Energy nonlinearity correction of a high resolution metallic magnetic calorimeter

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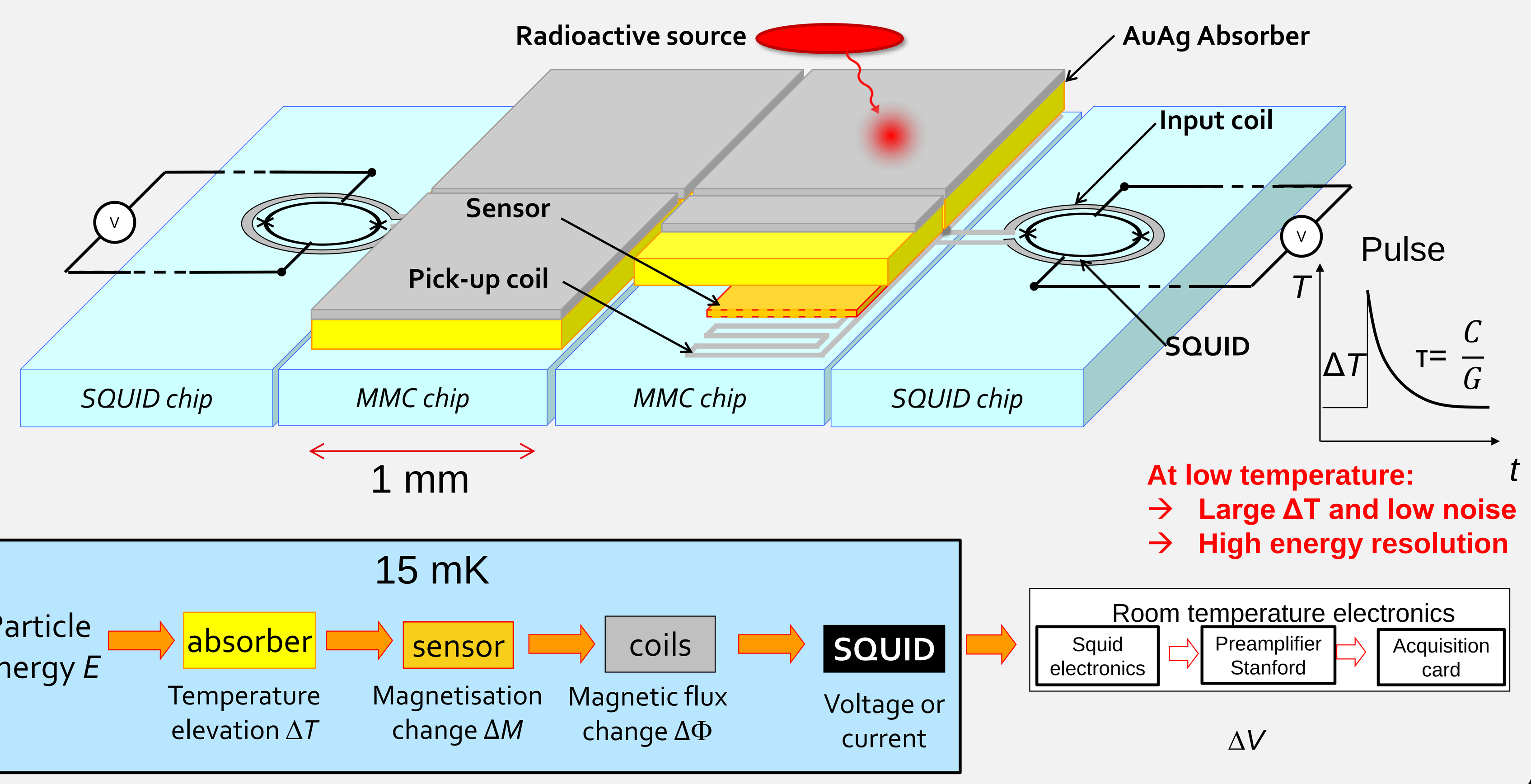
Precise measurements of X-ray and ϒ-ray energies are important for the study of atomic and nuclear structure. They contribute to the advancement of our fundamental knowledge in physics. Cryogenic detectors offer excellent energy resolution and are ideal for precise energy measurements, but they have intrinsic and extrinsic nonlinearities. It is crucial for cryogenic detector to correct their nonlinearity in order to accurately interpret the measured energies. The main nonlinearity is intrinsic to the detector. Other contributions to nonlinearity can arise from the electronics and the signal processing. Therefore, it is important to assess the impact of these contributions for the subsequent nonlinearity correction.

MMC

MMC operation

Metallic magnetic calorimeters convert the energy of a photon into a temperature rise

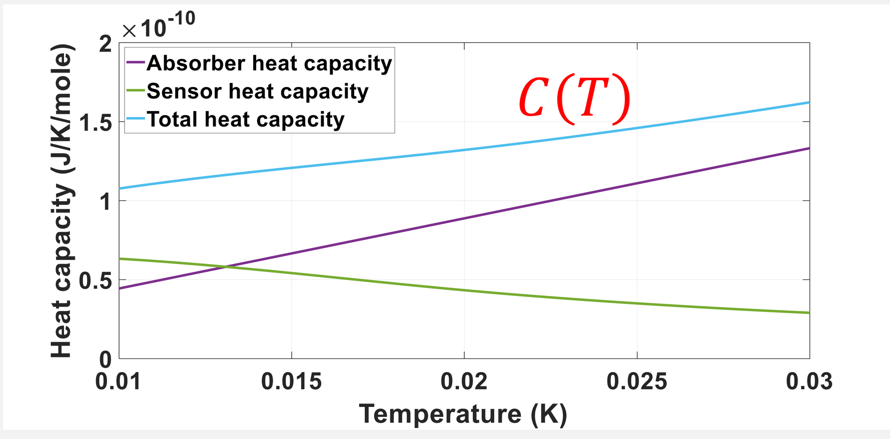


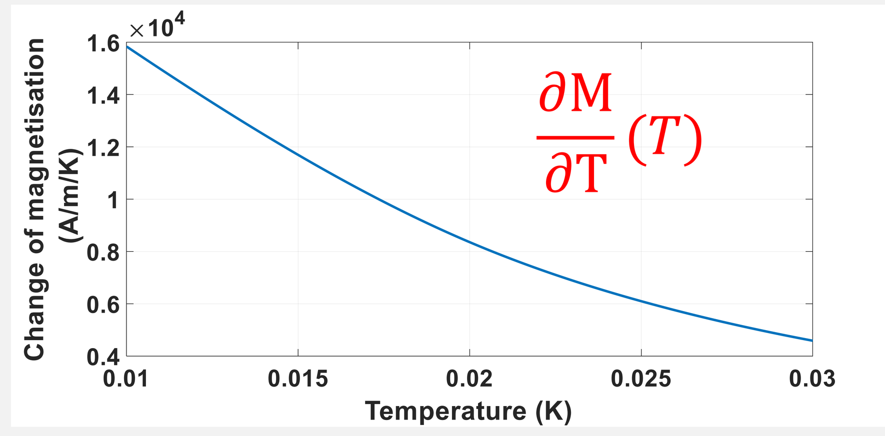
Detector intrinsic nonlinearity

Ideal linear case: $\Delta T = \frac{E}{C}$ $C = constant$ $\Delta M = \frac{\partial M}{\partial T}\Delta T$ $\frac{\partial M}{\partial T} = constant$

ΔM: Magnetisation variation ΔT: Temperature variation $\frac{\partial M}{\partial T}$: Temperature dependence of the magnetisation variation

Real nonlinear case: $E = \int_{T_0}^{\Delta T + T_0} C(T)\,dT$ $\Delta\Phi \propto \Delta M = \frac{\partial M}{\partial T}\delta T = \frac{\partial M}{\partial T}\frac{\Delta E}{C_{tot}}$



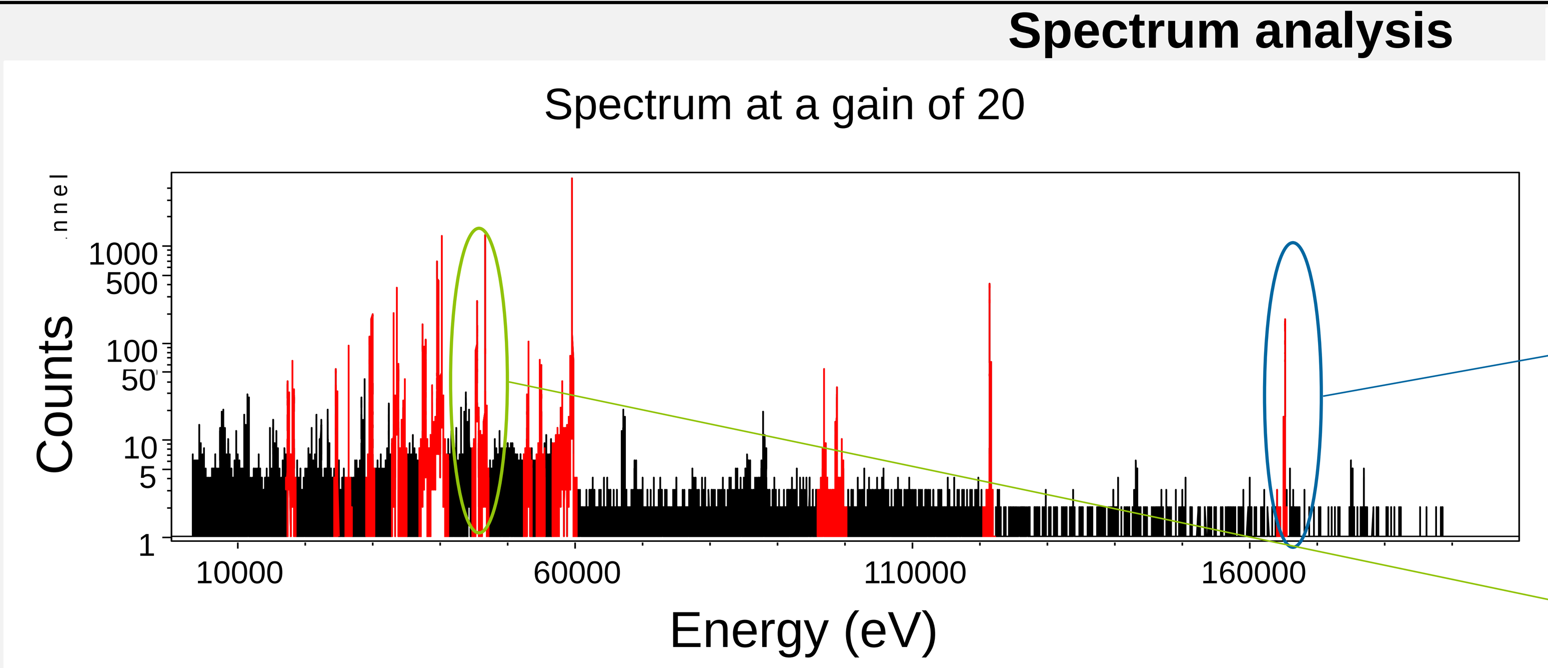


Method and analysis

We measured energies between 17 keV and 165 keV to determine the energy nonlinearity from:

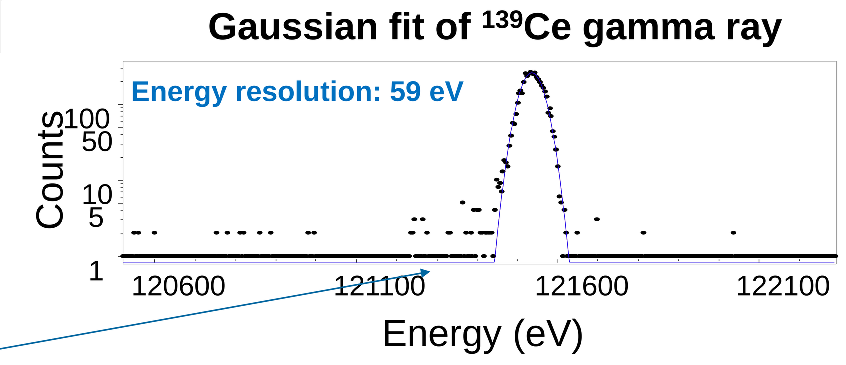
- **The detector**
- **Different pulse processing**
- **The electronics (different amplification gain)**

Spectrum analysis

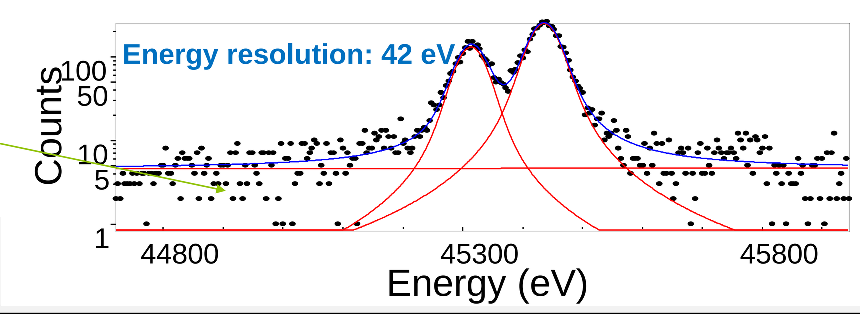


First, the peaks were fitted with Colegram software. The X-rays have been fitted with a Voigt function, while the gamma rays have been fitted with a Gaussian function.

Gaussian fit of ^{139}Ce gamma ray



Voigt fit of X rays of ^{152}Eu $X_{K\beta3}$ and $X_{K\beta1}$

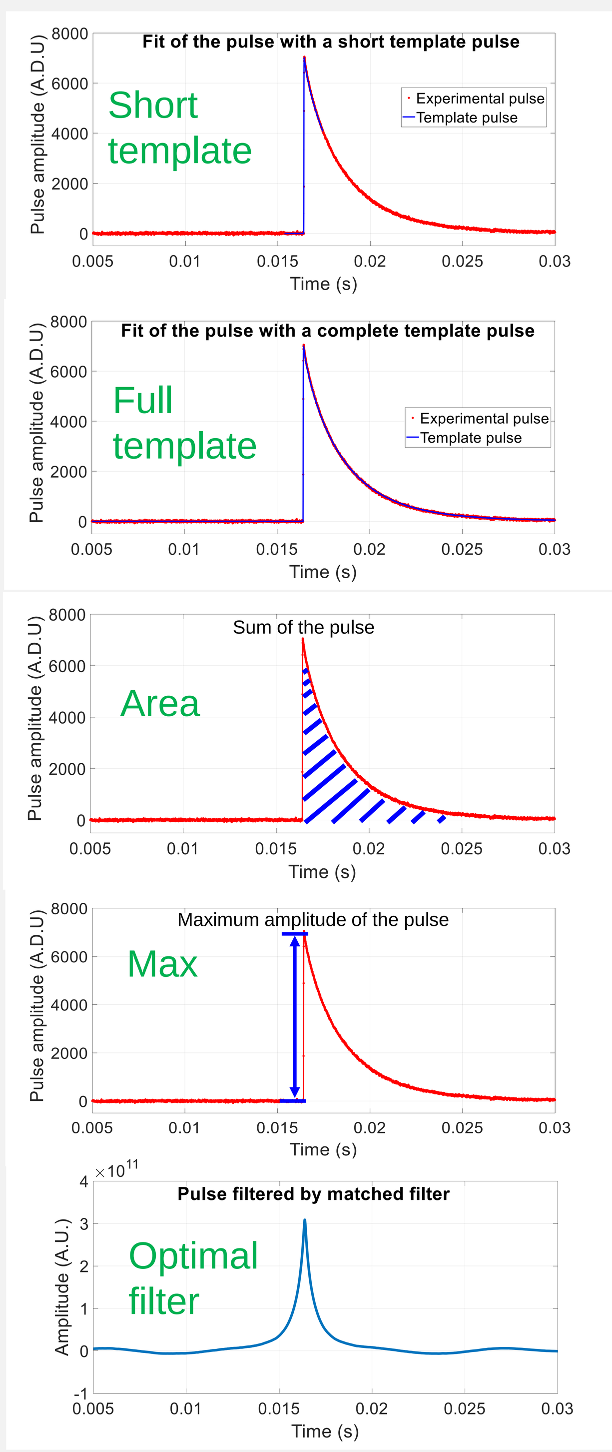


Reference energies

	Energy (keV)	Origin (X, ϒ, escape)
^{241}Am	17.9893 (35)	X
	26.3446 (2)	ϒ
	59.5409 (1)	ϒ
	37.377983 (105)	Escape
	37.55060 (14)	Escape
^{210}Pb	46.539 (1)	ϒ
	24.3761 (11)	Escape
	24.5487 (11)	Escape
^{152}Eu	45.2886 (49)	X
	40.118481 (60)	X
	39.52339 (10)	X
	45.4130 (49)	X
	121.7817 (3)	ϒ
	18.128181 (117)	Escape
	52.97720 (35)	Escape
	54.79097 (38)	Escape
	99.79140 (32)	Escape
	99.61878 (31)	Escape
	17.36047 (11)	Escape
	17.53309 (15)	Escape
^{129}I	29.458250 (50)	X
	29.77878 (10)	X
	33.62424 (12)	X
	33.56320 (12)	X
	39.578 (4)	ϒ
^{139}Ce	33.03438 (26)	X
	33.44212 (27)	X
	37.80145 (51)	X
	37.72060 (68)	X
	38.7303 (13)	X
	165.8575 (11)	ϒ
	97.05300 (22)	Escape
	98.866770 (25)	Escape
Absorber X ray escape Au	46.641583 (183)	Escape
	46.81420 (21)	Escape
X from W collimator	57.98177 (14)	X
	59.318847 (50)	X

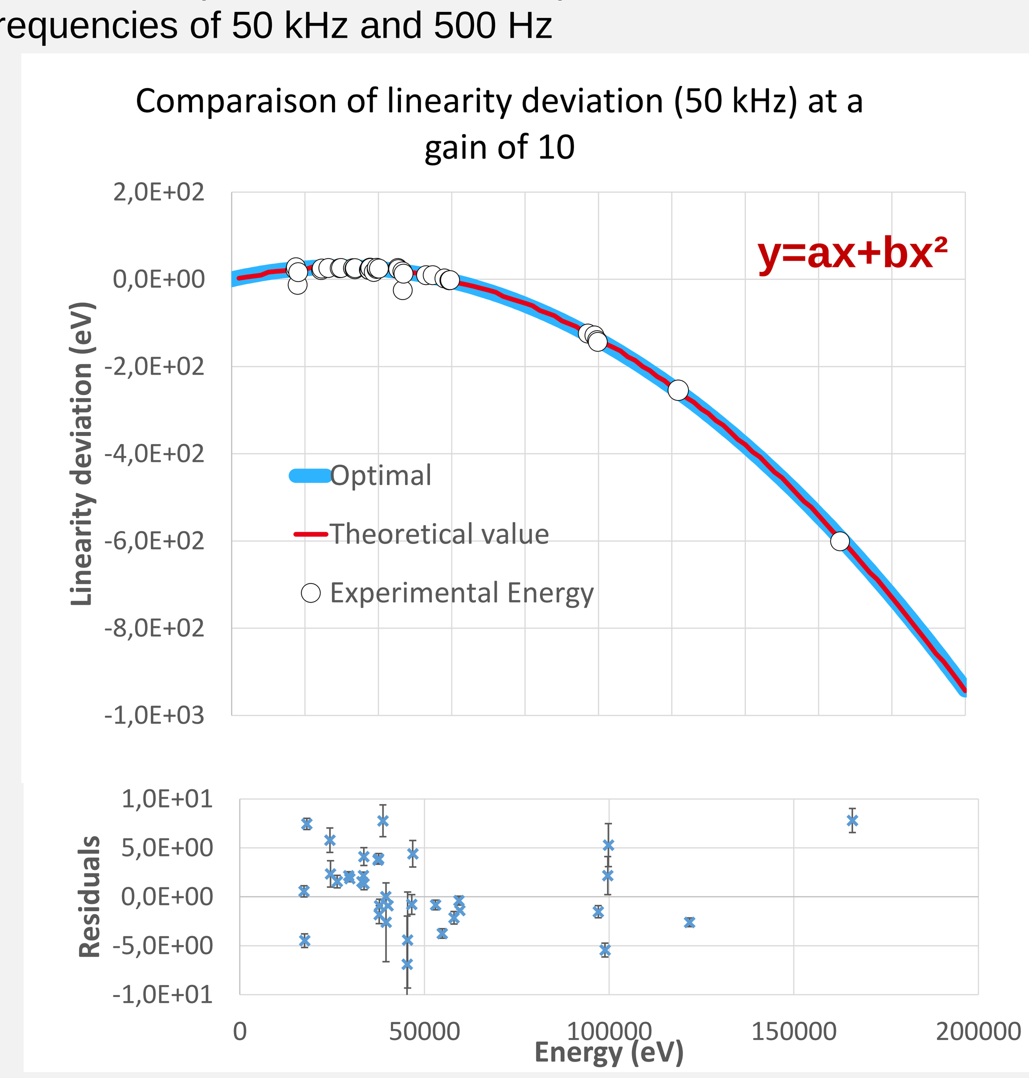
Pulse processing

Five different ways to determine the pulse energy



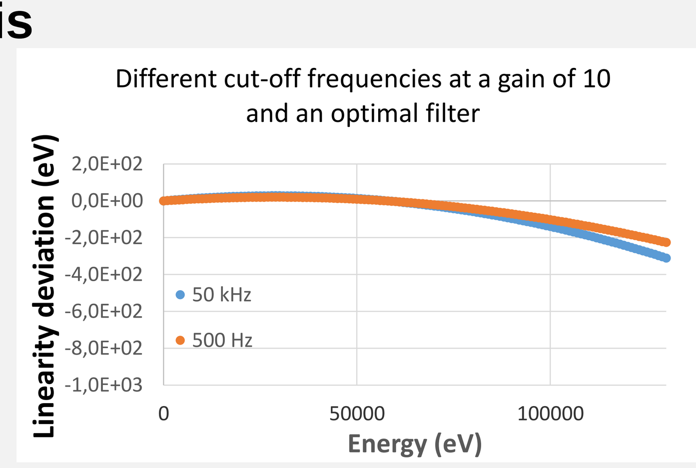
Nonlinearity analysis

Pulses were prefiltered with 2 low pass filter with cut-off frequencies of 50 kHz and 500 Hz

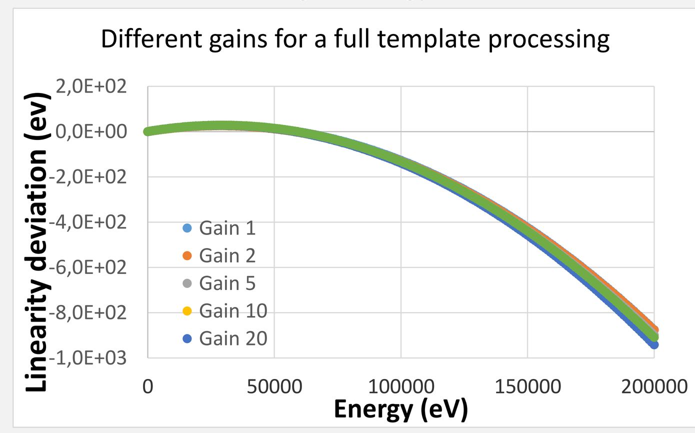


The experimental values are fitted with a second degree polynomial. The theoretical values match with the optimal template.

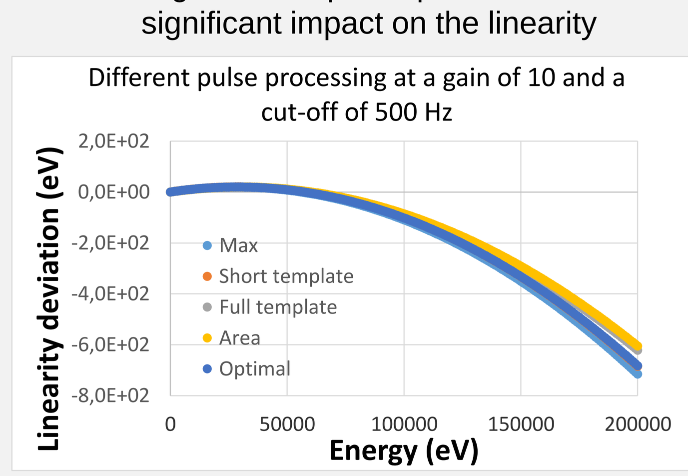
	Short template	Full template	Area	Max	Optimal filter
Resolution (eV)	30.8	33.7	80	32.6	27.3



Less nonlinearity for the 500 Hz cut-off at high energy



The gain of the preamplifier has not a significant impact on the linearity



The full template and the area methods have a better linearity than the optimal filter and the short template

Conclusion

The detector nonlinearity remains predominant. We observe a small impact on the linearity due to signal processing.

For now, the gain does not have any impact on the nonlinearity which means that we do not observe nonlinearity from the electronics. However if in the future we are able to correct the intrinsic nonlinearity of the detector, it is possible that the electronics becomes a source of nonlinearity. The theoretical calculation of the nonlinearity is consistent with the experimental data using the optimal method. This shows that the calculations are reliable enough to be used for correcting the nonlinearity in subsequent measurement. However, it is still important to confirm the calculations reliability using additional data.

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