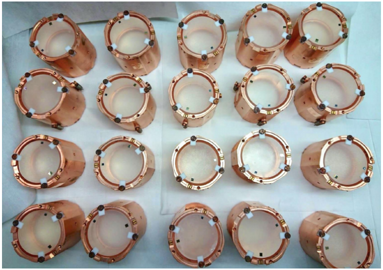
CUPID-Mo: Paving the way to next generation bolometric $2\beta0\nu$ experiments

Pia Loaiza on behalf of the Cupid-Mo collaboration

XIX Int. Workshop on Neutrino Telescopes, 24 February 2021



A demonstrator for next generation experiment CUPID (Cuore Upgrade with Particle IDentification)

A competitive $2\beta0\nu$ experiment by itself:

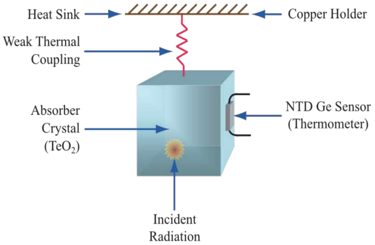
World's best limit $T_{1/2}$ in ^{100}Mo

CUPID-Mo concept

CUORE ^{130}Te

Bolometers

Heat

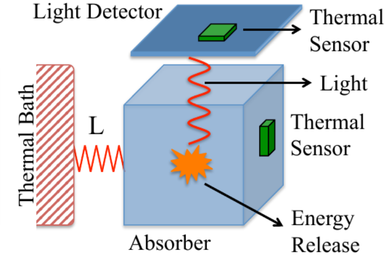


No γ/β - α identification

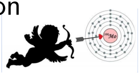
CUPID-Mo ^{100}Mo

Scintillating bolometers

Heat and Light

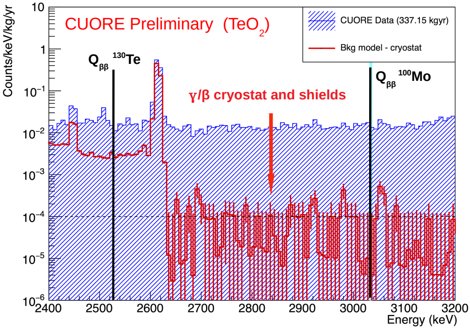


γ/β - α identification

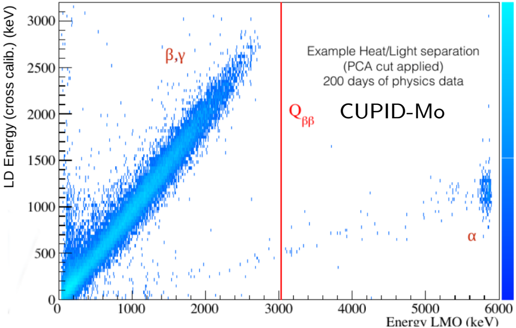


CUORE Background

The main background comes from α particles (from surface contaminations close to the crystals) $\rightarrow$ flat continuum



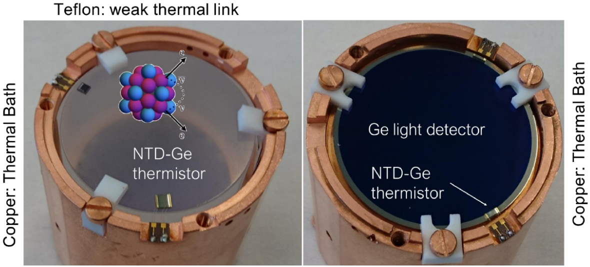
α rejection with scintillating bolometers



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

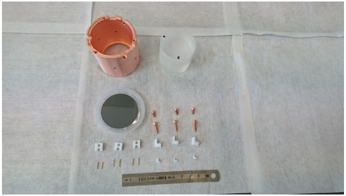
CUPID-Mo detectors

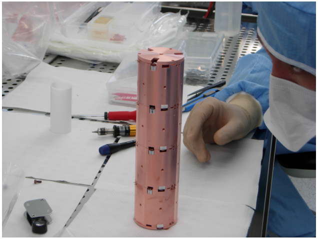
- $Li_2{}^{100}MoO_4$ scintillating crystals + Neutron Transmutation Doped (NTD) Ge sensors → heat
- Ge wafers + NTD → light detectors
- Crystals in copper holders, surrounded by a reflecting foil

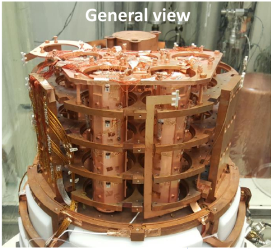


CUPID-Mo towers and set-up

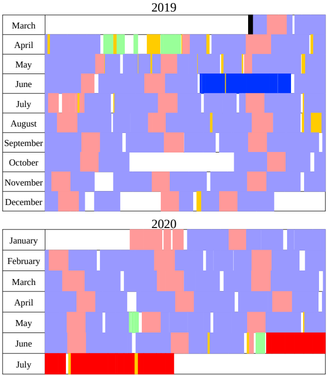
- Installed in the EDELWEISS-III cryogenic set-up at the Laboratoire Souterrain de Modane, France (4800 m.w.e)
- 20 $Li_2{}^{100}MoO_4$ crystals of 210 g, 97% enriched in ^{100}Mo → 2.26 kg of ^{100}Mo

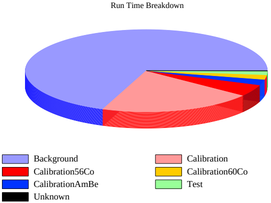






The data

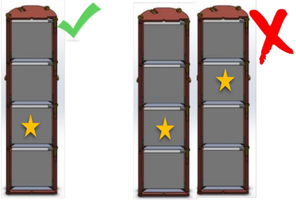


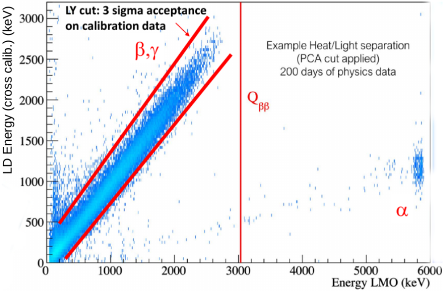


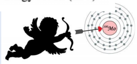
- Data taking
  March 2019 - July 2020 (427 days)
- Exposure for physics data:
  2.16 kg·y
- Significant amount of time dedicated to calibration

Data production

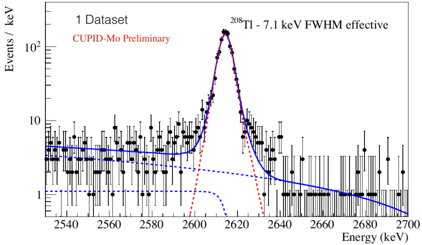
- Blinded data analysis in 3034 keV $\pm$ 50 keV
- Data analysis : Base cuts + Multiplicity cut M1-single crystal + Pulse shape analysis + Light yield cut + muon veto anticoincidence
- Total efficiency after cuts (exposure weighted average)
  $\epsilon = (90.5 \pm 0.4\ (\text{stat})\ ^{+0.9}_{-0.2}\ (\text{syst}))\%$







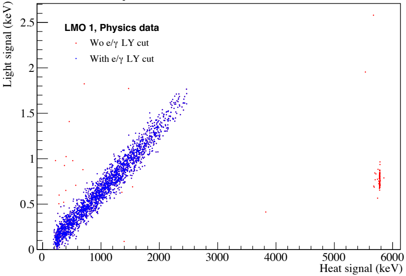
Energy resolution



- ΔE (FWHM) = 7 keV at 2615 keV (CUPID goal: $\sim$ 5 keV at $Q_{\beta\beta}$ = 3034 keV)
- Can be improved at lower temperature and no stabilization issue.
  LUMINEU@LSM:
  ΔE(FWHM)=5-6 keV at 3034 keV

  [Eur. Phys. J. C 77, 785 (2017)]

Alpha discrimination

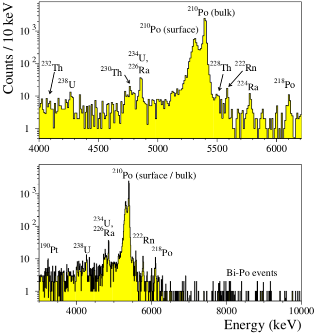


- > 99.9% alpha separation for all detectors

CUPID-Mo performances and prospects, EPJ-C 80:44 (2020)

Radiopurity of LMO crystals

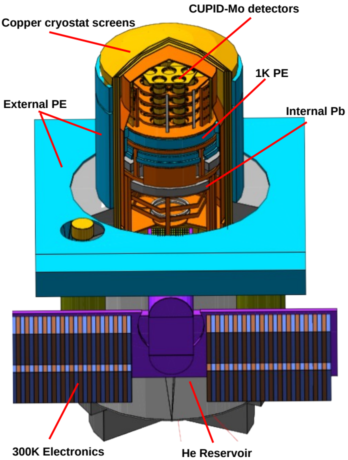
- The α region is populated by α decays occurring in the crystals and/or in components directly facing them. Radiopurity in the bulk of the crystals obtained from the counting rate in α peaks.



Chain	Nuclide	Bulk activity (μBq/kg)
^{232}Th	^{232}Th	0.22(9)
	^{228}Th	0.38(9)
	^{224}Ra	0.34(9)
	^{212}Bi	0.22(7)
^{238}U	^{238}U	0.35(10)
	^{234}U + ^{226}Ra	1.22(17)
	^{230}Th	0.48(12)
	^{222}Rn	0.47(10)
	^{218}Po	0.35(9)
	^{210}Po	95(6)
	^{190}Pt	0.19(8)

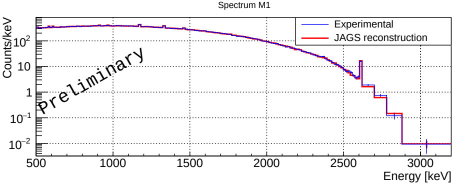
- ^{238}U/^{232}Th and daughters $\sim$ (0.2 - 1) μBq/kg $\rightarrow$
- Background contribution for CUPID: $2 \cdot 10^{-6}$ cts/(keV·kg·y) (CUPID Background goal: 10^{-4} cts/(keV·kg·y)

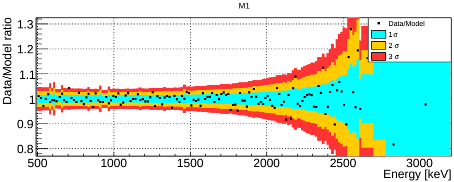
Background model



Geant4 rendering of CUPID-Mo

- Data for background model: 1.66 kg·y exposure
- RooFit and JAGS-based fits





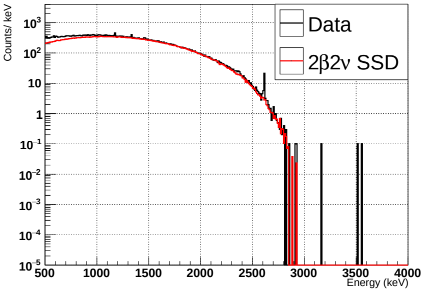
BI [2985 - 3085] keV:

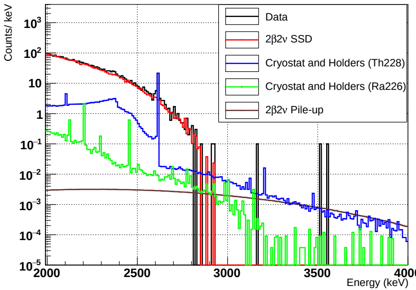
$(4 \pm 2)\ 10^{-3}$ counts/(keV kg y)

PRELIMINARY

Background model

WORK in progress



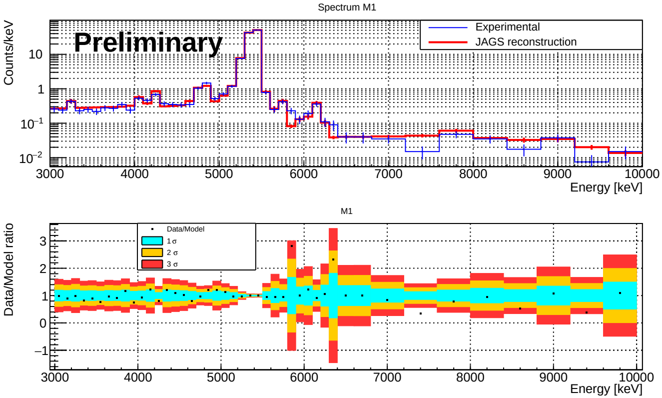


- Dominant $2\beta2\nu$ spectrum E $<$ 3 MeV
- Background in ROI : ^{208}Tl, ^{214}Bi in external sources, $2\beta2\nu$ pile-up

Background model: Surface contaminations

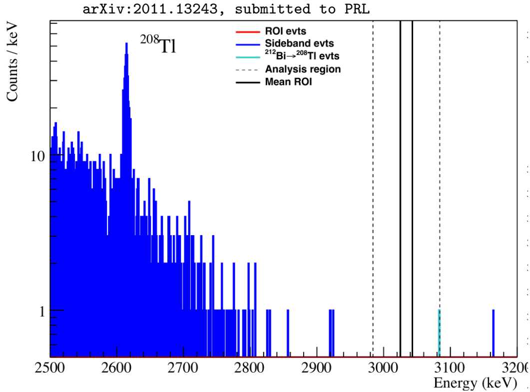
WORK in progress

Surface contaminations from fit of data in α region



- U/Th crystal surface contamination < 3 nBq/cm^2

New limit on $2\beta0\nu$ of ^{100}Mo



New world leading limit on $2\beta0\nu$ of ^{100}Mo:

$T_{1/2} > 1.5 \cdot 10^{24}$ y (90% CI)

$m_{\beta\beta} <$ (310 - 540) meV

($T_{1/2} > 1.1 \cdot 10^{24}$ y, NEMO-3, 2015

$T_{1/2} > 0.95 \cdot 10^{23}$ y, AMoRE, 2020)

Considering g_A=1.27 and Nuclear Matrix Elements :

- F. Šimkovic, V. Rodin, A. Faessler, P. Vogel, Phys. Rev. C 87, 045501 (2013)
- N.L.Vaquero, T.R. Rodríguez, J.L Egido, Phys. Rev. Lett. 111, 142501 (2013)
- J. Barea, J. Kotila, F. Iachello, Phys. Rev. C 91, 034304 (2015)
- J. Hyvärinen, J. Suhonen, Phys. Rev. C 91, 024613 (2015)
- L.S. Song, J. M. Yao, P. Ring, J. Meng, Phys. Rev. C 95, 024305 (2017)
- P. K Rath, P. K. et al, Phys. Rev. C 88, 064322 (2013)
- F. Šimkovic, A. Smetana, and P. Vogel, Phys. Rev. C 98, 064325 (2018)
- P.K Rath, R. Chandra, K. Chaturvedi and P. K. Raina, Front. in Phys., 64 (2019)

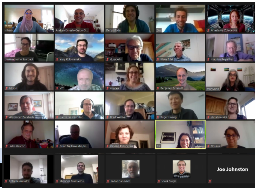
Conclusions

- CUPID-Mo: 20 $Li_2{}^{100}MoO_4$ detectors operated with simultaneous readout of heat and light $\rightarrow \alpha$ rejection
- Data taking March 2019 - July 2020
- Has succesfully demonstrated the maturity of the technology for the next generation experiment CUPID
- World leading limit on $2\beta 0\nu$ of ^{100}Mo, with 1.21 kg·y of ^{100}Mo: $T_{1/2} > 1.5 \cdot 10^{24}$ y (90% CI)
- 4th most stringent limit $m_{\beta\beta} <$ (310 - 540) meV
- Data taking is over (total exposure for physics data=2.8 kg·y). On-going studies on $2\beta 2\nu$ of ^{100}Mo, $2\beta 2\nu$ excited states, potential for dark matter search

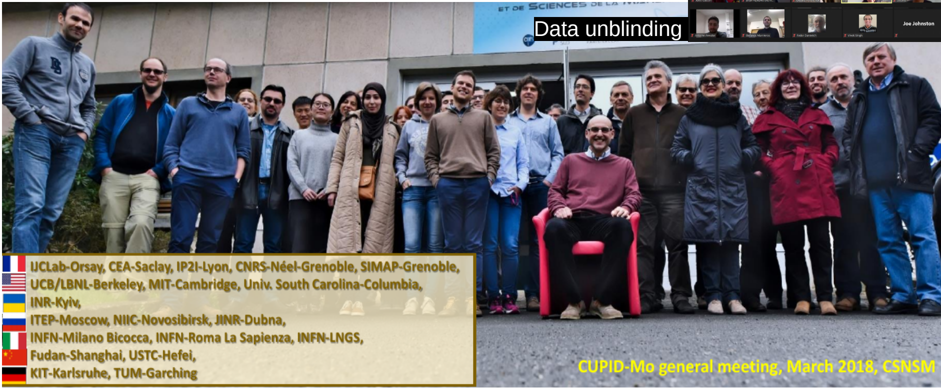
At XIX Int. Workshop on Neutrino Telescopes

- G. Fantini, ‘Latest resulst from the CUORE experiment’ (23/02)
- E. Celi, ’Double beta decay results from the CUPID-0 experiment’ (23/02)
- A. Campani, ’The search for OνEC$\beta+$ of ^{120}Te with CUORE’ (23/02)
- A. Ressa, ’Scintillating $Li_2{}^{100}MoO_4$ bolometers for $2\beta0\nu$ search’ (23/02)
- S. Dell’Oro, ’A novel technique for the study of pile-up events in cryogenic bolometers’ (23/02)
- A. Giuliani, ’ CUPID: a next generation bolometric neutrinoless double beta decay experiment’ (24/02)

The CUPID-Mo collaboration



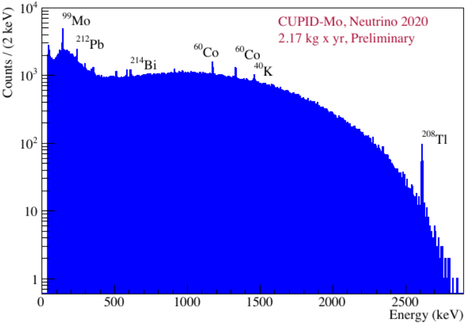
Data unblinding



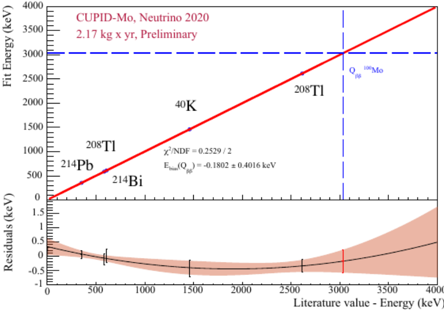
Back up slides

CUPID-Mo - Energy scale

- Energy scale is set with pol2 in calibration data
- Check consistency in time in calibration data

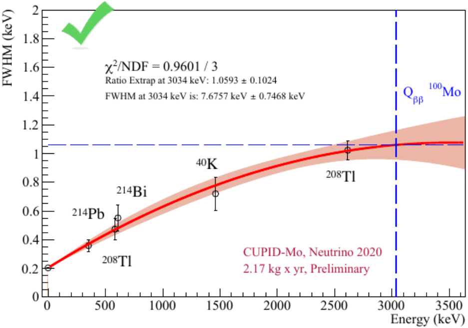


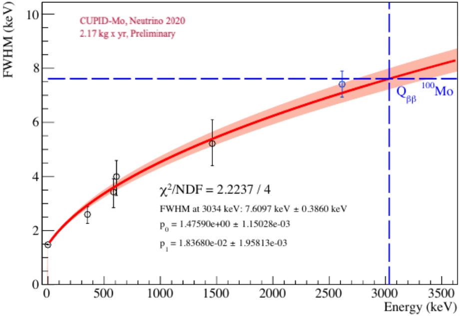
- Estimate possible energy bias based on physics data, E_B = (-0.2 ± 0.4) keV



CUPID-Mo ROI resolution scaling

- Obtain a global scaling factor Calibration @2615 keV <-> Physics @3034 keV
- Test several hypothesis:
  - linear, sqrt, pol2 fit -> linear is ruled out by calibration data -> take remaining more conservative estimate (pol2)



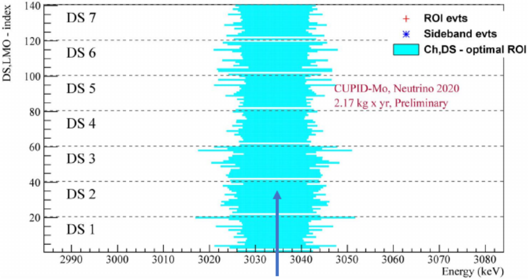


Definition of the ROI

Before unblinding, we have defined the ROI for each data set and for each channel

Optimization of the signal ROI based on Poisson counting analysis in Signal, Background likelihood space, assuming:

- An expected final CUPID-Mo exposure of 2.8 kg × y
- A background index b = 5 × 10^{-3} counts/(keV kg y)



Large central ROI ~ 18 keV average width

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