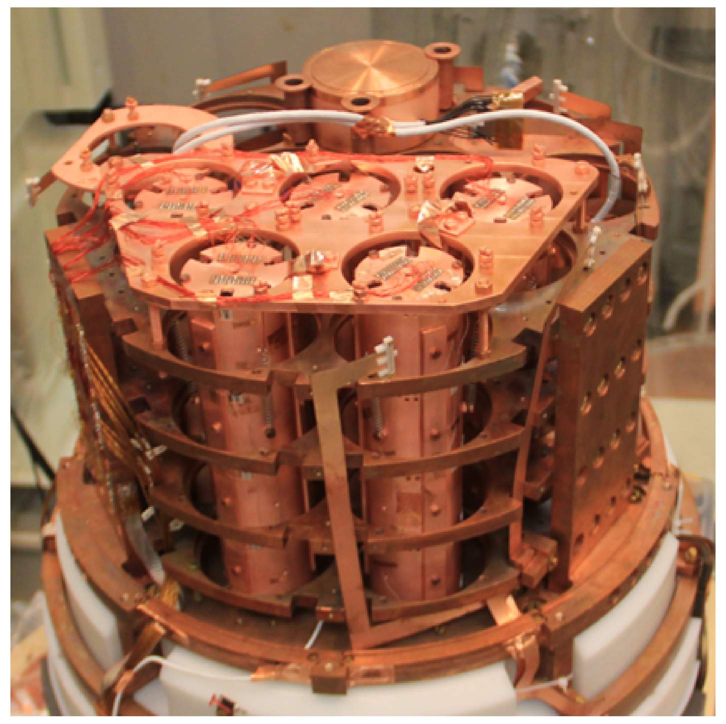
Background model of the CUPID-Mo $0\nu\beta\beta$ experiment

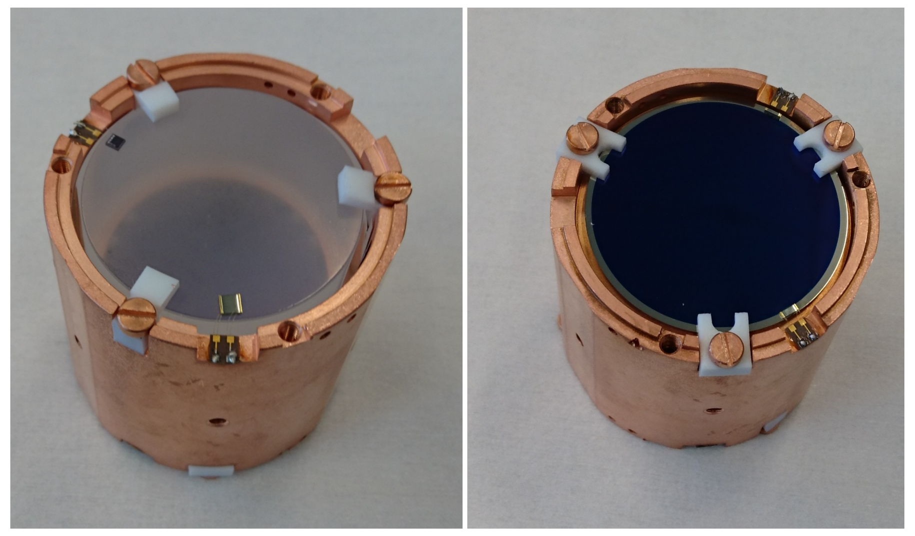
Pia Loaiza on behalf of the CUPID-Mo collaboration
IJCLab, CNRS, Université Paris-Saclay

The CUPID-Mo detector

- 20 ^{100}Mo enriched $Li_2{}^{100}MoO_4$ crystals, ~200 g each, operated in the Edelweiss-III set-up at the Laboratoire Souterrain de Modane
- Detection of heat and scintillation light signals allowing alpha discrimination



CUPID-Mo detectors installed in the Edelweiss-III cryostat.



- (Left) Top view of the crystal with NTD Ge sensor glued on the crystal surface
- (Right) Bottom view: Ge-wafer light detector, Ge-LD
- PTFE clamps hold the crystal and the light detectors
- Holders are made of radiopure NOSV copper

Radiopurity of materials

Element	Mass	Activity (mBq/kg)		
	(Mass at detect. plate)	^{226}Ra	^{228}Th	Others
Ge-LD[a]	27.4 g	^{238}U: < 0.019	^{232}Th:<6 10^{-3}	
NTD[a]	2 g	^{238}U: < 12	^{232}Th: <4.1	
PTFE clamps[a]	216 g	^{238}U: <0.022	^{232}Th: <6.1 10^{-3}	
Springs	8.1 g	(11 ± 3)	(21 ± 5)	^{228}Ra:(26 ± 9); ^{40}K:(3600 ± 400)
Kapton connect.	33.12	14 ± 7	67 ± 31	
Cu Kapton cables	510 g (106 g)	8 ± 6	15 ± 10	
NOMEX cables	4 g	21	19	
MillMax connect.	0.5 g	102 ± 59	(980 ± 196)	^{238}U:(12000 ± 200)
Brass screws	2 kg (400 g)	-	3.5 ± 0.9	^{210}Pb:(620 ± 254); ^{137}Cs:(2.6 ± 1.5)
Cu NOSV [b]	289 kg	<0.040	0.024 ±0.012	
Cu CUC2[b]	65 kg	0.025 ± 0.015	0.033 ± 0.016	
PE internal	151 kg (20 kg)	0.65 ± 0.08	0.30 ± 0.07	
Conn. 1K to 100K	430 g	2600 ± 400	450 ± 44	

[a]CUORE-0, Measurement of the two neutrino double-beta decay half-life of ^{130}Te with COURE-0 experiment, Alduino et al, EPJC 77 (2017) 13

[b] M. Laubensten, private comm.

Measurements of the detector components. All measurements made by Edelweiss-III and CUPID-Mo collaborations have been made by HPGe γ-spectroscopy. The MillMax connectors have also been measured by ICPMS.

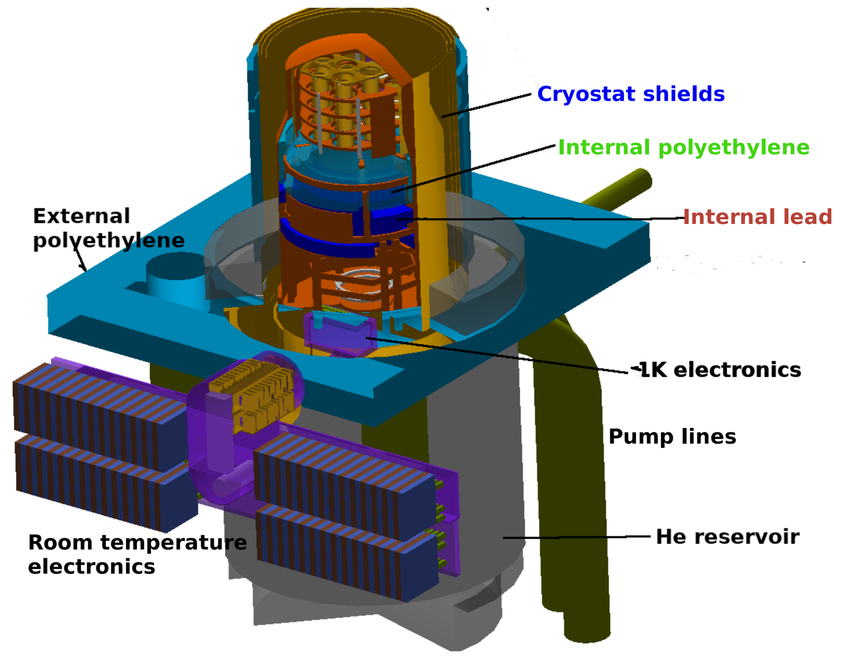
Data

- Physics data taking started in March 2019
- Total exposure for data release at Neutrino 2020, $0\nu\beta\beta$ analysis : 2.17 kg y
- Exposure in background model: 1.66 kg y

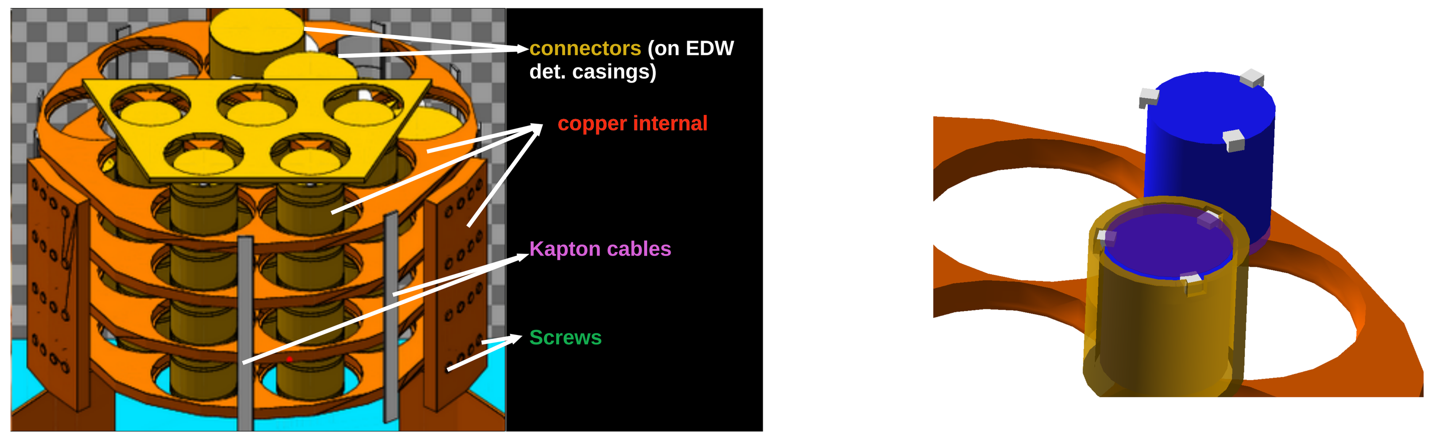
Monte Carlo simulations

The identified background sources are simulated with a GEANT4 based program, version 10.04.01.

- Radioactive decays are generated with DECAY0 [1] event generator. Each radionuclide in the decay chains of ^{232}Th and ^{238}U is simulated separately.
- Livermore physics list used for physics processes
- Production threshold for secondary γ/β particles down to keV energies



GEANT4 rendering of the CUPID-Mo detectors in the Edelweiss-III set-up



GEANT4 rendering of the CUPID-Mo detectors. Left: 10 mK set-up, Right: a CUPID-Mo individual module

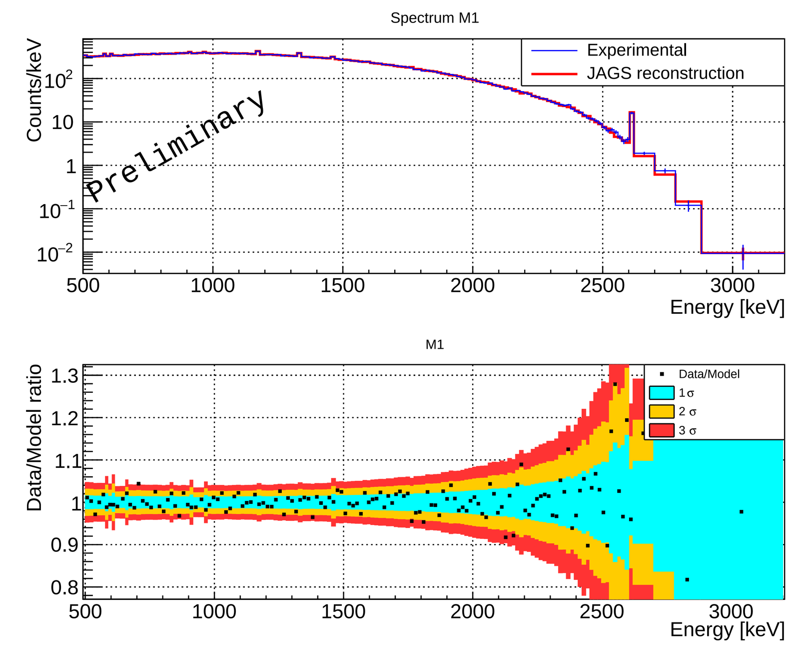
Background model

1. We use the radiopurity measurements, the crystal radiopurity obtained from α region data [2], and distinct gamma lines in the data itself to select the most probable background sources.
2. We use the sum of the energy spectra of γ/β events which triggered only one bolometer (multiplicity 1, M1).
3. The most intense γ lines are produced by the decay of ^{214}Pb and ^{214}Bi from the ^{238}U chain, ^{208}Tl from the ^{232}Th chain, and ^{40}K. Particularly intense γ lines from ^{60}Co are clearly visible, the ^{60}Co contamination being an accidental contamination in the set-up.
4. 36 background sources are included in the fit:
   - Crystal : $2\nu\beta\beta \rightarrow {}^{100}$Ru g.s and ^{100}Mo $\rightarrow {}^{100}$Ru 0^+_1, ^{210}Pb and ^{40}K
   - Elements in contact with crystals and copper 10 mK : Copper internal includes holders and supports (^{228}Th, ^{226}Ra, ^{60}Co). This contribution is used to represent also all parts facing directly the crystal: light-detectors, PTFE, NTDs, reflectors, bonding wires. Other elements: Reflectors ^{210}Pb, ^{60}Co in one light detector
   - Nearby: Springs (^{228}Th, ^{226}Ra, ^{40}K), Kapton cables (^{228}Th, ^{226}Ra, ^{60}Co), connectors (^{228}Th, ^{226}Ra), screws (^{228}Th, ^{226}Ra, ^{228}Ac)
   - Cryostat shields: NOSV copper (^{228}Th, ^{226}Ra), CuC2 copper (^{228}Th, ^{226}Ra, ^{228}Ac)
   - Shields: Internal PE (^{228}Th, ^{226}Ra, ^{228}Ac), Internal Pb (^{228}Th, ^{226}Ra, ^{228}Ac), Cryostat Outer Vacuum Chamber (^{228}Th, ^{226}Ra, ^{228}Ac, ^{60}Co)
5. The fit is performed with a Bayesian approach based on Just Another Gibbs Sampler, JAGS [3] and RooFit.

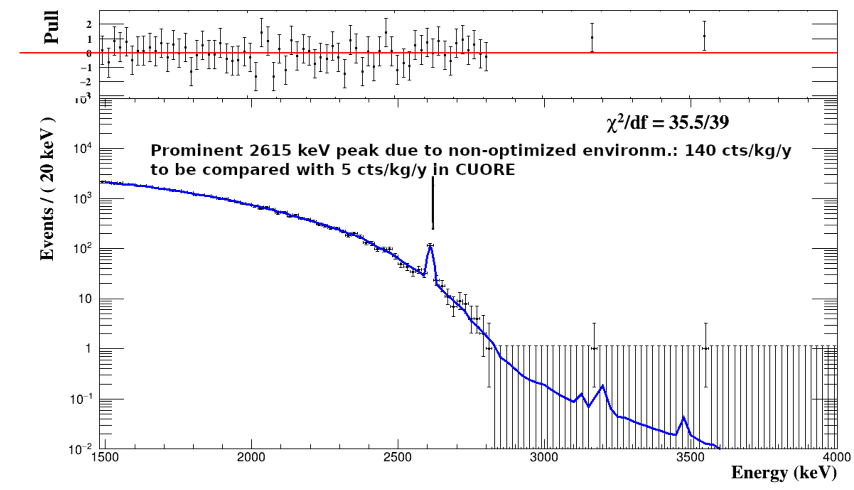
Results

The fit to the CUPID-Mo M1 data is inconsistent with the high state dominance, HSD, model of ^{100}Mo $2\nu\beta\beta$ decay and clearly favors the single state dominance, SSD mechanism.

- Surface contaminations are not included in this study
- JAGS fit : Data collected during 1.66 kg y. Fit range: [500 - 3200] keV . γ/β Multiplicity 1 events.



- The results are consistent with an independent fit based on RooFit using data collected during 0.64 kg y and fit range [1500 - 3600] keV. γ/β Multiplicity 1 events.



From the background model we can say that:

- Crystal impurities are not contributing to the background in the $0\nu\beta\beta$ ROI region
- ^{208}Tl decays in near and close elements are responsible for a substantial part of the observed background in the $0\nu\beta\beta$ ROI. Let us stress that the components of the Edelweiss-III set-up have not been selected to minimize the background in the 3 MeV region.
- Preliminary estimation of CUPID-Mo background rate in [2985 - 3085] keV: $(4 \pm 2)\ 10^{-3}$ counts/(keV kg y)
  $\rightarrow$ Remarkably low considering that the background environment of the cryostat have not been optimized for $0\nu\beta\beta$ searches.
- Consistent with an independent estimation based on the fit of M1 γ/β data with exponential+constant (exponential approximates ^{208}Tl tail and $2\nu\beta\beta$ above 2.7 MeV, constant approximates $2\nu\beta\beta$ pile-up and muons): 4 - 5 x 10^{-3} counts/(keV kg y)

References

1. Ponkratenko, V.I. Tretyak, Y. Zdesenko Phys. Atom. Nucl. 63 (2000) 1282.
2. Neutrino 2020 Poster #404, Denys Poda and E. Armengaud et al, Eur. Phys. J. C 80 (2020) 44.
3. M. Plummer, *JAGS version 3.3.0 user manual* (2012) and Alduino et al, Eur. Phys. J. C 77 (2017) 13.