Precision spectroscopy of Kaonic Helium *3d*→*2p* X-rays

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for KEK-PS E570 collaboration

KEK-PS E570 collaboration list

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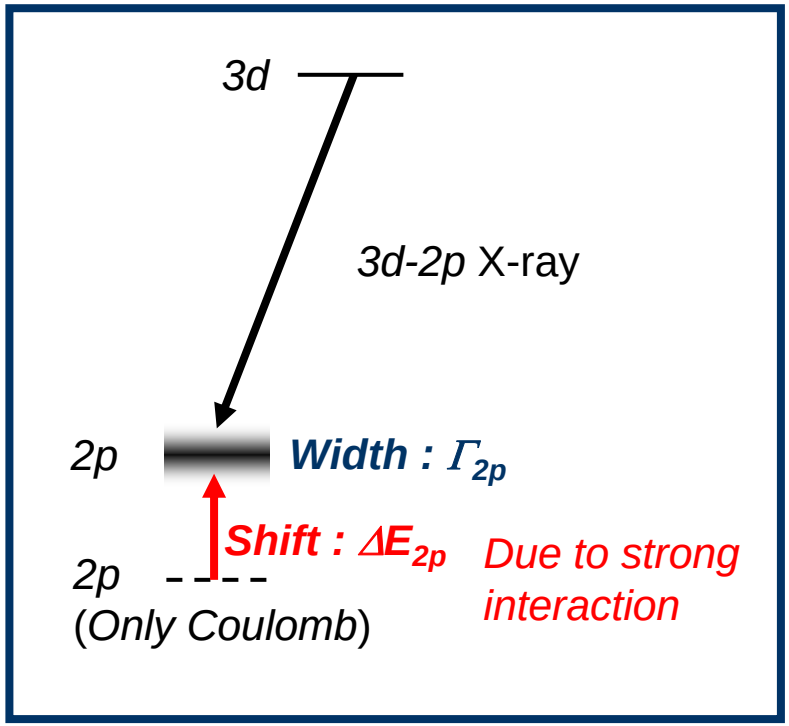
Introduction

Last orbit level shift of Kaonic atom

Last orbit level shift of Kaonic atom is sensitive to **K-nucleus strong interaction**.

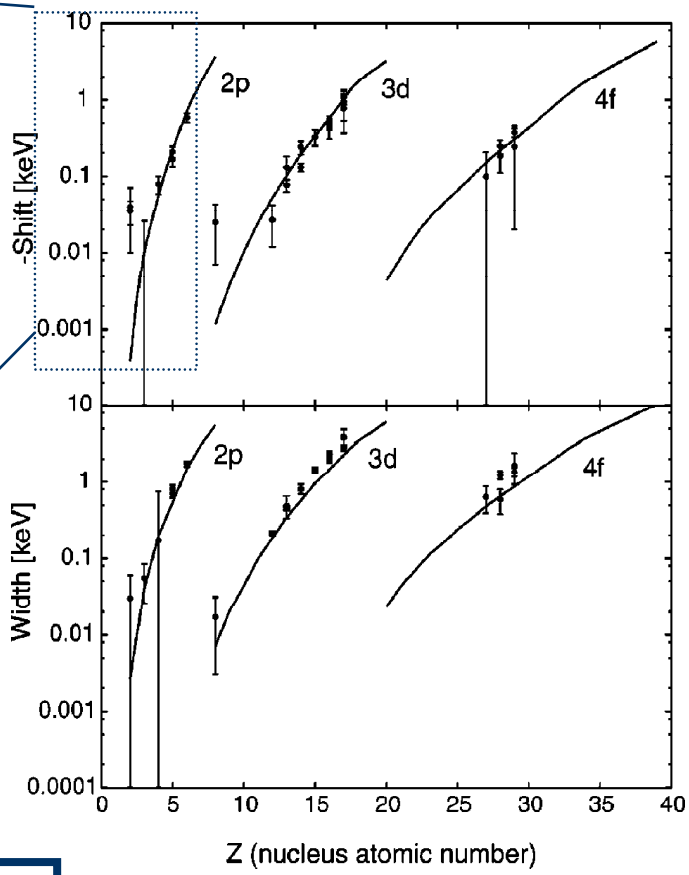


- Kaonic Helium atom:
  - Last orbit = *2p*
  - *3d*→*2p* shift : ?

→ Kaonic Helium Puzzle

The Kaonic Helium Puzzle

Last orbit energy level shift and width of kaonic atoms

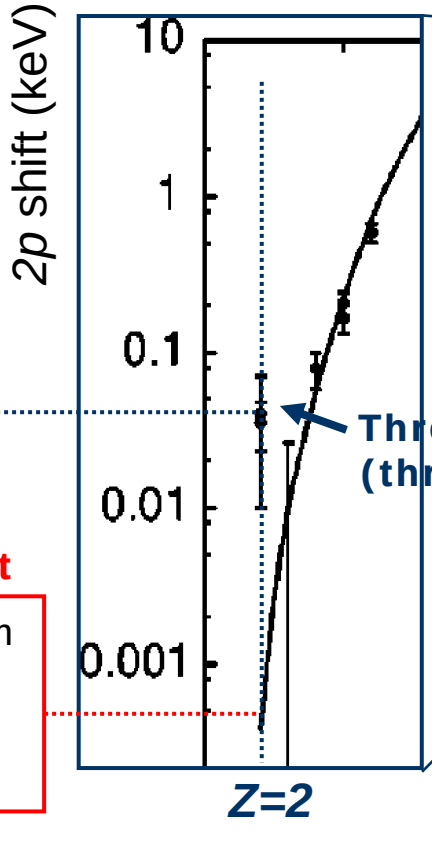


Very large repulsive shift

Exp.
~40eV

Very small shift

Calculation from chiral unitary+ optical model:
~0.2eV

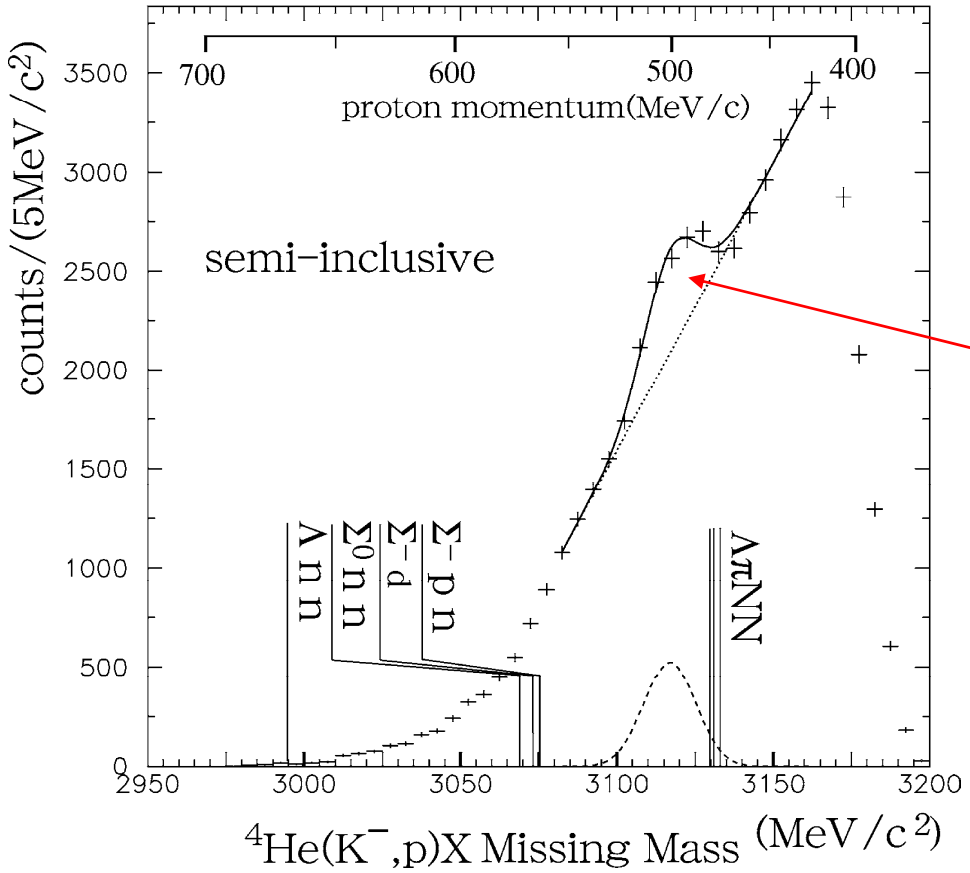


Three data points (three exp.)

No theory can reproduce such a large shift (~40eV) !

S.Hirenzaki, Y.Okumura, H.Toki, E.Oset, and A.Ramos
Phys. Rev. C 61 055205

Physics motivation



$S^0(3115)$
Mass : 3117MeV
Strangeness : -1
Isospin : 1

@ KEK-PS E471

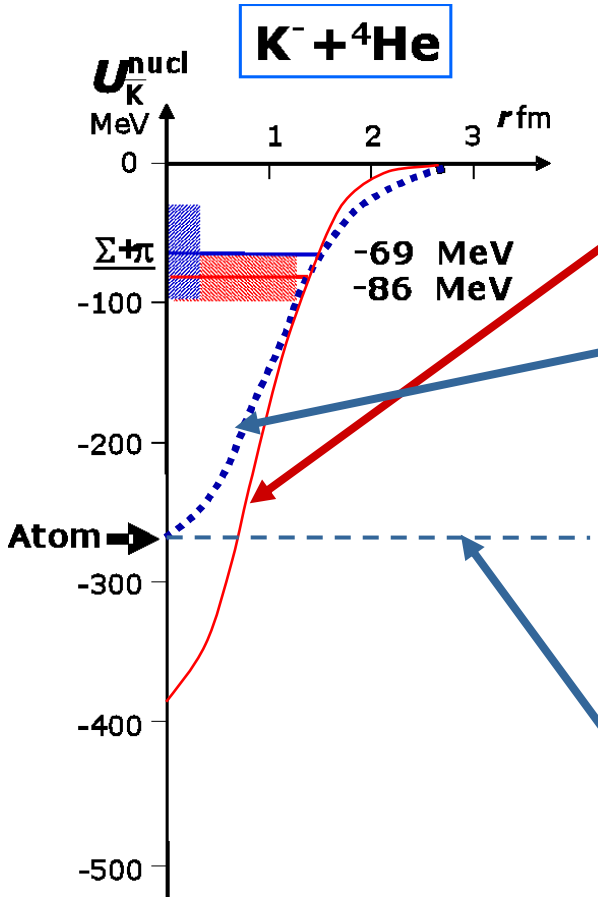
T.Suzuki *et al*,
Phys. Lett. B597,
263 (2004)

Is this interpretable as Kaonic deeply bound state ($T=1, K^-pnn$)?

K-nucleus potential information

Y.Akaishi,
EXA05 proceedings (2005)

which can be extracted by the data of
"Kaonic nuclei and atoms"



Kaonic nuclei
→ the shrunk-core potentials

Kaonic atoms
→ the unchanged-core potentials

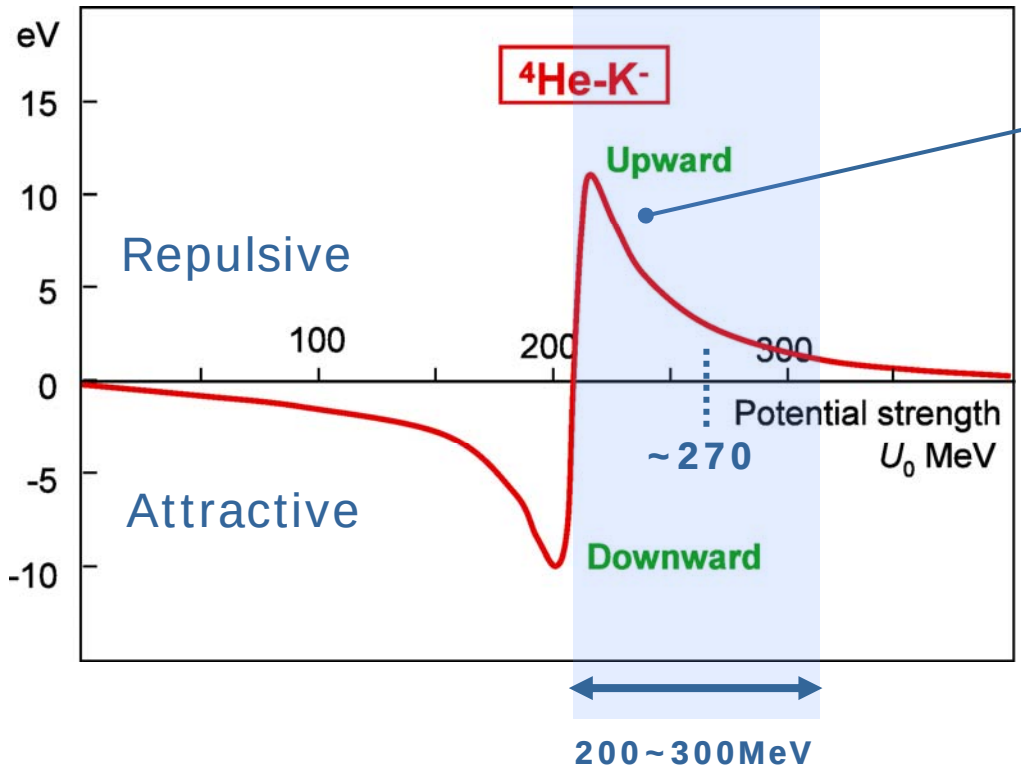
More directly related to the free KN interaction with less medium modifications.

Unchanged-core potential
depth for K^--He = **~270MeV**
(Akaishi and Yamazaki theory …"Deeply bound K")

A possible **large repulsive shift !**

with **"Deep optical pot. + Coupled-channel model"**

***2p* level shifts of the K^--^{4}He atom**



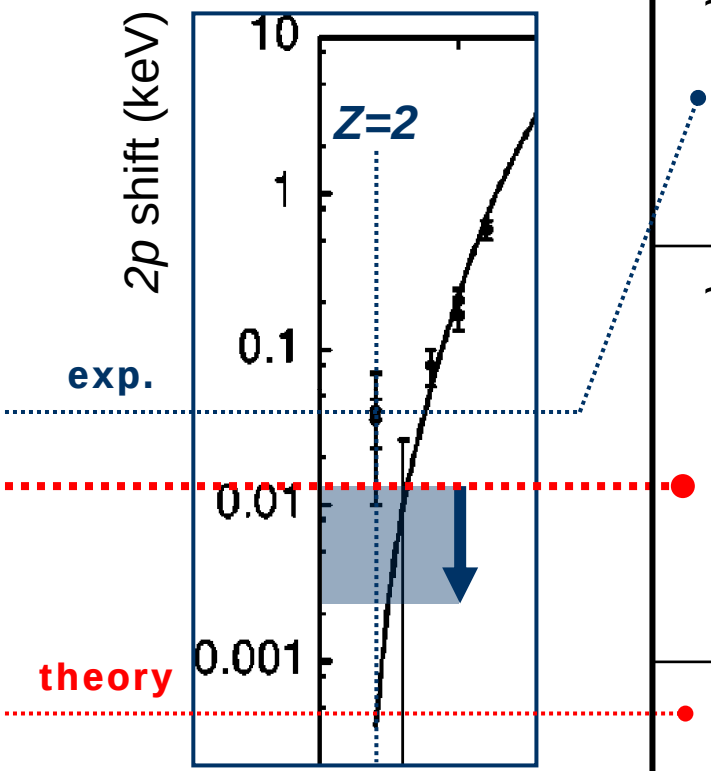
Repulsive shift for K^--^{4}He
< ~ 11 eV

Shift : ΔE^{cc}_{2p} = **-11eV**
(at a maximum)
Width : Γ^{cc}_{2p} = 21eV

Y.Akaishi, EXA05
proceedings (2005)

If the measured *2p* energy shift were...

Kaonic Helium Puzzle



2p level shift of kaonic helium4 atom

Shift	Significance
~ -40 eV	■ Consistent with three past experiments. ■ Existing theory cannot reproduce the large shift.
~ -11 eV	■ A strongly attractive potential (deep K system) will be justified. ■ X-ray data **endorses** the picture that $S^0(3115)$ being a kaon-nucleus bound state.
~ 0 eV	■ No rigid constraint to existing theories.

Experiment

2p level shifts of the K^--^{4}He atom

Three early experiments

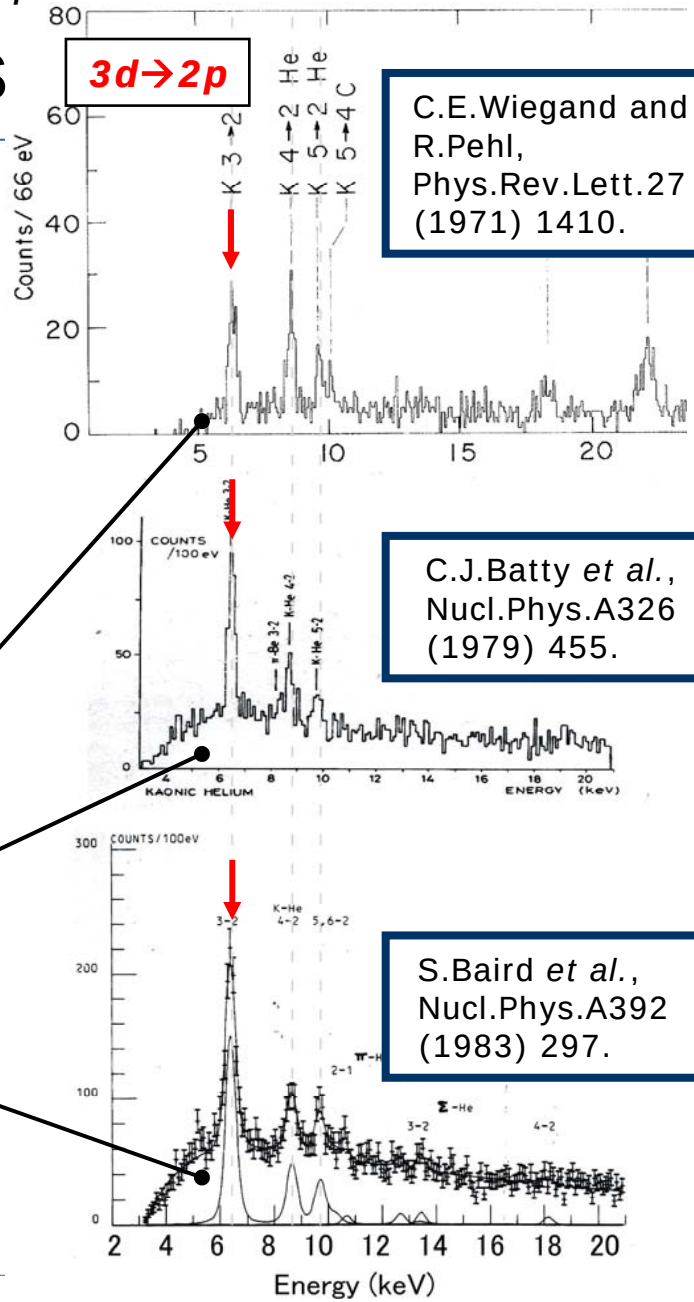
Exp.

ΔE_{2p} (eV)	Γ_{2p} (eV)
-41 ± 33	–
-35 ± 12	30 ± 30
-50 ± 12	100 ± 40
Average -43 ± 8 eV	55 ± 34 eV
Shift	Width

⇨ **Very large repulsive shift**

- Large background
- No in-beam energy calibration

etc...



KEK-PS E570 experiment

- Measure the strong-interaction shift of K^--^{4}He 3d→2p X-rays with a precision better than 3 eV

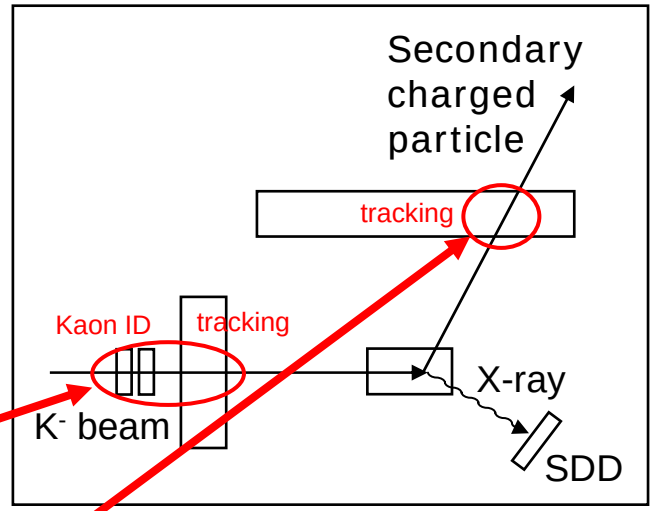
- Using X-ray detector "SDD" mounted inside the helium target (same as E471/E549)

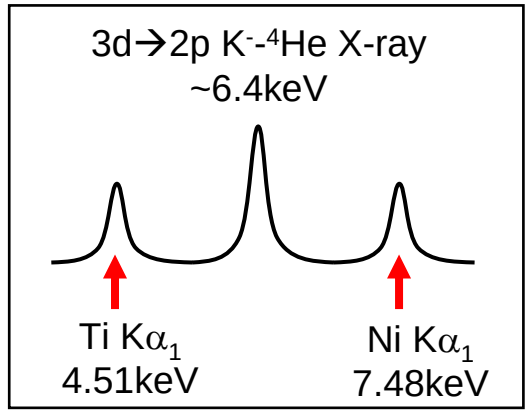
- Stopped K^- reaction on Liq. ^{4}He target

Experimental feature

- **Silicon Drift Detector (SDD) :**
  for high-resolution X-ray energy measurement
- **Fiducial volume cut :**
  by means of kaon stopping position measurement with
  - kaon tracking detectors
  - drift chambers for secondary particles
- **In-beam energy calibration :**
  using characteristic X-rays from titanium and nickel foils (accurate in-situ calibration)

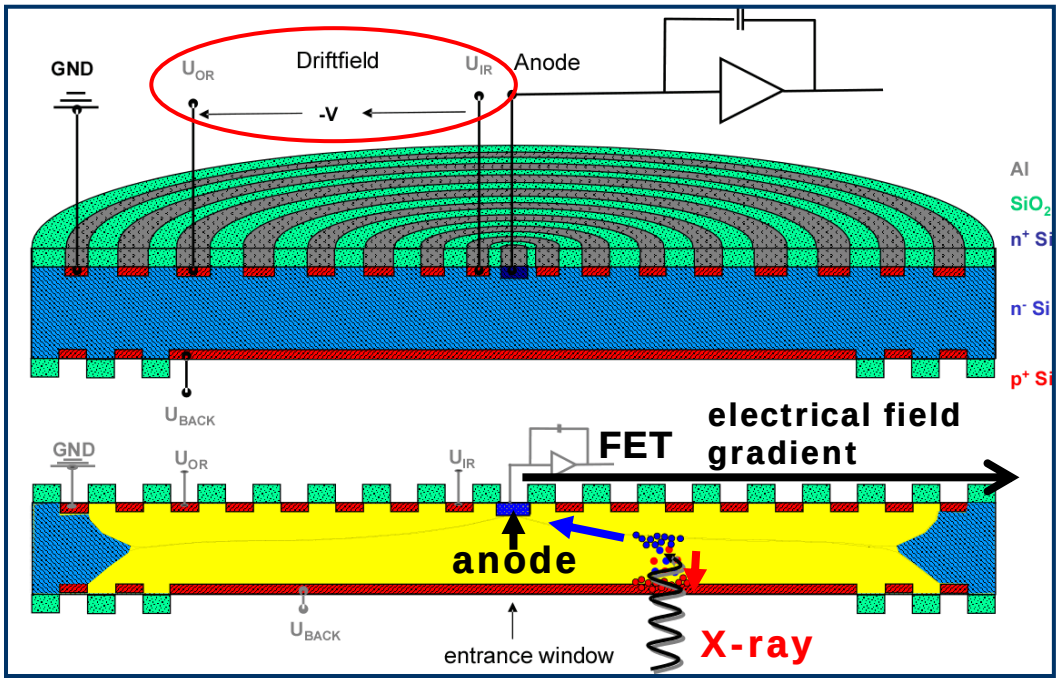
Schematic drawing of E570



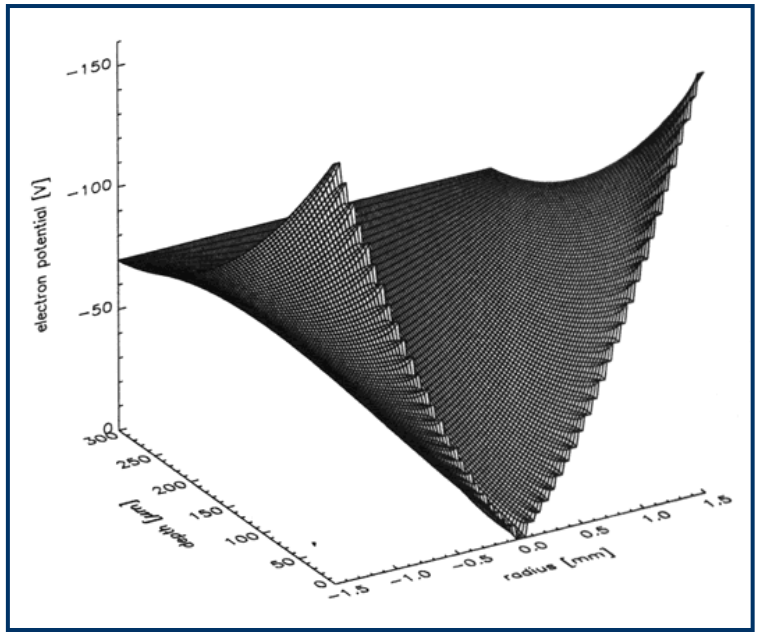


SDD (Silicon Drift Detector)

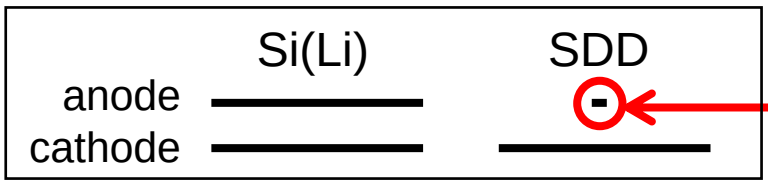
Schematic drawing of a SDD



Simulated potential energy distribution in a SDD



electrode type



$$Q = CV = (\varepsilon_0 S / d) V$$

Small capacitance

SDD feature

- **Small capacitance** (small anode)
  - **Good energy resolution**
  - **Thin active layer**

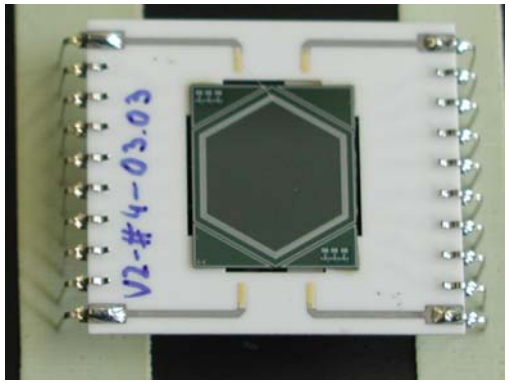
  (0.26mm<<4mm in previous exp.)

  → Good reduction of main background due to the fake X-ray signals from soft Compton scattering

  → **Good S/N**

$$Q = CV = (\varepsilon_0 S / d) V$$

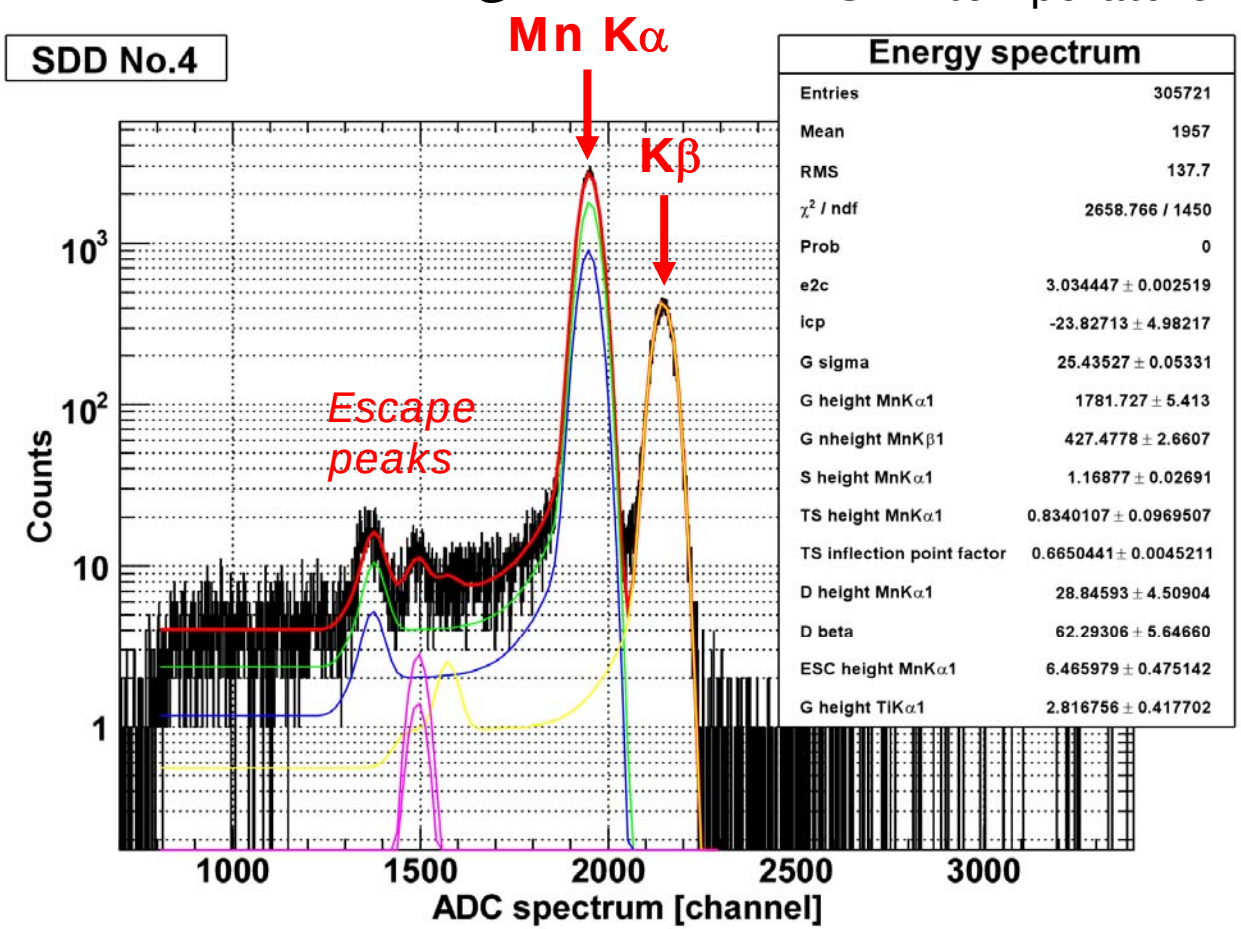
- **Large effective area** (100mm^2)



KETEK 100mm^2 SDD

Typical resolution (with ^{55}Fe source)

Test setup
- Same experimental setup with that of E570
- SDD temperature : 85K



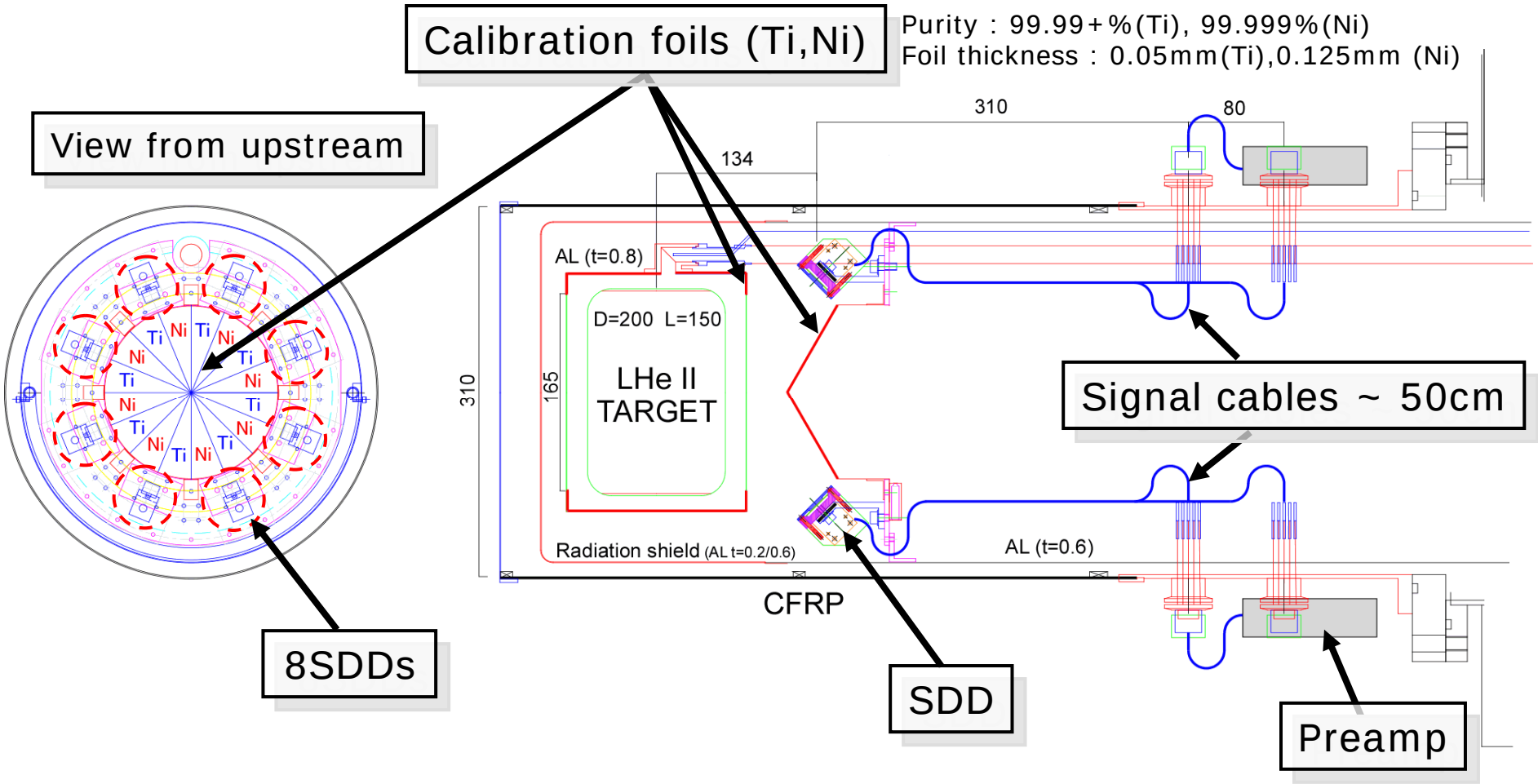
FWHM
= 181.8±0.41eV
@MnKα_1=5.899keV
→ 185 eV @6.5keV

(past exp:
~300eV @6.5keV)

$$\mathrm{FWHM} = 2.355w\sqrt{W_N^2 + \frac{FE}{w}}$$

Fano Factor : F=0.12
An erectron-hole pair creation energy in Si(77K) : w = 3.18eV
White noize : WN = constant

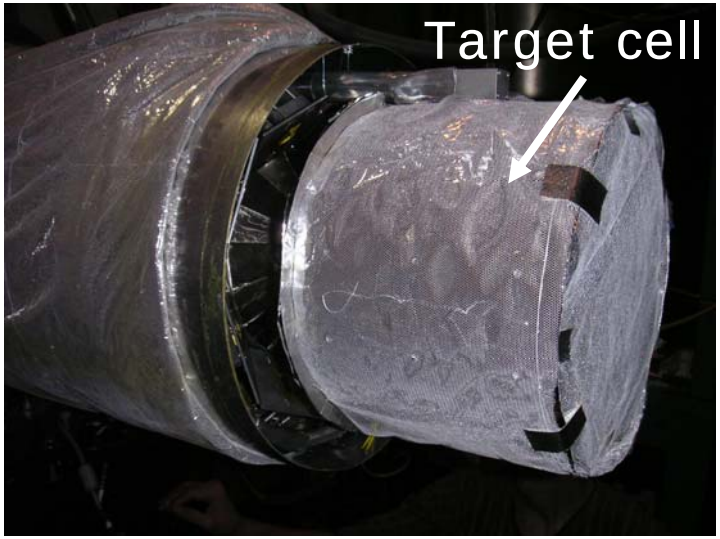
E570 setup (SDD and L-HeII target)

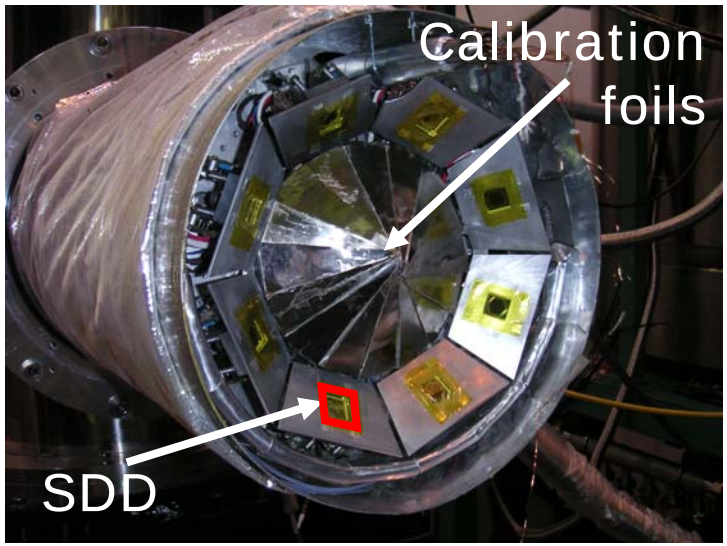


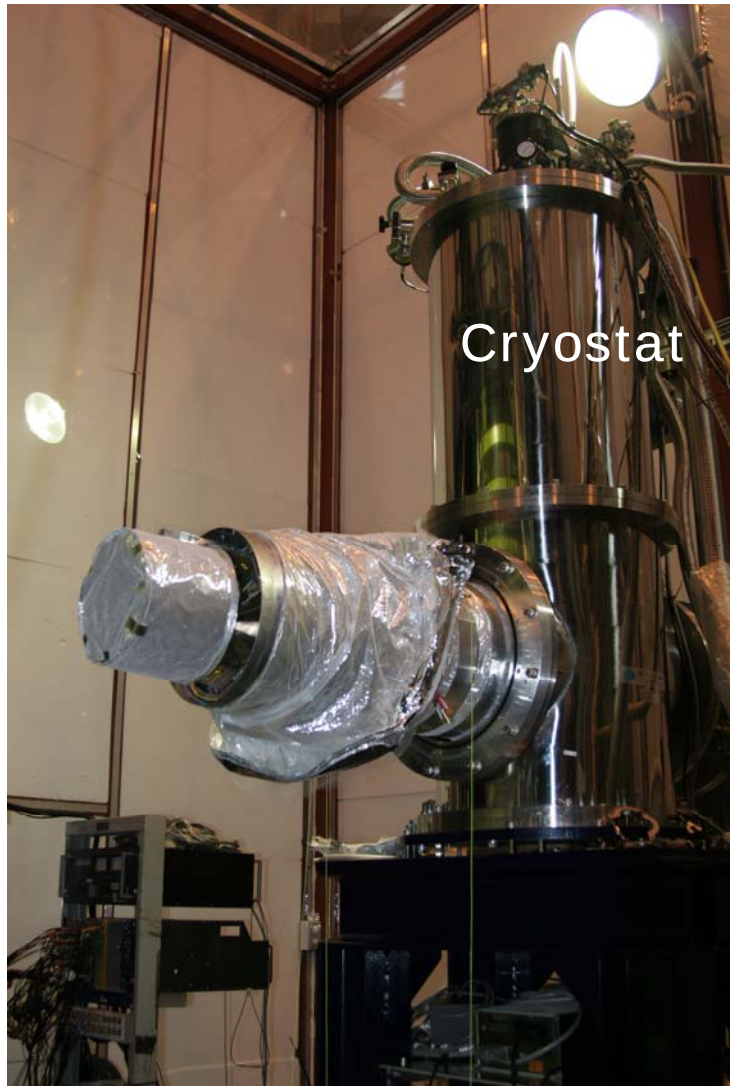
Kaon beam direction

To avoid background X-rays from other materials (Fe etc.), pure Aluminum foils were installed around the SDDs.

Setup pictures





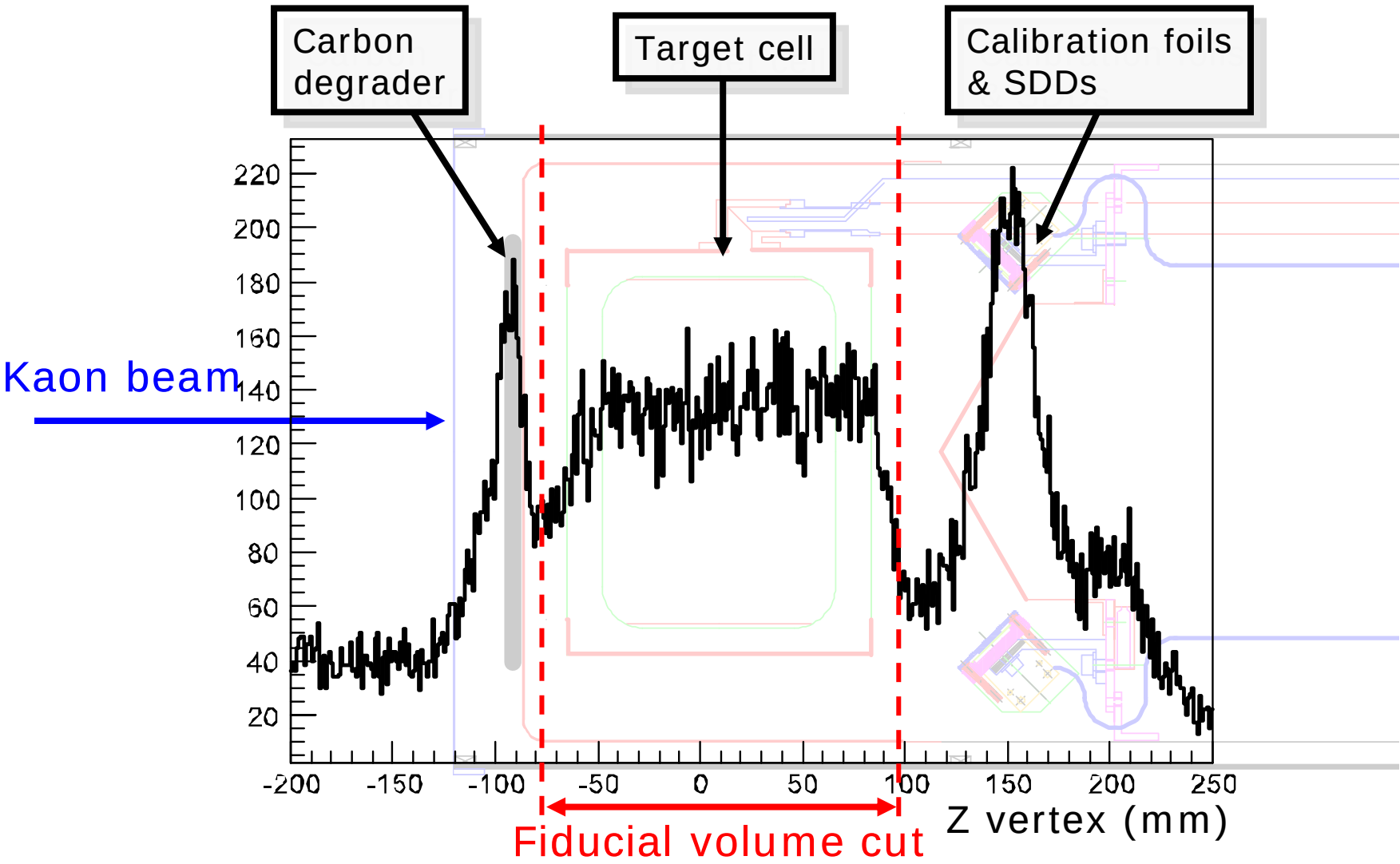


Experimental condition

- Experimental period :
  - October, 2005 (first cycle) ... ~ one month
  - December, 2005 (second cycle) ... ~ two weeks
- Trigger :
  - (stopped K^-) * (secondary charged particles)
  - SDD self trigger
- Beam (@KEK-PS K5 beamline):
  - π/K ratio : ~ 200
  - (stopped) Kaon beam : 4k/spill (trigger level)
    → total : ~3G stopped K^-
- SDD
  - SDD temperature : ~85K
  - SDD preamp : water cooling @6~7 degrees C
  - Typical SDD hit rate : ~ 1k / spill for each SDD

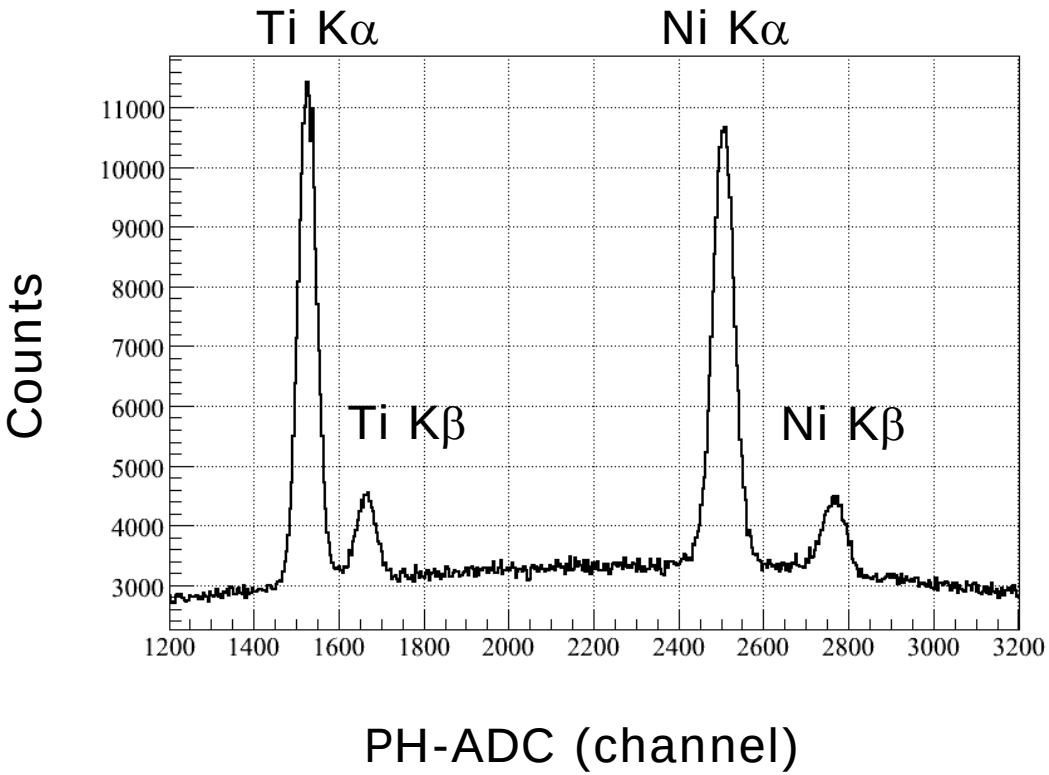
Preliminary result

Target image and fiducual volume cut



Typical spectrum for self trigger events

- For Typical 1 SDD
- All runs (E570 2nd cycle)

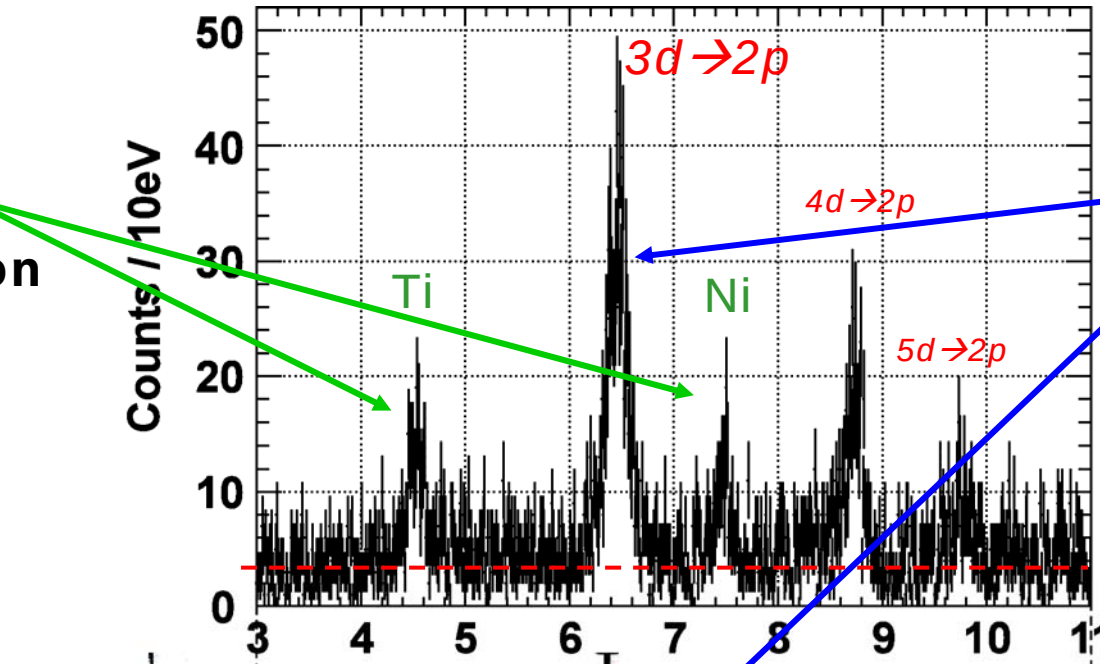


→ Energy calibration (gain adjustment) : for about every 8 hours.

Preliminary spectrum

(Comparison with a past experiment)

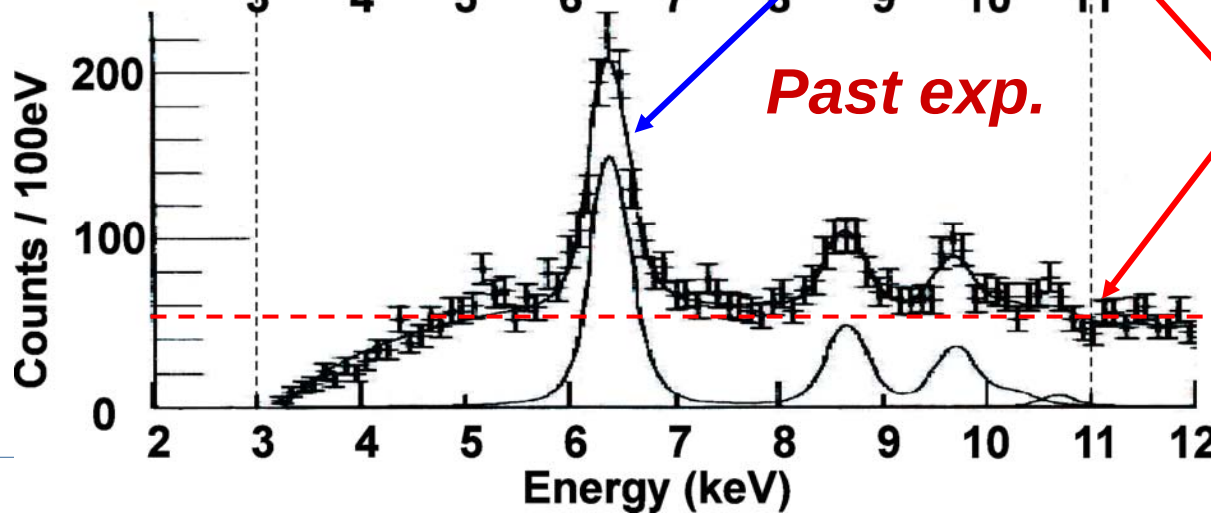
In-situ Energy calibration



High resolution

~300eV → ~180eV FWHM@6.5keV

- K stop trigger event
- E570 first cycle data
- For all SDDs
- Fiducial volume cut



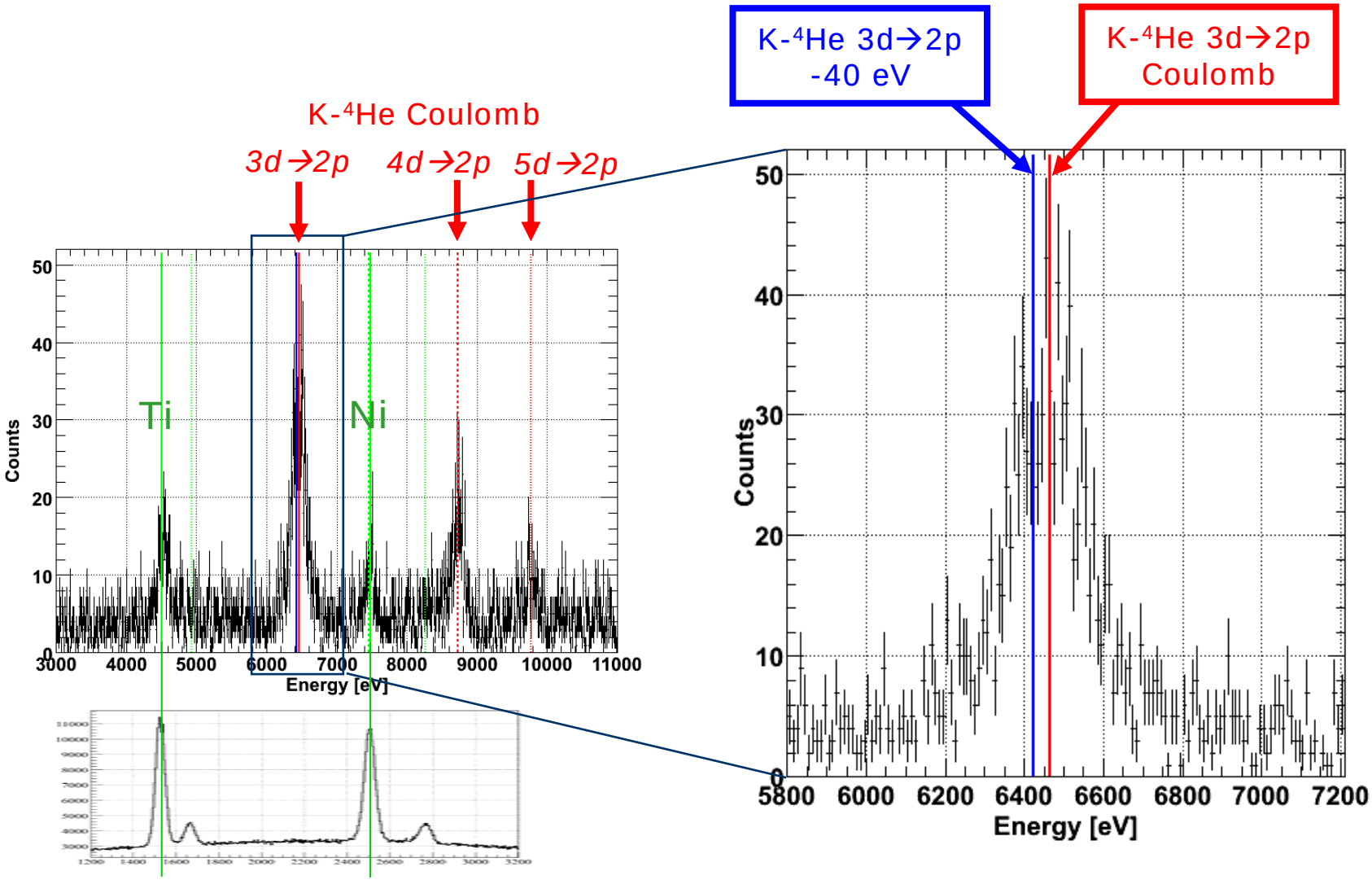
Good S/N ratio

~0.8 → ~6

for 3d→2p peak

S.Baird *et al.*, Nucl.Phys.A392 (1983) 297.

-40eV shift is very clearly rejected



Energy calibration →Using self trigger events

Summary

- Accurately measured K^--^{4}He *3d*→*2p* X-rays energy spectrum
  - High energy resolution : 185 eV @6.5keV
  - Good S/N ratio : applying fiducial volume cut (~6)
  - Energy calibration was successfully done using characteristic X-rays from Ti and Ni foils
- Cleary rejected -40eV (repulsive) shift reported in the three past experiments.

Spare

Comparison with past experiments

	E570 (present)	Past exp.
Resolution (FHWM)	~185eV @6.5keV	~300eV @6.5keV
Effective area	100mm^2 * 8 SDDs	300 mm^2
Detector Thickness	0.26mm → Good S/N	~4mm
Energy calibration	In-beam calib. (Ti,Ni)	Not in-beam calib.
Fiducial volume cut	Yes	No