Analysis techniques for the signal processing of the HOLMES detectors

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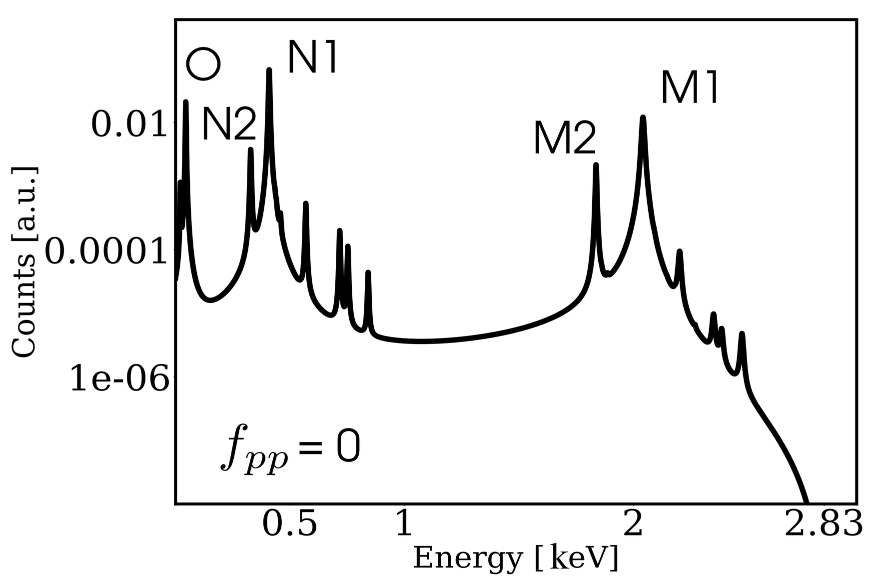
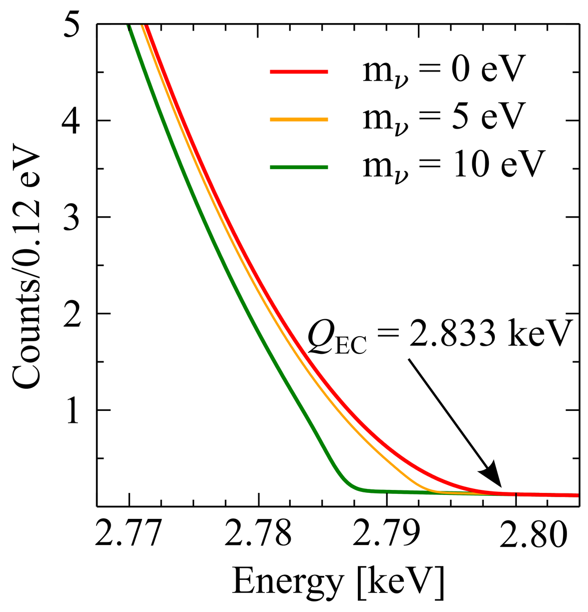
Overview

HOLMES is an experiment with the aim to directly measure the neutrino mass. HOLMES will perform a calorimetric measurement of the energy released in the Electron Capture decay of the artificial isotope ^{163}Ho. Random coincidence events are one of the main sources of background which impairs the ability to identify the effect of a non-vanishing neutrino mass. In order to resolve these spurious events, detectors with fast response and pile-up recognition algorithms are needed. We have developed a code for testing the discrimination efficiency of a Singular Value Decomposition algorithm. This algorithm is based on the work of Alpert et al. (J.Low Temperature Phys., Vol 184 (2016)). The obtained time resolution closely matches the baseline specification of the HOLMES experiment.

HOLMES

- Direct neutrino mass measurement through the calorimetric measurement of the de-excitation spectrum of the dysprosium $^{163}Ho + e^- \rightarrow ^{163}Dy^* + \nu_e(E_c)$
  - The neutrino is not detected, but its mass affects the shape of the spectrum
  - Spectrum distortion is statistically significant only in a region close to the end point





- Detectors : microcalorimeters Transition Edge Sensors with ^{163}Ho implanted Au absorber

HOLMES target:

- 1000 channels for 3×10^{13} events collected in 3 years
- Energy resolution: O(eV)
- Pixel activity A_{EC} ~ 300 Bq/det
- Time resolution: τ_{eff} <3 us

Expected sensitivity m_ν < 2eV

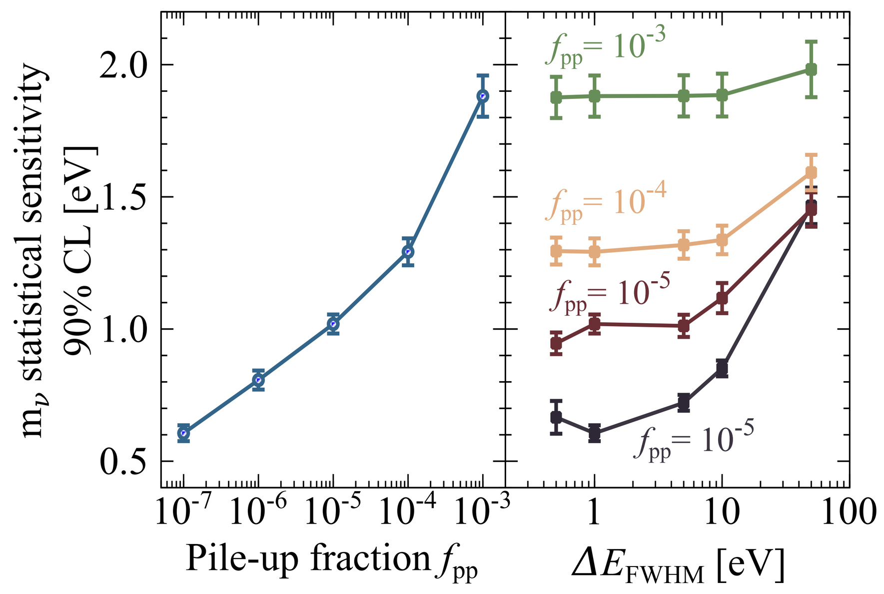
Statistical sensitivity $\Sigma(m_\nu)$ from MC simulations

- Strong on statistic

$$N_{ev} = A_{EC} \times N_{det} \times T_M \rightarrow \Sigma(m_\nu) \propto N_{ev}^{1/4}$$

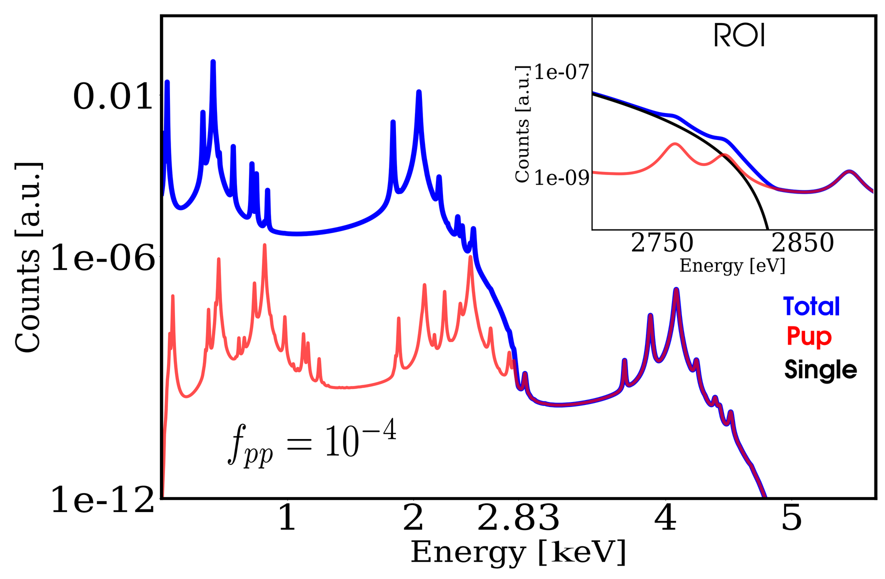
T_M Measurement live time
N_{det} Number of detectors
A_{EC} Single pixel activity

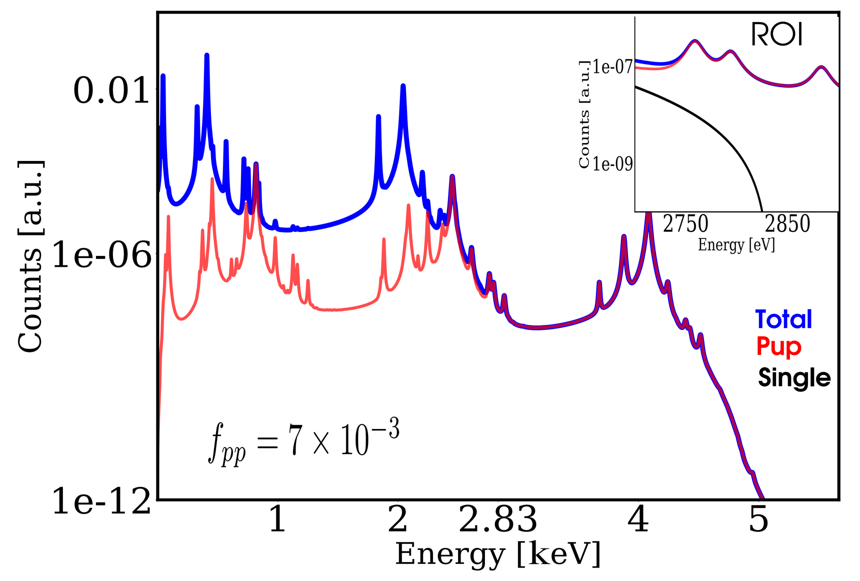
- Weak on energy resolution



- Strong on rise time pile-up

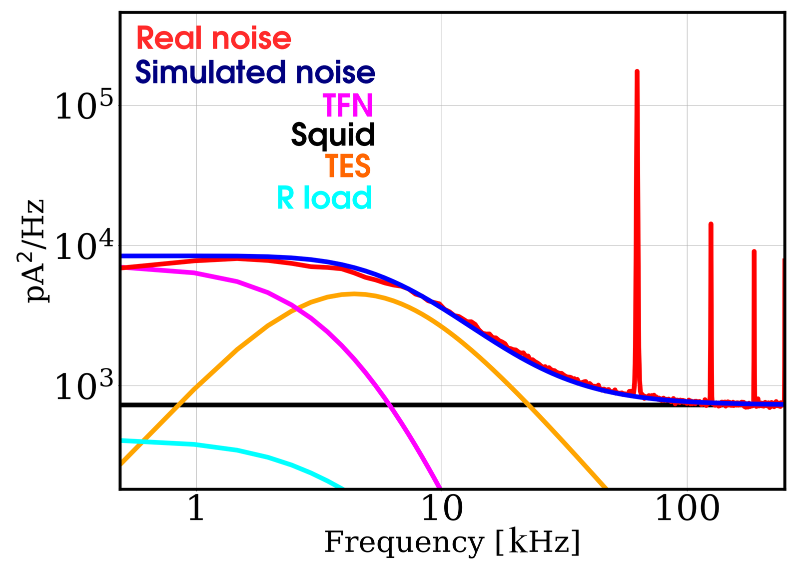
$$\frac{\text{number of pup pulses}}{\text{number of single pulses}} = f_{pp} \simeq A_{EC} \times \tau_{eff}$$

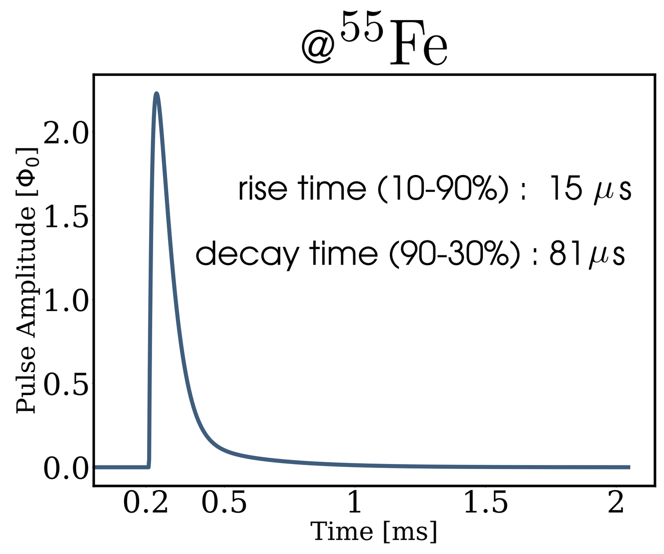


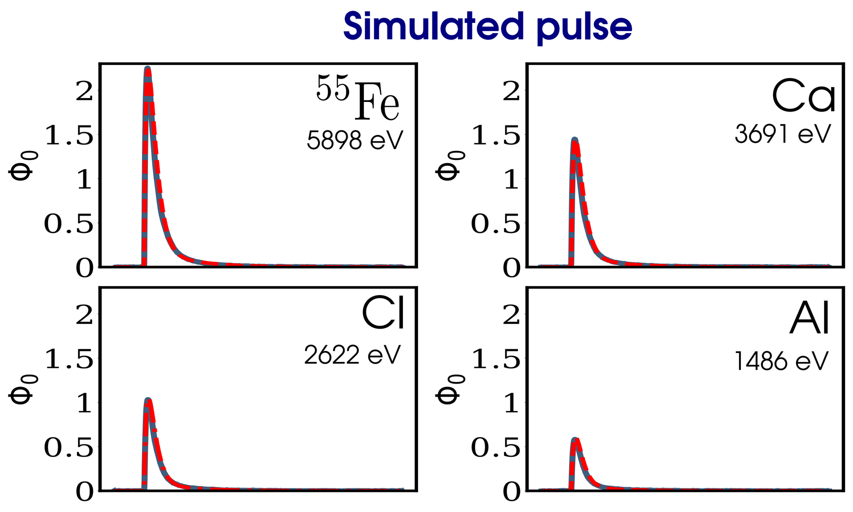


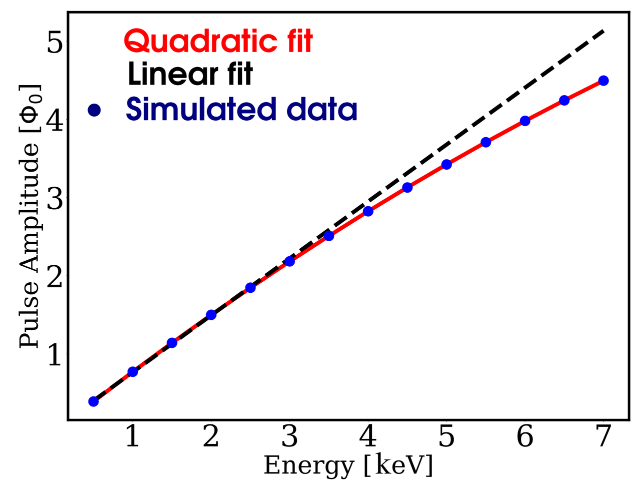
Simulations of TES response

- Noise profile from the Irwin Hilton 1-body model
  - AutoRegressive Moving Average (1,1)
- Pulse profile obtained by solving three coupled differential equations (2-body model) + correction on the energy
  - Only 52% of the energy is converted into the current pulse
  - Fourth order Runge-Kutta method
  - Non linear behavior taken into account
- Sampling rate: 500 kHz









Simulation goal:

- Estimate the time resolution with our current analysis algorithms
  - Raw filters, Optimum filter shape parameters (OFTV L,R)
  - Singular Value Decomposition (SVD)

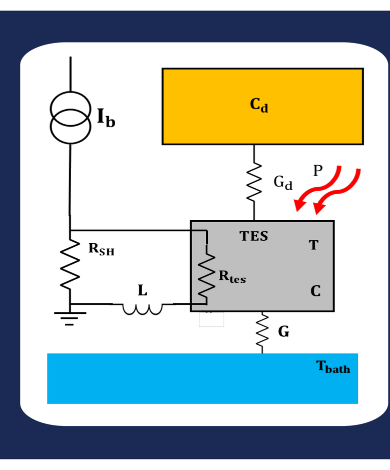
Simulation details:

- Realistic* pulse data
  - *Simulated pulses equal to the one obtained in our previous measurements
  - *Simulate energies according to the one and two hole electron excitation spectrum...
    ...with a 300 Hz activity (61% single pulses, 31% double p. 6 % triple p., 2 % quadruple p.)
  - ~ 700000 events simulated (~1h measure, one detector)
- Energies only from the Ho spectrum (no external source)

TES parameters

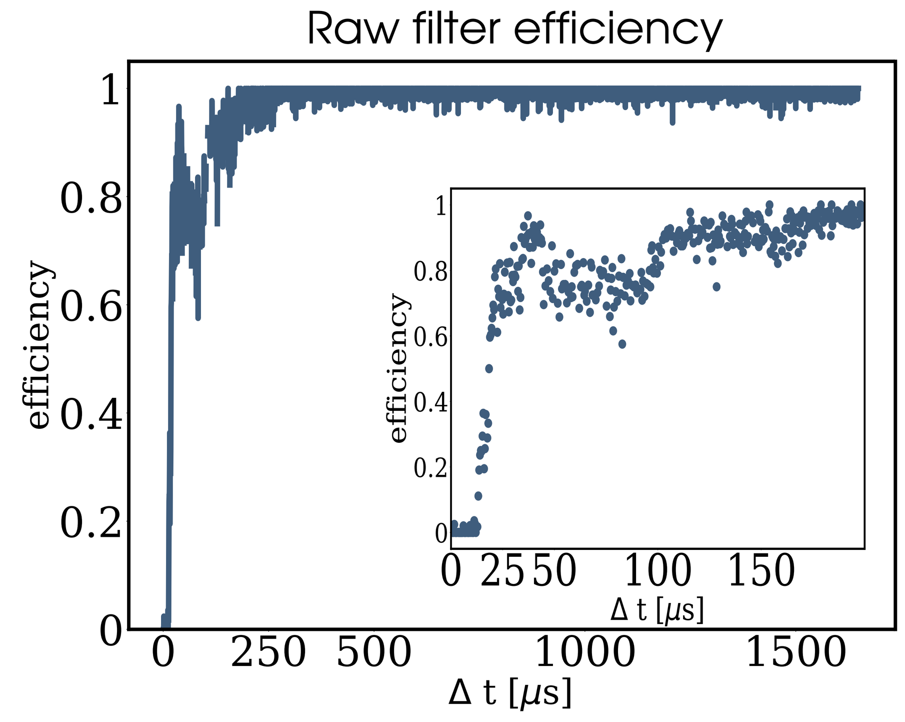
n = 2.5
C = 0.8 pJ/K
G = 700 pW/K
alpha = 100
beta = 2
R_L = 3 mΩ
R_N = 7.7 mΩ
R0 = 1.4 mΩ
L = 50 nH

n_d = 2
G_d = 1200 pW/K
C_d = 0.2 pJ/K
TC = 0.1K
T_bath = 0.04 K



Pile-up discrimination

Procedure: 1) Discard pile-up (pup) events at the M1 using *raw filters* + OFTVL, OFTVR



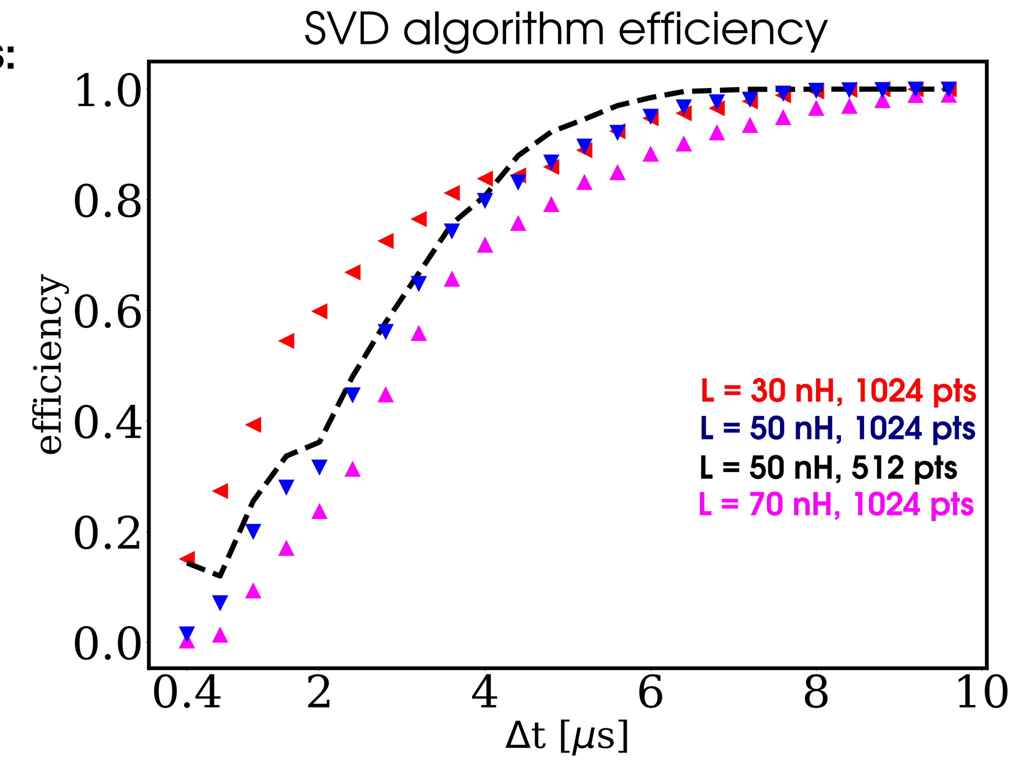
Δt = time interval between two consecutive pulses

efficiency = fraction of events identified as pup

2) With SVD create a model for the single pulses at M1 peak (@ 2041 eV)
A similar version of the algorithm developed by Alpert is used *Alpert, B. et al, J. Low Temperature Phys., 184 (2016)*
No noise whitening. 4 Singular vectors used. Events are normalized to remove the amplitude dependence

3) Apply the model to a set of uniform distributed ((0,10) μs) pile-up events in the ROI
ROI @ (2700,2900) eV

Results:



τ_{eff} is an effective time resolution
It is the ratio of number of retained pup pulses to single pulses, divided by that ratio of original events, times 10 μs

L	Rise time 10-90 @M1	Points	f_{sample}	τ_{eff}
(nH)	(μs)	(# samples)	(kHz)	(μs)
30	11.2	1024	500	2.16
50	**17.6**	**1024**	**500**	**2.81**
50	17.6	512	500	2.97
70	20	1024	500	3.32

$f_{pp} \simeq 8 \times 10^{-4}$

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