



Spectral broadening induced by spatial effects in X-ray microcalorimeters with superconducting absorber



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In this work we use numerical simulations to investigate how the different positions of absorption of the photons can affect the pulse height distribution produced by a single pixel X-ray microcalorimeter with superconducting Sn absorber and NTD-Ge thermistor.

The pulse height can depend on the position of absorption because during the early phase of escape the number and the spectrum of the phonons entering the thermistor is related to the evolution of the initial phononic bubble with respect to the location of the thermistor on the absorber surface. The spectral and spatial evolution of the excitations, the geometry of the detector and the escape of phonons from the absorber into the thermistor are properly taken into account in our microscopic model [Perinati et al., *SPIE Proc.* 2002, 4851, 812]

For symmetry, we simulate photons (@ 5.89 KeV) absorbed along a semi-diagonal, all at the same depth $z=d_x/2$ (since the absorber thickness d_x is much smaller than the width, we neglect the z -dependence). We investigate the produced pulse heights as a function of the radial distance of the absorption point from the center of the detector. The pulse height distribution is then obtained accounting for the different geometrical probabilities of the absorption events.

Geometry B

In this case, we obtain that the pulse height is independent on the absorption position, thus there is not a spectral broadening arising from spatial effects. Furthermore, the amount of energy detected by the thermistor is increased, actually we have a 2.26 KeV pulse height for an interface with $\eta=0.025$ and a 2.58 KeV pulse height for an interface with $\eta=0.125$

In this geometry thus the spectral resolution should be limited only by the macroscopic noise sources and the fraction of energy effectively thermalized and transferred to the thermistor. Assuming that the macroscopic noise sources limit the resolution of such detectors to 1 eV FWHM, we have that the effective spectral resolution due to reduction of the SNR by incomplete thermalization becomes 2.6 eV FWHM for an interface with $\eta=0.025$ and 2.2 FWHM eV for an interface with $\eta=0.125$

In general, the height and rise time of the detected signal pulses depend on the fraction of energy effectively converted into phonons in the absorber, on the value of η and on the time constant τ of the link to the thermal bath.

Here we compare two different detector geometries (A and B in the following), and for both we discuss two different values of η . Namely, we assume that η can likely vary in the range (0.025, 0.125), due to the presence of a thin layer of epoxy between the absorber and the thermistor, that we cannot exactly model. We present simulations for $\eta=0.025$ (that we consider as a lower limit by the constraint that in such detectors the experimentally measured pulse rise times usually do not exceed ~40 microseconds) and $\eta=0.125$ (which should be an upper limit, corresponding to the theoretical estimate for a direct contact Sn/Ge).

Notice that in our simulations the link to the thermal bath is supposed to be the same in both the described geometries, and the value of τ is set according to the experimental estimate.

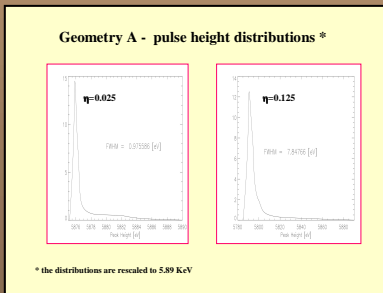
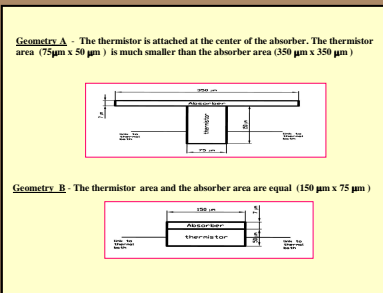
Geometry A - simulations data set

Absorption Position (μm)	$\eta=0.025$		$\eta=0.125$	
	Rise Time (µsec)	Pulse Height (KeV)	Rise Time (µsec)	Pulse Height (KeV)
x=25, y=25	43.3	0.9367	18.8	1.85375
x=50, y=50	43.3	0.93972	18.8	1.85462
x=75, y=75	43.2	0.93977	18.7	1.85533
x=100, y=100	43.2	0.93985	18.7	1.85631
x=125, y=125	43.0	0.94050	18.5	1.85919
x=150, y=150	42.3	0.94101	17.8	1.87318
x=175, y=175	41.7	0.94199	17.2	1.88546

In summary, the comparison between the two detectors gives:

Geometry A		Geometry B	
$\eta=0.025$	$\eta=0.125$	$\eta=0.025$	$\eta=0.125$
$\Delta E_{\text{sp}} = 0.97 \text{ eV}$	$\Delta E_{\text{sp}} = 7.84 \text{ eV}$	$\Delta E_{\text{sp}} = 0.00 \text{ eV}$	$\Delta E_{\text{sp}} = 0.00 \text{ eV}$
$\Delta E_{\text{th}} = 6.25 \text{ eV}$	$\Delta E_{\text{th}} = 3.12 \text{ eV}$	$\Delta E_{\text{th}} = 2.6 \text{ eV}$	$\Delta E_{\text{th}} = 2.2 \text{ eV}$
$\Delta E_{\text{tot}} = 6.3 \text{ eV}$	$\Delta E_{\text{tot}} = 8.4 \text{ eV}$	$\Delta E_{\text{tot}} = 2.6 \text{ eV}$	$\Delta E_{\text{tot}} = 2.2 \text{ eV}$

* ΔE_{sp} is the spectral broadening coming from spatial effects, ΔE_{th} is thermodynamic limit to the spectral resolution (for such detectors ~ 1 eV FWHM) scaled to account for the effective fraction of energy detected by the thermistor, ΔE_{tot} is the total spectral broadening calculated by adding in quadrature the two contributions.



We conclude with some considerations about the presented results:

- The microcalorimeter with geometry A was already used in laboratory tests and at present it permits to achieve a spectral resolution as good as about 5 eV @ 5.89 KeV. This may mean that in the real case the value of the coefficient η is an intermediate one between the two extreme values we have investigated, as it is reasonable. In fact, since, in principle, the functions ΔE_{sp} vs. η and ΔE_{th} vs. η can be non-linear, some η intermediate between 0.025 and 0.125 could produce a total spectral broadening lower than 6.3 eV. However, even if the accordance between experimental and numerical data has to be improved, the results indicate that, in a detector with this geometry, spatial effects can be a non negligible source of spectral broadening.
- The microcalorimeter with geometry B was recently manufactured just to test the predictions of the simulations and it will be tested soon at CTA.

