Measurement of X rays from Ξ^- atom

XiX Collaboration

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30/June/2006

Collaboration

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- *Tohoku University*
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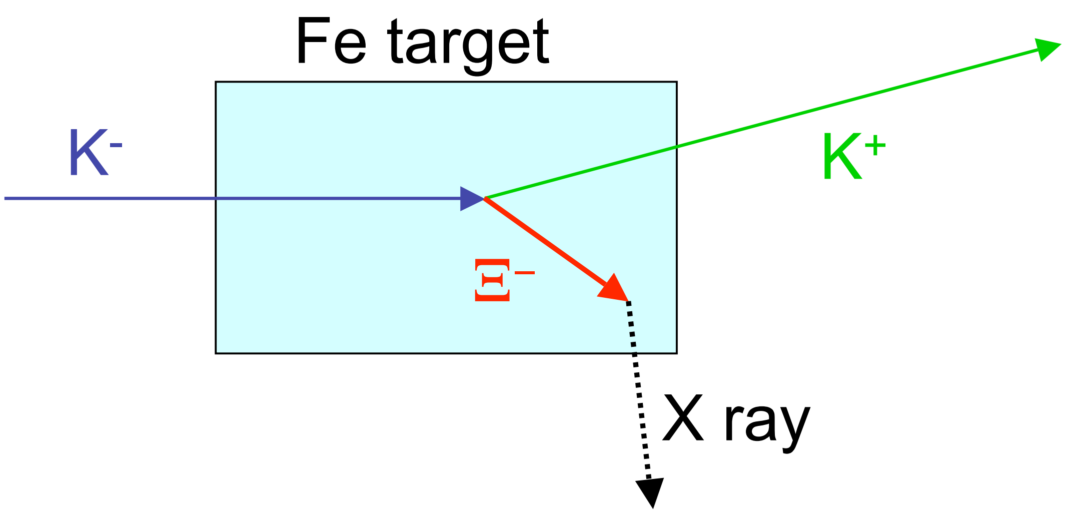
Outline of the experiment

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



- Requested beamtime: 100 (+ 20/50) shifts
- Aiming at establishing the experimental method

Physics motivation

- Strangeness nuclear physics at S=-2 sector
  - Significant step forward from *S* = -1 system towards the multi-strangeness hadronic systems (e.g., neutron star)
    - First place where hyperon-hyperon interaction appears
  - Could be more dynamic than S=0 and S=-1 systems.
    - Large baryon mixing? Inversely proportional to mass difference
      ΞN-ΛΛ: 28 MeV → strong mixing in hypernuclei?
      ΛN-ΣN: ~80 MeV
      NN-ΔN: ~300 MeV
    - Does H dibaryon exist? As mixed state of ΞN-ΛΛ–ΣΣ?
- Very little is known so far
  → Main motivation of the 50 GeV PS.

Importance of Ξ systems

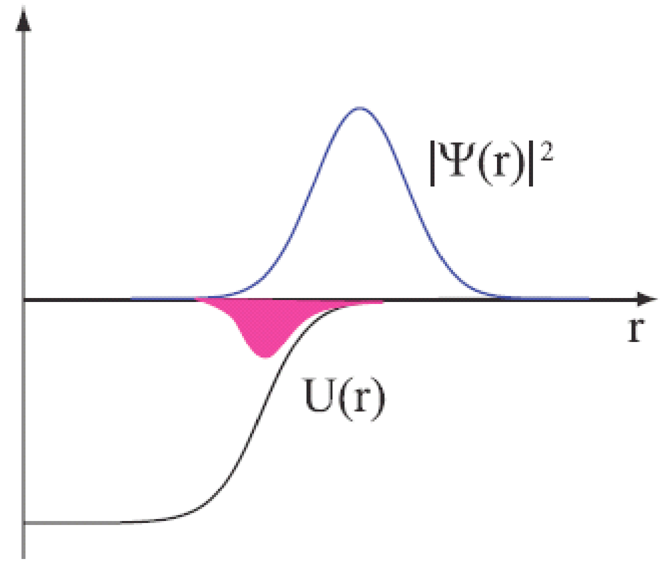
- Valuable information on ΞN (effective) interaction
  - e.g., How strong ΞN → ΛΛ (and thus ΞN-ΛΛ mixing) is?
    - Relevant to the existence of H dibaryon
    - ΞN component in ΛΛ-hypernuclei
- How about A dependence?
  - One-meson exchange models predict significant A dependence.
  - In contrast to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

Principle of the experiment

- Atomic state – precisely calculable if there is no hadronic interaction
- 1st order perturbation

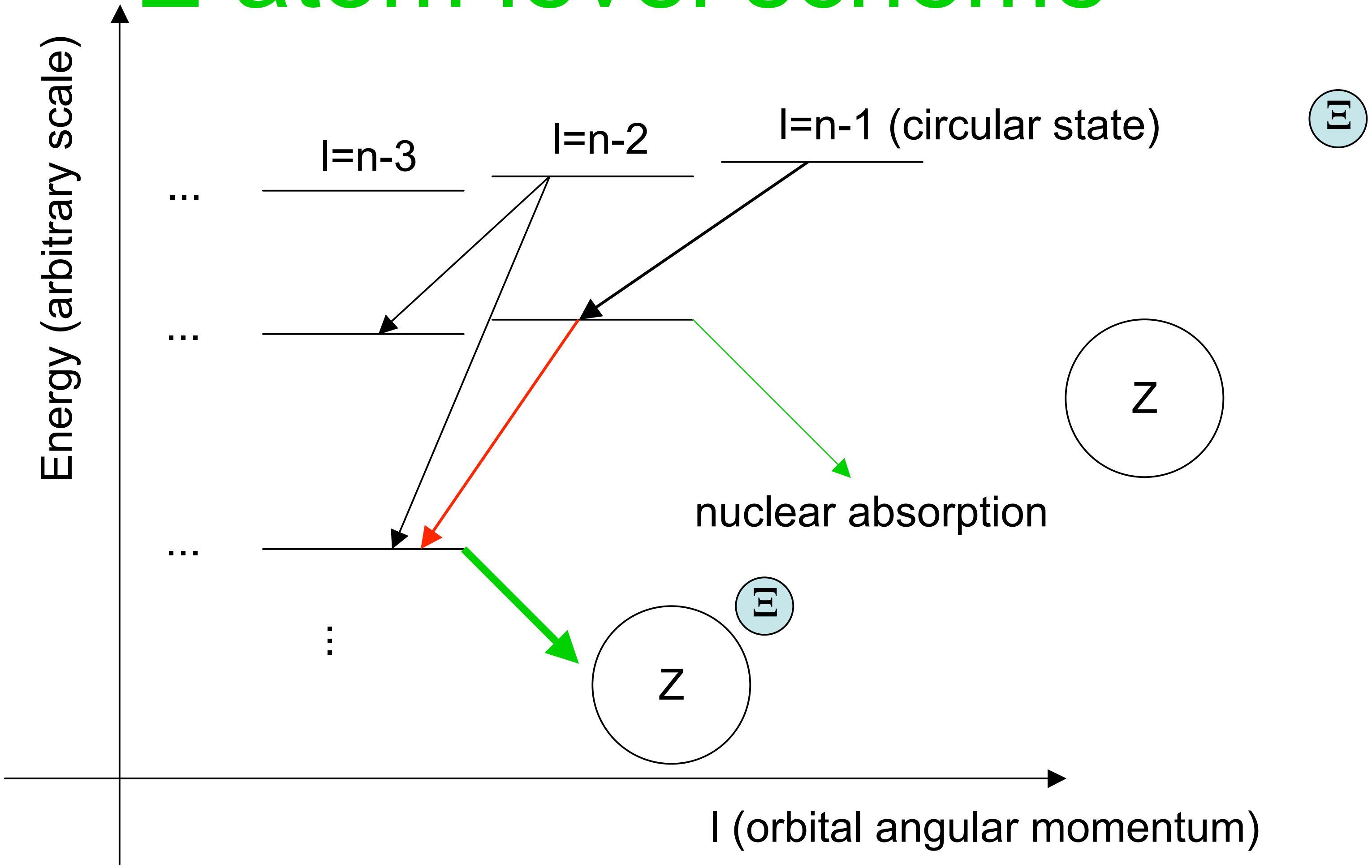
[illegible]

  - If we assume potential shape, we can accurately determine its depth with only one data
  - Shape information can be obtained with many data
  - Even if 1st order perturbation is not good, this is still the same.



- Peripheral, but direct (⇔ P05 Nagae et al.)
- Successfully used for π^-, K^-, $\bar{p}$, and Σ^-

Ξ atom level scheme



X ray energy shift – real part
Width, yield – imaginary part

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

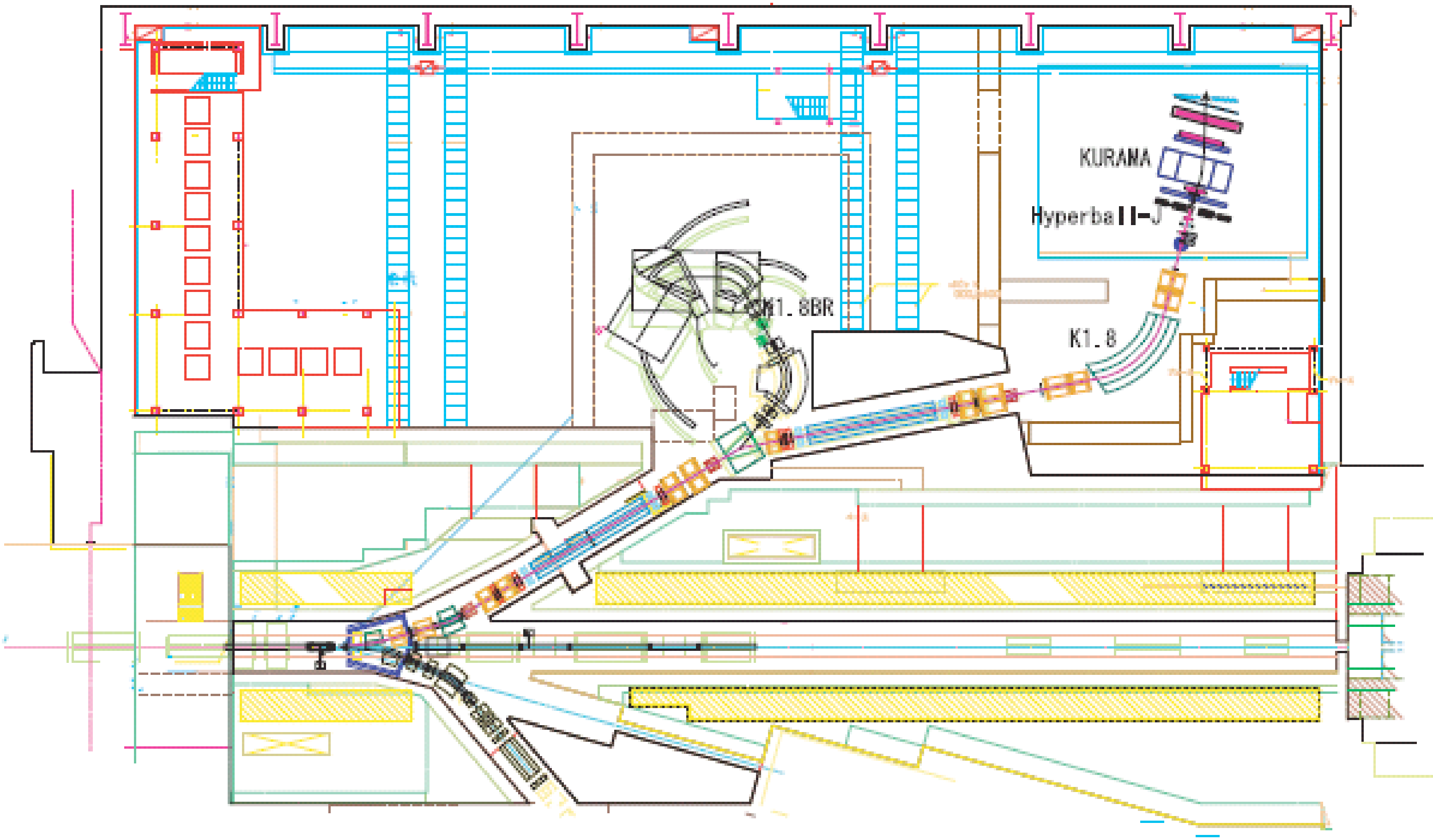
  → We can't know before the 1st experiment

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, $\beta\gamma c\tau$ ~ 2cm)
  - X-ray absorption: significant at large Z

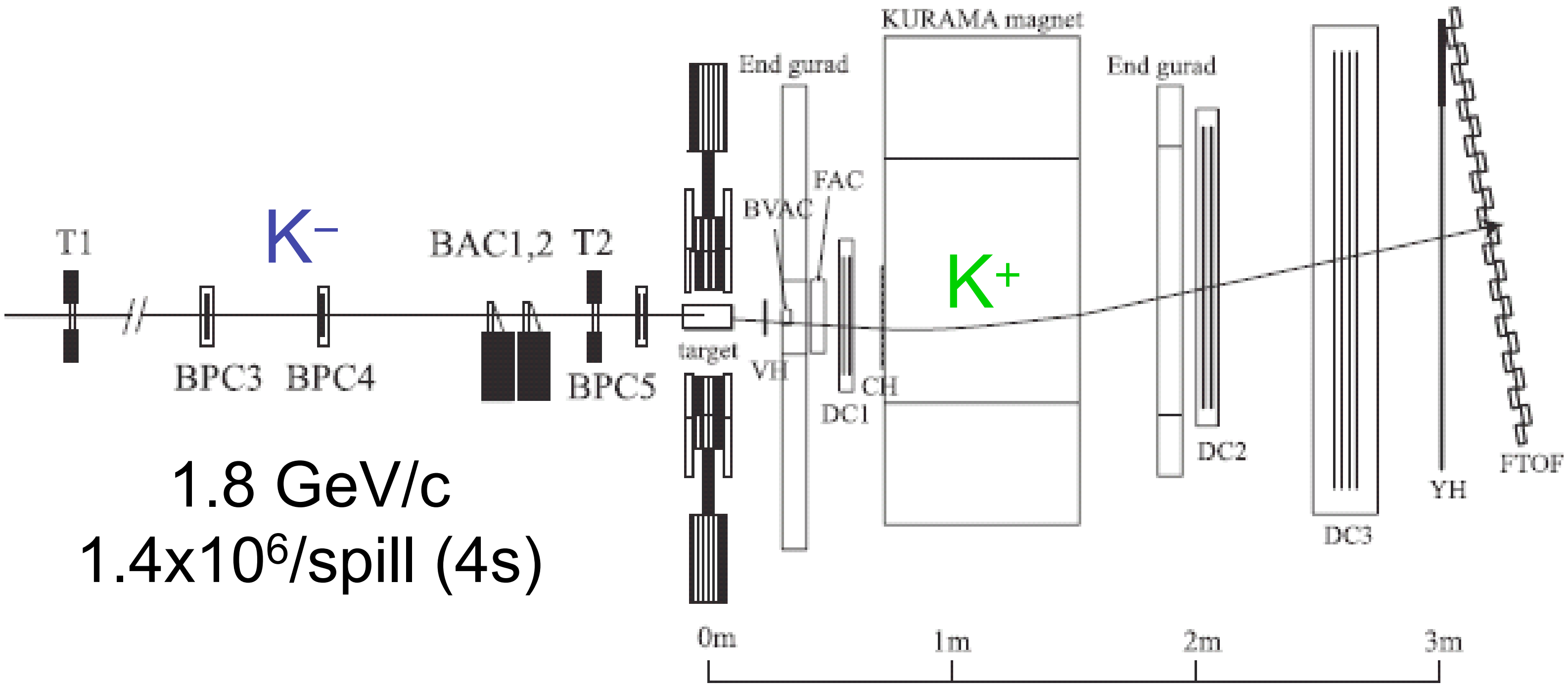
  → Small Z(A), yet high density
- Koike calculated the energy shift (width) & yield of the Fe X ray (n=6 → 5)
  - Woods-Saxon potential: –24 – 3i MeV
  - Energy shift: 4.4 keV, width: 3.9 keV
  - Yield per stopped Ξ^-: 0.1 (~0.4 without absorption)

Experimental Setup



K1.8 beamline of J-PARC

(K^-,K^+) detection system



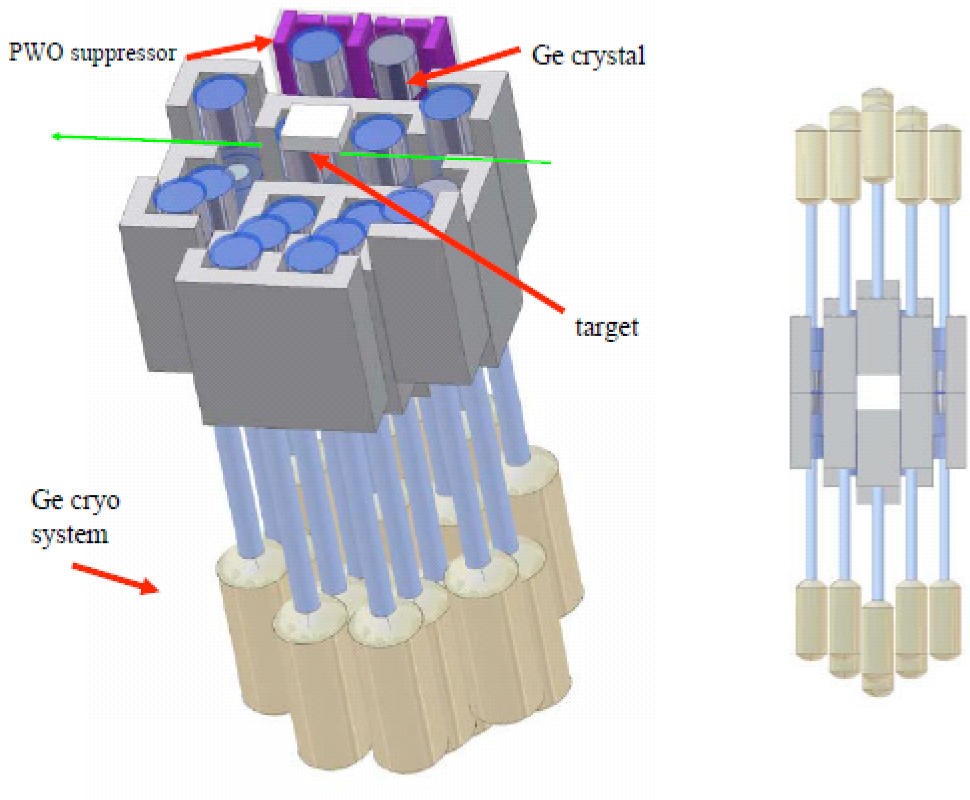
- Mostly common with Hybrid-Emulsion experiment (P07: Nakazawa et al.)
- Long used at KEK-PS K2 beamline (E373, E522, ...)
  - Minor modification is necessary to accommodate high rate.
- Large acceptance (~0.2 sr)

Target setup

- Target: Iron plate of 6cm(w) x 1.5cm(h) x 3cm(t)
  - To accommodate expected K^- beam size
  - Height is important to reduce X-ray absorption
  - Actual size will be determined after beam-size measurement
- Stopping probability of produced Ξ^-
  - ~20% according to GEANT4 simulations
- X-ray absorption
  - 58% at 284 keV (Ξ^--Fe n=6→5)
  - 68% at 171 keV (Ξ^--Fe n=7→6)

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)



Notes on triggering

- 1st level trigger: (K^-,K^+) trigger similar to E373
  - Expected rate: 10000/spill
  - Mostly due to (K^-,p) reaction (Note: there is no detector that rejects protons at the 1st level trigger in E373)
- We need an extra rejection factor ~ 10, even if we consider 2nd level triggers
- Cherenkov counter: n~1.1
  (threshold: 1.1 GeV/c for K+, 2.05 GeV/c for p)
  - High density silica aerogel becomes available
    - Chiba University (Kawai group) & Russia (Dubna)
  - We just got a few samples of n~1.2
  - Backup: supercritical fluid (CF_4)

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.

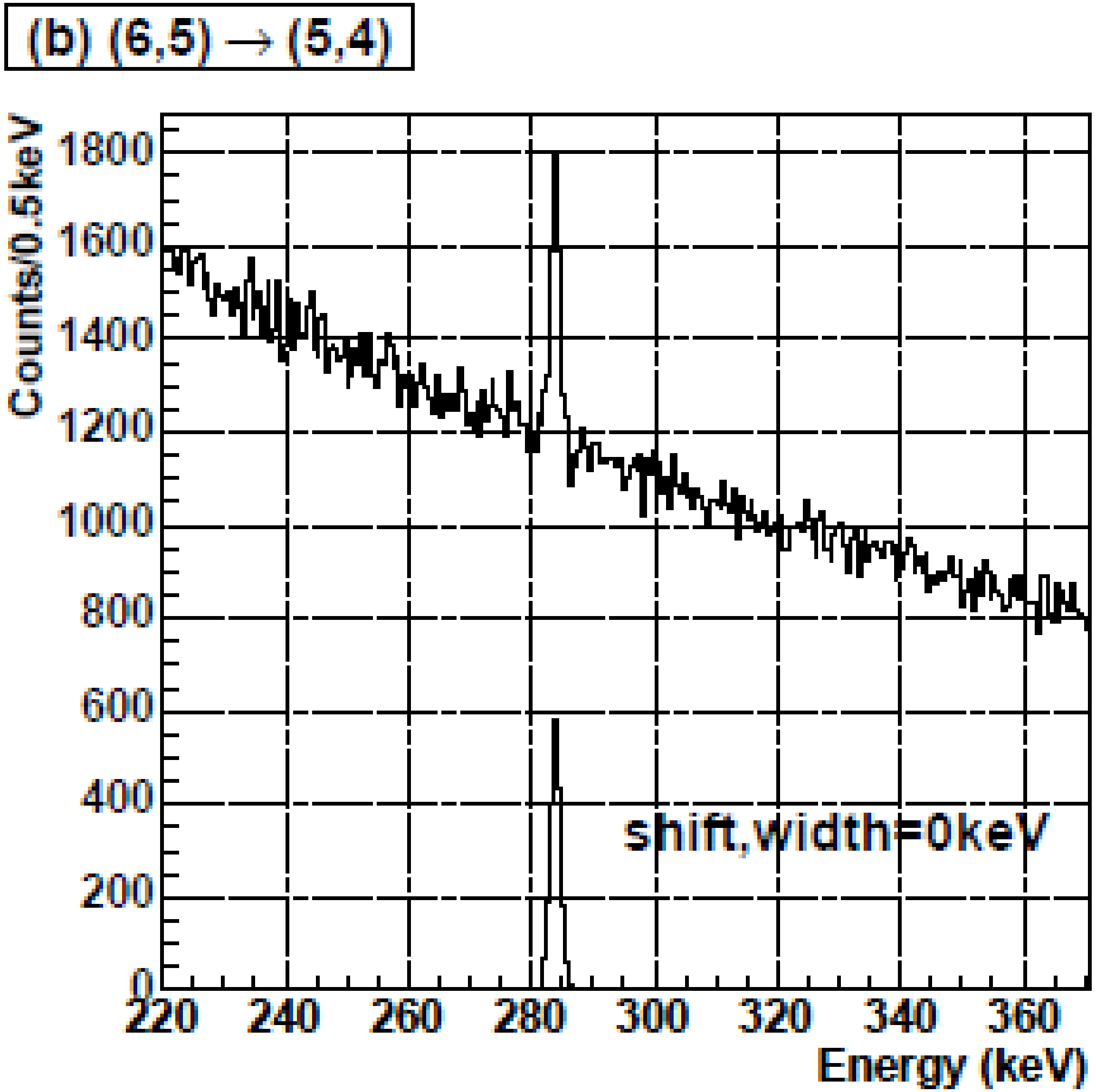
Yield & sensitivity estimation

- 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.

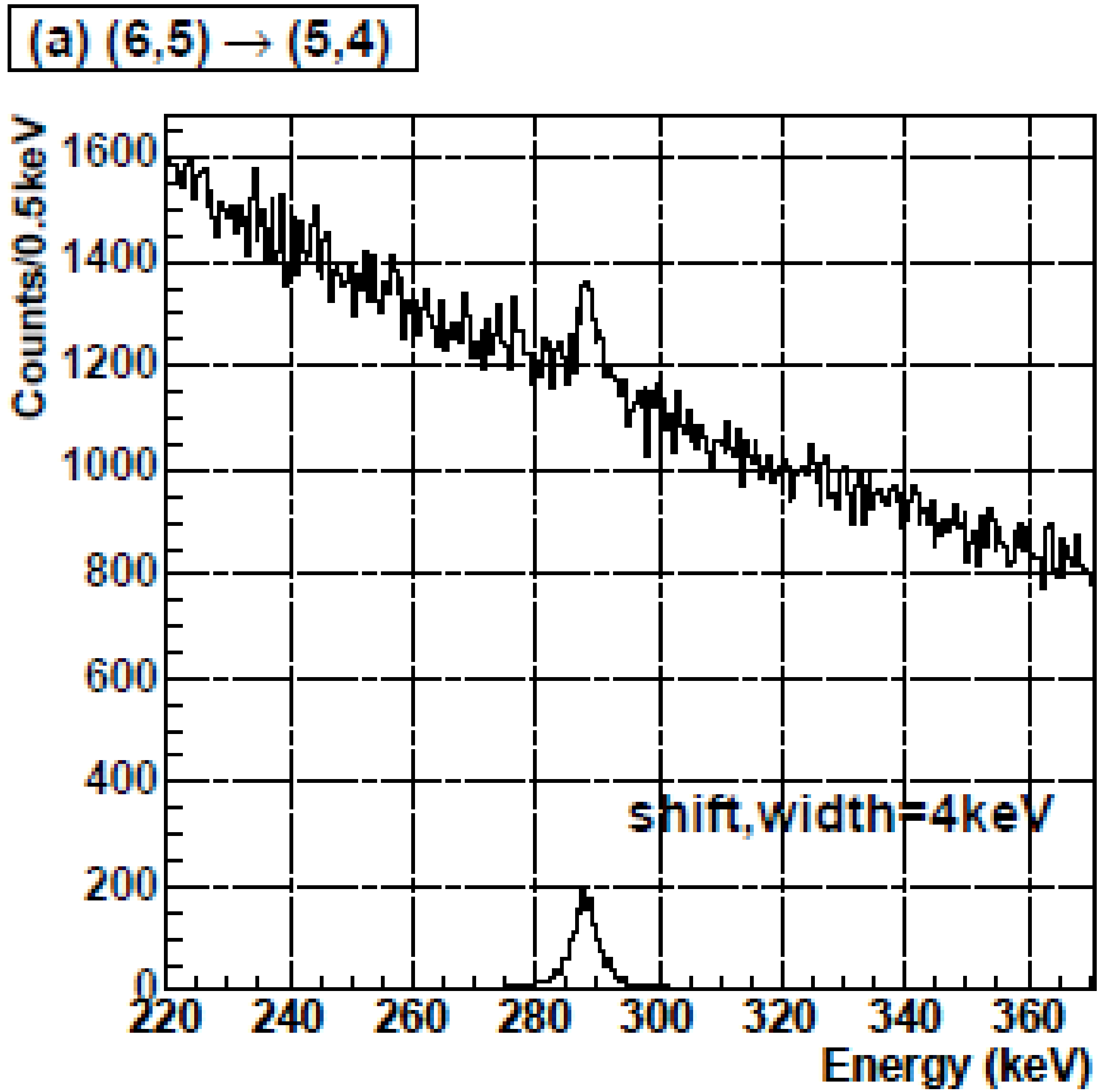
Expected X-ray spectrum



n= 6→5

shift & width
0 keV

Expected X-ray spectrum(2)



n= 6→5

shift & width
4 keV

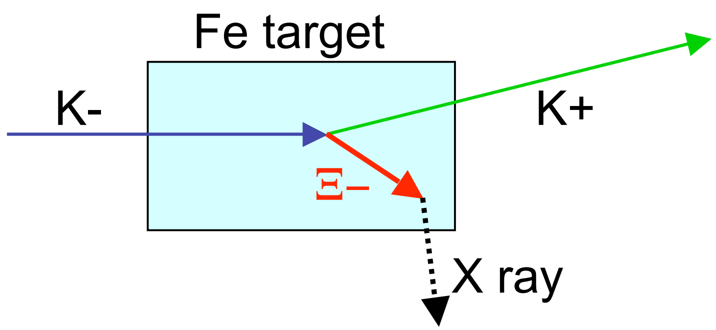
Summary

- 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
- 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.
- Future experiments will be planned based on the results of this experiment.

Backup slides

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）= 2.6×10^{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

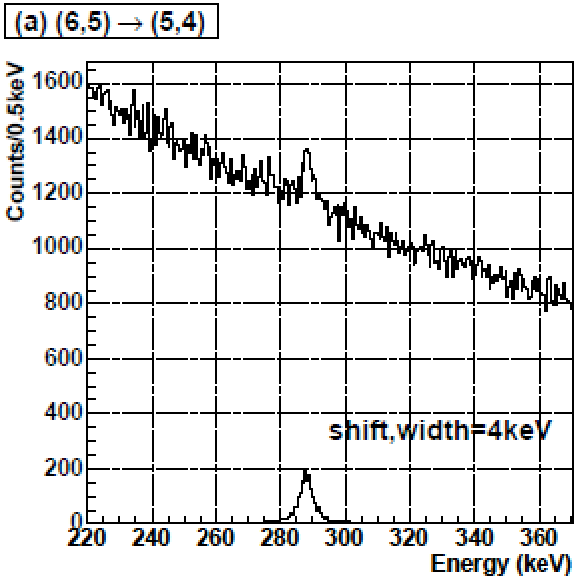
X-ray background

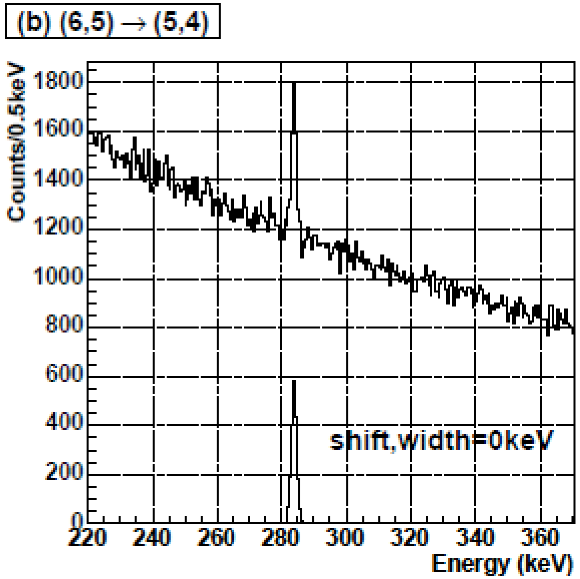
- Estimation based on E419
- E419: 8 x 10^{-5} counts/keV/(π^+,K^+), around 284 keV
  - X-ray detection efficiency: x4
  - Other effect: x2 (considering different reaction)

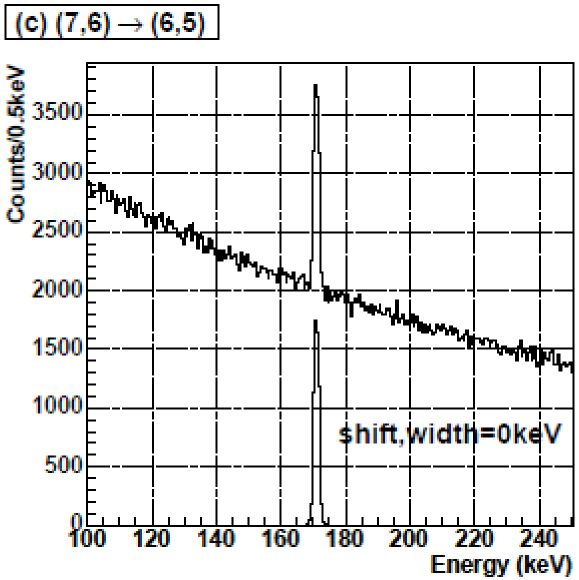
→ ~2400 counts/keV

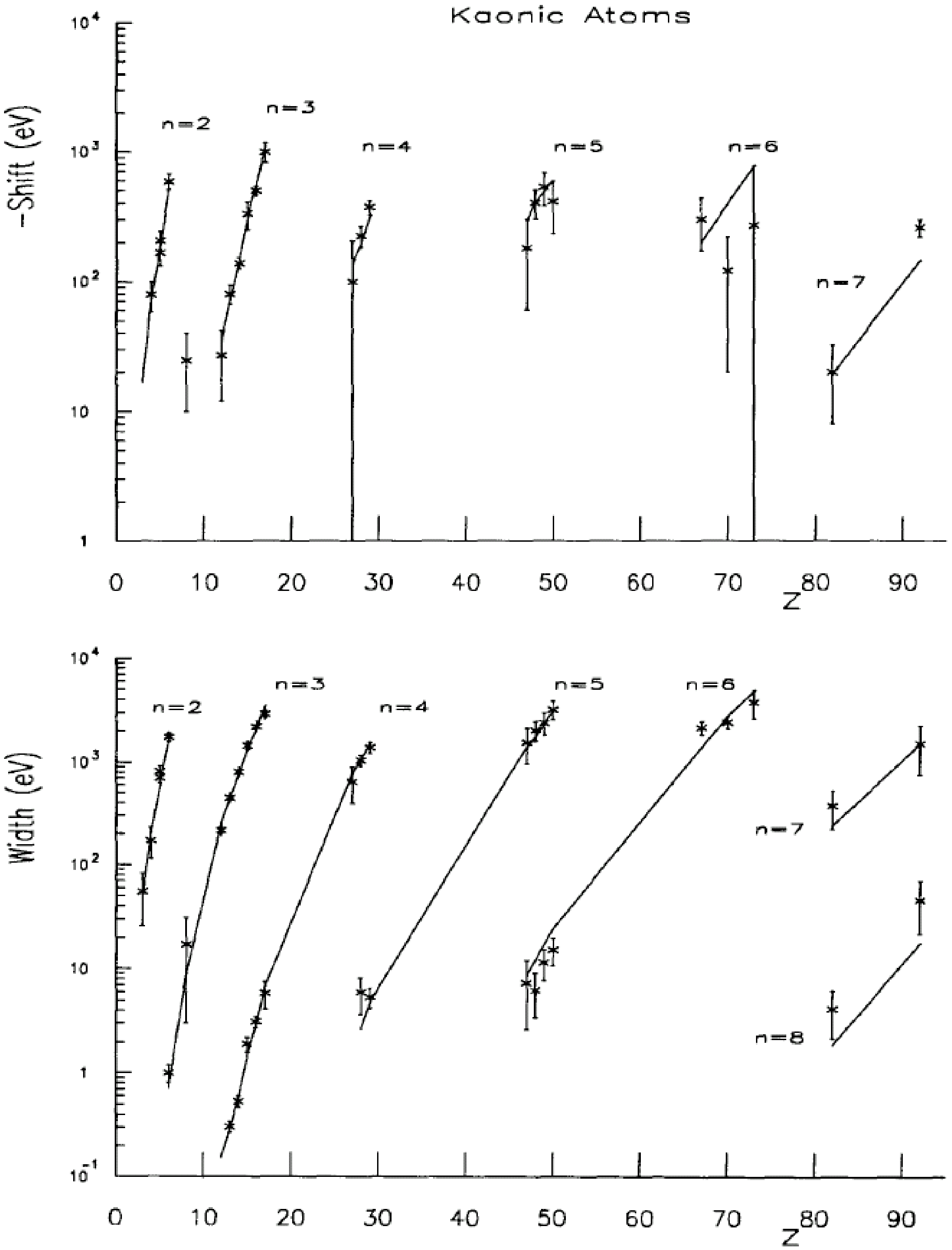
- Continuous BG is OK
- Line background might be a problem, though unlikely.
  - there seem no strong lines in this energy from normal nuclei around A=50.
  - Completely unknown for (single) hypernuclei
  - Even weak lines may deform the peak shape

Expected X-ray spectrum

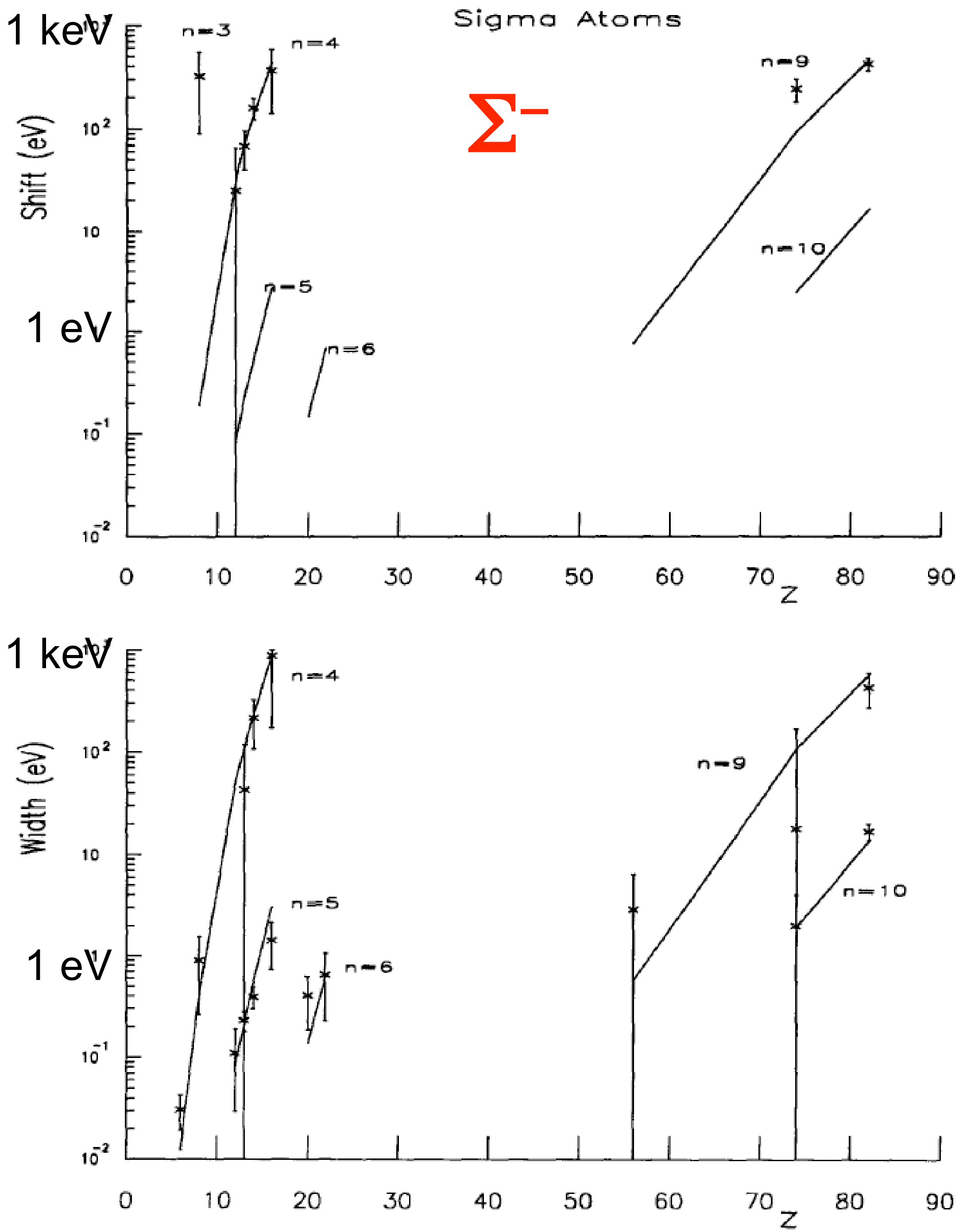


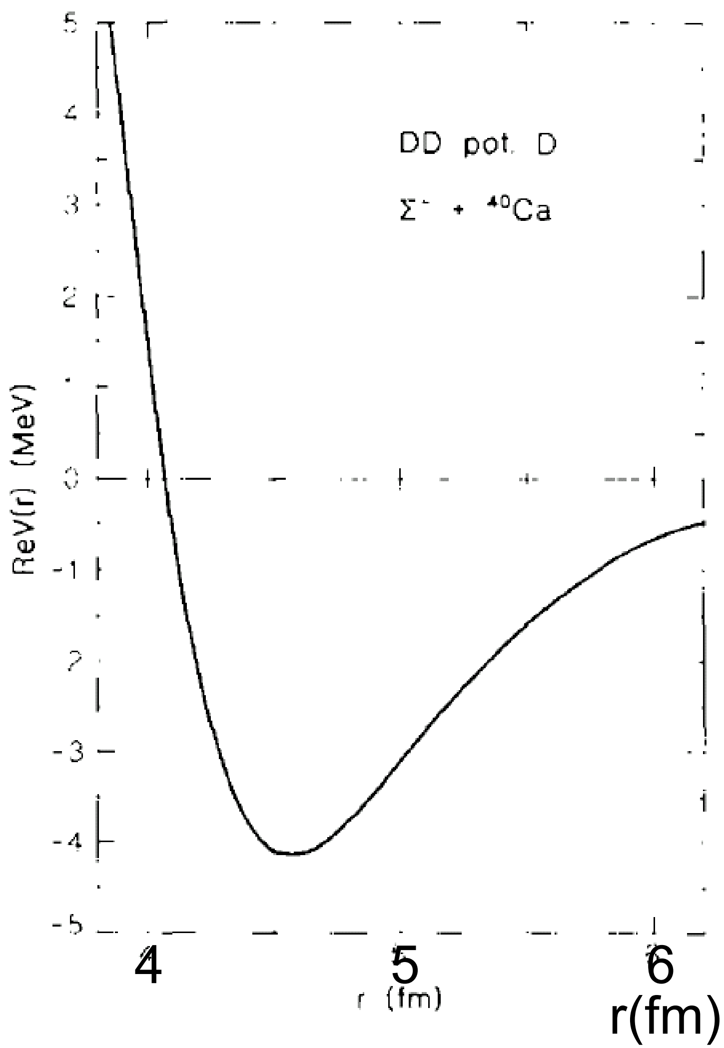






Kaonic Atoms
-Shift (eV)
n=2
n=3
n=4
n=5
n=6
n=7
Z
Width (eV)
n=2
n=3
n=4
n=5
n=6
n=7
n=8
Z





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