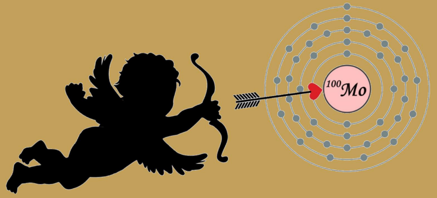


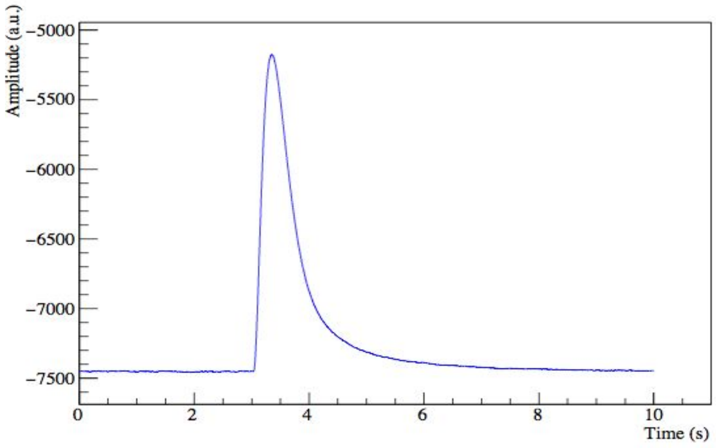
Designing the next-generation 0νββ decay experiment CUPID

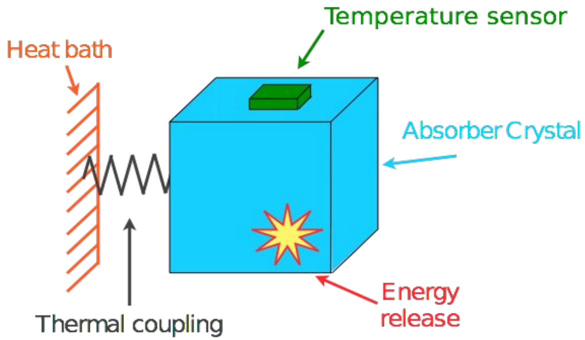
Giovanni Benato

General Meeting of the Fellini Program, Ferrara, May. 30-31, 2022

Cryogenic calorimeters a.k.a. bolometers

- Low heat capacity @ T ~ 10 mK
- Excellent energy resolution (**~0.2% FWHM**)
- Detector agnostic to origin of energy deposition
- Detector response of O(1) sec if readout with Neutron Transmutation Doped (NTD) Ge sensors

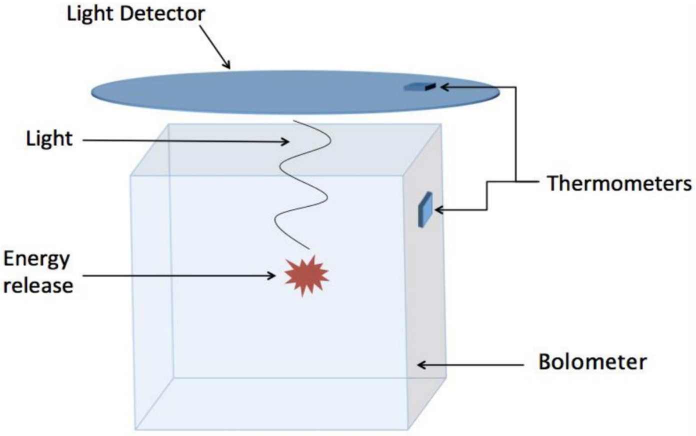


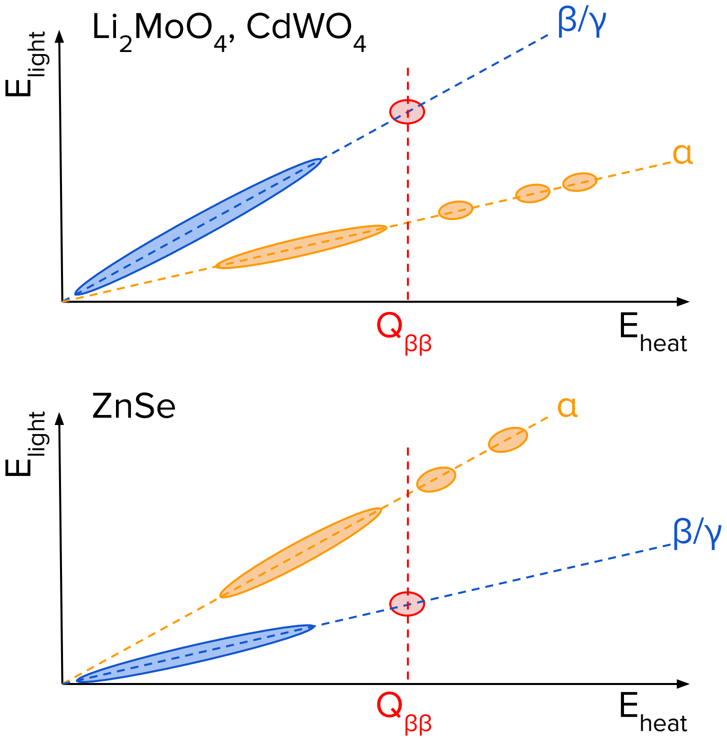


Simplified thermal model

- Crystal heat capacity: C
- Conductivity of coupling to thermal bath: G
- Signal amplitude ∝ $\Delta T = E_{dep}/C$
- Decay constant: $\tau = G/C$

Scintillating bolometers

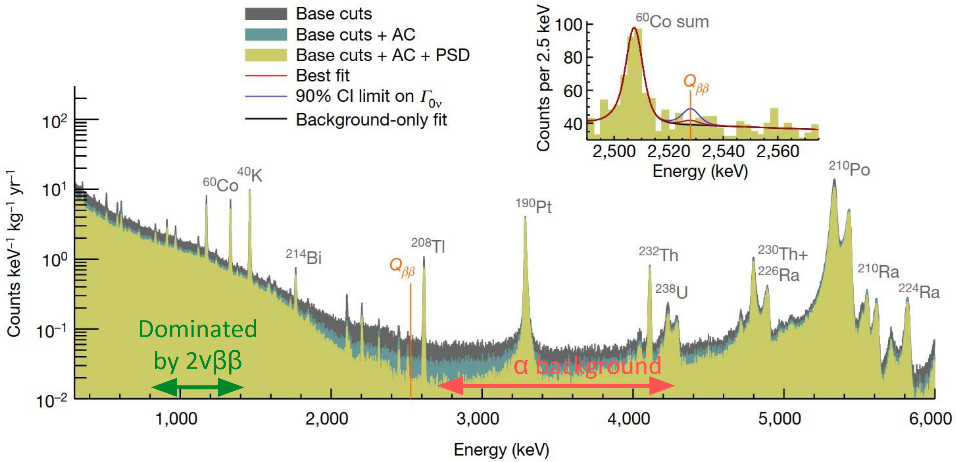




- Main background: surface α events
- Couple main crystal with secondary bolometer reading the scintillation (or Cherenkov) light
- Exploit different light yield (LY) of α vs β/γ to actively suppress background
- Typical light detector: thin Ge wafer coupled to thermometer (NTD, TES, KID, MMC)

CUORE: searching for 0νββ decay in ^{130}Te

- 988 TeO_2 crystals with natural Te composition
  → **742 kg of total mass**, 206 kg of ^{130}Te mass
- Located in [Hall A of the Gran Sasso National Lab]
- Current limit: **$T^{0\nu}_{1/2}$ > 2.2·10^{25} yr @ 90% C.I.**
- Published on [Nature]! → Part of the writing team



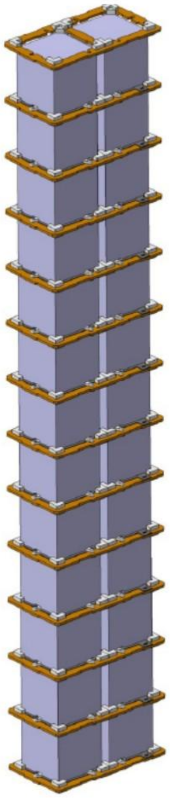
CUPID: CUORE Upgrade with Particle Identification

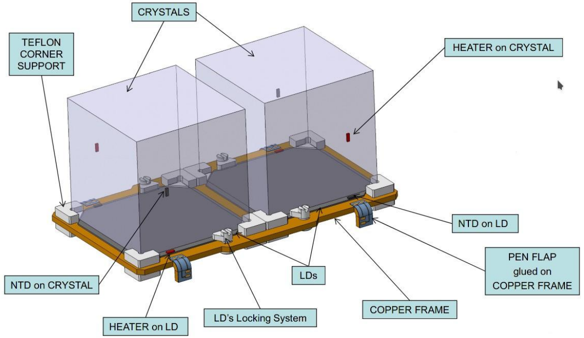
Goals:

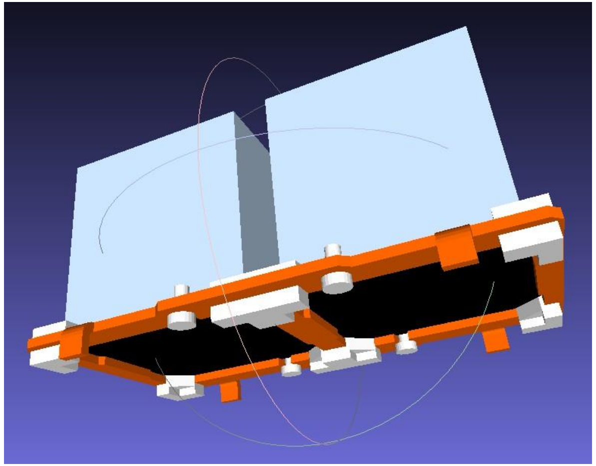
- ~1500 $Li_2{}^{100}MoO_4$ scintillating crystals
  → ~250 kg of ^{100}Mo
- FWHM: 5 keV at $Q_{\beta\beta}$
- α rejection via PID with light detectors (LD)
- Background: 10^{-4} counts/keV/kg/yr
- Discovery sensitivity: $T^{0\nu}_{1/2} = 10^{27}$ yr

Monte Carlo simulation program

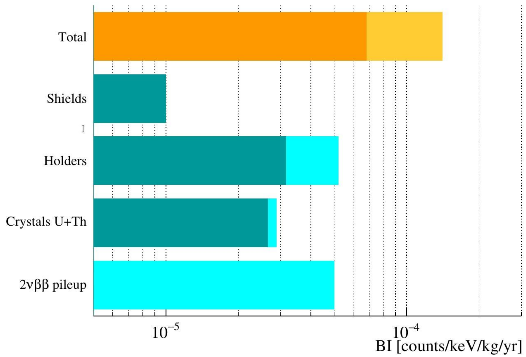
- Full geometry implemented in Geant4 application
  → Reciprocal feedback with engineering team
- Major update of background projection presented to DOE and INFN in Summer 2021
- Muon and neutron veto design under optimization
- Additional background sources under study

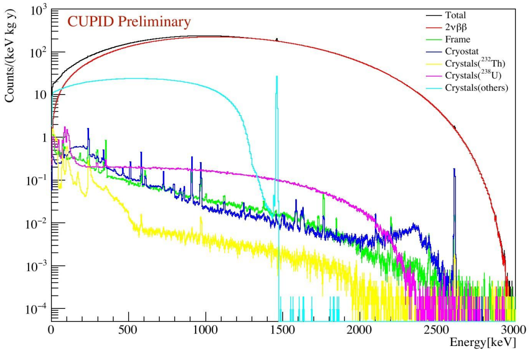






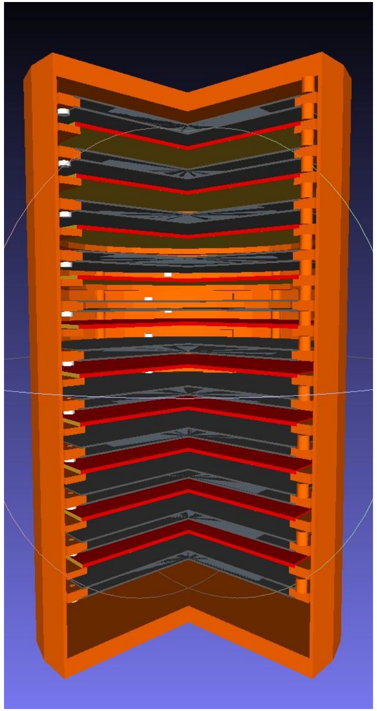
CUPID background budget





- CUORE infrastructure clean enough for CUPID
- LiMoO crystal cleanliness under control
  → Some improvement possible by better controlling crystal production
- Pile-up of 2νββ events is a potential issue
  → Dedicated measurements and event simulation ongoing
- Crystal holder background from surface uranium and thorium contamination
  → CUORE data show U and Th at the level of 10 nBq/cm^2
  → Is it possible to reduce this background by better cleaning or substituting copper with another material?
  → **Dedicated setup to measure surface radioactivity of material sample under realization within the Fellini project**
- Residual background from radiogenic neutrons with <10 MeV
  → Simulations ongoing
  → Dedicated measurement highly desirable

A bolometric setup for surface α screening



Goals and requirements

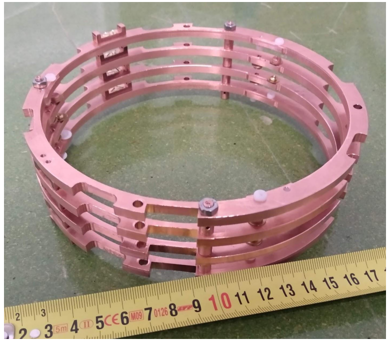
- Sensitivity of few nBq/cm^2 with few weeks of measurement
  → Sensitive area > 0.1 m^2
  → Background ≤1 nBq/cm^2 (current best ~250 nBq/cm^2)
- Design must allow easy exchange of material sample

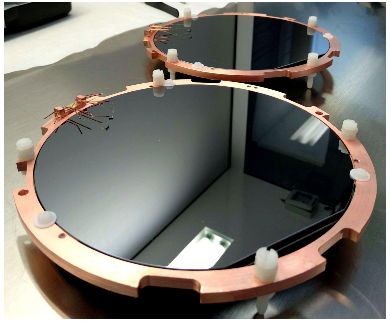
Design

- Tower of silicon wafers (∅=15cm) operated as bolometers
- Material sample can be inserted between detectors

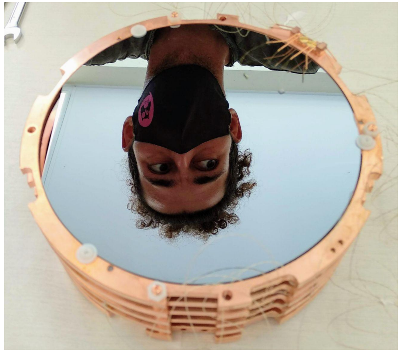
Status

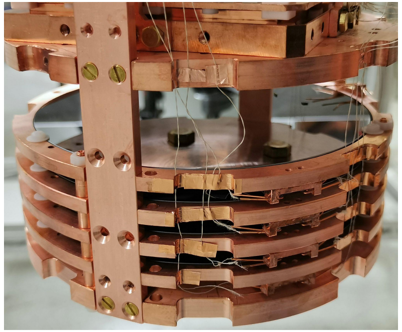
- Design optimized with Geant4 MC simulation
- First prototype (4 detector modules) realized in Spring 2021 and operated in Fall 2021 to test the detector performance





Performance of α bolometer prototype



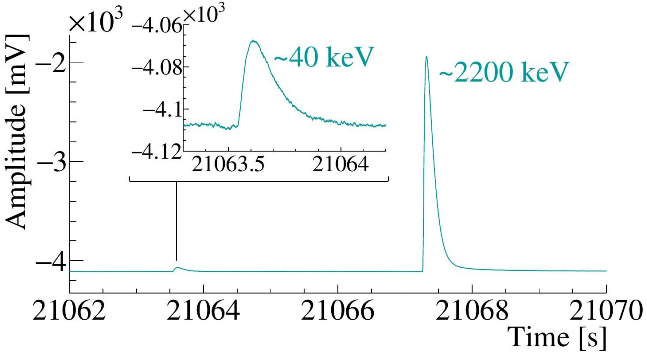


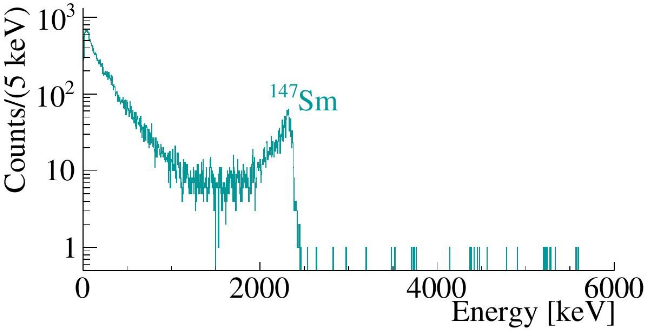
Results

- Collected data: 6.5 days
- Threshold: 1-6 keV
- Energy resolution on pulser events: 0.5-4 keV FWHM
- Risetime: 30-60 ms
- Decay time: 50-200 ms
- α background: <100 nBq/cm^2
  → Lowest ever w/o any special care!

Next steps

- Presenting at LRT conference in June
- Publication of present results
- Precise calibration with α source
- Long background measurement
- Full scale setup with ~20 detectors





Development of portable neutron detector

Goals

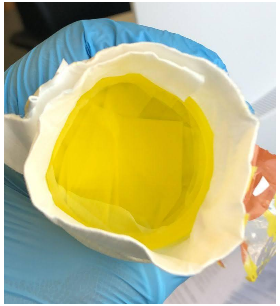
- Measure neutron spectrum in 0-10 MeV range in the CUORE/CUPID location
- Realize a portable, high-sensitivity setup to perform the measurement elsewhere, too

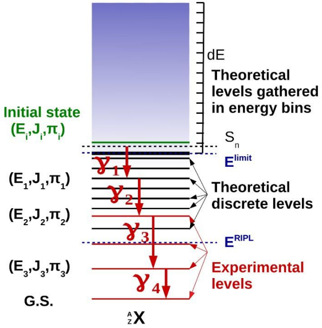
Detector concept

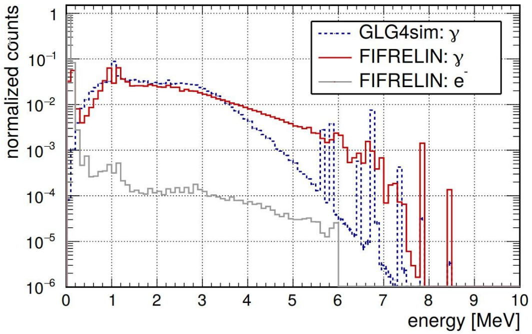
- $Gd_3Al_2Ga_3O_{12}$ (GAGG) scintillating crystal + PMT
- $n + {}^{157}Gd \longrightarrow {}^{158}Gd^* \longrightarrow {}^{158}Gd + \gamma$'s (8 MeV)
- High light yield, 100% separation of α vs β/γ

Status and plans

- All components available as of last week
- MC simulations ongoing (thanks to new collaboration with the developers of FIFRELIN code @CEA)
- Summer: characterize crystal and PMT







Summary

- CUORE collecting data stably since 2019
  ⟶ Physics Board coordination since October 2021
  ⟶ Major improvement of data analysis ongoing
- CUPID design under quick progress from the engineering and background minimization point of view
  ⟶ Coordinator of the MC simulation working group until October 2021
- Minimization of backgrounds for CUPID
  ⟶ Dedicated setup for measurement of materials' surface contamination developed within Fellini project
  ⟶ In the long term, the setup could become a screening facility for other low background experiments
  ⟶ Low-background portable neutron detector under development
- Side-projects:
  ⟶ Global sensitivity analysis for $0\nu\beta\beta$ decay experiments (already adopted by APPEC)
  ⟶ Review paper on $0\nu\beta\beta$ decay under revision for Rev. Mod. Phys.