Status of X-ray spectroscopy of Ξ^--atom (J-PARC E03)

2019/10/24

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for the E03 collaboration

Contents

- X-ray spectroscopy of Ξ^- atom
- First try in J-PARC E07
- Coming measurement in J-PARC E03
    - Pilot run for detector optimization [2017-2018]
        - Ge detector live time measurement
        - B.G. level study
    - Present status & schedule

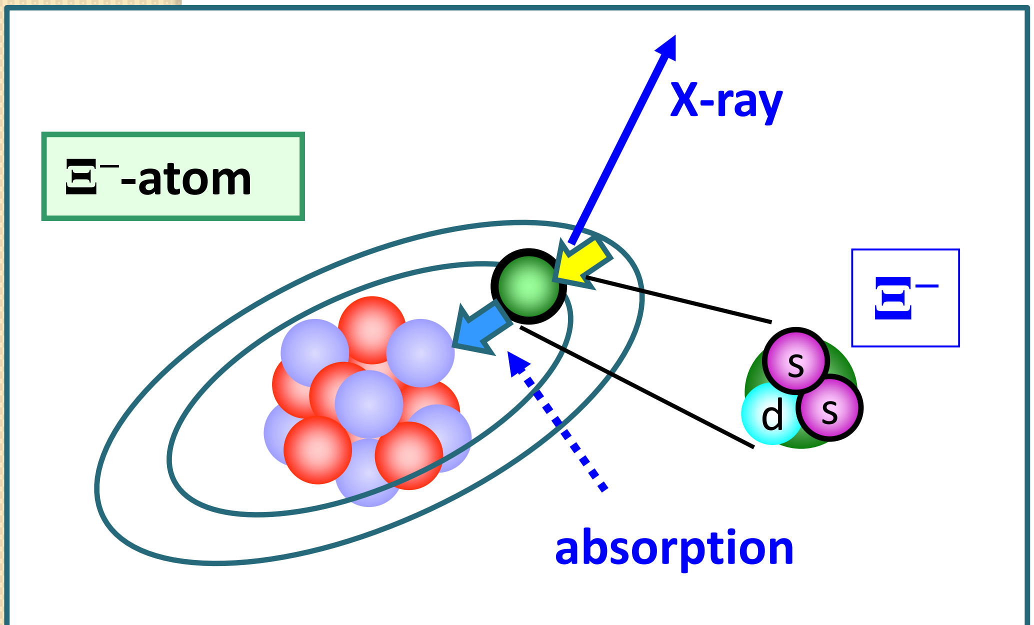
Data taking in 2020?

- Summary

X-ray spectroscopy of Ξ⁻-atom

We (J-PAEC E03 group) are aiming for
world first measurement of X ray from Ξ⁻-atom

→ Information on the ΞA optical potential

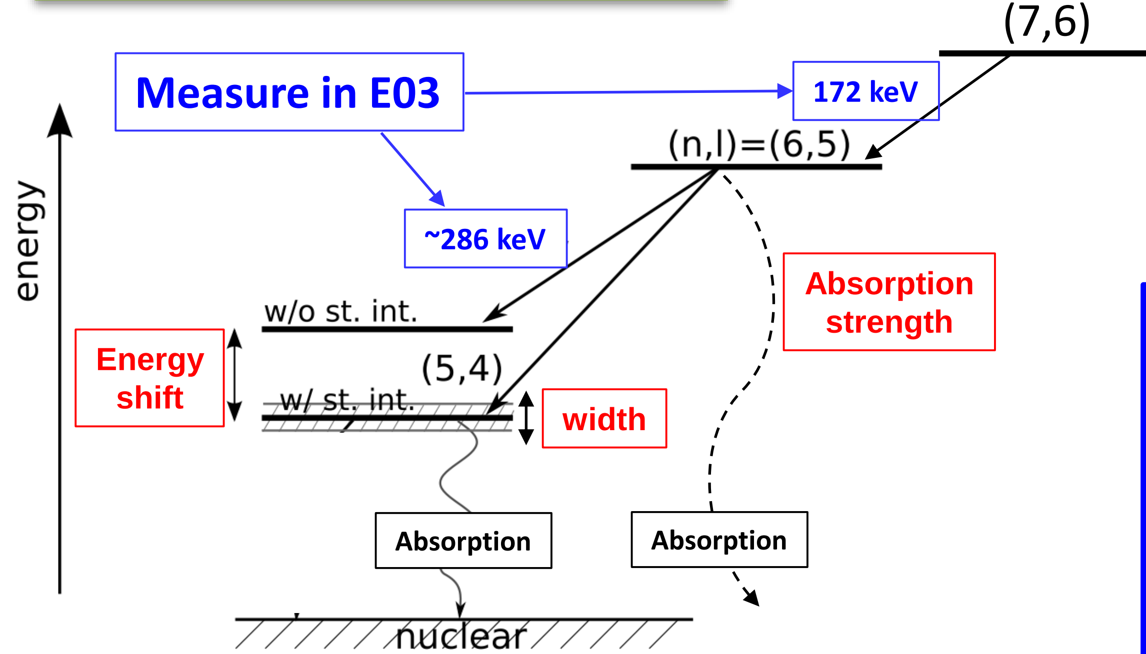


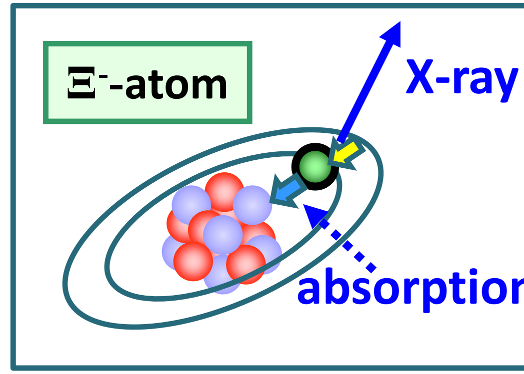
- Information on (effective) ΞN interaction
  large baryon mixing?
  (small ΔM(ΞN-ΛΛ)=28 MeV)
- ΞA interaction and it's A dependence
  Role of Ξ⁻ in neutron star?

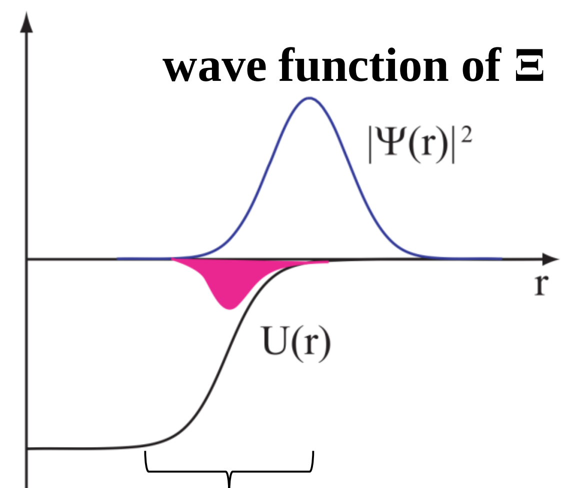
Establishment of experimental method in the J-PARC E03 (Fe-Ξ⁻ atom)
→ Systematic measurement (over wide mass range) in future

X-ray spectroscopy of Ξ⁻-atom

Level scheme of Fe-Ξ⁻ atom







Sensitive to near surface potential shape

Measurement of energy shift and width
→ Ξ⁻A real and imaginary term (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**

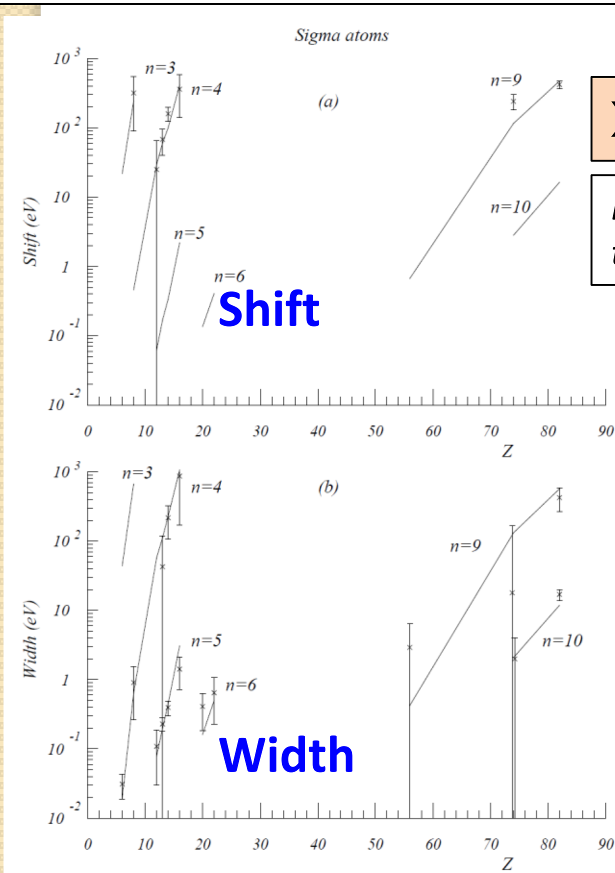
Need systematic X-ray measurement over wide mass range

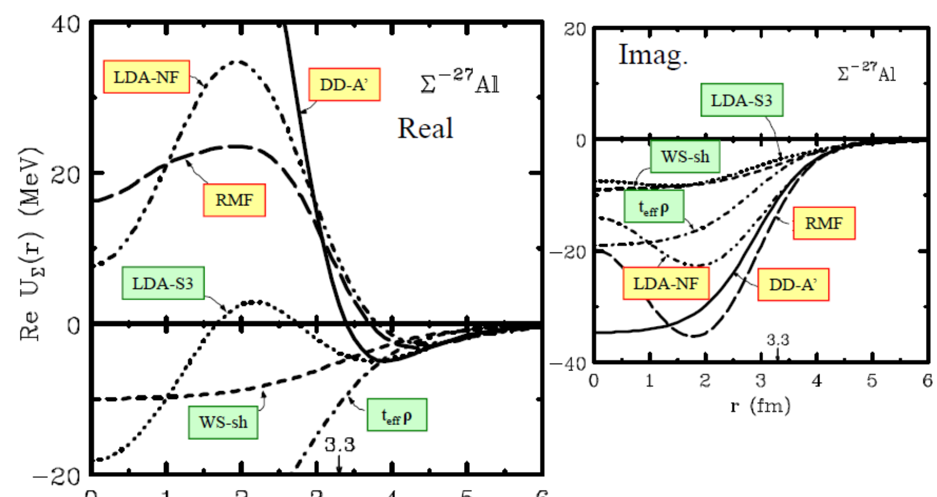
→ Potential shape, mass dependence

as in the case of Σ^- atom data

Σ^- atom data

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





Physics motivation

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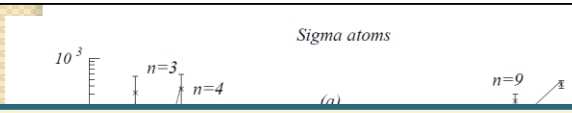


as in the case of Σ^- atom data

Our strategy for Ξ^--atom

No Ξ^--atom data so far

A

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

(also N-atom, O-atom…)

Fe (Z=26)-atom : Coming J-PARC E03 [Todays talk]

Br (Z=35)-atom :

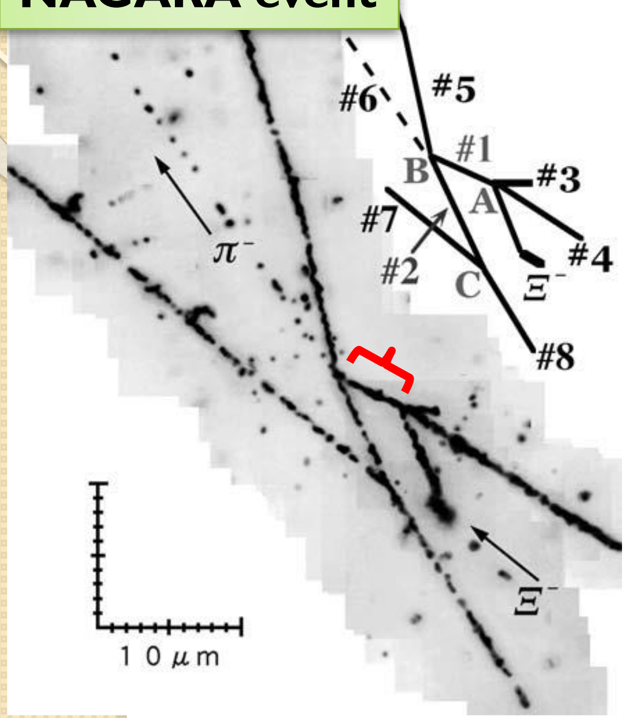
Ag (Z=47)-atom :

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

Pb (Z=82)-atom : PANDA [morning talk]

Impact on emulsion data

NAGARA event



Stopped Ξ^-s form Ξ-atoms before reaction

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

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

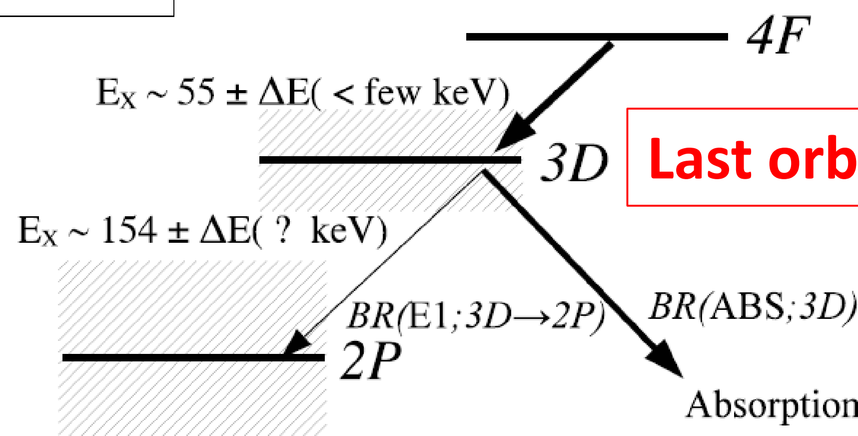
$B_{\Lambda\Lambda}$ = 6.91 ± 0.16 MeV

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] (energy center and error)

Ξ^- C atom



Last orbit ?

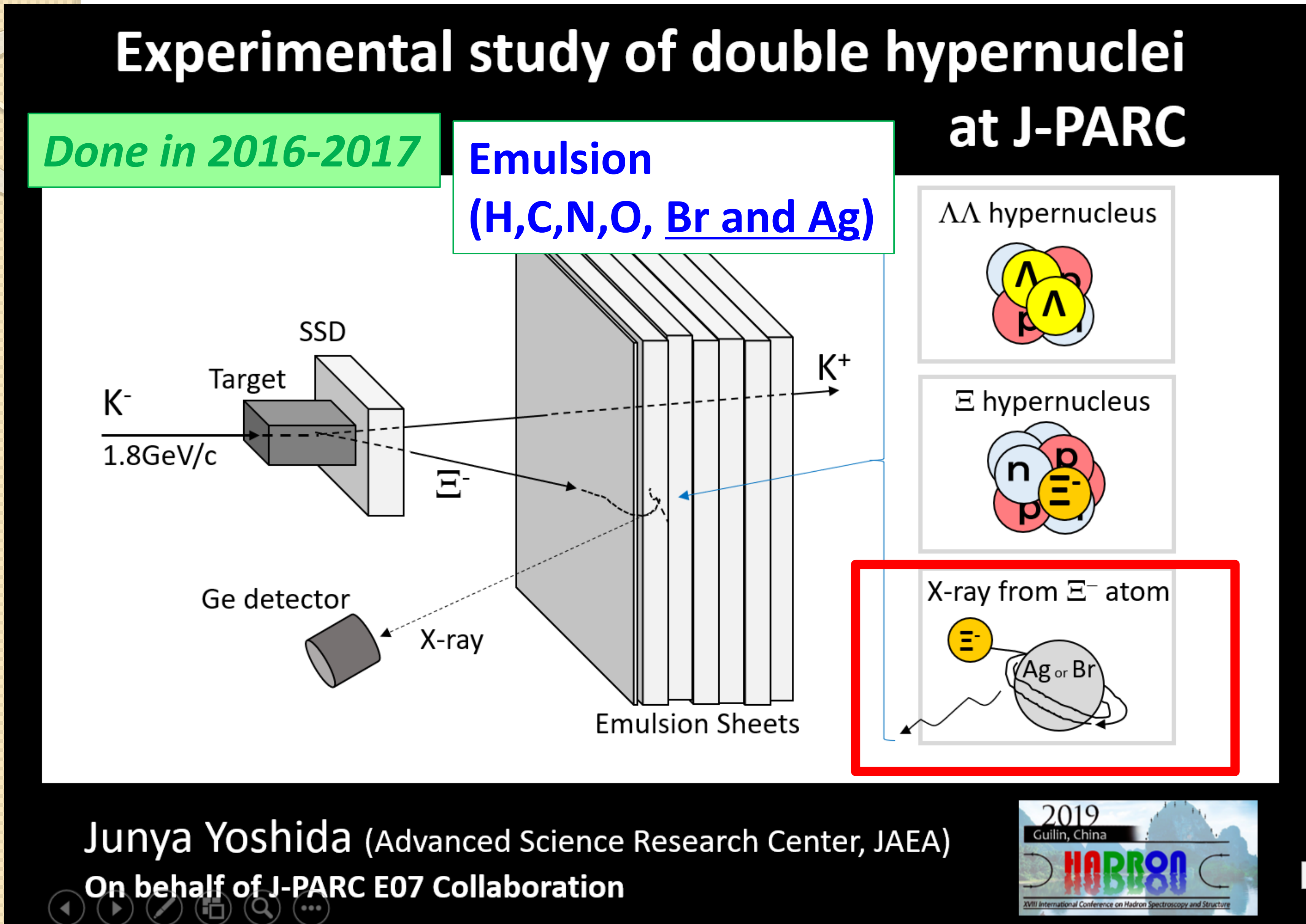
Theoretical prediction:

3D absorption is dominant

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

X-ray data will support $B_{\Lambda\Lambda}$ analysis

Our first try in J-PARC E07



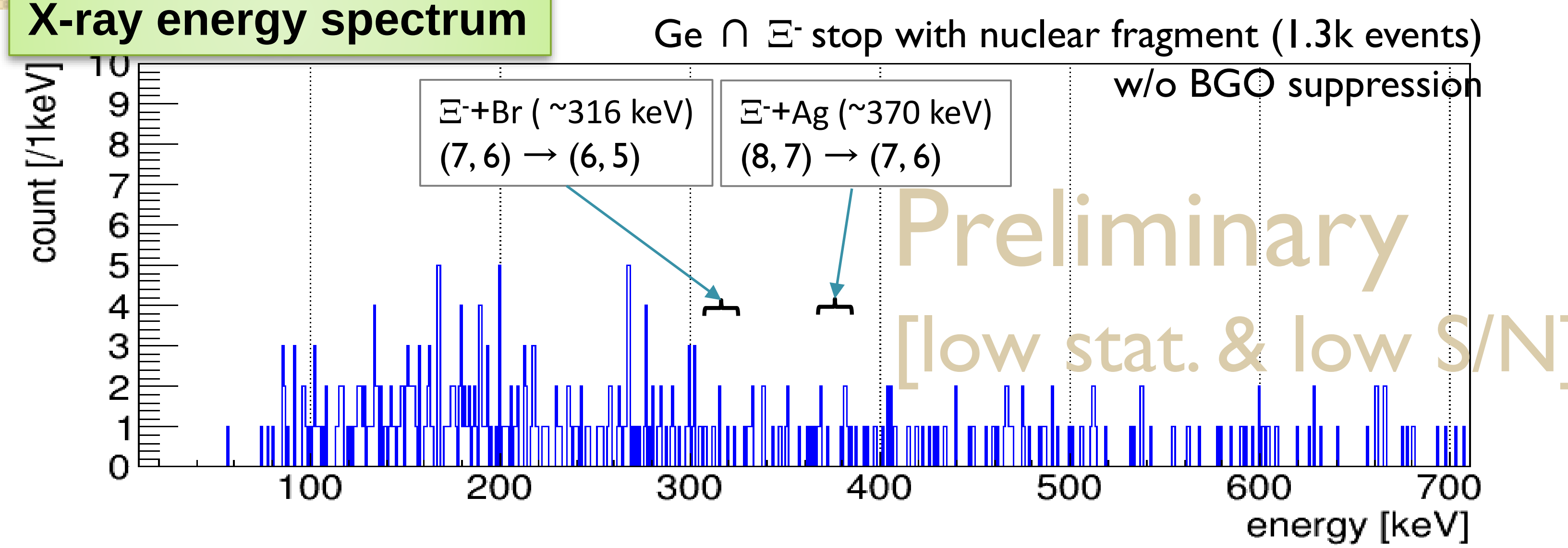
Our first try in J-PARC E07

Feature of the measurement:

- Good S/N ratio [we can tag Ξ^- stop in emulsion]
- Low yield rate
  - Low stop probability (long flight, low density)
  - Mixture target (H, C, N, O, Br and Ag)
  - Not optimum setup for X-ray detector

J. Yoshida and M. Fujita
HADRON 2019

X-ray energy spectrum



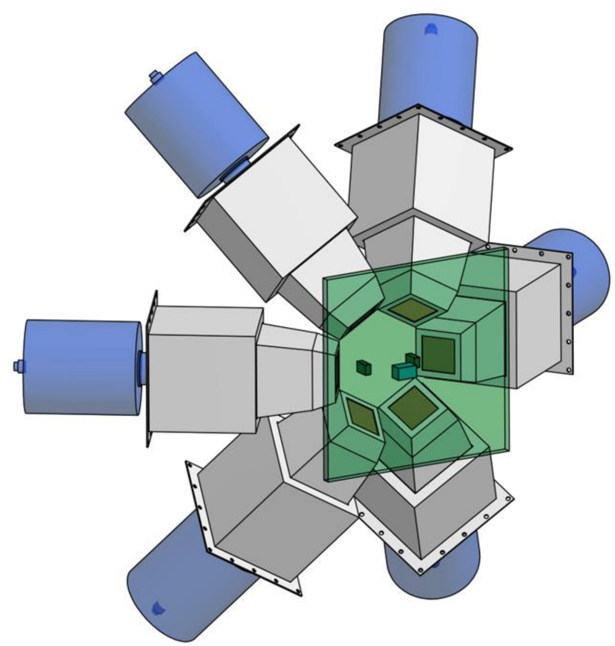
Expected # of event
= 10-20 (for Ag) w/ full stat.

Emulsion analysis is on going to search "special" event
→Not enough analyzed Ξ stop event (10-20%) so far

Our first try in J-PARC E07

We checked performance of
X-ray spectrometer (Hyperball-X Ge array)

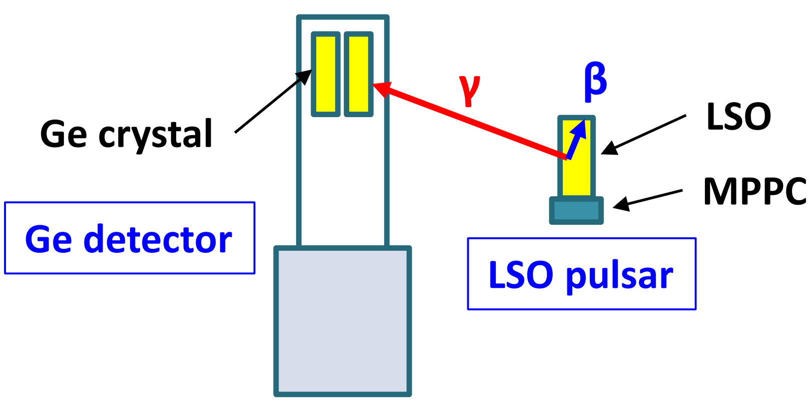
Almost same system as
our coming measurement



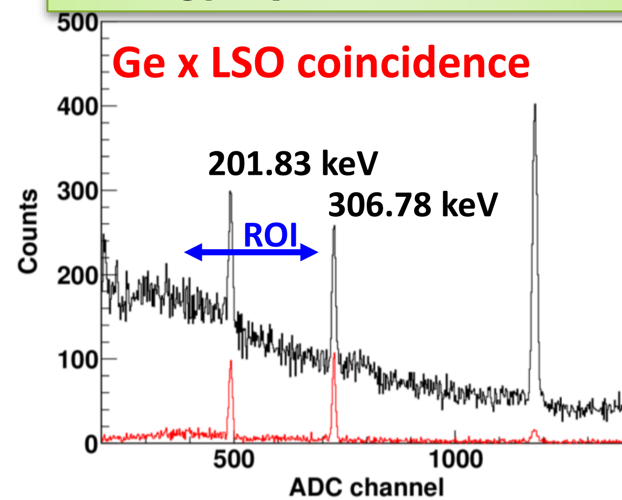
- Energy resolution: 2.0~2.5 keV [FWHM]
- Calibration accuracy: < 0.05 keV

LSO triggerable source
[β-γ coincidence]

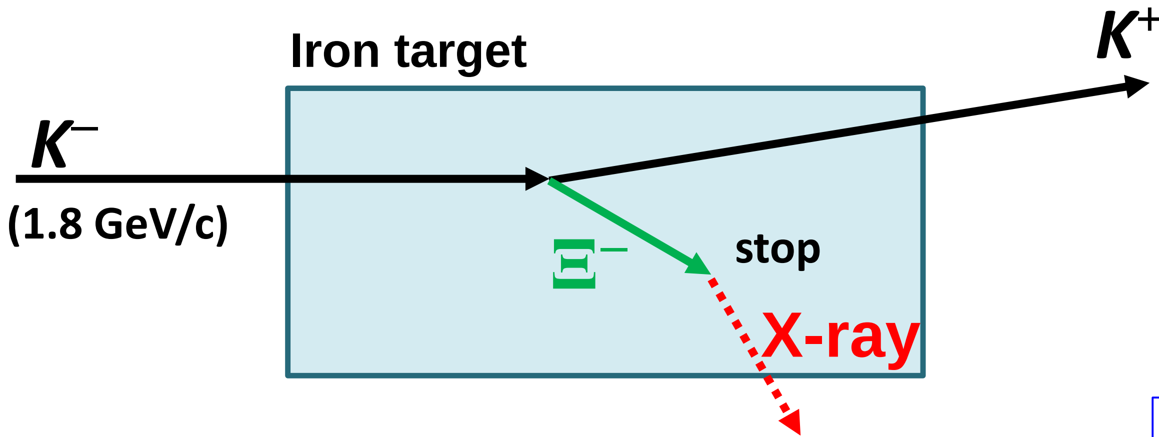
In beam calibration
[every one hour]



Energy spectrum w/ LSO



Experimental method [J-PARC E03]



J-PARC E03

Fe target for the first measurement

* Absorption strength (and width) reported in theoretical case study is suitable for our measurement
((5,4) state : $\Delta E \sim \Gamma \sim$ 4keV [W.S. shape potential of -24-3i MeV])

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

- 1.8 GeV/c kaon beam → J-PARC K1.8 beam line
- large yield of the Ξ^- production for coincidence measurement
  → Wide acceptance spectrometer KURAMA (~0.2 msr)
- A few keV resolution for X-ray measurement → Ge detector

Experimental setup (E03)

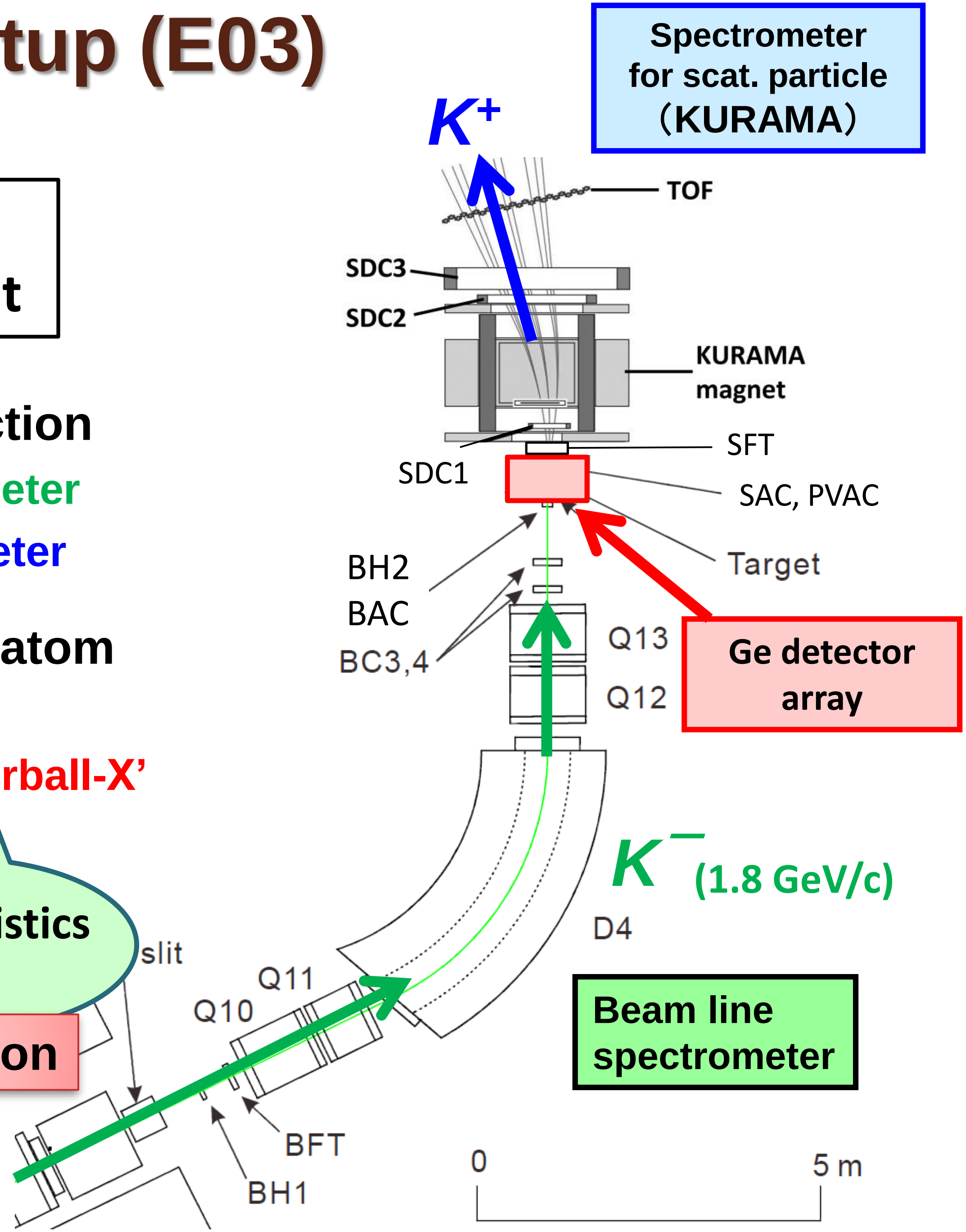
reaction-X ray coincidence experiment

- **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

10% statistics run

Focus on



Hyperball-J Ge detector array

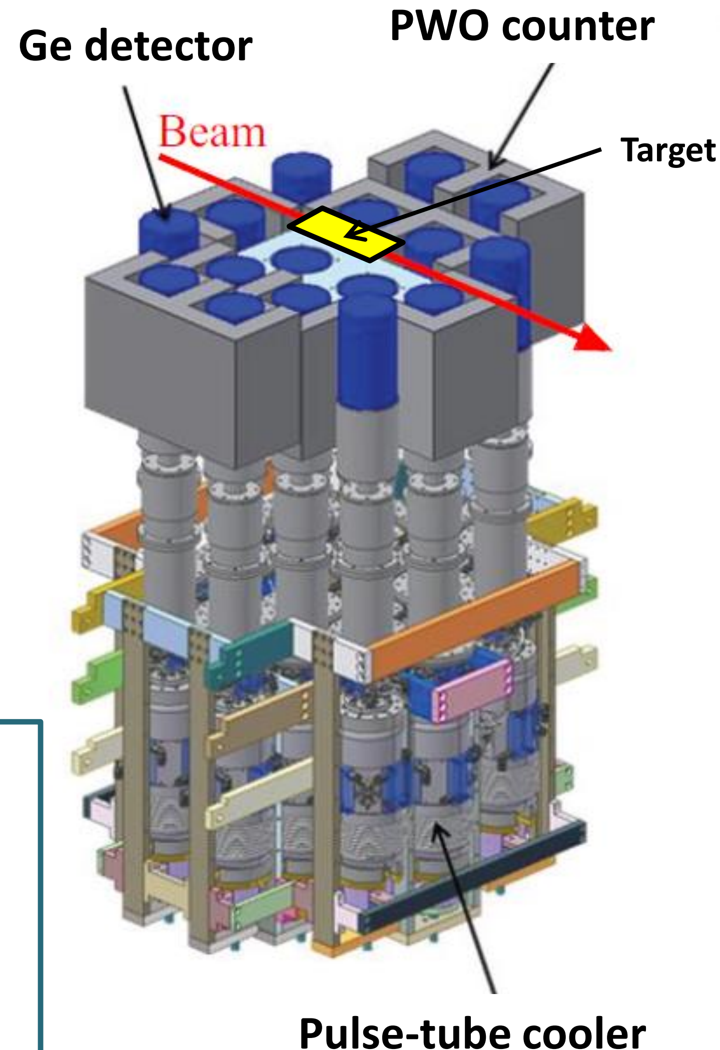
will be used in Full statics E03 run

Features

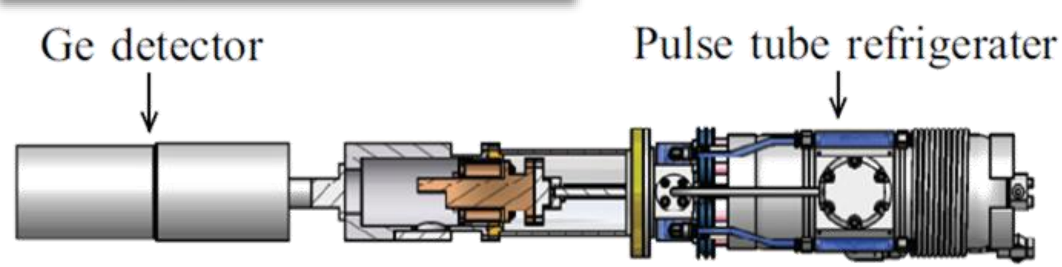
- **Large photo-peak efficiency**
  → **ε ~6 % @1 MeV with 32 Ge detectors**
- **Fast readout system**
- **Low temp. Ge detector for radiation hardness**
  → **Mechanical cooling**
- **Fast background suppressor**
  → **PWO counter**

for high intensity hadron beam

Lower half of Hyperball-J



Developed Ge detector



Strategy of E03

We decided to run with 10% statistics (1st-phase) for not full accelerator intensity

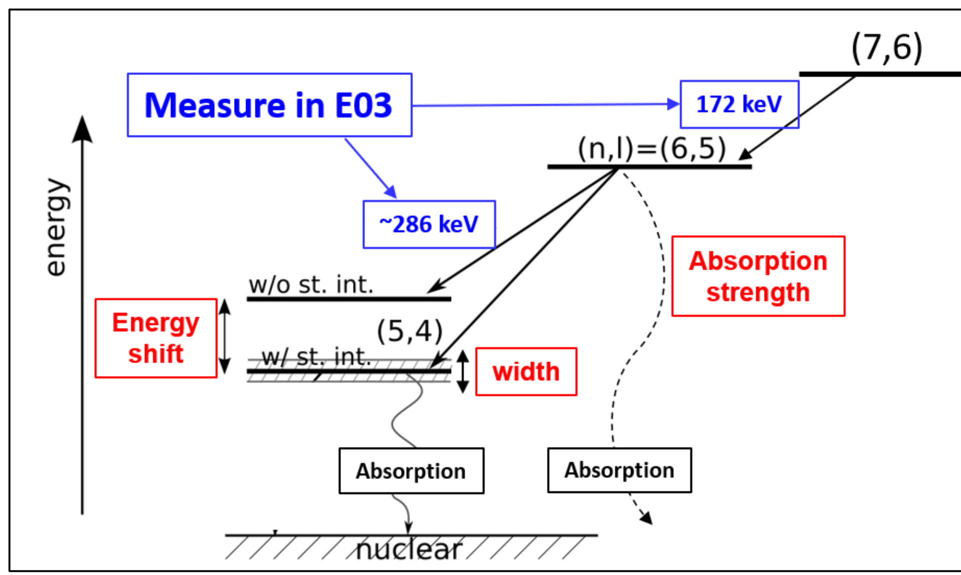
< 1st phase > 10% statistics **(~20 days with present beam power)**

- (7→6) transition will be seen
  → **"World first measurement of X ray from Ξ atom"**
- (6→5) finite shift & width (if $\Gamma<1$ keV)
- information of absorption strength from (6→5)/(7→6)

< 2nd phase > 100% statistics

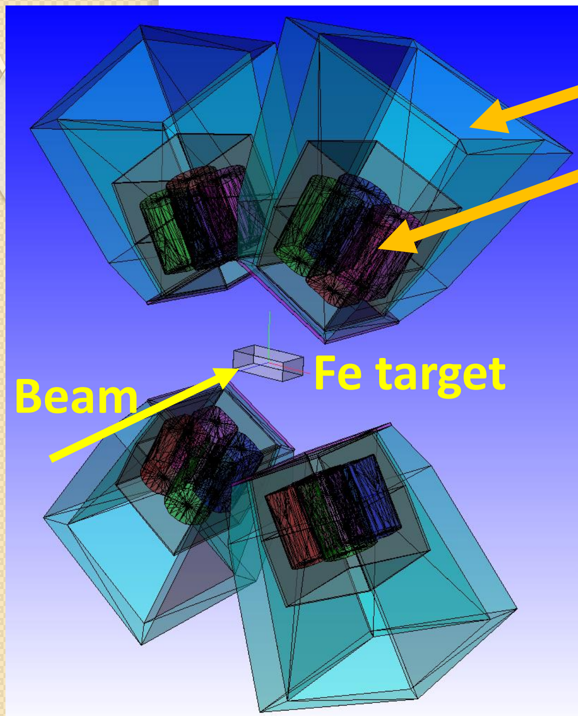
- (6→5) shift & width
  (if $\Gamma\sim4$ keV)

Reported from
theoretical case study
(no strong experimental constrain)



Hyperball-X’ for 1st phase

Optimum for low beam intensity



BGO suppressor

“clover-type” Ge detector (4 segmented crystals)

4 detector units with vertically covered configuration

- Horizontally wide beam profile and target
- Self-absorption of X ray is serious for horizontal direction

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

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

Pilot run for realistic estimation

First time to use our Ge detector array with "heavy" target

We have experience for A $\leq$ 19 target,
but A=56 target will be used in J-PARC E03

<Unknown factor>

- Live time of Ge detector
- B.G. level in final X-ray spectrum

Need data with actual beam and target

Pilot run for E03-1st June 2017 (2.5h) + Feb. 2018 (19h)

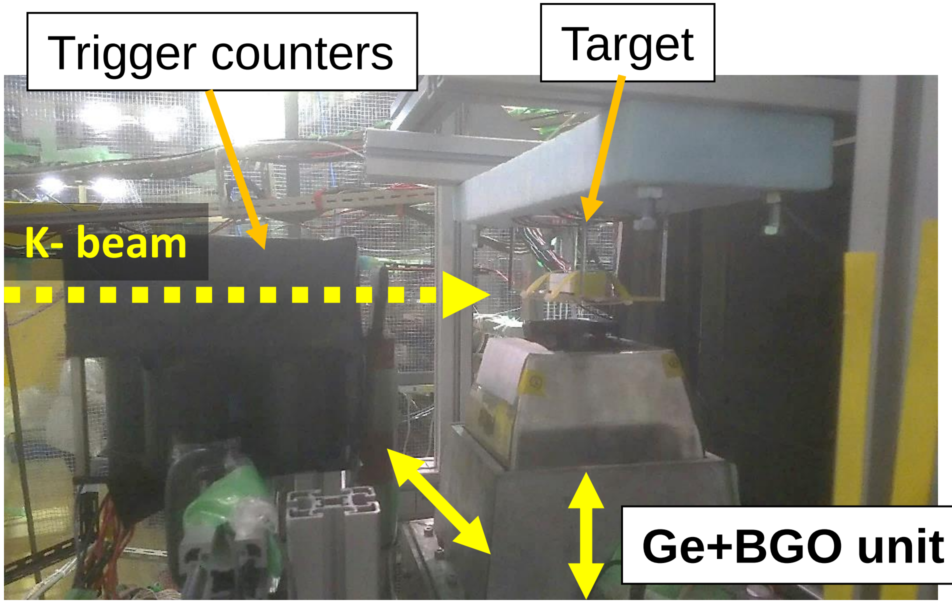
Setup: KURAMA + clover-type Ge + Iron target

- optimization of Ge detector position and beam intensity (Live time vs coverage)
- data for realistic B.G. estimation

Pilot run

- **study ①**
  Position and beam intensity dependence of "Ge live time"
  Direct measurement using dummy signal

- **study ②**
  B.G. level in energy spectrum
  Ξ^- production x Ge coincidence
  (very low statistics physics run)

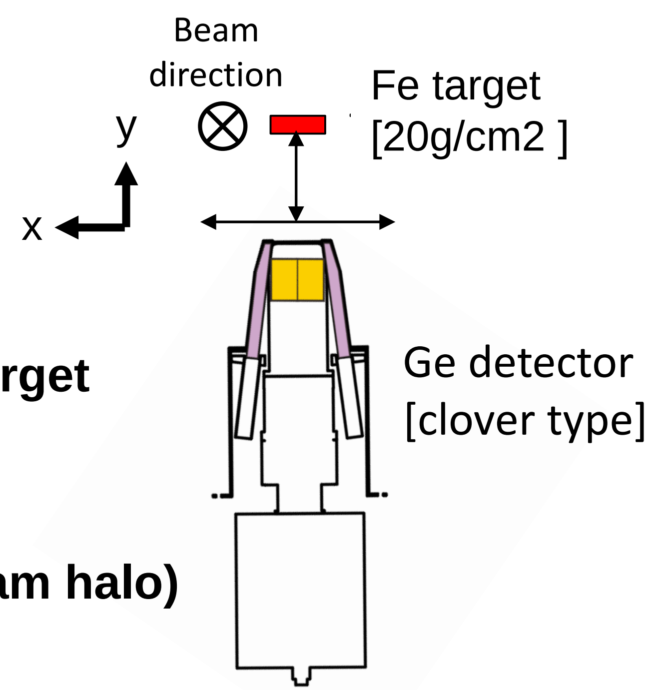


<Scan parameters>

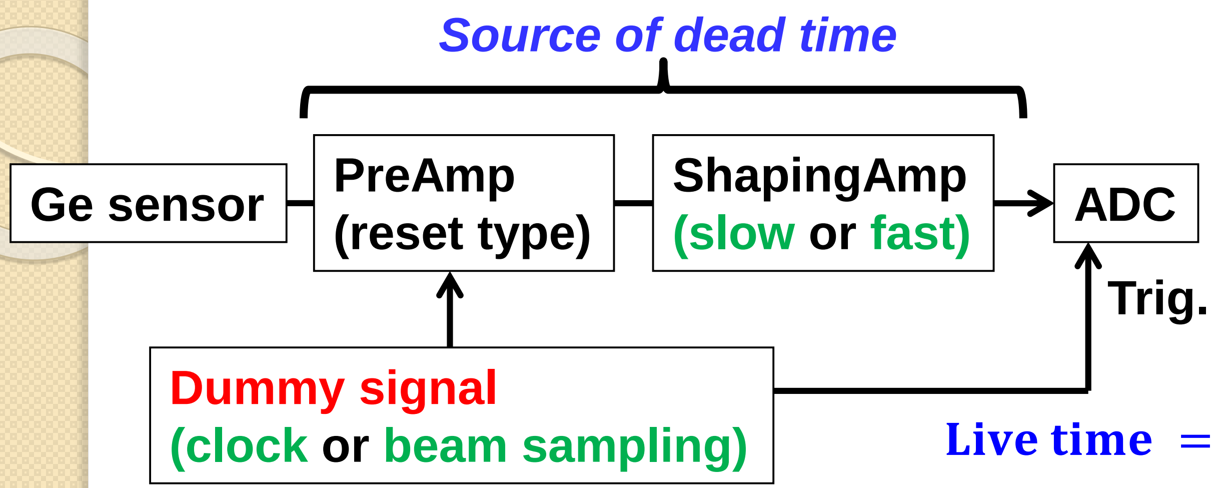
- **Ge detector position**
  X, Y(2D) scan
- **Beam intensity**
  π+K = 200 - 800 k/spill
- **Slow amp. or fast amp.**

Y : distance Ge↔Target

X : horizontal
(effect of not symmetrical beam halo)

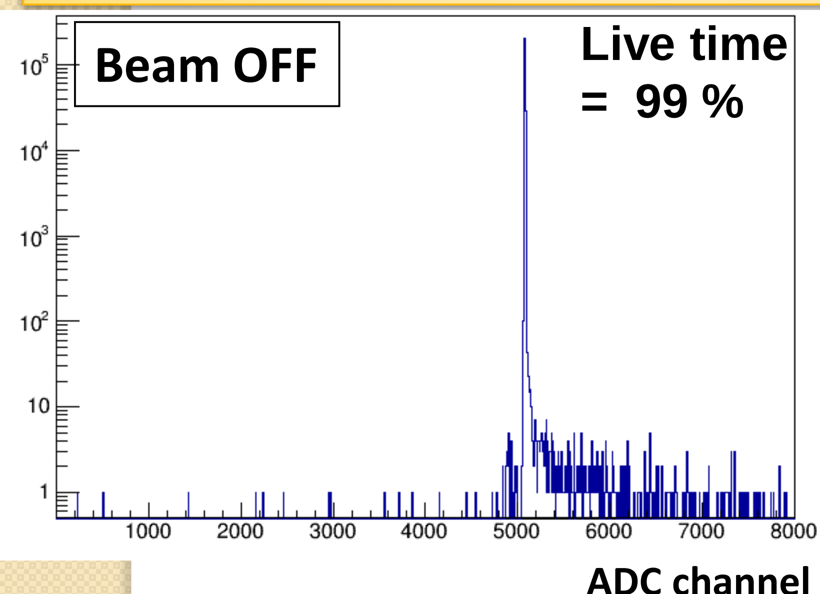


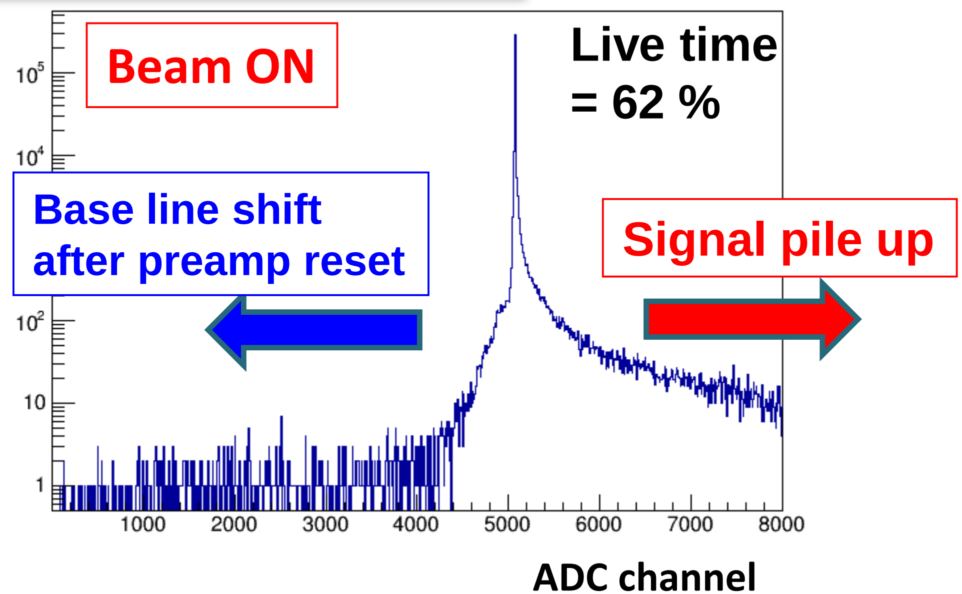
Direct measurement of live time



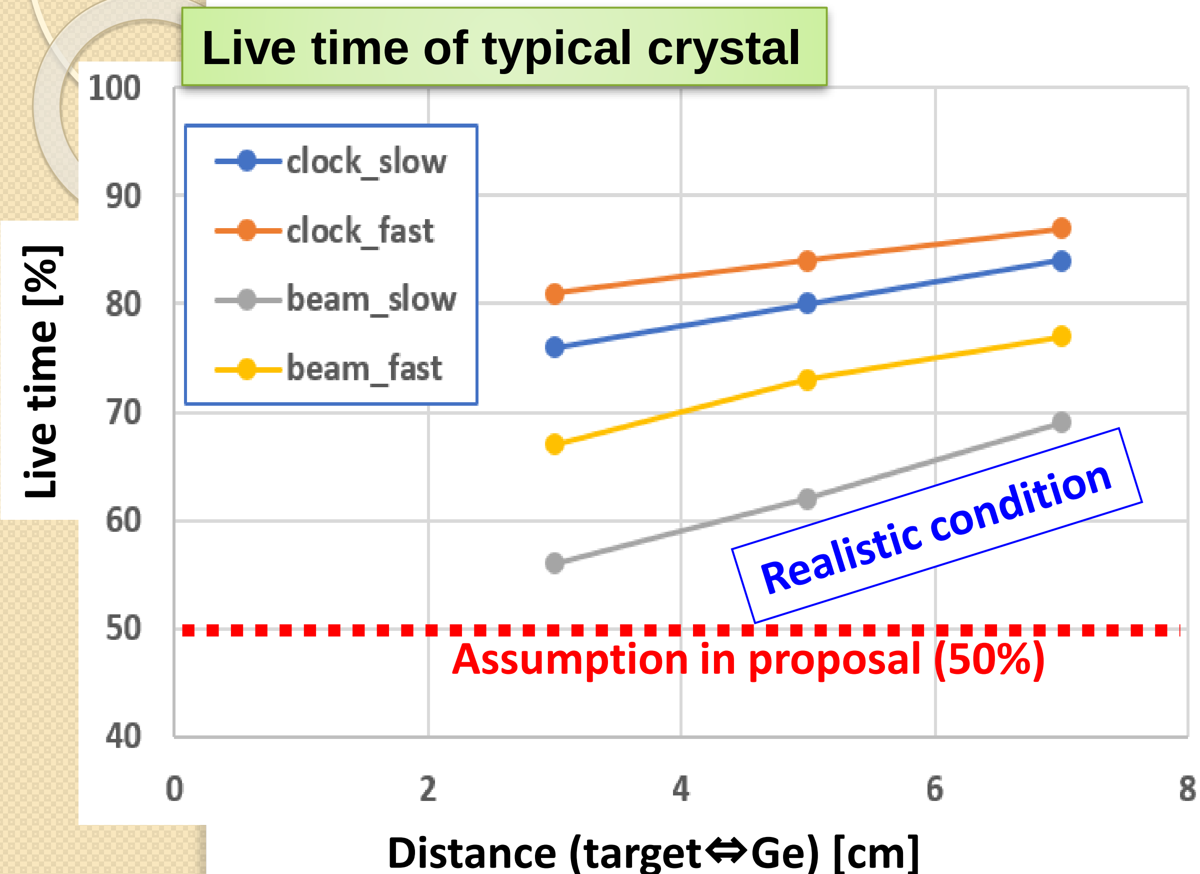
$$\text{Live time} = \frac{\text{\# of peak counts in ADC}}{\text{\# of trig.}}$$

Energy spectrum w/ dummy input trig. (typical condition)

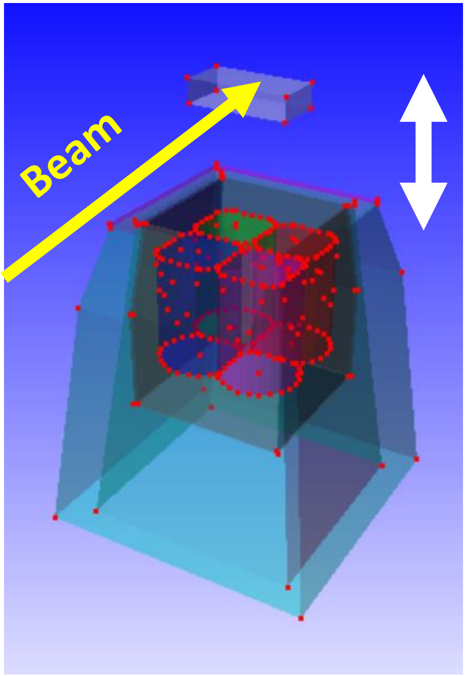




Measured live time



Beam condition:
K$^-$ beam [1.8GeV/c]
π+K= ~500k/spill



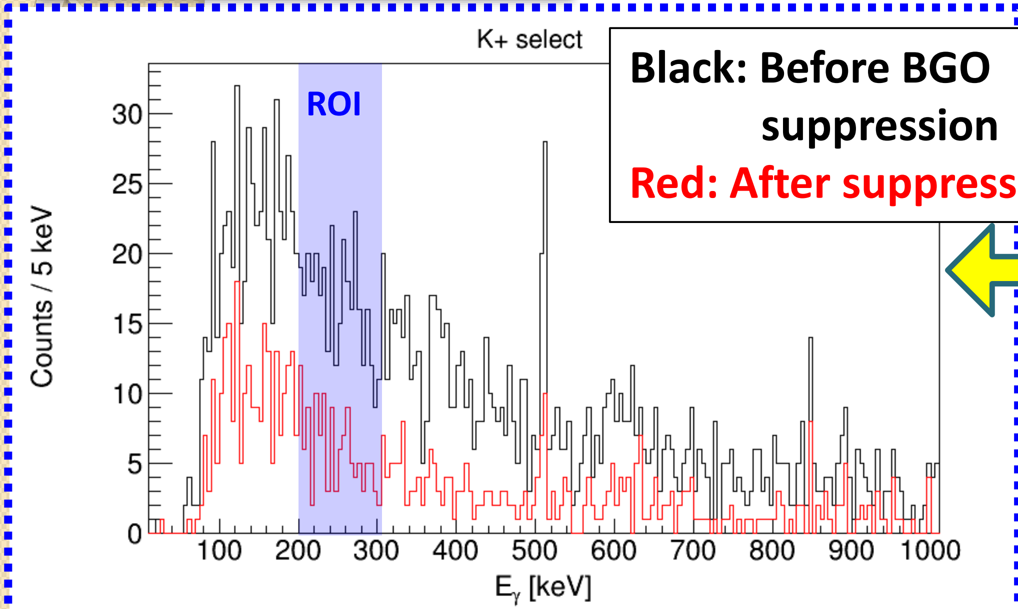
Yield ∝ Photo-peak eff * Live time * analysis eff

Optimum condition:

~6cm distance + 500k/spill(2s) beam intensity

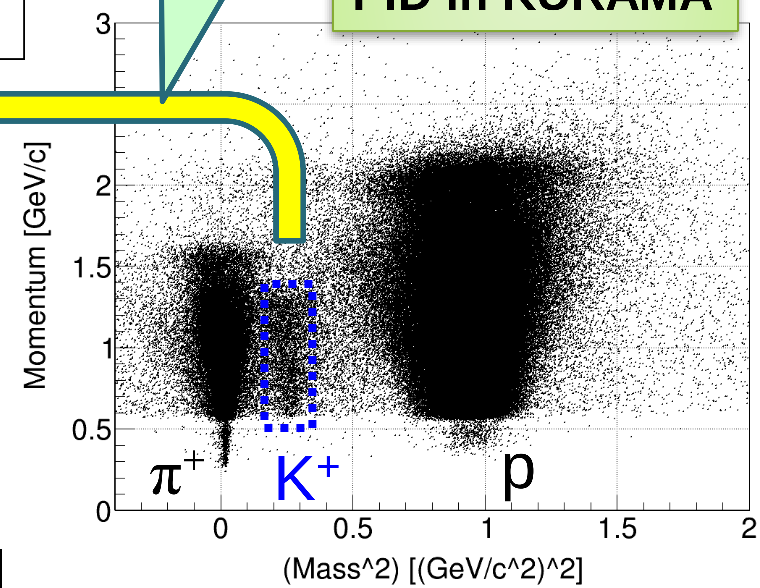
B.G. level measurement

Ge energy spectrum



Select Ξ^- production events

PID in KURAMA



Integrated event# (200-300 keV)

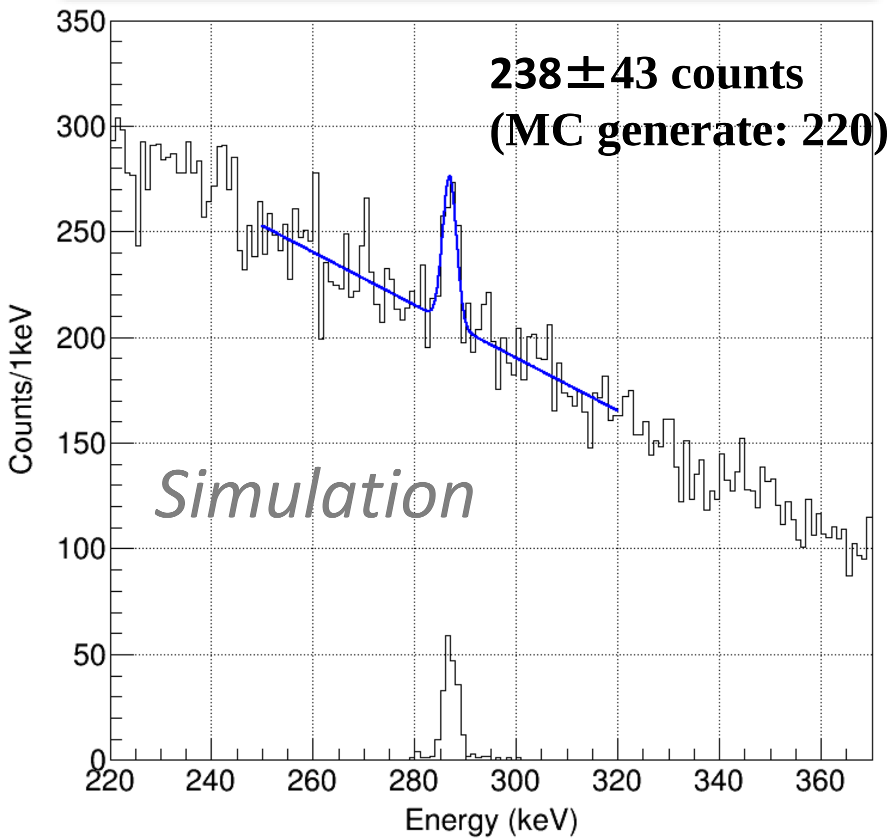
PID	nEvent Ξ^- production	nEvent in Ge spectrum	
		Before	After
K^+	4744	335 (7.1%)	123 (2.6%)

B.G. level [/ Ξ^- production]: 90% of our assumption

Not serious

Expected spectrum for E03-1st phase

Expected X-ray energy spectrum for (6→5) transition [width=1 keV]



We re-estimated yield & B.G. level using result of the pilot run

(7→6) transition will be seen

- **Weak absorption [width~=0]**
- **Higher X-ray yield**
  [×3 yield of (6→5) transition]

No physics output, but first measurement of Xi-atom X-ray

(6→5) transition will be seen

if width ~= 1 keV

Physics outputs

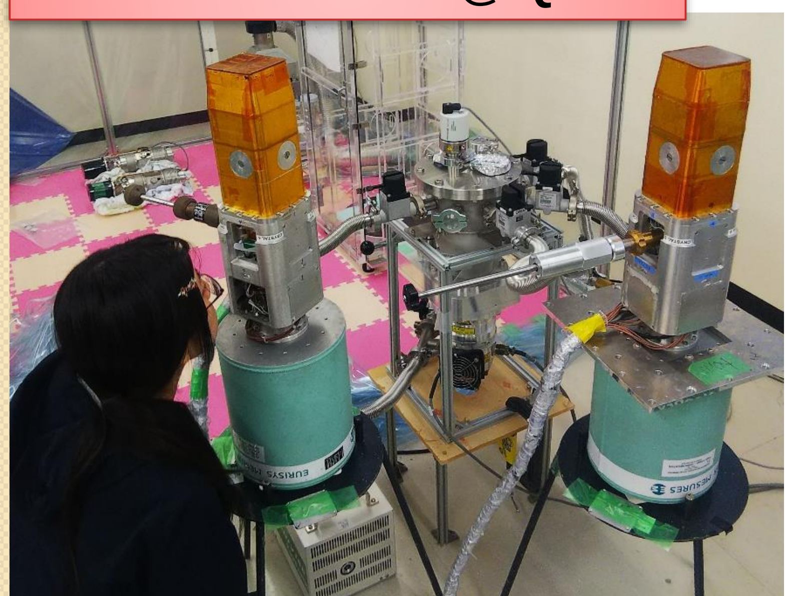
- **Chance for finite shift & width**
  error in shift : 0.3 keV
- **Yield for absorption strength**

Preparation status

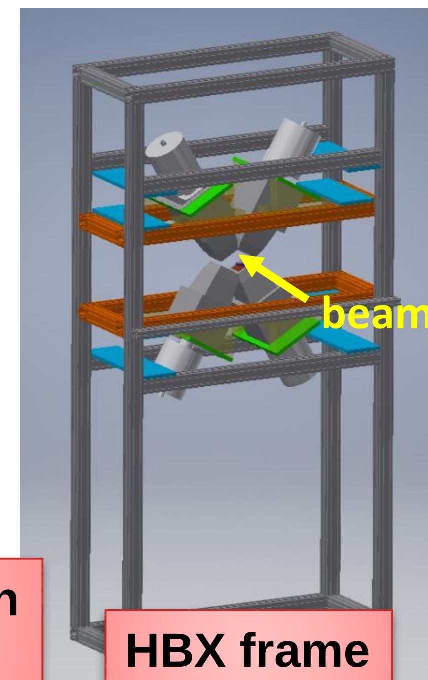
Detector preparation: almost ready

- KURAMA detectors: common with E07/E40(now running)
  no special development necessary
- Hyperball-X: common with E07
  - Maintenance of Ge detectors: Finish (2019.06)
  - Modified frame: under construction [-2020.2]

Maintenance work @IQBRC



Frame construction @ Hadron-hall



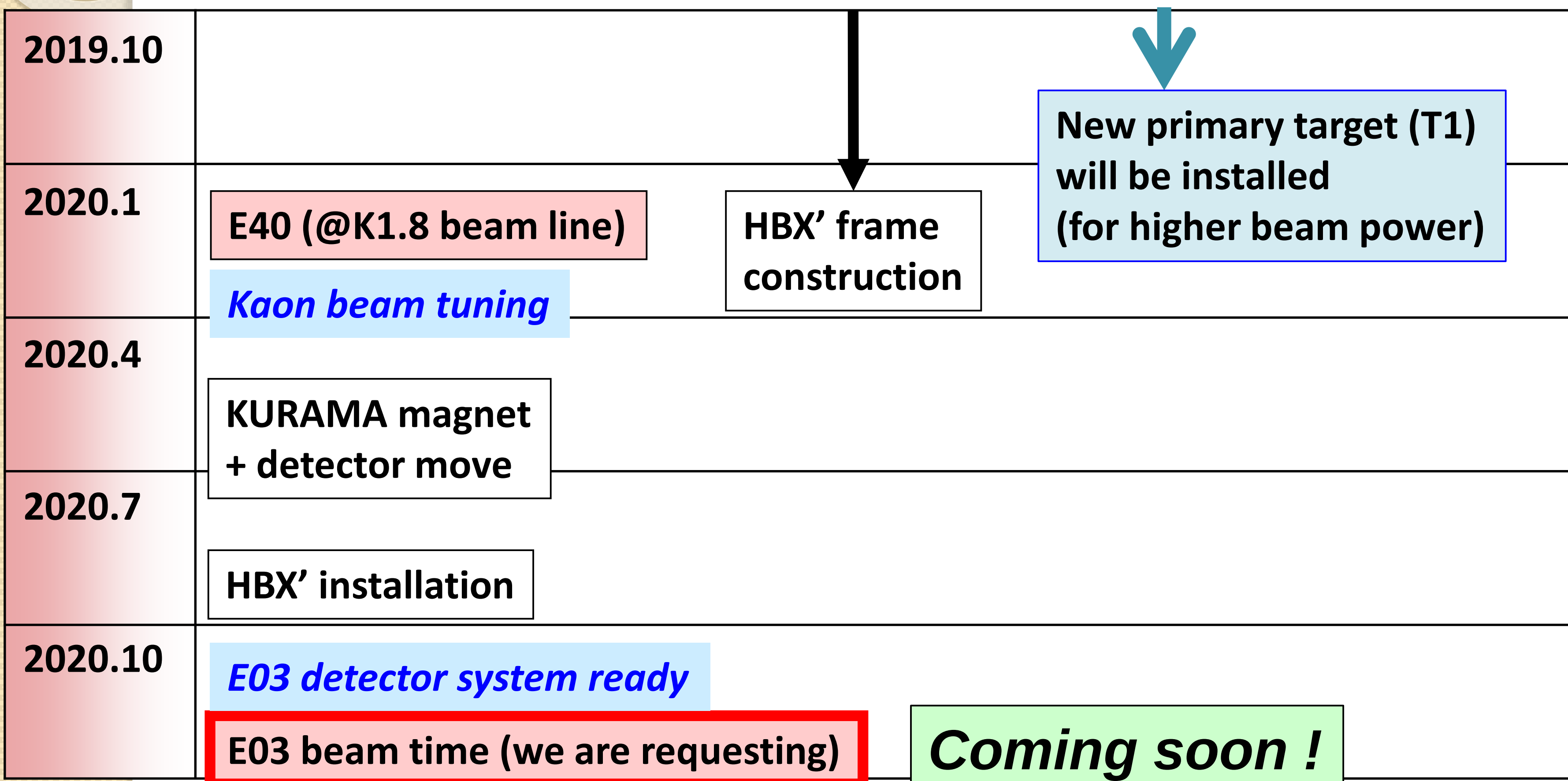
HBX frame

Schedule for E03-1st phase

Delay due to ACC trouble in this spring

We are aiming for beam time after J-PARC E40

* need “KURAMA magnet move” and “HBX’ installation”



Summary

We (J-PAEC E03 group) 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
- E03 2 phase strategy for current ACC condition
- Pilot run for optimization of 1st-phase [2017-2018]
    - Ge detector live time measurement
    - B.G. level study

    → Realistic yield and B.G. estimation was done
- Detectors are almost ready

We are aiming for beam time in Autumn 2020