CUPID-Mo: a world leading limit on neutrinoless double beta decay of ^{100}Mo

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LOMONOSOV CONFERENCE

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Neutrinoless double beta decay

2νββ

- 2n -> 2p + 2e- + $2\bar{\nu}_e$
- even-even nucleus
- Observed for 12 isotopes

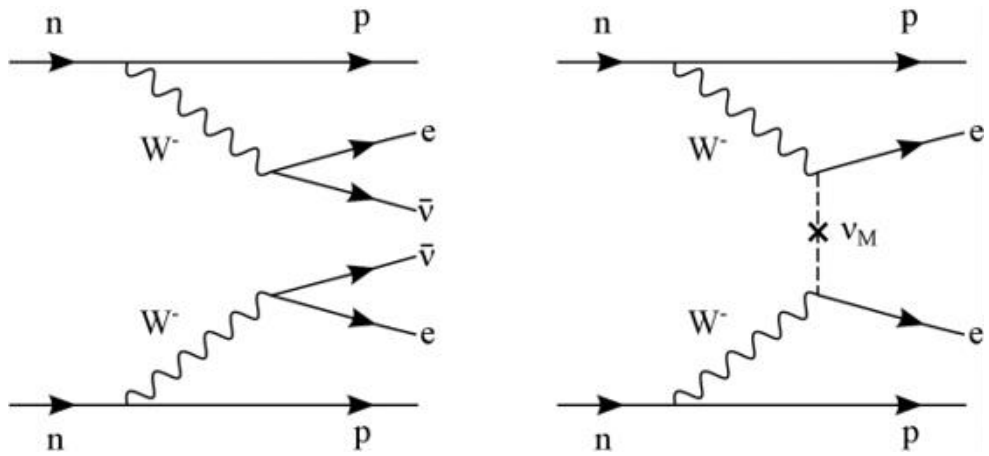
0νββ

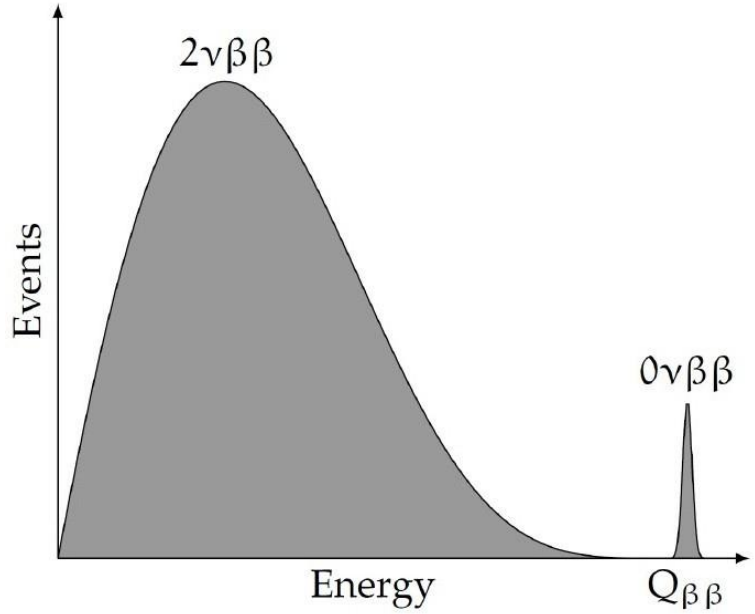
- Hypothetical decay
- 2n -> 2p + $2e^-$
- Peak in the sum of electrons energy spectrum
- **Lepton number violation**
- Majorana neutrino $\nu = \bar{\nu}$

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

For light Majorana neutrino exchange

- Majorana neutrino needed in leptogenesis



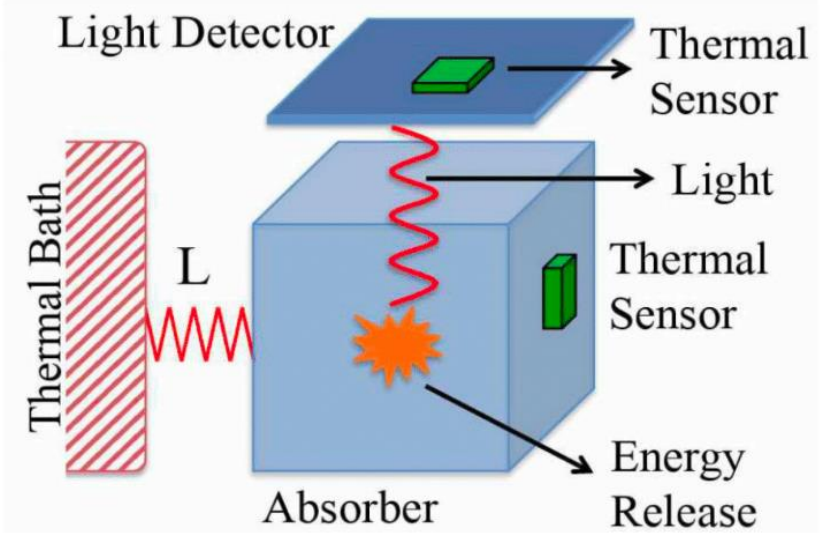


Scintillating bolometers

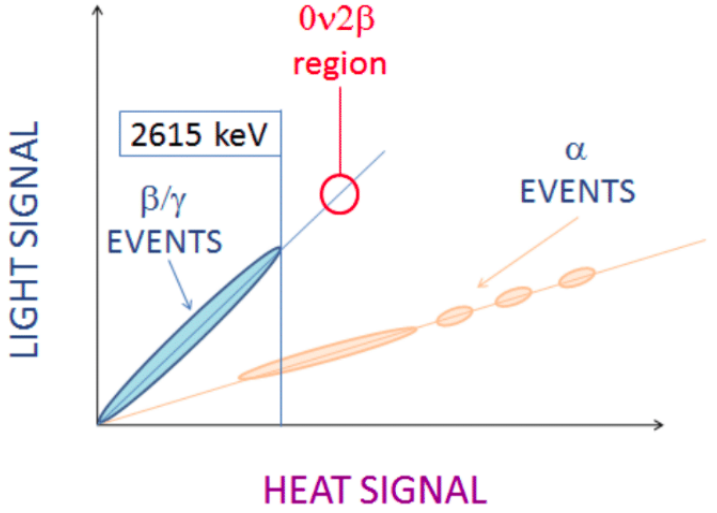
- Crystals cool down to ~ 10-20 mK
- $\Delta T = E/C$
- Detector = source
- High detection efficiency
- Excellent energy resolution

- Simultaneous read out – light and heat
- Ge wafer operated as bolometer to measure scintillation light
- Discrimination between β/γ and α particles

Scintillating Bolometer



Particle Identification



CUPID-Mo set-up

Demonstrator for CUPID

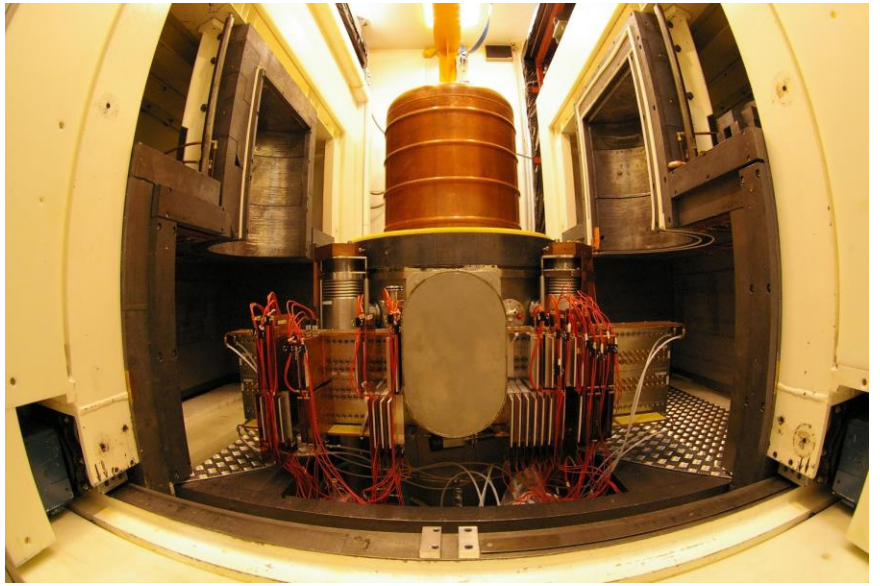
Installed at Laboratoire Souterrain de Modane (LSM) (4800 m.w.e)

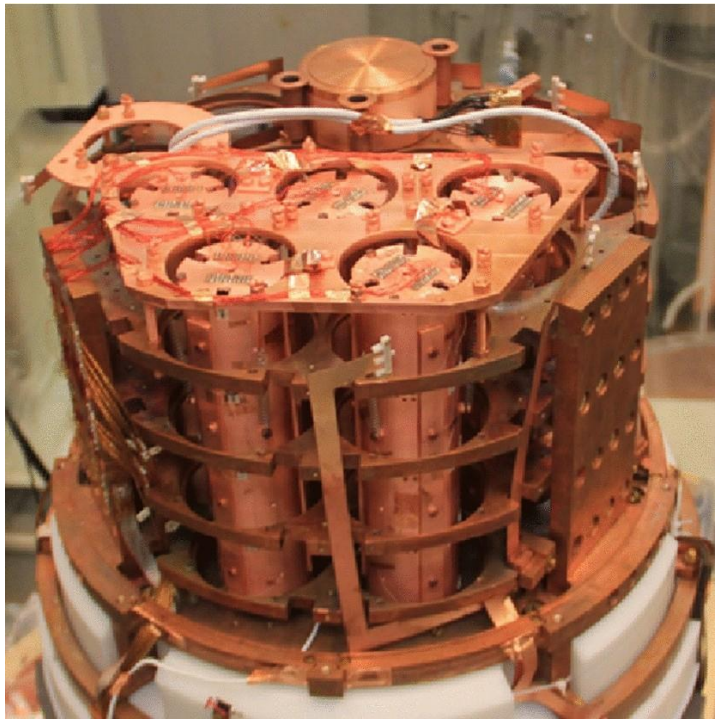
In EDELWEISS cryostat

^{100}Mo, $Q_{\beta\beta}$ = 3034 keV

20 $Li_2{}^{100}MoO_4$ scintillating bolometers

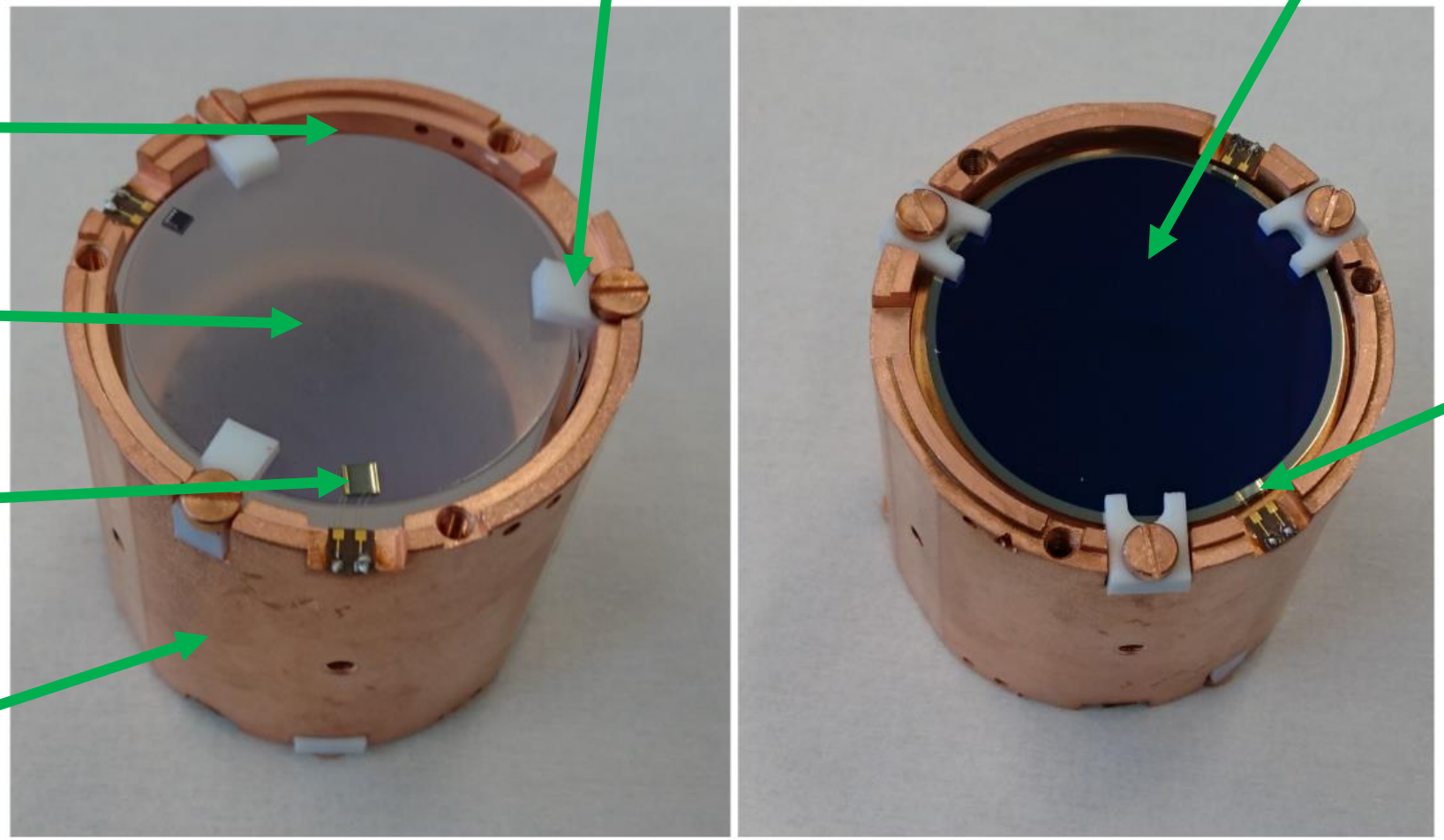
- ~ 0.2 kg $Li_2{}^{100}MoO_4$ cylindrical crystals
  - Ø 43.8 mm × 45 mm
- ^{100}Mo enrichment ~ 97 %
- 2.26 kg of ^{100}Mo
- 5 towers of 4 crystals
- Ge wafers as Light Detector
  - Ø 44.5 mm × 170 µm
  - SiO coating on both sides



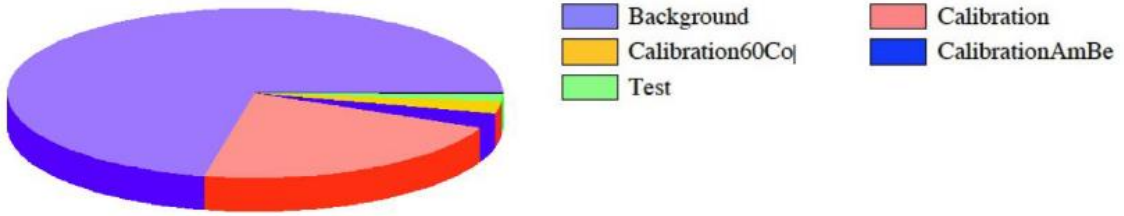


Armengaud, E., et al. "The CUPID-Mo experiment for neutrinoless double-beta decay: performance and prospects." The European Physical Journal C 80.1 (2020): 1-15.

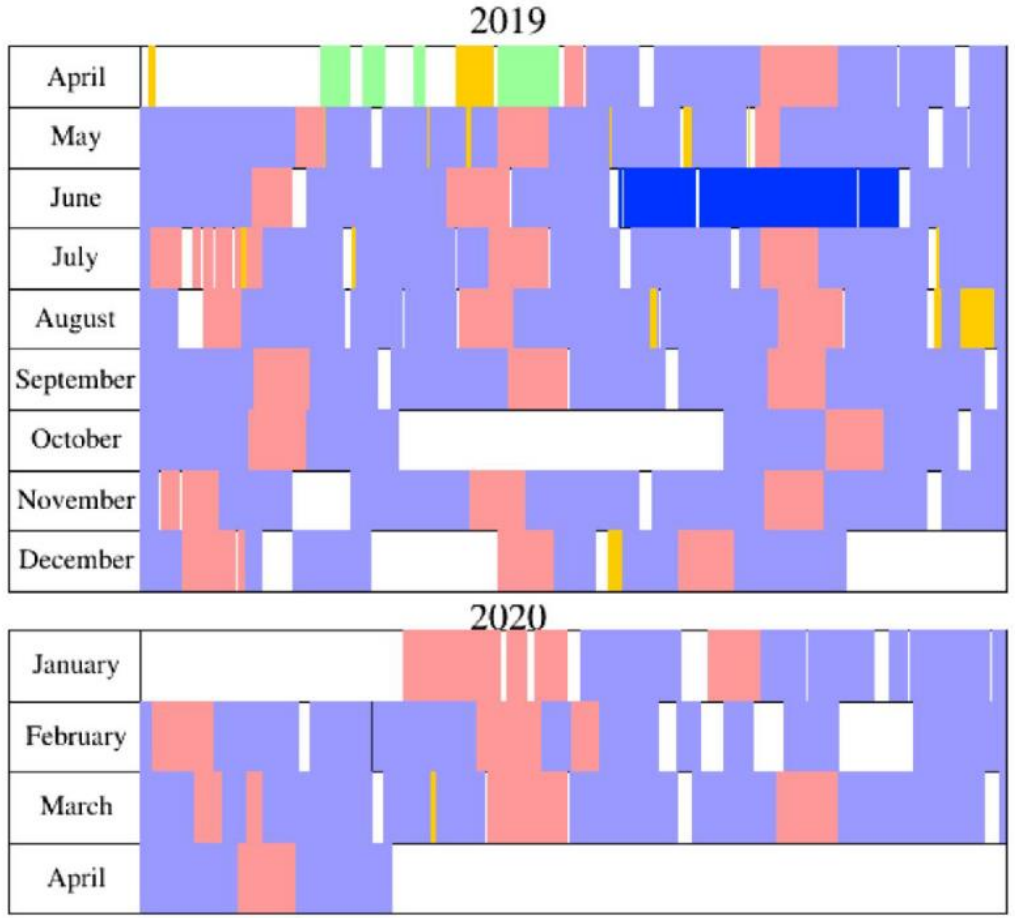
CUPID-Mo Detectors



CUPID-Mo Data Release @ Neutrino 2020



- Data acquired between March 2019 and June 2020
- The detectors were operated at 20-22 mK
- Data release @ Neutrino2020 and published in *PRL.126.181802 :*
- 2.16 kg.year exposure
  - 240 days of physic data
  - 73 days of calibration data
  - 6 days of ^{60}Co data
  - 10 days of AmBe data

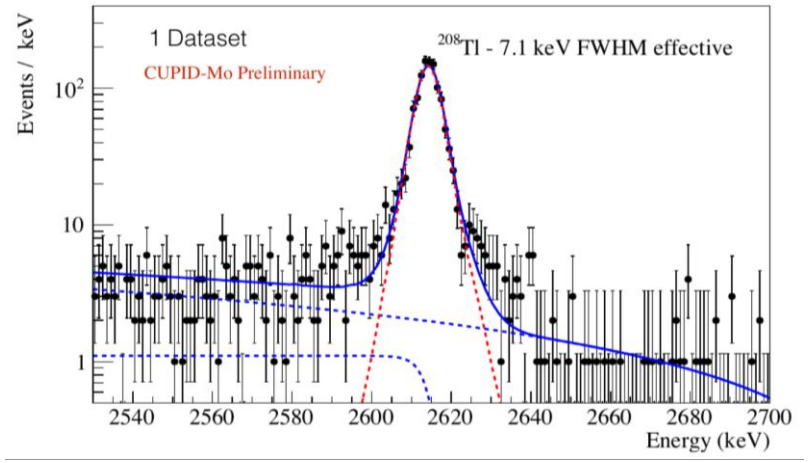


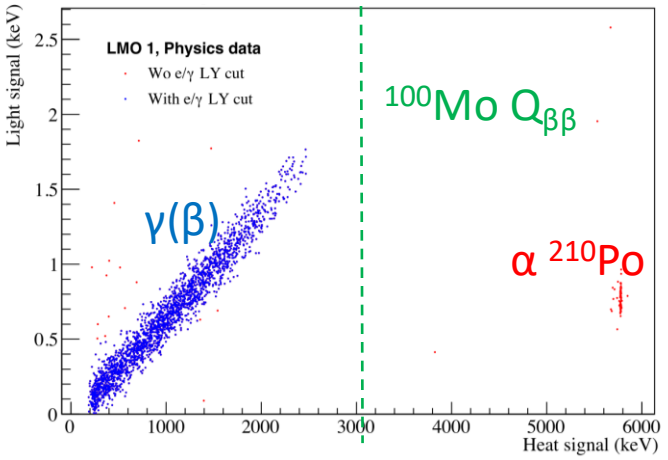
Release @ TAUP 2021

- Exposure 2.71 kg.year
- New analysis

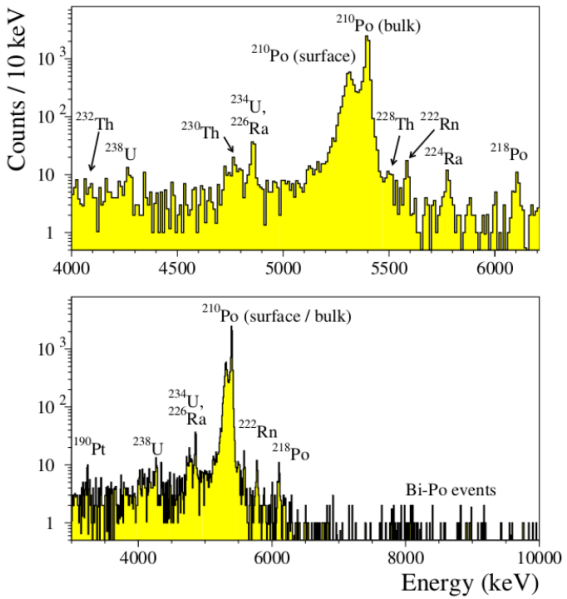
CUPID-Mo Performances

- Energy Resolution
  - ΔE(FWHM) @ $Q_{\beta\beta}$ = 7.6 ± 0.7 (stat.) ± 0.2 (syst.) keV
- Light Yield
  - β/γ Light Yield per LD ~ 0.7 keV/MeV
  - > 99.9 % γ(β)/α separation
- Crystals radiopurity
  - Bulk radiopurity obtained from the counting rate in α peaks
  - $^{238}U/^{232}Th$ and daughters ~ (0.2 - 0.5) μBq/kg





α events



Chain	Nuclide	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)

CUPID-Mo Data production

- Blinded data analysis in 3034 keV ± 50 keV

Trigger

(Optimal trigger)

CUORE Phys. Rev. Lett. 124.122501

Amplitude from optimal filter (maximises SNR)

Thermal gain stabilization from Th calibration data

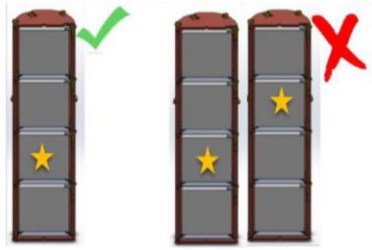
Calibration with Th/U peaks (2nd-order polynomial)

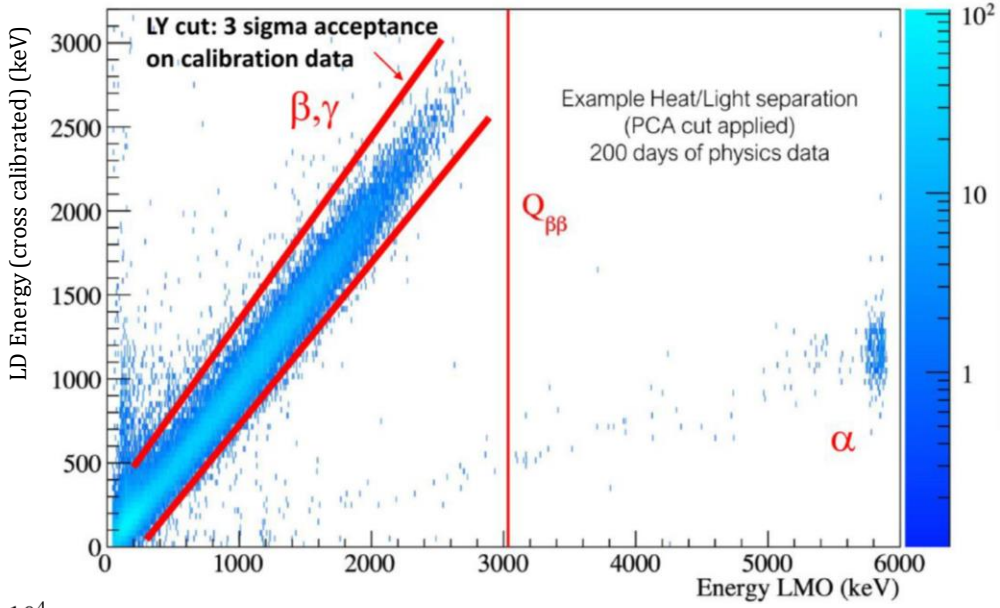
Cuts

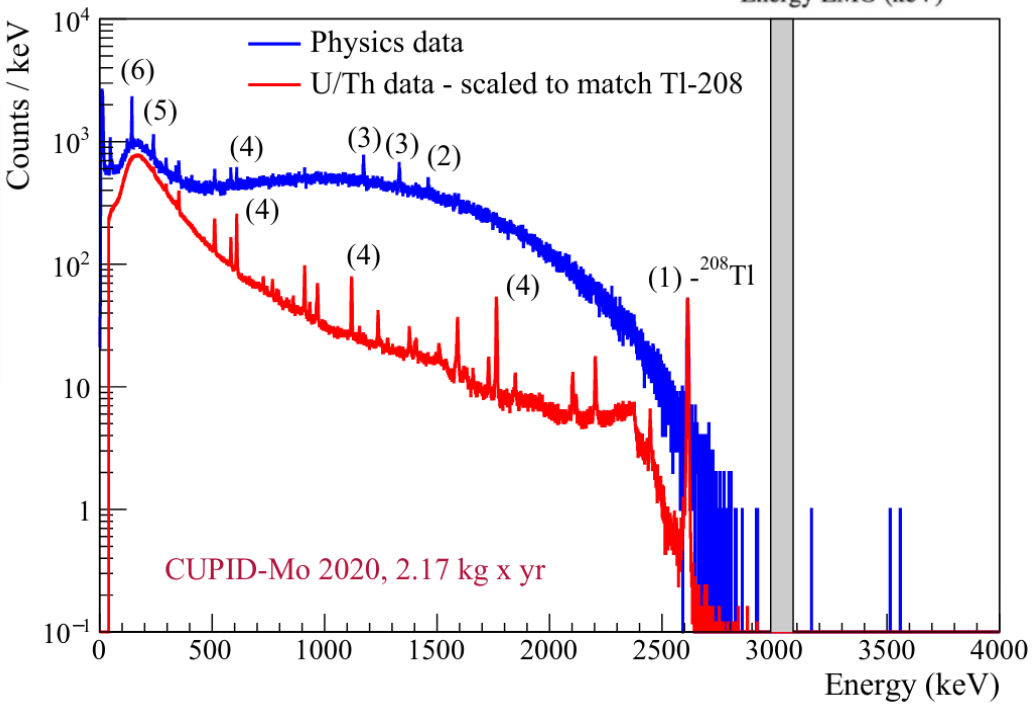
- Baseline
- Multiplicity
- Light Yield
- Pulse Shape
- Muon Veto

Total efficiency after cuts (exposure weighted average)

$$\epsilon = \left(90 \pm 0.4\,(\text{stat})\,^{+\,0.9}_{-\,0.2}\,(\text{syst})\right)\%$$

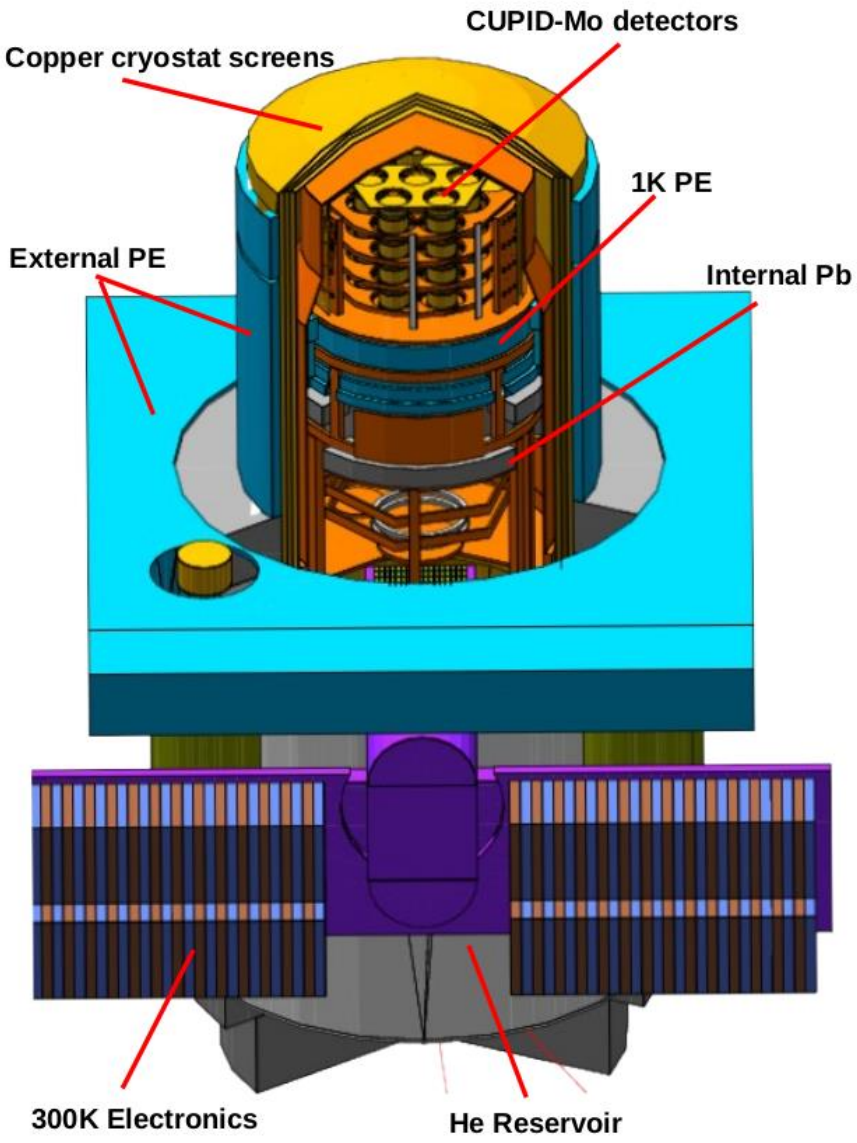






CUPID-Mo Simulations

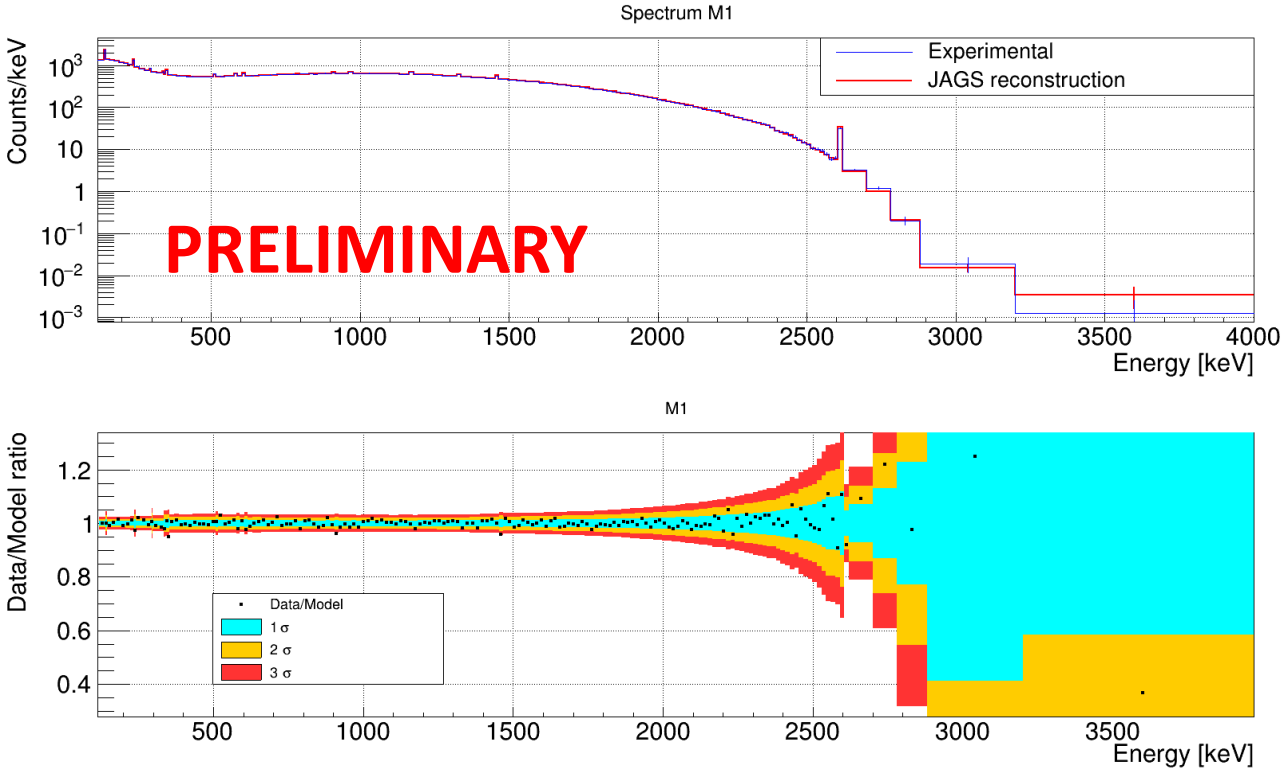
- Geant 4 based program
- **Decays of the ^{238}U and ^{232}Th chain, or other nuclei generated in all the different components**
- We can consider 4 main regions
  - Crystal bulk and surface
  - Reflecting foils bulk and surface
  - Close sources (10 mK)
  - Cryostat and Shields
- Detector effects convolved directly into MC spectra
  - Energy resolution and threshold
  - Cut Efficiencies
  - Anti-coincidences

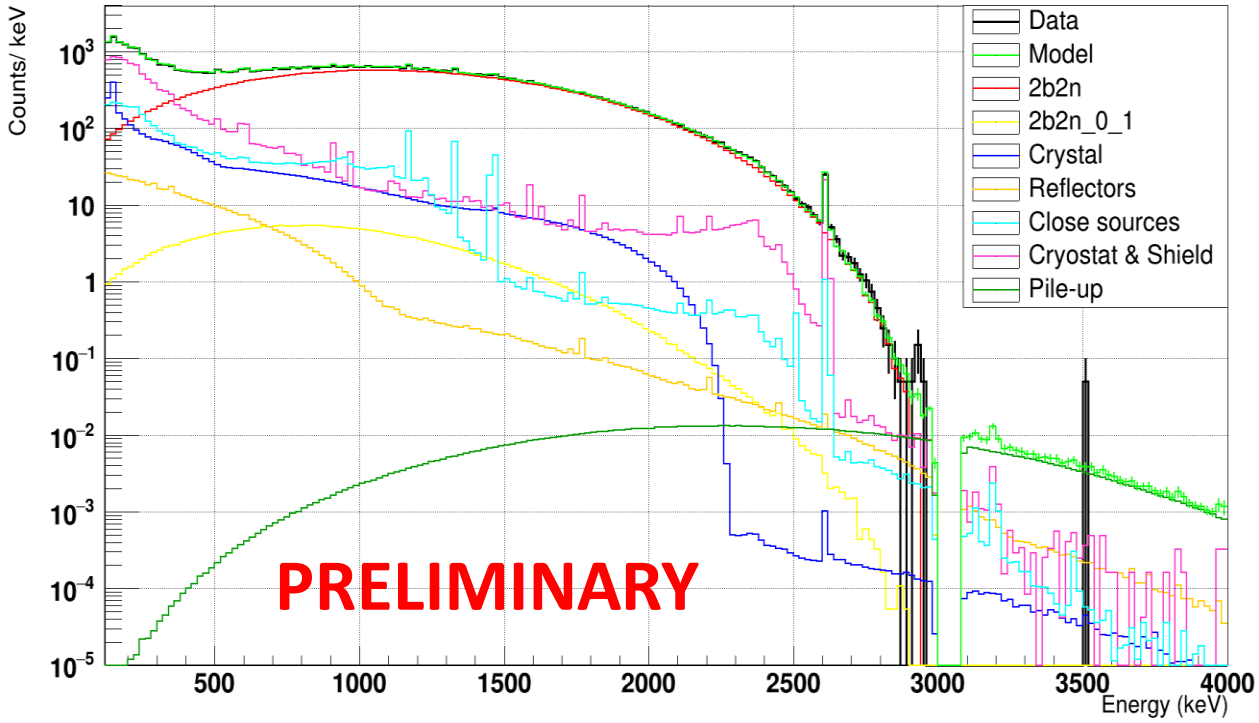


Geant4 Rendering of the Edelweiss set up with the CUPID-Mo detectors as implemented in the simulations

CUPID-Mo Background model

- Global fit to the data with MC simulations
  - Bayesian approach using Just Another Gibbs Sampler
  - JAGS-based tool of analysis is developed since 2014 for background model studies in the framework of the CUORE collaboration[1]
- Simultaneous M1, M1alpha, M2sum
- Data
  - Exposure 2.71 kg.y **blinded** (TAUP 2021 release)

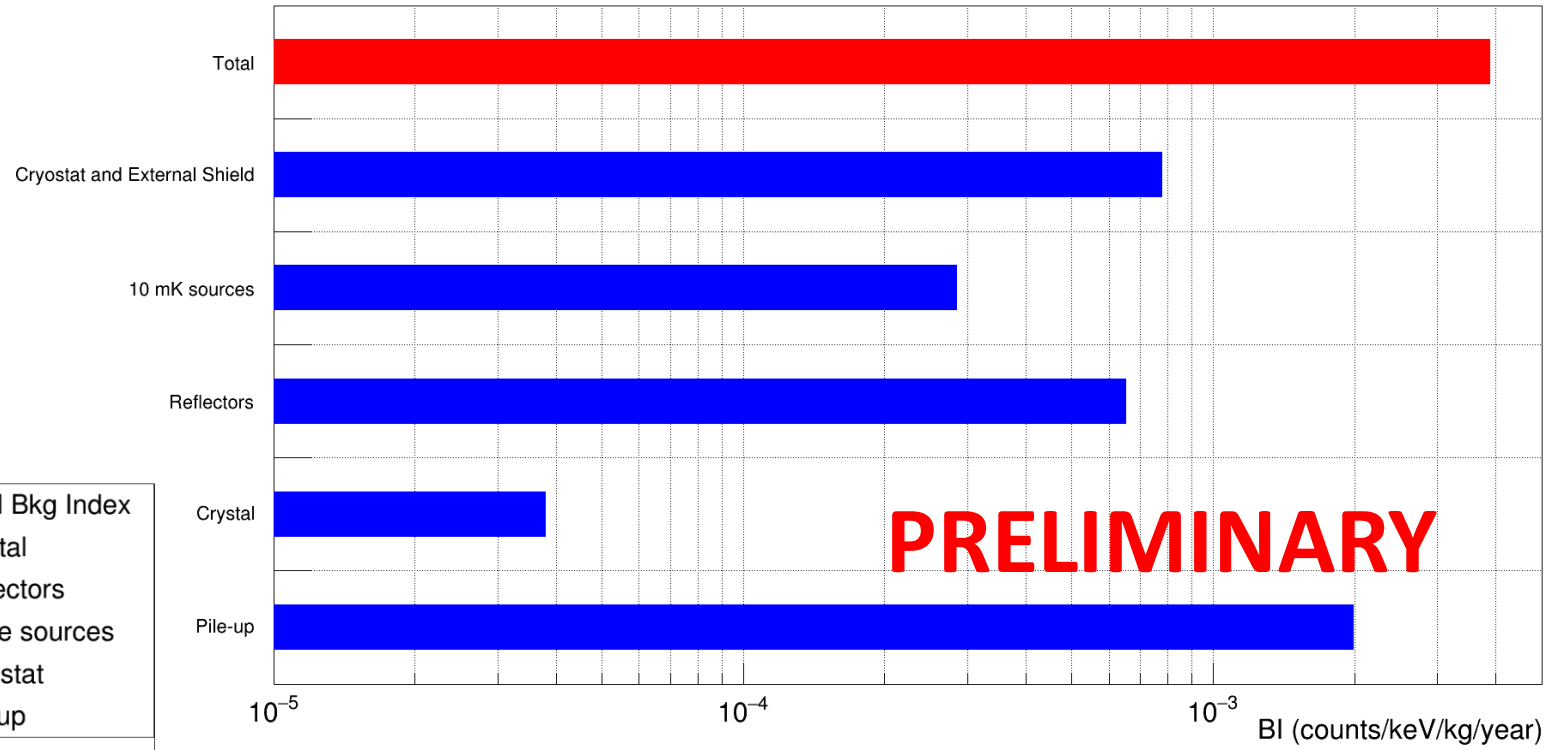


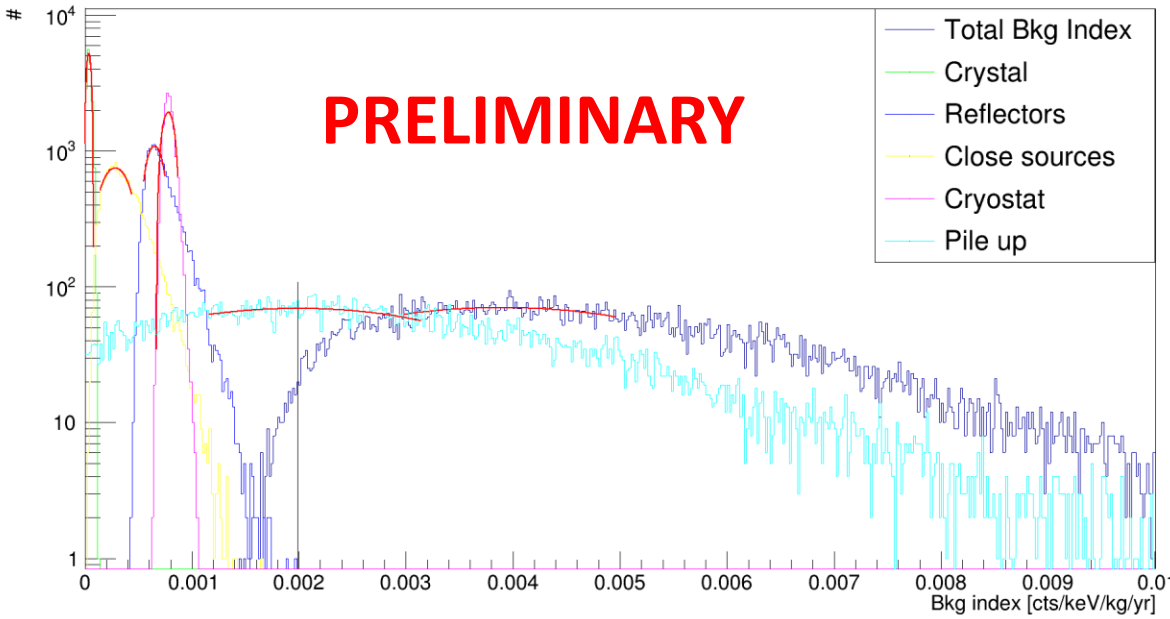


[1] Alduino, C., et al. "Measurement of the two-neutrino double-beta decay half-life of 130Te with the CUORE-0 experiment." The European Physical Journal C 77.1 (2017): 1-18.
[1] Azzolini, O., et al. "Background model of the CUPID-0 experiment." The European Physical Journal C 79.7 (2019): 583.

CUPID-Mo Background budget

- Results from the fit on blinded data
- Conservative Pile-up contribution (no prior)





ROI [3034 +/- 15] keV :

Total = $\left(3.9\ ^{+1.9}_{-1.5}\right) \times 10^{-3}$ **ckky**

Limit on 0νββ of ^{100}Mo

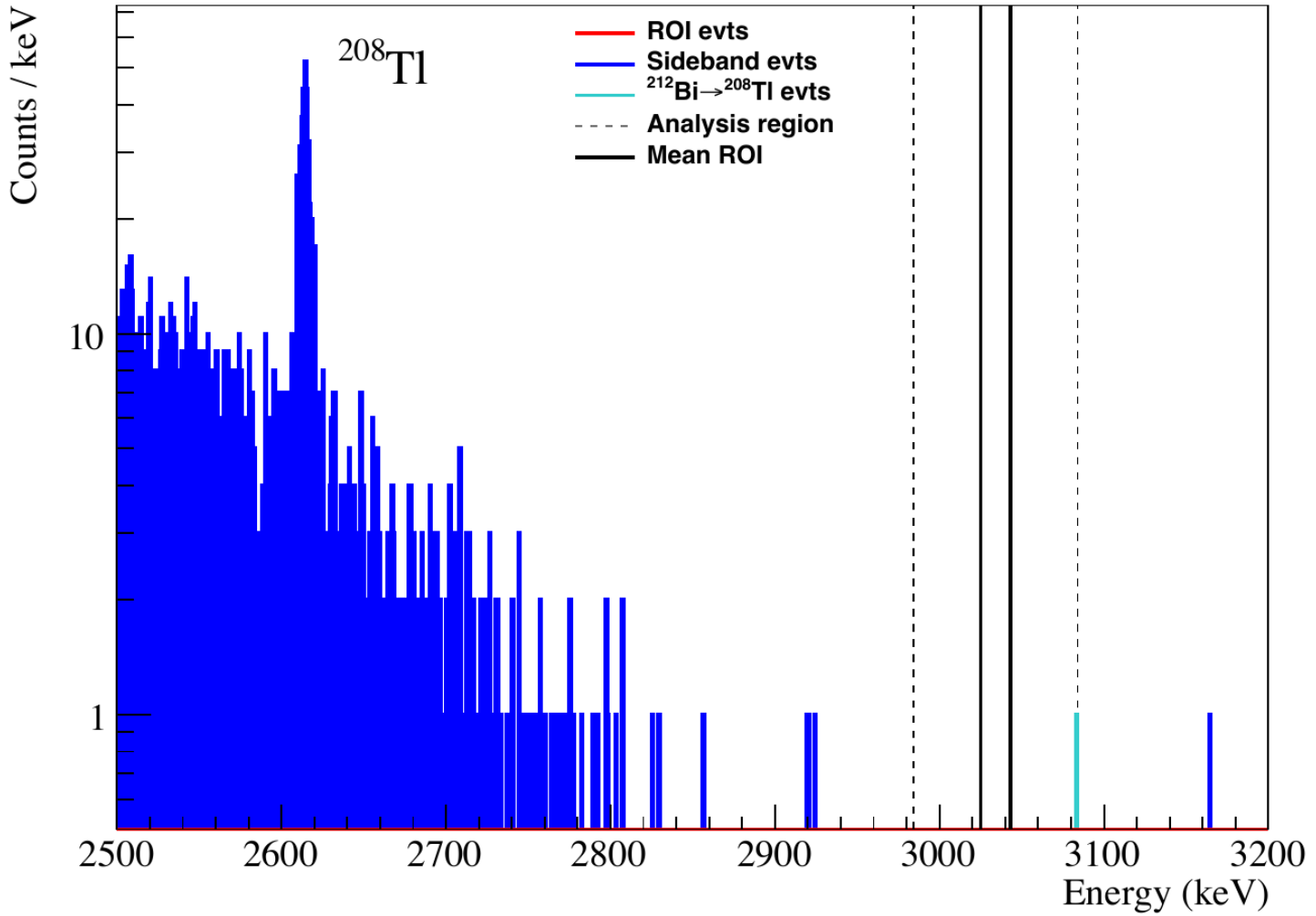
- Bayesian counting analysis used to extract limit
  - 3 region - one signal, two background
- Unblinding: No events in ROI or sideband
  - One ^{208}Tl DC event

Leads to world leading limit on 0νββ of ^{100}Mo:

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

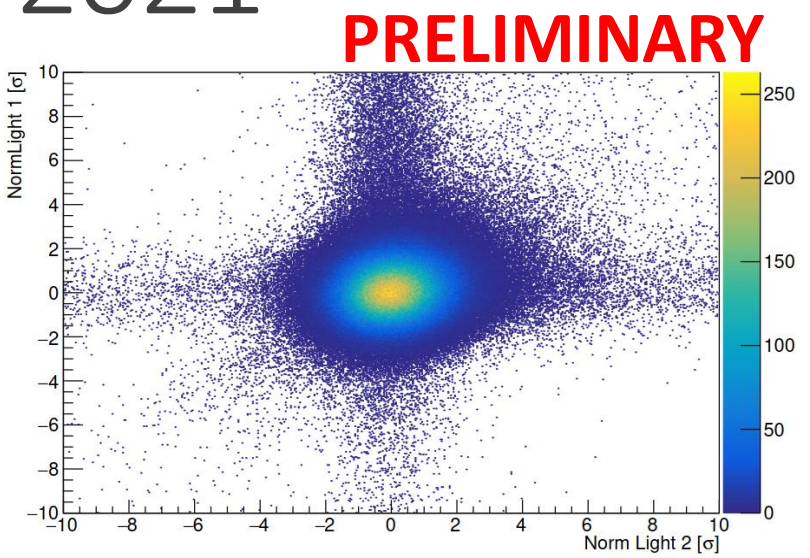
$$m_{\beta\beta} < (310 - 540)\ meV$$

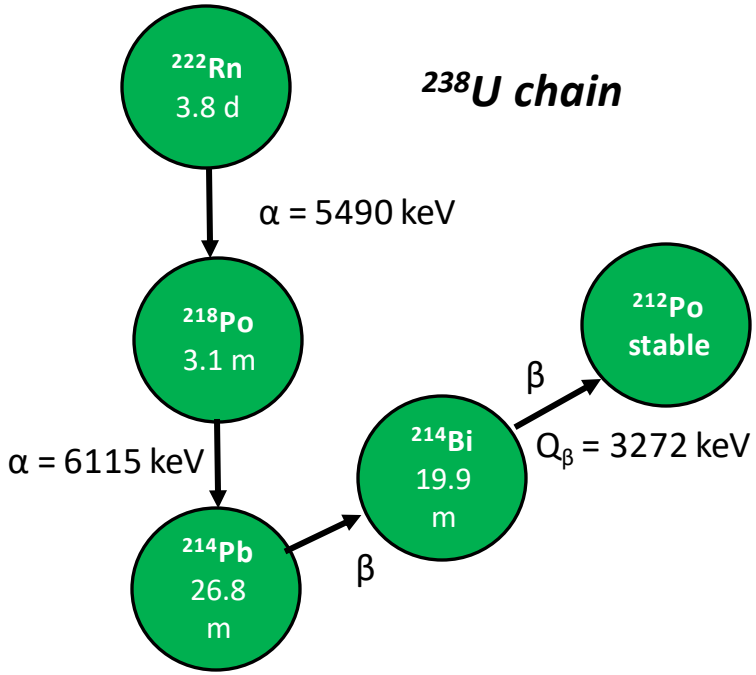
CUPID-Mo PRL.126.181802

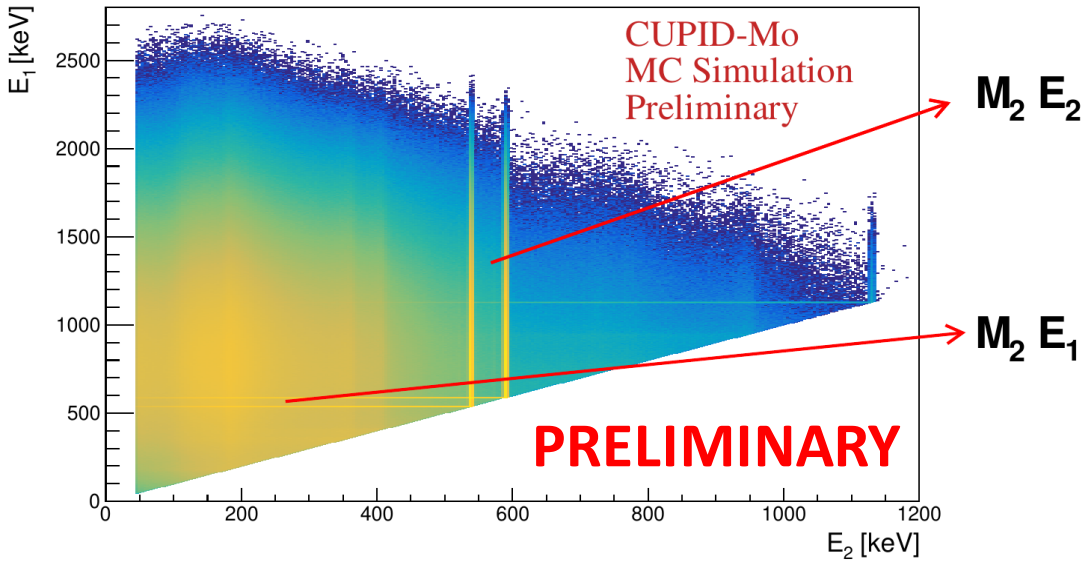


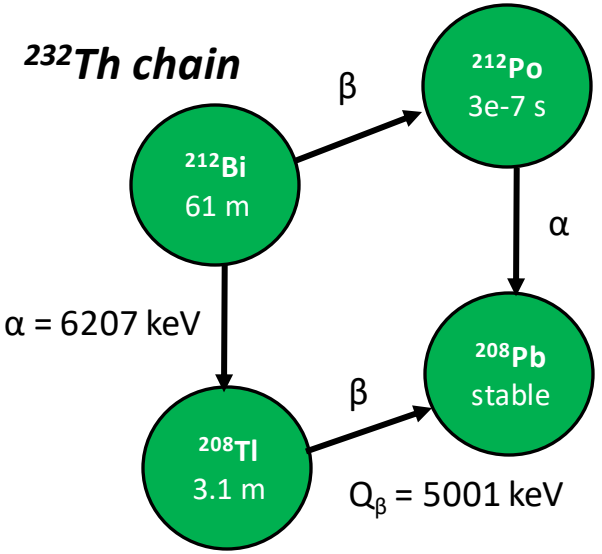
New data @ TAUP2021

- Exposure 2.71 kg.y
- Improved 0νββ analysis
  - Delayed Coincidences studies (rejection of high energy beta events)
  - Improved Light Yield cuts
  - New cuts for alpha rejection
  - New PCA cuts
- 2νββ and 0νββ Excited States analysis
  - Topological search for ES decays using multi-site events





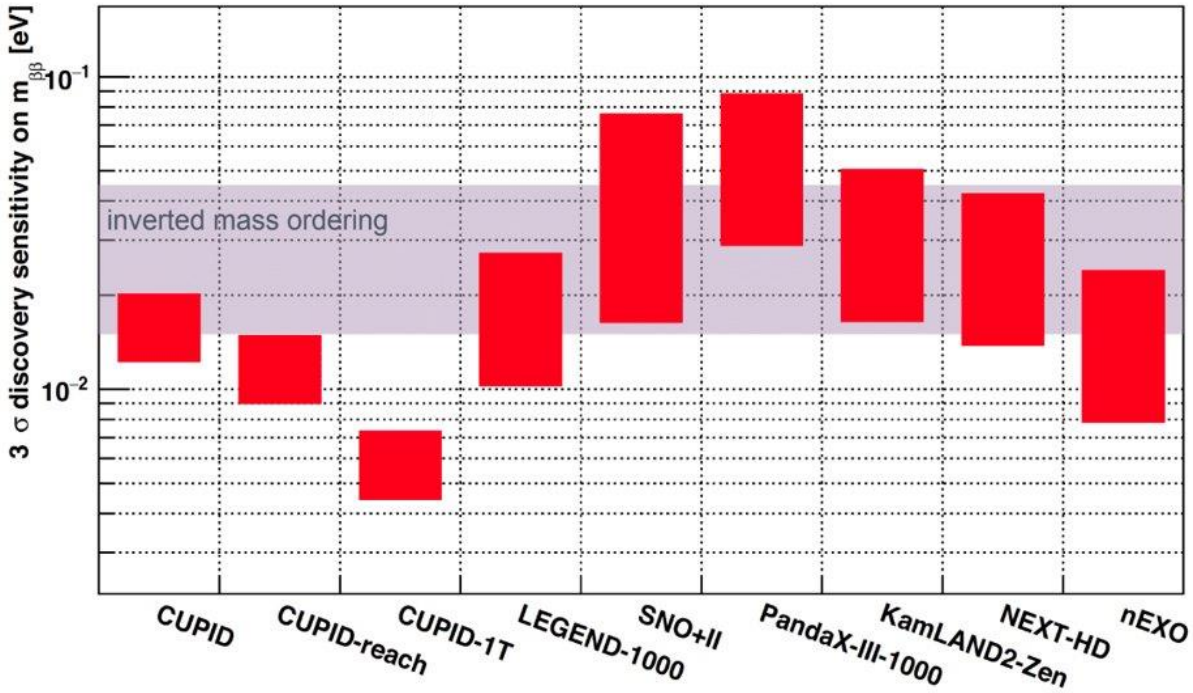




CUPID

Next generation ton scale bolometric 0νββ experiment

To be installed at **Laboratori Nazionali del Gran Sasso** (LNGS) in the **CUORE cryostat**



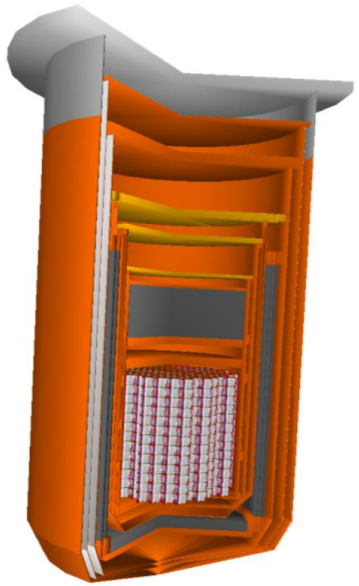
CUPID pre-CDR arXiv:1907.09376 (2019).

CUPID-Mo technology chosen for CUPID

^{100}Mo : $Q_{\beta\beta}$ = 3034 keV

$Li_2{}^{100}MoO_4$ scintillating crystals

- Enrichment > 95 %
- Cubic crystals : 45×45×45 mm³ -> 0.28 kg
- ~ 1500 crystals ~ 240 kg of ^{100}Mo
- ΔE FWHM ~ 5 keV @ Q-value 3034 keV
- α rejection using light signal



0νββ sensitivity

- $T_{1/2}$ ~ 10^{27} years
- $m_{\beta\beta}$ ~ 12 - 20 meV

Background Index goal : 10^{-4} ckky

Conclusions

CUPID-Mo: 20 $Li_2{}^{100}MoO_4$ detectors operated with simultaneous readout of heat and light → α 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 0νββ of ^{100}Mo, with 1.21 kg·y of ^{100}Mo :**

  $T_{1/2} > 1.5 \times 10^{24}$ y (90% CI)
- **4th most stringent limit $m_{\beta\beta} <$ (310 - 540) meV**

- **New limit will be presented @ TAUP2021**

BACK-UP

NME References

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Sensitivities references

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