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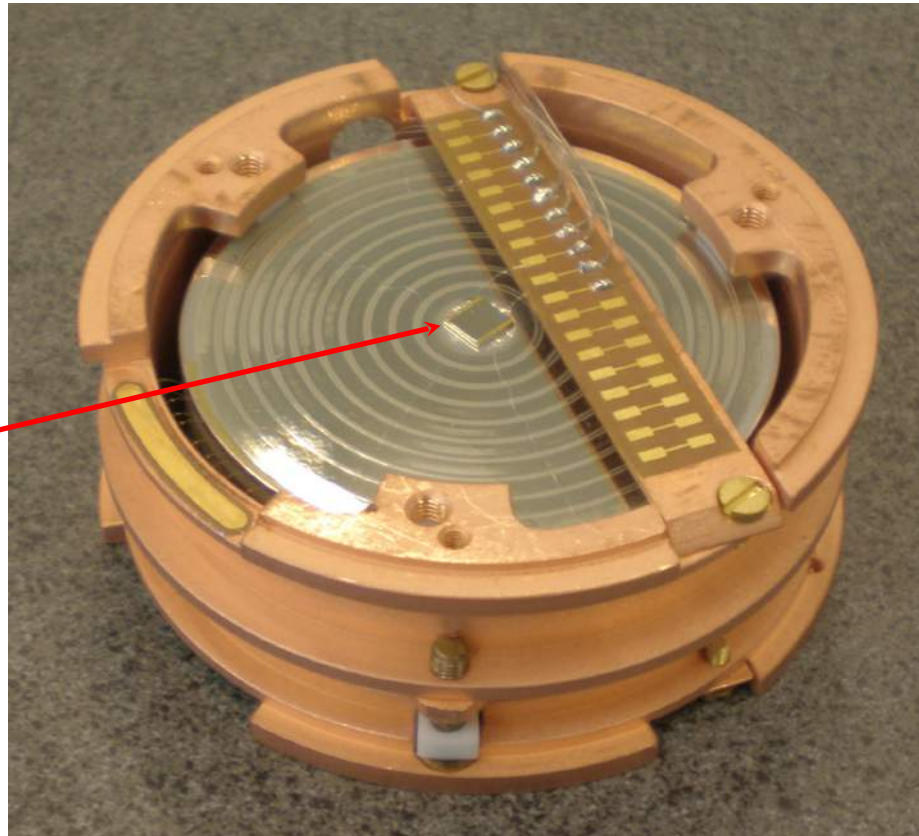
Heat signals associated with energy deposits within the NTD Ge thermometer in cryogenic germanium detectors for dark matter search

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Cryogenic ionization-and-heat germanium detectors fitted with NTD (neutron-transmutation doped) thermometers exhibit occasionally heat signals with unusual shapes, associated with energy deposits within the thermometer. Based on risetime measurements of the heat signals, a variety of situations are shown to arise, depending on whether the energy deposit took place within the thermometer or the detector crystal, or the energy was shared between both (as could be the case for a multiple interaction associated with the Compton scattering of a photon for instance). Templates for single energy deposits within the detector crystal on the one hand, and the thermometer on the other were obtained from a calibration experiment with 88 kV photons from a ^{109}Cd source. In the case of a compound interaction a fit of the heat signal to a linear combination of the templates enables to determine the amounts of energy deposited in the thermometer and the detector crystal respectively. Results are shown to be consistent with the ionization charge created with the detector crystal, as measured by the amplitude of the charge collection signals.

FID 201 cryogenic Ge detector: outlook of the device

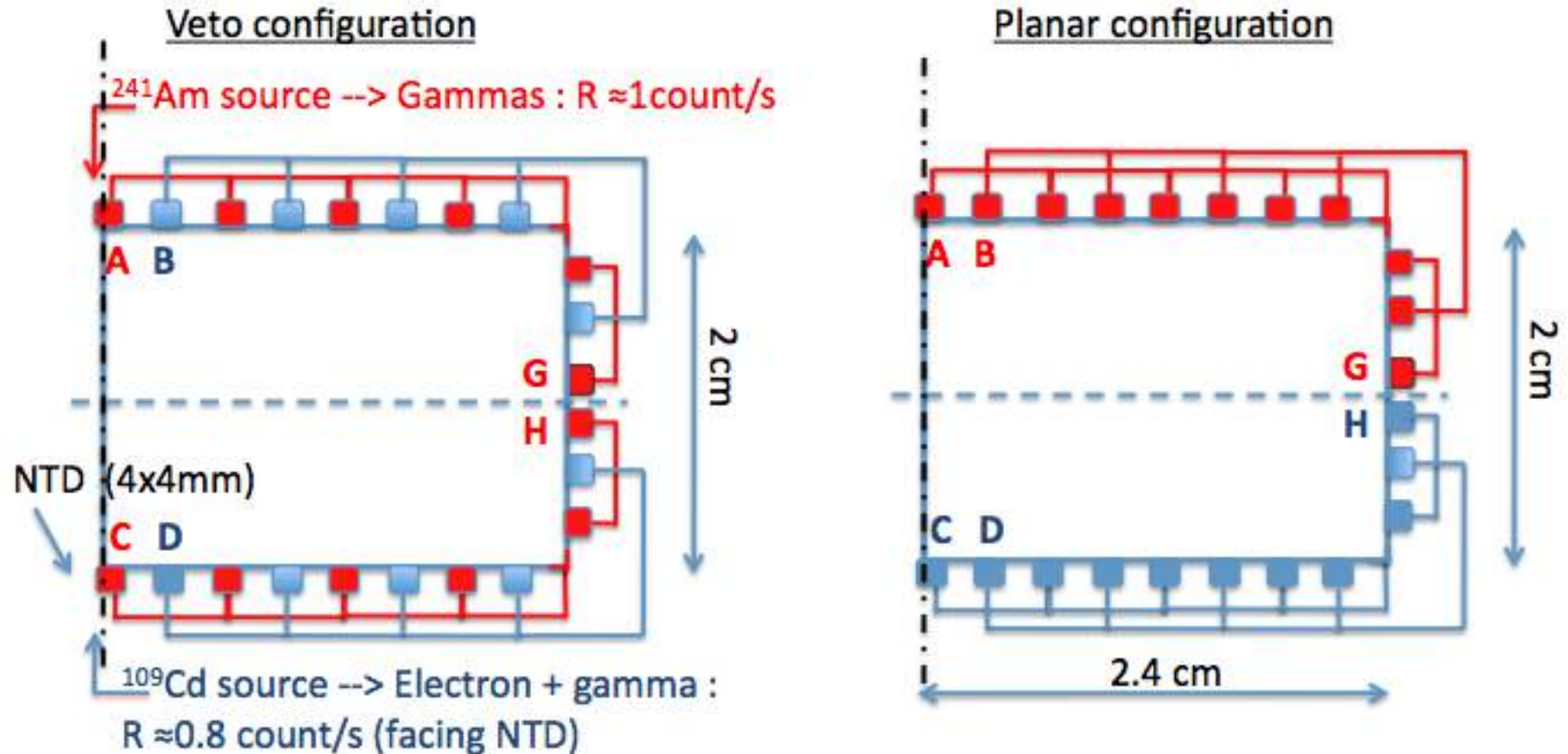


Neutron transmutation-doped (NTD) Ge thermometer

← 20 mm →

200 gram high-purity Ge crystal fitted with annular Al-evaporated collection electrodes and NTD Ge thermometer for operation at mK temperatures

FID201 : Experimental setup

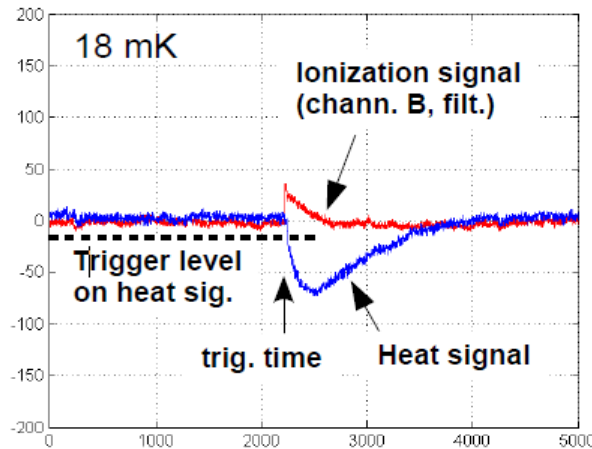


- 6 charge measurement channels A, B, C, D, G, H
- Setup allows to work in veto configuration and planar configuration
- High voltage bias up to 104 V
- Independent adjustment for each electrode set

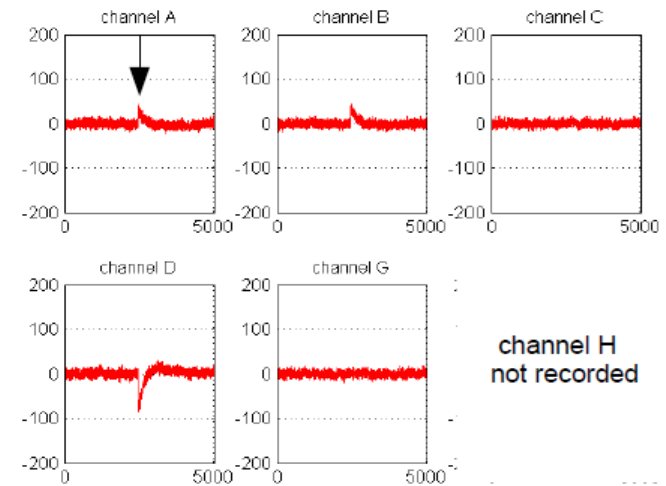
Measurement setup

'Regular' event
(ionization + heat
signals) from Am or Cd
sources

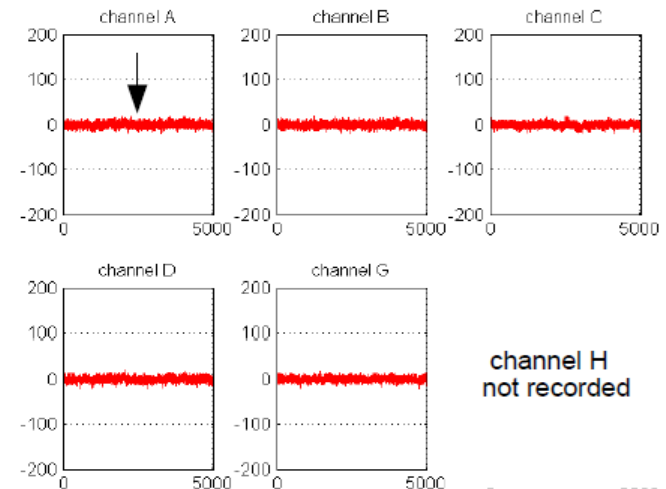
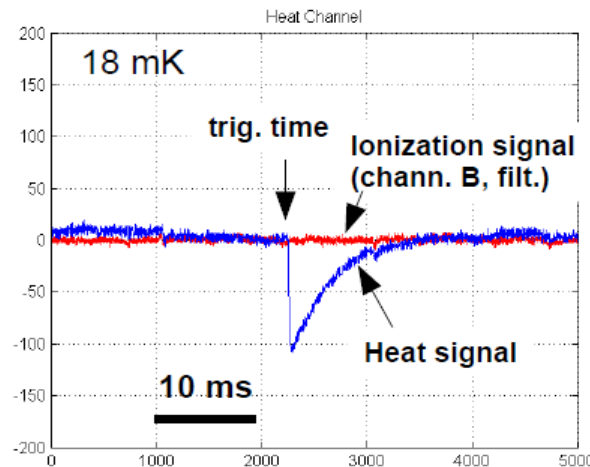
Scope #1 (master): Heat & ionization
(chann. B, filtered)



Scope #2 (slave): Ionization (all channels)



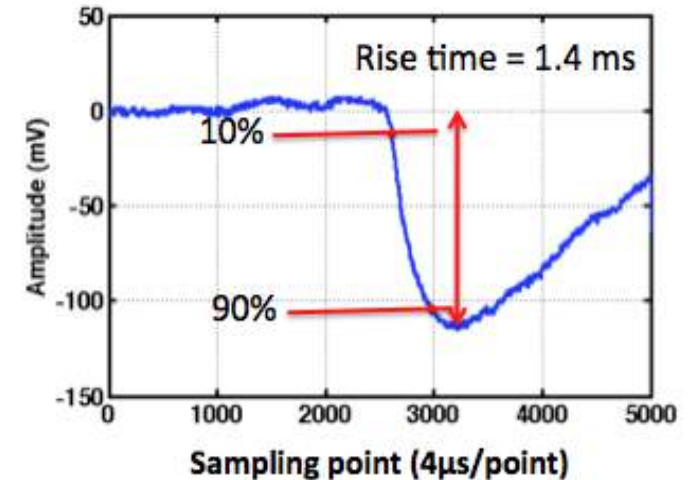
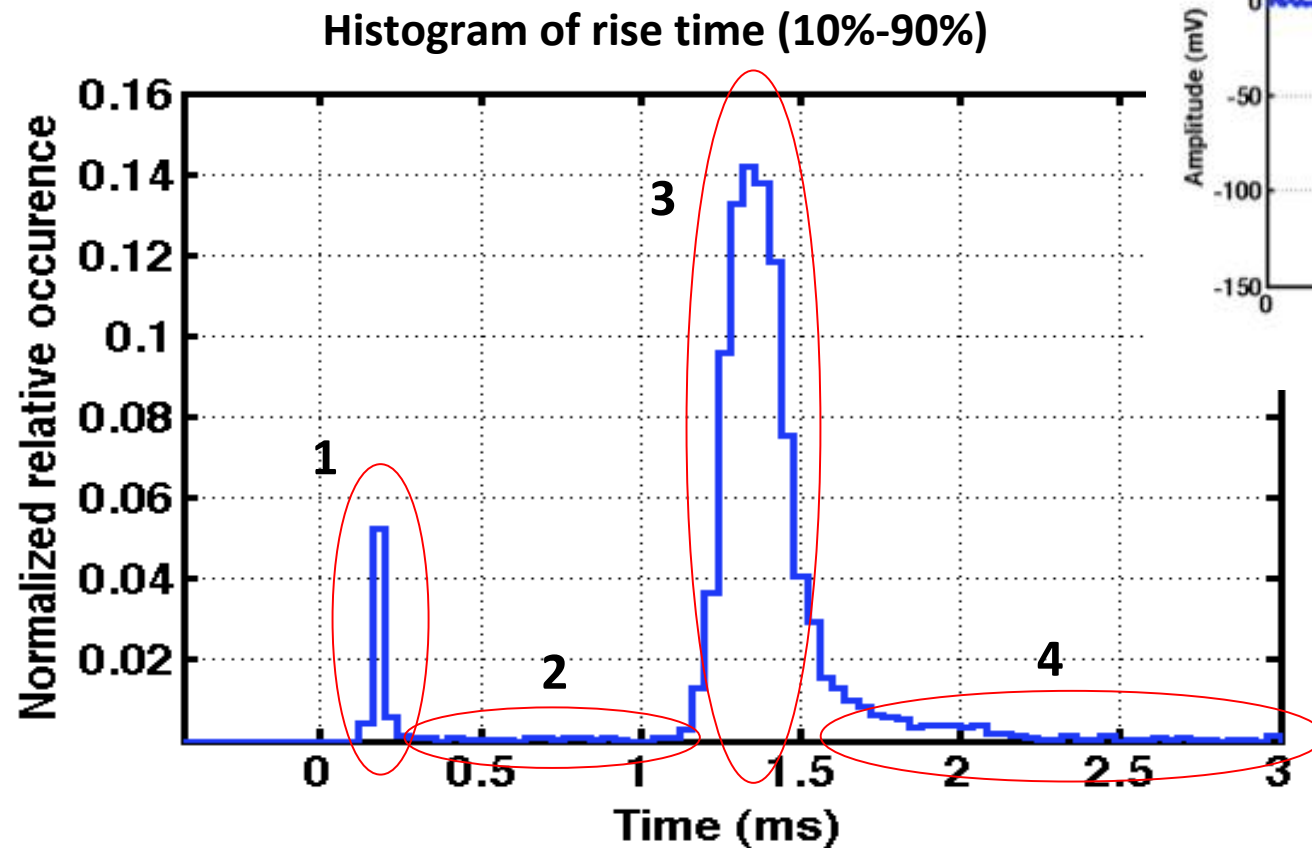
Heat-only event
(no signal is seen in the
the ionization channels)



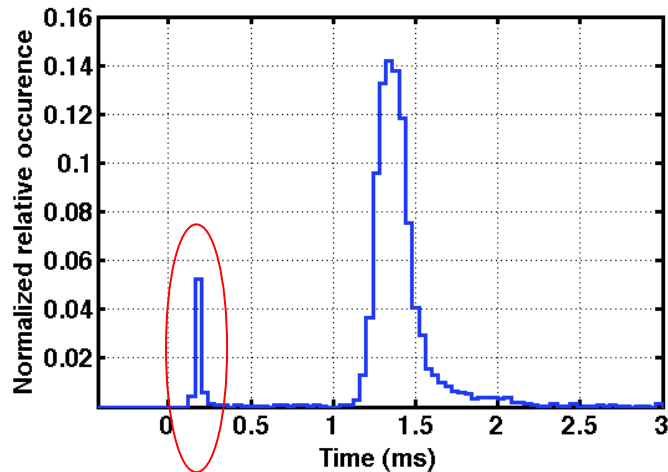
- Trigger is on the heat channel in scope #1.
- Sampling rate = 10 μ s/pt, the same for both ionization and heat channels.

Heat signal characterization at 18mK : event categories

- NTD is biased in dc mode (no modulation)
- Detector is operated in planar mode : $\pm 13\text{V}$ polarization
- Data acquisition : trigger on heat channel
- Comparative shapes for heat signals based on rise time
--> 4 distinct event populations

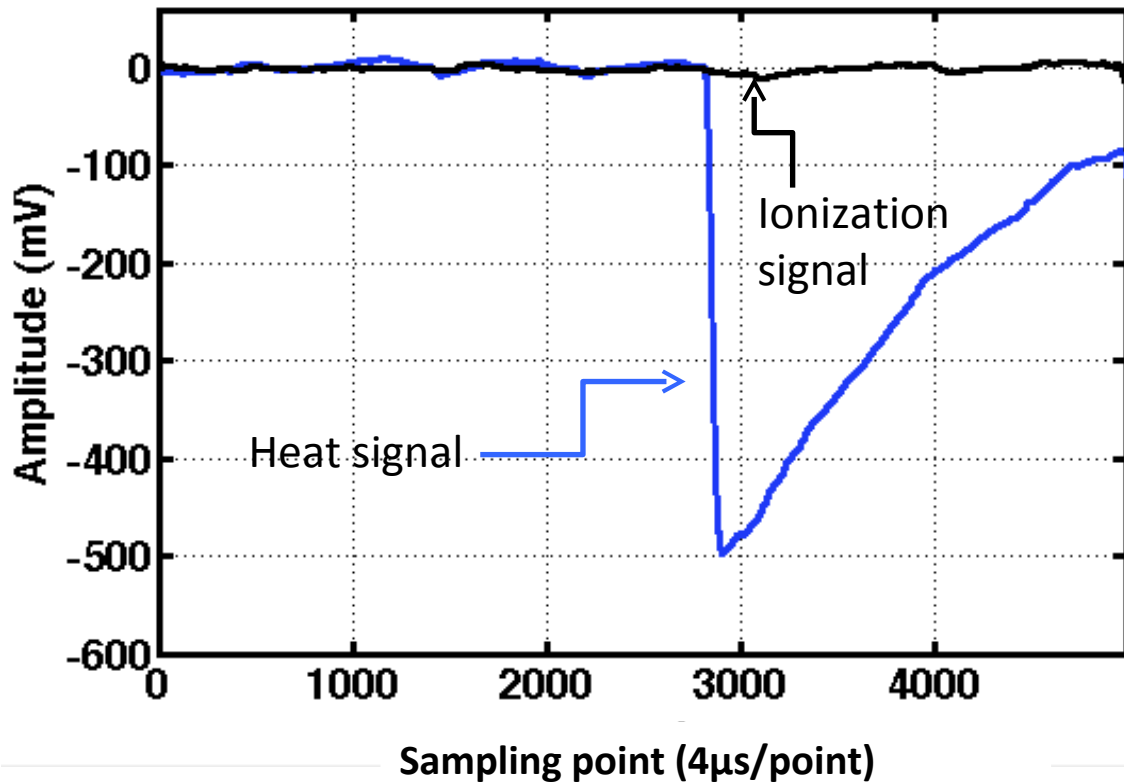


Type 1 : NTD heat-only events

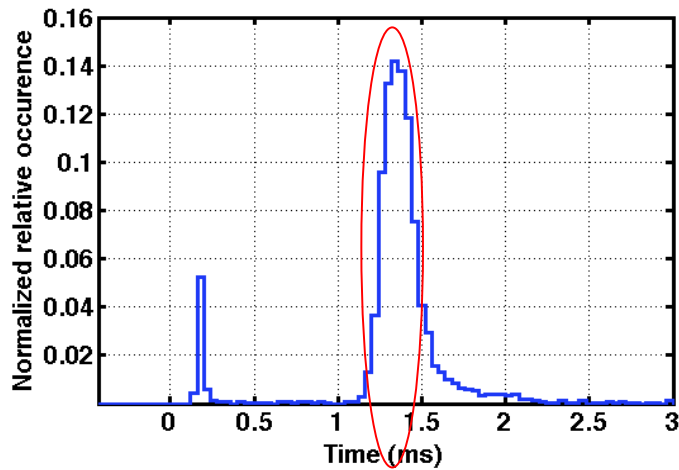


- No Ionization signal
- Rise time between 0.1 and 0.3 ms
- In black : composite charge signal $[A+B+G - (D+C)]/2$ (H channel missing)

- Steep rising edge
- Slower monotonous return to baseline (thermal leak to heat bath)

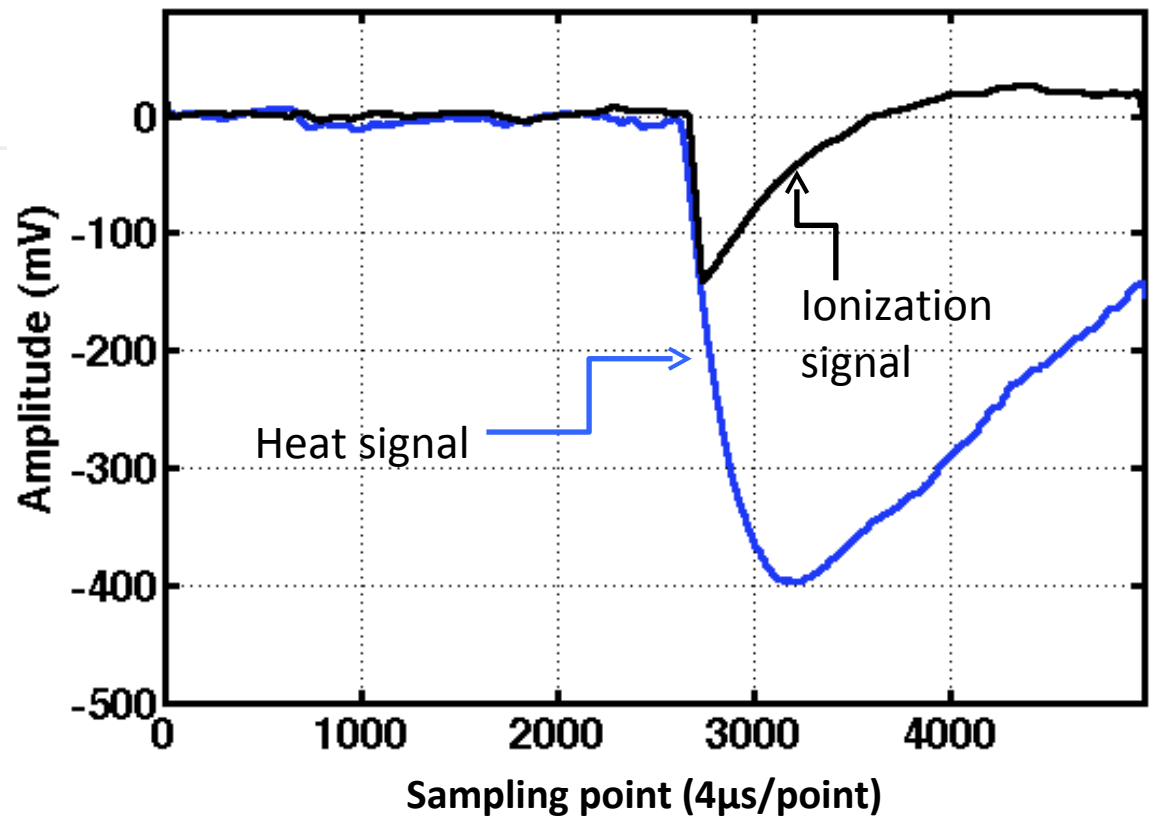


Type 3 : Regular ionization events

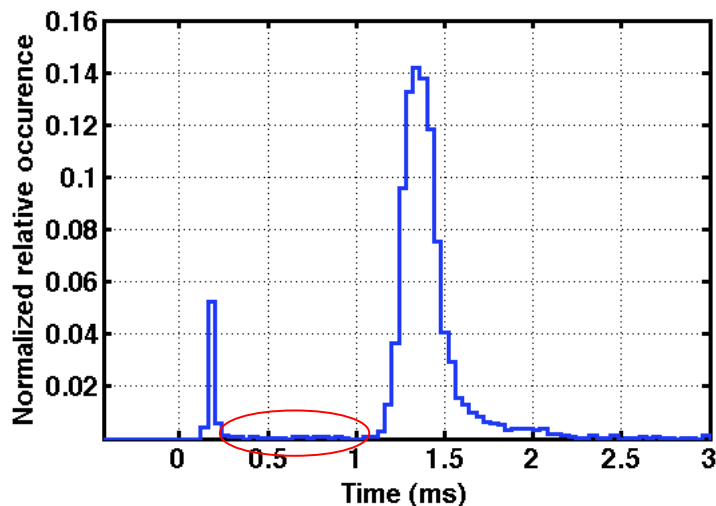


- Ionization+ heat signals
- Rise time between 1 and 1.5 ms
- In black : charge signal

- Smooth rising edge
- Slower return to baseline



Type 2 : double energy deposit (NTD + bulk)



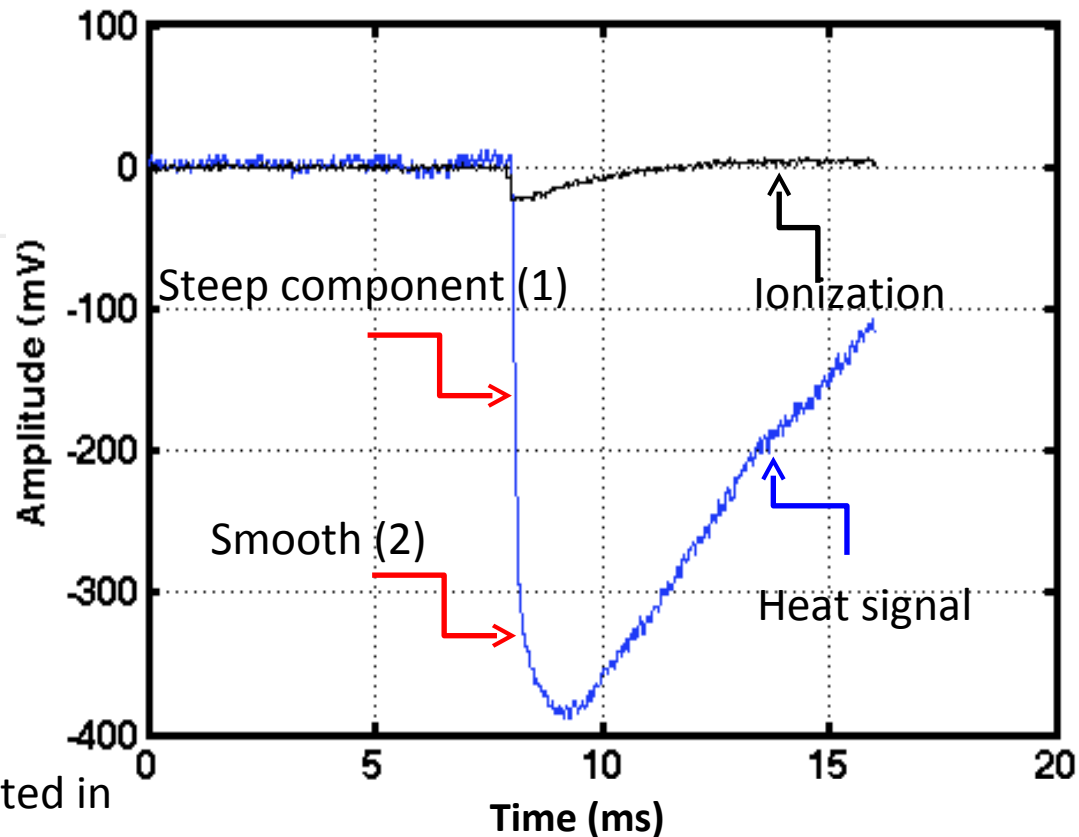
- Rising edge has 2 components:
 - (1) steep + (2) smooth

--> Double energy deposit, either coincident or too close in time to be separated from each other :

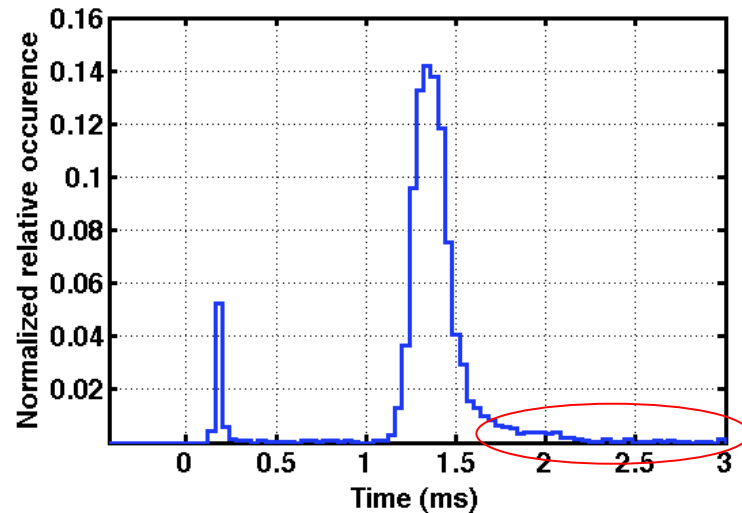
- Deposit (1) --> Heat only
- Deposit (2) --> Ionization

(could be coincident or closely separated in time, $\Delta t < \sim 10 \mu s$)

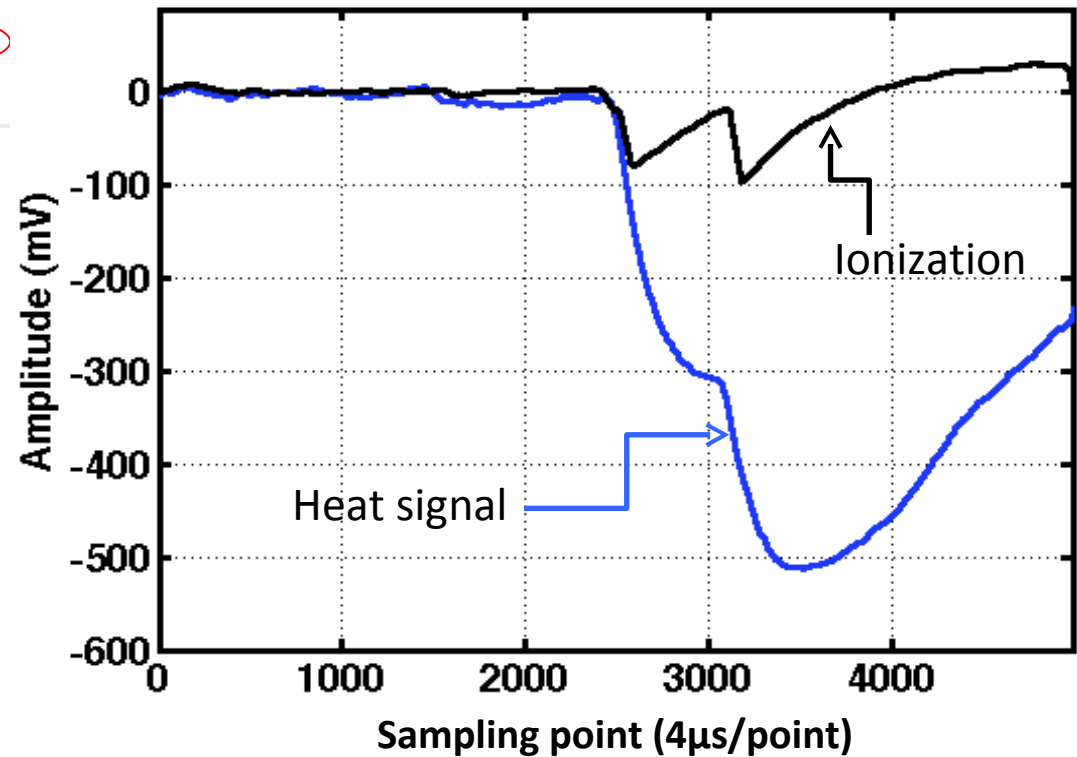
- Rise time between 0.3 ms and 1 ms
- In black : charge signal



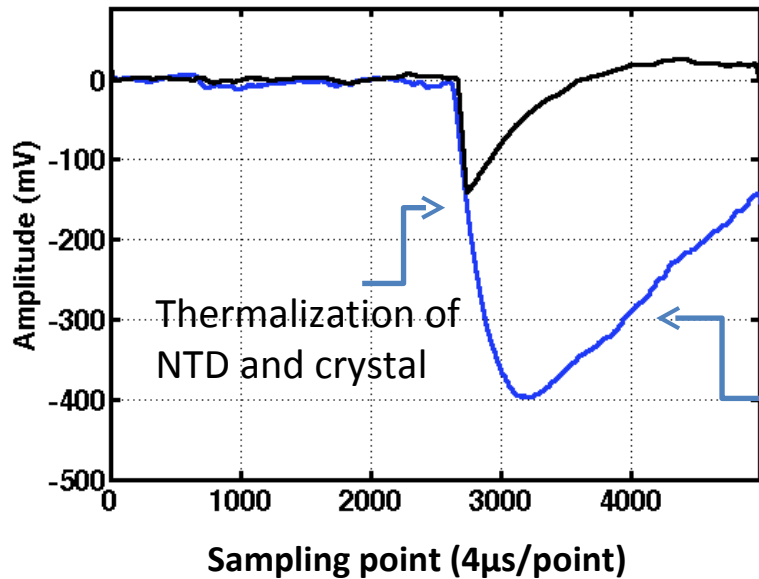
Type 4 : pile-up of ionization events



- Two successive ionization events, well-separated in time --> Pile-up
- Rise time > 1.7 ms
- In black : charge signal

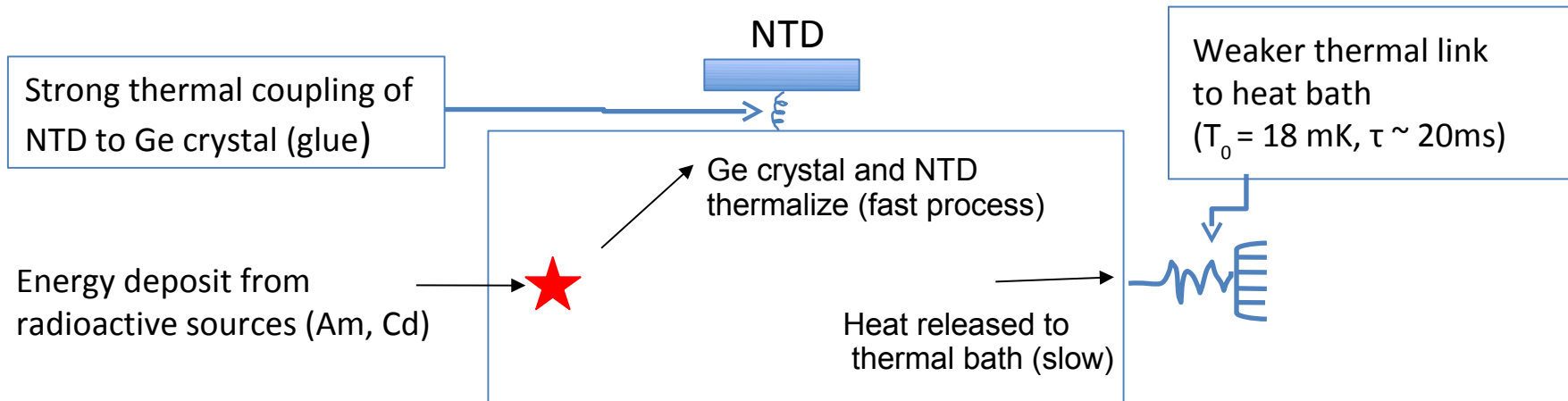


Interpretation of rise times : type 1 = energy deposit in the bulk

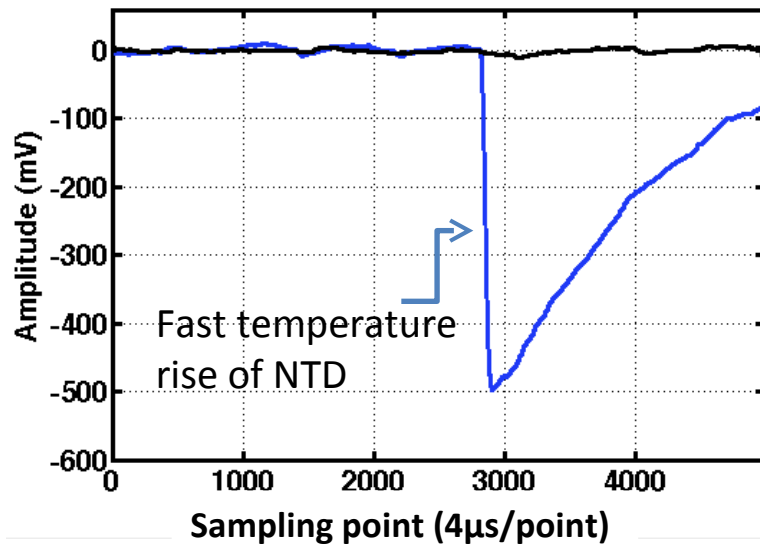


- NTD and Ge crystal thermalize --> leading edge of signal
- Heat released to thermal bath --> slow return of signal to baseline ($\tau \sim 20\text{ms}$)

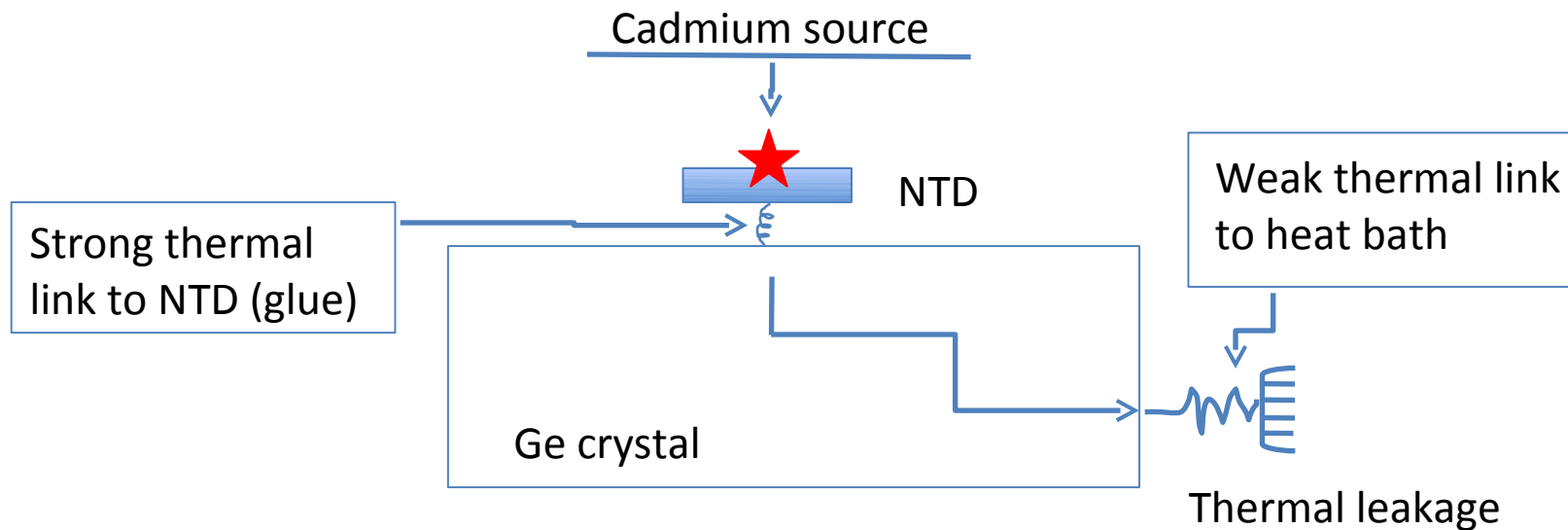
Heat is released to thermal bath



Type 2 = NTD heat-only event

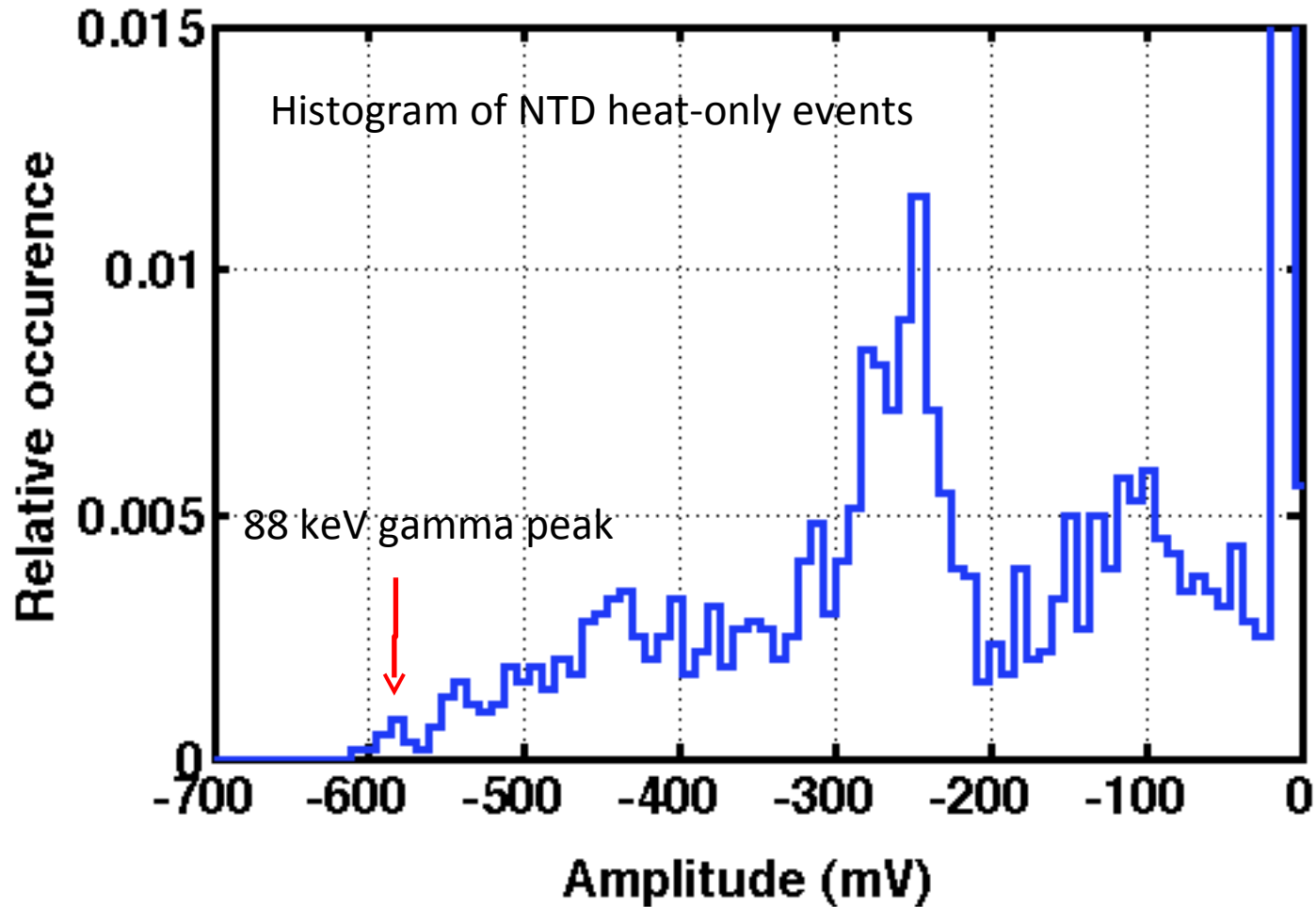


- Steep leading edge
- Slow return to baseline

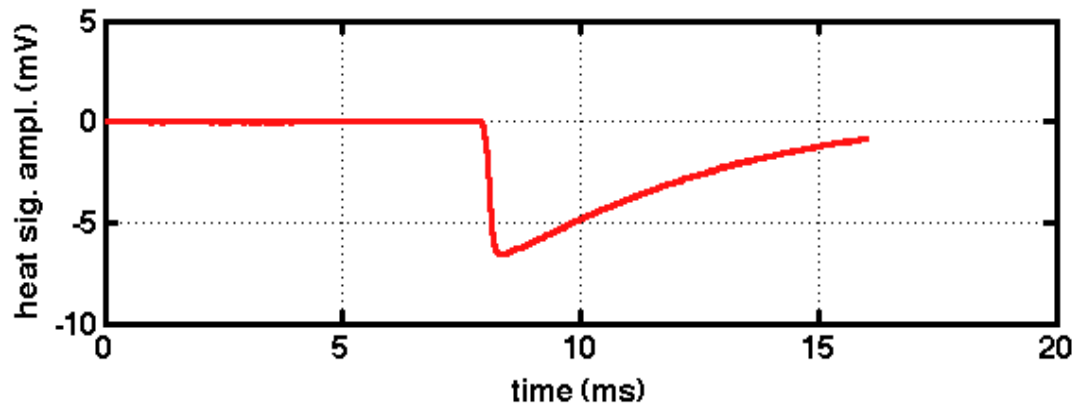


Calibration of NTD heat-only events

- ^{109}Cd source facing NTD emits gammas and electrons with maximum energy of 88keV

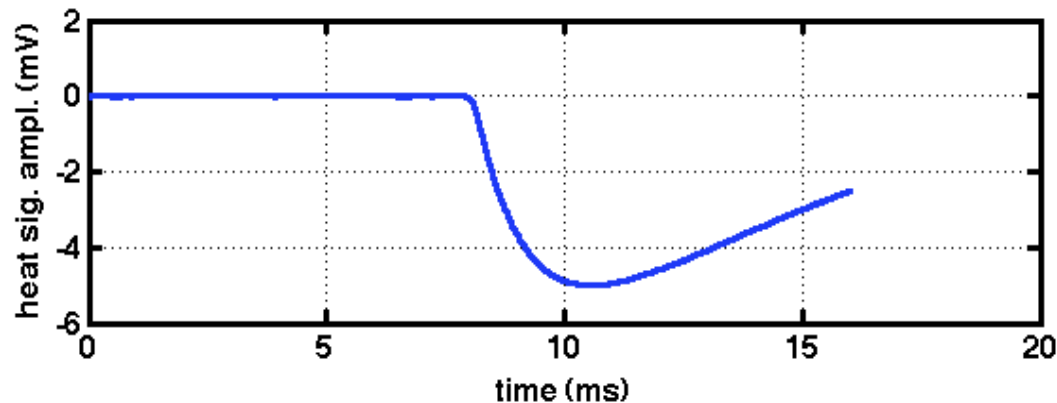


Templates for NTD and bulk Ge interactions



Template for NTD heat-only events (1 keV energy deposit)

Does not depend on detector bias.

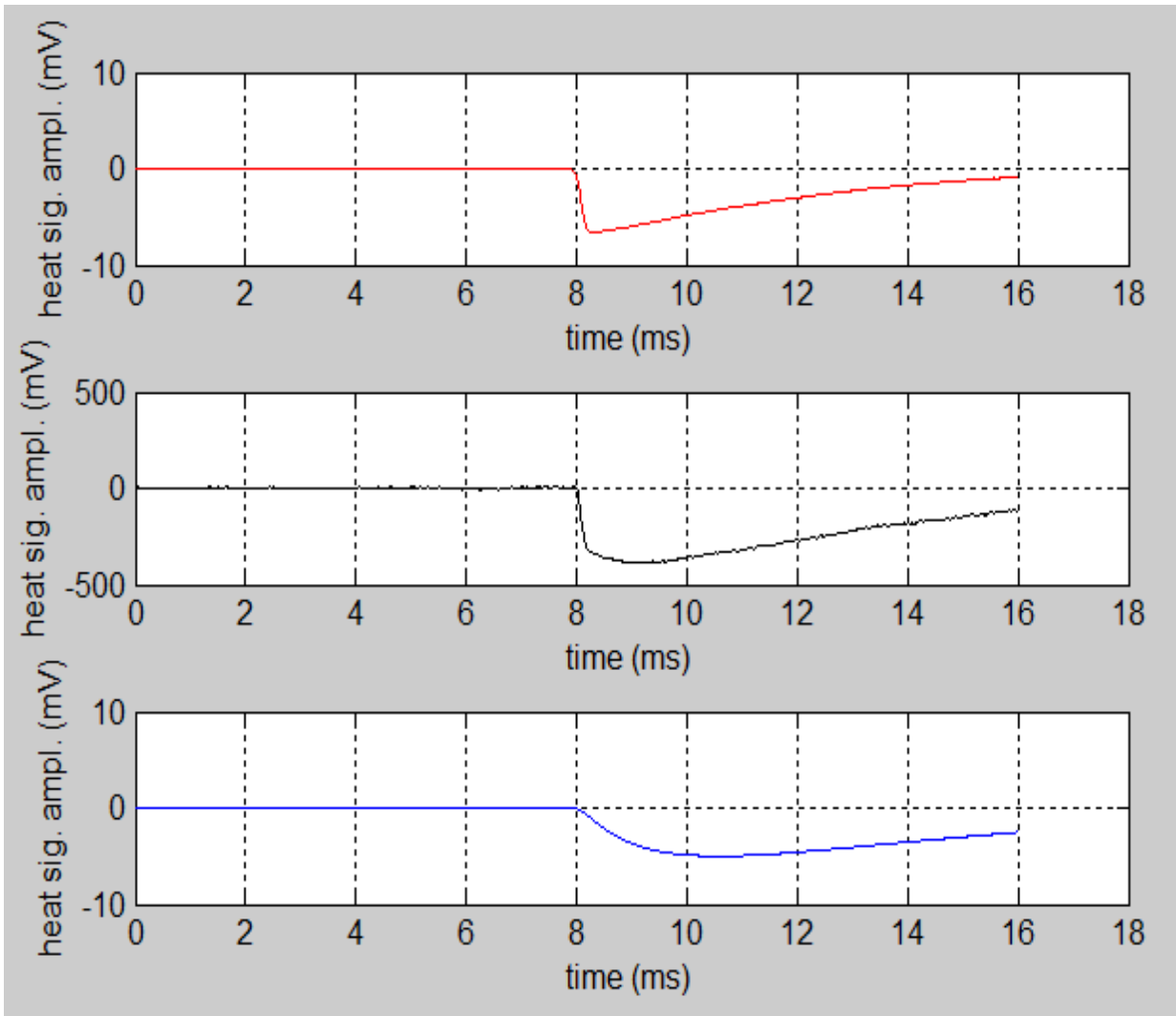


Template for electron recoils in bulk detector crystal (1 keV energy deposit)

Depends on detector bias (Luke effect)

- Mixing chamber temperature : 18mK
- NTD bias voltage (dc) : 50 mV
- Detector in planar mode (+/- 13V)

Analysis of type 2 = double energy deposits (NTD + bulk)

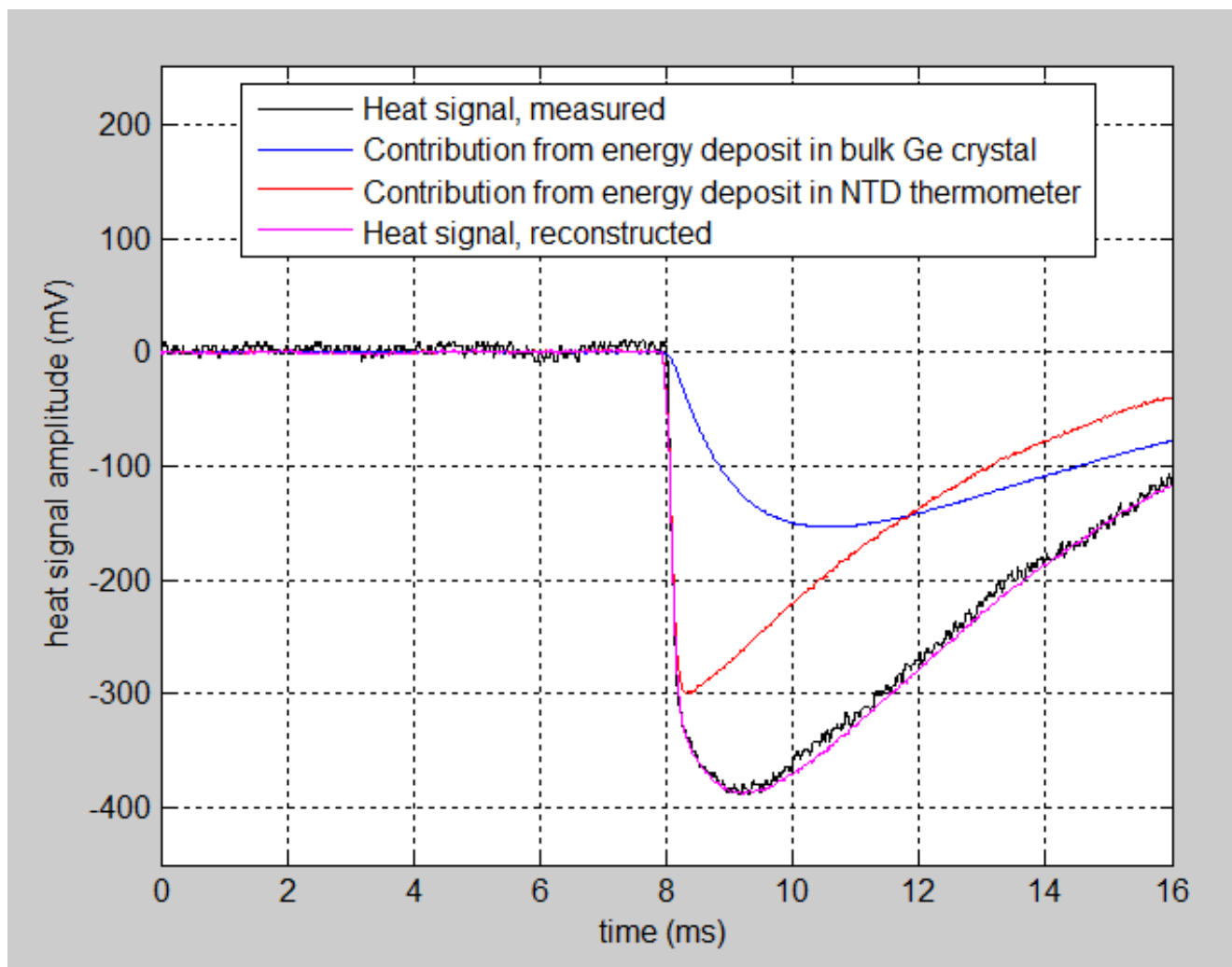


Template for NTD
heat-only events

Type 2 event, showing
compound risetime

Template for electron
recoils in bulk

Reconstruction of double energy deposit interaction (NTD + bulk)



energy deposit in NTD thermometer (keV)

30.7

energy deposit in Ge crystal (keV)

45.3

← consistent with
ionisation data !

Summary

- **Pulse-shape analysis of heat signals enables to distinguish between heat-only (NTD) events and regular energy deposits in the bulk, and to reconstruct double energy deposits.**