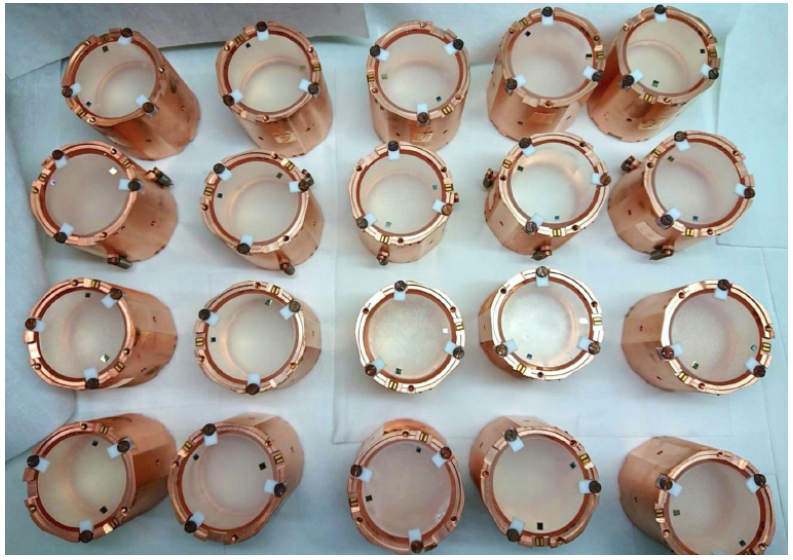
The Background model of the CUPID-Mo experiment

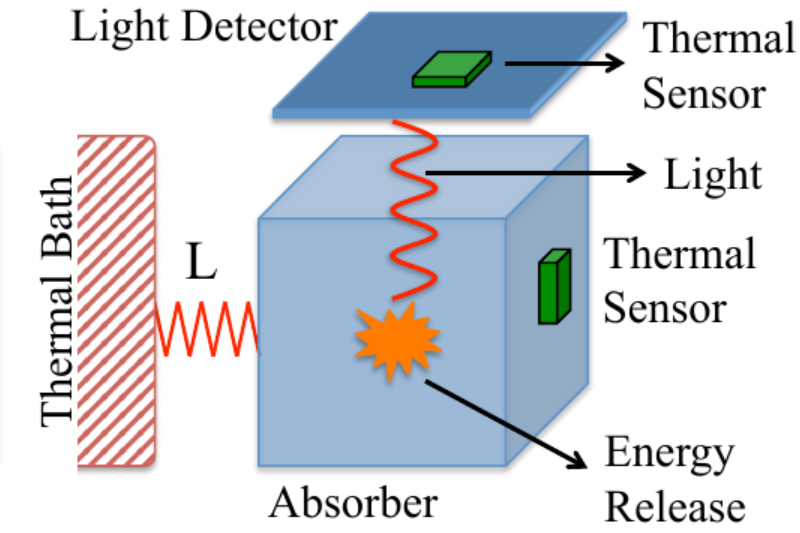
Pia Loaiza on behalf of the CUPID-Mo collaboration

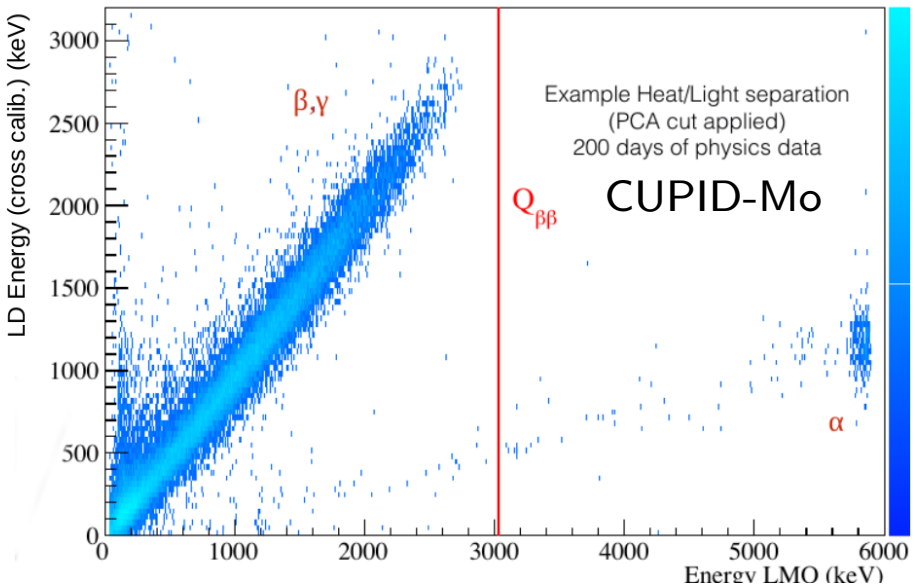
LRT 2022, 17 June 2022



$0\nu\beta\beta$ with scintillating bolometers

Heat and light measurement

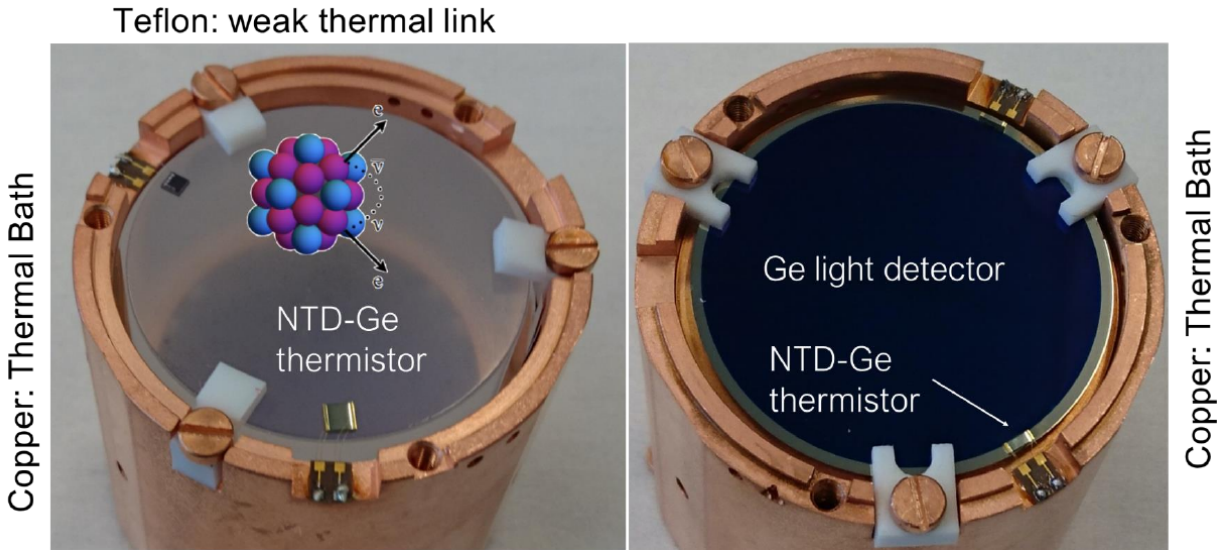




γ/β - α identification

The CUPID-Mo experiment

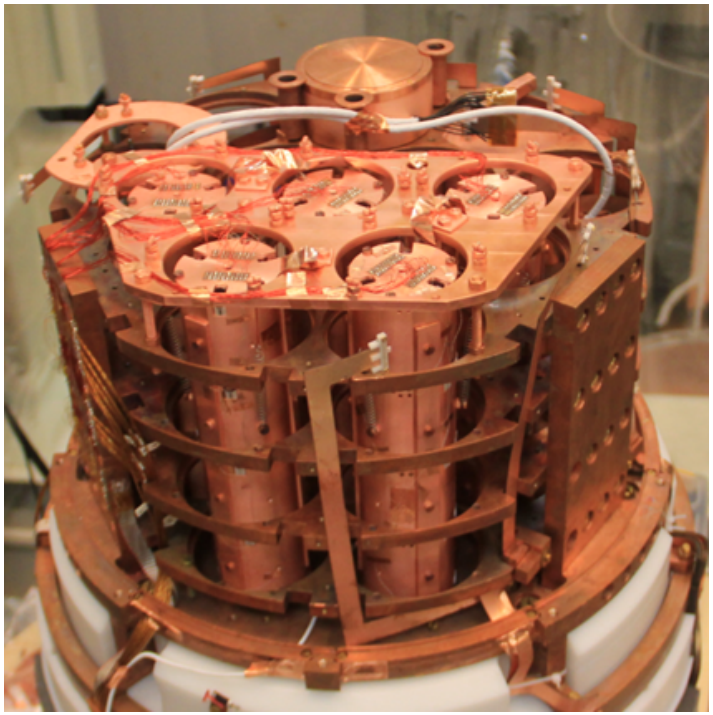
- A demonstrator for next generation experiment CUPID (Cuore Upgrade with Particle IDentification)
- ^{100}Mo $Q_{\beta\beta} = 3034$ keV
- A competitive $0\nu\beta\beta$ experiment in its own right
  World's best limit $T_{1/2}$ in ^{100}Mo
- $Li_2{}^{100}MoO_4$ scintillating crystals + NTD Ge sensors → heat
- Ge wafers + NTD → light detectors



CUPID-Mo and CUPID

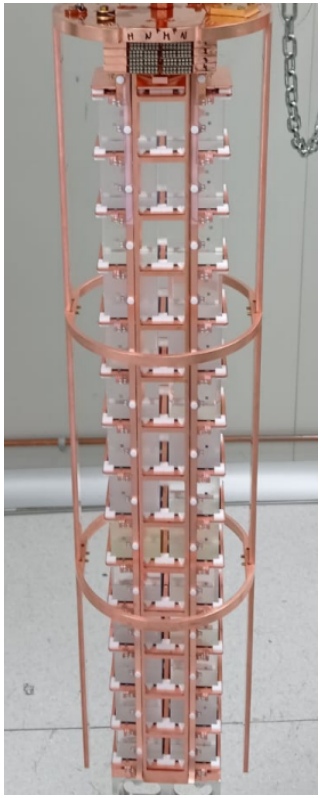
CUPID-Mo

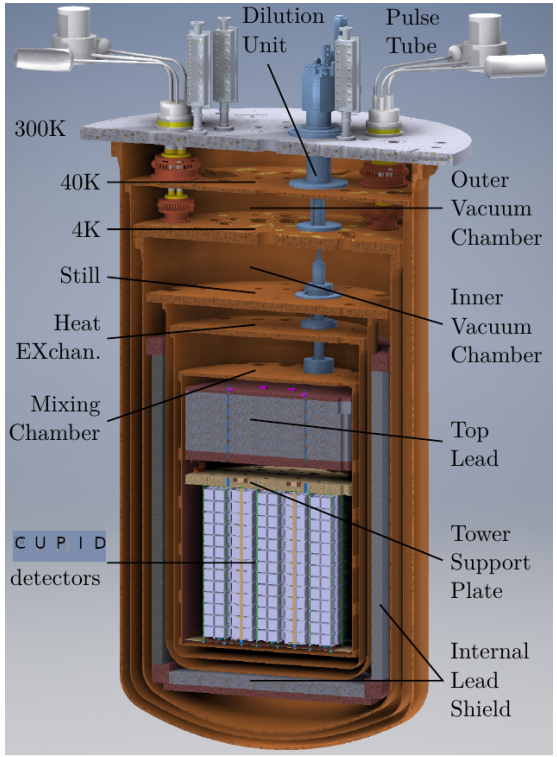
- Installed at LSM, in the EDELWEISS-III cryogenic set-up
- 20 $Li_2{}^{100}MoO_4$
- Copper casings



CUPID

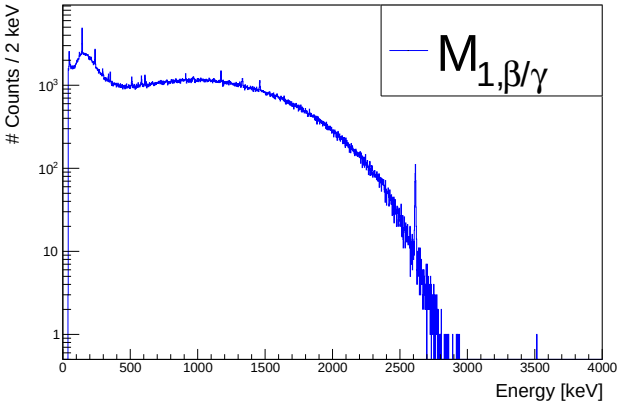
- To be installed at LNGS
- 1596 $Li_2{}^{100}MoO_4$
- Open structure

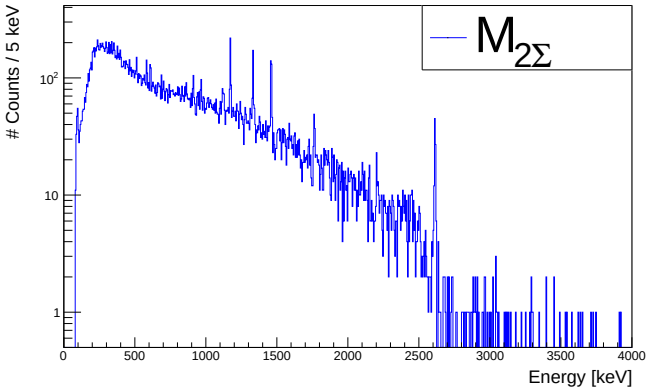


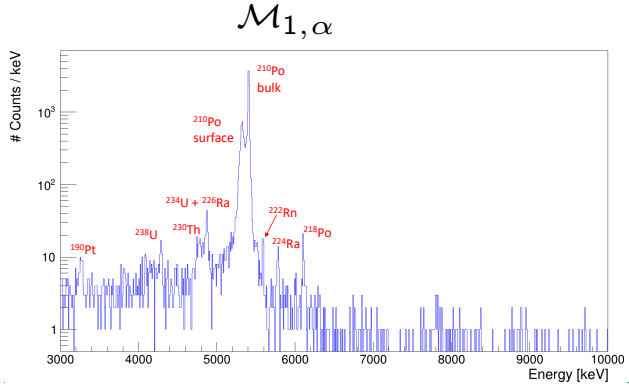


Data

- Data taking between March 2019 and June 2020
- Exposure: 2.71 kg · y
- $\mathcal{M}_{1,\beta\gamma}$
  - Events in one detector identified as β, γ
  - $0\nu\beta\beta$ signal like
- $\mathcal{M}_{2\Sigma}$
  - Coincidences between 2 crystals above energy threshold in $\pm$ 10 ms time window
  - Sum of the two deposited energies
  - Constrains levels of external contaminations
- $\mathcal{M}_{1,\alpha}$
  - $\mathcal{M}_1$ events with Energy $>$ 3 MeV
  - Constrains levels of contaminations for crystal and reflectors
  - Allows differentiation between bulk and surface events in crystals



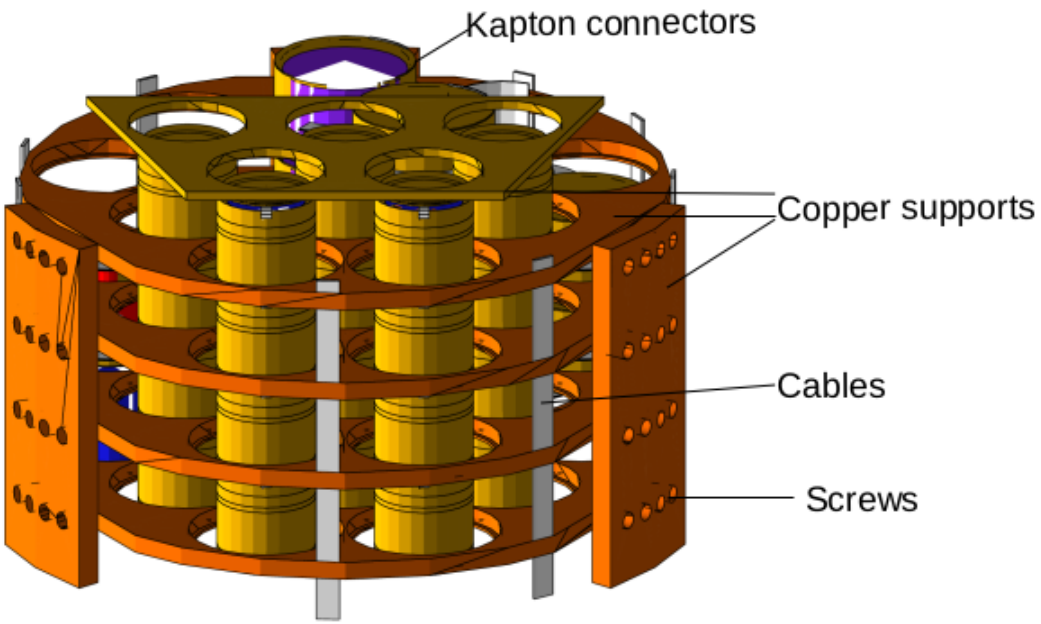




Monte Carlo simulations

Detailed implementation of the set-up geometry
Background sources considered:

- Crystals, Reflectors (account for sources facing directly the crystals)
  - Bulk
  - Surface, exponential density profile $e^{x/\lambda}$
- '10 mK' sources:



Geant4 rendering of the CUPID-Mo detectors

Monte Carlo simulations

- Cryostat and shields
  - Cryostat screens
  - Outer cryostat screen
  - Polyethylene internal (1K)

Detector response model

- Detector effects convolved

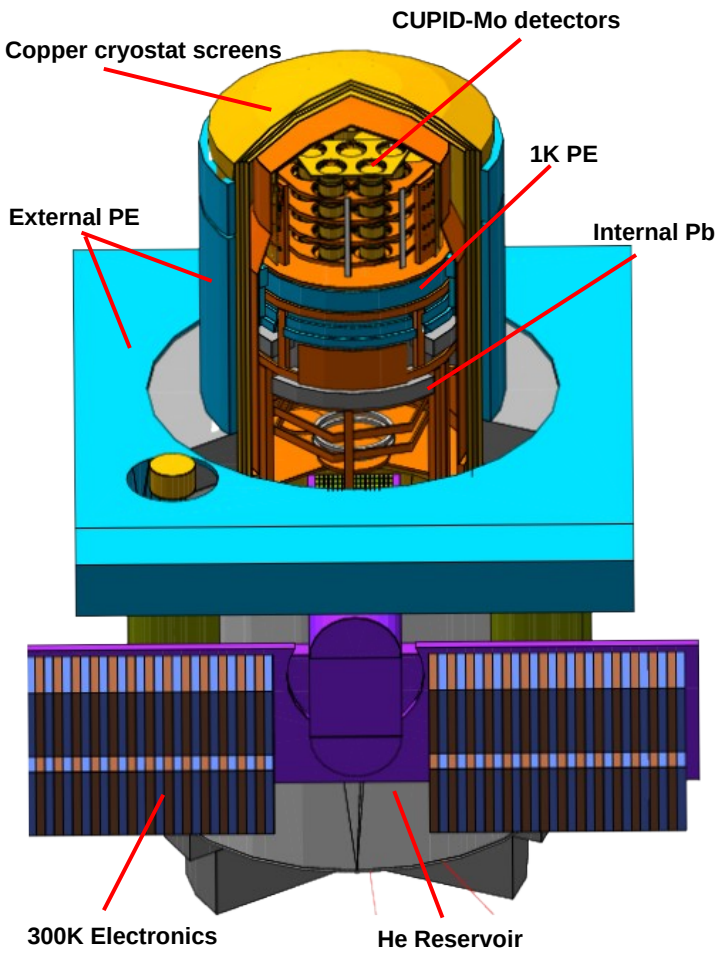
into MC spectra

  - Energy resolution
  - Efficiency

As in data, we compute:

- Multiplicity
- Delayed coincidences
- Light detector signal. For each

energy deposited in the crystal a scintillation light is randomly generated according to the light distribution in the data

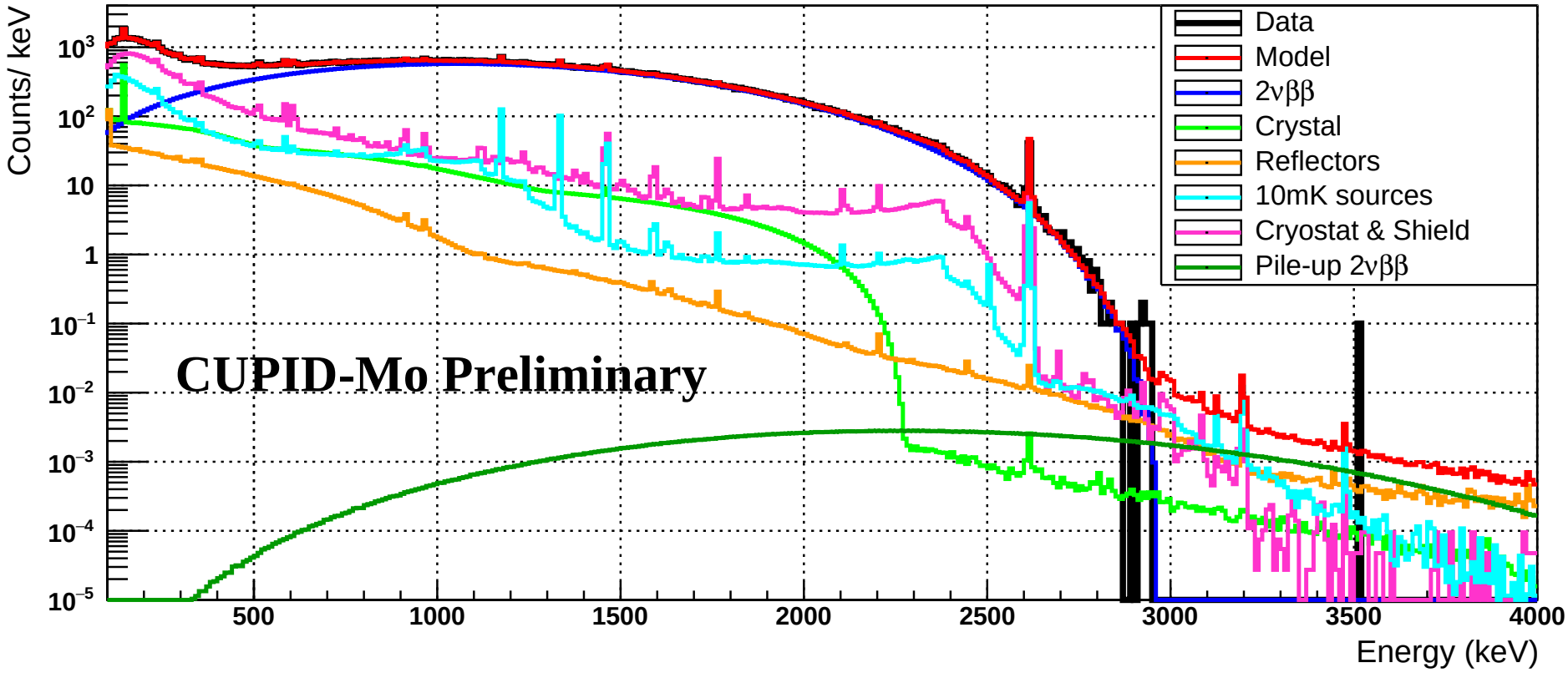


Background model

- Describe the experimental data by a linear combination of the MC spectra
- The parameters of the model tell us the radioactive contamination of the various components
- A robust background model allows for several further physics studies

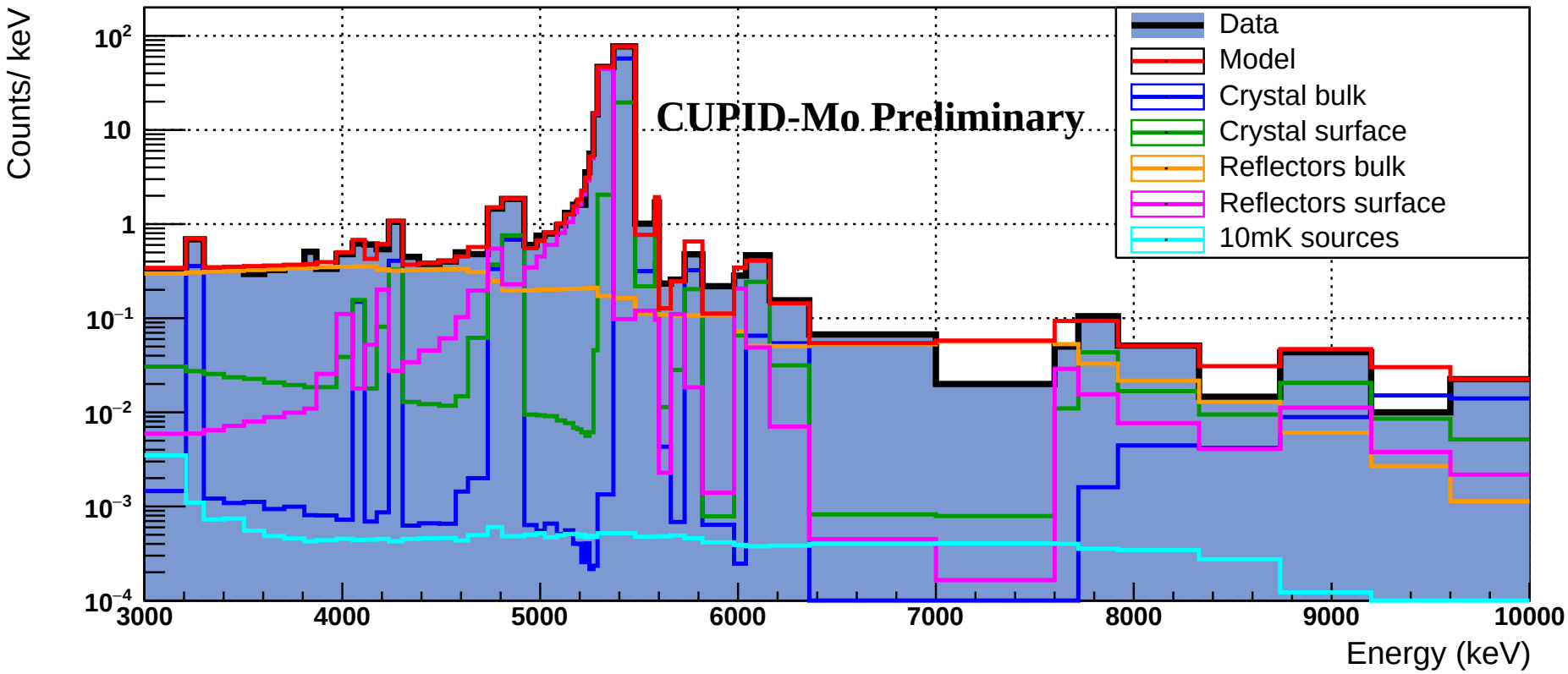
- Simoultaneous fit of $\mathcal{M}_{1,\beta\gamma}$, $\mathcal{M}_{2\Sigma}$, and $\mathcal{M}_{1,\alpha}$, with a Bayesian approach (JAGS based)
- 66 Monte Carlo sources
- Variable binning
- Surface contamination implantation depth $\lambda = 10$ nm
- Intervals:
  - $\mathcal{M}_{1,\beta\gamma}$ [100; 4000] keV
  - $\mathcal{M}_{2\Sigma}$ [400; 4000] keV
  - $\mathcal{M}_{1,\alpha}$ [3000; 10000] keV

$\mathcal{M}_{1,\beta\gamma}$ fit



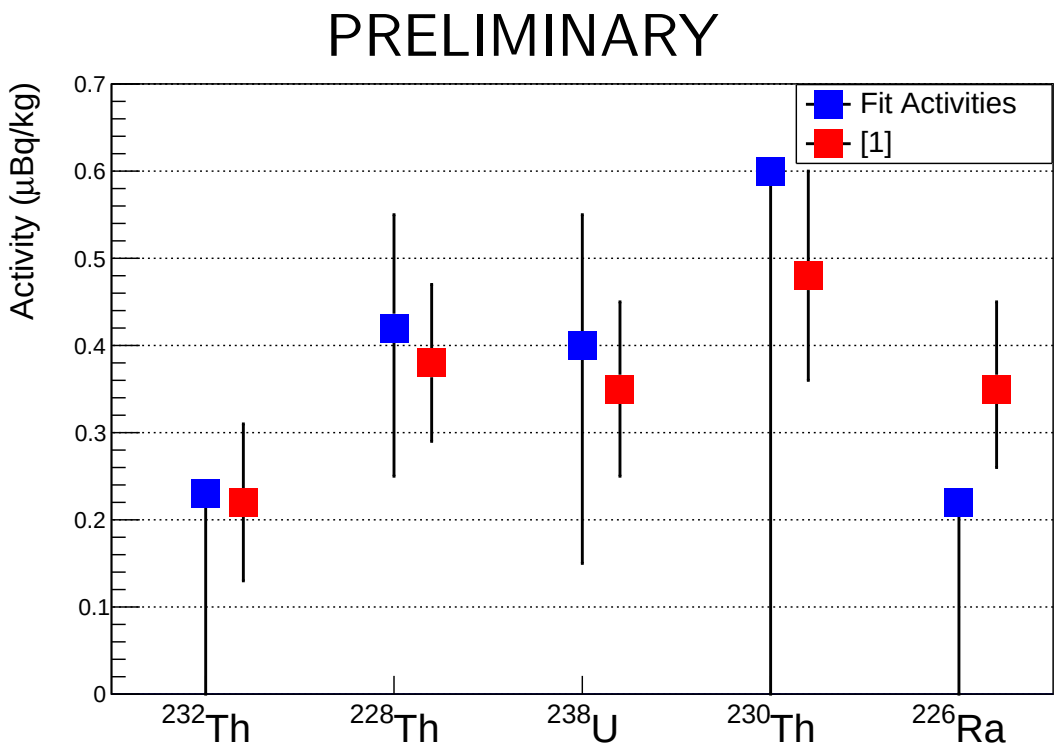
- The model is able to describe our experimental data very well
- χ^2/NDF= 148/168

Background model: components in $\mathcal{M}_{1,\alpha}$



- Crystal bulk contaminations characterized by sharp peaks
- Crystal surface contaminations include a continuum due to degraded α's
- Close sources bulk contamination give a flat continuum

Background model: $Li_2{}^{100}MoO_4$ bulk contaminations



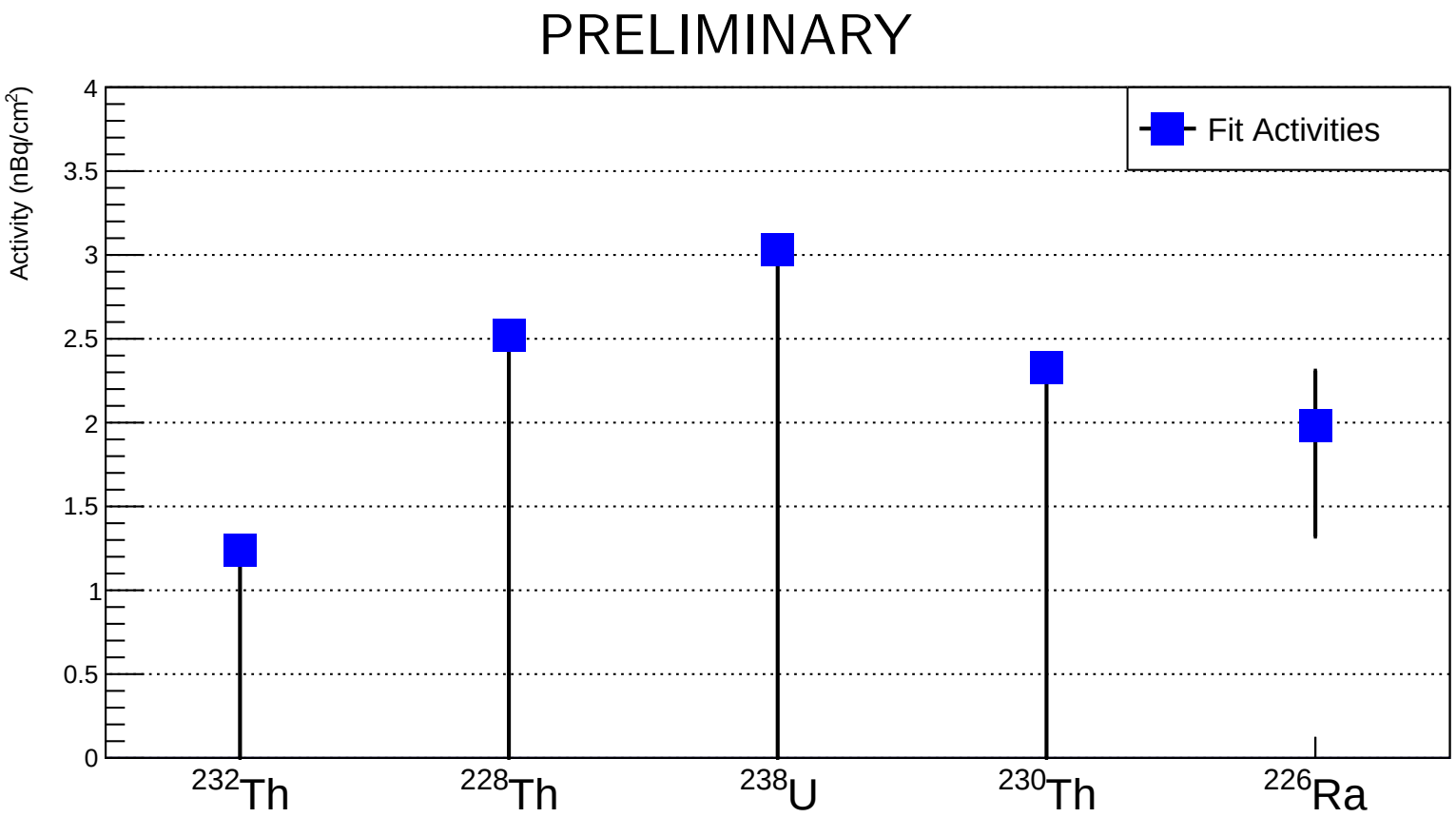
PRELIMINARY

Nuclide	Activity [μBq/kg]
^{210}Pb	$96\ ^{+4}_{-24}$
^{190}Pt	$0.39\ ^{+0.07}_{-0.12}$
^{87}Rb	< 98
^{90}Sr-Y	$179\ ^{+24}_{-46}$
^{40}K	$109\ ^{+23}_{-27}$

[1] D. Poda *et al* [CUPID-Mo collab], Neutrino 2020. (Ascribing all events in peak to bulk contaminations)

All U and Th contaminations in the crystal $< 1\ \mu$Bq/kg

Background model: $Li_2{}^{100}MoO_4$ Surface contaminations



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

Background from crystals in CUPID

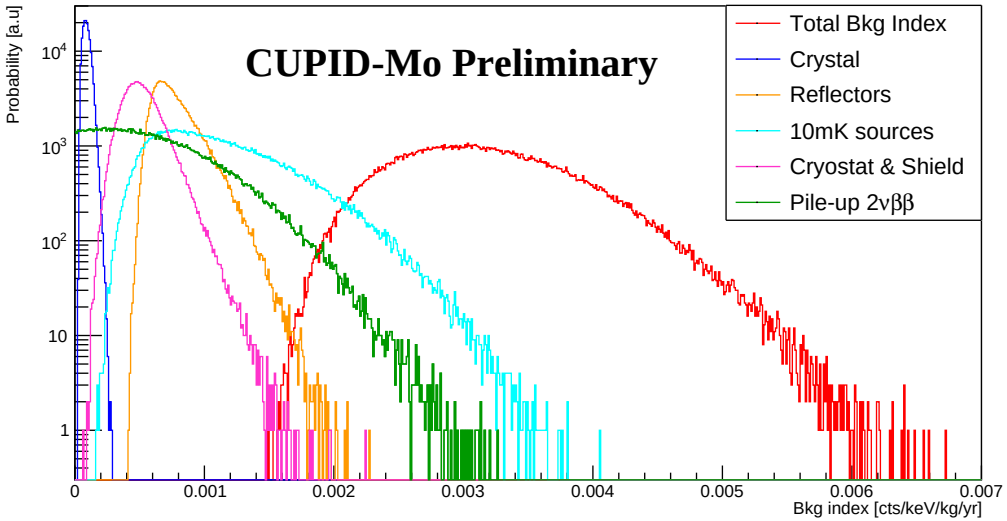
- We have used these crystal contaminations to estimate the crystal contribution in CUPID :

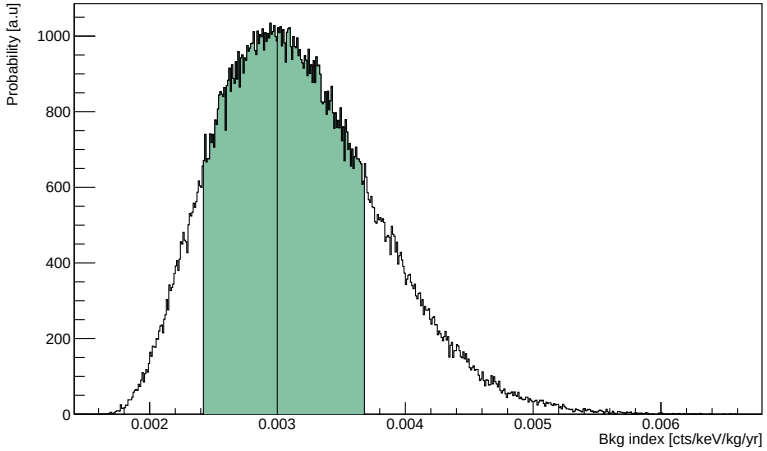
	Activity ^{226}Ra	Activity ^{228}Th	BI ^{226}Ra/^{228}Th [ckky]
Bulk	< 0.2 μBq/kg	$0.4^{+0.2}_{-0.1}$ μBq/kg	-/ $(2.0^{+1.0}_{-0.6}) \times 10^{-6}$
Surface	$2.0^{+0.3}_{-0.7}$ nBq/cm^2	< 2.5 nBq/cm^2	$(1.0^{+0.2}_{-0.4}) \times 10^{-5}$ / $< 1. \times 10^{-5}$

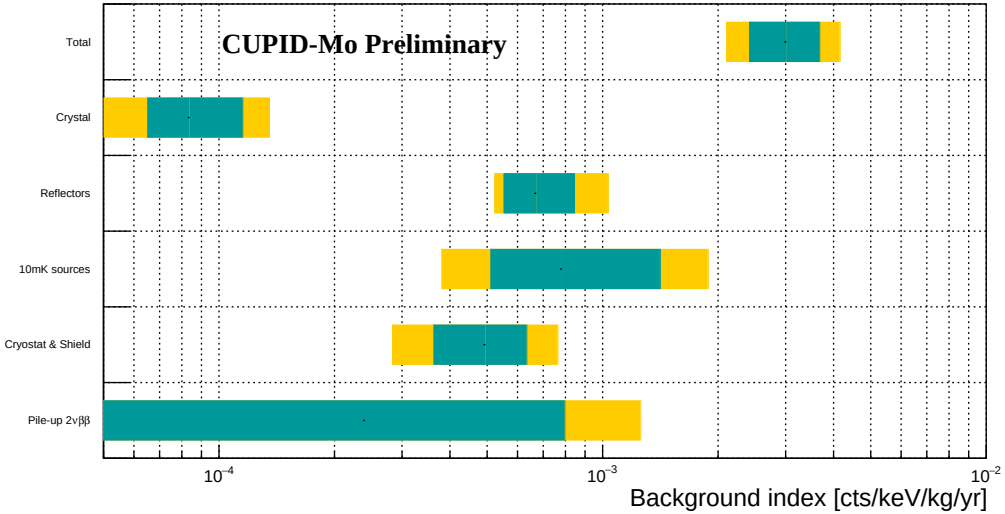
$2 \cdot 10^{-5}$ cts/(keV·kg·y) $<<$ 10^{-4} cts/(keV kg y)
(CUPID background goal)

CUPID-Mo Background Index

Posterior distributions of background index:







Background index in

3034 ± 15 keV:

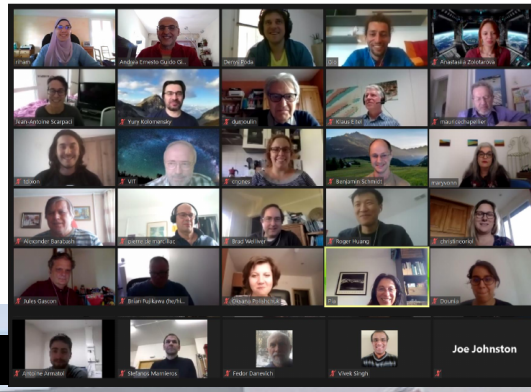
$3.0^{+0.7}_{-0.6} \cdot 10^{-3}$ cts/(keV kg y)

CUPID-Mo PRELIMNARY

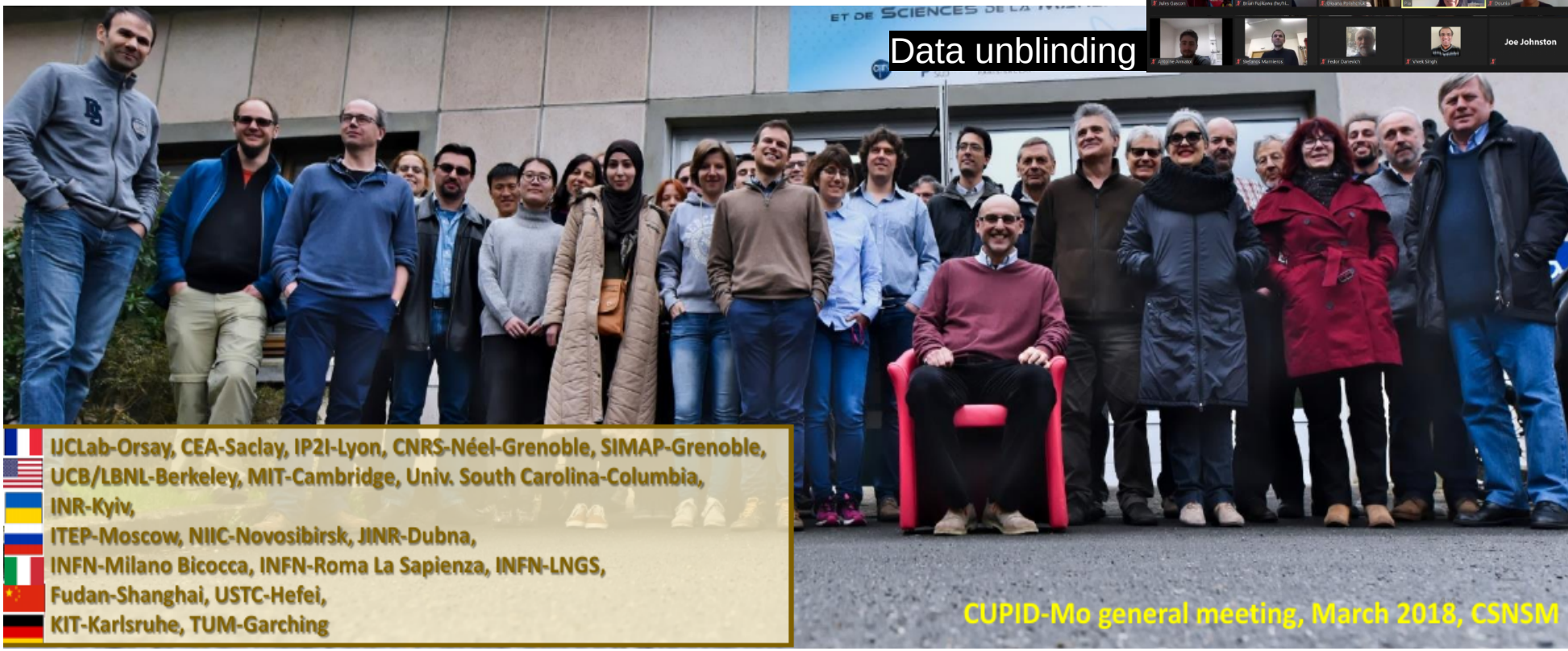
Conclusions

- CUPID-Mo was a demonstrator for CUPID and a $0\nu\beta\beta$ experiment in its own right (world's best limit $T_{1/2}$ in ^{100}Mo)
- We have developed a background model based on Bayesian statistics. The parameters of the model tell us the radioactive contamination of the various components, and, in particular, the $Li_2{}^{100}MoO_4$ crystals
- $Li_2{}^{100}MoO_4$ $^{238}U/^{232}Th$ daughters bulk contaminations < 1 μBq/kg, surface contaminations < 3 nBq/cm^2. Sufficient for CUPID background goal $= 10^{-4}$ counts/(keV kg y)
- CUPID-Mo background index in ROI: $3.0^{+0.7}_{-0.6} \cdot 10^{-3}$ cts/(keV kg y)

The CUPID-Mo collaboration



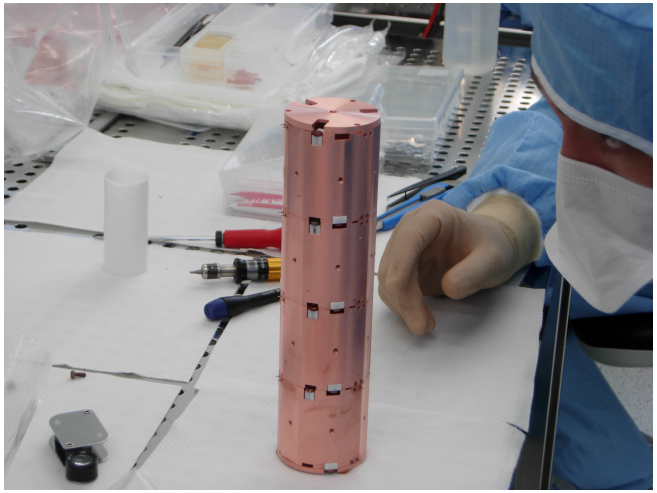
Data unblinding

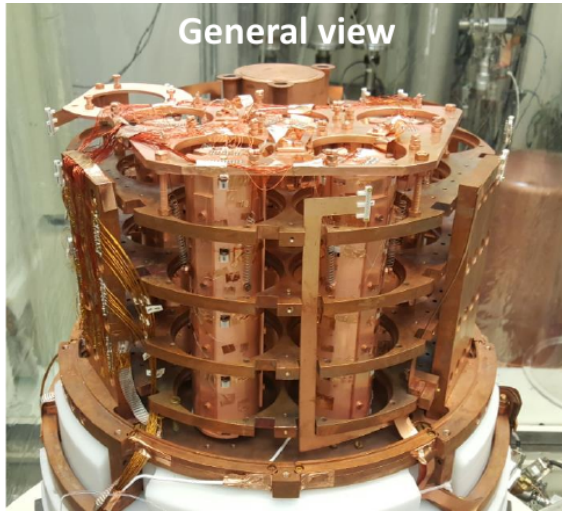


Back up slides

CUPID-Mo towers and set-up

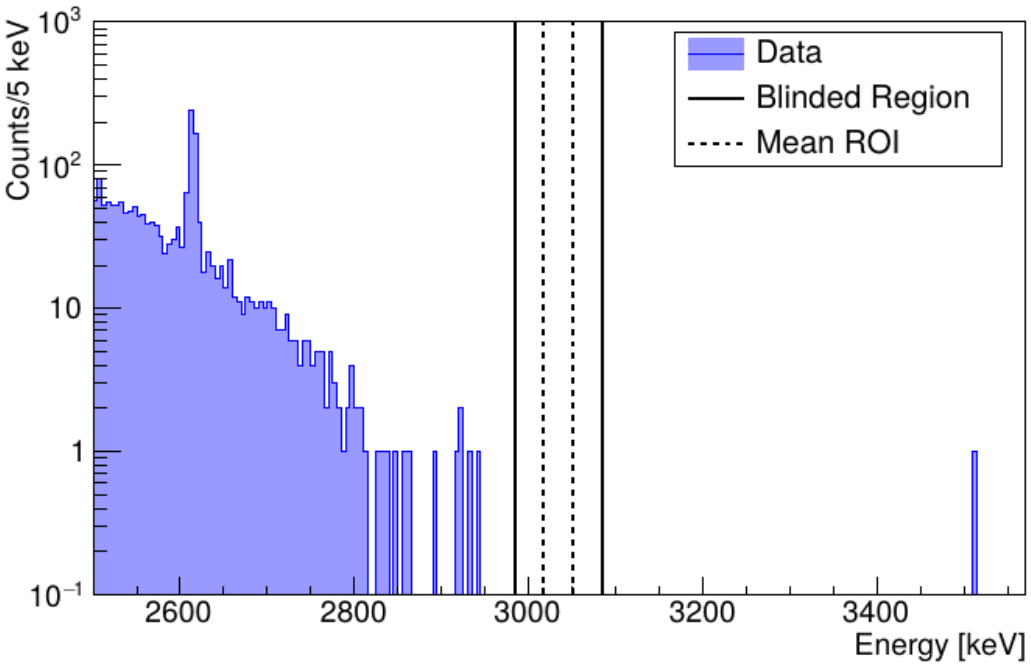
- 20 $Li_2{}^{100}MoO_4$ crystals of 210 g, 97% enriched in ^{100}Mo $\rightarrow$ 2.26 kg of ^{100}Mo





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

arXiv:2202.08716 [nucl-ex], submitted to EPJC



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

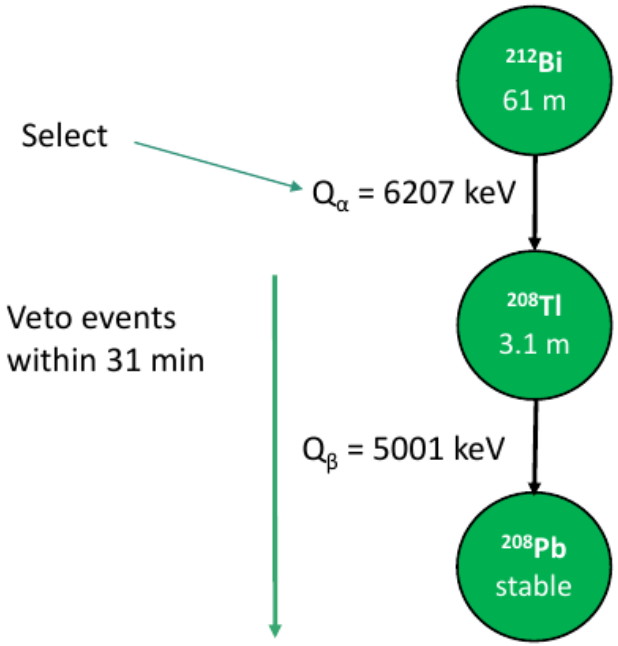
$T_{1/2} > 1.8 \cdot 10^{24}$ y (90% CI)

$m_{\beta\beta} <$ (0.28-0.49) eV

Delayed coincidences

Thorium chain :

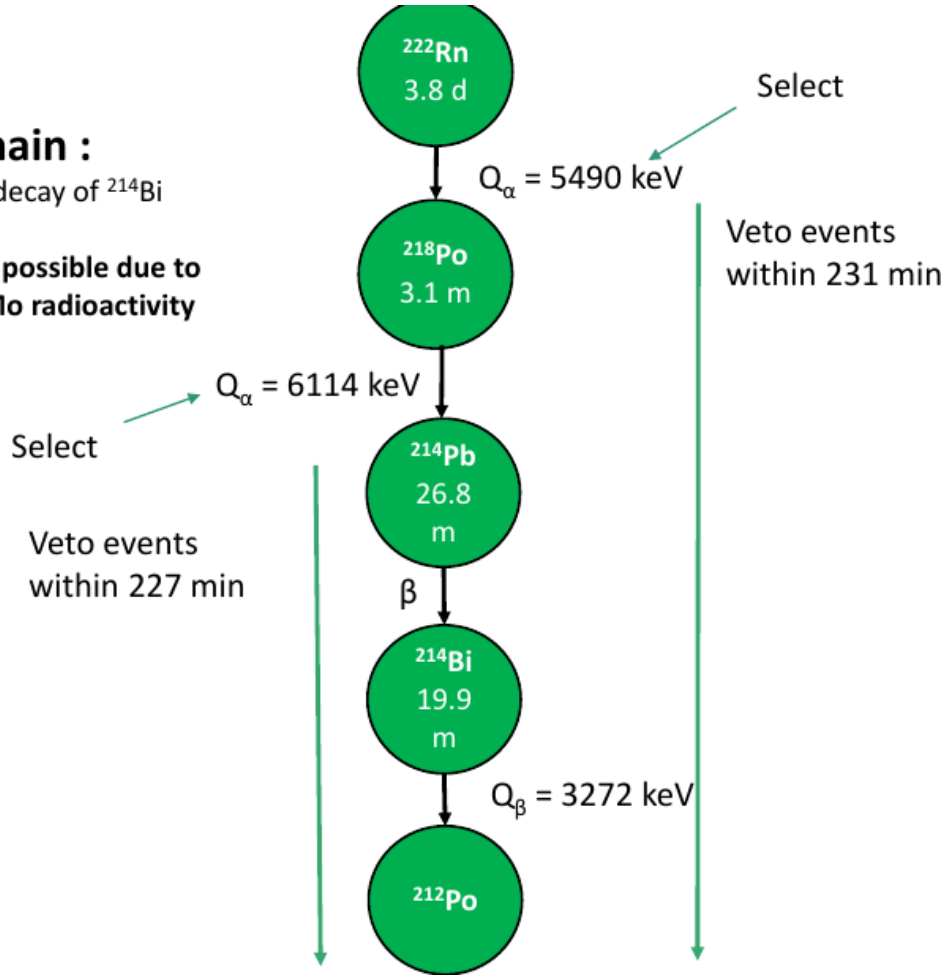
Goal : remove β decays of ^{208}Tl from the crystals

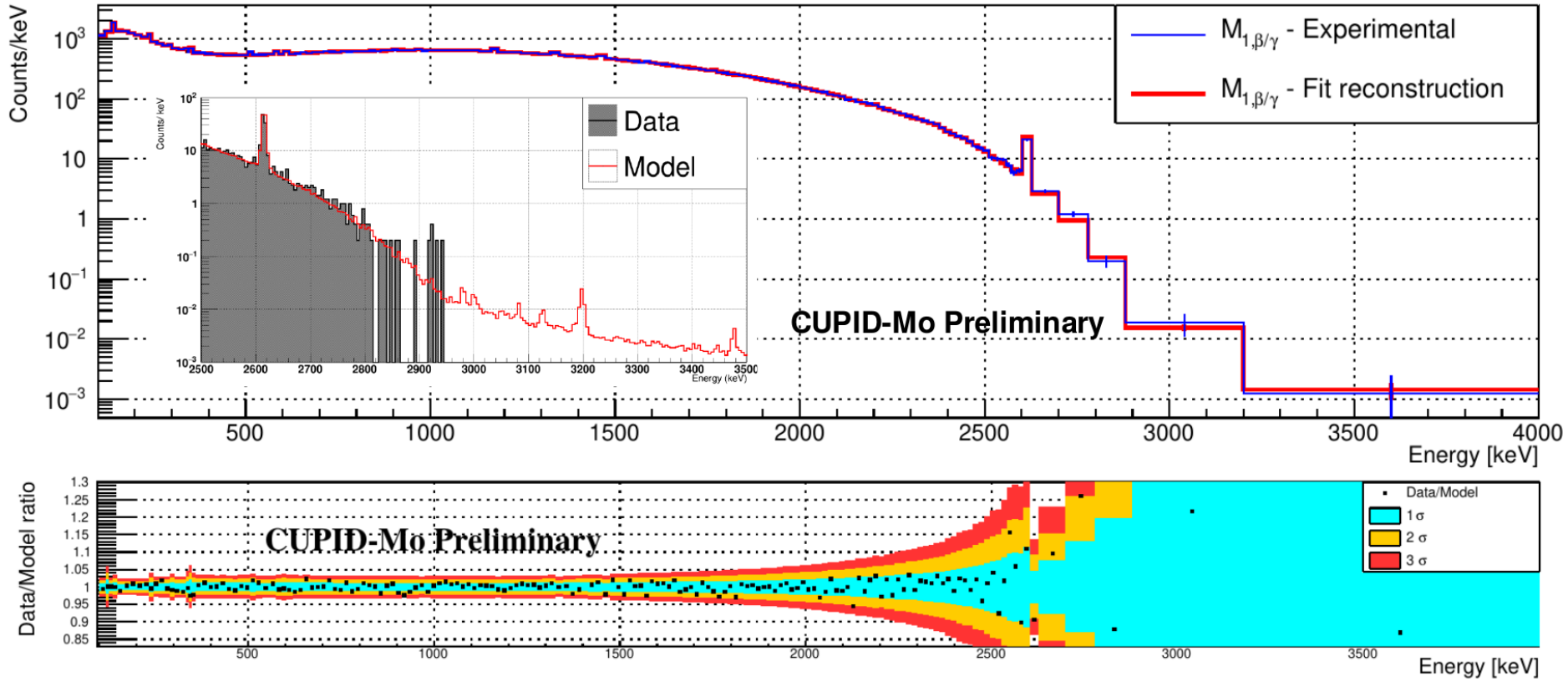


Uranium chain :

Goal : remove β decay of ^{214}Bi from the crystals

Novel analysis is possible due to the low CUPID-Mo radioactivity




Counts/keV
$M_{1,\beta/\gamma}$ - Experimental
$M_{1,\beta/\gamma}$ - Fit reconstruction
Data
Model
CUPID-Mo Preliminary
Energy [keV]
Data/Model ratio
Data/Model
1 σ
2 σ
3 σ
CUPID-Mo Preliminary
Energy [keV]