

E570: Precision spectroscopy of Kaonic Helium $3d \rightarrow 2p$ X-rays

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THE UNIVERSITY OF TOKYO

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The E570 collaboration

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M. Iwasaki⁸, B. Juhasz³, P. Kienle³, J. Marton³, Y. Matsuda⁸,
H. Ohnishi⁸, S. Okada⁸, H. Outa⁸, M. Sato⁶, P. Schmid³,
S. Suzuki⁹, T. Suzuki⁸, H. Tatsuno⁷, D. Tomono⁸,
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Tokyo Tech⁶, Univ. of Tokyo⁷, RIKEN⁸, KEK⁹

we are proud to show that

the kaonic-helium puzzle

has now been solved



Available online at www.sciencedirect.com



PHYSICS LETTERS B

Physics Letters B 653 (2007) 387–391

www.elsevier.com/locate/physletb

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

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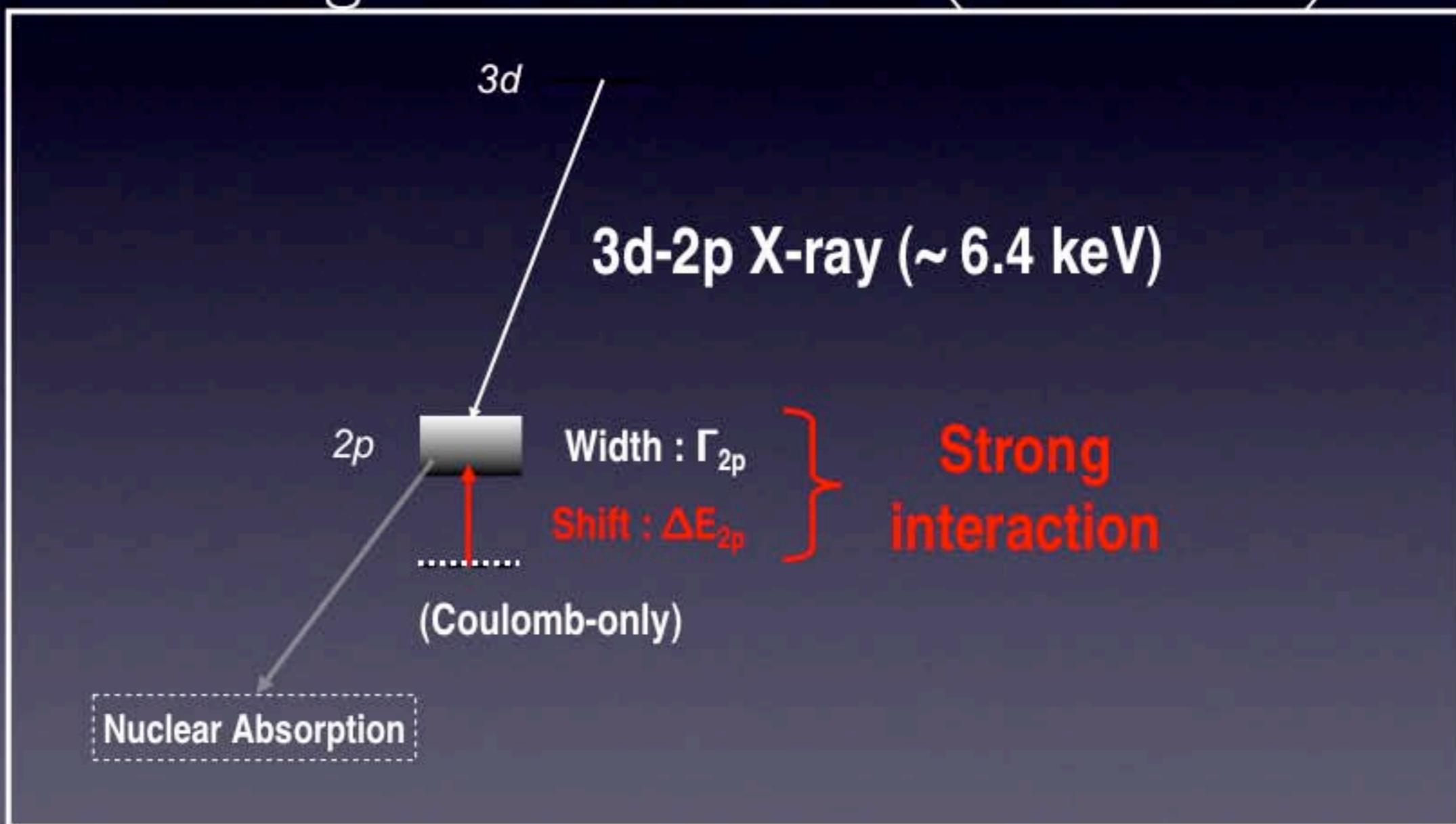


What has been the
problem?

K⁻ He atom 3d-2p X-ray Energy

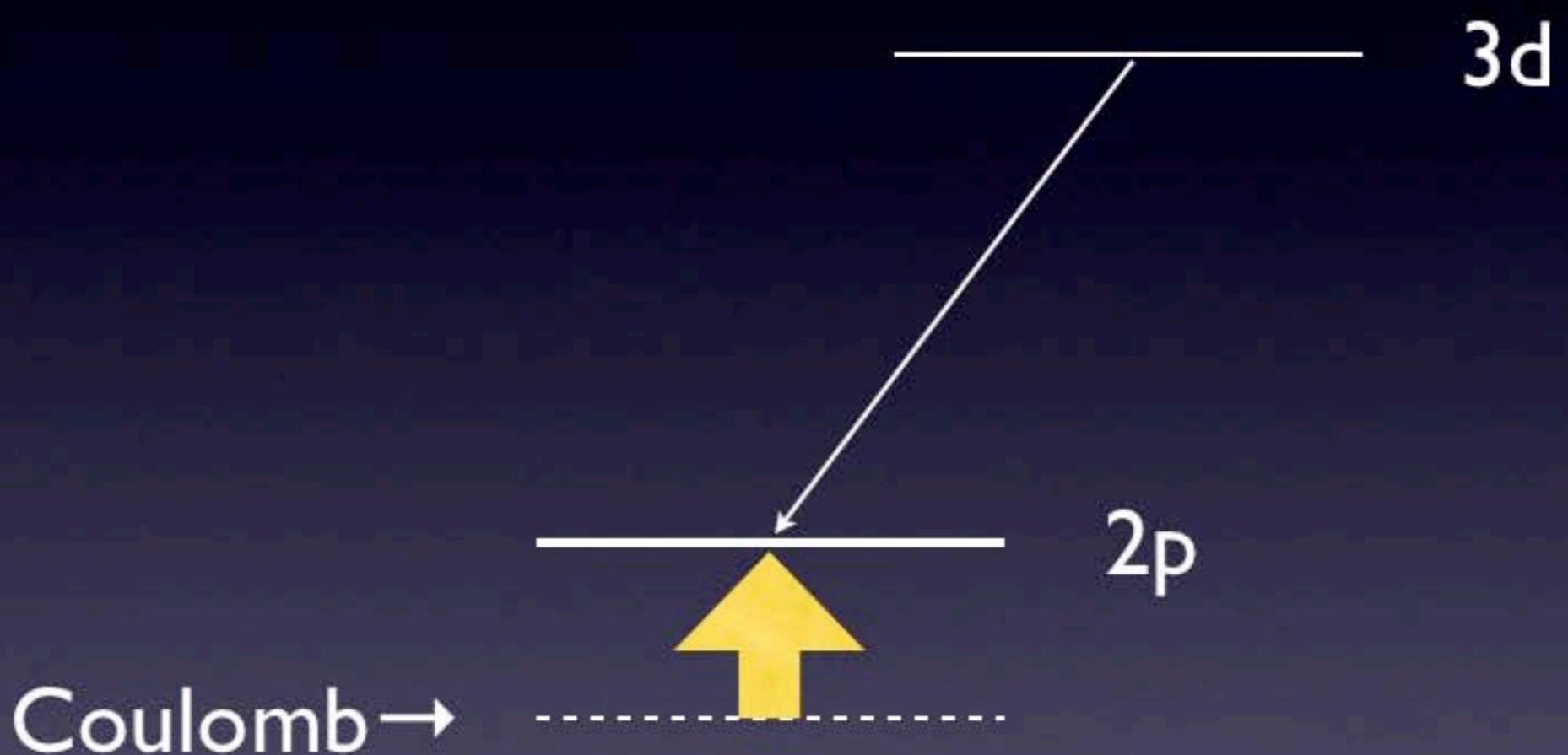


Strong-interaction shift (and width)



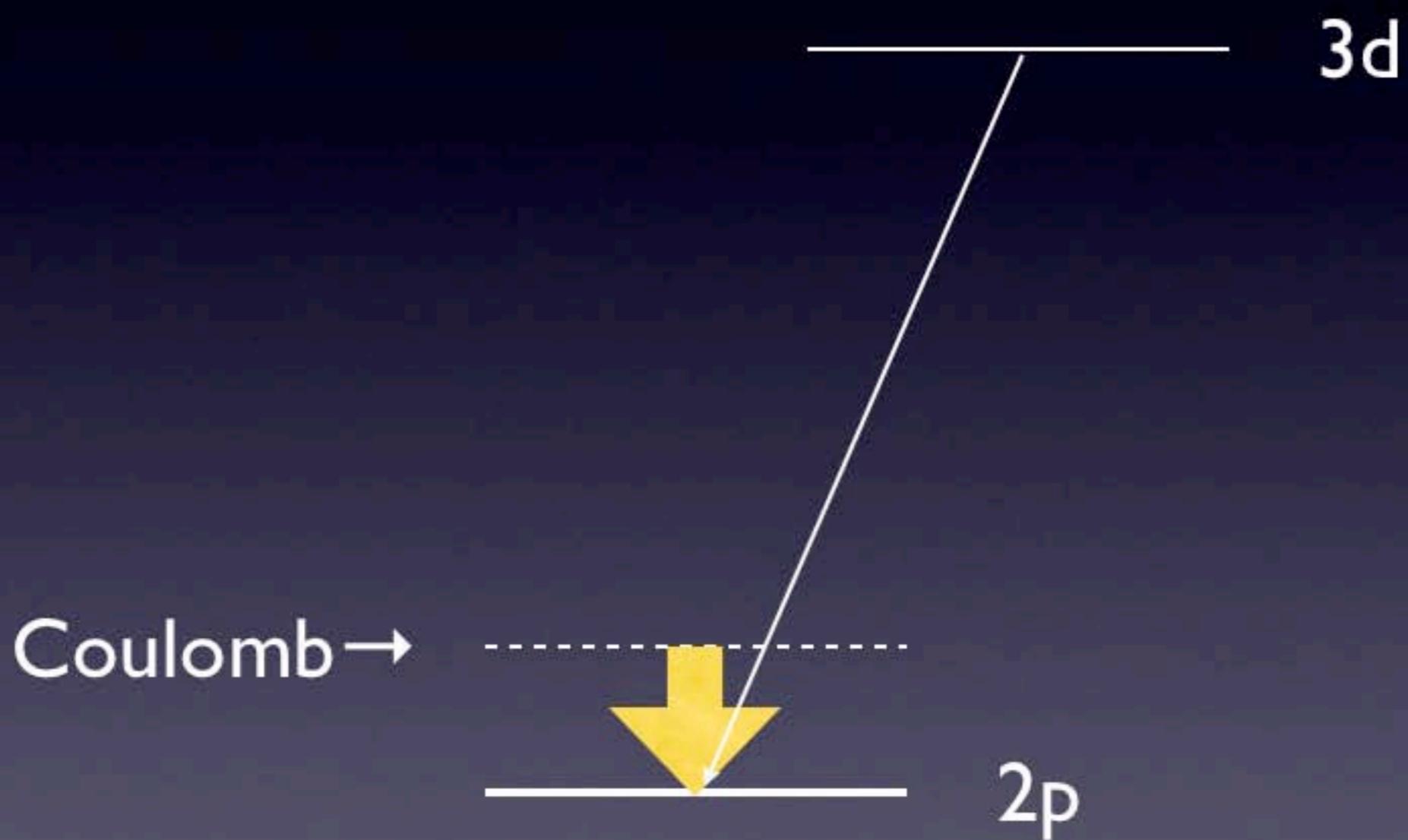
“repulsive”

X-ray energy reduced (shift sign negative)



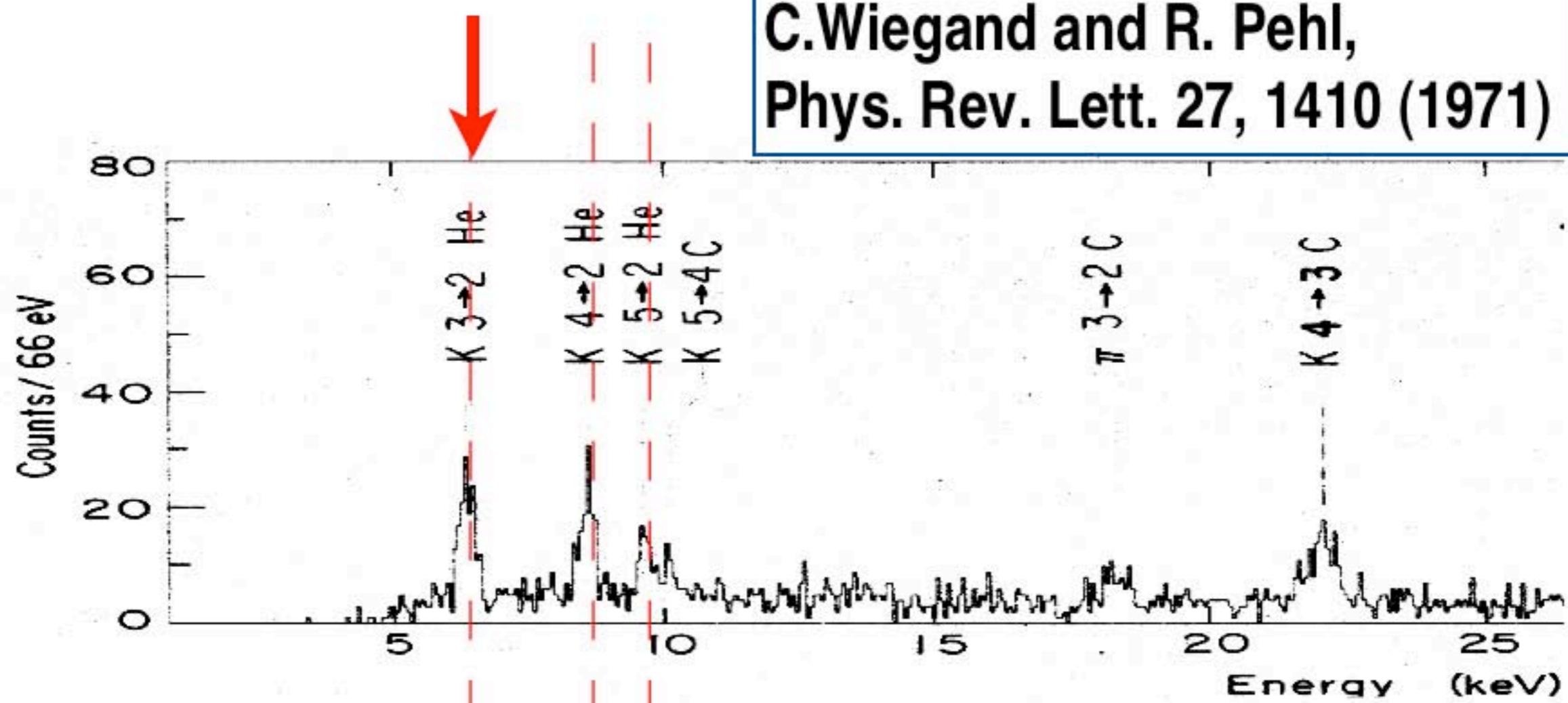
“attractive”

X-ray energy increased (shift sign positive)

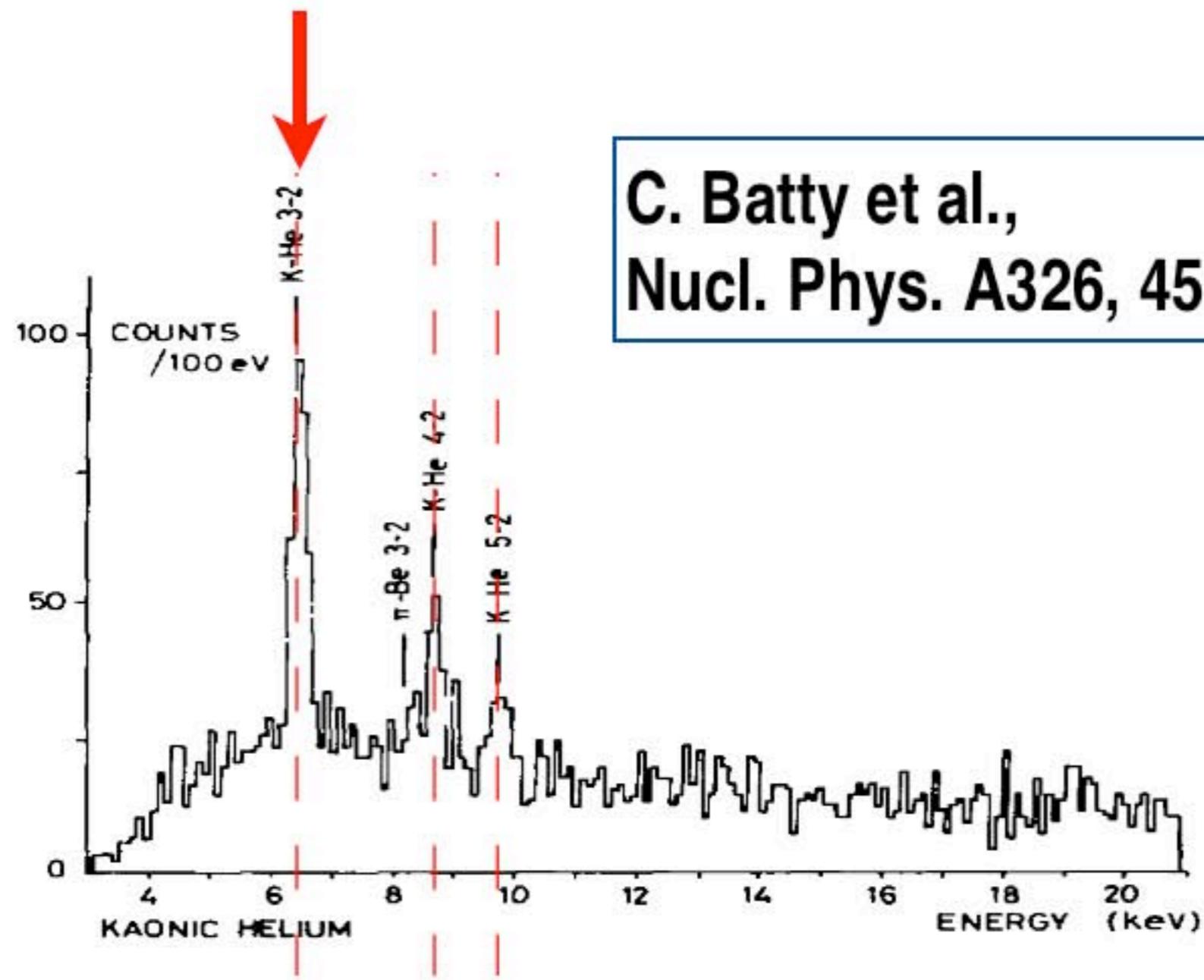


I - 1971

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

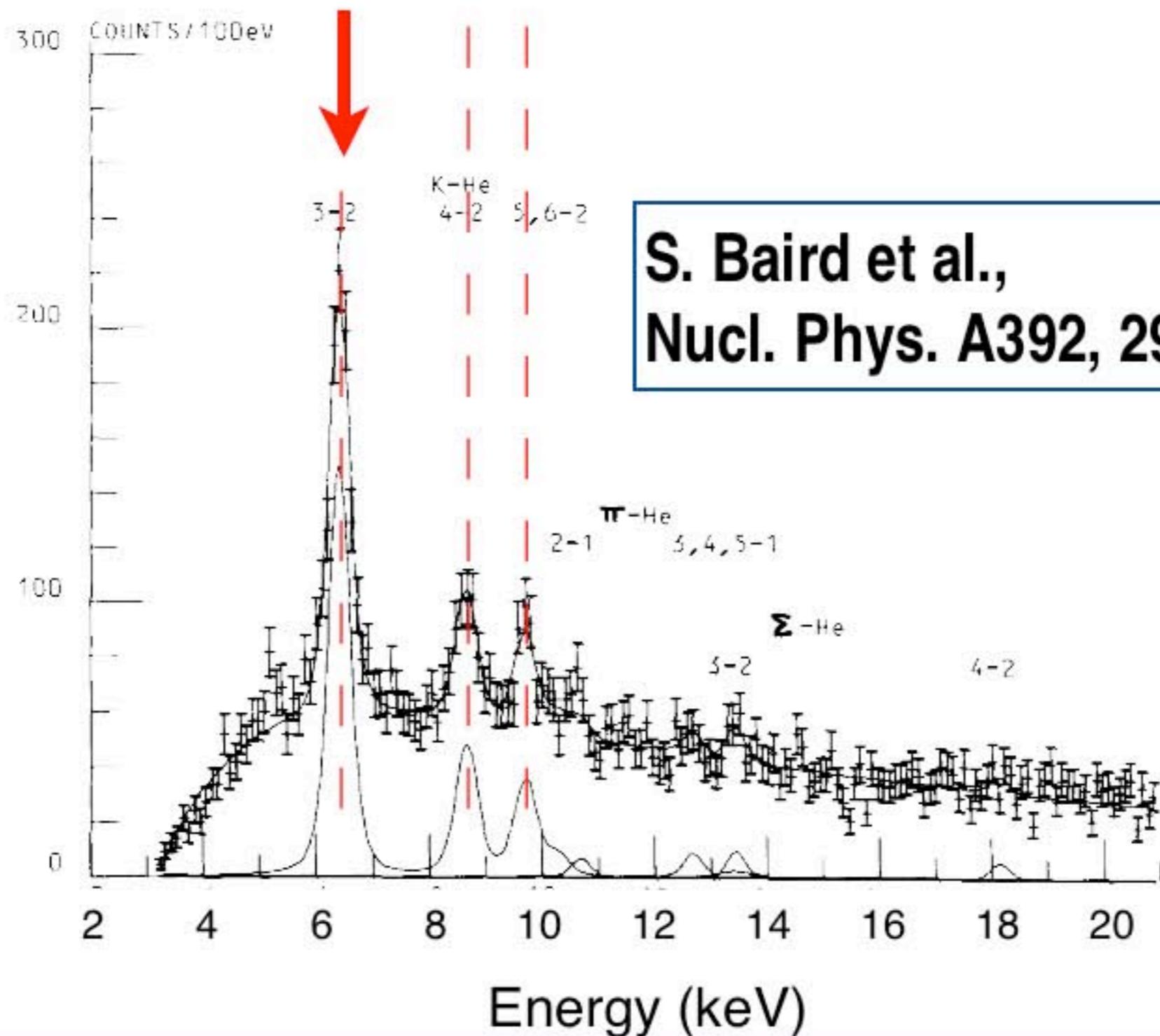


2 - 1979



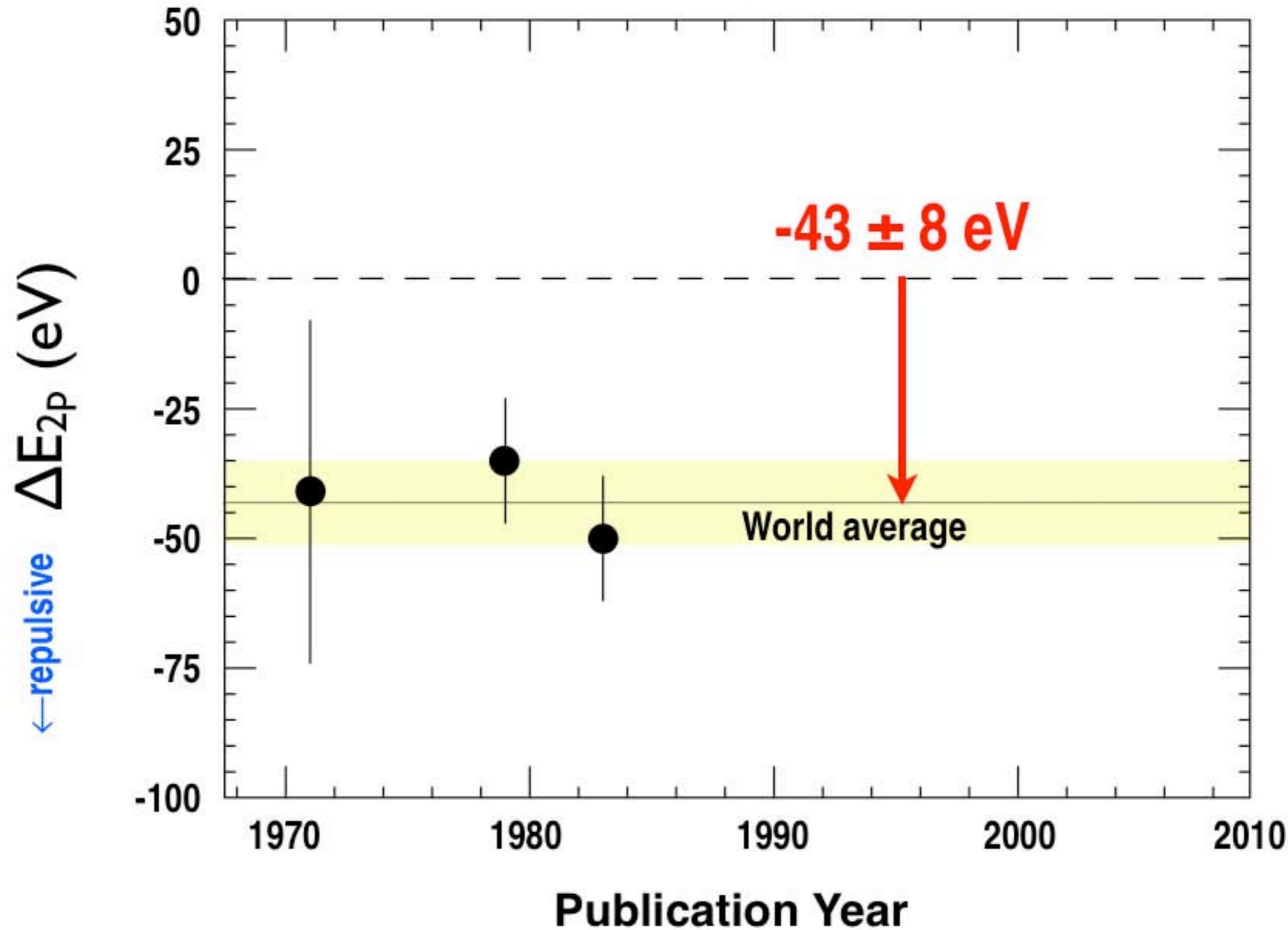
C. Batty et al.,
Nucl. Phys. A326, 455 (1979)

3 - 1983



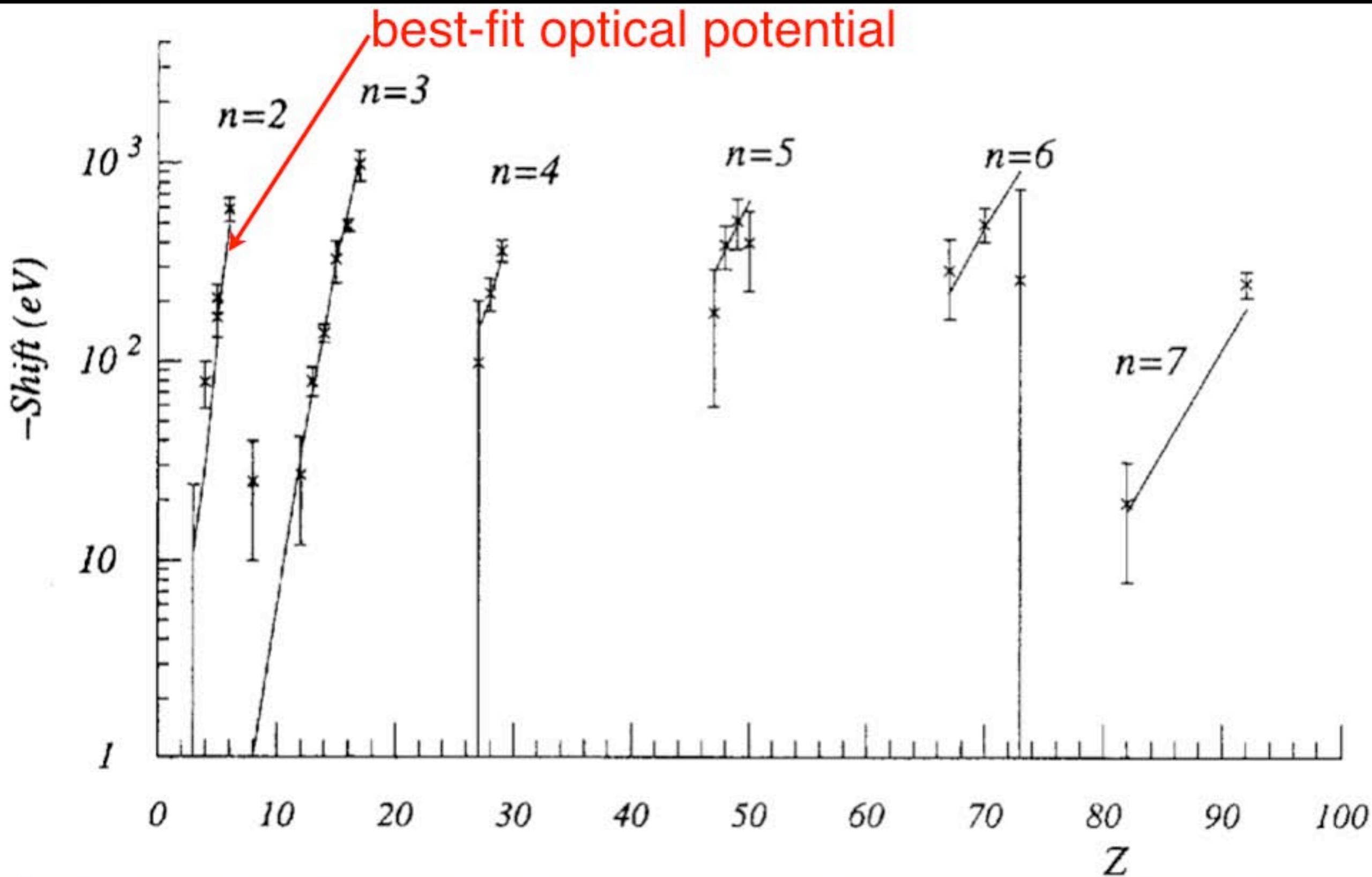
S. Baird et al.,
Nucl. Phys. A392, 297 (1983)

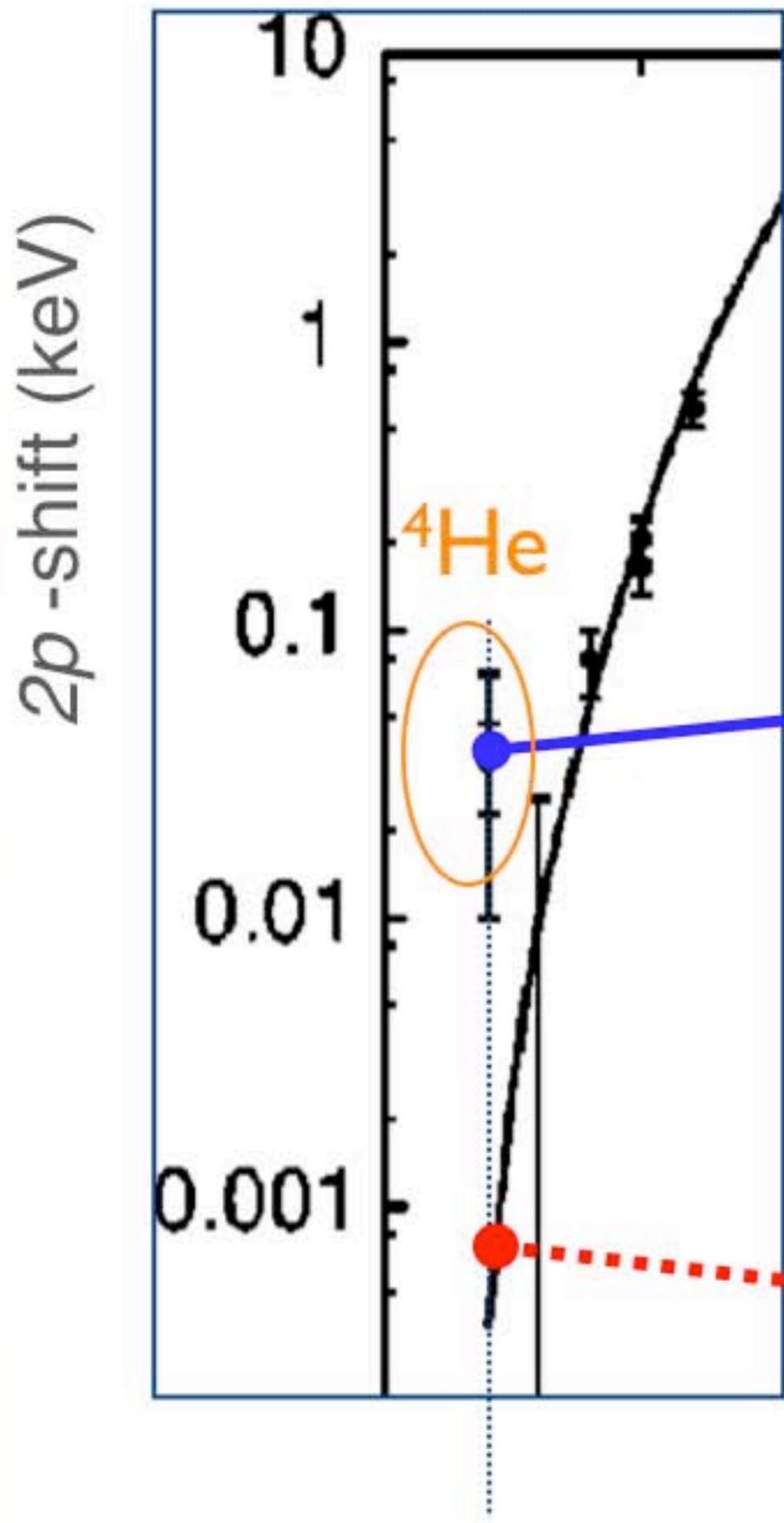
Kaonic Helium X-ray Spectroscopy



kaonic atom strong-interaction shift

C.J.Batty, E. Friedman, A. Gal, Phys.
Reports 287, 385 (1997)





i.e., More than 5σ difference
between experiment and
theory

Experiment

Theory

$\sim -0.2\text{eV}$

Batty (1990),
Hirenzaki et al (2000),
Friedman (2007)

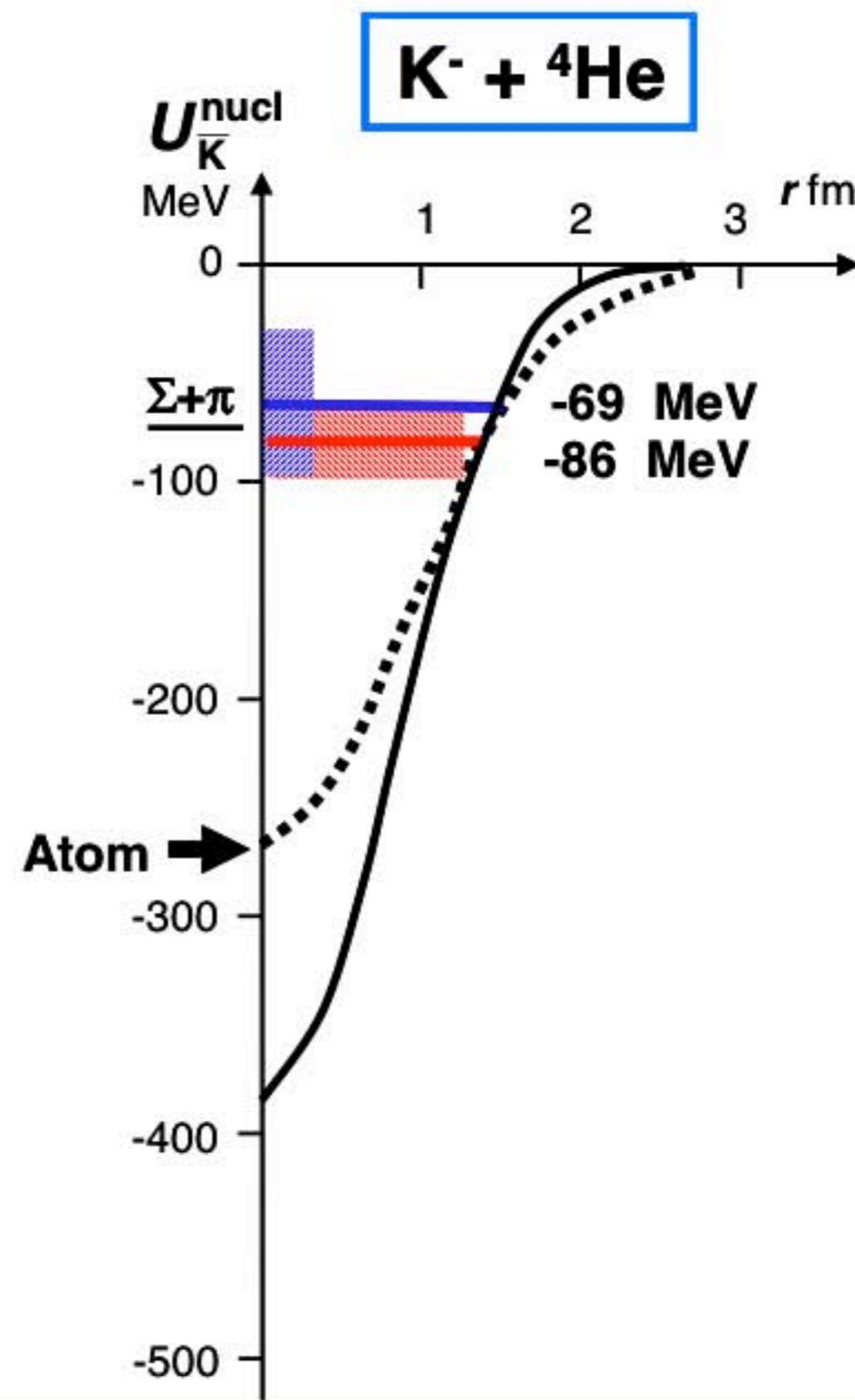
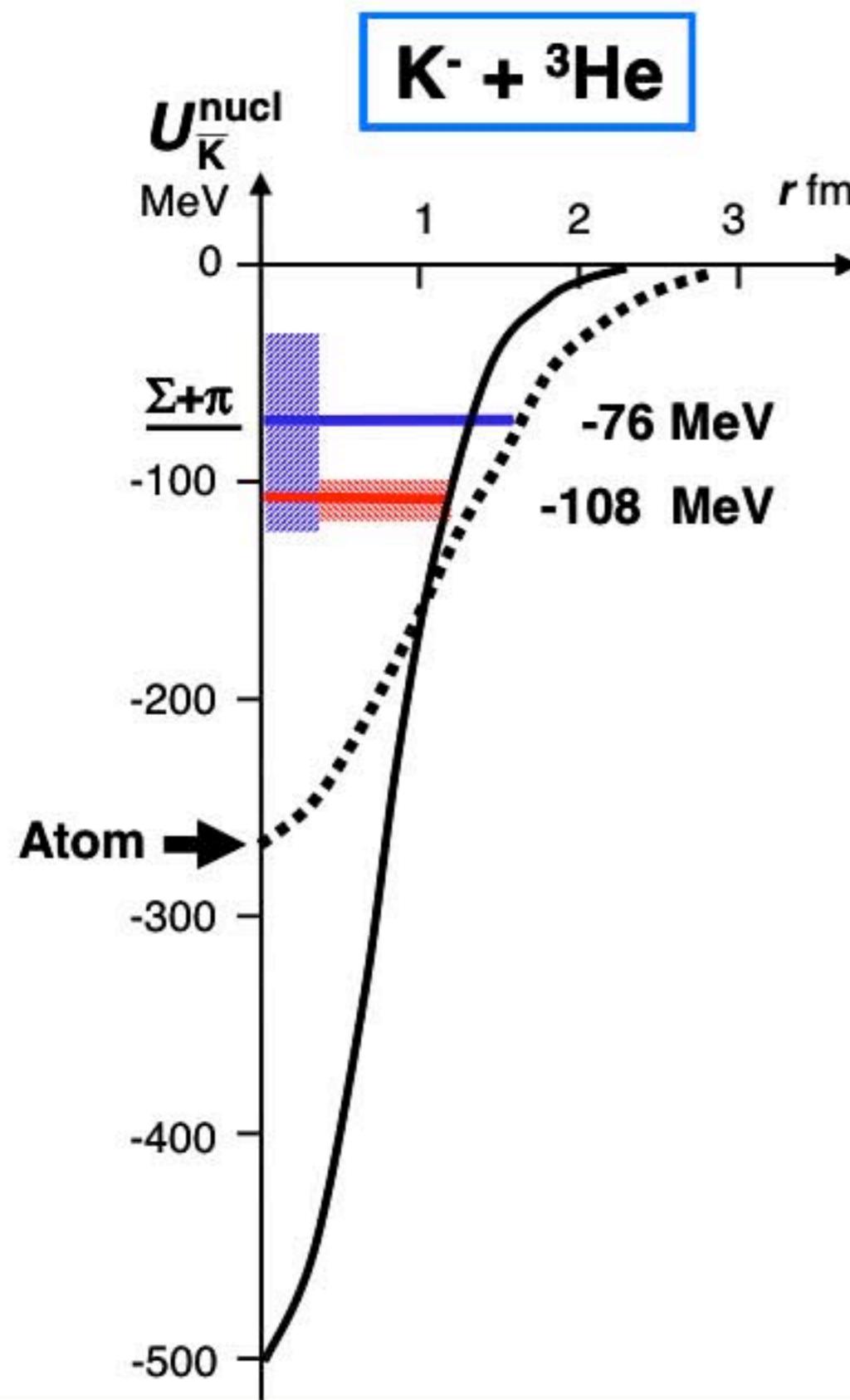
A new experiment with a detector of
- high resolution and
- good energy calibration
is urgently required.

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

興味

Renewed interest

After some 15 years,
Akaishi-Yamazaki prediction convinced us
(once again) the importance of the
measurement



optical model

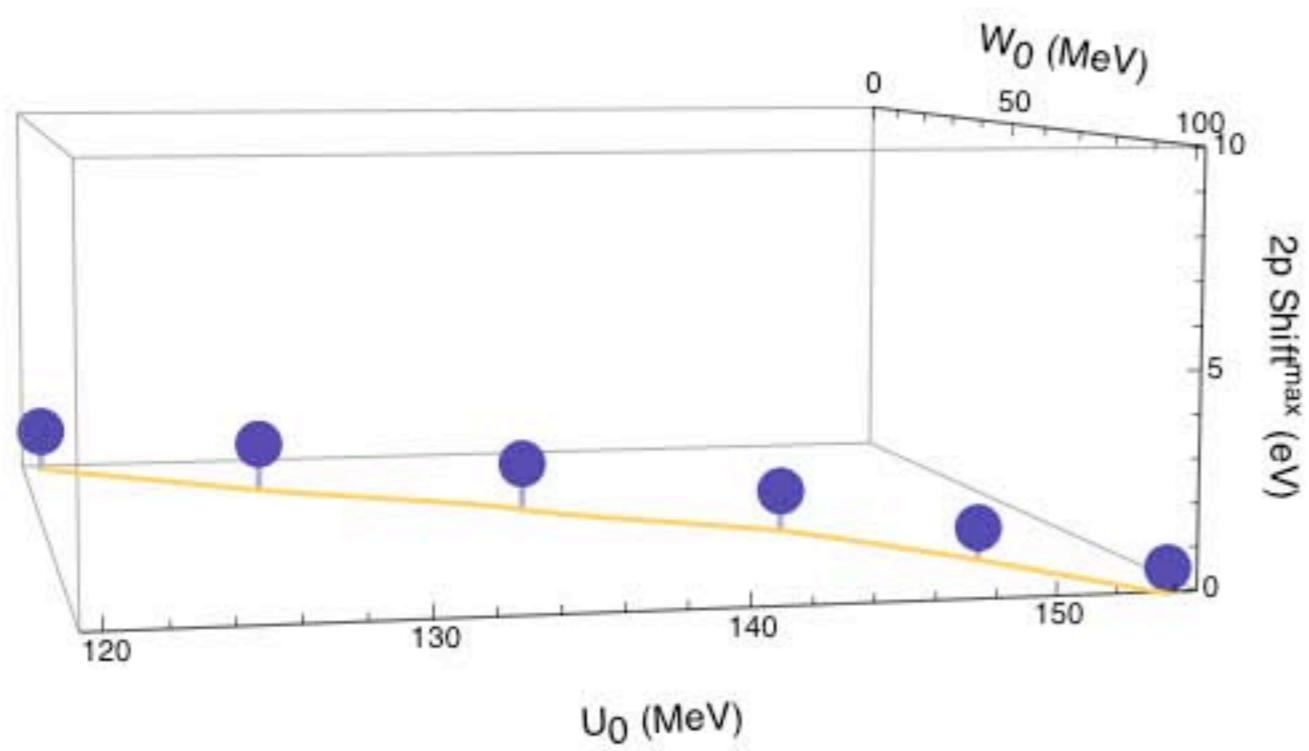
$$U^{\rm opt}(r) = -(U_0+iW_0)F(r)$$

$$F(r)=\frac{1+w_0(r/R_0)^2}{1+\exp((r-R_0)/a_0)}$$

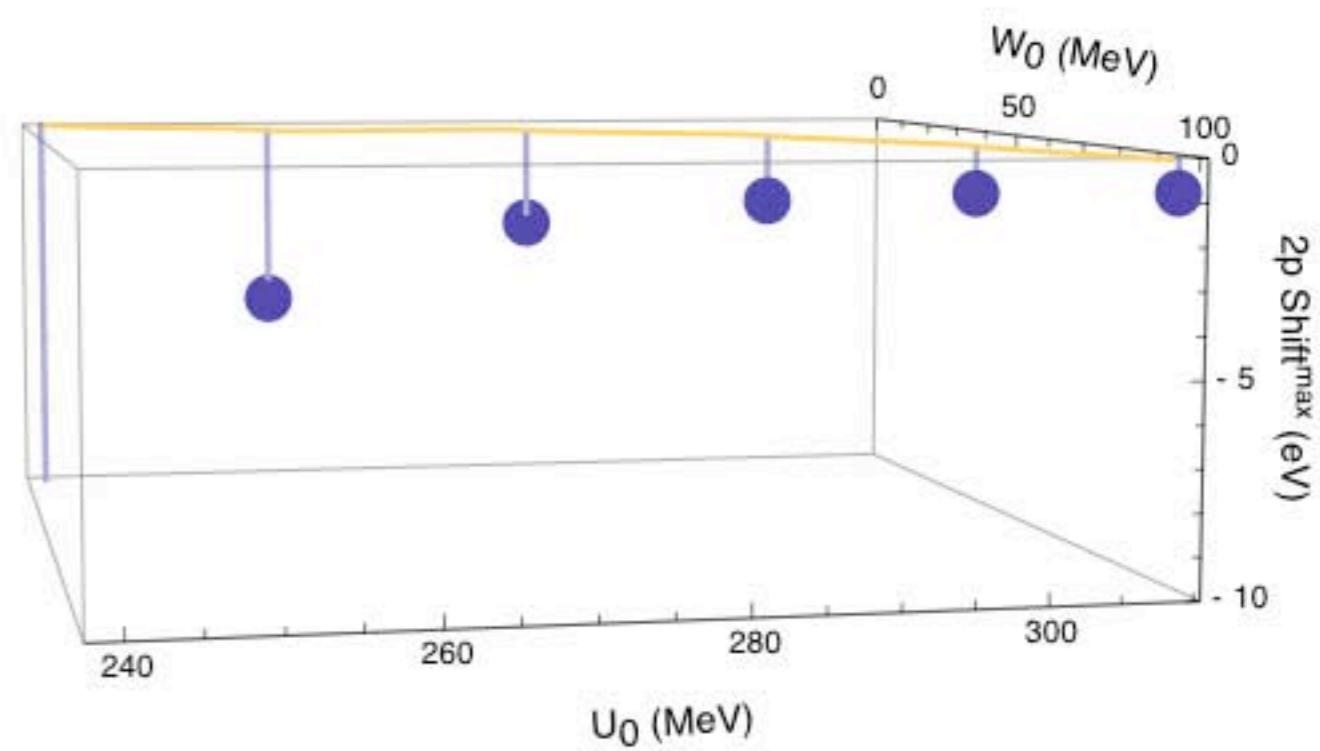
$$\left\{-\vec{\nabla}^2+2\mu(V_c+U^{\rm opt}-\epsilon)-(V_c-\epsilon)^2\right\}\Psi=0$$

$$V_c:\,\mathrm{Coulomb}$$

optical model



shallow potential



deep potential

Akaishi's coupled-channel model calculation

Yukio Akaishi
Kyoto University

coupling to the $\pi^- + {}^4_\Sigma \text{He}$ channel

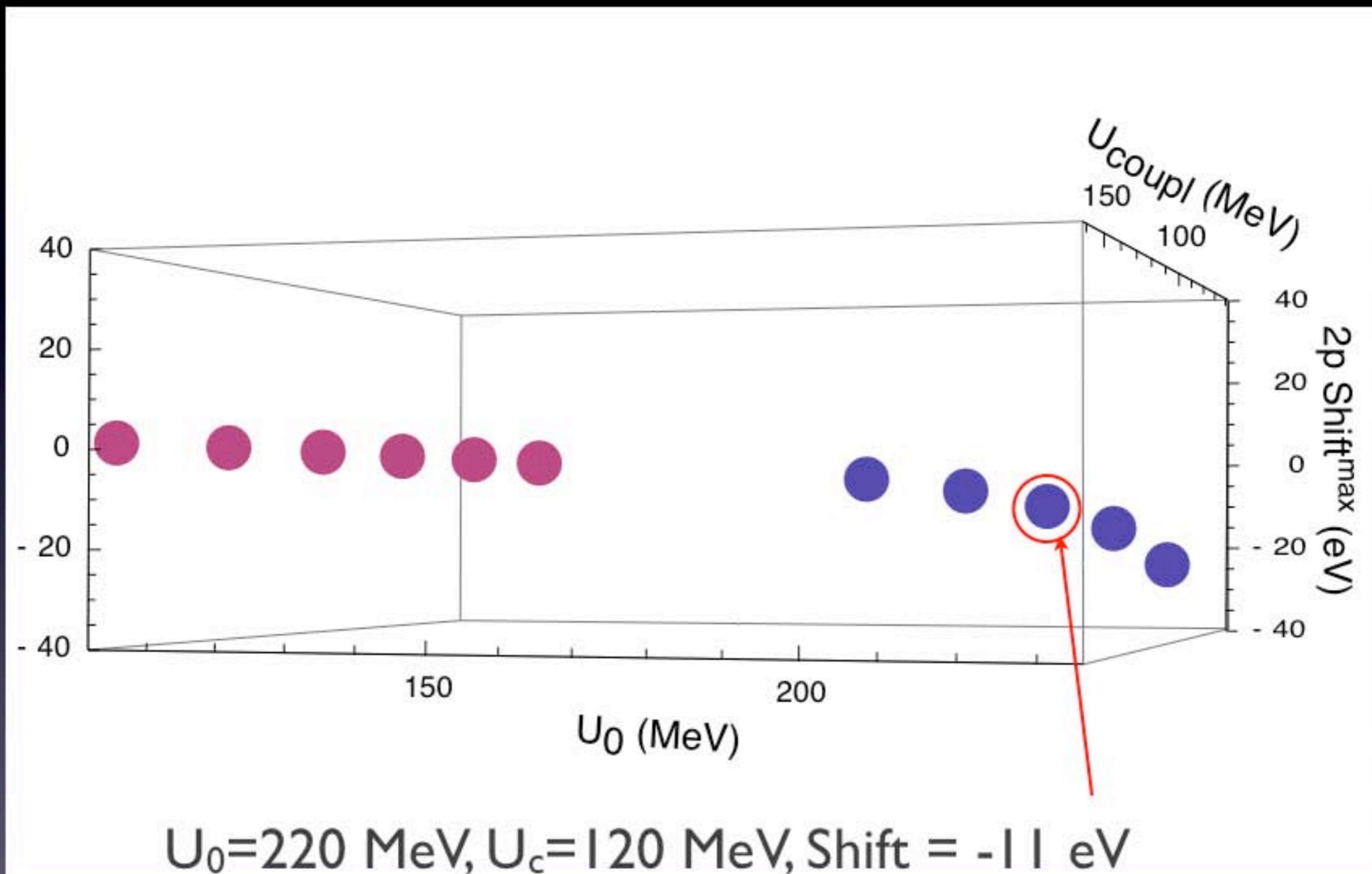
$$\text{diagonal: } U_D = -U_0 F(r)$$

$$\text{coupling: } U_C = U_{\text{coupl}} F(r)$$

$$\left\{ -\vec{\nabla}^2 + 2\mu(V_c + U_D - \epsilon) - (V_c - \epsilon)^2 \right\} \Psi + 2\mu U_C \Phi = 0$$

$$\left\{ -\vec{\nabla}^2 + 2\mu'(Q - \epsilon) - (Q - \epsilon)^2 \right\} \Phi + 2\mu' U_C \Psi = 0$$

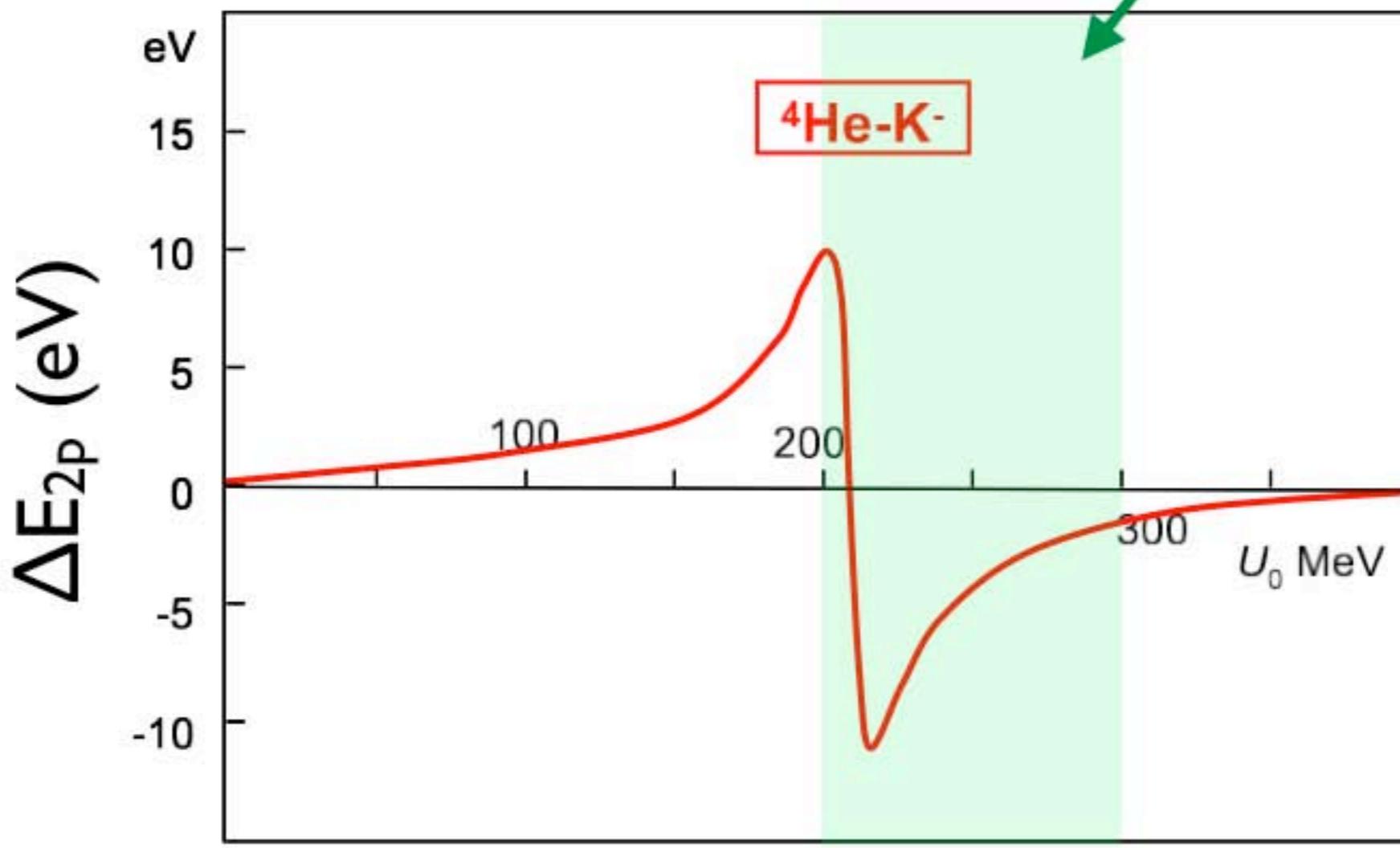
$$Q \equiv M_{}^{} {}^4_\Sigma \text{He} + m_{\pi^-} - M_{}^{} {}^4 \text{He} - m_{K^-}$$



Akaishi's prediction

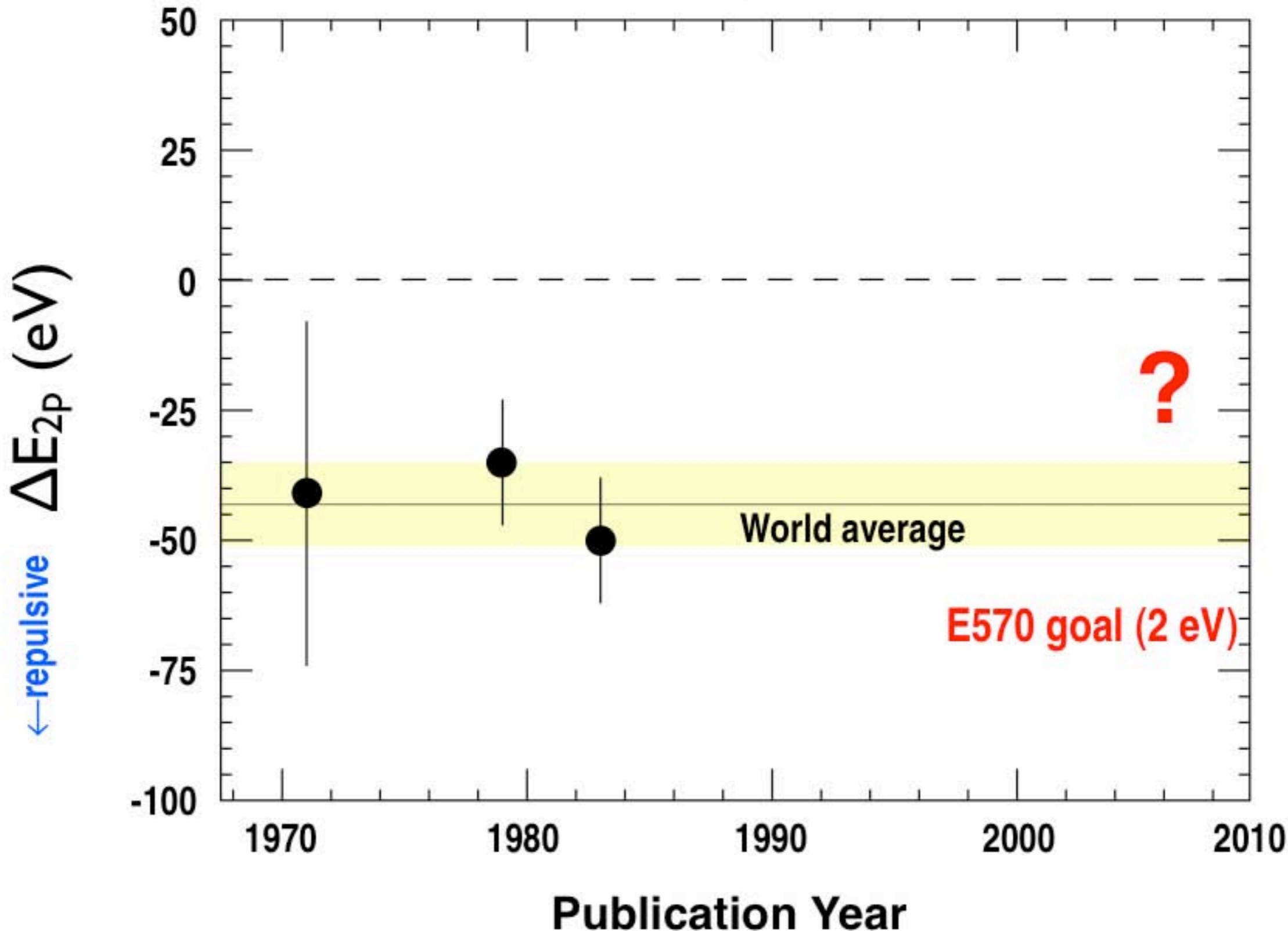
(accommodates kaonic nuclear states)

→ repulsive attractive →



U_c fixed to 120 MeV, U_0 varied

Kaonic Helium X-ray Spectroscopy

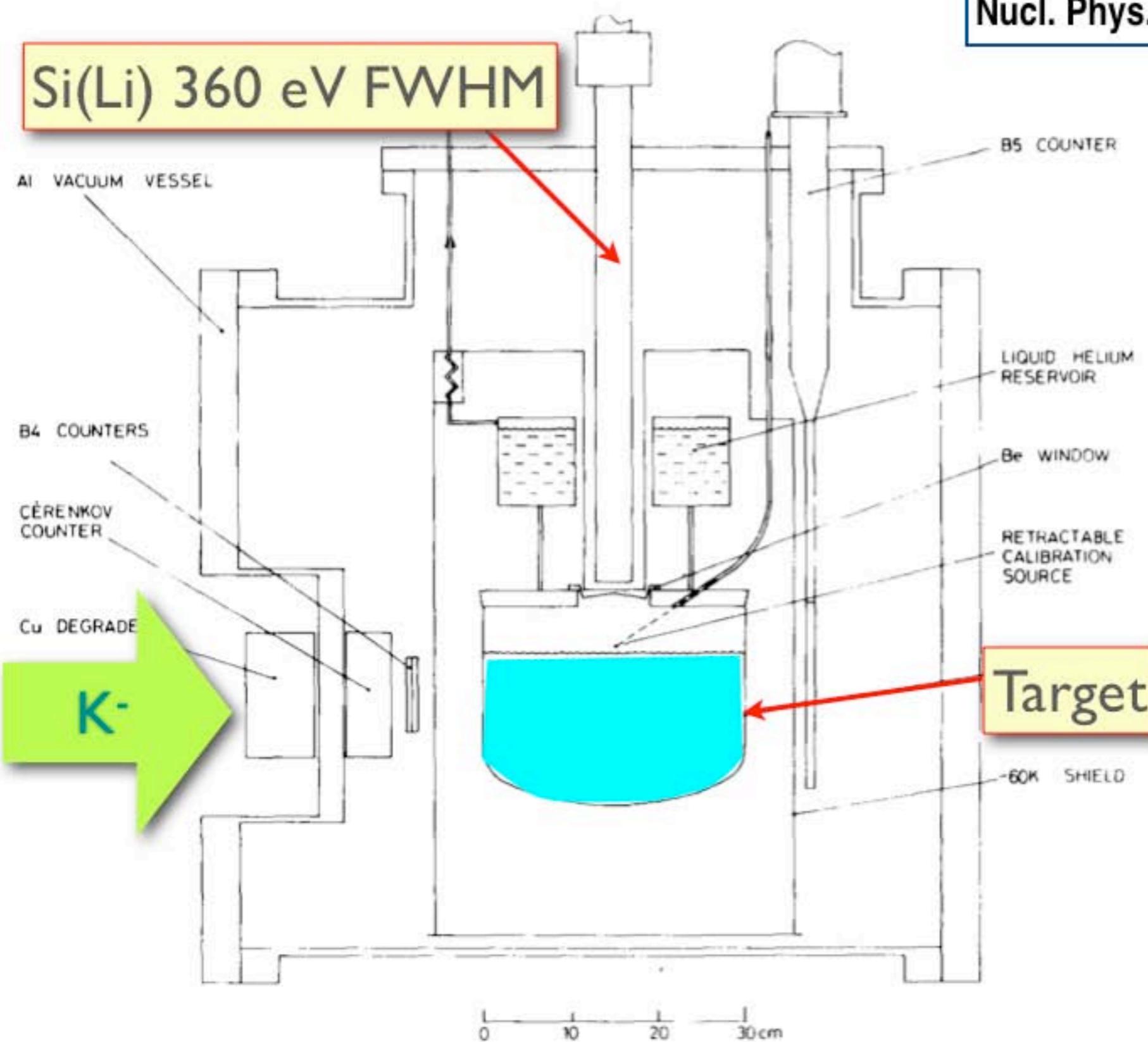


方法

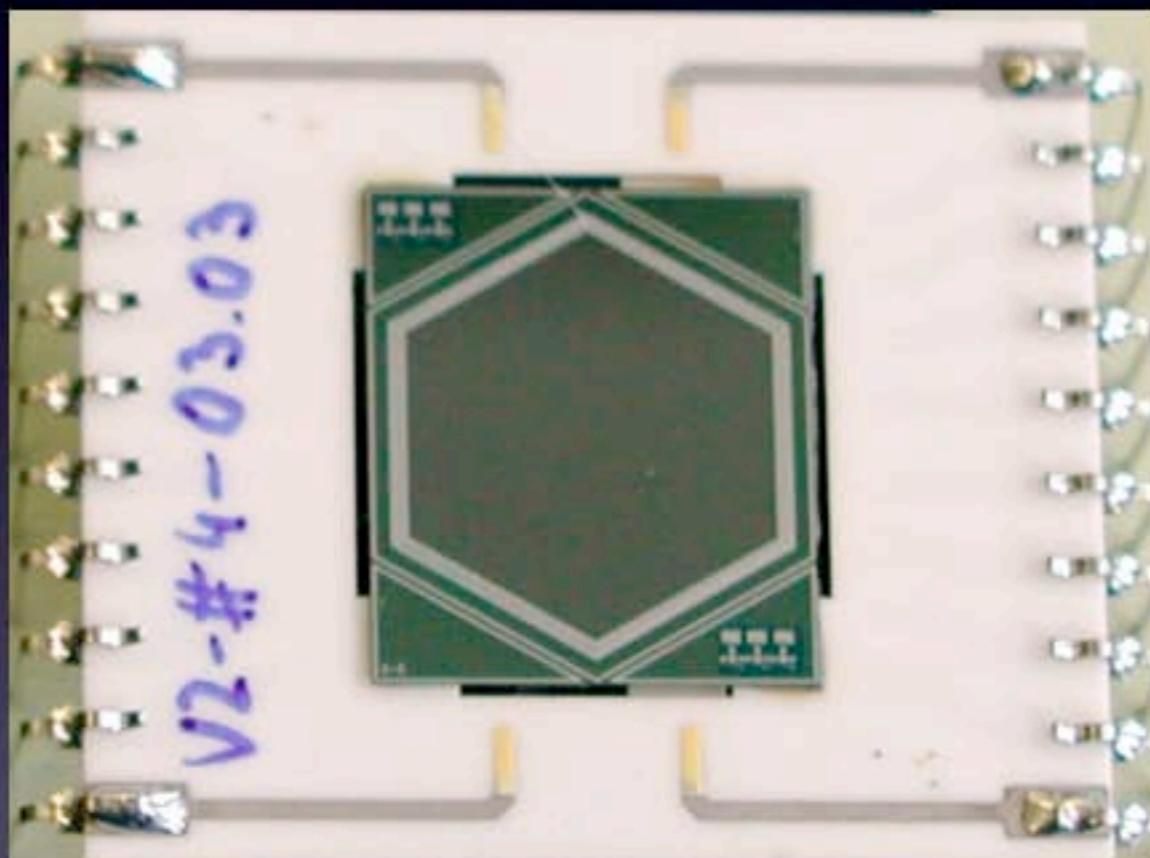
E570 Methods

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

Si(Li) 360 eV FWHM



I. High Resolution SDD (silicon drift detector)

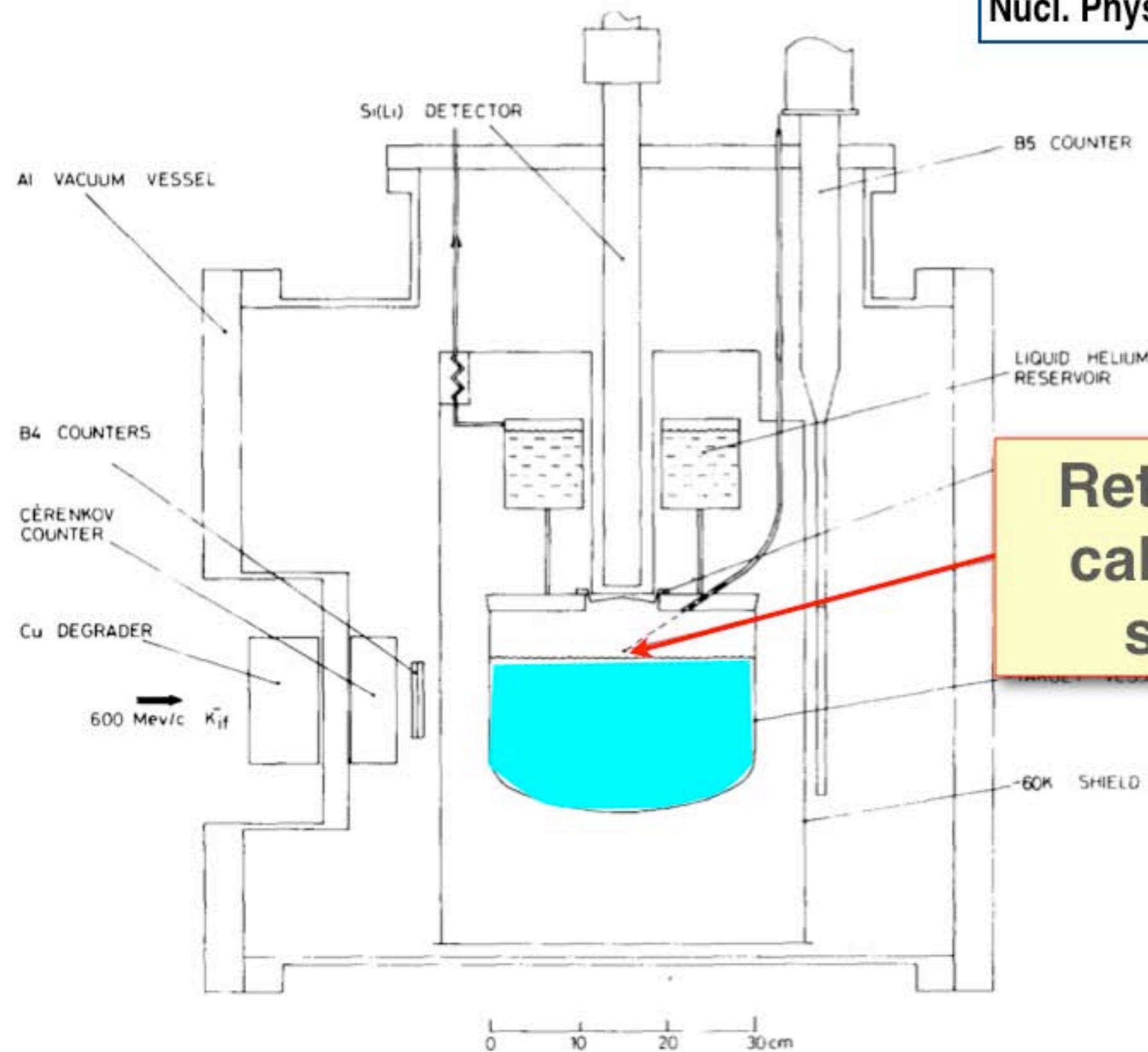


Produced by KETEK GmbH

electrons drift to a small anode (small capacitance)

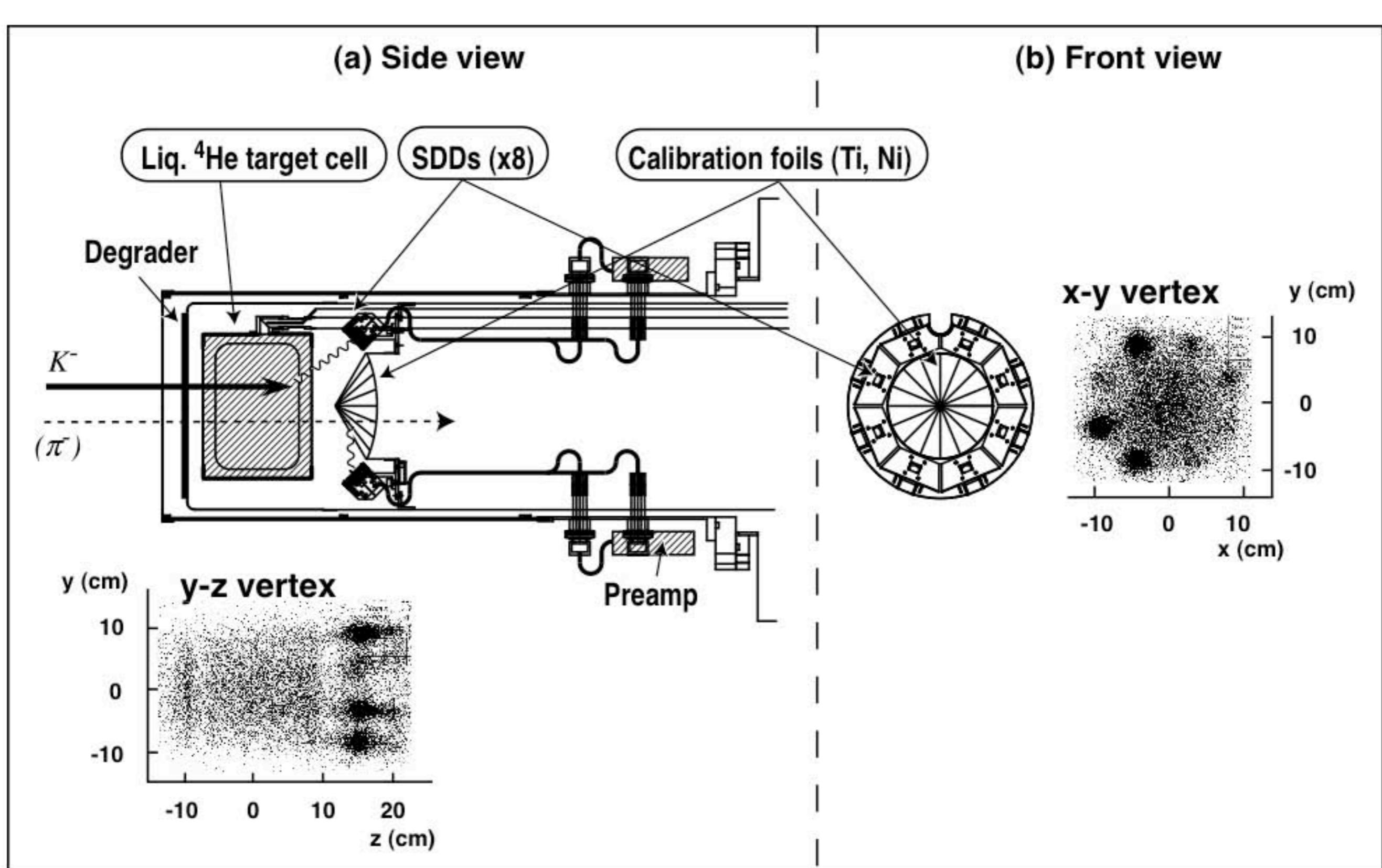
high resolution (185 eV FWHM @ 6.4 keV), despite large area (100 mm^2)
 Si(Li) : 300-350 eV

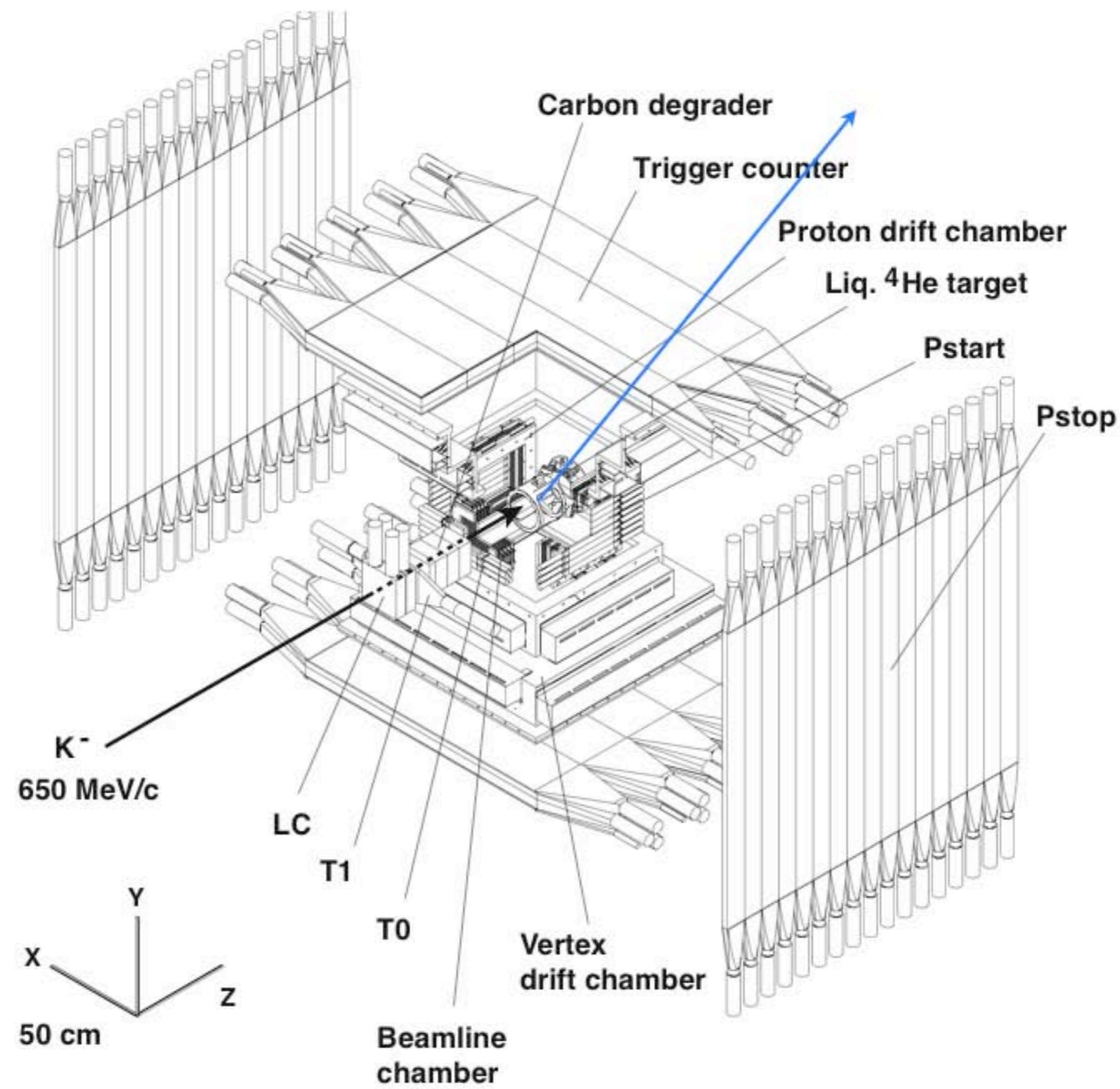
8 such SDDs used in E570



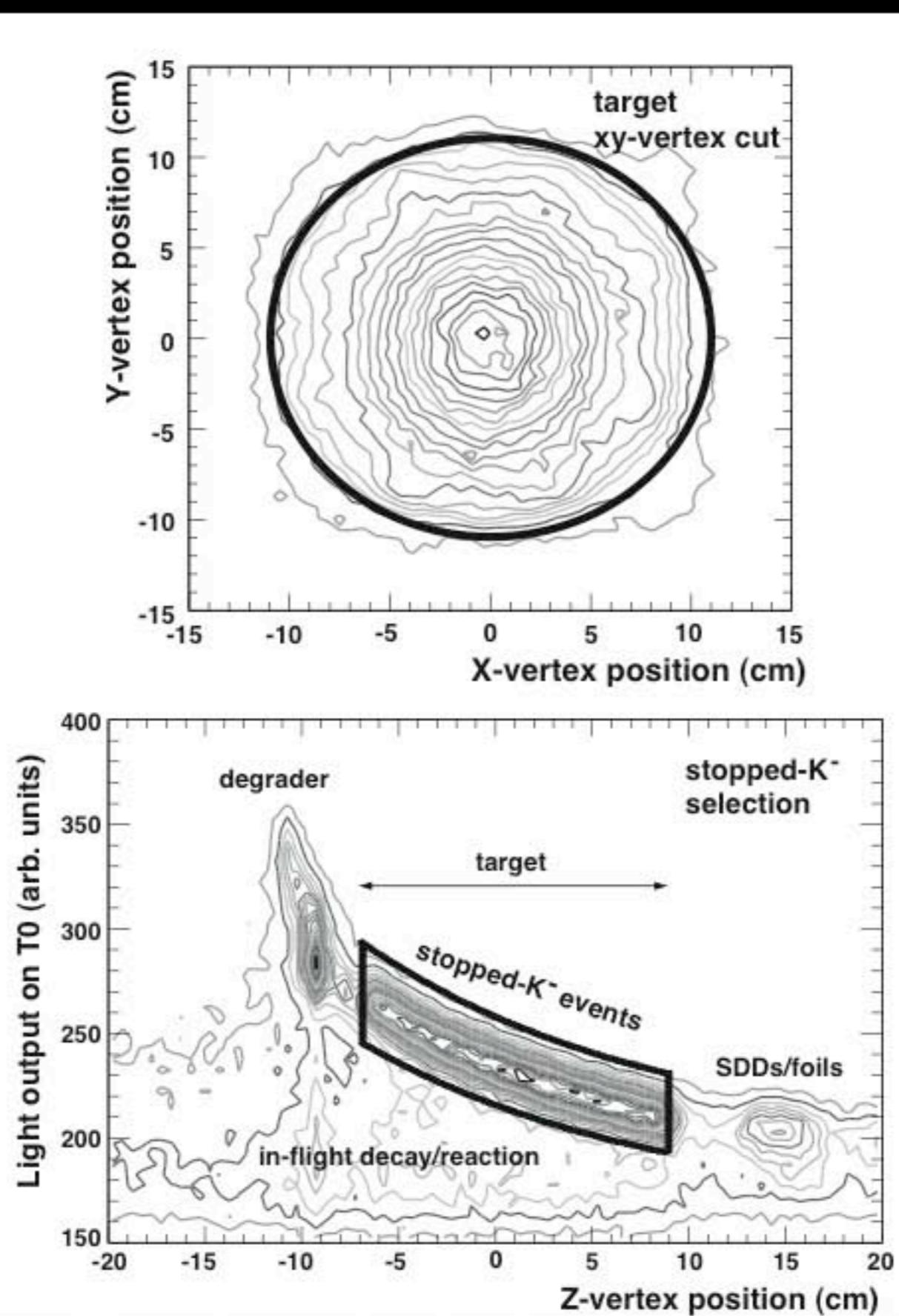
**Retractable
calibration
source**

2: in-situ calibration, 3: fiducial selection





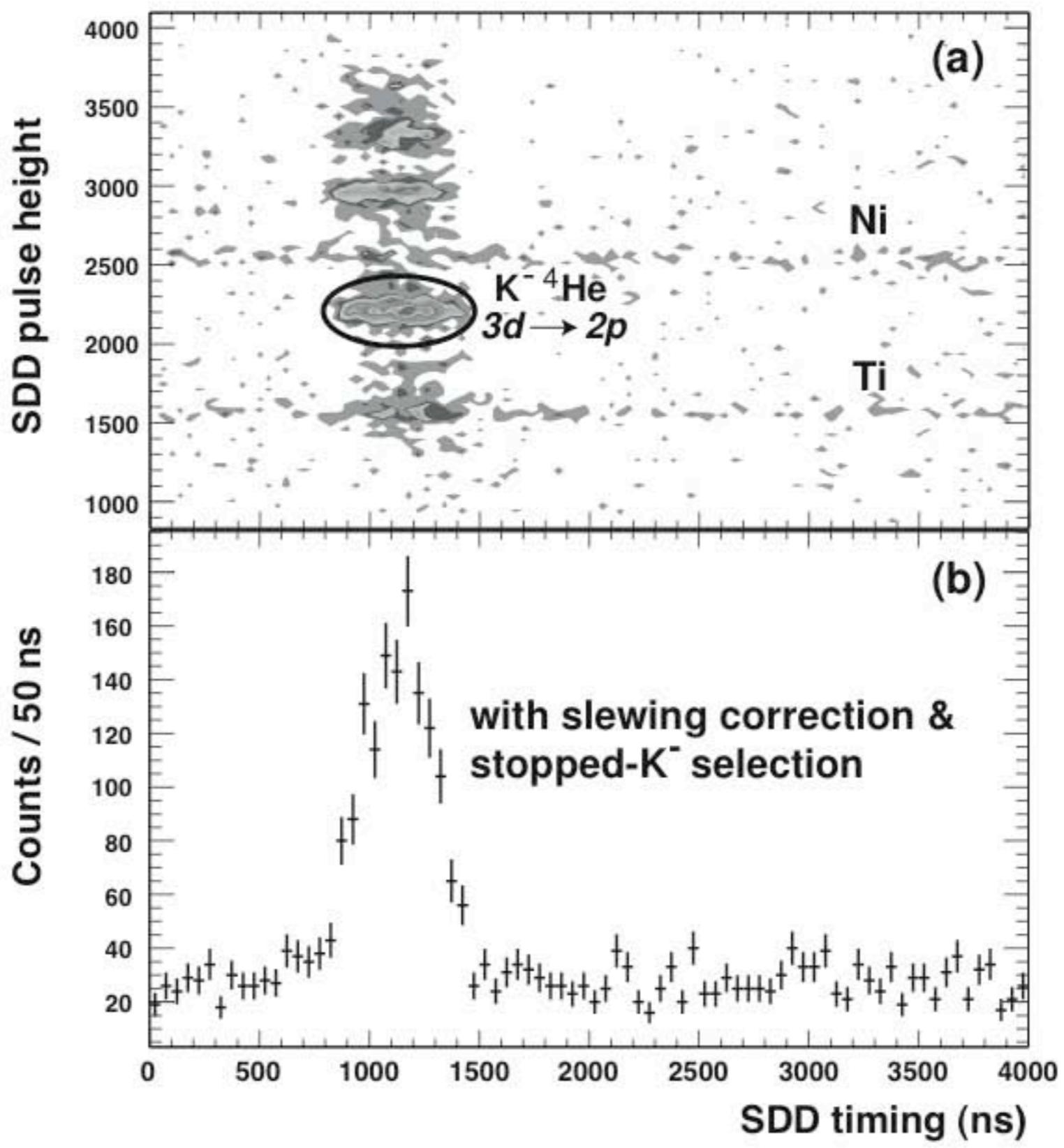
Fiducial selection

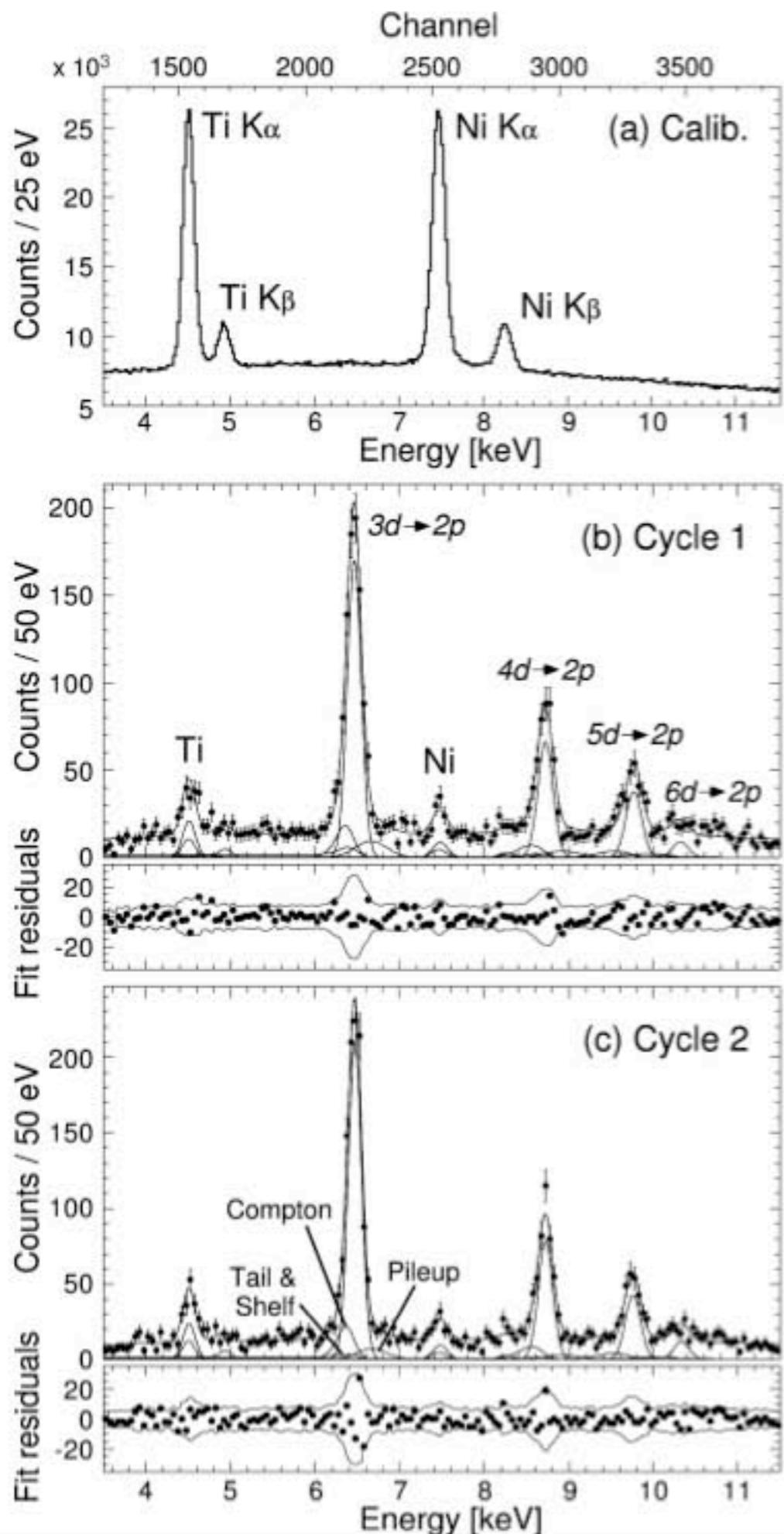


front view

side view

Timing selection

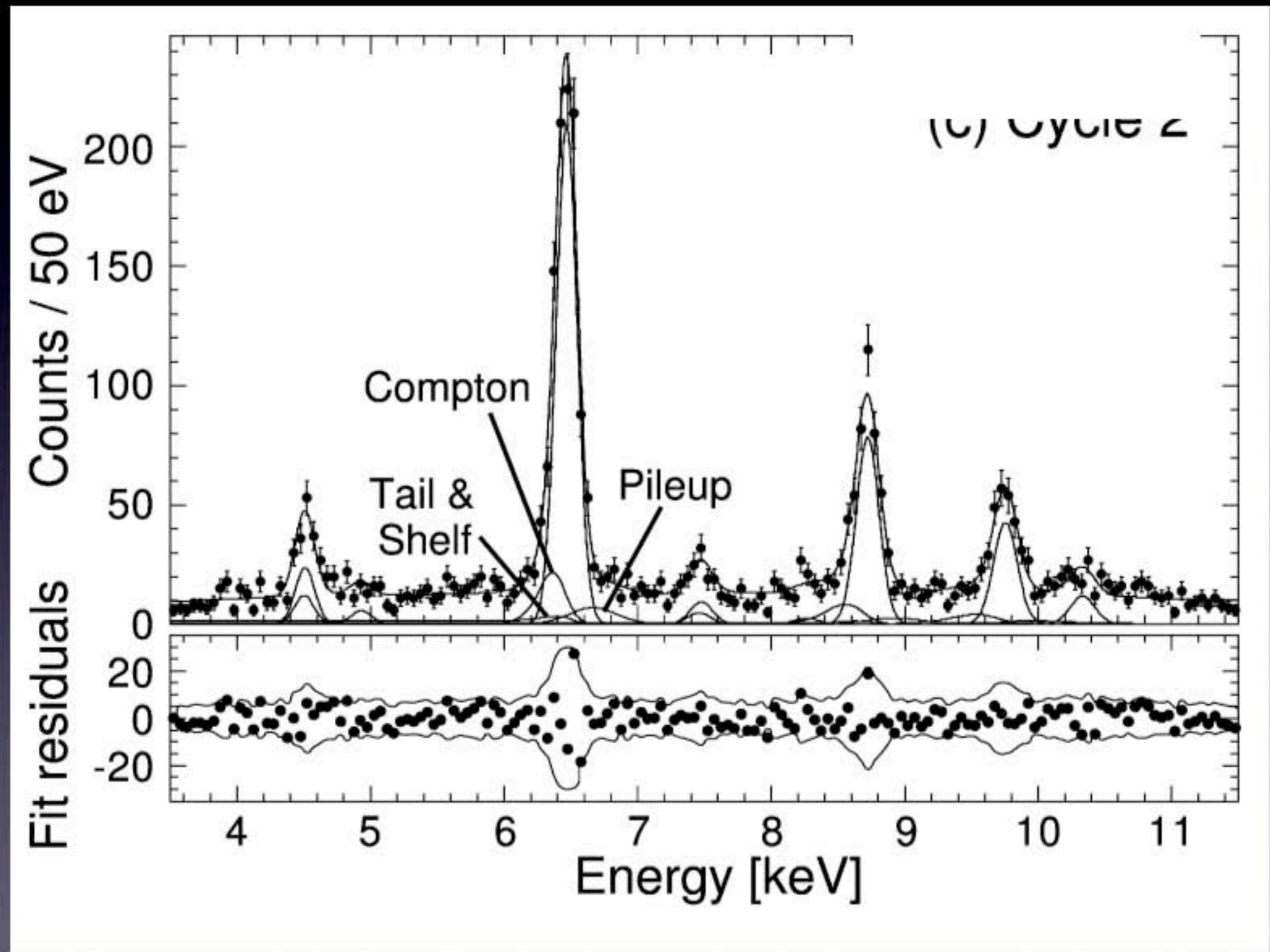




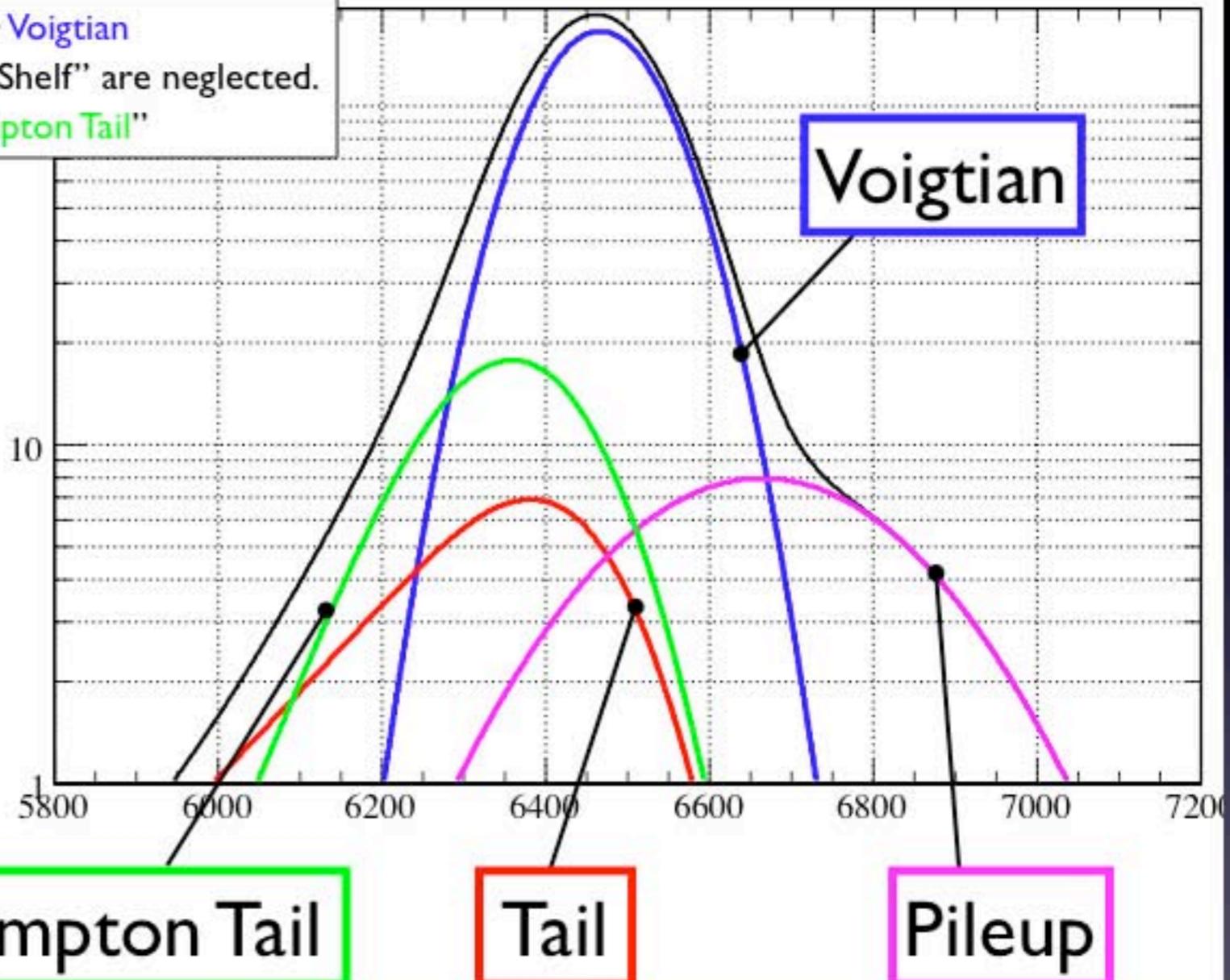
SDD Self trigger high-statistics in-situ calibration

Kaon trigger, fiducial & timing cut

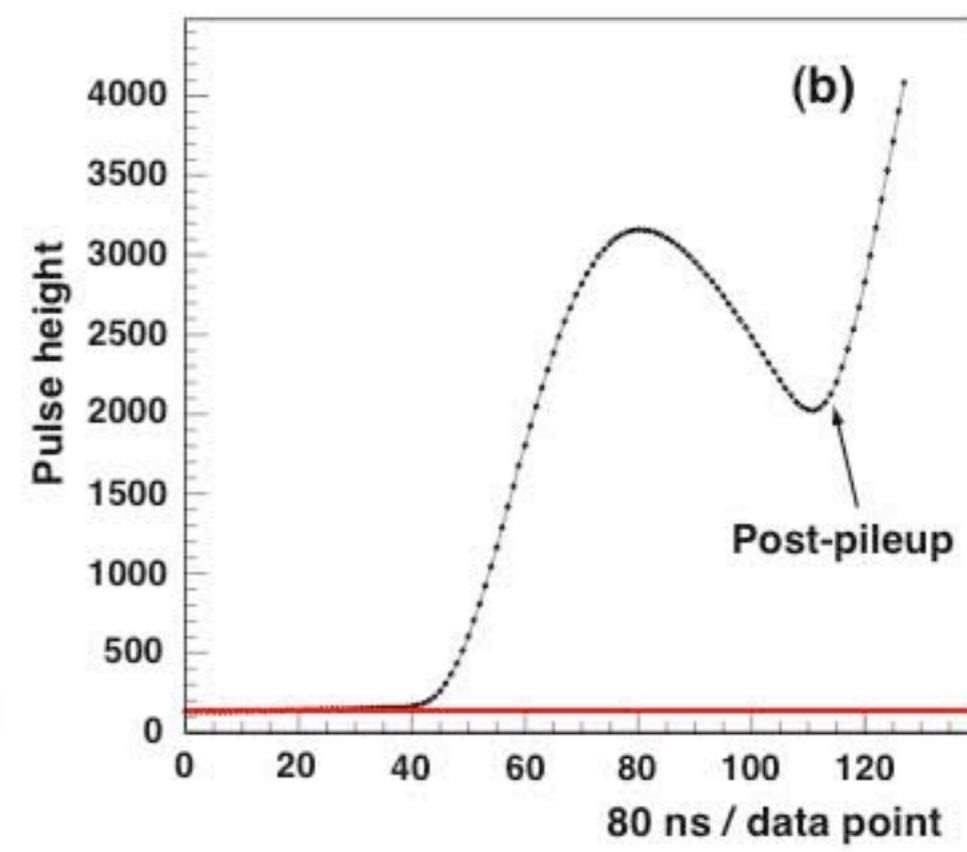
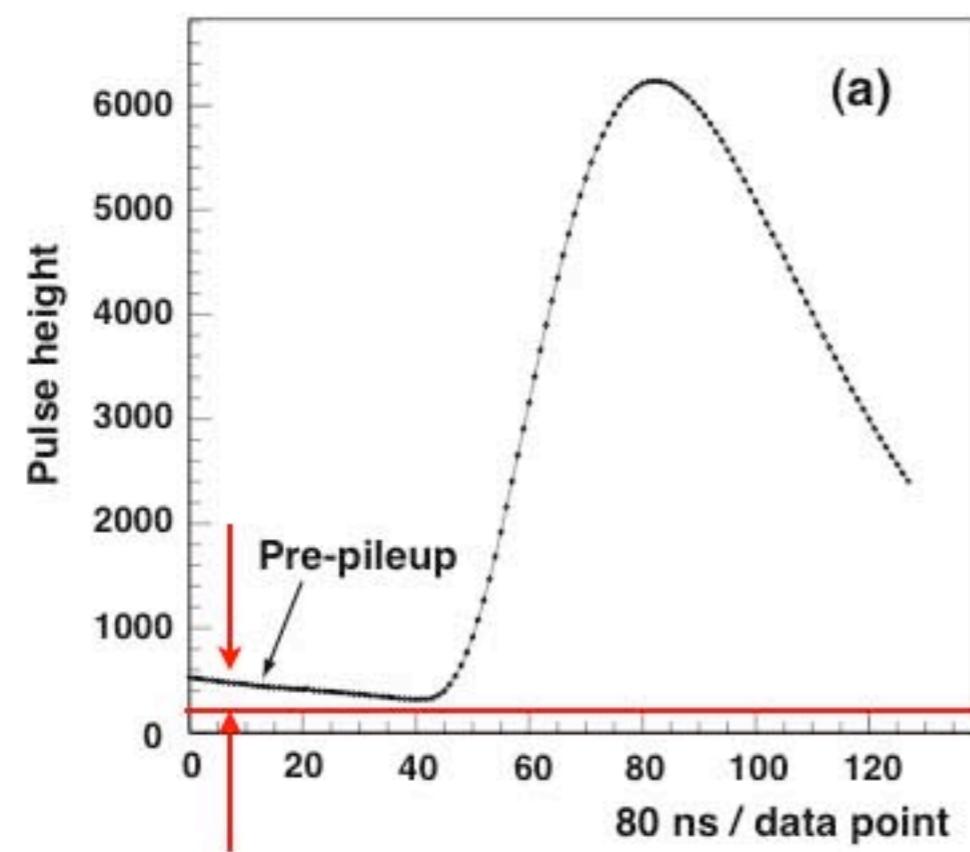
understanding the resolution function (critical!)

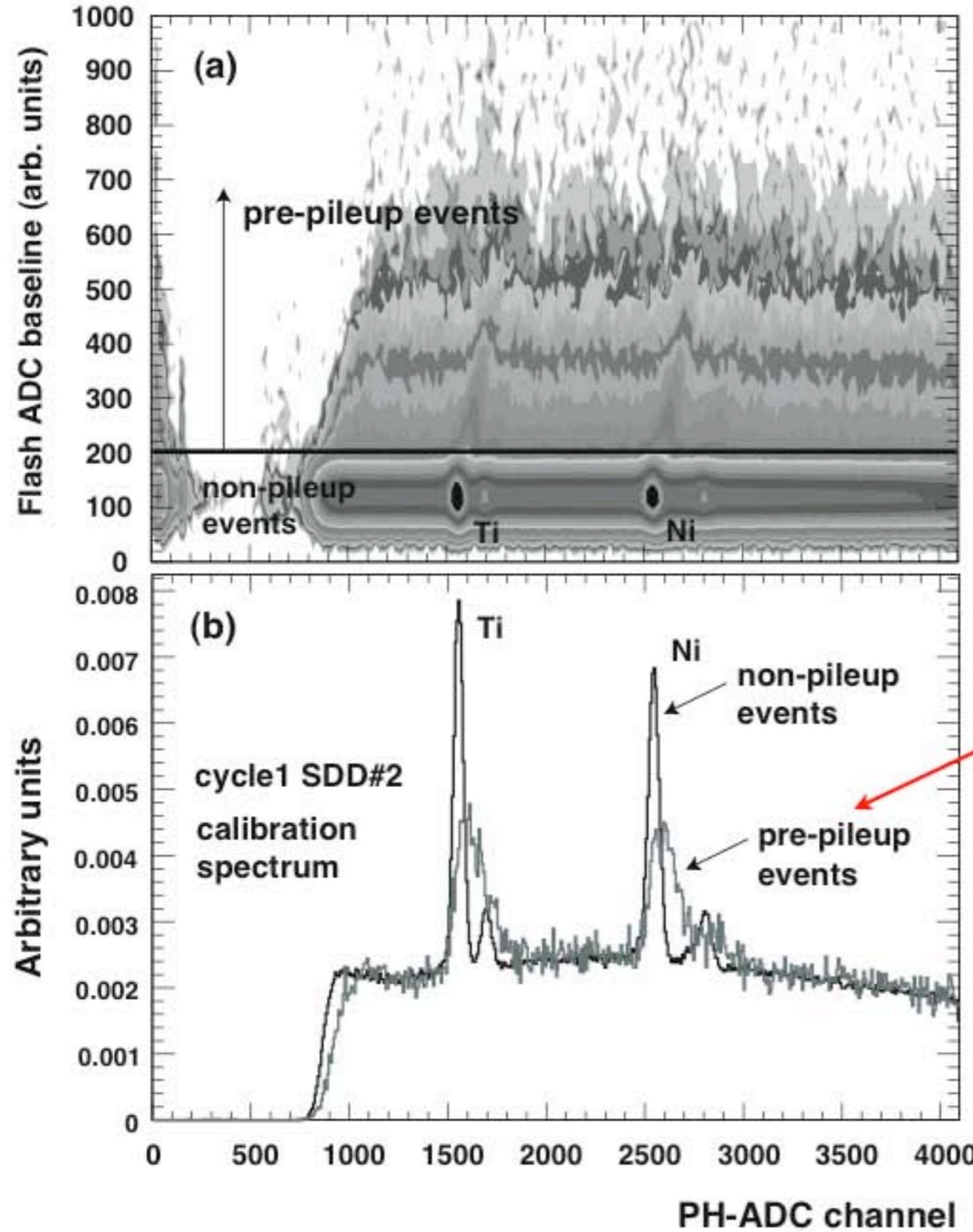


- ▶ Gaussian --> Voigtian
- ▶ “Escape” & “Shelf” are neglected.
- ▶ added “Compton Tail”



Pileup (typical flash-adc waveforms)



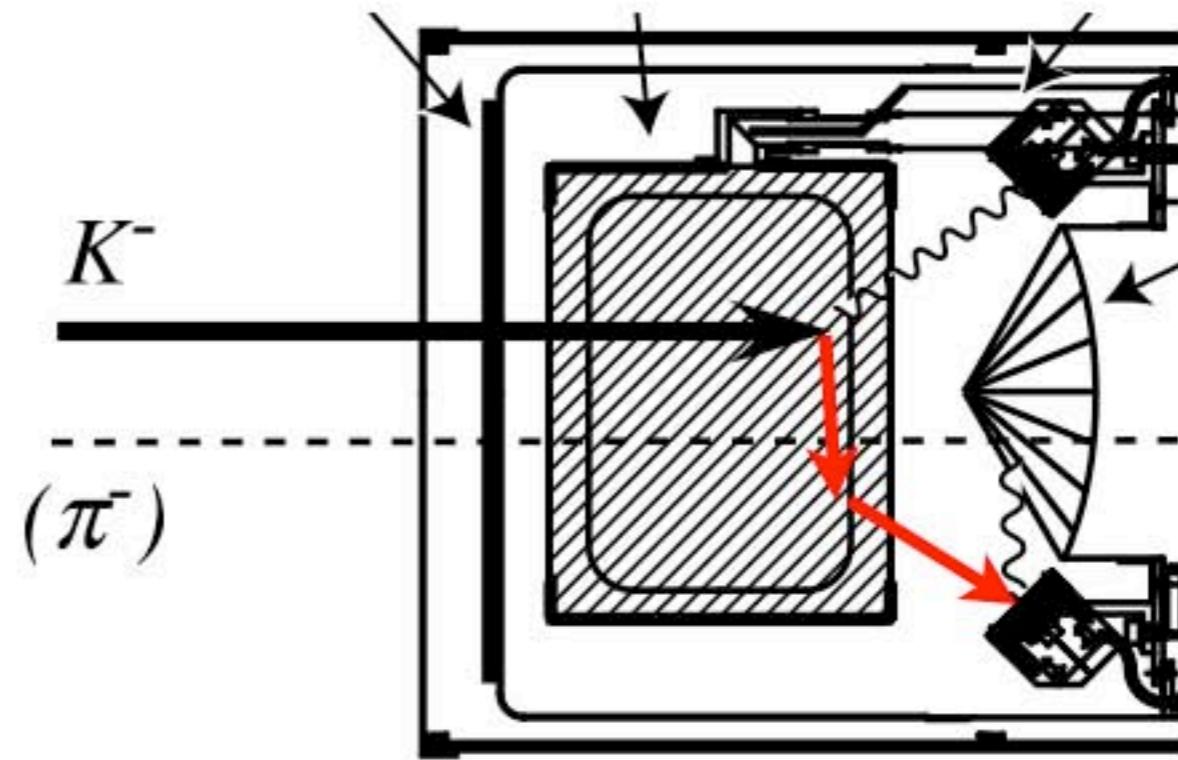
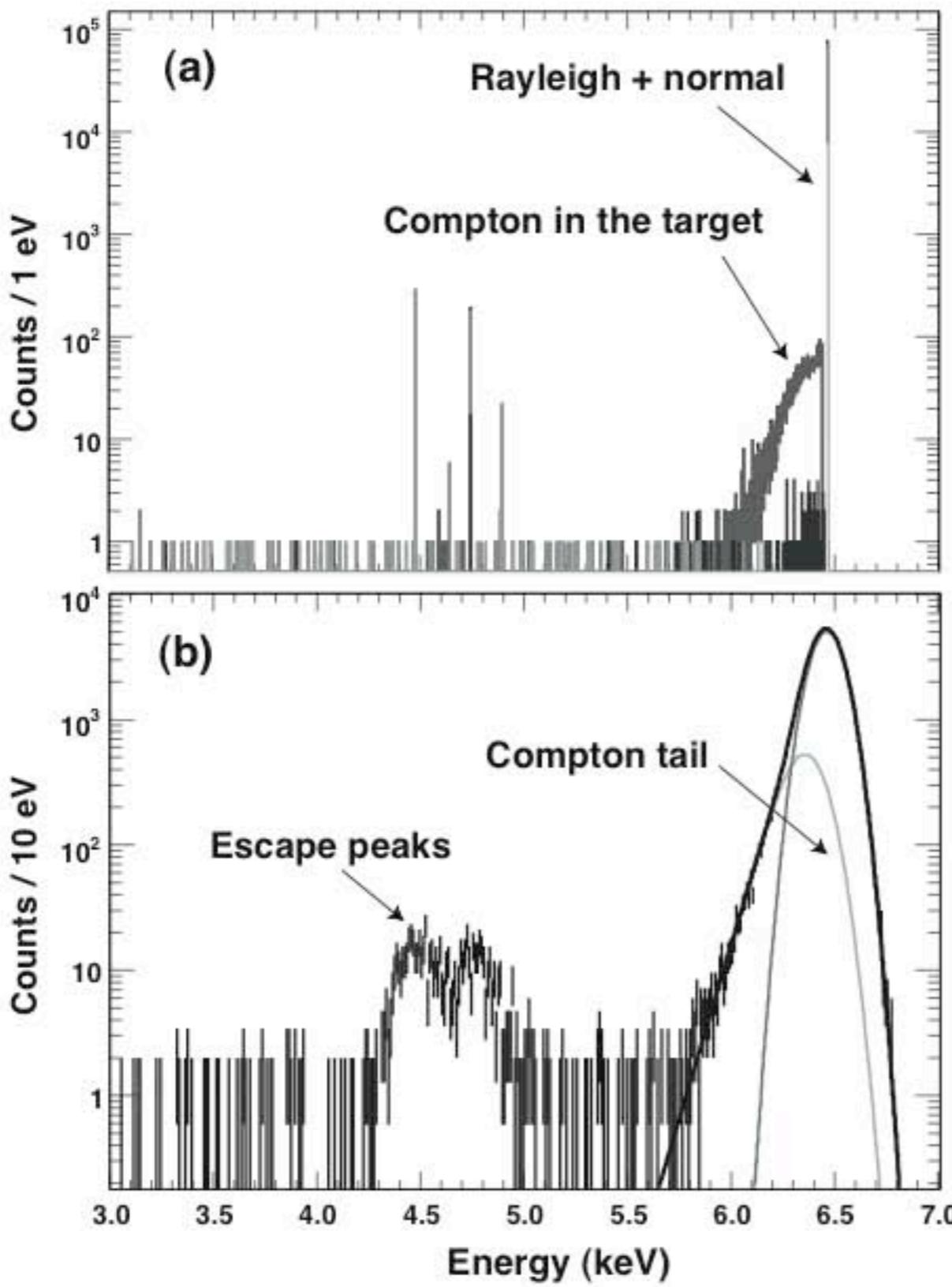


flash ADC baseline
vs energy

such shape & fraction
used to fit the K-He X-rays

Compton tail

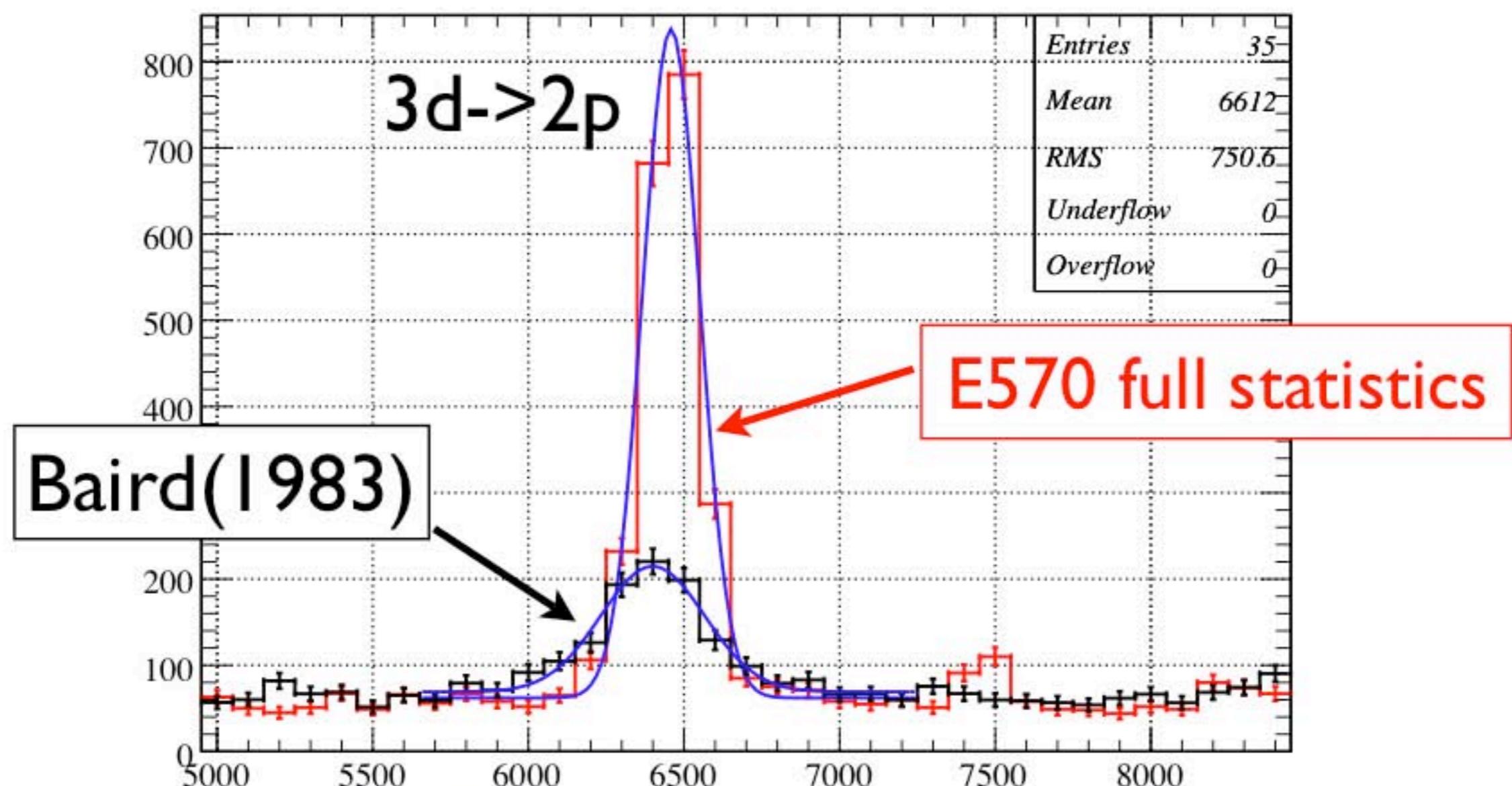
GEANT4



結果

Results

past exp : Baird et.al. NPA392, 297 (1983)



statistics

x3

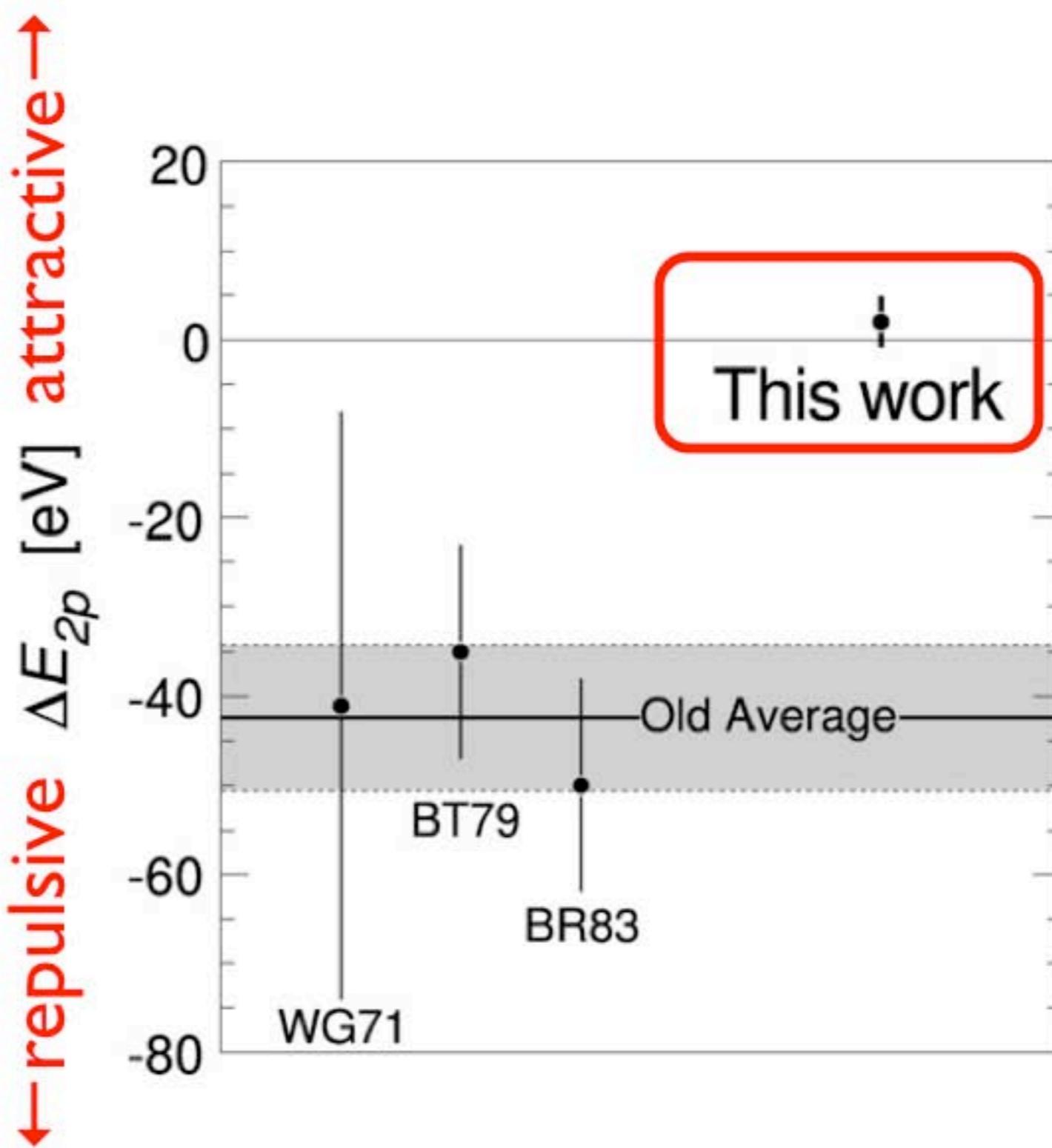
s/n ratio

x6

resolution

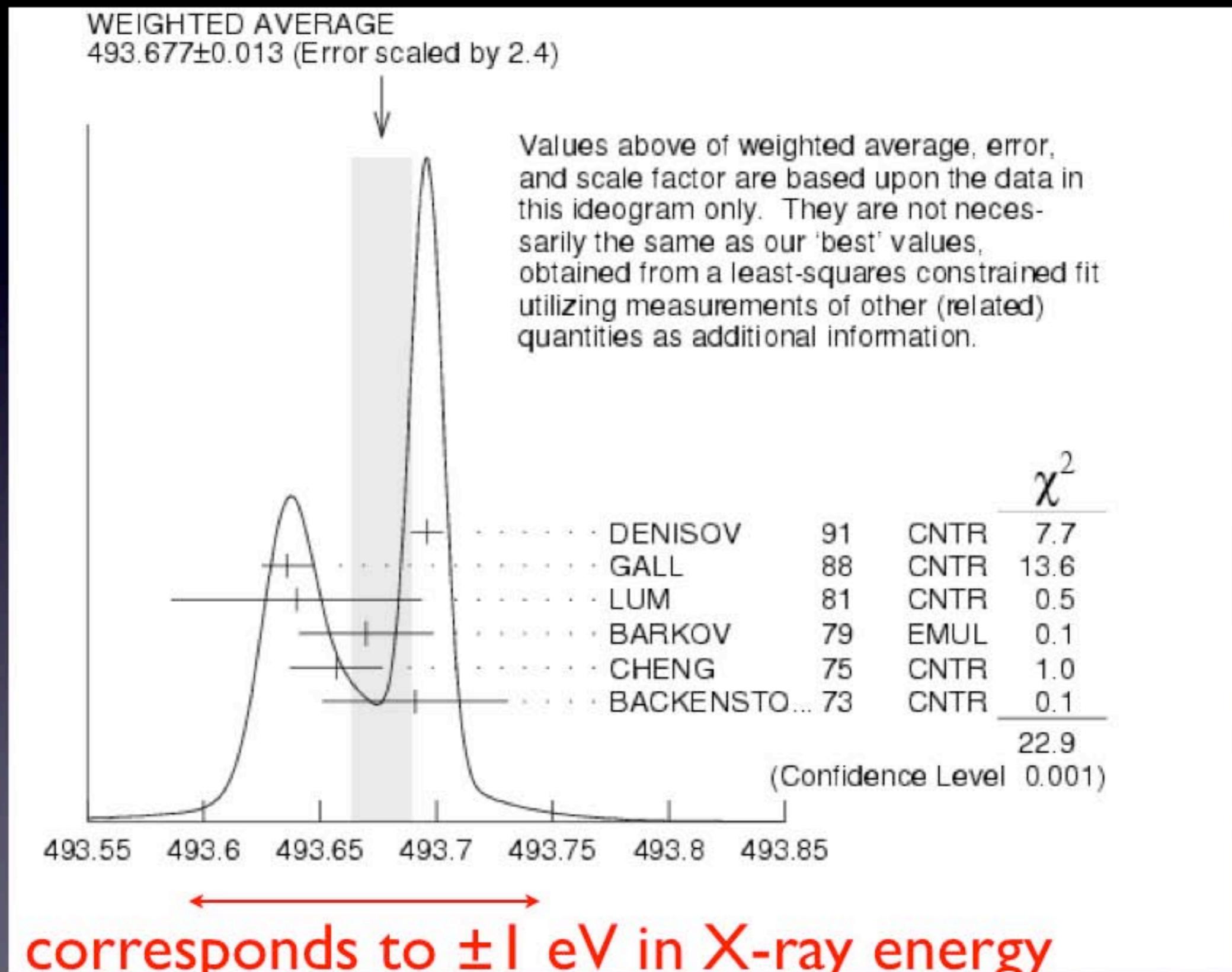
x2

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



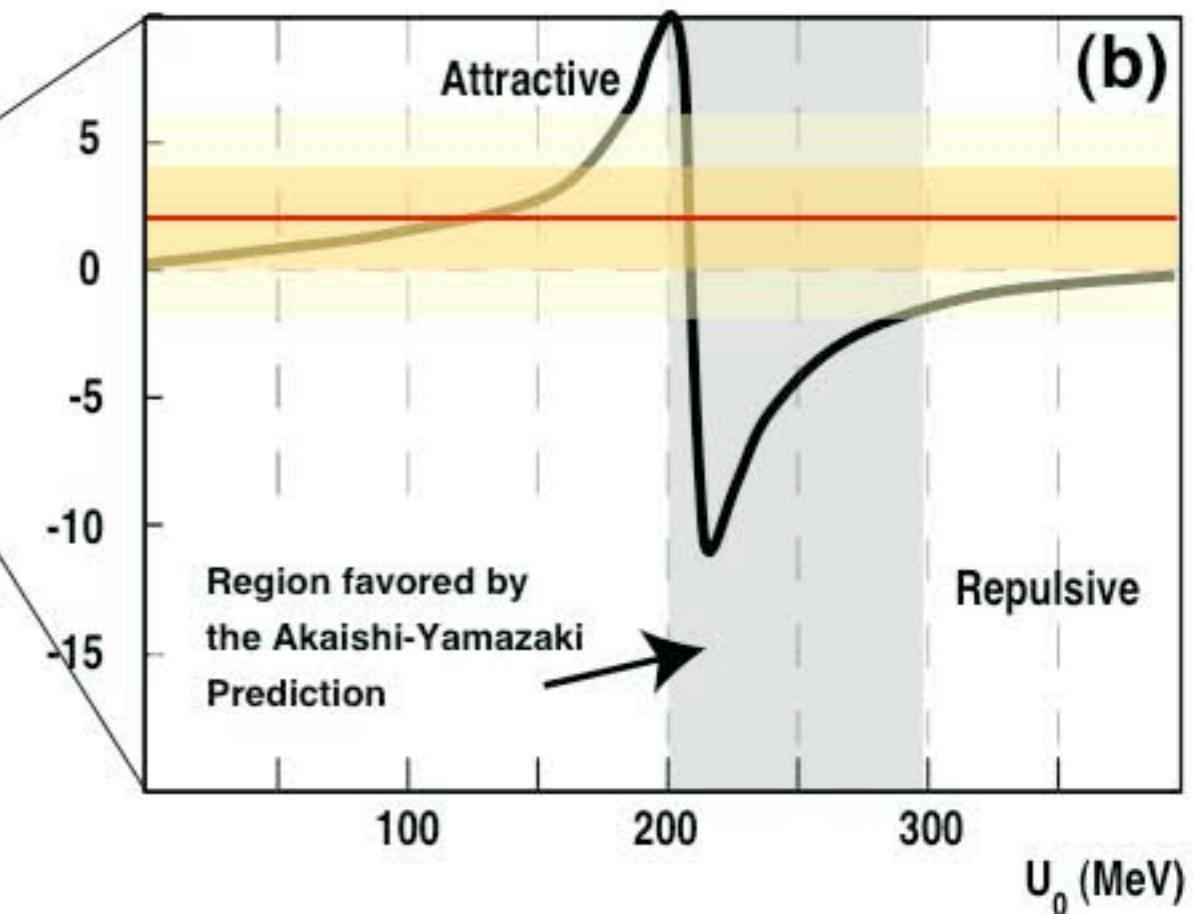
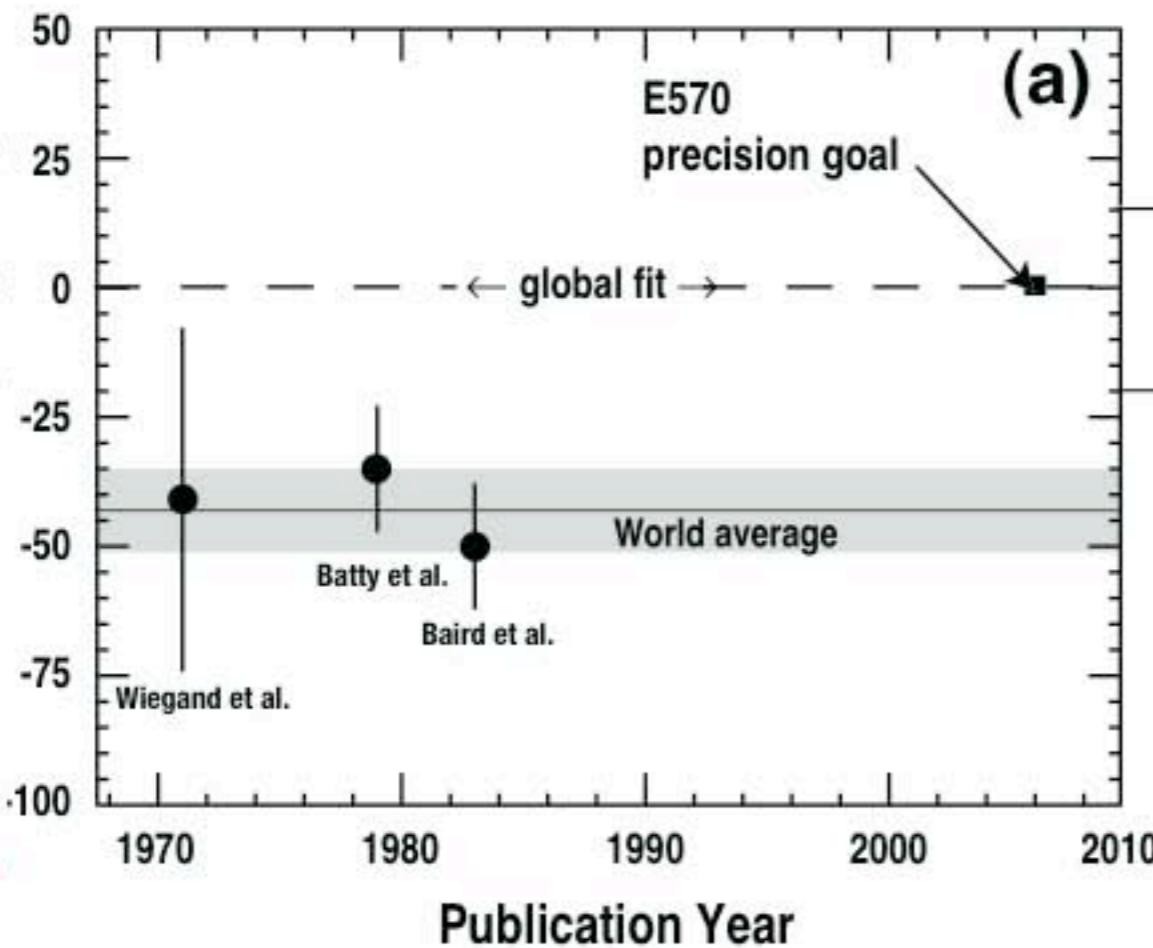
theory error (~ 0.2 eV) dominated by K mass error

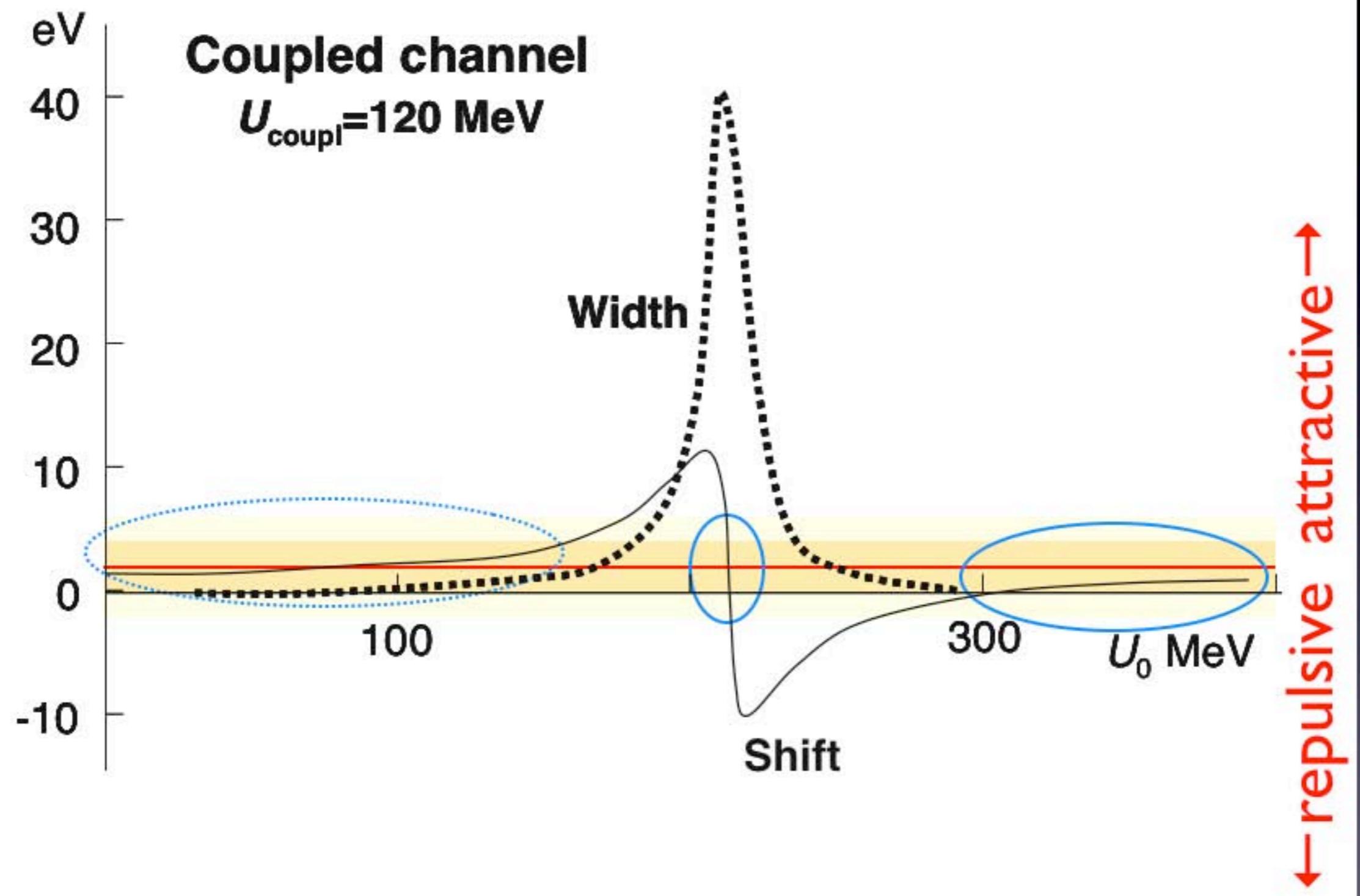
Koike

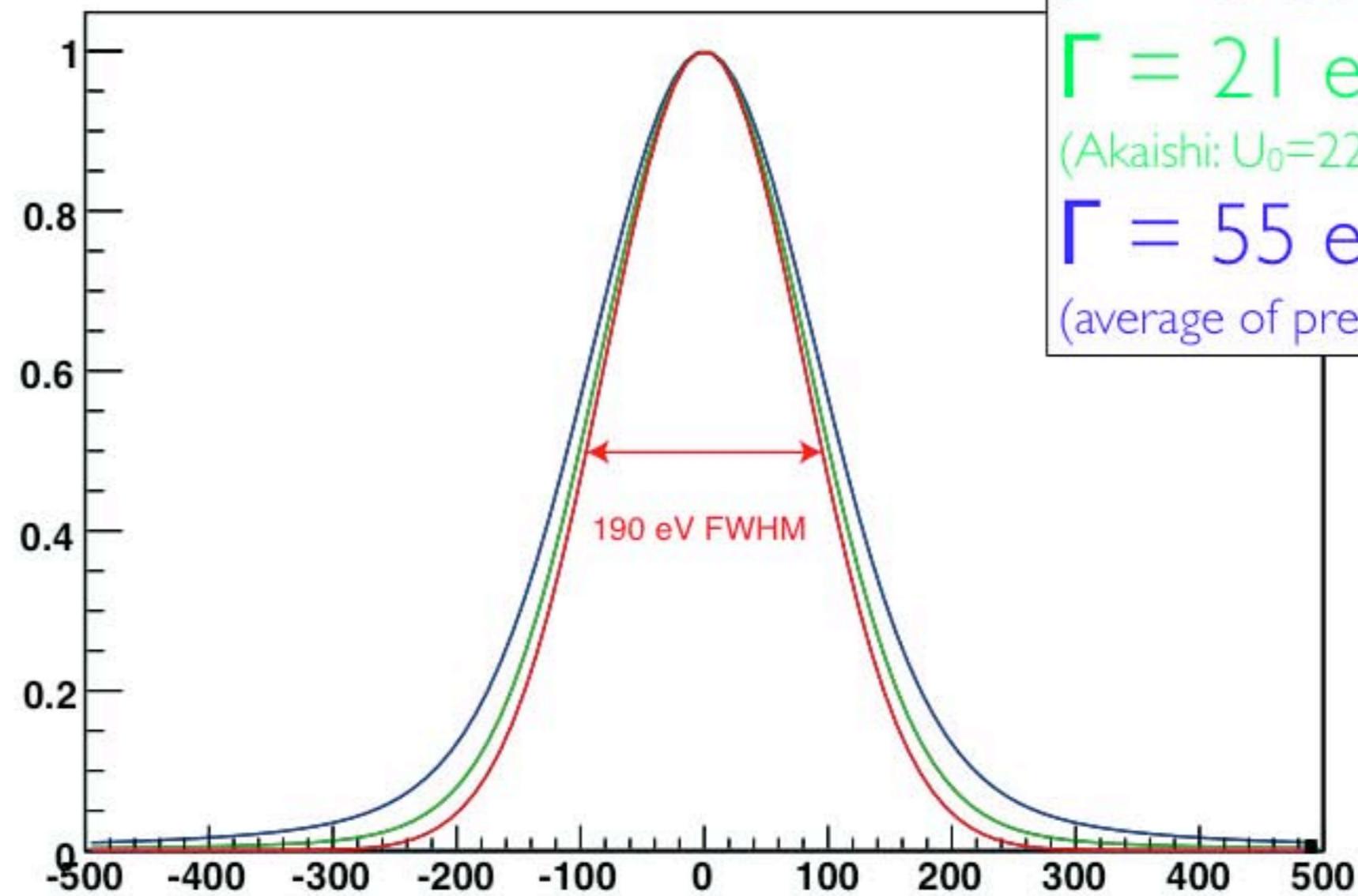


→ repulsive ΔE_{2p} (eV) attractive →

K- ${}^4\text{He}$ 2p level shift







$\Gamma = 0 \text{ eV}$

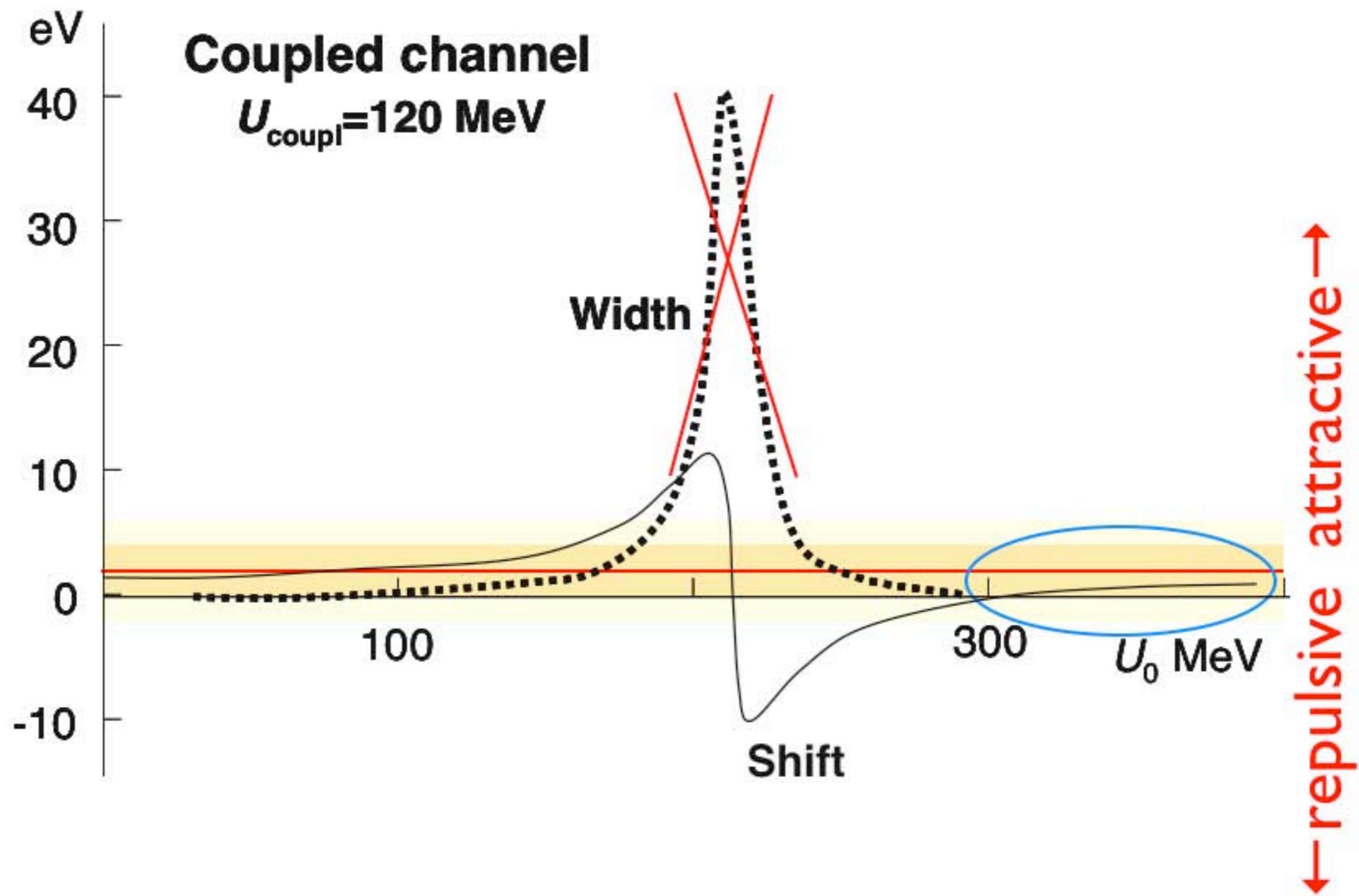
$\Gamma = 21 \text{ eV}$

(Akaiishi: $U_0=220, U_c=120$)

$\Gamma = 55 \text{ eV}$

(average of prev. experiments)

large width unlikely



結論

Summary

- Now the $2p$ shift is consistent with all theory calculations
- No more Kaonic Helium puzzle
- Width also appears to be small
- large $K^-{}^3He$ shift still a possibility

J-PARC E17 will measure K^- - ${}^3\text{He}$

