Status report

E03: Measurement of X rays from Ξ^- atom

XiX Collaboration
Spokesperson: K. Tanida (Kyoto Univ.)

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Collaboration

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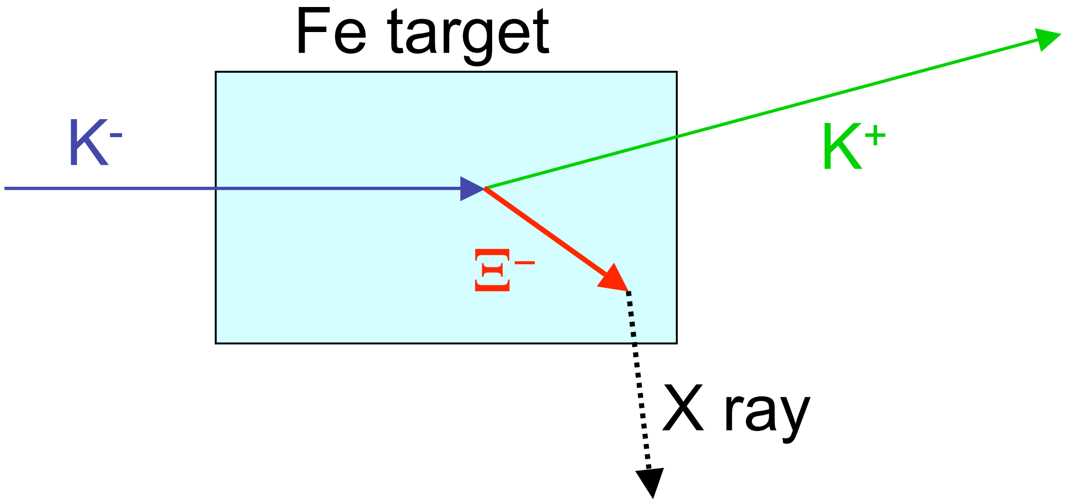
Outline of the experiment

- 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.

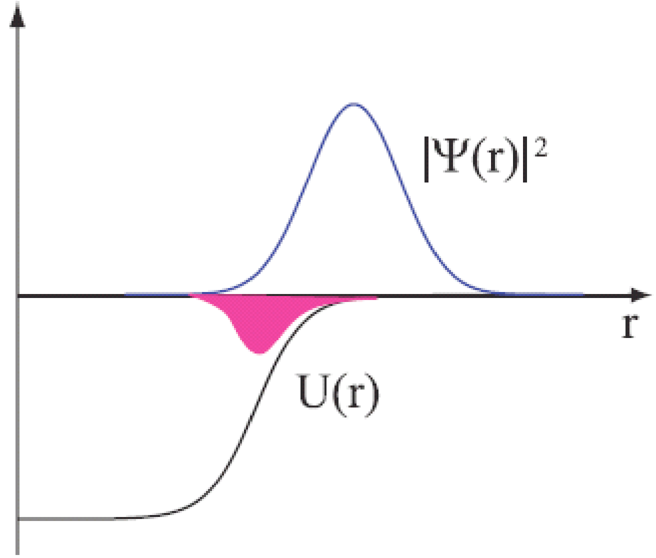


- Requested beamtime: 100 (+ 20/50) shifts
- Aiming at establishing the experimental method

Principle

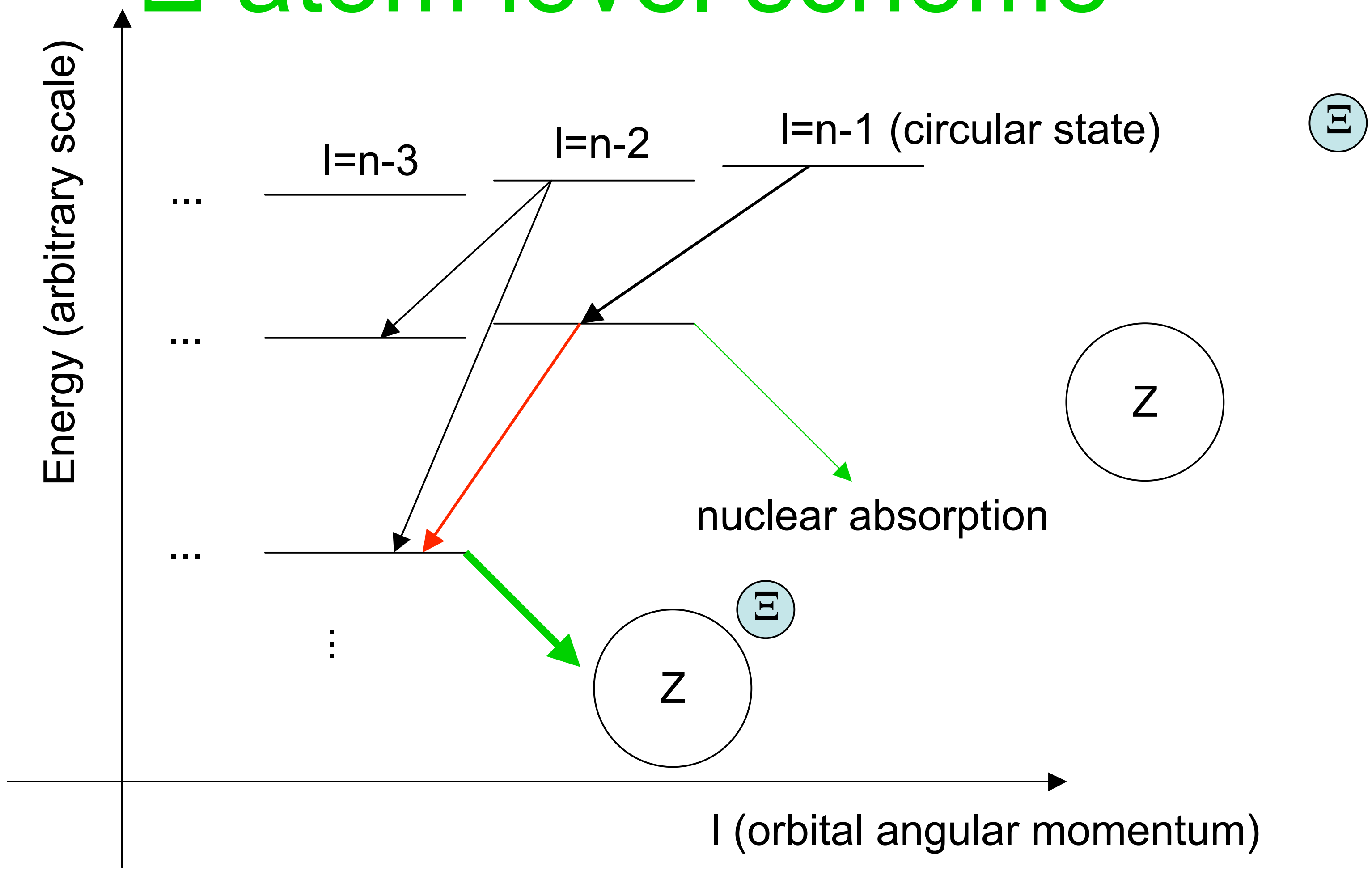
- Atomic state – precisely calculable if there is no hadronic interaction
- 1st order perturbation

  [illegible]

  – If we assume potential shape, we can accurately determine its depth with only one data
- Peripheral, but direct & potential independent (⇔ E05 Nagae et al.)
- Targetting precision: 0.05 keV for energy shift
  – Energy shift up to O(1 keV) expected
- Successfully used for π^-, K^-,$\bar{p}$, and Σ^-

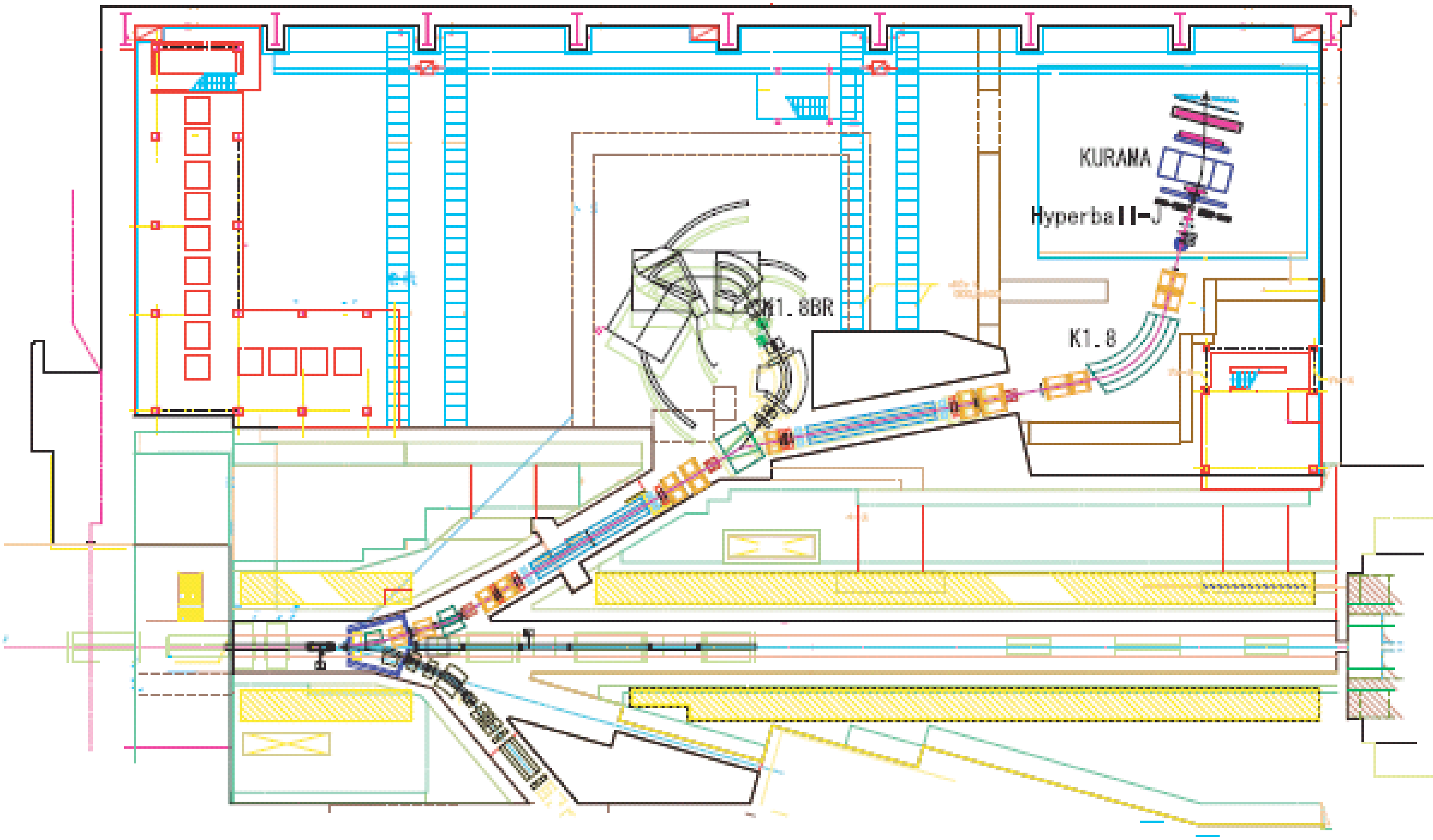
Ξ atom level scheme



X ray energy shift – real part

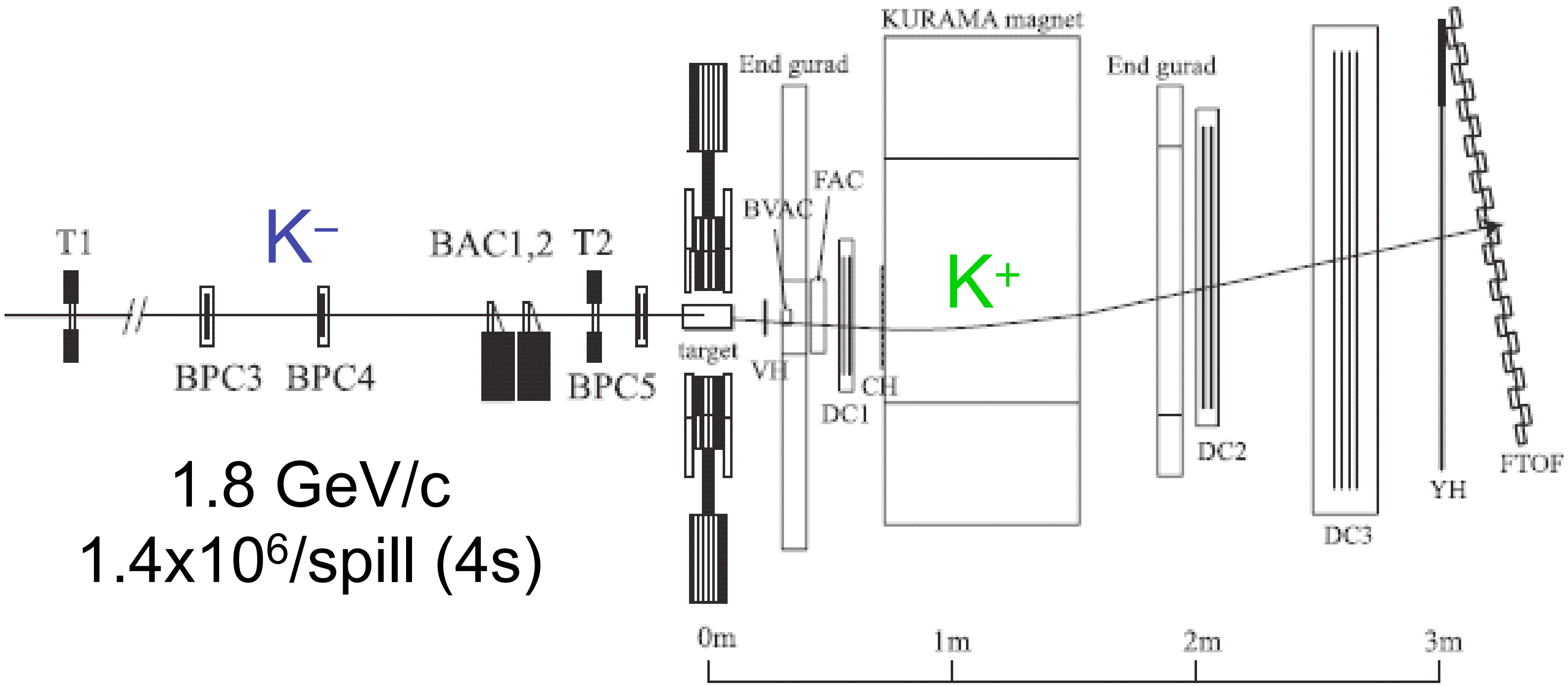
Width, yield – imaginary part

Setup Overview



K1.8 beamline of J-PARC

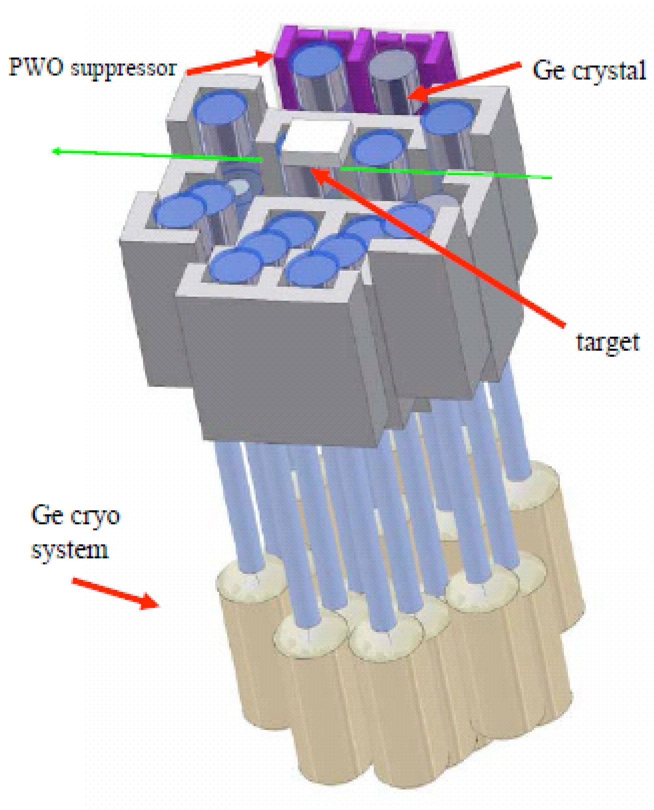
(K^-,K^+) detection system

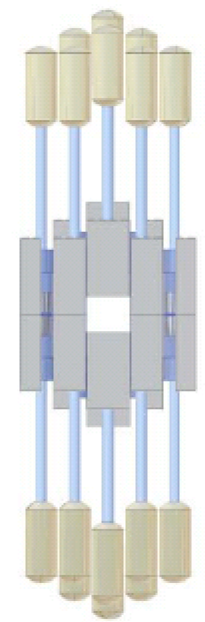


- Mostly common with Hybrid-Emulsion experiment (E07: Nakazawa et al.)
- Long used at KEK-PS K2 beamline (E373, E522, ...)
  - Minor modification is necessary to accommodate high rate.
- Large acceptance (~0.2 sr)

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)





Report from FIFC

- **The committee do not see particular problems** in the detector system, however, following comments are raised.

1) Estimate the overall efficiency for SKS and KURAMA quantitatively and to take the better choice.
2) Experiment group should pay more attention to the reduction of the dead time.
3) Explore the X-ray energy calibration method using scintillator embedded source.
4) Study continuous background more in detail by utilizing the existing data
5) Consider a possibility that the experiment is scheduled prior to E07.

Issues pointed out by PAC

a. It was pointed out that the DAQ dead time is high due to the slow signal of the germanium detectors. Optimization of the overall efficiency should be worked out including the DAQ, the layout of the Ge detectors and the choice of the spectrometer magnet.
b. Methods for the online calibration should be worked out, considering the signal overlap due to the high rate and slow response of the Ge detectors.
c. Estimation of the continuous X-ray background needs to be further studied.

Some immediate answers (1)

- Estimate the overall efficiency for SKS and KURAMA quantitatively and to take the better choice. (FIFC comment 1)

  → KURAMA is the better

  – Acceptance of SKS(-minus) is ~1/2 of KURAMA

  – This can be partly compensated by the performance of Hyperball-J, for which larger space is available with SKS

    - Ball-type configuration is possible, but actually the acceptance is not larger (~80%).
    - Better background suppression capability would make the S/N ratio better by 20-30% (up to factor 2).

  – In total, FOM is better for KURAMA by factor ~2.

  – We already decided to use wall-type together with E13.

Some immediate answers (2)

- Consider a possibility that the experiment is scheduled prior to E07 (FIFC comment 5)

  → Yes, it's certainly possible

  – We just think it is most efficient to run E07 and E03 sequentially.

  – E07 requests less intense beam and takes more time after the beamtime for emulsion handling and analysis.

Issues pointed out by PAC

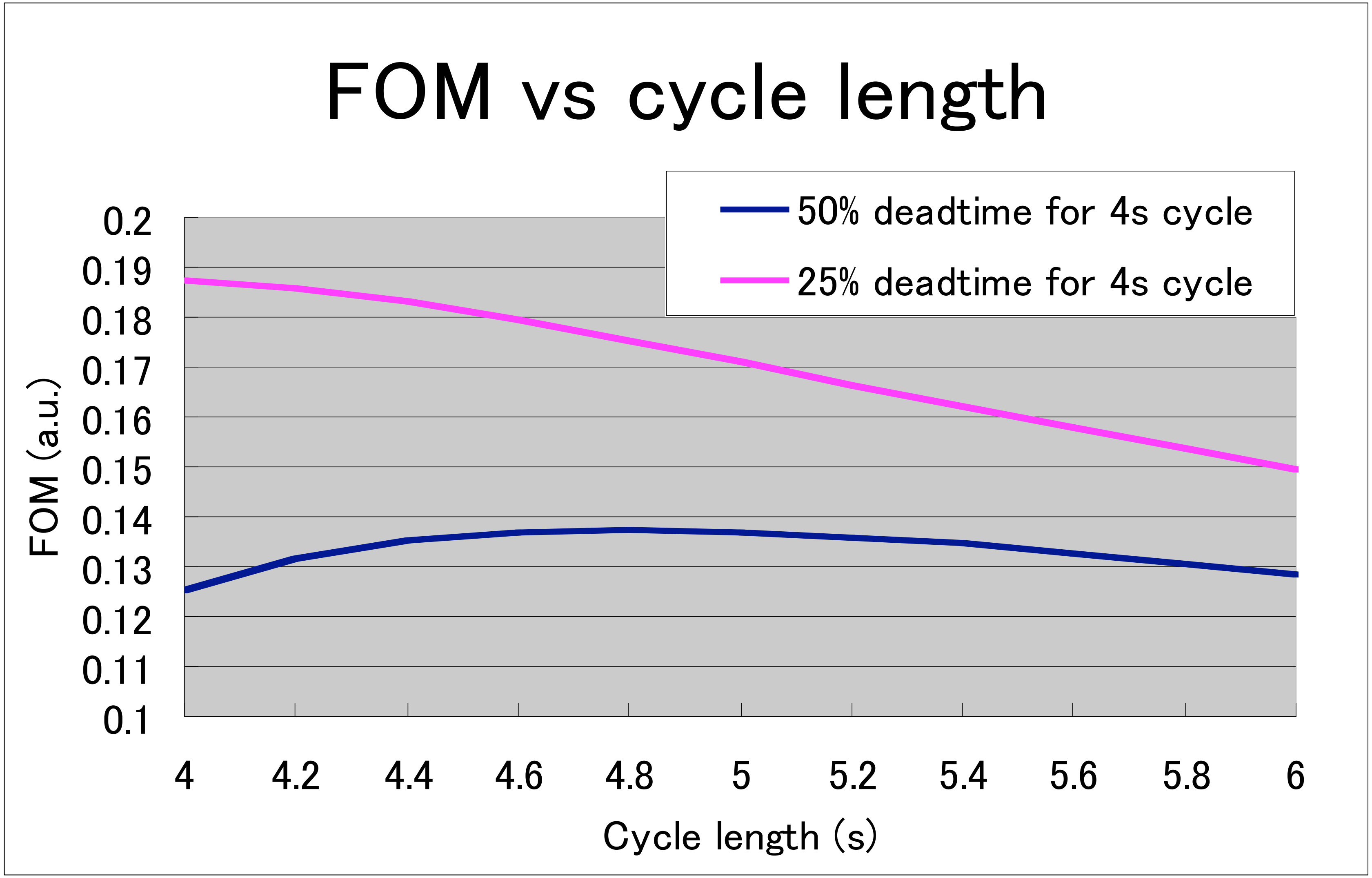
a. It was pointed out that the DAQ dead time is high due to the slow signal of the germanium detectors. Optimization of the overall efficiency should be worked out including the DAQ, the layout of the Ge detectors and the choice of the spectrometer magnet. (→ FIFC comment 2,1)

b. Methods for the online calibration should be worked out, considering the signal overlap due to the high rate and slow response of the Ge detectors. (→ FIFC comment 3)

c. Estimation of the continuous X-ray background needs to be further studied (→ FIFC comment 4)

a. Optimization of overall efficiency

- 50% deadtime is a conservative estimation
  - Estimation from the past experiences show 25% is more likely
  - 50% deadtime is for 3 MHz beam, while we expect < 1.5 MHz for E03.
- If deadtime is too large, we will reduce the instantaneous intensity by making spill length longer
  - e.g. for 50% deadtime with 4s cycle (1.2s spill)
    31% with 5s cycle (2.2s spill), 23% with 6s cycle
  - Yield (FOM) is proportional to (livetime)/(cycle length)
- Moving Ge away doesn't help very much
  - Though we don't know exactly how much.
    Approximately, single rate is proportional to solid angle.



4~5s cycle is optimum

For the same FOM, lower intensity is preferred.

b. X-ray energy calibration

- Executive summary:

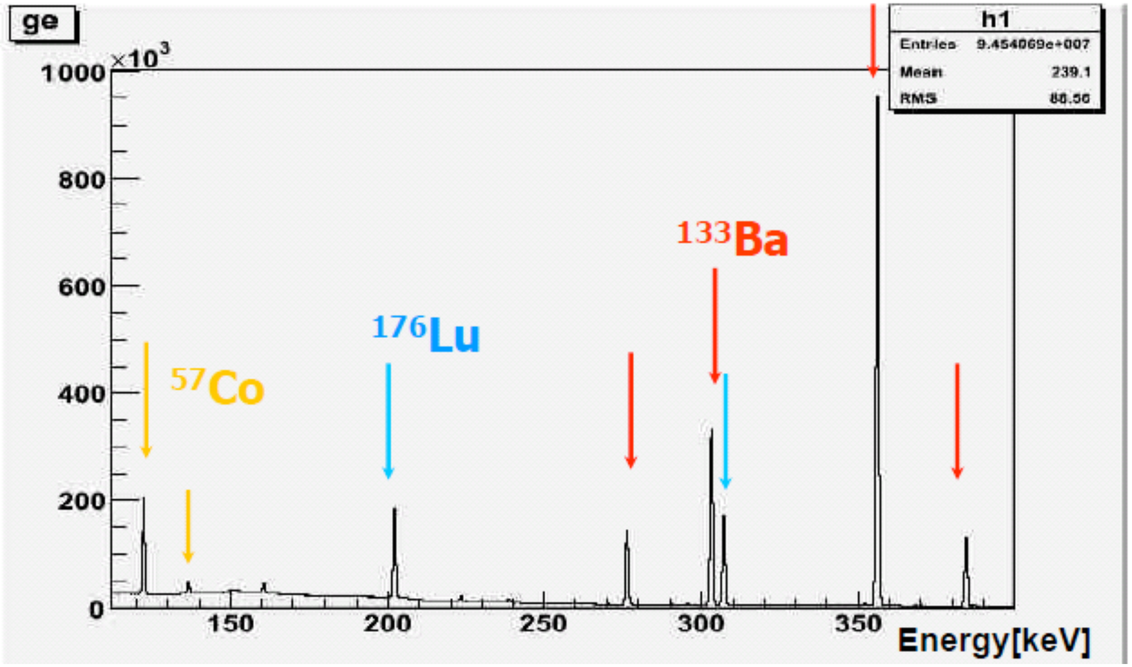
  It is more complicated than we first thought, but now we are sure we can.

- Target: 0.05 keV
- Calibration source -- ^{133}Ba, ^{192}Ir, ^{152}Eu, ...
  - e.g., ^{133}Ba: 80.997 keV, 276.400 keV, 302.851 keV, 356.013 keV, 383.848 keV

    → good for 284 keV (& 171 keV)

Off-beam calibration test (1)

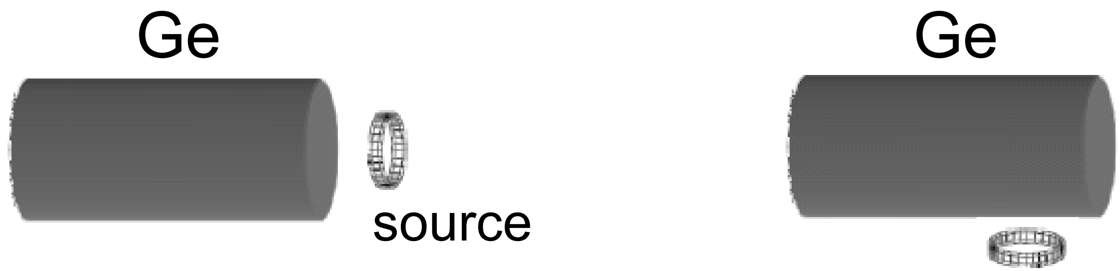
- Test 1: ^{133}Ba
  - Try to reproduce 302 keV & 356 keV γ-ray energy from the other 2 lines at 276 keV and 384 keV



  - Good agreement within 2 eV (stat. limited)
  - Non-linearity is negligible. BG treatment is OK.

Off-beam calibration test (2)

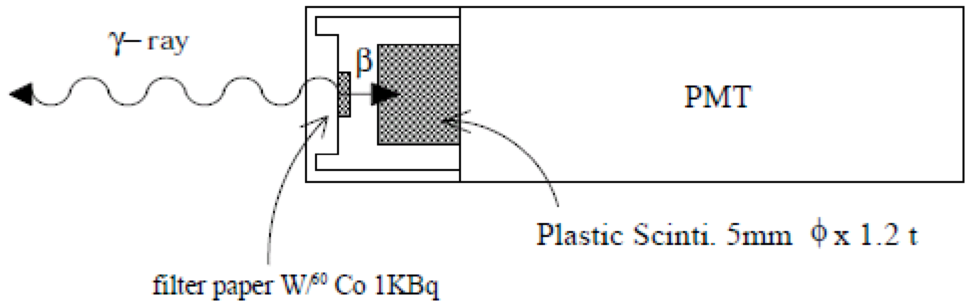
- Test 2: ^{133}Ba & ^{152}Eu
  - Try to reproduce 344 keV line of ^{152}Eu from 4 ^{133}Ba lines
  - Stat. error is ~2 eV, but failed to reproduce it by 50 eV
- Why?
  - Source position dependence of peak position
    When we carefully placed the two sources as near as possible, the discrepancy is gone.
  - Up to ~100 eV shift observed.



  - Shift is estimated to be small (~10 eV) within the actual target volume. We will measure it for every Ge, anyway.

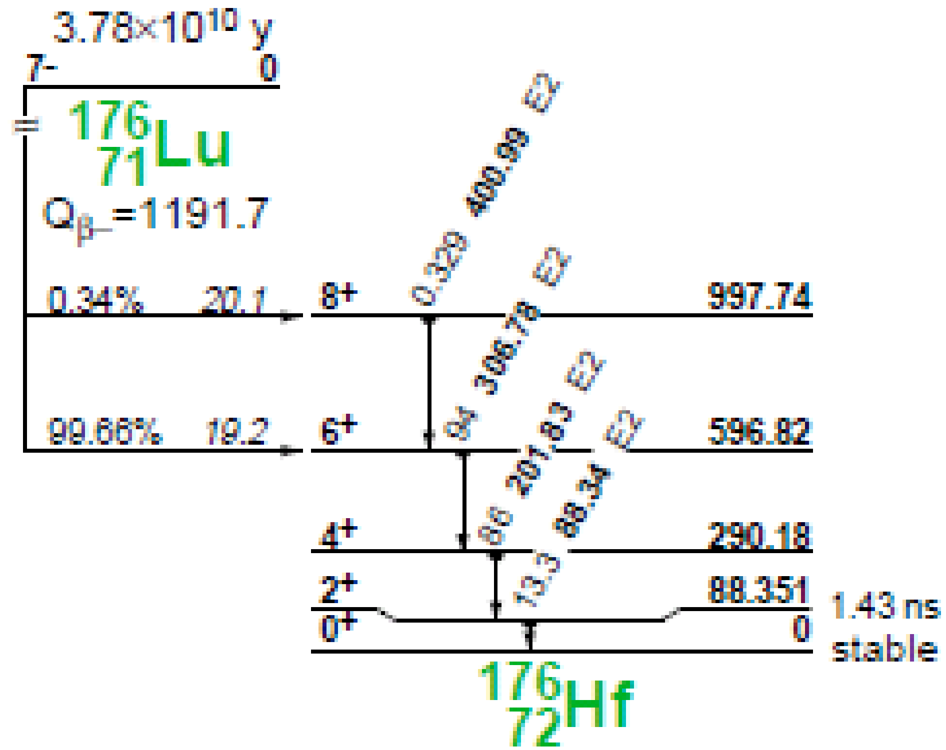
In beam calibration

- Issues:
  - huge background
    single rate: ~1 KHz (off-beam) → ~50 kHz (in-beam)
  - rate dependent peak position shift (~1 keV) and peak broadening
- Need to take data simultaneously.
  - Method 1: special run using strong source.
    → Not exactly simultaneous data taking
  - Method 2: Use scintillator embedded source
    ← recommended by FIFC and PAC



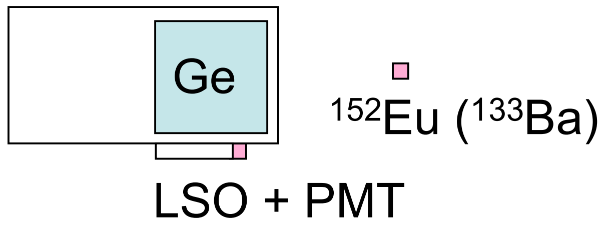
LSO source

- LSO: Lu_2SiO_4, known as a good scintillator
- Naturally contains radioactive isotope: ^{176}Lu (2.6%, half-life = 38 billion year)
  - γ-ray energy: OK
  - ~100% β-ray tagging
- One LSO for each Ge
  - 8mmϕ x 1mm: 15 Bq
  - must be small to avoid backgrounds
  - coincidence rate with Ge
    ~5 Hz (off-beam)
    < ~30 Hz (in-beam)
  - photo-peak rate: ~1 Hz



Calibration procedure

- Put LSO on the side of Ge
  - Position dependence must be calibrated first using standard sources (^{152}Eu and/or ^{133}Ba (^{192}Ir)) at the position of target
    → Measure effective energies of ^{176}Lu γ rays for each Ge



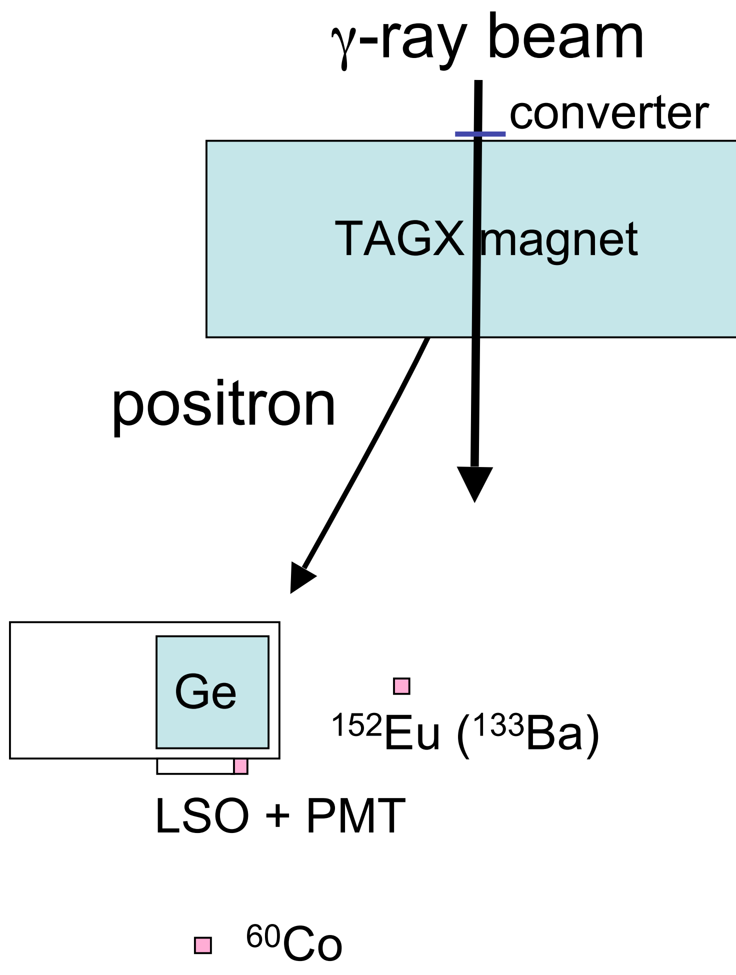
- Take LSO data continuously
- Make sure γ-ray energies of (other) standard sources at the target position are reproduced
  - Especially for in-beam
- Peak shape and position may change with time
  - Peak drift, radiation damage.
  - We would like enough events every a few hours.

Test exp. at LNS

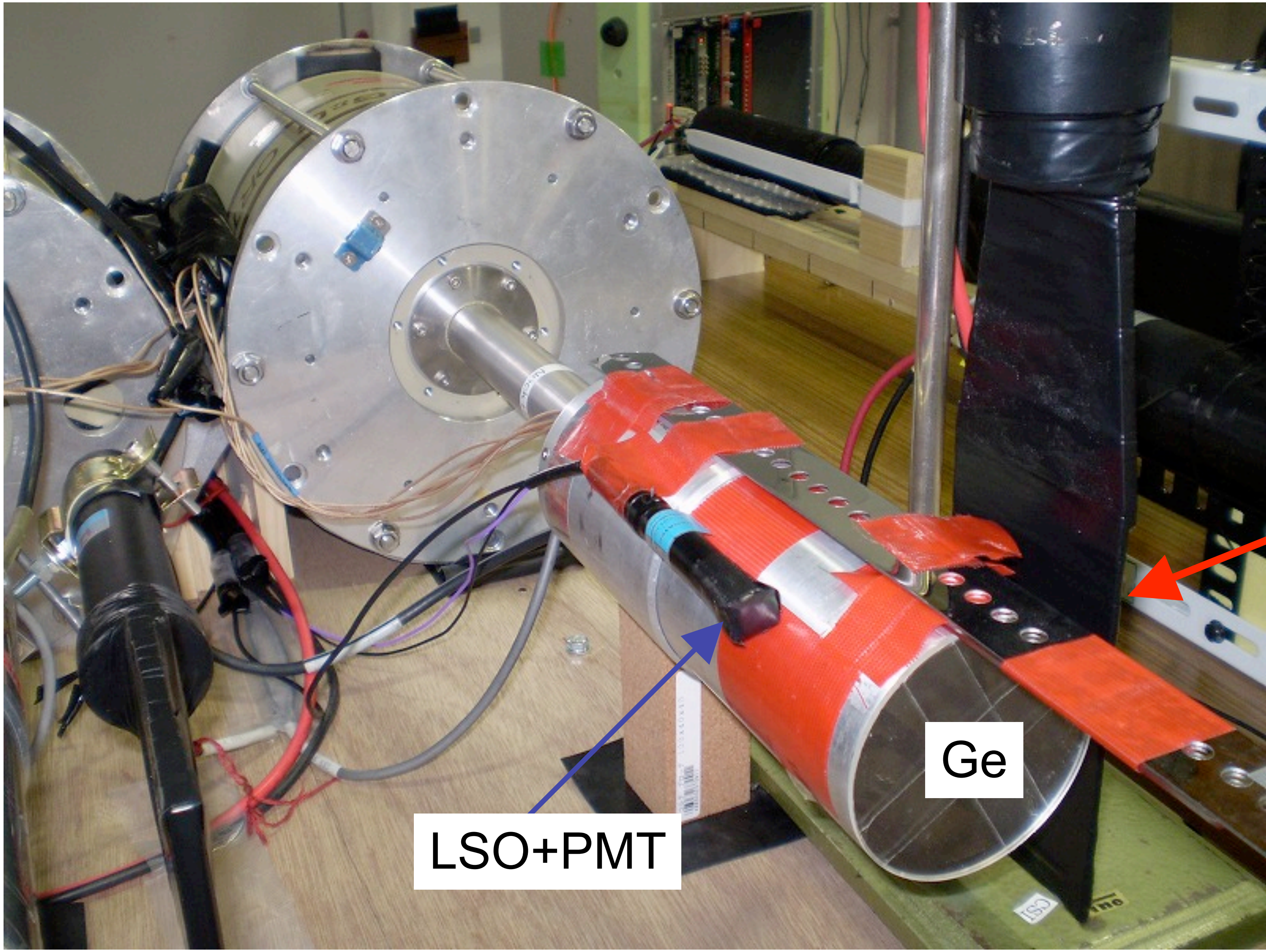
- Tested in-beam performance using positron beam of 650 MeV
- Beamtime: Dec. 10-14
  - along with other tests
  - effective beamtime: ~24h
- 3 beam intensities

beam (kHz)	Ge rate (kHz)	reset (kHz)	dead time
20	100	7	~60%
10	60	4	~30%
5	40	2.5	~25%
E566		3	46%

  - beam on for 1~6s, off for ~8s



Test exp. at LNS

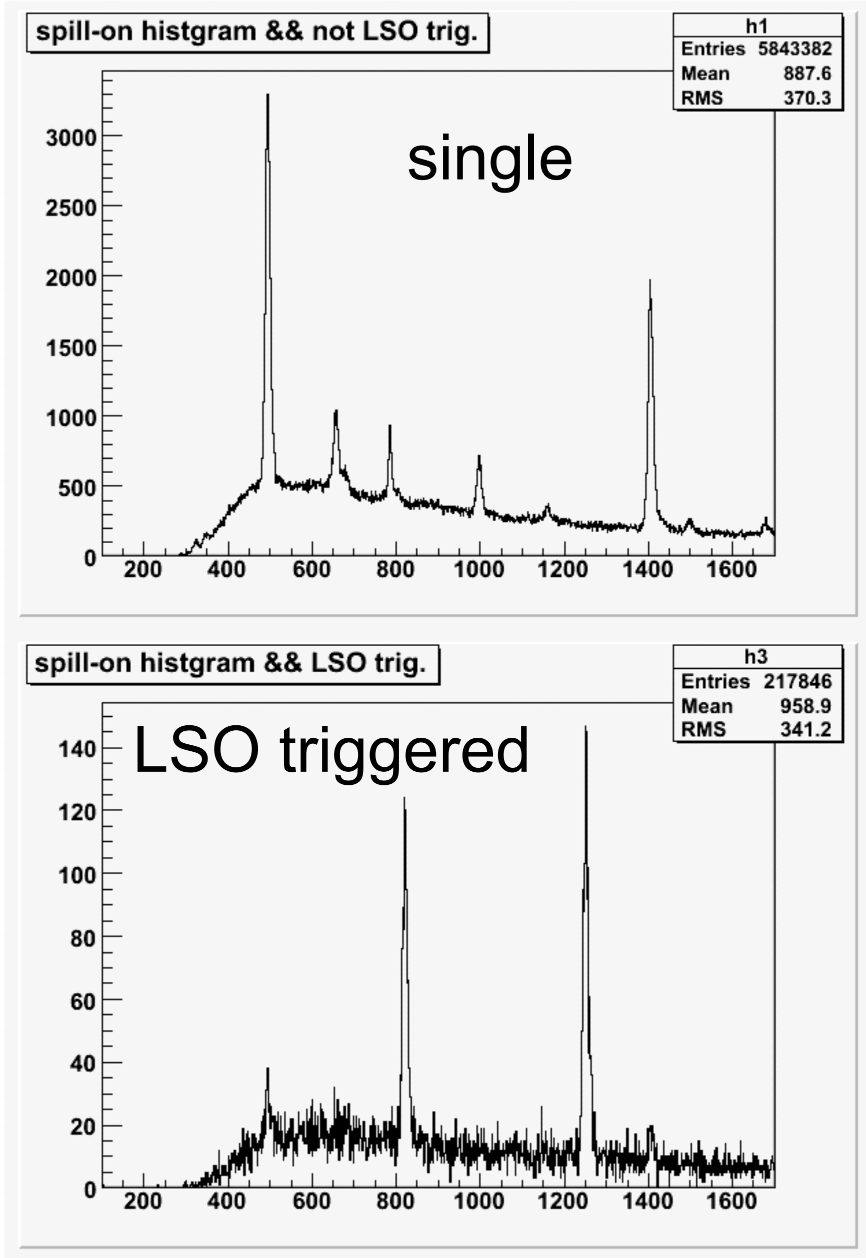


e^+ beam

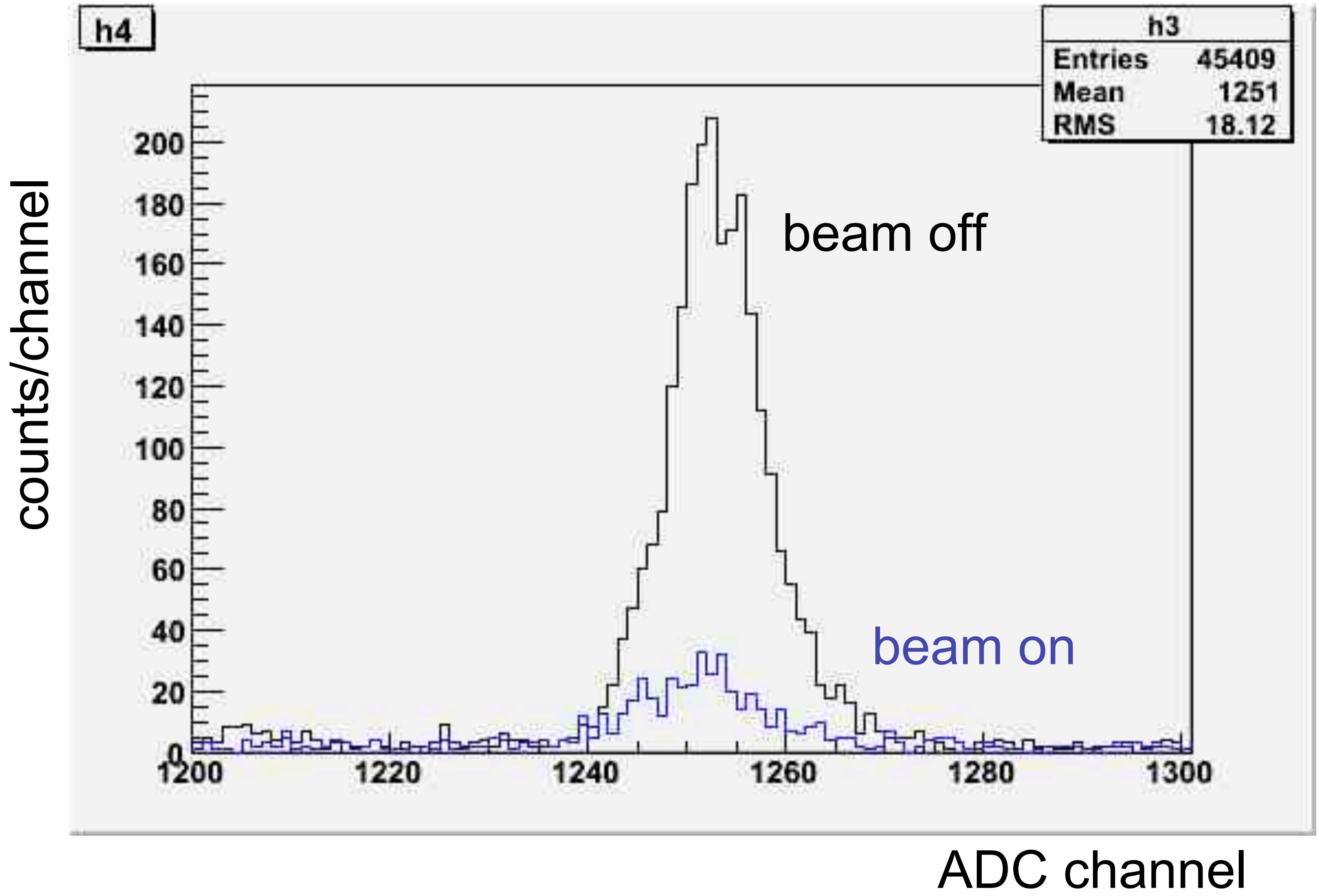
LSO spectra

In-beam spectra
under the presence of
LSO + ^{152}Eu + ^{60}Co

~1000 times better S/N was
obtained with LSO trigger

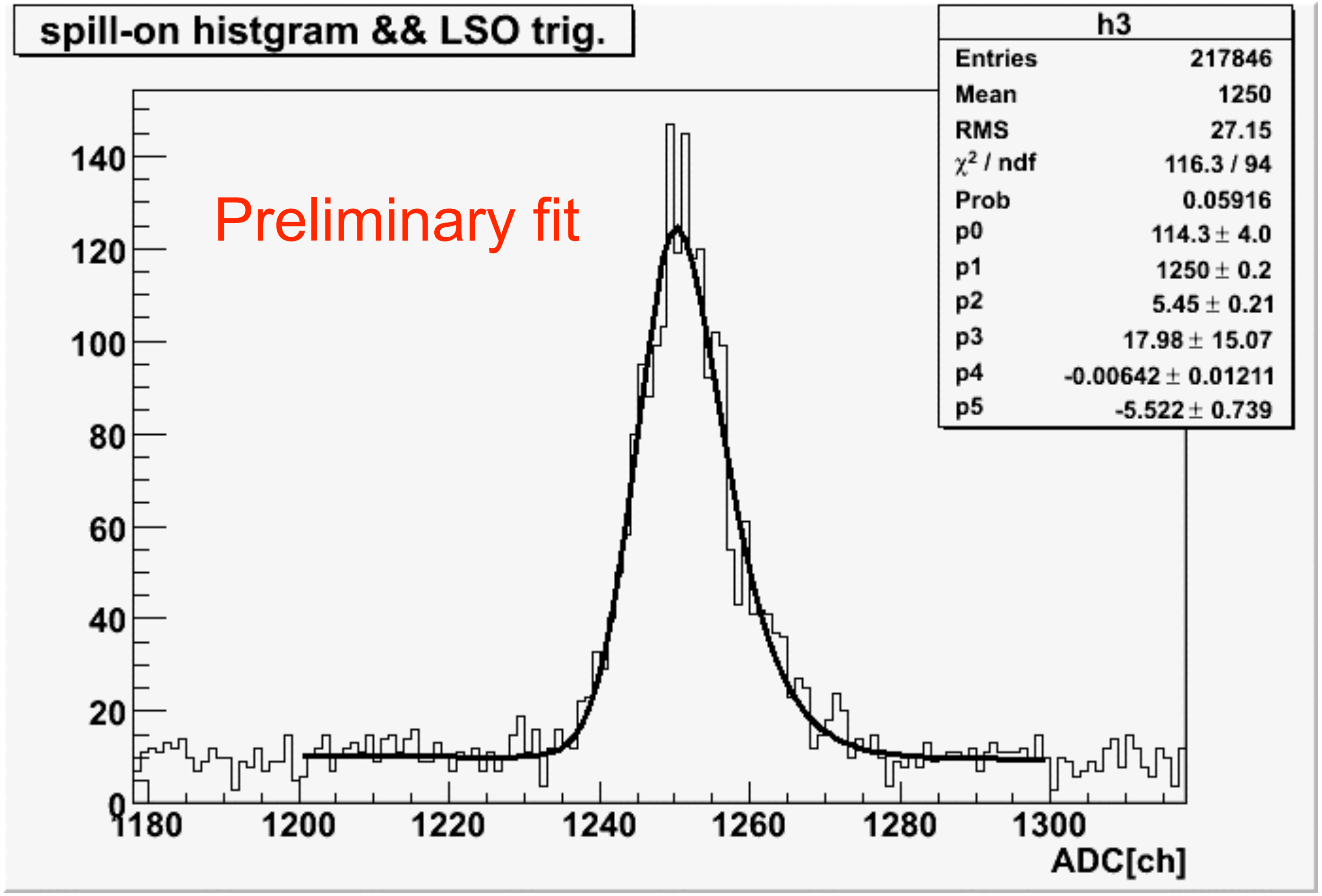


In-beam peak shift



~2ch shift (~500 eV) was observed

Peak+B.G. fitting



- "Skewed Gaussian + linear BG" is good enough in this case
- Fitting is not perfect, but acceptable down to ~20 eV
  when same method is used for all peaks

Preliminary result

Effective γ-ray energies for 306 keV peak

beam intensity	peak shift (keV)	beam off (keV)	beam on (keV)	difference (eV)
20 kHz	~0.5	306.635±0.017	306.684±0.061	49±63
5 kHz	~0.15	306.734±0.038	306.725±0.052	-9±64

*Data with ^{152}Eu only.
*Eu source was placed in different positions for each setting
*Not enough data for 10 kHz was taken by mistake

- No deviation from stat. error even at the highest rate
  - Deadtime ~60%: Ge rate is 1.5~4 times higher than E03.
  - Data taking time ~6h, corresponding to ~3h of beam time in E03 (considering duty factor).
    → 50 eV calibration should be possible every ~5h

Summary for online calibration

- Off-beam calibration test: 1 eV is possible.
  - Non-gaussian tail (depending on Ge and its damage), gives systematic uncertainty (now ~20 eV). We are improving this.
  - There is significant source position dependence
- Calibration using triggerable LSO scintillator
  - Naturally contains calibration source
  - Enables truly simultaneous calibration with good S/N.
  - Source position dependence will be calibrated for every Ge
- In-beam performance was tested with e^+ beam.
  - 50 eV calibration should be possible every ~5h even for ~60% deadtime.

c. Continuous background

- PAC comment: Estimation of the continuous X-ray background needs to be further studied
- E03 proposal: estimation based on KEK-PS:
  8 x 10^{-5} counts/keV/(π^+,K^+), around 284 keV
  - X-ray detection efficiency: x4
  - Other effect: x2 (safety factor)

  → 6.4 x 10^{-4} counts/keV/(K^-,K^+)
- We confirmed this estimation is reasonable from other Hyperball and Σ^- X-ray experiments.

Past Hyperball experiments

- 3 experiments
  - E419: (π^+,K^+) reaction
  - E509: stopped K^- reaction
  - E566: (π^+,K^+) reaction with Hyperball-II

(There is trigger bias for experiments with (K^-, π^-) reaction)

Exp.	# of reactions	BG@284 keV (counts/keV)	efficiency @284 keV	eff. corrected BG/reaction
E419	8×10^4	6	2%	4×10^{-3}
E509	1.7×10^8	4800	0.7%	4×10^{-3}
E566	1.8×10^5	45	8.1%	3×10^{-3}
E03	3.7×10^6	2400	8%	8×10^{-3}*

*Safety factor 2 included

consistent for those 3 experiments.

Σ X-ray measurements

[1] Pb, W: [D. W. Hertzog et al., PRD 37 (1988) 1142]

[2] O, Mg, Al, SI, S: [C. J. Batty et al., PLB 74 (1978) 27]

[3] C, P, Ca, Ti, Zn, Nb, Cd, Ba:
[G. Beckenstoss et al., Z. Phys. A273 (1975) 137]

- Difficult to estimate BG/stopped Σ^-
  - Stopped K^- was used to produce Σ^- , and no information was given in those papers on
    - Number of stopped Σ^-
    - Absolute efficiency of Ge detectors
  - Instead, we will discuss S/N ratio in these experiments.

S/N for Σ X rays

- Ref. [1] gives Σ X-ray spectrum with 83 MeV pion from the $K^- + p \rightarrow \Sigma^- + \pi^+$ tagged

S/N~3 for 11→10 transition @ 303 keV

Purity of this tagging is not shown

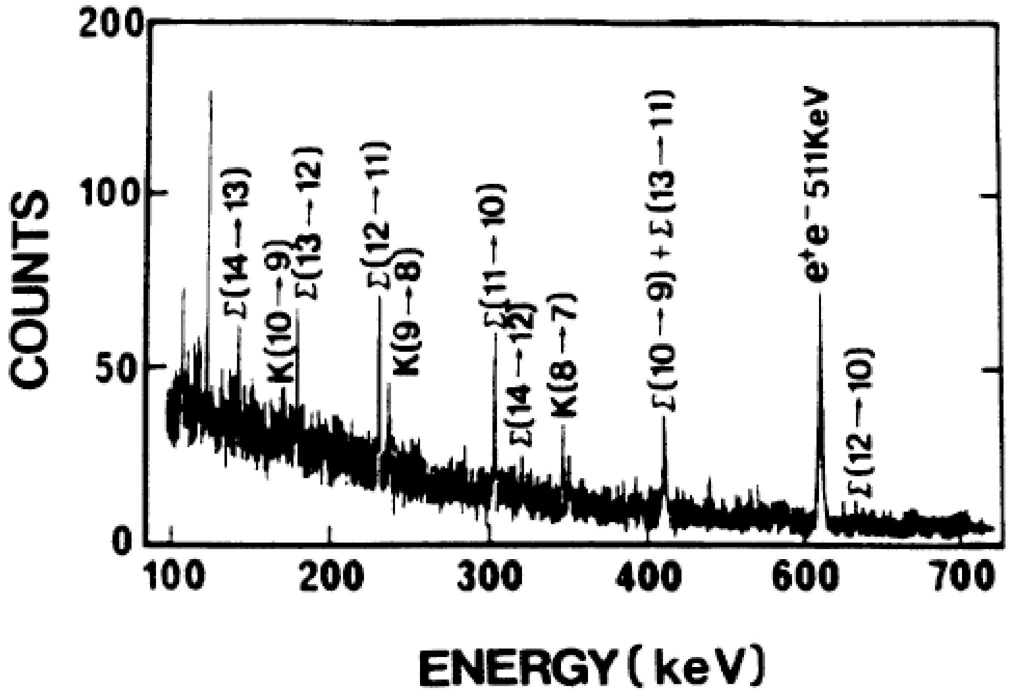
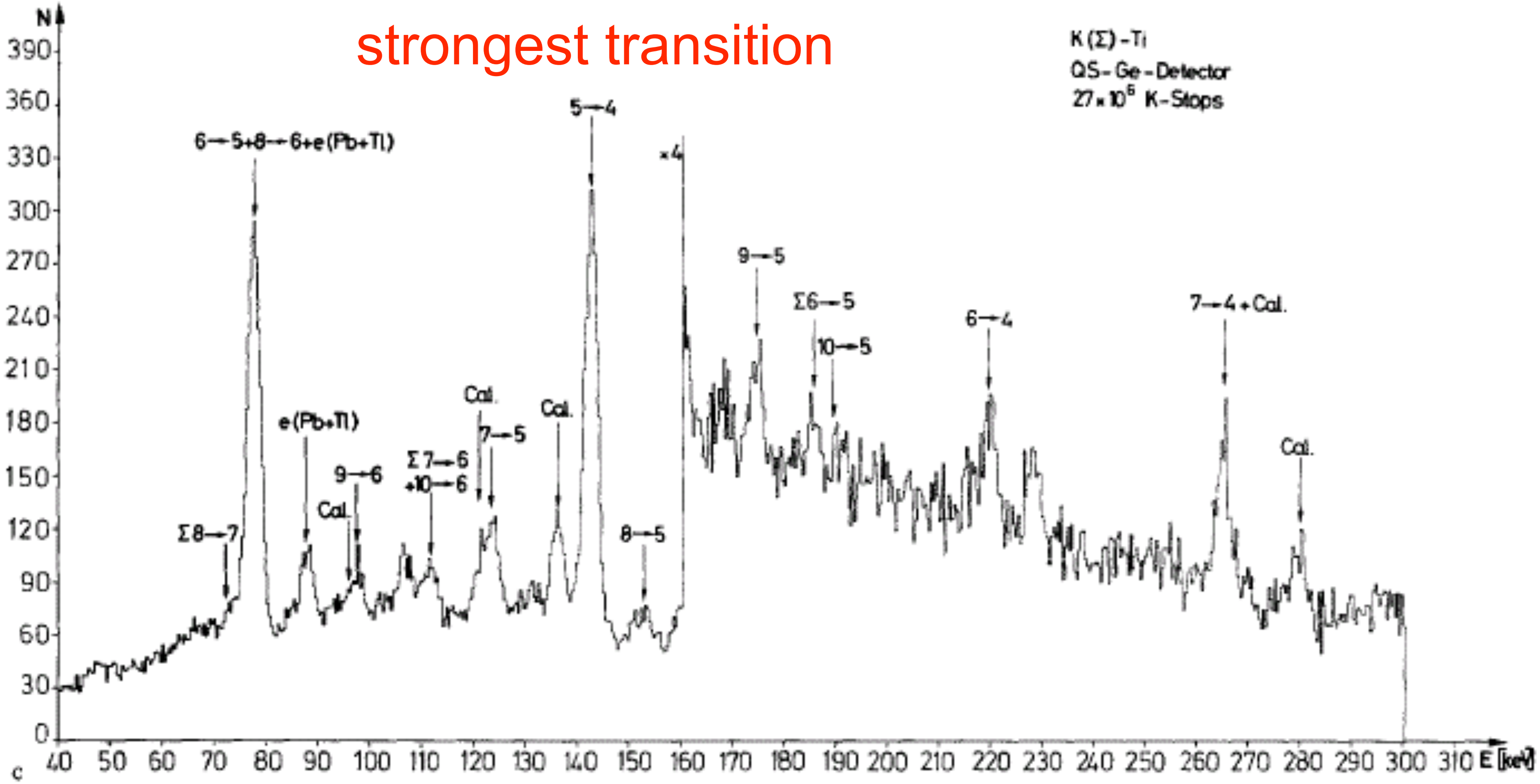


FIG. 9. The equivalent tagged W x-ray data. The Σ^- x rays are enhanced by the tagging technique.

S/N for kaonic X rays

- Unbiased X-ray energy spectrum is given in [3].

S/N~5 for the strongest transition

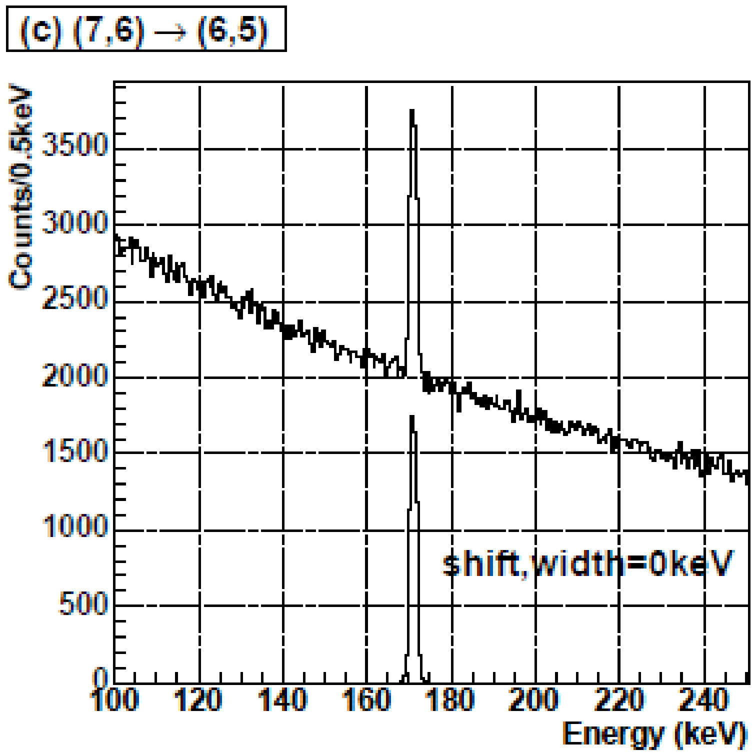


c

Fig. 4a – c. Spectra obtained by stopping kaons in C, Ca and Ti. The Σ-atomic lines (marked Σ) have about 10 times smaller intensities than the main K-atomic transitions; no marks means kaonic transitions

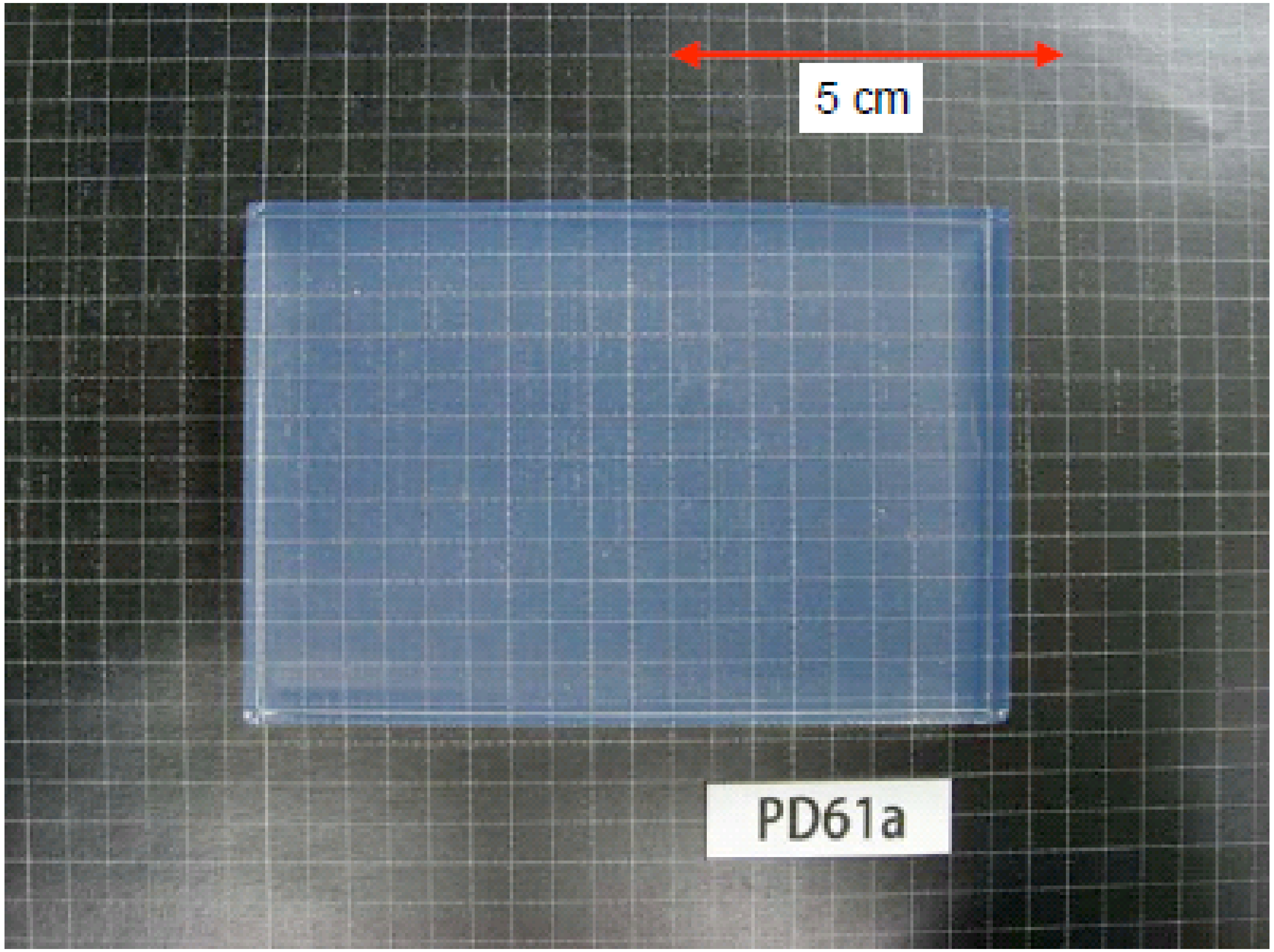
S/N estimation

- S/N > 3 can be expected for strongest transitions
- In E03
  - PWO background suppressor → x2
  - Worse resolution → x1/2
  - No stopped Ξ selection → x1/5
  - Detector size → x~1?
    → S/N ~ 1 can be (roughly) estimated
- S/N~1 is what we expect for the strongest (7→6) transition in E03
  - reasonable



Other works

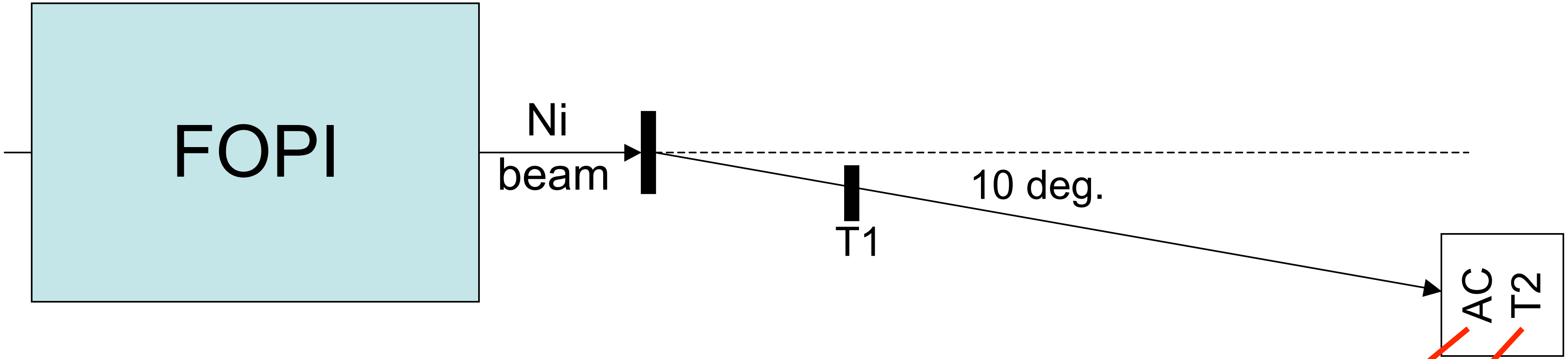
- High density Silica aerogel counter to suppress (K^-,p) events in the (K^-,K^+) trigger

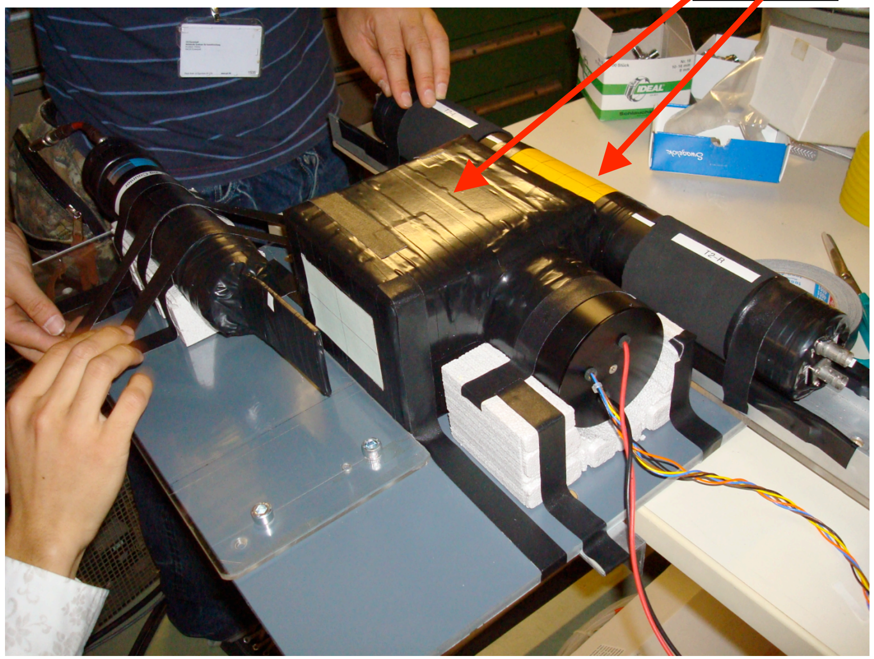


n=1.13

Test exp. @GSI

- CAVE B, Parasitic to FOPI (working with HypHI)





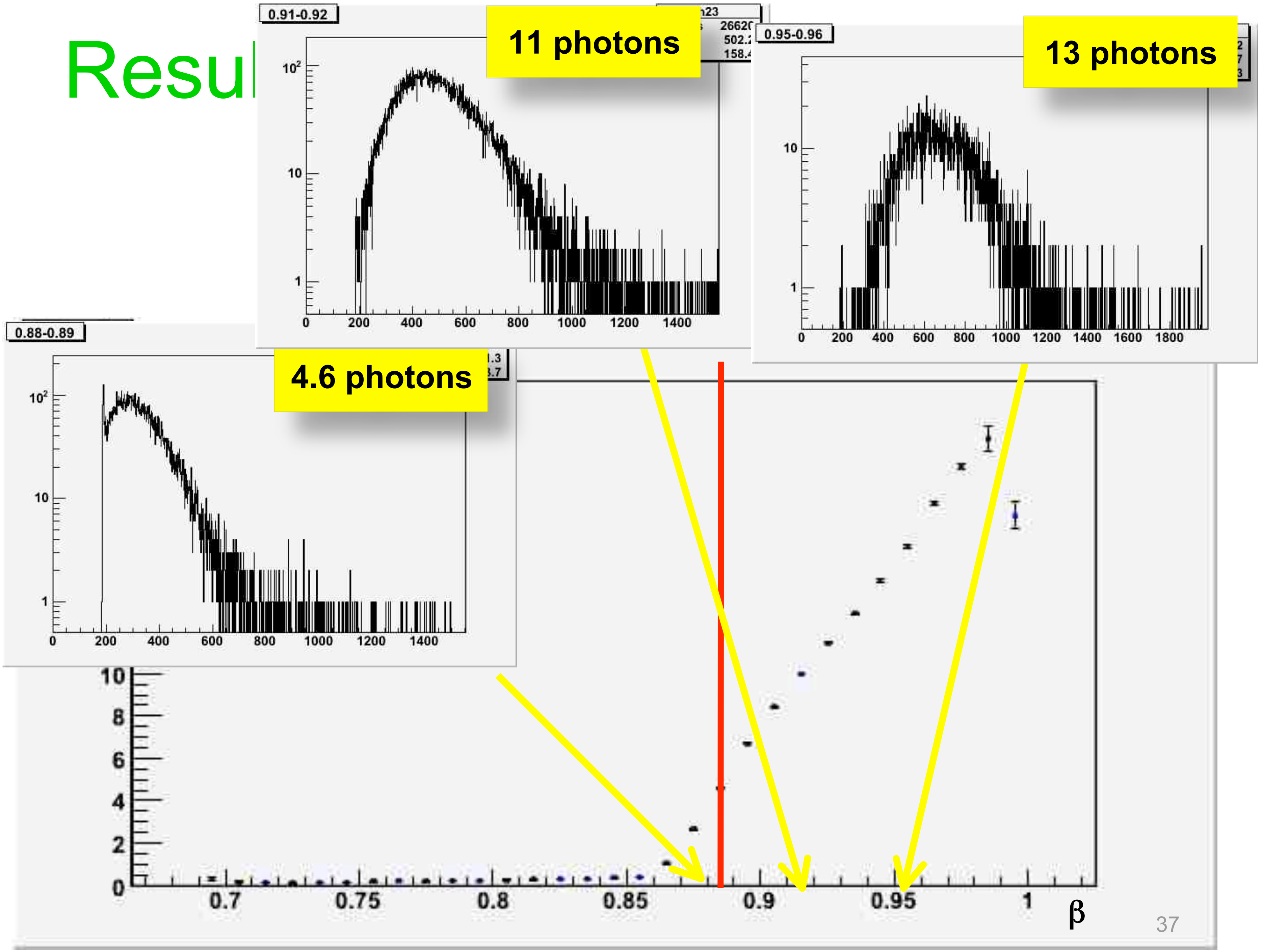
TOF between T1-T2 (~7.5m)

- measure β ($\delta\beta$~0.0025)

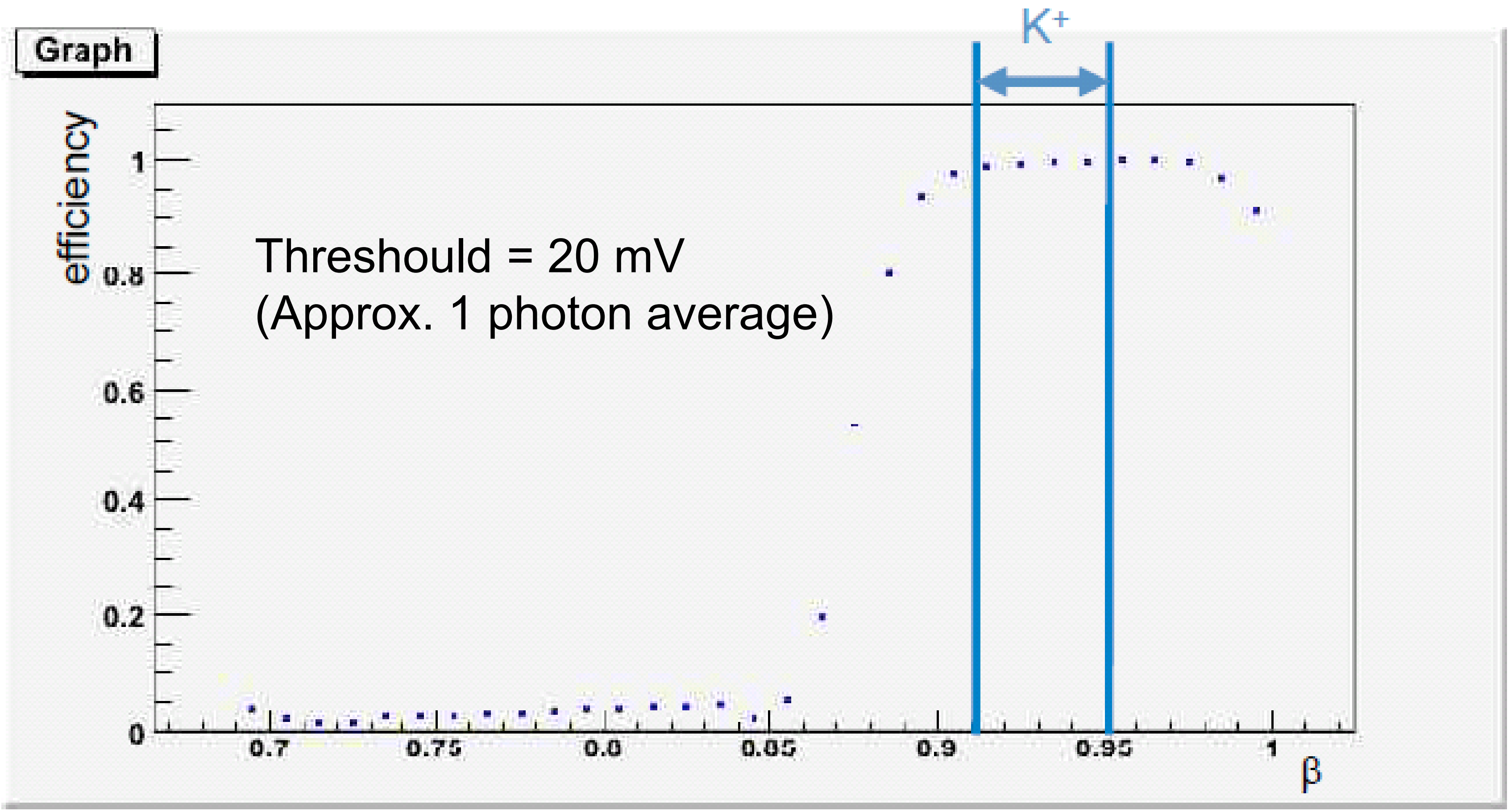
Measure Cherenkov light yield as a function of β

- turn on curve near threshold
- determine n for actual counter

Resul



Result (2) – efficiency curve



efficiency < 5% for β < 0.85 (1.5 GeV/c for proton)

n=1.13 is OK, slightly lower n is better

Summary

- Measurement of Ξ-atomic X rays
  - Aiming to establish the method
- Online calibration
  - LSO active source method worked.
  - Precision down to 0.05 keV is possible, 0.06 keV demonstrated in the test exp. at LNS.
- Background estimation is strengthened using data from other experiments.
- Prototype Cherenkov counter worked very well.
- We are confident on the feasibility of the experiment.

Backup slides

Run strategy

performance test using low intensity beams

1. Trigger rate
2. Performance of KURAMA spectrometer
   - High beam intensity can be mimicked by artificially worsening K/π ratio.
3. Performance of Ge detectors
4. Backgrounds, especially, possible line background.
5. Check on accuracy of X-ray energy determination

We need ~1/10 of requested total beam (1×10^{11} K^-)

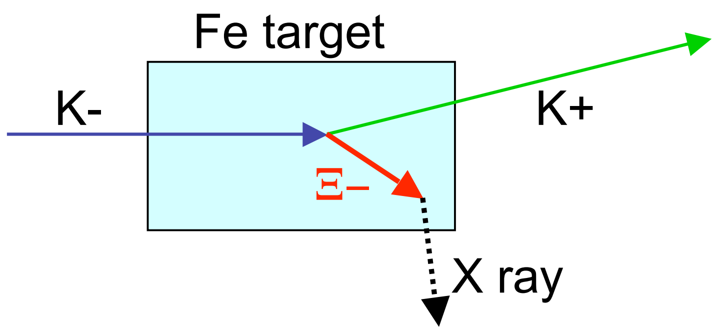
– e.g., 10 days with 4×10^5 K^-/spill

X ray in the test

- Could the X ray of interest [(6,5)→(5,4)] be seen?
  Yes, if the absorption of Ξ is very weak.
  - X-ray emission probability: 10% → 40%
  - Width is 0
    →1000 count peak expected, FOM = S/sqrt(S+10N) =17
  - If seen, we would use heavier target (Co, Ni,...)
- (7,6)→(6,5) transition
  - Not affected by strong interaction
    → Always expected to be seen.
  - 720 counts expected, FOM = S/sqrt(S+10N) = 10
  - Its energy can be precisely calculable
    → good test of our accuracy of energy determination.

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

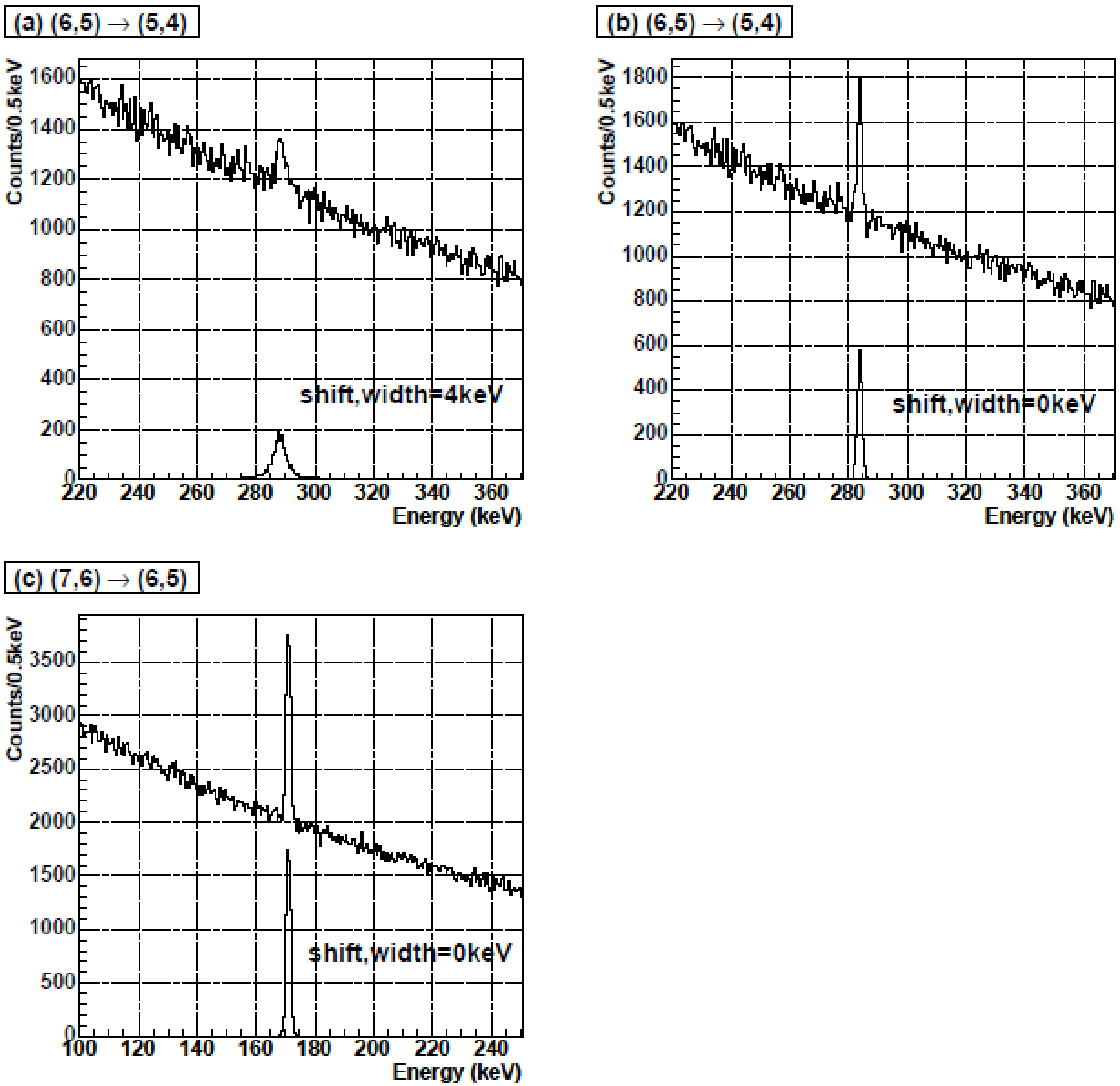
Yield estimation

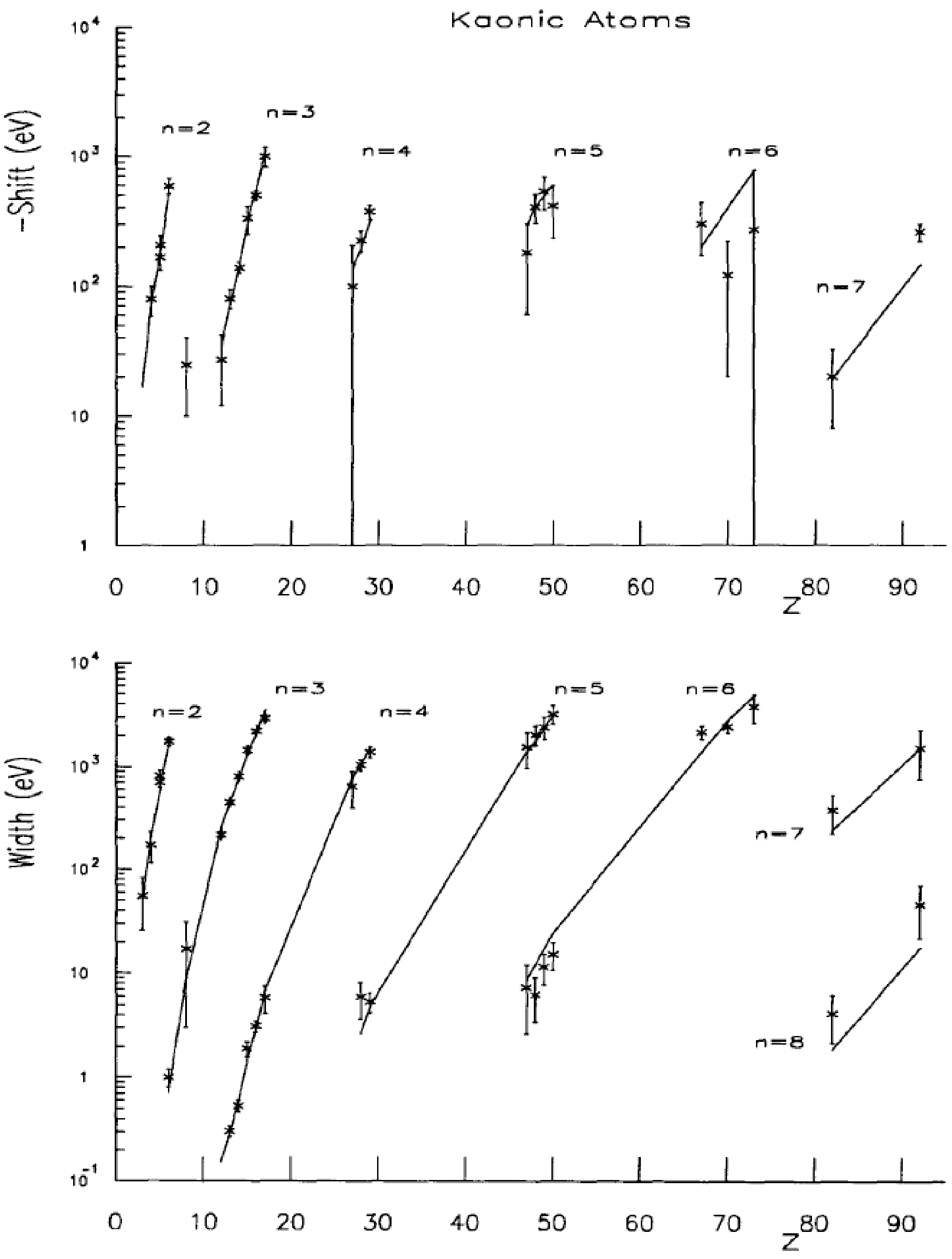
$Y = N_K \times \sigma_\Xi \times t \times \Omega_K \times \varepsilon_K \times R_\Xi \times R_X \times (1-\eta_X) \times \varepsilon_X \times \varepsilon_o$

- Beam: N_K (total number of K-) = 1.0×10^{12}
- Target:
  - σ_Ξ: (differential) cross section = 180 μb/sr
    Taken from Iljima 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)

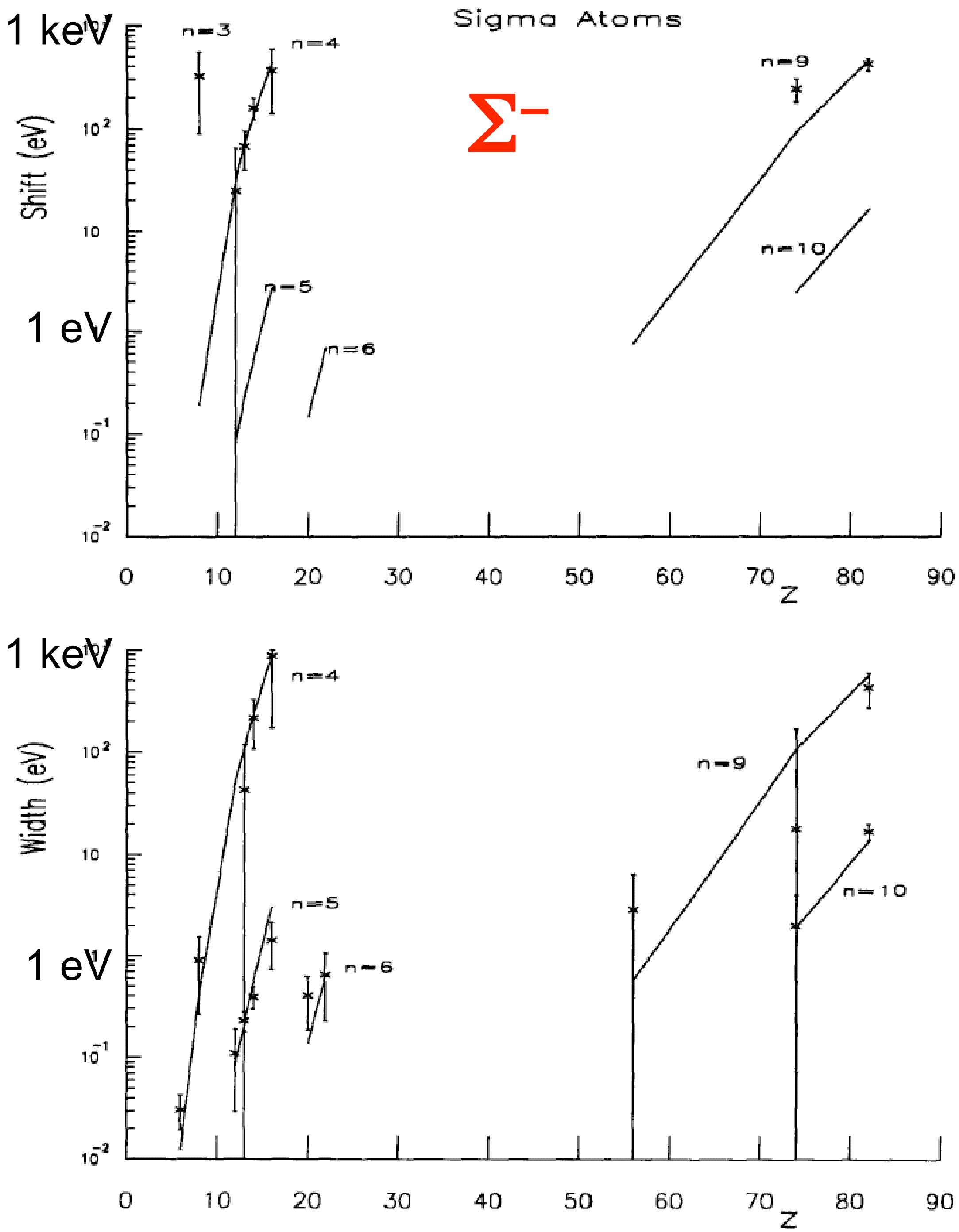
- K+ spectrometer
  - Ω_K: acceptance = 0.2 sr
  - ε_K: detection efficiency = 0.51
    (taken from the proposal of BNL-AGS E964)
- X-ray detection
  - ε_X: X-ray detection efficiency = 8%
    [16% (GEANT4 simulation) x 0.5 (in-beam live time)]
- Others
  - ε_o: overall efficiency (DAQ, trigger, etc.)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

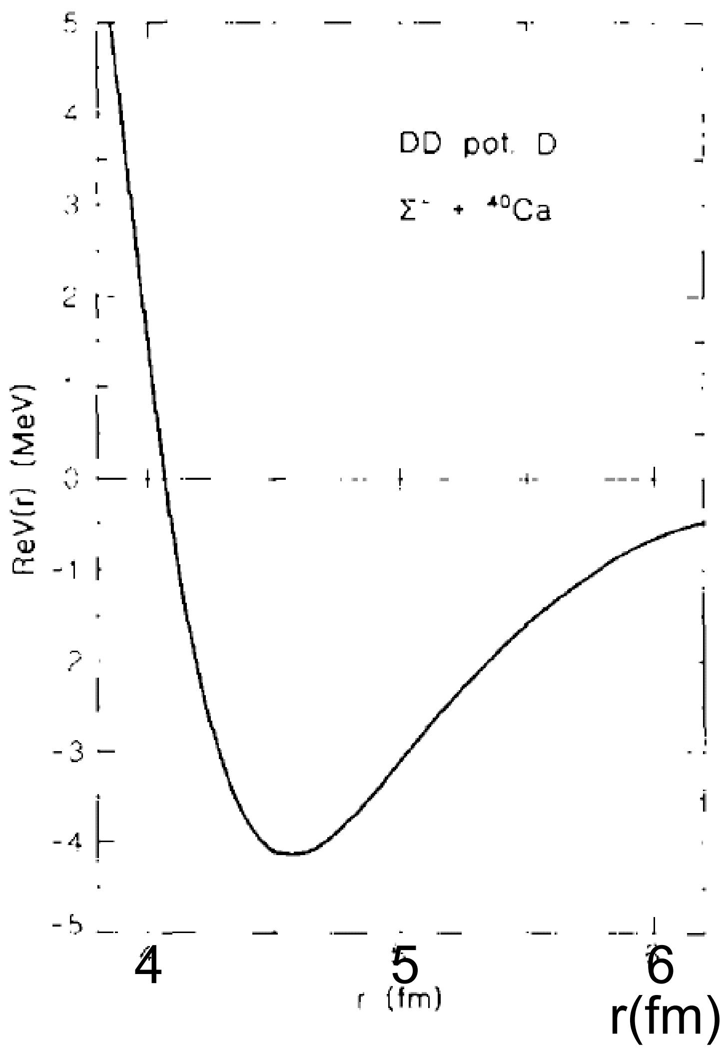
Expected X-ray spectrum





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