Backgrounds of the CUPID experiment

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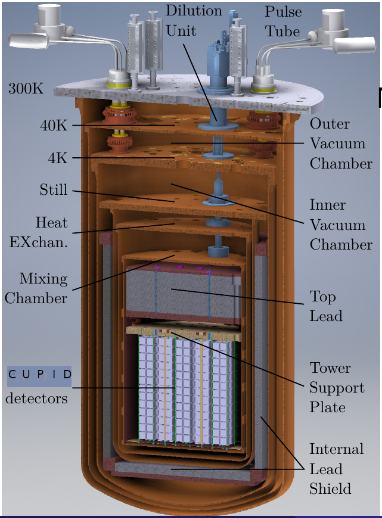
CUPID

CUORE Upgrade with Particle IDentification

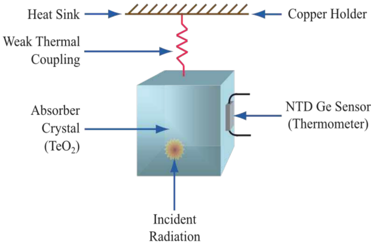


Next generation $0\nu\beta\beta$ bolometric ton-scale experiment in CUORE infrastructure

Discovery sensitivity:
$T_{1/2}(^{100}Mo) > 10^{27}$ y
$m_{\beta\beta} < 20$ meV

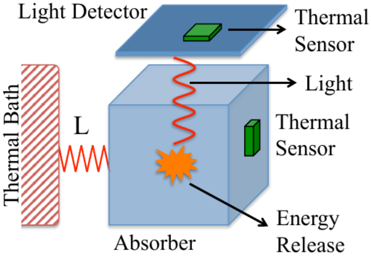
The detection concept

CUORE ^{130}Te
Bolometers
Heat



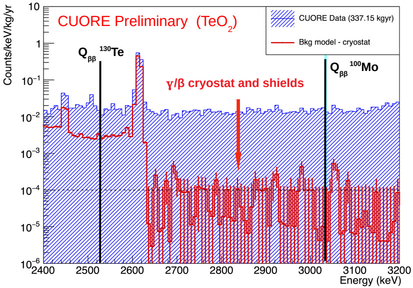
No γ/β - α identification

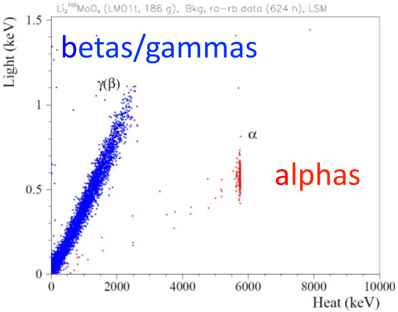
CUPID ^{100}Mo
Scintillating bolometers
Heat and Light



γ/β - α identification

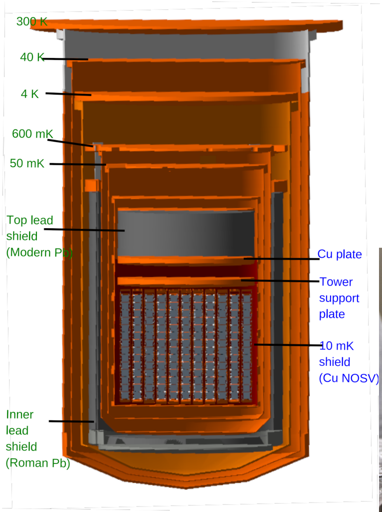
From CUORE to CUPID



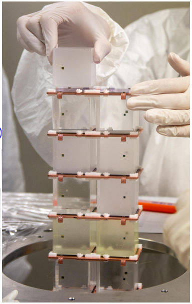


- $Q_{\beta\beta}$ (^{100} Mo) = 3034 keV, above γ background from natural radioactivity
- Heat and light detection allows α rejection

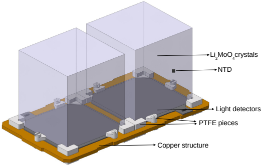
The CUPID detectors



- $Li_2{}^{100}MoO_4$ scintillating crystals,
- 1596 crystals, 45 x 45 x 45 mm^3
- Enrichment $> 95\% \rightarrow$ 240 kg ^{100}Mo
- 1710 Ge light detectors, with Neganov-Trofimov-Luke amplification
- **Objective:** Energy resolution 5 keV FWHM at 3034 keV



CUPID prototype tower



CUPID Background sources

1. Radioactivity from crystals
2. Radioactivity from holders
3. Radioactivity from cryostat shields and infrastructure
4. Muons
5. Neutrons
6. $2\nu\beta\beta$ pileup

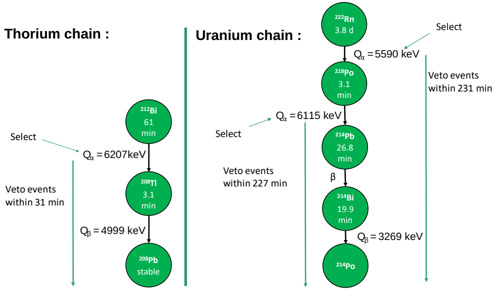
Simulations and Selection cuts

1- GEANT4 based Monte Carlo

2- Detector response: energy resolution, light yield, NTL on light and ionization

Selection cuts:

- Light yield selection: remove α particles
- Delayed coincidences cut: remove events from ^{214}Bi and ^{208}Tl decays
- Select events with energy deposit in only one crystal

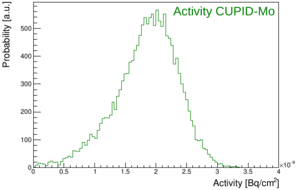


ROI: (3034 ± 15) keV

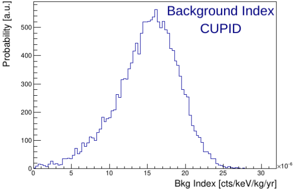
Method to obtain the background from radioactivity

- Activities from background models of previous experiments.

Probability density functions Cupid-Mo/CUORE → Background Index using the number of events in ROI



CUPID MC →

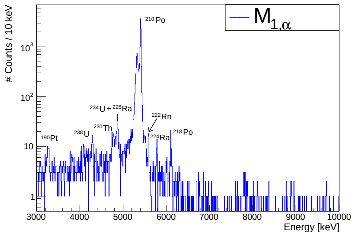


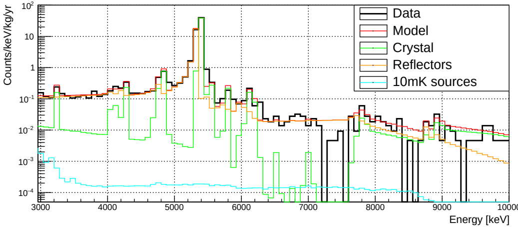
- To take into account correlations, we sample the full posterior distribution for each step in the Markov Chain.

$Li_2^{100}MoO_4$ crystals contamination

From CUPID-Mo (EPJC 83, 675 (2023))

^{226}**Ra to** ^{210}**Pb**	^{228}**Th to** ^{208}**Pb**
$<0.2\ \mu$Bq/kg	$0.4 \pm 0.2\ \mu$Bq/kg
2.0 ± 0.5 nBq/cm^2	<2.5 nBq/cm^2





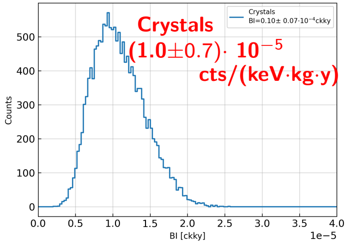
+ ^{210}Pb, ^{40}K, ^{90}Sr+^{90}Y ($Q_\beta < Q_{\beta\beta}$ (^{100} Mo))

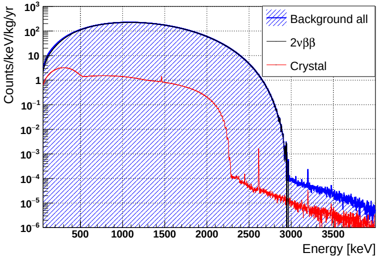
Background from $Li_2{}^{100}MoO_4$ crystals

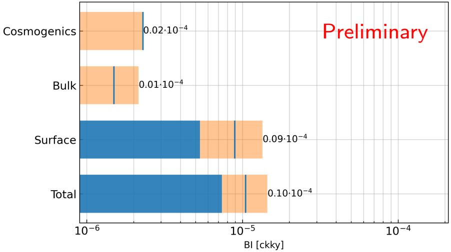
^{226}Ra/^{228}Th

- Bulk → $1.5 \pm 0.7 \cdot 10^{-6}$ cts/(keV·kg·y)
- Surface → $9.0 \pm 4 \cdot 10^{-6}$ cts/(keV·kg·y)

Cosmogenics: 90 days at sea level and 1 y cooling-down (ACTIVIA). ^{42}K, ^{82}Rb, ^{88}Y, ^{56}Co → $2.3 \cdot 10^{-6}$ cts/(keV·kg·y)



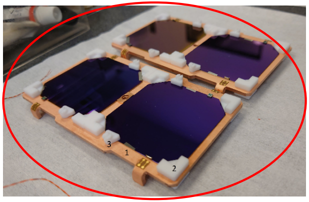




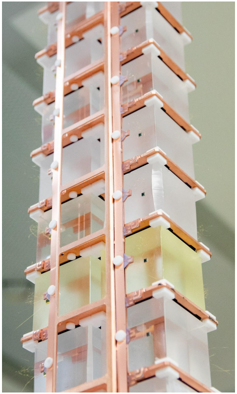
Close components

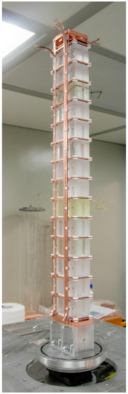
- Probability density functions for **activity** from CUORE background model. (arXiv:2405.17937 (2024), S. Ghislandi poster@LRT).

^{226}**Ra**	^{228}**Th**
<0.5 μBq/kg	<0.4 μBq/kg
8.4 ± 0.7 nBq/cm^2	11.5 ± 0.5 nBq/cm^2



NOSV copper + PTFE spacers + readout wires



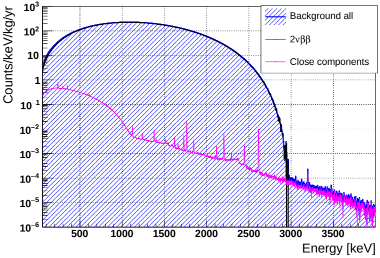


Background from close components

Mainly from **Ra/Th on surfaces**

- Bulk:
  $< 1.0 \cdot 10^{-6}$ cts/(keV·kg·y)
- Surface:
  $4.6 \pm 0.4 \cdot 10^{-5}$ cts/(keV·kg·y)

Total: $4.7 \pm 0.8 \cdot 10^{-5}$ cts/(keV·kg·y)

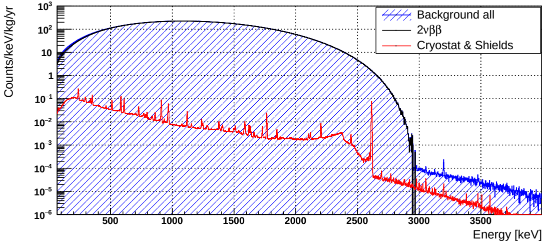


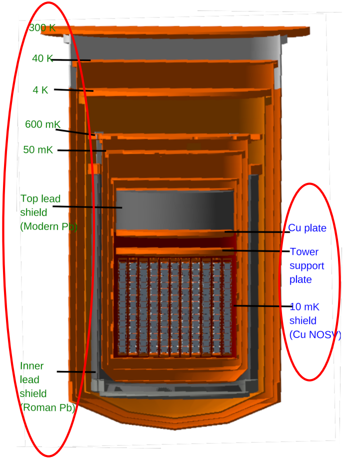
Can be reduced by improvements on surface contaminations by

- cleaner machining practices with laser cutting
- extreme controlled storage and construction conditions

Background from cryostat shields

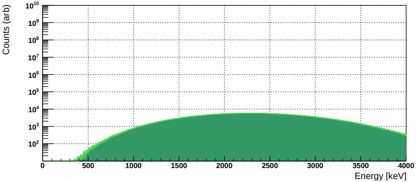
- Activities from CUORE background model. arXiv:2405.17937 (2024).
- Primary contribution: ^{226}Ra and ^{228}Th on surfaces of 10 mK shield.
- Other cryostat shields: Background from ^{226}Ra and ^{228}Th in bulk.
- **Total cryostat: $1.2 \pm 0.3 \cdot 10^{-5}$ cts/(keV·kg·y)**



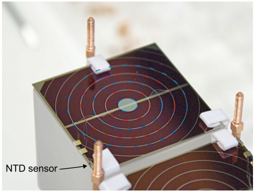


$2\nu\beta\beta$ pile-up

- Two $2\nu\beta\beta$ events close enough in time that are not resolved, but reconstructed as a single event $\rightarrow$ background at 3 MeV



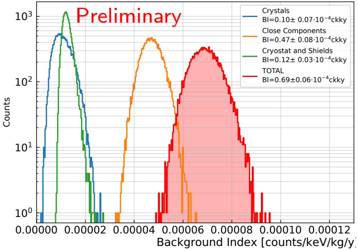
- Parameters that determine the ability to identify pile-up events: **rise time** and **signal-to-noise ratio**
- CUPID baseline: Light Detector instrumented with Neganov-Trofimov-Luke, NTL, amplification



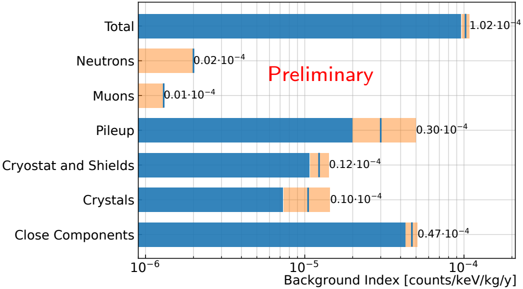
- R&D results of NTL performances combined with a phenomenological law used for background estimate $\rightarrow 3 \cdot 10^{-5}$ cts/(keV·kg·y)

Total predicted background

Predictions based on results from precursor experiments, CUORE and CUPID-Mo, and on improved new design.



Probability density functions of the backgrounds from radioactivity in CUPID materials

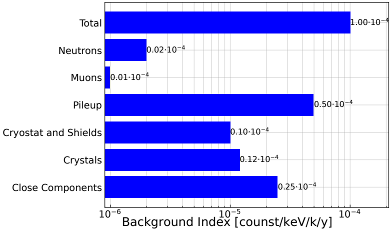


Vertical blue bar: mode of the pdf distribution.
Orange band: $\pm 1\sigma$ uncertainty

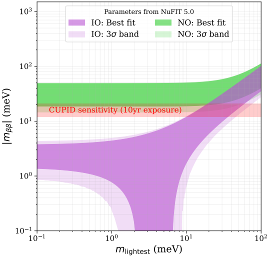
Room for background reduction on close components by improvements on surface contaminations

Summary

- CUPID background from simulations, based on precursor experiments and light detector performances: $1.0 \cdot 10^{-4}$ cts/(keV·kg·y). Reaches the background goal of the project →



- Allows exclusion sensitivity at 90% C.L with 10 years livetime:
  - $T_{1/2}^{0\nu} > 1.4 \cdot 10^{27}$yrs
  - $m_{\beta\beta} <\ 10 - 17$ meV



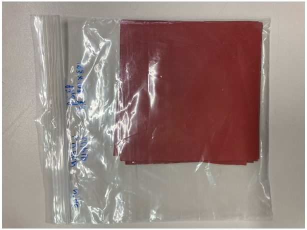
- Full prototype-tower tests at LNGS
- $Li_2{}^{100}MoO_4$ crystals pre-production on going

Extra slides

Some radioactivity measurements

PTFE (Plastics & Seals) : ICPMS

	^{238}U	^{232}Th
PTFE bulk [μBq/kg]	< 120	< 40
PTFE surface [nBq/cm^2]	< 26	< 8.7
(assigning all contamination on surface)		



CuPEN : HPGe (Measured with full copper layer)

	^{226}Ra	^{228}Th
bulk [μBq/kg]	< 1000	< 800
surface [nBq/cm^2]	< 11	< 9
(assigning all contamination on surface)		

- Sensitivity of planned HPGe copper measurement (slabs 1mm thick): ^{226}Ra$<$12 nBq/cm^2; ^{228}Th $<$20 nBq/cm^2

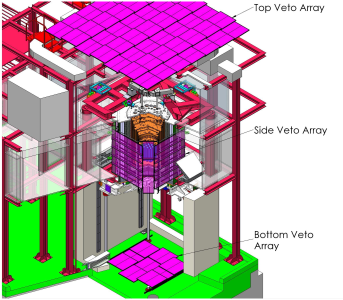
Background from muons and neutrons

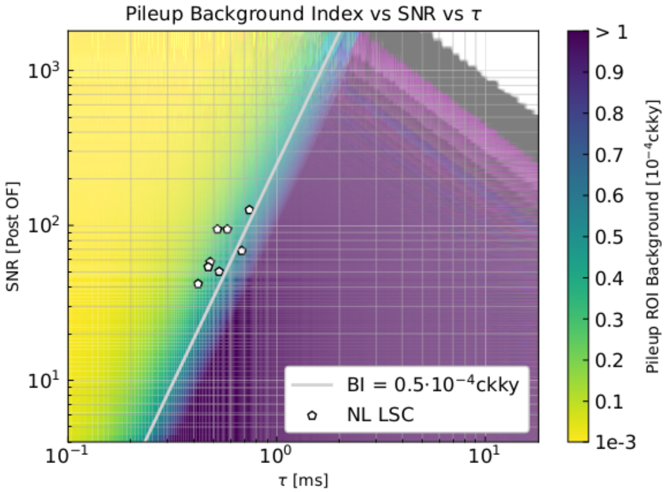
Muons

- Additional muon veto. Construction on-going
- From simulations, muon rejection efficiency $\sim$98 % $\rightarrow$ $1.3 \cdot 10^{-6}$ cts/(keV·kg·y)

Neutrons

- Neutron shielding to be expanded to mitigate (n,γ) reactions in Mo and Cu
- With additional 10 cm of polyethylene on the top and at sides, neutron backgrounds suppressed to $\sim 2 \cdot 10^{-6}$ cts/(keV·kg·y)





Pileup Background Index vs SNR vs τ
SNR [Post OF]
τ [ms]
BI = 0.5·10⁻⁴ckky
NL LSC
Pileup ROI Background [10⁻⁴ckky]
> 1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
1e-3