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Photon, electron, and neutron? detection with diamond at elevated temperatures

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Outline

- Spectroscopic photon counting
- Electron/β^- particle spectroscopy
- Modelling Gd-diamond for neutron detection
- Outlook, challenges, and questions

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Motivation

- Nuclear science
- Space science
- No cooling required?
- Radiation tolerant? Less or no detector shielding, longer operational lifetime

Diamond benefits

- Wide bandgap material (5.47 eV)
- High drift mobility,

  e^- = 4500 cm^2 V^{-1} s^{-1}

  h^+ = 3800 cm^2 V^{-1} s^{-1}
- Light insensitive ≈ 220 nm

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Diamond detriments

- Wide bandgap (5.47 eV)
  Large e^{-}-h^{+} pair creation energy
  ≈ 13 eV (X-ray photons)
  Small signal to noise ratio of the charge pulse
- Defects/impurities/charge trapping/recombination/polarisation

Photon spectroscopy - diamond and other materials

$$I(z) = I_0 \exp(-\mu z)$$

$$\mu = \mu_m \rho$$

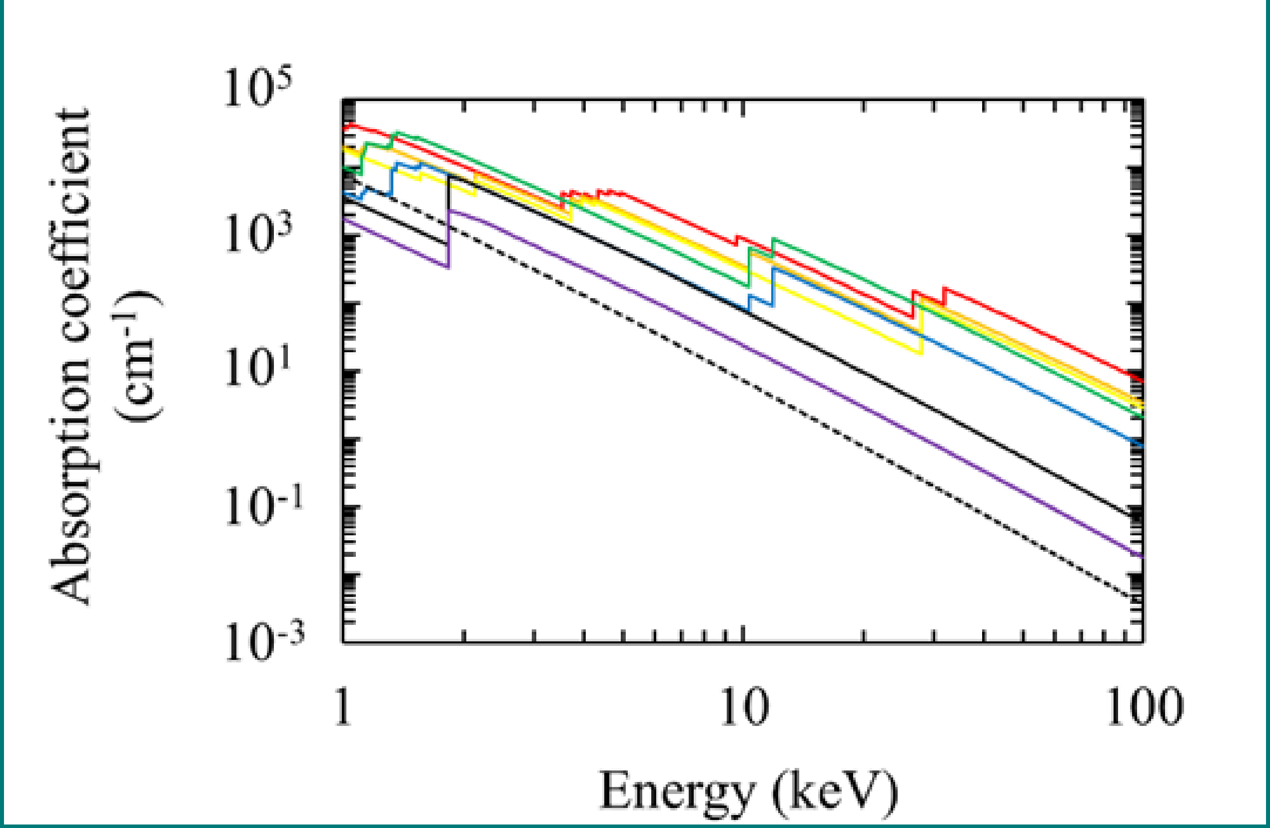
Si

SiC

Diamond

$Al_{0.8}Ga_{0.2}As$

CdZnTe



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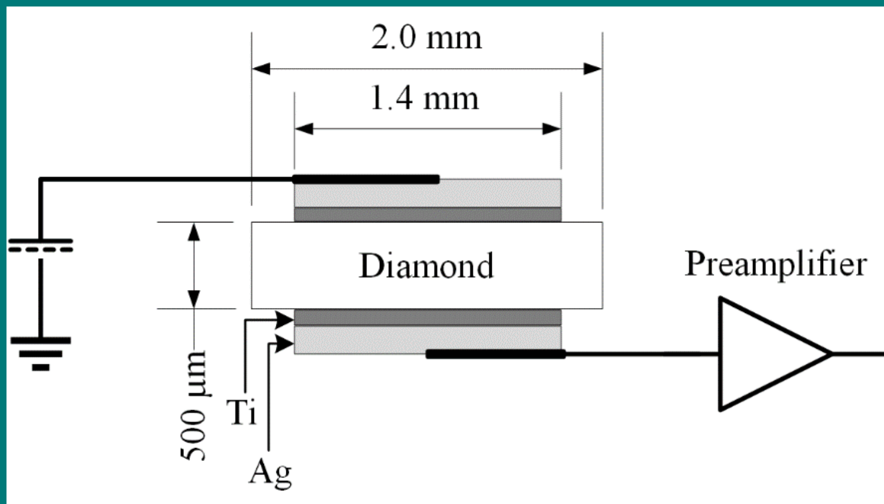

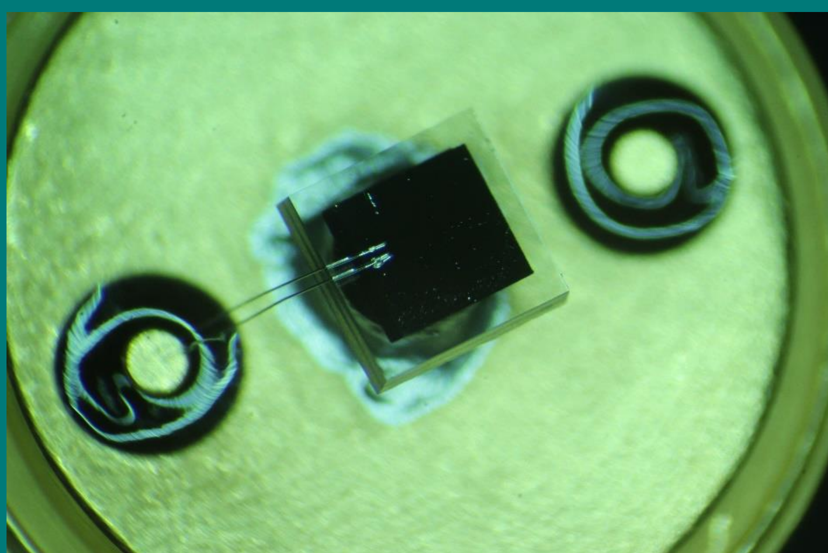

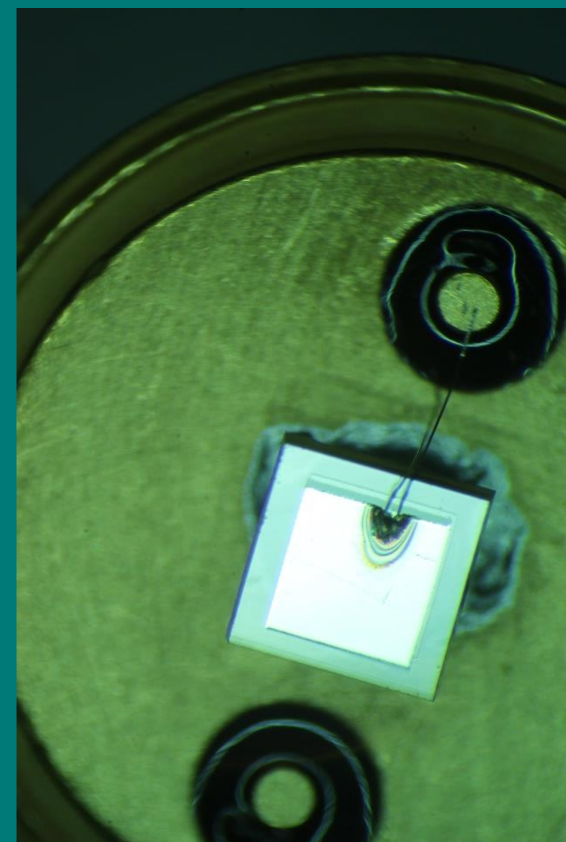

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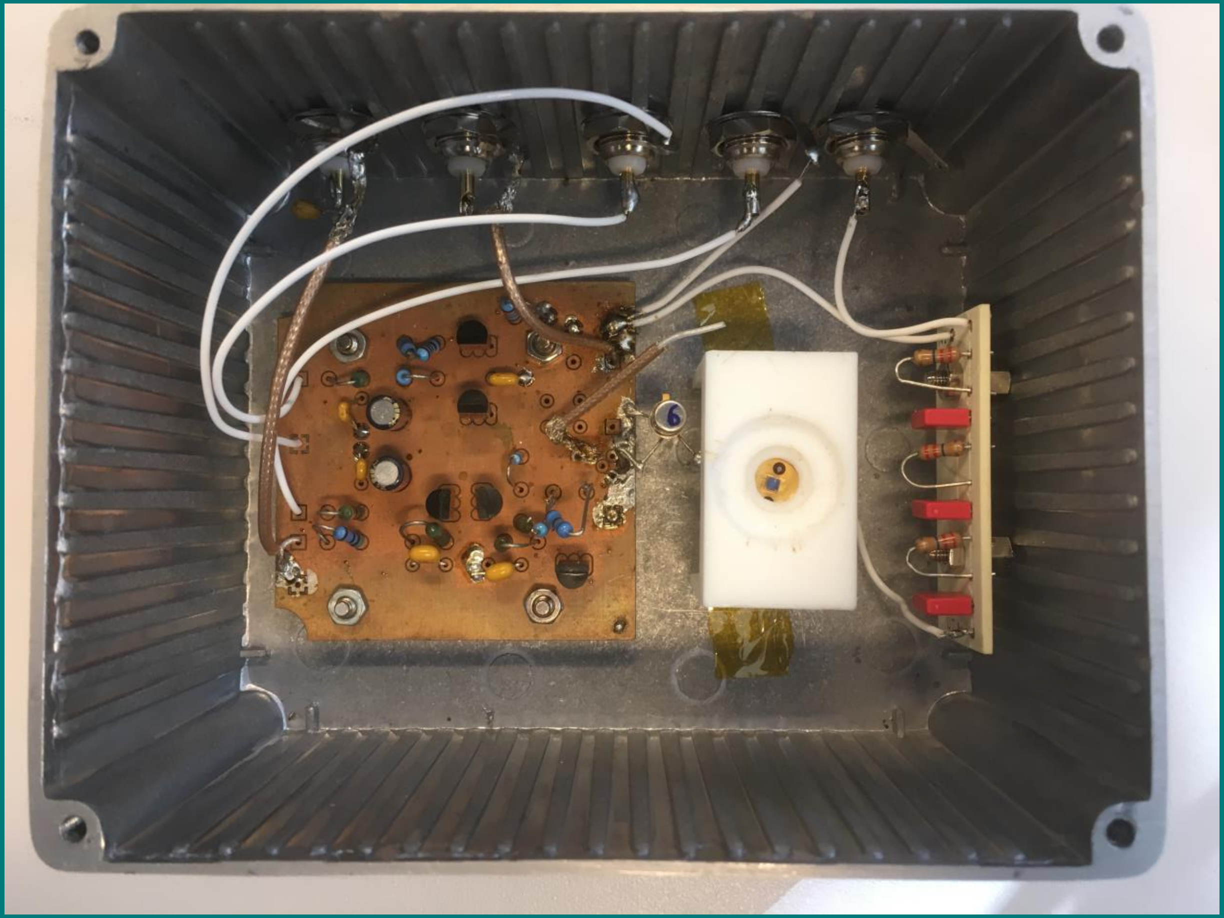
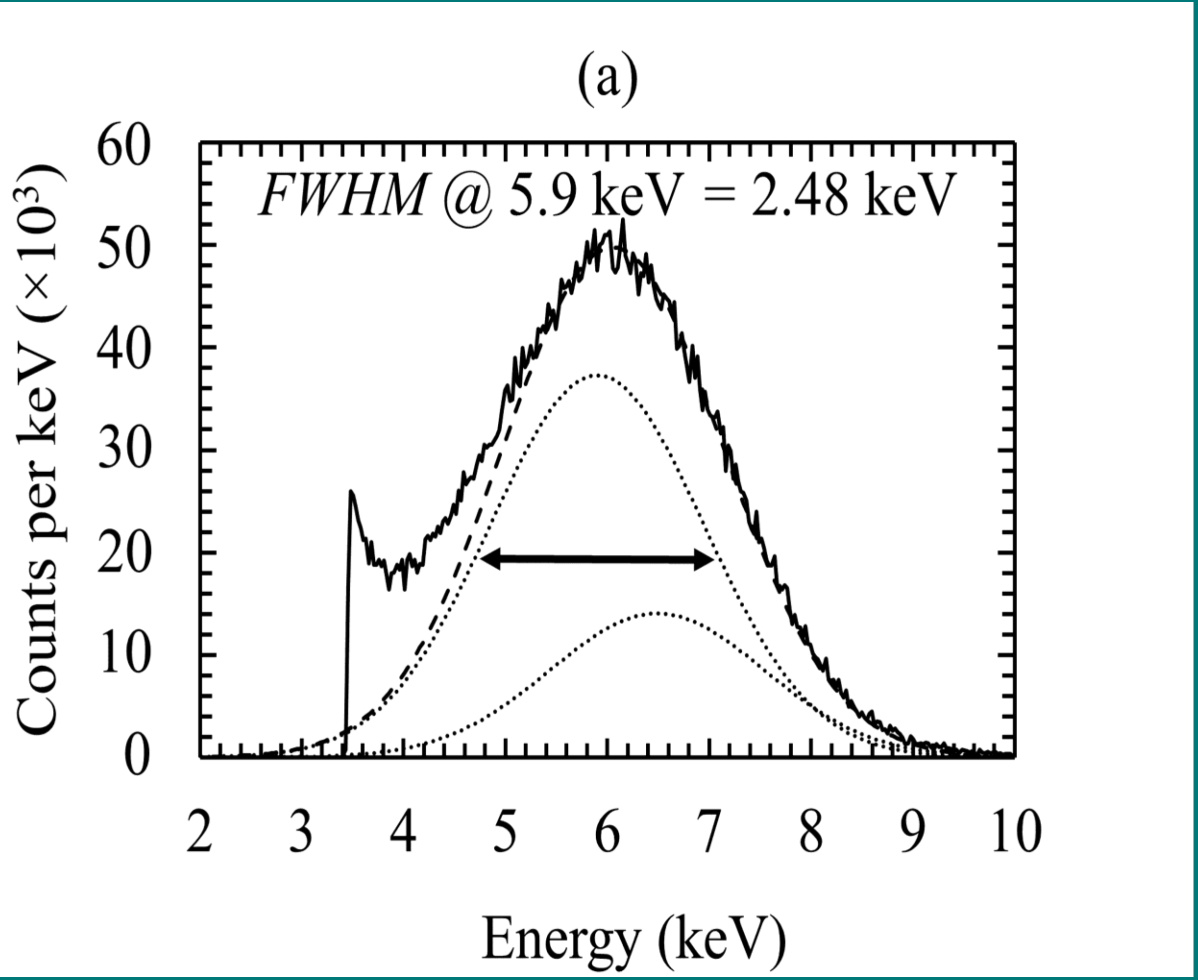
Pre-amplifier(s)



Results - Room temperature (20 °C)

Source = ^{55}Fe
Shaping = 3 μs
$V_{applied}$ = 50 V
Acc time = 90 s



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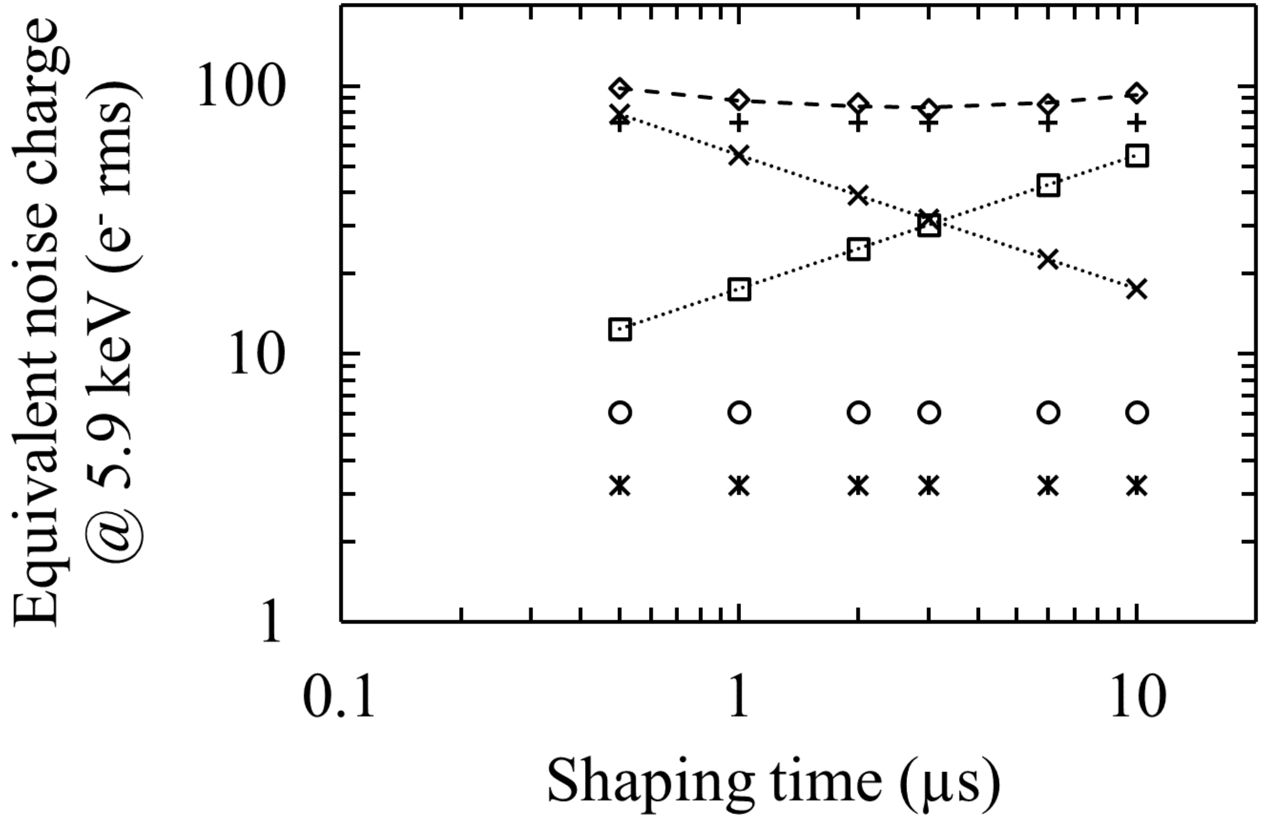
Noise analysis (20 °C)



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High temperatures (≤ 100 °C)

Highlights

- Mn Kα (5.9 keV) photopeak *FWHM* = 2.93 keV at 60 °C
- Ag $K\alpha_1$ (22.16 keV) photopeak *FWHM* = 4.75 keV at 100 °C
- ^{109}Cd (88.03 keV) γ-ray *FWHM* = 4.13 keV at 100 °C

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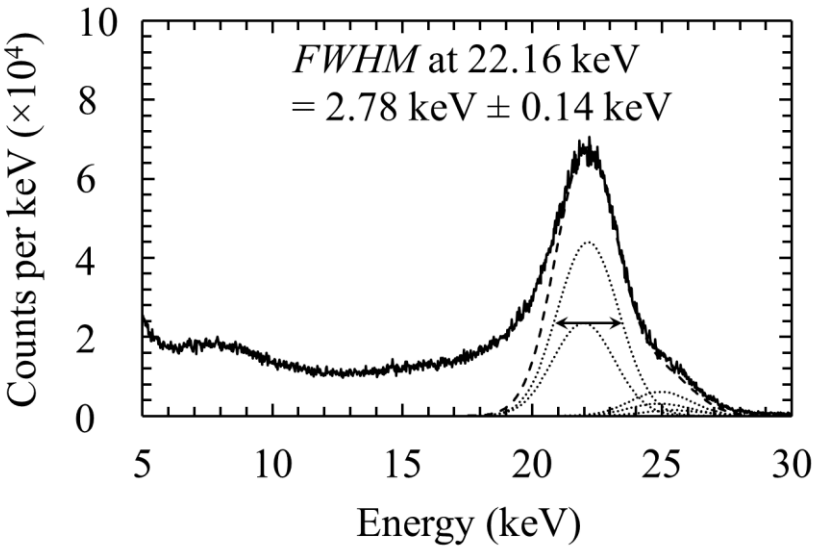
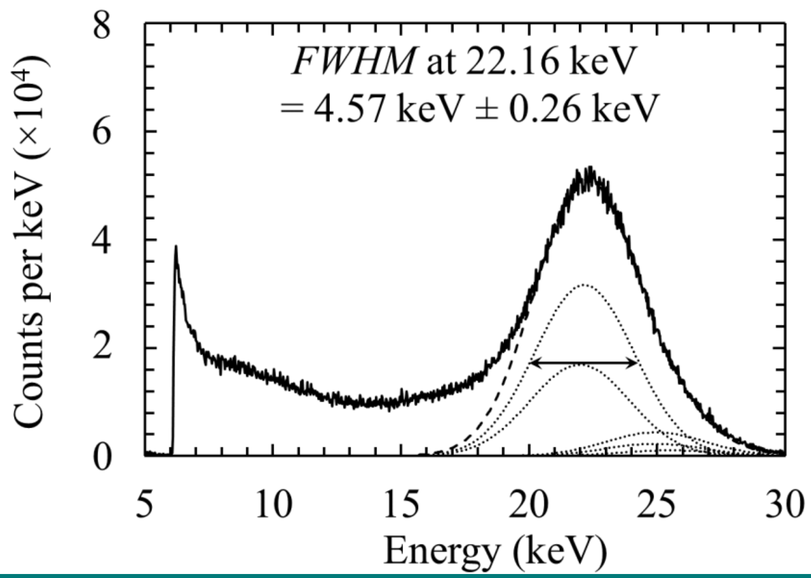
T = 20 °C

T = 100 °C





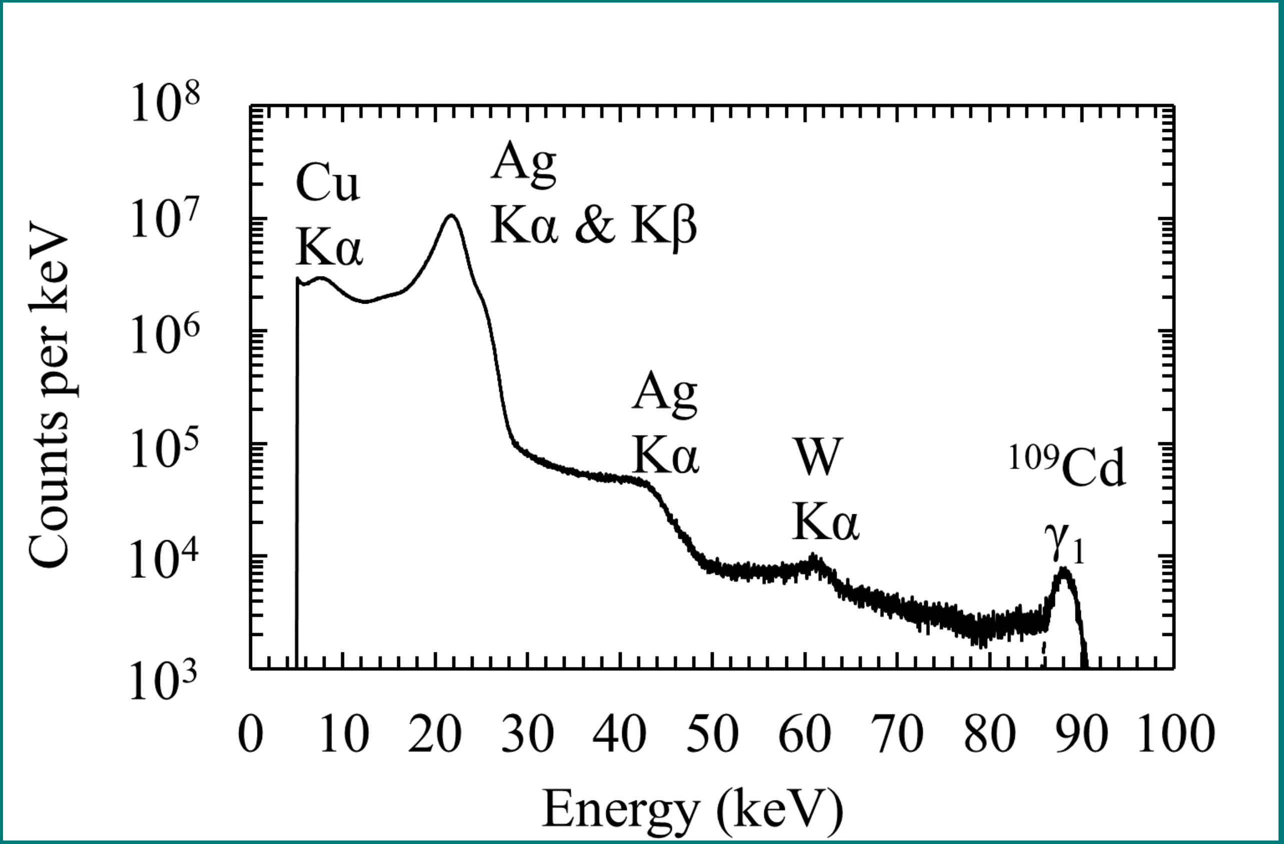
Source = ^{109}Cd, Shaping = 1 µs

$V_{applied}$ = 50 V, Acc time = 90 s

T = 20 °C

4 hours accumulation

88 keV count rate = 2 s^{-1}



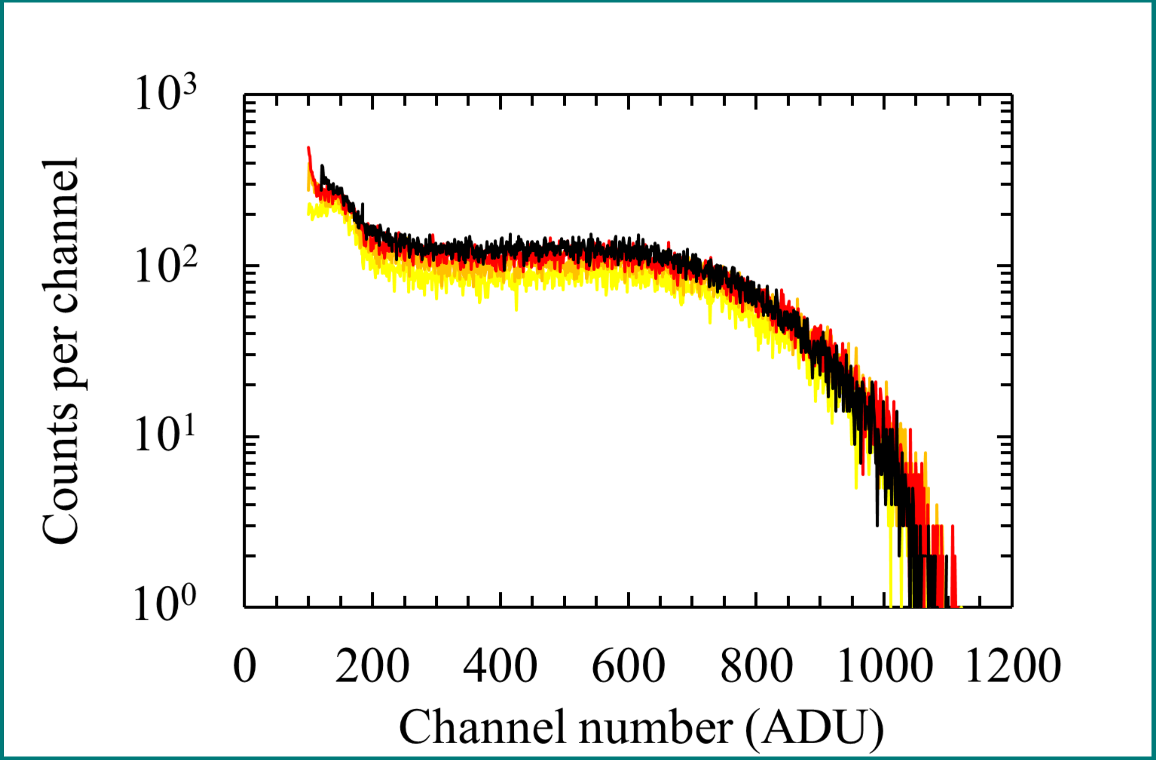
Higher temperatures (≤ 100 °C)

Lowlights

- Inconclusive results with respect to incomplete charge collection noise
- Dissimilar counting rates at 5.9 keV and 22.16 keV could have introduced parasitic effects
- Count rate varied as a function of shaping time at T > 60 °C

β⁻ spectroscopy

β Source = ^{63}Ni
τ = 2 μs
$V_{applied}$ = 50 V
Acc time = 30 mins
T = 80 °C (black)
T = 60 °C (red)
T = 40 °C (orange)
T = 20 °C (yellow)



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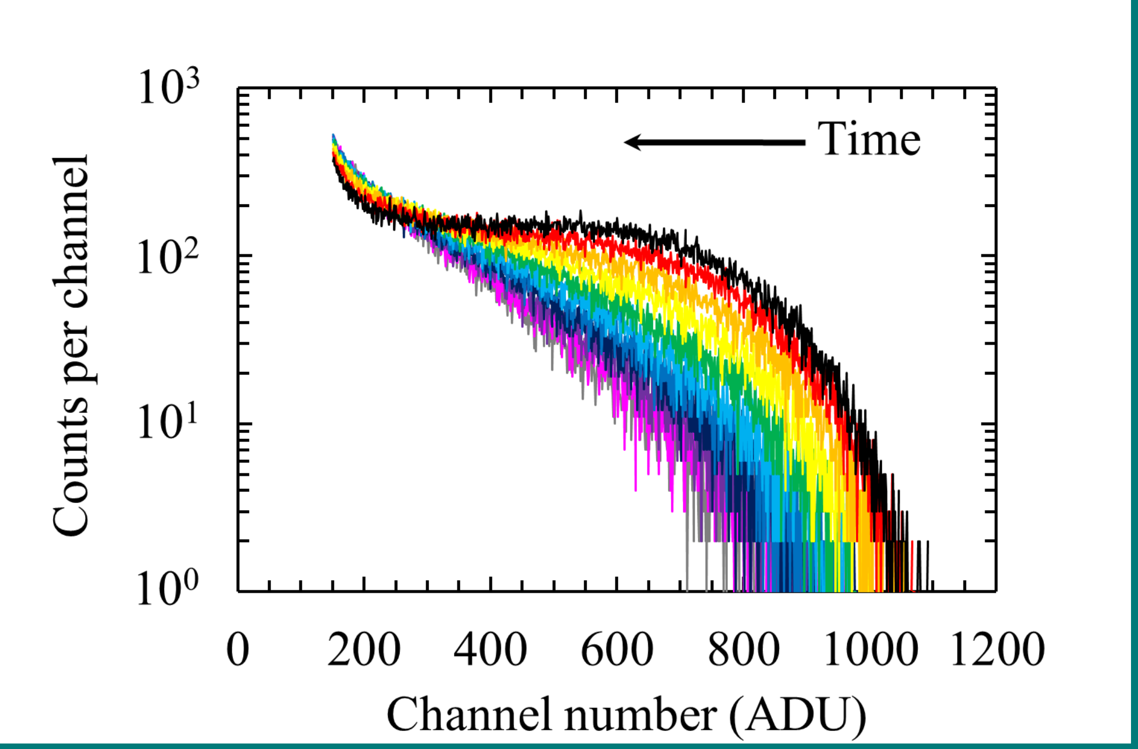
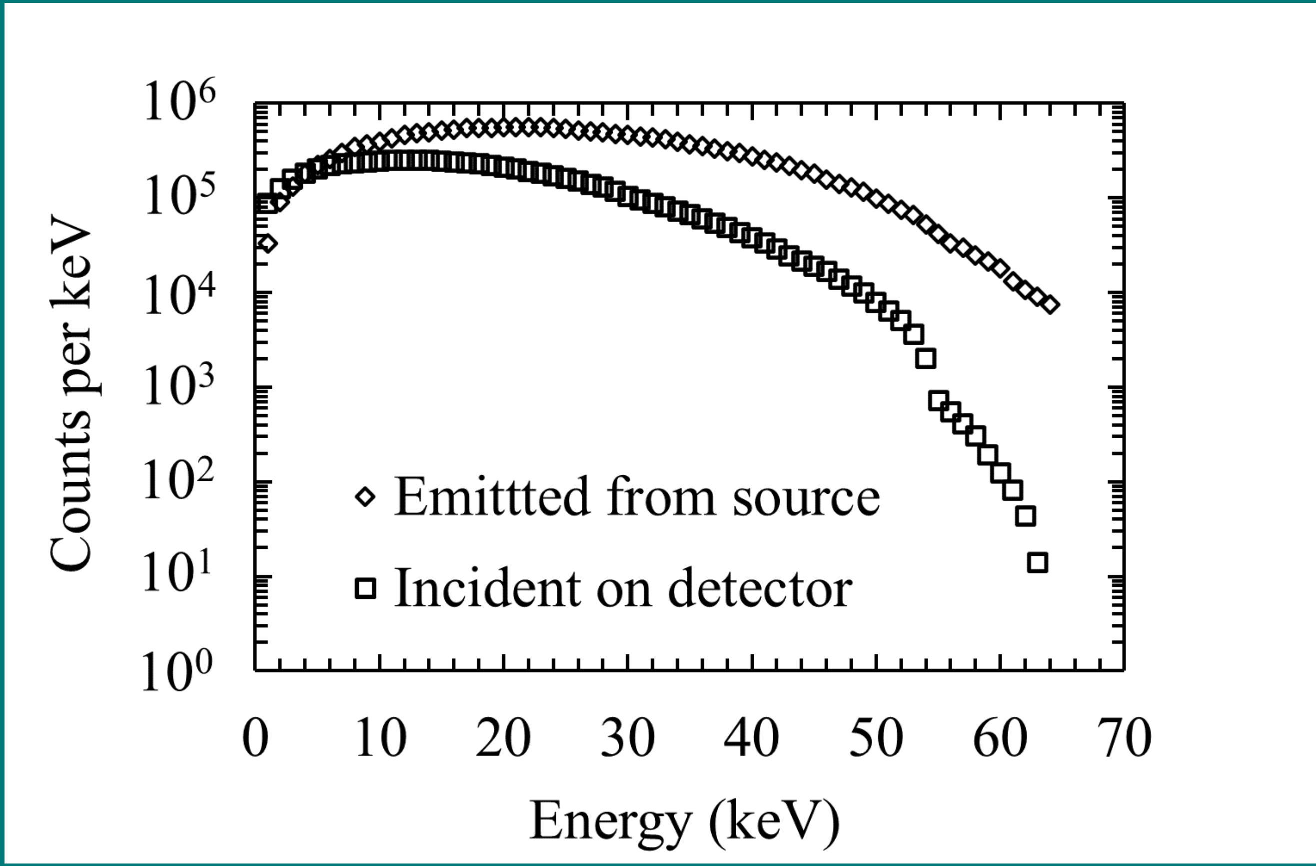
β⁻ spectroscopy

β Source = ^{63}Ni
τ = 2 µs
Acc time = 30 mins
$V_{applied}$ = 50 V
T = 100 °C



β⁻ spectroscopy calibration - emission spectrum



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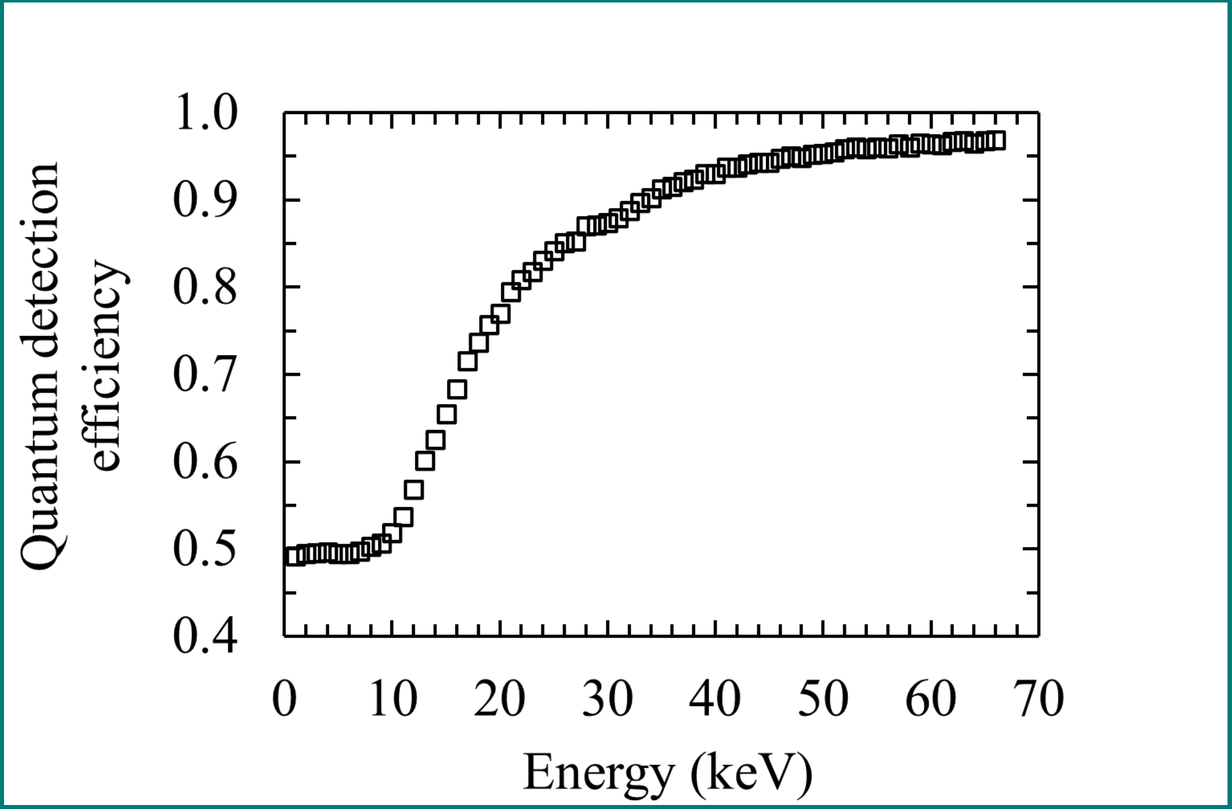
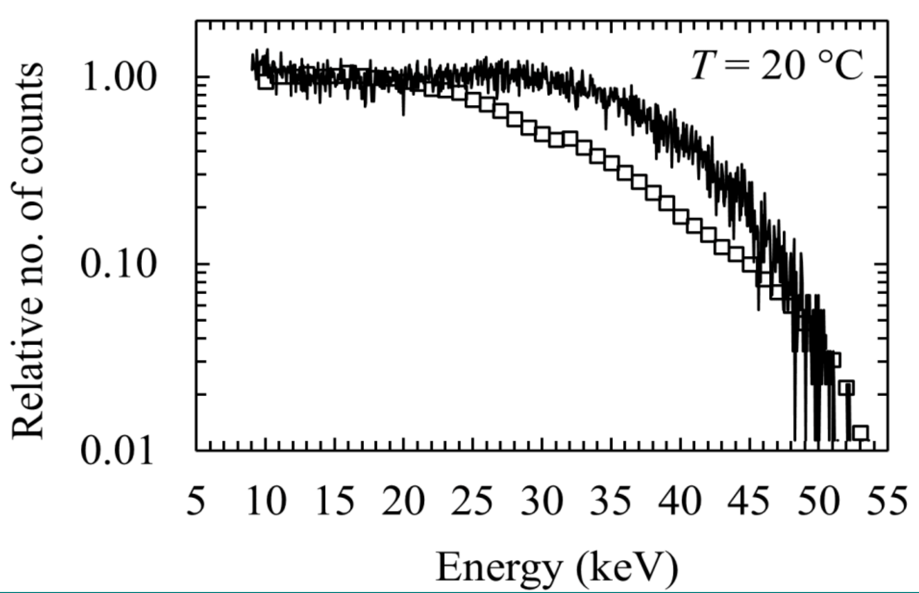
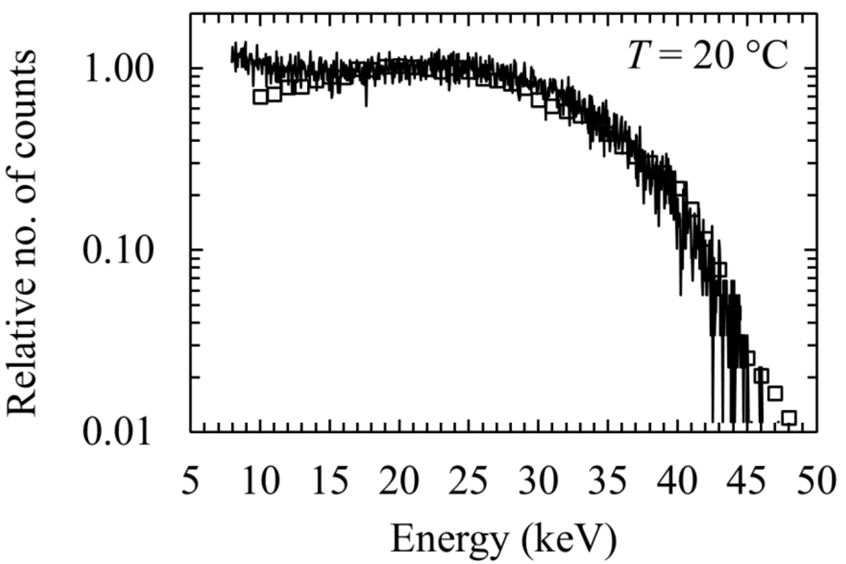
β⁻ spectroscopy calibration – detector efficiency



β⁻ spectroscopy calibration - combined





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Modelling Gd-diamond neutron detectors

- ^{6}Li cross section ≈ 940 b
- ^{10}B cross section ≈ 749 b
- ^{155}Gd and ^{157}Gd

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Modelling Gd-diamond neutron detectors

Gd isotope (Nucleon number)	Isotopic abundance f_i (%)	Cross section σ_i (b)	Fractional interaction C_i (%)
152	0.2	755 ± 20	0.003
154	2.2	85 ± 12	0.004
155	14.8	60330 ± 500	18.293
156	20.5	1.8 ± 0.7	0.001
157	15.7	254000 ± 815	81.698
158	24.8	2.22 ± 0.1	0.001
160	21.8	1.4 ± 0.3	0.001

$$\sigma_t = 48800 \text{ b} \pm 200 \text{ b}$$

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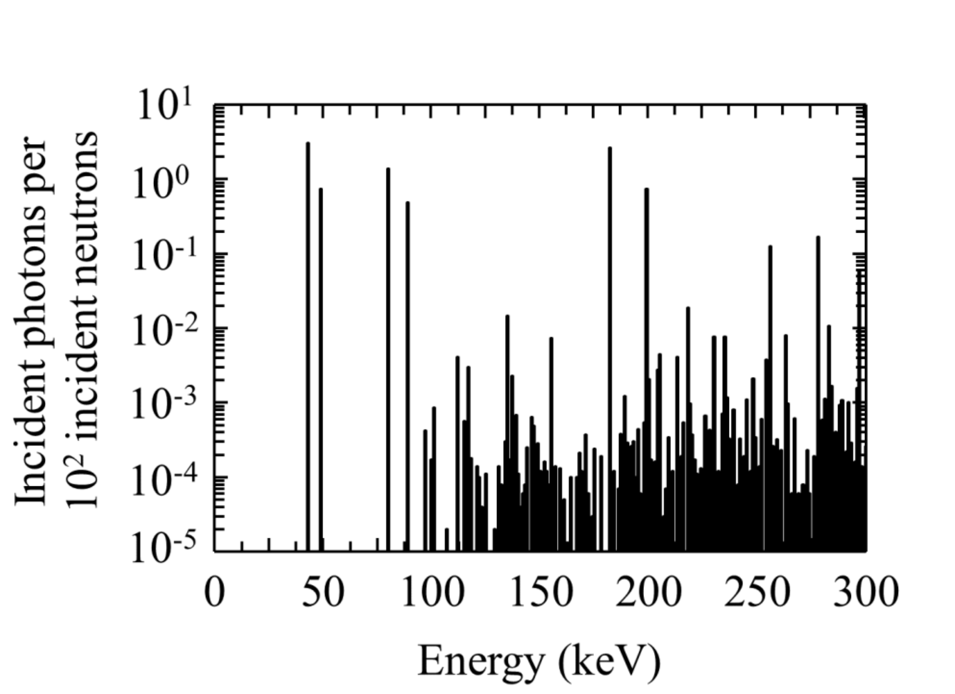
$$^{155}_{64}\mathrm{Gd} + ^{1}_{0}\mathrm{n} \rightarrow ^{156}_{64}\mathrm{Gd}^{*} + \gamma - \mathrm{ray} + \mathrm{e}^{-}; Q = 8536\ \mathrm{keV} \pm 0.07\ \mathrm{keV}$$

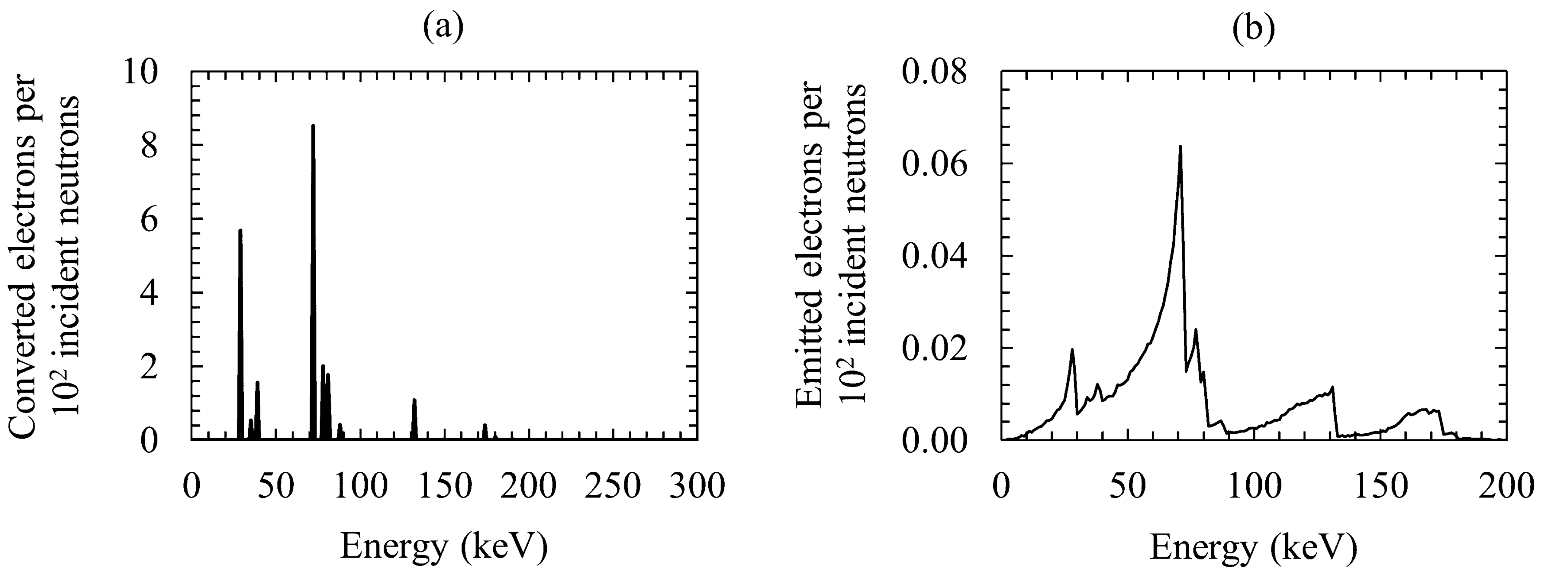
$$^{157}_{64}\mathrm{Gd} + ^{1}_{0}\mathrm{n} \rightarrow ^{158}_{64}\mathrm{Gd}^{*} + \gamma - \mathrm{ray} + \mathrm{e}^{-}; Q = 7937\ \mathrm{keV} \pm 0.06\ \mathrm{keV}$$



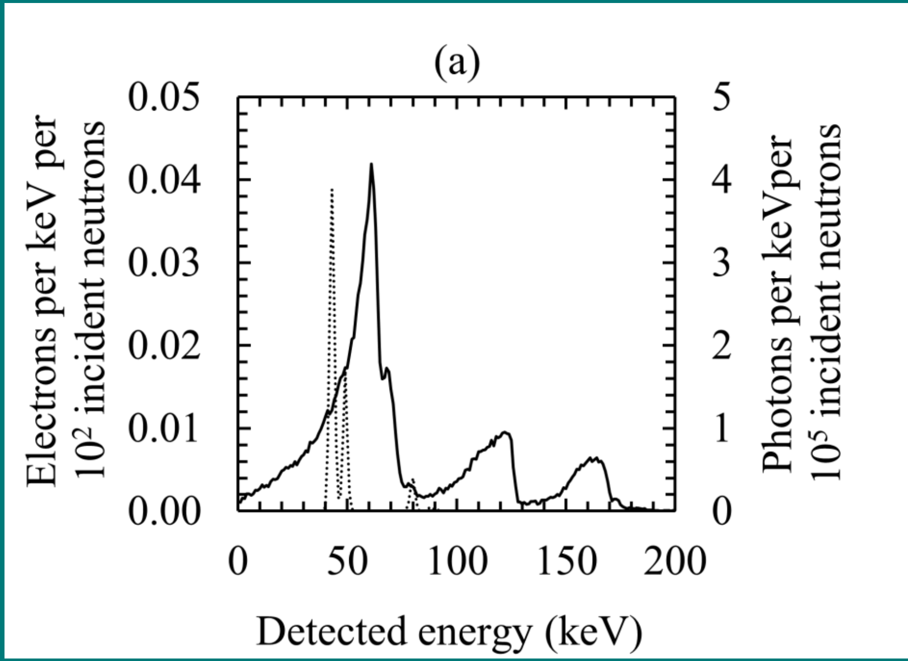
Conversion electrons in 10 μm foil of Gd

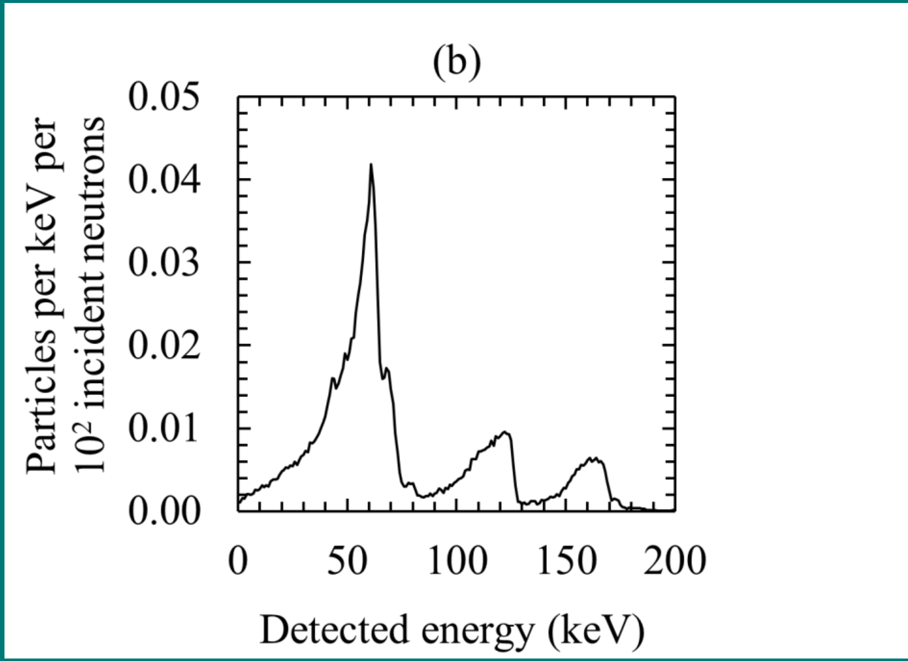
Prior to energy straggling

After straggling through remaining layer



10 µm foil of Gd – diamond detector





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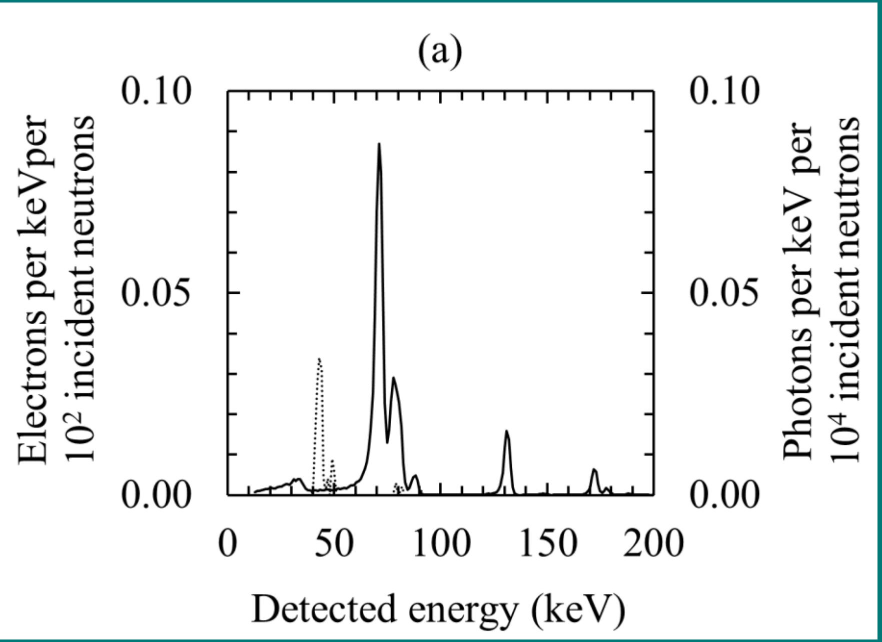
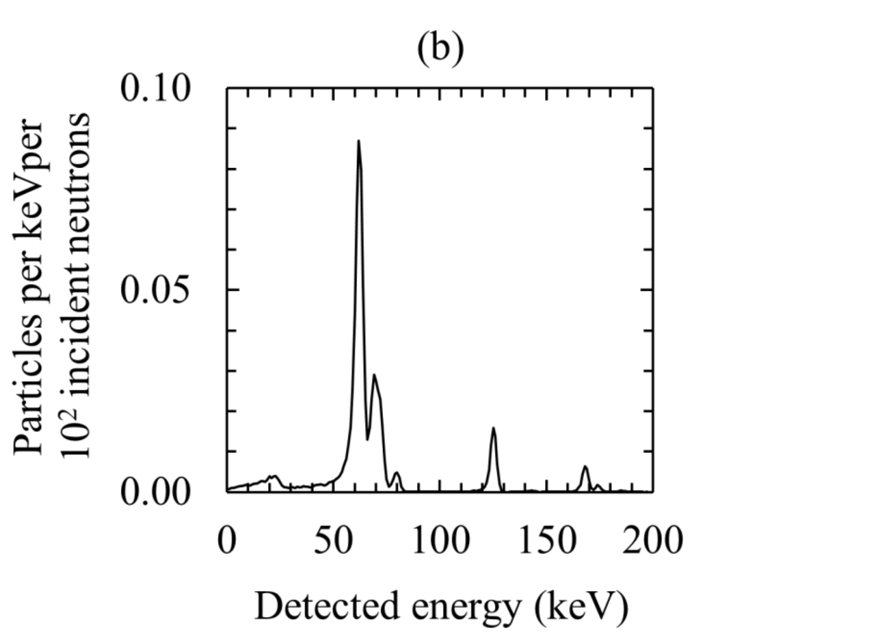
0.7 µm foil of Gd – diamond detector





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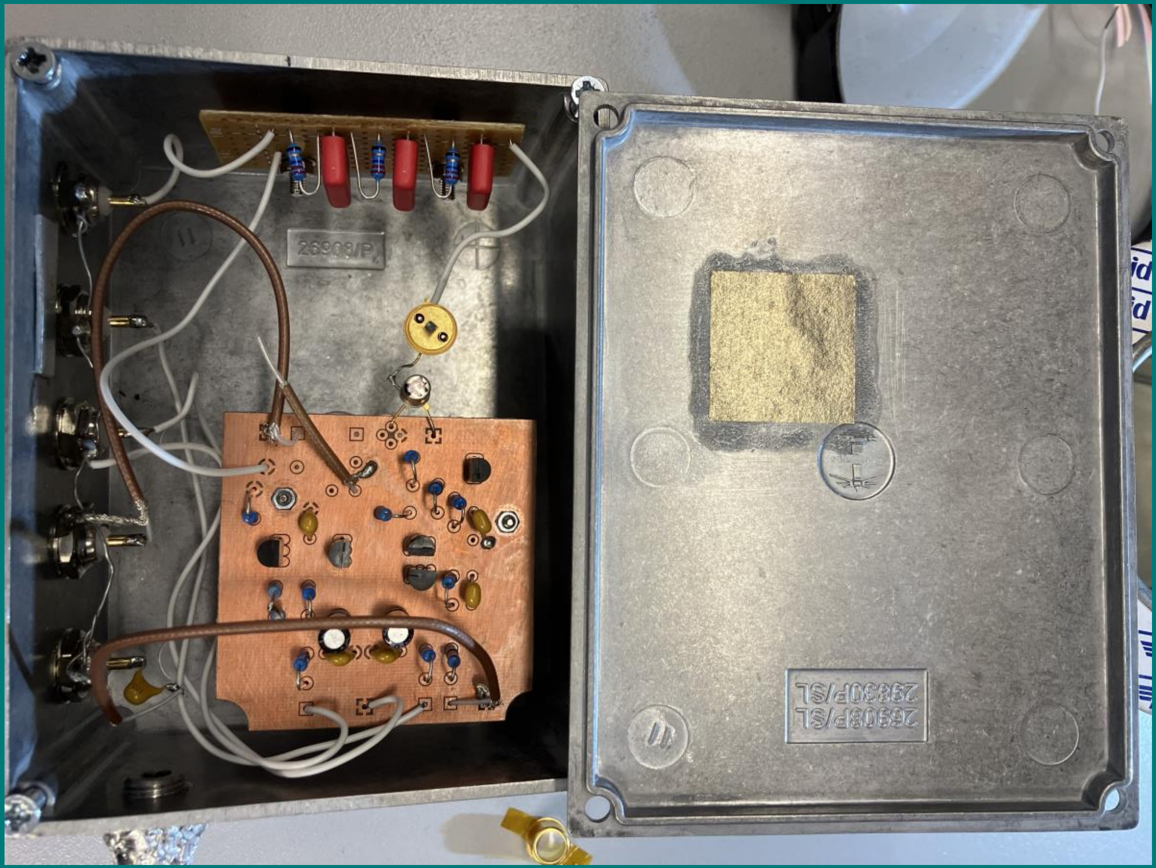
Outlook, challenges, questions?



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