Feasibility Study of Dark Matter Searches with the CUORE Experiment

Marco Vignati

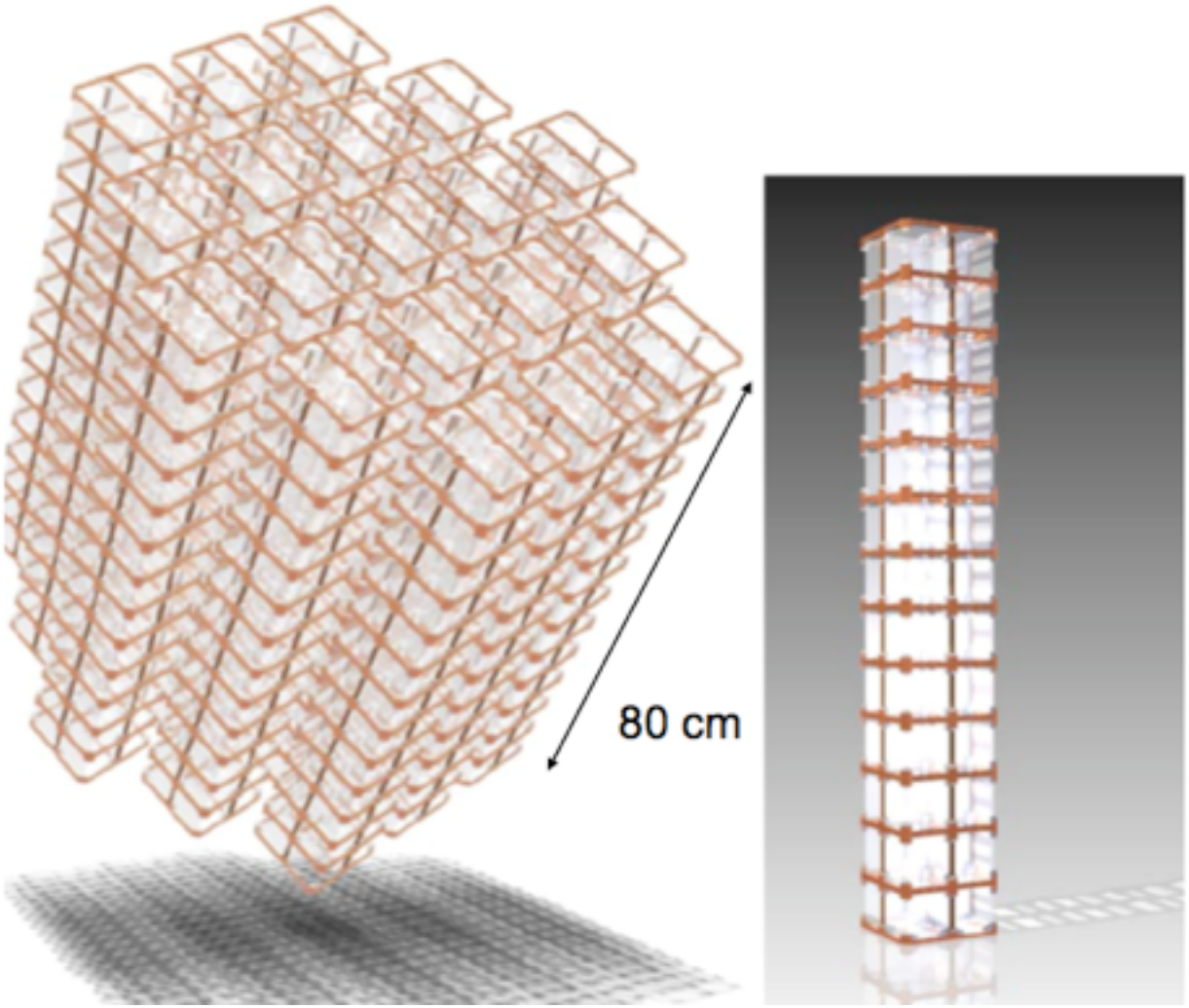
University of Rome “La Sapienza” & INFN Rome
on behalf of the CUORE collaboration

IDM 2010, July 26-30, Montpellier

CUORE

Ton scale bolometric experiment for the search of neutrinoless double beta decay of ^{130}Te

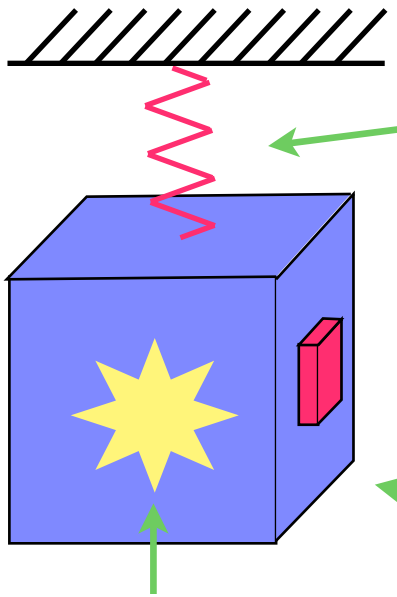
- 988 TeO_2 crystals
- 19 towers of 52 crystals each
- 750 g per crystal
- 741 kg TeO_2
  - 593 kg Te (204 kg ^{130}Te)
  - 148 kg ^{16}O
- Start data taking in 2013



Hosted @ Laboratori Nazionali del Gran Sasso, Italy, a natural shield of 1400 m of rock (3500 m.w.e.)

Bolometric technique

- Particle energy converted into phonons → temperature variation.
- TeO_2 crystals (dielectric, diamagnetic) → detector = source
- Low crystal heat capacitance and low base temperature to see small temperature variations → $\Delta T \sim E/C$



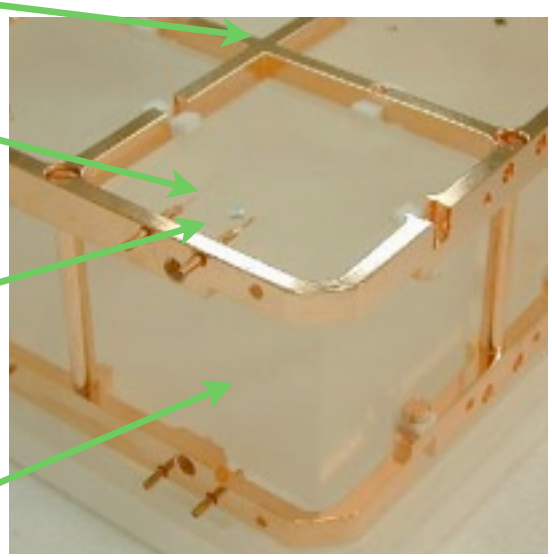
Heat bath ~ 8mK

Weak thermal coupling

Thermometer:
NTD Ge thermistor
R ~ 100 MΩ

Absorber Crystal
TeO_2 C~10^{-9} J/K

Energy release



- Detector response in this configuration: ~ 0.2 mK / MeV
- Resolution @0νDBD (2527 keV) ~ 5 keV FWHM

The demonstrator: Cuoricino

Active mass:

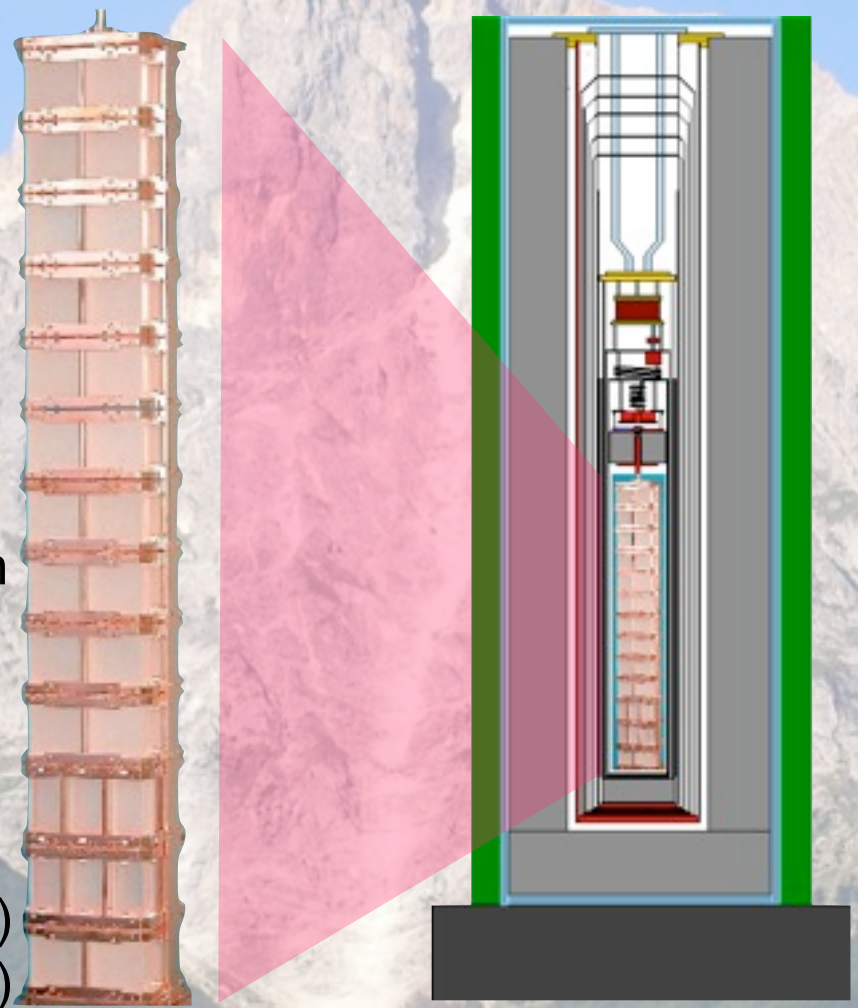
- TeO_2: 40.7 Kg
- ^{130}Te: 11.3 Kg
- ^{128}Te: 10.5 Kg

11 modules:

- 4 detectors of
  5x5x5 cm^3 = 790 g each

2 modules:

- 9 detectors of
  3x3x6 cm^3 = 330 g each
  2 enriched in ^{128}Te (82%)
  2 enriched in ^{130}Te (75%)



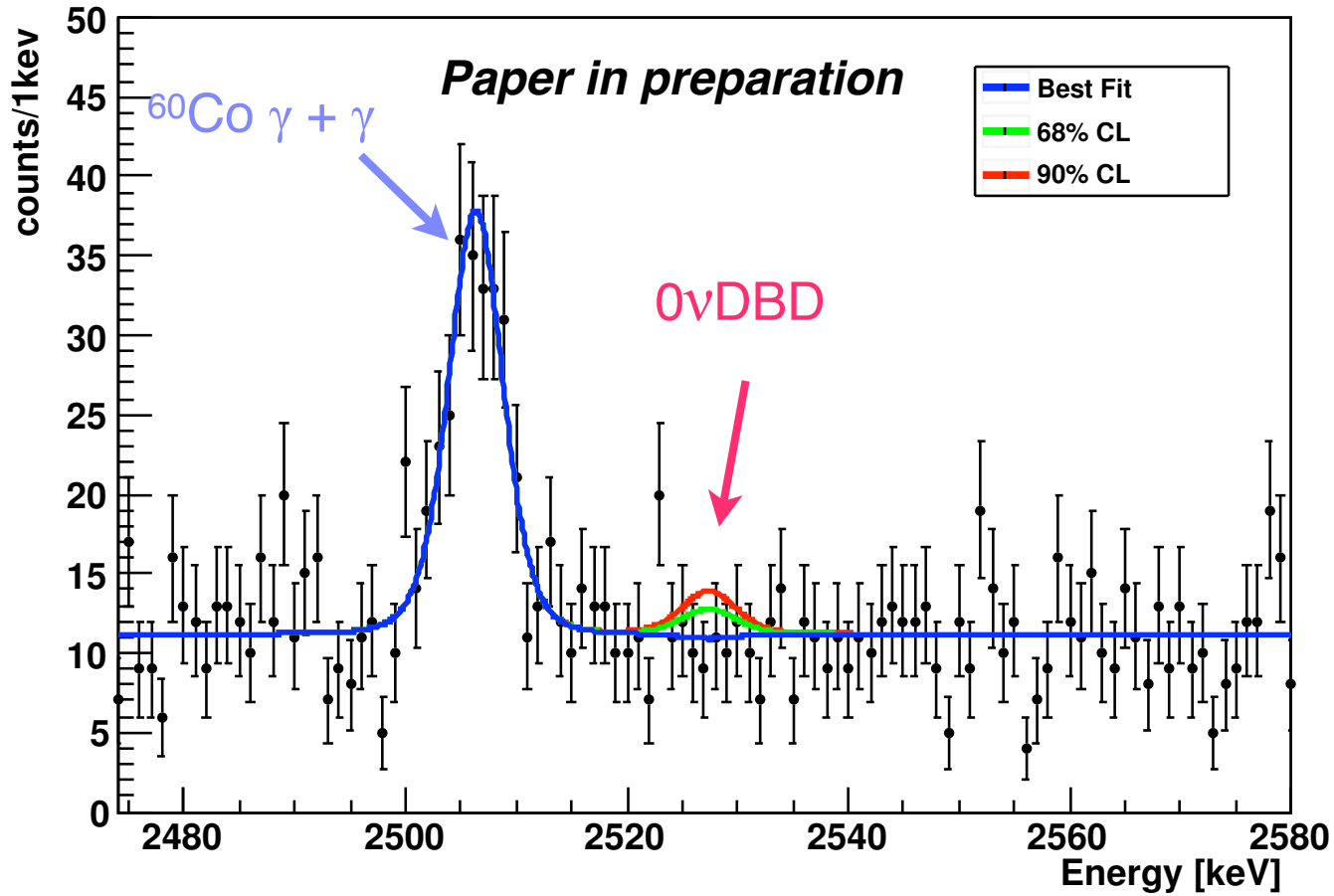
Data taking 2003-2008

Installed in a dilution refrigerator:

- Inner shield:
  - 1cm Roman Pb
    A (^{210}Pb) < 4 mBq/Kg
- External Shield:
  - 20 cm Pb
  - 10 cm Borated polyethylene
- Nitrogen flushing to avoid Rn contamination.

Cuoricino limit on 0νDBD half-life

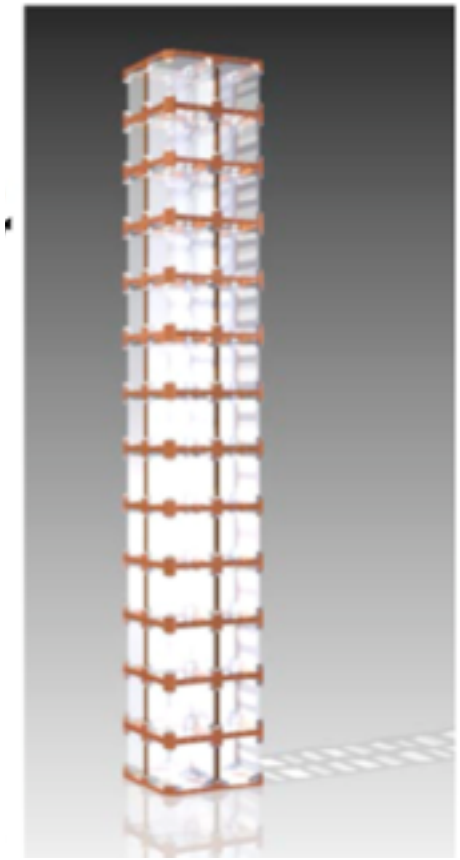
- Analyzed statistics: $M \cdot t = 19.75\,\mathrm{kg}(^{130}\mathrm{Te}) \cdot y$
- 0νDBD Half-life limit (90% C.L): $\tau_{1/2} > 2.8 \cdot 10^{24}\,\mathrm{y}$
- Effective neutrino mass limit: $m_{\beta\beta} < 0.3 \div 0.7\,\mathrm{eV}$
- Resolution: $\Delta E = 7\,\mathrm{keV\,FWHM}$



NME bibliography:
1 Šimkovic et al., PRC 77 (2008) 045503
2 Civitarese et al., JoP:Conference series 173 (2009) 012012
3 Menéndez et al., NPA 818 (2009) 139
4 Barea and Iachello, PRC 79 (2009) 044301

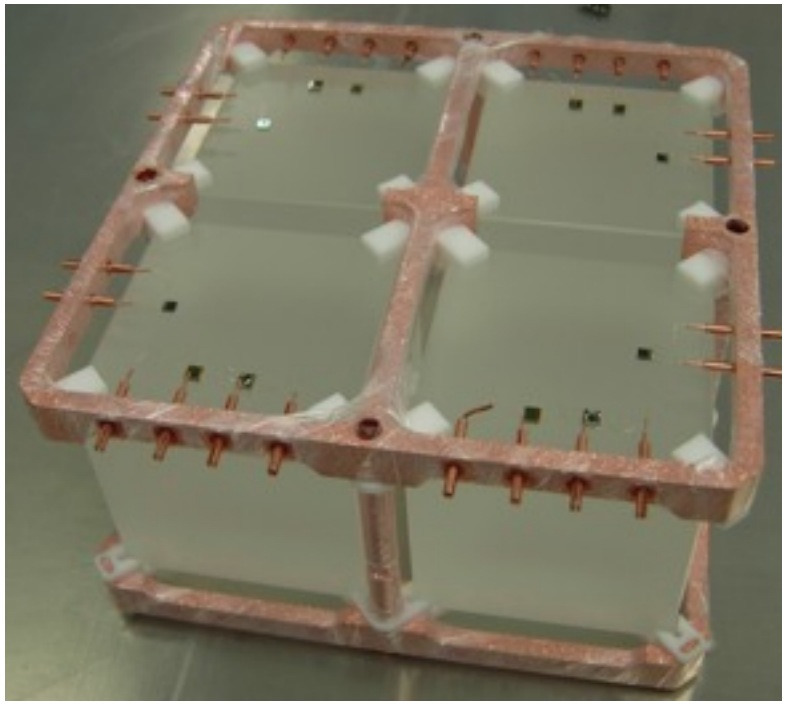
On the way to CUORE

- R&D to reduce the background in the 0nuDBD region.
- Periodic radioactivity checks of the CUORE crystals as they arrive from China (CUORE crystals validation runs).
- Construction of a CUORE-like tower.
  CUORE-0 (52 crystals, 39 kg TeO_2)
  will test the new assembly.
  - data taking in 2011.



Dark Matter searches

- In principle CUORE, thanks to its mass and to the good resolution, could look for an annual modulation of the counting rate at low energies.
- We are developing new trigger and pulse shape algorithms to lower the threshold down to the few keV region (in CUORICINO the software threshold was set above 30 keV).
- Here we present studies on a CUORE crystal validation run
  - 4 CUORE crystals arranged in a CUORE-like floor
  - Operated in the Hall-C test cryostat
  - ~3 weeks live time



The optimum filter algorithm

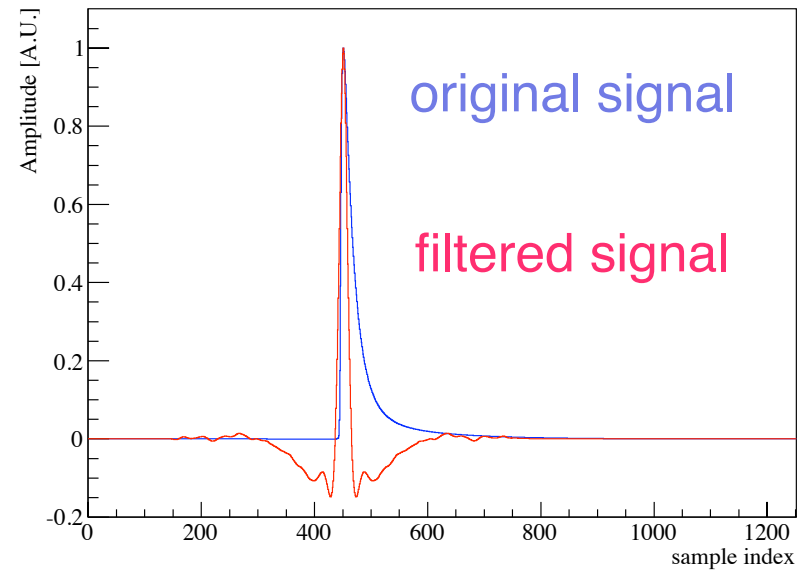
- The slices of data are filtered in the frequency domain with the optimum filter algorithm, maximizing the signal to noise ratio:

average signal shape
(estimated from data)

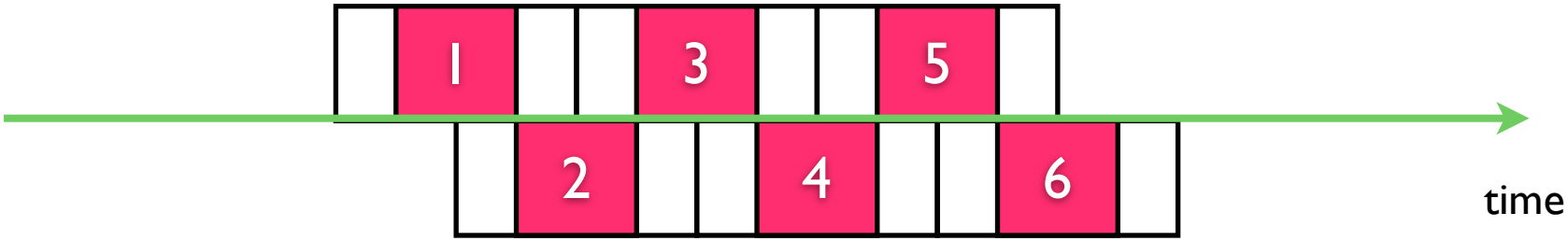
$$H(\omega) = \frac{S^*(\omega)}{N(\omega)} e^{-i\omega t_m}$$

maximum
position

noise power spectrum
(estimated from data)

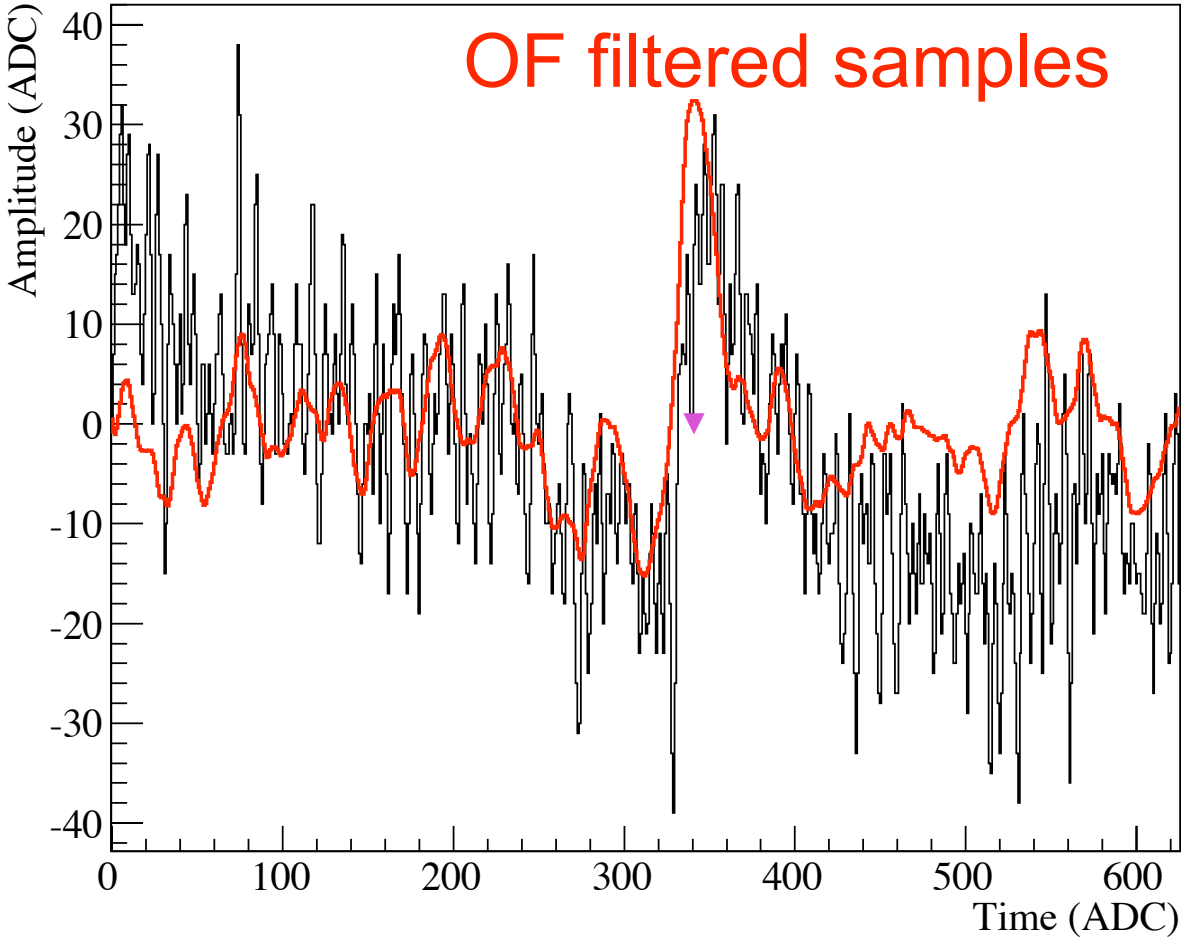


- The continuous data flow is filtered at interlaced intervals, to ensure that the FFT convolution is always valid:



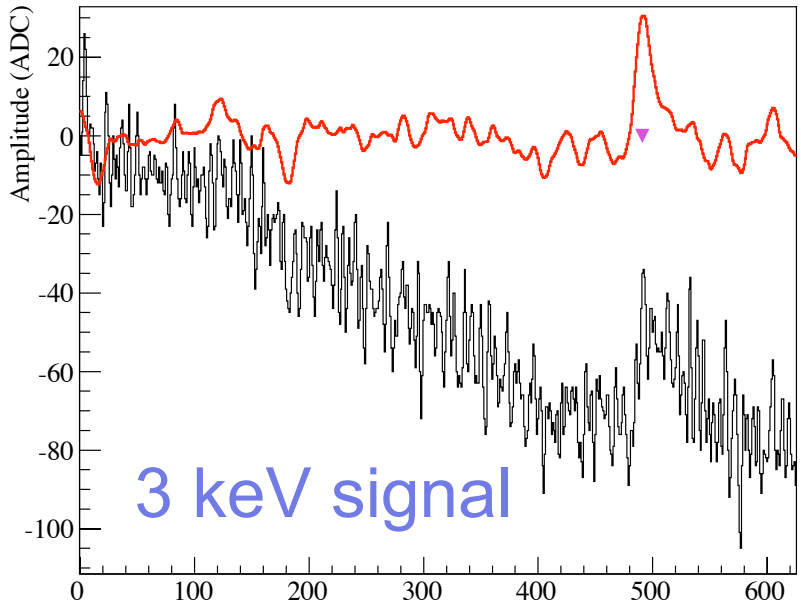
(see W. H. Press et al., Numerical recipes in C (2nd ed.) New York, Cambridge University Press, 1992.)

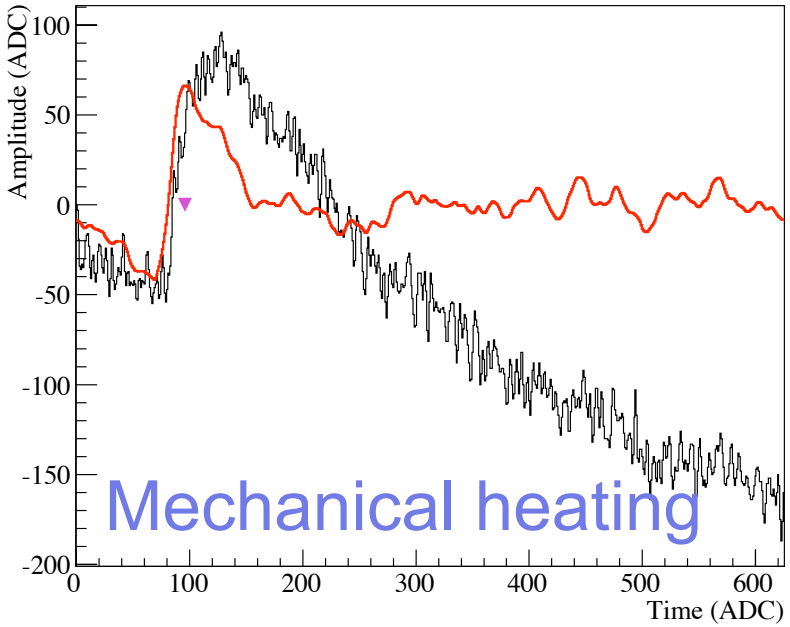
Triggering the data

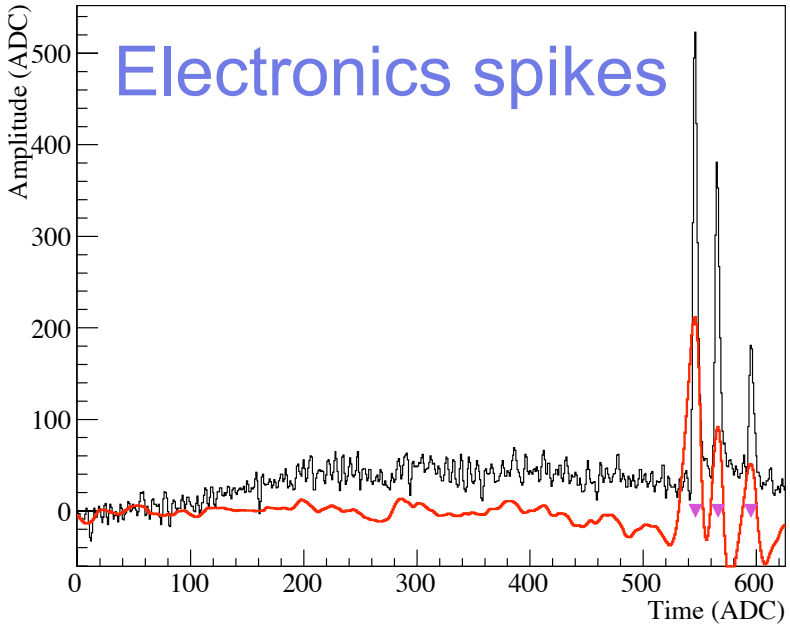


- The trigger is implemented on the filtered samples setting a threshold and a debounce time.

Pulses in the 3-6 keV range

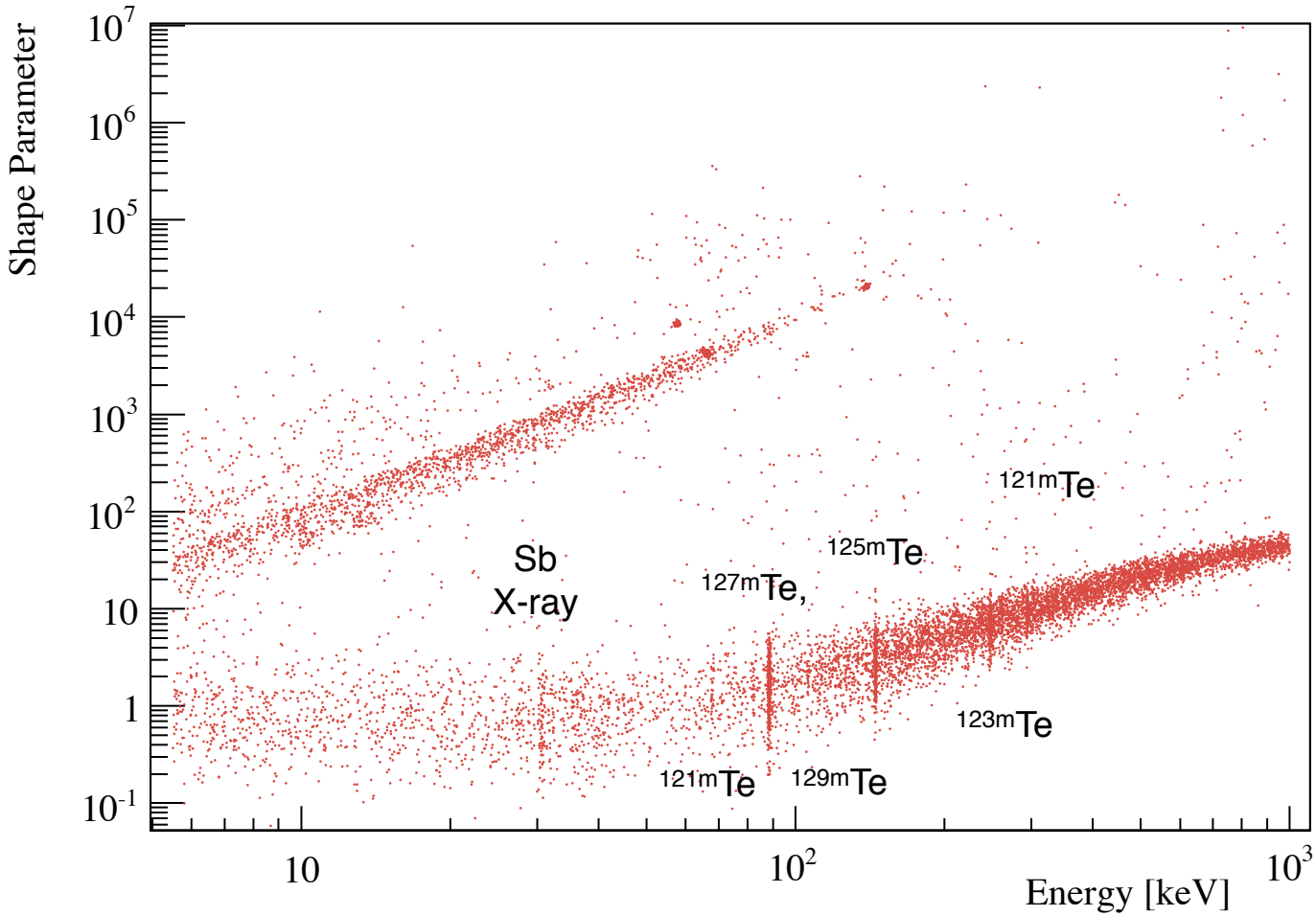






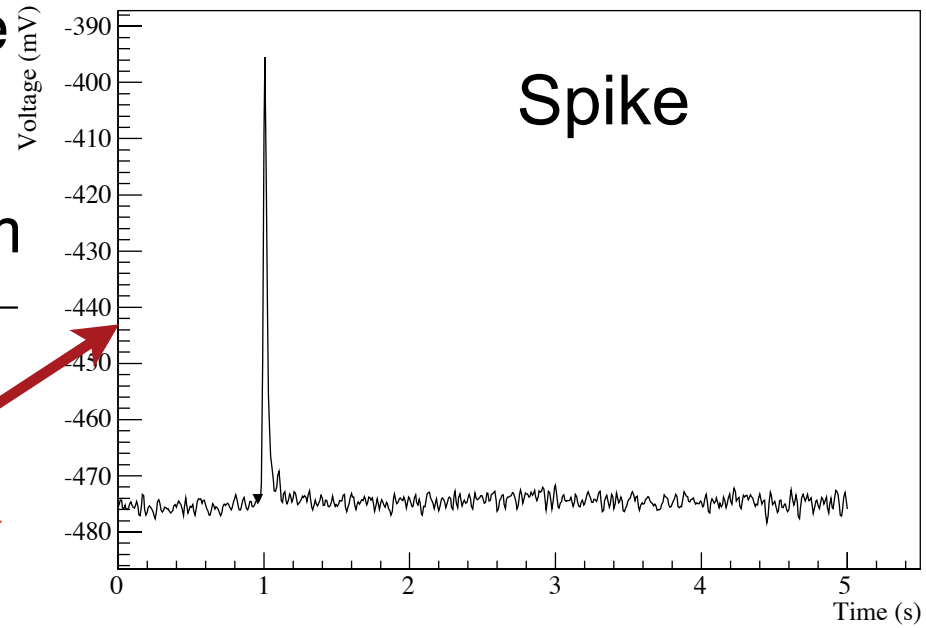
Pulse shape discrimination

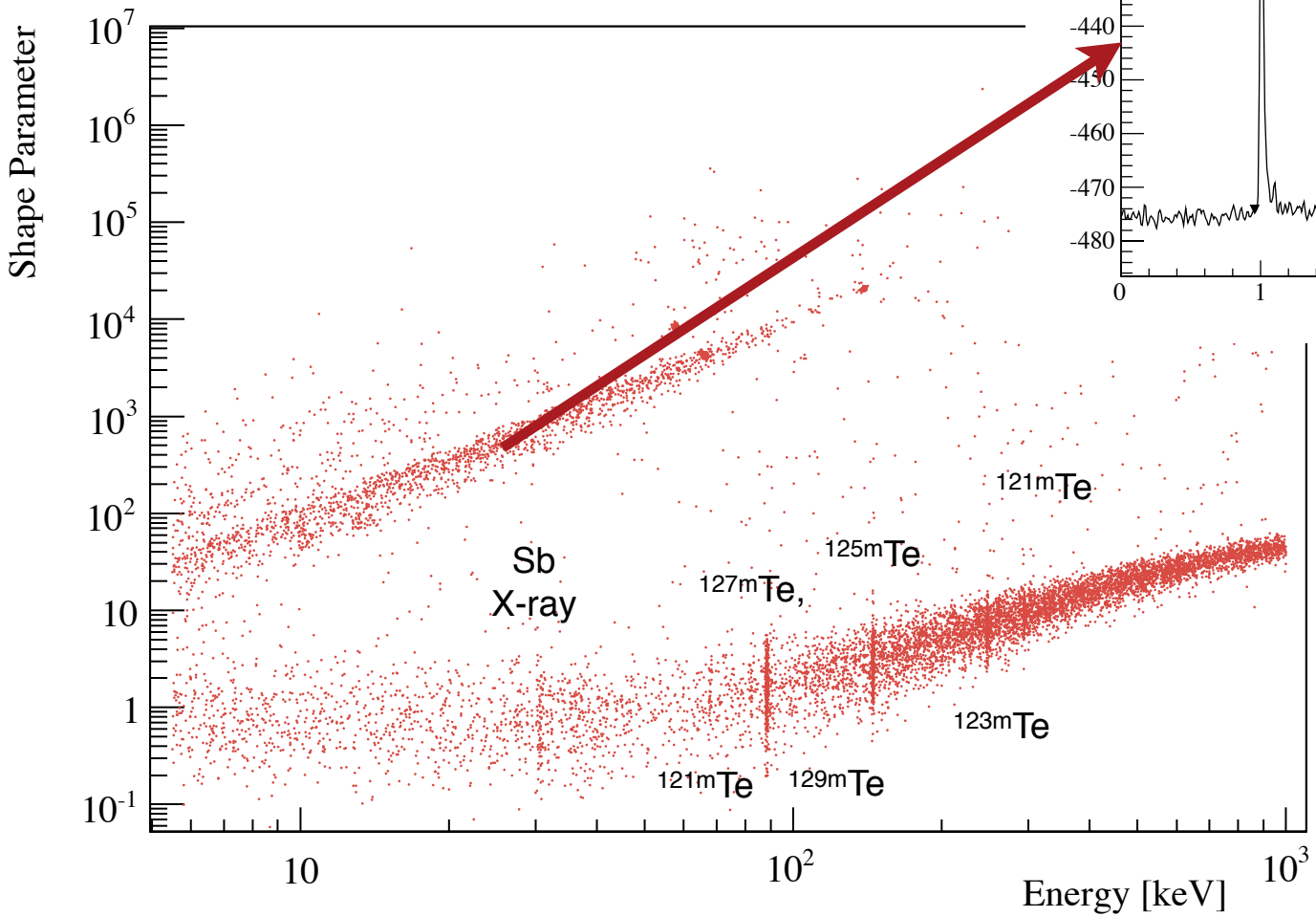
- To remove non-physical pulses we fit the filtered pulses with the known shape of physical pulses
- The χ^2/ndf is used as shape parameter.



Pulse shape discrimination

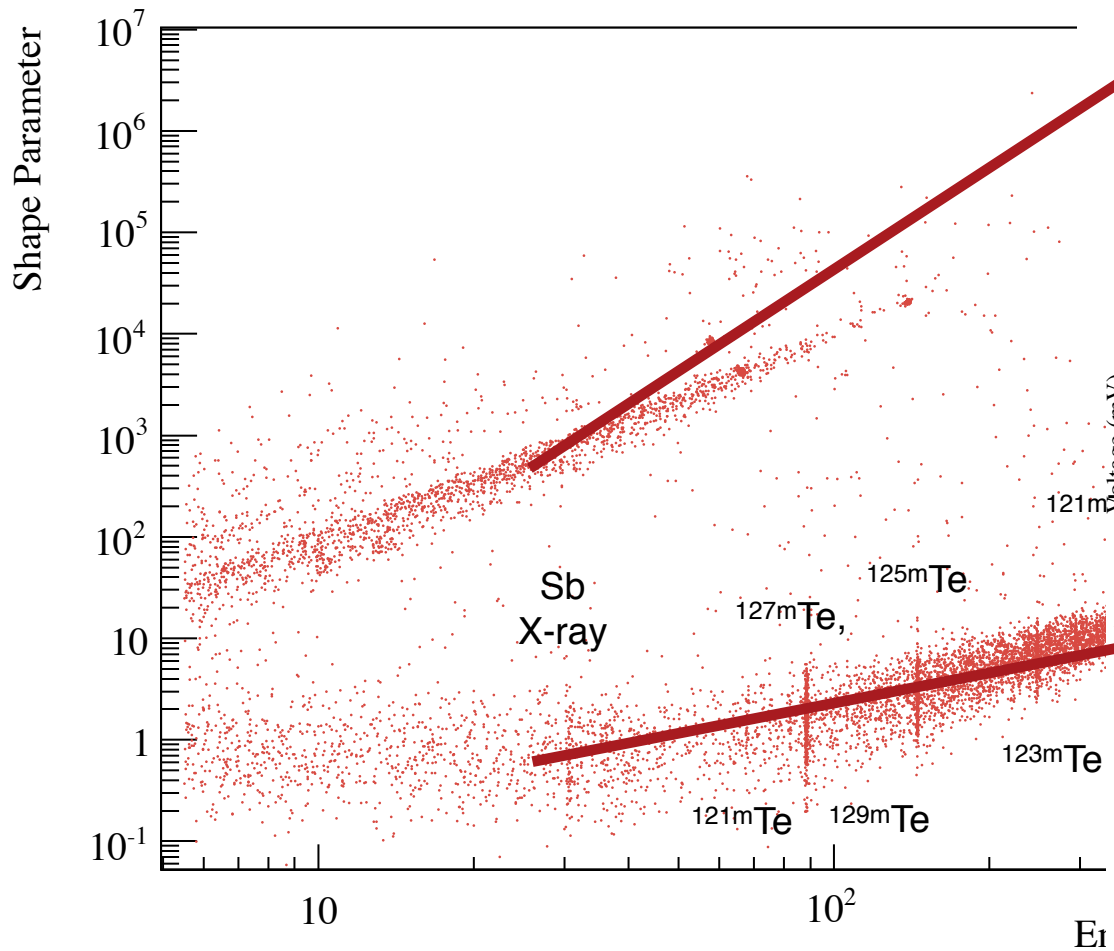
- To remove non-physical pulses we known shape of physical pulses
- The χ^2/ndf is used as shape param

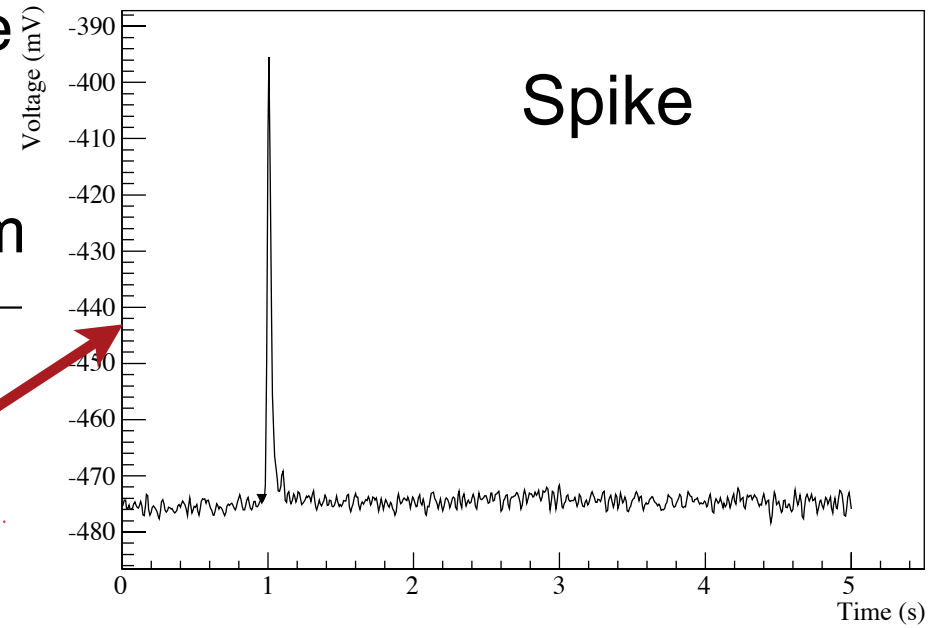


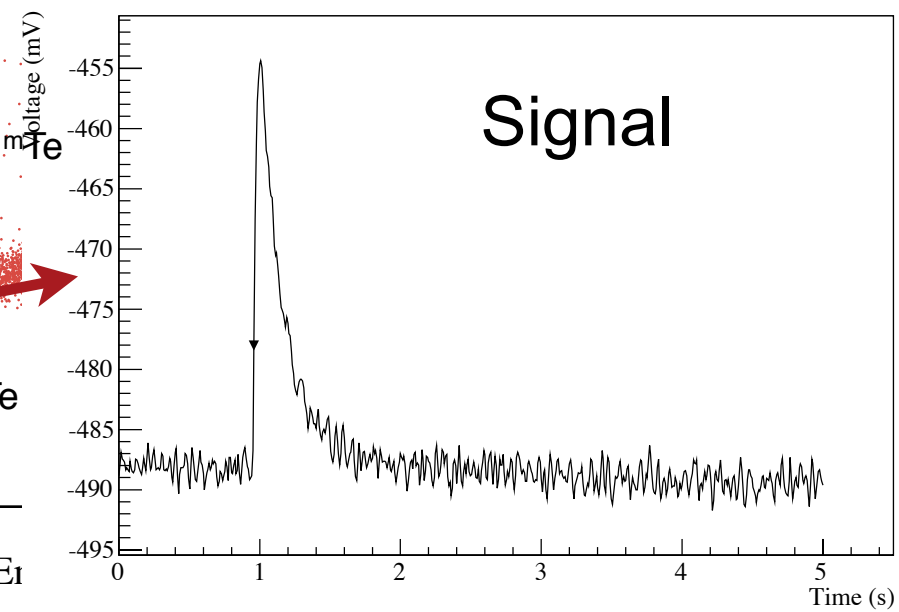


Pulse shape discrimination

- To remove non-physical pulses we known shape of physical pulses
- The χ^2/ndf is used as shape param

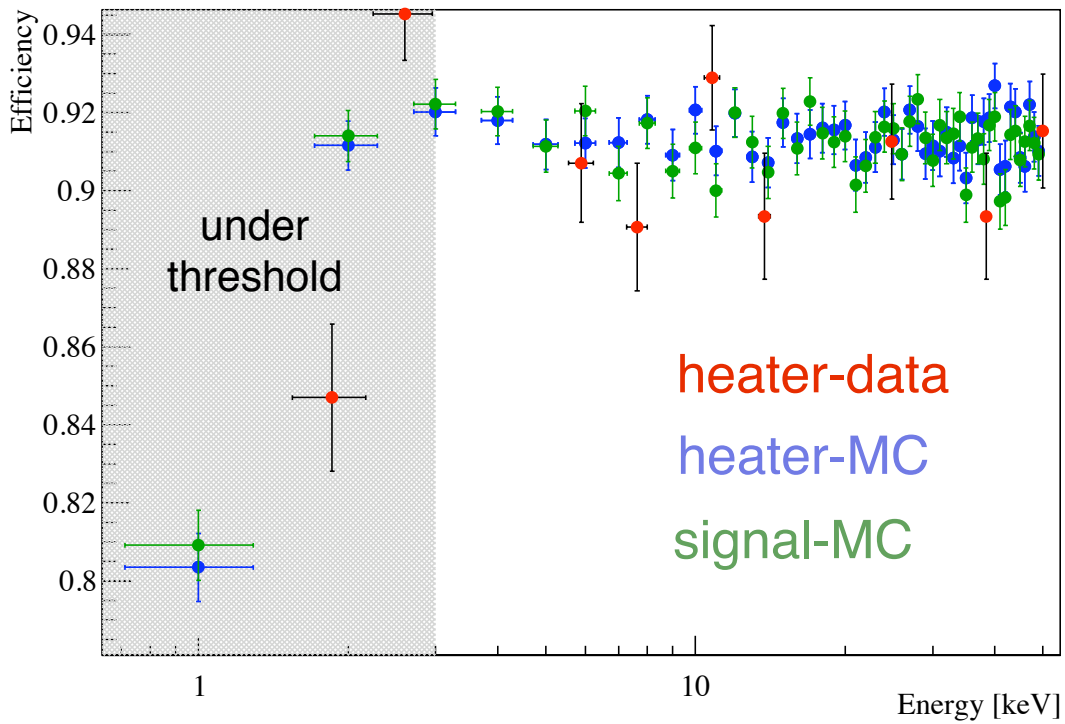






Detection efficiencies

- Each crystal has a joule heater attached, to emulate physical pulses.
- Heater pulses are controlled by the DAQ, and flagged in the data.
- We estimated the detection efficiencies on an energy scan performed on heater pulses.

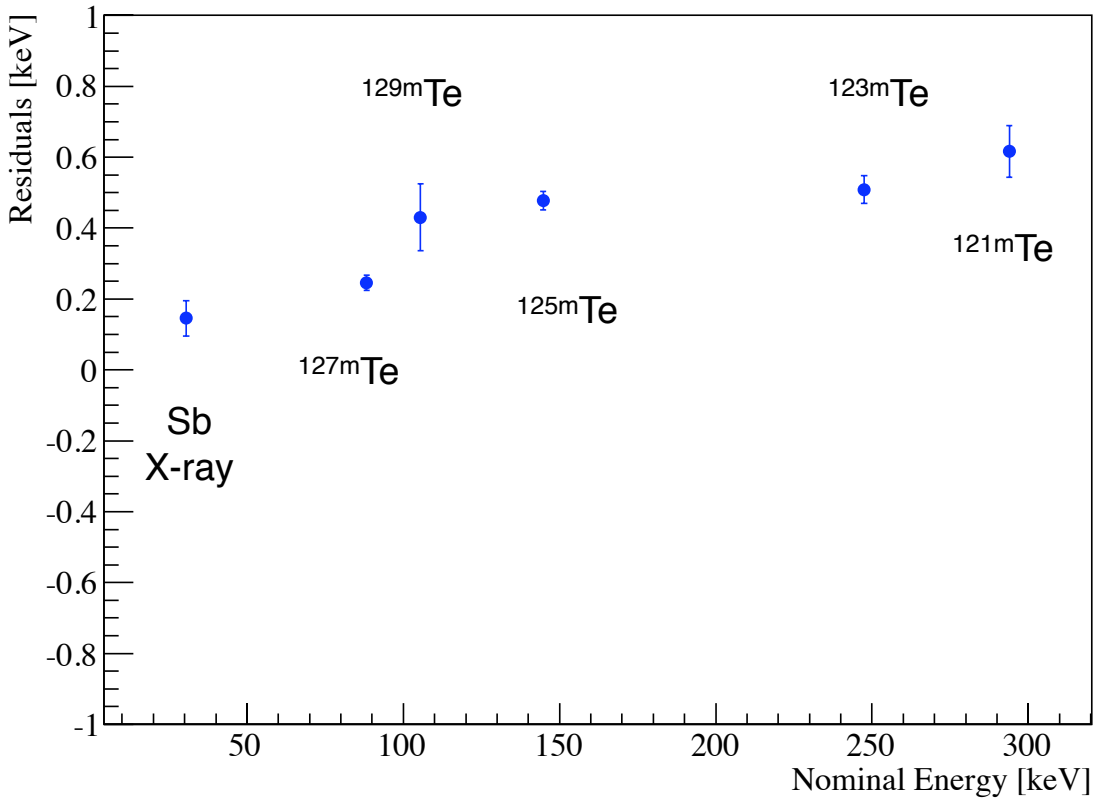


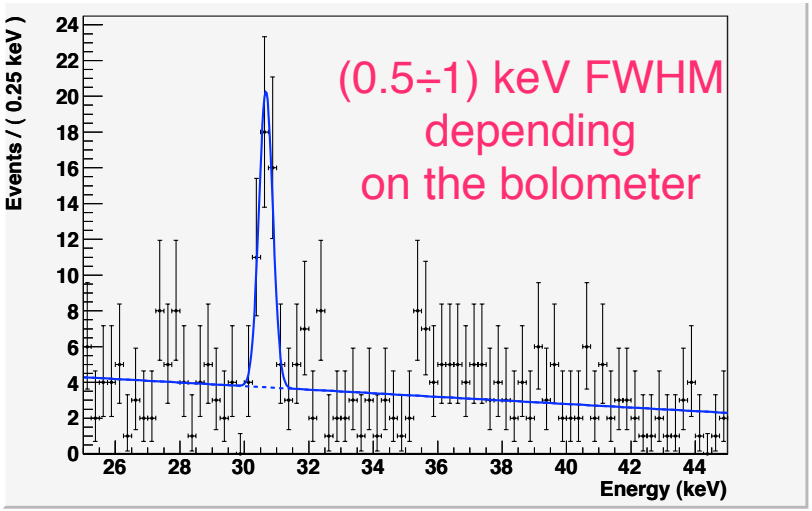
Efficiency above threshold > 90 %

Energy threshold 3 keV

Calibration and resolution

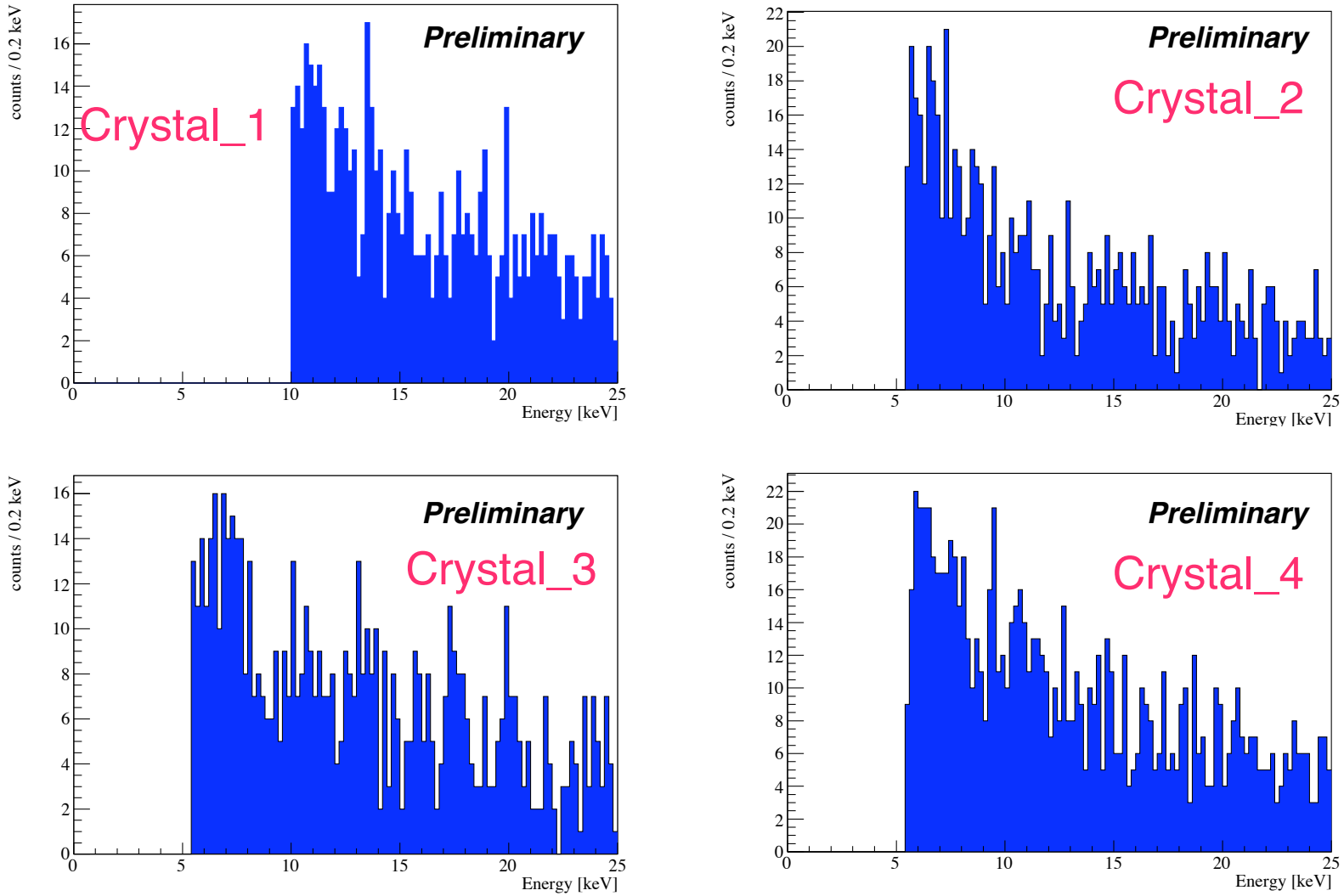
- The calibration function is evaluated on the peaks of a ^{232}Th source exposed to the bolometers. These peaks lie in a [511,2615] keV energy interval.
- Nevertheless, the function performs well on the low-energy peaks visible in background runs:





The energy resolution is much better than at higher energies (5 keV @ 2.5 MeV)

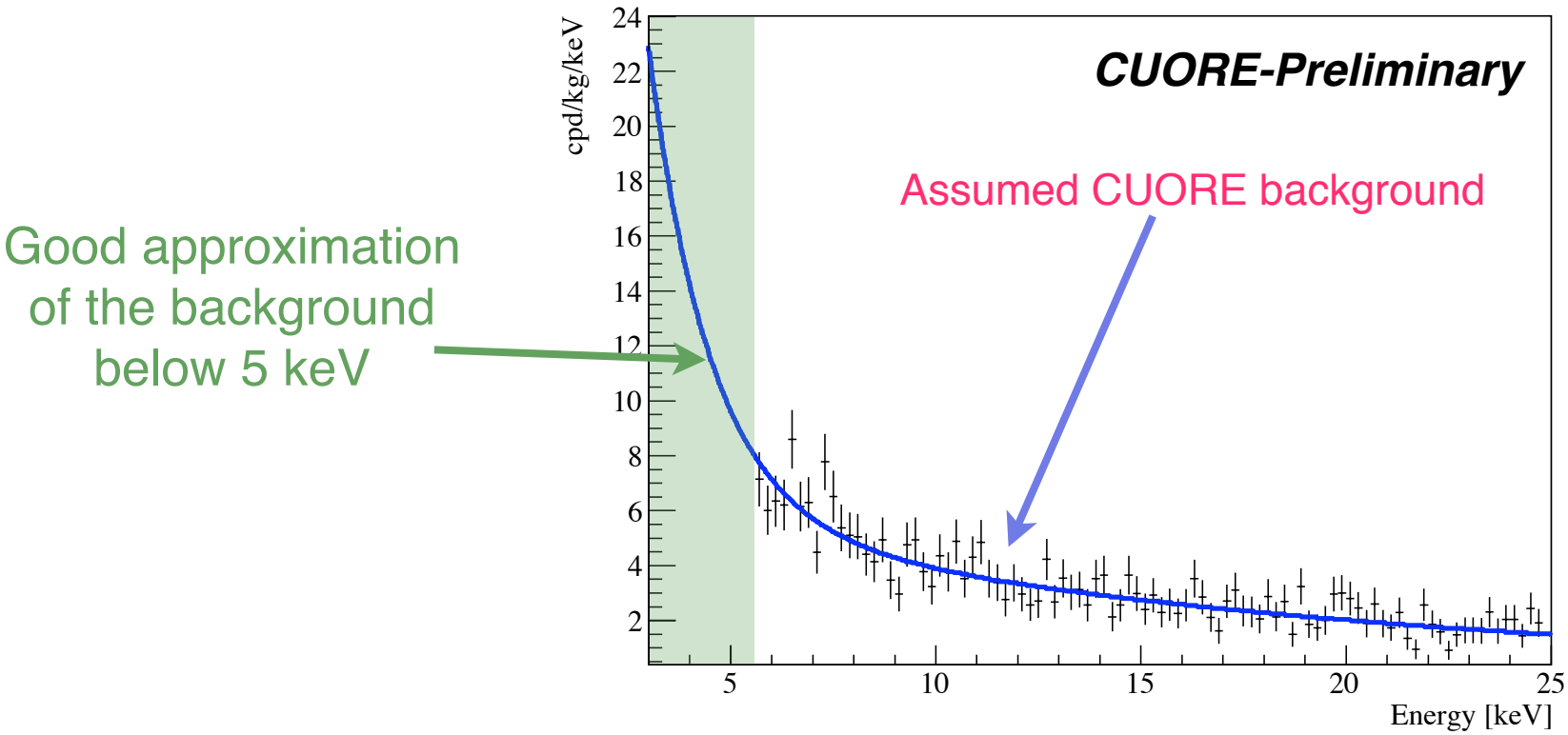
Energy spectra of the 4 crystals



- Crystal_1 has the threshold at ~10 keV (probably high vibration noise)
- On the other crystals we set a software threshold at ~5 keV.
- The background in the [3,5] keV region is being studied.

Dark matter sensitivity study

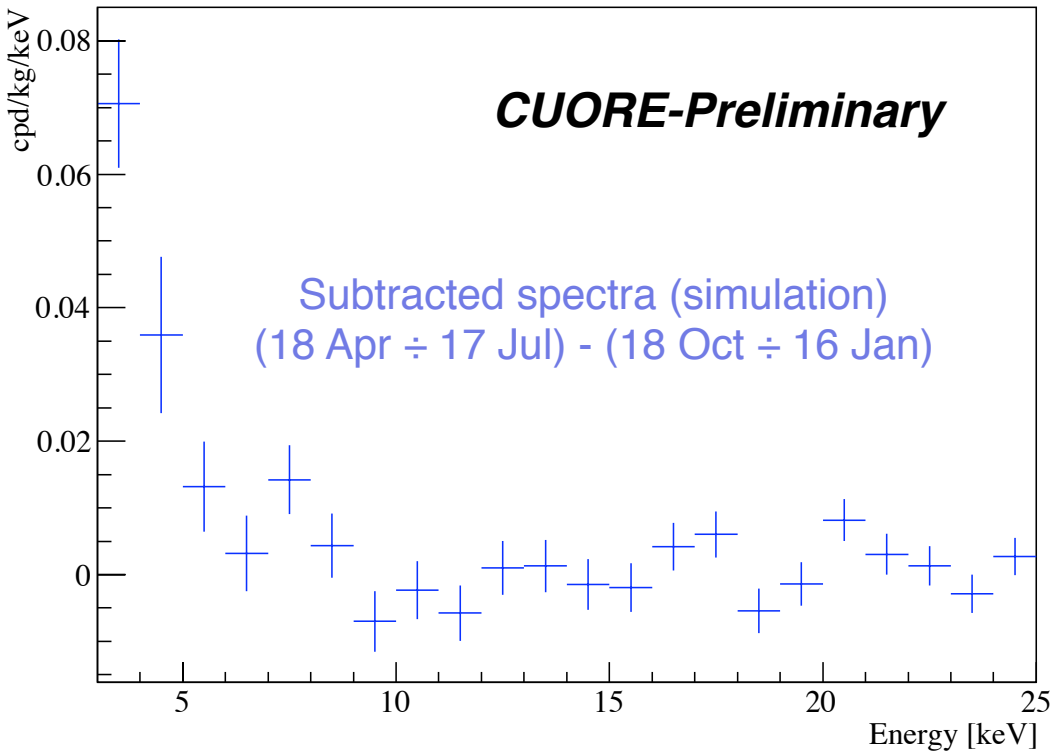
- The background averaged over the 3 good crystals can be projected to CUORE-0 and CUORE, assuming that it will be the same.



- With this background we can simulate the effect of a dark matter modulation signal. Here we present a preliminary study on the sensitivity to WIMPs.

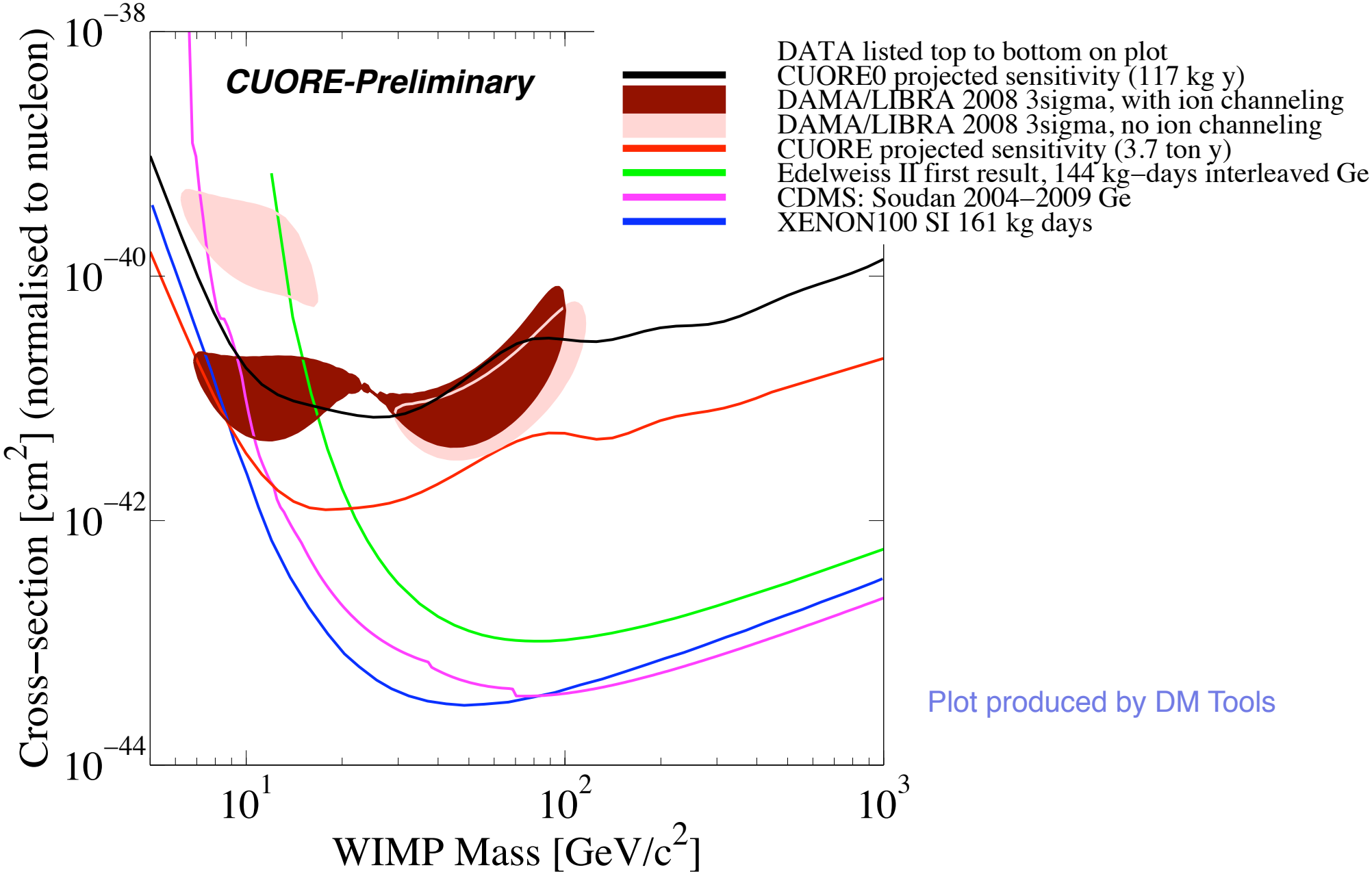
Simulation of WIMP interactions

- We assume that the quenching factor for nuclear recoils in TeO_2 is 1 (*A. Alessandrello et al., NIM A, vol. 409, pp. 451–453,1998).*
- The sensitivity to a WIMP modulation signal in CUORE-0 (39 kg of TeO_2, 3 years) and in CUORE (741 kg of TeO_2, 5 years) is evaluated with toy MonteCarlo's.



CUORE simulated modulation (WIMP)
M_W = 10 GeV, $\sigma_0 = 10^{-41}$ cm^2

Sensitivity to WIMPs @90% CL



Plot produced by DM Tools

Conclusions

- We developed a trigger and a pulse shape algorithm that pushed the threshold of CUORE bolometers down to the few keV region.
- 3 test crystals out of 4 have a 3 keV threshold, the fourth has high noise.
- Projecting the background of the 3 crystals (2.25 kg) to CUORE (741 kg) we found that CUORE, if the vibrational noise will be under control, could play a role in the Dark Matter game.
- We will redo the analysis on the CUORE-0 tower (2011), to check deeply the prospects of this study.