Perspective for the Measurement of Ξ^- atomic X rays at J-PARC

XiX Collaboration

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NP07@Tokai

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Collaboration

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- *Tohoku University*
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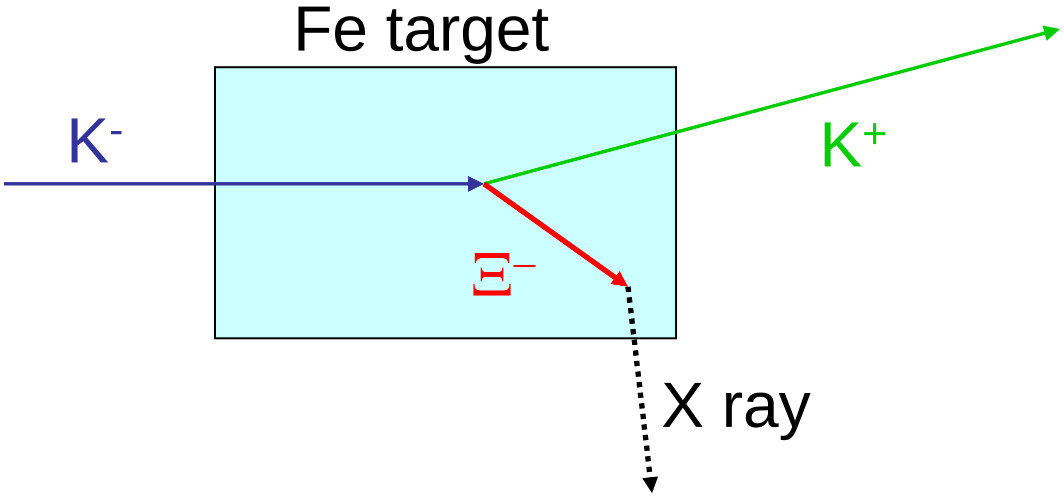
Outline of the experiment

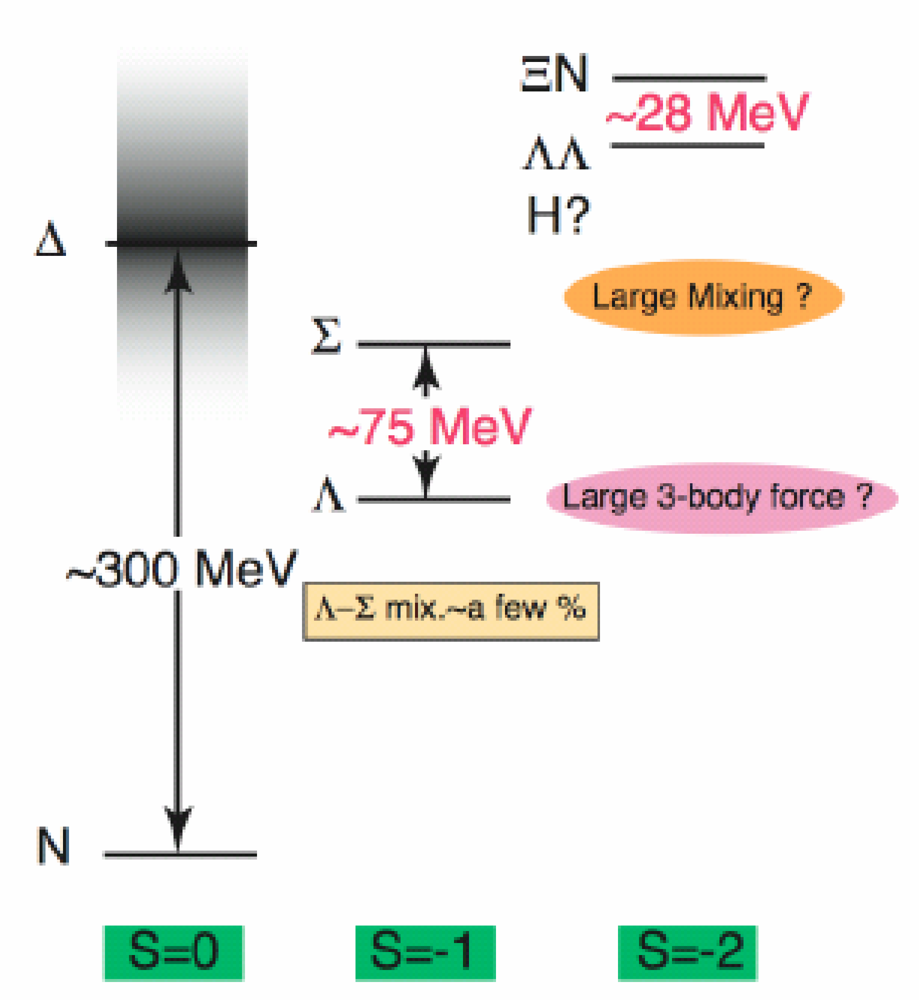
- The first measurement of X rays from Ξ-atom
  - Gives direct information on the ΞA optical potential
- Produce Ξ^- by the Fe(K^-,K^+) reaction, make it stop in the target, and measure X rays.



- Aiming at establishing the experimental method

Physics Motivation

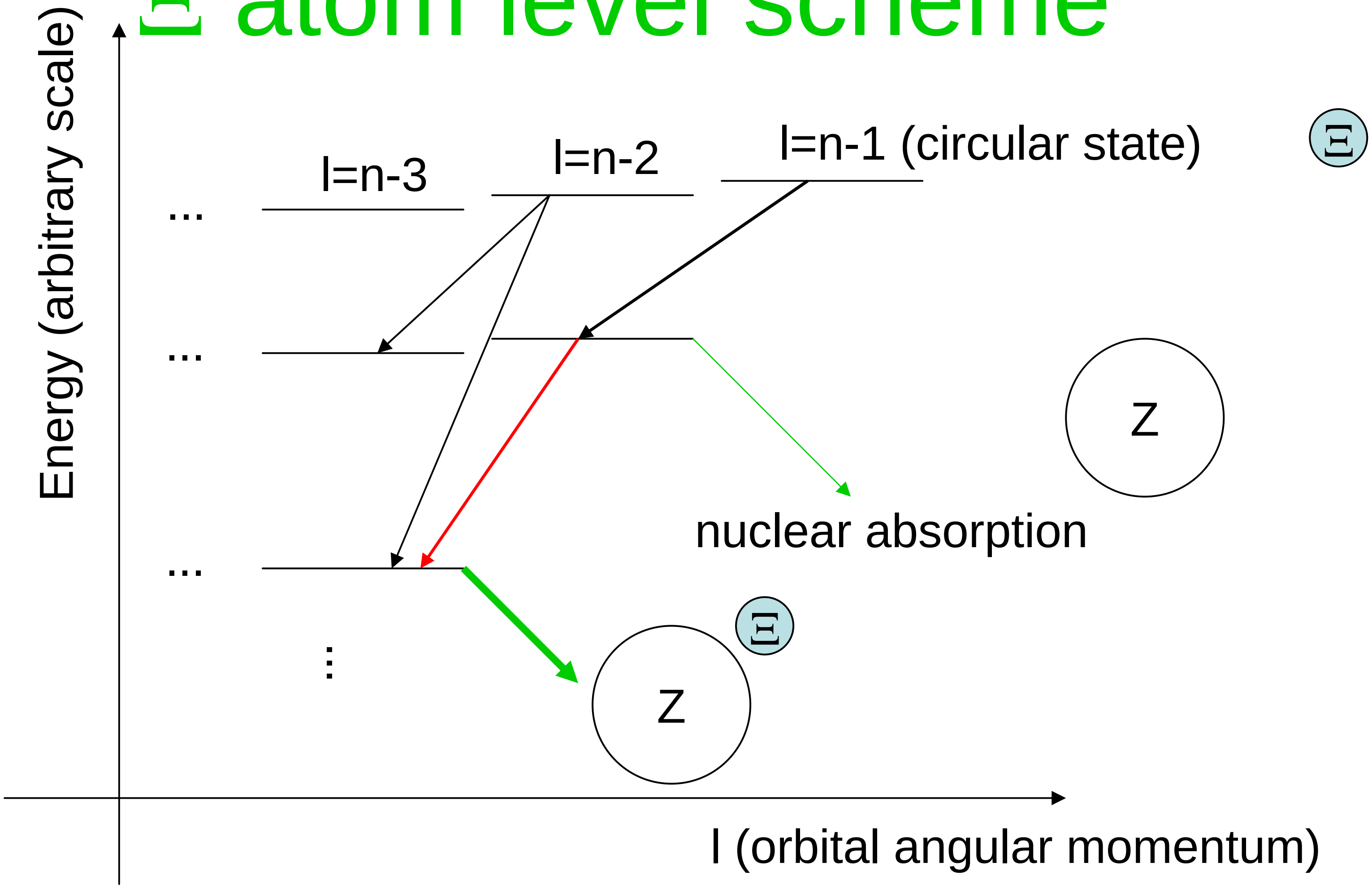
- strangeness nuclear physics at S=-2
  - – A doorway to the multi-strangeness system
  - – Very dynamic system?
    - Large baryon mixing? Inversely proportional to mass difference.
    - H dibaryon as a mixed state of ΛΛ-ΞN-ΣΣ?
- Little is known so far → Main motivation of the J-PARC



Importance of Ξ systems

- Valuable information on ΞN (effective) interaction
  - e.g., How strong ΞN → ΛΛ (and thus ΞN-ΛΛ mixing) is?
    - Relevant to the existence of H dibaryon
    - ΞN component in ΛΛ-hypernuclei
  - Exchange interaction is prohibited in one-meson exchange models
- How about A dependence?
- Impact on neutron stars
  - Does Ξ^- play significant role in neutron stars because of its negative charge?
  - Σ^- was supposed to be important, but its interaction with neutron matter is found to be strongly repulsive.

Ξ atom level scheme



Real part – energy shift, Imaginary – width, yield

Regardless of potential: attractive/repulsive, wide/narrow

Successfully used for π^-, K^-, $\bar{p}$, and Σ^-

Selection of targets

- Physics view: Batty et al. PRC59(1999)295
  - For given state, there is optimal target
    - Nuclear absorption is reasonably small
    - X-ray energy shift and width are the largest (~1 keV)
  - They suggested $_{9}$F, $_{17}$Cl, $_{53}$I, and $_{82}$Pb for n=3,4,7,9.

n:4→3	5→4	6→5	7→6	8→7	9→8	10→9
F(Z=9)	Cl(17)	Co(27)?	Y(39)?	I(53)	Ho(67)?	Pb(82)
131 (keV)	223	314?	394?	475	518?	558

- The choice depends on the optical potential itself

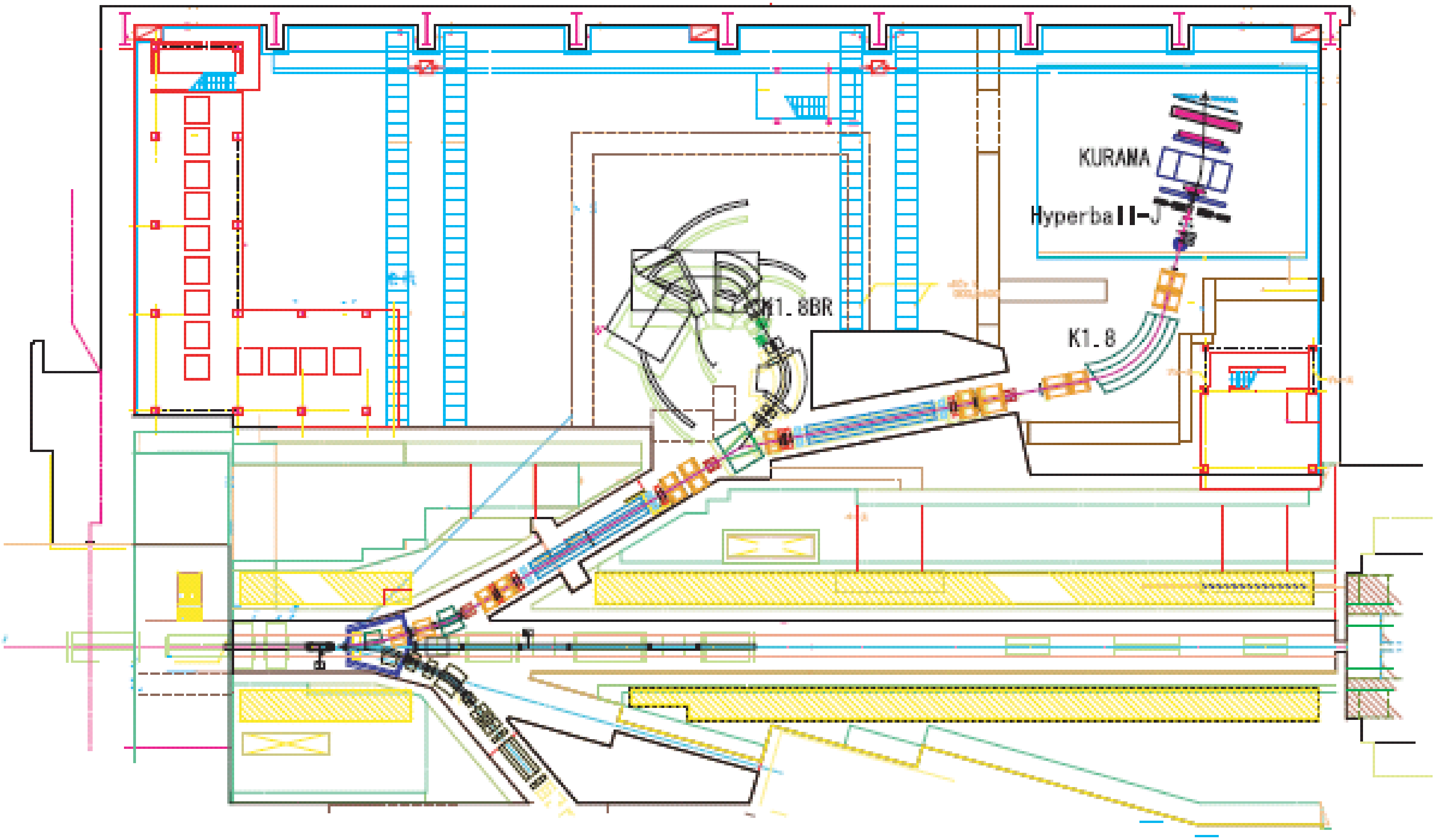
→ We can't know before the 1st experiment

For the 1st experiment

- We chose Fe (Iron) because of (mostly) experimental reason
  - Production rate: $A^{-0.62}$ as cross section scales with $A^{0.38}$
  - Stopping probability: requires high target density
    (Ξ^- range: 10-20 g/cm^2, $\beta\gamma c\tau \sim$ 2cm)
  - X-ray absorption: significant at large Z

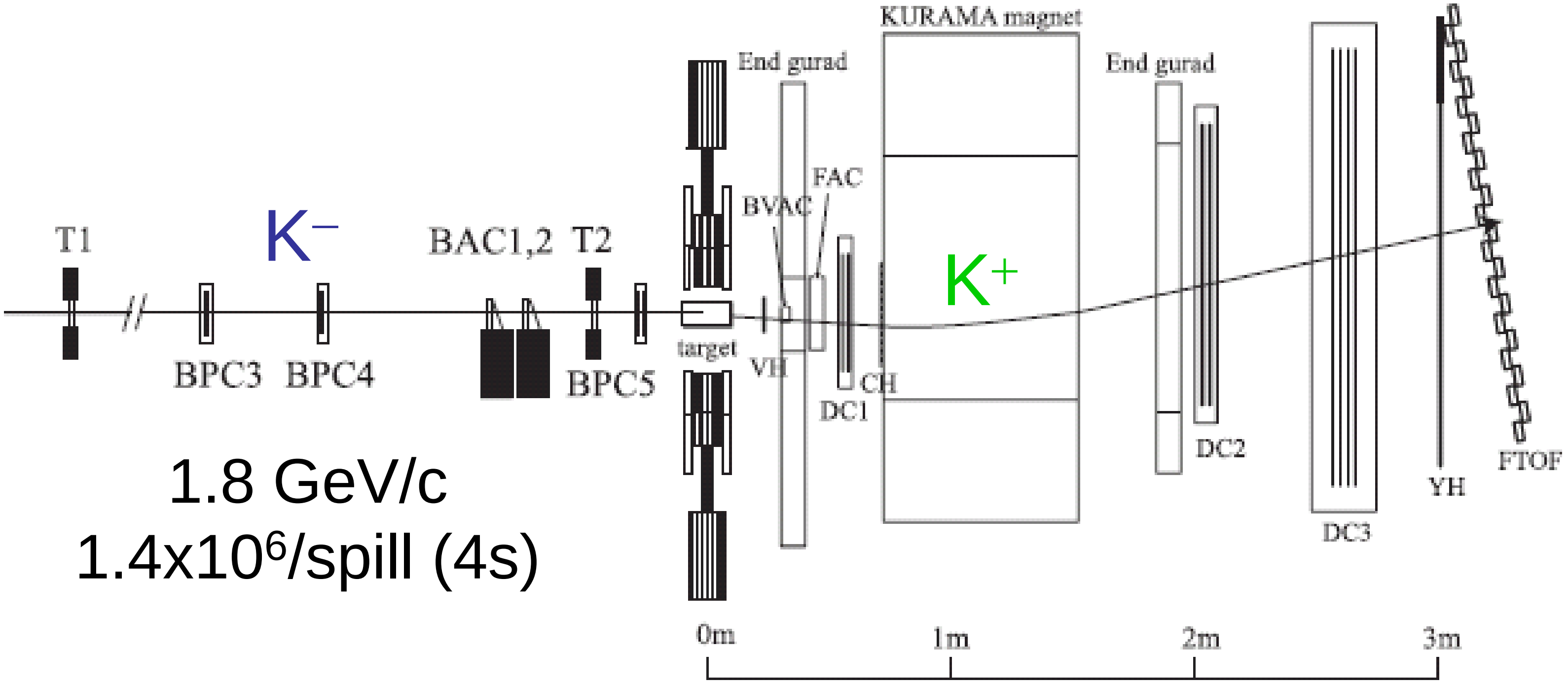
  → Small Z(A), yet high density
- Koike calculated the energy shift (width) & yield of the Fe X ray (n=6 → 5)
  - Woods-Saxon potential: –24 – 3i MeV
  - Energy shift: 4.4 keV, width: 3.9 keV
  - Yield per stopped Ξ^-: 0.1 (~0.4 without absorption)

Experimental Setup



K1.8 beamline of J-PARC

(K^-,K^+) detection system



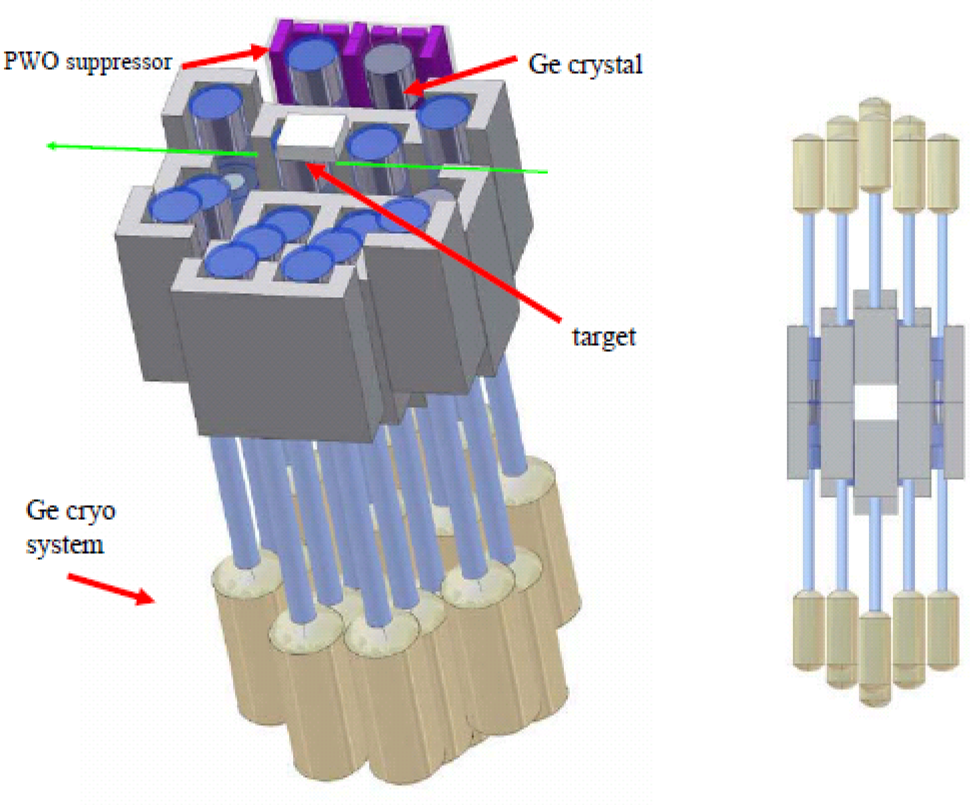
1.8 GeV/c

$1.4\text{x}10^6$/spill (4s)

- Mostly common with Hybrid-Emulsion experiment
- Long used at KEK-PS K2 beamline (E373, E522, ...)
  - Minor modification is necessary to accommodate high rate.
- Large acceptance (~0.2 sr)

X-ray detection

- Hyperball-J
  - 40 Ge detectors
  - PWO anti-Compton
- Detection efficiency
  - 16% at 284 keV
- High-rate capability
  - < 50% deadtime
- Calibration
  - In-beam, frequent
  - Accuracy ~ 0.05 keV
- Resolution
  - ~2 keV (FWHM)

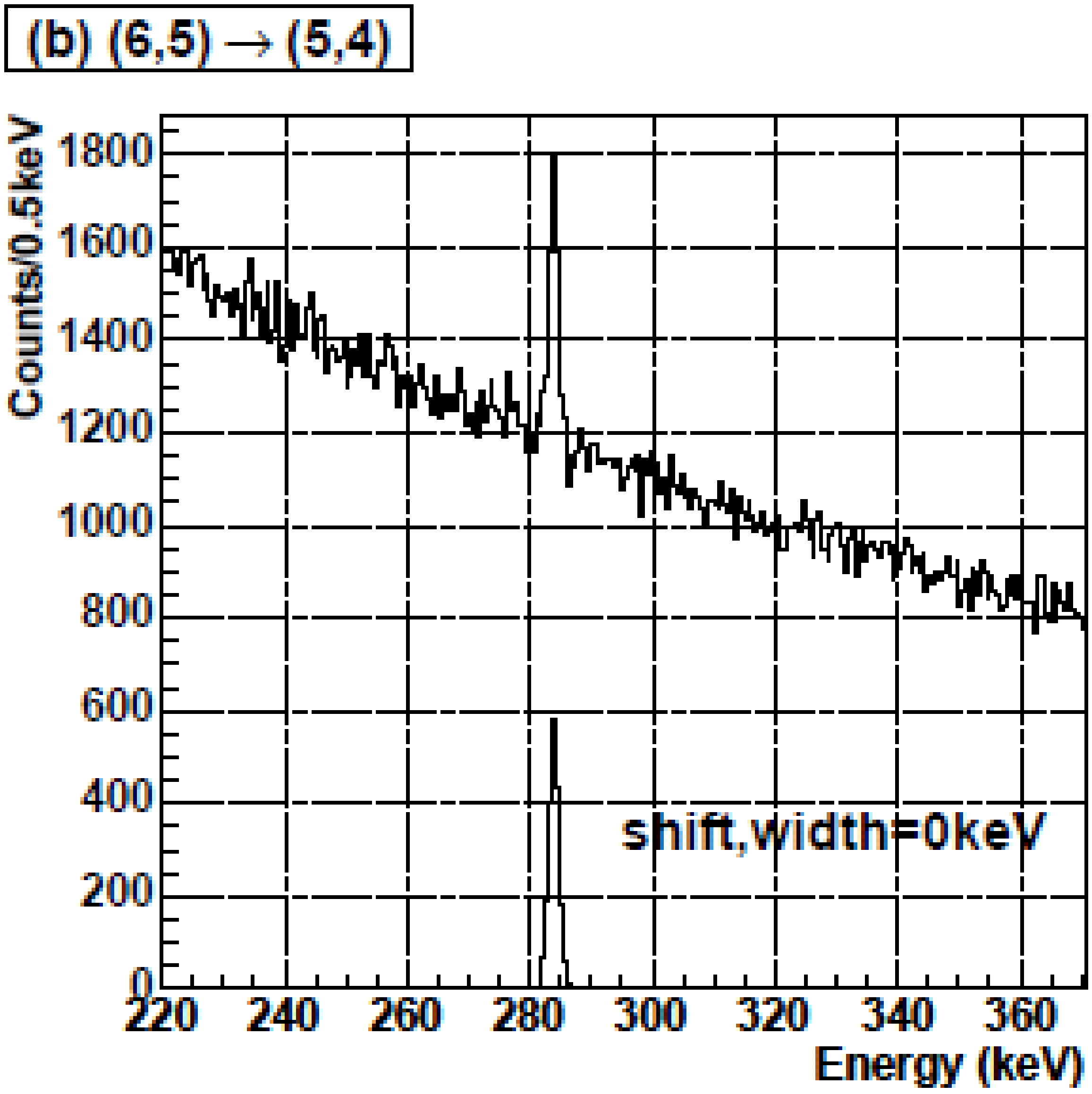


Yield & sensitivity estimation

- Total number of K^-: 1.0×10^{12} for 100 shifts.
- Yield of Ξ
  - production: 3.7×10^6
  - stopped: 7.5×10^5
- X-ray yield : 2500 for n=6→5 transition
  - 7200 for n=7→6
- Expected sensitivity
  - Energy shift: ~0.05 keV (systematic dominant)

    → Good for expected shift (~1 keV, 4.4 keV by Koike)
    < 5% accuracy for optical potential depth
  - Width: directly measurable down to ~ 1 keV
  - X-ray yield gives additional (indirect) information on absorption potential.

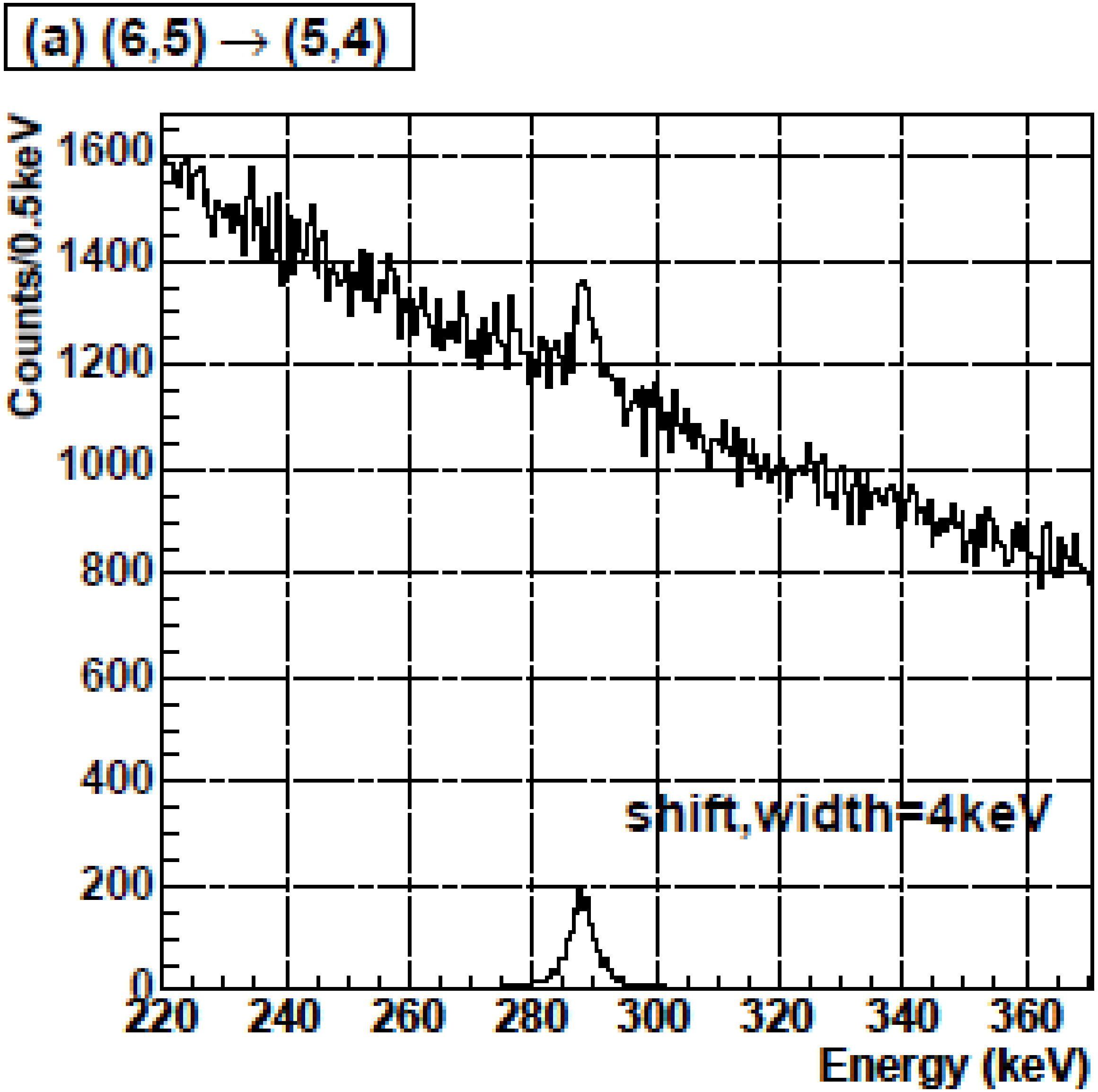
Expected X-ray spectrum



n= 6→5

shift & width
0 keV

Expected X-ray spectrum(2)



n= 6→5

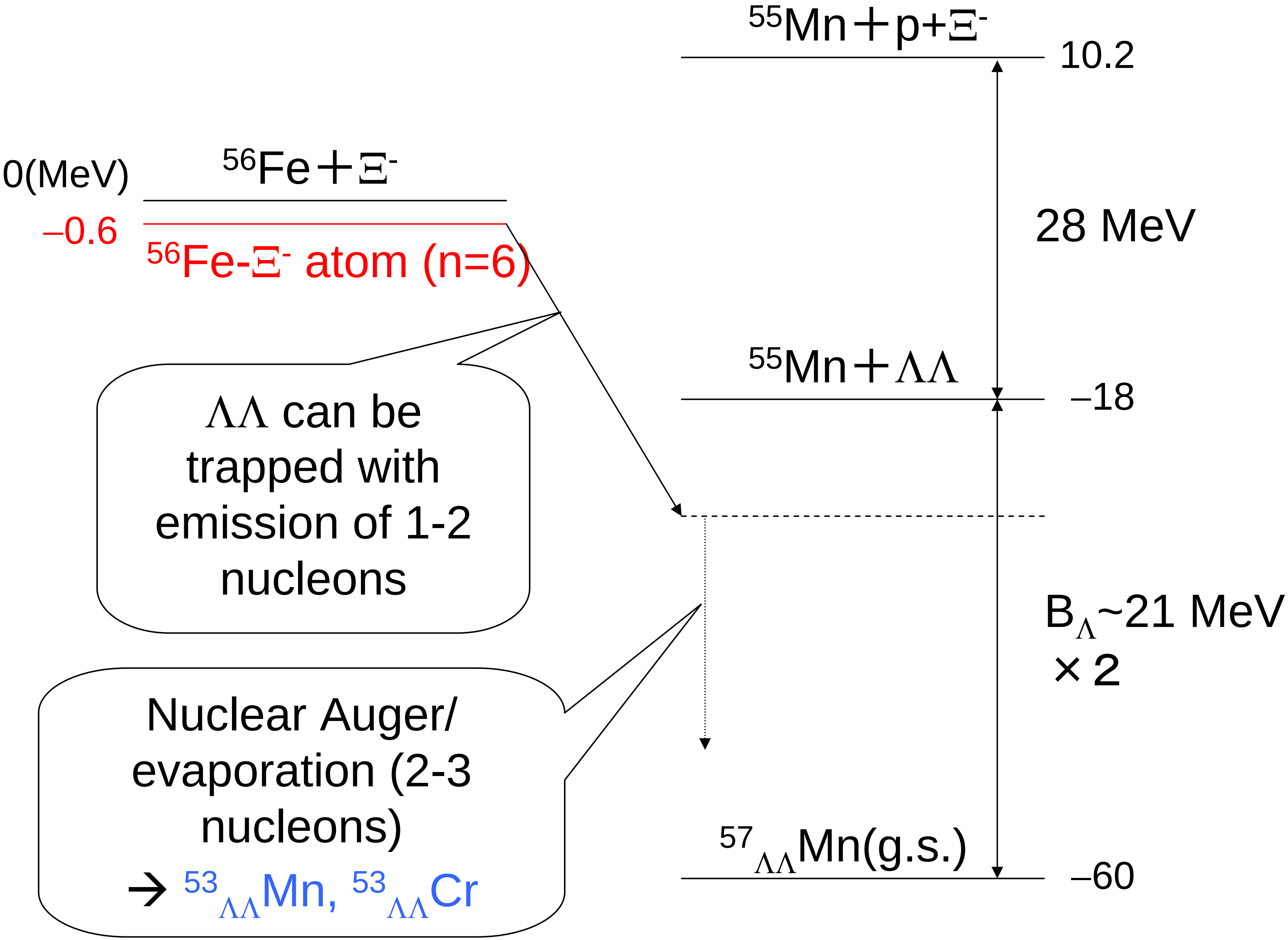
shift & width
4 keV

Double Λ hypernuclear γ ray

- Good byproduct: possible to observe if intensity is larger than a few %/stopped Ξ

  → **Expected to be seen**

  - Calc. by Hirata et al. [nucl-th/9711063] 0.11 (0.44) double (single) hypernuclei per stopped Ξ on C target → similar (or even larger) on Fe
  - L~5 is brought by Ξ → hypernuclei should be excited
- Issue: no systematic way for identification
  - Backgrounds from normal nuclei are (probably) distinguishable.
  - Q value is small, so only a few baryons (n/p/Λ) can escape → limited number of possible hypernuclei.
  - γγ conicidence measurement possible



^{55}Mn + p + Ξ^- 10.2

0(MeV) ^{56}Fe + Ξ^-

–0.6 ^{56}Fe-Ξ^- atom (n=6)

28 MeV

^{55}Mn + $\Lambda\Lambda$ –18

$\Lambda\Lambda$ can be trapped with emission of 1-2 nucleons

B_Λ~21 MeV × 2

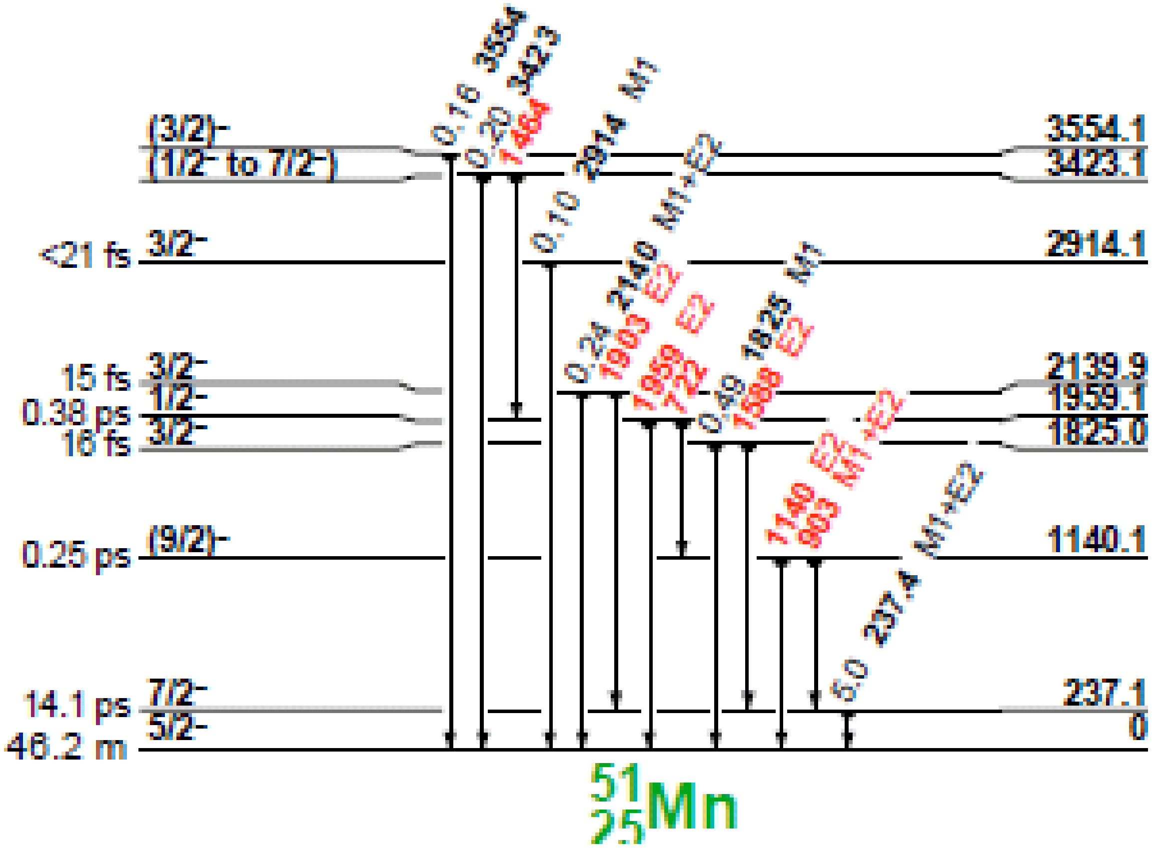
Nuclear Auger/ evaporation (2-3 nucleons)

→ $^{53}_{\Lambda\Lambda}$Mn, $^{53}_{\Lambda\Lambda}$Cr

$^{57}_{\Lambda\Lambda}$Mn(g.s.) –60

e.g. $^{53}_{\Lambda\Lambda}$Mn

- Core nucleus is ^{51}Mn
  - High spin states are preferably produced
  - Level energies are similar for low-lying states (2 Λ's are in 0s orbits) → identifiable by γγ



2nd ex. → 1st ex.

(1140 keV 9/2-) (237 keV 7/2-)

B.R.=86%

Status and Prospects

- Stage1 approval (scientific approval) is already granted at the PAC meeting of J-PARC
  - No essential difficulty
  - Trying to get Stage-2 (full) approval as soon as possible
- We will be ready by 2008
  - The first experiment is (hopefully) in 2010
- Final goal: > 2 targets for each n
  - ~10 targets in total
  - Select next targets based on the first experiment.
  - Not only strength, but also shape can be determined.
  - 1-2 weeks for each target (if everything is as expected)
- **New collaborators are very welcome!**

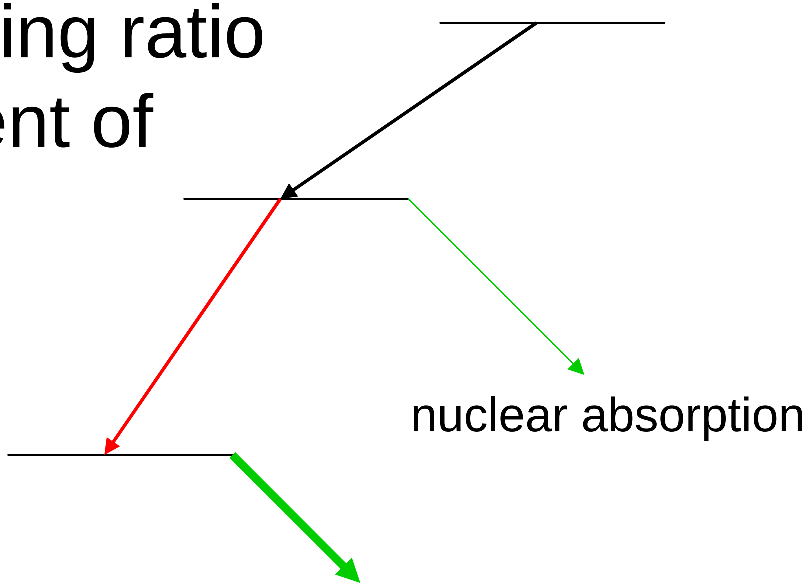
Summary

- We propose to measure Ξ-atomic X rays
  - To determine Ξ-A optical potential
  - First of the series of experiments
  - Aiming to establish the method
- Scientific approval is granted for the 1st experiment
  - Iron (Fe) target is used
- X-ray yield: ~2500
- Precision of X-ray energy ~ 0.05 keV
  - Good accuracy for expected energy shift (~1 keV)
  - Width: measurable down to ~ 1 keV, X-ray yield gives additional information on imaginary part.
- 1st experiment will be in 2010, more will follow.

Backup slides

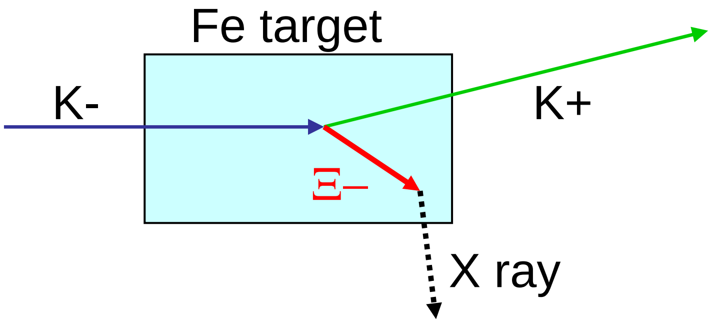
X-X coincidence

- Measurement for the branching ratio of X-ray emission independent of atomic cascade model
- Gives ~12 better S/N ratio
- Statistics: ~60 events



Summary of the experiment

- Produce Ξ^- by the (K-,K+) reaction, make it stop in a Fe target, and measure X rays from Ξ^- atom.



- Physics:
  - Ξ-nucleus interaction (optical potential)
  - Real part – shift of X-ray energy (up to ~10 keV)
    Imaginary part – width, yield
- Sensitivity
  - X-ray enerygy shift: ~0.05 keV

    → Good for expected shift of O(1keV)
  - Width: directly measurable down to ~ 1keV

Yield estimation

$Y=N_K \times \sigma_\Xi \times t \times \Omega_K \times \varepsilon_K \times R_\Xi \times R_X \times (1-\eta_X) \times \varepsilon_X \times \varepsilon_o$

- Beam: N_K (total number of K-) = 1.0×10^{12}
- Target:
  - σ_Ξ: (differential) cross section = 180 μb/sr
    Taken from IIjima et al. [NPA 546 (1992) 588-606]
  - t: target thickness（particles/cm^2）= $2.6\text{x}10^{23}$
  - R_Ξ: stopping probability of Ξ in the target = 20%
    (according to a GEANT4 simulation)
  - R_X: branching ratio of X-ray emission = 10%
    (estimated by Koike)
  - η_X: probability of self X-ray absorption in the target = 58%
    (GEANT4 simulation: mean free path for 284 keV X-ray is ~8 mm)

- K+ spectrometer
  - Ω_K: acceptance = 0.2 sr
  - ε_K: detection efficiency = 0.51
    (taken from the proposal of BNL-AGS E964)
- X-ray detection
  - ε_X: X-ray detection efficiency = 8%
    [16% (GEANT4 simulation) x 0.5 (in-beam live time)]
- Others
  - ε_o: overall efficiency (DAQ, trigger, etc.) = 0.8

X-ray background

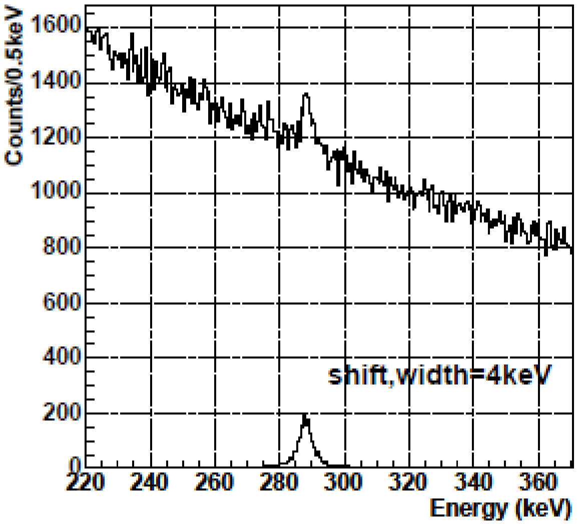
- Estimation based on E419
- E419: 8 x 10^{-5} counts/keV/(π^+,K^+), around 284 keV
  - X-ray detection efficiency: x4
  - Other effect: x2 (considering different reaction)

→ ~2400 counts/keV

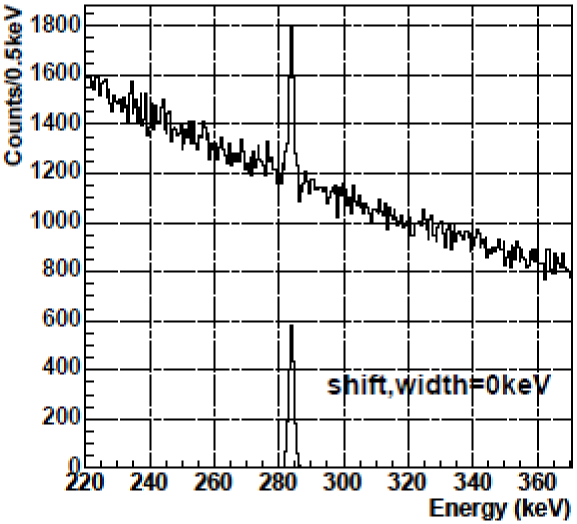
- Continuous BG is OK
- Line background might be a problem, though unlikely.
  - there seem no strong lines in this energy from normal nuclei around A=50.
  - Completely unknown for (single) hypernuclei
  - Even weak lines may deform the peak shape

Expected X-ray spectrum

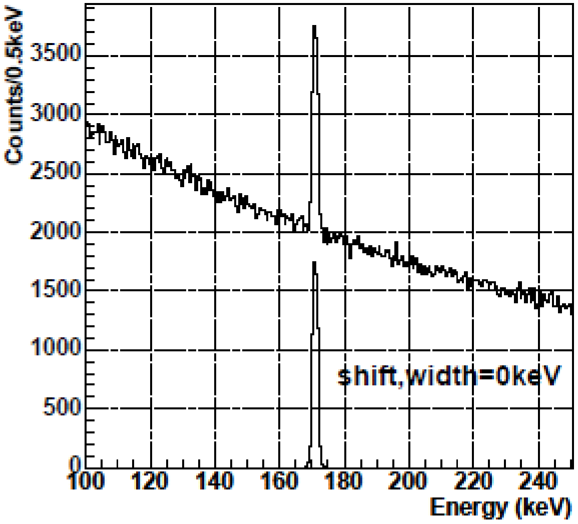
(a) (6,5) → (5,4)

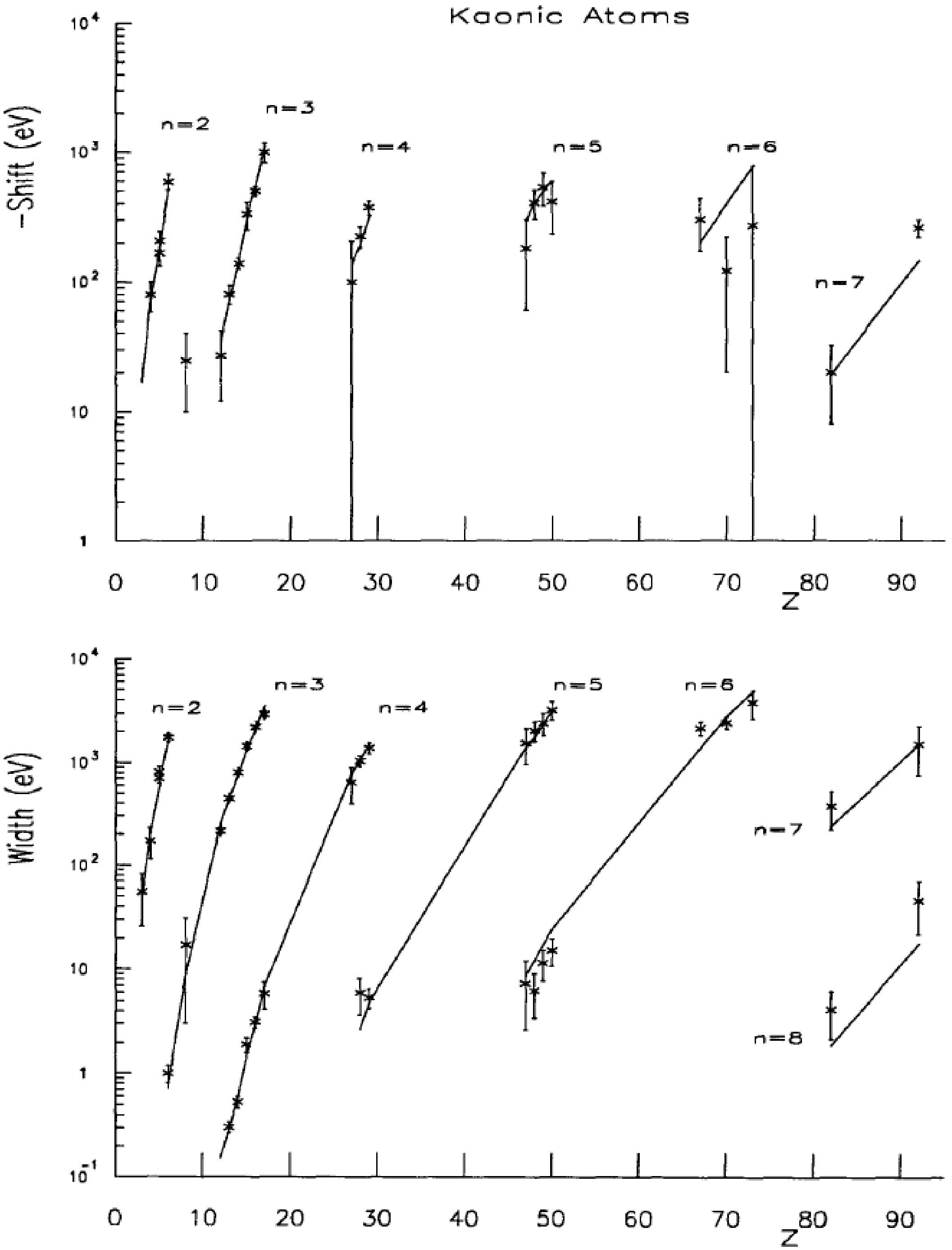


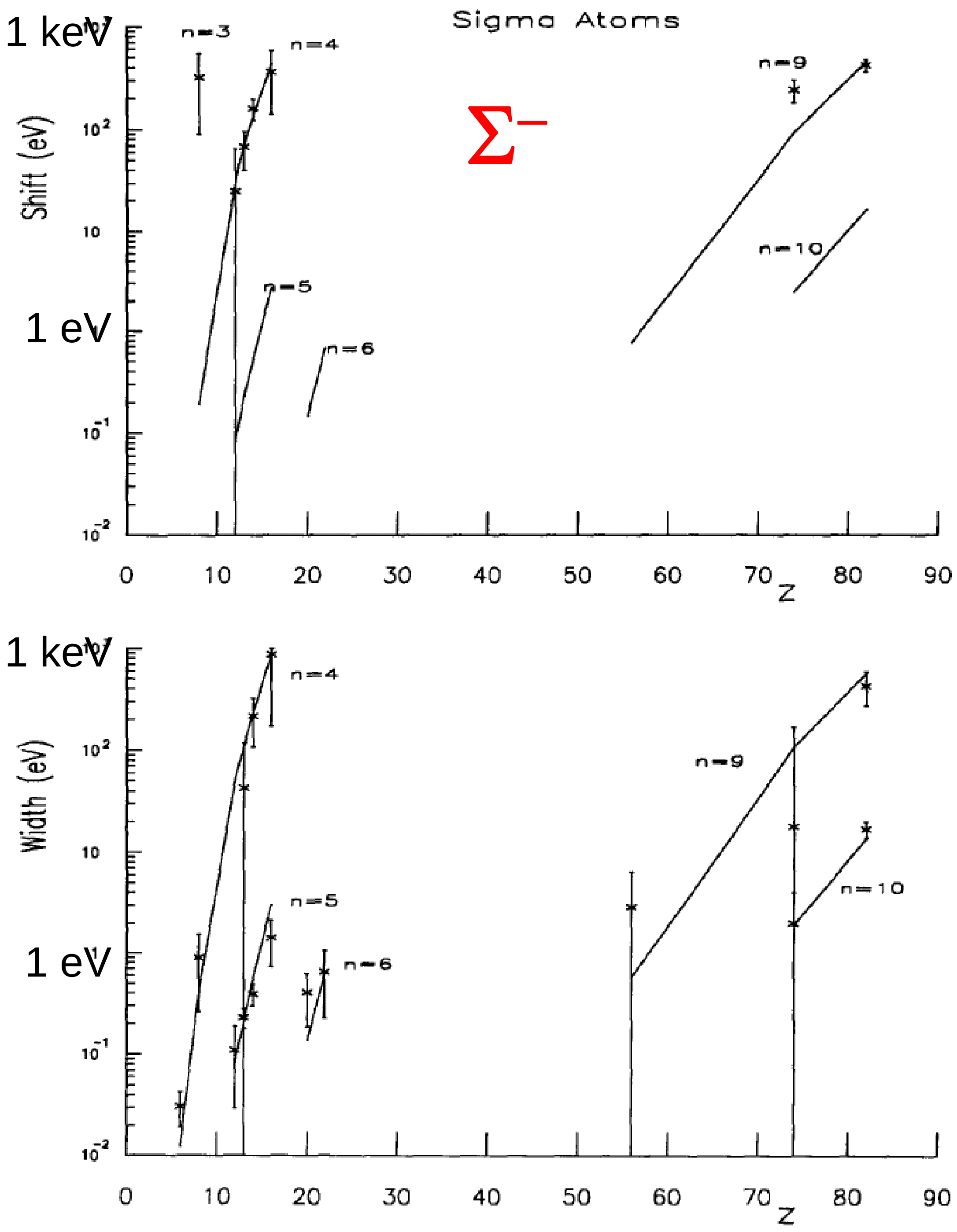
(b) (6,5) → (5,4)

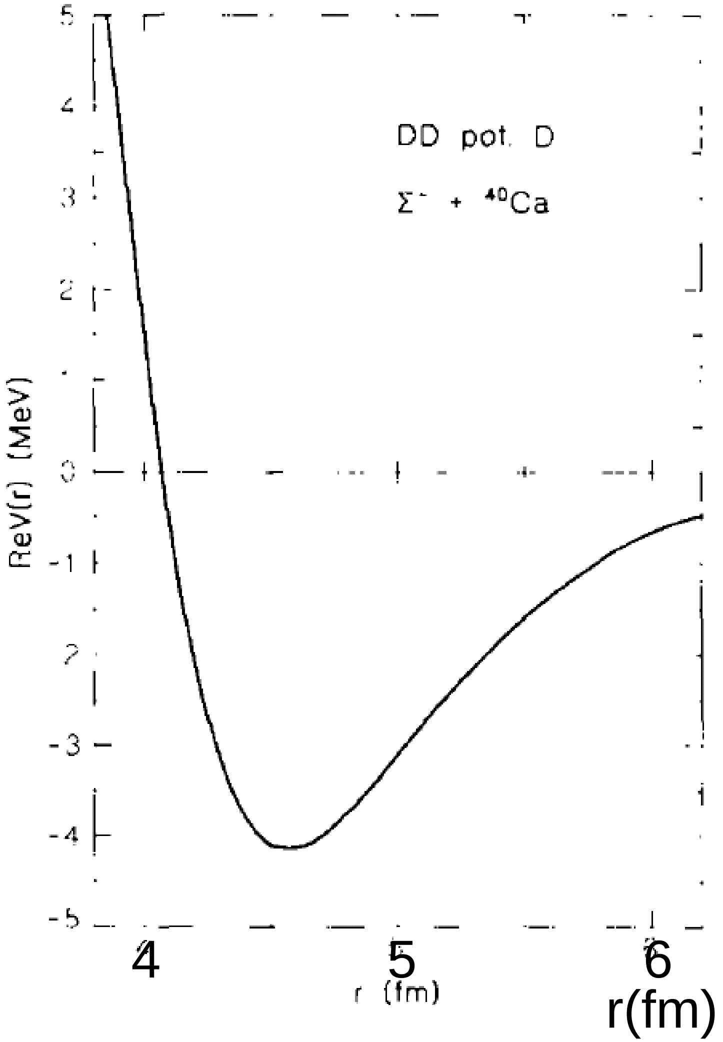


(c) (7,6) → (6,5)




Kaonic Atoms
-Shift (eV)
10^4
10^3
10^2
10
1
n=2
n=3
n=4
n=5
n=6
n=7
0
10
20
30
40
50
60
70
80
90
Z
Width (eV)
10^4
10^3
10^2
10
1
10^{-1}
n=2
n=3
n=4
n=5
n=6
n=7
n=8
0
10
20
30
40
50
60
70
80
90
Z





(weakly) attractive at peripheral
(strongly) repulsive at center

Schedule & budget

- Beamline detectors (~100 Myen):
  - – Will be constructed by Kakenhi grant “Quark many-body systems with strangeness” (2005-2009)
  - – Commonly used with other experiments
- KURAMA
  - – Mostly reuse of the existing spectrometer.
  - – New Cerenkov counter will be made in 2007.
- Hyperball-J (~300 Myen)
  - – Will be constructed by Tohoku University with the Kakenhi grant.
- Construction & installation will finish by 2008.