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Kirchhoff-**I**nstitute
for **P**hysics

Gamma spectroscopy to measure the ^{229}Th isomer energy using *maXs30* the 2-dimensional array of metallic magnetic microcalorimeters

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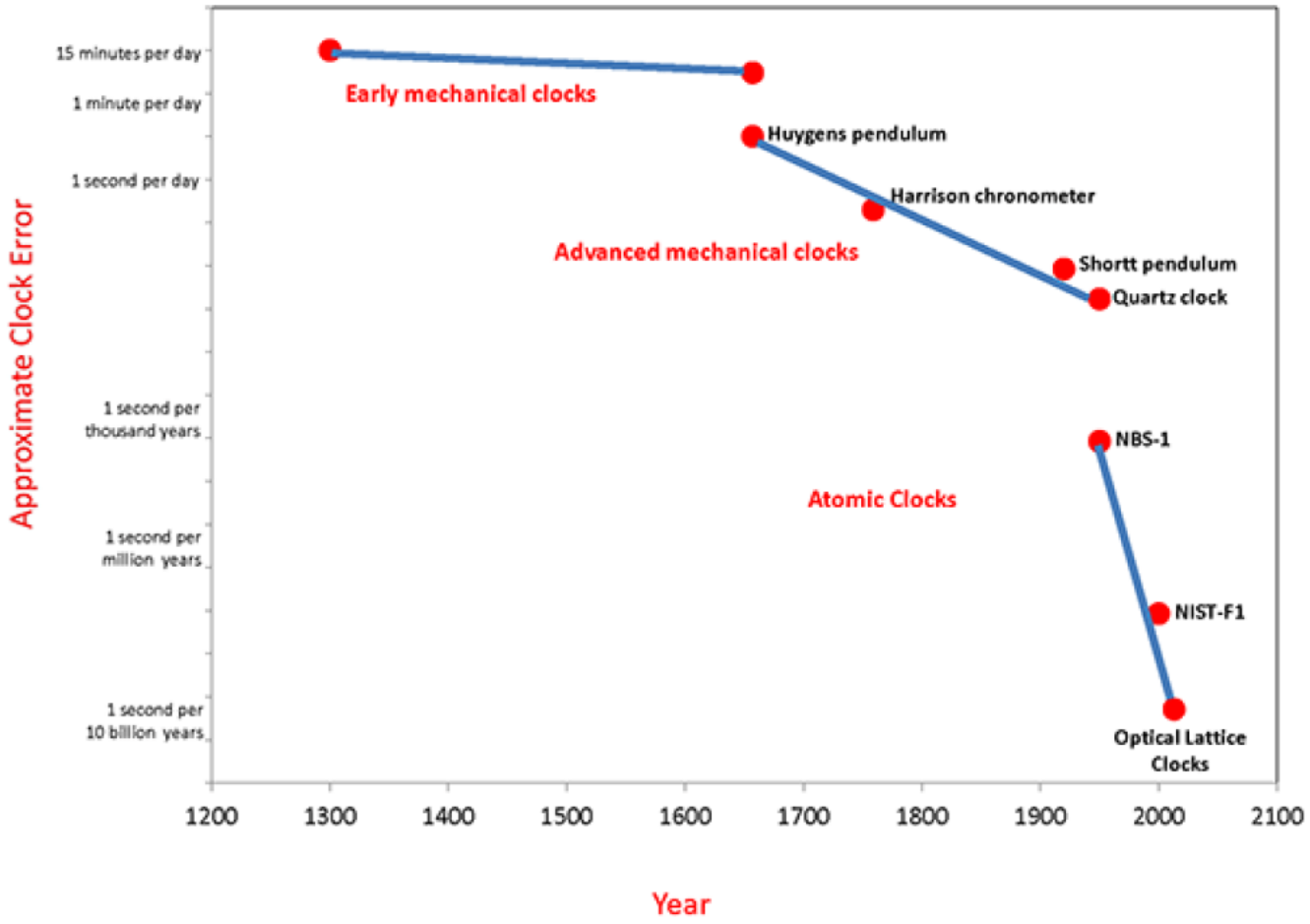
Jkelt Beeks, Georgy A. Kazakov, Tomas Sikorsky
and Thorsten Schumm

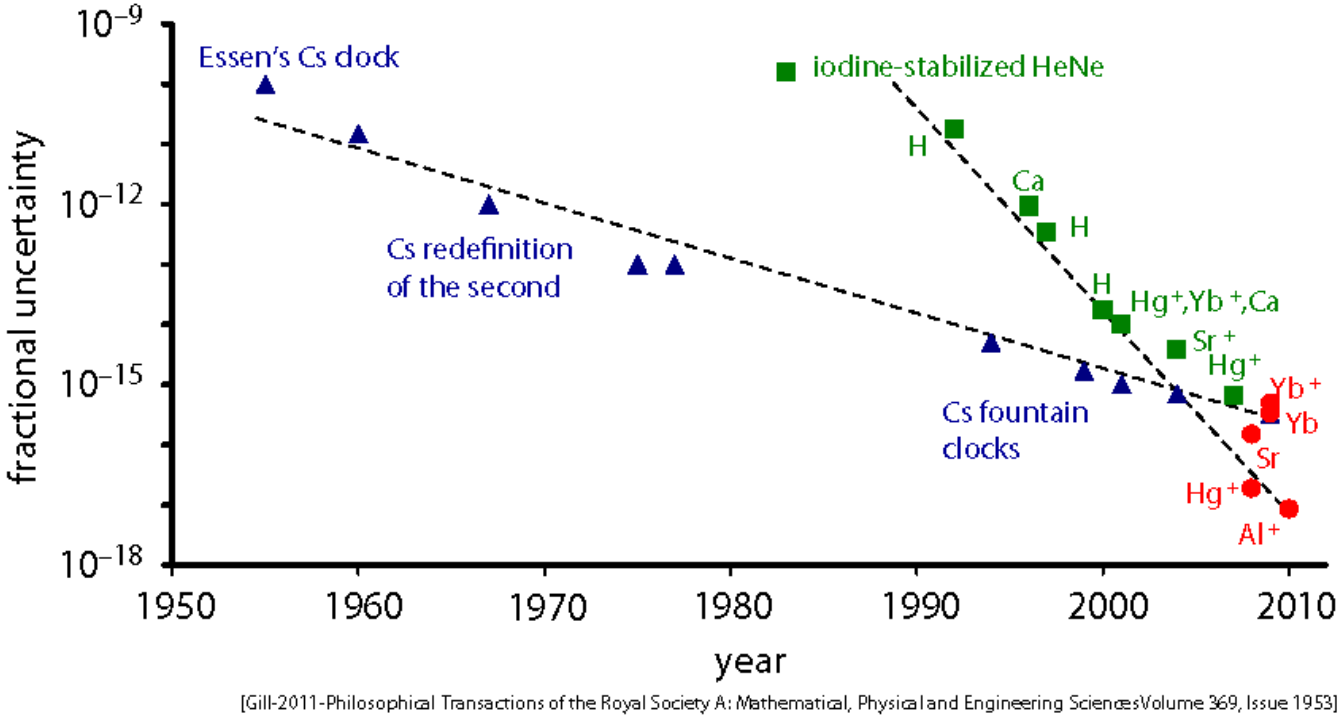
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Christoph Mokry, Jörg Runke and Christoph E. Düllmann

history of clocks



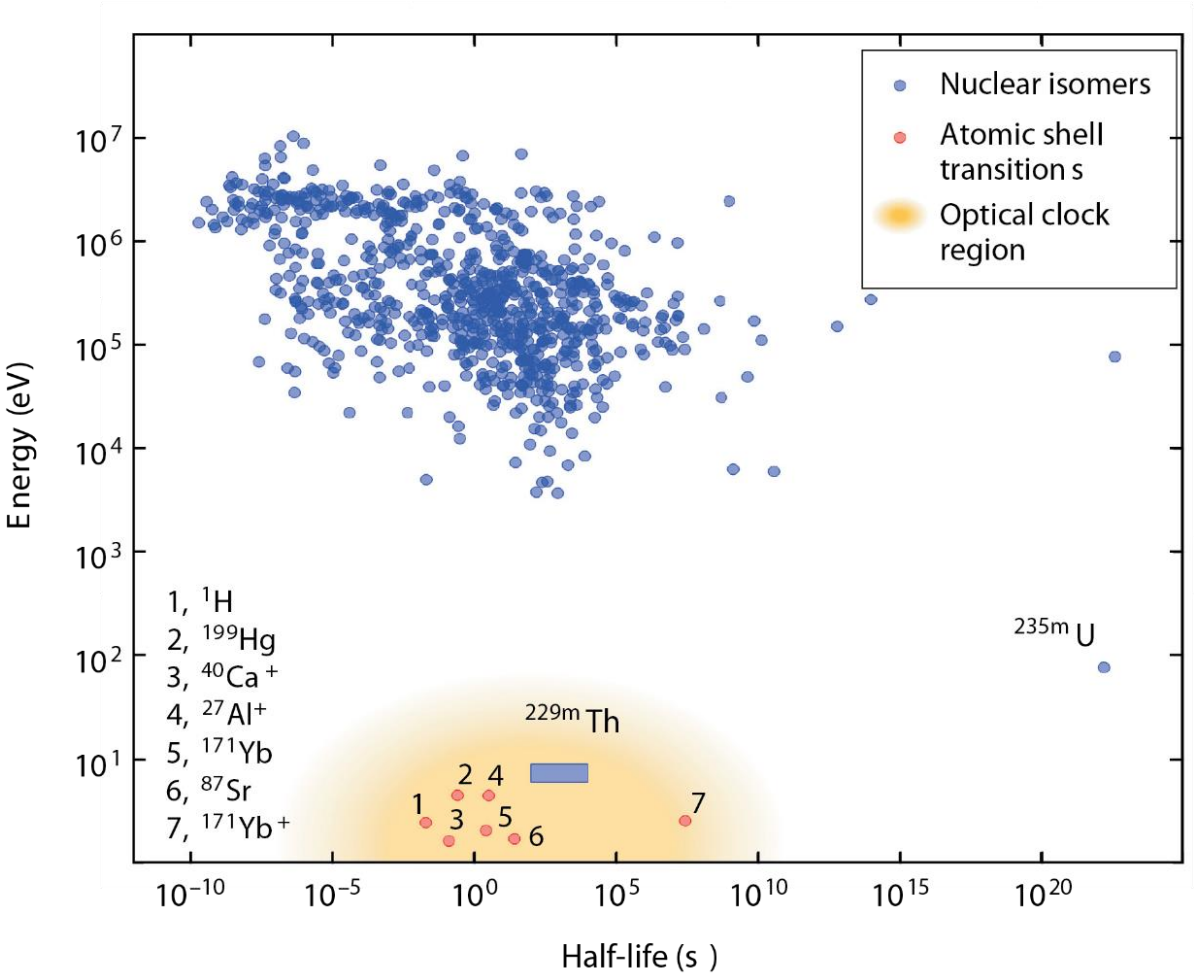
history of clocks



[Gill-2011-Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering SciencesVolume 369, Issue 1953]

limited by natural linewidth!

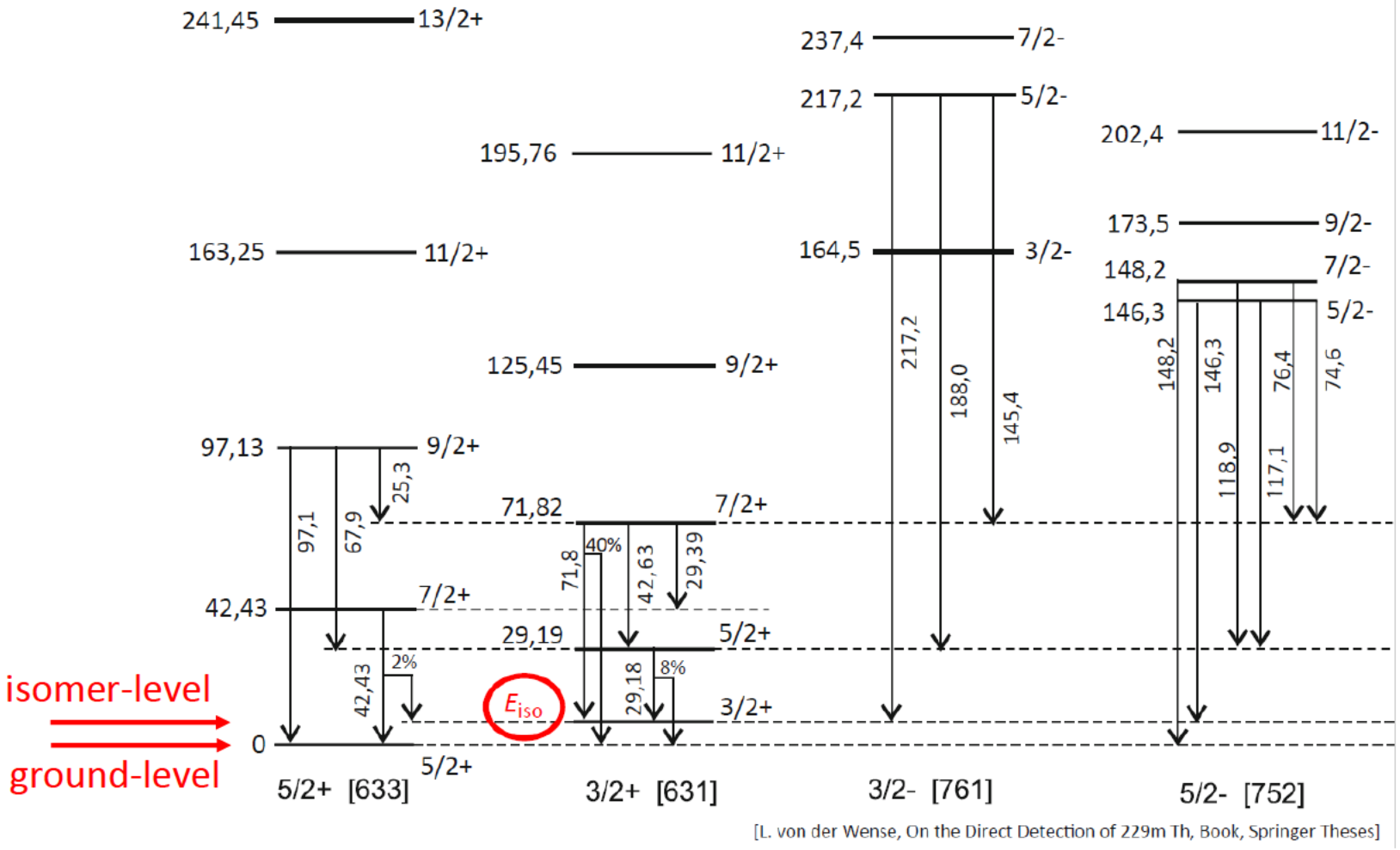
nuclear isomers



[L von der Wense et al. Nature 533, 47–51 (2016) doi:10.1038/nature17669]

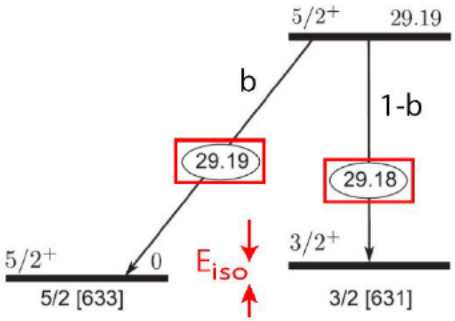
existence of ^{229m}Th confirmed [vdW16]

energy levels of ^{229}Th



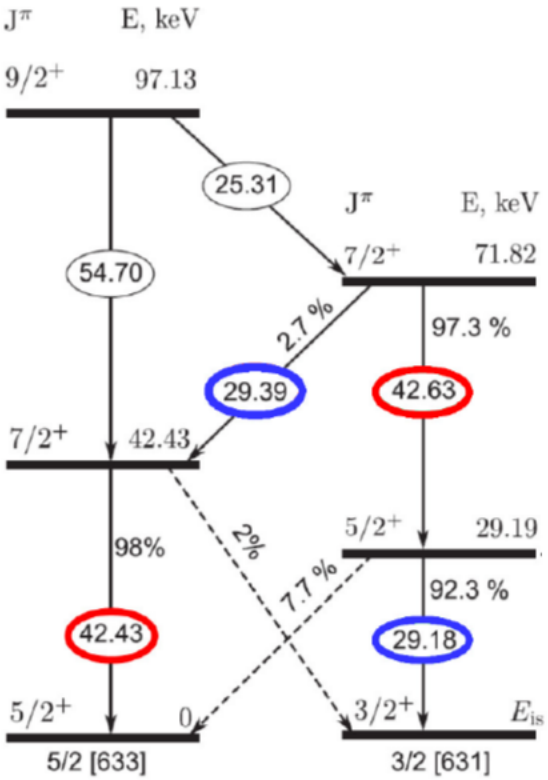
[L. von der Wense, On the Direct Detection of 229m Th, Book, Springer Theses]

measurement strategy



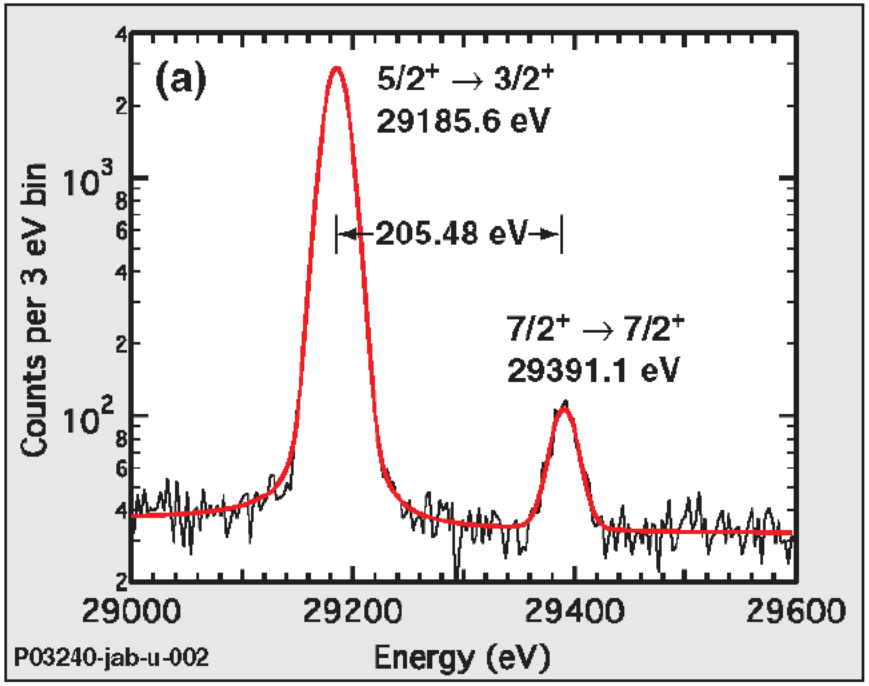
requires $\Delta E_{\mathrm{FWHM}} < E_{iso}$ @29keV

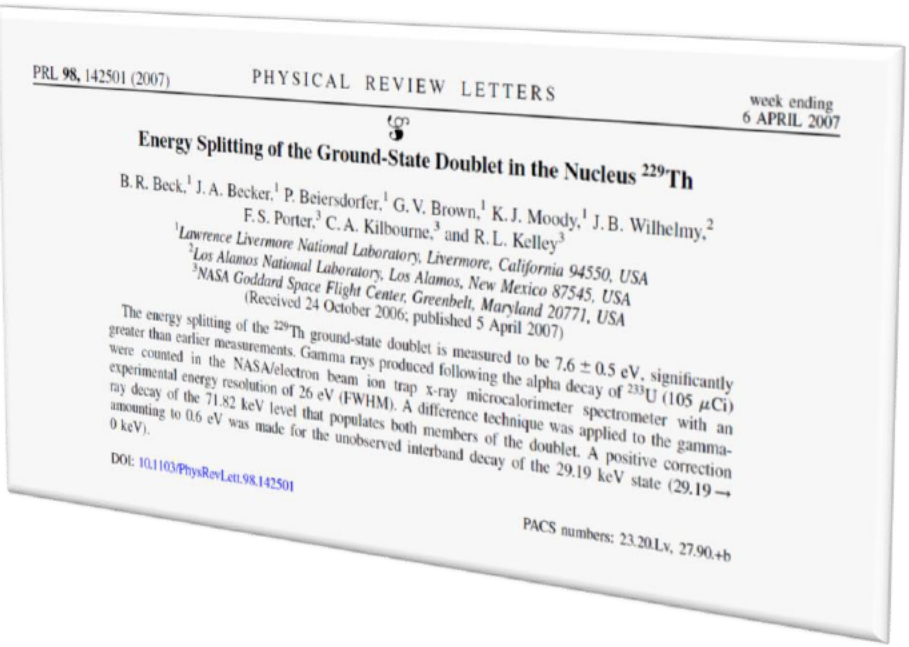
$$E_{iso} = E_{29.39\,keV} - E_{29.18\,keV} - (E_{42.63\,keV} - E_{42.43\,keV})$$
$$= \Delta E_{29\,keV} - \Delta E_{42\,keV}$$



best result so far

$E_{\mathrm{iso}} = (7.8 \pm \mathbf{0.5})$ eV [Beck et al 2010]





PRL 98, 142501 (2007) PHYSICAL REVIEW LETTERS week ending 6 APRIL 2007

Energy Splitting of the Ground-State Doublet in the Nucleus ^{229}Th

B. R. Beck,[1] J. A. Becker,[1] P. Beiersdorfer,[1] G. V. Brown,[1] K. J. Moody,[1] J. B. Wilhelmy,[2] F. S. Porter,[3] C. A. Kilbourne,[3] and R. L. Kelley[3]
[1]*Lawrence Livermore National Laboratory, Livermore, California 94550, USA*
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[3]*NASA Goddard Space Flight Center, Greenbelt, Maryland 20771, USA*
(Received 24 October 2006; published 5 April 2007)

The energy splitting of the ^{229}Th ground-state doublet is measured to be 7.6 ± 0.5 eV, significantly greater than earlier measurements. Gamma rays produced following the alpha decay of ^{233}U (105 μCi) were counted in the NASA/electron beam ion trap x-ray microcalorimeter spectrometer with an experimental energy resolution of 26 eV (FWHM). A difference technique was applied to the gamma-ray decay of the 71.82 keV level that populates both members of the doublet. A positive correction amounting to 0.6 eV was made for the unobserved interband decay of the 29.19 keV state (29.19 →
0 keV).

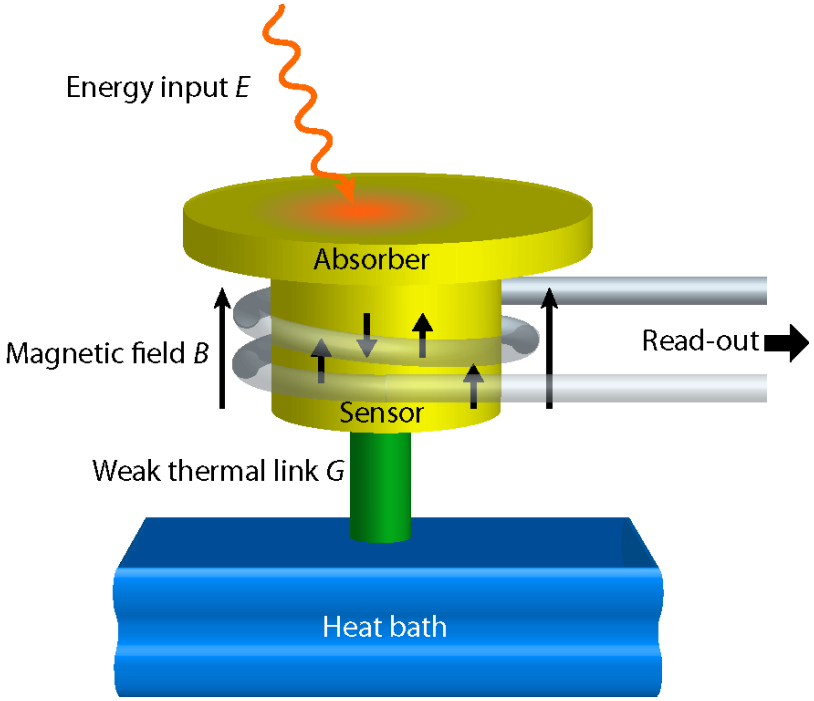
DOI: 10.1103/PhysRevLett.98.142501

PACS numbers: 23.20.Lv, 27.90.+b

instrumental linewidth 26 eV (FWHM)

~ 1000 counts in the weak 29.4 keV line

MMC principle



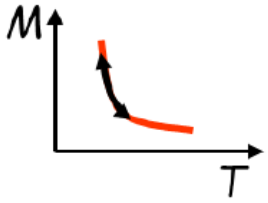
temperature change:

$$\Delta T \simeq \frac{E}{C_{\mathrm{tot}}}$$

relaxation to bathtemperature:

$$\tau \simeq \frac{C_{\mathrm{tot}}}{G}$$

paramagnetic sensor **Ag**:Er



signal size:

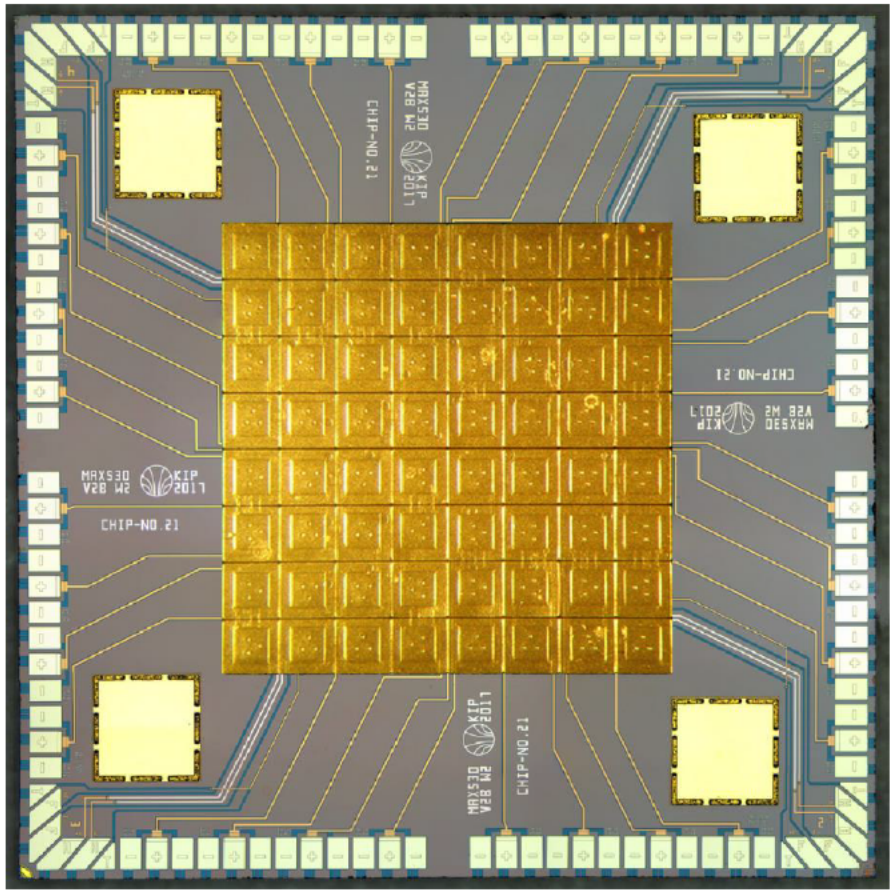
$$\Delta\Phi \propto \Delta M(T) \simeq \frac{\delta M(T)}{\delta T}\frac{E}{C_{\mathrm{tot}}}$$

M and **C** of weakly interacting spins well understood

excellent linearity

outstanding energy resolution

maXs30 detector array

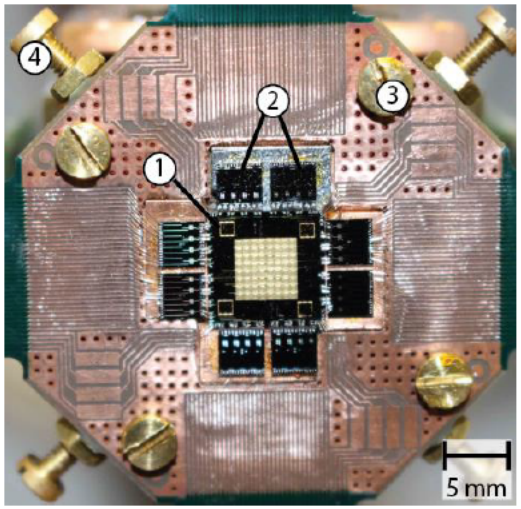


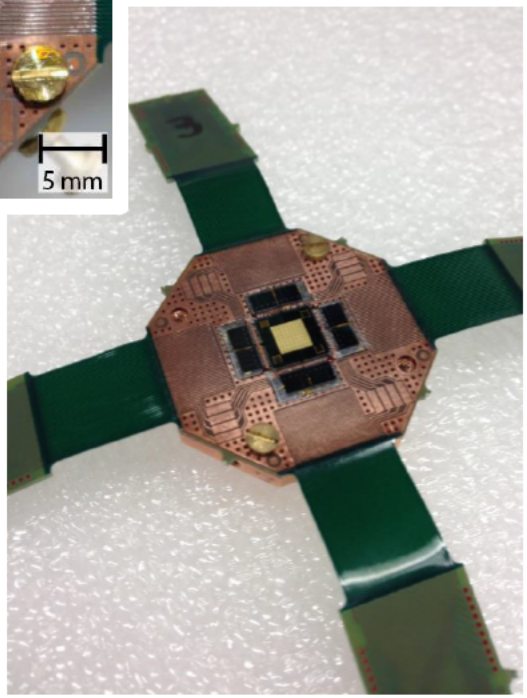
- 8 x 8 MMC pixel array
- detection area: 4 x 4 mm²
- 4 temperature-sensitive detectors

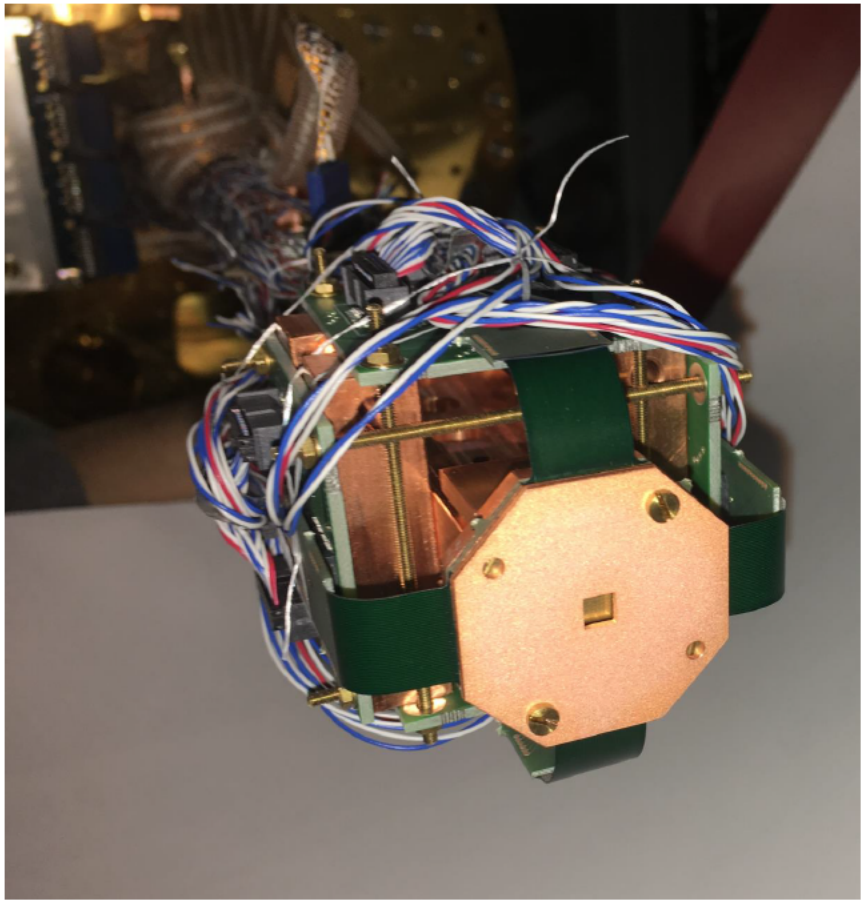
adjusted absorber thickness $\approx 20\ \mu m$

talk by Daniel Hengstler on Wednesday

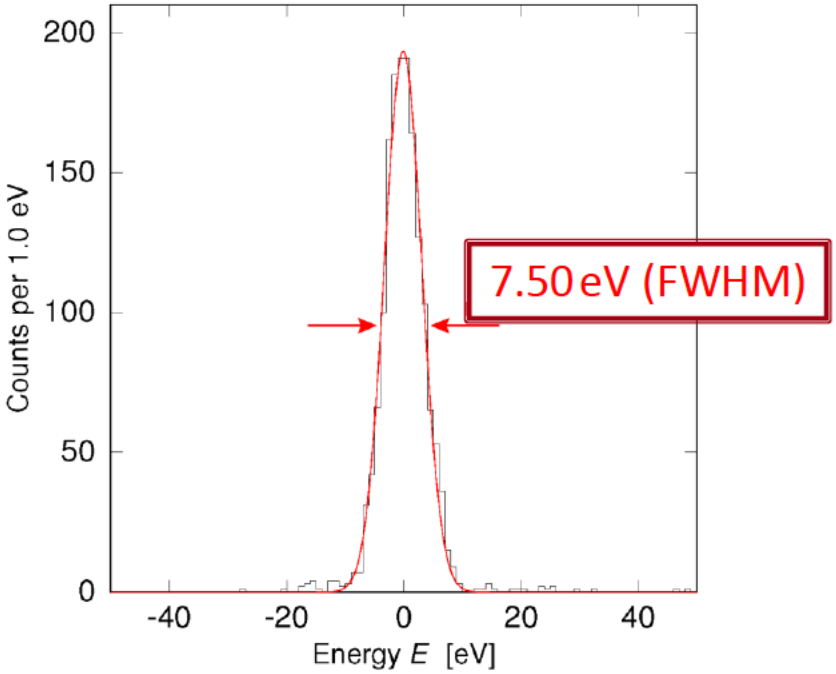
experimental setup

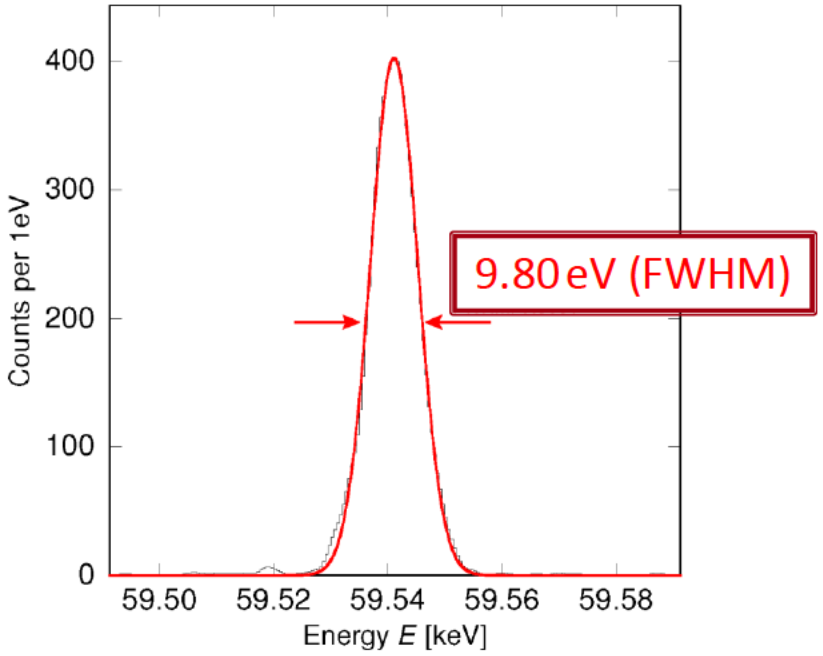






detector performance

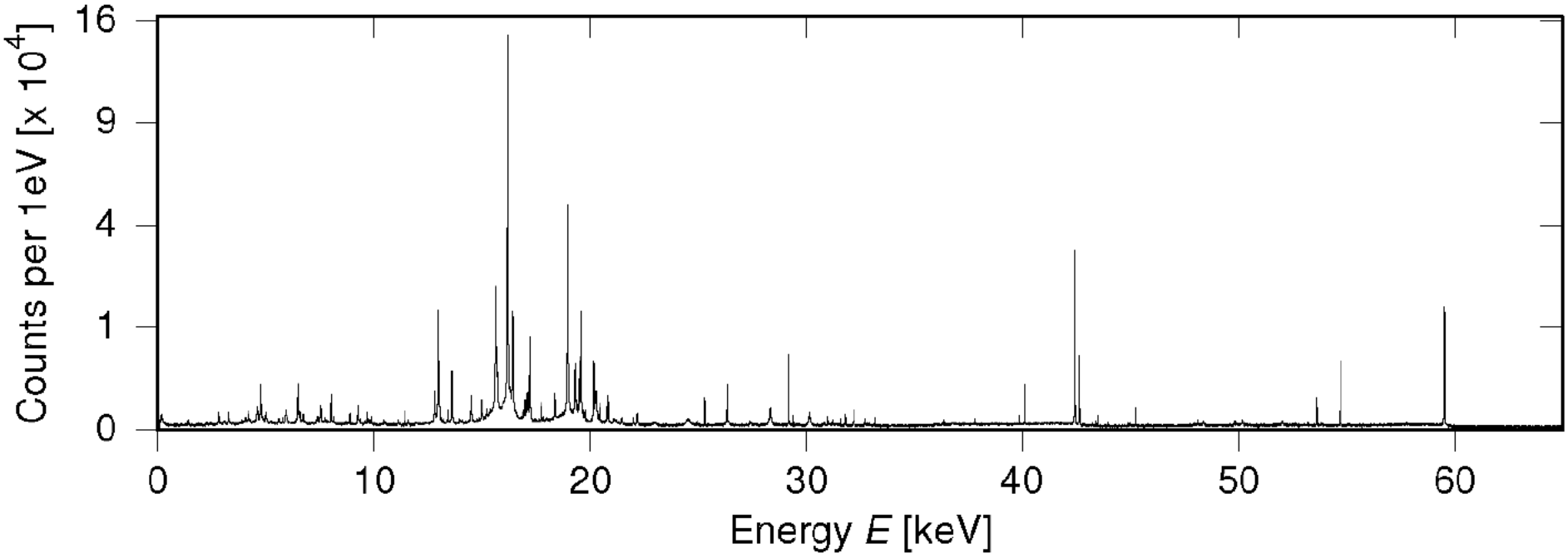




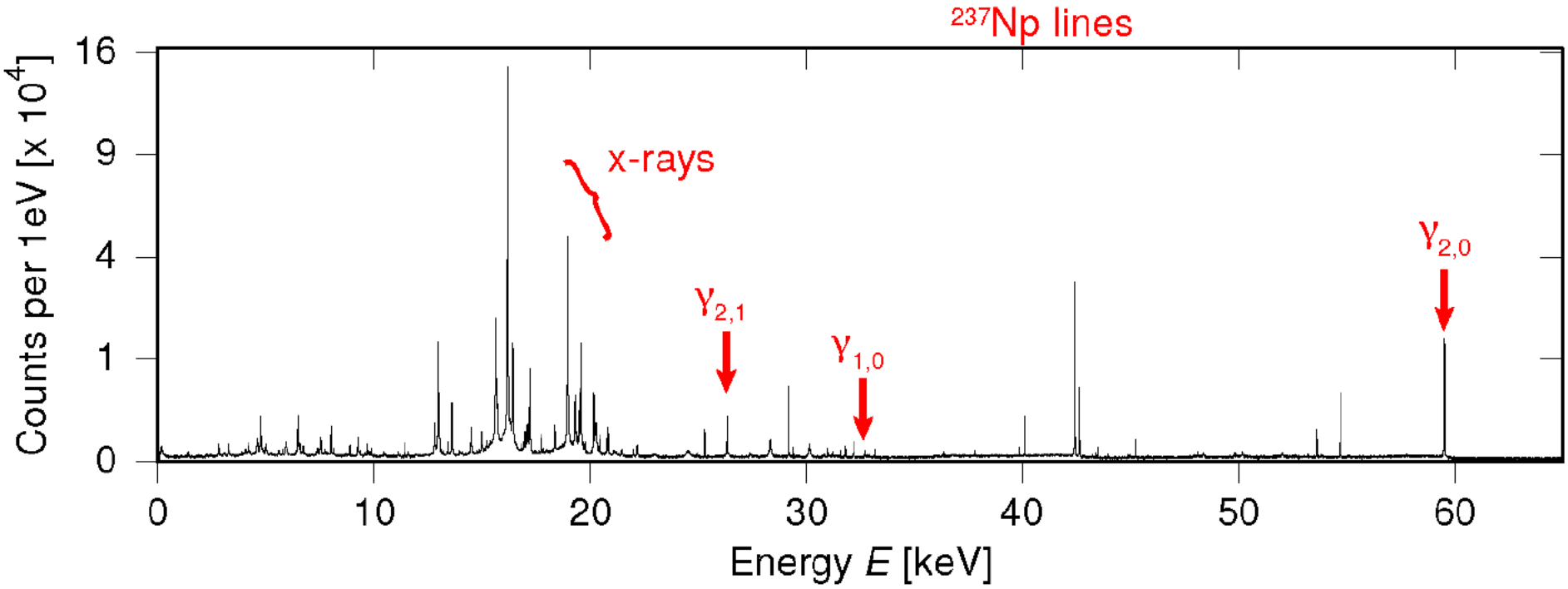
instrumental linewidth
close to design value

resolving power $\frac{\Delta E}{E}$ > 6000 !!!

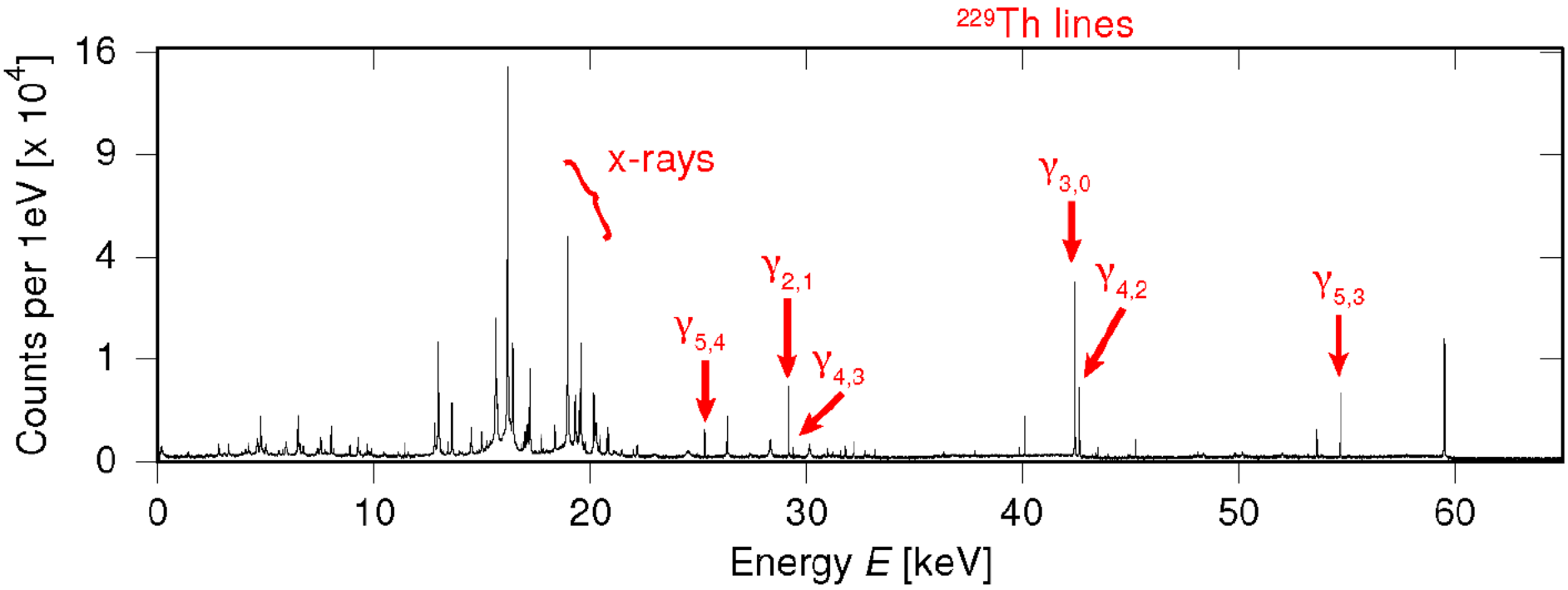
$^{233}U + {}^{241}Am$ energy spectrum



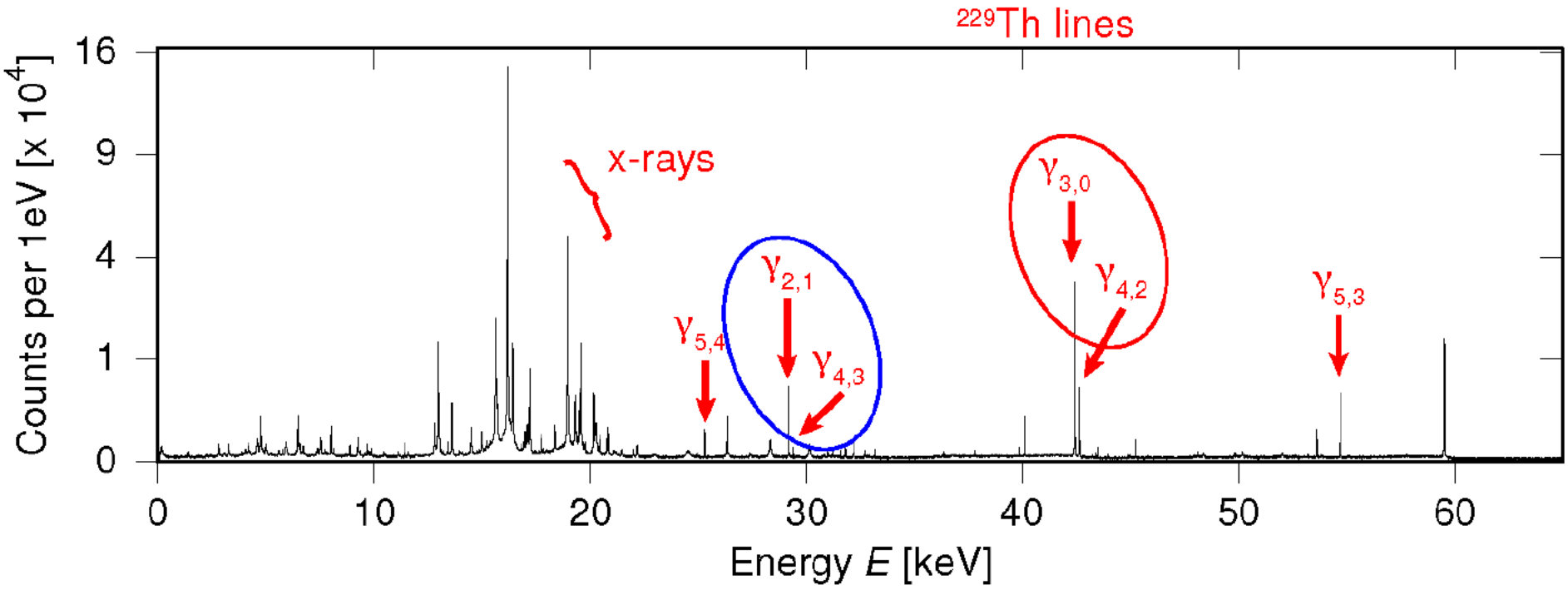
$^{233}U + {}^{241}Am$ energy spectrum



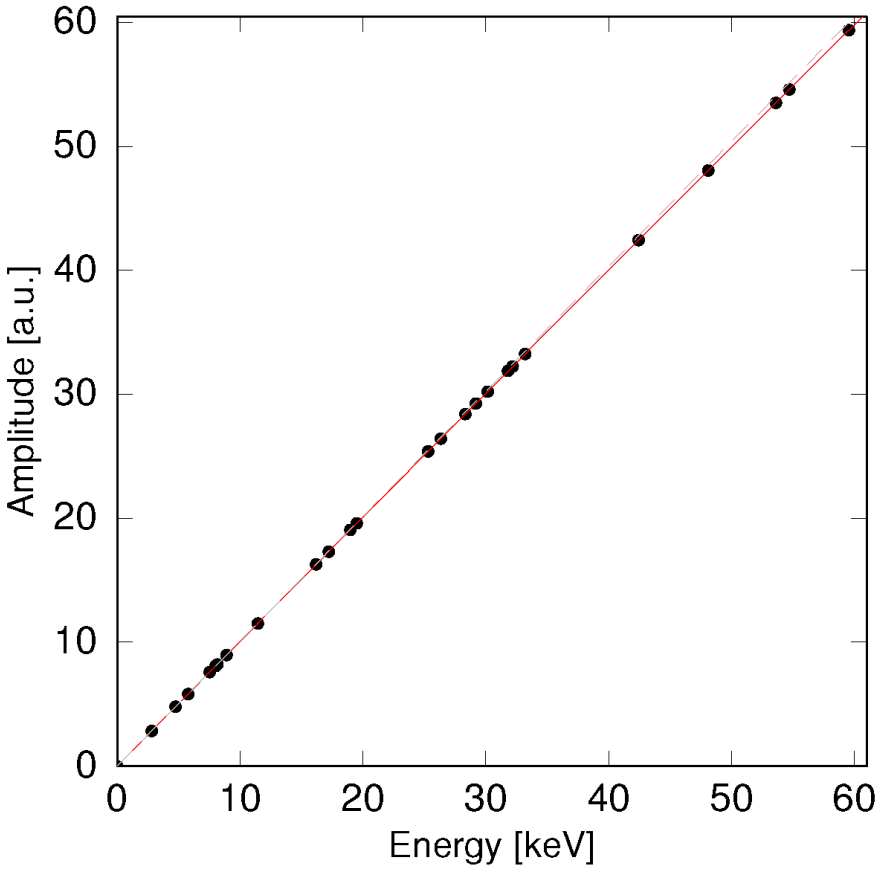
$^{233}U + {}^{241}Am$ energy spectrum



$^{233}U + {}^{241}Am$ energy spectrum

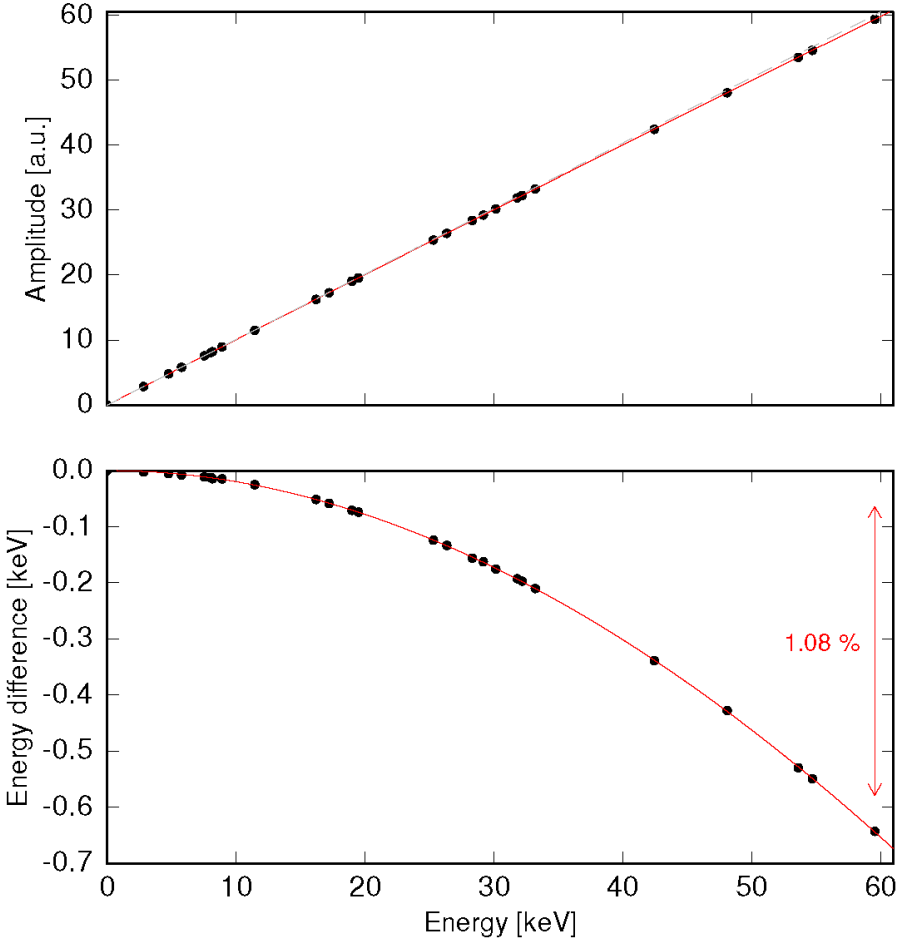


linearity calibration



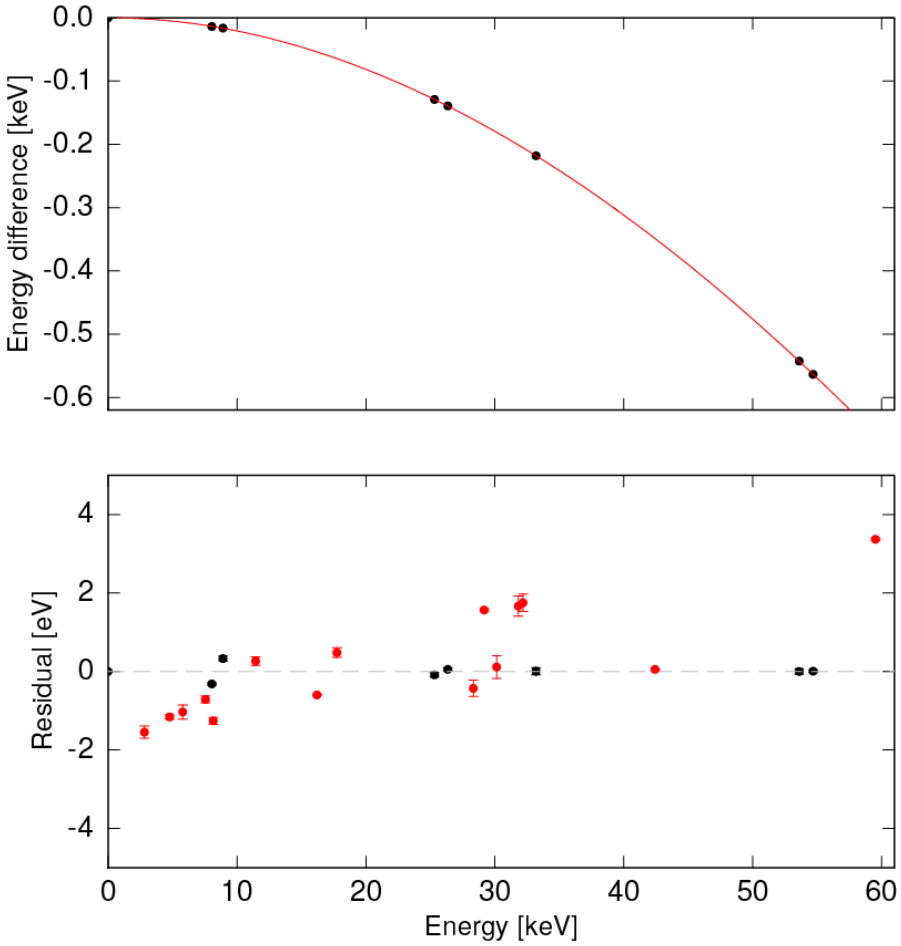
- identify many lines

linearity calibration



- identify many lines
- deviation from linearity $< 0.5\,\%$ @ $30\,\mathrm{keV}$

linearity calibration



- identify many lines
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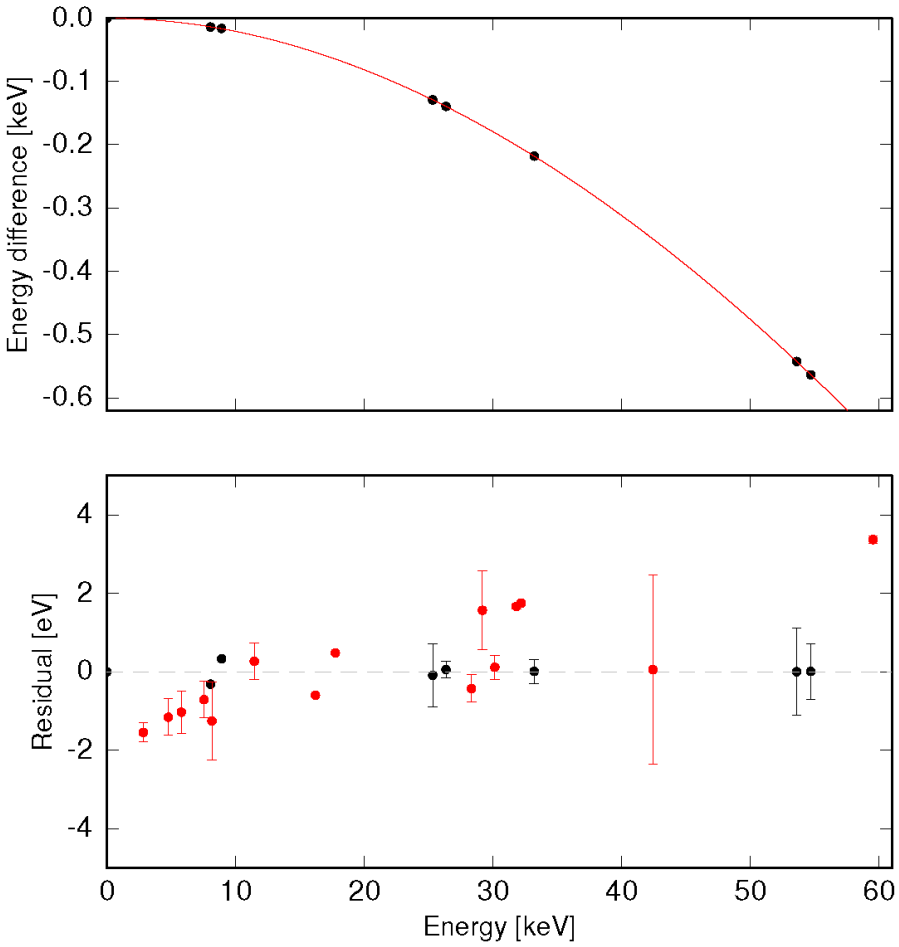
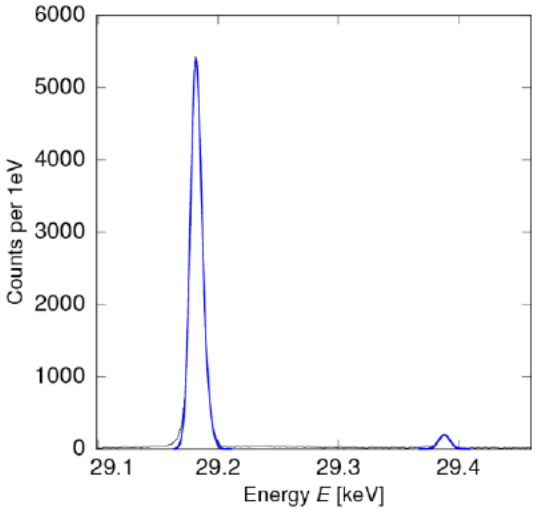
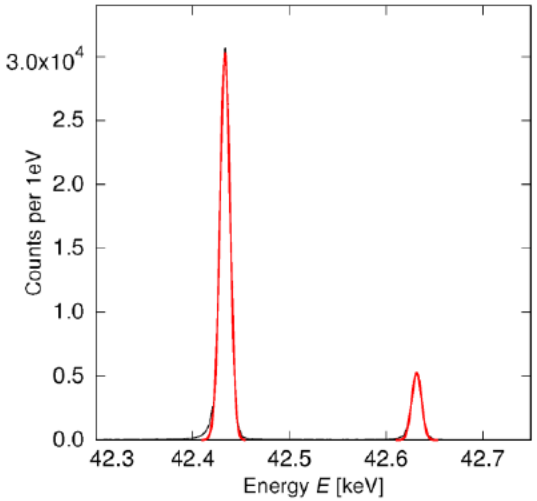
linearity calibration



- identify many lines
- deviation from linearity < 0.5 % @ 30 keV
- selection of well-known reference lines

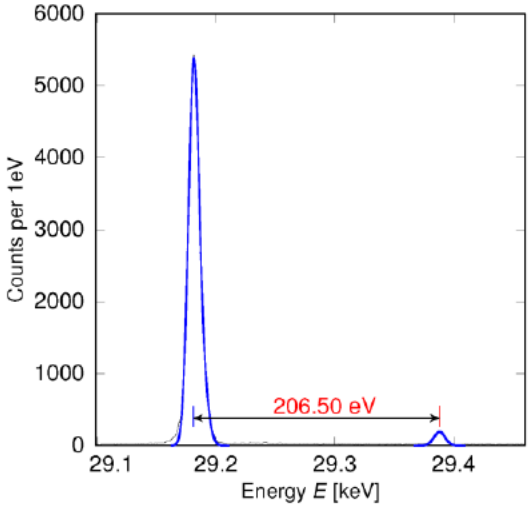
isomere energy of ^{229}Th

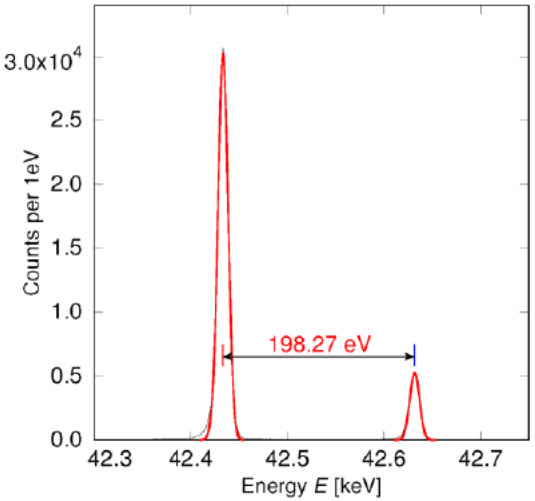




$$E_{\mathrm{iso}} = E_{29.39\mathrm{keV}} - E_{29.18\mathrm{keV}} - (E_{42.63\mathrm{keV}} - E_{42.43\mathrm{keV}})$$

isomere energy of ^{229}Th





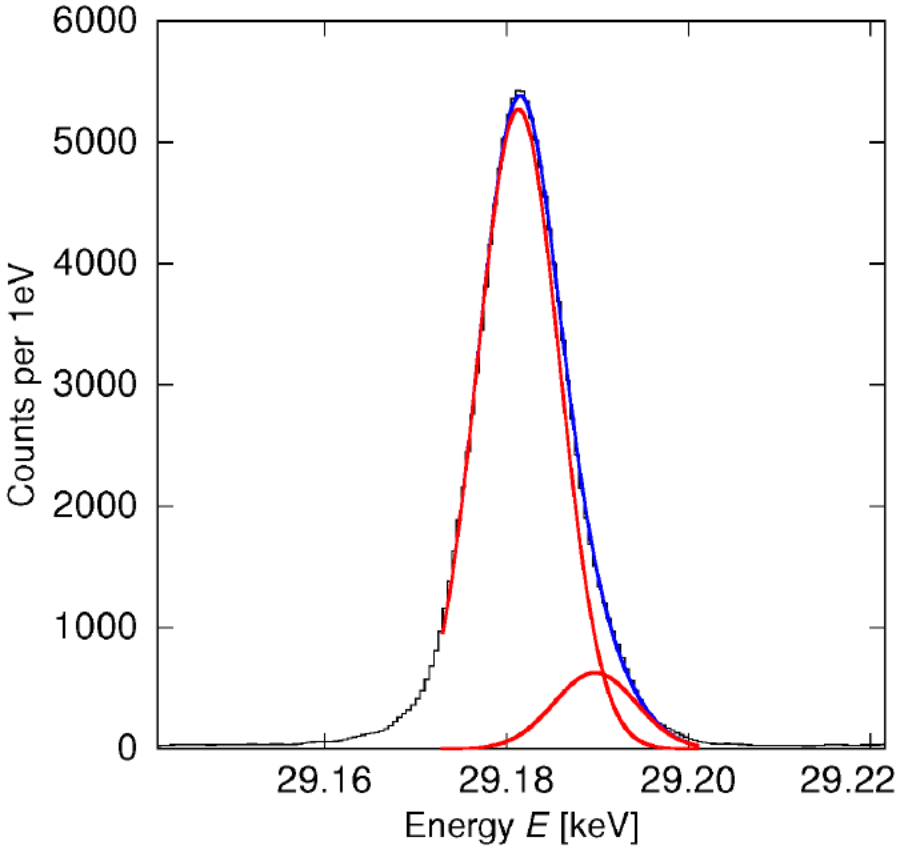
$$E_{\mathrm{iso}} = E_{29.39\mathrm{keV}} - E_{29.18\mathrm{keV}} - (E_{42.63\mathrm{keV}} - E_{42.43\mathrm{keV}})$$

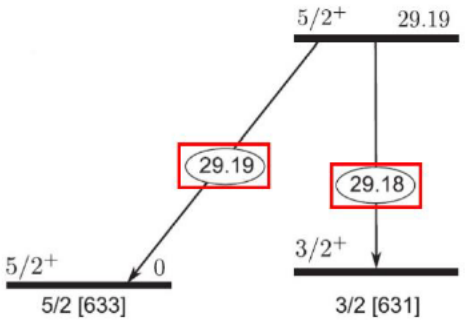
$$= (8.23 \pm 0.13_{\mathrm{stat}} \pm 0.3_{\mathrm{syst}})\ \mathrm{eV}$$

preliminary

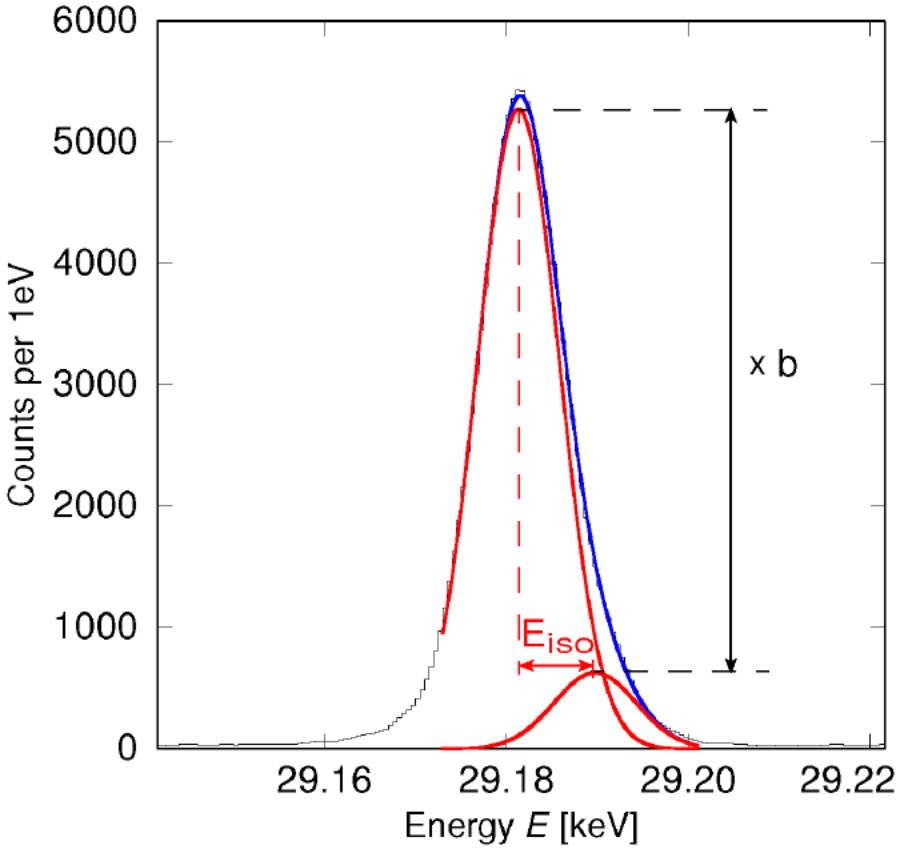
(preliminary - to be published soon)

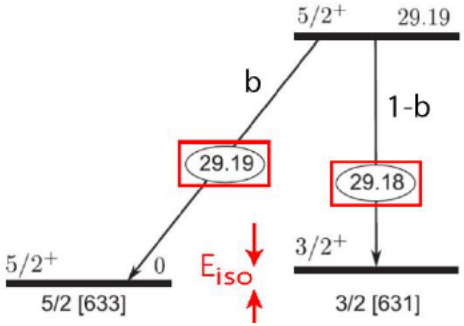
resolving the 29.2 keV doublet





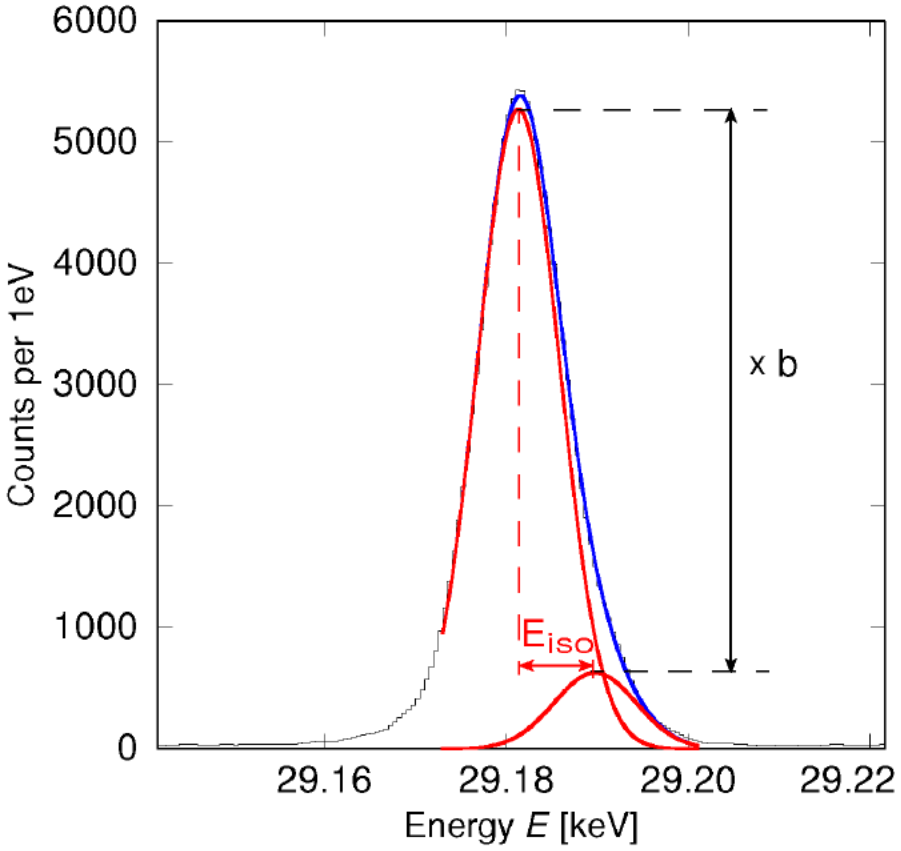
resolving the 29.2 keV doublet

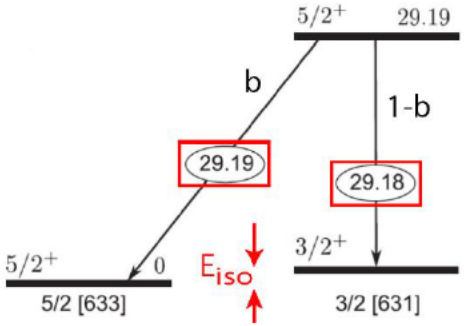




fix $E_{\mathrm{iso}} = 8.23$ eV $\rightarrow$ $b = \frac{1}{9.8}$

resolving the 29.2 keV doublet



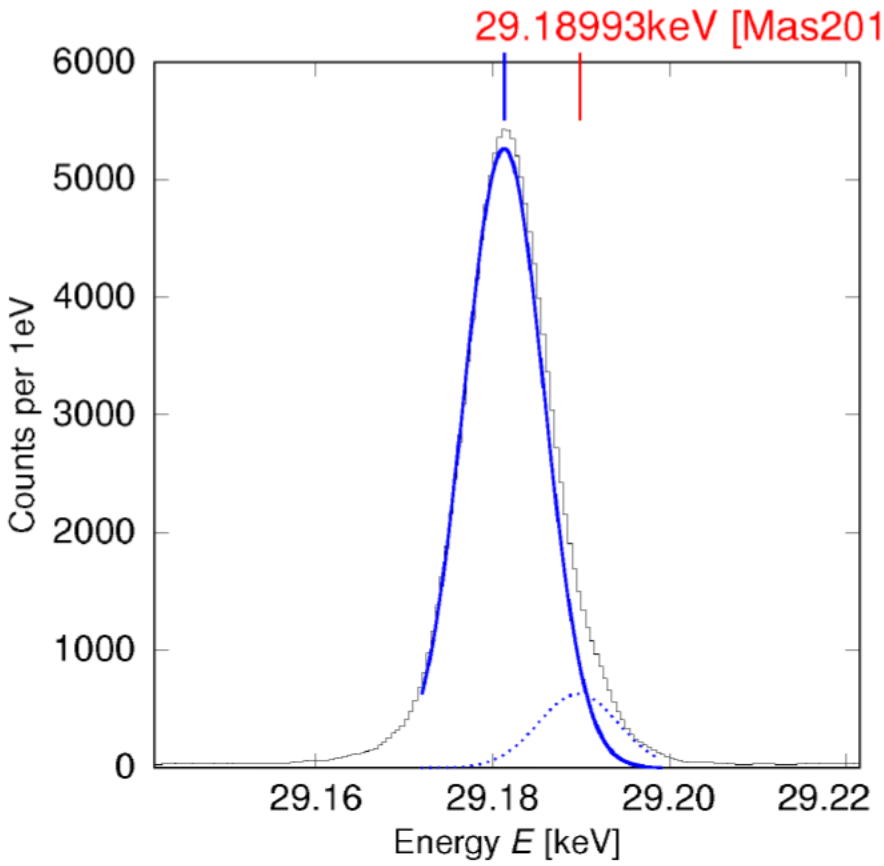


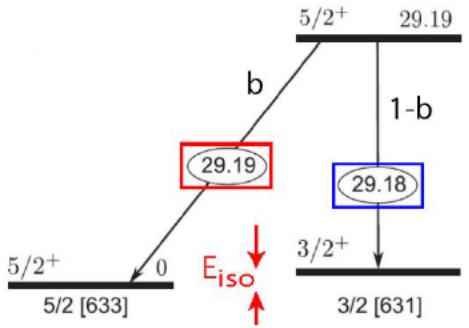
fix $E_{\mathrm{iso}} = 8.23$ eV $\rightarrow$ $b = \frac{1}{9.8}$

fix $b = \frac{1}{9.4 \pm 2.4}$ [Masuda2019]

$\rightarrow E_{\mathrm{iso}} = (8.2 \pm 1)$ eV

absolute position of the 29.2 keV - line

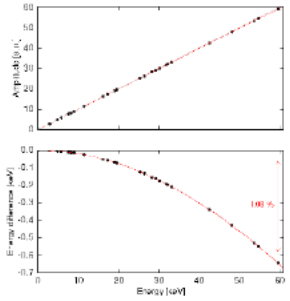


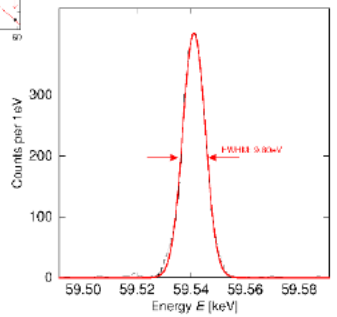


$E_{iso} = (8.30 \pm 0.74(stat) \pm 0.36(syst))$ eV

Poster by Haruka Muramatsu

summary and outlook





KIP
Heidelberg

- excellent linearity ✓
- out-standing energy resolution ✓
- co-addibility of many pixels ✓
- stability for long time measurements ✓

next steps

- include more lines for calibration
- calibrate non-linearity of ADCs
- resolve the 29.2 keV doublet

preliminary

$$E_{iso} = (8.23 \pm 0.13_{stat} \pm 0.3_{syst})\ eV$$