# Neutron Activation Analysis via Nuclear Decay Kinetics using Gamma-ray Spectroscopy at SFU

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Banff, Alberta

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Thermo Scientific P 385 neutron generator

^{2}H + ^{3}H $\longrightarrow$ n + α
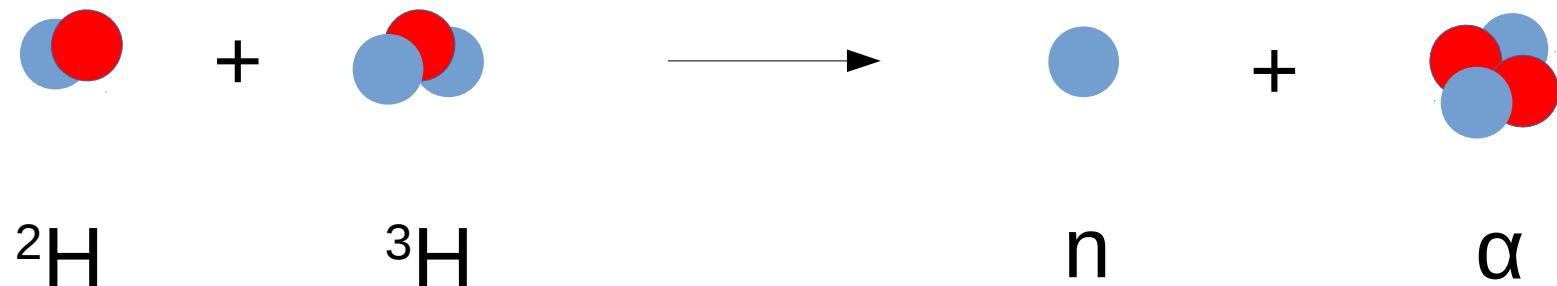
Metals available for neutron activation

Neutron activation

$n + {}^{27}Al \longrightarrow {}^{28}Al$

$n + {}^{27}Al \longrightarrow {}^{27}Mg + p$

$n + {}^{27}Al \longrightarrow {}^{26}Al + 2n$

$n + {}^{27}Al \longrightarrow {}^{24}Na + \alpha$

| Z	${}^{26}Si$ 2.2 s Decay: EC	${}^{27}Si$ 2.2 s Decay: EC	${}^{28}Si$ Stable Decay: EC	${}^{29}Si$ Stable Decay: EC
	${}^{25}Al$ 7.2 s Decay: EC	${}^{26}Al$ 7.2×10^5 a Decay: EC	${}^{27}Al$ Stable Decay: EC	${}^{28}Al$ 2.2 min Decay: β^-
	${}^{24}Mg$ Stable Decay: EC	${}^{25}Mg$ Stable Decay: EC	${}^{26}Mg$ Stable Decay: EC	${}^{27}Mg$ 9.4 min Decay: β^-
	${}^{23}Na$ Stable Decay: EC	${}^{24}Na$ 15 h Decay: β^-	${}^{25}Na$ 59 s Decay: β^-	${}^{26}Na$ 1.1 s Decay: β^-
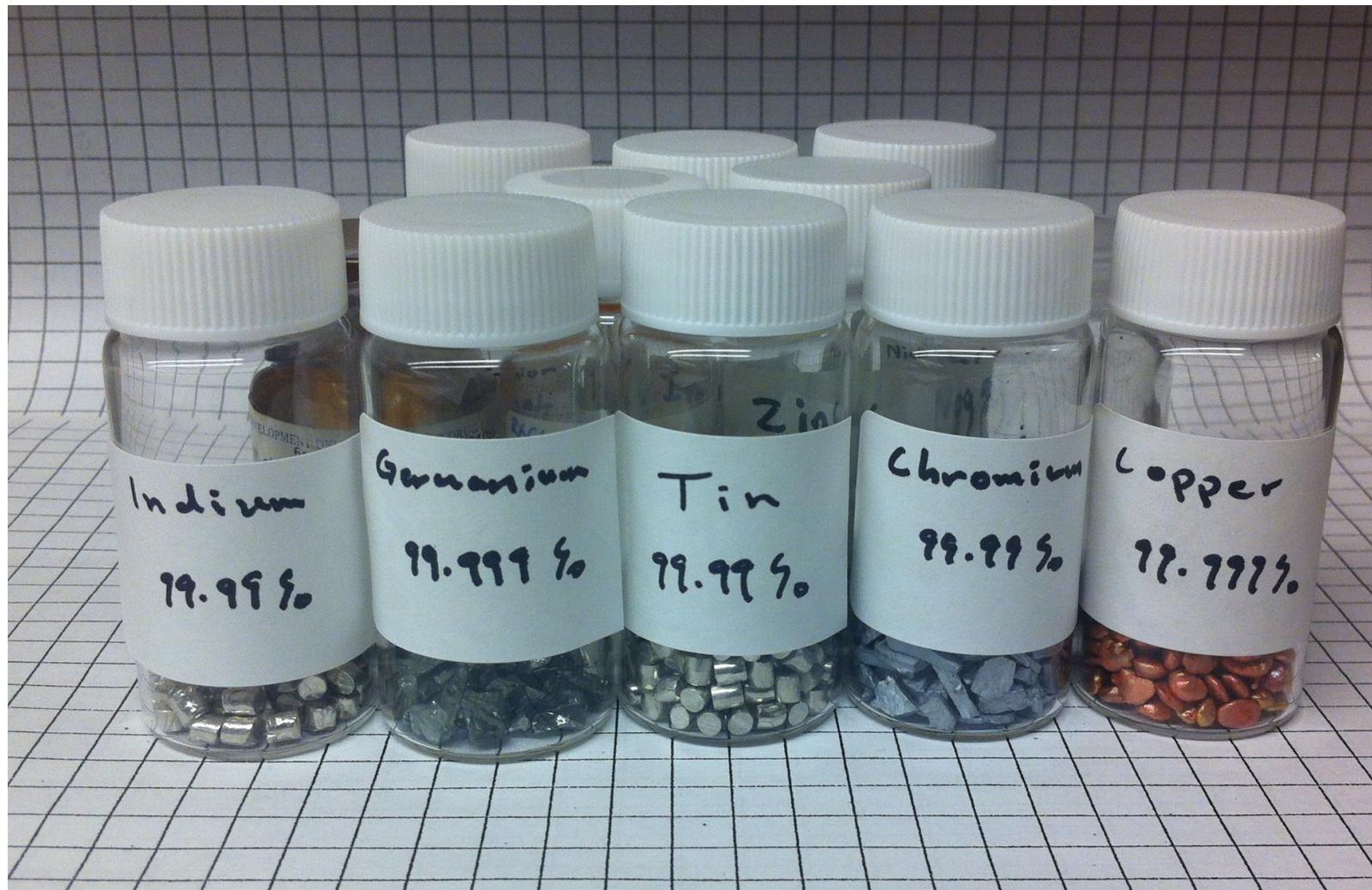
N
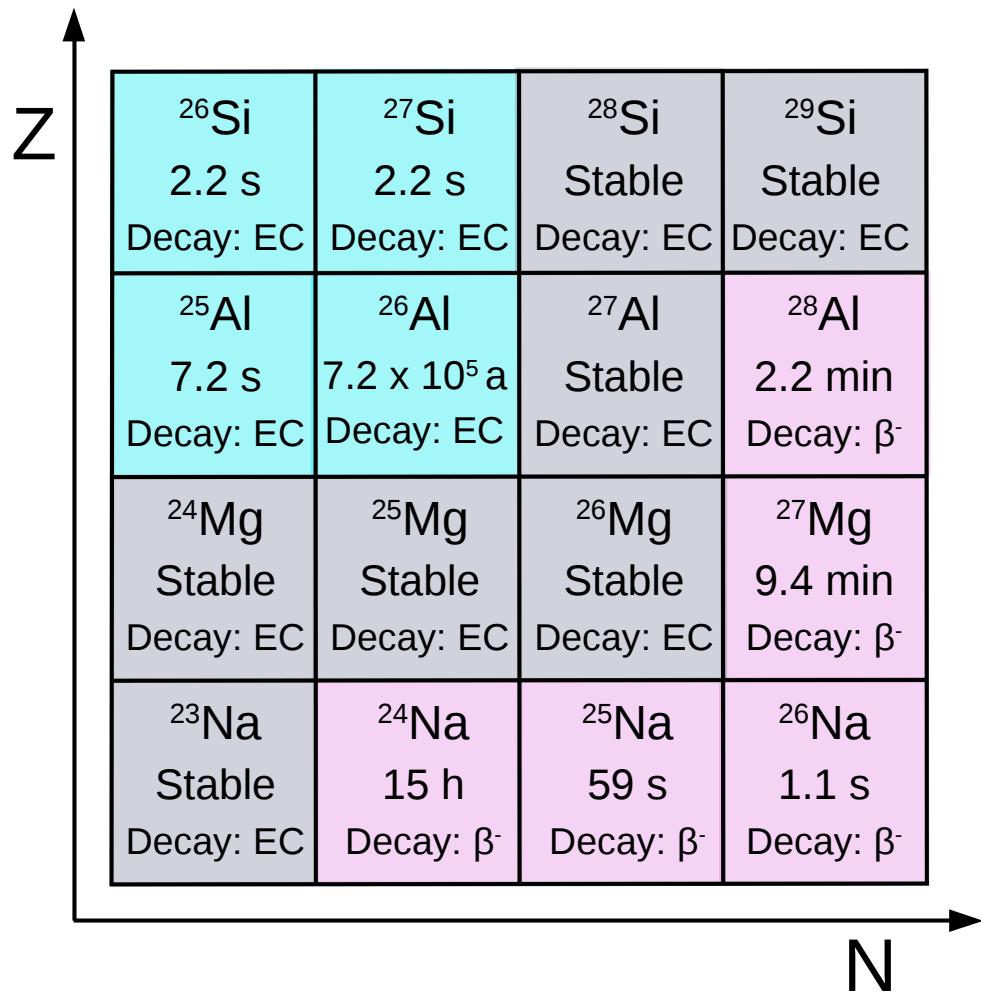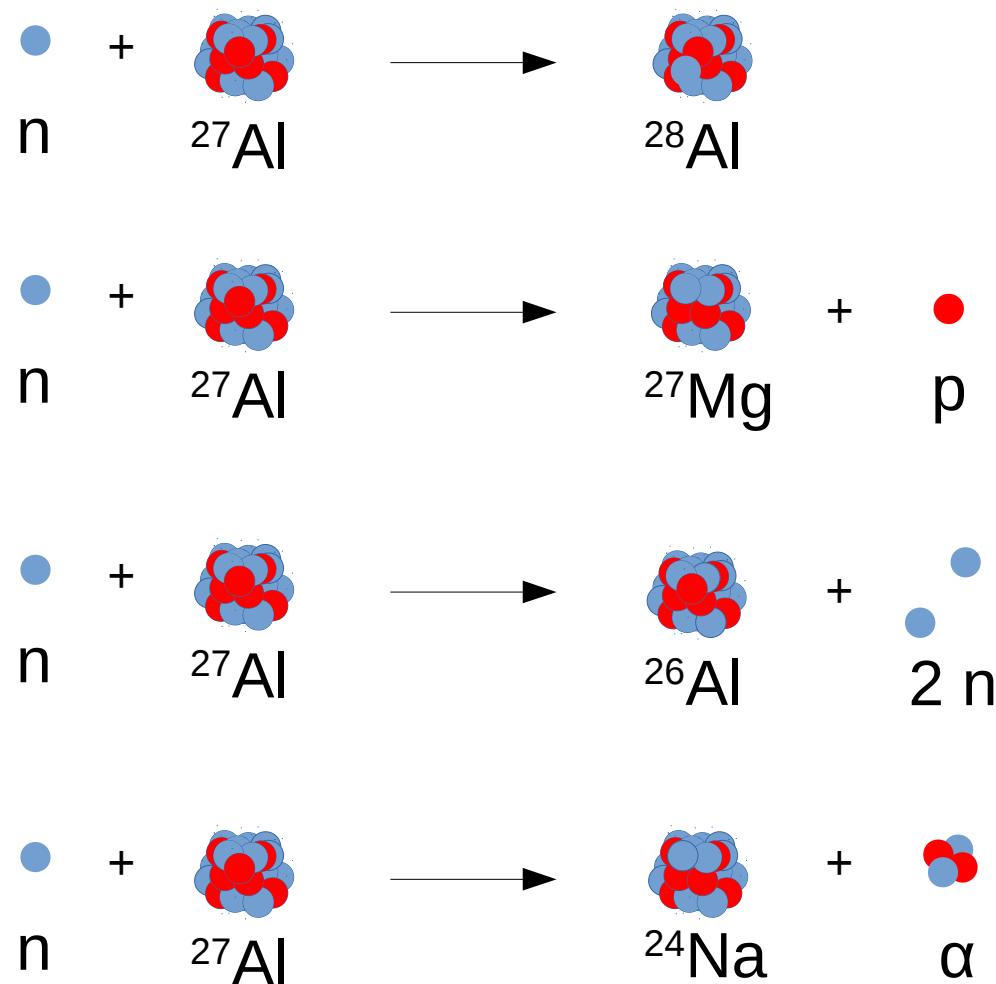
The Germanium detector for Elemental Analysis and Radioactivity Studies (GEARS)
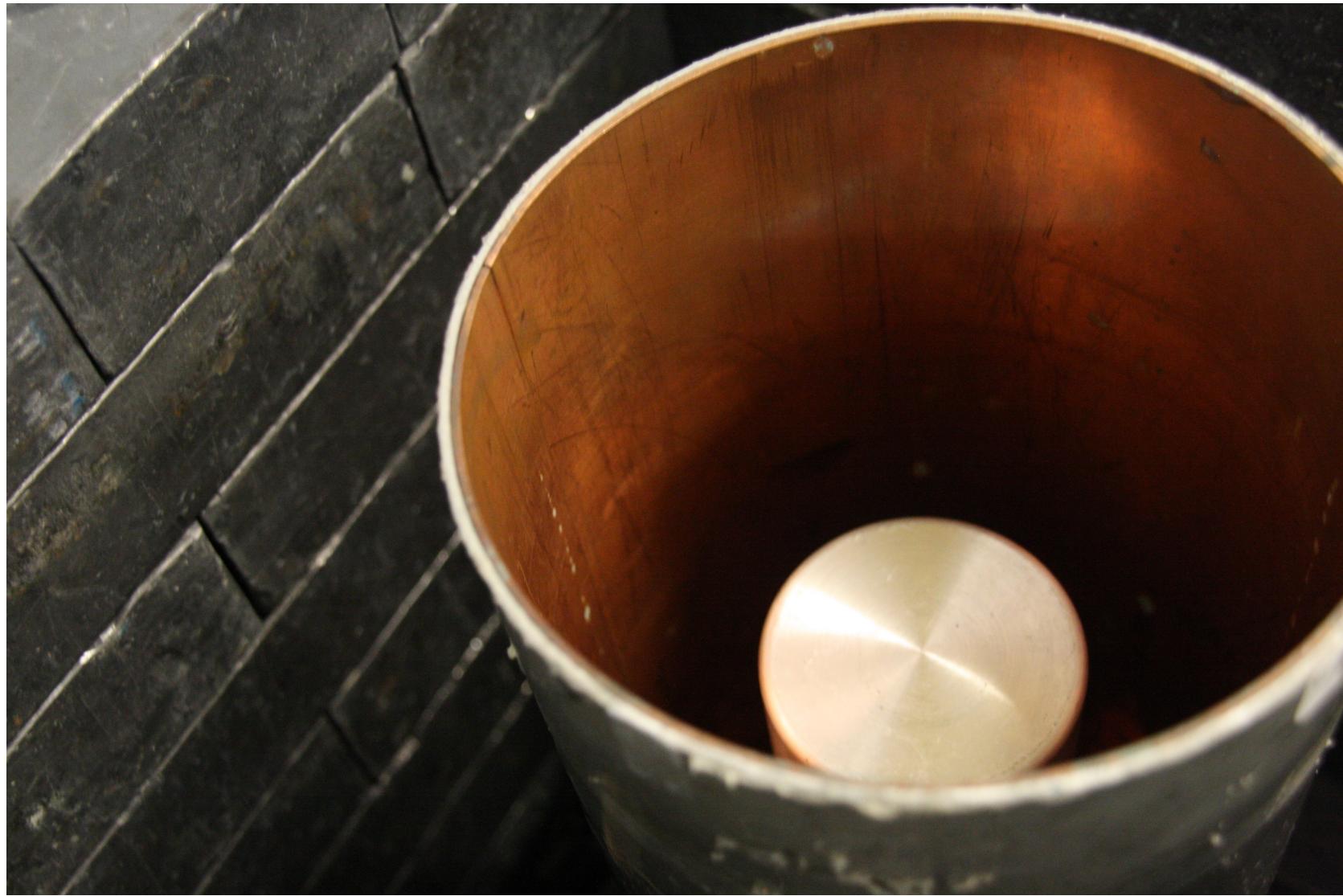

A. Chester et al, *Journal of Environmental Radioactivity*, vol. 124, pp. 205-213, 2013.
T. Domingo et al. *Radiation Physics and Chemistry*, in press.

Measuring long-lived radioisotopes
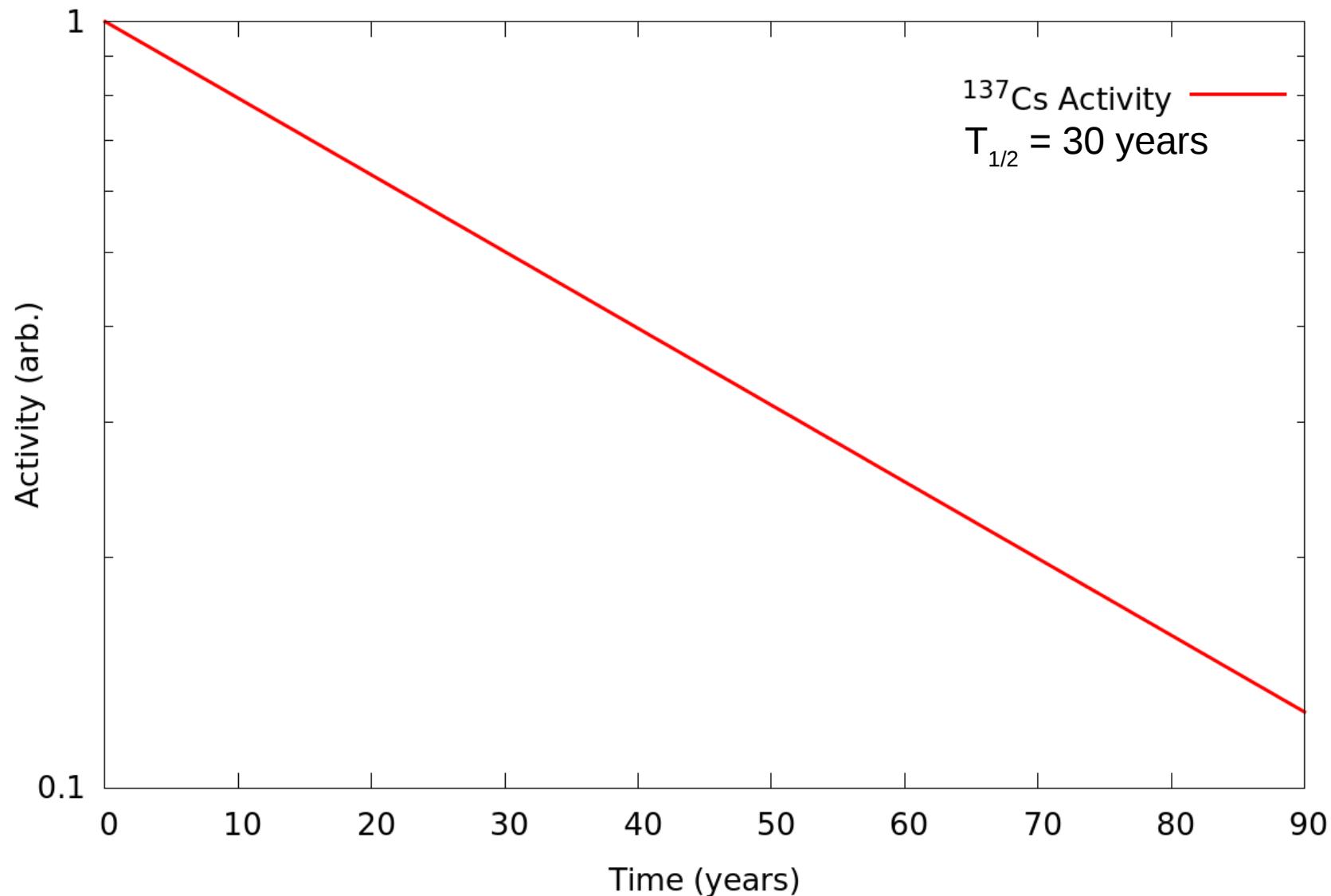
Measuring long-lived radioisotopes
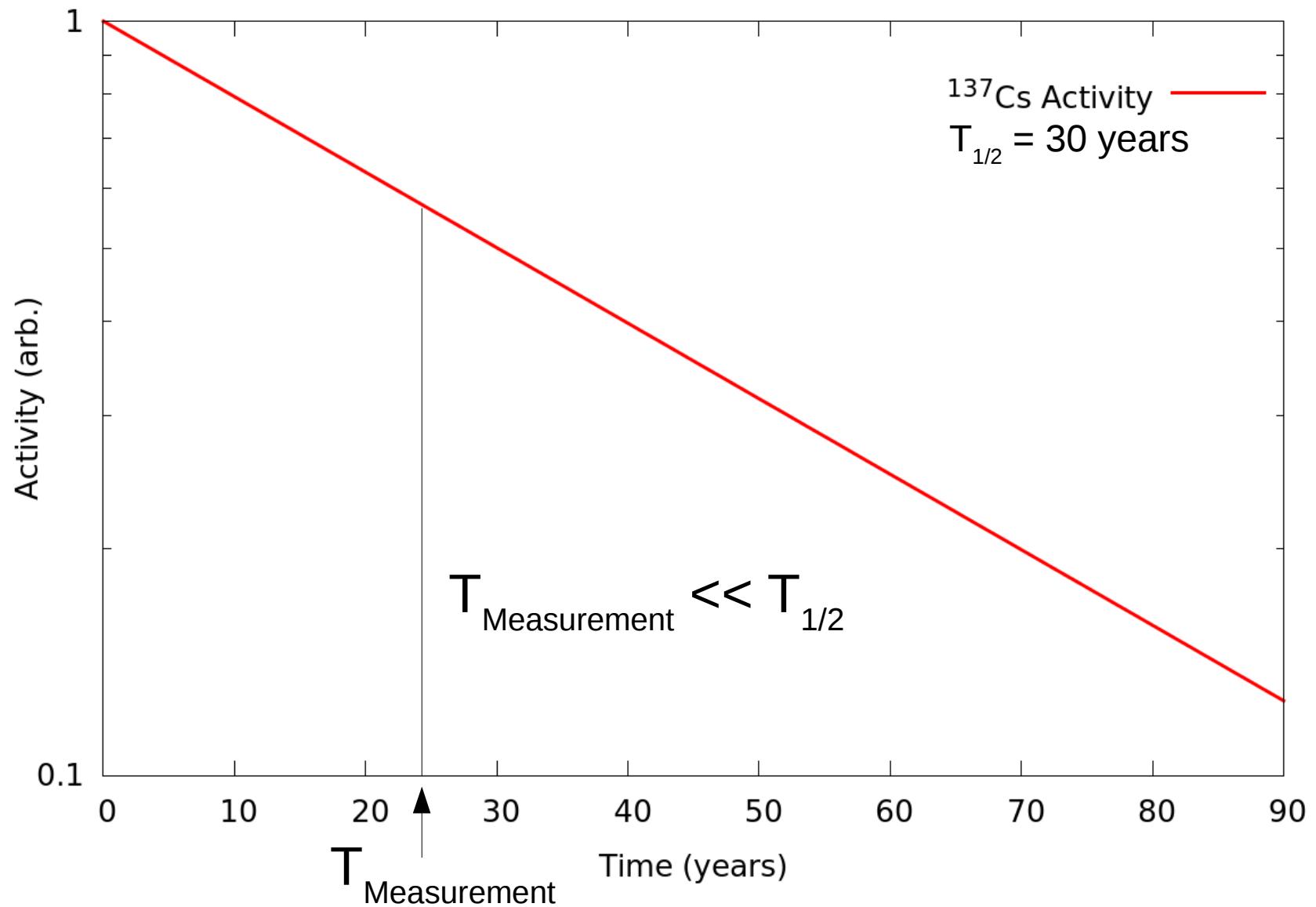
Measuring short-lived radioisotopes
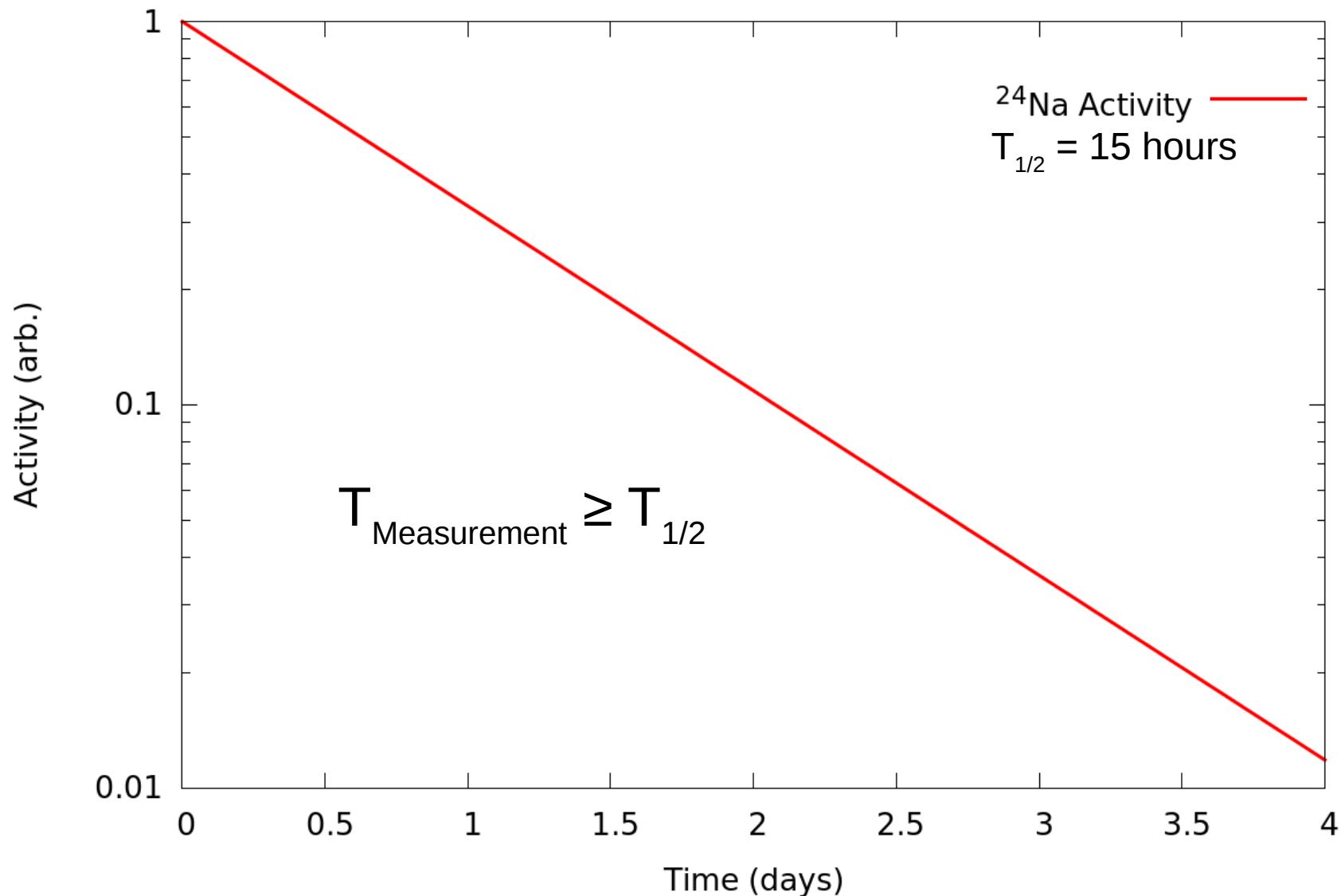
Introduce time-resolution to gamma-ray spectroscopy

Replace the Ortec Dspec jr. 2.0 with a CAMAC-based data acquisition system

1) Maintain or improve the energy response from the detector

2) Add a time stamp to each recorded energy event
   - Requires a fast clock

3) Measure the "deadtime" of the data acquisition system
   - Required for having a high quality efficiency characterisation of the detector

Measurement of the energy response

Energy Response →

Analog to Digital Converter

FWHM at 1332 keV ≈ 1.7 keV

1) Maintain or improve the energy response

- ^{60}Co is the standard used for reference
- Energy resolution improved by 12%

Counts per 100000 seconds

1173 keV   1332 keV

Energy [keV]

Measurement of the energy response

$$FWHM(E) = \sqrt{H \times E^2 + G \times E + F}$$
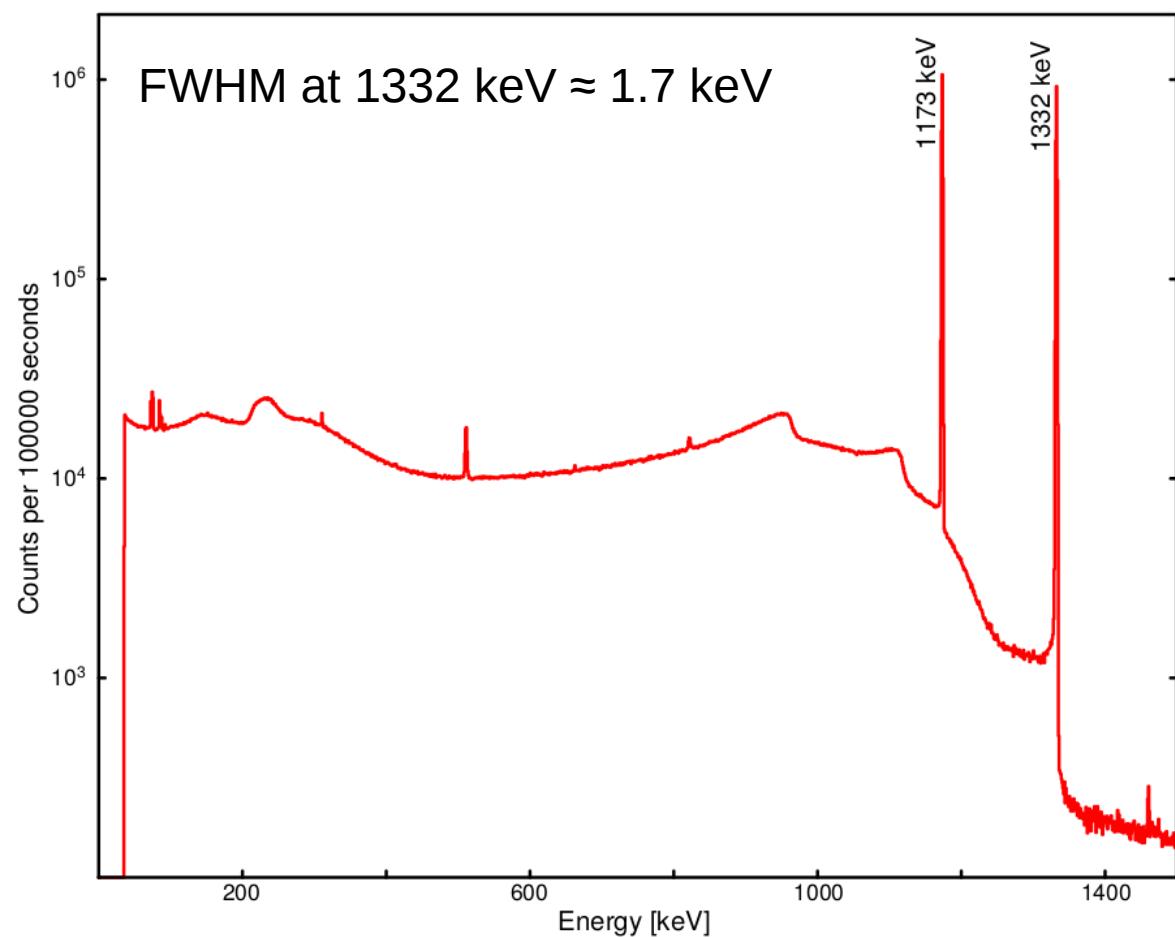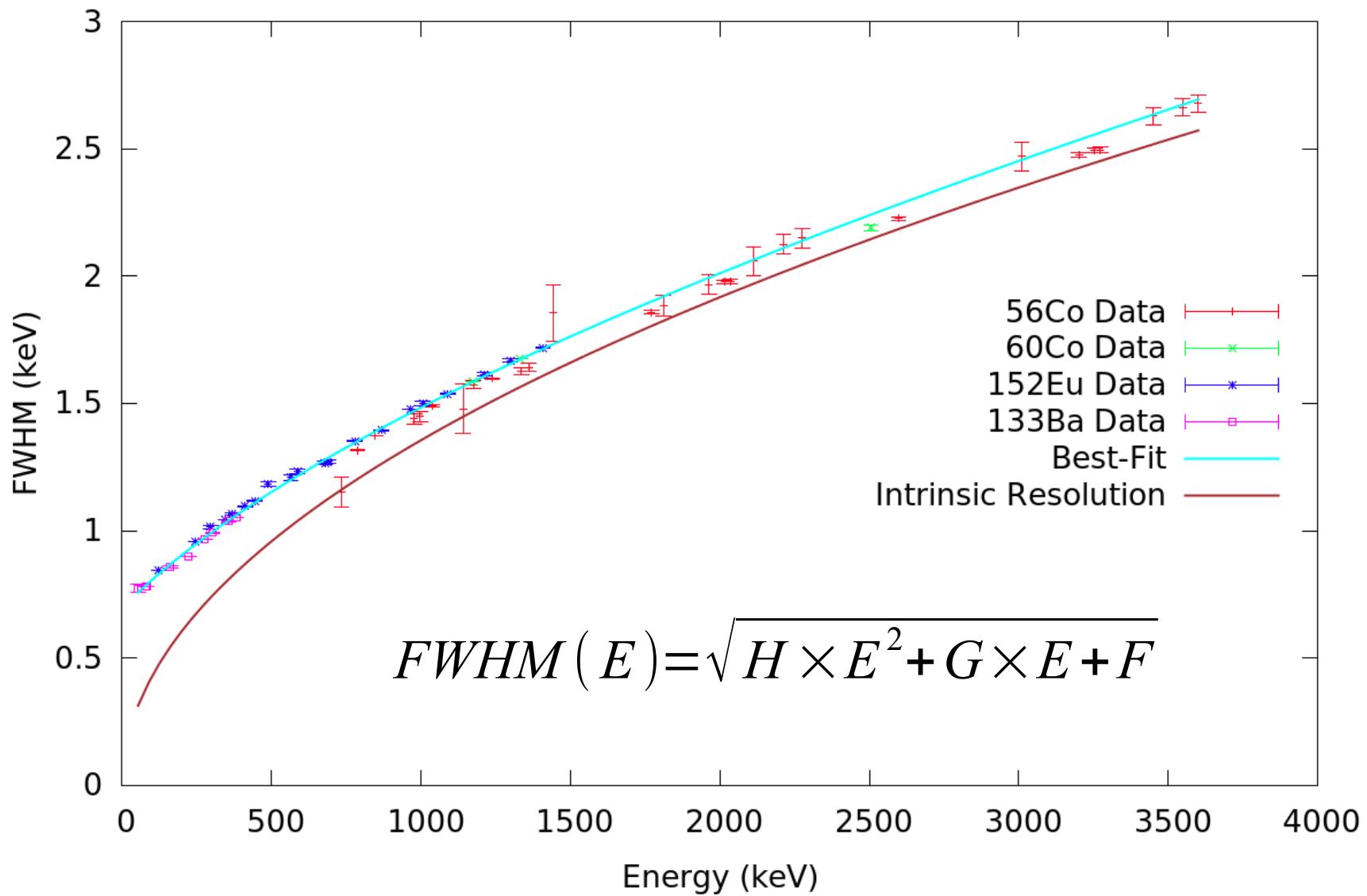
Upgrading GEARS: Adding a fast clock

2) Add a time stamp to each recorded energy event
- Requires a fast clock

Energy Response

Analog to Digital Converter

Scaler

Scaler (Inhibited)

10 MHz Oscillator
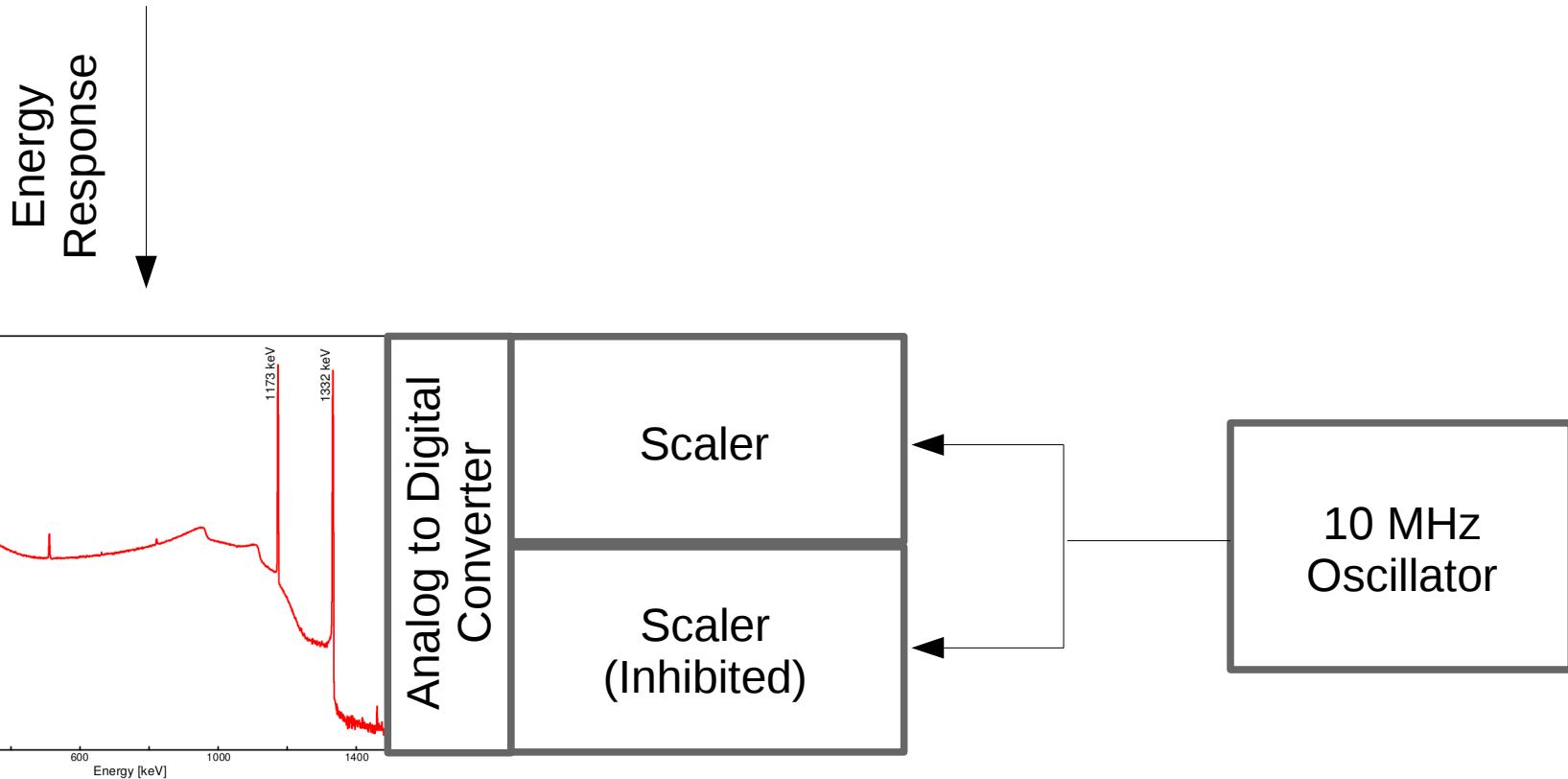
Upgrading GEARS: generating a trigger

Output Signal

Timing Filter Amplifier

Amplified Signal

Constant Fraction Discriminator

Energy Response

Analog to Digital Converter

Scaler

Scaler (Inhibited)

10 MHz Oscillator

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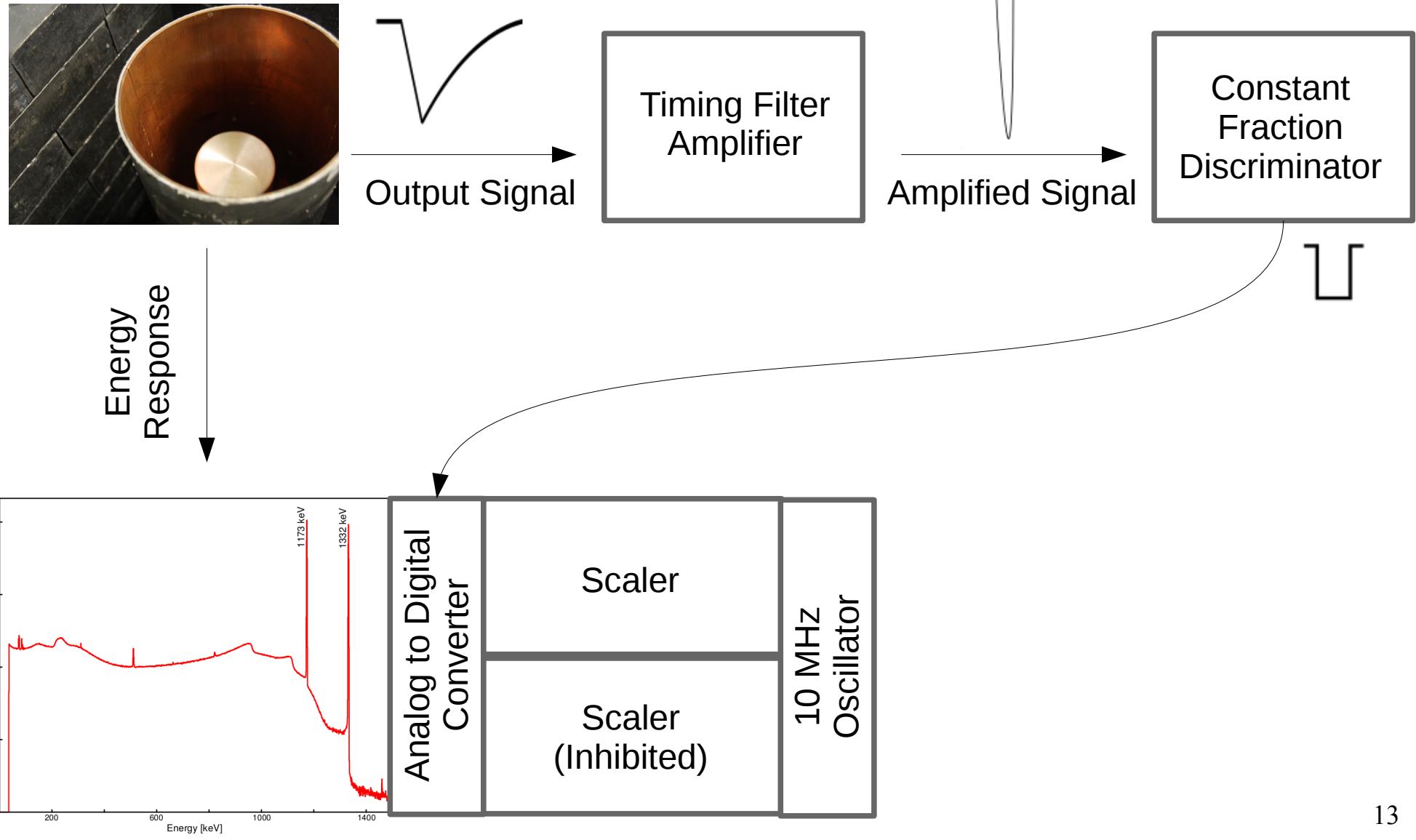
# Upgrading GEARS: measuring the deadtime

14
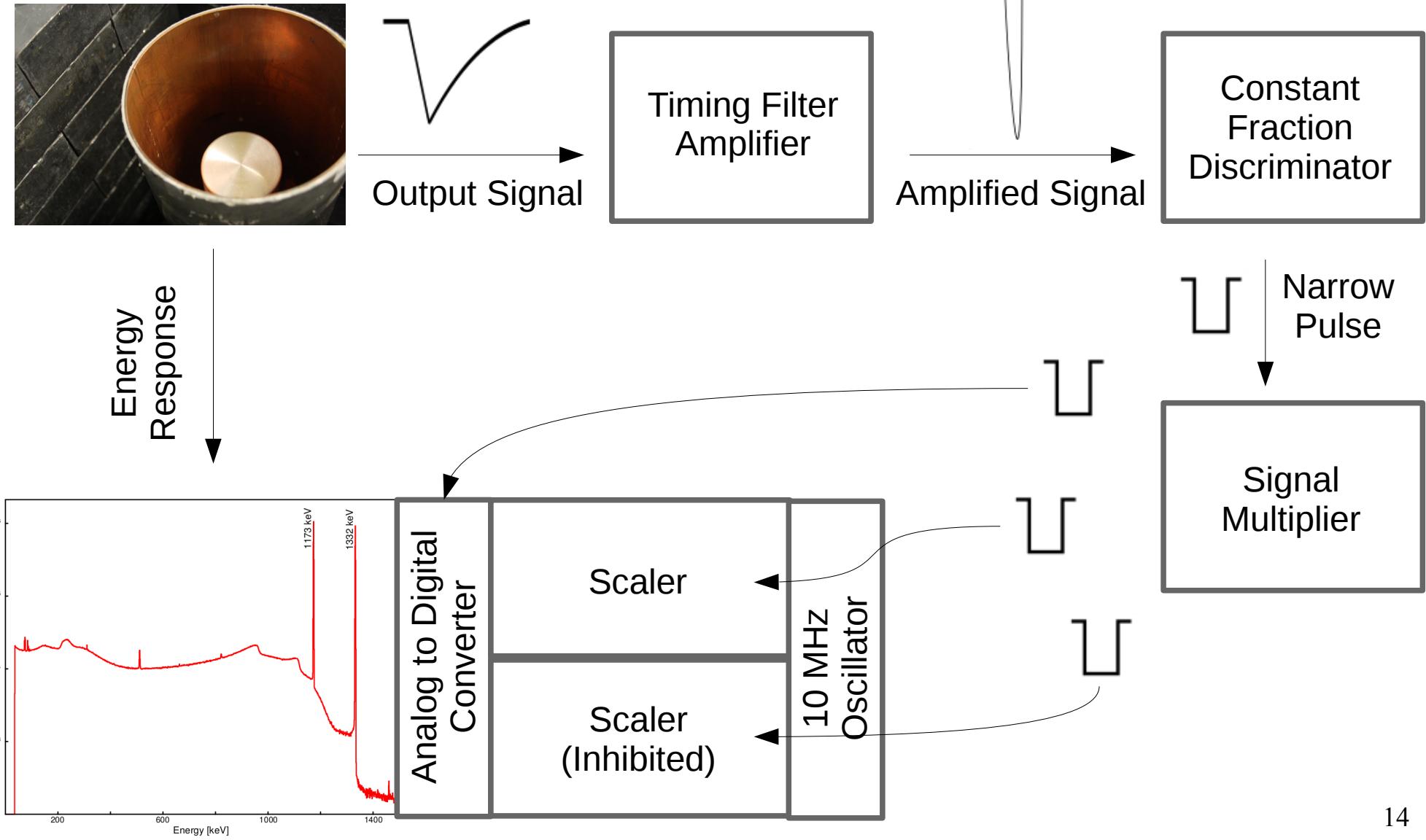
# Verification of the deadtime measurement
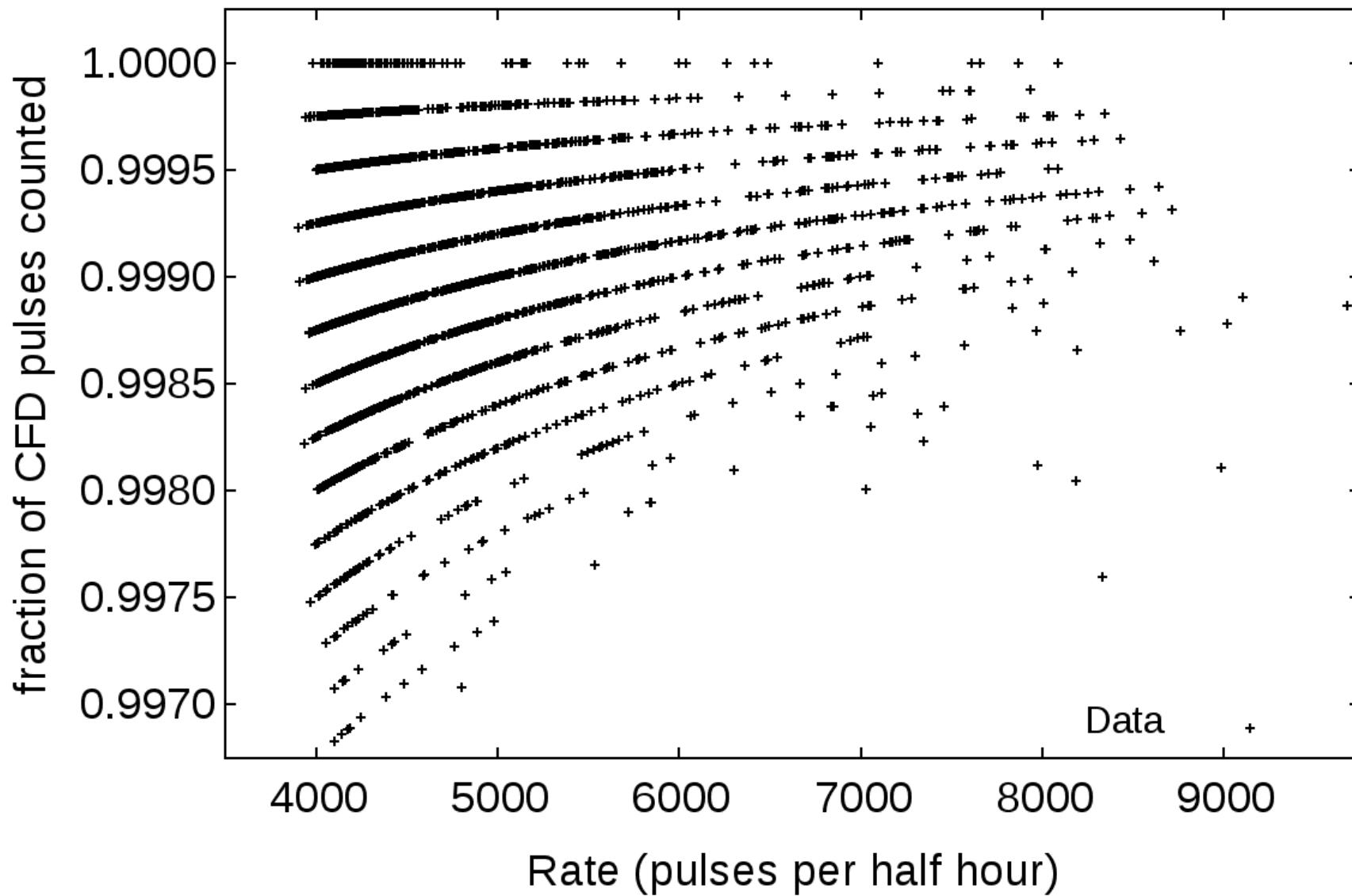
Verification of the deadtime measurement
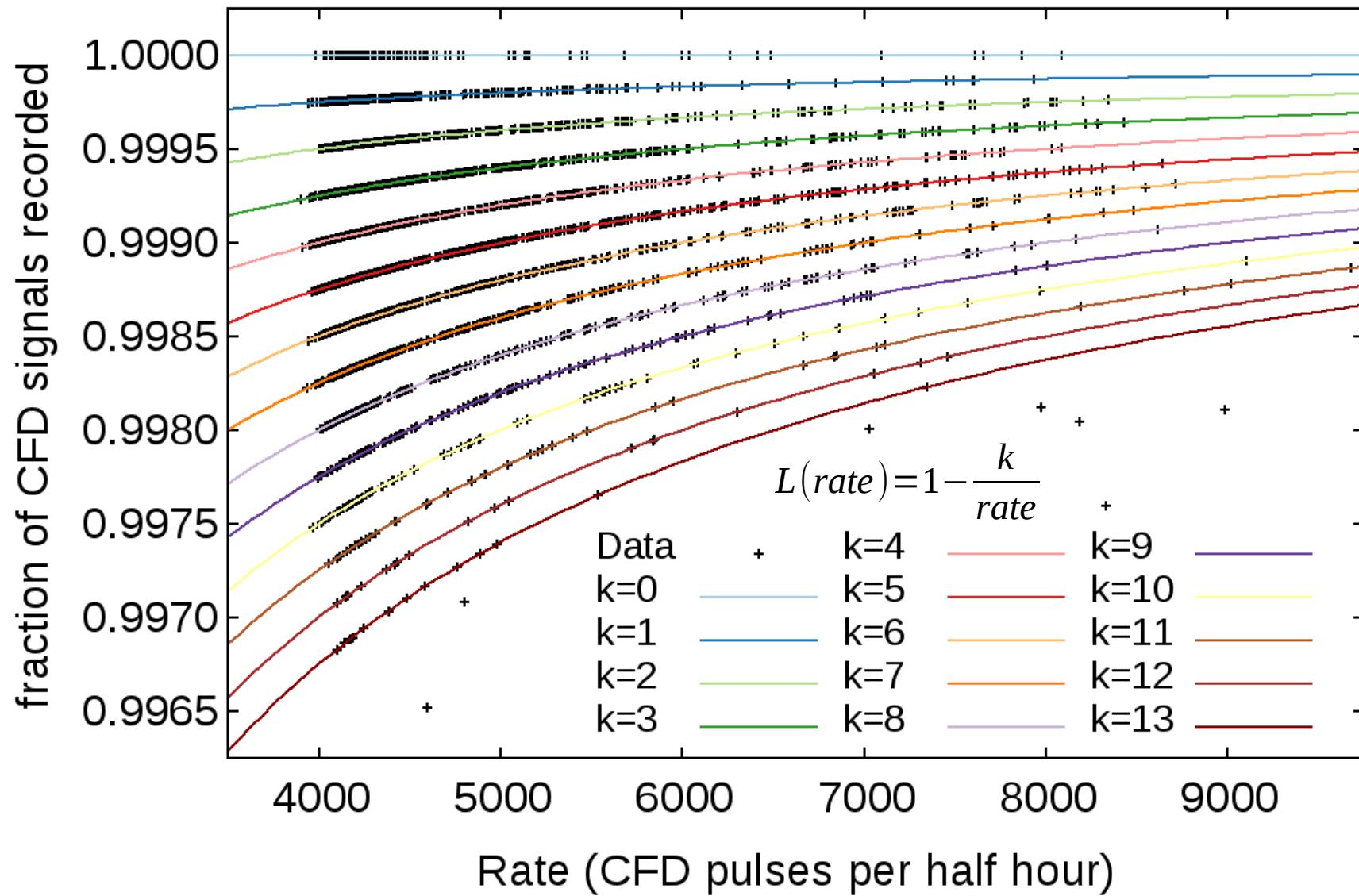
# The number of half hour intervals with k events lost
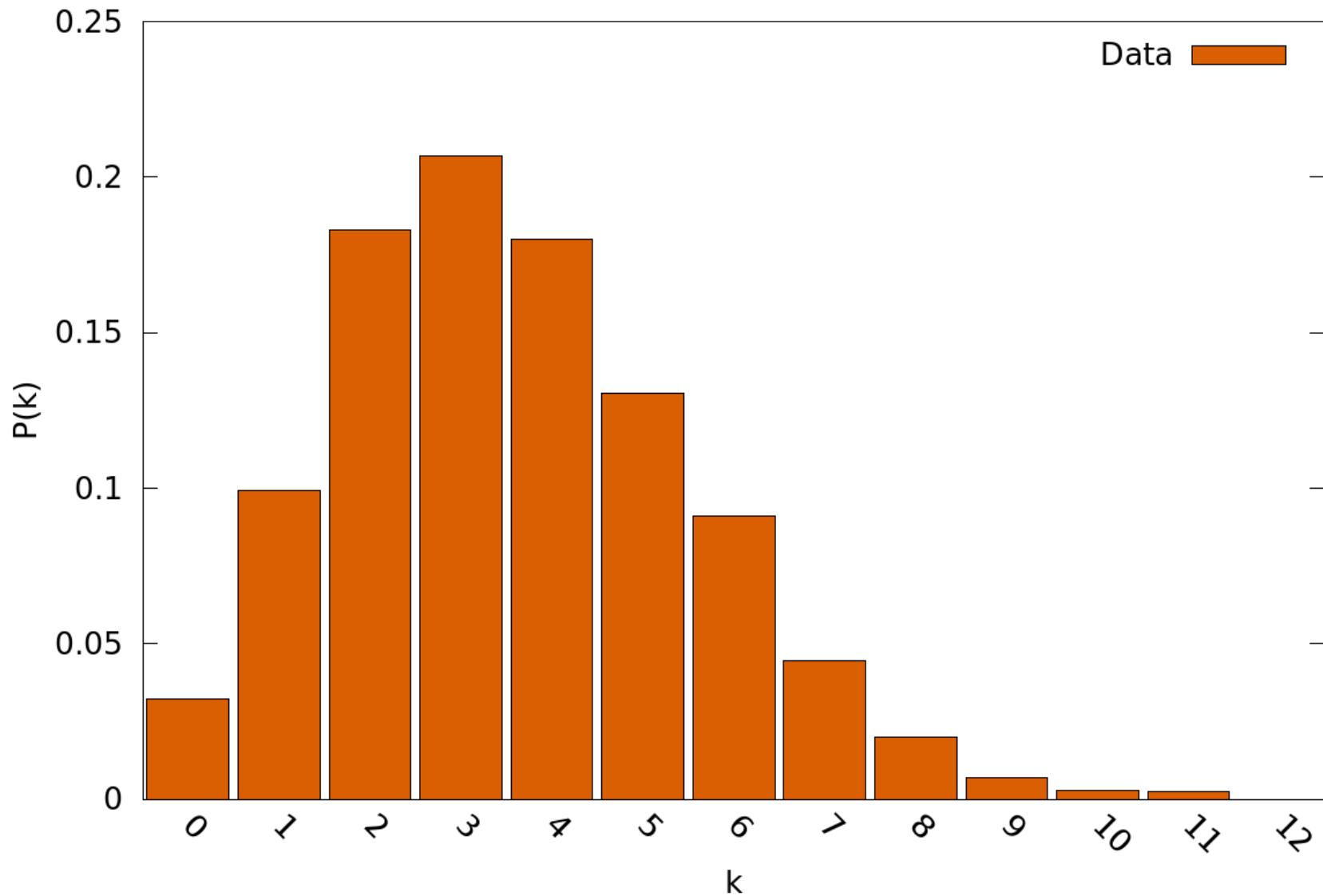
The number of half hour intervals with k events lost
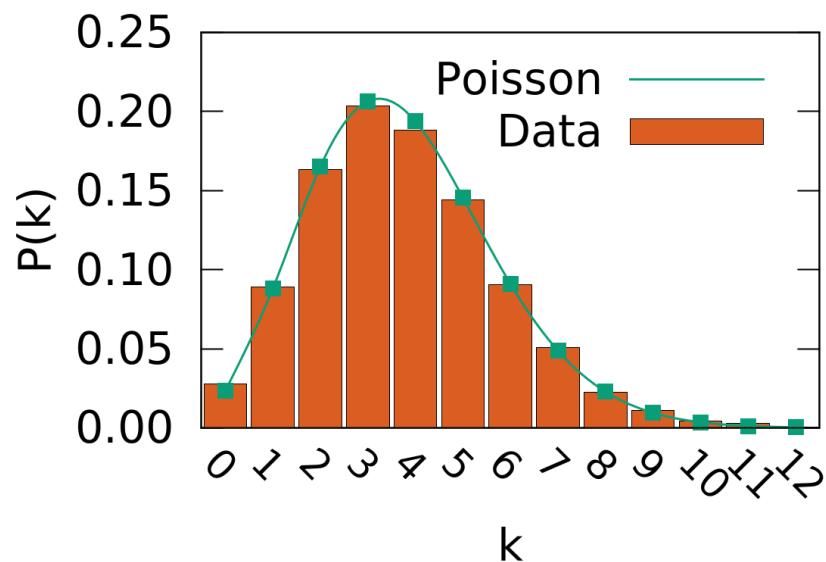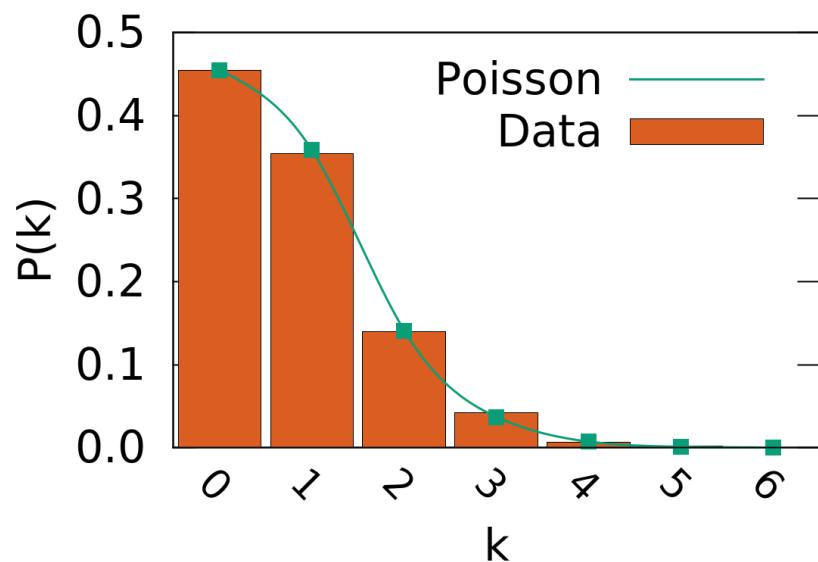
# Upgrading GEARS: the addition of timing

Activation of Aluminium-27

Activation of Aluminium-27

$n + {}^{27}Al \rightarrow {}^{24}Na + \alpha$
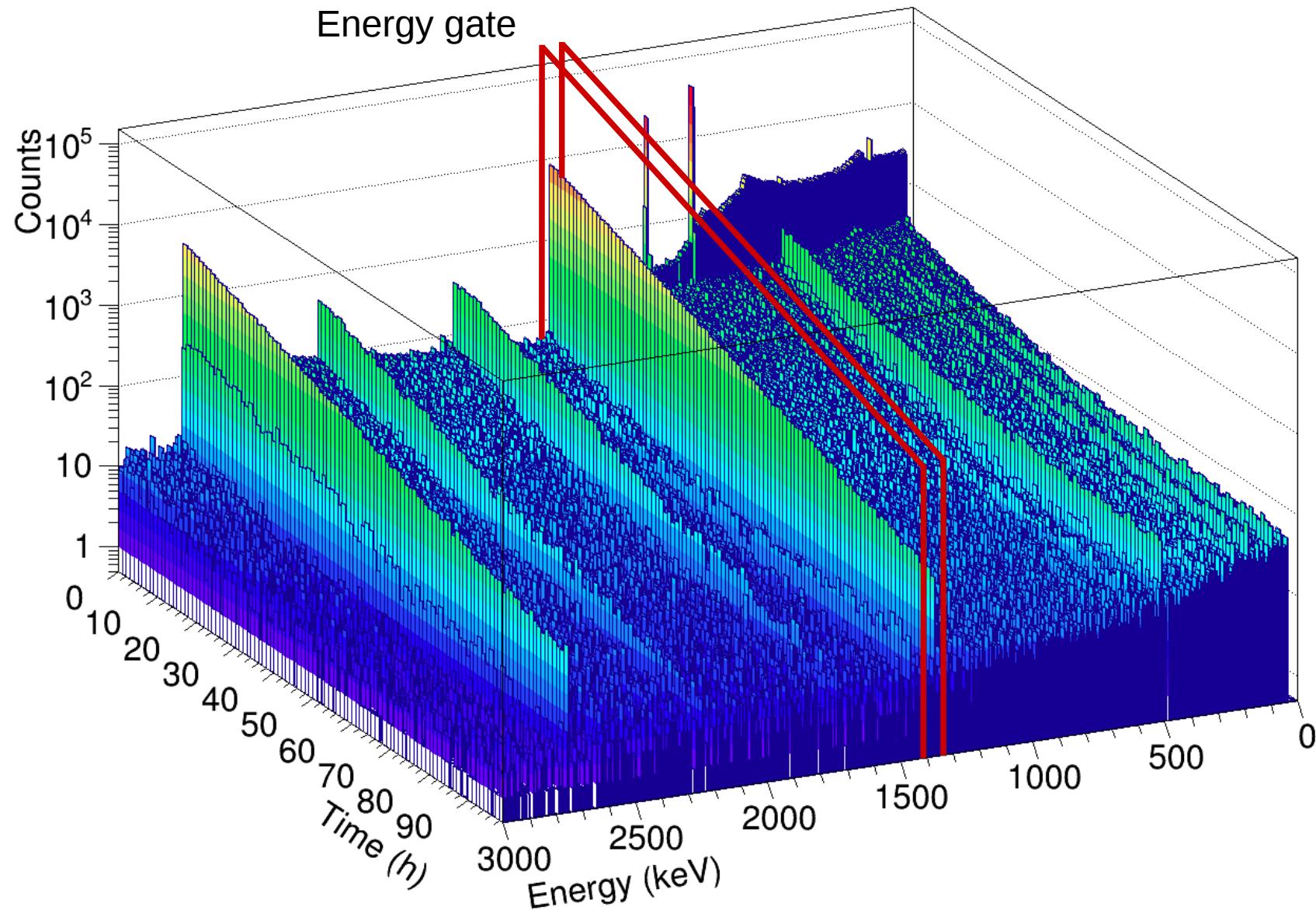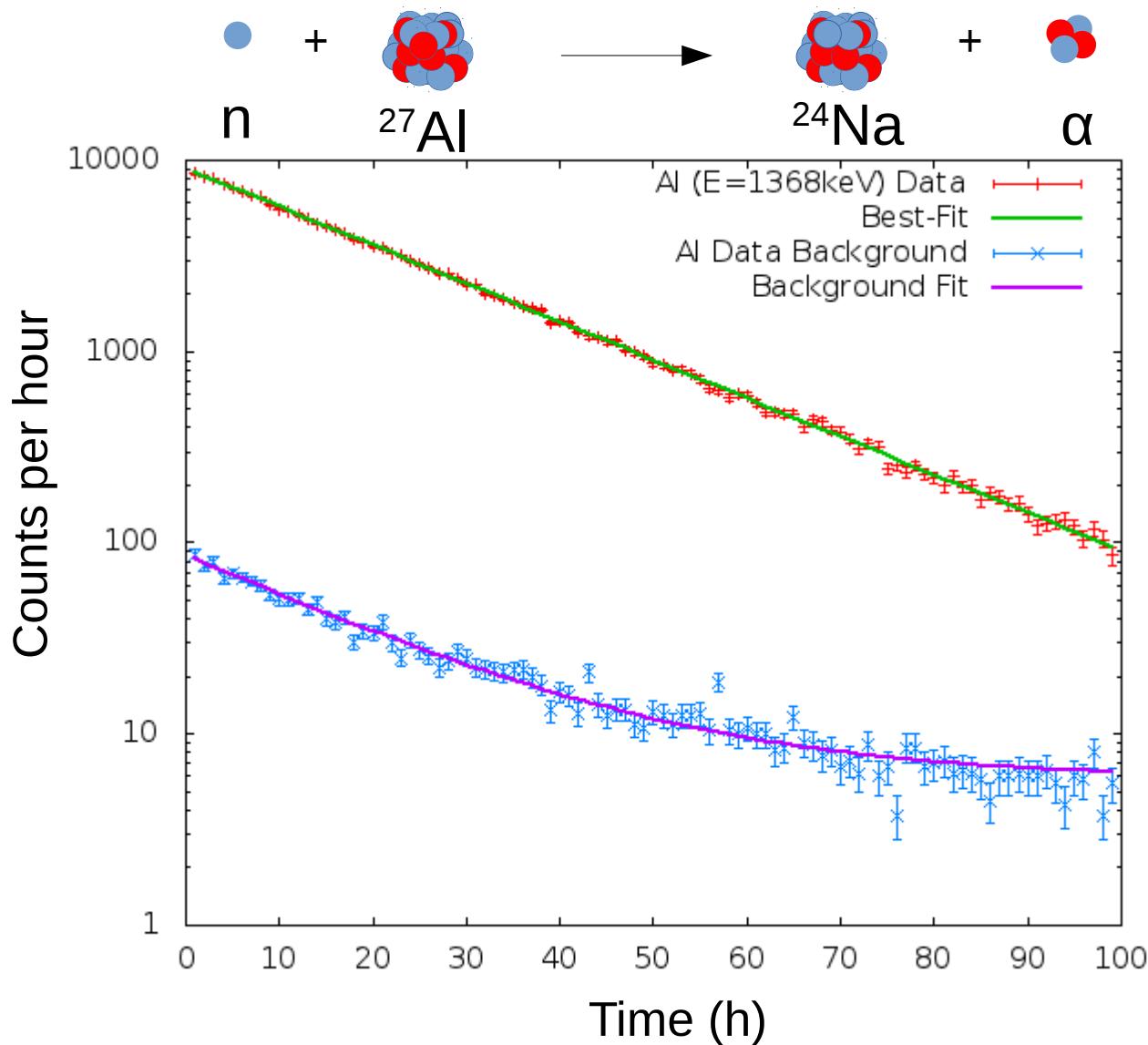
Literature $T_{1/2}$ (h): 14.997(12)

Extracted $T_{1/2}$ (h): 14.99(6)

Activation of Aluminium-27

n + ^{27}Al → ^{27}Mg + p
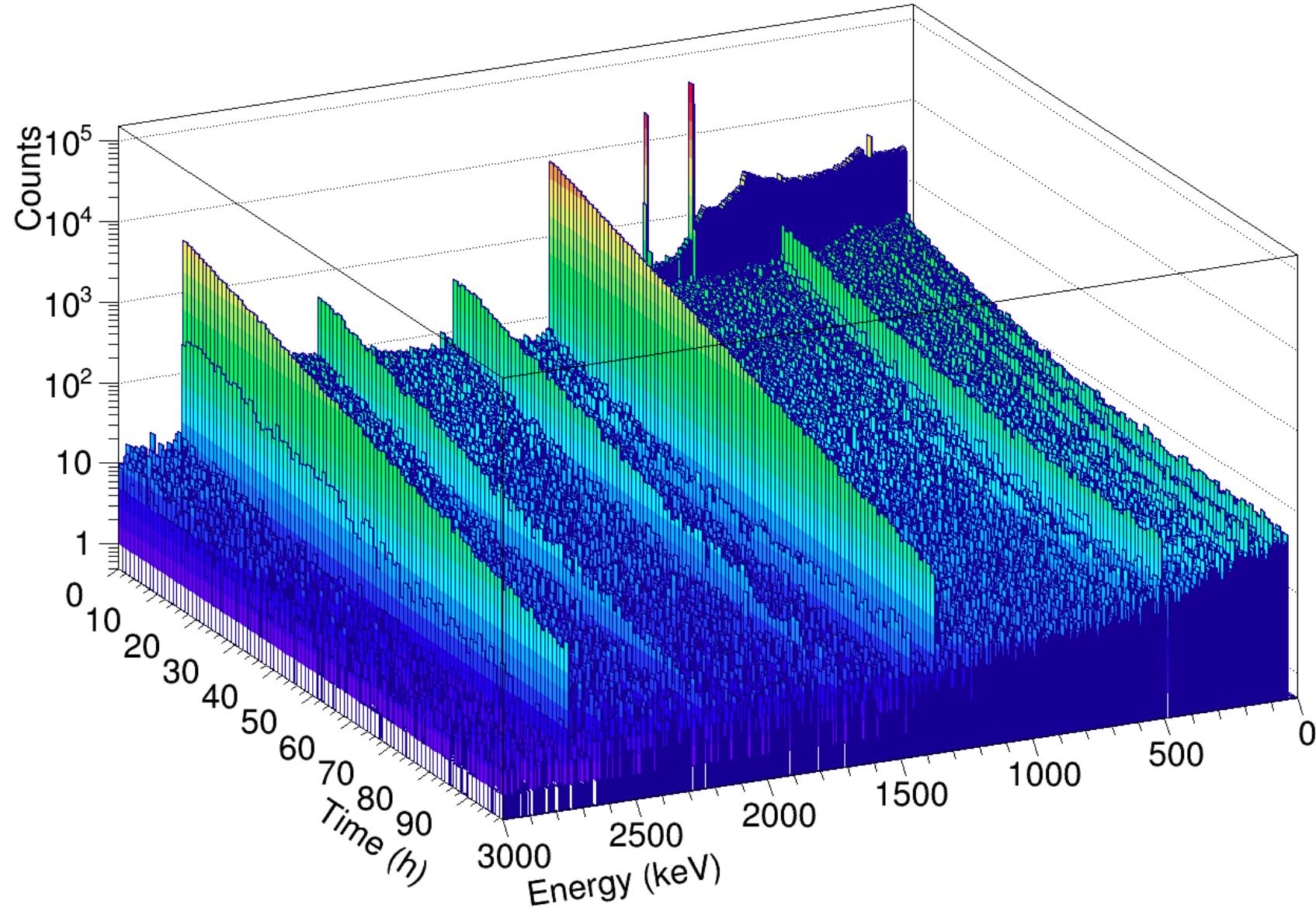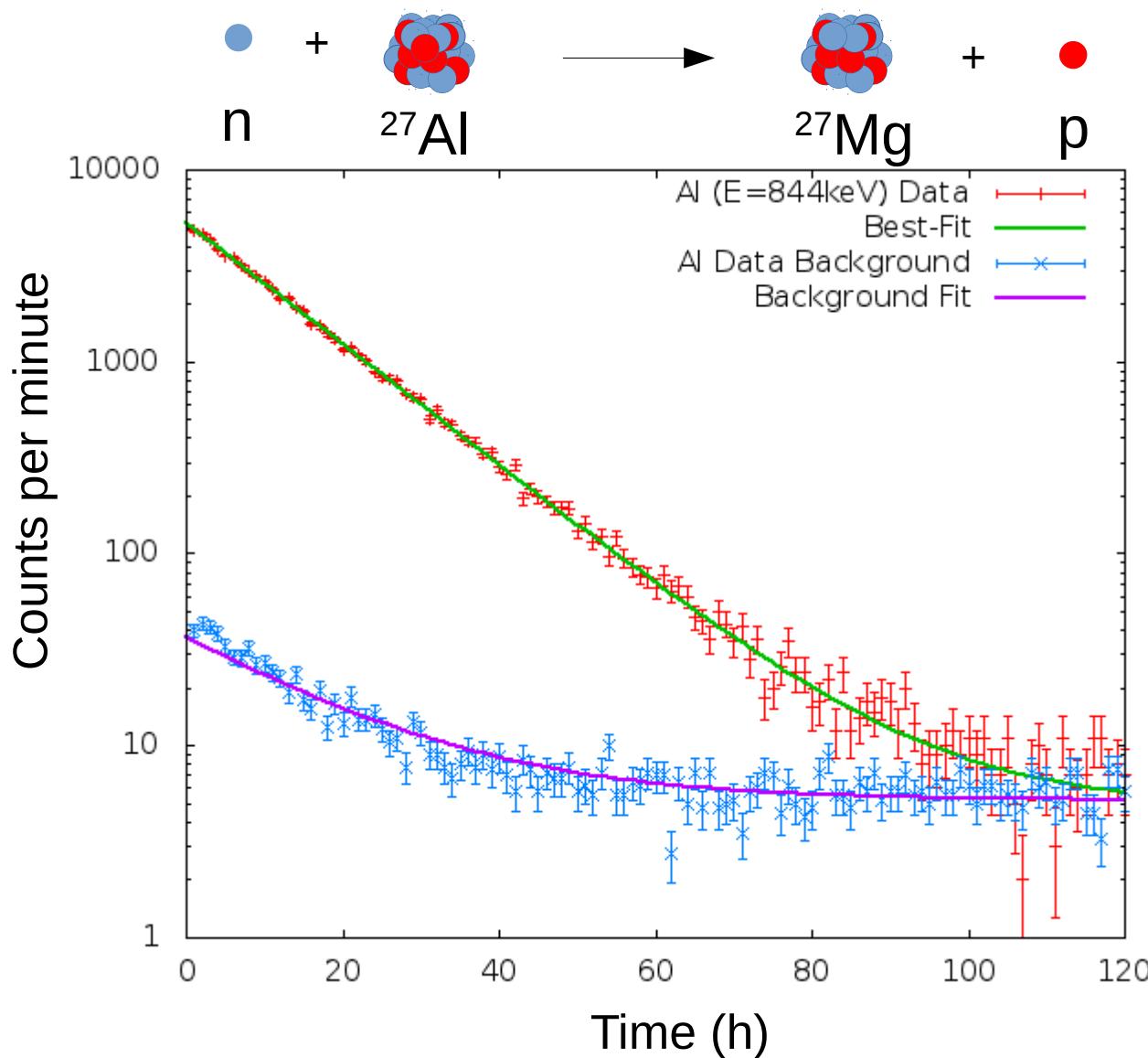
Literature $T_{1/2}$ (min): 9.458(12)

Extracted $T_{1/2}$ (min): 9.49(5)

^{117m}Sn

^{117m}Sn-Diethylenetriaminepentaacetic (DTPA)

- In clinical trials to treat metastatic bone pain
- Decays via gamma emission (E_γ = 158.5 keV, I = 86%)
- Emits Auger electrons
  - High bone surface dose to red bone marrow dose ratio

$T_{1/2}$ (days)	Reference
14.00(25)	Mihelich et al., 1950
14.0(5)	Cork et al., 1951
13.60(4)	Kato et al., 1977
13.98(4)	Popov et al., 2003

$$n + {}^{116}Sn \longrightarrow {}^{117m}Sn$$

$$n + {}^{117}Sn \longrightarrow {}^{117m}Sn + n'$$

$$n + {}^{118}Sn \longrightarrow {}^{117m}Sn + 2n$$

$$n + {}^{117}Sn \longrightarrow n \; p + {}^{117}In \xrightarrow{\beta^-} {}^{117m}Sn$$
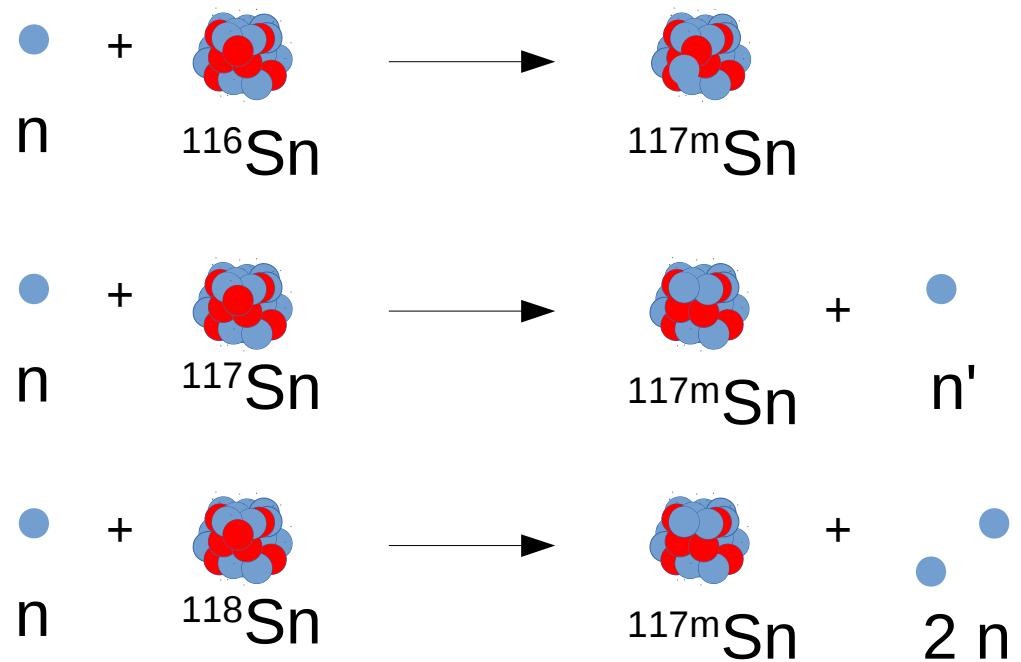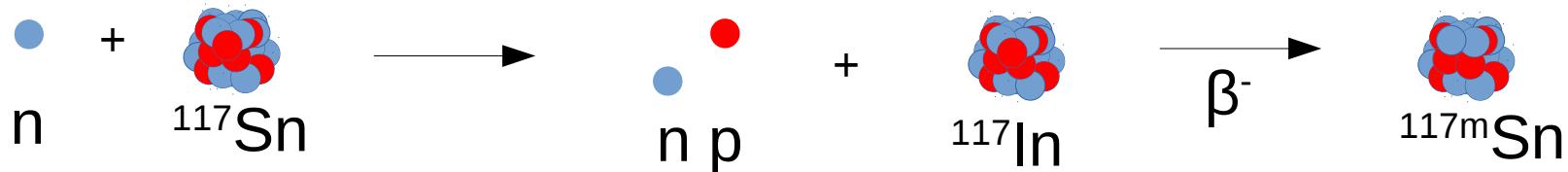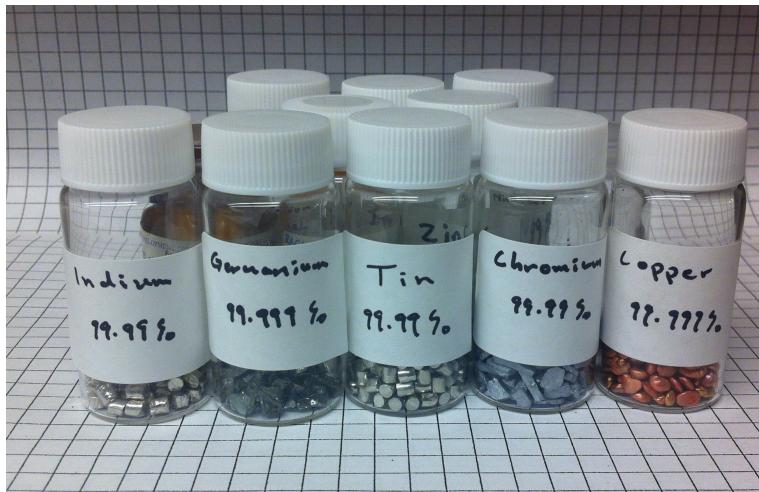
^{117m}Sn decay curve

T. Domingo et al. *Applied Radiation and Isotopes*, vol 119, pp. 101-104, 2017.

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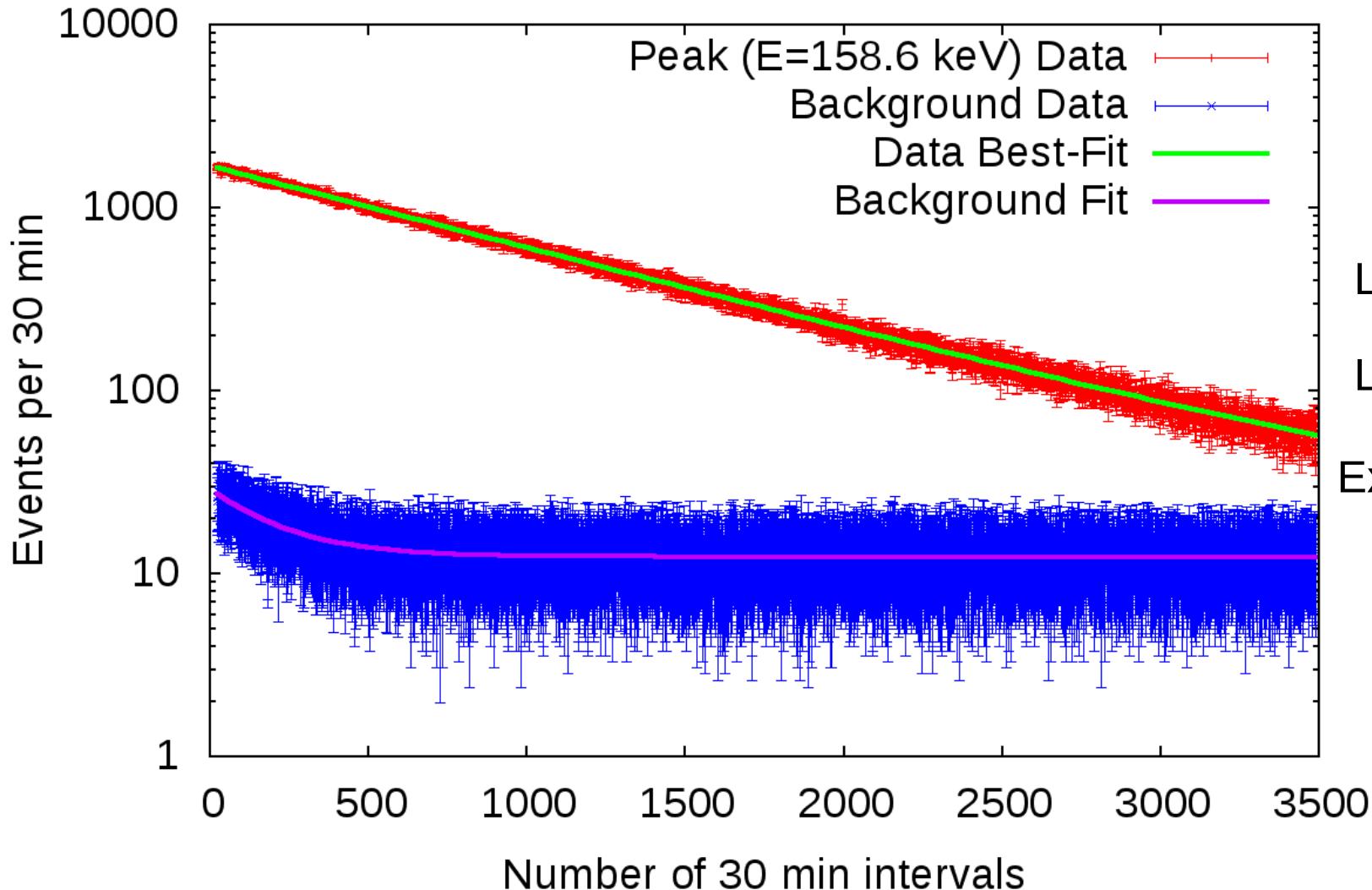
In summary

- Replace the Ortec Dspec jr. 2.0 with a CAMAC crate

    1) Maintain or improve the energy response from the
       detector (Improved by 12%)

    2) Add a time stamp to each recorded energy event
          (Added successfully)

    3) Measure the "deadtime" of the data acquisition system
          (Deadtime verified)

The Starosta Group

- Aaron Chester
- Jonathan Williams
- Usman Rizwan (Former)
- Dr. Kris Starosta
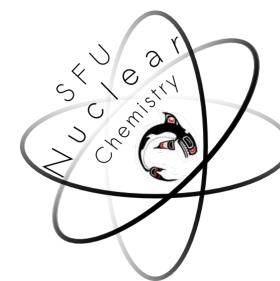
- The SFU Science Machine Shop
- The SFU Electronics Shop
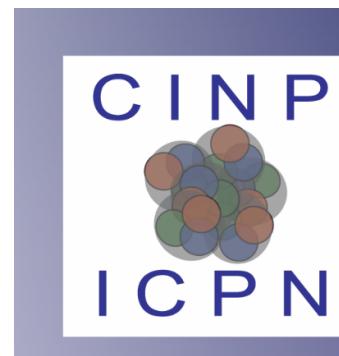
The absolute efficiency of GEARS has been established for a point source 10.5cm away
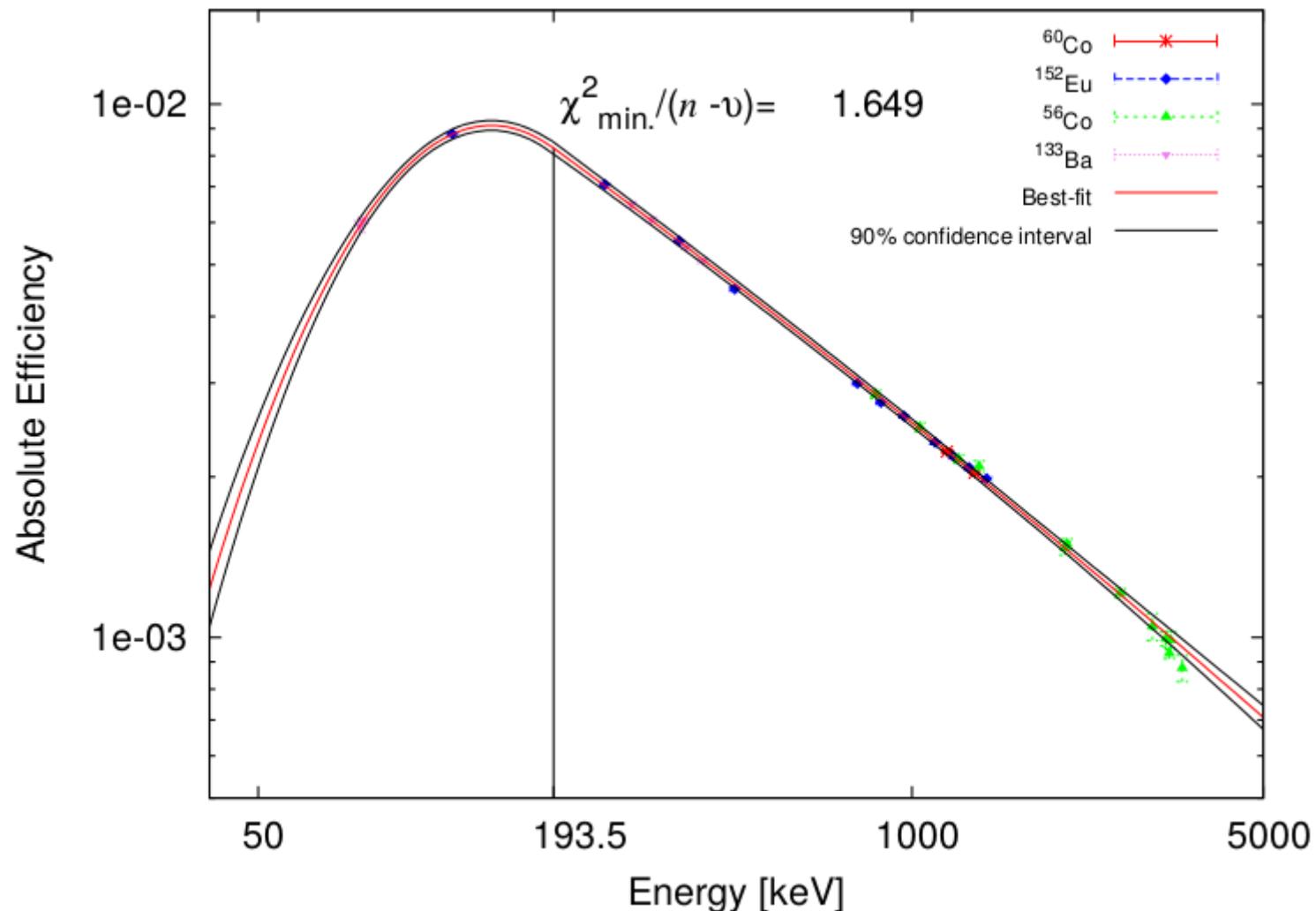
A. Chester et al, *Journal of Environmental Radioactivity*, vol. 124, pp. 205-213, 2013.
U. Rizwan et al, Nuclear Instruments and Methods in Physics Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, vol. 802, pp. 102-112, 2015.

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Verification of the energy response

FWHM at 1332 keV = 1.6771(4) keV

$$FWHM(E) = \sqrt{H \times E^2 + G \times E + F}$$

Legend: 56Co Data, 60Co Data, 152Eu Data, 133Ba Data, Best-Fit, Intrinsic Resolution