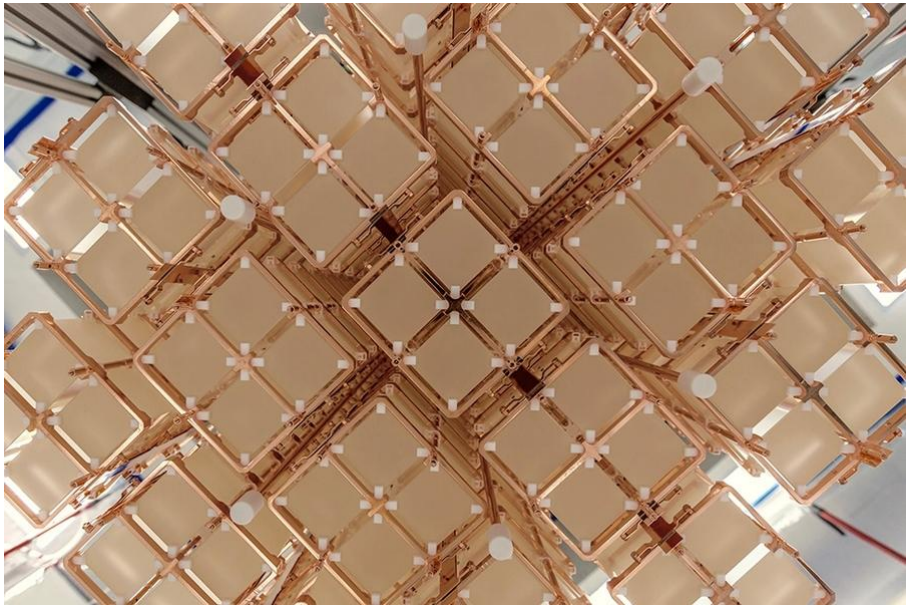
Swiss Institute of Particle Physics

PSI2022

Physics of fundamental Symmetries and Interactions

NuPECC



Search for Neutrinoless Double Beta Decay of ^{130}Te

Latest results from the CUORE experiment

CUORE

GSSI GRAN SASSO SCIENCE INSTITUTE
SCHOOL OF ADVANCED STUDIES
Scuola Universitaria Superiore

INFN LNGS

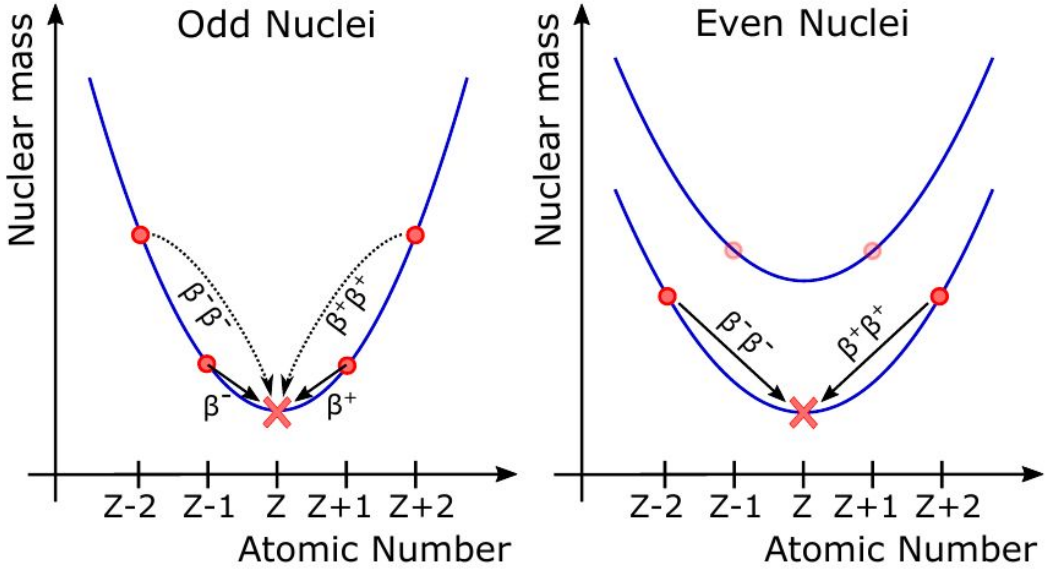
***Stefano Ghislandi**, on behalf of the CUORE collaboration*

Double Beta Decay ($2\nu\beta\beta$)

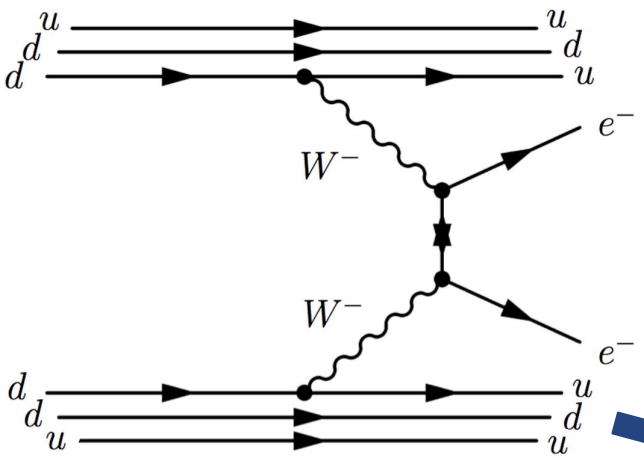
$$\beta^-\beta^- \qquad (A,Z) \longrightarrow (A,Z+2) + 2e^- + 2\bar{\nu}_e$$

$$\beta^+\beta^+ \qquad (A,Z) \longrightarrow (A,Z-2) + 2e^+ + 2\nu_e$$

- 2nd order SM process
- Only **even mass number nuclei** (i.e. ^{76}Ge, ^{82}Se, ^{100}Mo, ^{128}Te, ^{130}Te, ^{136}Xe)
- Half-lives in the order of 10^{18}-10^{21} yr
- Precision measurements of the spectral shape → **tests of the nuclear models**



Neutrinoless Double Beta Decay ($0\nu\beta\beta$)



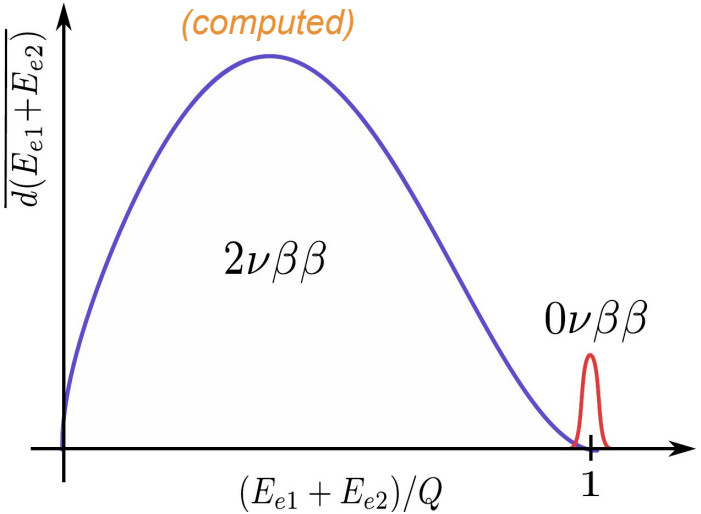
- Beyond SM ($\Delta L = 2$)
- **Constraints on neutrino mass** hierarchy and scale
- **Neutrino nature**

Experimental observable — *Nuclear physics (models + experiments)* — *Majorana mass (parameter of interest)*

$$T^{0\nu}_{1/2} = \left[G_{0\nu} \, | \mathcal{M}_{0\nu} |^2 \, g_A^4 \left(\frac{m_{\beta\beta}}{m_e} \right)^2 \right]^{-1}$$

Phase space factor (computed)

Expected spectrum



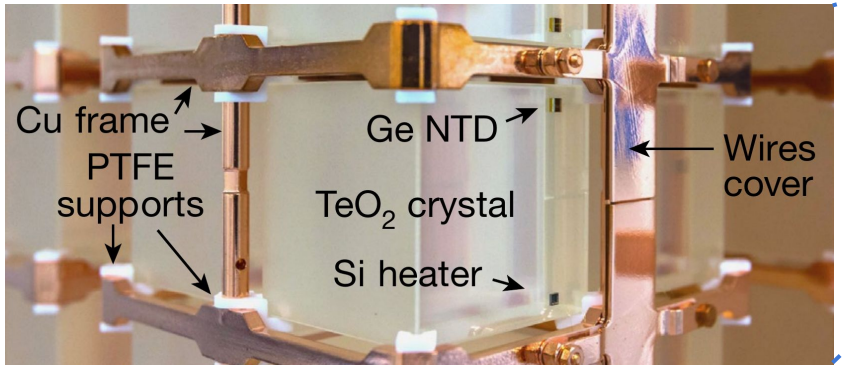
EXPERIMENTAL SENSITIVITY $S^{0\nu} \propto \sqrt{\frac{MT}{B\Delta}}$

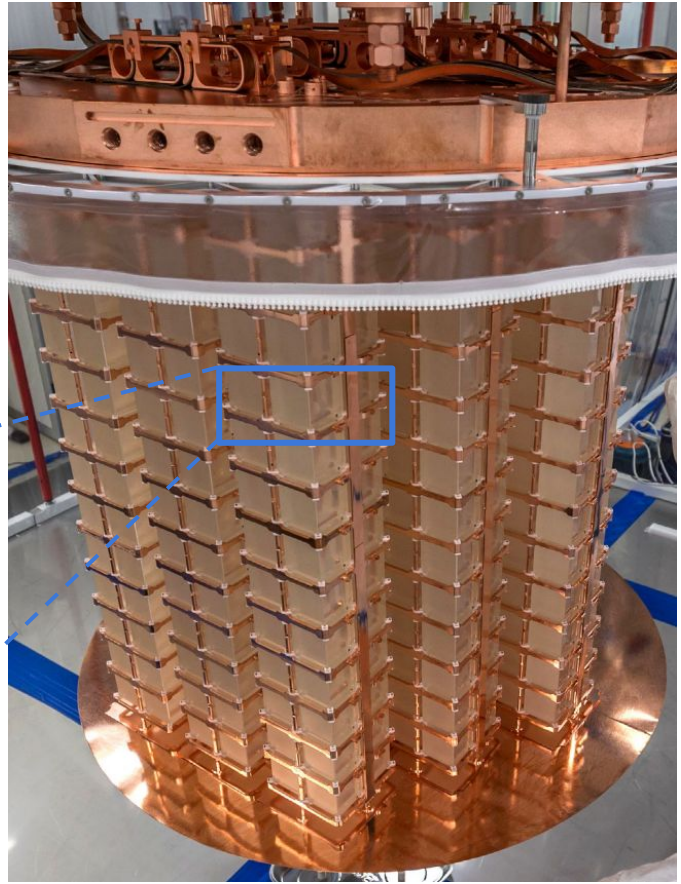
- MT — Exposure [Mass · Active Time]
- B — Background index [counts / keV / kg / yr] in the ROI
- Δ — Energy resolution [keV] in the ROI

The CUORE experiment

Cryogenic **U**nderground **O**bservatory for **R**are **E**vents

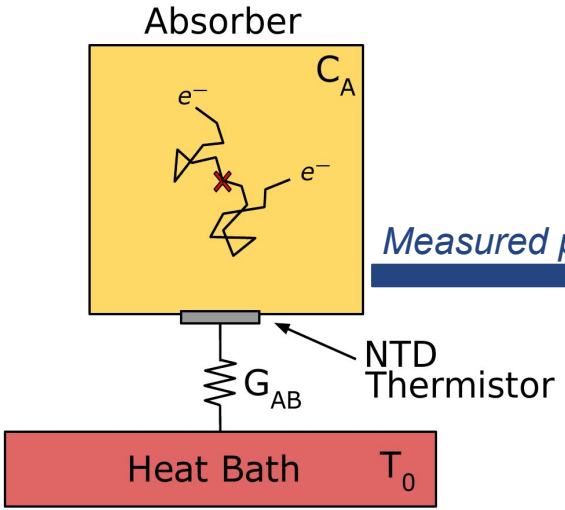
- **988 TeO_2 crystals operated at ~ 15 mK** with natural ^{130}Te abundance
- Low background index ~ 10^{-2} counts / keV / kg / yr
- Background energy resolution ~ 7.8 keV FWHM @ $Q_{\beta\beta}$
- **Sensitivity goal $T^{0\nu}_{1/2}$ ~ 9 $\cdot 10^{25}$ yr** with 5 yr of active time



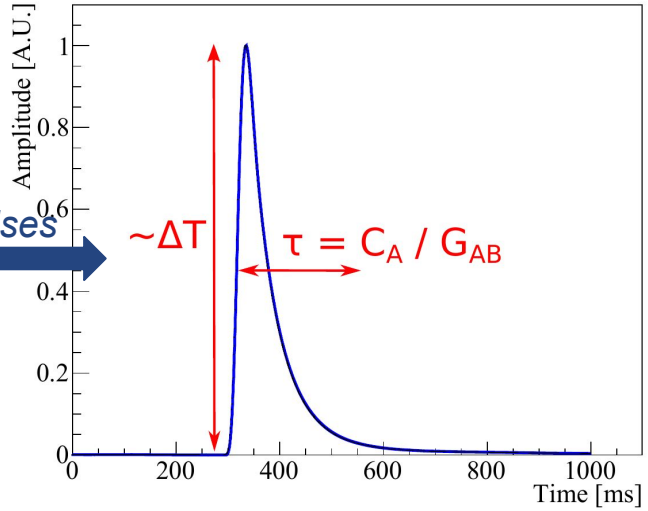


Bolometric technique

Particles release energy in the absorber (crystal) → Phonon production and thermalization, $T_0 \rightarrow T_0 + \Delta T$ → Resistance of the temperature sensor (NTD thermistor) changes with temperature → Bias readout of the thermistor, fed with constant current



Measured pulses



$$\begin{cases} \Delta T_{\text{crystal}} = \frac{\Delta E}{C} \sim \frac{0.1\,\text{mK}}{\text{MeV}} \\ C(T) \sim T^3 \\ \tau = \frac{C}{G} \sim 1\,\text{s} \\ R(T)_{\text{thermistor}} = R_0 e^{\sqrt{\frac{T_0}{T}}} \end{cases}$$

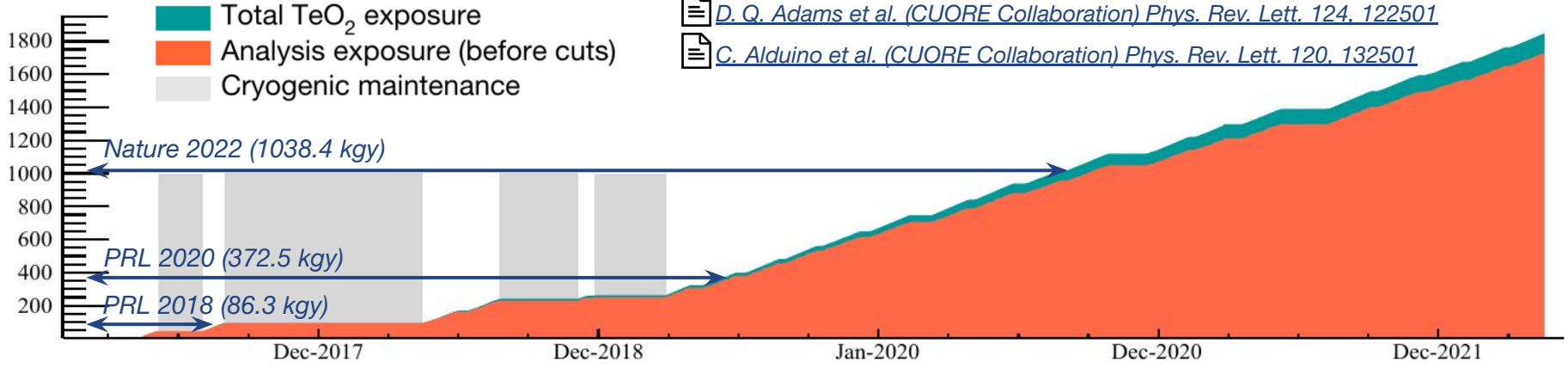
Low temperatures

✔ **Energy resolution (≳0.1%)**
✘ **Slow signals**

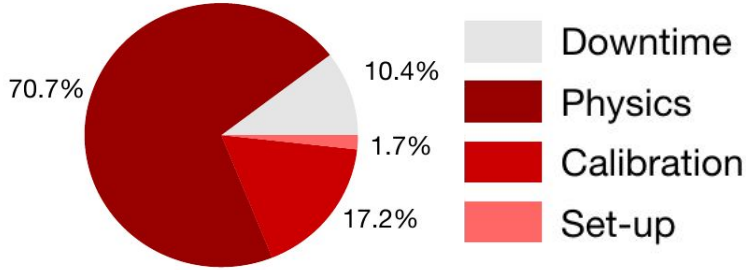
CUORE data taking

Data releases:

- Adams, D.Q. et al. (CUORE Collaboration) Nature 604, 53-58 (2022)
- D. Q. Adams et al. (CUORE Collaboration) Phys. Rev. Lett. 124, 122501
- C. Alduino et al. (CUORE Collaboration) Phys. Rev. Lett. 120, 132501

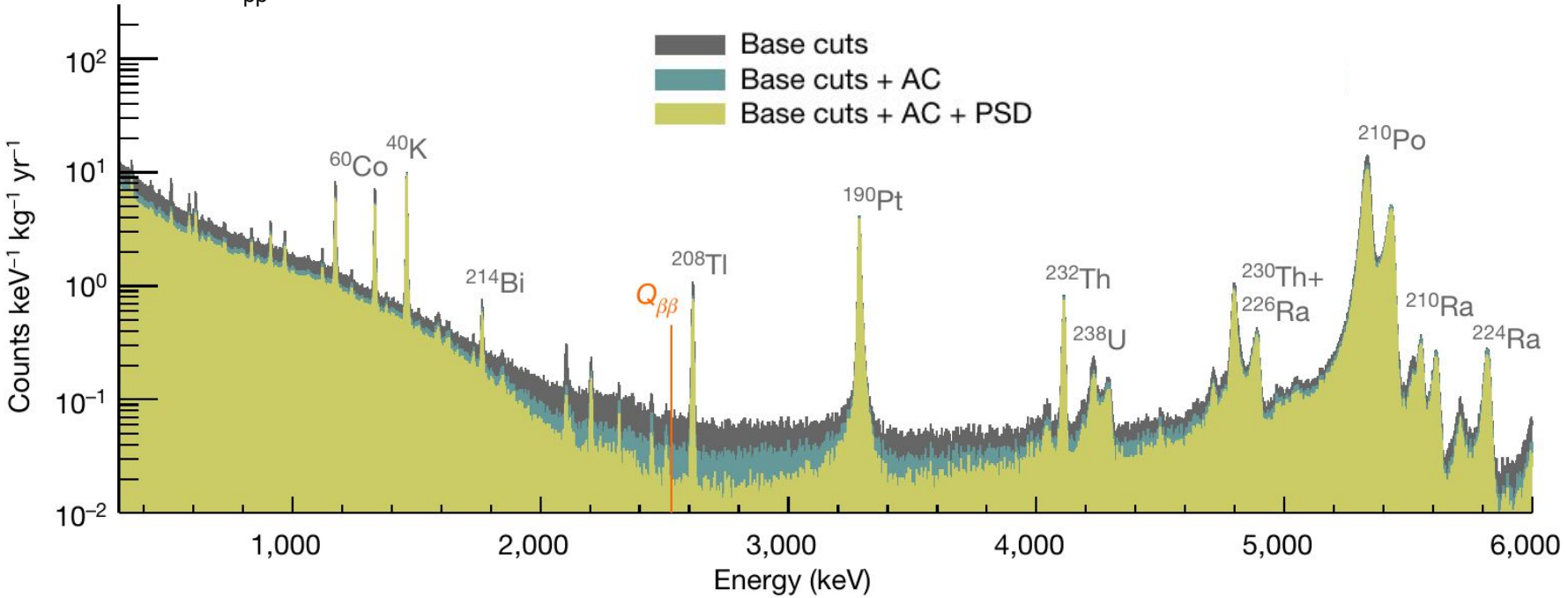


- Data collection started in May 2017
- From March 2019 stable data taking (90% uptime)
- October 2022 → ***reached 2 t·yr*** (total exposure)
- Average data collection rate ~ 60 kg·yr / month



CUORE energy spectrum

- TeO_2 Total exposure: 1038.4 kg · yr
- ^{130}Te Total exposure: 288.4 kg · yr
- $Q_{\beta\beta}$: 2527.5 keV
- FWHM at $Q_{\beta\beta}$: 7.8(5) keV
- ROI background index: $1.49 \cdot 10^{-2}$ counts/(keV · kg · yr)



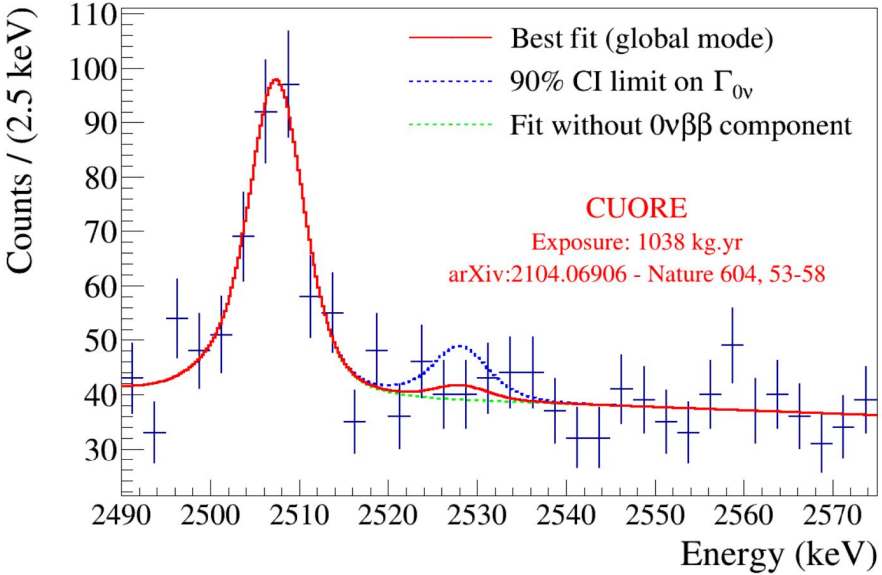
$0\nu\beta\beta$ fit results

Region Of Interest model

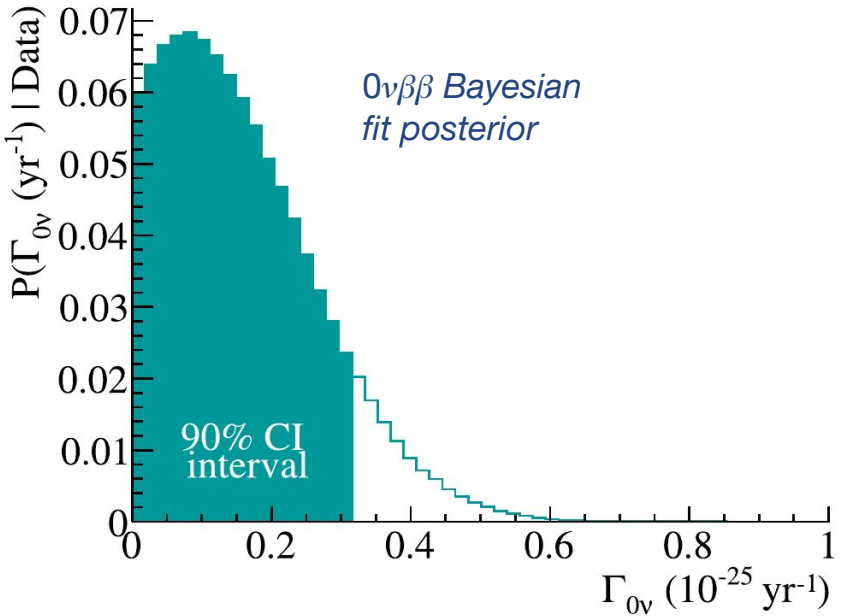
- Linear background
- ^{60}Co gamma peak @ 2505.7 keV
- $0\nu\beta\beta$ peak at the expected Q-value

Unbinned Bayesian fit (with non-negative uniform prior)

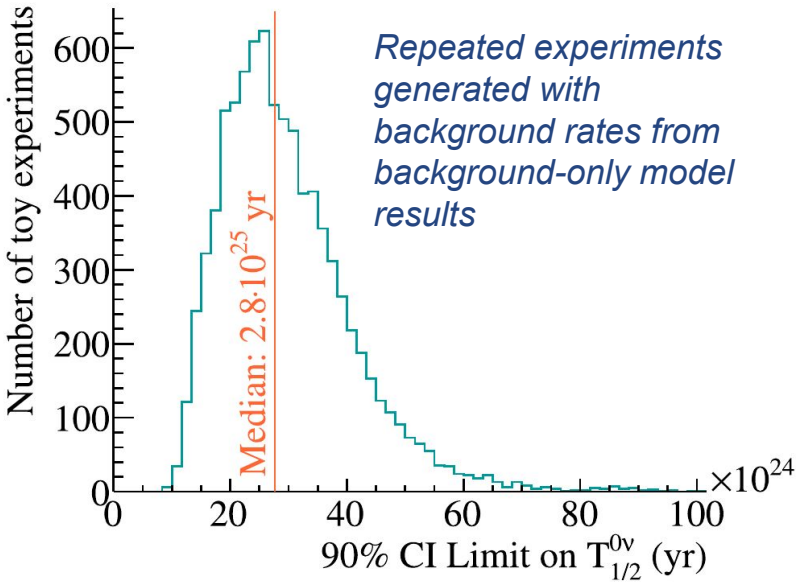
No evidence for $0\nu\beta\beta$
$T^{0\nu}_{1/2} > 2.2 \cdot 10^{25}$ yr (90% C.I.)



Adams, D.Q. et al. (CUORE Collaboration) Nature 604, 53-58 (2022)



$0\nu\beta\beta$ fit results (2)



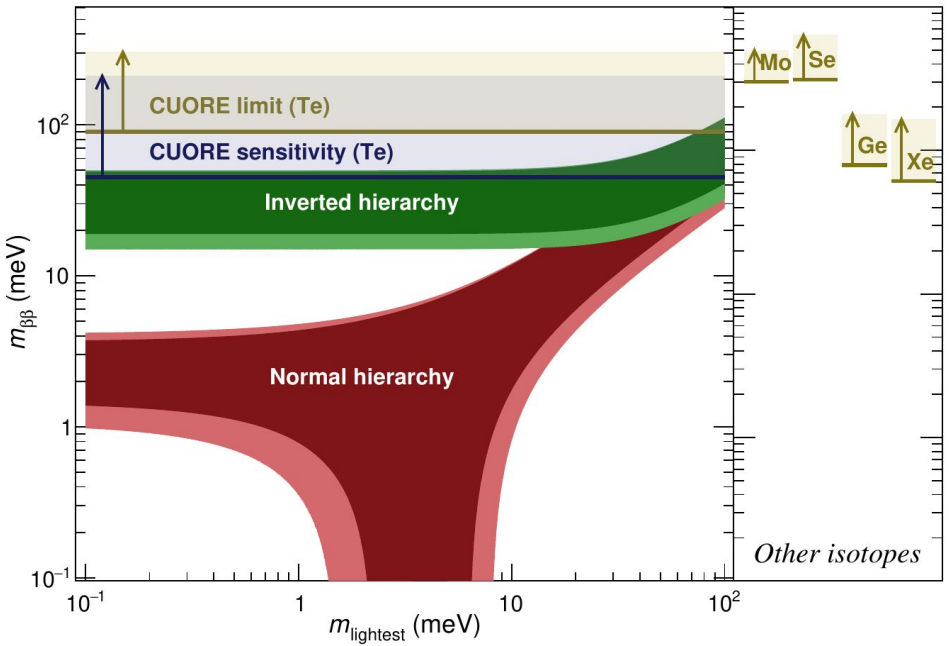
Repeated experiments generated with background rates from background-only model results

$2.8 \cdot 10^{25}$ yr median sensitivity

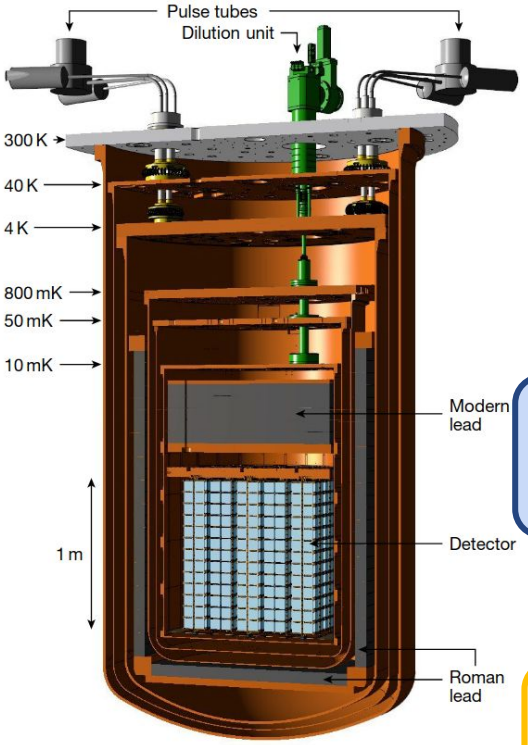
72% to obtain a better limit

$m_{\beta\beta}$ < 90-305 meV (90% C.I.)

UPDATE LOBSTER PLOT



CUORE background model



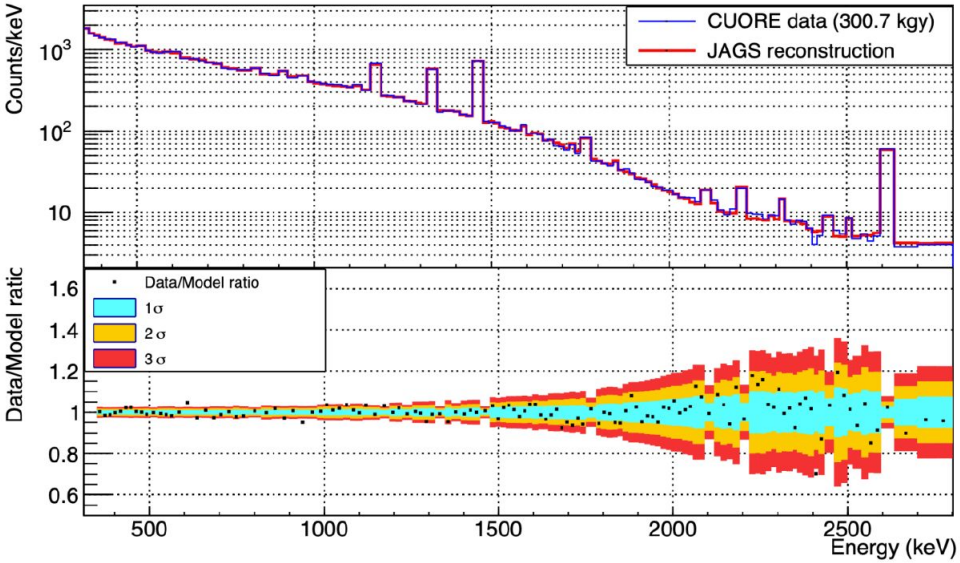
CUORE cryostat and detector geometry

Reproduce the CUORE geometry and materials

Propagate the 62 contaminants (β/γ + muons + ^{130}Te $2\nu\beta\beta$)

Smear the detector response feature with the Geant4 output

MCMC binned Bayesian fit of the generated simulations to data with JAGS



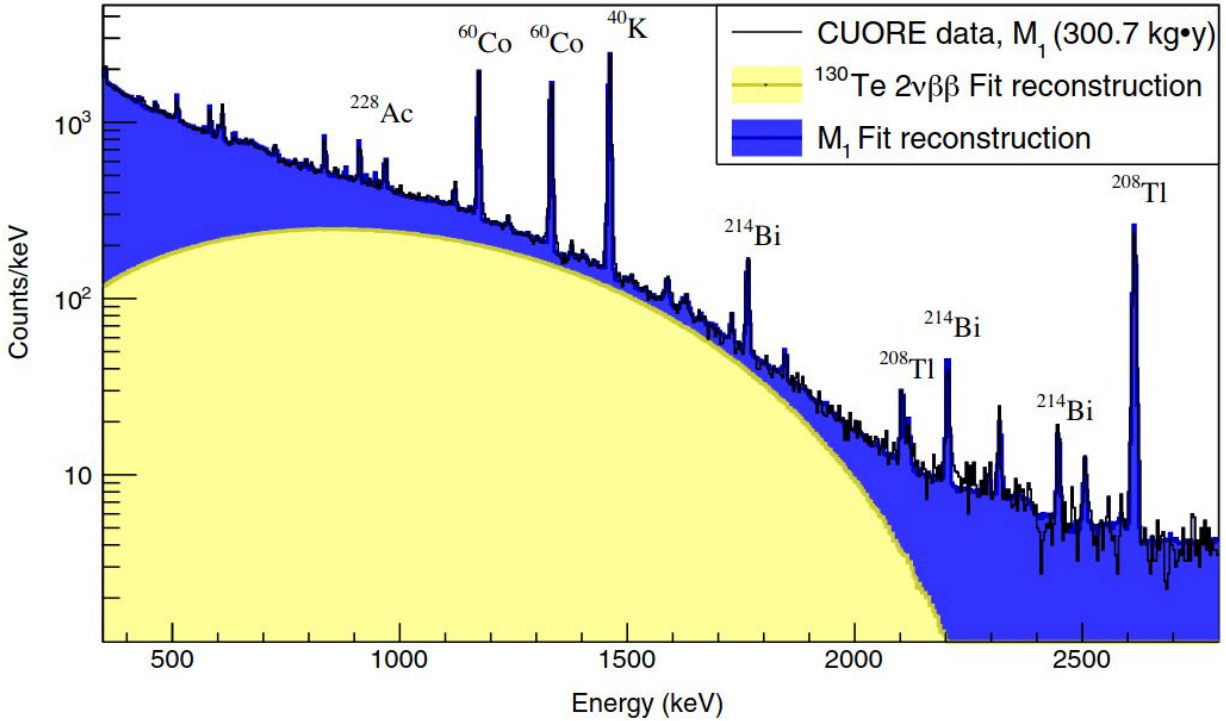
CUORE results on ^{130}Te $2\nu\beta\beta$

SPECTRAL FIT

- ^{130}Te $2\nu\beta\beta$ component from background model fit to single hits (M1) data
- **^{130}Te $2\nu\beta\beta$ > 50% of events in the 1-2 MeV** energy region

SYSTEMATICS

- 2 model (SSD vs HSD)
- ^{90}Sr inclusion (high correlations)
- Detector geometrical splitting



$$T^{2\nu}_{1/2} = 7.71^{+0.08}_{-0.06}(\text{stat})^{+0.12}_{-0.15}(\text{syst}) \times 10^{20}\ \text{yr}$$

Phys. Rev. Lett. 126, 171801 (2021)

Conclusions and perspectives

- CUORE demonstrated the ***feasibility of a tonne-scale experiment operating cryogenic detectors***

- CUORE is ***collecting data*** since 2017, accumulating ~ 2 tonne · yr of TeO_2 total exposure

- ***No evidence of $0\nu\beta\beta$ in ^{130}Te*** with 1038.4 kg · y exposure:
  - **$T^{0\nu}_{1/2} > 2.2 \cdot 10^{25}$ yr (90% C.I.)**
  - **$m_{\beta\beta} < 90\text{-}305$ meV (90% C.I.)**

- **Most precise measurement of ^{130}Te $2\nu\beta\beta$:**
  - $T^{2\nu}_{1/2} = 7.71^{+0.08}_{-0.06}(\text{stat})^{+0.12}_{-0.15}(\text{syst}) \times 10^{20}$ yr

- ***Next-generation experiment CUPID*** in preparation

Thanks for the attention!

CSNSM

Yale

INFN

Berkeley Lab

Cal Poly San Luis Obispo

Massachusetts Institute of Technology

VirginiaTech Invent the Future®

Lawrence Livermore National Laboratory

Sapienza Università di Roma

Università degli Studi di Milano Bicocca

UCLA

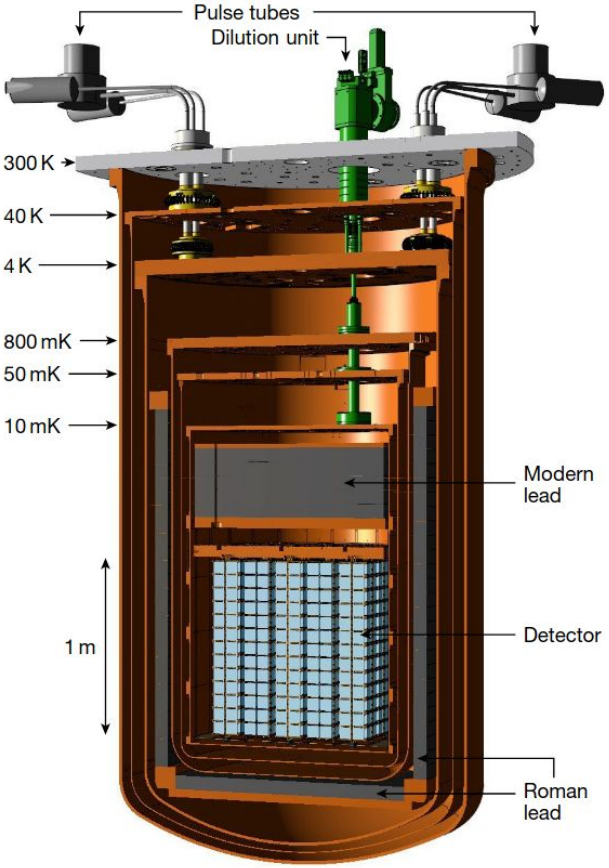
SINAP

University of South Carolina

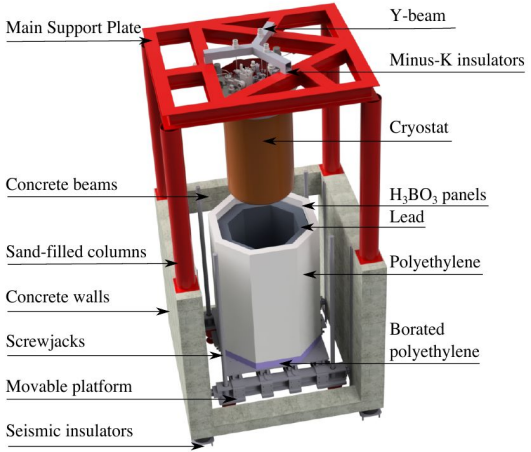
CUORE

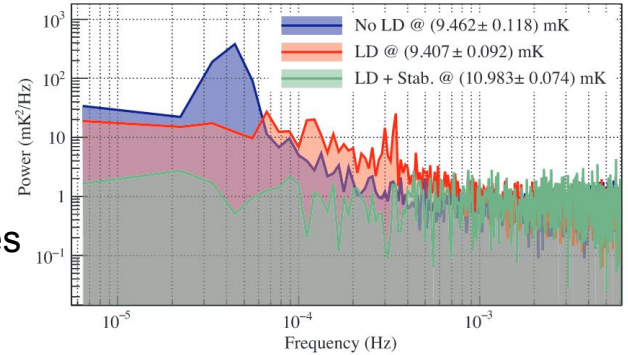
Backup Slides

CUORE infrastructure



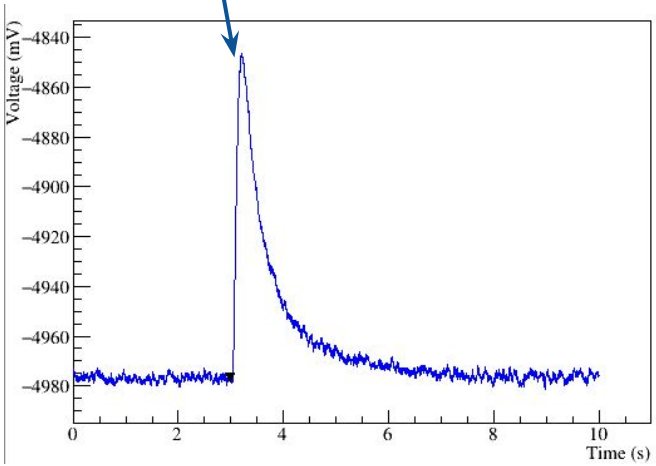
- Dilution refrigerator with 4μW @ 10 mK cooling power
  Cryogenics 102 (2019) 9-21
- Radiopurity and mechanical stability constraints
- Located @ LNGS underground labs, 3600 m.w.e., for a low muon flux
- External decoupling system for vibration isolation
- Pulse Tubes noise active cancellation system + linear drives
  Cryogenics 93, 55-56 (2018)

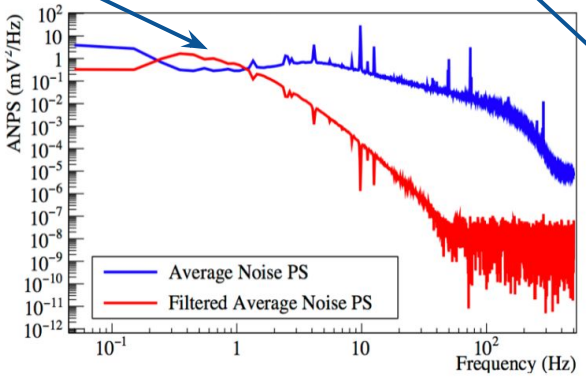


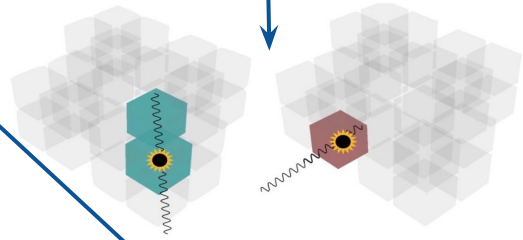


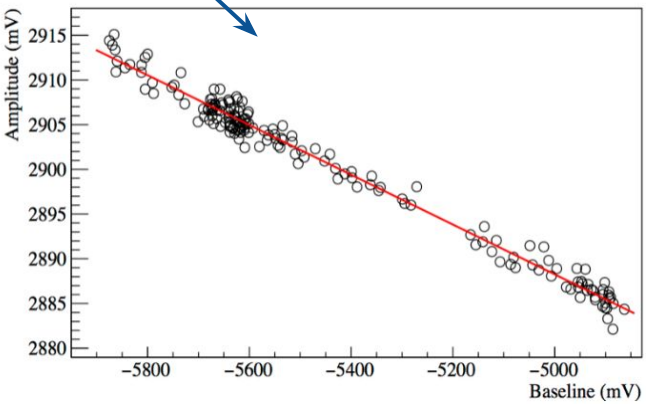
Analysis chain

Trigger events → Pulse and noise template and amplitude evaluation → Thermal gain stabilization → Coincidences and Pulse Shape Discrimination





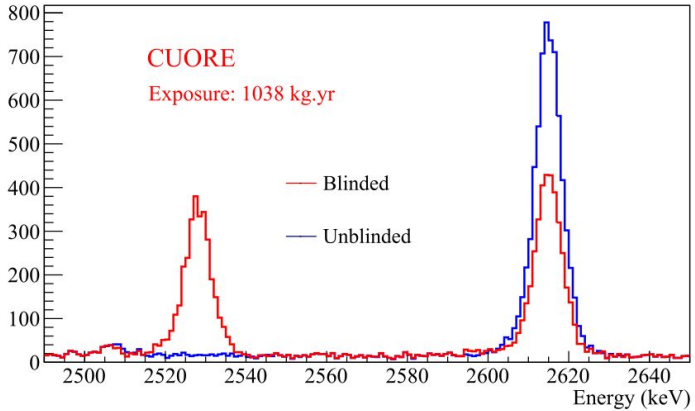


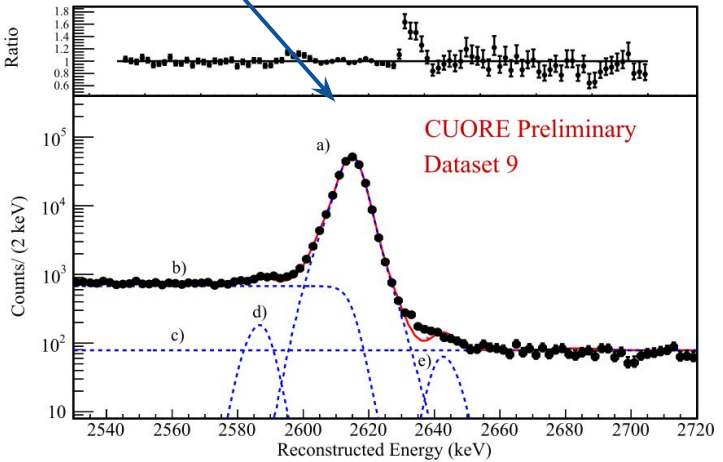


Analysis chain

Blinding → Total efficiency evaluation → Convolution with the detector response → Region Of Interest fit

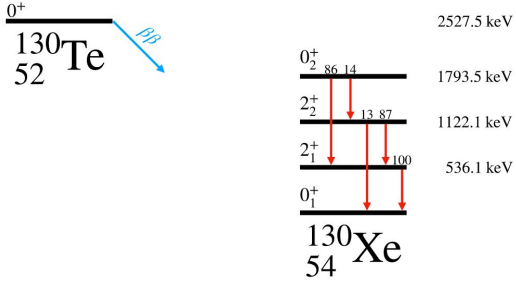
Total analysis efficiency (data)	92.4(2)%
Reconstruction efficiency	96.418(2)%
Anticoincidence efficiency	99.3(1)%
PSD efficiency	96.4(2)%
Containment efficiency (MC)	88.35(9)%





Other studies

0ν - 2ν on ^{130}Xe excited states

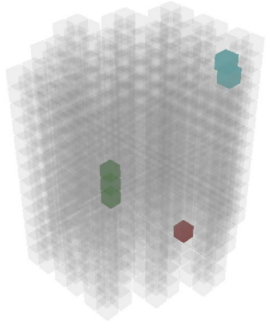


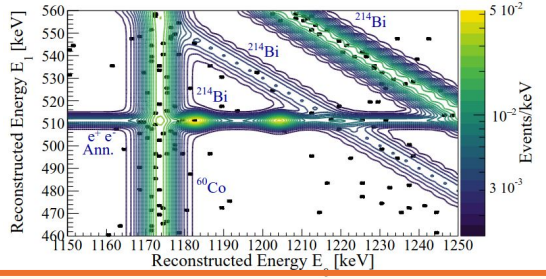
$T^{0\nu}_{1/2} > 5.9 \cdot 10^{24}$ yr (90% C.I.)

$T^{2\nu}_{1/2} > 1.3 \cdot 10^{24}$ yr (90% C.I.)

Eur. Phys. J. C, 81 567 (2021)

β^+EC of ^{120}Te



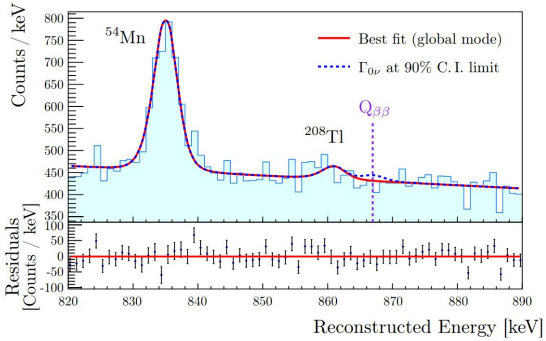


$T^{\beta+EC}_{1/2} > 2.9 \cdot 10^{22}$ yr (90% C.I.)

Phys. Rev. C, 105, 065504 (2022)

0νββ of ^{128}Te

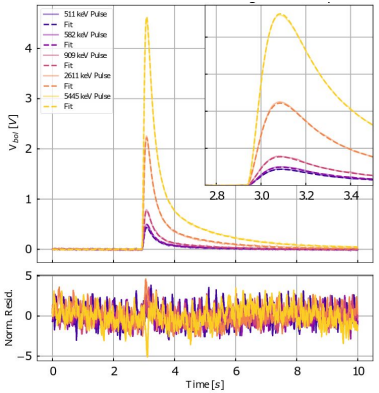
arXiv:2205.03132 Sub. to PRL



$T^{0\nu}_{1/2} > 3.6 \cdot 10^{24}$ yr (90% C.I.)

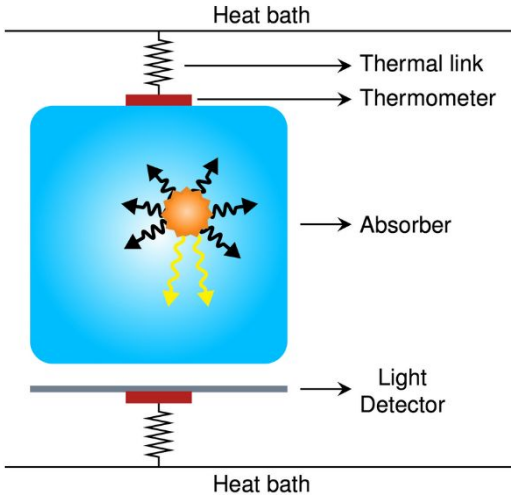
CUORE thermal response model

- Study of vibrational sources
- Low energy pulse reconstruction
- Background budget for CUPID



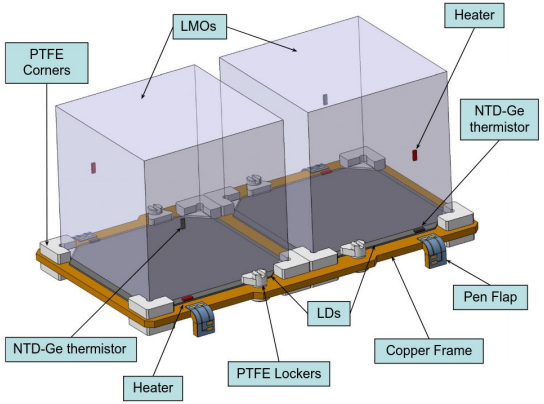
arXiv:2205.04549 Sub. to JINST

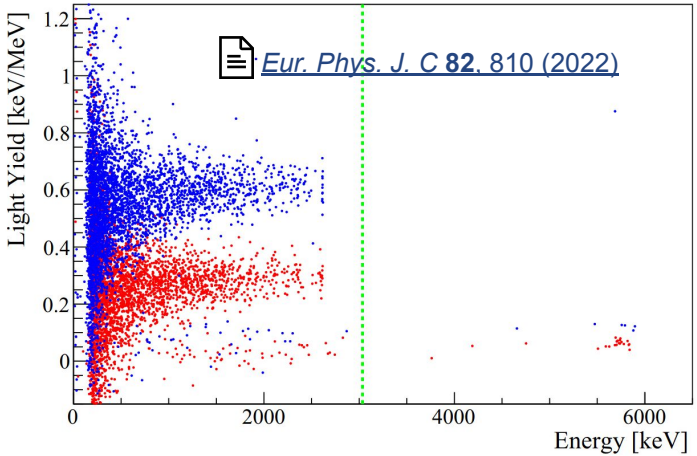
CUPID: Cuore Upgrade with Particle IDentification



HEAT + LIGHT DETECTION

- New $\beta\beta$ source: ^{100}Mo **($Q_{\beta\beta}$~3035 keV)**
- **Scintillating crystals** to exploit heat and light channels → **99% α/β discrimination**
- New detector frame design





CUPID SPECIFICATIONS

- High energy resolution (~5 keV)
- ~ 1600 Li_2MoO_4 crystals operated at ~ 10-20 mK
- Same cryogenic setup of CUORE

→ **Explore the entire inverted hierarchy region**