Absorber crystals for cryogenic detectors: status and challenges

IFD 2022 Workshop - ‘Calorimeters’ session

Oct.19th, 2022 - Bari

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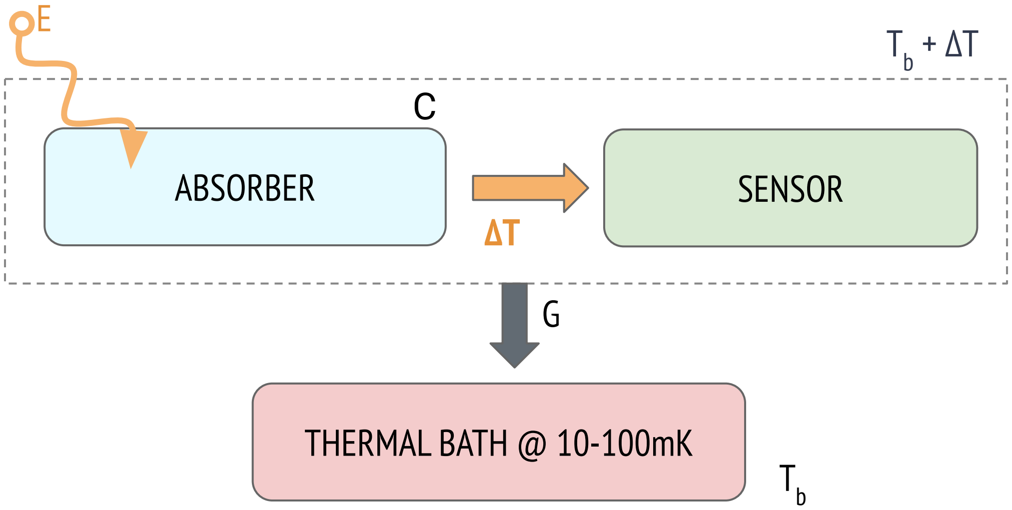
Cryogenic detectors



Absorber crystal:

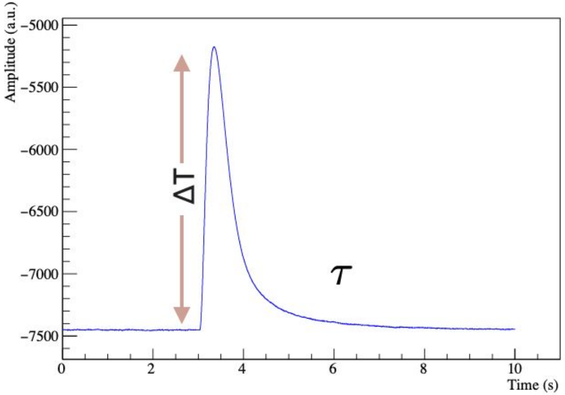
- Energy deposition ⟶ phonons/heat ⟶ **$\Delta T = E/C$**
- Completely **active**
- Wide choice of absorber compounds depending on the physics case
- **Macro (O(g,cm)) vs. micro (O(mg,100μ))**
- Monolithic vs Composite detectors

Temperature sensor:

See talk from M. Faverzani

Absorber crystals at low temperatures: heat capacity

The role of the heat capacity:
sensitivity, thermalization time & energy resolution



$\Delta T = E/C$

$\tau = C/G$

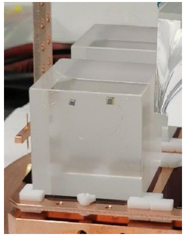
$\Delta E \sim \sqrt{C} \times T$ (intr. therm. limit)

$C(T) = c_{tot}(T) \times M$

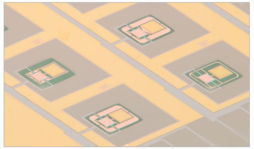
$c_{tot}(T)$ [for $T \ll 1K$]: lattice ($\sim T^3$)
+ electric ($\sim T$ for metals, $\sim T^{-1} \times \exp(a/T)$ for supercond, 0 for semicond)
+ magnetic ($\sim T^{-2}$ dipole/shottky)

Choice of crystal compounds:

- Dielectric and diamagnetic for macro (eg. TeO_2, Li_2MoO_4, ZnSe, $CaMoO_4$)
- Metals (eg. Au) or dielectric (eg. $AgReO_4$) for micro



Li_2MoO_4



^{163}Ho:Au layer

Cryogenic detectors: applications in particle physics

Macro calorimeters

Micro calorimeters

Neutrinoless ββ decay
Majorana nature of neutrino

Direct Dark Matter searches

Spectral shape of β decay/EC
Neutrino mass

Rare event search: **large mass of ββ emitter (ton-scale)** and low background

High energy resolution: ~5-10 keV @2-3 MeV-scale

CUORE

CUPID

AMoRE
Advanced Mo-based Rare process Experiment

Rare event search: **large mass (different elements)**, low background

Low energy thresholds: 0.1-1 keV

COSINUS

CRESST
Cryogenic **Rare Event Search** with Superconducting Thermometers

High β source activity (uniformly spread among multiple channels)

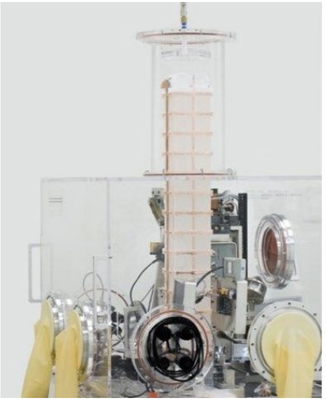
Optimal energy resolution:
~ eV @ 3 keV

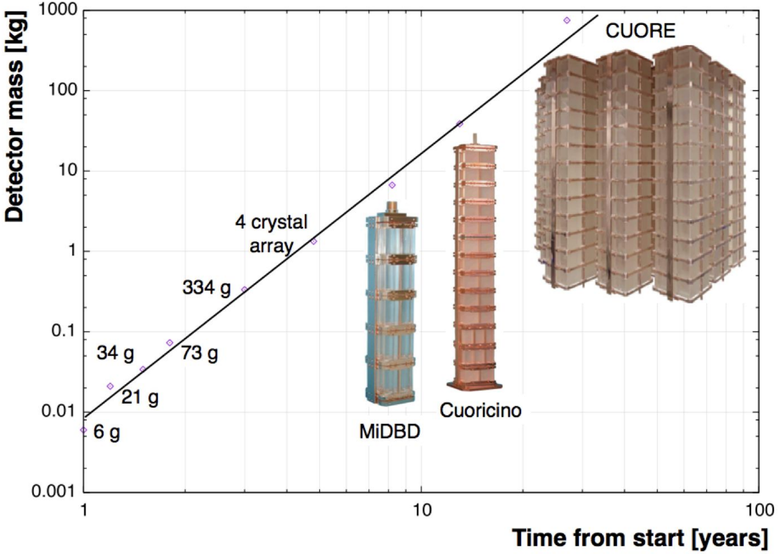
HOLMES

ECHo

Macro calorimeters for rare events

- Crystal structure:
  resistance to thermal & mechanical stress
- Crystal growth:
  ⟶ Scalability and reproducibility on a
  1000 detectors / 1 ton mass scale (eg. CUORE)
  ⟶ Radiopurity of different compounds and different
  growth procedures
- Avoid re-contamination
  during handling and assembly





Macro calorimeters: pile-up in the absorber

Large crystals enriched in ββ isotope

- Enrichment process: risks of contamination
- **2nuββ pile-up in the absorber** and its contribution to background in 0nuββ ROI

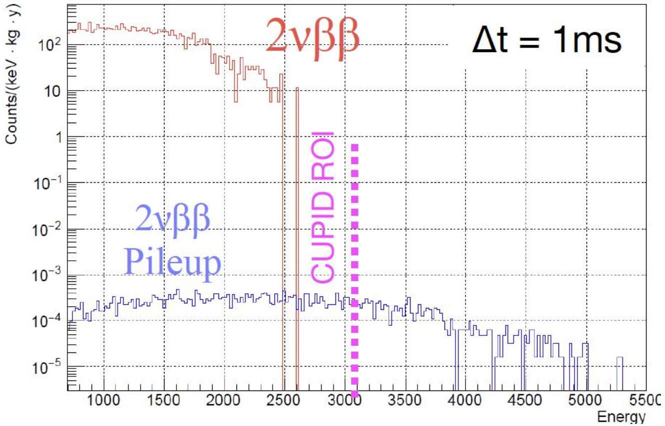
  Mo-based detectors:

  ^{100}Mo 2νββ fast decay time = 7.1 × 10^{18} yr

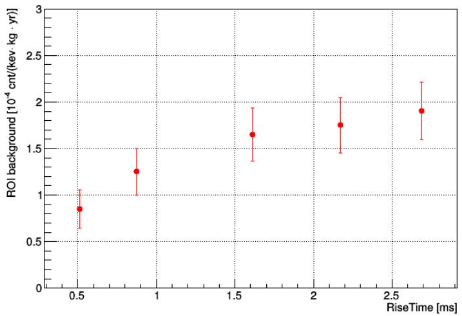
  3 mHz rate 2νββ for CUPID detectors

  (300g Li_2MoO_4 enriched at > 95% in ^{100}Mo)

  ⟶ optimize and improve the time resolution of the detectors (RT & dt)



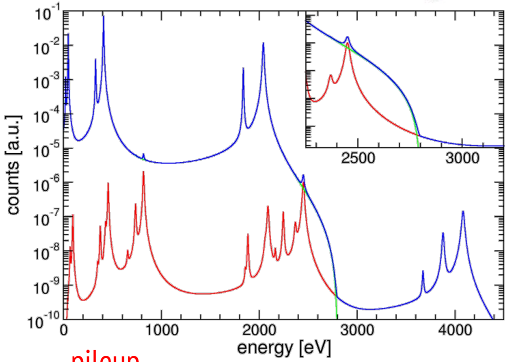
Residual ROI bkg vs RiseTime - Small Noise



Micro calorimeters: pile-up in the absorber

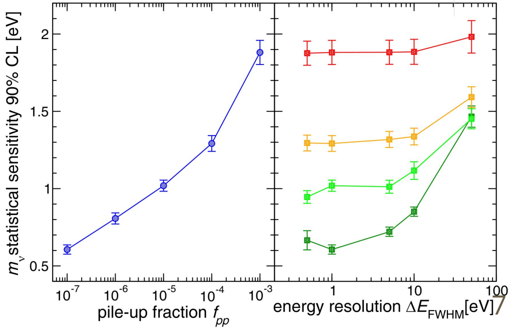
High activity source in substrate

- Source realization line: technical challenges for realizing high activities and for ensuring **uniform** irradiation over substrates with ~10^6 micro-detectors (**~100Bq/det**)
- High quantity of ^{163}Ho isotope and **effect on thermal capacitance**
- **Pile-up** is a major **systematics**, but its impact on sensitivity can be mitigated via optimal dt ~1 us of micro-calos



MC Simulation

pileup

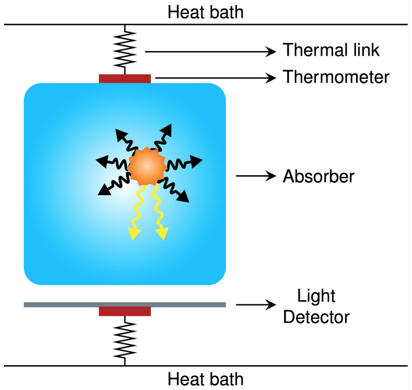


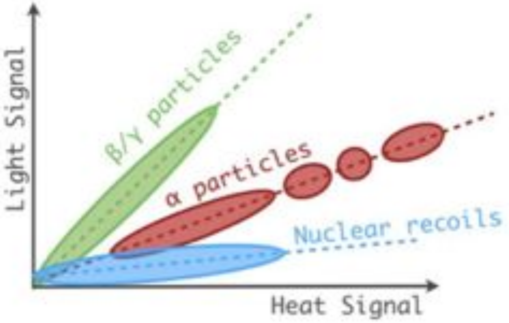
(sx) N_{ev} 10^{14}, dE 1eV
(dx) f_{Pu} 10^{-7}, 10^{-5}, 10^{-4}, 10^{-3}

Scintillating cryogenic crystals

Double readout: heat & light

→ **PID** for background discrimination





Scintillating compounds

Examples: Li_2MoO_4, ZnSe, $CaMoO_4$, … (ββ decay); NaI, $CaWO_4$, … (Dark Matter)

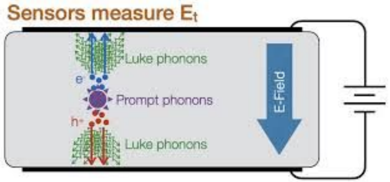
Generally **intrinsic scintillators** → vacancies/defects as luminescent centers: challenge of reproducible light emission among multiple crystals

Characterization of scintillation processes at low T → **traps**: reduced/delayed light emission and effect on heat channel

Scintillating cryogenic crystals

Strategies for **improving the information from scintillation light** at 10mK

- Light emission: crystal doping
- Light collection: coating of surfaces ⟶ reflective coating of scintillating absorber + anti-reflective coating of Light Detectors
- Improve the sensitivity of the Light detector:
  - Improve LD internal gain - Neganov-Luke effect
  - Better coupling LD to thermal sensor (eg. eutectic bonding)



Neganov-Luke effect