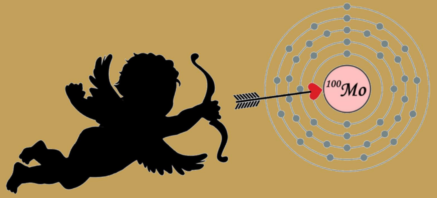


Designing the next-generation 0νββ decay experiment CUPID

Giovanni Benato

General Meeting of the Fellini Program, online, Mar. 4-5, 2021

Matter producing 0νββ decay

What is conserved in the SM?

- ~~B and L~~ $\Longrightarrow$ Non-perturbative effects at high energy
- (B-L), ~~(L_e-L_μ), $(L_\mu-L_\tau)$, $(L_\tau-L_e)$~~ $\Longrightarrow$ Oscillation experiments

S. Dell'Oro, S. Marcocci and F. Vissani, PoS NEUTEL2017 (2018) 030

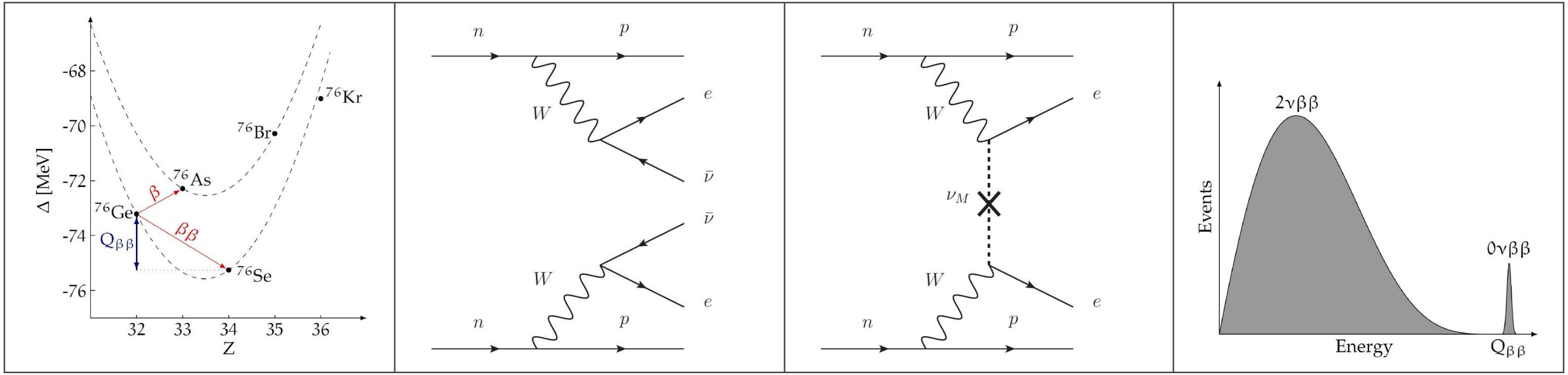
M. Agostini, G. Benato, J. Detwiler, J. Menendez and F. Vissani
Review paper coming out soon(ish)

How can we test the conservation of B, L, (B-L)?

ΔL	ΔB	Δ(B-L)	Process
-1	**-1**	0	$p \longrightarrow e^{+} + \pi^{0}$
+2	0	-2	$(A,Z) \longrightarrow (A,Z+2) + 2e^{-}$

⇒ **Matter creation and destruction**

Expected 0νββ decay signature



ββ decay signature

- Continuum for 2νββ decay
- Peak at $Q_{\beta\beta}$ for 0νββ decay
  ⟹ Energy peak is the only necessary and sufficient signature to claim a discovery
- Additional signatures from signal topology, pulse shape discrimination, multiple channel readout, daughter tagging, …

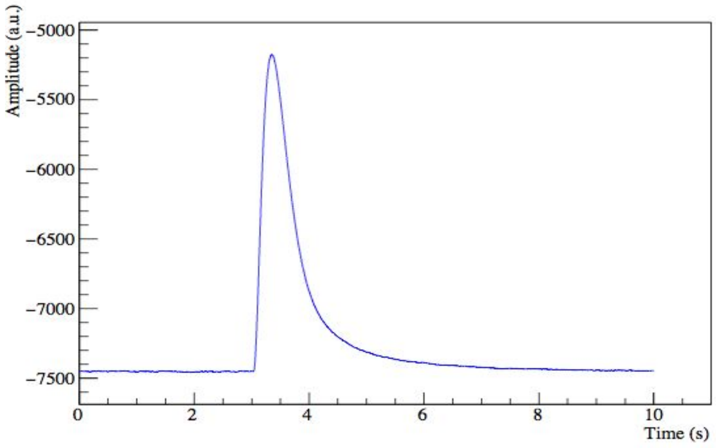
0νββ decay rate

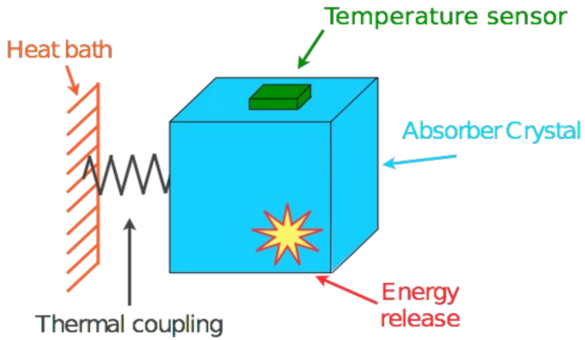
$$(T_{1/2}^{0\nu})^{-1} = G_{0\nu} \cdot |M_{0\nu}|^2 \cdot |f|^2 / m_e^2$$

- $T_{1/2}^{0\nu}$ = 0νββ decay halflife
- $G_{0\nu}$ = phase space (known)
- $M_{0\nu}$ = nuclear matrix element (NME)
- f = new physics term

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

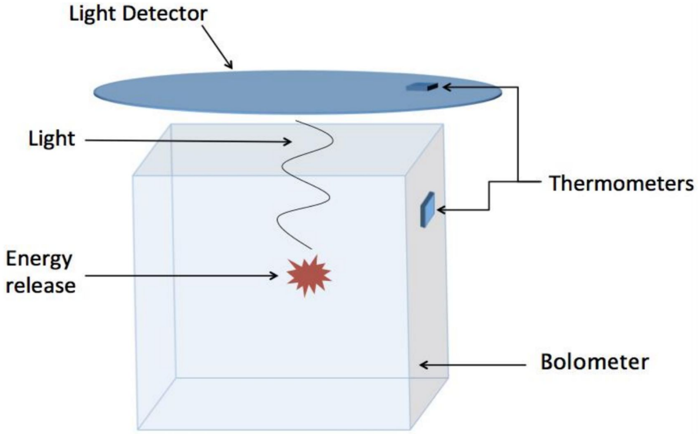


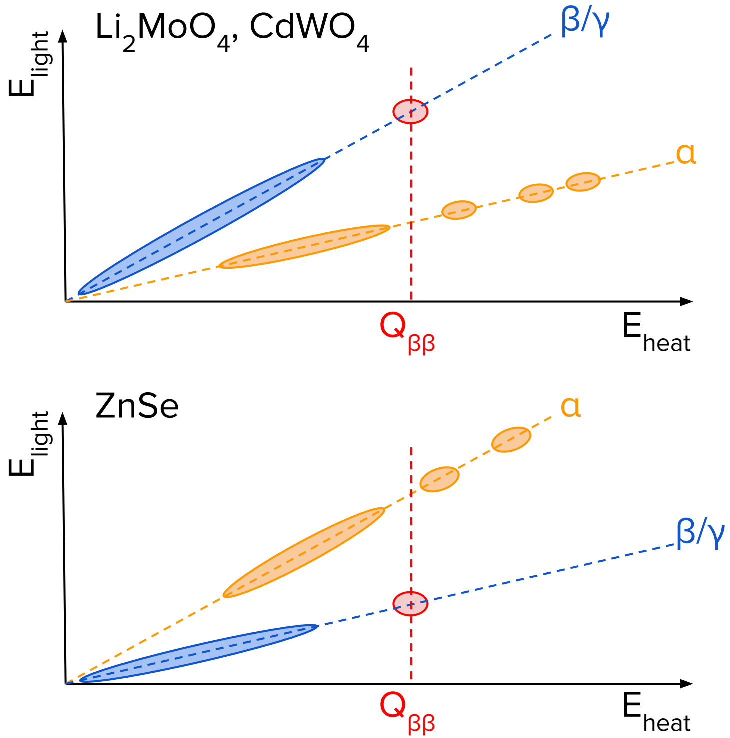


Simplified thermal model

- 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

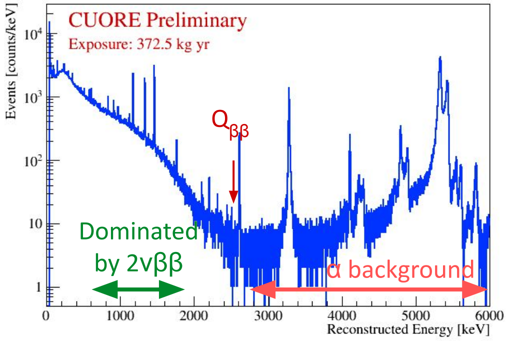


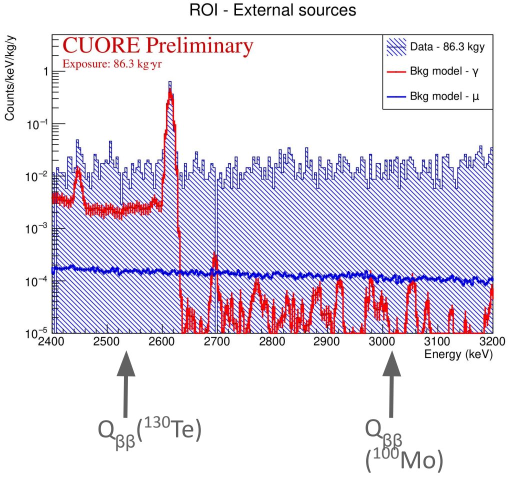


- Main background: surface α events
- Couple main crystal with secondary bolometer reading the scintillation (or Cherenkov) light
- Exploit different light yield (LY) of α vs β/γ to actively suppress background
- Typical light detector: thin Ge wafer coupled to thermometer (NTD, TES, KID, MMC)

CUORE: searching for $0\nu\beta\beta$ 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: **$T^{0\nu}_{1/2}$ > $3.2\cdot10^{25}$ yr @ 90% C.I.**
- $Q_{\beta\beta}(^{130}Te)$ = 2527.5 keV





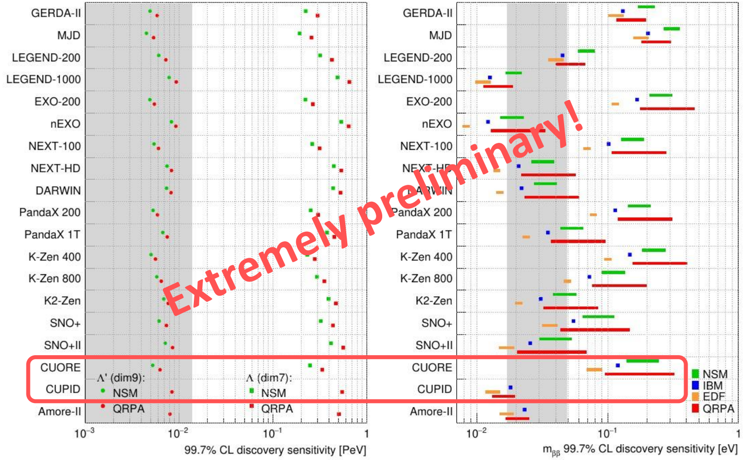
CUPID: CUORE Upgrade with Particle Identification

Goals:

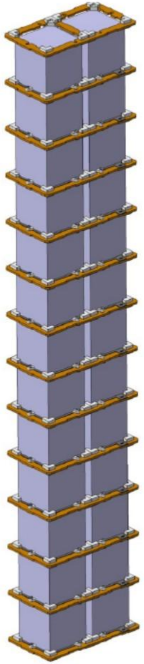
- ~1500 $Li_2{}^{100}MoO_4$ scintillating crystals
  → ~250 kg of ^{100}Mo
- FWHM: 5 keV at $Q_{\beta\beta}$
- α rejection via PID with light detectors (LD)
- Background: 10^{-4} counts/keV/kg/yr
- Discovery sensitivity: $T^{0\nu}_{1/2} = 10^{27}$ yr

How do we get there?

- Large cryogenic infrastructure → Re-use CUORE cryostat
- Demonstrate LMO resolution
- Demonstrate PID performance of LDs
- Demonstrate reproducibility of performance
- Demonstrate low background



Designing CUPID

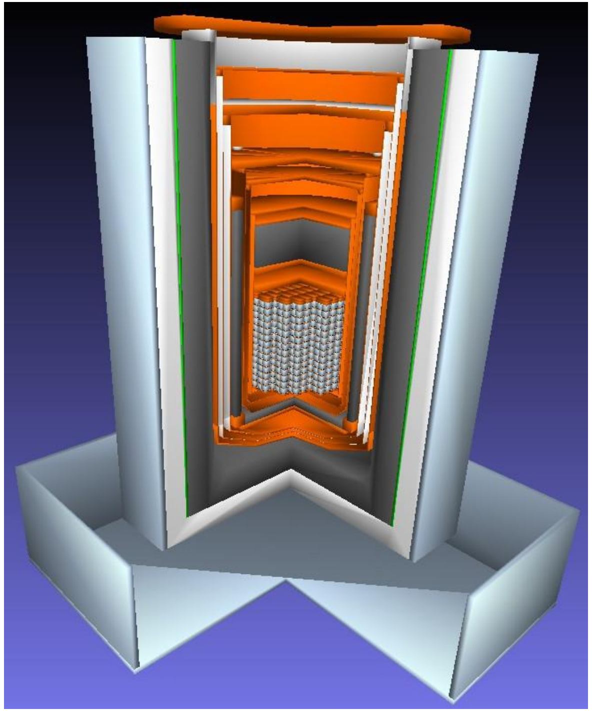


Innovative structural design

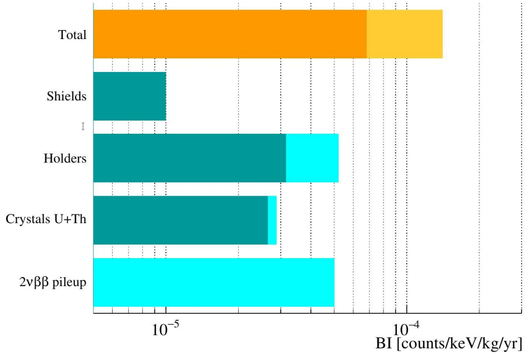
- Crystals floors “sitting” on each other
- Extremely simple frame geometry
  ⟶ Easy machining and assembling
  ⟶ Copper can be in substituted with cleaner materials

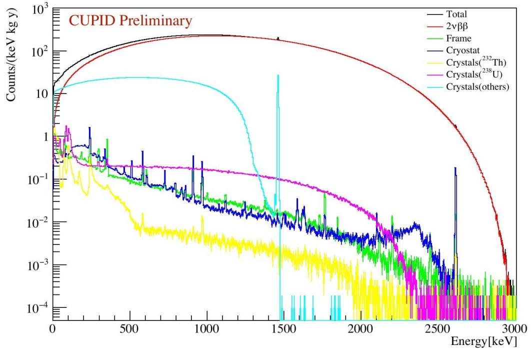
Monte Carlo simulation program

- Full geometry implemented in Geant4 application
- Geometry can be easily modified
  ⟶ Reciprocal feedback with mechanical engineering team
- Major update of background projection in summer 2020
- Muon veto design under optimization
- Additional background sources under study



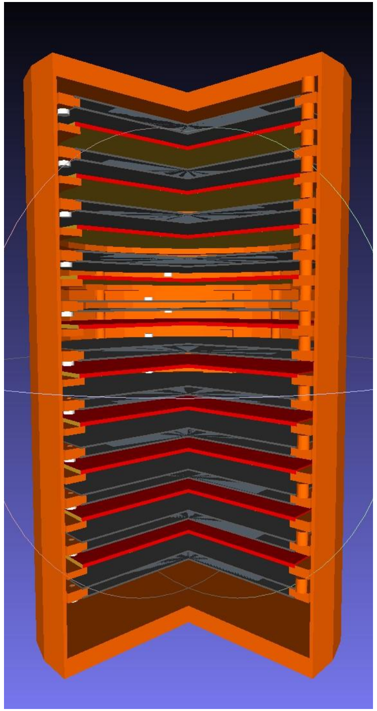
CUPID background budget





- 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!**

A bolometric setup for surface α screening



Goals and requirements

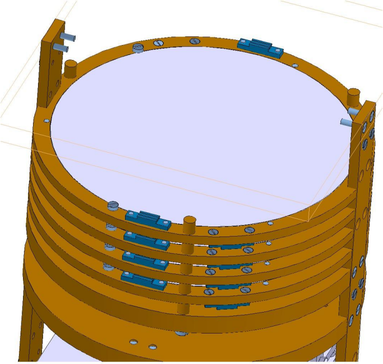
- Sensitivity of few nBq/cm^2 with few weeks of measurement
  → Sensitive area > $0.1\ m^2$
  → Background ≤1 nBq/cm^2
- Design must allow easy exchange of material sample

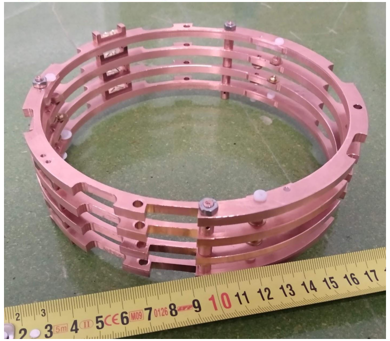
Design

- 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) under construction
- First test foreseen in 1-2 months





Summary

- CUPID design under quick progress from the engineering and background minimization point of view
  ⟶ G. Benato coordinator of the MC simulation working group
- Minimization of crystal holder surface background fundamental for CUPID
  ⟶ Dedicated setup for measurement of materials' surface contamination under construction within Fellini project
  ⟶ If successful, the setup could become a screening facility for other low background experiments
  ⟶ If successful, the setup could be modified for precision measurements of β decay spectra
- Side-projects:
  ⟶ Global sensitivity analysis for 0νββ decay experiments (already adopted by APPEC)
  ⟶ Review paper on 0νββ decay under preparation for Rev. Mod. Phys.