Improving scintillating cryogenic calorimeters for rare events

Mattia Beretta, INFN of Milano–Bicocca, for the CUPID collaboration

mattia.beretta@mib.infn.it

Scintillating cryogenic calorimeters

Cryogenic calorimeter: measure energy as temperature increase

Absorber → *Thermal capacity (C) where E is deposited*

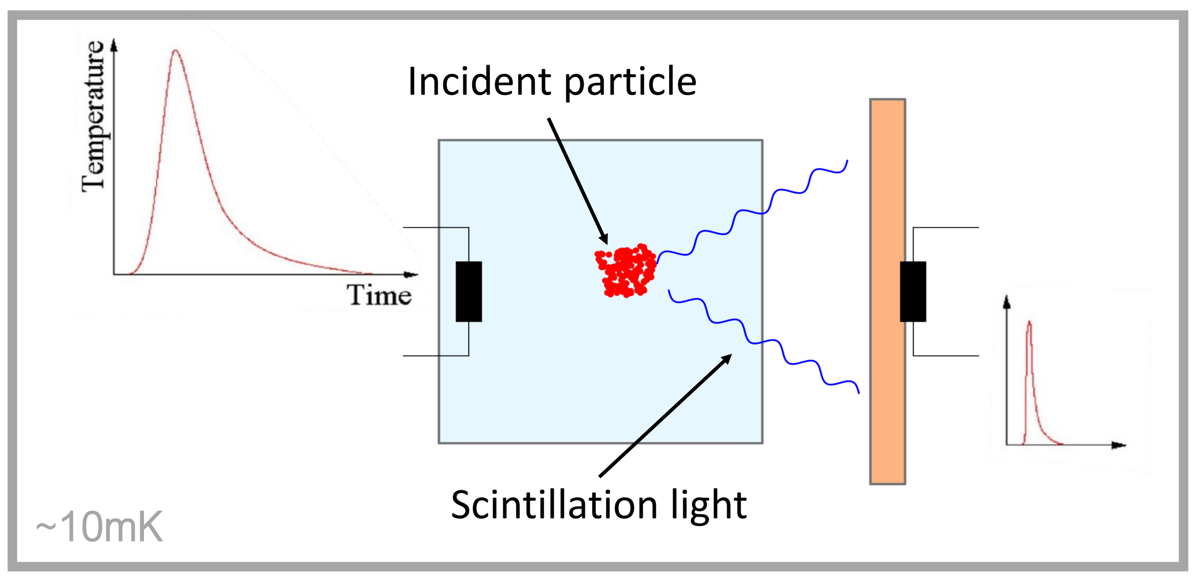
Thermometer → *Measure the T = E/C increase*

Operated at ~10mK to minimize C

Excellent energy resolution
Reproducing small modules ensures high mass

No particle identification capabilities
Degraded alphas provide background

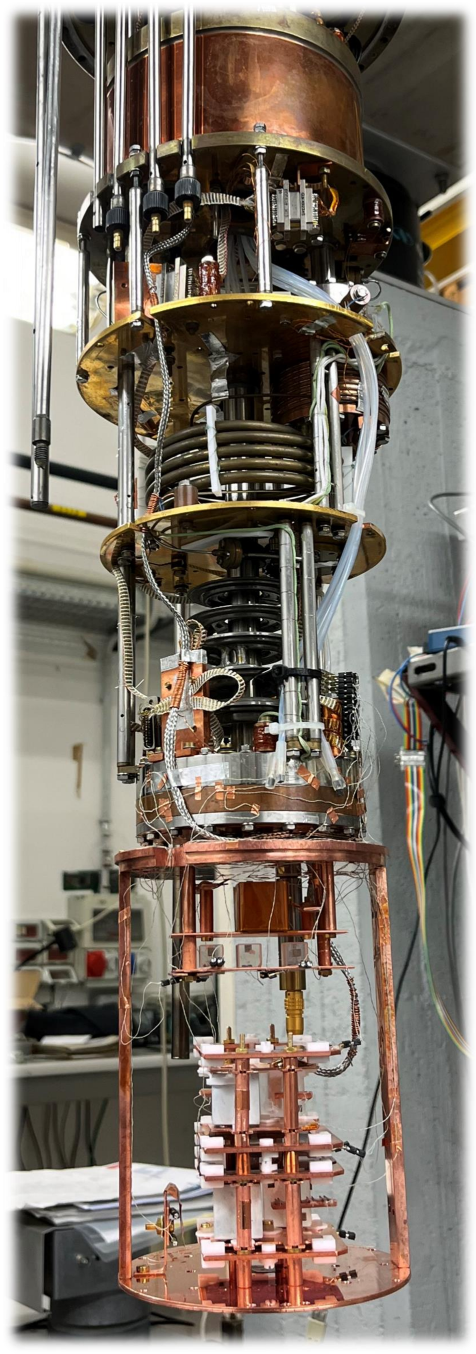
Scintillating crystal as main cryogenic calorimeter



Cryogenic calorimeter used as light detector → Particle identification with light pulse shape

Background identification

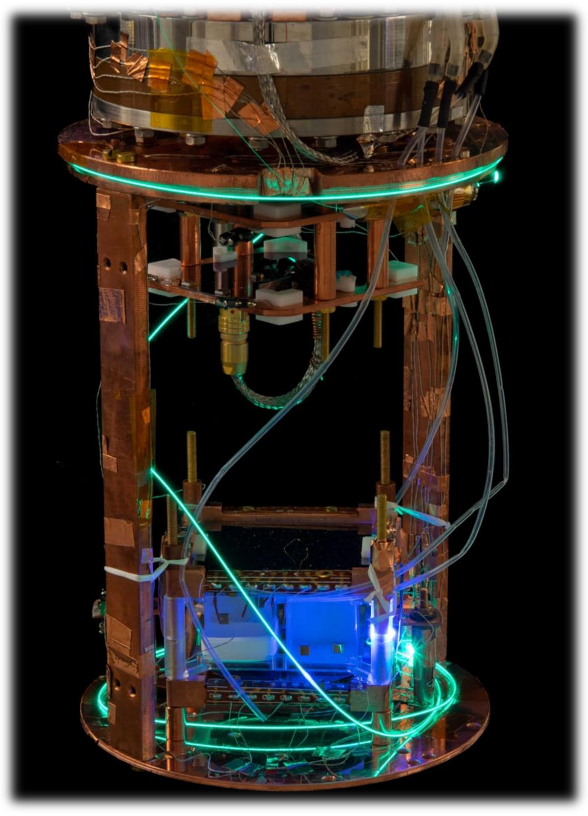
MiB cryo facility



Oxford TL 200

~3000 cm^3 space at O(20mK)

Equipped with **diffusive optical fibers** for light characterization



Improving light yield

More light improves the signal identification

Crucial when the light emission is limited, as with Li_2MoO_4 (LMO)

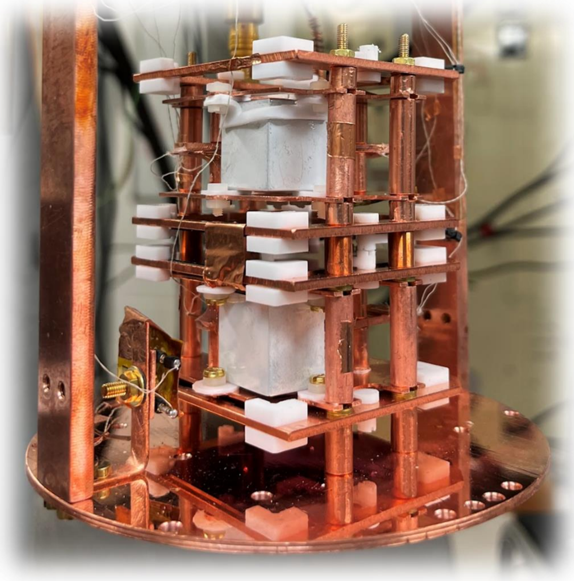
CUPID (Cuore Upgrade with Particle IDentification), searching for 0νββ of ^{100}Mo

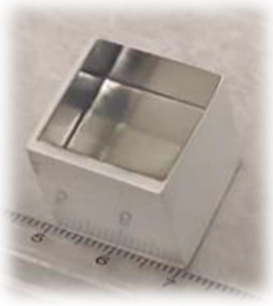
Proposed strategy: Coating the crystal with reflective (metal) layers

COLD: *Coatings for Optimized Low temperature Devices - PRIN2022*

Test at ~20mK to verify the effects of the coating on the cryogenic calorimeter

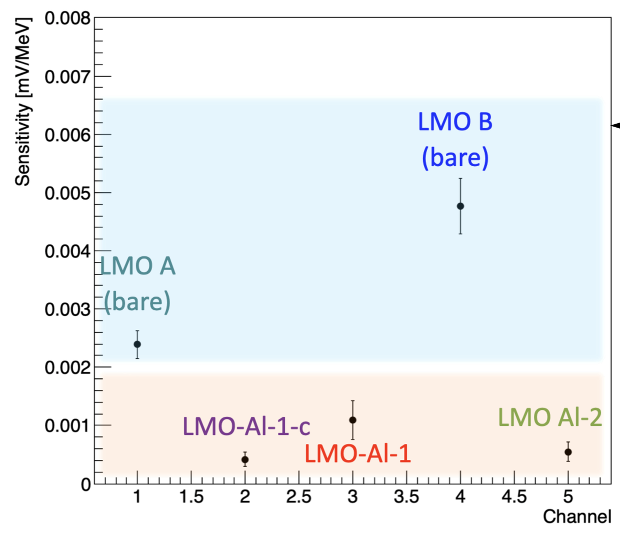
Operating bare and coated crystals in the same conditions





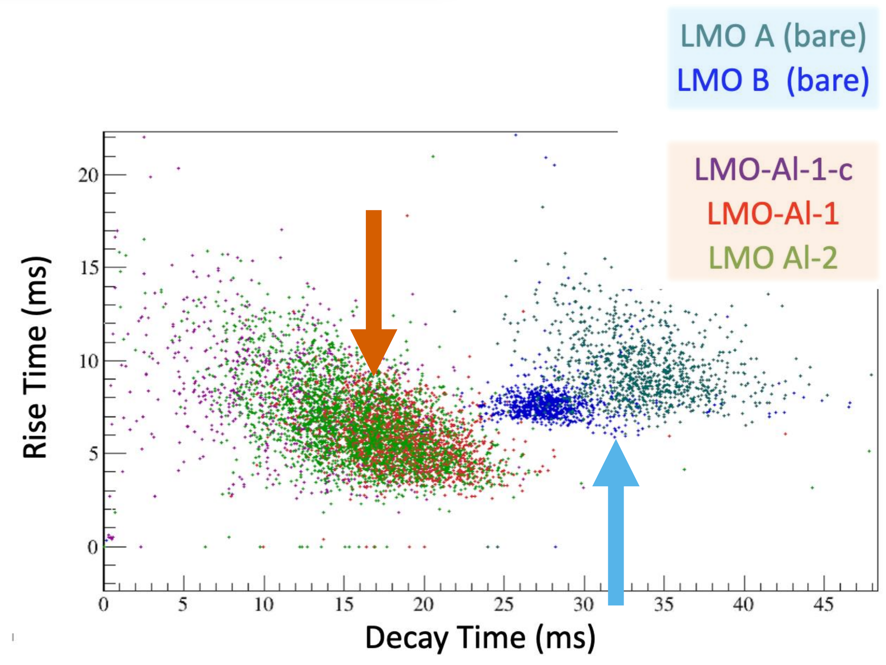
Al-coated LMO

5 sides coating



Coating reduces sensitivity:
phonon trapping due to Al superconductivity (Tc = 1.2K)

Time evolution is different
Similar rise time (signal collection) faster decay time (thermalization)
New element in the thermal circuit.



Next steps Measure difference in LY | Test other coatings | Perform simulations

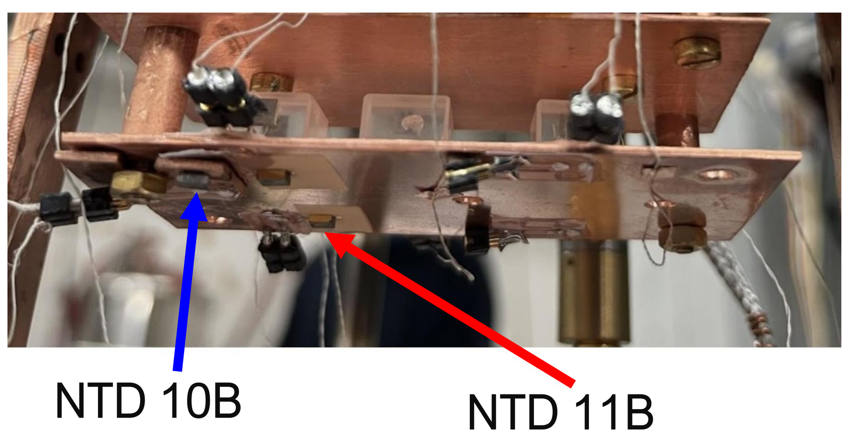
Improvement of the sensitivity

NTD sensitivity to energy deposition (uV/KeV) and time response depends on its thermal capacity (ΔT = E/C, τ~C)
Smaller C_{NTD} are preferable

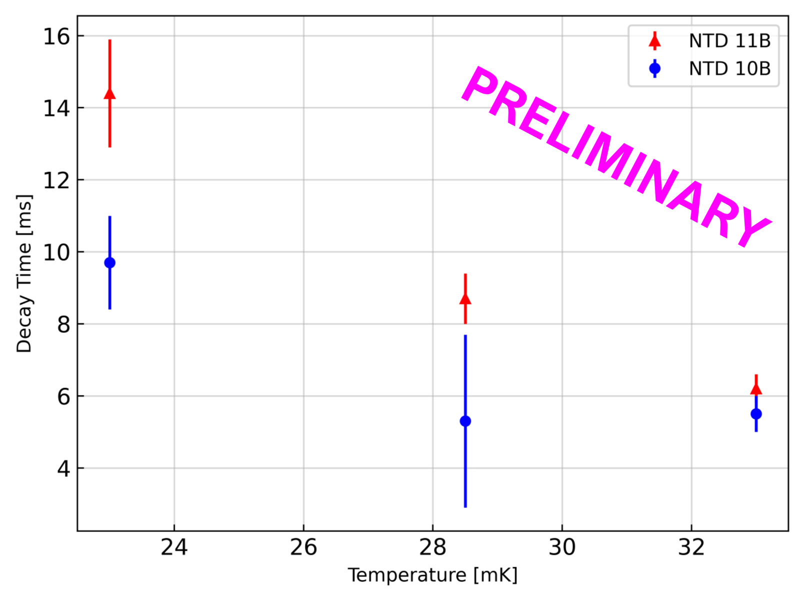
^{10}B/^{11}B ion isotopes of the NTD electrode implants have a different specific heat (C_s) at low temperatures
$C_{s,11B} \sim 10\ C_{s,10B}$ @ < 500mK

It is possible to reduce C_{NTD}: **$C_{10B\text{-}NTD} < C_{11B\text{-}NTD}$ @10mK**

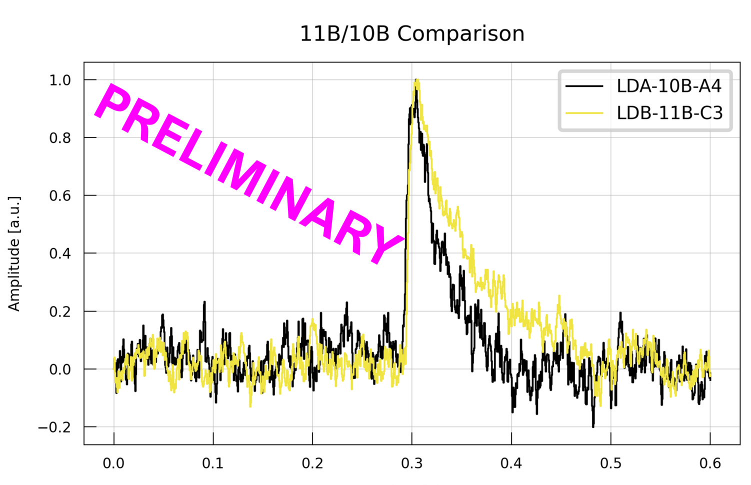
First test: NTD on Cu — Differences in time constants due to different C



A small difference can be appreciated.
To be tested if it affects light detectors

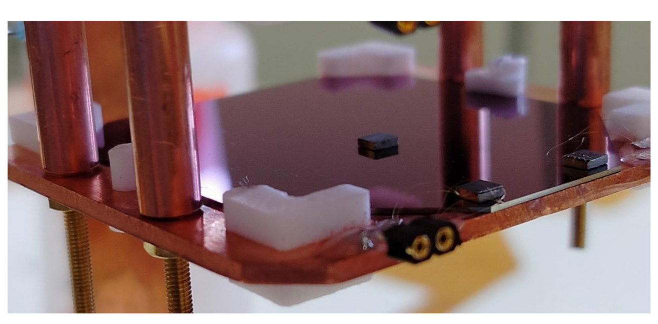


Current test: NTDs on LD — Determining if NTD C affects performances



Multiple NTDs on single LD, to maximize the C effect and modify the response times

Effect on the characteristic times

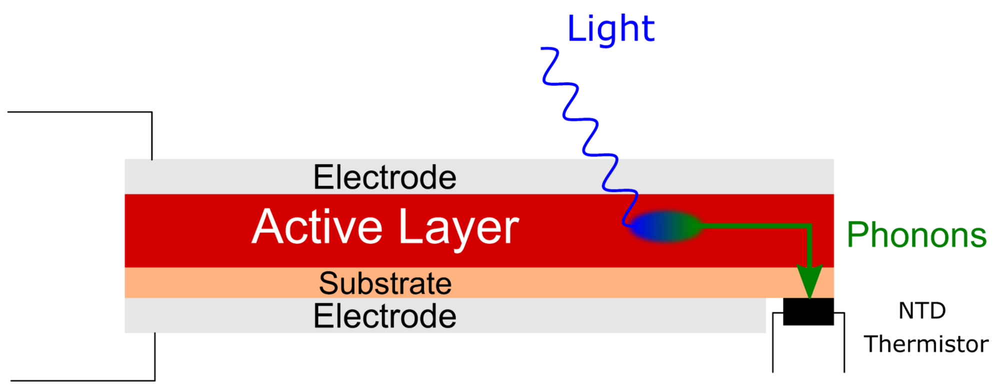


Electrodes production @IMM/CNR and INFN Bologna
Sensor cut and polishing @INFN MiB

Application of nanomaterials

Use nanomaterial-based photosensitive layer to build cryogenic light detectors optimized for specific wavelengths

Perovskite layer O(100nm) thick to detect photons
Select the formulation providing better absorption at LMO wavelength (570nm)
Different substrates: Silicon for initial tests, flexible (PET)
NTD thermistor readout



First prototypes being produced $MA_3Bi_2I_9$ on silicon

INFN CSN5 grant

Transparent electrodes for signal amplification

Concept: drifting e/h pairs to create phonons through scattering
Neganov-Trofimov-Luke effect

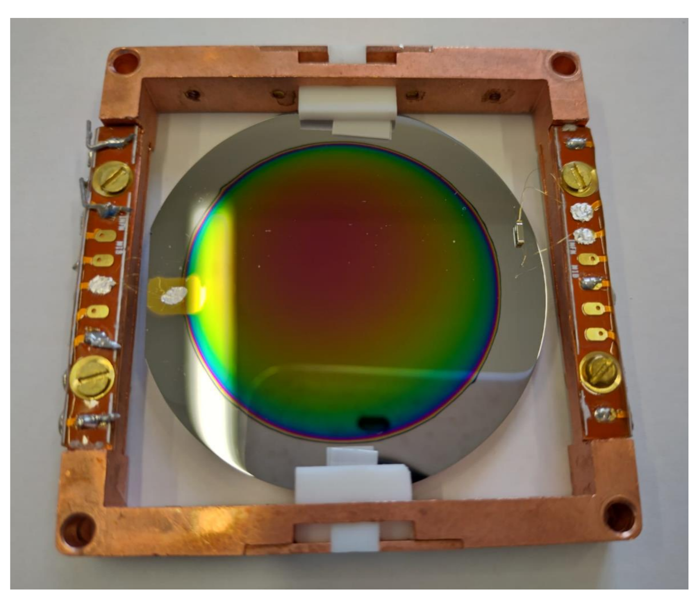
E_0: ionizing energy
ε: energy for an electrone/hole pair
η: amplification efficiency
q: elementary charge
V_{el}: potential between elecrodes

$$E_{tot} = E_0\left(1 + \frac{q \cdot V_{el} \cdot \eta}{\epsilon}\right)$$

Gain only on signal

Standard approach: Metallic electrodes on Si/Ge wafers

Known and tested | Prevents light collection



Transparent electrodes using thin films
Indium Tin Oxide (ITO) – used in solar cell development

Wide area electrodes separated by wafer thickness (<500μm)
High field for low voltage, less edge effects

First detectors being tested at cryogenic temperatures

ITO evaporation @LNL