E17 Status Report

K^--^{3}He 3d→2p x-rays

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for J-PARC E17 Collaboration

THE UNIVERSITY OF TOKYO

J-PARC E17 collaboration

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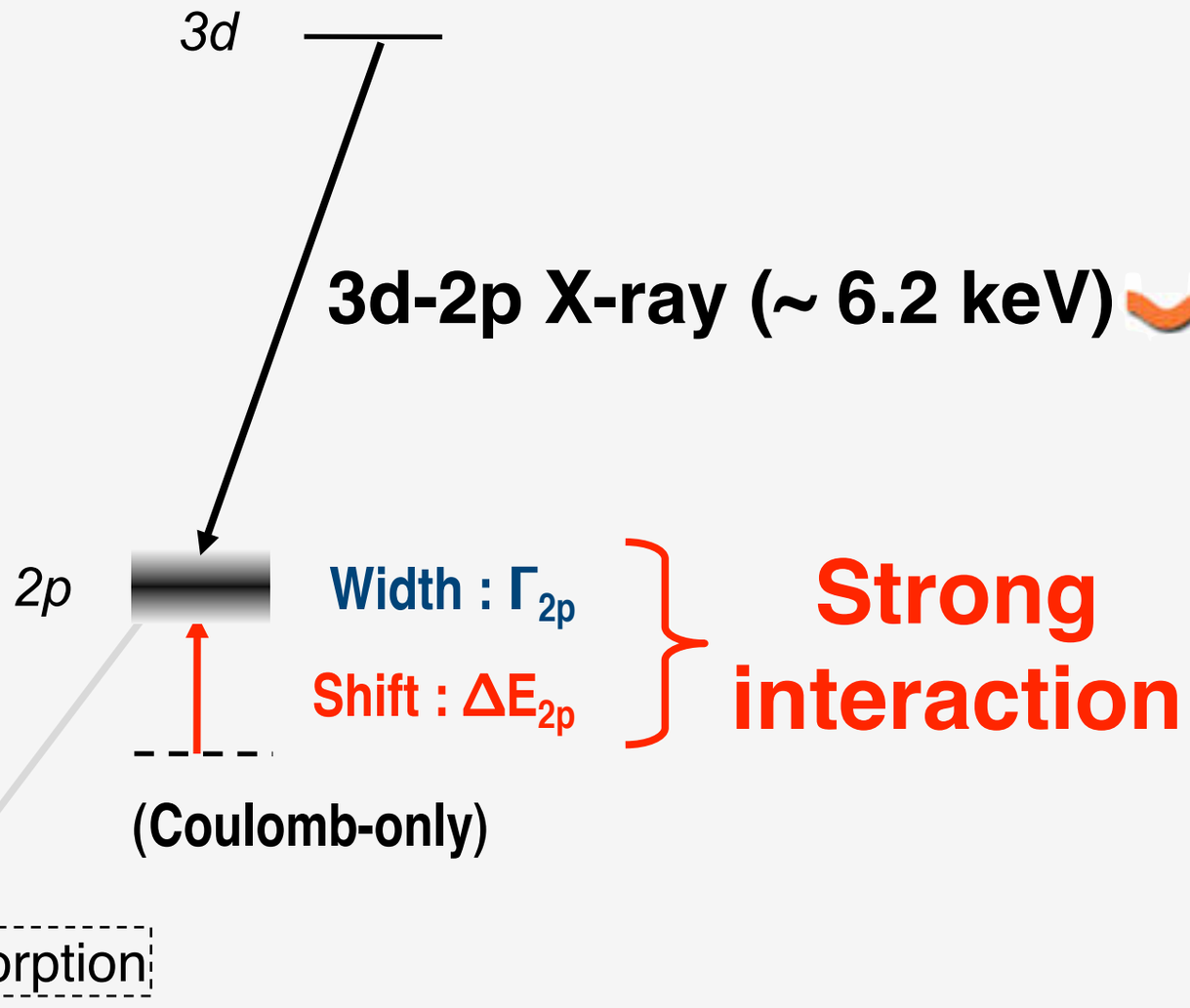
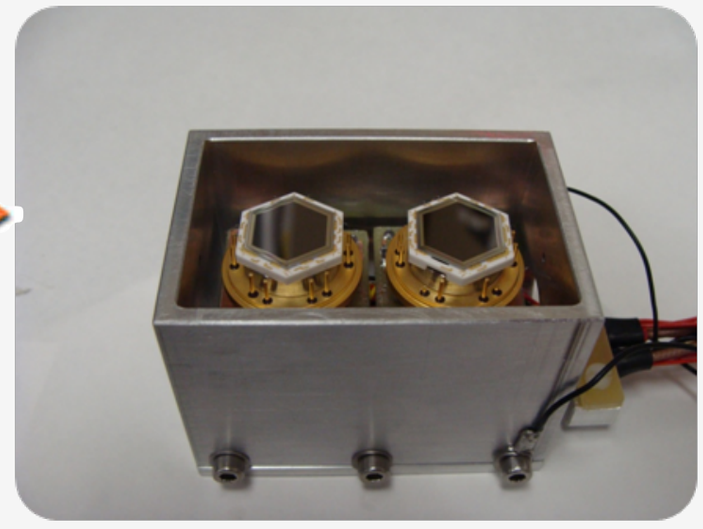
E17 : K^--^{3}He 3d→2p x-rays

related closely to E15 and other experiments studying "deeply-bound kaonic systems"

ΔE_{2p} Precision Goal: ± 2 eV (stat) ± 2 eV (syst)

Proposed in 2006





8 x SDDs
(silicon drift detectors)
~150 eV FWHM

E17 Conclusions

1. E17 is ready to run & can be completed in 20 kW-weeks

2. Beamtime request

		beam intensity	duration
Reproducibility check for 0.9 GeV/c beam		$\sim$ 1 kW	5 days
Range measurement (K^- stop tune)		$\sim$ 3 kW	3 days
Full commissioning with ^4He target		$\sim$ 3 kW	3 days
Production			
①	K^4HeX measurement	10 kW	4 days
②	K^3HeX measurement *without* Nd	10 kW	6 days
③	K^3HeX measurement *with* Nd	10 kW	4 days

c.f. original E17 proposal requested 5 weeks at 27 kW = 135 kW・weeks

2. Expected physics outputs

①&② → kaonic ^{3}He-^{4}He ISOTOPE SHIFT determined to 2 eV

②&③ → kaonic ^{3}He WIDTH measured to 3 eV

(independent of the resolution function of the SDD x-ray detector)

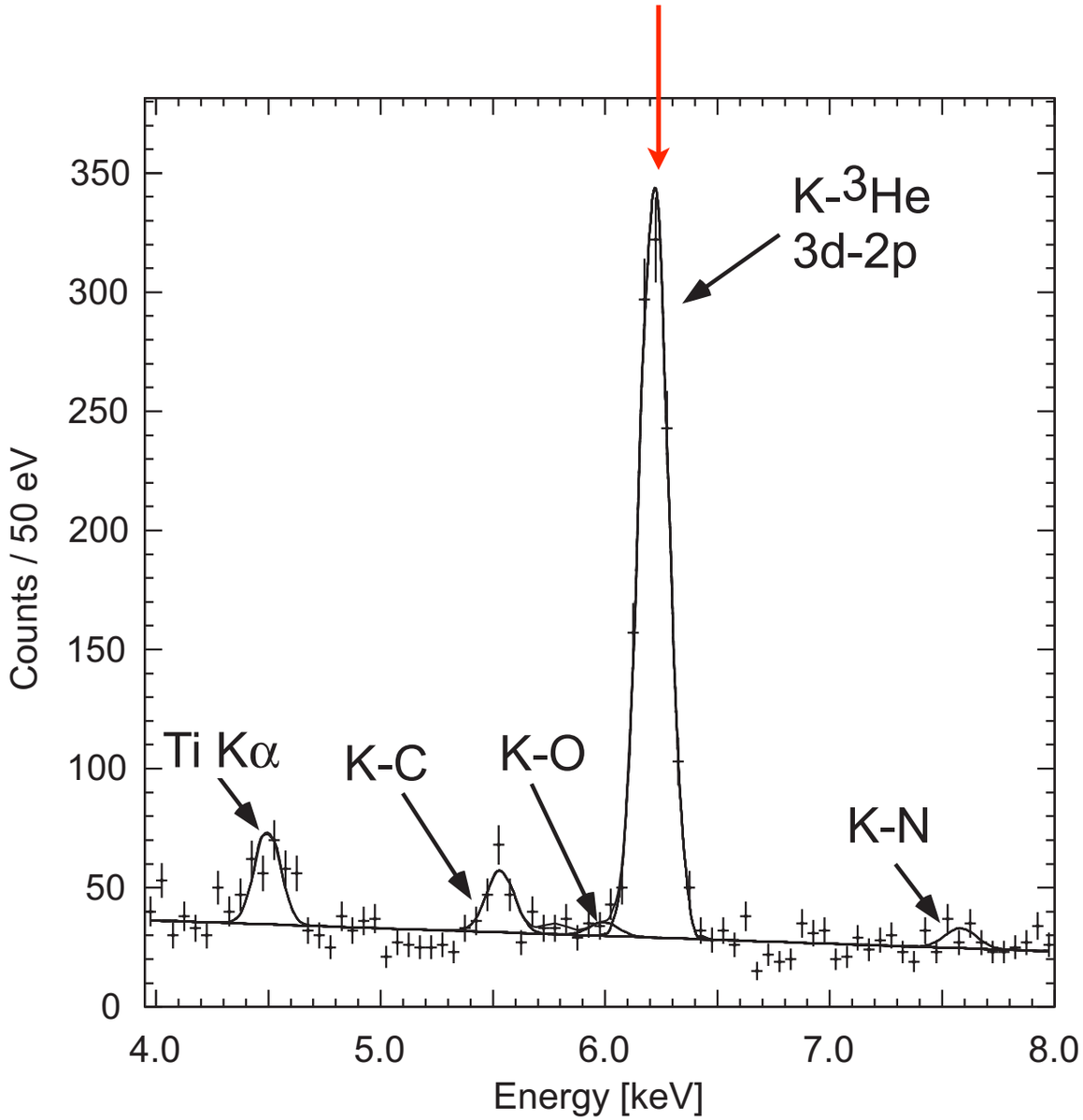
presented at PAC11

1. WHY ISOTOPE SHIFT?

E17 has been ready to run, but meanwhile...

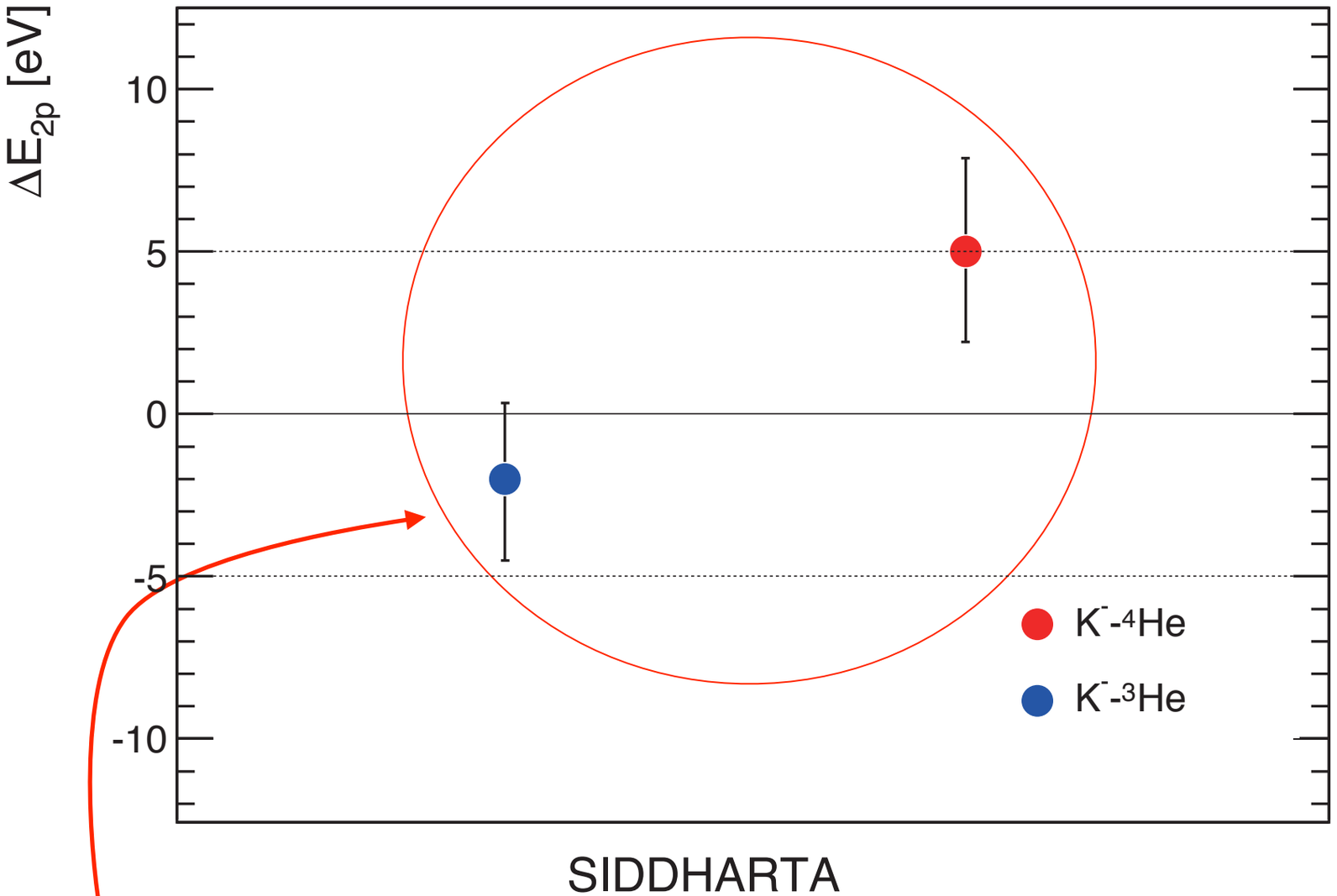
SIDDHARTA (at DAΦNE) published K-^{3}He

SIDDHARTA main goals:
Φ → K^+K^-, K^-p, K^-d in gas, using 144 SDDs



SIDDHARTA Collaboration, Physics Letters B 697, 199 (2011).

SIDDHARTA $K^{-3}He$ & $K^{-4}He$



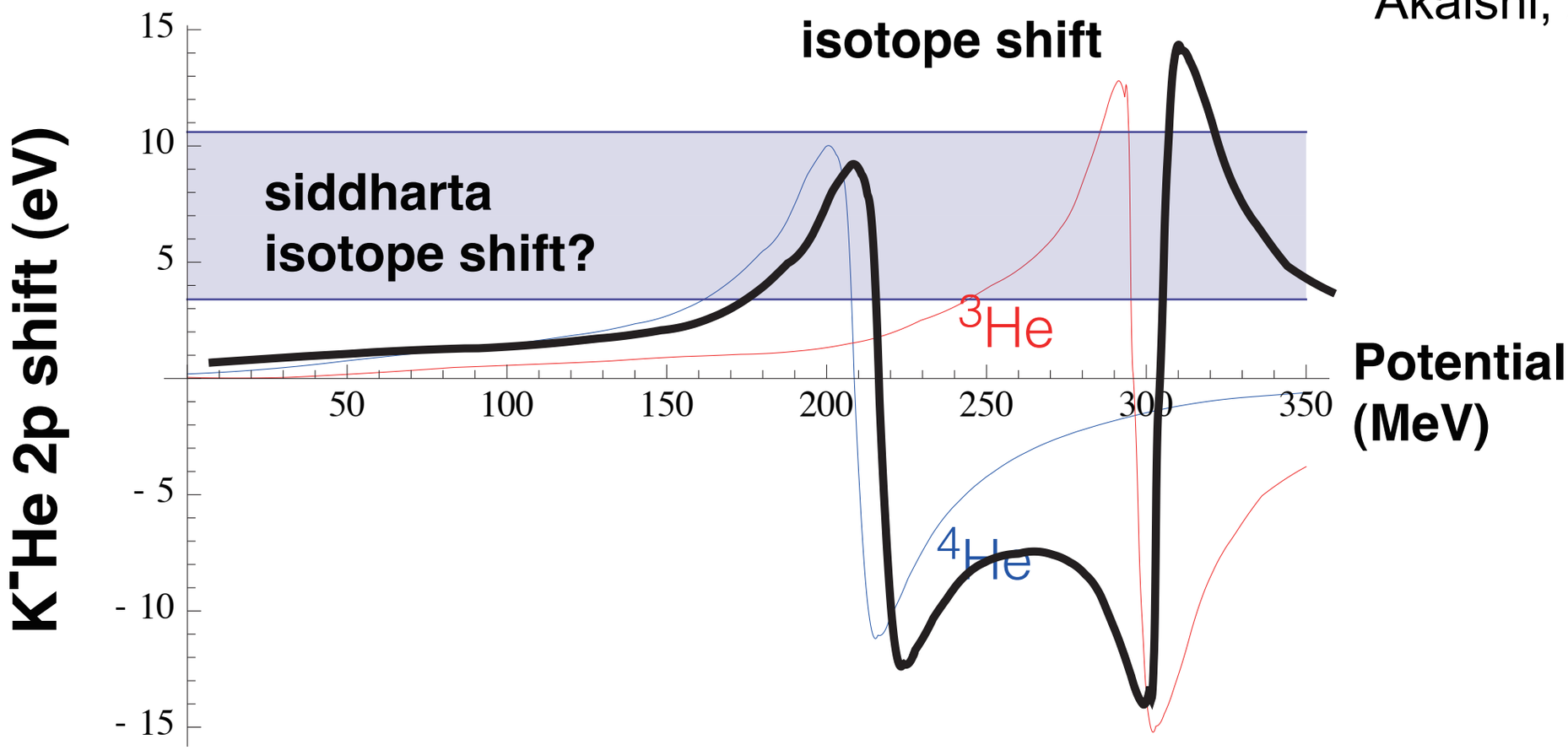
SIDDHARTA	
$K^{-3}He$	-2 ± 2 ± 4
$K^{-4}He$ (new)	5 ± 3 ± 4

All results consistent with small (~0 eV) shift, BUT

is this an indication of "finite isotope shift" of 7 ± 3.6 eV ? (~2 σ)

Isotope shift : theory

Akaishi, 2005



	2p shift (eV)	2p width (eV)
Kaonic ^{4}He	-0.3 – 0.4	1.6 – 2.3
Kaonic ^{3}He	-0.1 – 0.3	1.9 – 2.1
Isotope shift	0.0 – 0.5	

E. Friedman, talk at EXA 2011

Summary of systematic errors (shift)

uncertainties	systematic errors (eV)	
	$\Delta E(^{3,4}He)$	$\Delta E(^3He) - \Delta E(^4He)$
(1) SDD response		
Low energy tail	±0.40	~0
Pileup contamination	<+0.10	±0.10
Compton tail	±0.17	~0
Shelf structure	±0.10	~0
Energy resolution	<±0.03	<±0.05
(2) Energy scale		
Linearity	±0.50	~0
Calibration accuracy	±0.14	±0.2
(3) Background shape	±0.08	±0.12
(4) E. M. value from Kaon mass	±0.2	~0
Quadratic sum of (1)–(4)	±0.72	±0.26

Systematic error of 3He/4He shift : 0.72 eV — isotope shift : 0.26 eV

(Statistical error) (1.0 eV) (1.5 eV)

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Systematic error of 3He/4He shift : 0.72 eV		isotope shift : 0.26 eV
(Statistical error)	(1.0 eV)	(1.5 eV)

isotope shift measured by E17 to ±1.8 eV can clarify the situation

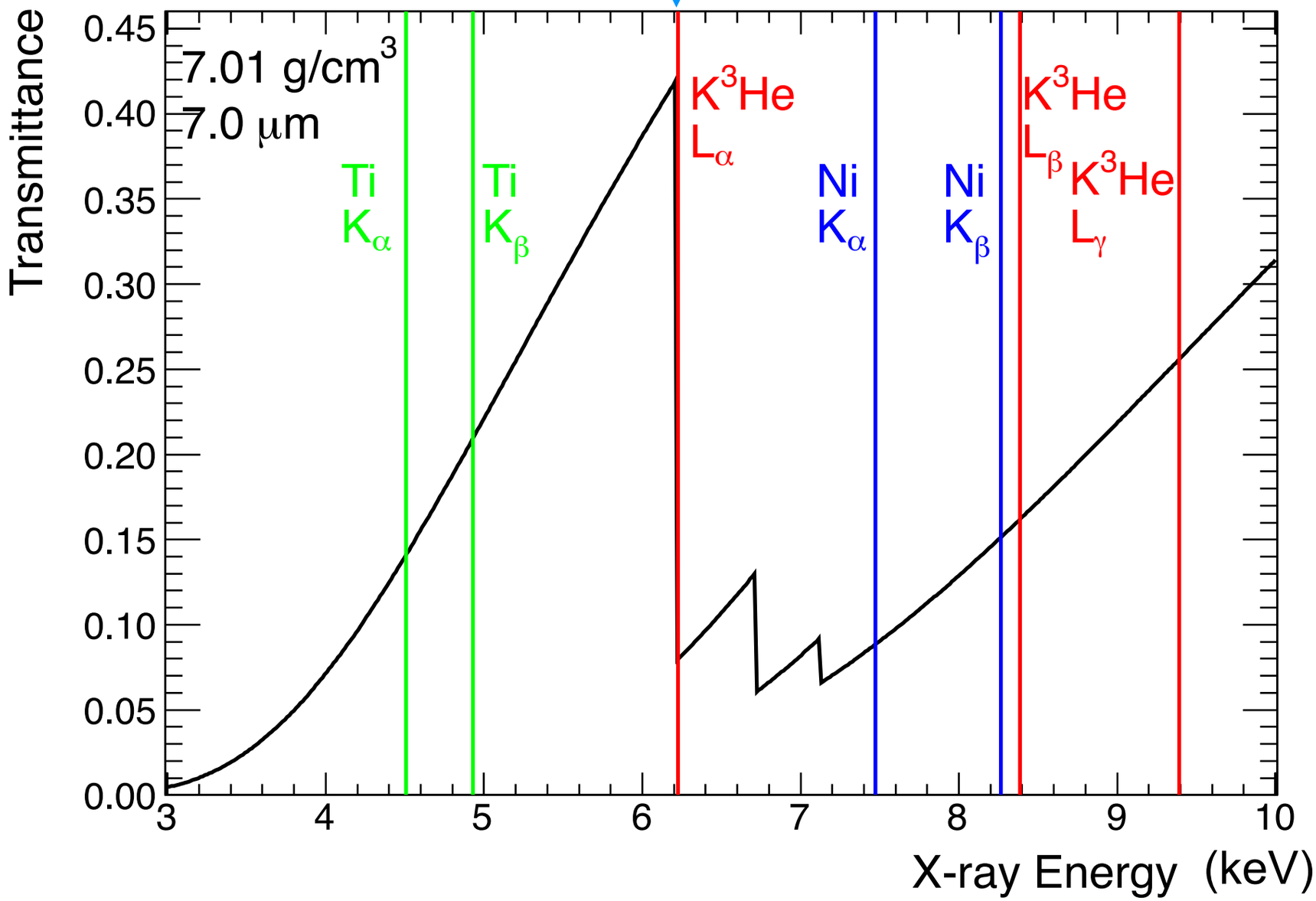
presented at PAC12

2. WIDTH in addition to shift

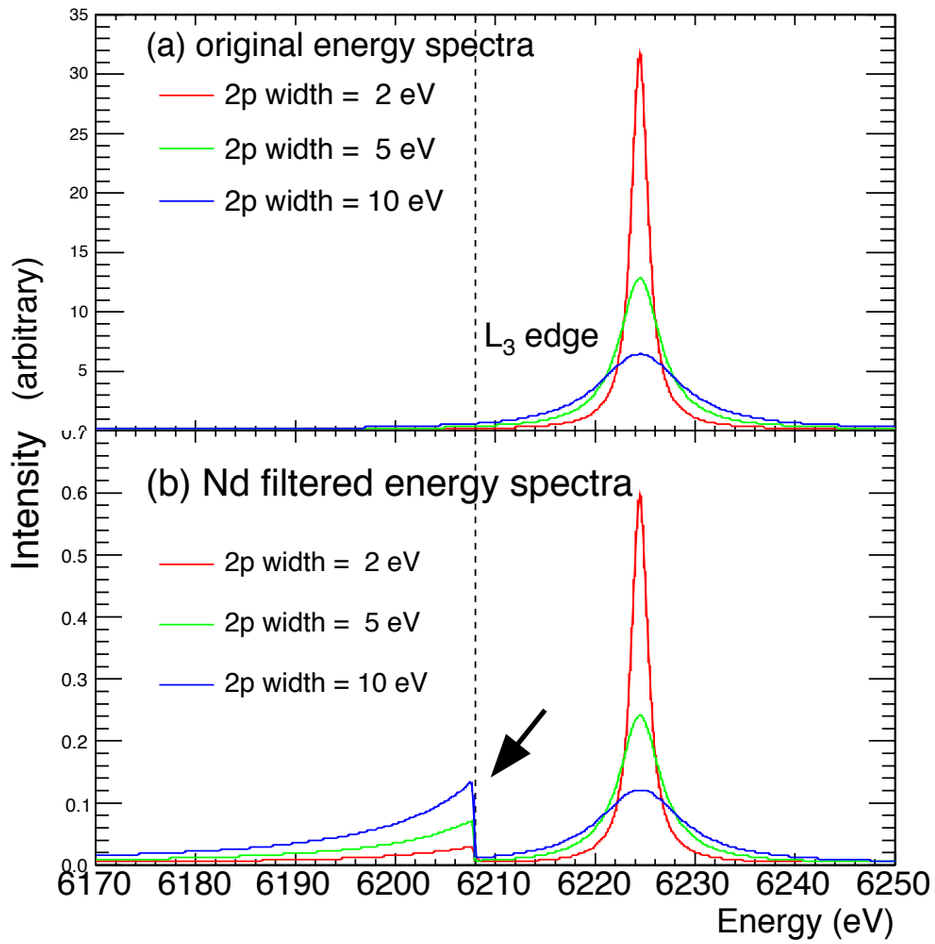
Determining the width by fitting a Voigt to the peak is impossible, unless the width is $\gtrsim$ 20 eV, but we've found a better way

The method: X-ray absorption spectroscopy

L_3 edge of Nd	6209.4 eV
K ^{3}He L_α (EM energy)	6224.6 eV
difference	15.2 eV



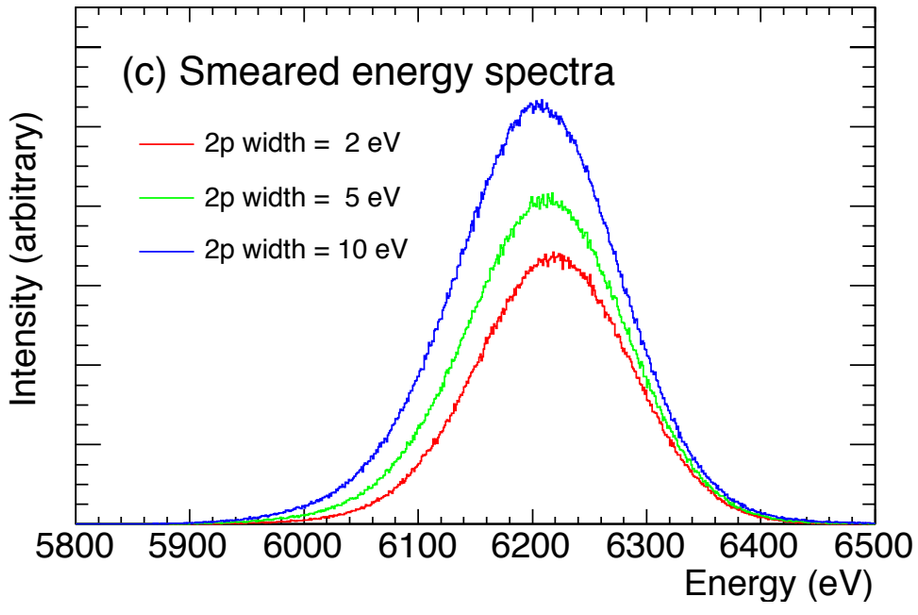
The attenuated L_α counts → width



raw spectra for
width 2, 5, 10 eV

Nd-filtered spectra for
width 2, 5, 10 eV

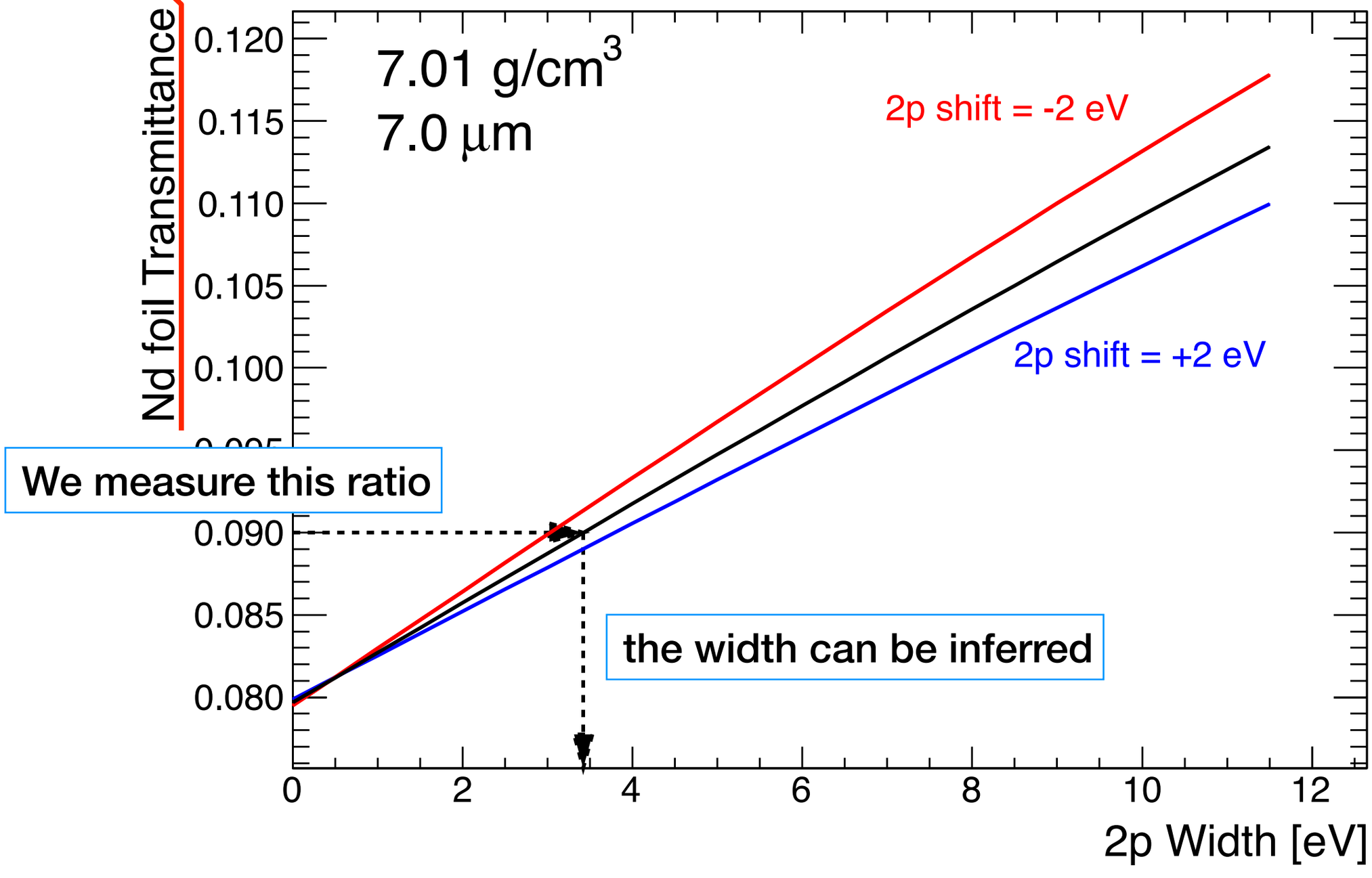
larger width → less attenuation below the Nd L_3 edge



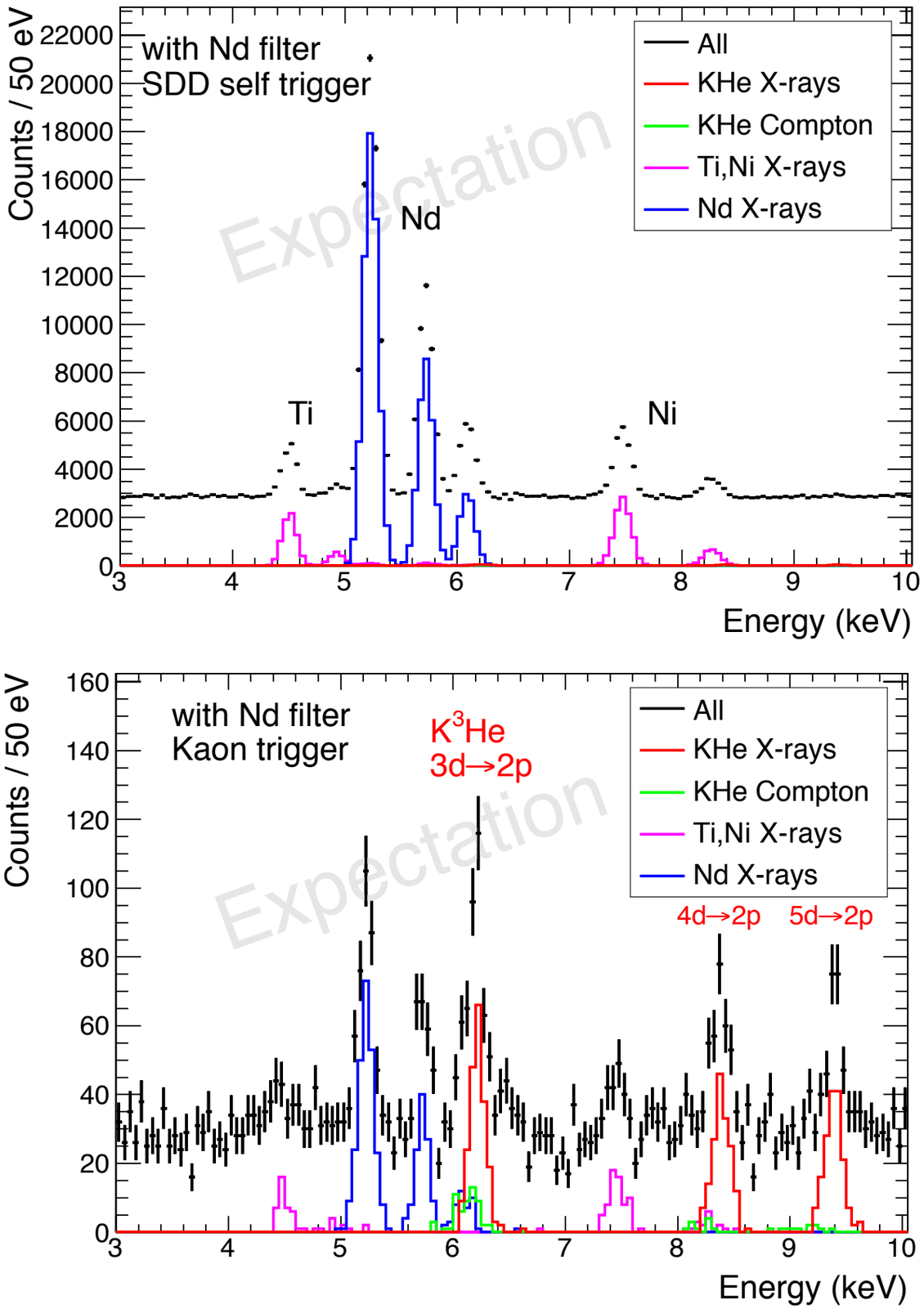
Nd-filtered spectra measured with SDD
width 2, 5, 10 eV

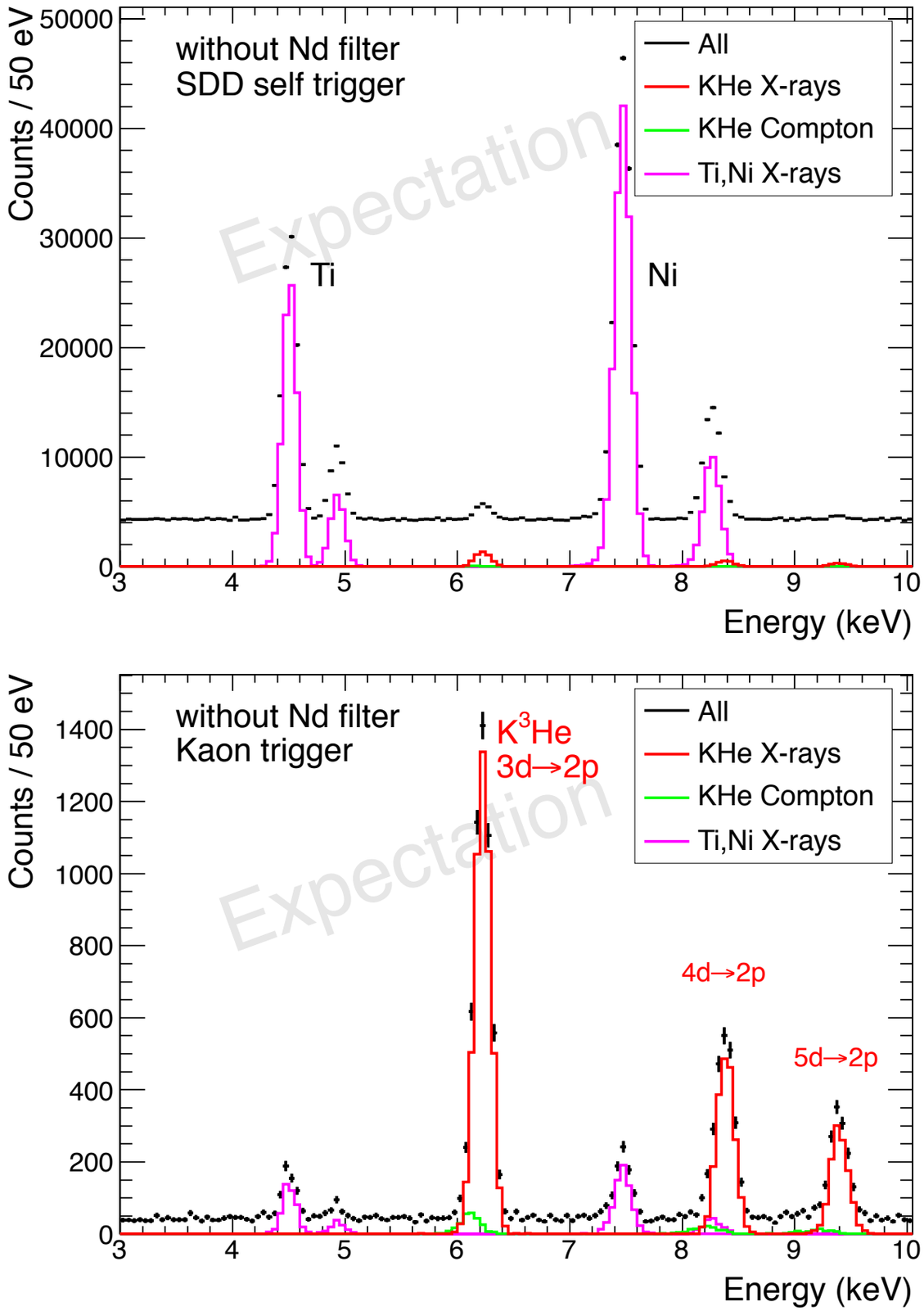
Yield depends on the width

(counts with foil)/(counts without foil)

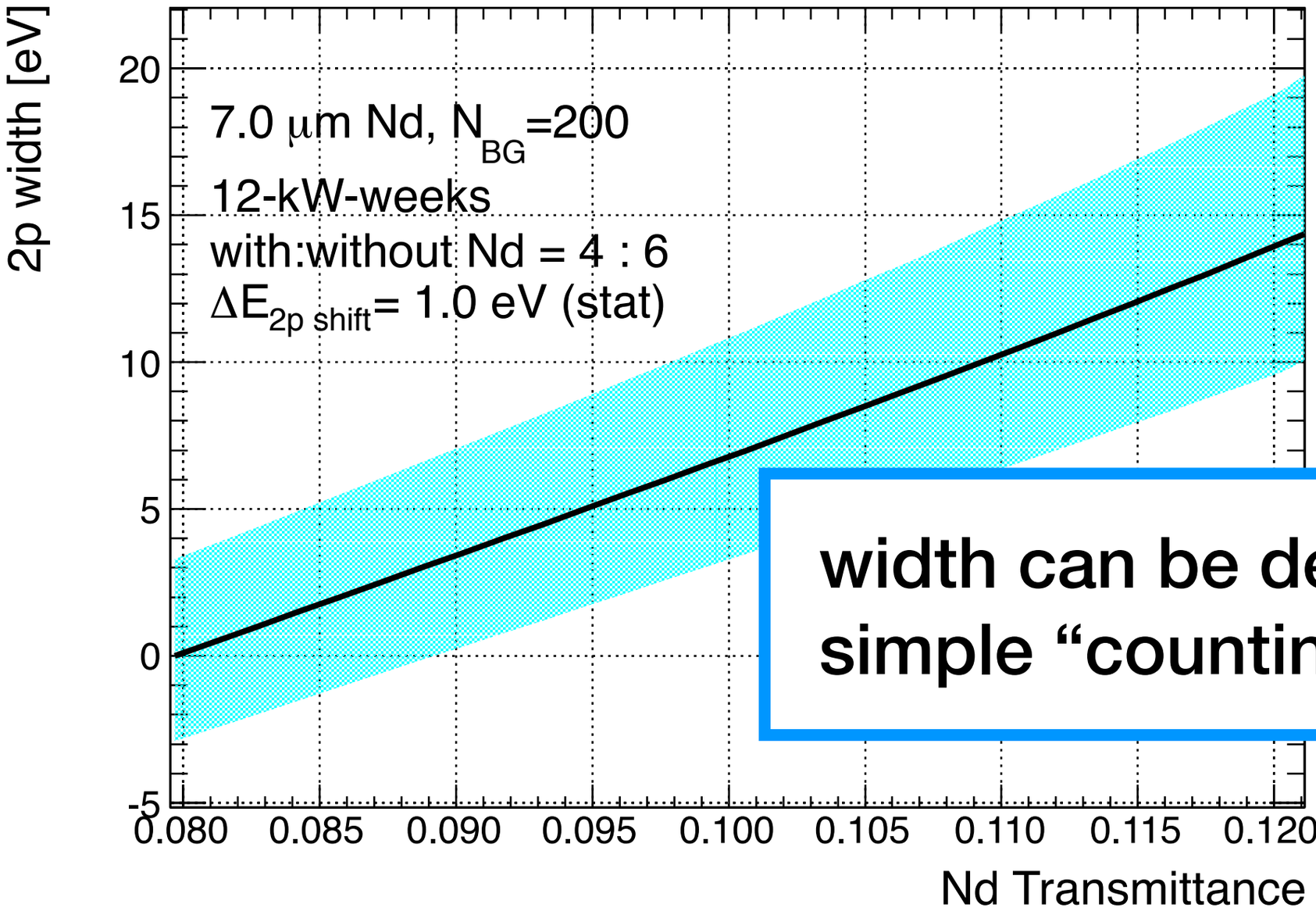


Expected K-^{3}He x-ray spectra w/wo Nd foil





Width can be determined to 3 eV precision



width can be determined by a simple “counting” experiment.

E17 Conclusions

1. E17 is ready to run & can be completed in 20 kW-weeks

insensitive to the spill structure

2. Beamtime request

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Reproducibility check for 0.9 GeV/c beam		$\sim$ 1 kW	5 days
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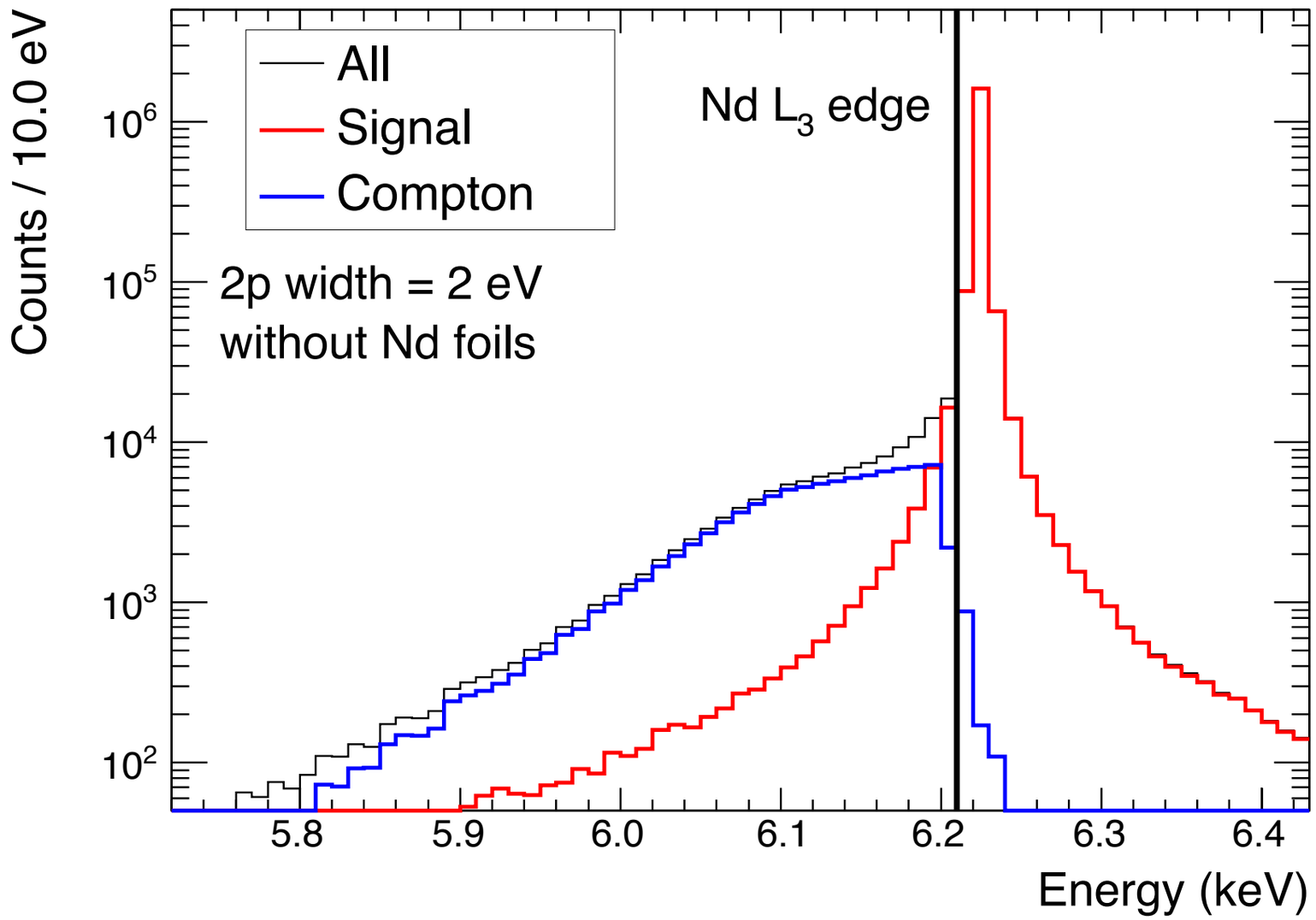
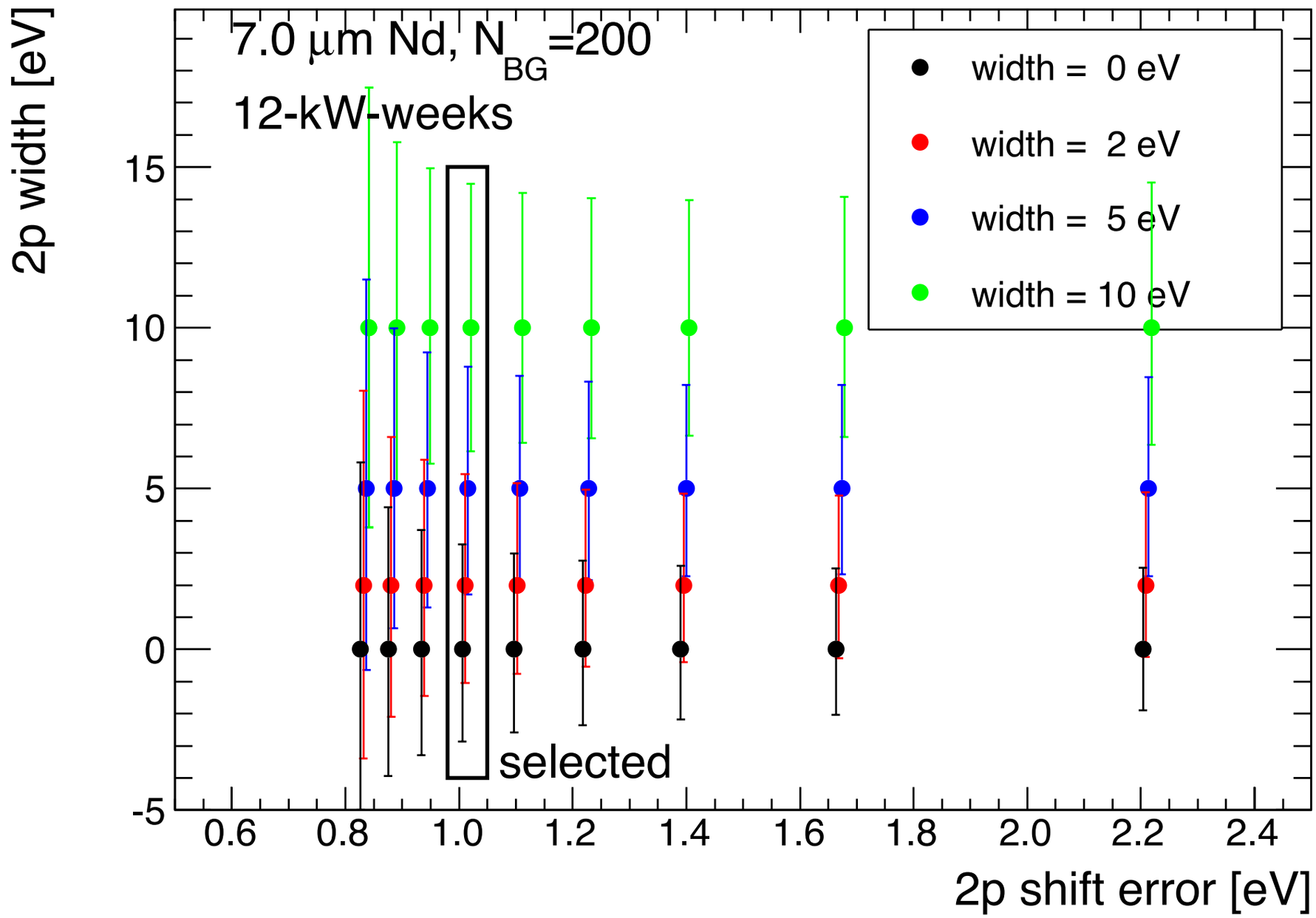
backup slides

Contribution of Compton scattering in the target

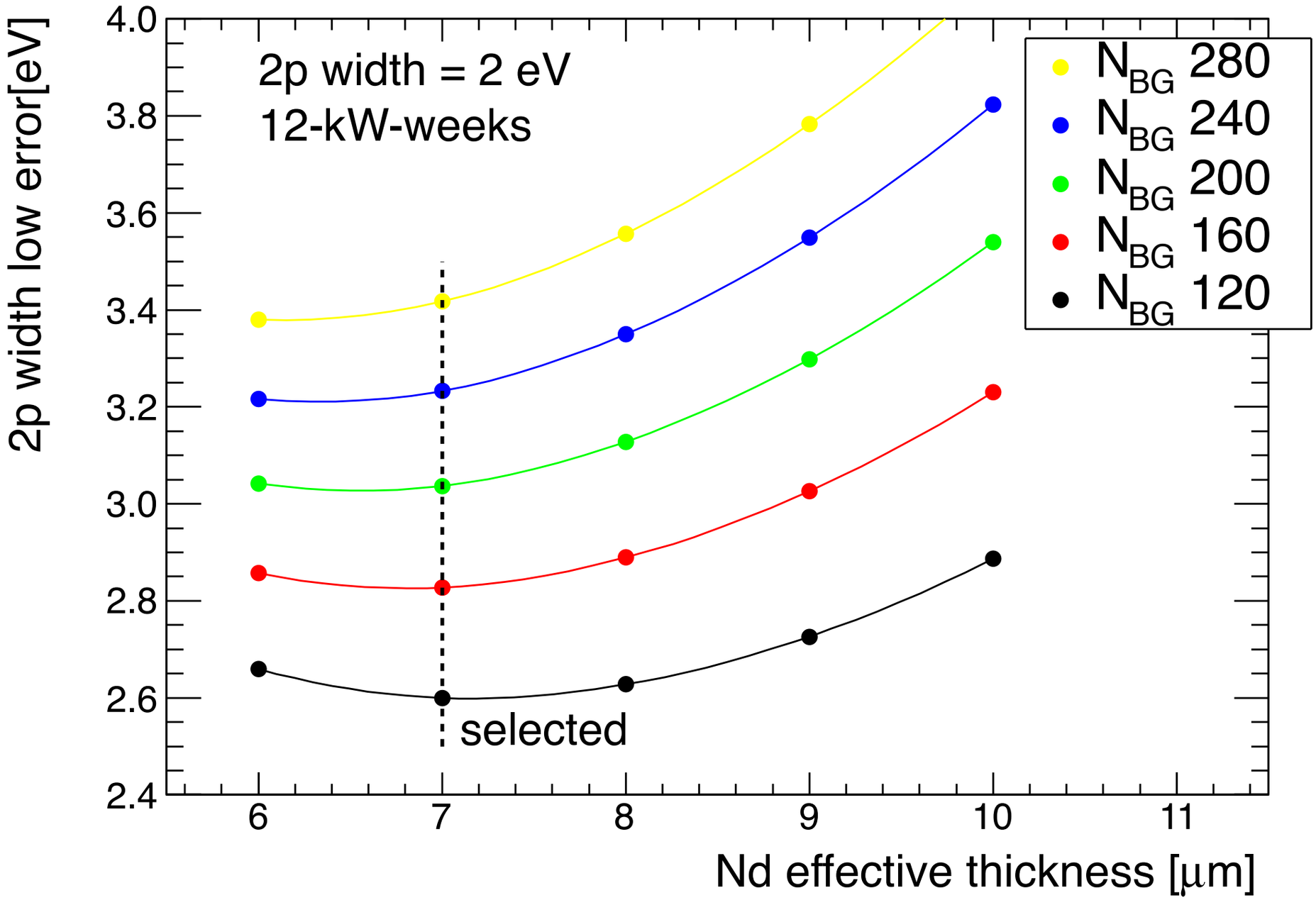


optimizing the beamtime allocated for foil measurement



← less time allocate for foil measurement more time allocate for foil measurement→

optimizing the Nd foil thickness



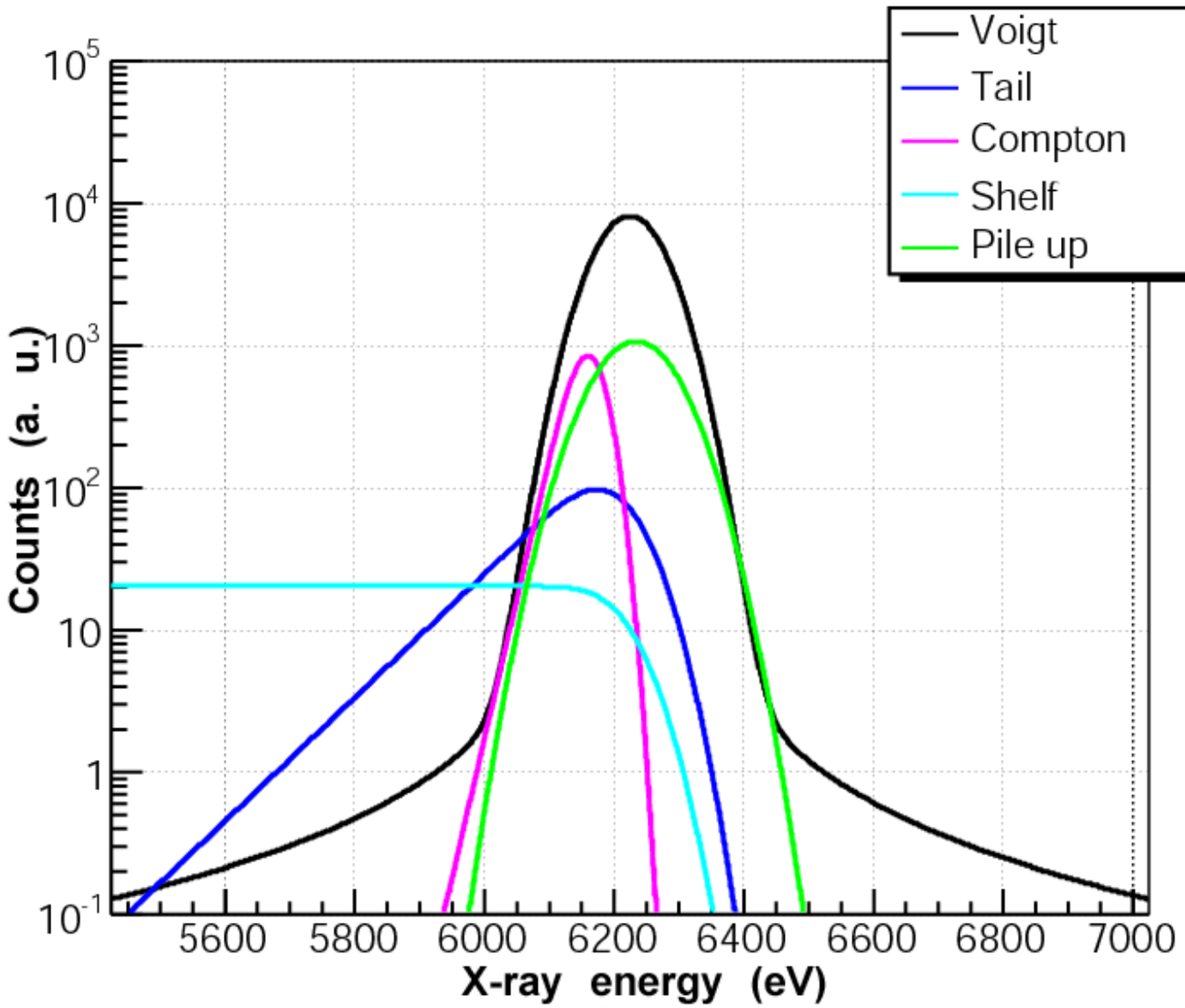
Breakdown of the systematic errors:

- SDD response
- Energy calibration
- Background shape
- E. M. value from Kaon mass

SDD response

- Response function of SDD :

  Voigtian + Tail + Shelf (+ Compton + Pileup)



(free/fixed)

- ✓ Voigtian

  energy, width, yield, σ,

- ✓ Tail

  Ratio, slope

- ✓ Shlef

  Ratio

- ✓ Compton

  Ratio, energy, width, slope

  fixed tail shape by MC

- ✓ Pileup

  Ratio

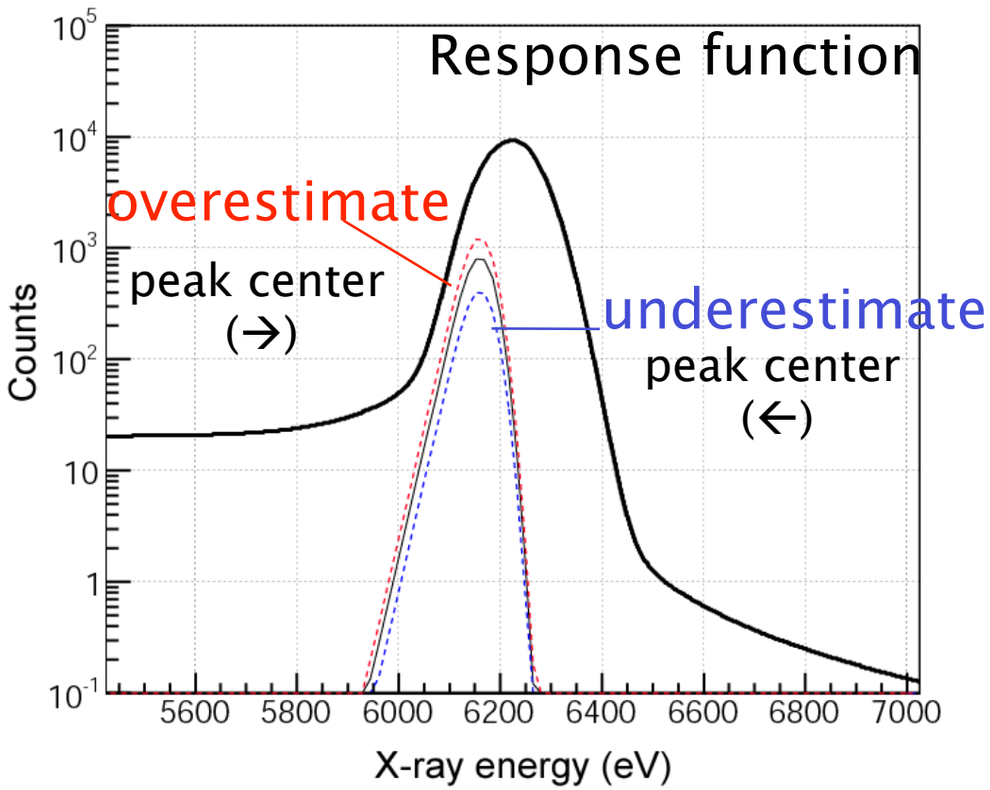
Due to statistical limitation

Free parameters are only: energy, width and yield of 2p level.

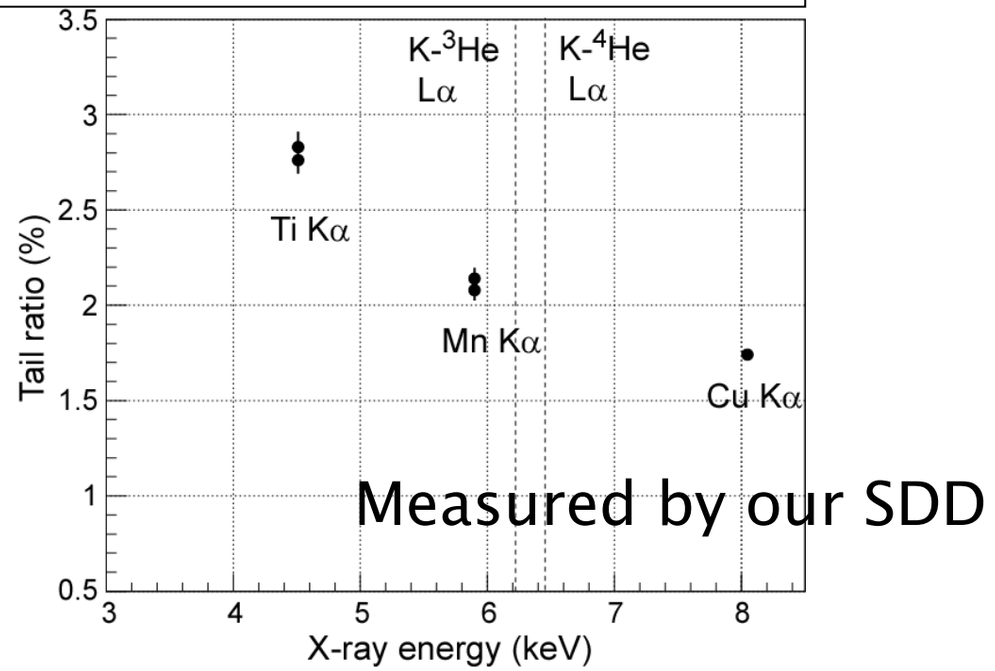
Others are estimated (fixed) in the fitting.

SDD response (1) : Low-energy tail

- Intensity of tail structure : fixed in the K-He spectrum fitting

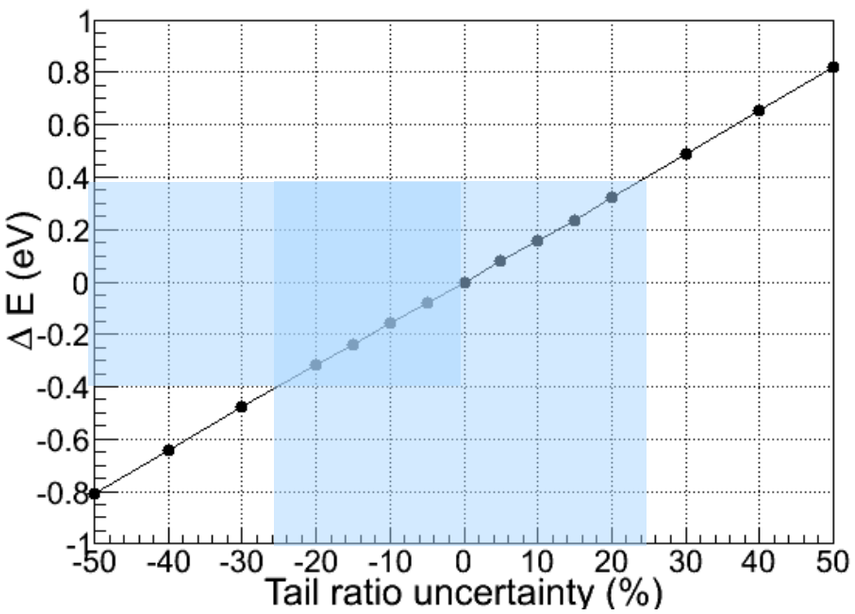


E-dependence of the tail intensity



Measured by our SDD

Uncertainty of tail intensity VS ΔE



Fit error of tail parameters in the calibration spectrum (~500 K events) : ~ 25 %

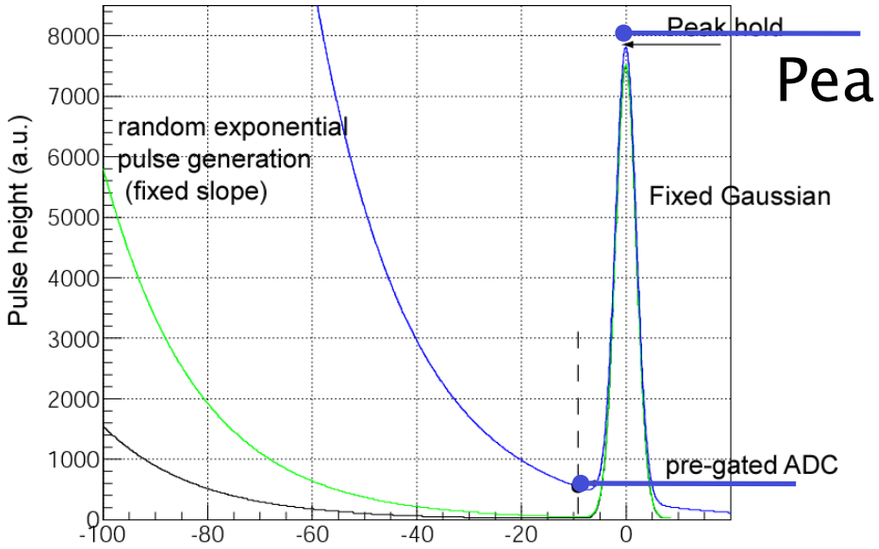
systematic error of shift
ΔE(3He), ΔE(4He) : ±0.4 eV

Cancelled in ΔE(3He) – ΔE(4He) : ~ 0 eV
(SDD responses are identical in
3He and 4He measurements)

SDD response (2) : Pileup contamination

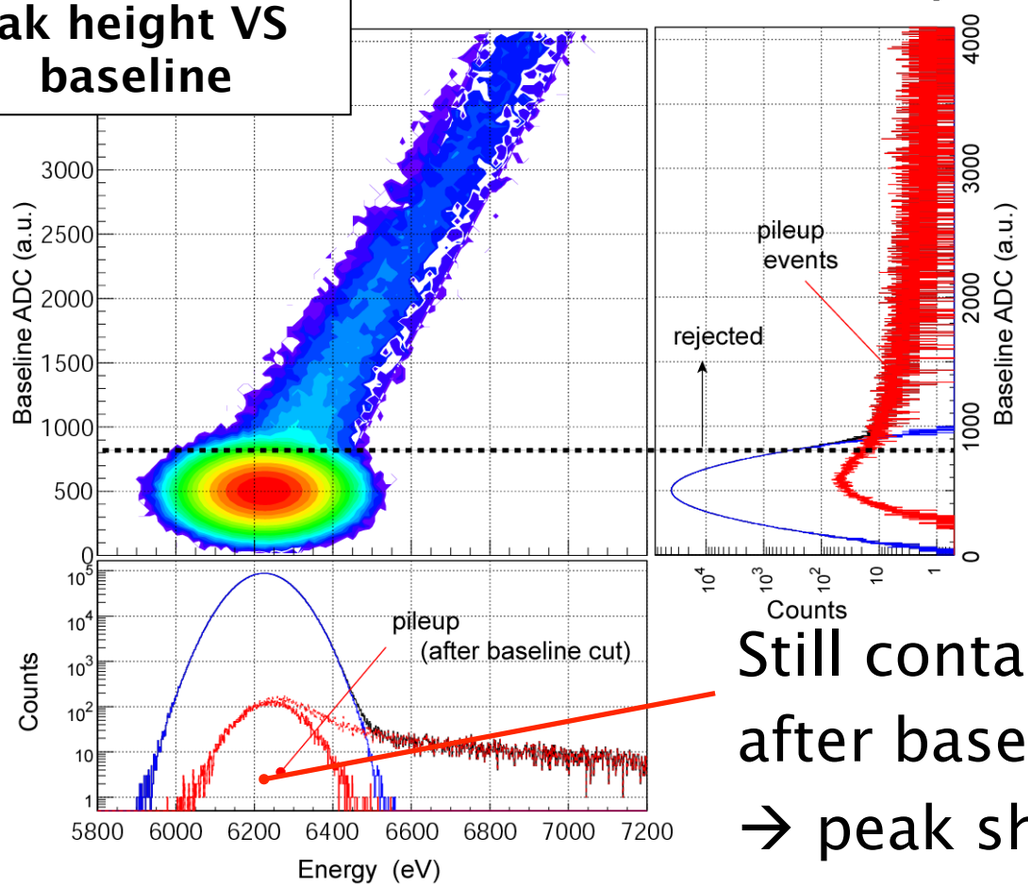
- Monte Carlo simulation of pre-gate (baseline) and peak heights

Monte Carlo



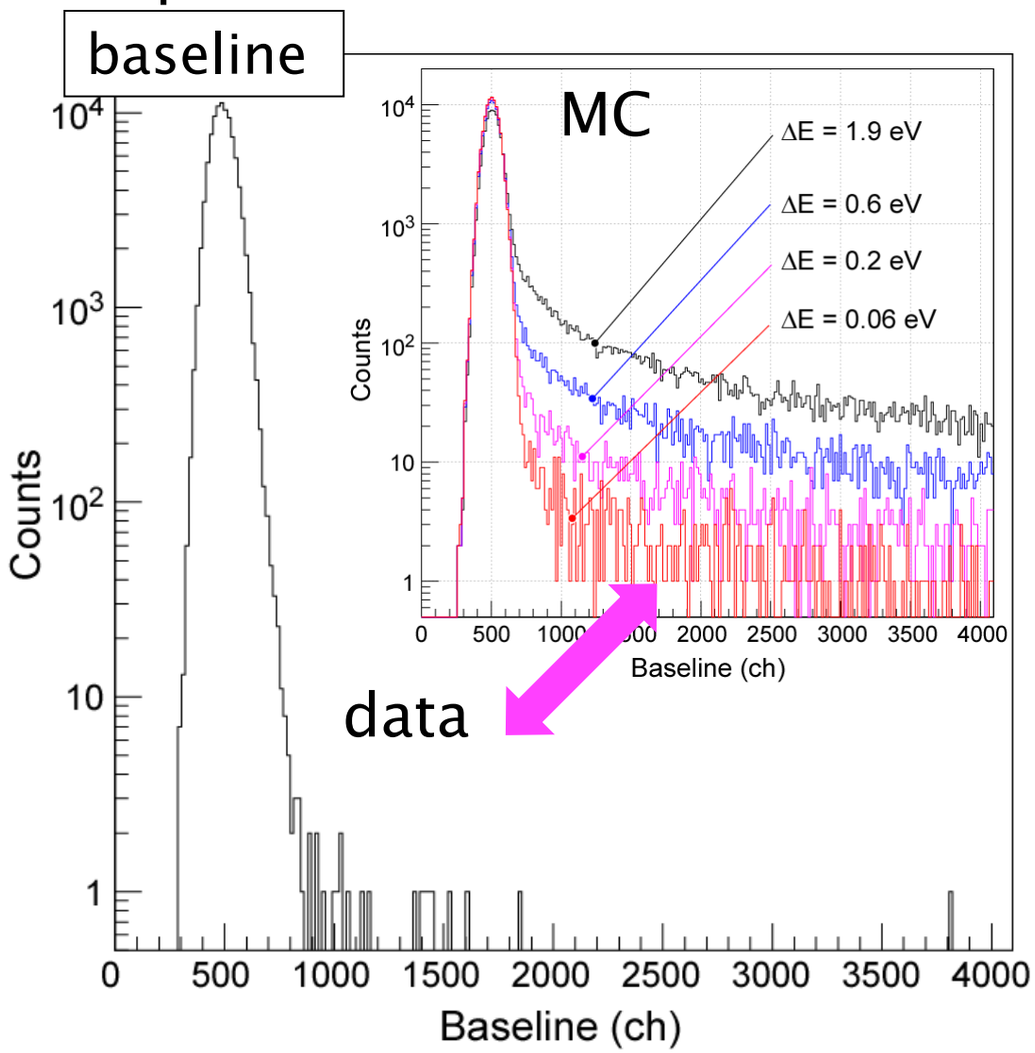
Baseline
(pre-gate)

Peak height VS baseline



Still contaminated after baseline cut
→ peak shift : ΔE

Compare data with MC simulation



Peak shift : < +0.1 eV

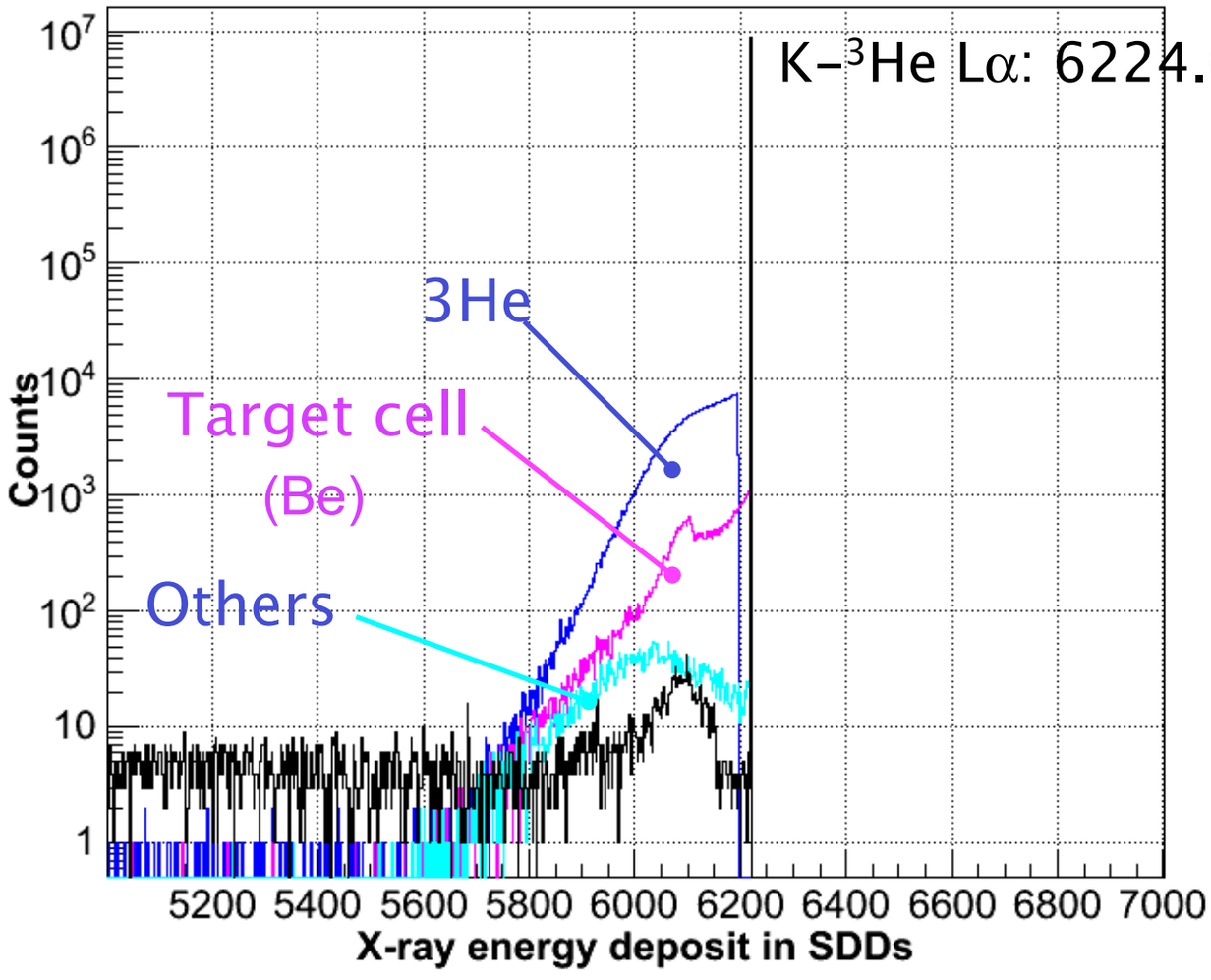
Pileup rate might be changed in 3He / 4He : isotope shift ±0.1 eV

SDD response (3) : Compton scattering

- Compton scattering (mostly inside liquid helium target)

→ Making tail structure in the low energy side

Probabilities	
He target	4.9 %
Be cell	0.6 %
others	< 0.1 %
Total	5.6%



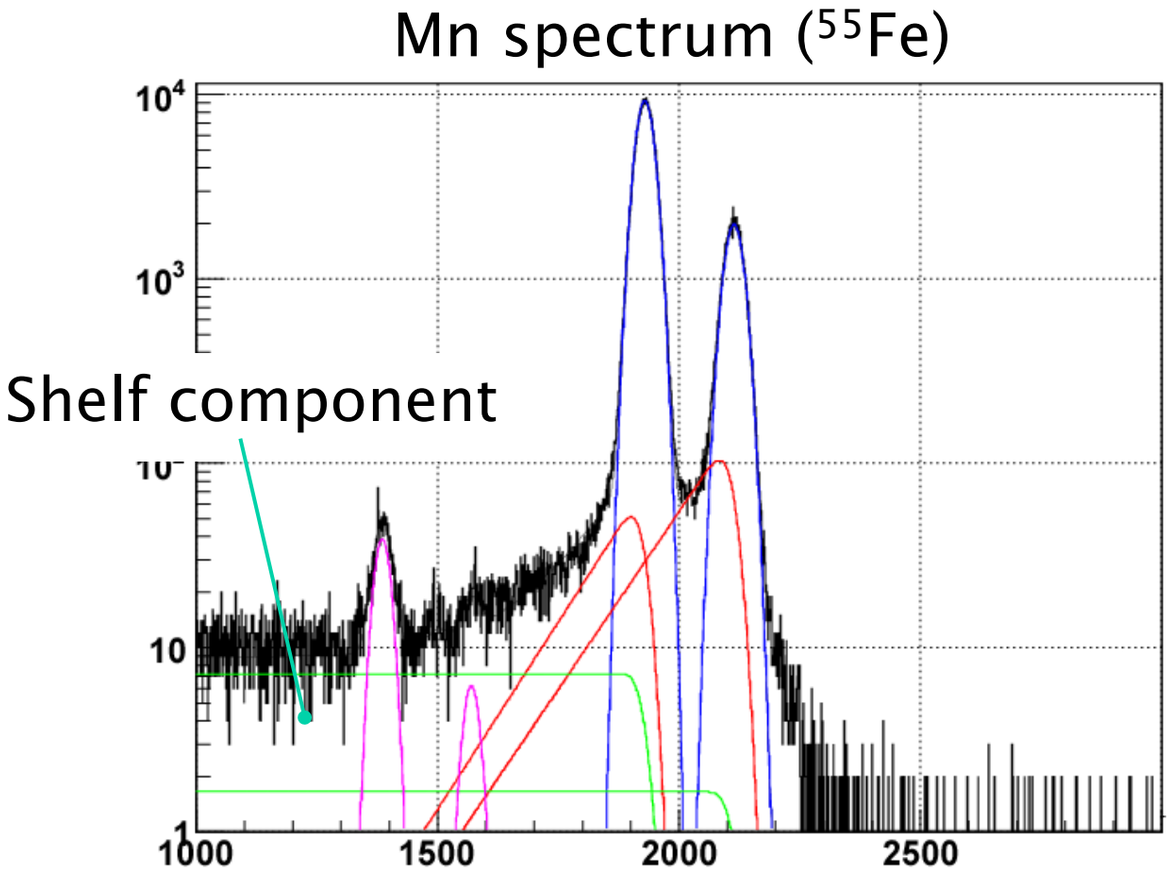
Accuracy of the cross section in GEANT4 : ~5 %

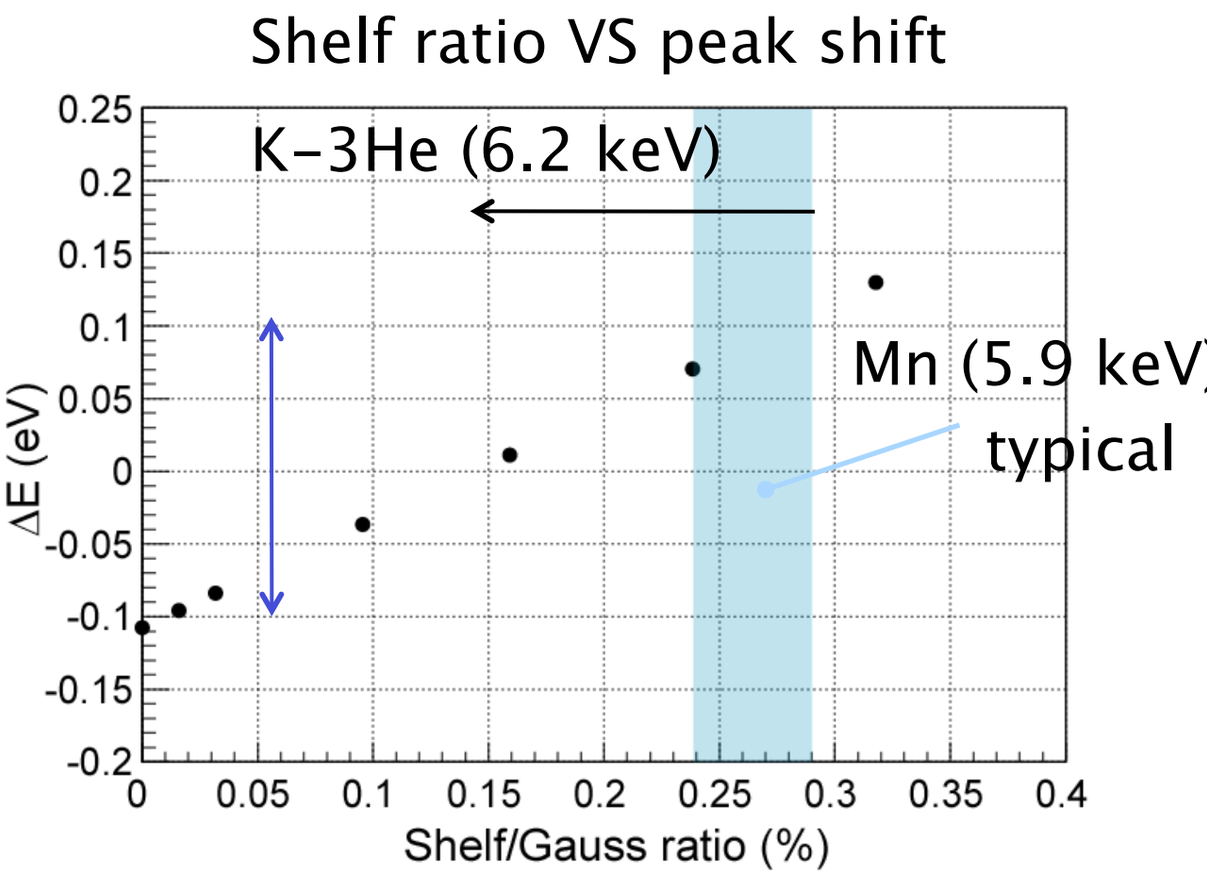
Peak shift due to uncertainty
3He (@ 6224.6 eV) : ±0.17 eV
4He (@ 6463.5 eV) : ±0.17 eV

Same tendency for 3He and 4He :
systematic errors in ΔE(3He) – ΔE(4He) : ~ 0 eV (cancelled)

SDD response (4) : Shelf structure

- Shelf profile is much smaller component than tail profile





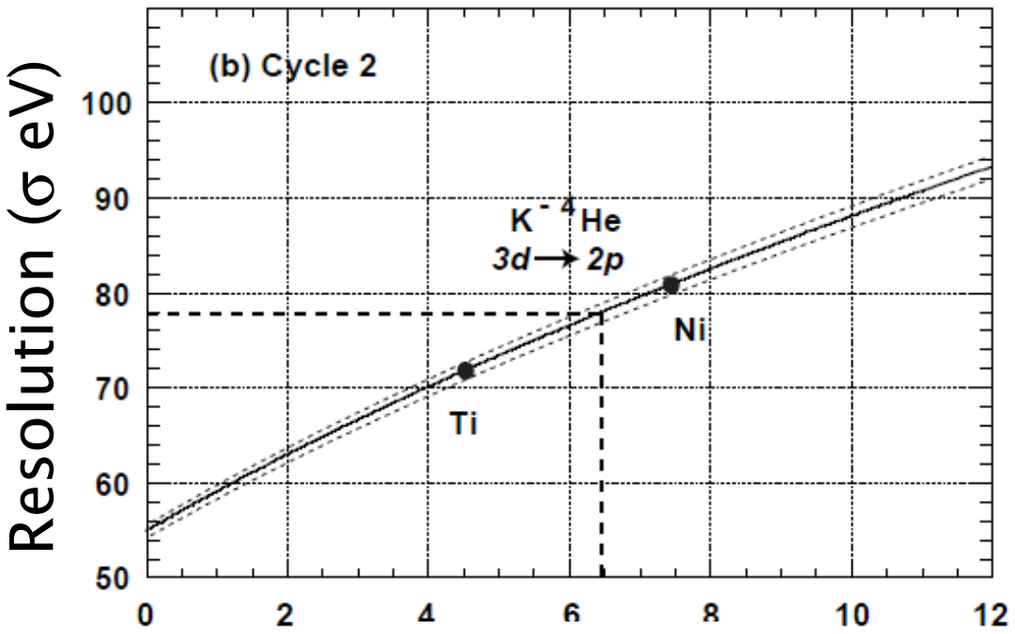
- From Si(Li), shelf intensity has negative E-dependence
  → shelf ratio should be smaller than that of Mn (5.9keV)

Same tendency for 3He and 4He : → ΔE ~ +-0.1 eV

systematic errors in ΔE(3He) – ΔE(4He) : ~ 0 eV (cancelled)

SDD response (5) : Energy resolution

- Energy resolution will be determined by the calibration spectrum



→ fixed in the final fitting

A: Counts
E: peak center
Γ : Width
σ: detector resolution

… free

… fixed

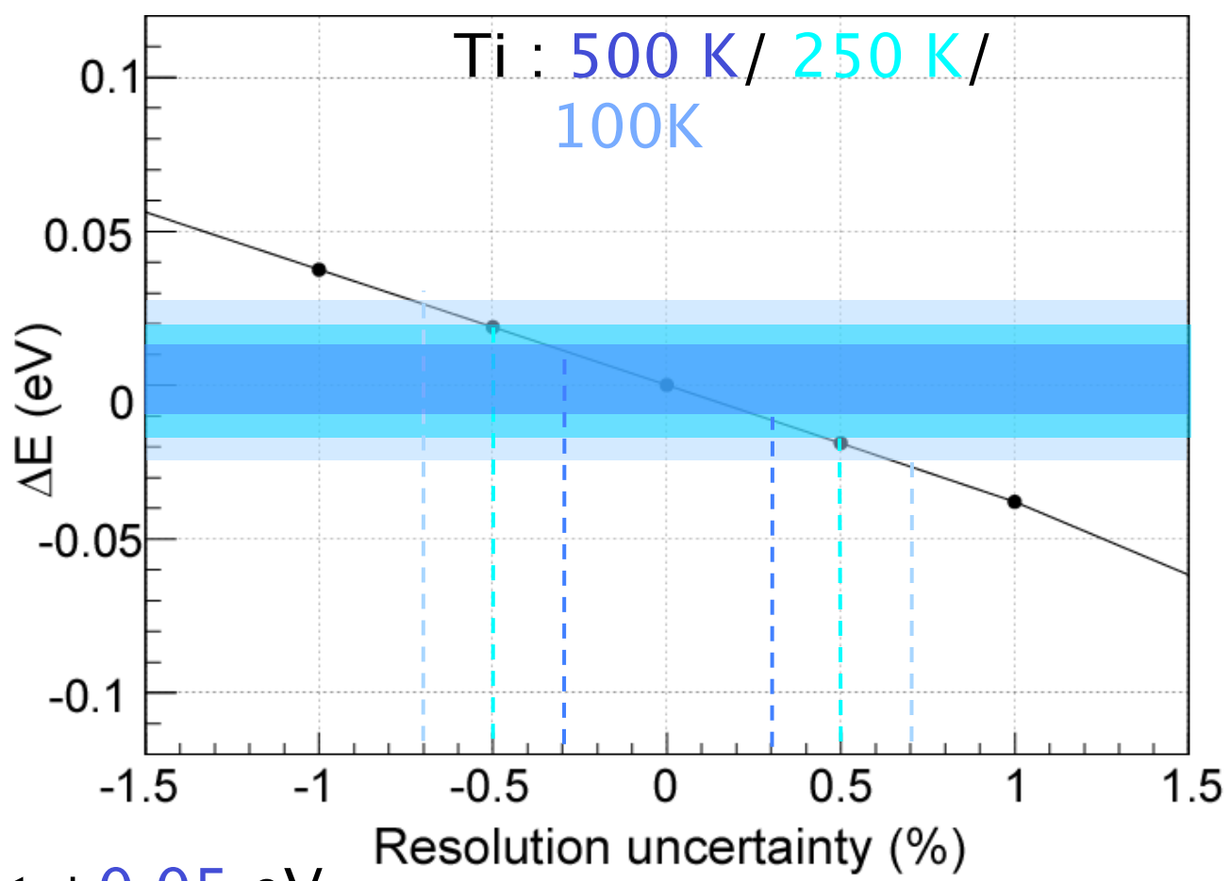
Estimated from Ti / Ni peak

$$\sigma(E) = \omega\sqrt{W_N^2 + FE/\omega},$$

Peak shift due to energy resolution uncertainty

E(3He) , E(4He) : < ±0.03 eV

resolution uncertainty VS deviation

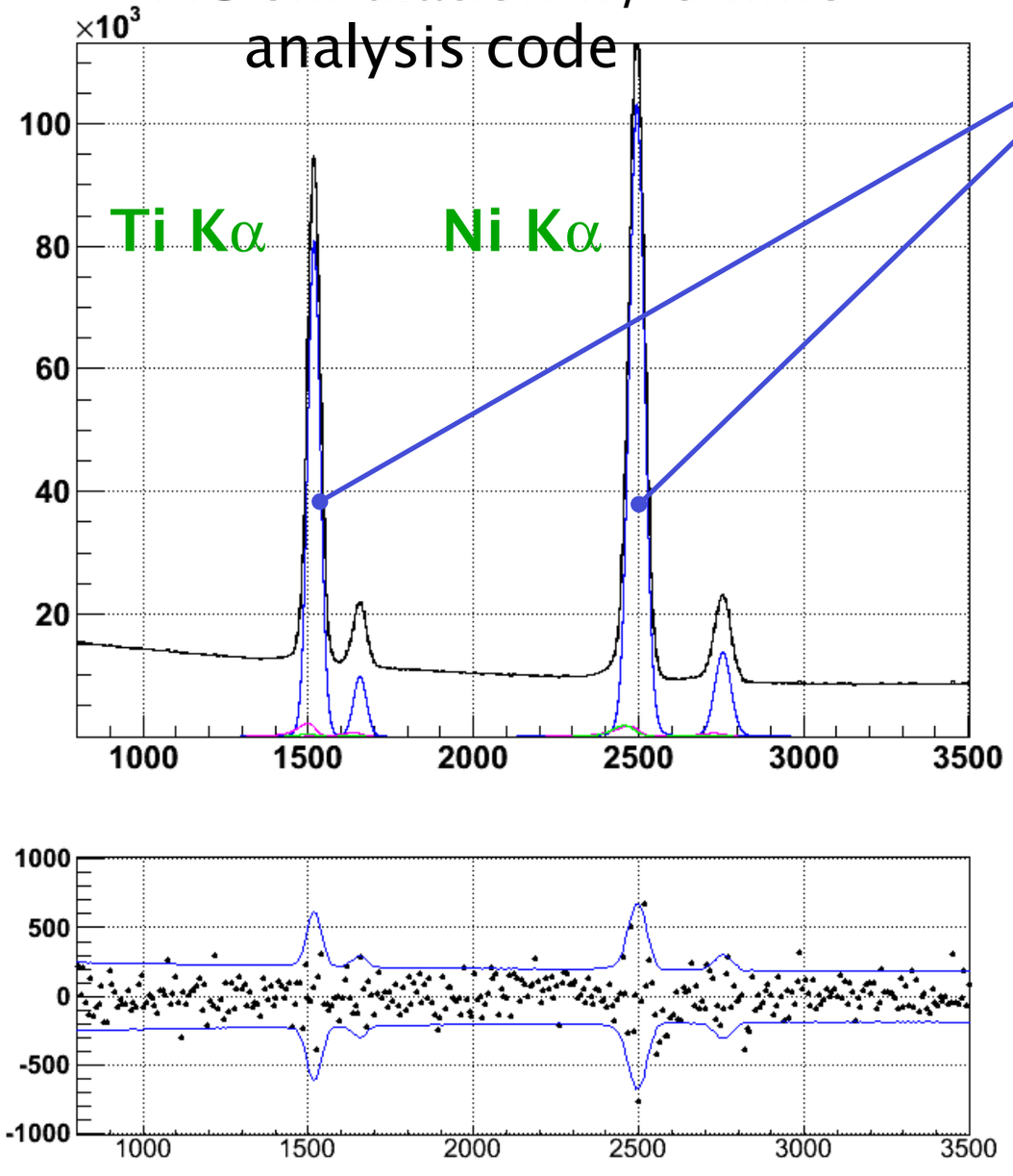


systematic errors of ΔE(3He) – ΔE(4He) : < ±0.05 eV

Energy scale (1): calibration peak statistics

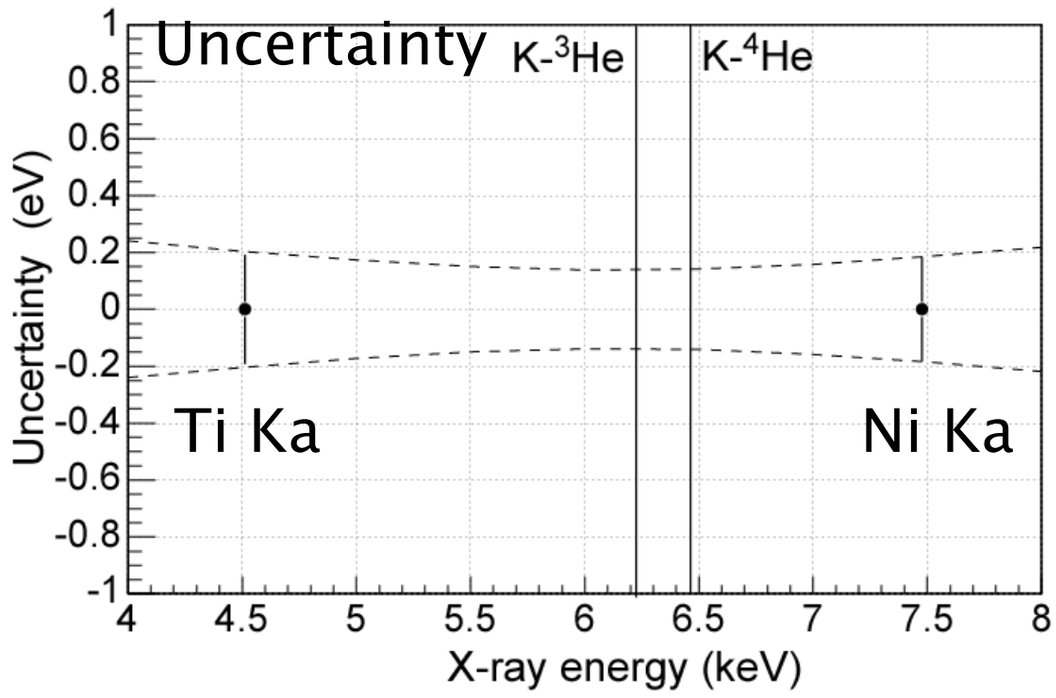
- Accuracy of calibration peak energy (dominated by statistics)

MC simulation w/ offline analysis code



- Statistics of calibration Peak
  (~4 k counts /hour/8 SDDs
  from Run35, 400k on def. counter)

Ti counts : ~500 k events



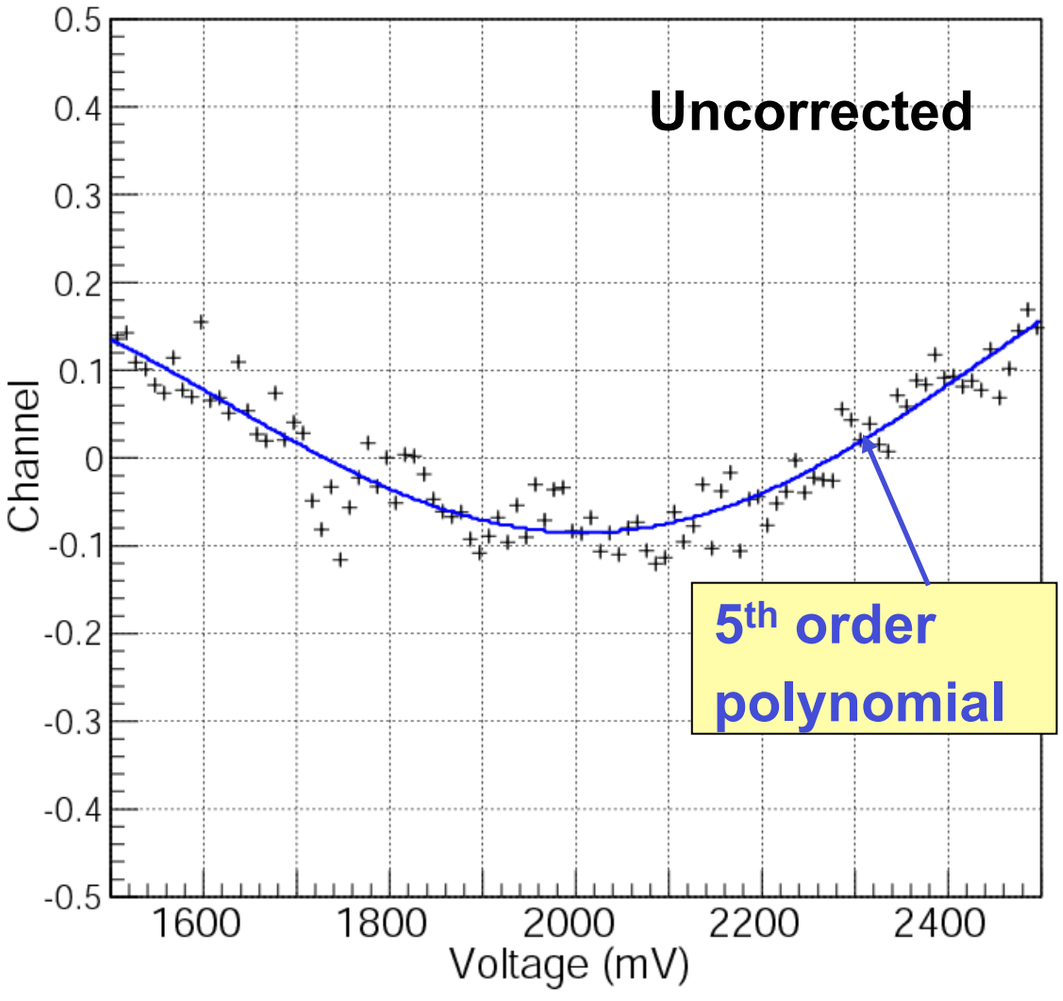
Energy scale uncertainty
3He (@ 6224.6 eV) : 0.14 eV
4He (@ 6463.5 eV) : 0.14 eV

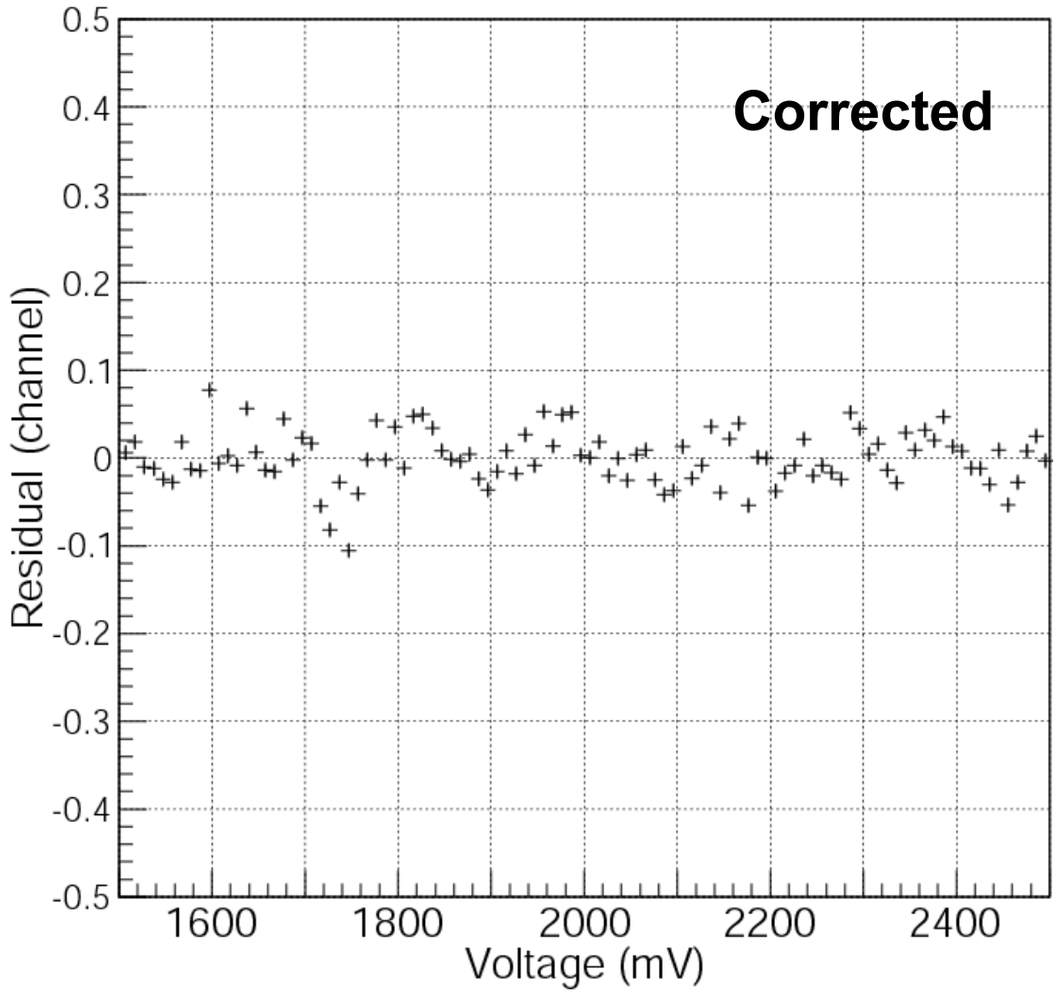
3He/4He measurements are separated
→ systematic errors in isotope difference : ±0.2 eV

Energy scale(2) : non-linearity

- ADC non-linearity (CAEN V785 peak hold ADC)
  12 bit (0-4V) 1V/ch (~ 3eV/ch)

Residual after linear fit





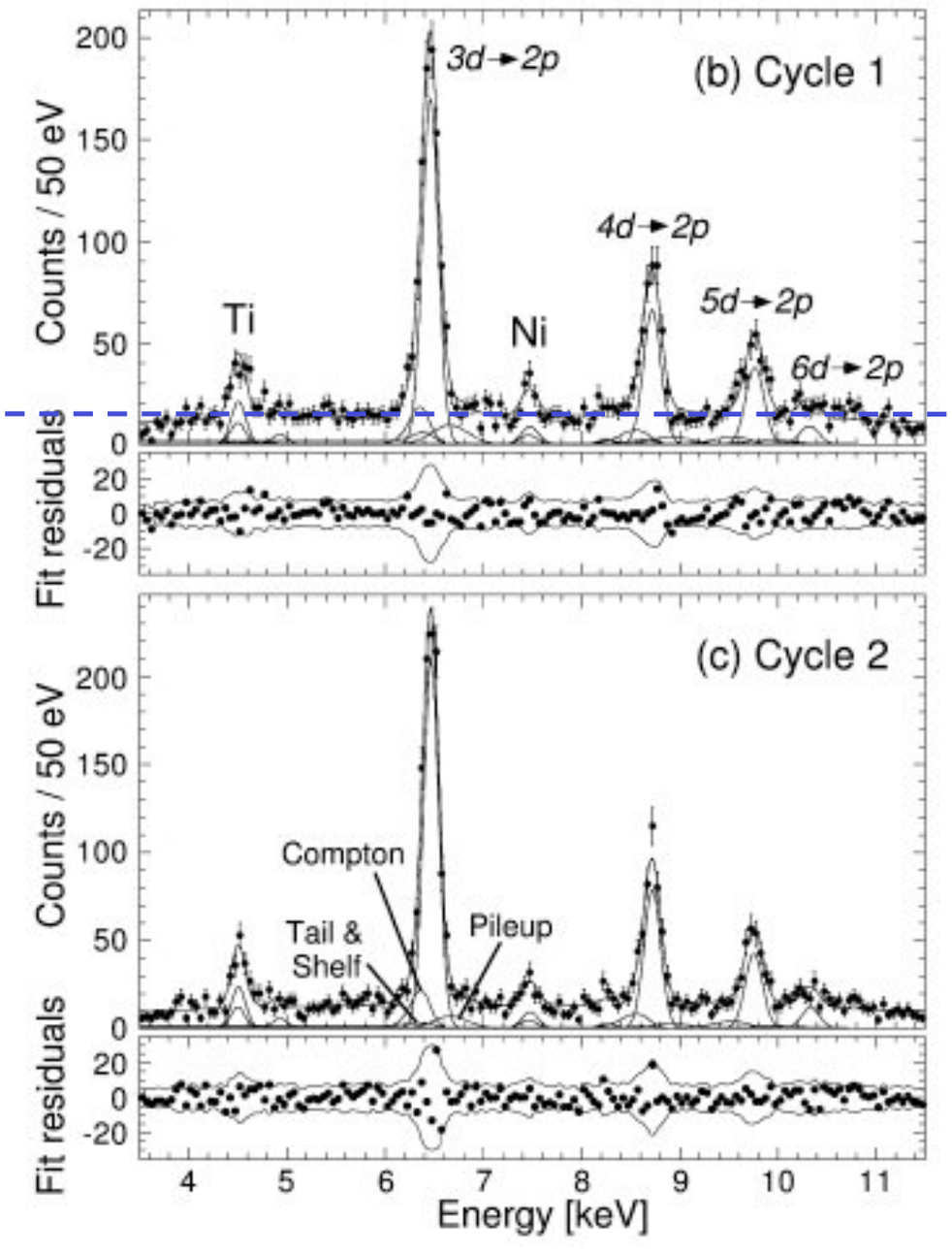
Non-linearity of overall system will be measured with the final setup. Presently we use an error obtained in E570 : ±0.5 eV

(should be cancelled in the isotope measurement)

Background shape

- 2^{nd} order polynomial background will be used

E570 data



Peak shift by changing background fitting function

1^{st} <-> 2^{nd} order polynomial

impossible to estimate before taking actual spectrum

In E570 analysis

Systematic error : ±0.08 eV

→ take this value for ΔE(3He) and ΔE(4He)

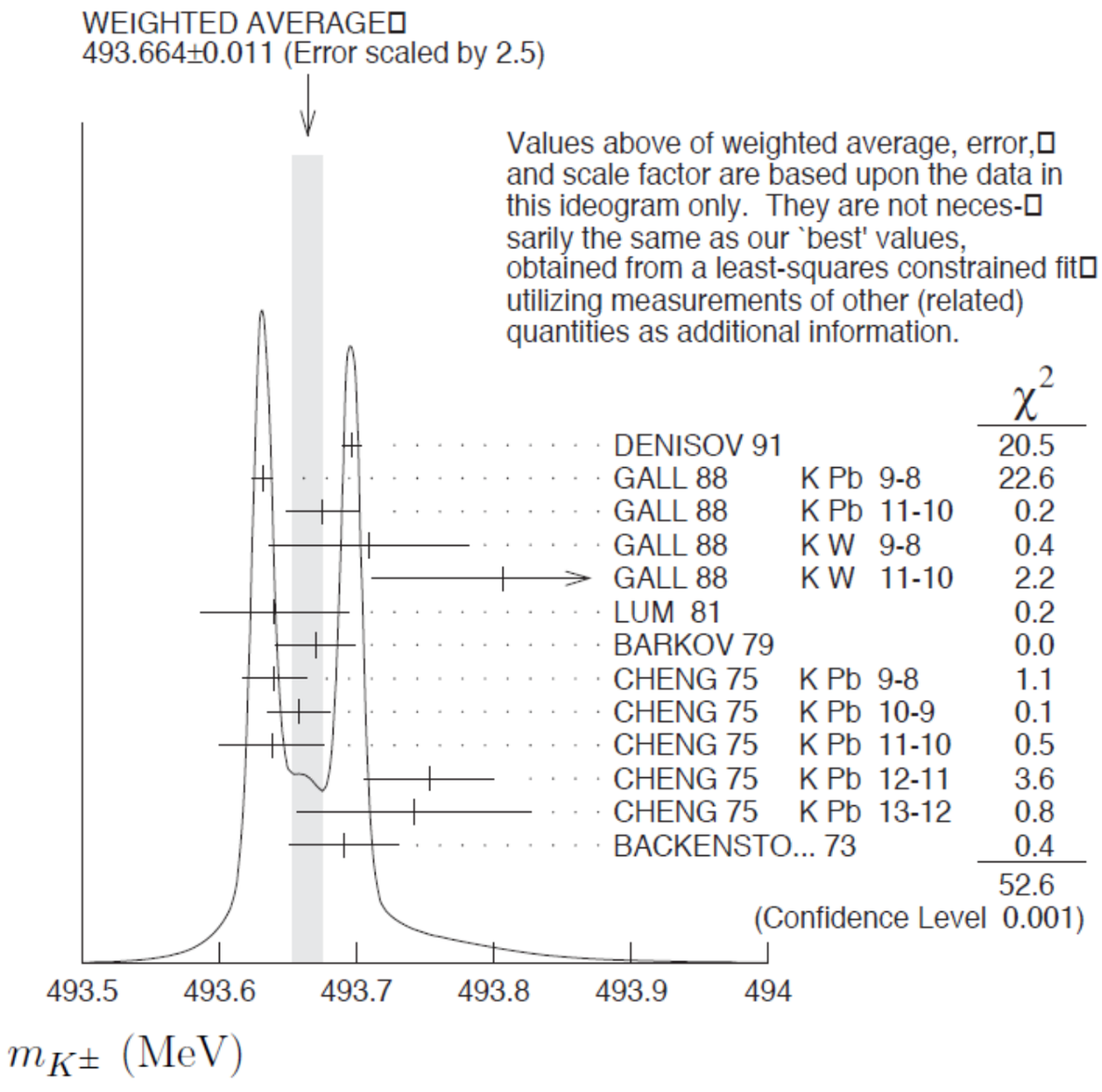
Errors in isotope shift

might be uncorrelated in 3He and 4He spectra

systematic error of isotope shift : ±0.12 eV

E. M. value from Kaon mass

- Uncertainty of negative kaon mass



Weighted average

493.663 ±0.011 eV

E.M value of K-3He, K-4He 2p shift has uncertainty of

ΔE : ±0.2 eV

(Leading order only)

Correlated with each other

ΔE(3He) - ΔE(4He) : ~0 eV