June 2, 2007
(Nuclear physics at J-PARC)

Precision spectroscopy of Kaonic Helium X-rays

KEK-PS E570 :

Cycle 1 : October 2005

Cycle 2 : December 2005

RIKEN
Shinji Okada
for KEK-PS E570 collaboration

KEK-PS E570 collaboration list

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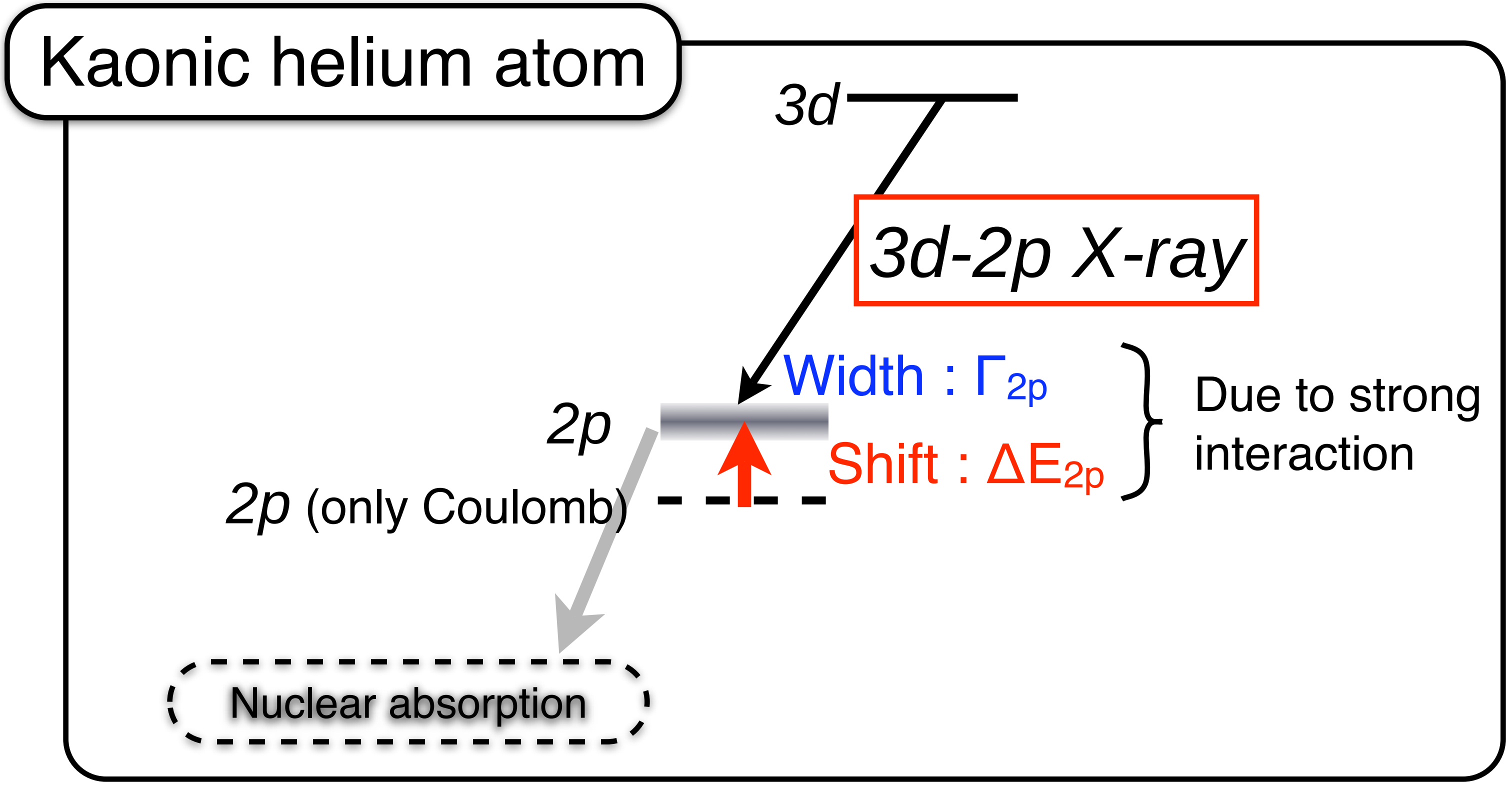
Introduction

What do we measure ?

Last orbit level shift of Kaonic atom is sensitive to
$\overline{K}$-nucleus strong interaction.

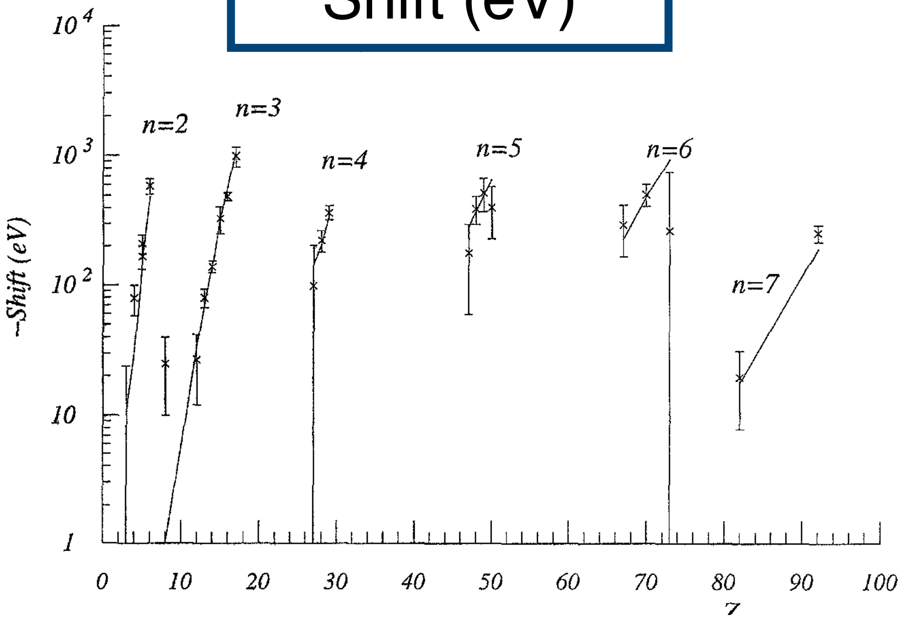


Precisely determine the $\overline{K}$-nucleus strong interaction at vanishing relative energy
-> many experiments have been done (from Helium to Uranium)

Kaonic atoms

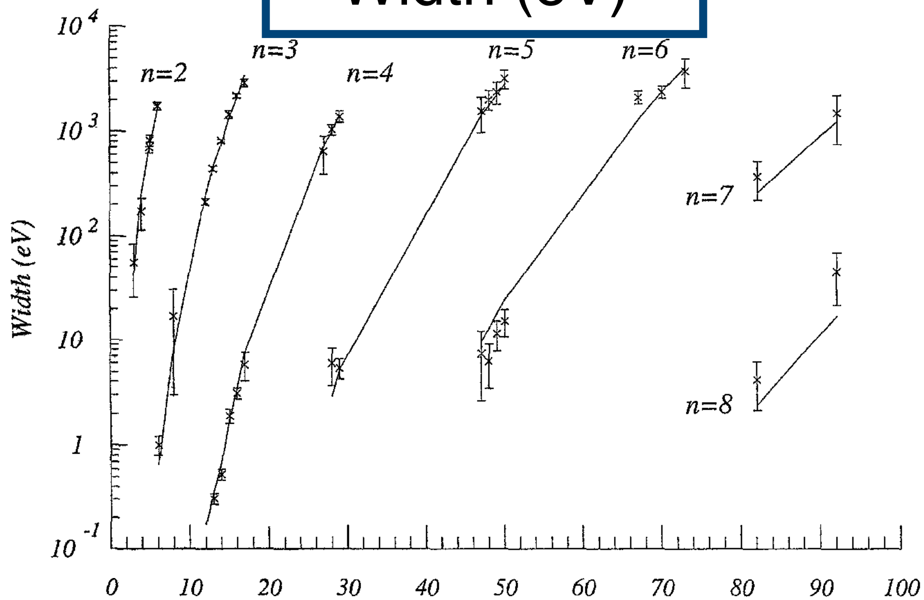
Last-orbit energy-level shift and width of kaonic atoms

Shift (eV)



Z (nucleus atomic number)

Width (eV)



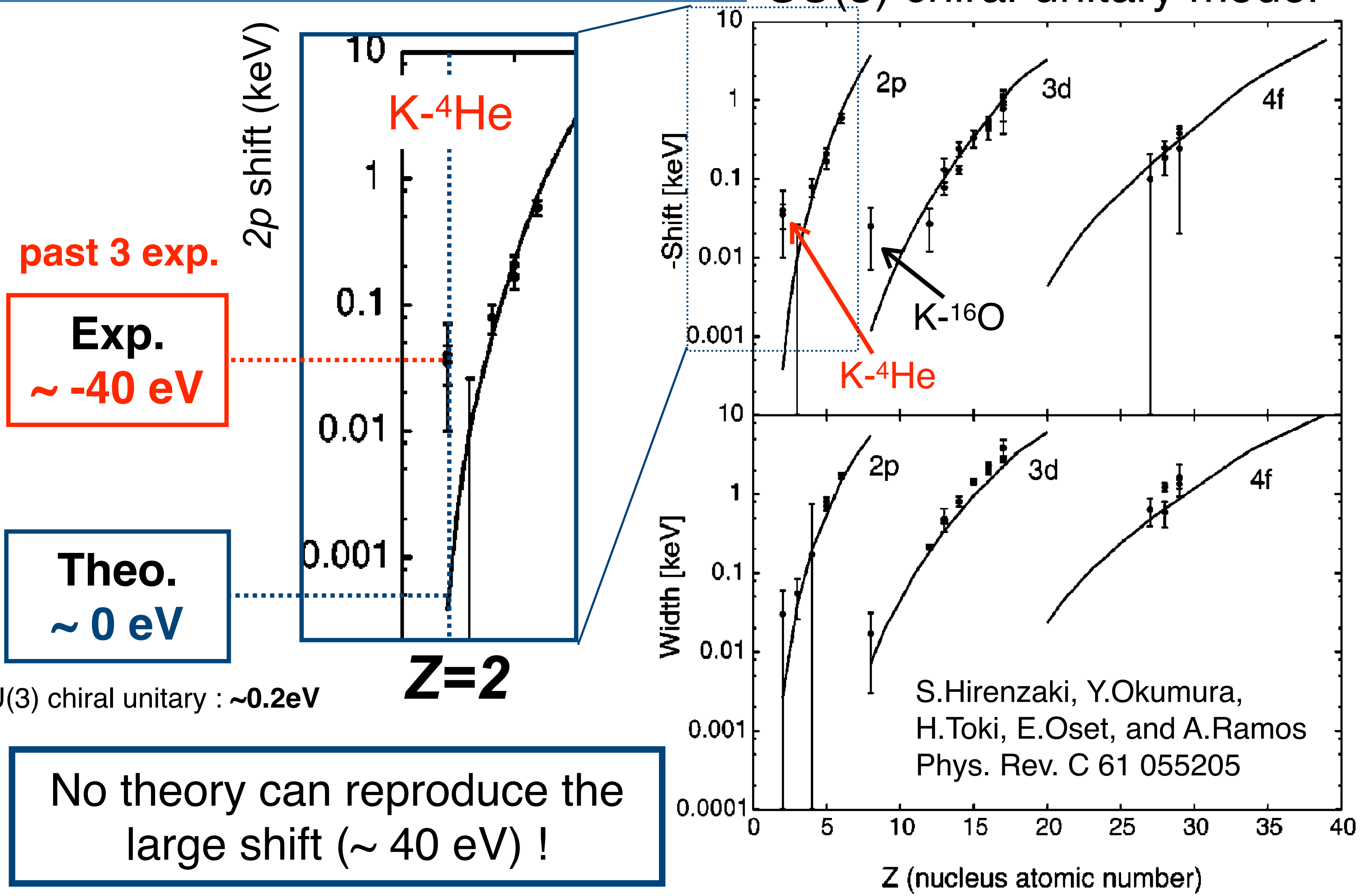
Z (nucleus atomic number)

fitted fairly well by optical-potential model

Batty, Friedman and Gal, Phys. Rep. 287 (1997) 385

The Kaonic Helium Puzzle

SU(3) chiral-unitary model



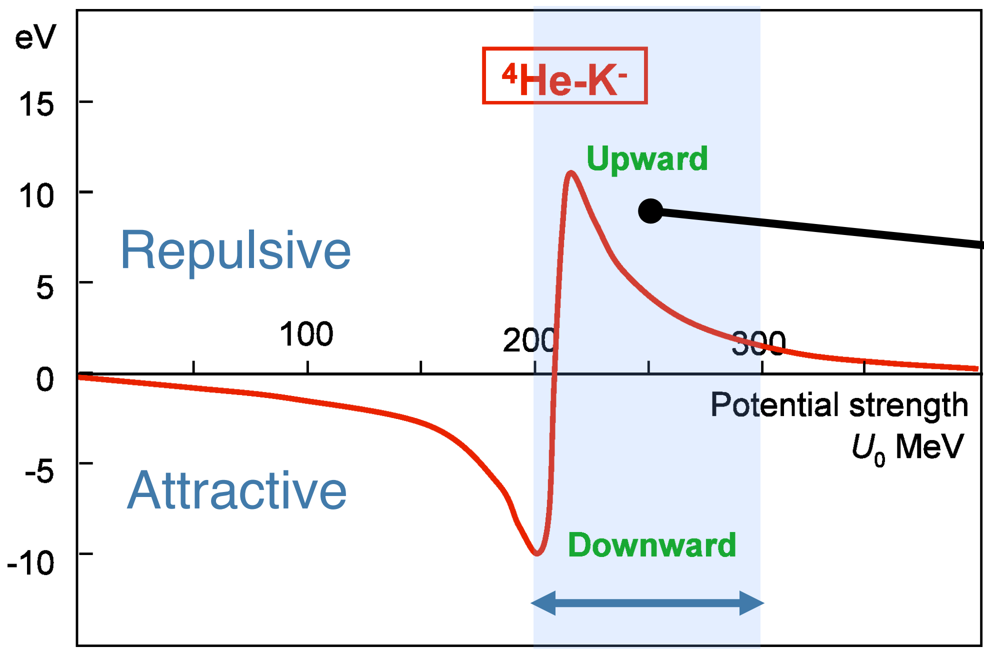
SU(3) chiral unitary : **~0.2eV**

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

A possible **large shift**

Coupled-channel calculation by Y. Akaishi
($\bar{K}N$ channel - $\Sigma\pi$ decay channel)

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



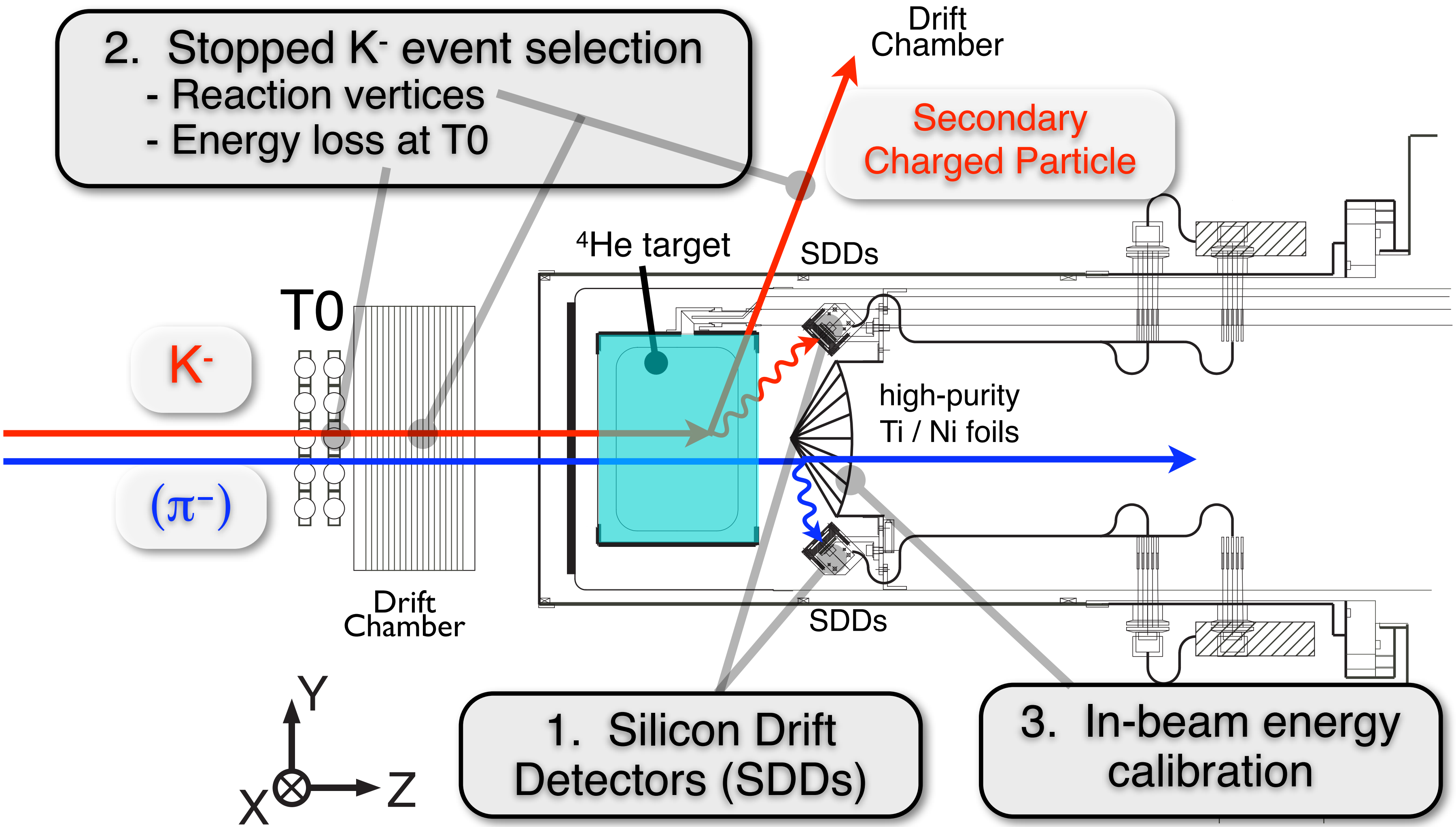
200~300MeV
Predicted region

Large shift is acceptable
$|\Delta E_{2p}|$ ~ 10 eV (at max.)

Y.Akaishi, EXA05 proceedings (2005)

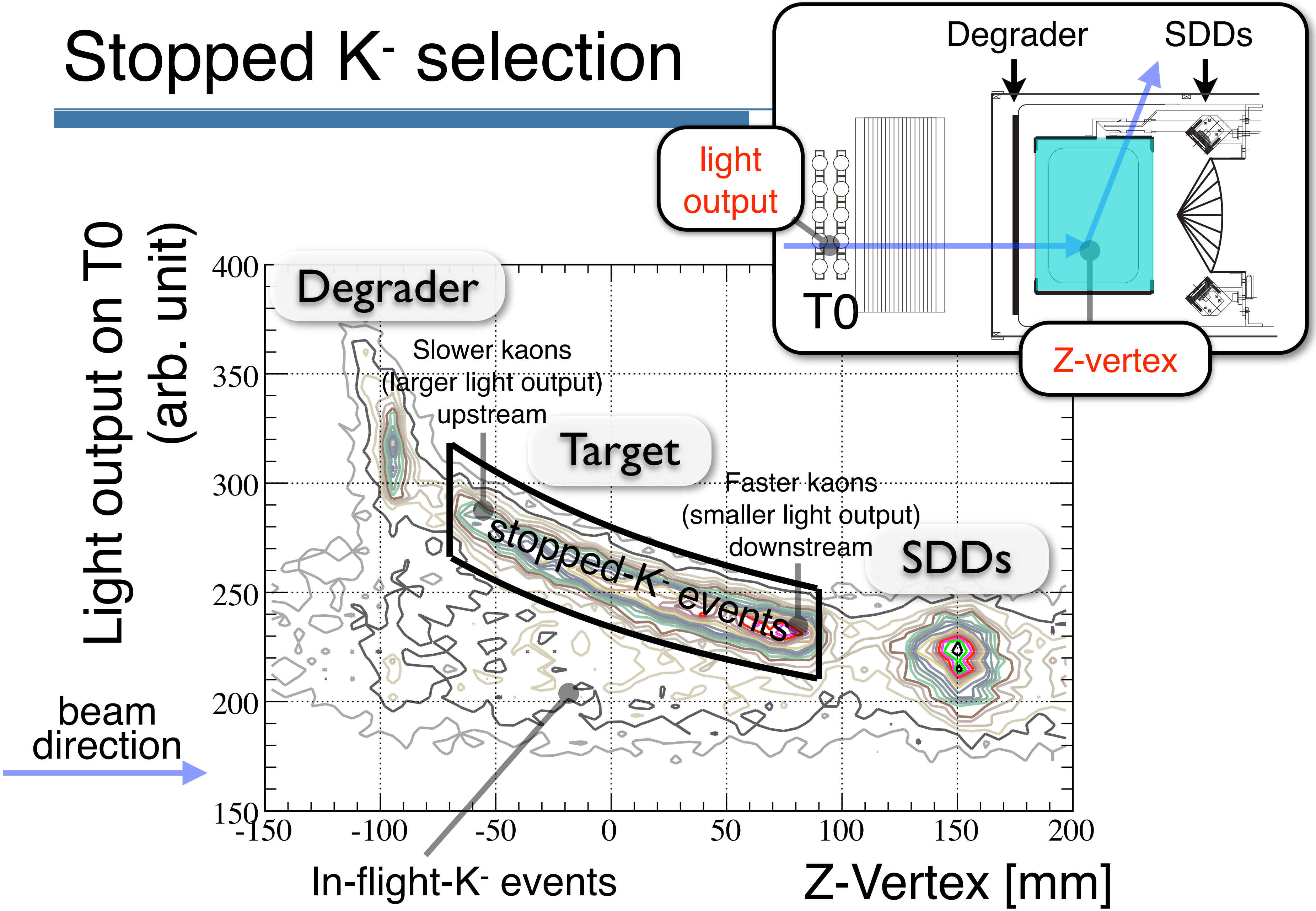
Experiment

Experimental setup



Analysis

Stopped K- selection

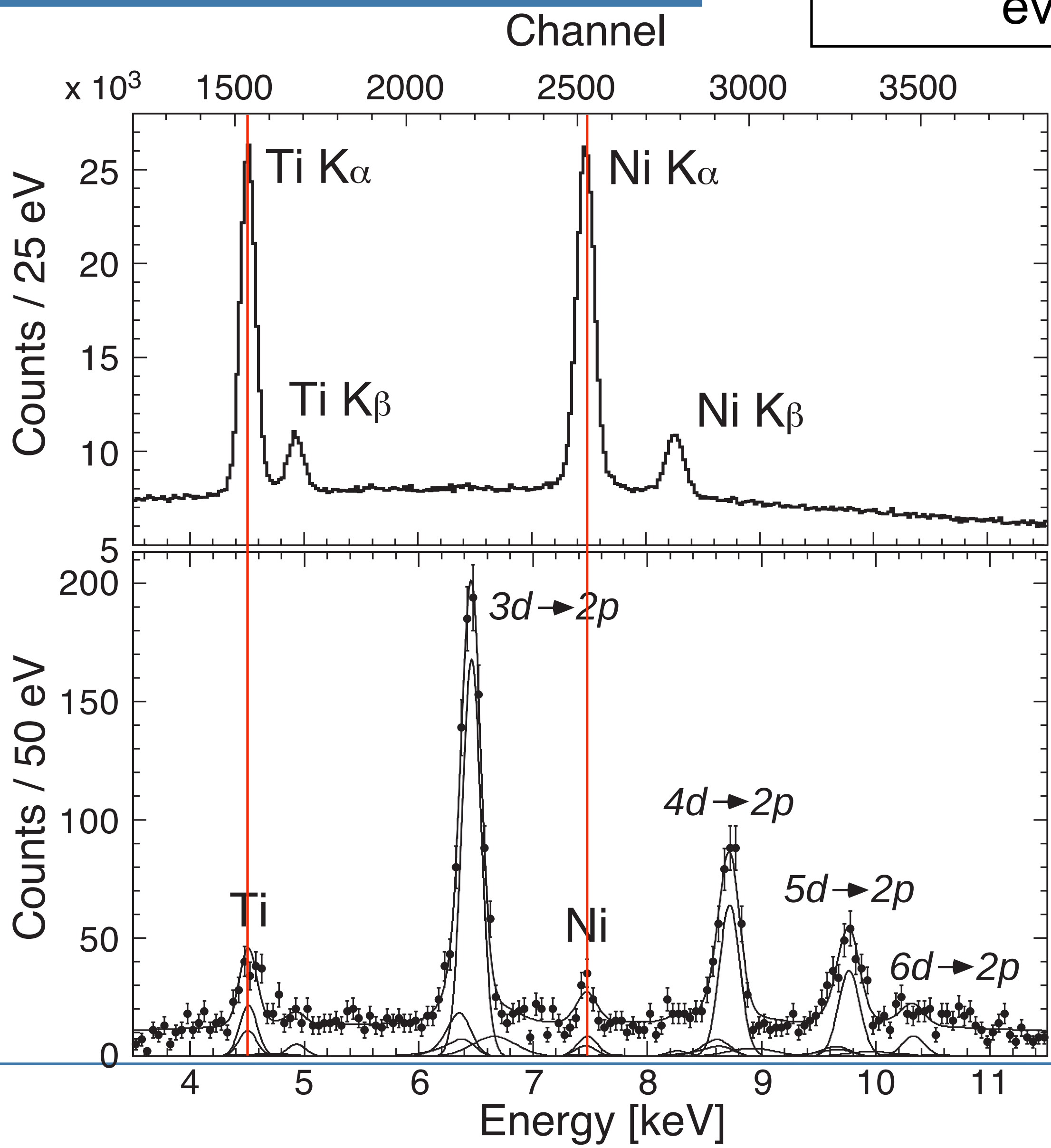


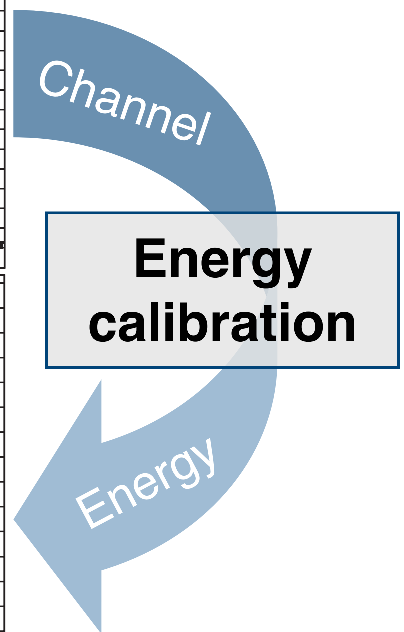
Energy calibration

Ti Kα : 5 ×10^2 / hour / SDD
Gain drift adjustment : every ~20 hours

SDD self triggered events

Stopped-K$^-$ triggered events

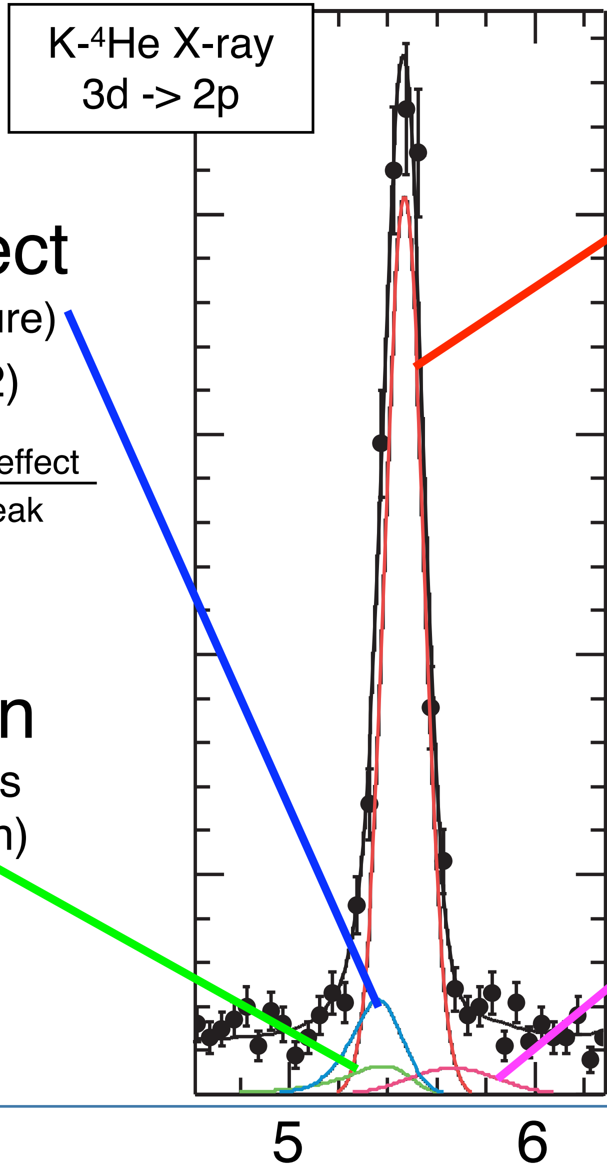




Spectral fitting

Fitting functions

Cycle 1 : 520 hours in Oct. 2005
Cycle 2 : 260 hours in Dec. 2005



1) Compton scattering effect

(low-energy tail structure)

~ 14 % (cycle 1 & 2)

Intensity ratio = $\frac{\text{Compton effect}}{\text{Main peak}}$

Main peak

(Voigt function)

Convolution of Gaussian & Lorentzian

Gaussian: Detector response

Lorentzian: for Natural width

3) Tail function

(empirically known as the response function)

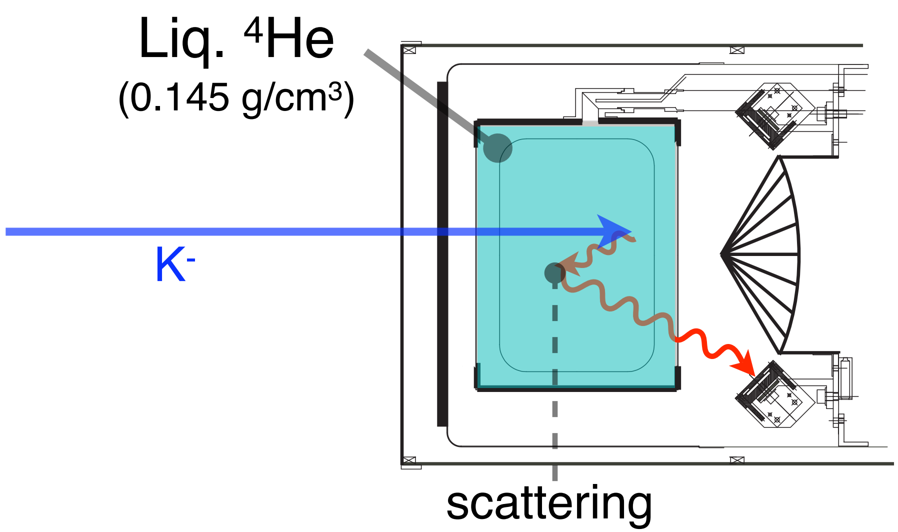
~ 4 % (cycle 1)
~ 3 % (cycle 2)

2) Pileup effect

~ 11 % (cycle 1)
~ 6 % (cycle 2)

This is spectrum for cycle 2

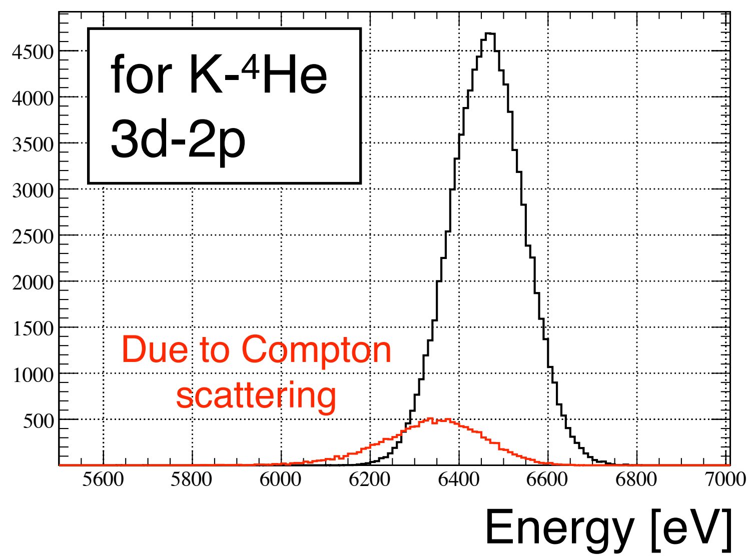
1) Compton scattering effect



Incoherent
(Compton) scattering

The cross section for liq. ^{4}He :
~ 1 barn/Atom @10keV

This cause the low energy tail structure.

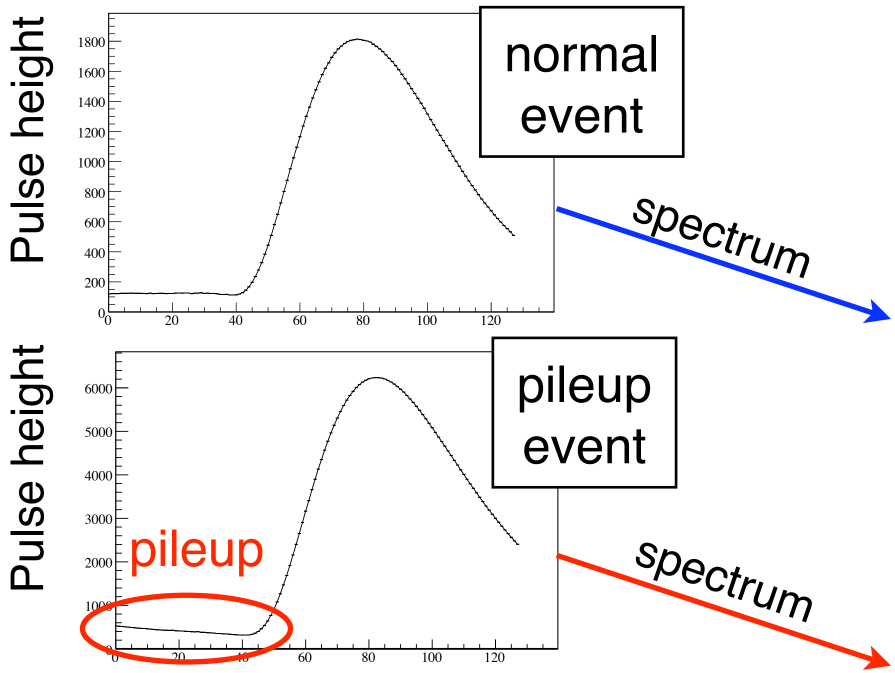


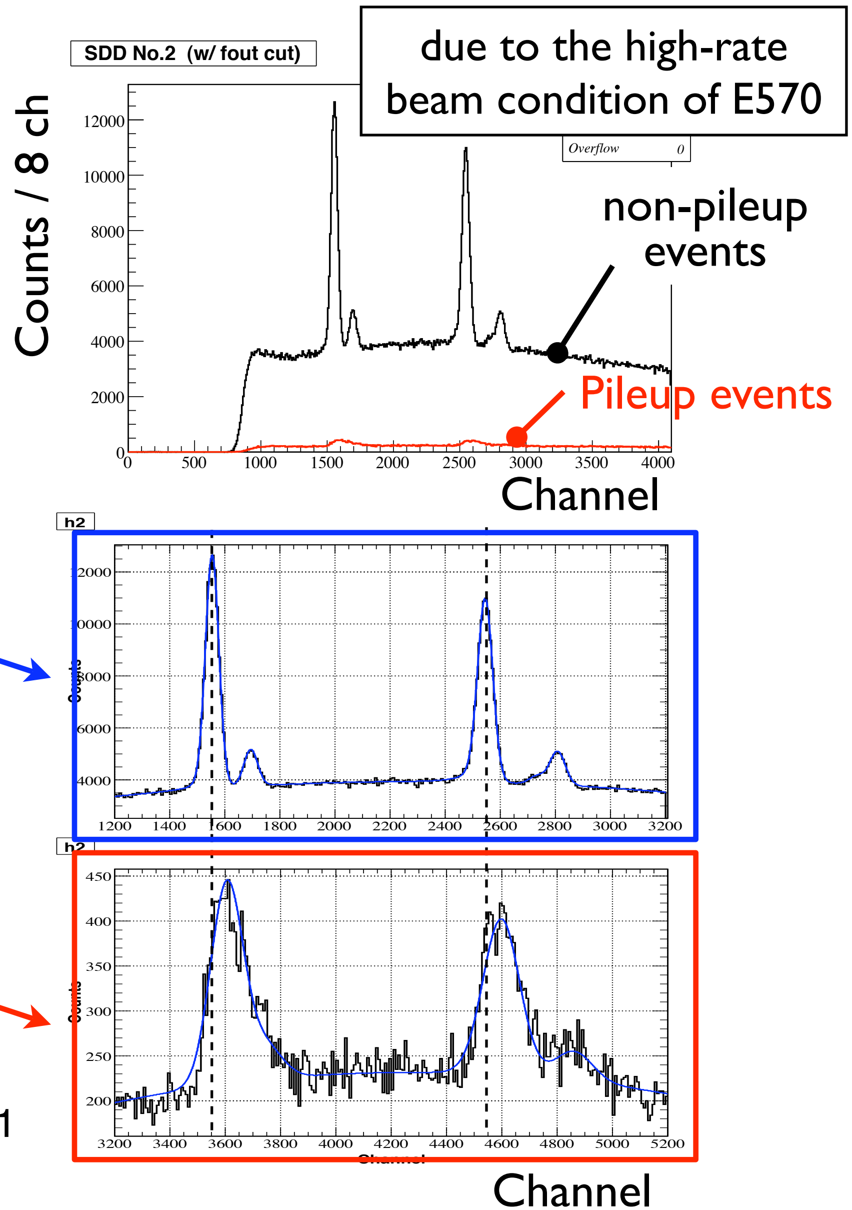
Estimated by Monte carlo simulation (Geant4 : LECS package)
- Spectral shape
- Intensity ratio

2) Pileup effect

Waveform data of flash ADC

typical signal shape





80 nsec / data point (12.5 MHz) shaping time 3 μs

available FADC data : only for about half of cycle 1

Estimation of the pileup function

The spectra obtained by event selection using FADC data is used for the estimation of the relative mean value and width by fitting those spectra.
... Intensity ratio : by fitting calib. spectra fixing these parameters (mean & width)

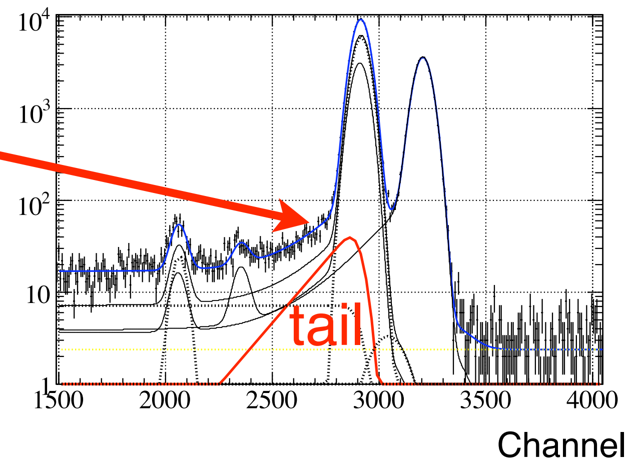
3) Tail function

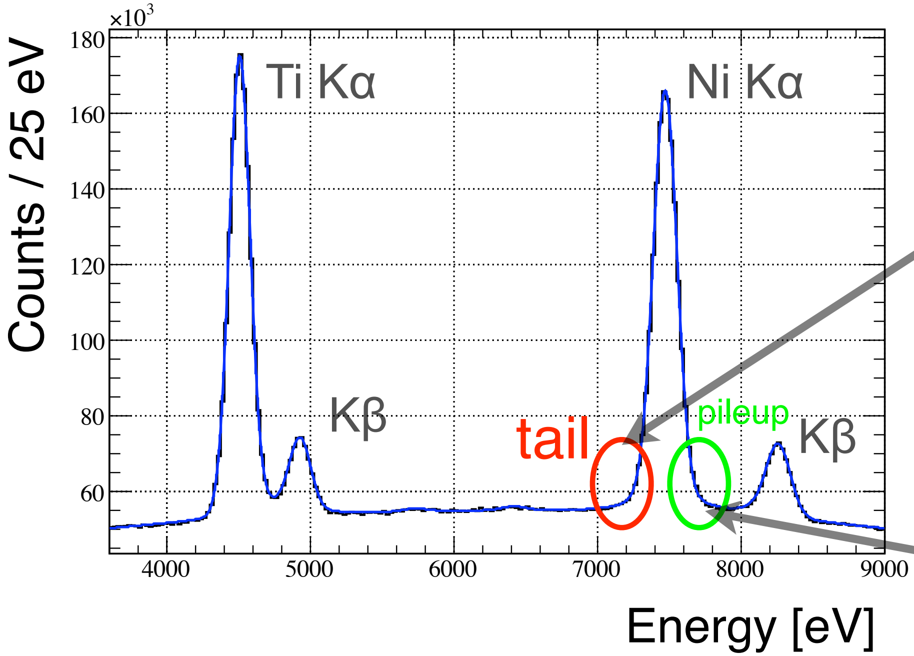
--> Due to detector response

--> The tail function is empirically known for silicon detector as :

$$Tail(E) = \frac{F^{G}_{tail}(E) \cdot Gain}{2\beta\sigma} \exp\left(\frac{E - E_0}{\beta\sigma} + \frac{1}{2\beta^2}\right) \cdot \text{erfc}\left(\frac{E - E_0}{\sqrt{2}\sigma} + \frac{1}{\sqrt{2}\beta}\right)$$

Typical x-ray spectrum from ^{55}Fe source



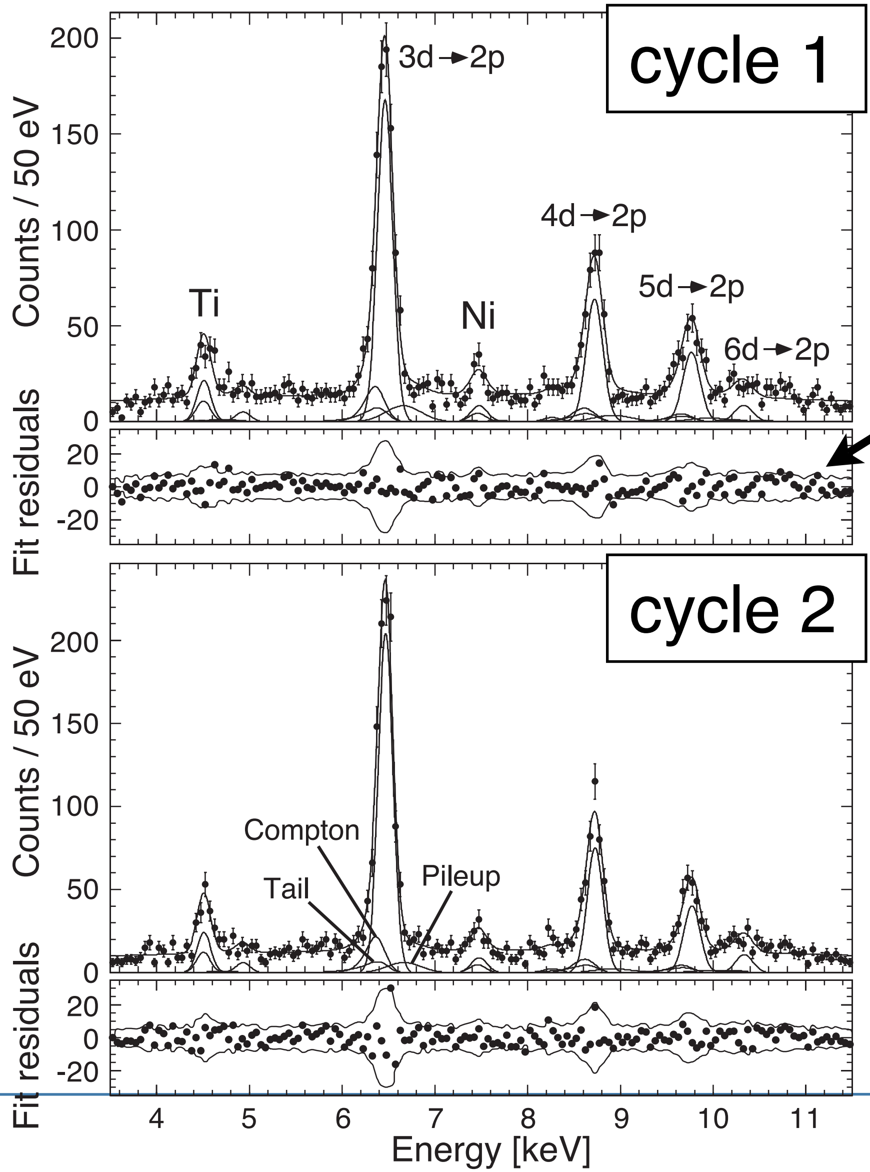


estimated by fitting the high-statistics calibration spectra. (self-triggered events)

Intensity ratio of pileup effect is also estimated by this fitting

Result

Fitting results



Cycle 1 : October 2005

Cycle 2 : December 2005

Thin lines denote the ±2σ values of the data.

The fit residuals are within these lines.

In comparison to the previous exp :

✓ 2 times better resolution (185eV@6.4keV)

✓ 2.5 times higher statistics

✓ 10 times better S/N ratio

2p-level shift (preliminary)

Transition energies (with only statistical errors)

	energy [eV]	EM value
3d->2p	*	*
4d->2p	*	*
5d->2p	*	*

-- EM calculation --

* T.Koike : private communication

* J.P.Santos et al., Phys. Rev. A 71, 032501 (2005)

using 3d-2p energy

$$\Delta E_{2p} = E_{3d\text{-}2p} - E^{EM}{}_{3d\text{-}2p} = * \pm * \text{ (stat) eV}$$

using all transition energies

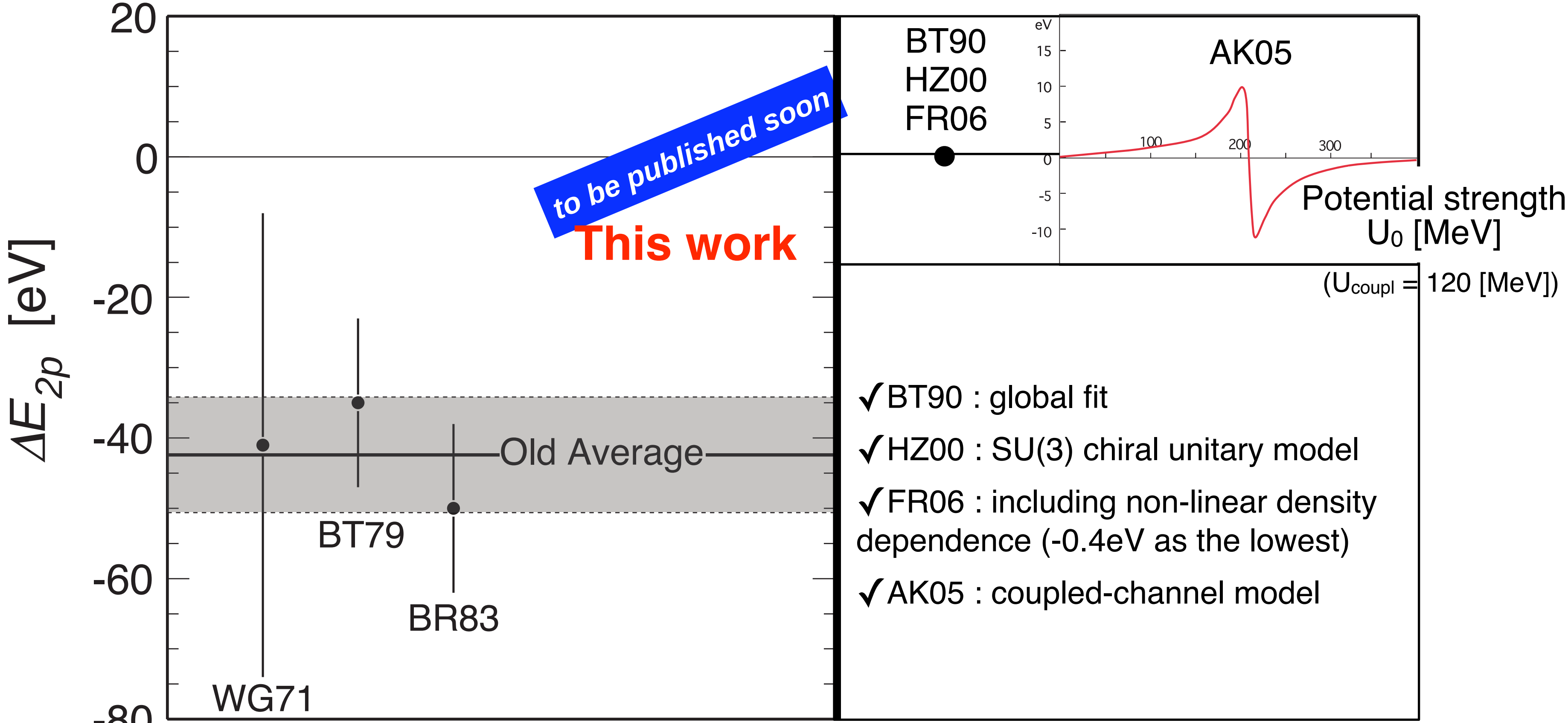
$$\Delta E_{2p} = * \pm * \text{ (stat) eV}$$

Systematic error is comparable to the statistical error.

Comparison

WG71 : C.E. Wiegand and R. Pehl, PRL27,1410 (1971).
BT79 : C.J. Batty et al., NPA326, 455 (1979).
BR83 : S. Baird et al., NPA392, 297 (1983).
BT90 : C.J. Batty, NPA 508, 89c (1990).
HZ00 : S. Hirenzaki et al., PRC 61, 055205 (2000).
FR06 : E. Friedman, private communication (2006).
AK05 : Y.Akaishi, EXA05 proceedings (2005)

Experiment | Theory



previous 3 exp.

Here, statistical and systematic errors are quadratically added.

Summary

- Precisely measured K^{-}-^{4}He x-ray spectrum
  - High energy resolution : 185 eV @6.5keV
  - Good S/N ratio : applying stopped-K- event selection
  - Energy calibration was successfully done by using characteristic X-rays from Ti and Ni foils
- 3d->2p energy : $E_{3d\text{-}2p}$ = **** ± * (stat) eV
- Using all transition energies : ΔE_{2p} = * ± * (stat) eV
- Our precise determination of ΔE_{2p} resolved the long-standing kaonic helium puzzle.

Now, we are preparing to publish the result.