CUPID-0: cryogenic calorimeters with light and heat read-out for 0νββ searches

Nicola Casali for the CUPID-0 collaboration. Neutrino Oscillation Workshop, Rosa Marina, Ostuni, Italy, 9-16 September 2018
CUORE Experiment

- The new standard for the cryogenic calorimeters searching for neutrino-less double beta decay:

1. One ton of active detectors with hundreds of kg of $\beta\beta$ emitting isotope
2. Energy resolution $\sim 0.1\%$
3. BKG in the RoI $\sim 250$ counts/ton in 5 y data taking

![Graph showing counts per keV kg yr against energy.](image)

**MAIN CONTRIBUTION FROM $\alpha$ particle**

CUORE Preliminary
Exposure: 86.3 kg yr

P. Gorla’s Talk
CUPID: CUORE Upgrade with Particle IDentification

CUPID Interest Group arXiv:1504.03612v1

- Possibility to use the CUORE infrastructure for a future ton-scale 0νββ experiment with a sensitivity on $m_{\beta\beta} \sim 10$ meV:

1. One ton of emitting isotope (isotopic enrichment)

2. BKG in the RoI $\sim 1$ counts/ton (to be demonstrated)

The first certain step is the active $\alpha$ particle rejection
Particle Identification techniques

- Couple to each bolometer a light detector
- Exploit differences in the LY between $\alpha$ and $\beta/\gamma$ interactions
Particle Identification techniques

- Couple to each bolometer a light detector
- Exploit differences in the LY between α and β/γ interactions

*With TeO₂ crystal also ~100 eV signal too low for the sensitivity of the current light detectors*

Intense R&D activities exploiting TES, KID, NTD-Ge, + Neganov-Luke effect technologies.. but none is ready for such application

M. Willers et al., JINST 10 P03003 (2015)
Particle Identification techniques

- Couple to each bolometer a light detector
- Exploit differences in the LY between α and β/γ interactions

But for scintillating crystal like ZnSe or Li₂MoO₄ the LY is ~ keV/MeV

Furthermore the higher Q-Value ensures a lower β/γ background

**CUPID-0 -> Zn⁸²Se scintillating crystals**
CUPID-0: the first demonstrator

- $^{82}$Se 0νββ decay Q-Value: 2998 keV
- 26 ZnSe (24 95% enriched + 2 natural) -> 10.5 kg of
  ZnSe ($3.8 \times 10^{25}$ $^{82}$Se nuclei)
- 31 Ge slabs (Light Detector)
- Arranged in 5 towers
- Assembled in an underground radon free clean-room
  @ LNGS
- Hosted in the same CUORE-0 dilution refrigerator (Hall A)
- BKG goal in the RoI ~ $10^{-3}$ counts/(keV kg y)
CUPID-0: towers assembly
CUPID-0 time-line

Reached base temperature

Start cool-down

Commissioning

2017

2018

56Co calibration

First Result on the Neutrino-less Double Beta Decay of $^{82}$Se with CUPID-0,
https://doi.org/10.1103/PhysRevLett.120.232502

This talk: full statistics acquired until the end of April: 5.46 kg x y
CUPID-0 continues data-taking.
Energy calibration to $\beta/\gamma$ interactions

Example of energy spectrum in periodical calibration runs (all Channels)

$^{82}\text{Se}$

$\gamma$ lines from thoriated wires used for energy calibration
Detector response function

Response to monochromatic energy release ($^{208}$Tl $\gamma$ line)

The exposure-weighted harmonic mean FWHM energy resolution at the Q-value is (23.0±0.6) keV

Deviation from single gaussian commonly measured on bolometric experiments
Energy calibration to $\beta/\gamma$ interactions

Cross-check with $^{56}$Co calibration (Q-value ~ 4.57 MeV, T1/2 ~ 77 days)

Energy [keV]

Counts

$^{82}$Se
Cross-check result

Energy resolution in ROI = (22.5 ± 1.2) keV FWHM

Consistent with (23.0 ± 0.6) keV extracted from $^{232}$Th calibration, used for PRL analysis
Physics spectrum 5.46 kg×y
ZnSe

Cosmogenic activation

- Rejection of “non-particle-like” events through pulse shape on thermal pulses.
- Anti-coincidence between ZnSe crystals

$T_{1/2} = (9.2 \pm 0.7) \cdot 10^{19}$ yr

A. S. Barabash, https://doi.org/10.1016/j.nuclphysa.2015.01.001
Cosmogenic activation

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Physics spectrum 5.46 kg\,xy\,ZnSe

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RoI energy spectrum

- Rejection of “non-particle-like” events through pulse shape on thermal pulses.
- Anti-coincidence between ZnSe crystals

BKG = \((3.2 \pm 0.4) \times 10^{-2}\) counts/(keV kg yr)
The light signal shape depends on particle type.

Cut optimized in the RoI with a pure $\beta/\gamma$ sample $\rightarrow$ conservative at high energy.
RoI energy spectrum + α rejection

- Rejection of “non-particle-like” events through pulse shape on thermal pulses.
- Anti-coincidence between ZnSe crystals
  + α particles rejection

**BKG =** \((3.2 \pm 0.4) \times 10^{-2}\) counts/(keV kg yr)

**BKG =** \((1.3 \pm 0.2) \times 10^{-2}\) counts/(keV kg yr)
β/γ background from internal contaminations

We apply a 3 half-life time veto after all $^{212}$Bi $\alpha$ events

Rejection of the $^{208}$Tl induced background (internal crystal contamination)
We apply a 3 half-life time veto after all $^{212}$Bi $\alpha$ events

Rejection of the $^{208}$Tl induced background (internal crystal contamination)

Surface crystal contamination -> we veto after all $\alpha$ interactions with energy between 2 and 6.5 MeV
RoI energy spectrum + $\alpha$ rejection + Delayed coincidences veto

- Rejection of “non-particle-like” events through pulse shape on thermal pulses.
- Anti-coincidence between ZnSe crystals
  + $\alpha$ particles rejection
  + Delayed coincidence veto

All cuts efficiency 93±2%

7 events survive all cuts

UEML SIMULTANEOUS FIT OVER THE DATASETS

$$BKG = 3.2^{+1.3}_{-1.1} \times 10^{-3} \frac{counts}{(keV \cdot kg \cdot y)}$$
No evidence of $0\nu\beta\beta$ signal $\rightarrow$ Bayesian Lower Limit

$T_{1/2}^{0\nu} = 4.0 \times 10^{24}$ yr $\@ 90\%$ C.I

Previous value from Nemo $3.6 \times 10^{23}$ yr

Background budget

- Events triggered by many ZnSe to derive normalization for $\mu$ interactions
- Comparison simulation/data in ROI
- Muon’s interactions give important contribution to the ROI

$[1.8 \pm 0.2 \pm 0.5] \times 10^{-3} \text{counts/(keV} \cdot \text{kg} \cdot \text{y)}$

- Easily suppressed: more packed (CUORE-like) array or muon-veto
- Now increase statistics to investigate other background contributions
Conclusions

• The first next generation 0νββ demonstrator is smoothly in data taking from June 2017

• The complete α background rejection was demonstrated and allows to reach an unprecedented BKG level for a bolometric experiment

\[ BKG = 3.2^{+1.3}_{-1.1} \times 10^{-3} \text{counts/(keV} \cdot \text{kg} \cdot \text{y)} \]

• The analysis of the first data (5.46 kg y of ZnSe) allows to put the best limits on \(^{82}\text{Se 0νββ half-life}\)

\[ T_{1/2}^{0\nu} = 4.0 \times 10^{24} \text{ yr @ 90}\% \text{ C.I} \]

• We plan to reach an exposure of 10 kg y of ZnSe in order to obtain a reliable background model
Remove energy-dependency of the shape parameters for energy-independent cuts

Study the efficiency of signal and background as a function of the cut

Chose the cut value that optimizes the signal-to-background ratio
Choose events with $M>5$ (electromagnetic showers induced by muons interactions)

**almost pure $\beta/\gamma$ sample**

Study the distribution of the light shape parameter

Set the cut to have 100% efficiency on these events
Heat detector efficiency

Fit of the most prominent peak ($^{65}\text{Zn}$) validated on $^{40}\text{K}$ peak and M2 events

$\varepsilon_{\text{Zn}} = 0.938 \pm 0.025$
2νββ

- 2x10^5 events of 2νββ collected
- Now analysis of half-life

[CUPID-0 Preliminary graph]

CUPID-0 - Final spectrum
Se-82 2νββ (Reconstruction)
CUPID-0-2νββ

[Graph details]

CUPID-0 Preliminary