GRAN SASSO SCIENCE INSTITUTE

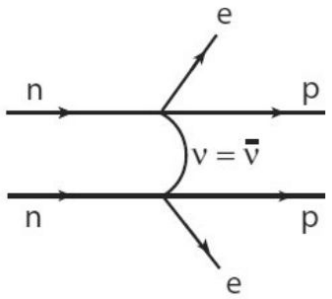
INFN

Neutrinoless double-beta decay searches

From CUORE to CUPID

GSSI scientific fair
February 2022
Dounia Helis

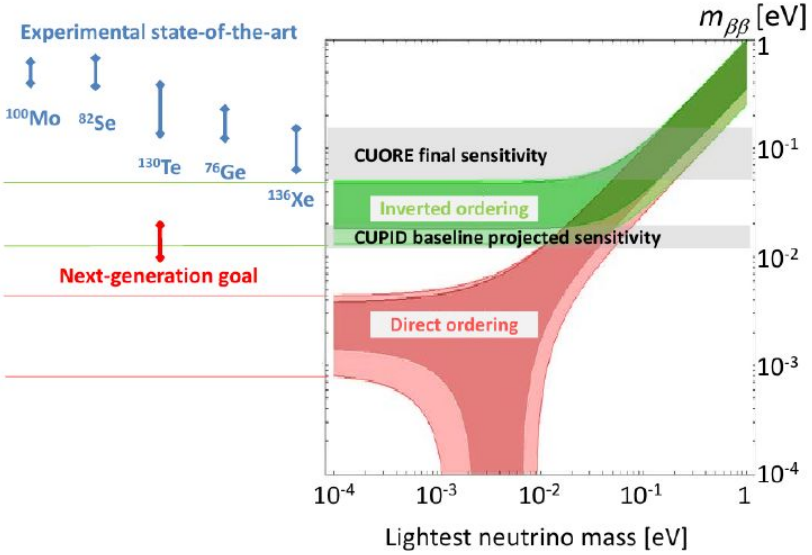
Outline



- Physics goal of CUORE and CUPID
- Bolometric technology in CUORE and CUPID
- From CUORE to CUPID
- Proposed thesis

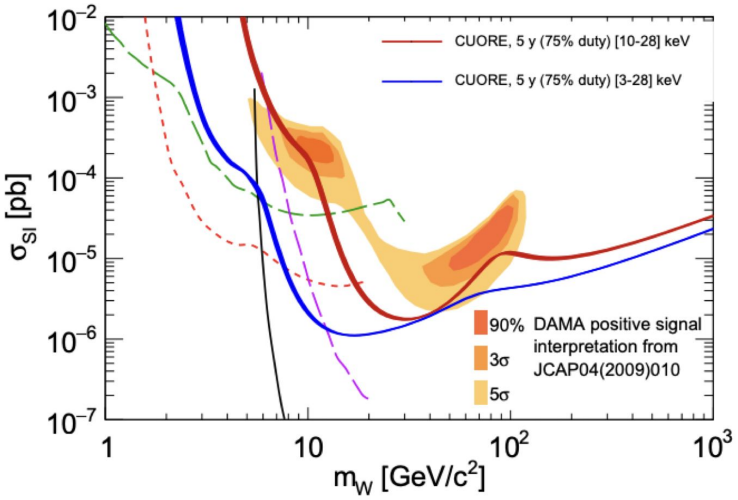
Physics goal of CUORE and CUPID

- Underground experiments to search for **neutrinoless double-beta decay**
- Neutrinoless double-beta decay:
  - Forbidden by the SM due to the lepton number violation
  - Possible only if neutrinos are Majorana particles
- If it is observed:
  - the neutrino absolute mass scale will be fixed: measurement of the effective Majorana mass
  - Majorana nature of neutrino will be proved: the neutrino is its own antiparticle
  - clues on asymmetry of matter/antimatter in the universe (creation of matter without antimatter)



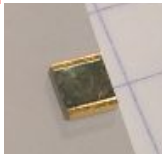
What else can we do with the CUORE/CUPID detectors?

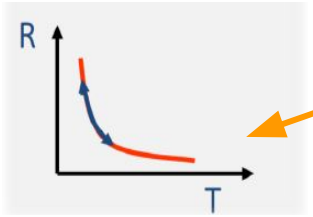
- Double beta decay on excited states
- Other rare events searches such as Dark Matter, Axion, solar/supernovae neutrinos, Tri-nucleon decay…
- Discovering new physics from the 2νββ spectral shape such as Majoron-emitting decays and Lorentz invariance and CPT violations
- Study the violation of fundamental principles such as Electric charge conservation and Pauli Principle violation

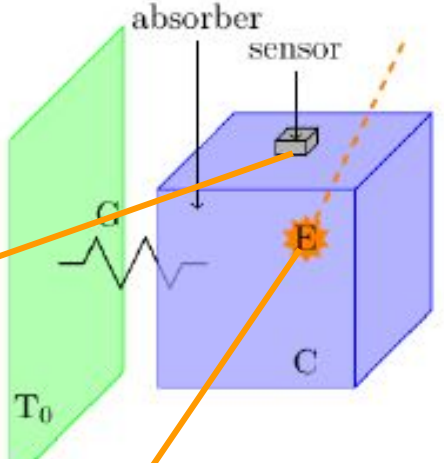


Working principle of a cryogenic bolometer

- Bolometer=absorber+thermal sensor+thermal bath
- Particle interaction = rise of temperature
- The thermal sensors **Neutron Transmutation Doped Ge (NTD)=>resistance variation**



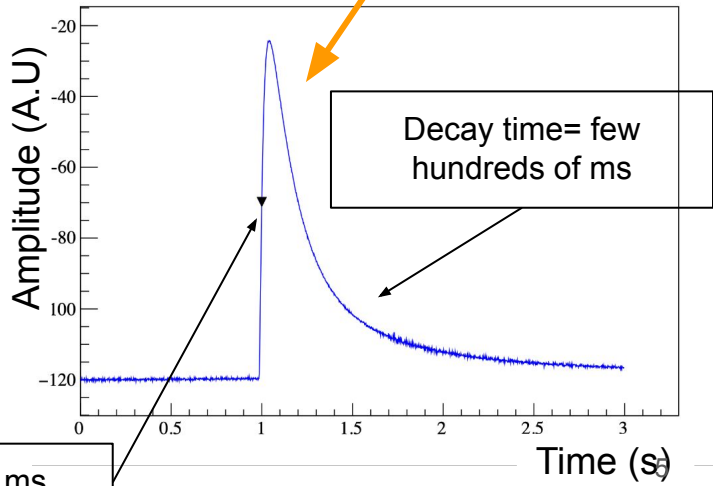




- Operated at few mK (10-20 mK)

$$C(T) \propto \left(\frac{T}{\theta_D}\right)^3 \qquad \uparrow \Delta T = E/C \downarrow$$

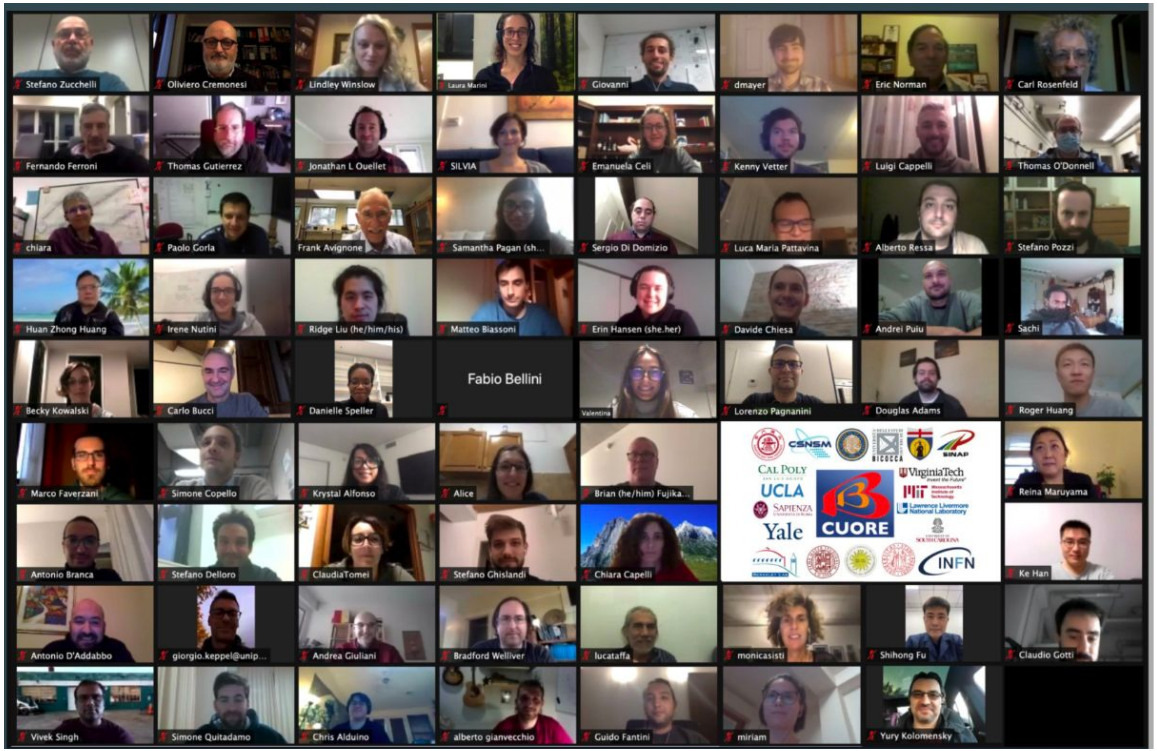
- Large choice of material for the absorber
- High energy resolution (~ 1% at 2.56 MeV)
- Slow thermal response suitable for low rate events
- Source=Detector => High efficiency detector



The most advanced experiment using bolometers

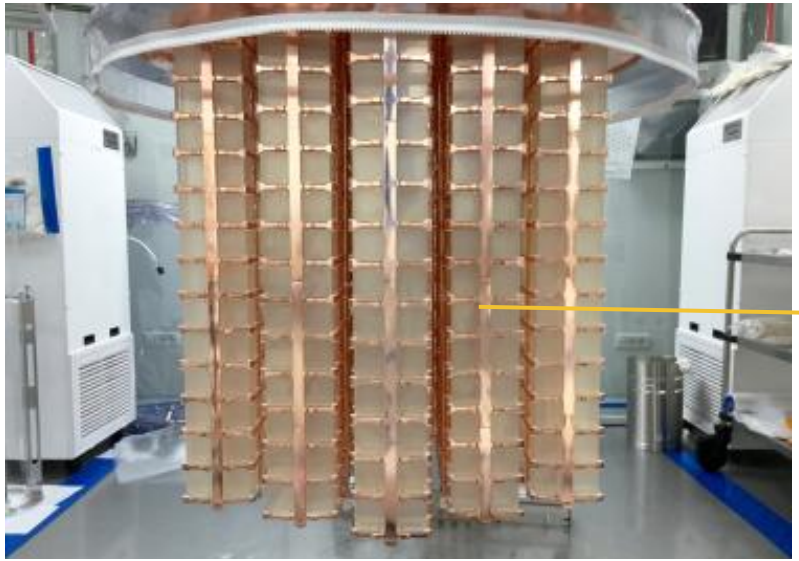
The CUORE (Cryogenic Underground Observatory for Rare Events) experiment

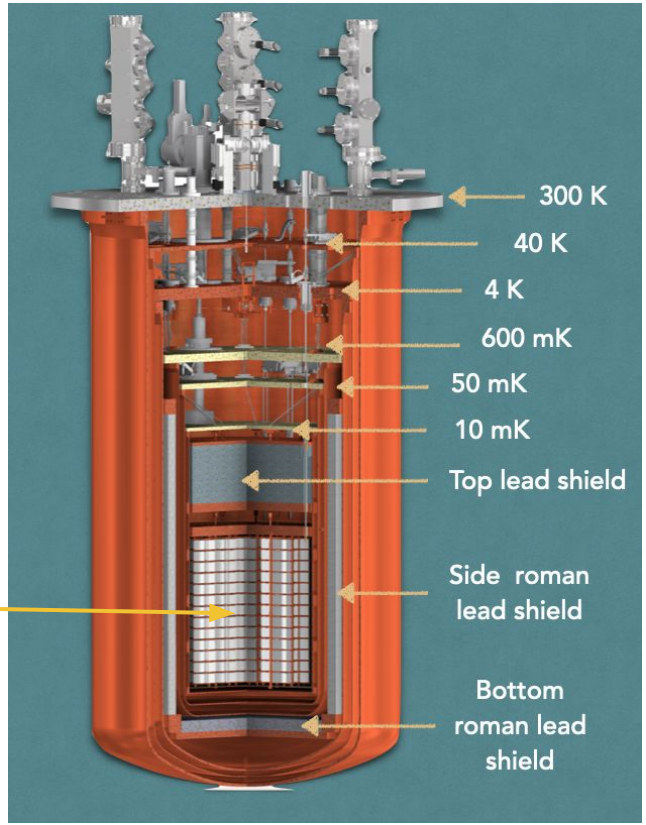
113 collaborators
from 27 institution
in 4 countries:
China
France
Italy
United States



CUORE cryostat and towers

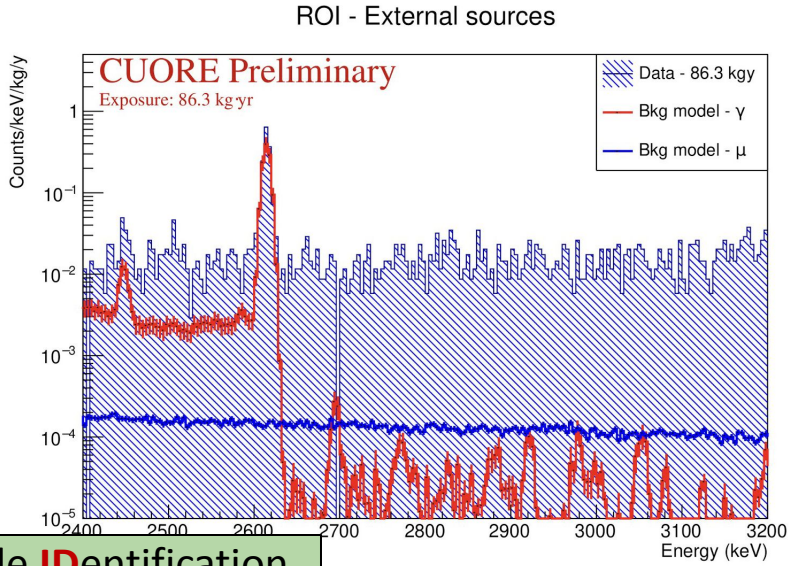
- One ton of detectors at 10 mK located in Hall A at LNGS
- 206 kg of ^{130}Te using 742 kg of natural TeO_2 crystals
- 988 TeO_2 crystals arranged in 19 towers
- $Q_{\beta\beta}$ ($^{130}TeO_2$)=2527.5 keV
- **World leading limit $T_{1/2}(^{130}Te) > 3.2 \times 10^{25}$ yr at 90% C.I.**



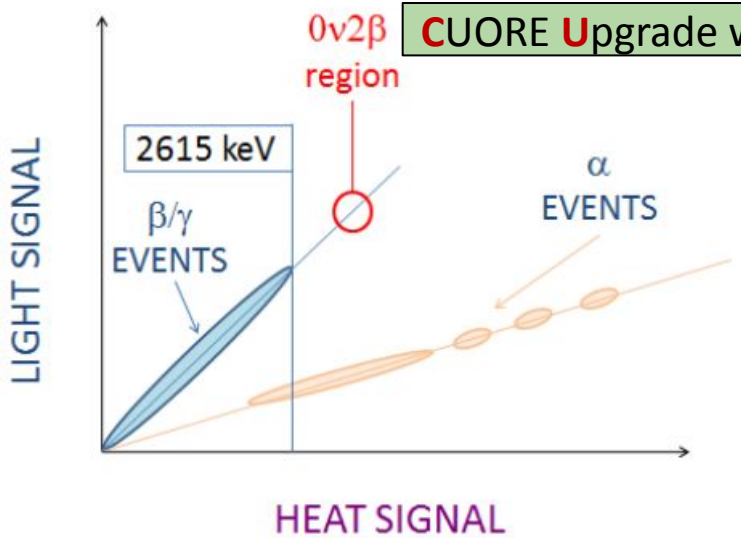


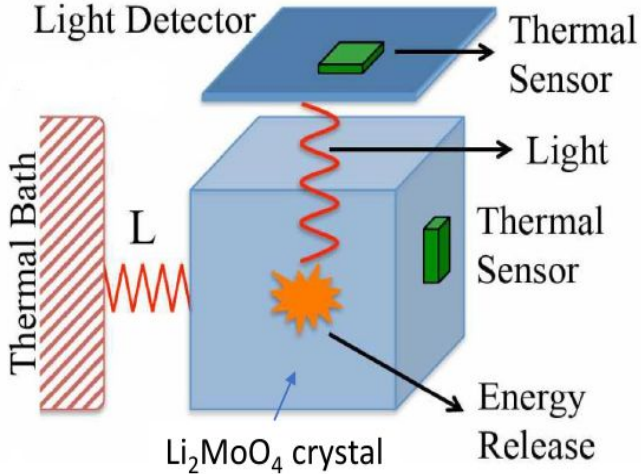
Lessons learned from CUORE

- The background in the ROI is mostly due to degraded alphas => A PID is needed to reject alphas
- Choice of an isotope with $Q_{\beta\beta}$ > 2.6 MeV to reduce the beta/gamma-background in ROI (Region Of Interest)
- An active muon veto is need
- **Solution**: dual readout bolometers



CUORE Upgrade with Particle IDentification

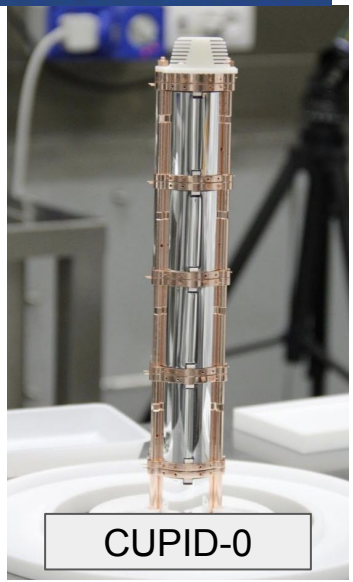




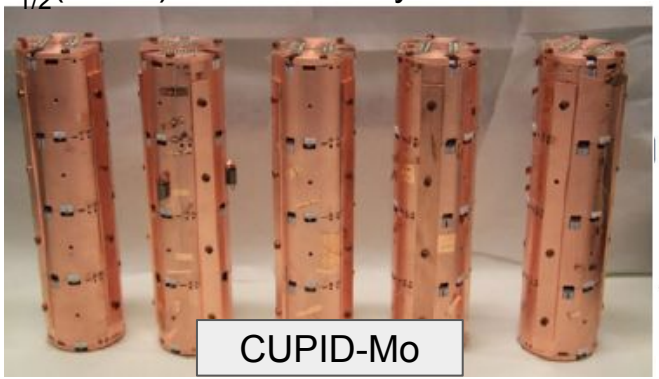
From CUORE to CUPID: New Collaboration

CUORE: you need PID to reach zero background conditions!

CUPID: Ok, we will use scintillating bolometers!



$T_{1/2}(^{100}Mo) > 1.8 \times 10^{24}$ year at 90% C.I.



$T_{1/2}(^{82}Se) > 4.7 \times 10^{24}$ year at 90% C.I.

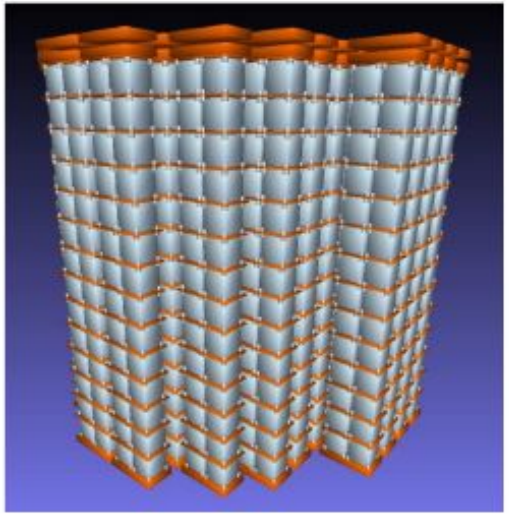
7 countries, 180 members

From CUORE to CUPID: New Collaboration

CUORE: you need PID to reach zero background conditions!

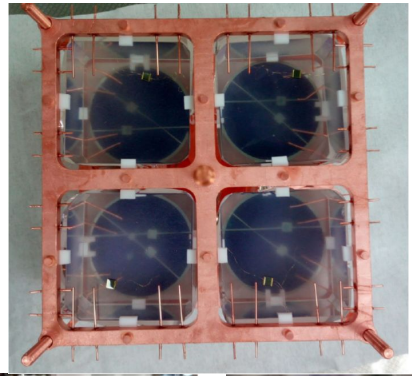
CUPID: Ok, we will use scintillating bolometers!

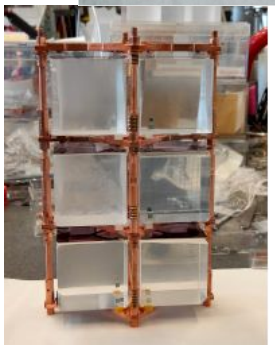
- Goal: fully cover the inverted hierarchy region
- Will be deployed in the CUORE cryostat (infrastructure ready!)
- 1596 cubic $Li_2{}^{100}MoO_4$ scintillating bolometers arranged in 57 towers x 14 floors (2 crystals/floor)
- Each crystal is ~ 280 g and 45x45x45 mm^3
- Total mass of 240 kg of ^{100}Mo (enrichment > 95%)
- Goal FWHM: 5 keV at $Q_{\beta\beta}$
- Background index ~ 10^{-4} counts/(keV.kg.yr)

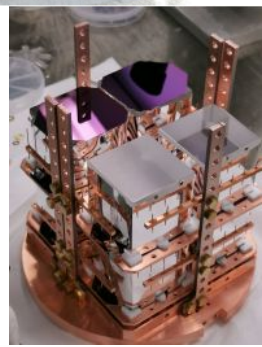


Past and future R&D tests towards CUPID

- Several R&D tests to define the baseline design
  - shape of the crystals
  - light detector geometry and position
  - design of the detector structure (copper detector support)







- Study the light collection efficiency with the different detector structures
- Pile up studies to control the background induced by random coincidences of 2vββ

CUPID, arXiv:1907.09376

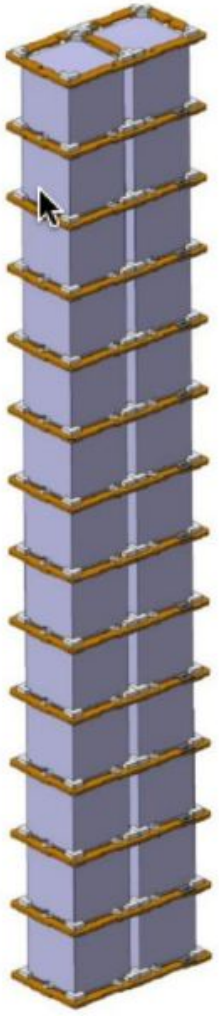
CUPID, EPJ C 81 (2021) 2, 104

CUPID, *Phys.Rev.C* 104 (2021) 1, 015501

CUPID, JINST 16 (2021) 02, P02037

Past and future R&D tests towards CUPID

- **Baseline design is ready !**
- A test of a CUPID single module was performed
- A test of a full CUPID tower is starting at LNGS



Proposed thesis topics

Data Analysis and Processing (CUORE / CUPID)

- List of the possible analysis in CUORE (excited states..., on 3T data)
- Background model and sensitivity studies
- Search for Beyond Standard Model processes in CUORE
- Discovery Potential for Supernova Neutrinos
- Dark Matter searches
- Development of algorithm for pileup-rejection in CUPID
- Pulse shape studies for alpha tagging in CUPID

CUPID detector design

- Optimization of the sensor performance (sensitivity, time response)
- Design and test of the CUPID prototypes
- Design and optimization of the CUPID (active and passive) shieldings

Joins us !

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