Precision spectroscopy of Kaonic Helium-4 X-rays

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For KEK-PS E570 collaboration

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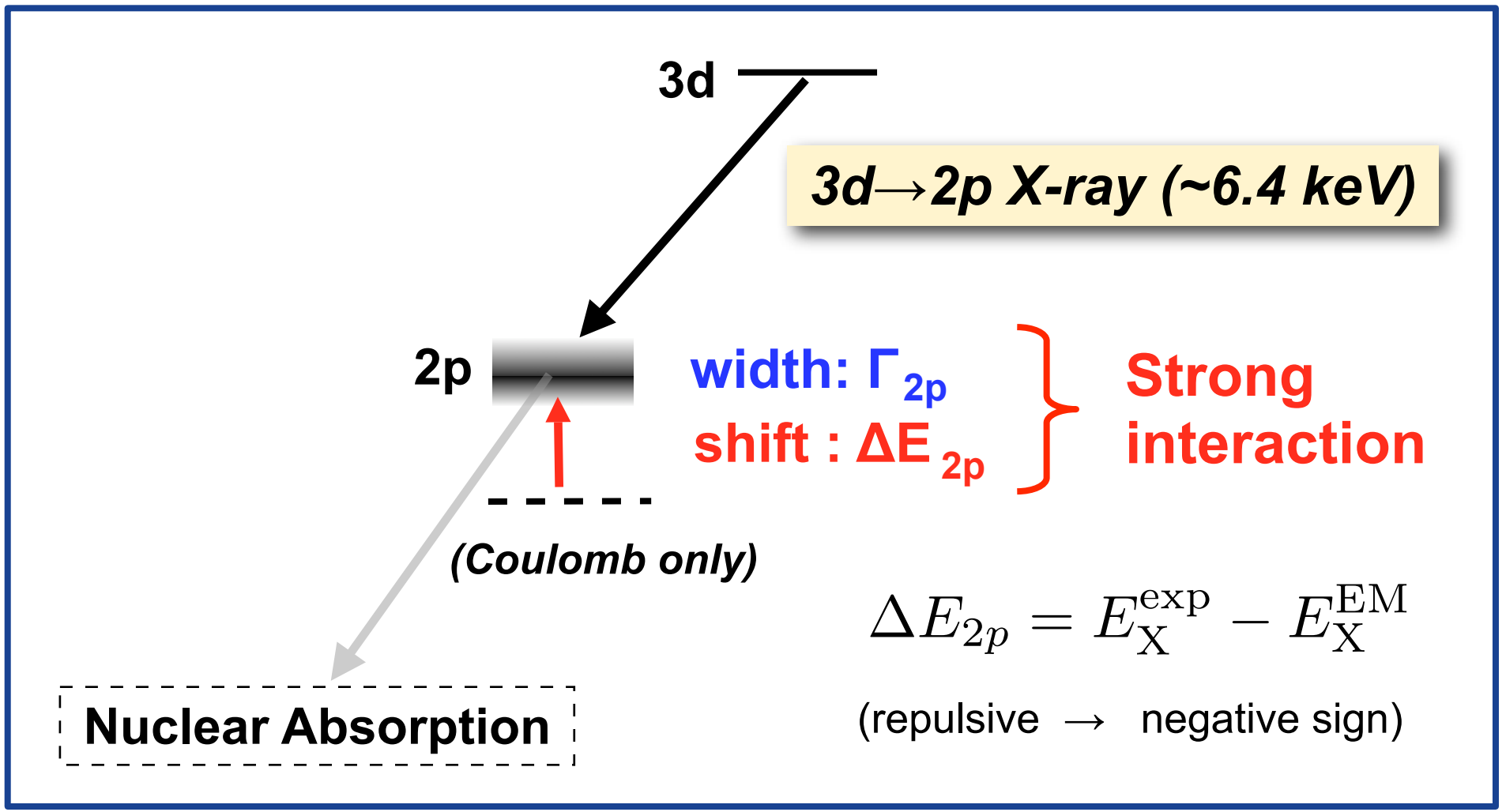
Introduction

$K^- {}^4He$ atom $3d \rightarrow 2p$ X-ray Energy

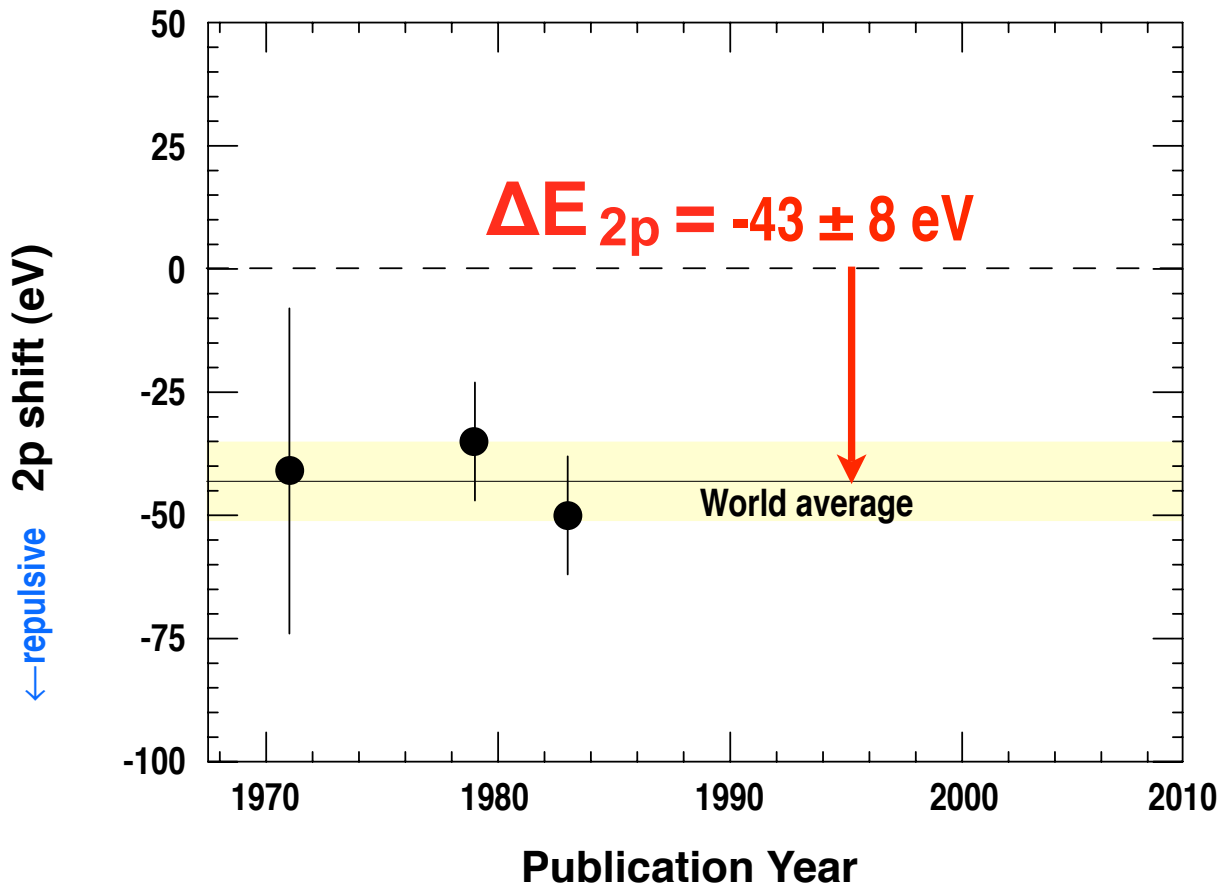
Strong-interaction shift and width

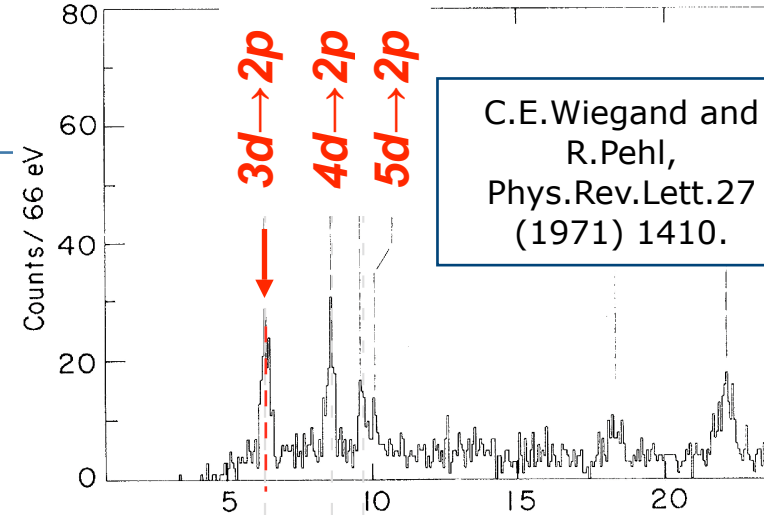


$$\Delta E_{2p} = E_{\mathrm{X}}^{\mathrm{exp}} - E_{\mathrm{X}}^{\mathrm{EM}}$$

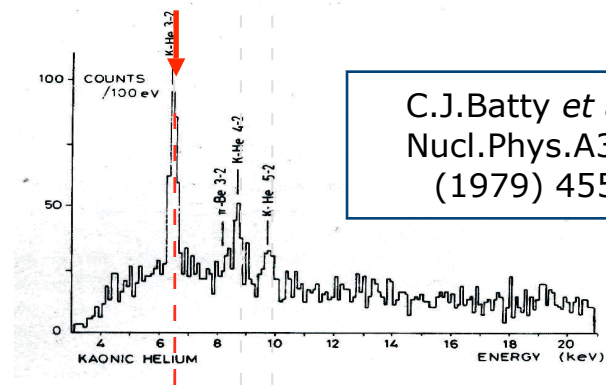
(repulsive → negative sign)

Three past experiments

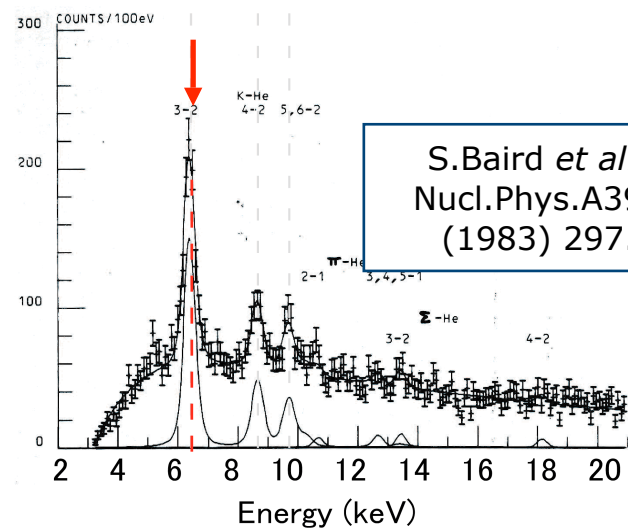




C.E.Wiegand and R.Pehl, Phys.Rev.Lett.27 (1971) 1410.



C.J.Batty *et al.*, Nucl.Phys.A326 (1979) 455.

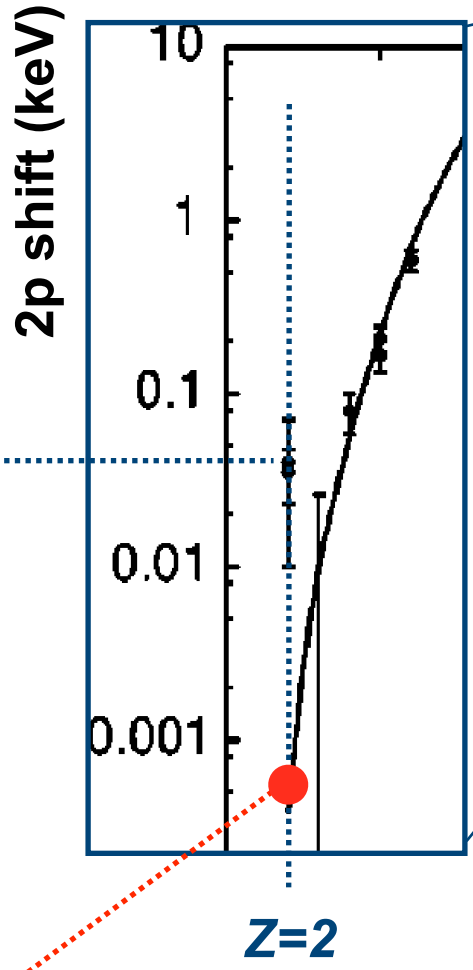


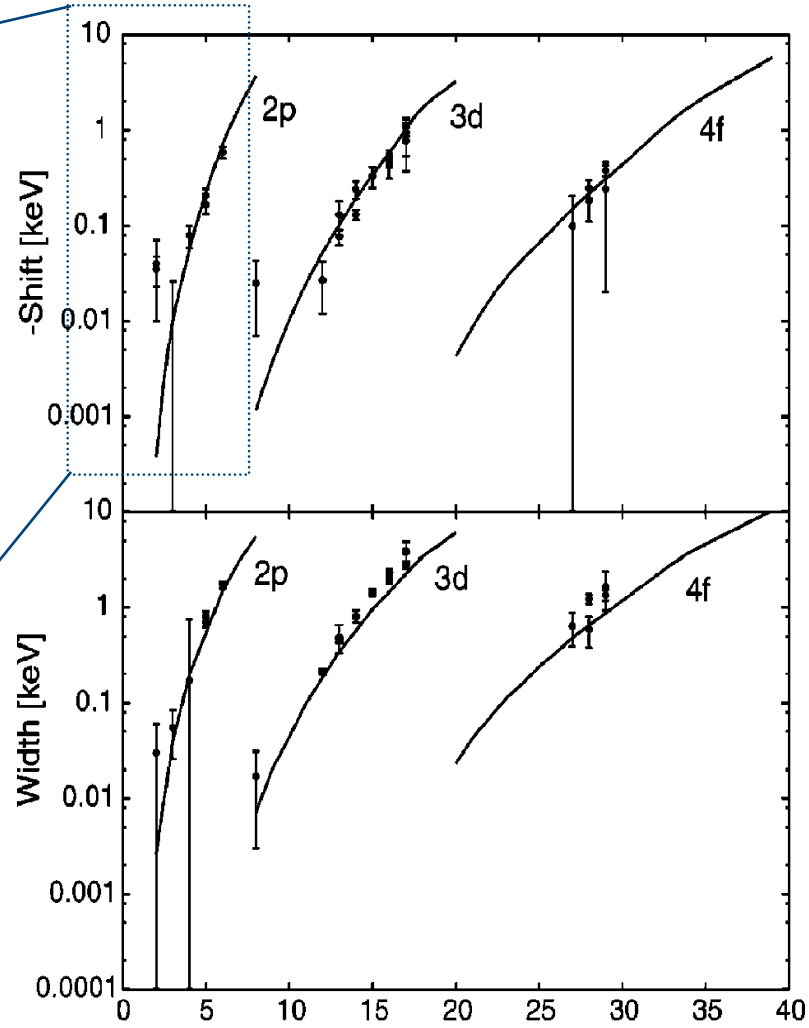
S.Baird *et al.*, Nucl.Phys.A392 (1983) 297.

Why measure again ?

Kaonic helium puzzle

Experiments
~−40eV





Z (atomic number)

Calculation
~ −0.2 eV

(chiral unitary + optical model)

Very small shift

S.Hirenzaki, Y.Okumura, H.Toki, E.Oset, and A.Ramos
Phys. Rev. C 61 055205 (2000)

Large shift:

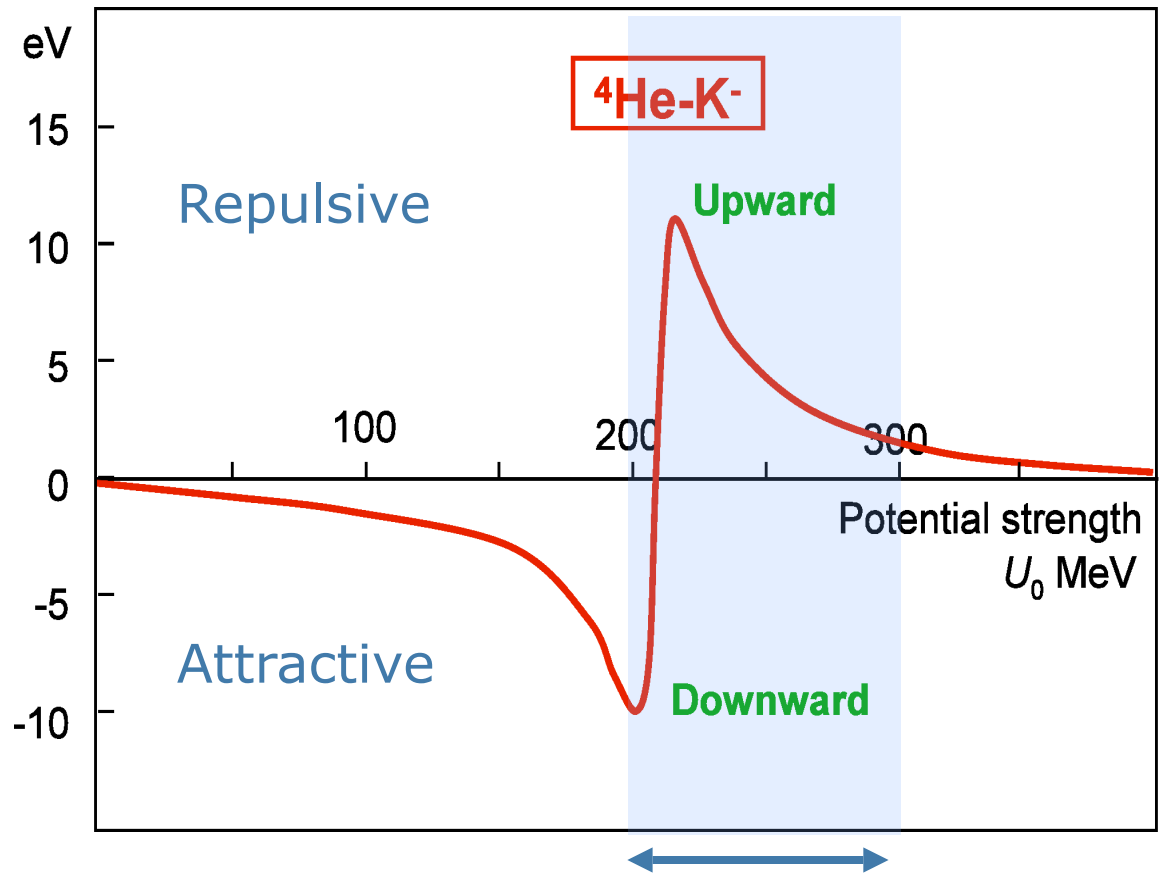
indication of a kaon bound state in the nucleus ?

C.J. Batty, Nucl. Phys. A508 (1990) 89c

Bound states of a kaon in the nucleus can give rise to ***large energy shifts and widths****...*

... these effects are only significant when the ***imaginary part*** *of the effective kaon-nucleus interaction* ***is small***

Akaiishi's prediction



$|\Delta E_{2p}| < \sim 10$ eV

Non-zero shift is acceptable !

Y.Akaishi, EXA05 proceedings (2005)

accommodates kaonic nuclear states (Akaishi-Yamazaki prediction)

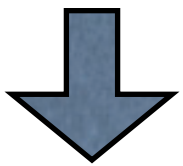
E570 goal

Resolve the kaonic helium puzzle

by high precision spectroscopy

motivated by the Akaishi's prediction

If non-zero shift is established,

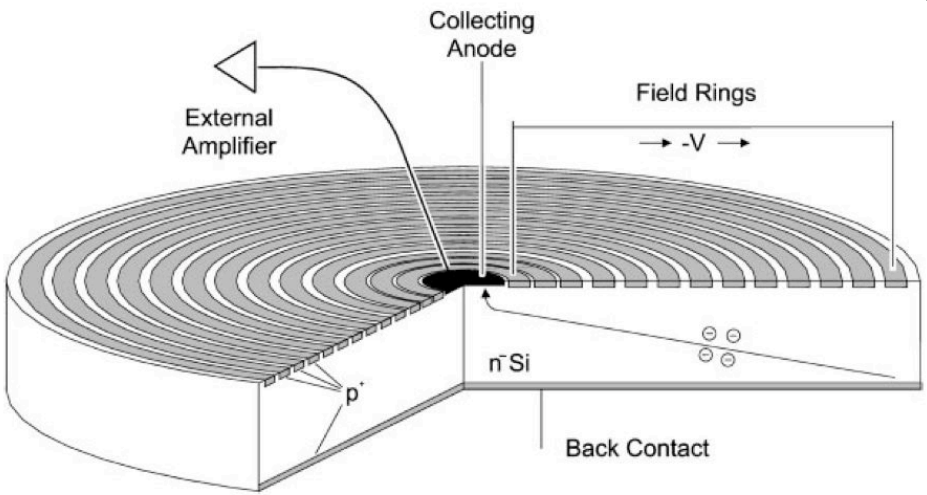


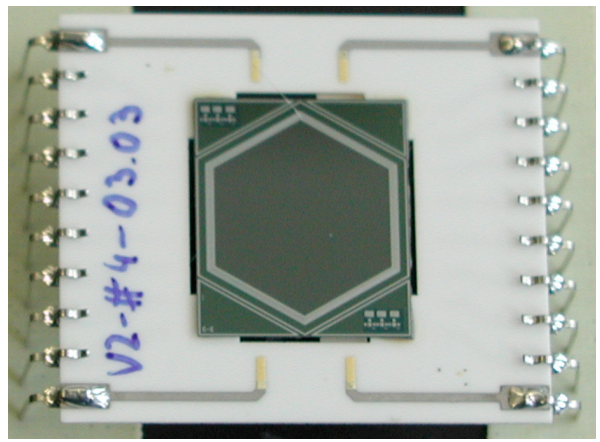
provides a positive support for the A-Y prediction

E570 Methods

1. high resolution
2. low background
3. good energy calibration

1. high resolution





Silicon Drift Detectors (SDDs)

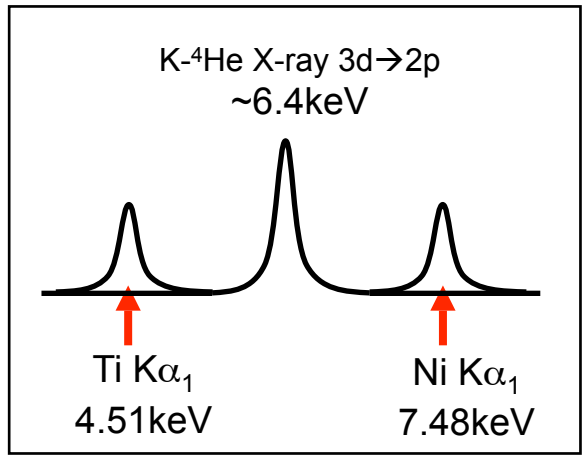
produced by KETEK GmbH

small anode
(small detector capacitance)

high resolution
(185 eV FWHM @ 6.4 keV)

large effective area (100 mm^2)
small detector thickness (0.26 mm)

2. background suppression and 3. good energy calibration



2) Reaction-vertex reconstruction

3) In-situ energy calibration

Secondary charged particle

K⁻ beam

π⁻(or K⁻)

X-ray

Characteristic X-rays (Ti and Ni)

Liq. Helium target

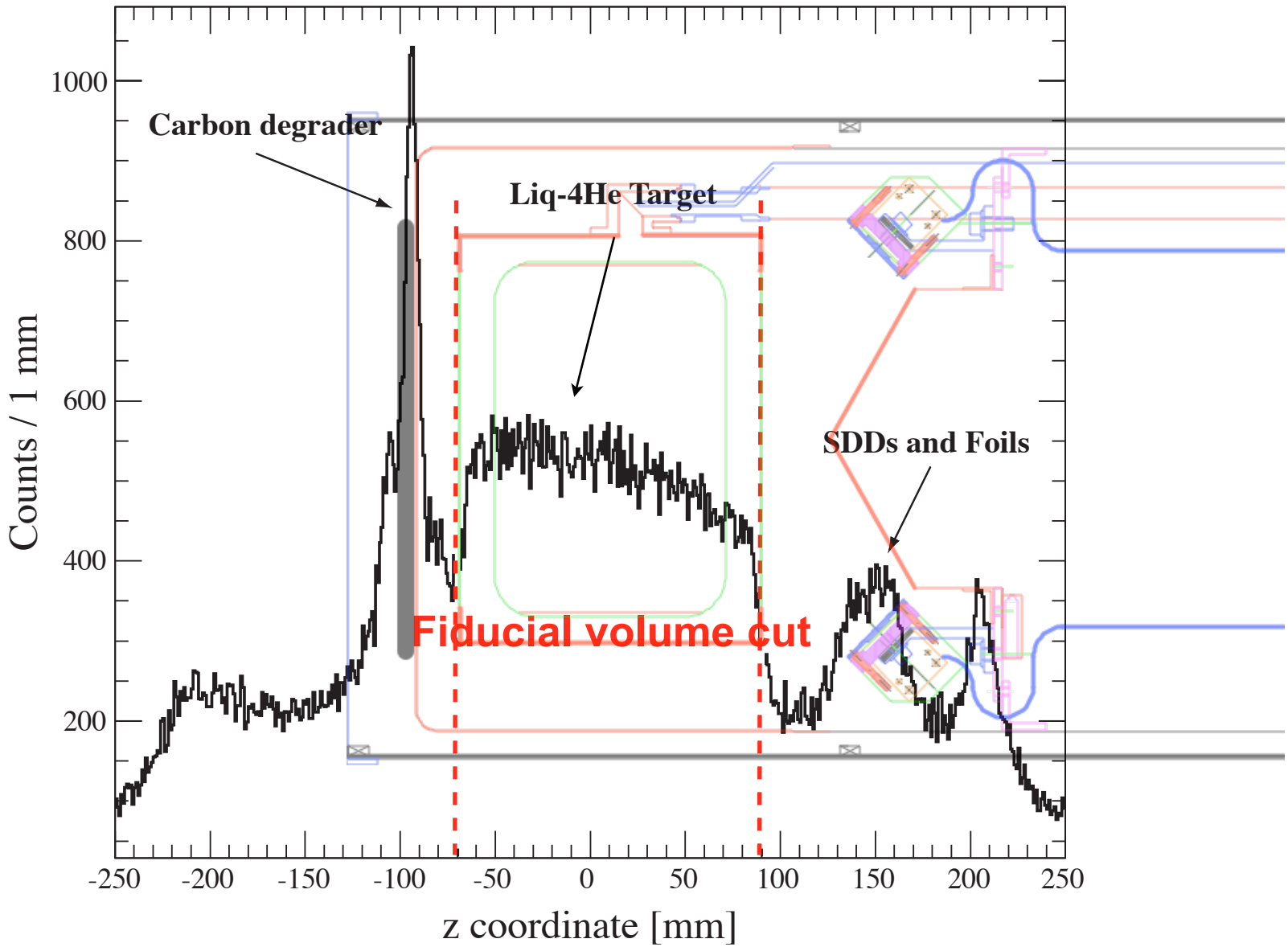
10 cm

1) X-ray detector
Silicon Drift Detector "**SDD**" (×8)

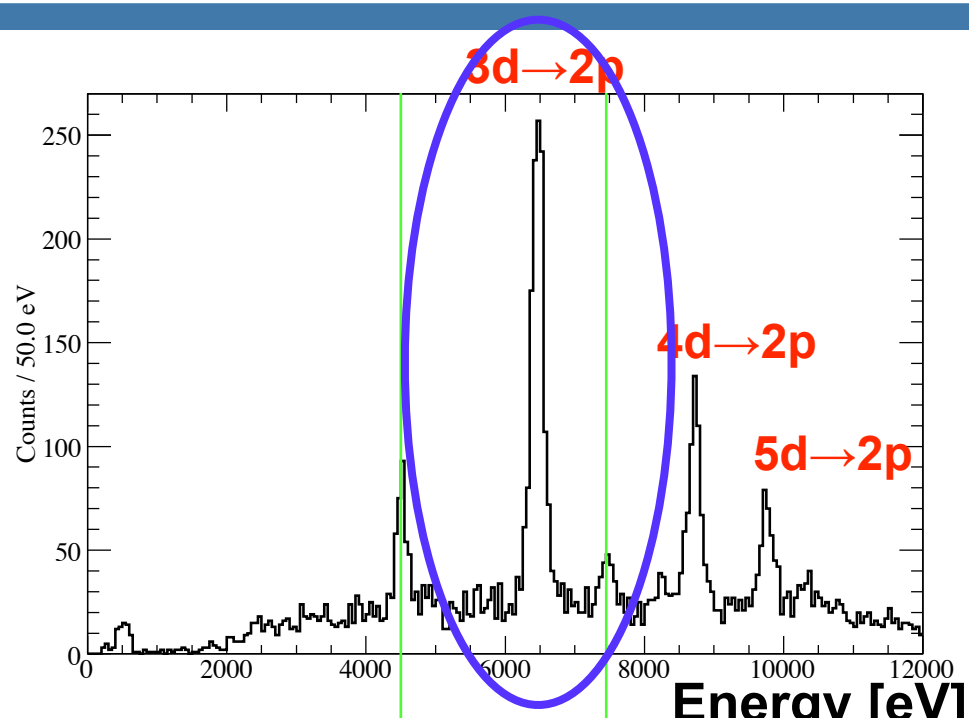
Analysis

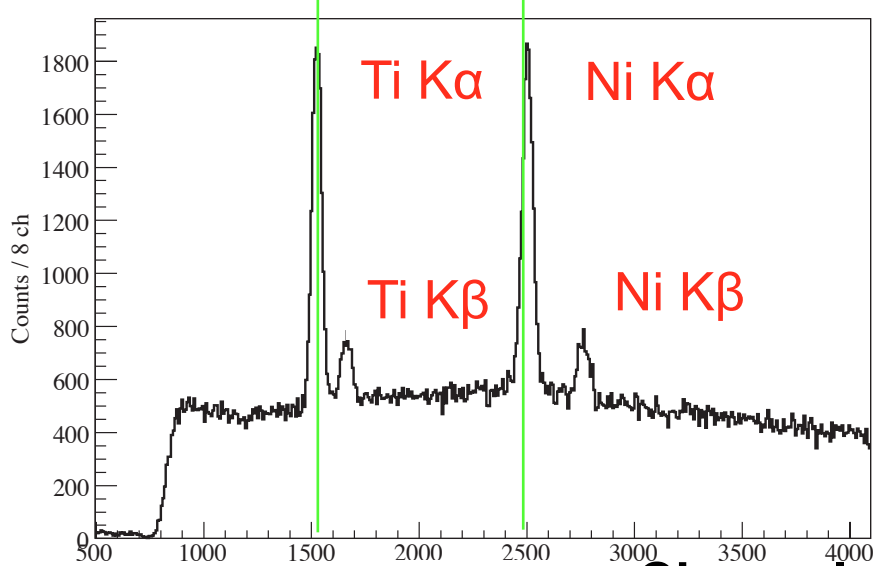
Fiducial volume cut

Kaon beam



In-situ energy calibration





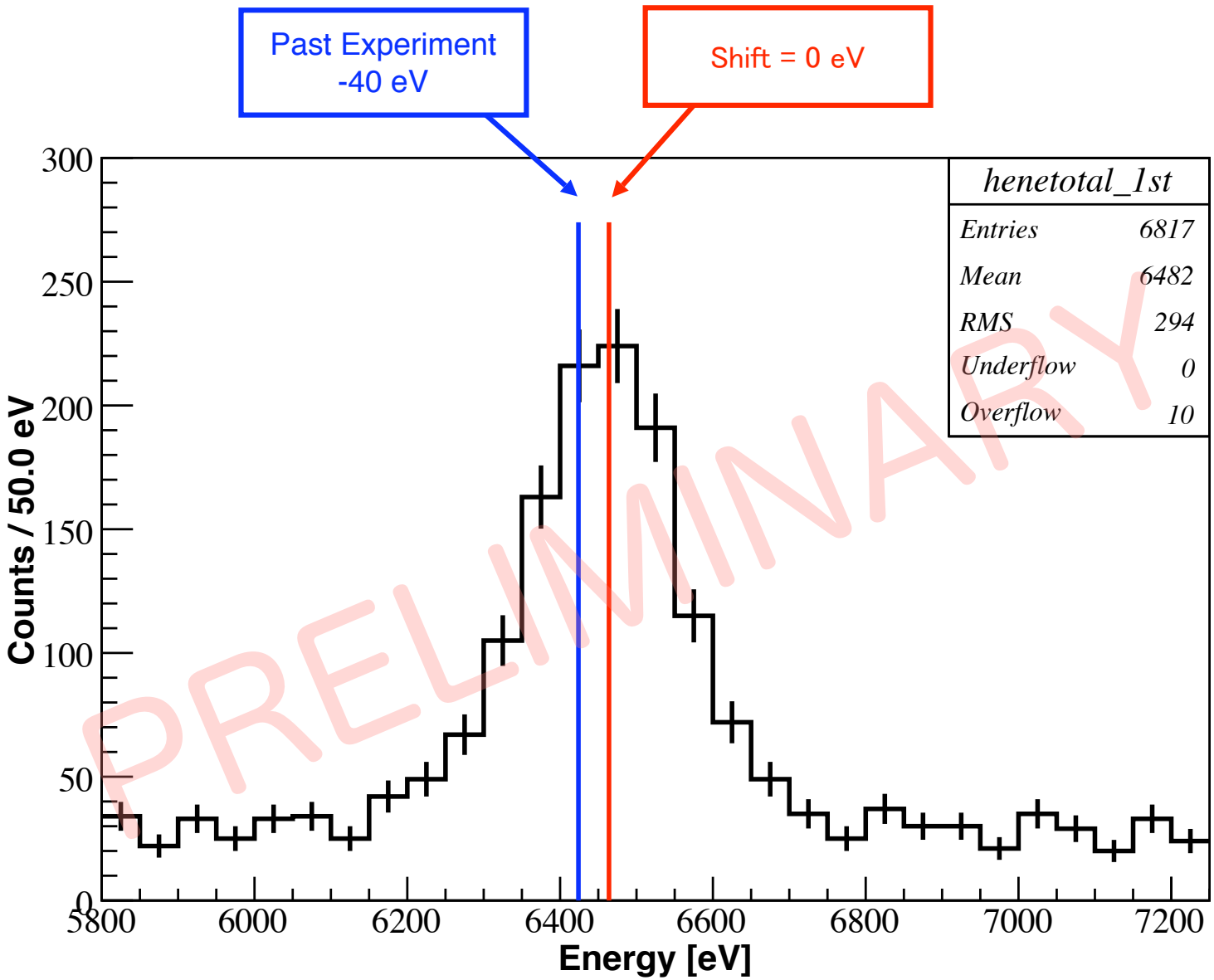
Energy

Channel

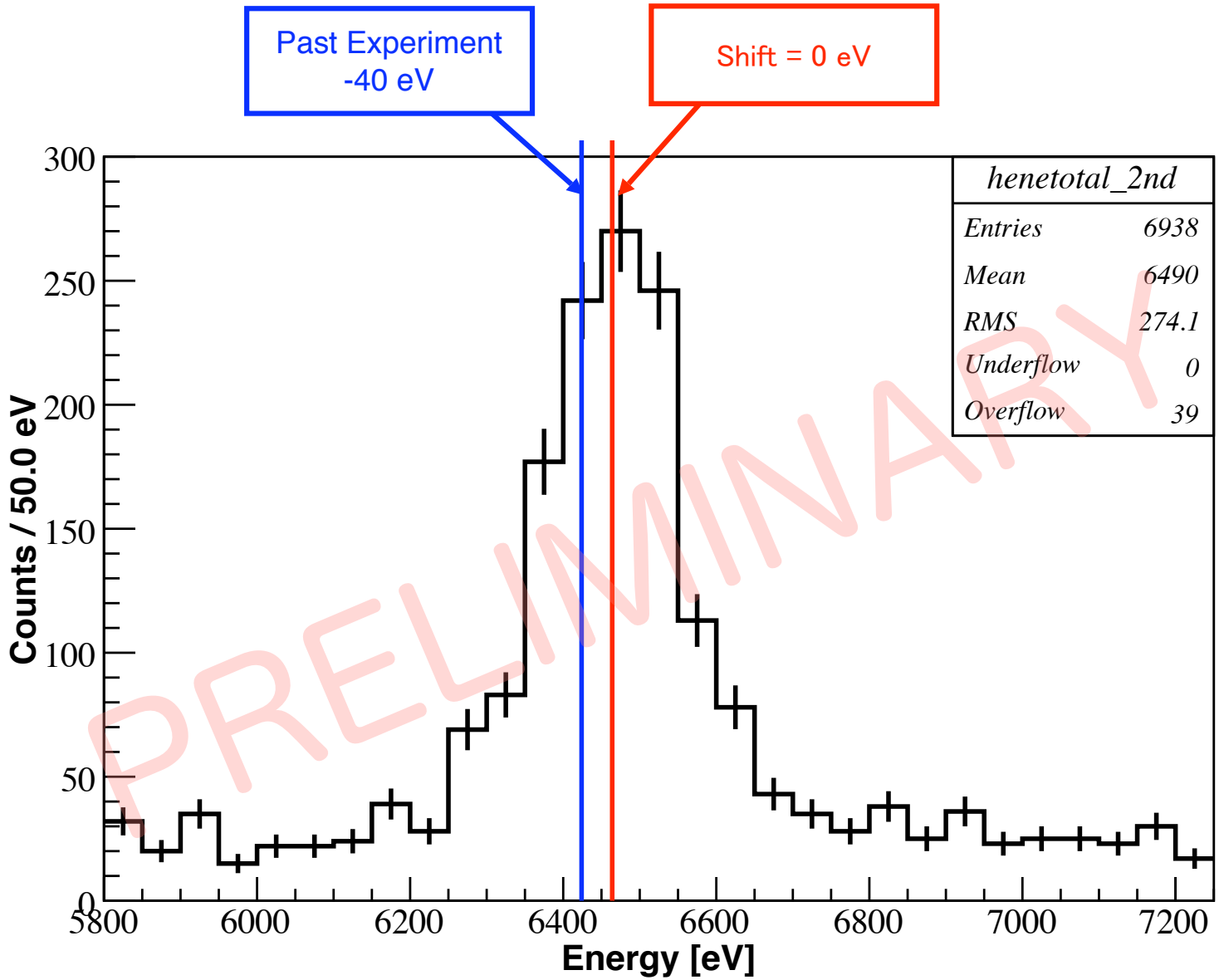
Kaon Trigger (timing and fiducial volume cuts)

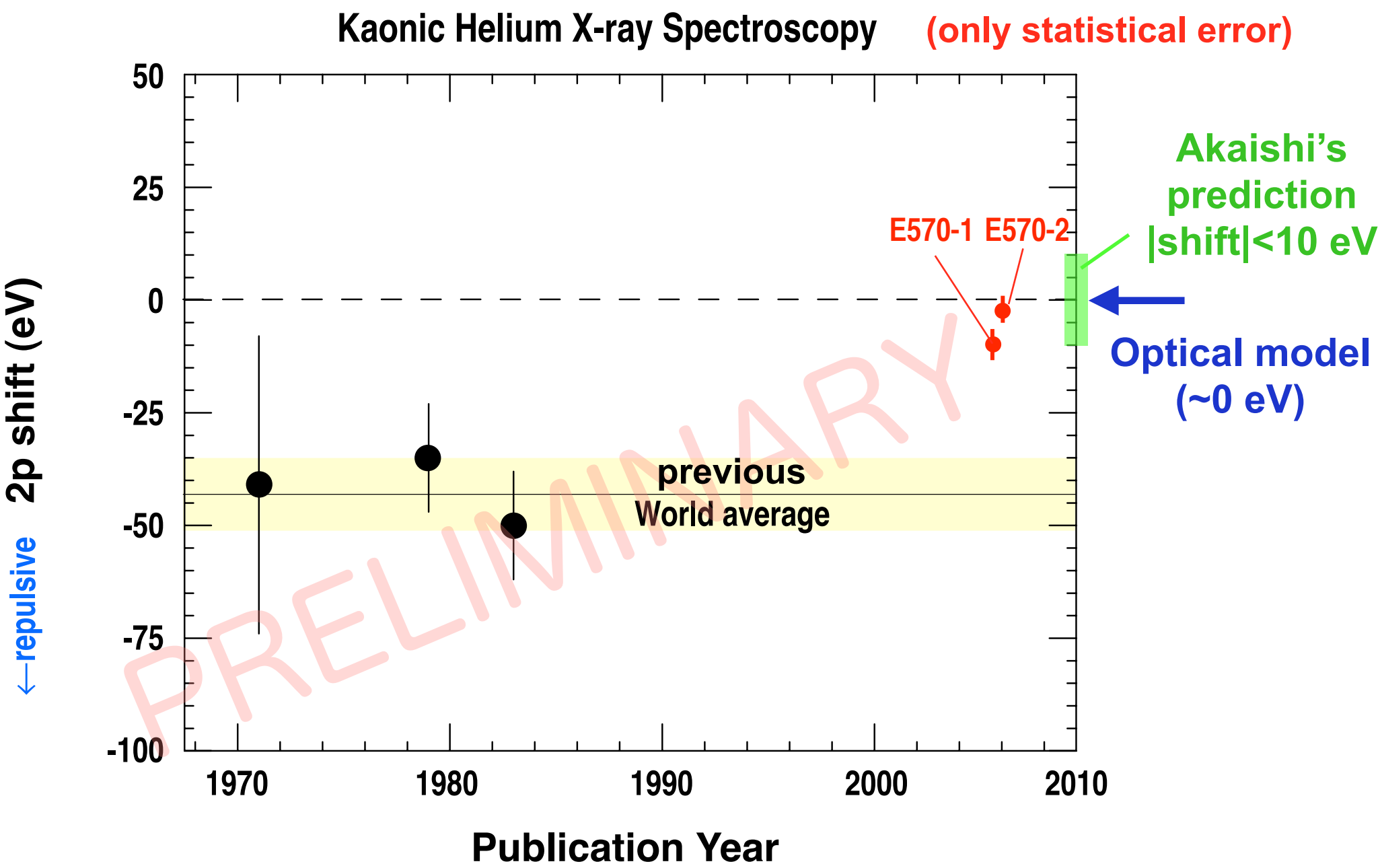
Calibration Trigger (characteristic X-rays)

E570 1st cycle (2005.Oct)



E570 2nd cycle (2005.Dec)




Kaonic Helium X-ray Spectroscopy
(only statistical error)
50
25
0
-25
-50
-75
-100
2p shift (eV)
←repulsive
1970
1980
1990
2000
2010
Publication Year
E570-1
E570-2
Akaishi's
prediction
|shift|<10 eV
Optical model
(~0 eV)
previous
World average
PRELIMINARY

Systematic error estimation

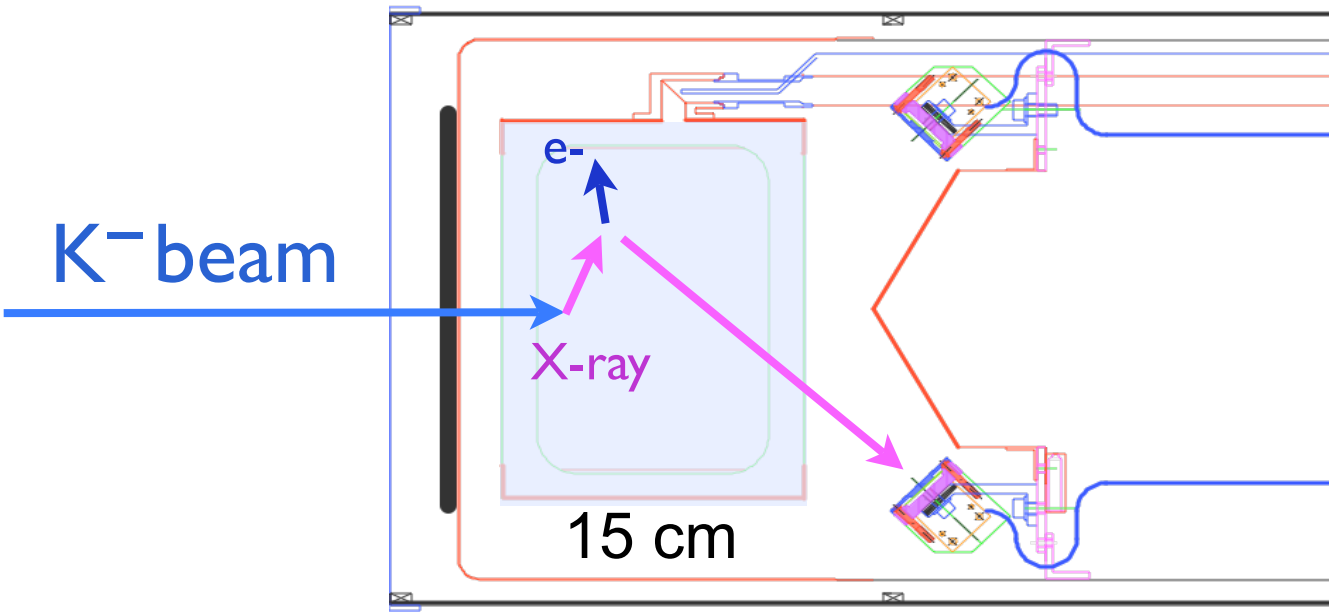
Now in progress...

Need some corrections to determine the systematic error.

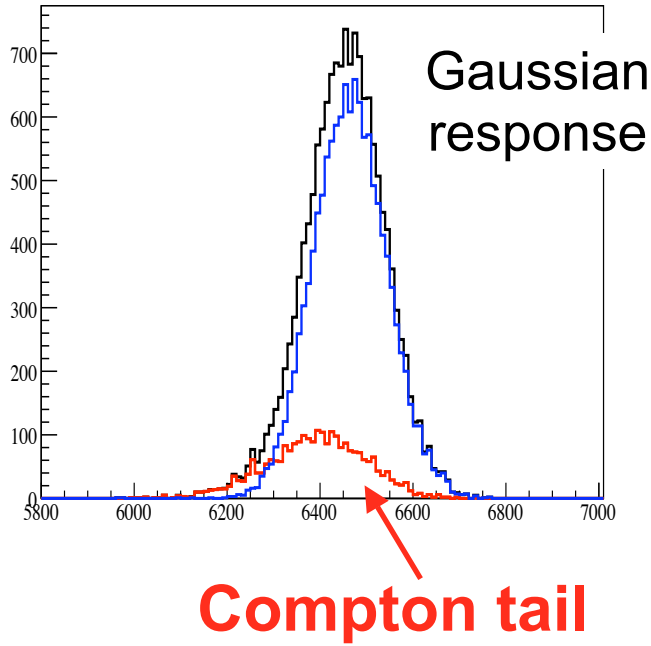
The most significant correction is

Compton scattering in the liquid helium target

Compton scattering in the liquid helium target (density=0.145 g/cm3)



simulation (3d→2p)

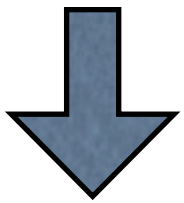


Scattered X-rays give rise to tail structure
~100 eV lower than the original peak

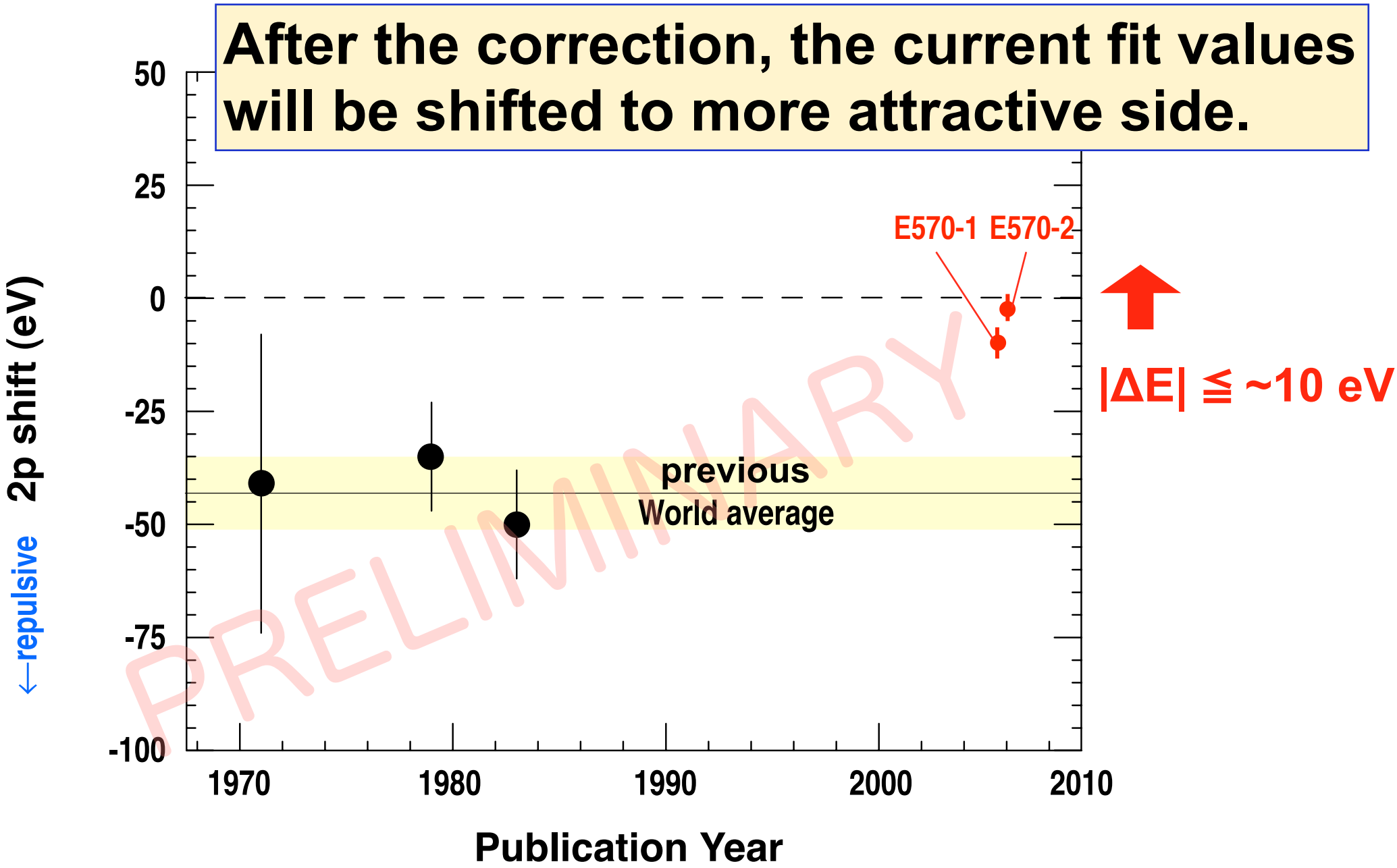
The "Compton tail" influences the estimation of ΔE_{2p} directly.

To correct

- Energy dependence of Compton scattering
- Stopped-kaons distribution (z-dependence)
- SDD's geometrical acceptance (z-dependence)
- Attenuation effect, coherent scattering, ...



Full similation


After the correction, the current fit values will be shifted to more attractive side.
50
25
0
-25
-50
-75
-100
2p shift (eV)
←repulsive
E570-1
E570-2
|ΔE| ≦ ~10 eV
previous
World average
PRELIMINARY
1970
1980
1990
2000
2010
Publication Year

Summary

- High quality data on ^{4}He accumulated
  - Resolution : 185 eV FWHM @ 6.4 keV (SDD)
  - Statistical error : ~2 eV, good S/N ratio (fiducial volume cuts)
  - In-situ energy calibration (Ti and Ni X-rays)

- Shift appears to be $|\Delta E| \leqq \sim 10$ eV (PRELIMINARY)
  (Kaonic helium puzzle is resolved)
- Systematic error estimation is now in progress
  (Compton tail correction is signifcant)