The kaonic helium puzzle

Ryugo S. Hayano
University of Tokyo

THE UNIVERSITY OF TOKYO

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Precision measurement of the $3d \rightarrow 2p$ 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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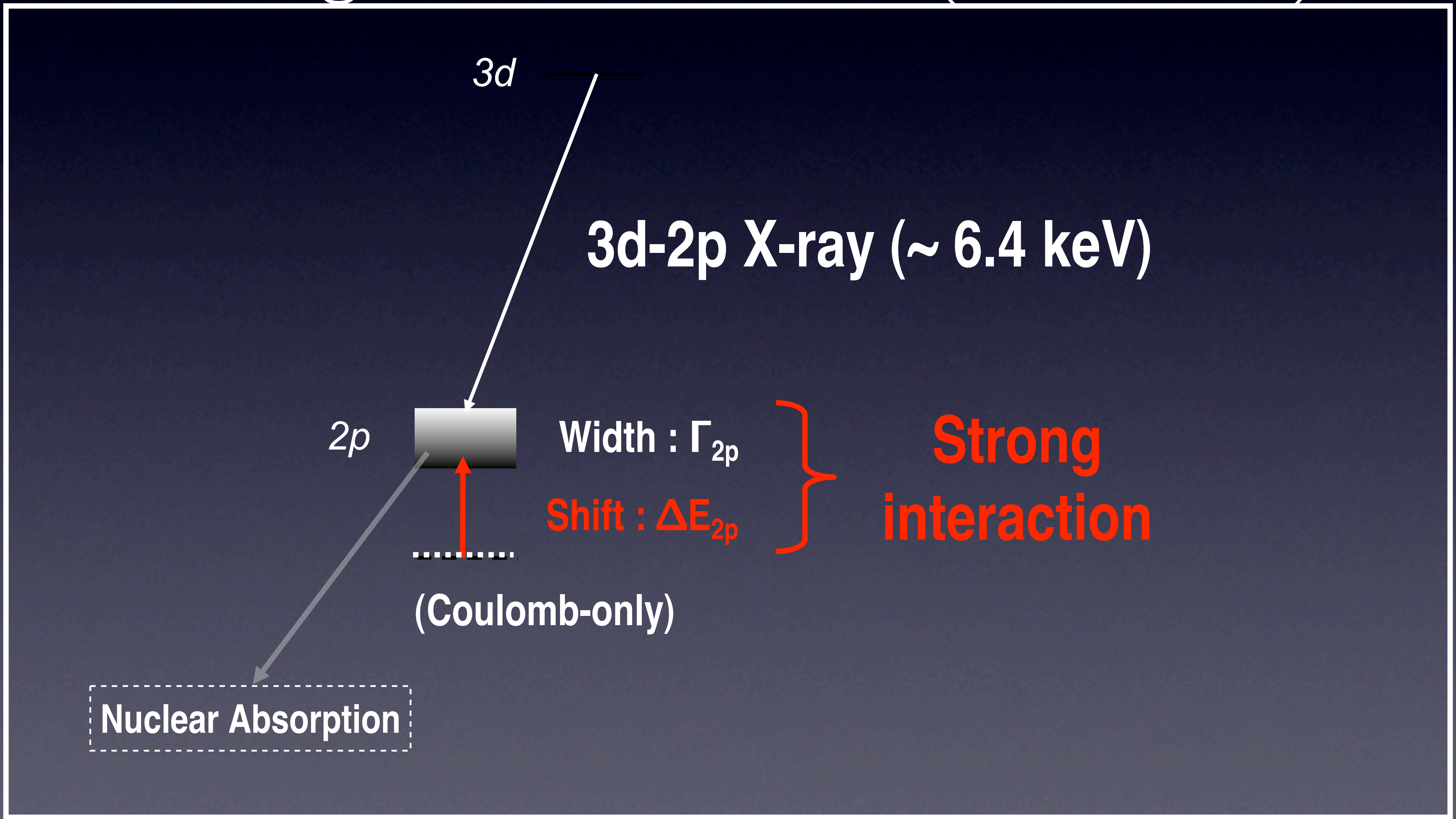
謎

What has been the problem?

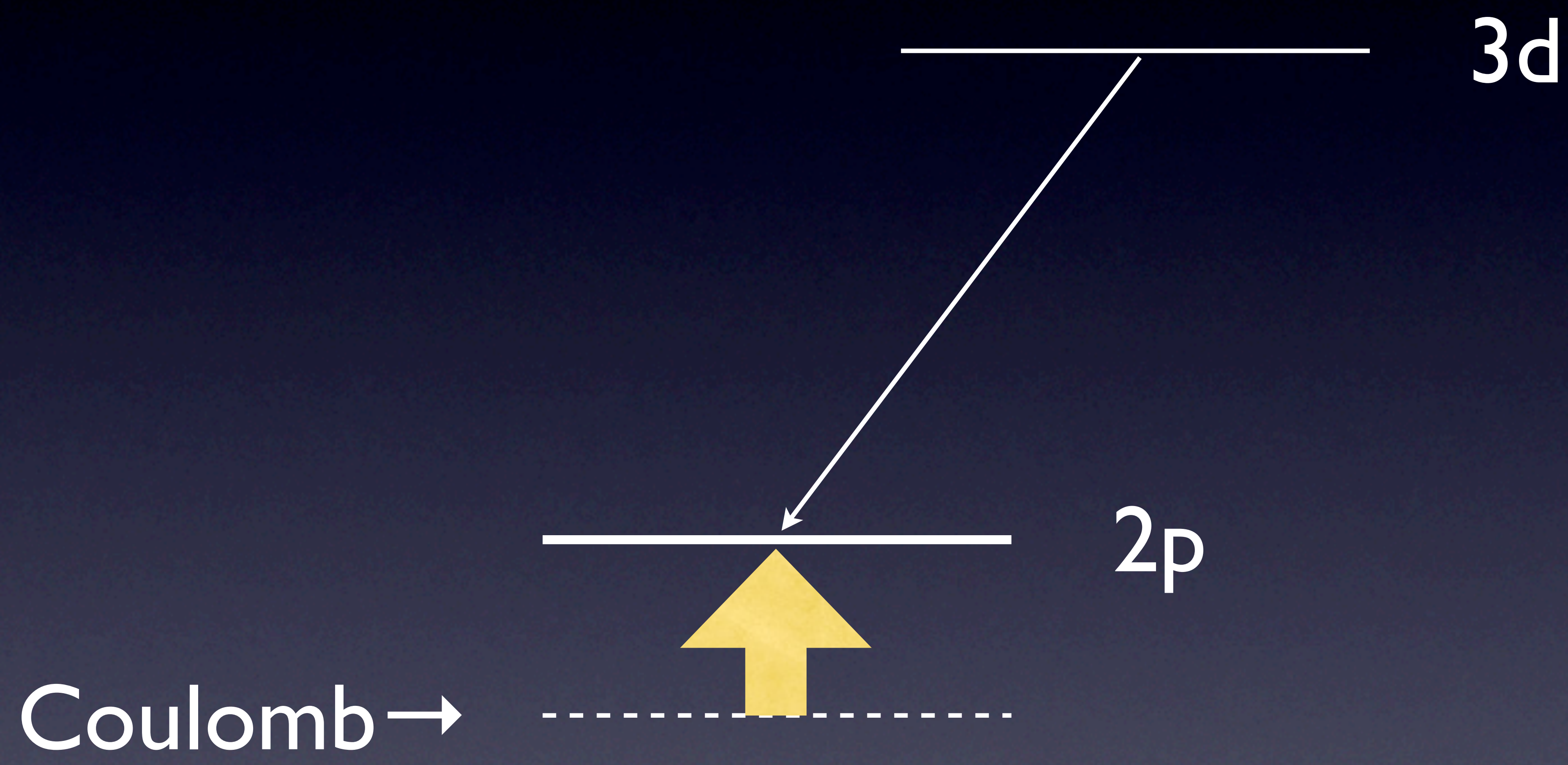
K$^-$ He atom 3d-2p X-ray Energy

Strong-interaction shift (and width)



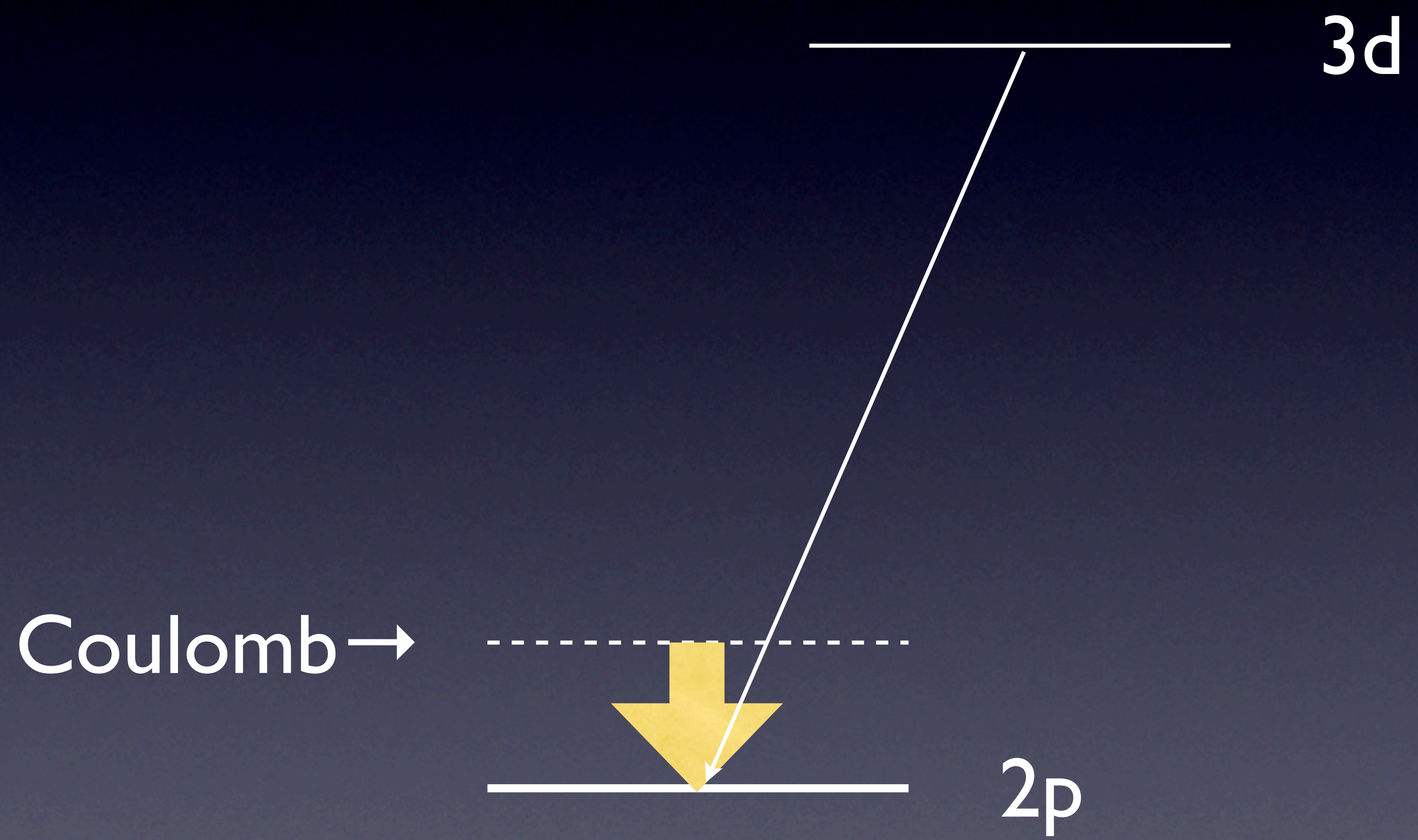
“repulsive”

X-ray energy reduced (shift sign negative)

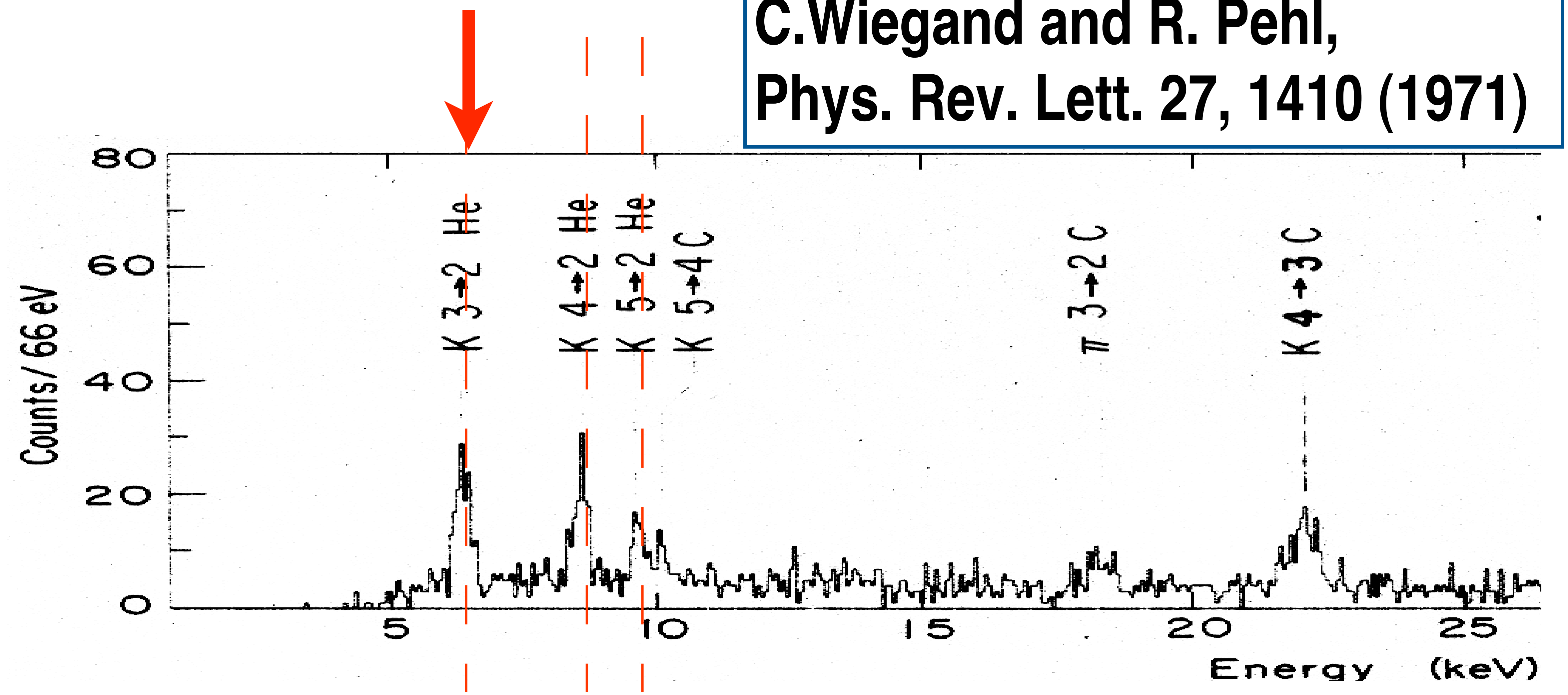


"attractive"

X-ray energy increased (shift sign positive)

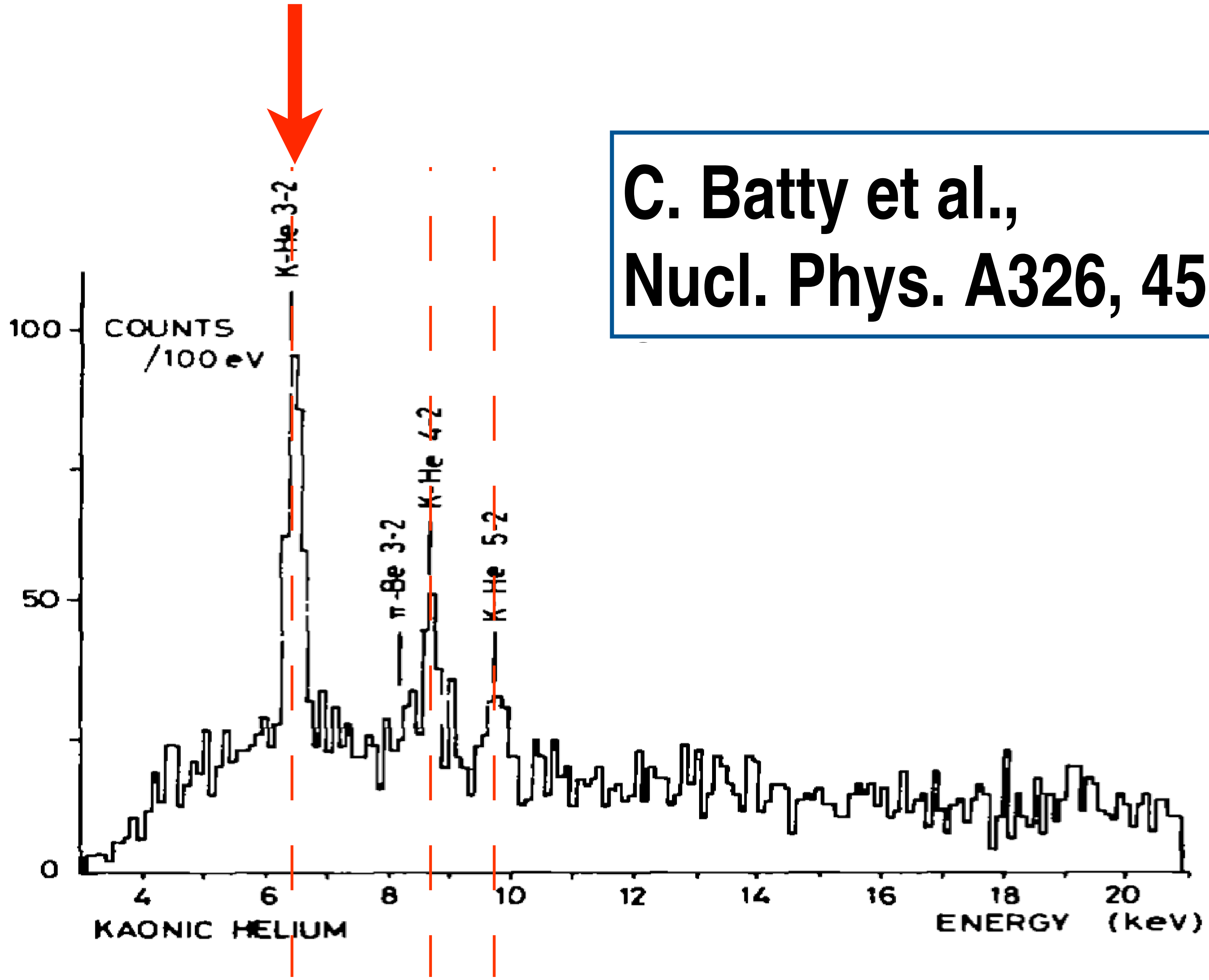


1 - 1971



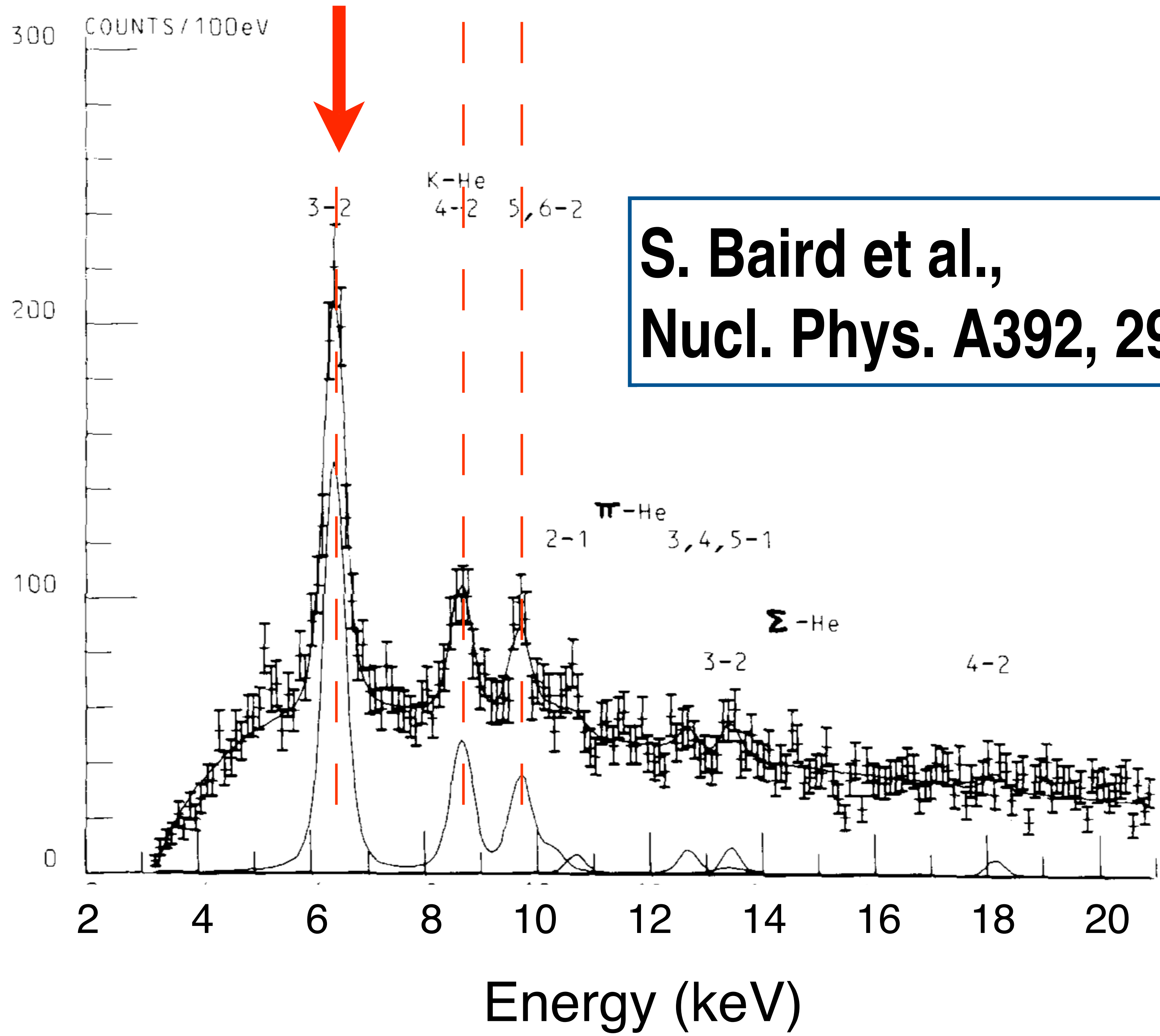
C.Wiegand and R. Pehl, Phys. Rev. Lett. 27, 1410 (1971)

2 - 1979

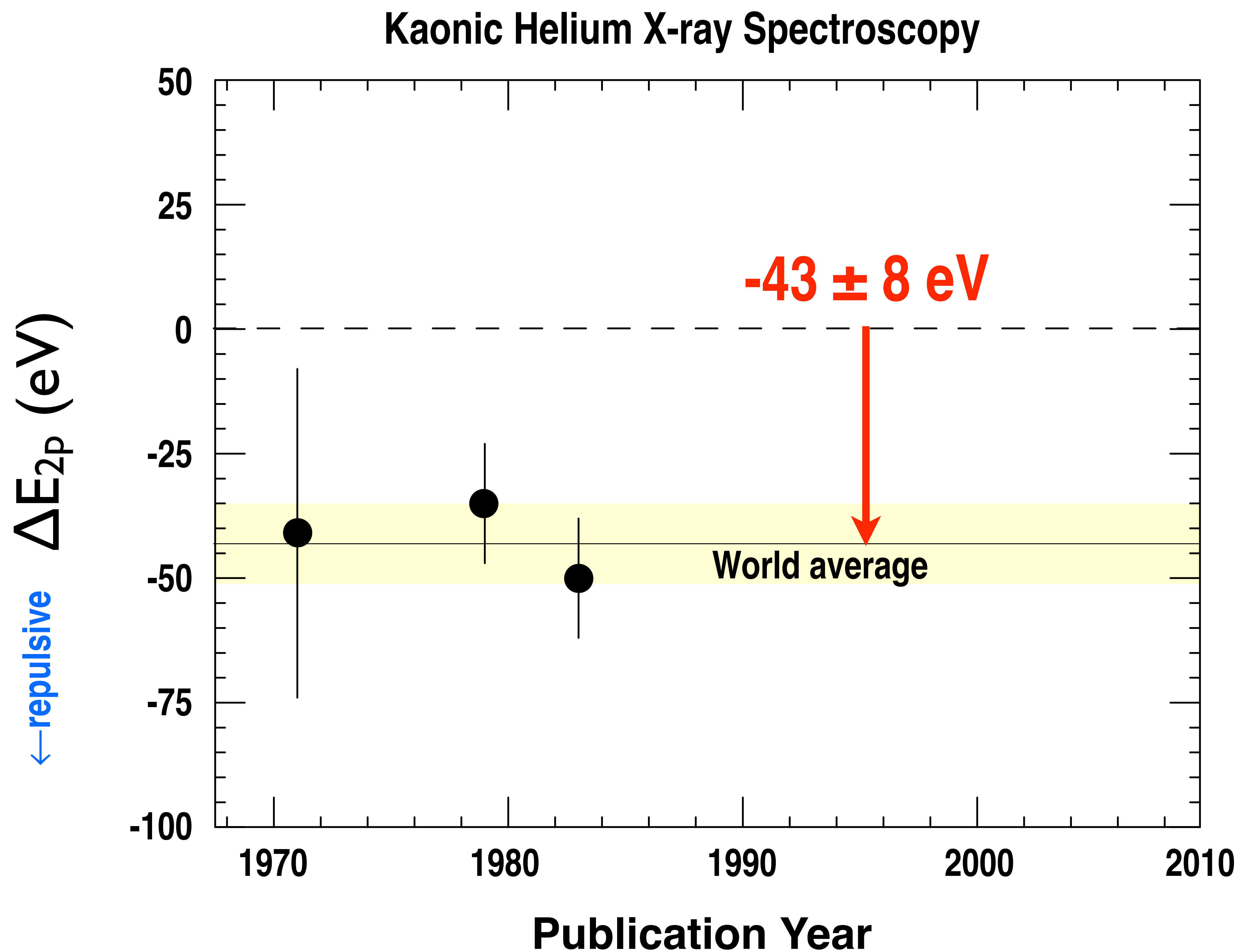


C. Batty et al., Nucl. Phys. A326, 455 (1979)

3 - 1983



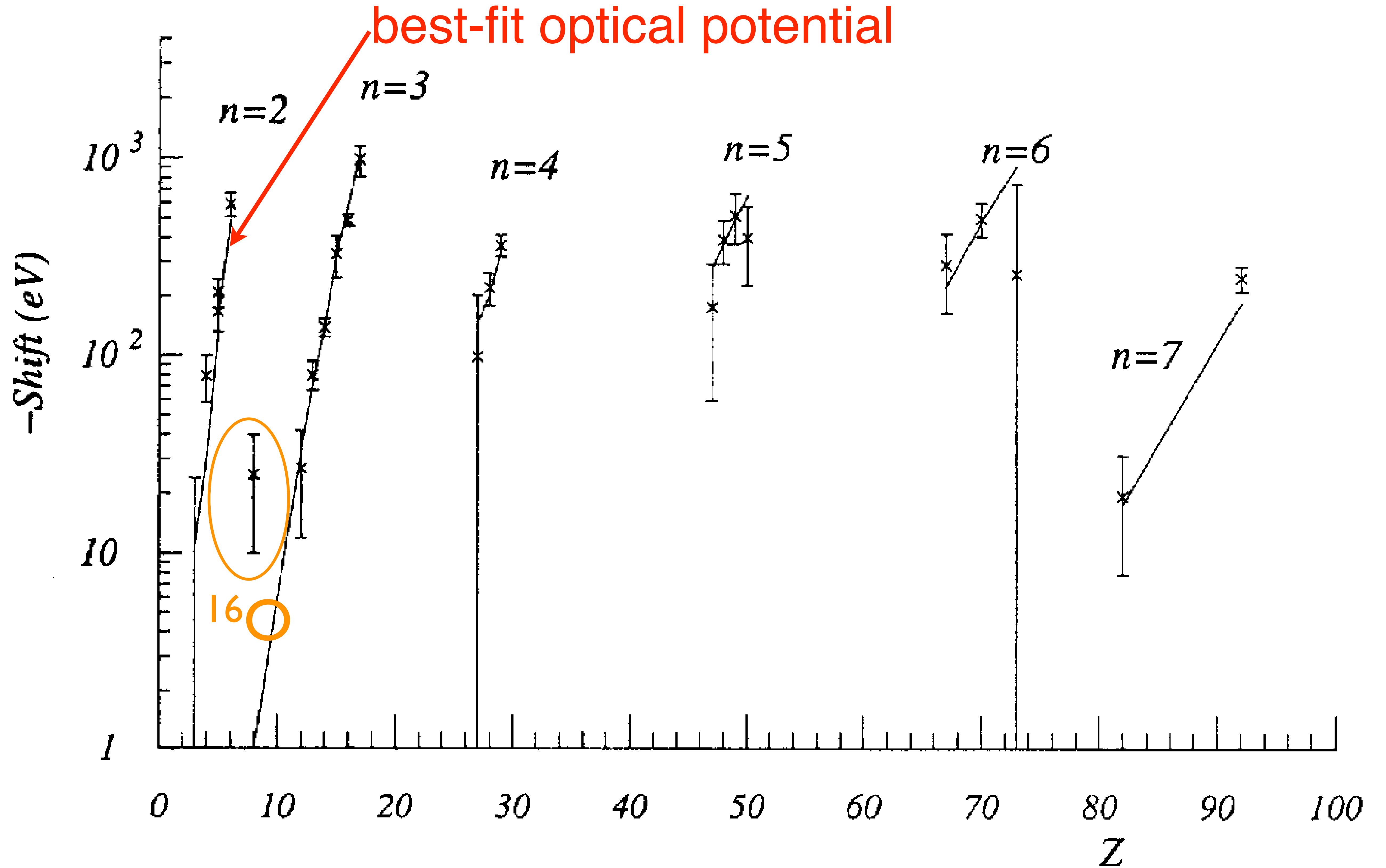
S. Baird et al., Nucl. Phys. A392, 297 (1983)



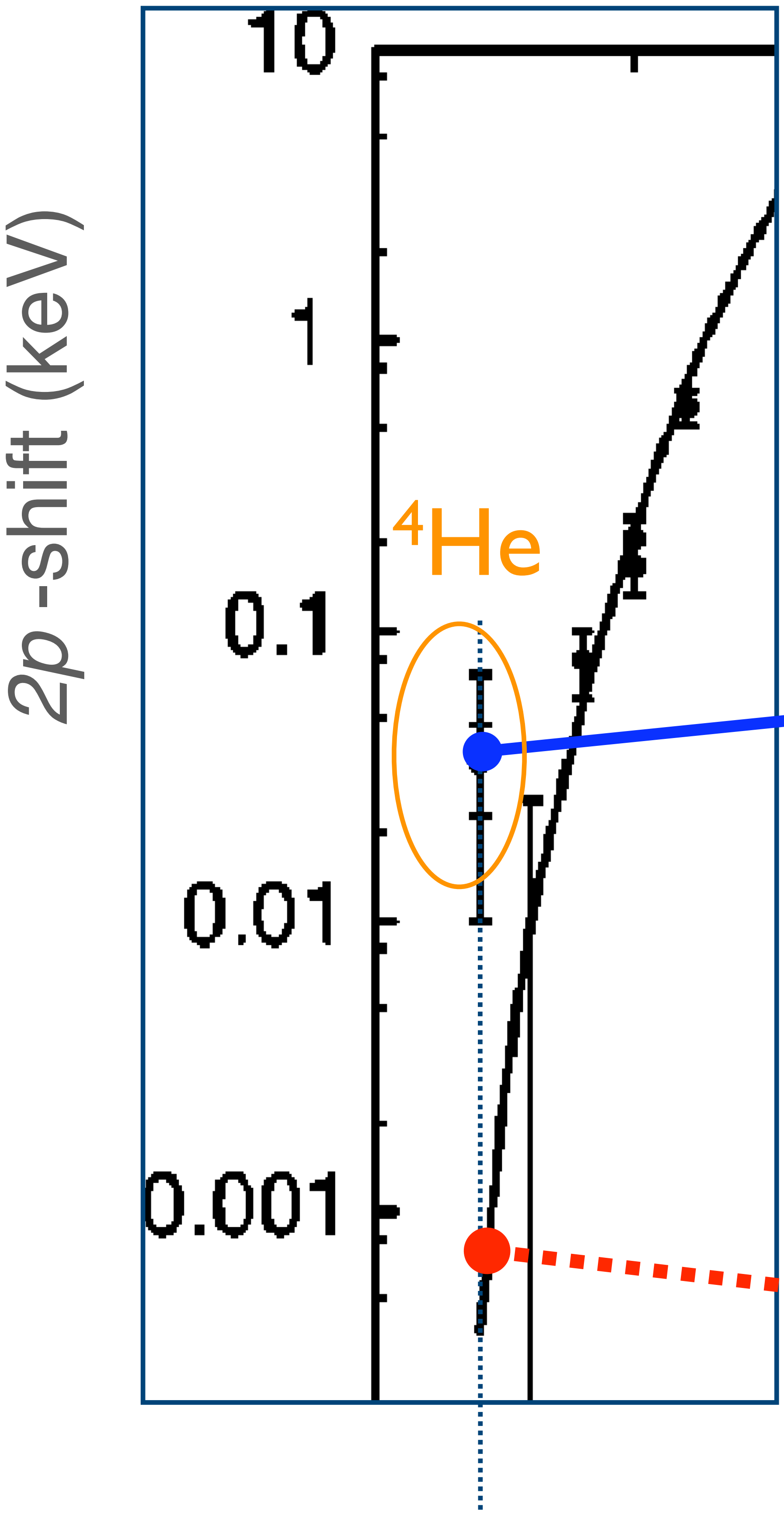
Kaonic Helium X-ray Spectroscopy
-43 ± 8 eV
World average
ΔE2p (eV)
←repulsive
50
25
0
-25
-50
-75
-100
1970
1980
1990
2000
2010
Publication Year

kaonic atom strong-interaction shift

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



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



Experiment

Theory

~ -0.2eV

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

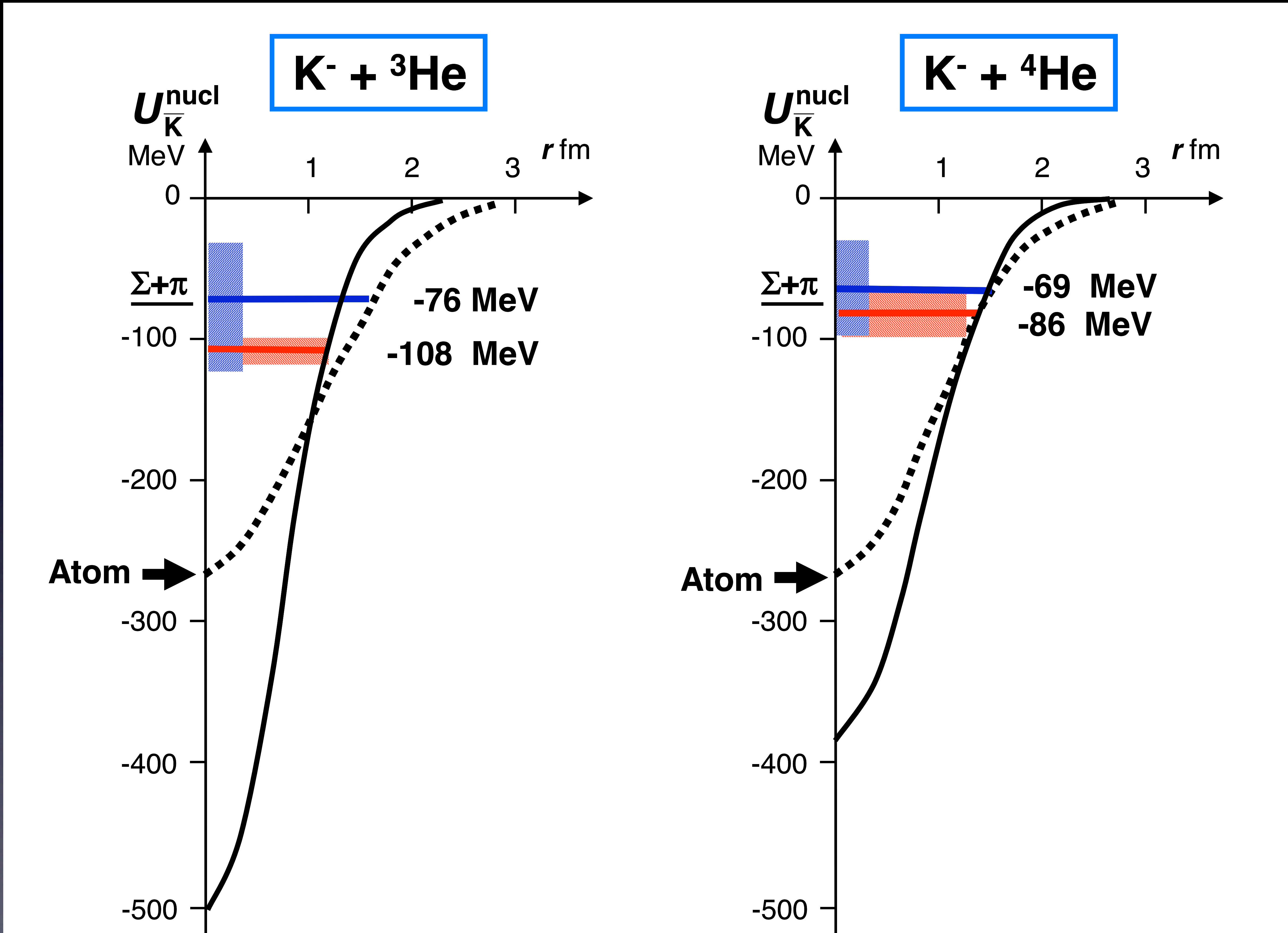
A new experiment with a detector of
- high resolution and
- good energy calibration
is urgently required.

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



Akaishi EXA05

optical model

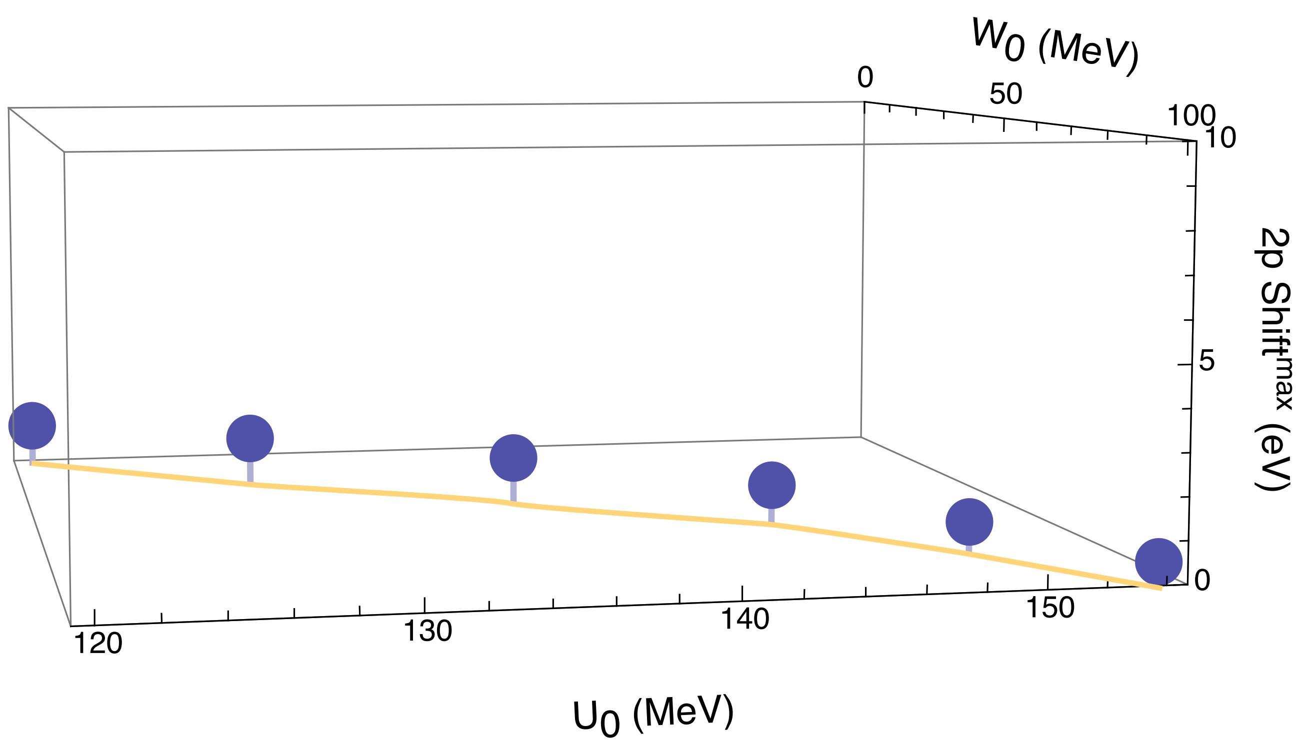
$$U^{\mathrm{opt}}(r) = -(U_0 + iW_0)F(r)$$

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

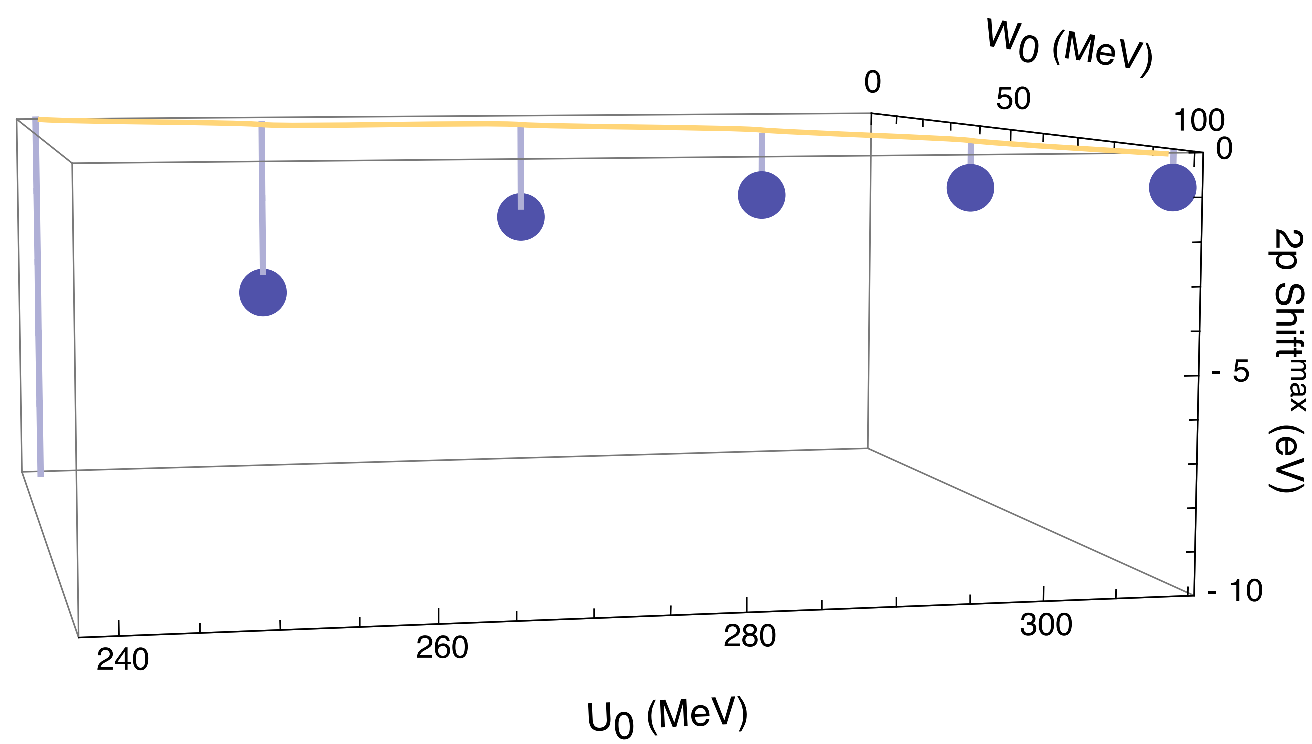
$$\left\{-\vec{\nabla}^2 + 2\mu(V_c + U^{\mathrm{opt}} - \epsilon) - (V_c - \epsilon)^2\right\}\Psi = 0$$

V_c : Coulomb

optical model



shallow potential



deep potential

Akaishi’s coupled-channel model calculation

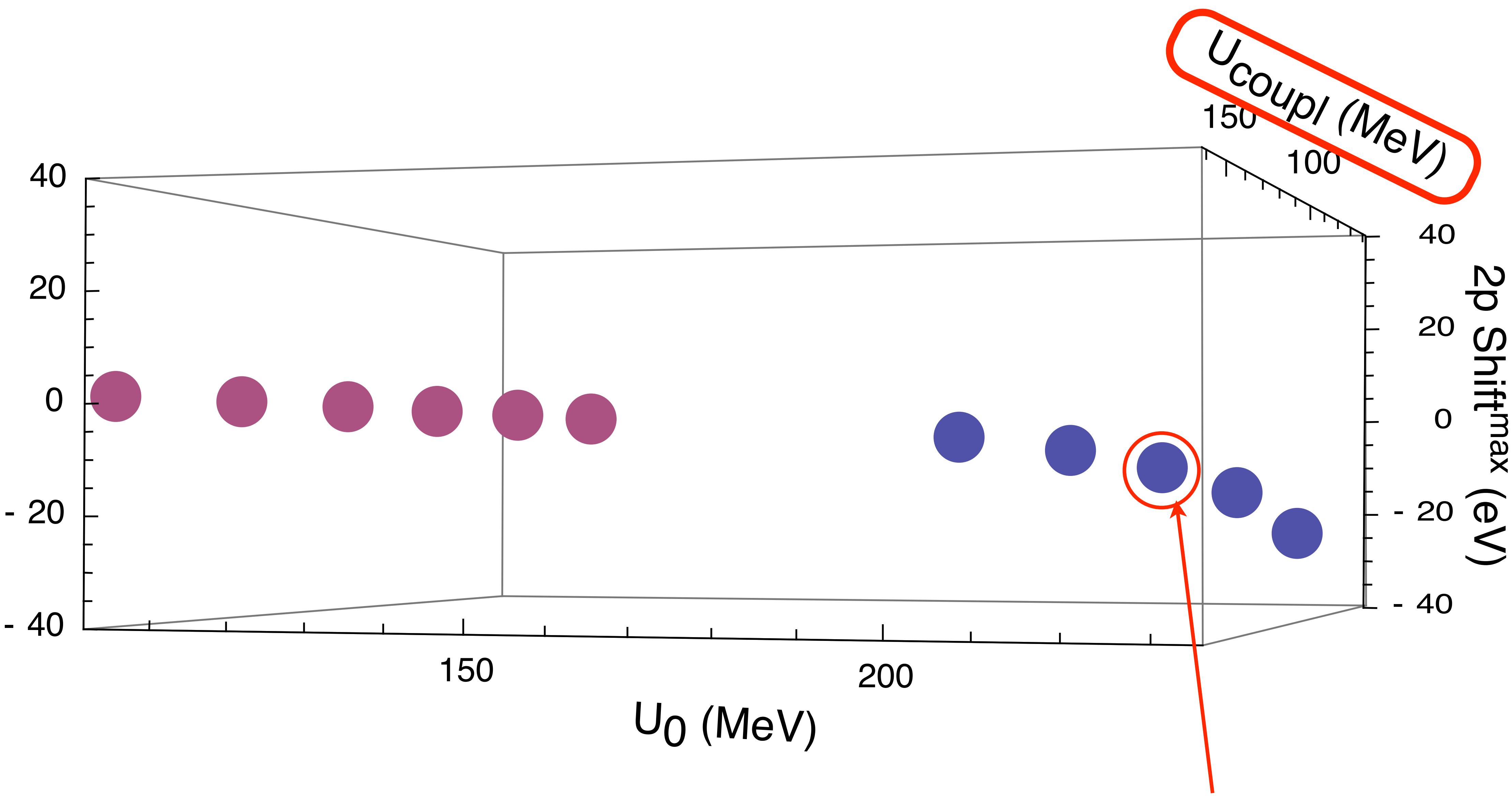
coupling to the $\pi^- +^4_\Sigma$ He channel

$$\begin{aligned} \text{diagonal: } U_D &= -U_0 F(r) \\ \text{coupling: } U_C &= U_{\text{coupl}} F(r) \end{aligned}$$

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

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

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

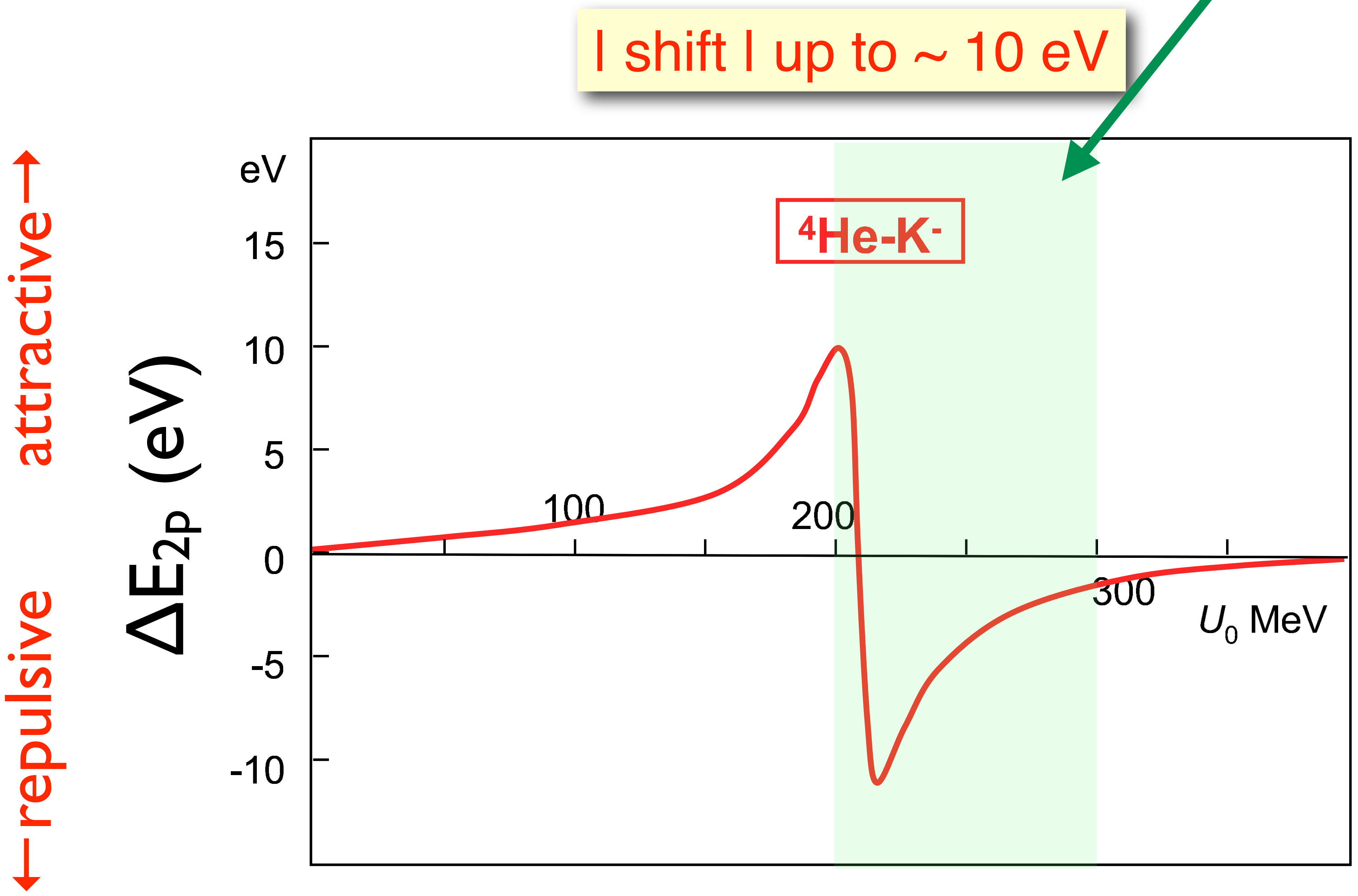


U_0=220 MeV, U_c=120 MeV, Shift = -11 eV

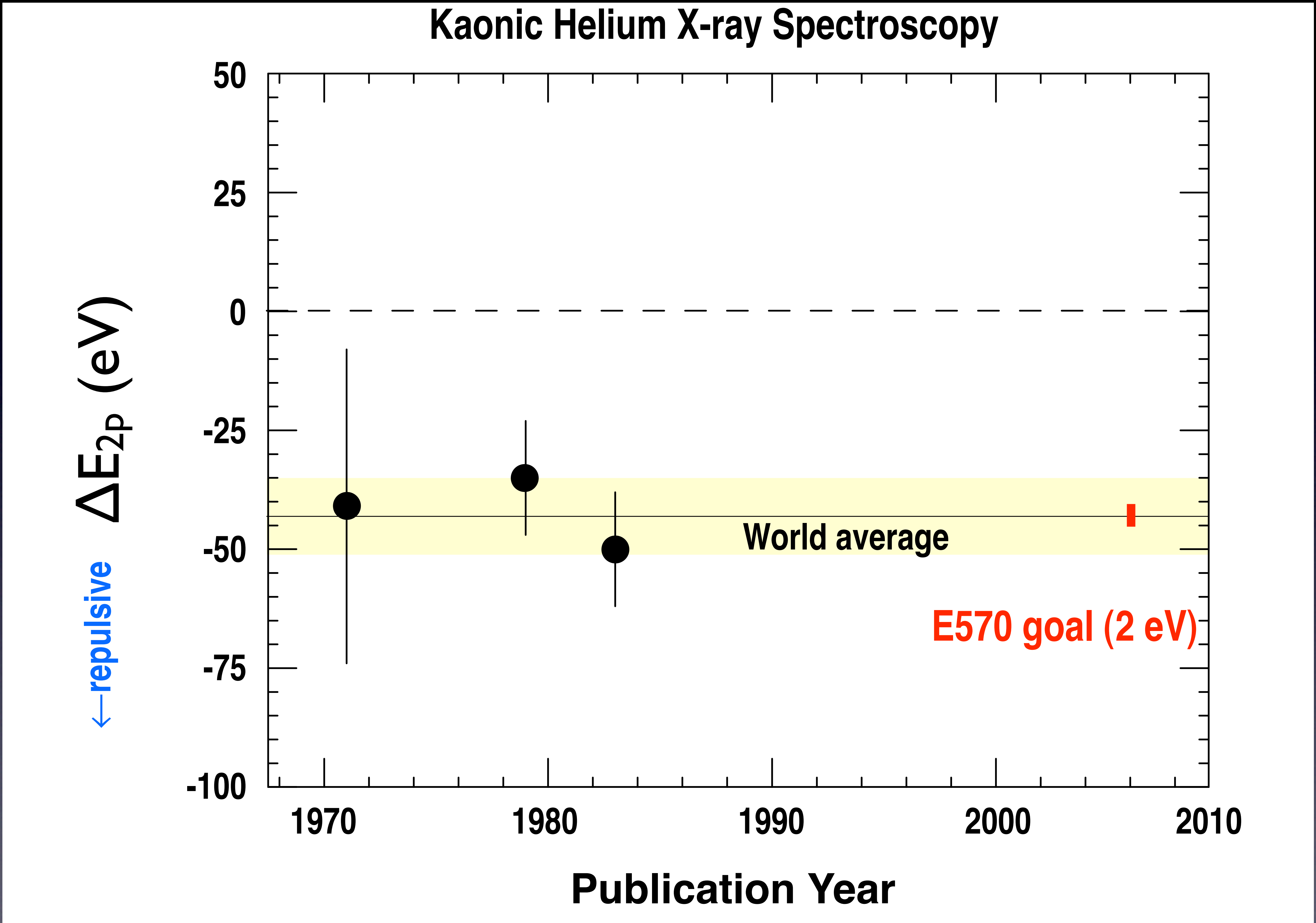
Akaishi EXA05

Akaishi's prediction

(accommodates kaonic nuclear states)



U_c fixed to 120 MeV, U_0 varied


Kaonic Helium X-ray Spectroscopy
50
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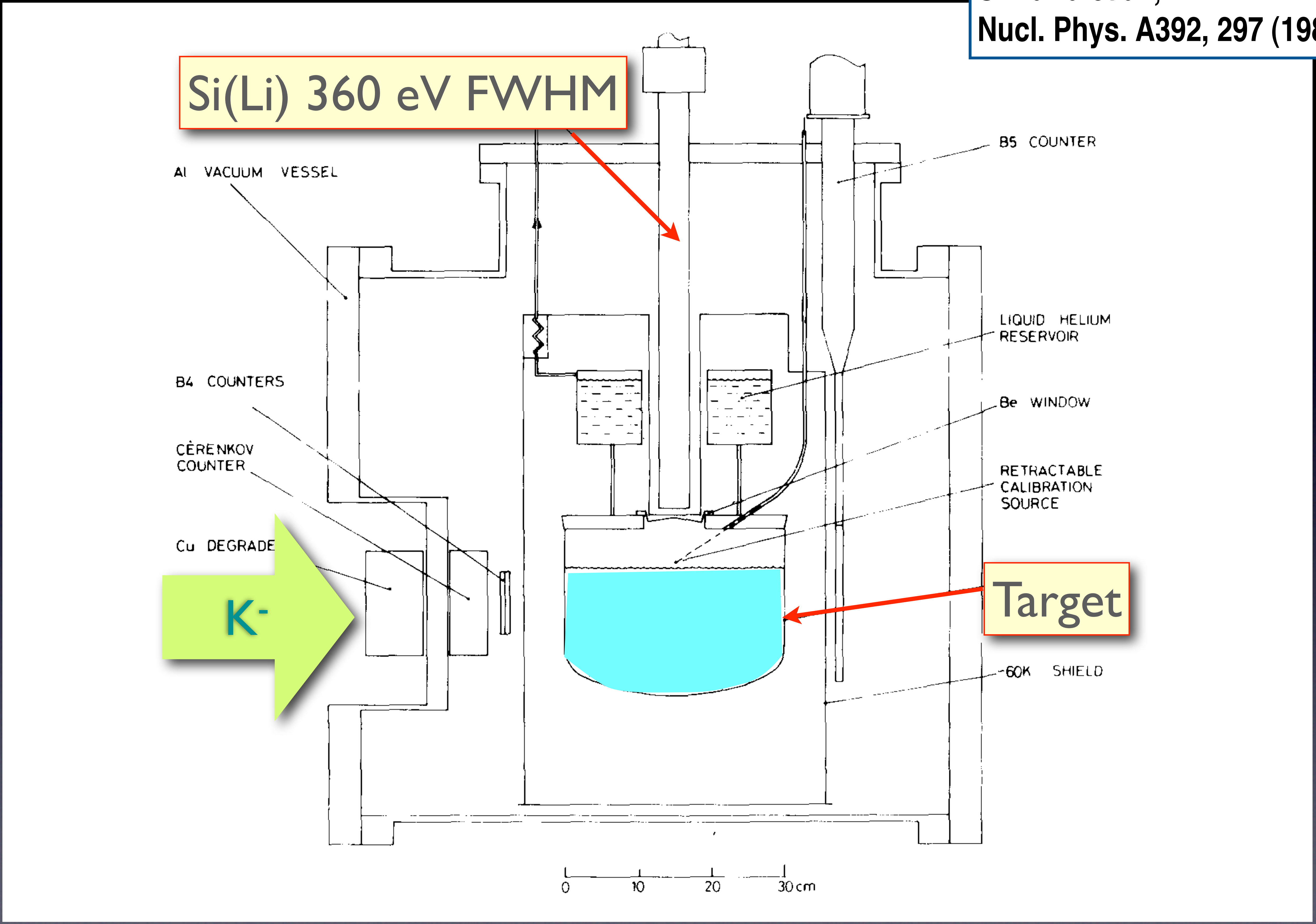
-50
-75
-100
1970
1980
1990
2000
2010
ΔE2p (eV)
←repulsive
World average
E570 goal (2 eV)
Publication Year

方法

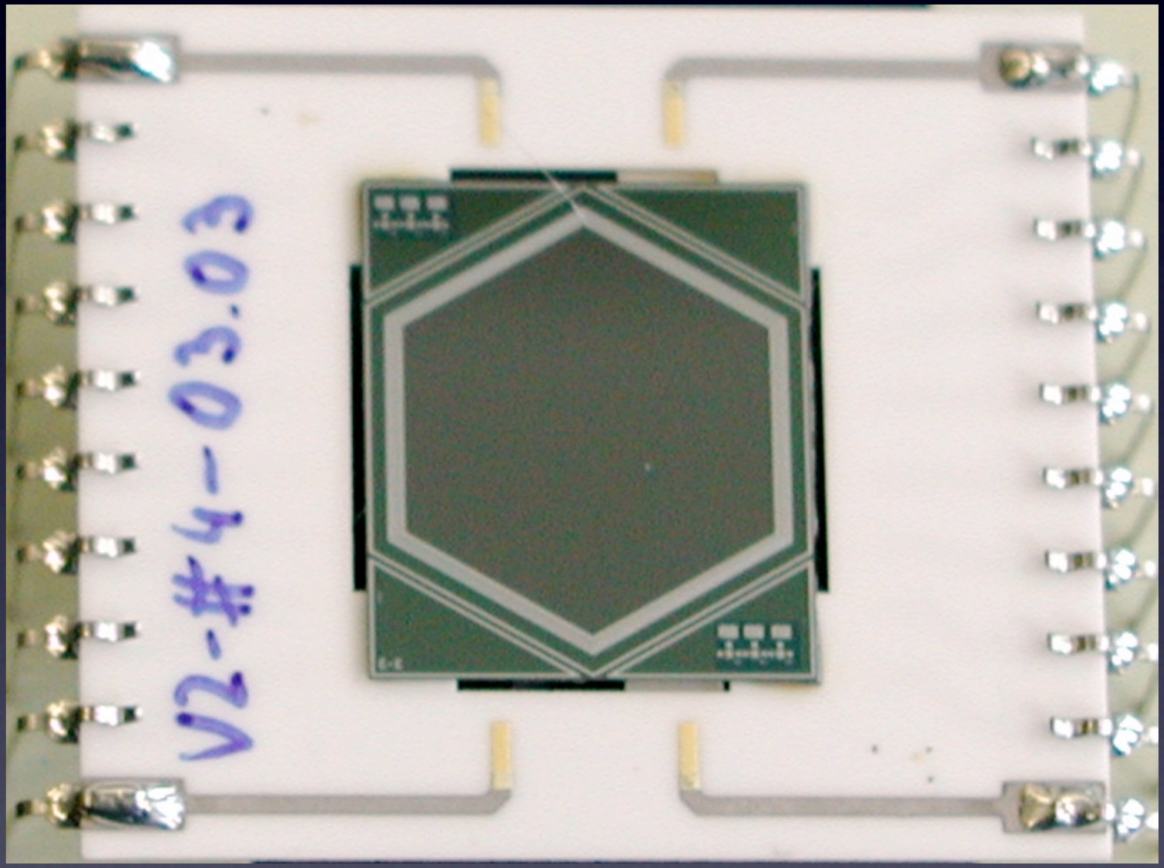
E570 Methods

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

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



1. High Resolution
SDD (silicon drift detector)



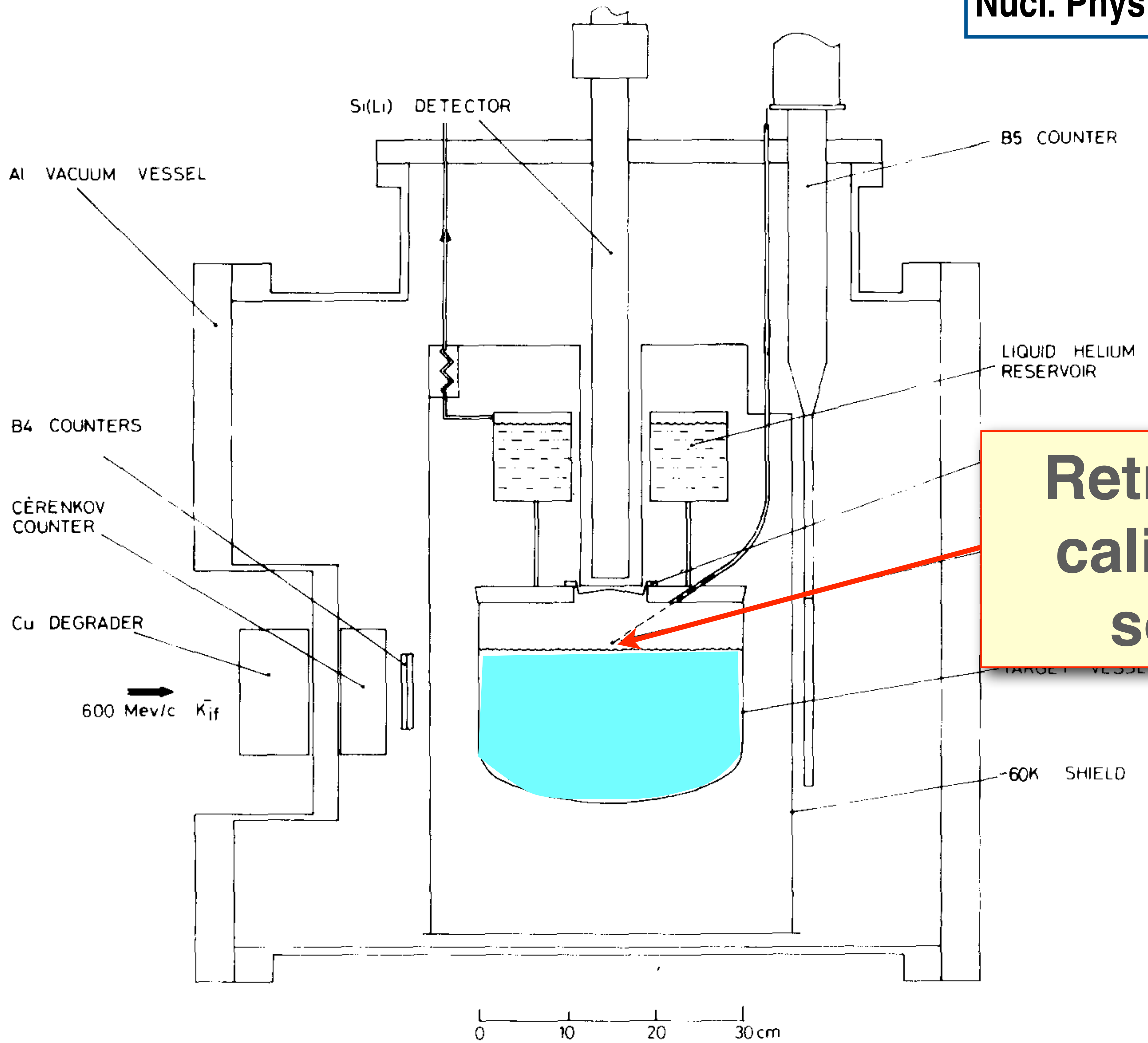
Produced by KETEK GmbH

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

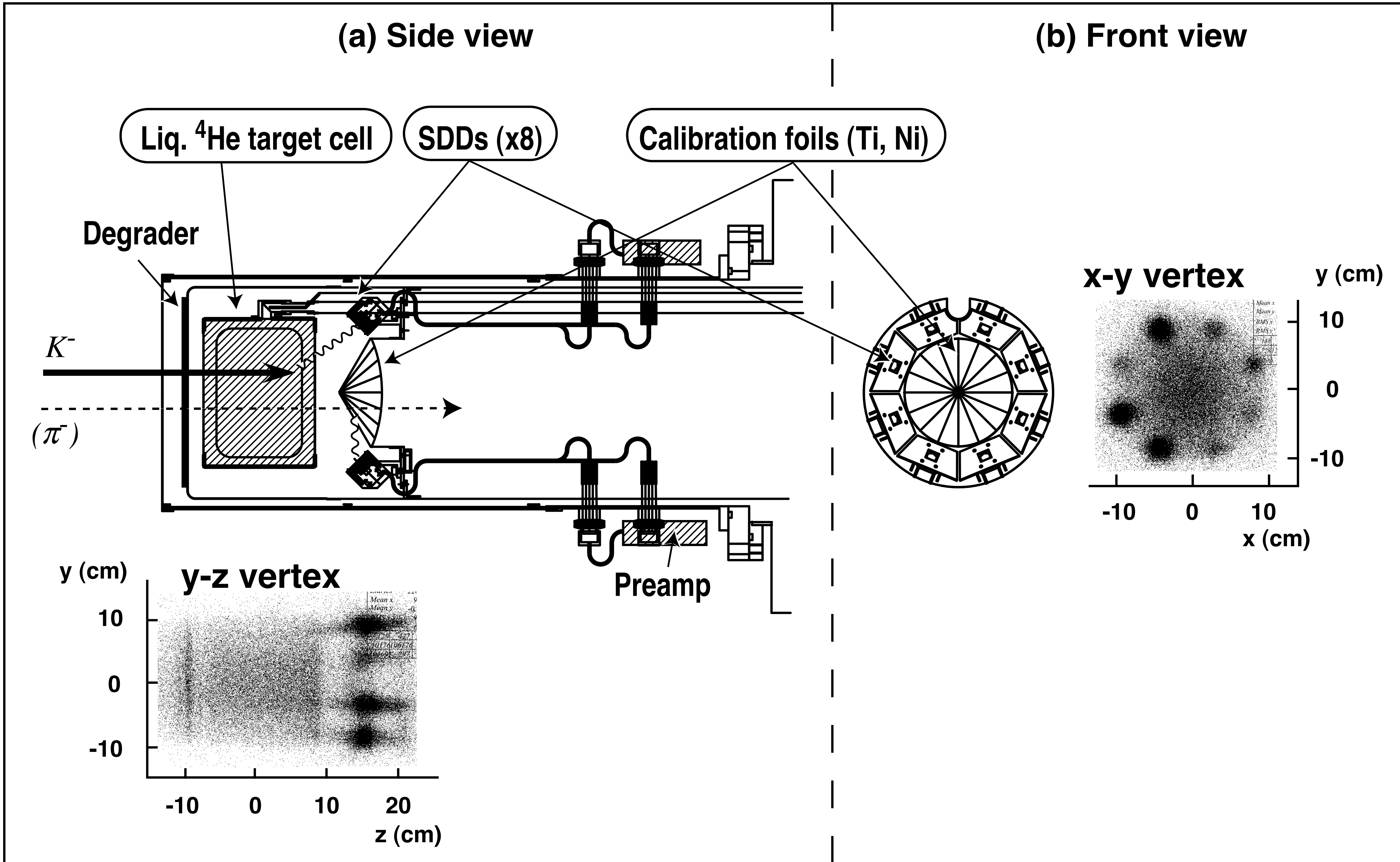
8 such SDDs used in E570

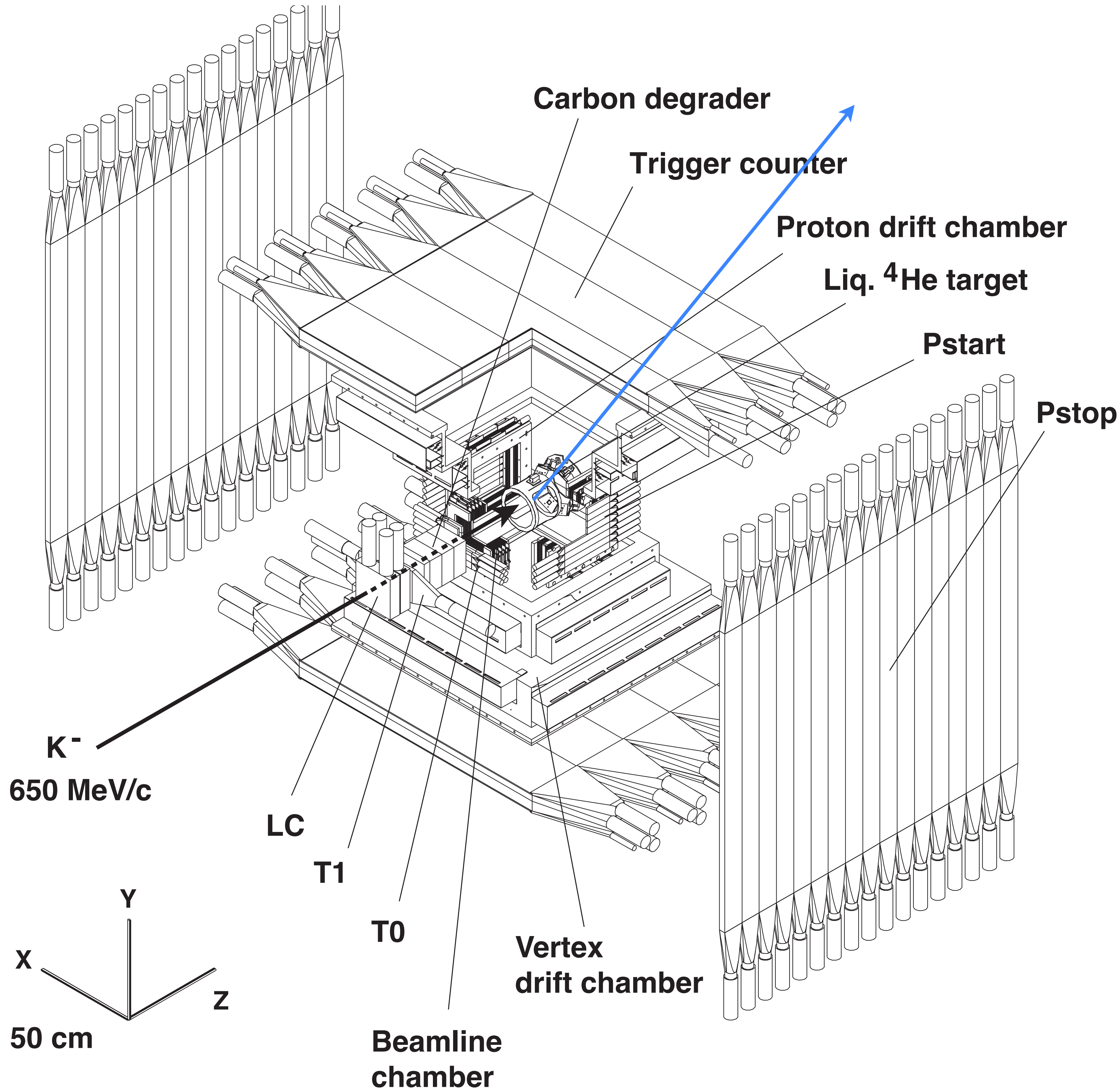
S. Baird et al.,
Nucl. Phys. A392, 297 (1983)



Retractable calibration source

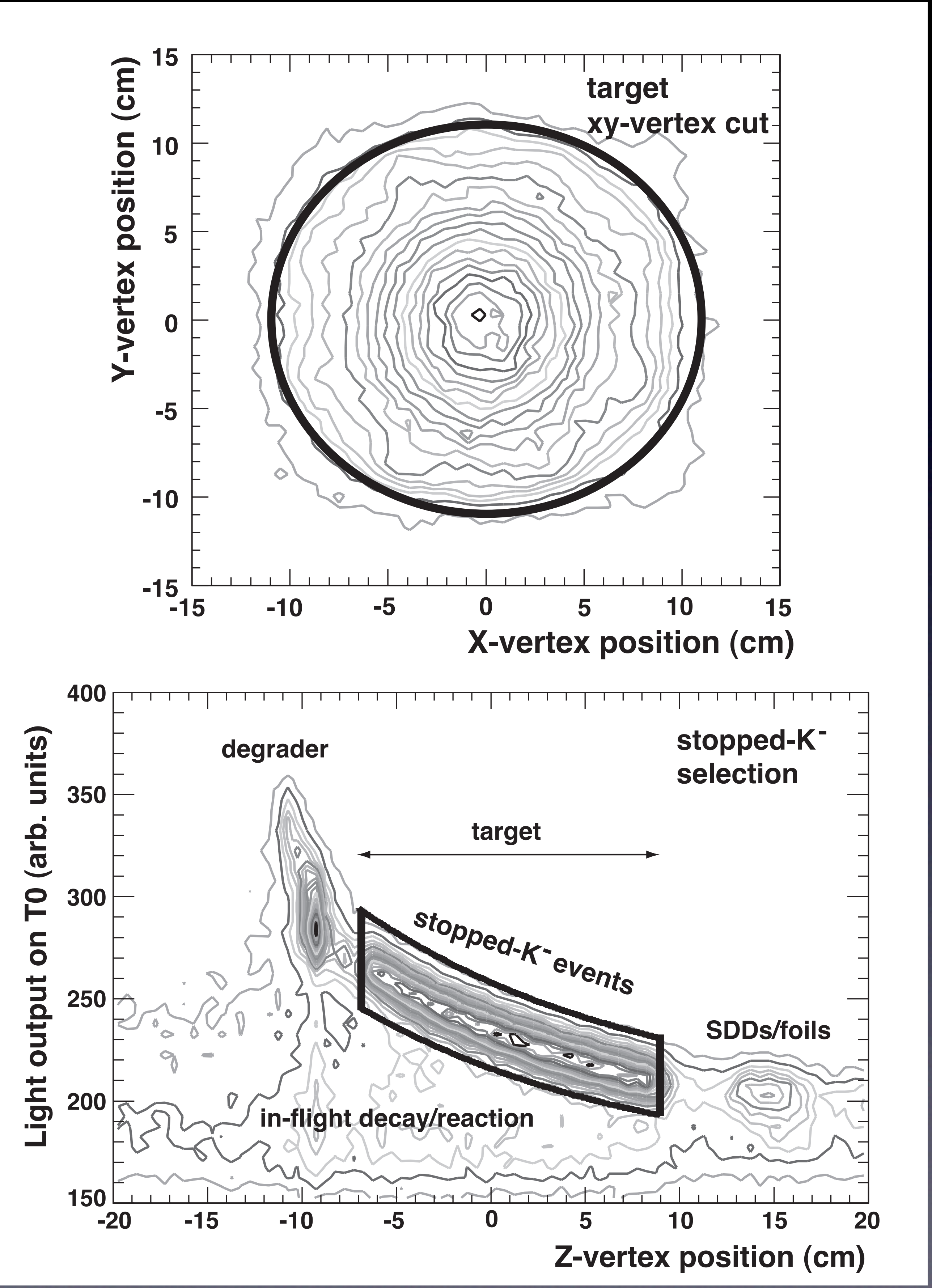
2: in-situ calibration, 3: fiducial selection





Carbon degrader
Trigger counter
Proton drift chamber
Liq. ^{4}He target
Pstart
Pstop
K$^-$
650 MeV/c
LC
T1
T0
Vertex
drift chamber
Beamline
chamber
Y
X
Z
50 cm

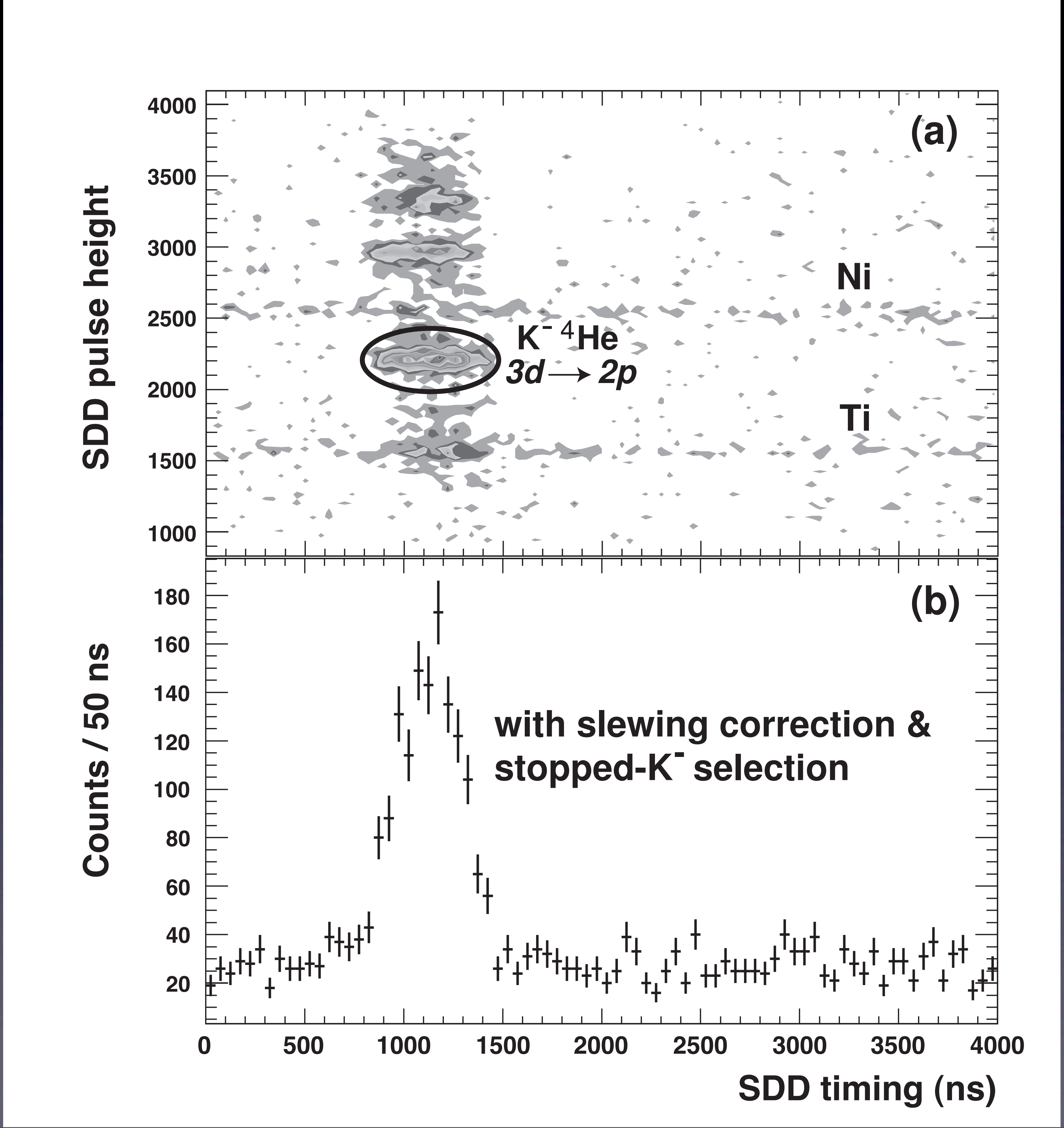
Fiducial selection

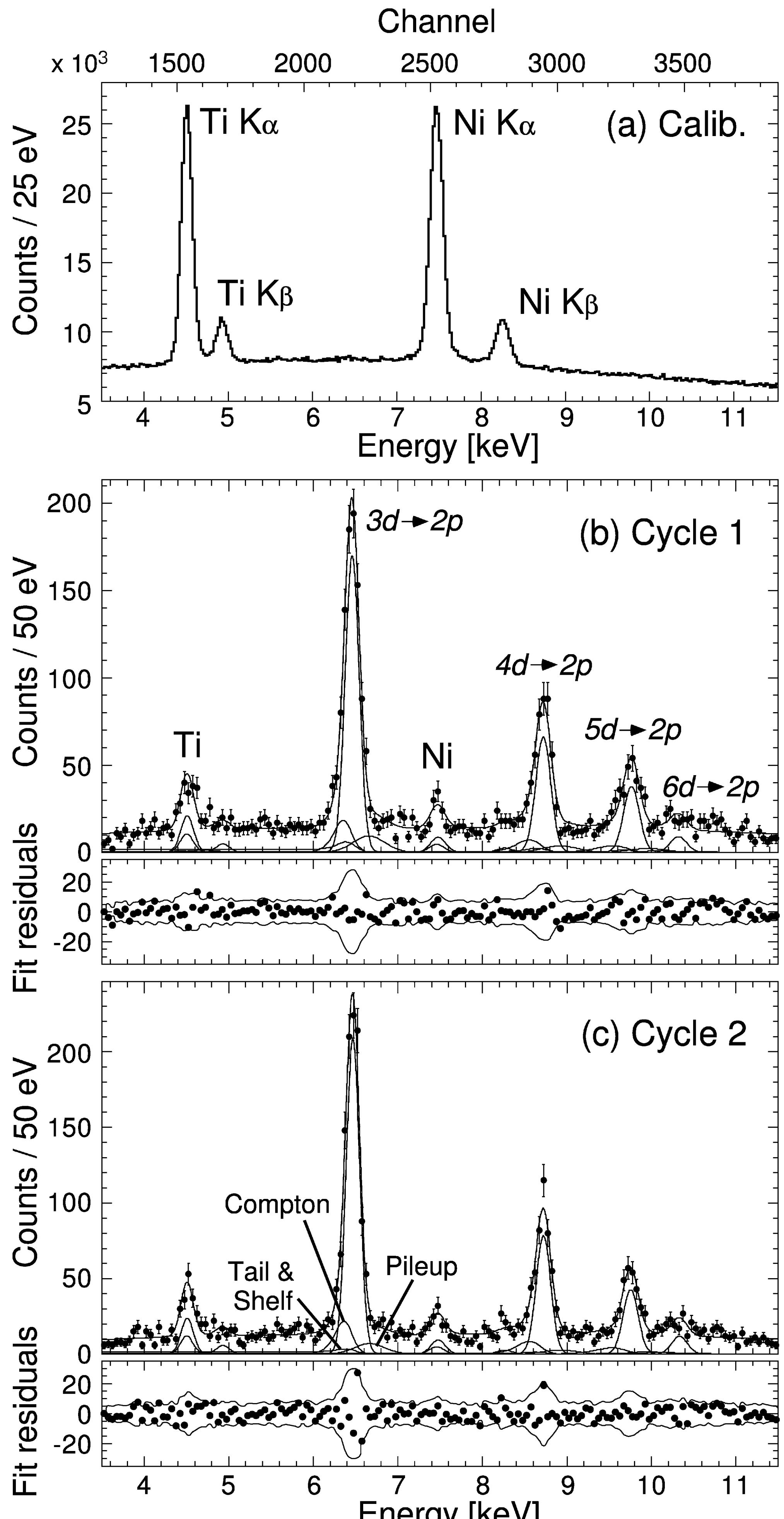


front view

side view

Timing selection





SDD Self trigger

Kaon trigger, fiducial & timing cut

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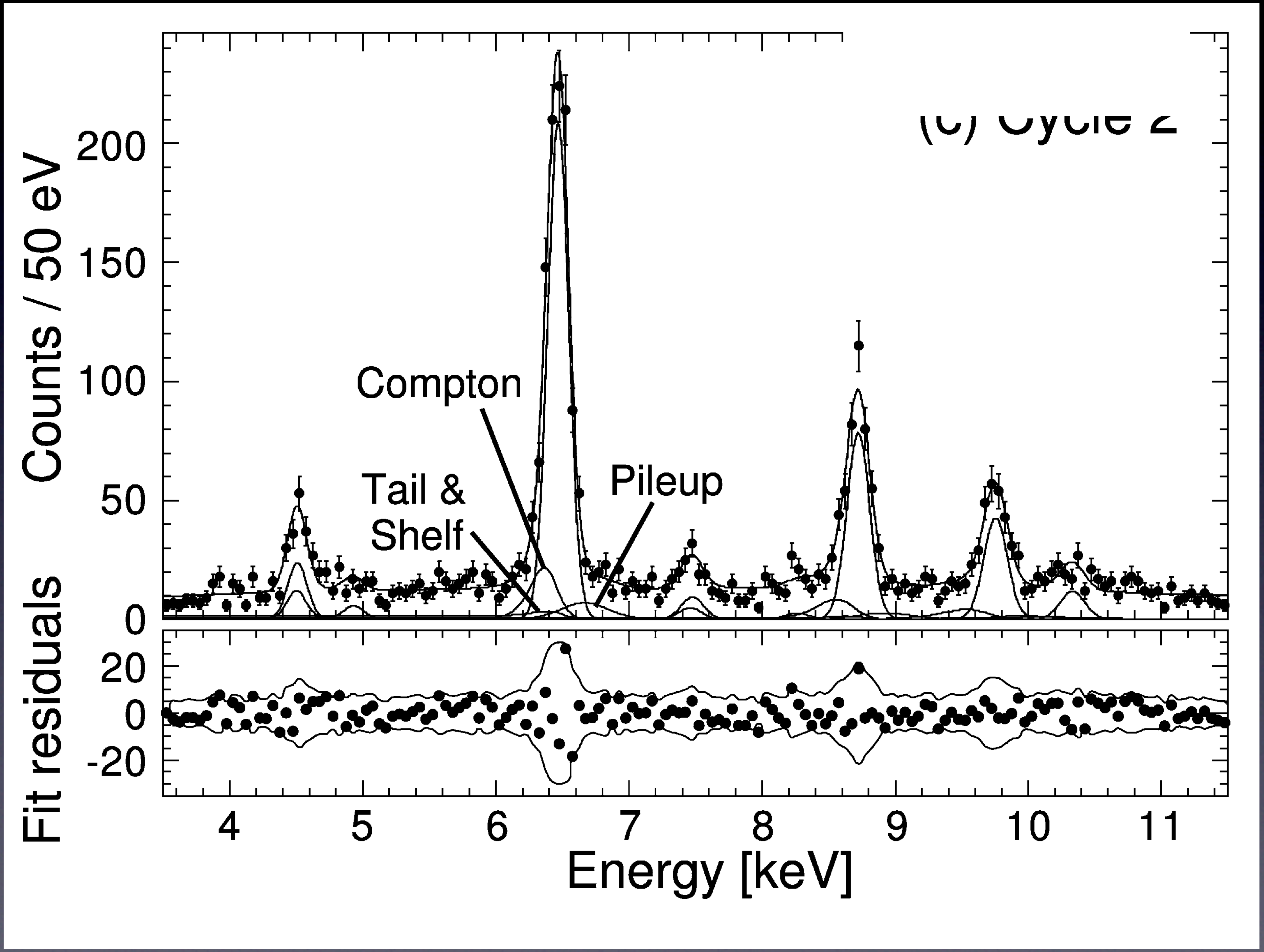
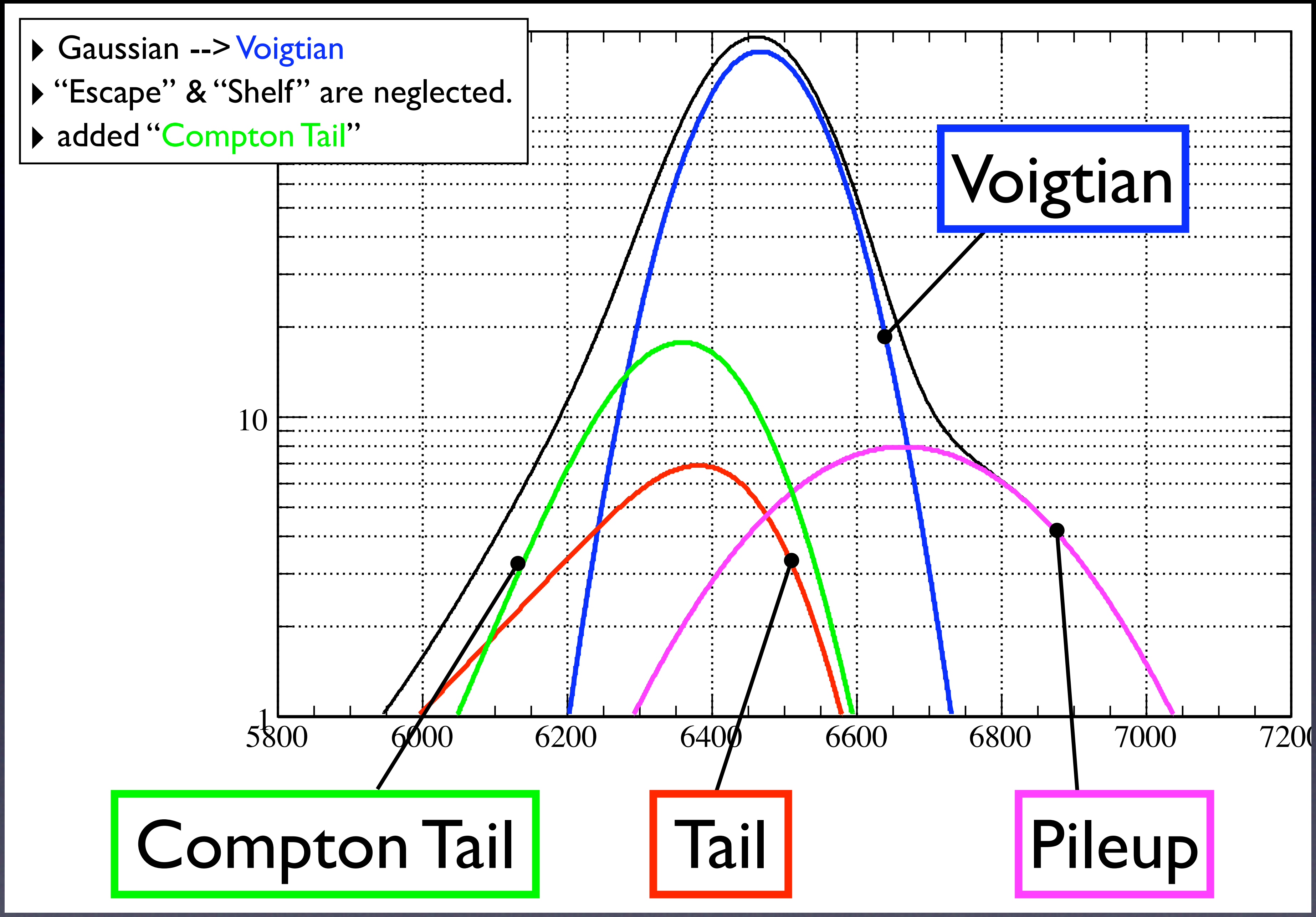
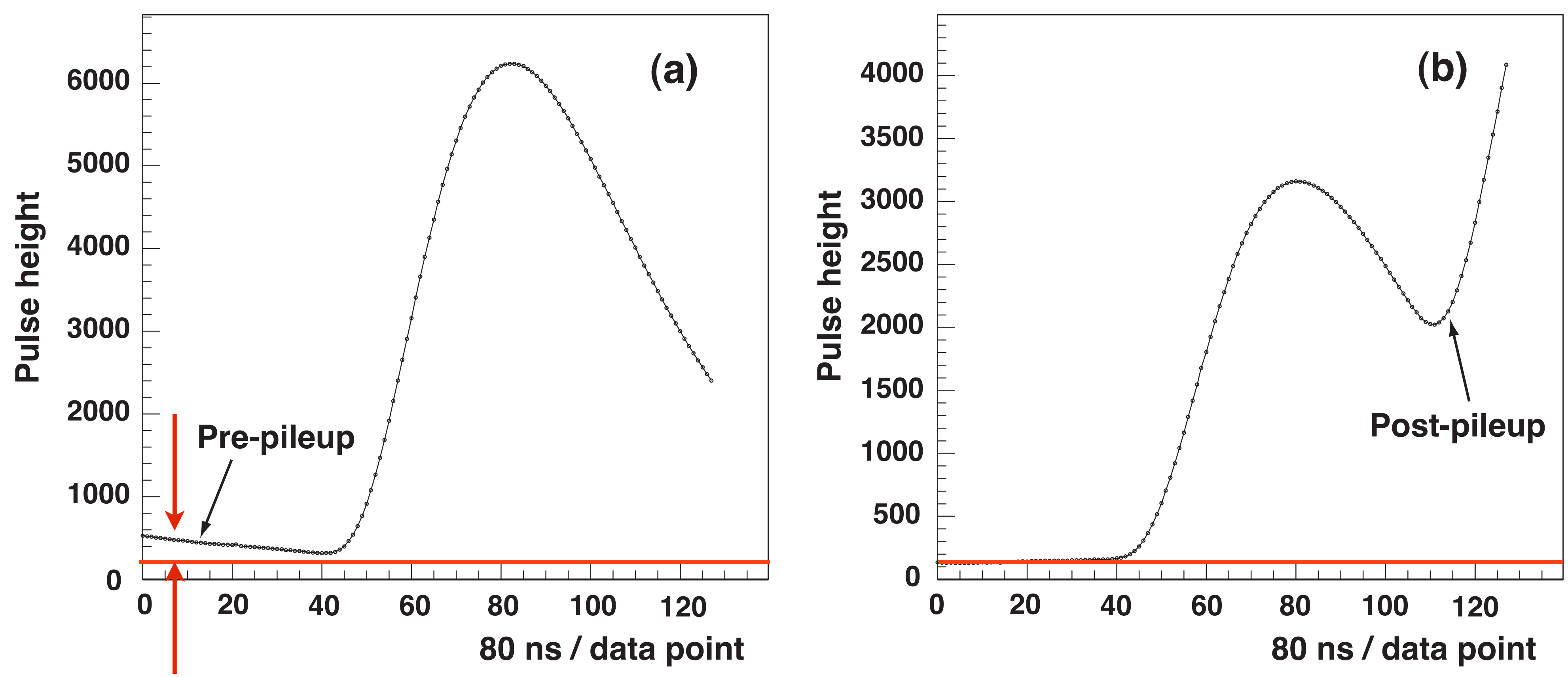
understading the resolution function (critical!)

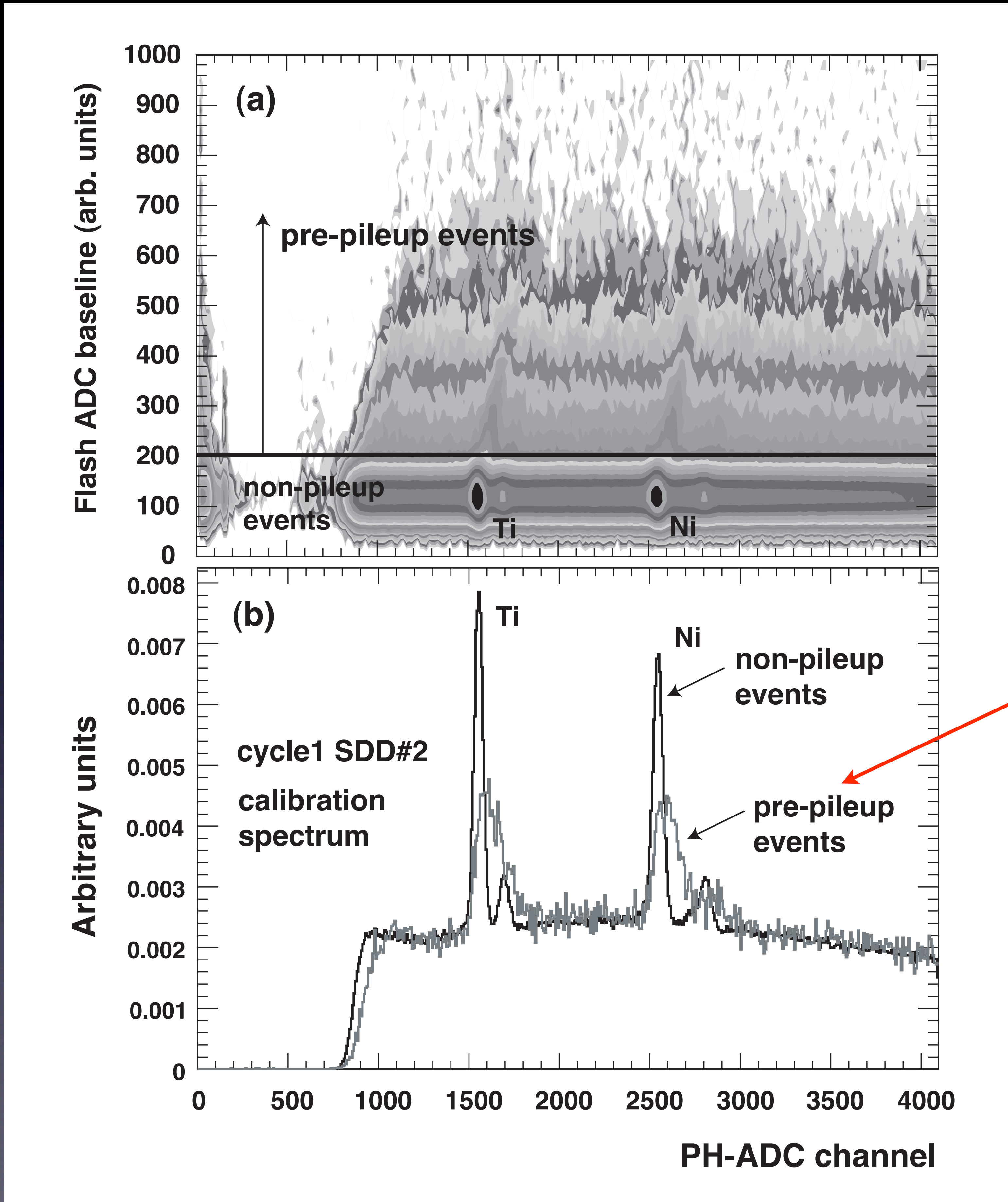




Gaussian --> Voigtian
"Escape" & "Shelf" are neglected.
added "Compton Tail"
Voigtian
10
1
5800
6000
6200
6400
6600
6800
7000
7200
Compton Tail
Tail
Pileup

Pileup (typical flash-adc waveforms)



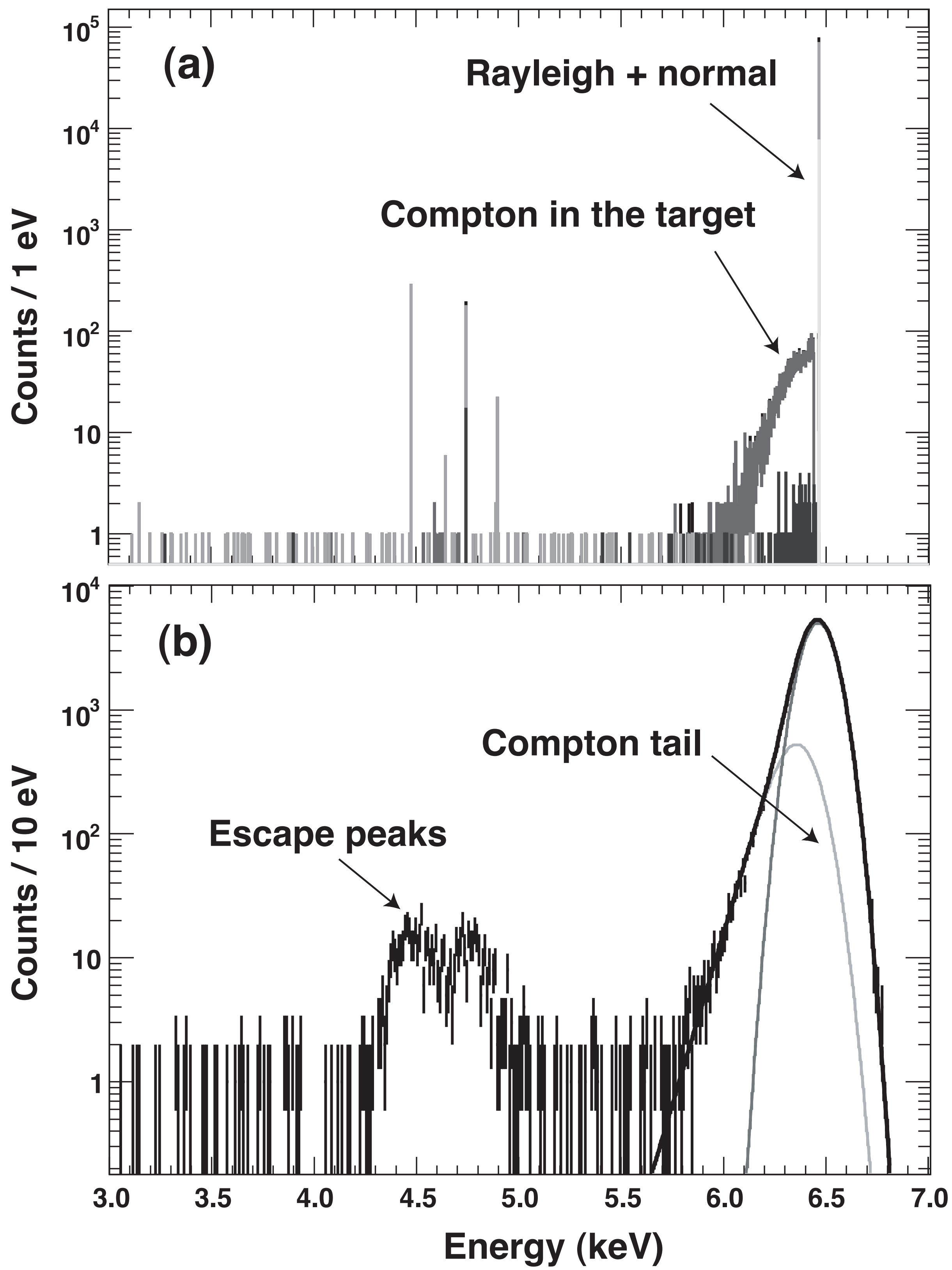


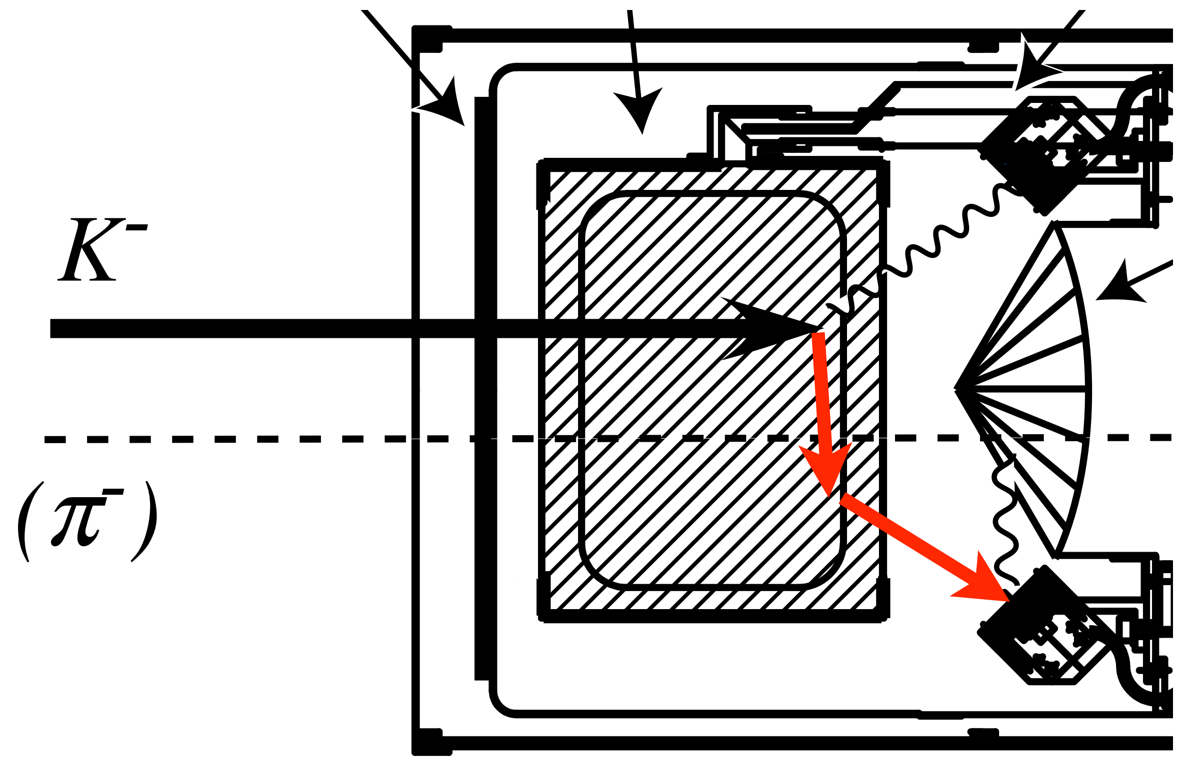
flash ADC baseline vs energy

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

Compton tail

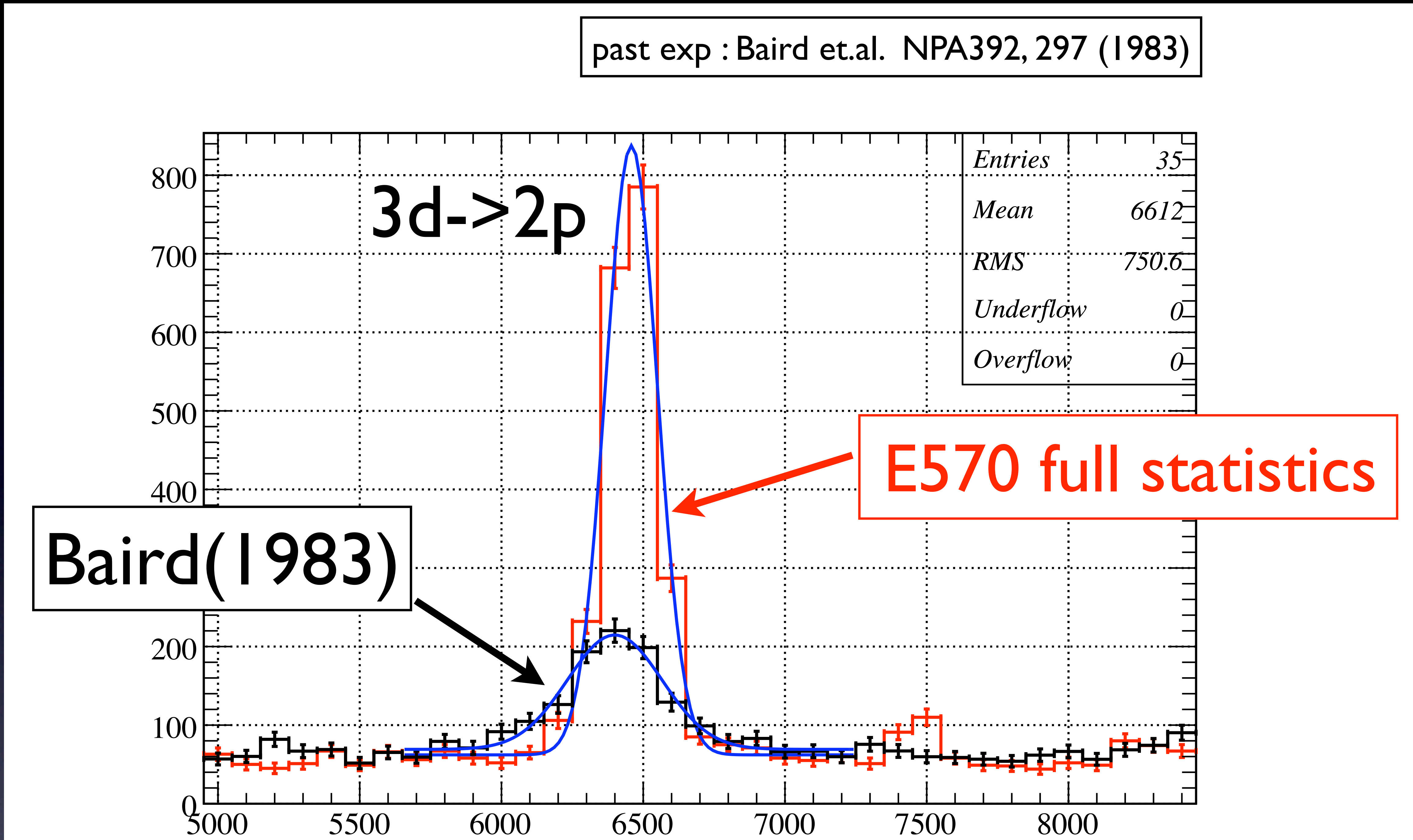
GEANT4





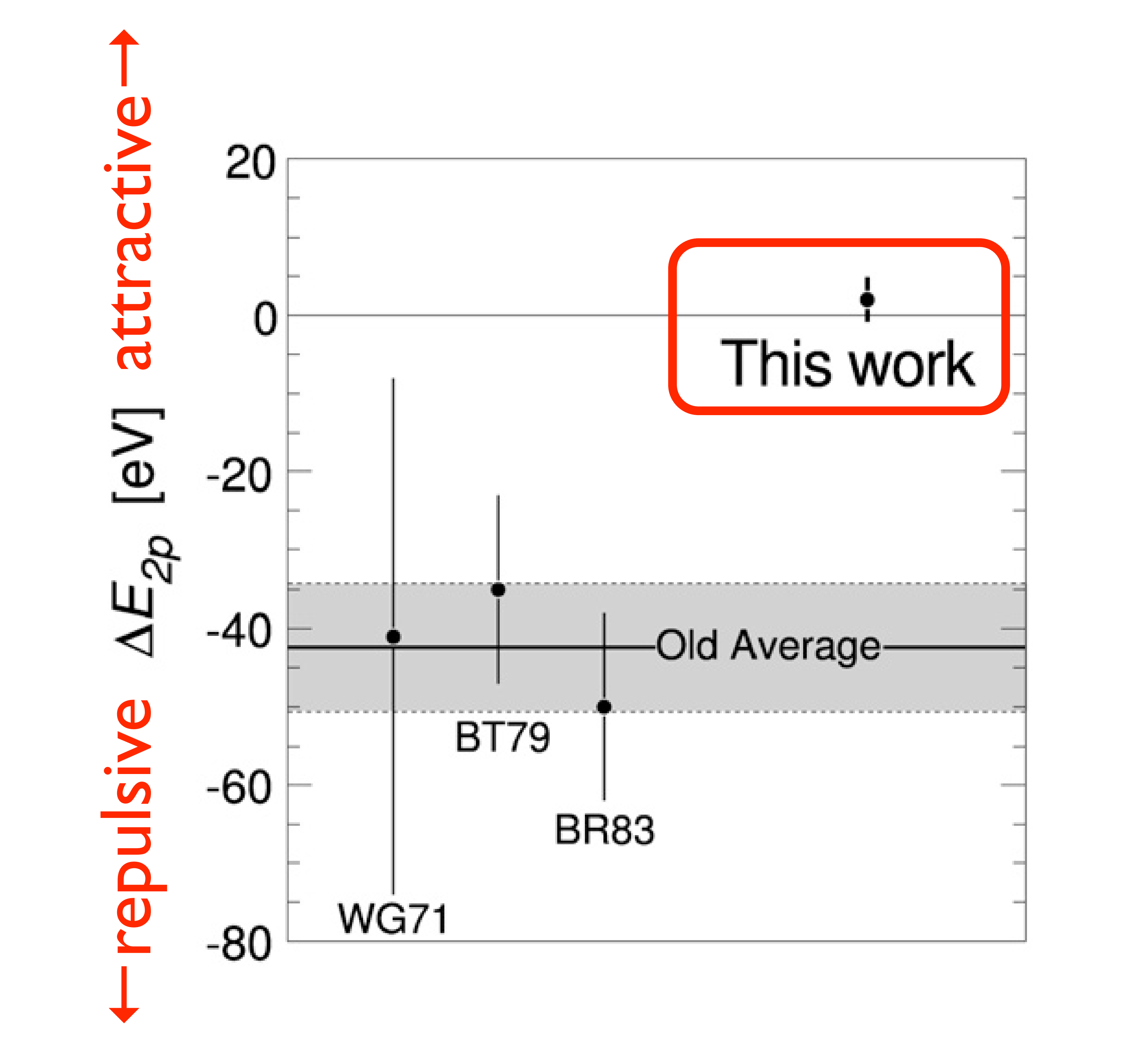
結果

Results



statistics	x3
s/n ratio	x6
resolution	x2

ΔE_{2p}=2 ± 2(stat) ± 2(sys) eV



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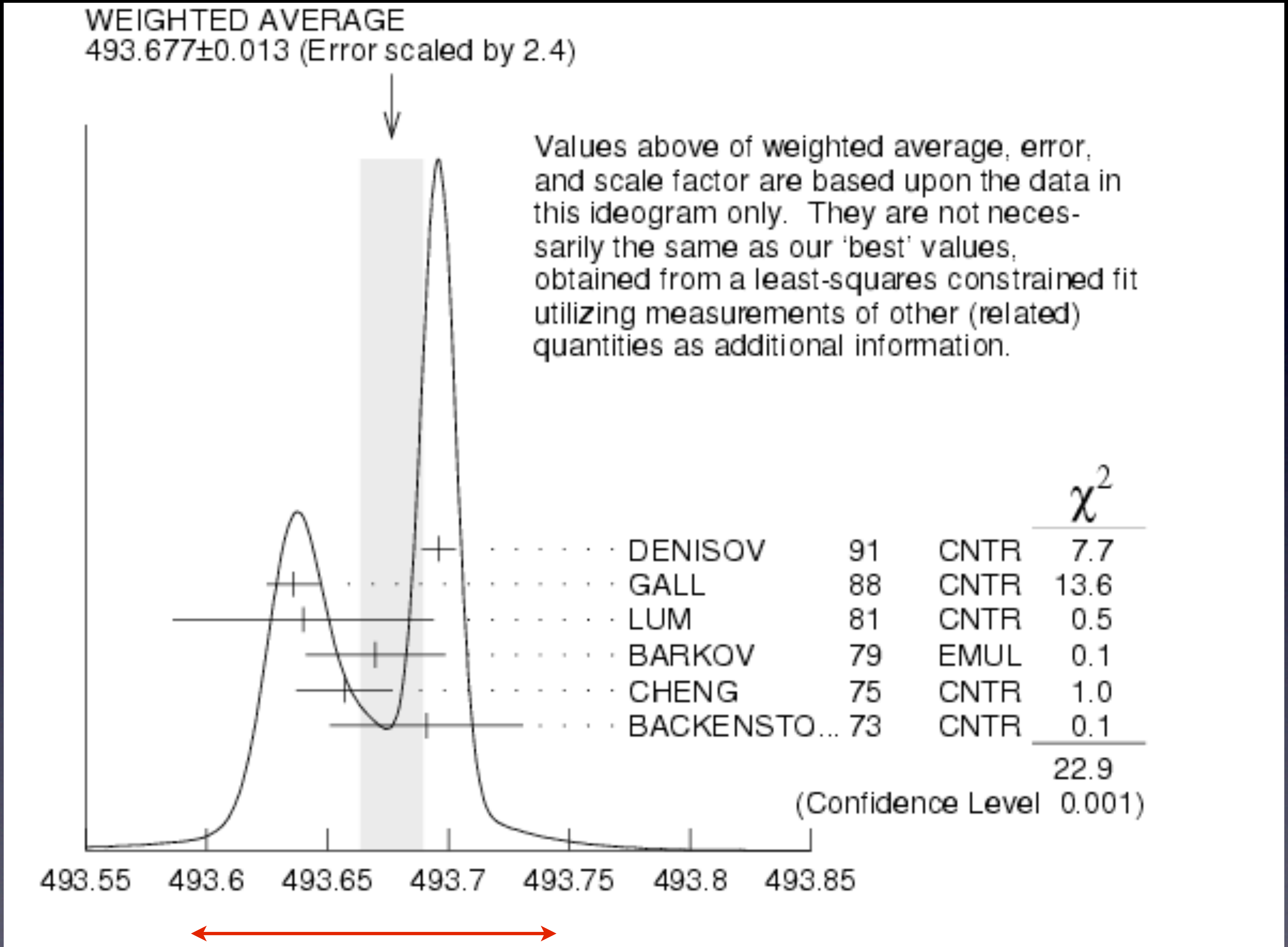
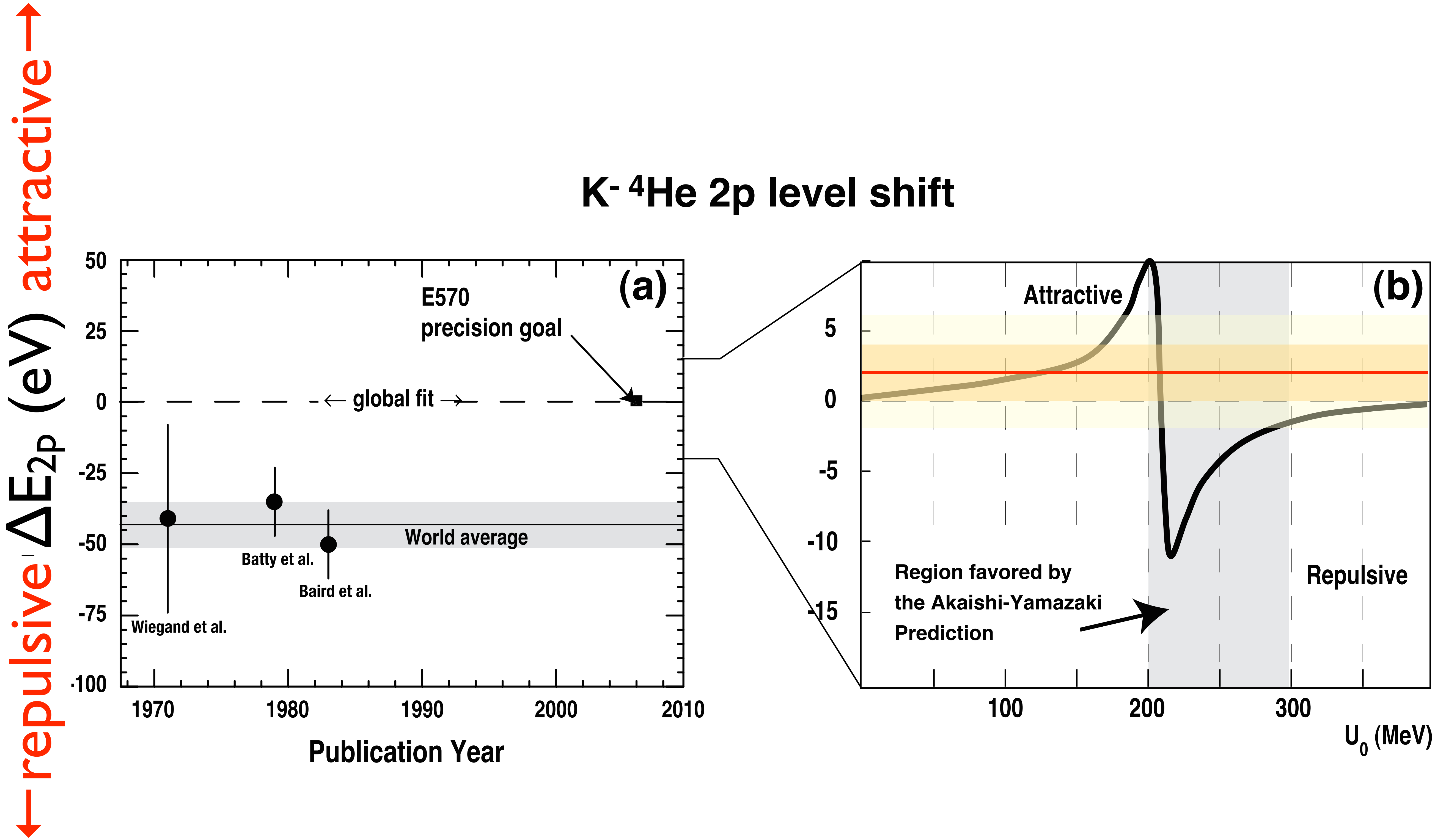
theory error (~0.2 eV) dominated by K mass error

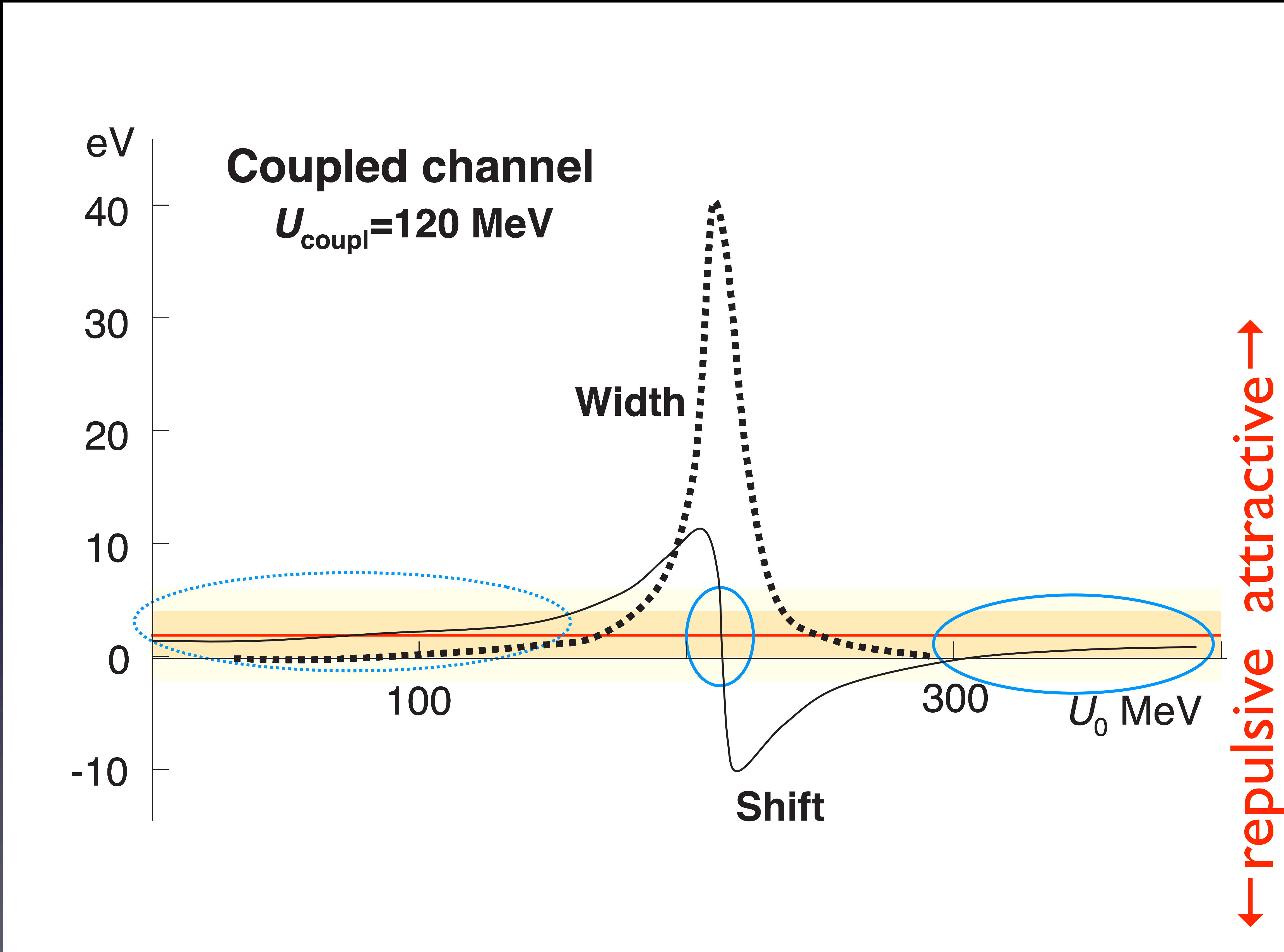
Koike



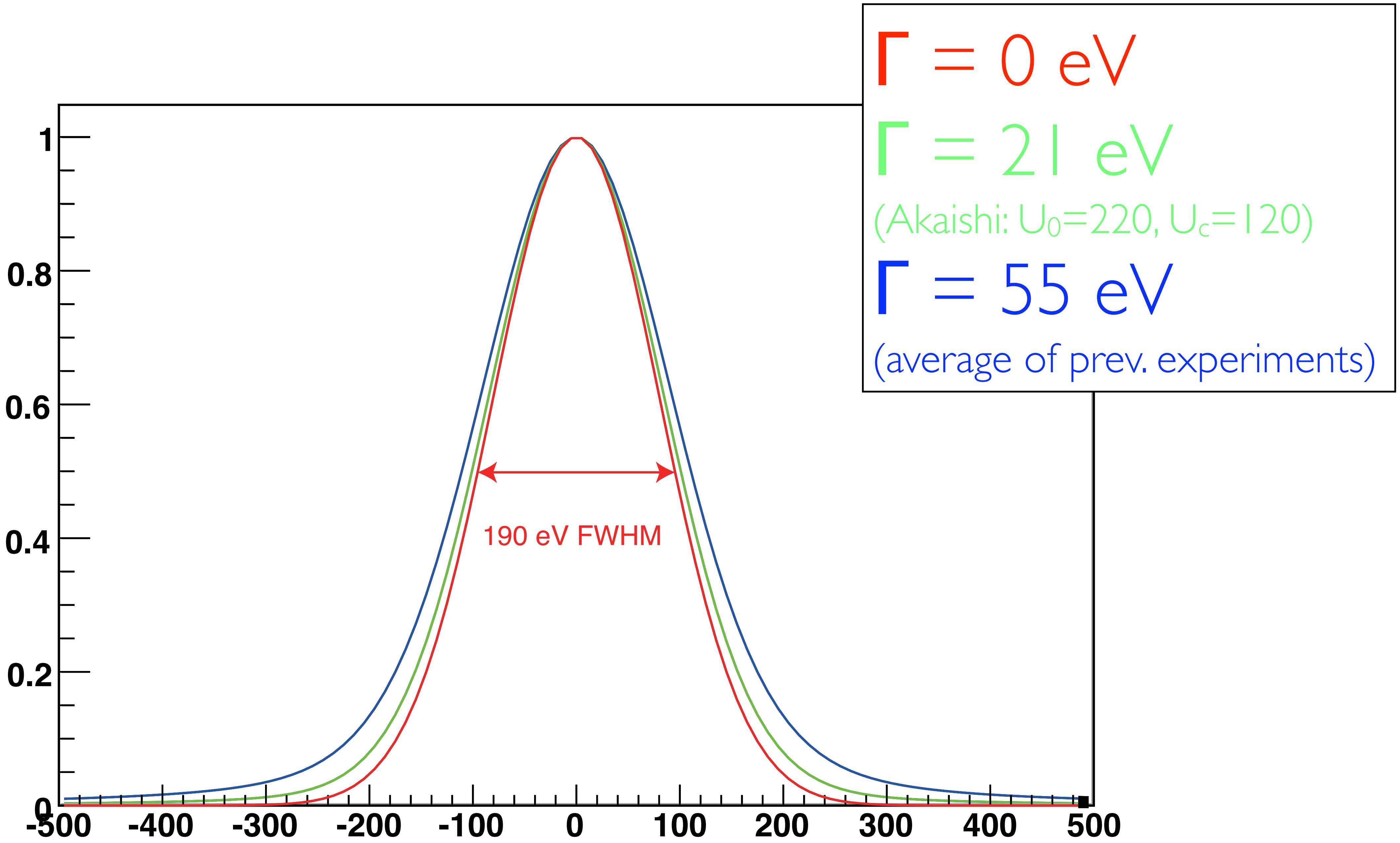
corresponds to ±1 eV in X-ray energy

K^{-} ^{4}He 2p level shift



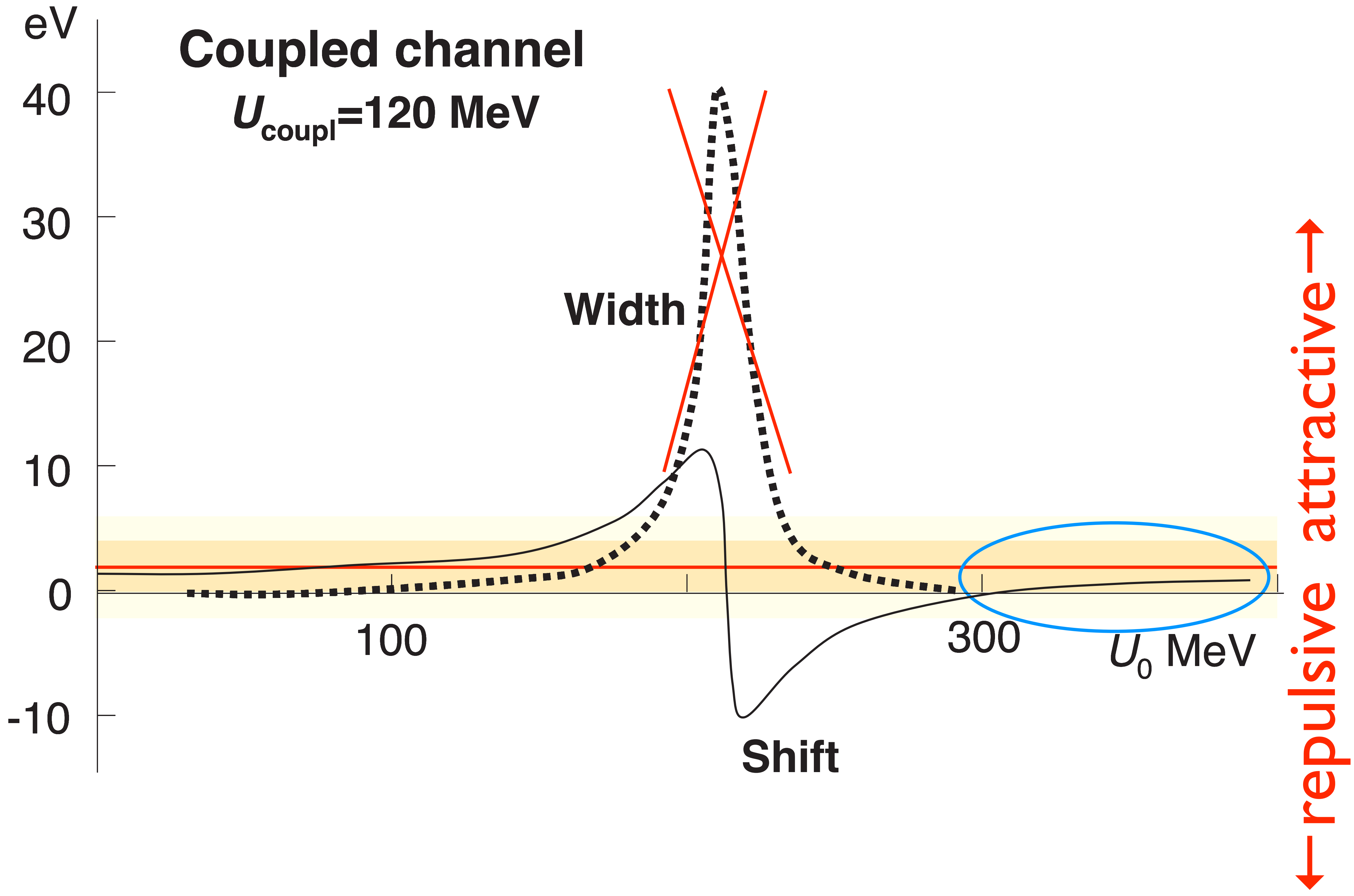


eV
Coupled channel
U_{coupl}=120 MeV
40
30
20
10
0
-10
Width
Shift
100
300
U_0 MeV
←repulsive attractive→



Γ = 0 eV
Γ = 21 eV
(Akaishi: U0=220, Uc=120)
Γ = 55 eV
(average of prev. experiments)
190 eV FWHM
1
0.8
0.6
0.4
0.2
0
-500
-400
-300
-200
-100
0
100
200
300
400
500

large width unlikely (to be published)

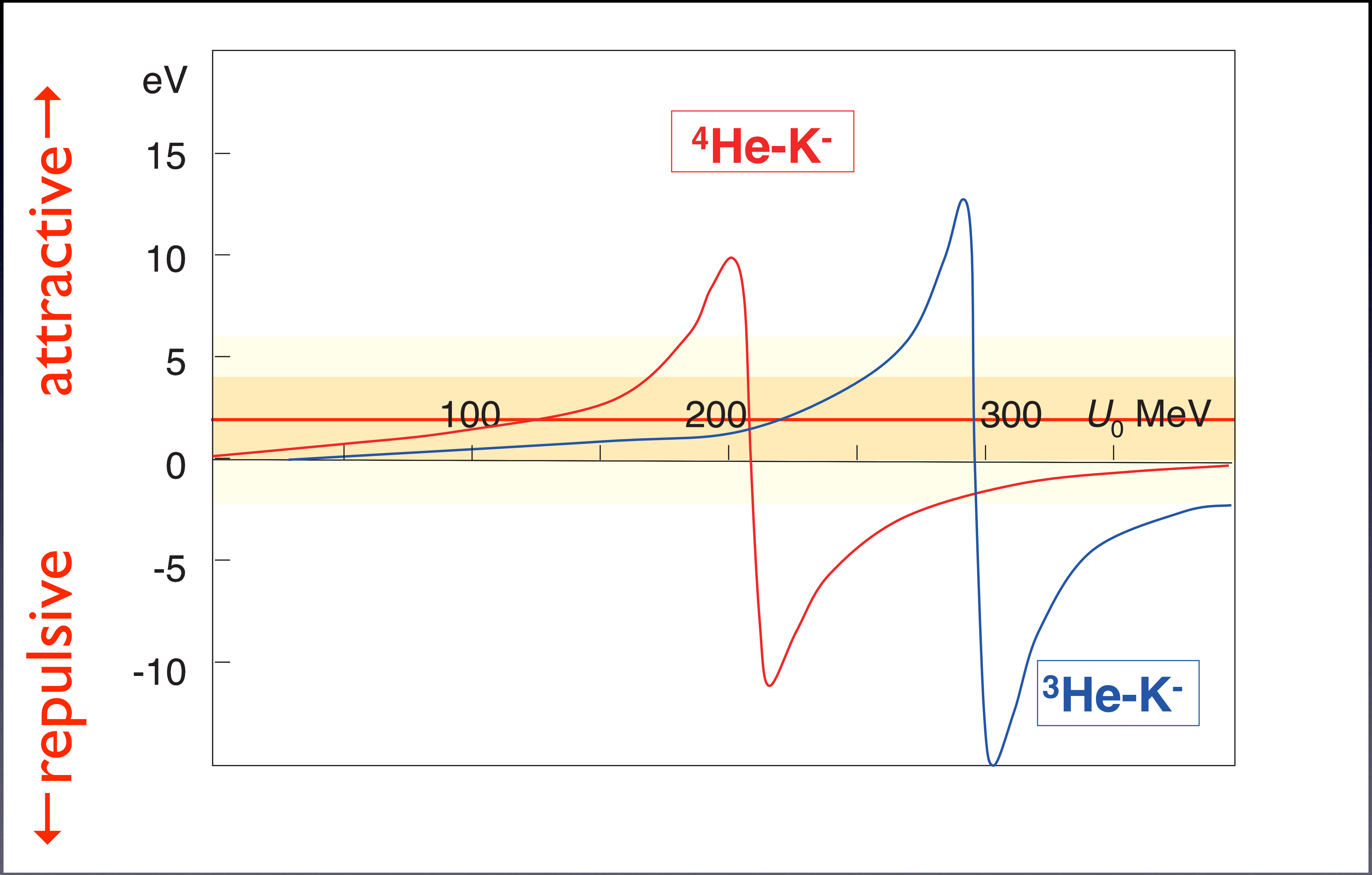


結論

Summary

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

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



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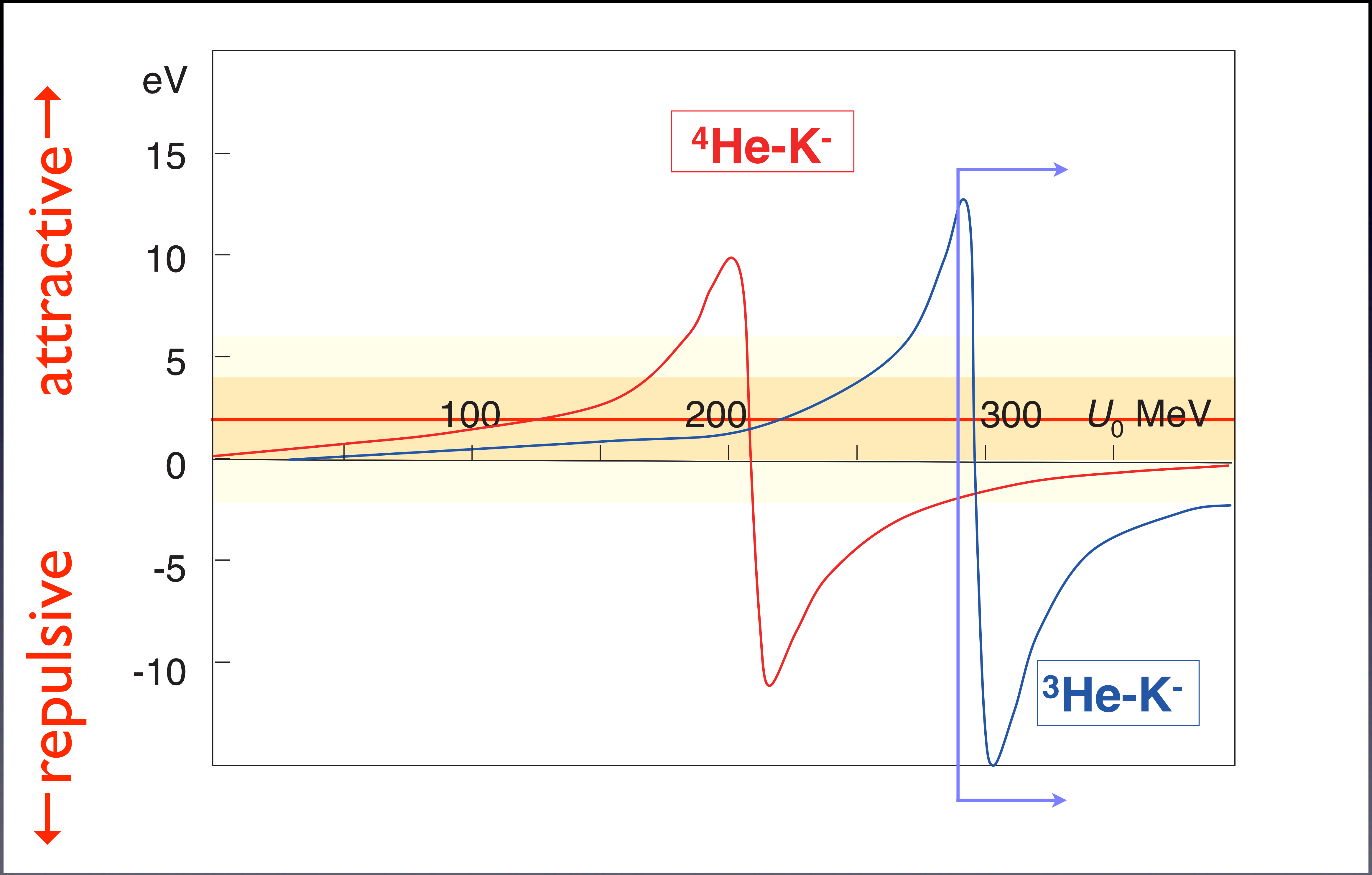

The proud team of E570

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Victoria Univ.[1], SNU[2], SMI[3], TUS[4], INFN(LNF)[5],
Tokyo Tech[6], Univ. of Tokyo[7], RIKEN[8], KEK[9]