Precise Determination of Kaonic 4He X-ray energy

-- Solve Kaonic Helium Puzzle--

T. Ishiwatari (SMI, Vienna)
On behalf of E570 experiment

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KEK PS-E570 collaboration

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Precision measurement of the $3d \to 2p$ x-ray energy in kaonic ^{4}He

S. Okada [a,*], G. Beer [b], H. Bhang [c], M. Cargnelli [d], J. Chiba [e], Seonho Choi [c], C. Curceanu [f], Y. Fukuda [g], T. Hanaki [e], R.S. Hayano [h], M. Iio [a], T. Ishikawa [h], S. Ishimoto [i], T. Ishiwatari [d], K. Itahashi [a], M. Iwai [i], M. Iwasaki [a,g], B. Juhász [d], P. Kienle [d,j], J. Marton [d], Y. Matsuda [a], H. Ohnishi [a], H. Outa [a], M. Sato [g,1], P. Schmid [d], S. Suzuki [i], T. Suzuki [a], H. Tatsuno [h], D. Tomono [a], E. Widmann [d], T. Yamazaki [a,h], H. Yim [c], J. Zmeskal [d]

[a] RIKEN Nishina Center, RIKEN, Saitama 351-0198, Japan
[b] Department of Physics and Astronomy, University of Victoria, British Columbia V8W 3P6, Canada
[c] Department of Physics, Seoul National University, Seoul 151-742, South Korea
[d] Stefan Meyer Institut für subatomare Physik, Austrian Academy of Sciences, A-1090 Vienna, Austria
[e] Department of Physics, Tokyo University of Science, Chiba 278-8510, Japan
[f] Laboratori Nazionali di Frascati, INFN, I-00044 Frascati, Italy
[g] Department of Physics, Tokyo Institute of Technology, Tokyo 152-8551, Japan
[h] Department of Physics, The University of Tokyo, Tokyo 113-0033, Japan
[i] High Energy Accelerator Research Organization (KEK), Ibaraki 305-0801, Japan
[j] Physik Department, Technische Universität München, D-85748 Garching, Germany

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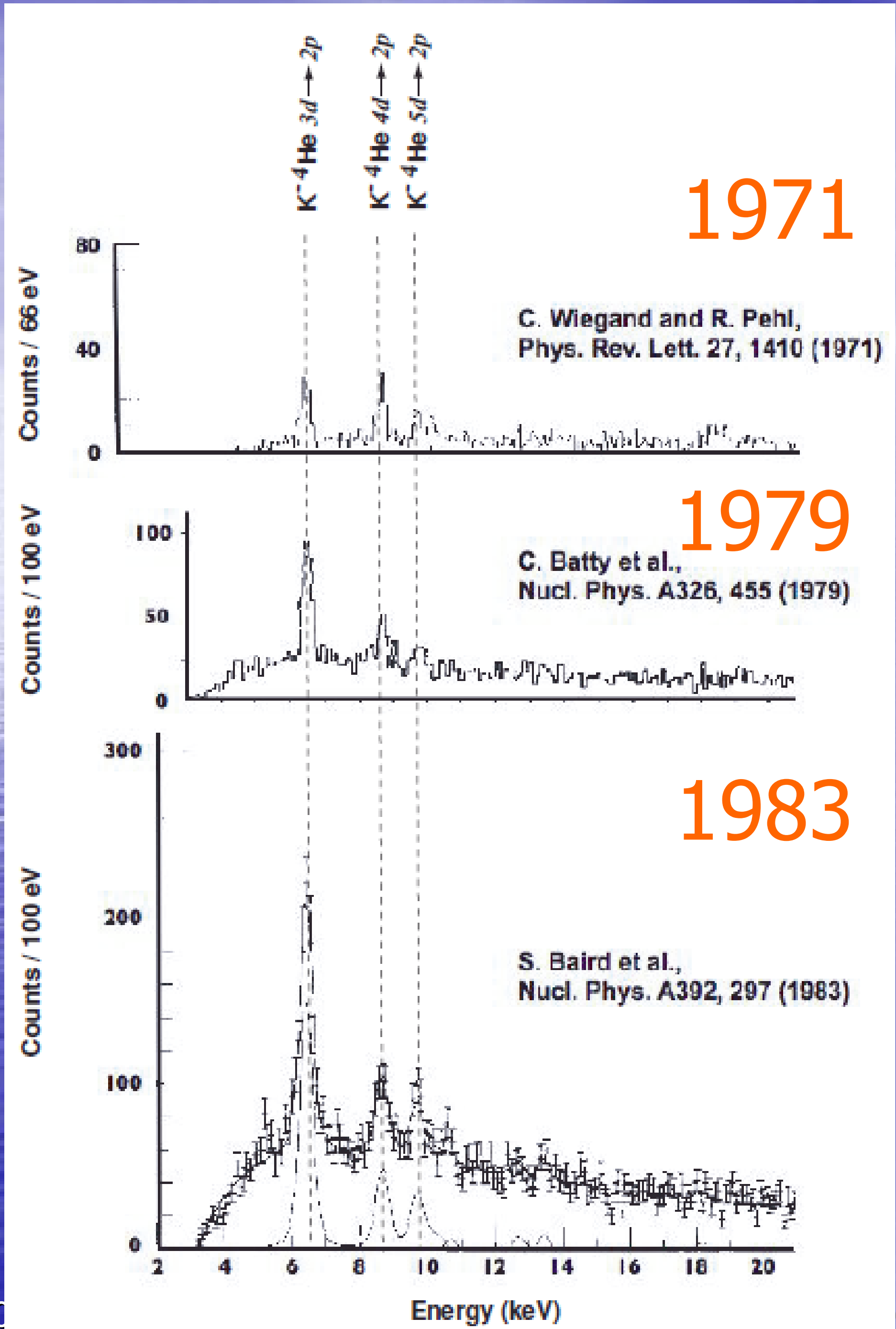
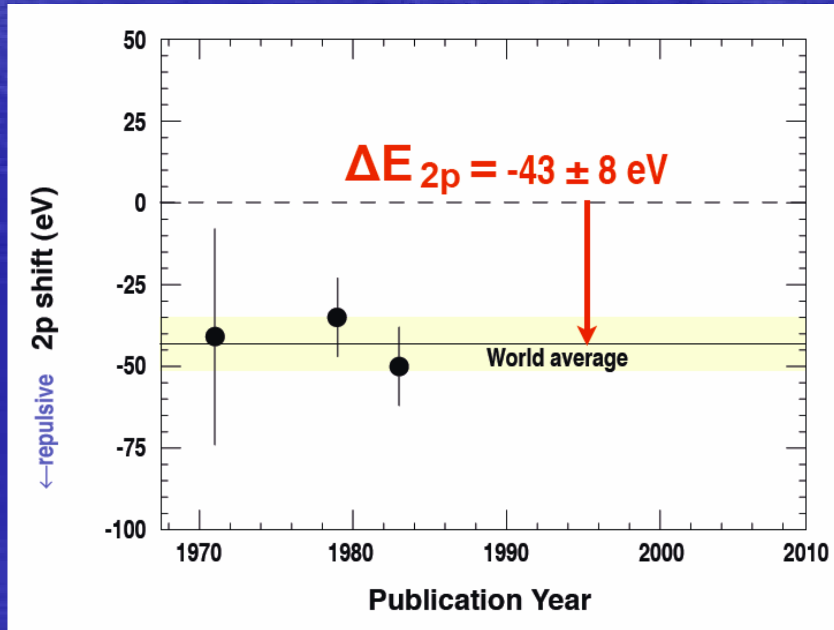
Kaonic 4He X-ray exp.



$$\Delta E_{2p} = E_{\exp} - E_{e.m.}$$

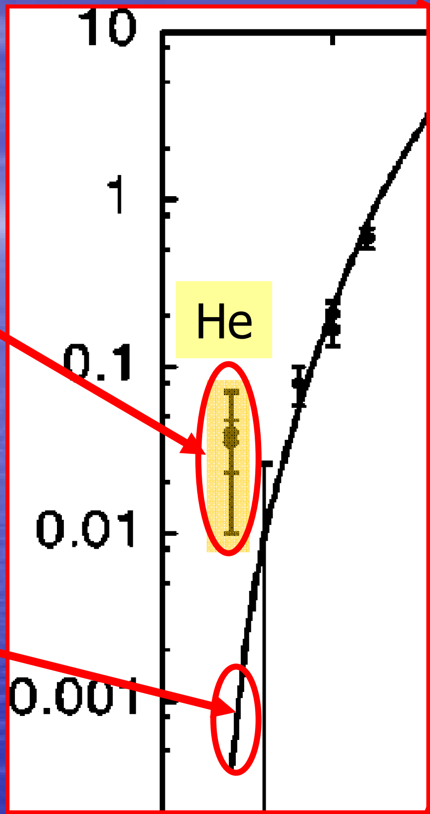
	ΔE_{2p} (eV)	Γ_{2p} (eV)
	-41 ± 33	–
	-35 ± 12	30 ± 30
	-50 ± 12	100 ± 40
Average	-43 ± 8 eV	55 ± 34 eV
	Shift	Width

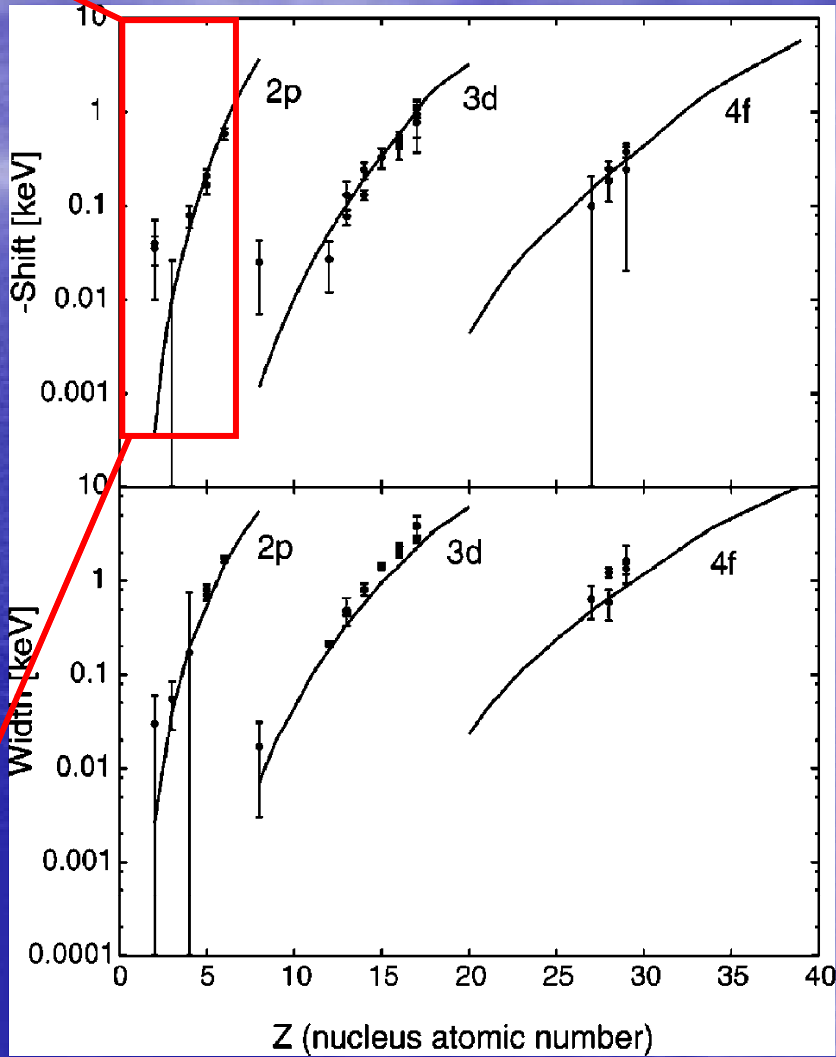


Comparison to other kaonic atoms

Large shift
(~-40 eV)

Tiny shift
(~-0.2 eV)

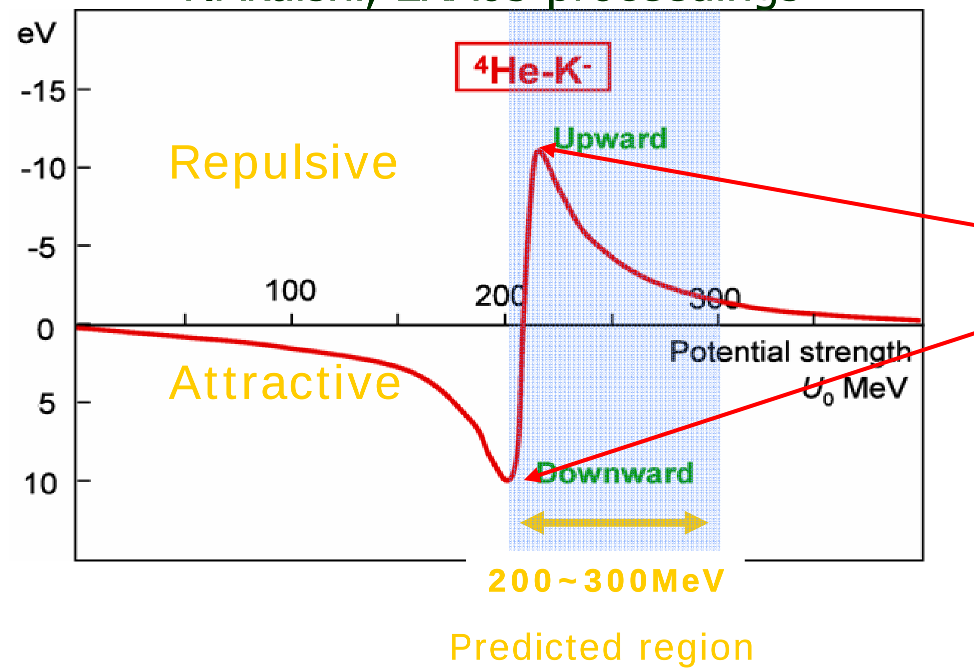




Kaonic Helium Puzzle
(Large in Exp⇔Tiny in Theory)

S.Hirenzaki PRC61(2000)055205

Y.Akaishi, EXA05 proceedings



Prediction of
"deeply bound kaonic nuclei"

Small (<±10 eV)

Large shift(-40eV) cannot be explained by any models.

Let's solve Kaonic He Puzzle!
Goal: precision of 2 eV

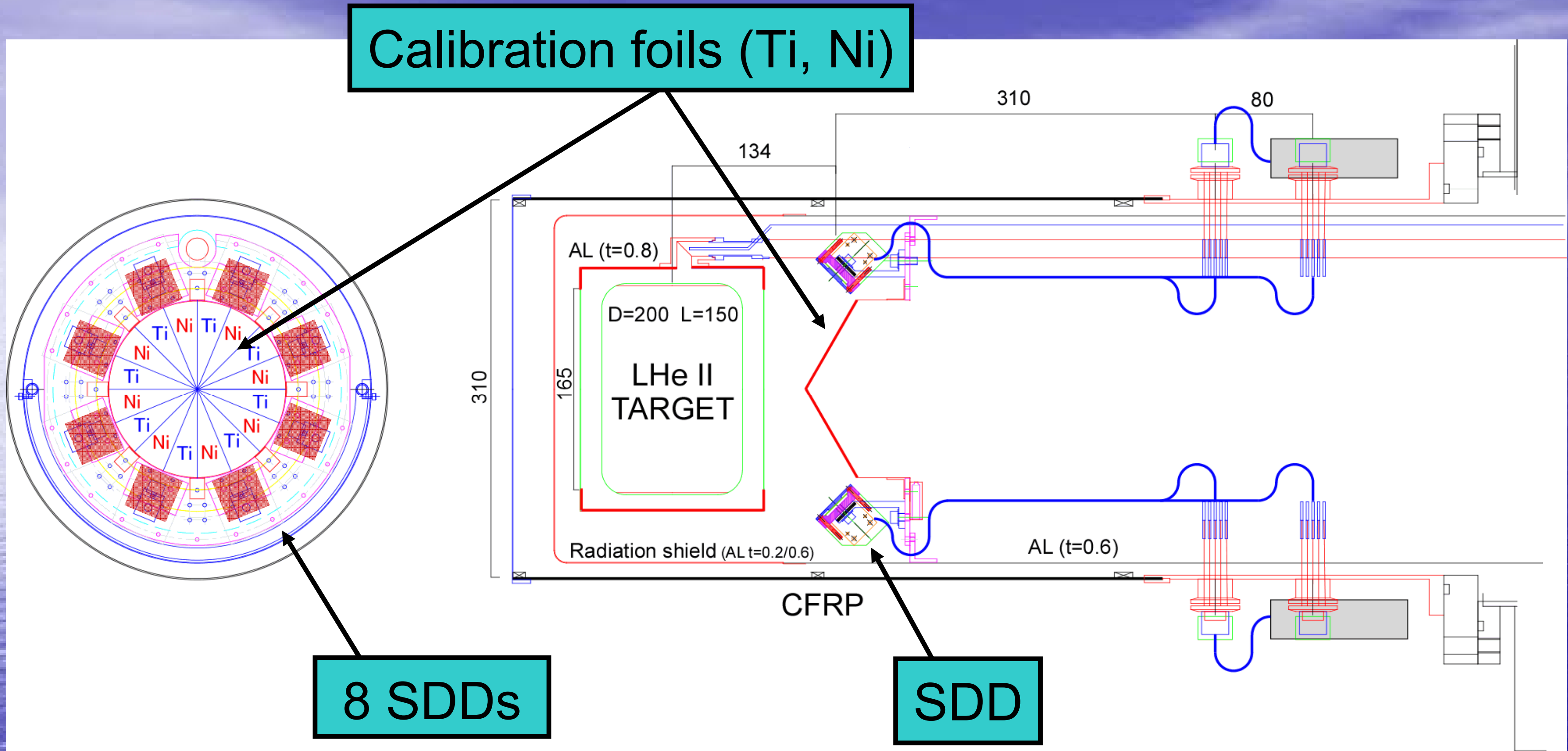
E570 exp.

K-He exp
Large (-40 eV)

K-nucl model
Small (<±10 eV)

Optical model
Tiny (~0 eV)

E570 experimental setup

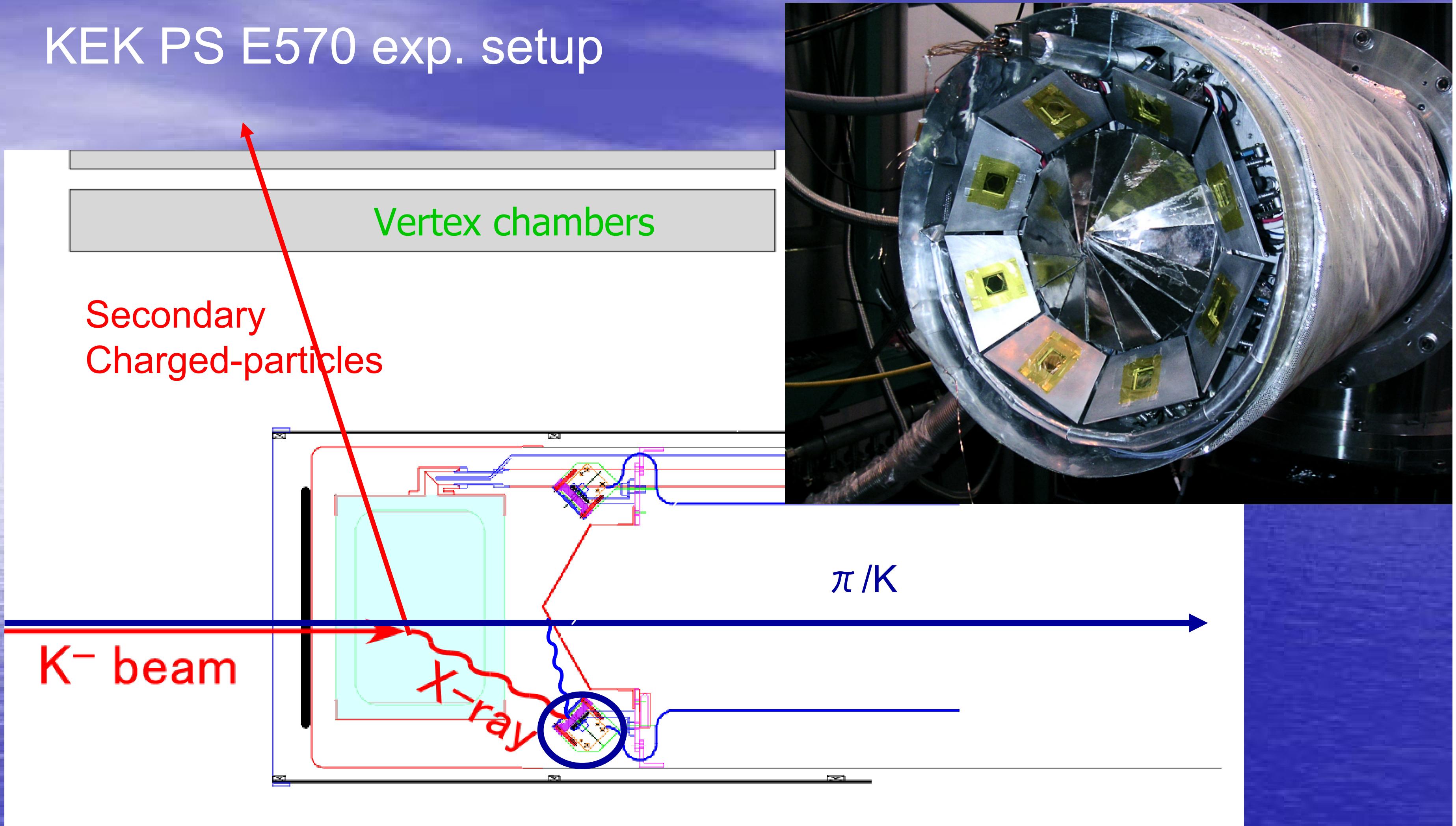


E549 setup + SDDs + Foils = E570
See: Dr. T. Suzuki's talk (Sep.13)

Pure Ti and Ni calibration foils
8 Silicon-Drift Detectors (8x $1cm^2$)

Liq. He target: ρ=0.145g/cm3
cylindrical shape
(R=10 cm, Z=15cm)

KEK PS E570 exp. setup

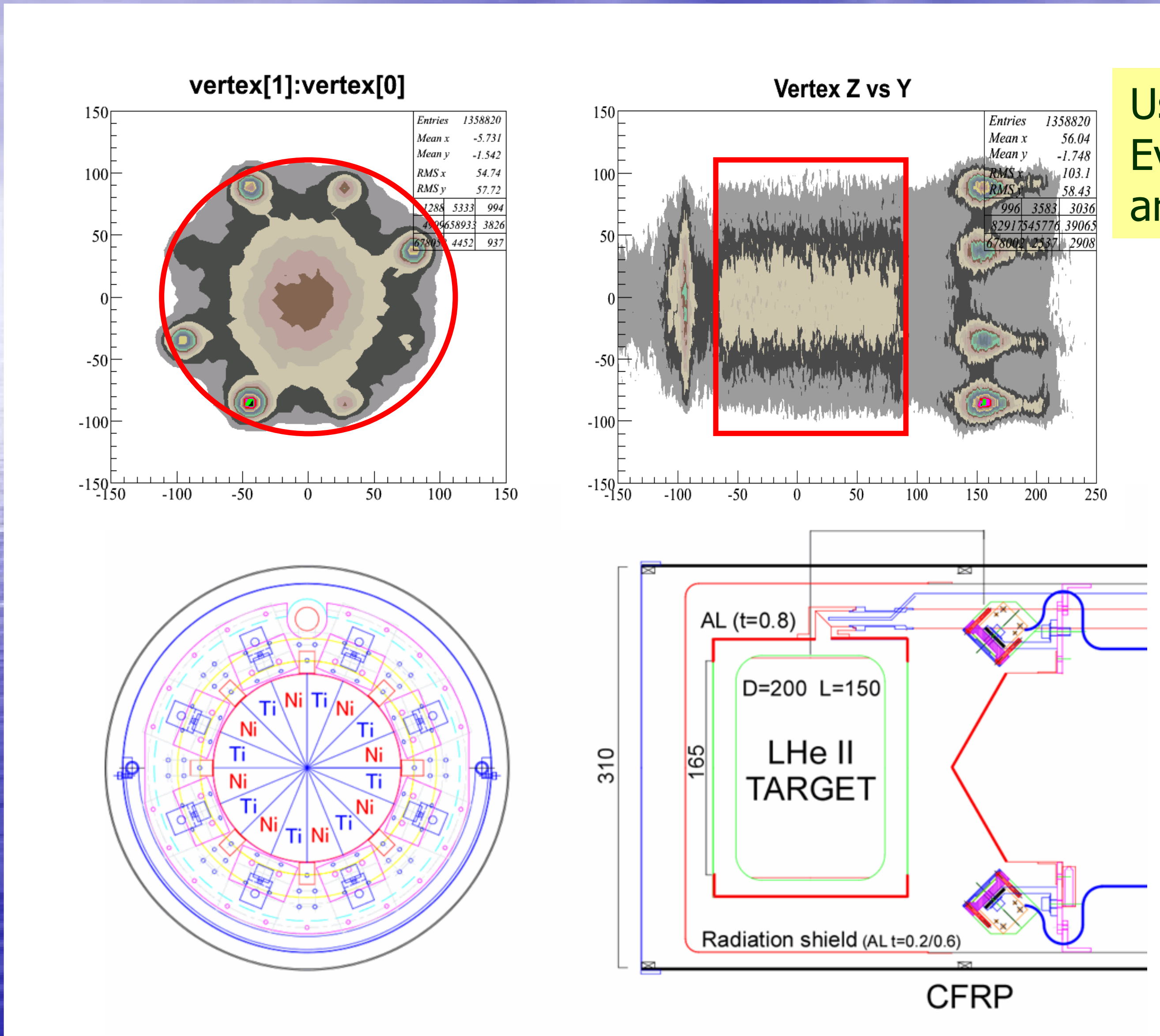


1) Silicon Drift Detectors (SDDs) as X-ray detectors

2) Reconstruct of reaction points

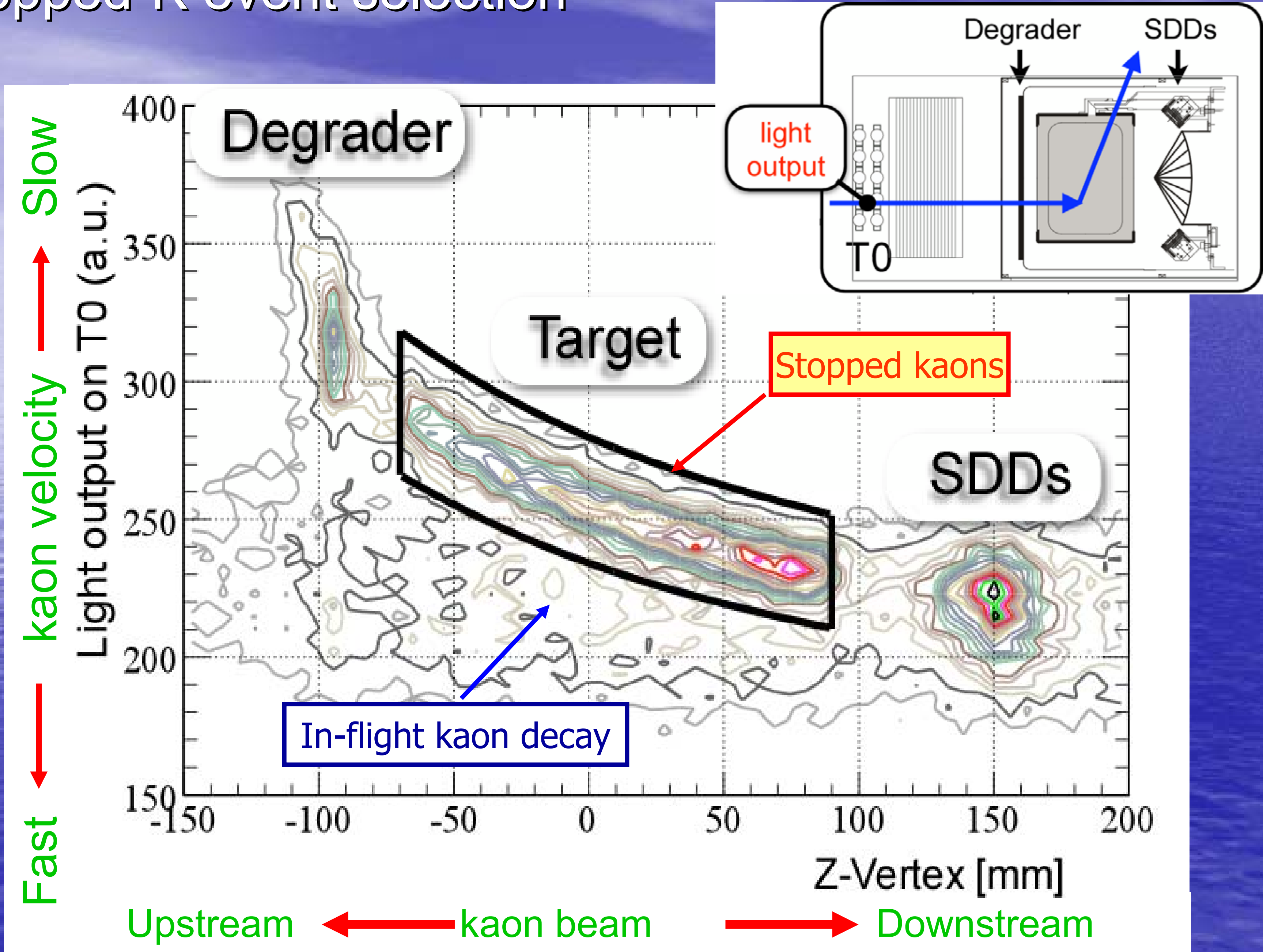
3) Simultaneous data taking of both kaonic and calibration X-rays

Event selection (fiducial volume cut)

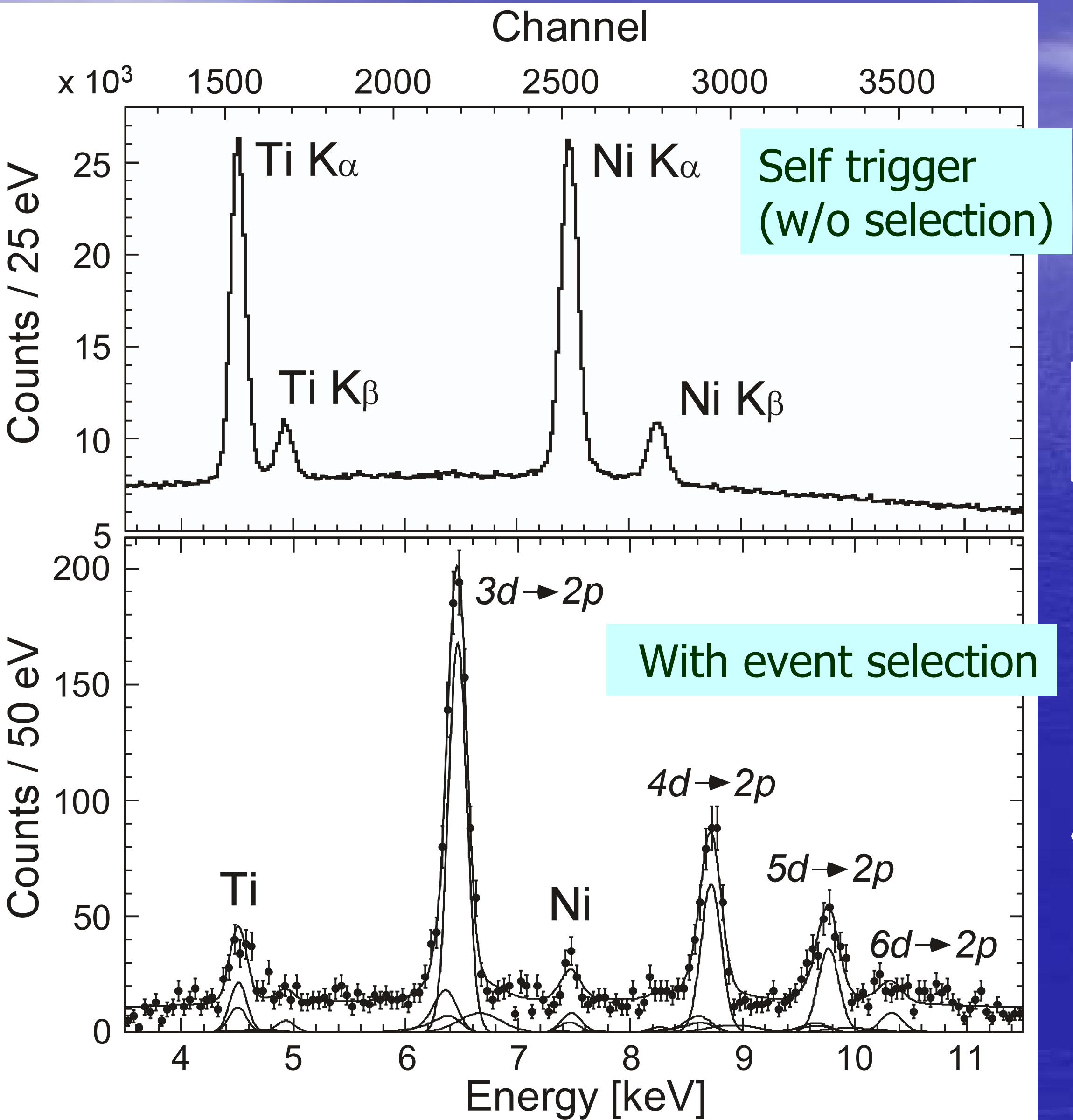


Using vertex chamber data, Events from He targets are selected.

Stopped-K event selection



Kaonic 4He X-ray energy spectra



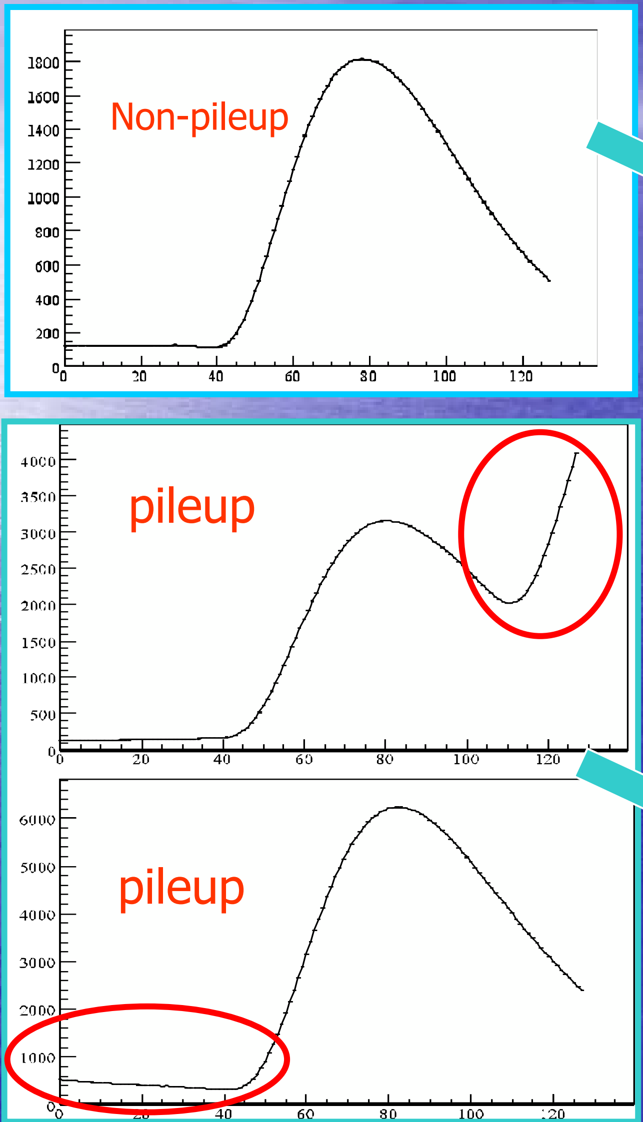
Energy calibration

High accuracy (~2 eV)

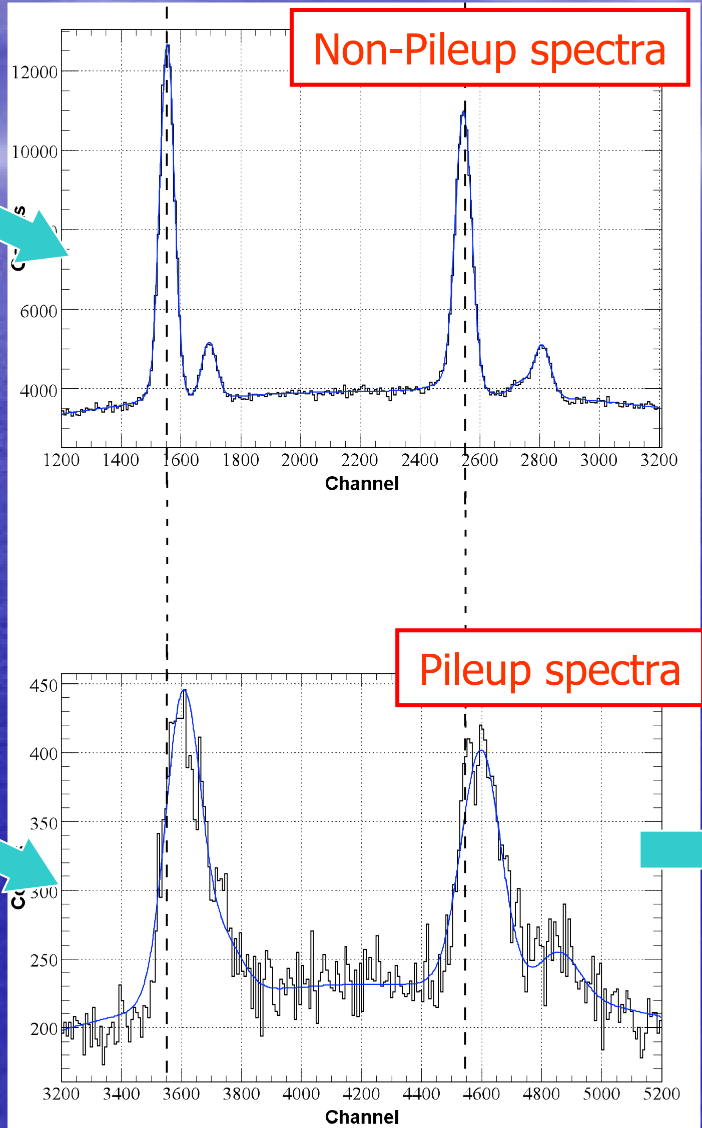
Detail study of Response function

Fit function (1): Pileup events

Signal shape by FADC

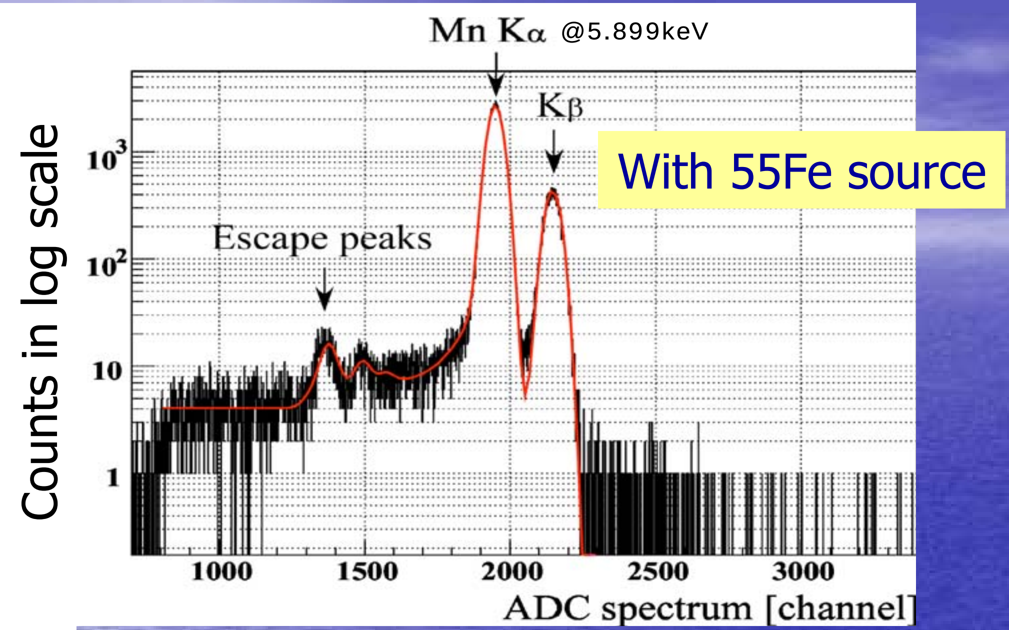


Energy spectra by PH-ADC



Select pileup events
and
Get information on
shape and intensity

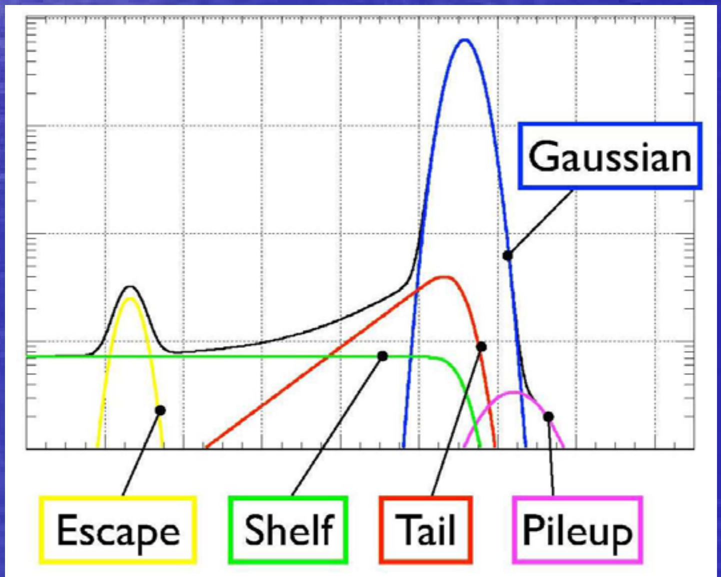
Fit function (2) :Detector response



Low-energy tailing on X-ray peaks

Fit parameters are obtained from Ti and Ni peaks of Self trigger data

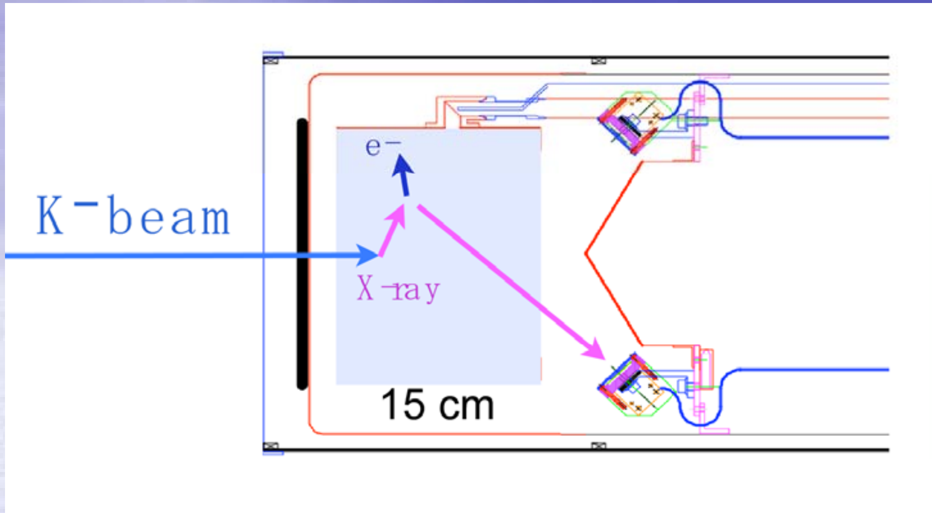
Full Fit function for Ti and Ni calibration peaks



Parameters of Pileup, Tail and Shelf funcs are obtained from Ti/Ni peaks on self-trigger spectra.

Energy dependency of these params are also obtained.

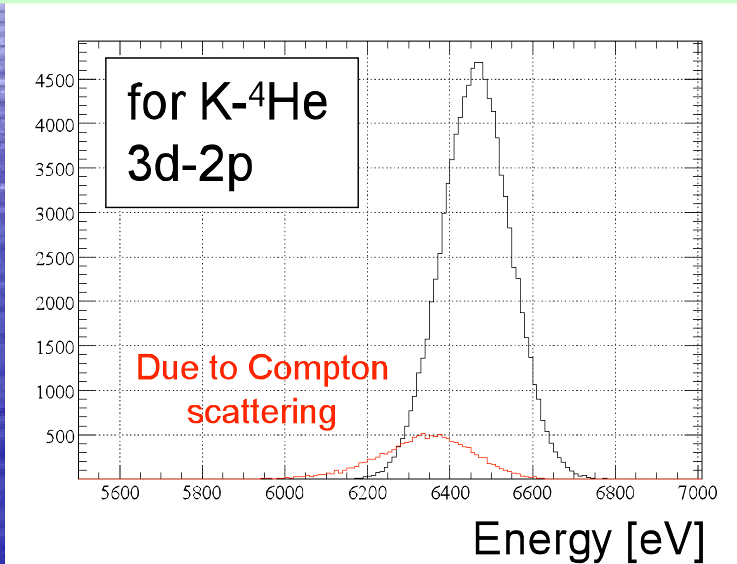
Fit func (3): Compton tail – Compton scattering on He atoms



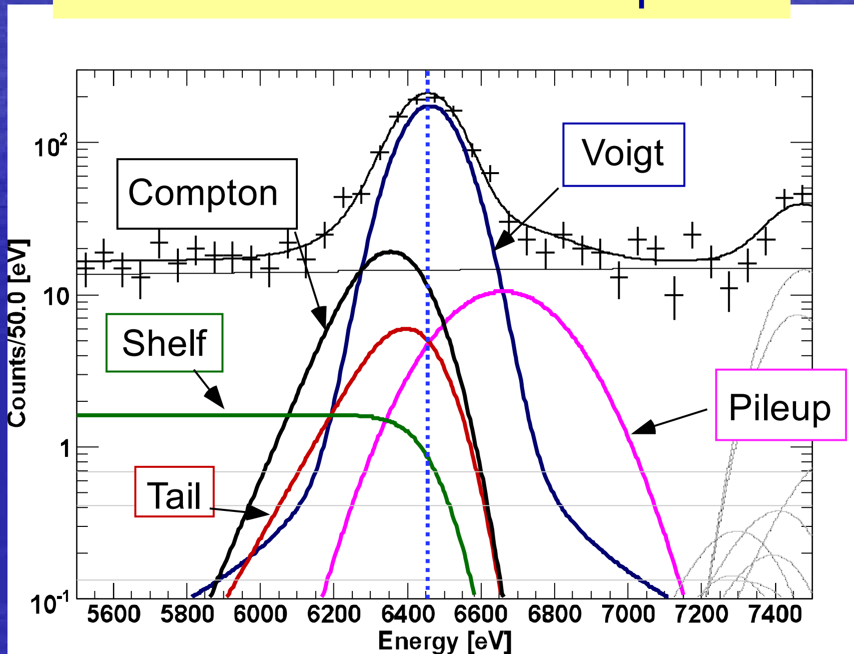
Kaonic He X-rays pass through He matter
↓
Compton scattering
↓
Energy loss

10cm He → 20% X-ray causes Compton Scatt.

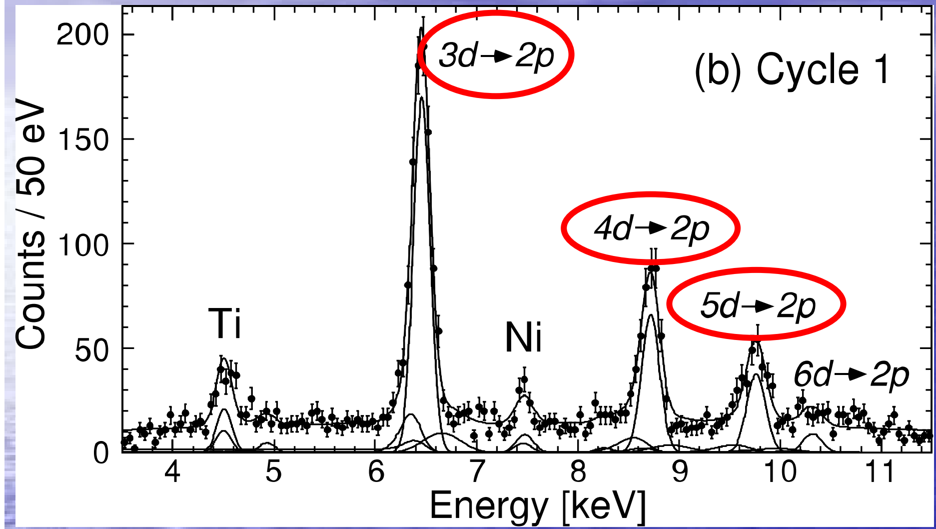
Geant4+G4LECS(Low-energy Compton) using kaon stopping distribution data.

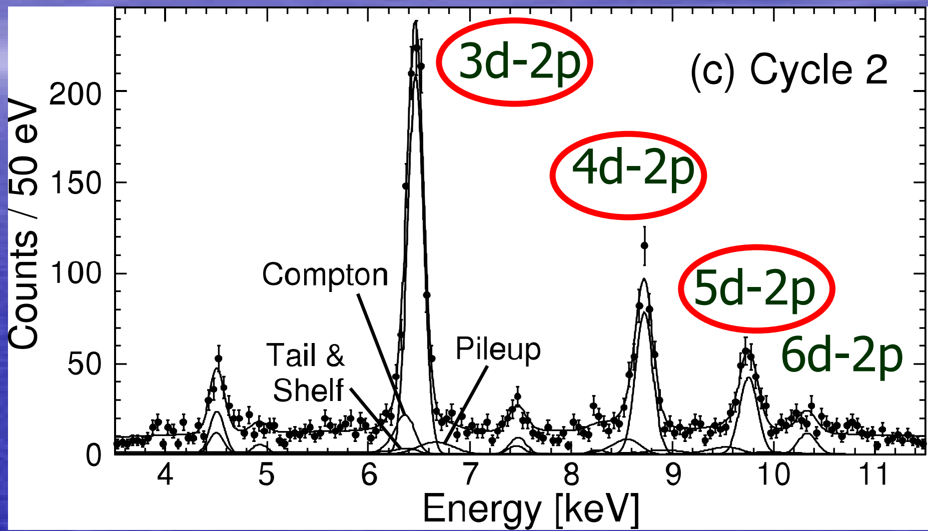


Full fit function for KHe peaks



Kaonic 4He energy spectra and Strong-interaction shift on kaonic 4He 2p state

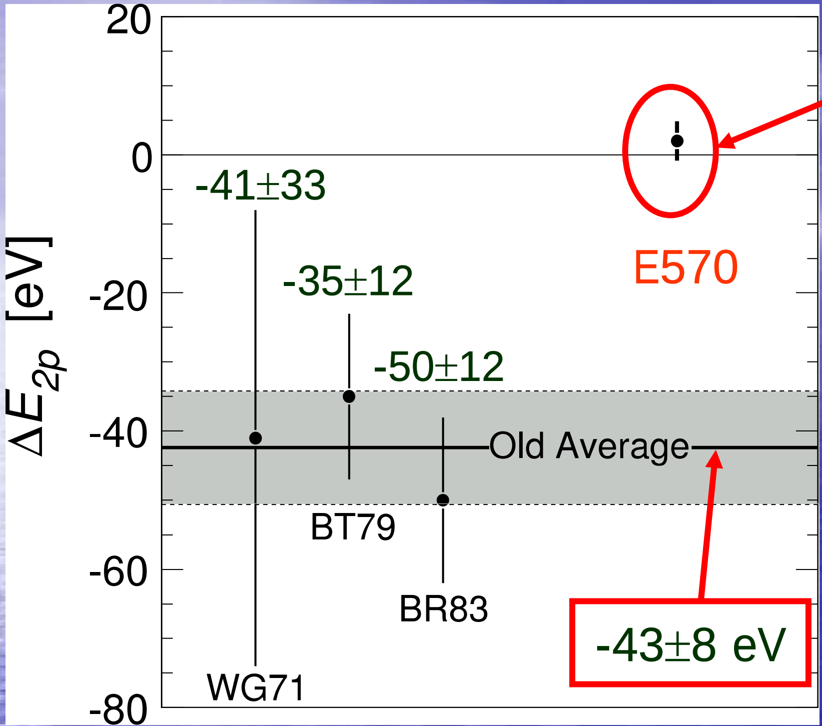




Transition	$3d \to 2p$	$4d \to 2p$	$5d \to 2p$
Measured energy (eV)	6466.7 ± 2.5	8723.3 ± 4.6	9760.1 ± 7.7
EM calc. energy (eV) [15]	6463.5	8721.7	9766.8

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

Comparison to OLD experiments



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

We obtain a smaller shift!

KHe 3d-2p: 1500 events
[700 (cycle1), 800 (cycle2)]

3x higher statistics
2x better Energy resolution
6x better S/N ratio

Large shift was not observed!

E570

~~K-He exp~~
~~Large (-40 eV)~~

K-nucl model
Small (<±10 eV)

Optical model
Tiny (~0 eV)

Summary

- Balmer-series of kaonic 4He atom X-rays are measured with a good energy resolution and a high S/N ratio.
- X-ray fit functions are studied carefully.
- Strong-interaction shift on kaonic 4He 2p state was deduced:

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

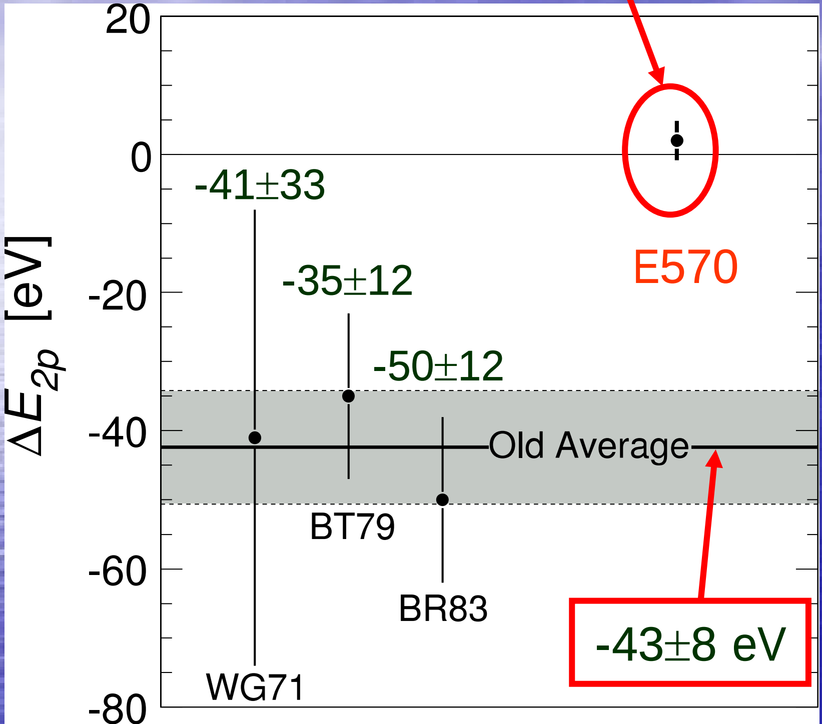
- Previously measured large shift (-40 eV) was not observed by E570.
- The shift is consistent with the values predicted by optical models (~0 eV) and K-nucl model (<±10 eV)
- Analysis for the width will be finished soon.
- We conclude that the long-standing kaonic helium puzzle was solved.

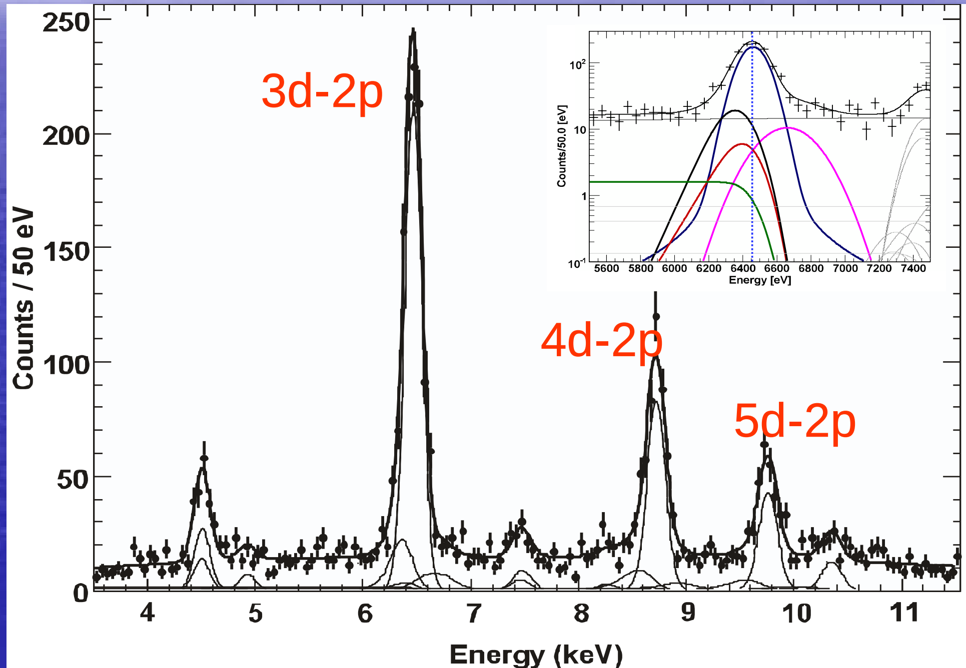
Outlook

- Kaonic 3He X-rays will be measured in J-PARC E15/E17 (Tokai-mura, Japan). → Dr. H. Ohnishi's talk (Sep. 13)
- Kaonic hydrogen, deuterium (as well as 3He, 4He) X-rays will be measured in SIDDHARTA (Frascati, Italy)

  → Dr. C. Curceanu 's talk (Sep. 10)

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





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Fitting functions

Cycle 1 : 520 hours in Oct. 2005

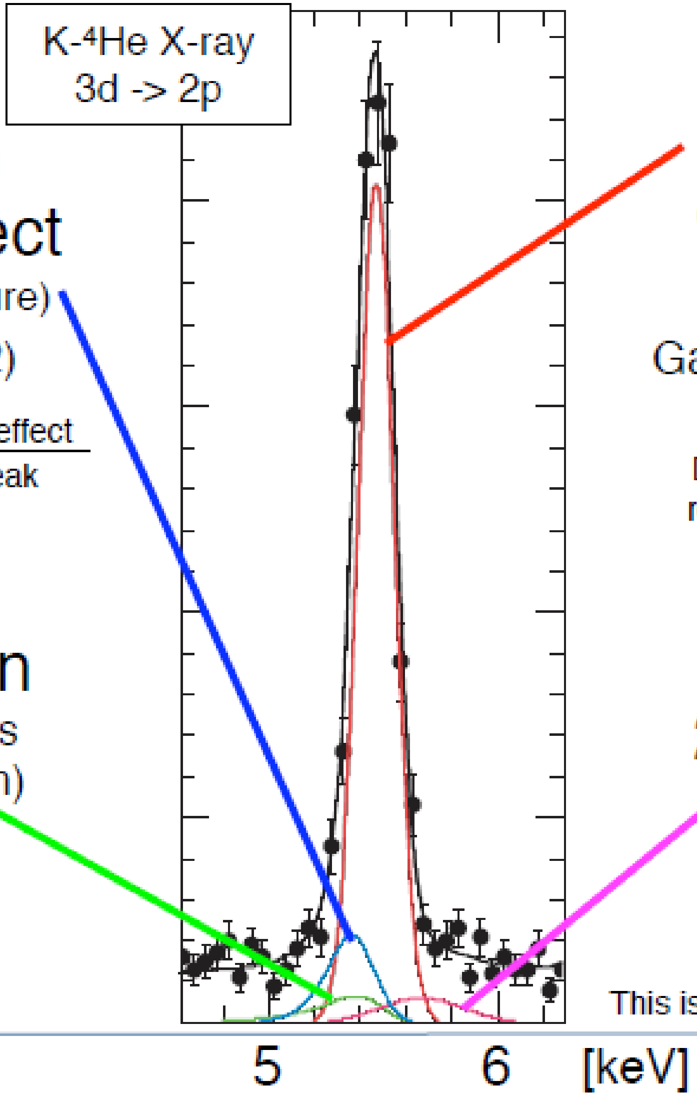
Cycle 2 : 260 hours in Dec. 2005

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)

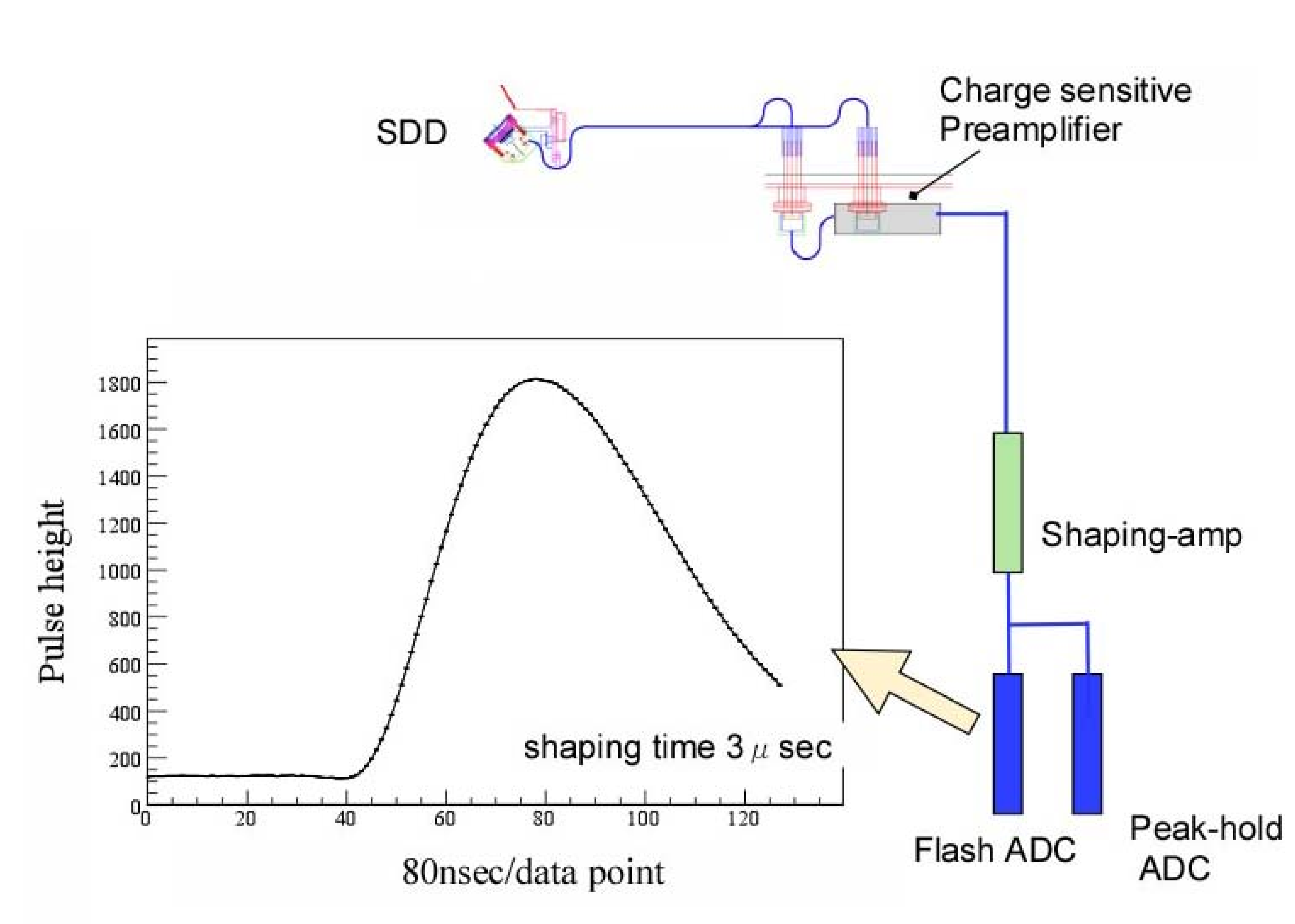
~ 3 % (cycle 2)

2) Pileup effect

~ 11 % (cycle 1)

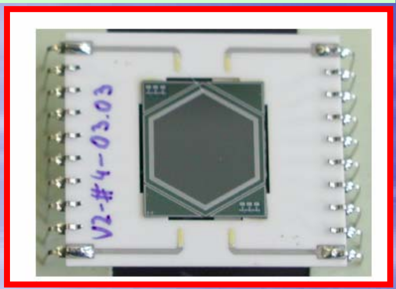
~ 6 % (cycle 2)

This is spectrum for cycle 2

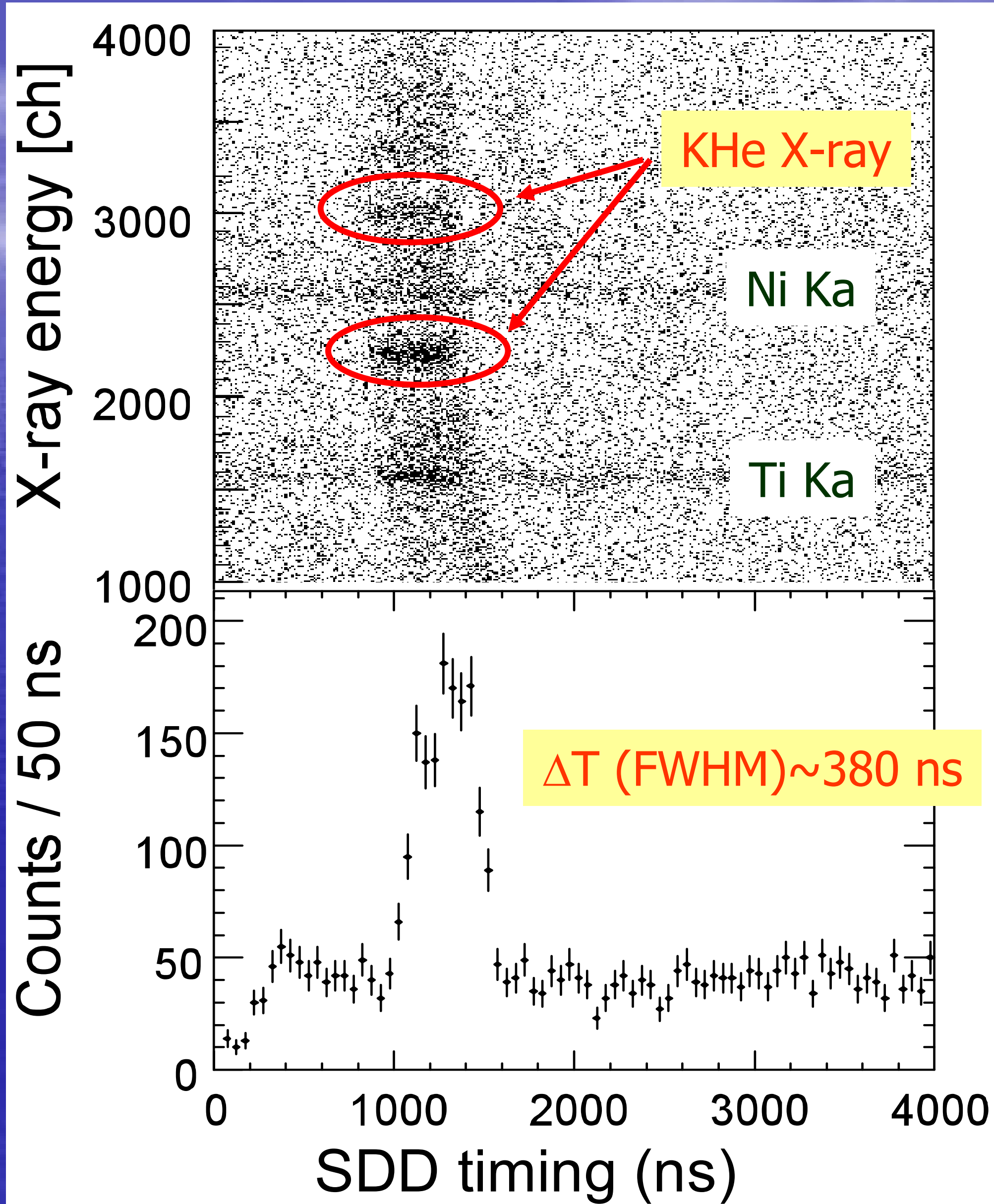

SDD
Charge sensitive Preamplifier
Shaping-amp
Flash ADC
Peak-hold ADC
Pulse height
80nsec/data point
shaping time 3 μ sec

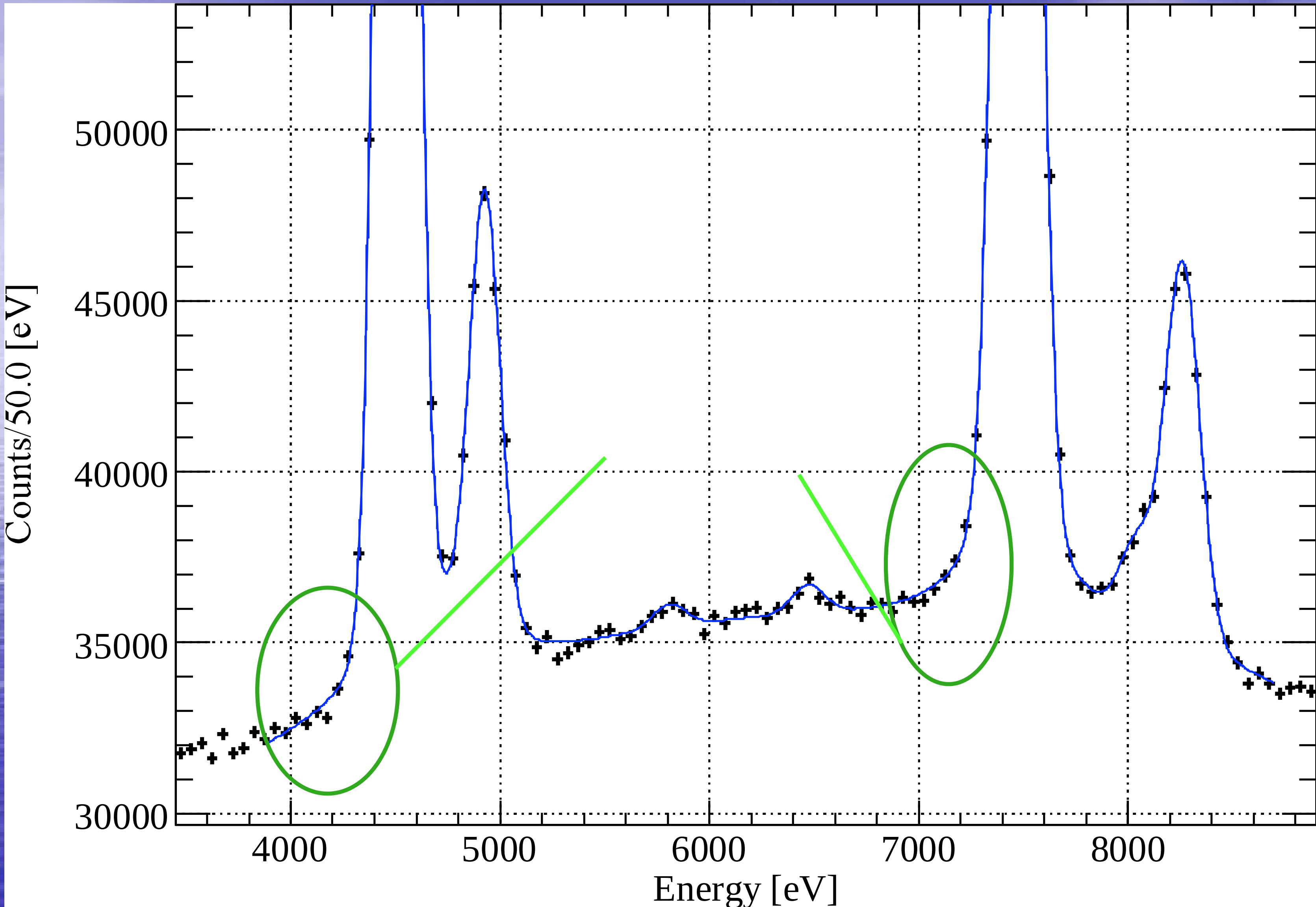
Silicon Drift Detectors

KETEK 1cm² SDD



	SDD
Effective area	1 cm^2
Thickness	260 μm
Energy resolution	190 eV at 6.4 keV
Time resolution	380 ns at 83 K
Temperature	83 K



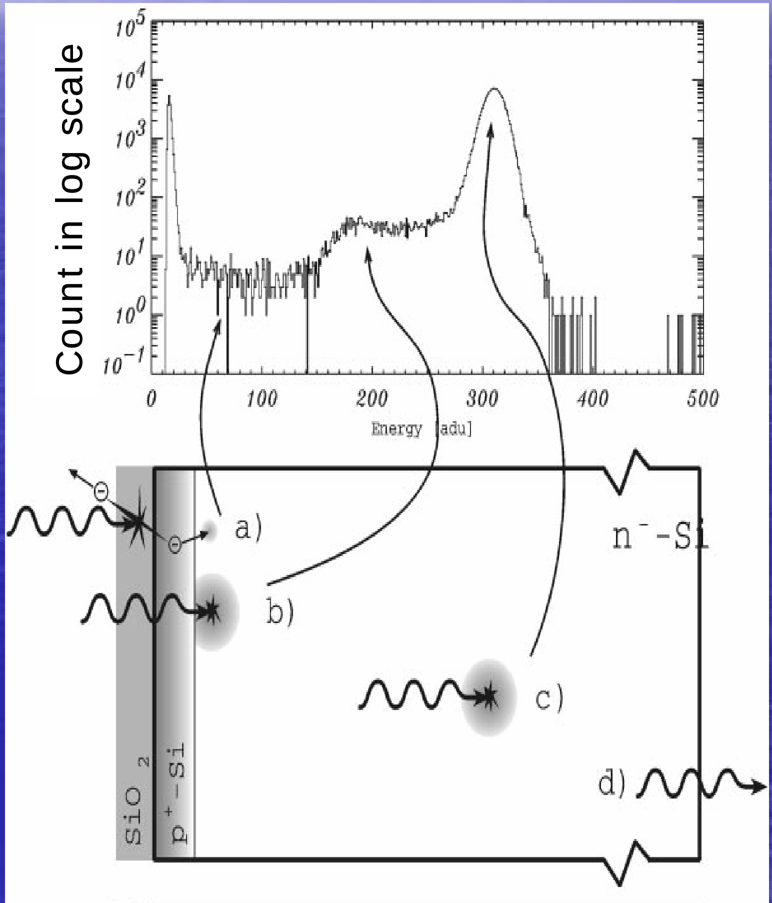


Counts/50.0 [eV]
50000
45000
40000
35000
30000
4000
5000
6000
7000
8000
Energy [eV]

TABLE 5

Strong interaction effects in kaonic helium

Measurement	This expt.	Batty [2]	Wiegand [8]	Average
ε_{2p} (keV)	-0.050 ± 0.012	-0.035 ± 0.012	-0.041 ± 0.033	-0.043 ± 0.008
Γ_{2p} (keV)	0.100 ± 0.040	0.030 ± 0.030		0.055 ± 0.034



Strueder,NIMA454(2000)73

	SDD
Effective area	1 cm^2
Thickness	260 μm
Energy resolution	190 eV at 6.4 keV
Time resolution	380 ns at 83 K
Temperature	83 K

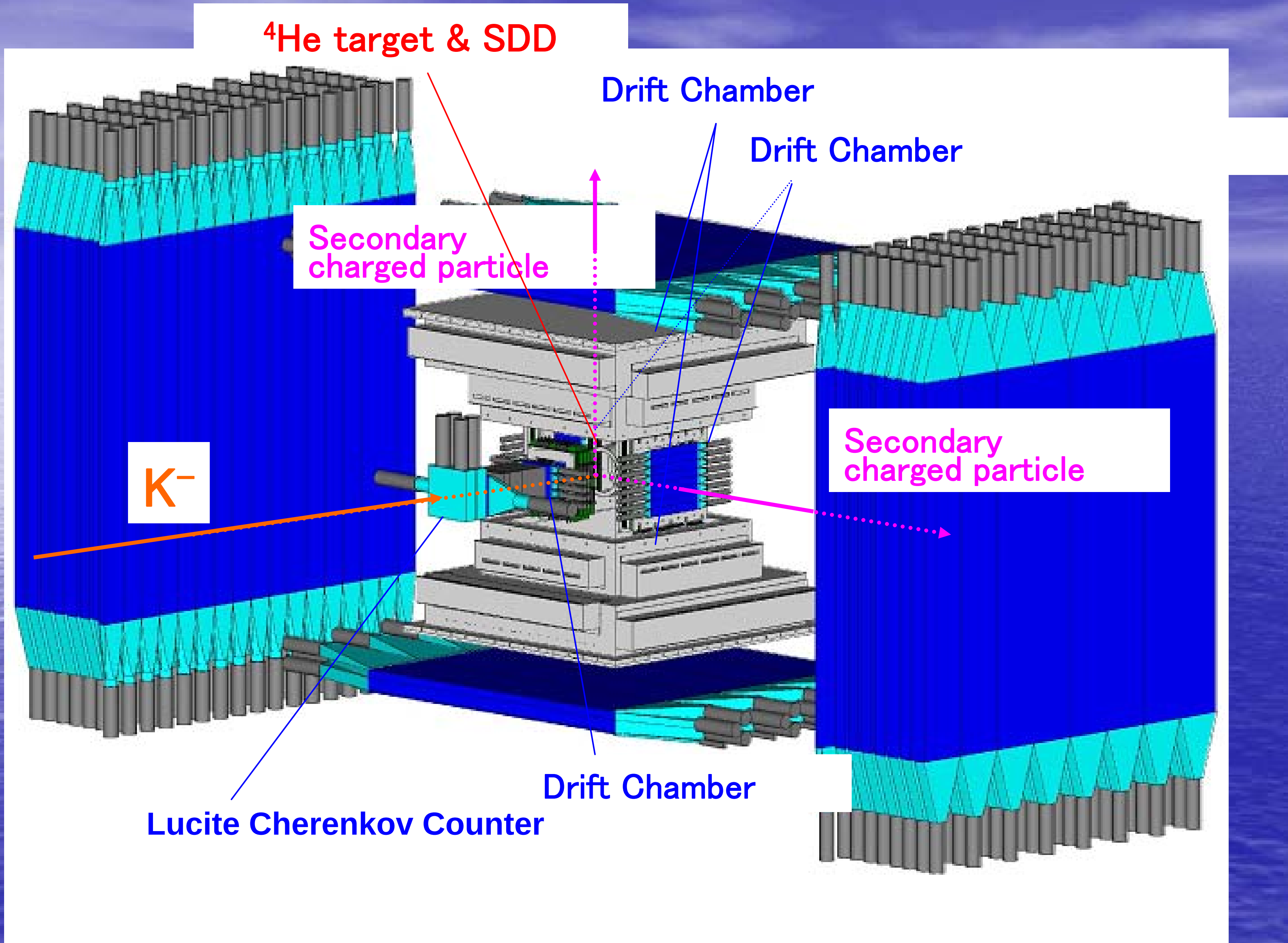
Si(Li)で行われた過去の３つの実験

ΔE_{2p} (eV)	Γ_{2p} (eV)	Si(Li) Detector area, thickness	Resolution @ 6.5 keV (eV FWHM)	Reference
-41 ± 33	–	254 mm^2, 4 mm	340	[7]
-35 ± 12	30 ± 30	300 mm^2, 5 mm	250	[8]
-50 ± 12	100 ± 40	300 mm^2, 5 mm	360	[9]
-43 ± 8	55 ± 34			Average

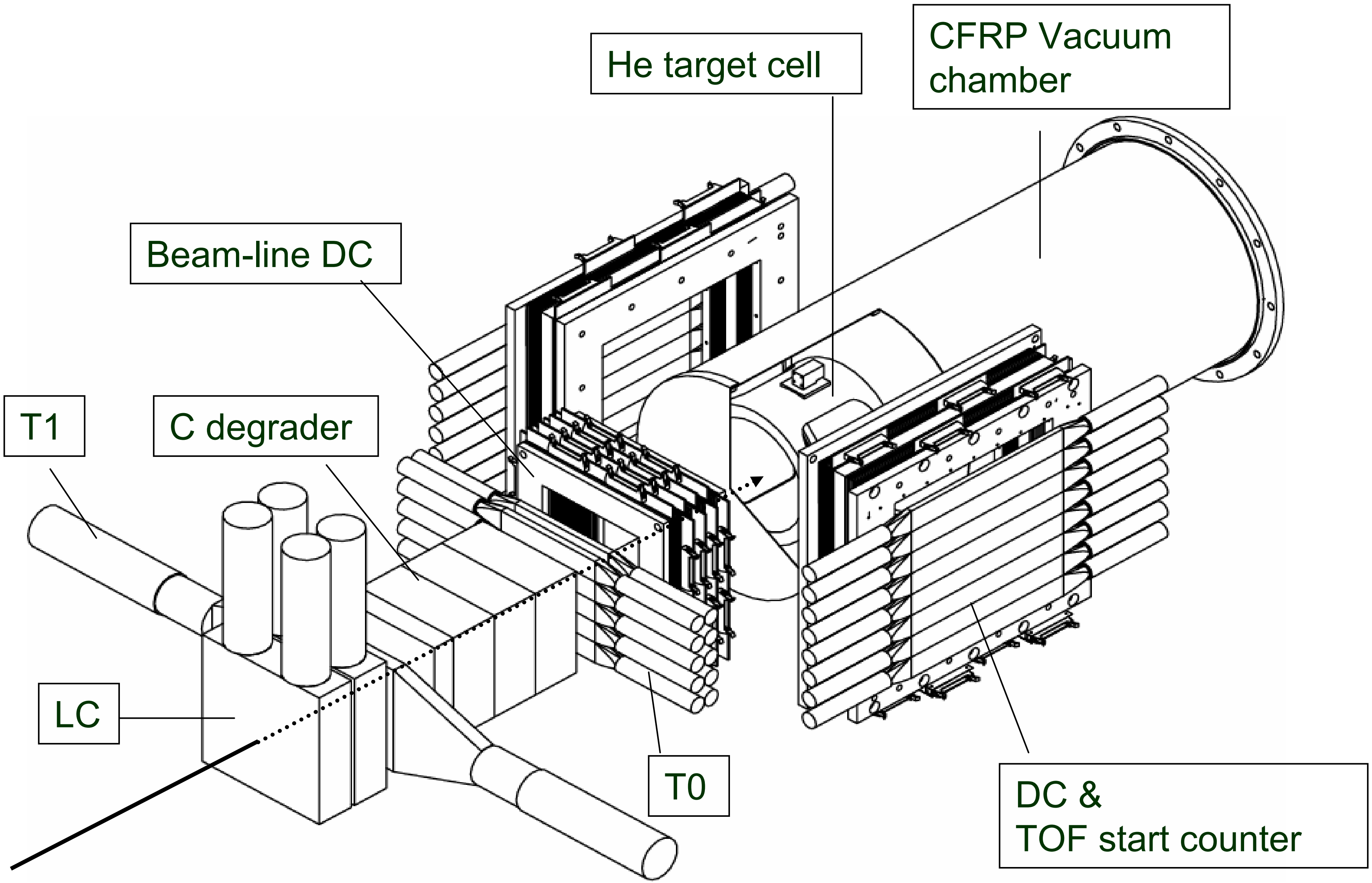
Experimental condition

- 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)

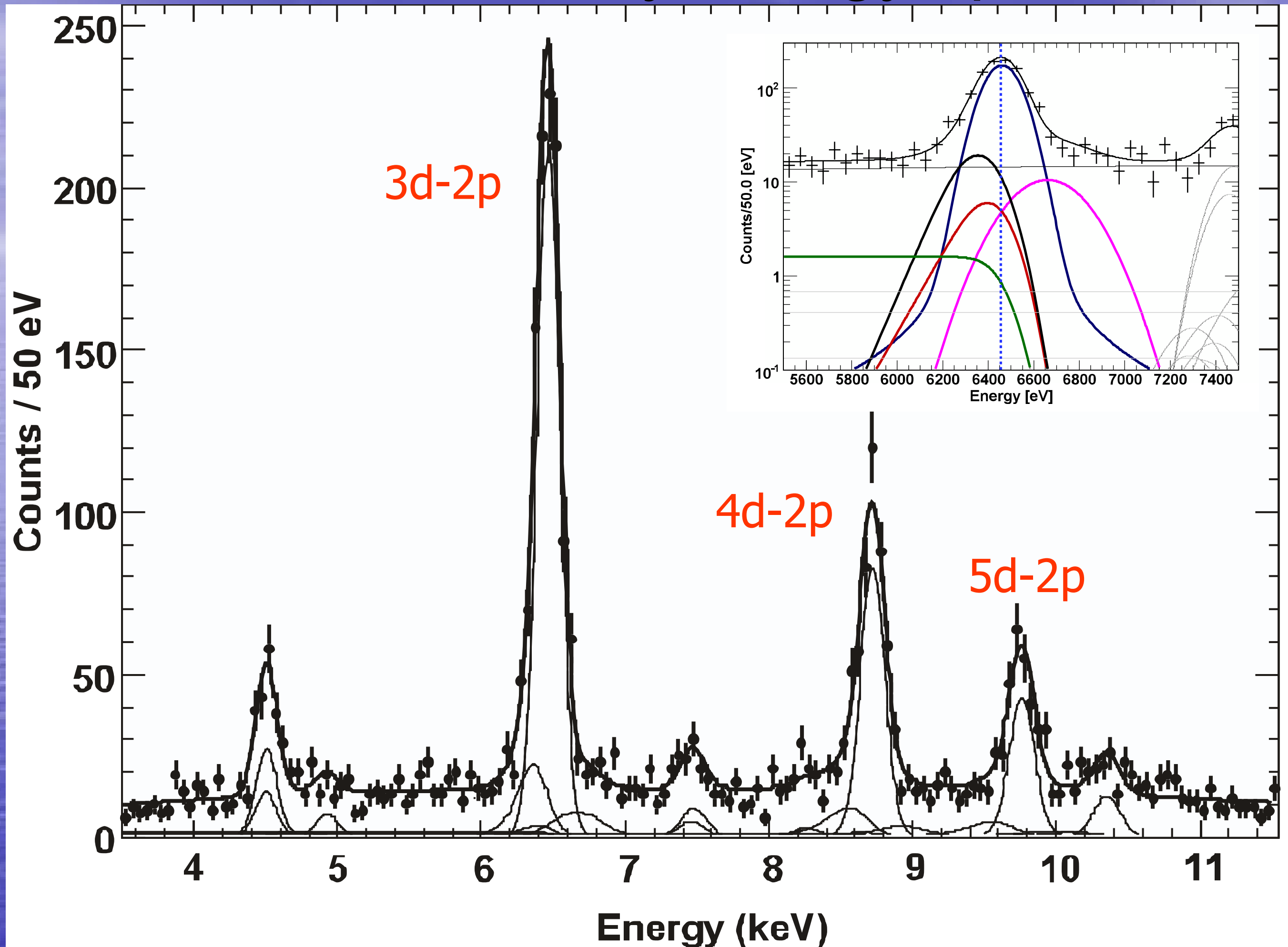
    → total : ~3G stopped K^-
- SDD
  - SDD temperature : ~85K
  - SDD preamp : water cooling @6~7 degrees C
  - Typical SDD hit rate : ~ 1k / spill for each SDD



^{4}He target & SDD
Drift Chamber
Drift Chamber
Secondary charged particle
Secondary charged particle
K⁻
Drift Chamber
Lucite Cherenkov Counter


CFRP Vacuum
chamber
He target cell
Beam-line DC
T1
C degrader
LC
T0
DC &
TOF start counter

Kaonic 4He X-ray energy spectra



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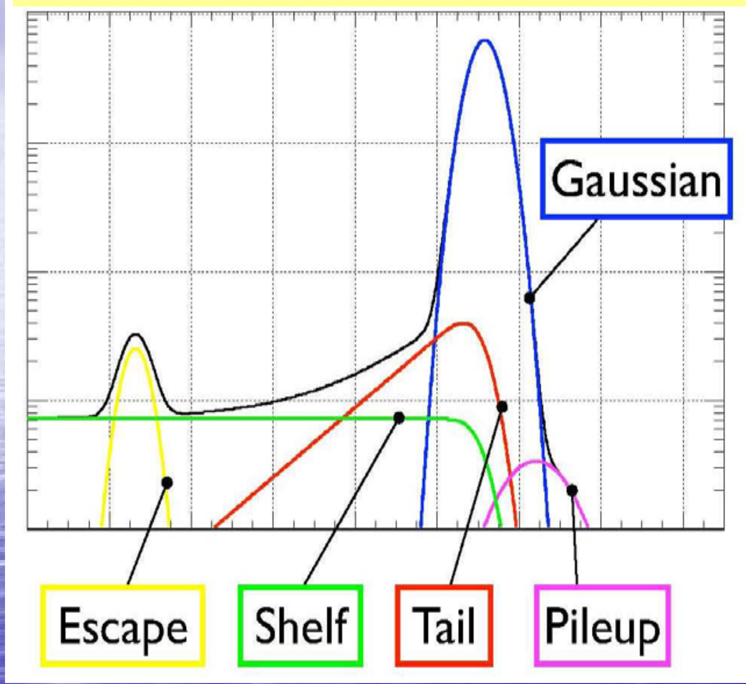
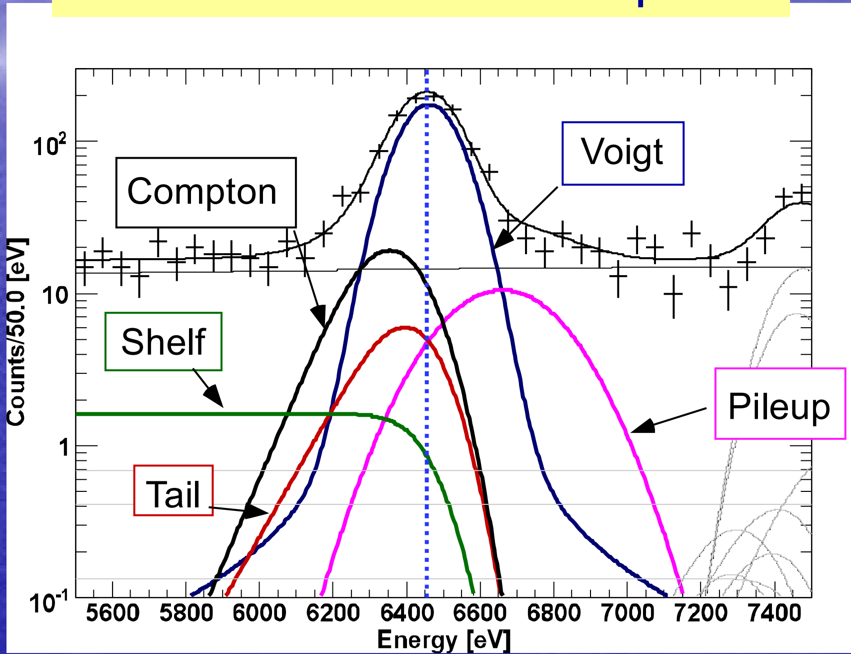
Summary for the X-ray peak function

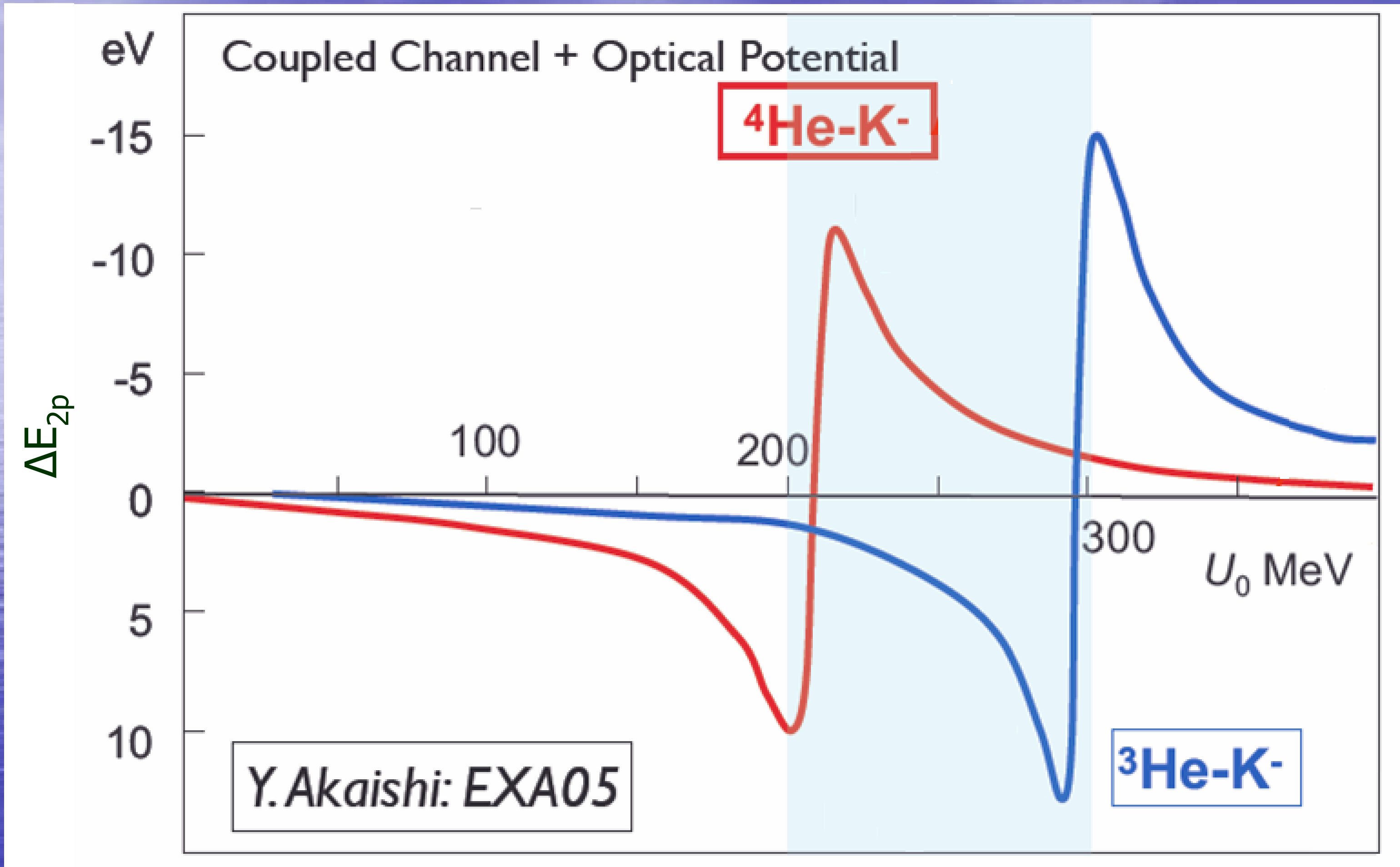
Full fit function for Ti/Ni peaks

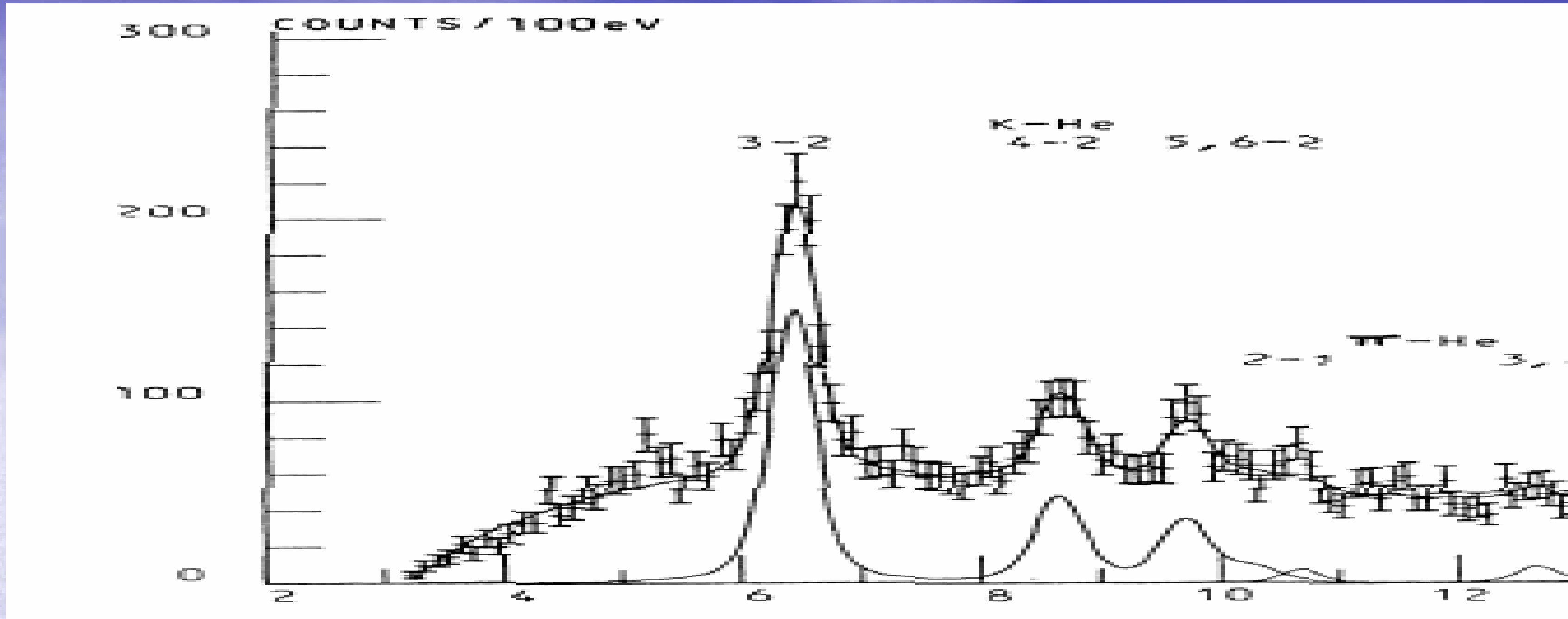


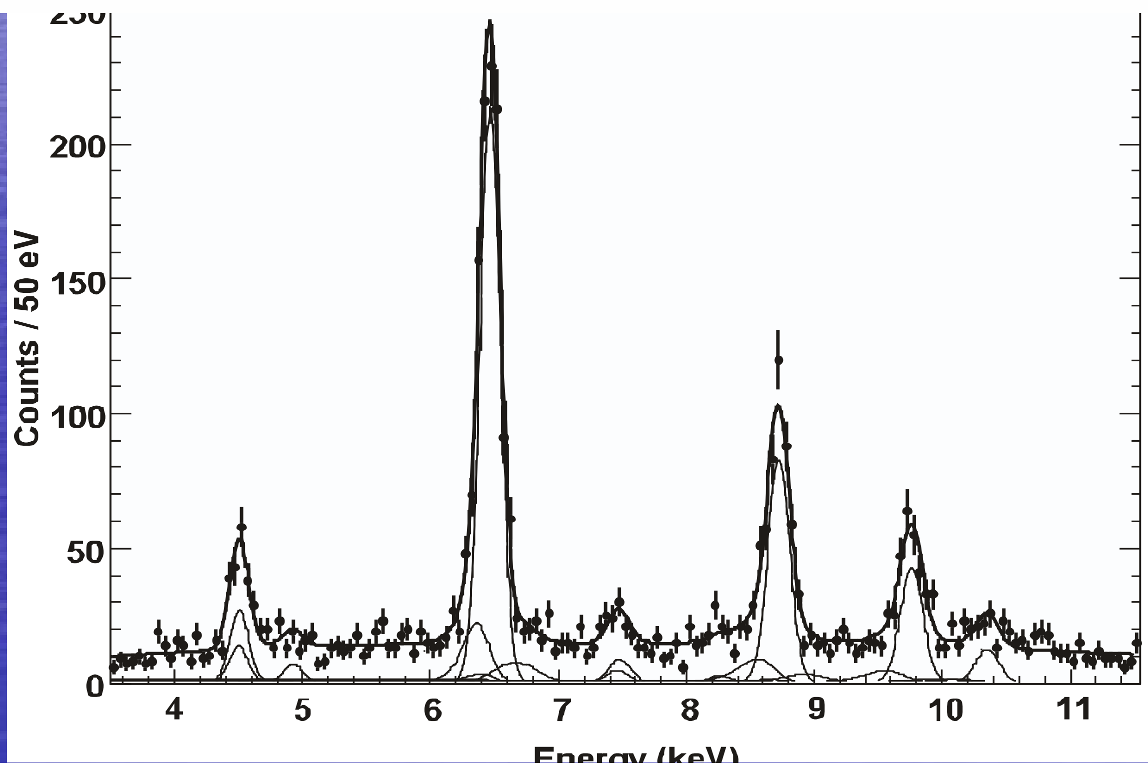
Full fit function for KHe peaks



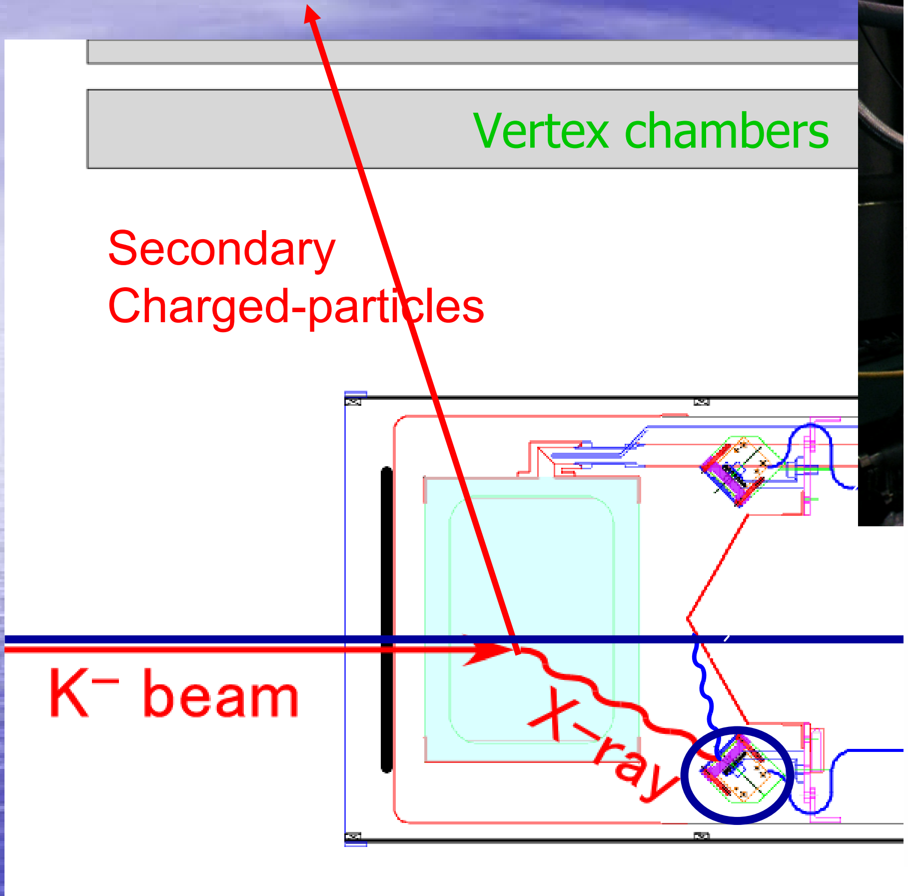
X-ray peak function is a complicated function to achieve a precision of a few eV . The parameters for the tails are obtained from the experimental data (and are checked). Compton tail is obtained from simulation and experimental data. Uncertainties related to these parameters gives main systematic errors for the final results.

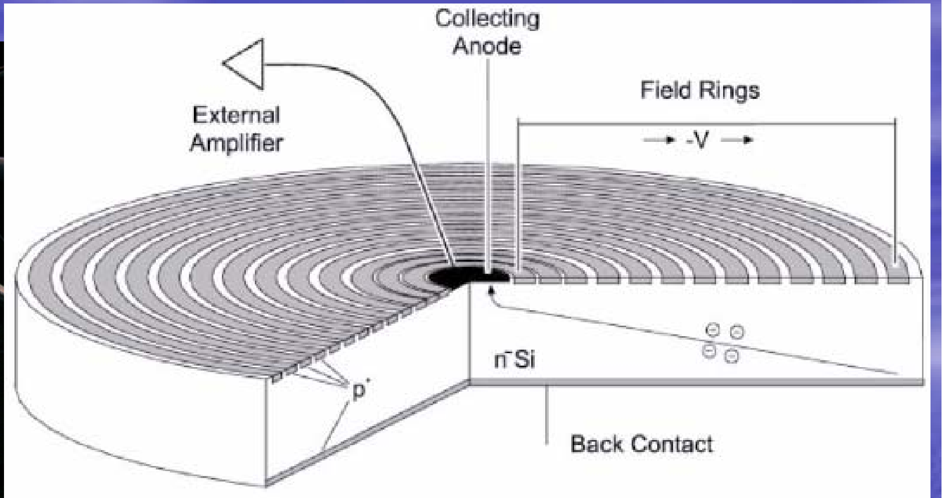

eV
Coupled Channel + Optical Potential
^{4}He-K$^-$
-15
-10
-5
0
5
10
ΔE_{2p}
100
200
300
U_0 MeV
^{3}He-K$^-$
Y. Akaishi: EXA05

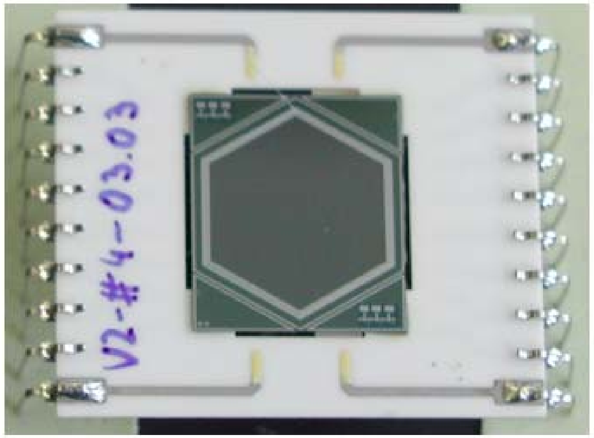

COUNTS / 100eV
300
200
100
0
3-2
K-He
4-2
5,6-2
2-1
π⁻-He
2
4
6
8
10
12


Counts / 50 eV
200
150
100
50
0
4
5
6
7
8
9
10
11

KEK PS E570 exp. setup







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