The CUORE bolometric detectors: pulse shape analysis of the thermal signals

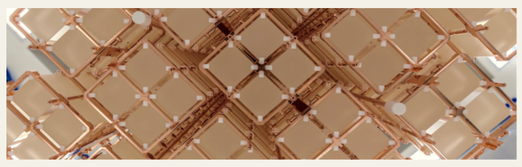
Irene Nutini (on behalf of the CUORE collaboration)
Università degli Studi Milano Bicocca - INFN Milano Bicocca
irene.nutini@mib.infn.it

The CUORE experiment

CUORE (Cryogenic Underground Observatory for Rare Events)
Located deep underground (3600 m.w.e)
at the Laboratori Nazionali del Gran Sasso (Assergi, Italy)

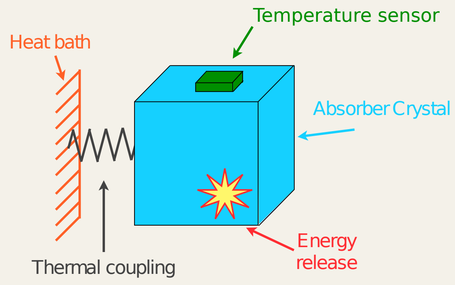
Primary goal: Search for 0νββ of ^{130}Te
- $Q_{\beta\beta}$ (130Te) 2527.5 keV
- Highest natural isotopic abundance (34.2%)
- Nominal background index in the ROI: 0.01 counts/keV/kg/yr
- Nominal energy resolution at $Q_{\beta\beta}$: 5 keV

Detectors: 988 TeO_2 crystals,
- Divided in 19 towers,
total mass 742 kg (206 kg of ^{130}Te)
- TeO_2 crystals are the 0νββ source material and are operated as bolometric detectors at ~10 mK



The CUORE detectors

Bolometric technique



- Low heat capacity @ T ~ few mK
- Excellent energy resolution (~0.2% FWHM)
- Same detector response for different particles (heat only)
- Slowness if coupled with NTDs (suitable only for rare event searches)

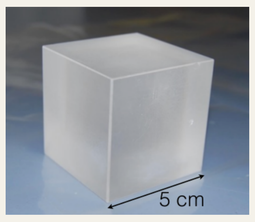
Simplified thermal model:

One thermal capacity C (crystal)
One thermal link G (btw crystal/heat bath)

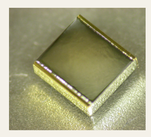
$$\Delta T \propto \frac{E_{dep}}{C} \qquad \tau = \frac{G}{C}$$

Amplitude of the pulse ∝ ΔT ∝ Energy deposition

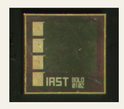
CUORE instrumented bolometers



(nat)TeO_2 crystal
Absorber = 0νββ source
5.0 × 5.0 × 5.0 cm³
750 g mass



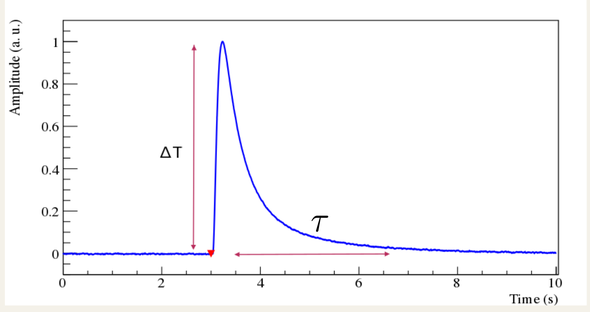
Ge-NTD thermistor
3.0 x 2.9 x 0.9 mm³
Voltage transducer: thermal phonons, produced by the energy release in the crystal, converted into a voltage pulse



Si heater
2.3 x 2.4 x 0.5 mm³
Joule heater: periodically provides a fixed amount of energy in the crystal for gain stabilization

CUORE operations: detectors characterization and optimization

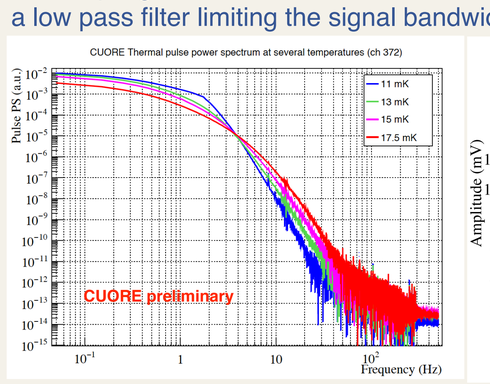
Cuore sample pulse

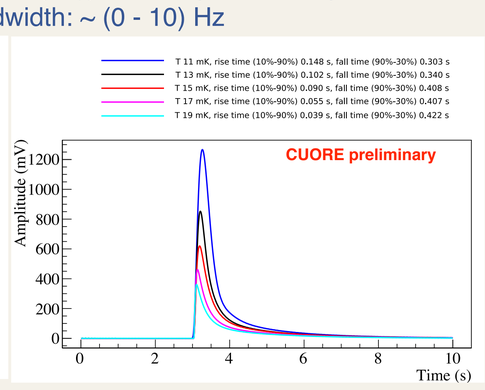


Thermal capacitance TeO2
C(T) ~ 2.3 x 10^{-9} J/K (@ 10 mK)
—> $\Delta T_{crystal}$ ~ 100 μK/MeV
—> τ ~ 0.1 - 1 s
Working impedance of the NTDs:
R_{wp} ~ 100 MΩ -1 GΩ
—> ΔV_{NTD} ~ 400 μV/MeV (@10 mK)

Detector response

RC coupling between the NTD resistance (R_{wp}) and the parasitic capacitance of the electrical links (C_{par}) acts as a low pass filter limiting the signal bandwidth: ~ (0 - 10) Hz

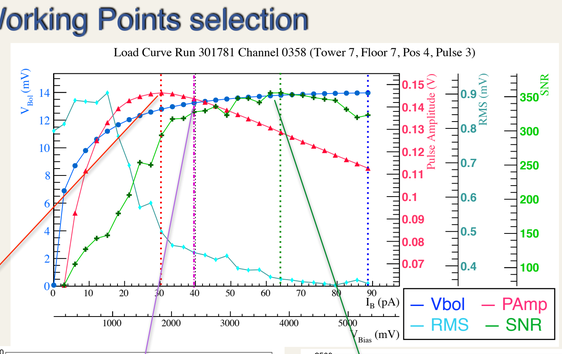


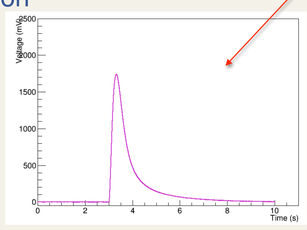


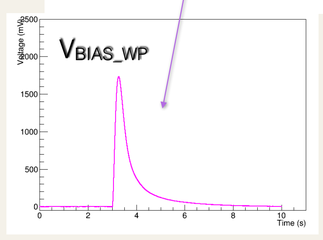
Lower temperature:
- Decrease Thermal capacitance TeO2
  → Higher internal Gain teo2 ($\Delta T_{crystal}$), higher amplitude pulses
  → Reduce pulse fall time (τ)
- Increase NTD impedance
  → Higher pulse rise time signal ($R_{wp}C_{par}$)

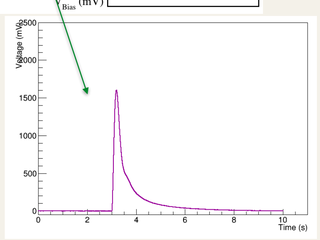
Load Curves analysis and NTDs Working Points selection

Dedicated procedures and algorithms in CUORE to automate the NTDs load curve measurement and the working point identification at each T_{base}.
- Optimize the sensor response to particles energy deposition
- Linear and uniform behavior for small temperature variations avoiding pulse deformation

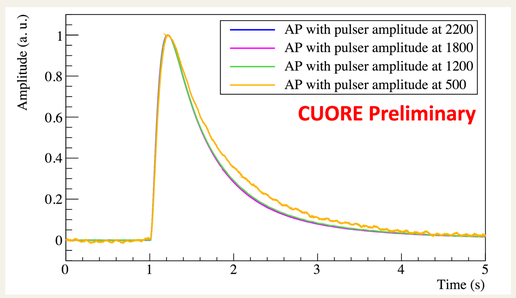


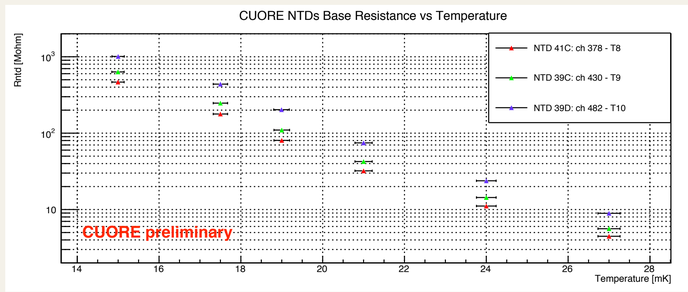






NTDs belonging to three different (neutron implantation) batches installed on the CUORE towers



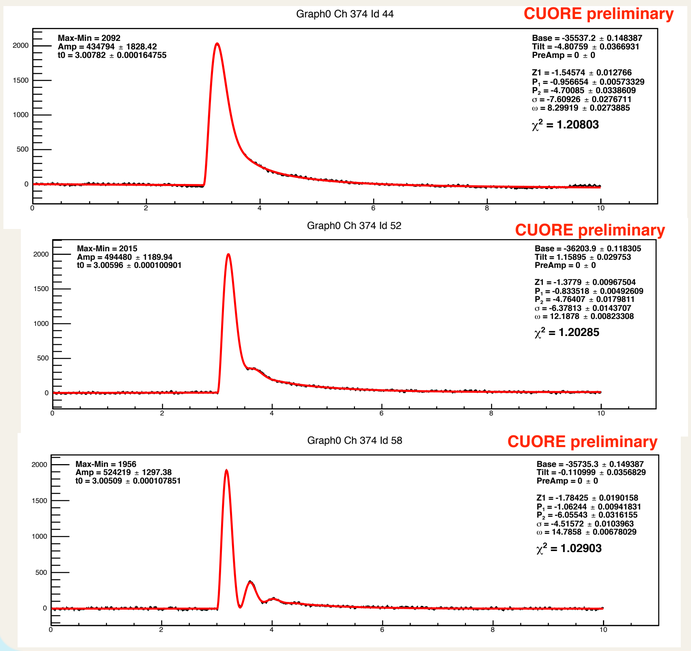


Reference pulses for different amplitudes @ V_{BIAS_WP}

Pulse shape and working point selection

Novel approach for checking the pulse shape at each NTD bias voltage: utilize the parameters coming from the fit of the heater pulses with a thermal model reproducing the main features of the thermal pulse

Thermal model fit function:
transfer function for the bolometer and NTD system composed by two real poles, two complex conjugate poles and one zero.



Working Point Bias (WP) chosen in region dominated by real poles
- pulse shape with 3 time constants
- uniform response: pulse shape is not amplitude dependent

Outlook
Developed a (phenomenological) pulse template to describe the CUORE pulses:
- Utilized to set WPs
- Correlate pulse analytical template parameters with physical quantities related to the thermal circuit.
- Utilize (energy dependent) analytical pulse templates for the Optimum Filter (OF) sequence for the CUORE standard data processing

Conclusions

The CUORE experiment started taking data in 2017.

- First time such a large number of bolometric detectors simultaneously operated in a completely new and unique cryogenic system
- **Detector optimization campaigns** performed during 2017 in order to characterize and improve the detectors and overall system performance, different compared to previous smaller scale bolometer experiment
  - Optimization procedures performed manually in small-size bolometric experiments with a limited number of channels (like CUORE-0)
  - CUORE: ~ 1000 channels to be optimized, high values and wide spread of NTD thermistors resistances. **New procedures and algorithms to automate the characterization measurements and the setting of the optimal operating conditions**.

References

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