase data taking was completed!
- Future measurement [J-PARC E70 byproduct]
- Summary

X-ray spectroscopy of Ξ^--atom

We are aiming for

world first measurement of X ray from Ξ^--atom

→ Information on the ΞA optical potential

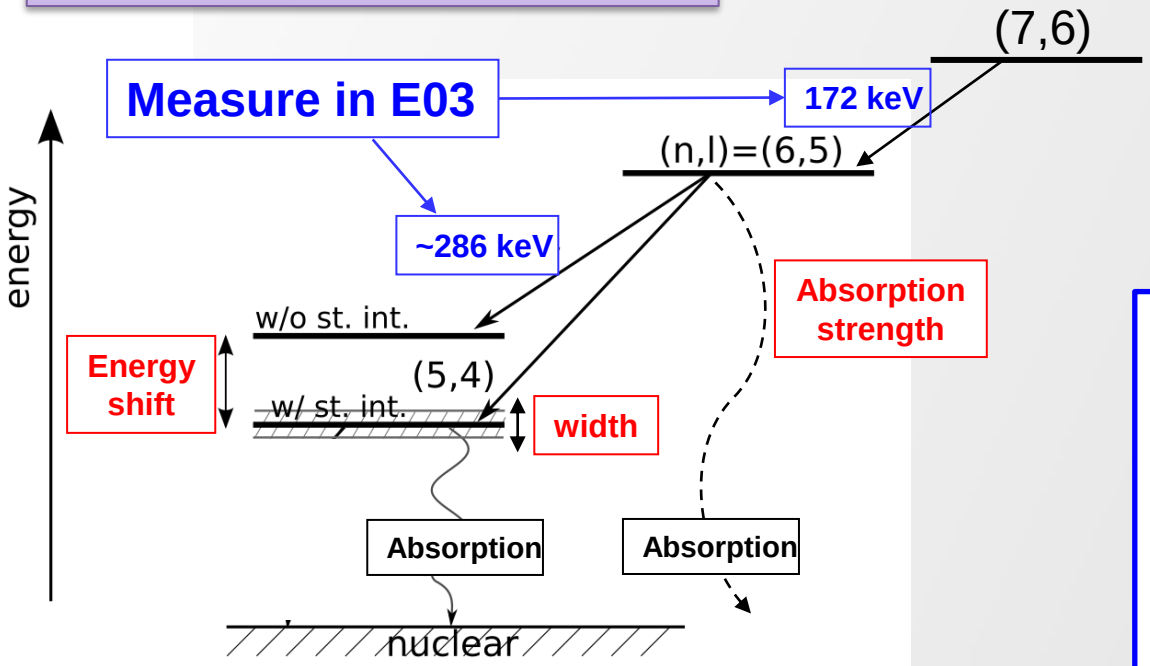


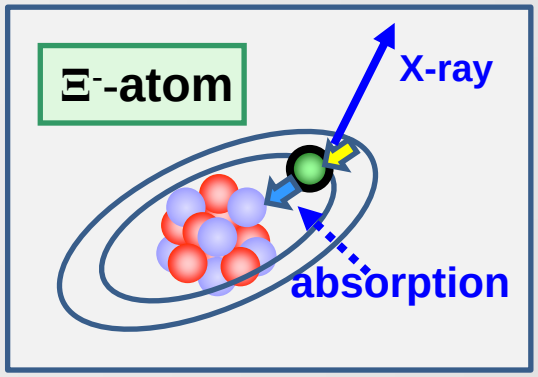
- **Information on (effective) ΞN interaction**
  large baryon mixing?
  (small ΔM(ΞN-ΛΛ)=28 MeV)
- **ΞA interaction and it's A dependence**
  Role of Ξ^- in neutron star?

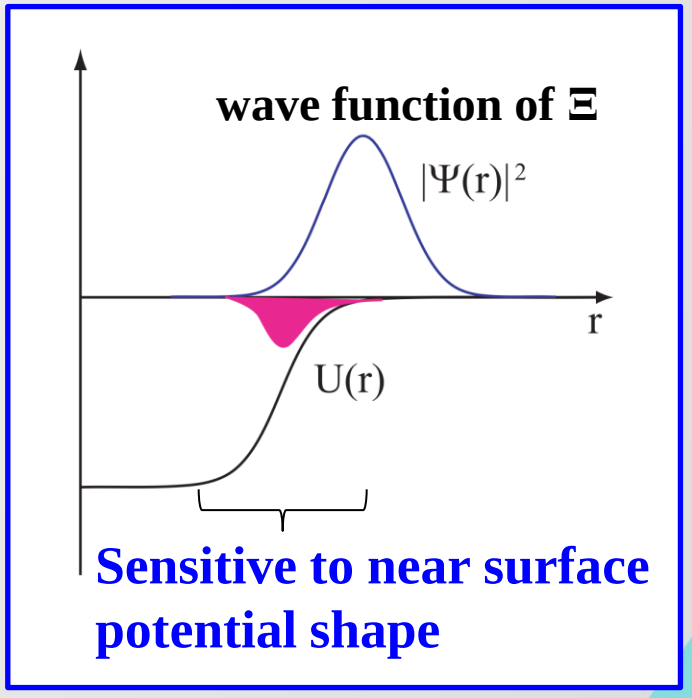
Establishment of experimental method in the J-PARC E07/E03
→ Systematic measurement (over wide mass range) in future

X-ray spectroscopy of Ξ⁻-atom

Level scheme of Fe-Ξ⁻ atom







Measurement of energy shift and width
→ Ξ⁻A real and imaginary terms (near surface)

This method has been successfully applied for negative charged particles (π^-, K^-, $\bar{p}$, Σ^-)

Physics motivation

- **Valuable information on ΞN (effective) interaction**

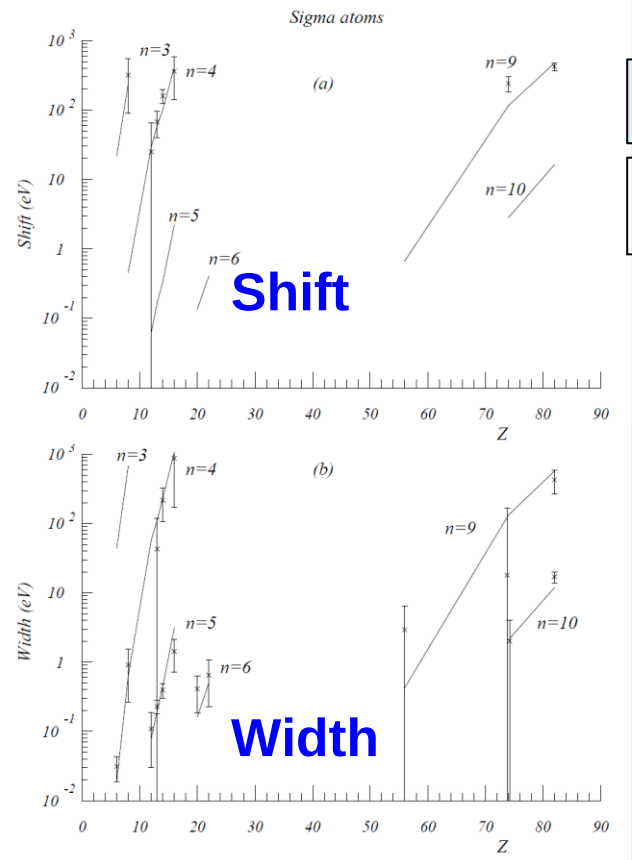
Need systematic X-ray measurement over wide mass range

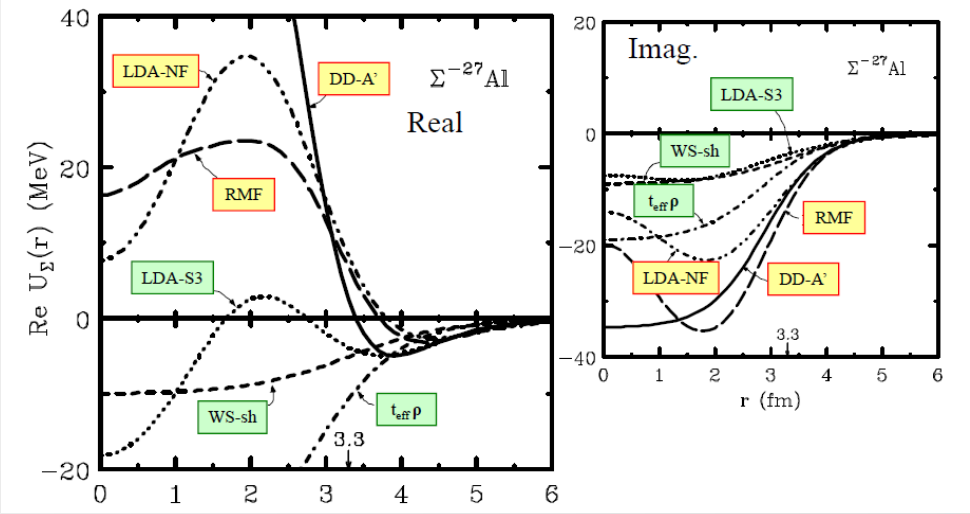
→ **Potential shape, mass dependence**

as in the case of Σ^- atom data

Σ^- atom data

E. Friedman, A. Gal
the International School of Physics Enrico Fermi (2007)





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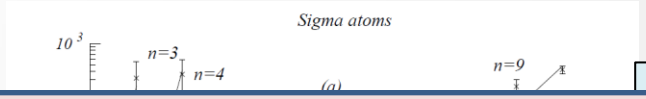


as in the case of Σ^- atom data

Our strategy for Ξ^--atom

No Ξ^--atom data so far

A

C (Z=6)-atom : J-PARC E07(-2017) & future measurement

(also N-atom, O-atom…)

Fe (Z=26)-atom : J-PARC E03 (-2021)

Br (Z=35)-atom :

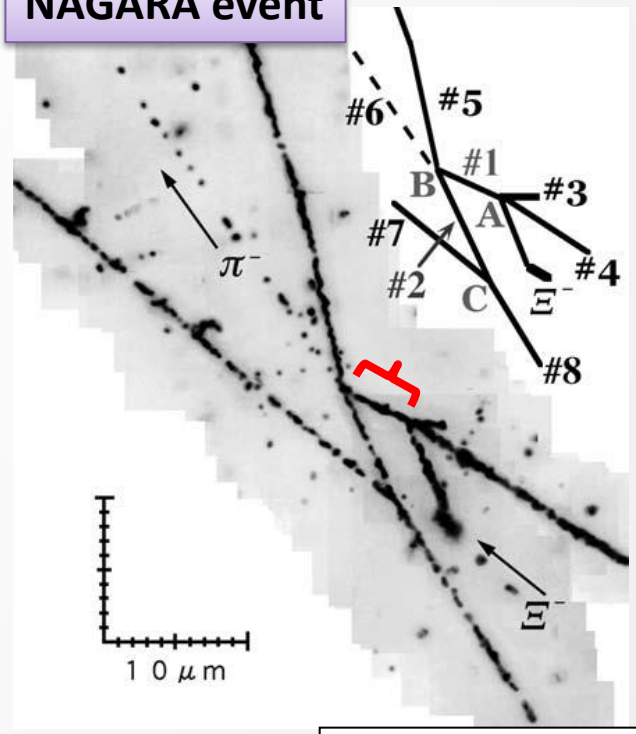
Ag (Z=47)-atom :

} **Our first try in J-PARC E07(-2017)**

Pb (Z=82)-atom : PANDA (2027+)

Impact on emulsion data

NAGARA event



C. J. Batty, E. Friedman, and A. Gal
Phys. Rev. C59, 295 (2001)

Stopped Ξ⁻s form Ξ-atoms before reaction

$$^{12}\mathrm{C} + \Xi^- \rightarrow {}^{6}_{\Lambda\Lambda}\mathrm{He} + {}^{4}\mathrm{He} + t$$

$$^{6}_{\Lambda\Lambda}\mathrm{He} \rightarrow {}^{5}_{\Lambda}\mathrm{He} + p + \pi^-.$$

$B_{\Lambda\Lambda}$ = 6.91 ± 0.16 MeV

H. Takahashi et al,
Phys. Rev. Lett. 87 (2001) 212502.

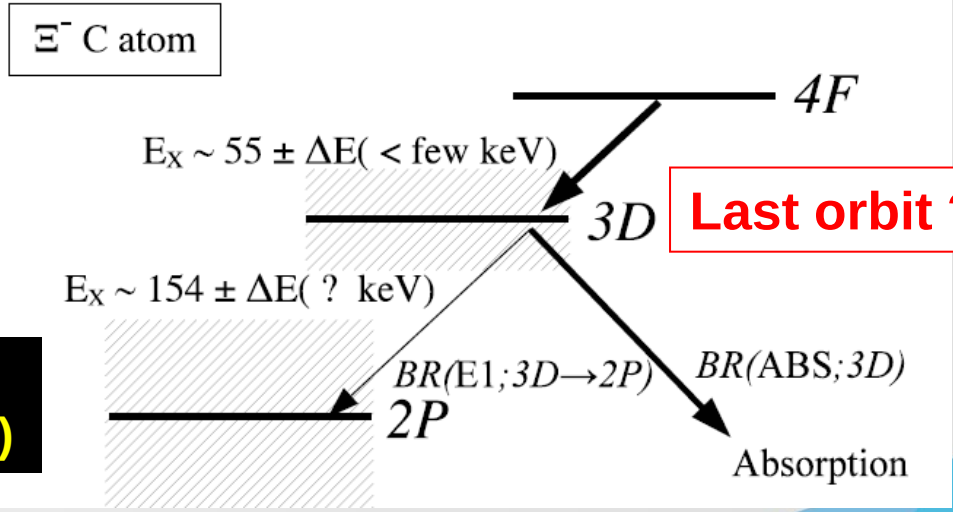
obtained from analysis of both production and decay point

Depends on B_Ξ of C Ξ⁻-atom [B_Ξ = 0.13 MeV]

Theoretical prediction:

3D absorption is dominant

Should be checked experimentally. (X-ray data will support $B_{\Lambda\Lambda}$ analysis)



Our first try in J-PARC E07

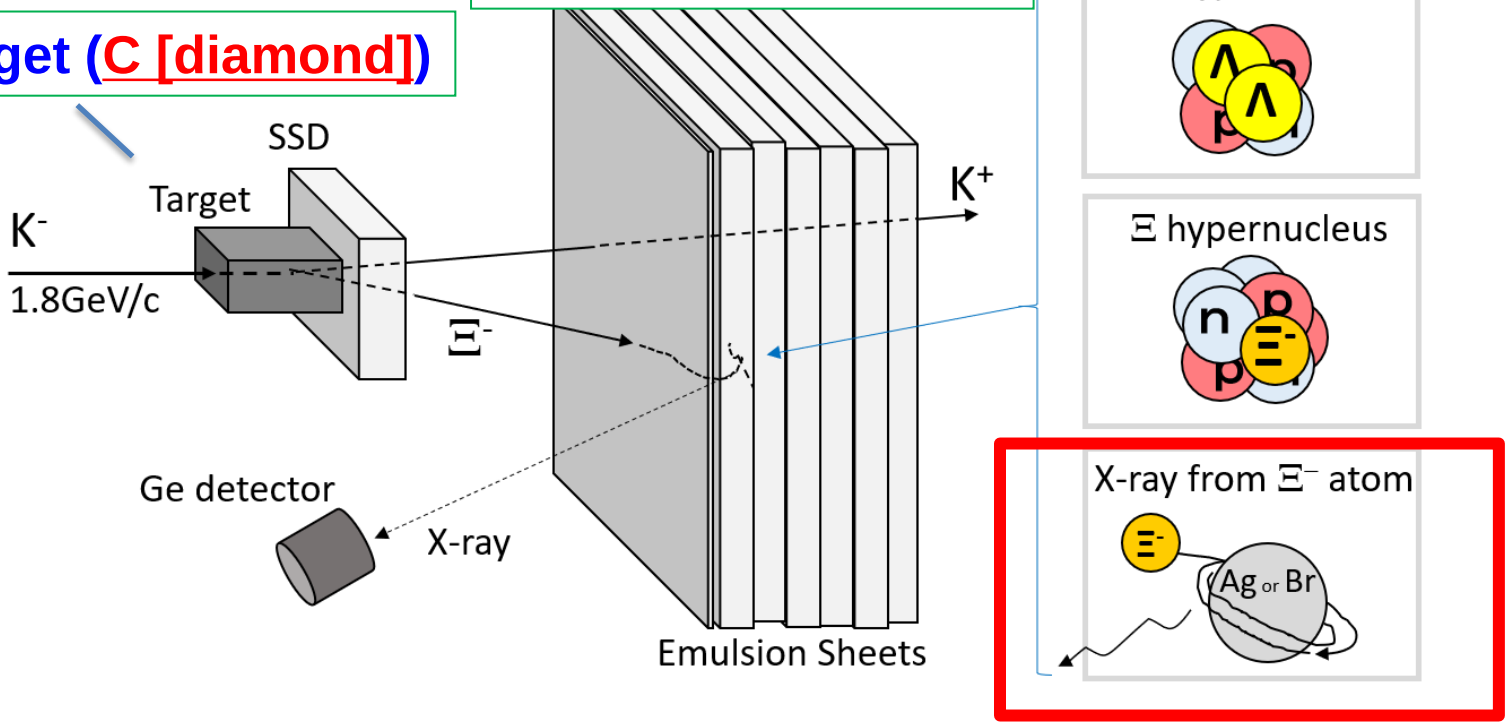
Detailed information: Talk by M. Fujita (6/30)

Experimental study of double hypernuclei at J-PARC

Done in 2016-2017

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

Target (C [diamond])



Junya Yoshida (Advanced Science Research Center, JAEA)

On behalf of J-PARC E07 Collaboration

Our first try in J-PARC E07

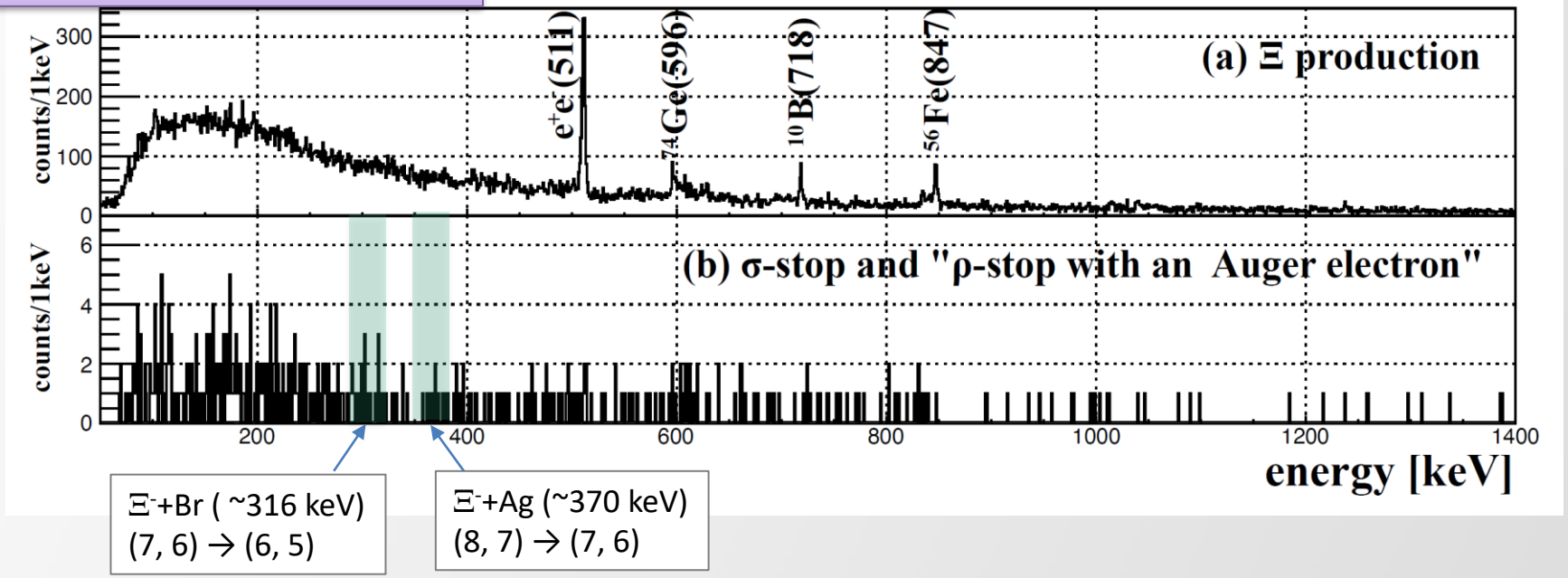
For Ag- and Br-atom

Measurement (1) : Emulsion combined analysis

- **S/N ratio ○ [we can tag Ξ⁻ stop in emulsion]**
- **Yield rate ×**
  - **Low stop prob. (long flight, low density)**
  - **Mixture target (H, C, N, O, Br and Ag)**
  - **Not optimum setup for X-ray detector**

Detailed information: Talk by M. Fujita (6/30)

X-ray energy spectrum



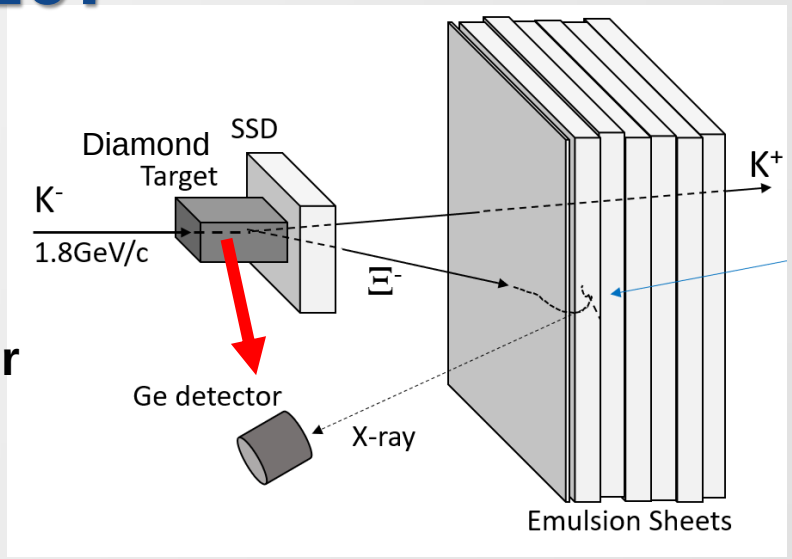
No clear peak structure was observed. (upper limits were given)

Our first try in J-PARC E07

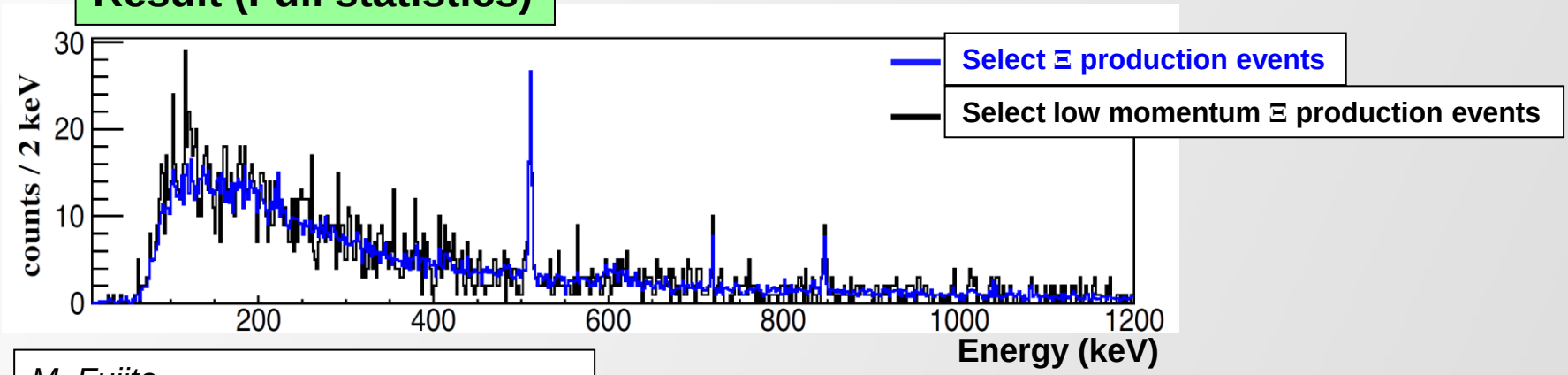
For C-atom

Measurement (2) : w/o emulsion info.

- **S/N ratio △ [only SSD hit rejection]**
- **Yield rate △**
  - **Low stop probability (low density)**
  - **Not optimum setup for X-ray detector**



Result (Full statistics)



M. Fujita
Doctoral Thetis, Tohoku Univ. (2019)

Unfortunately,
no significant peak was observed…

Our first try in J-PARC E07

For C-atom

Measurement (2) : w/o emulsion info.

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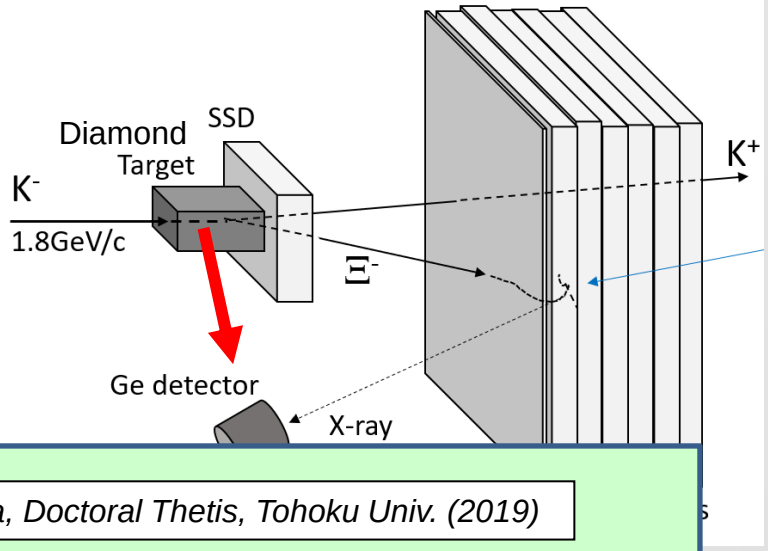
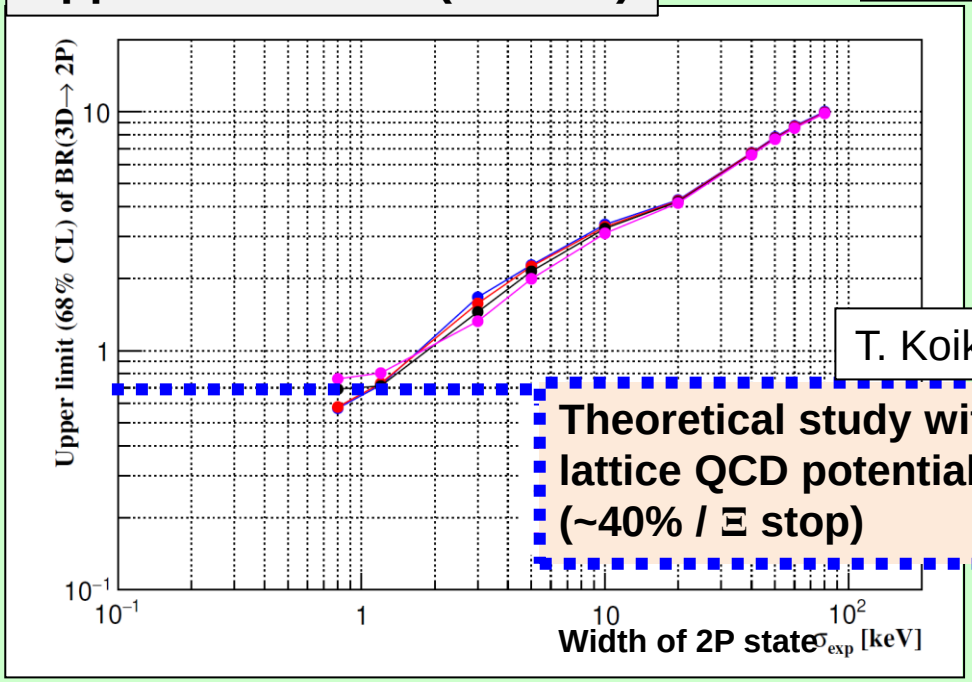


Upper limit for BR(3D->2P)

M. Fujita, Doctoral Thetis, Tohoku Univ. (2019)



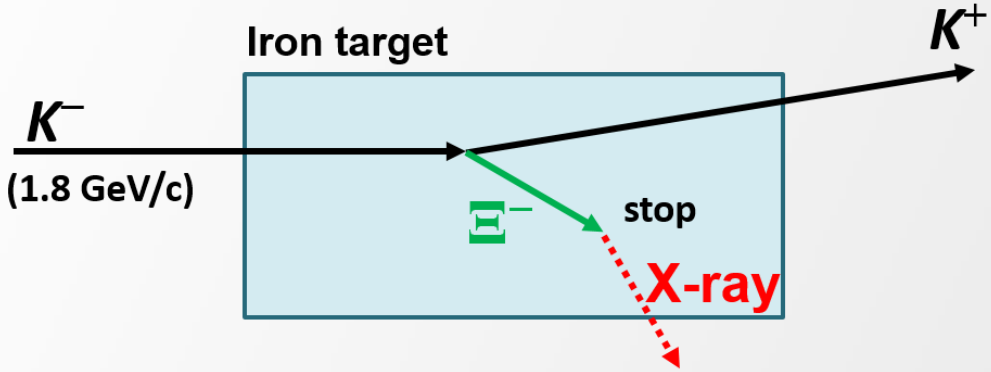
T. Koike

Theoretical study with lattice QCD potential (~40% / Ξ stop)

We achieved upper limit close to the prediction

We will retry C-atom measurement in future experiment.

Fe Ξ⁻ atom measurement [J-PARC E03]



Feature of the measurement:

- **S/N ratio △**
  [we can not tag Ξ⁻ stop, but high stopping prob.]
- **Yield rate ○**
  - **High stop probability**
  - **Optimum detector setup**

Advantage of Fe target

[Technical reason]

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

[Physics reason]

Absorption strength (and width) reported in theoretical case study is suitable for our measurement

Calculated by T. Koike

(5,4) state : ΔE~Γ~ 4keV [W.S. shape potential of -24-3i MeV]

Recent Lattice & ChiralEFT calc.
Shows <1/10 smaller imaginary strength

Experimental setup (E03)

reaction-X ray coincidence experiment

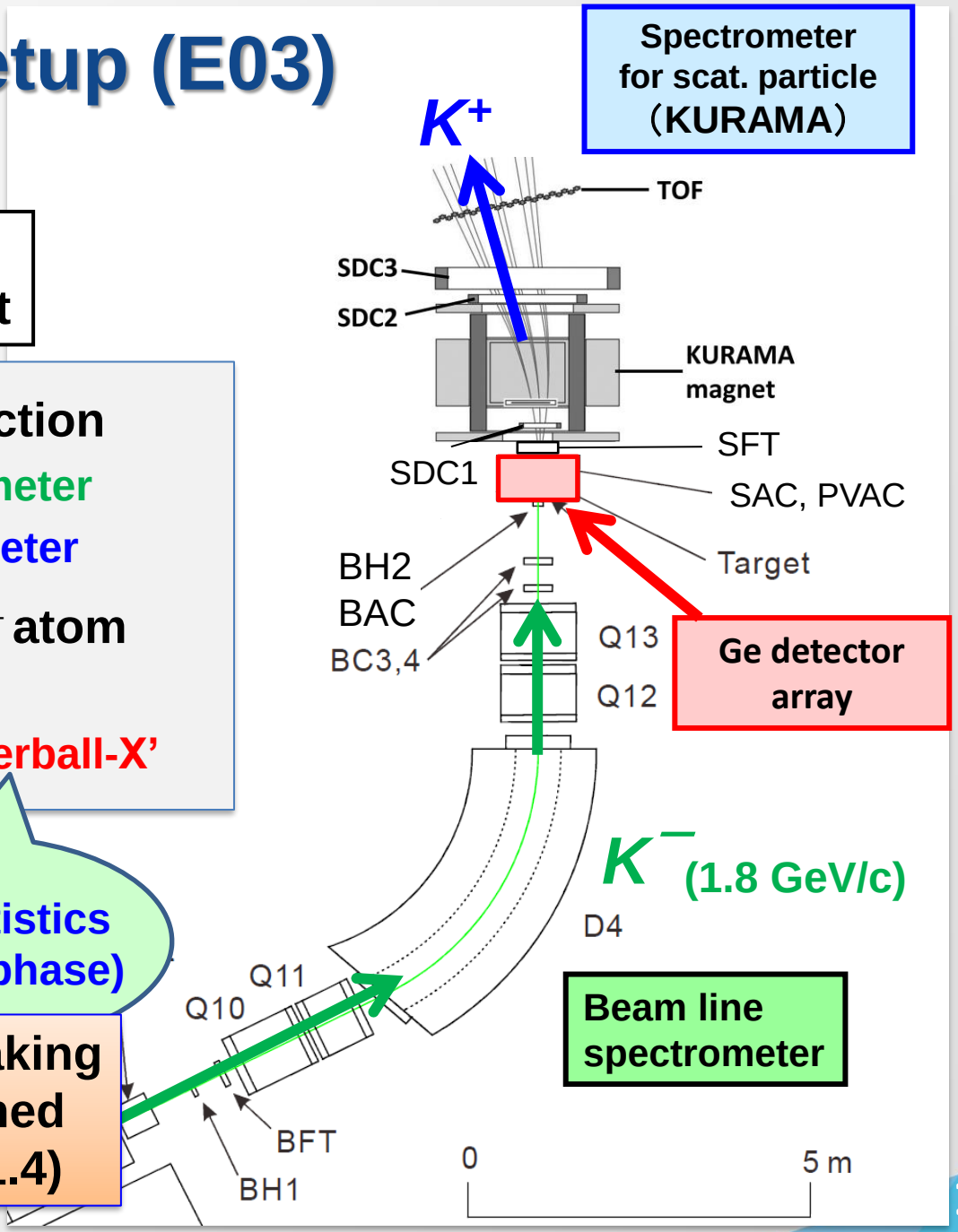
- **Tag $(K^-,K^+)\Xi^-$ production**
  - **Beam line spectrometer**
  - **KURAMA spectrometer**
- **Detect X ray from Ξ^- atom**
  - **Ge detector array**

  Hyperball-J or Hyperball-X'

Full statistics run (2^{nd}-phase)

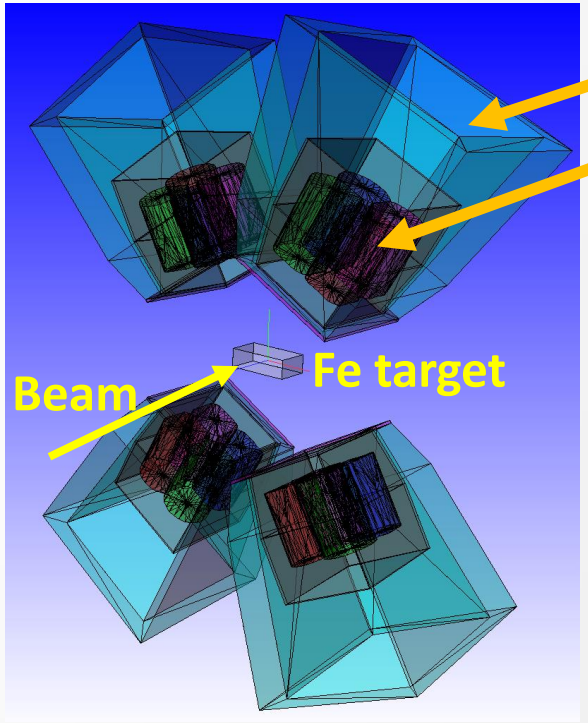
10% statistics Run (1^{st}-phase)

Data taking finished (2021.4)



Hyperball-X' for 1st phase

Constructed in 2020
for E03-1st phase



BGO suppressor

"clover-type" Ge detector (4 segmented crystals)

4 detector units
covering up and down of the target

- Horizontally wide beam profile and target
- Self-absorption of X ray

	HBX'	HBJ
High rate capability	△ * slow amp. * segmented crystal	○ * fast amp. * large crystal * radiation hardness
Energy resolution	2.5 keV (FWHM)	4 keV (FWHM)

Optimum for low (~250kHz) beam intensity

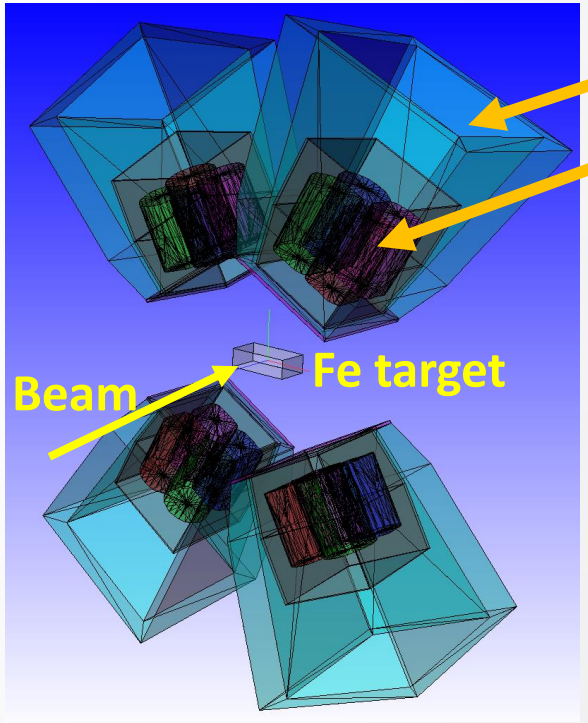
Γ~1keV case,

Higher energy resolution has great merit

- better peak significance
- small error on shift & width

Hyperball-X' for 1st phase

Constructed in 2020
for E03-1st phase



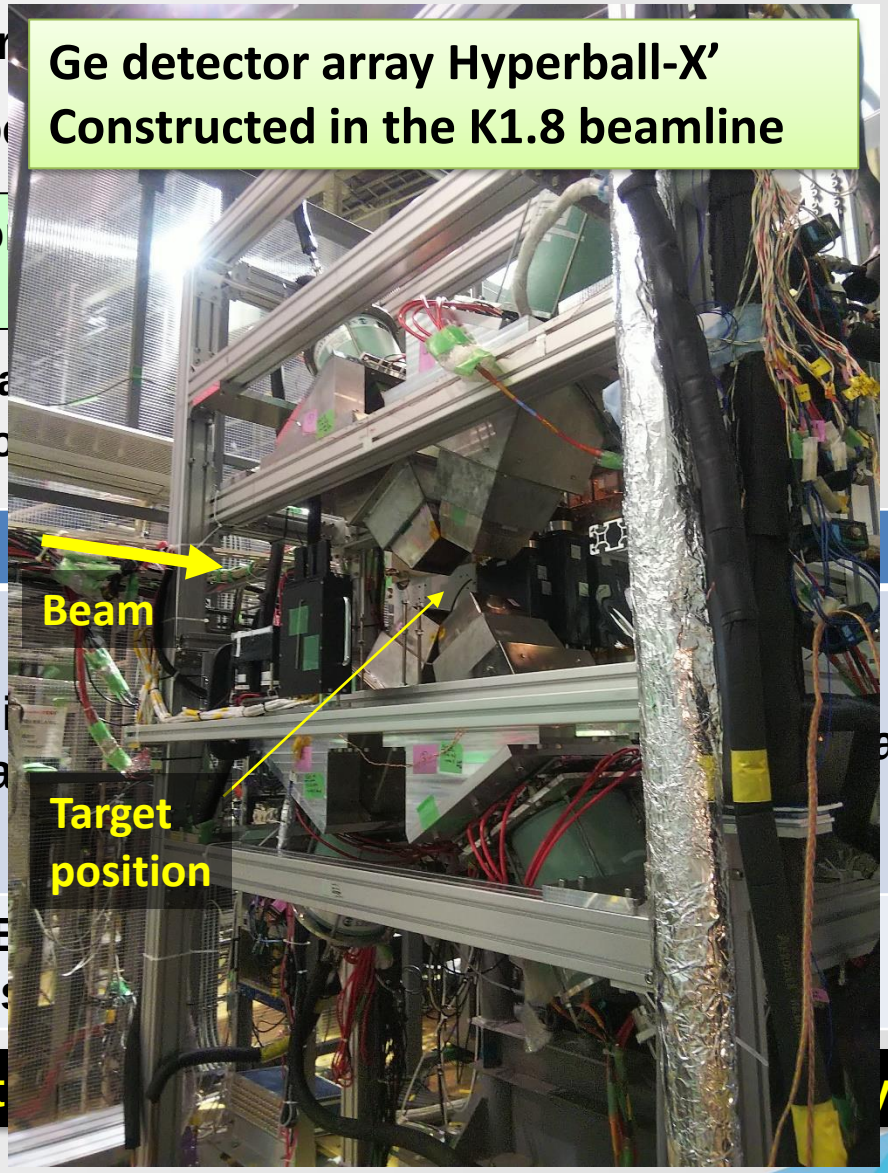
BGO suppr

"clover-typ

4 detecto
covering

- Horizonta
- Self-absc

Ge detector array Hyperball-X'
Constructed in the K1.8 beamline



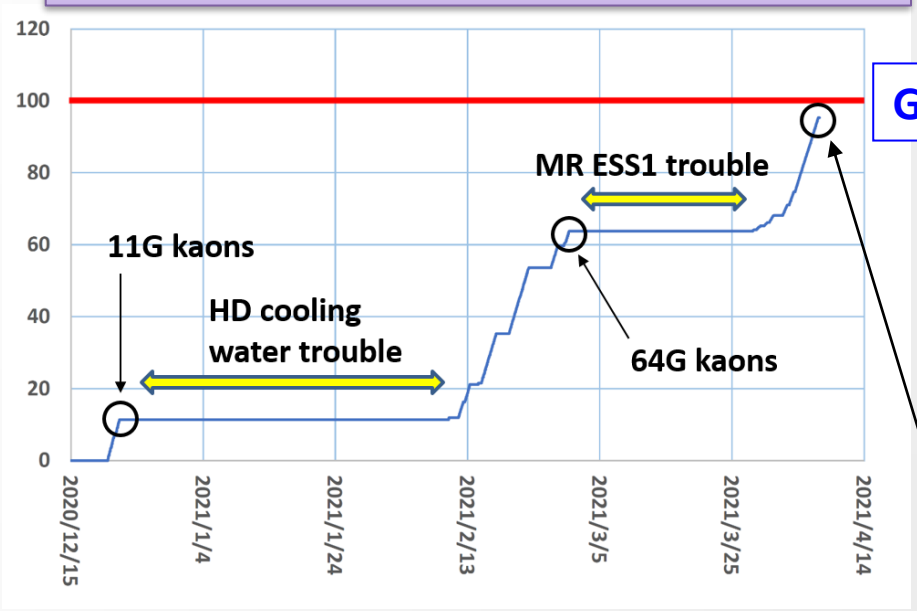
Γ~1keV case,
Higher energy resolution
has great merit
- better peak significance
- small error on shift & width

Opt

E03 data taking

We finished 1st phase data taking in 2021/4

Integrated # of Kaon beams at Iron target



Goal : 100G

Beam condition
K-: 410k/spill, π-: 90k/spill

We achieved 95G kaons!

with ~20 days beamtime

We got almost full statistics for 1st phase data taking

E03 preliminary result

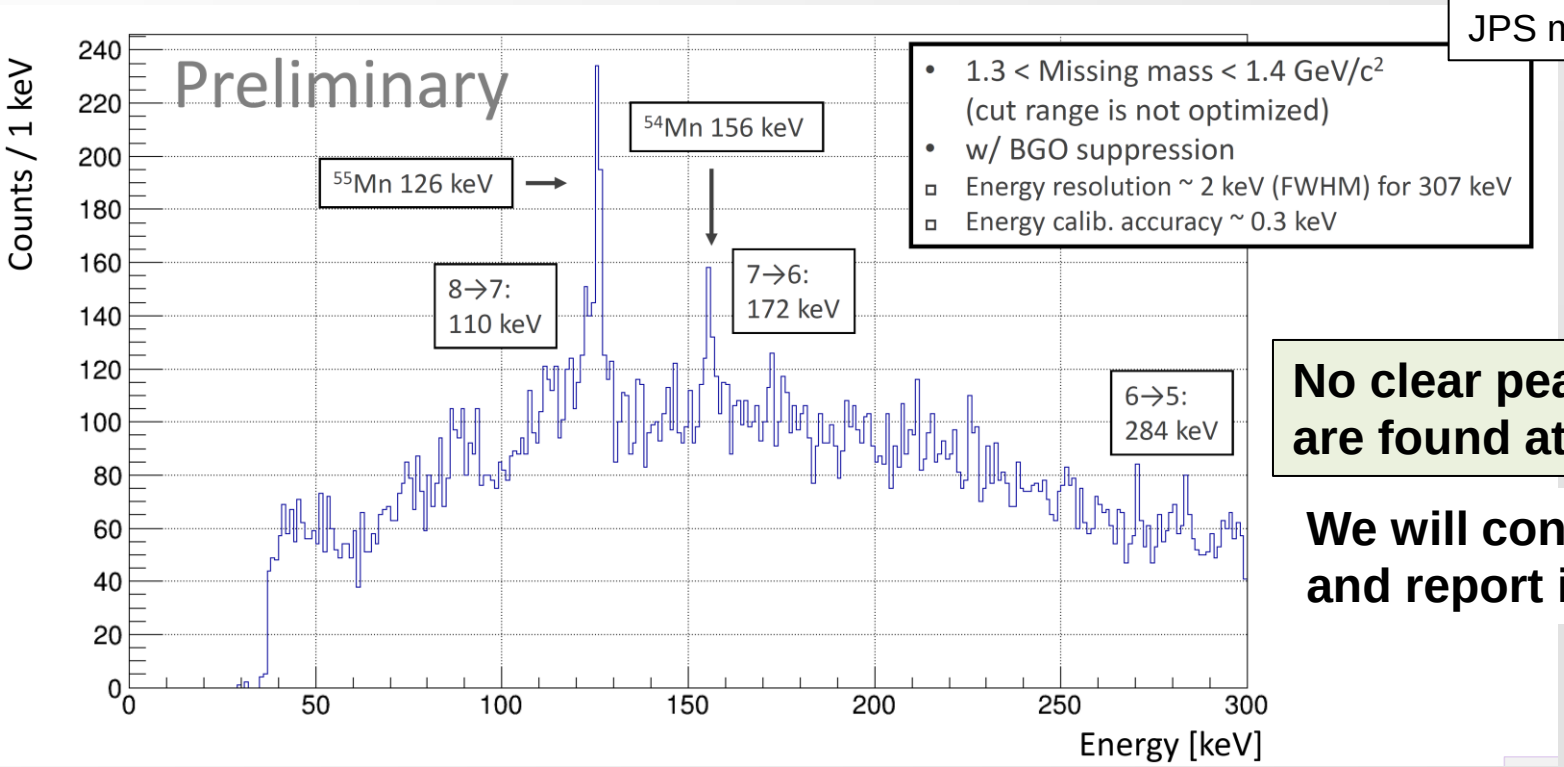
Detailed information:
Talk by Y. Ishikawa (6/29)

Analysis is now on-going.

This is very preliminary X-ray spectrum.

(not optimized event selection, background reduction and calibration)

Y. Ishikawa,
JPS meeting, 2022.3



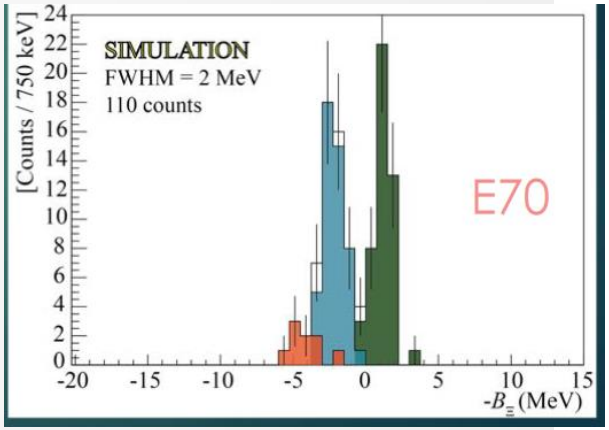
No clear peak structures are found at present.

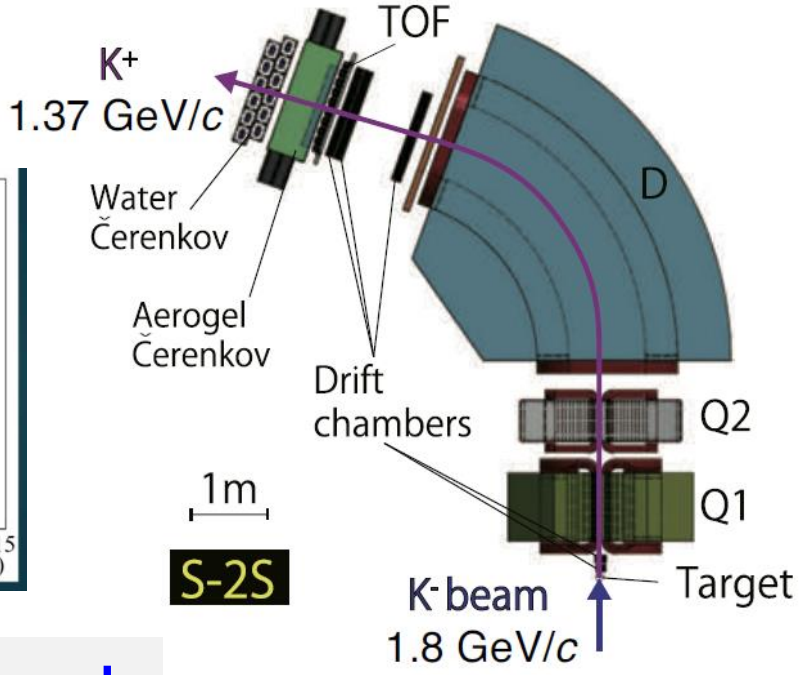
We will continue analysis and report in near future.

Future measurement with S-2S

High resolution Ξ^- hypernuclear spectroscopy with the same reaction.

T. Nagae, J-PARC PAC (2019)





Systematic measurement will be performed:

Target = ^{12}C (E70), ^{7}Li (E75), etc. in future?

Our second try in 2023.

Chance for X-ray measurement in parallel

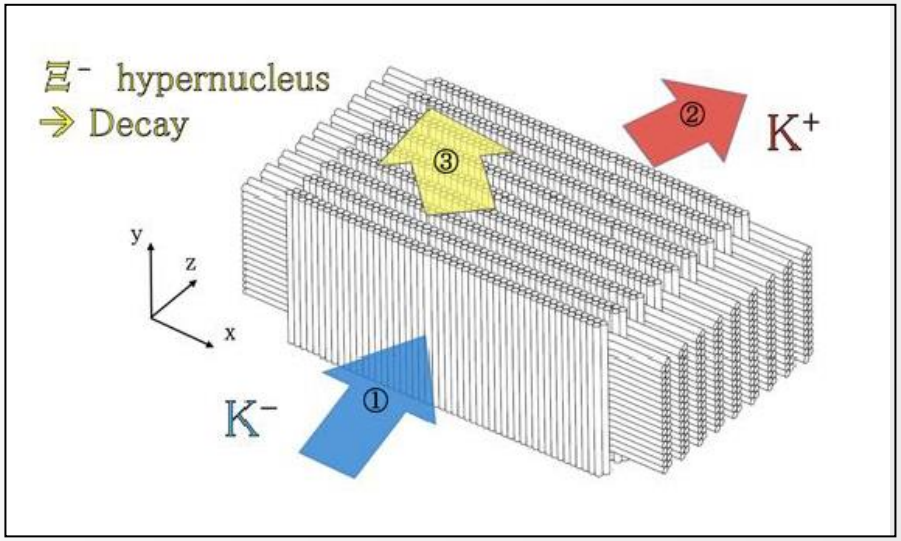
	S-2S
Magnet Configuration	QQD
Acceptance [msr]	55
Magnetic field [T]	1.5
Resolution [FWHM]	5.5×10^{-4}
Bending angle [deg]	70

Active fiber target

For C-atom

First target for S-2S experiment: ^{12}C

(E70 physics run in 2023)



Active fiber target for energy loss correction

Merit for X-ray measurement

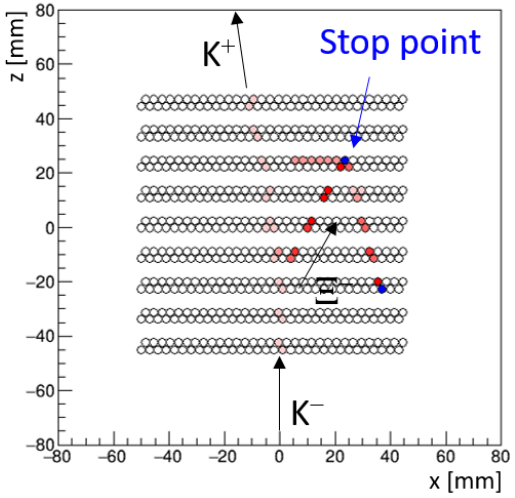
Feature of the X-ray measurement:

- **S/N ratio ○ [we can tag Ξ⁻ stop]**
- **Yield rate ×**
  - **Very low stop probability (low density)**
  - **Smaller acceptance of S-2S**

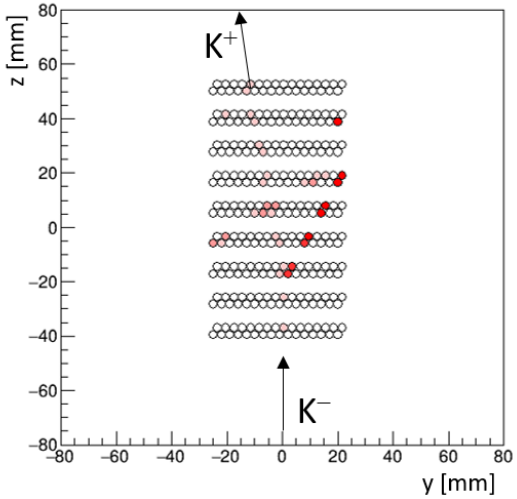
Active fiber target

For C-atom

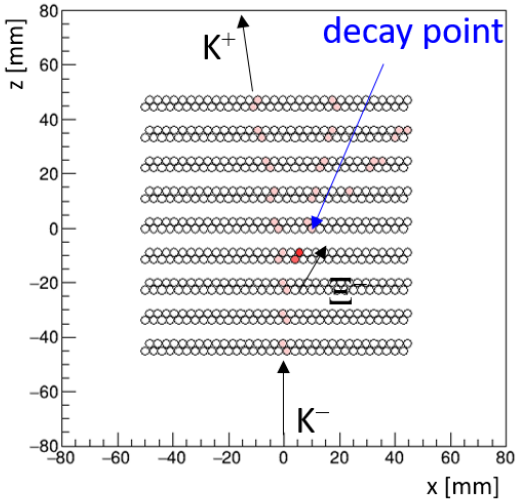
(a) Ξ^- stop event [signal]



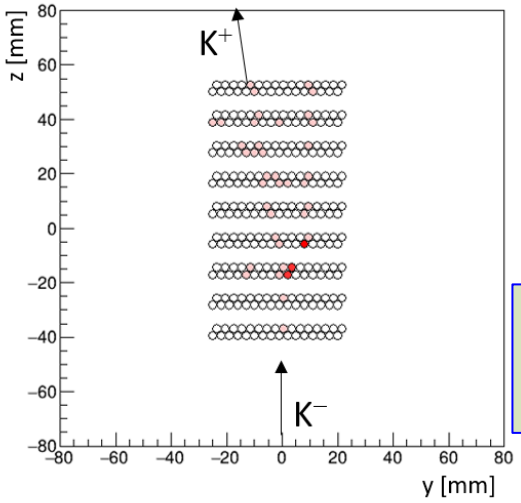
simulation



(b) Ξ^- decay event [background]



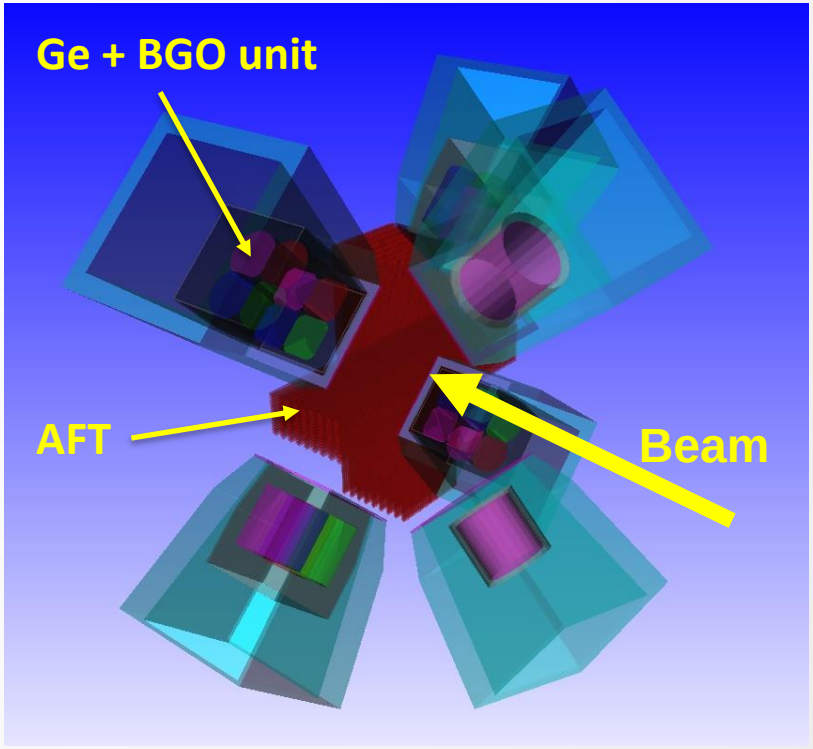
simulation



>90% of produced Ξ^- will decay before stop in target

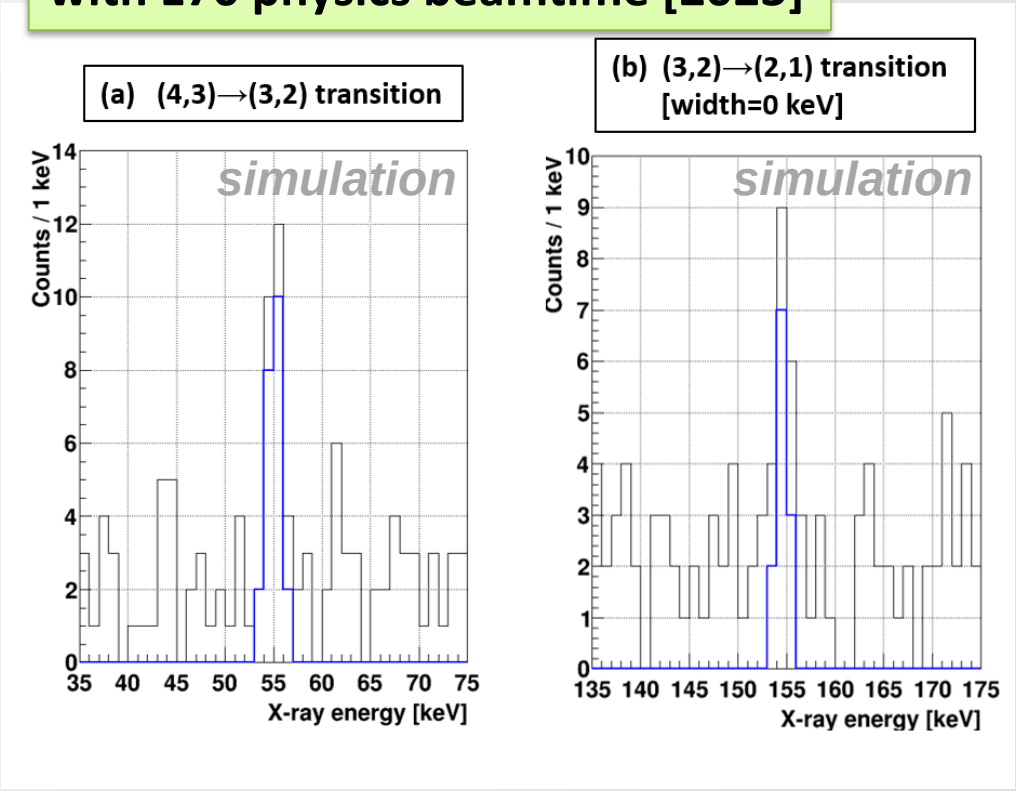
~95% background reduction may much improve S/N

Second try for C-atom measurement



By installing Ge detectors near AFT system,
parallel data taking
can be done in E70 beamtime
[expected in 2023]

Expected spectrum with E70 physics beamtime [2023]

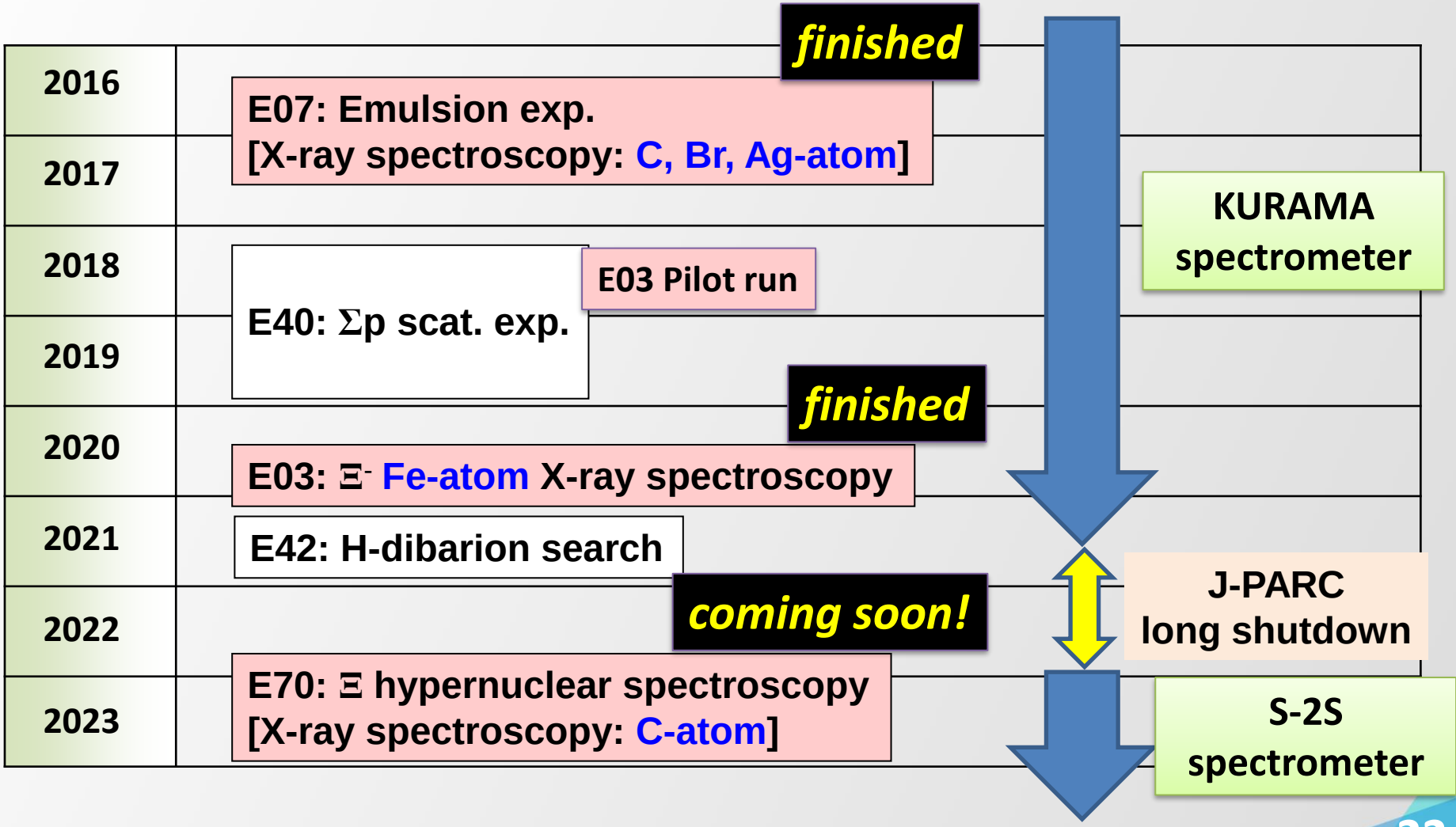


We have chance to observe X ray

Now, we are submitting the proposal and preparing detectors.

Timeline of X-ray spectroscopy of Ξ⁻-atom

at the J-PARC K1.8 beam line



Summary

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

→ Information on the ΞA optical potential

- **Test of Experimental technique in J-PARC E07**
  [X-ray spectroscopy: C, Br, Ag-atom]
- **E03 (Ξ^- Fe-atom measurement)**
  2 phase strategy for current ACC condition
  - **1st-phase data taking [2020-2021]**
- **Future measurement in S-2S exp. (J-PARC E70)**
  [X-ray spectroscopy: C-atom]