Results from the CUPID-Mo Experiment

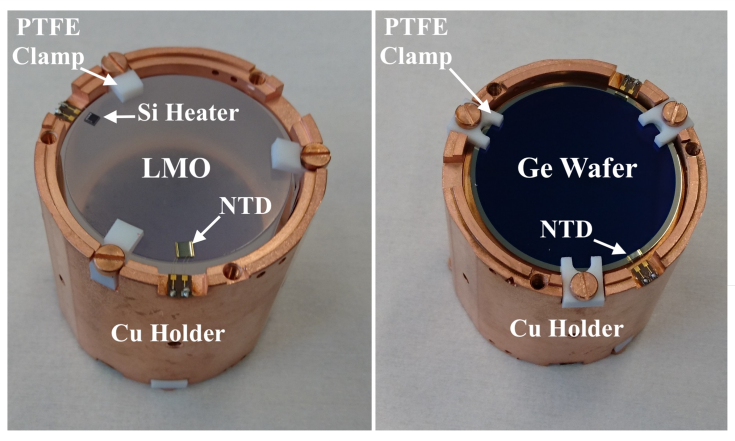
Contribution #489

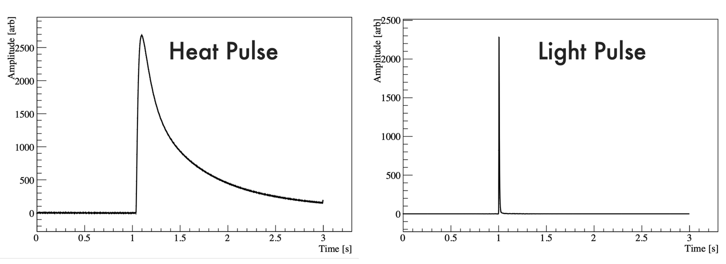
Bradford Welliver[1] & Pia Loaiza[2] on behalf of the CUPID-Mo Collaboration

1. University of California Berkeley Physics Department
2. Université Paris-Saclay, CNRS/IN2P3, IJCLab, 91405 Orsay, France

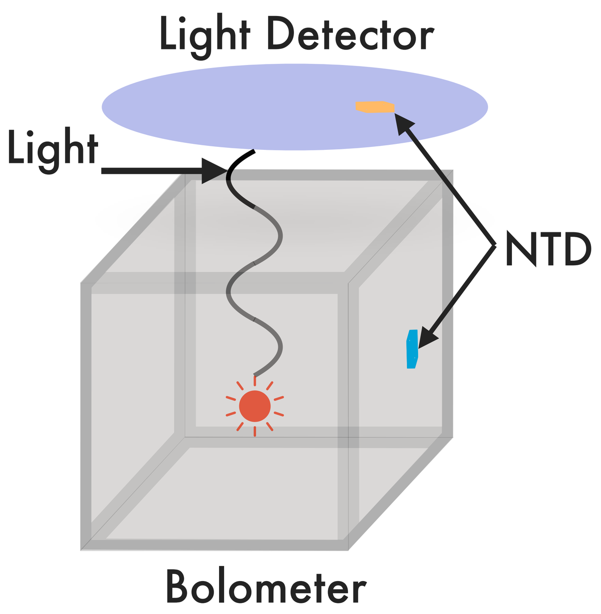
http://cupid-mo.mit.edu

The CUPID-Mo Experiment

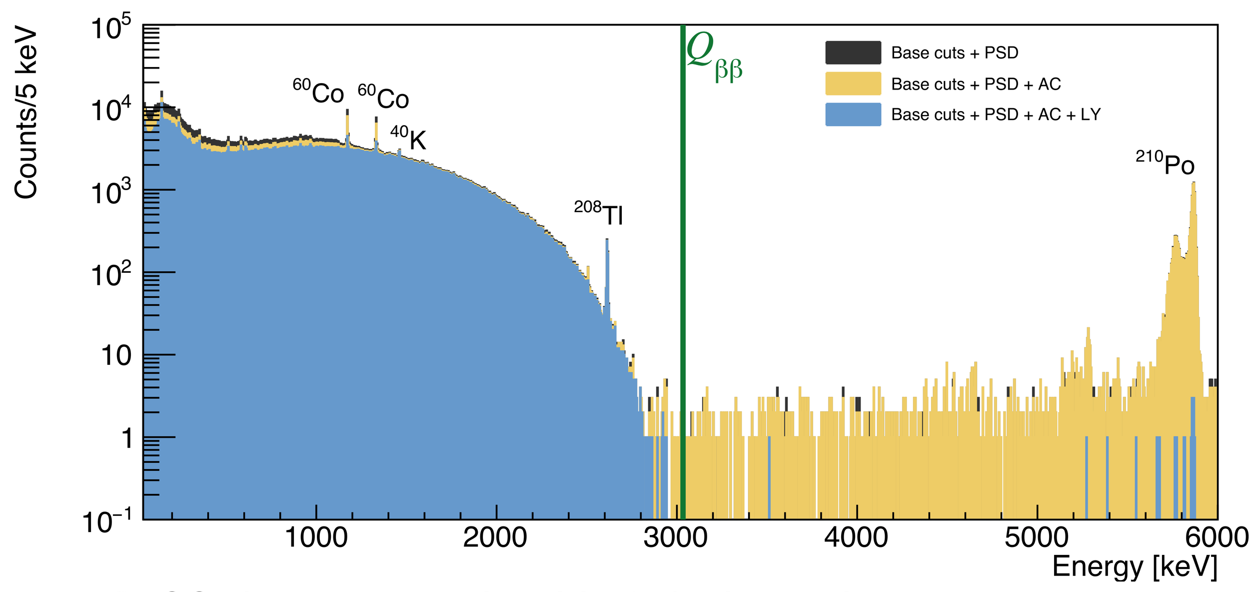




- Demonstrator for technology [1] for use in CUPID [2]
- 20 scintillating $Li_2{}^{100}MoO_4$ (LMO) bolometers
- Each LMO: ~ 0.2 kg with 97% enriched ^{100}Mo
- Ge wafer light detectors (LD)
- Instrumented with neutron transmutation doped (NTD) Ge thermistors



0νββ Decay Search



0νββ decay search with 1.47 kg-yr iso. exposure

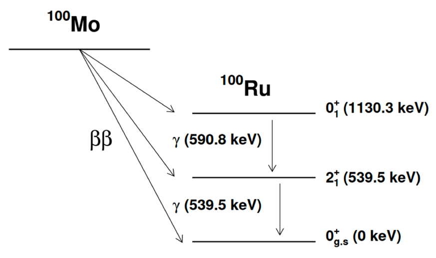
No events observed in region of interest

Bayesian counting analysis

Leading limit on decay half-life for ^{100}Mo [3]

$T_{1/2}^{0\nu} > 1.8 \times 10^{24}$ yr (90% c.i.) $m_{\beta\beta} < 0.28 - 0.49$ eV (90% c.i.)

Decay to Excited States

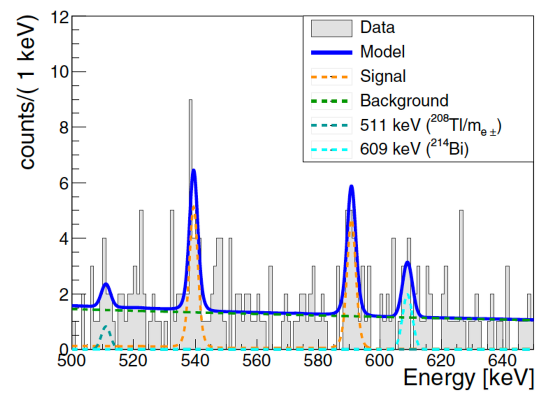


Search for decay to excited states

Both 2νββ and 0νββ decays searched

Various patterns of ββ accompanied by γ's possible

Often more than 1 crystal involved



Simultaneous fit to various γ lines categorized by multi-crystal decay types [4]

The CUPID-Mo Background Model

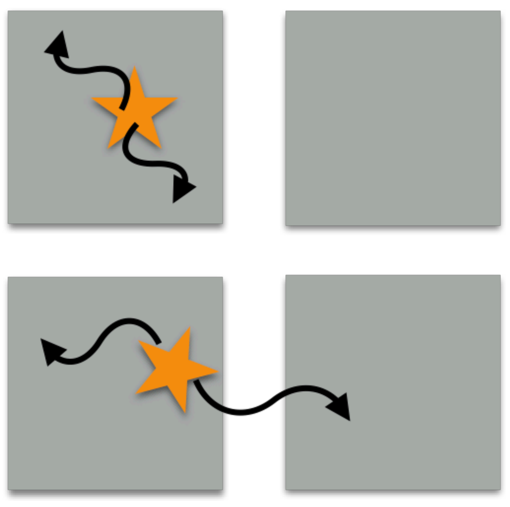
CUPID-Mo built thorough background model [5] to account for as many sources of background as possible.

Simulations via Geant4 model of Edelweiss cryostat with CUPID-Mo setup

Decays generated in: cryostat & shields, crystal bulk & surface, reflecting foil bulk & surface, and close sources (e.g. Cu supports)

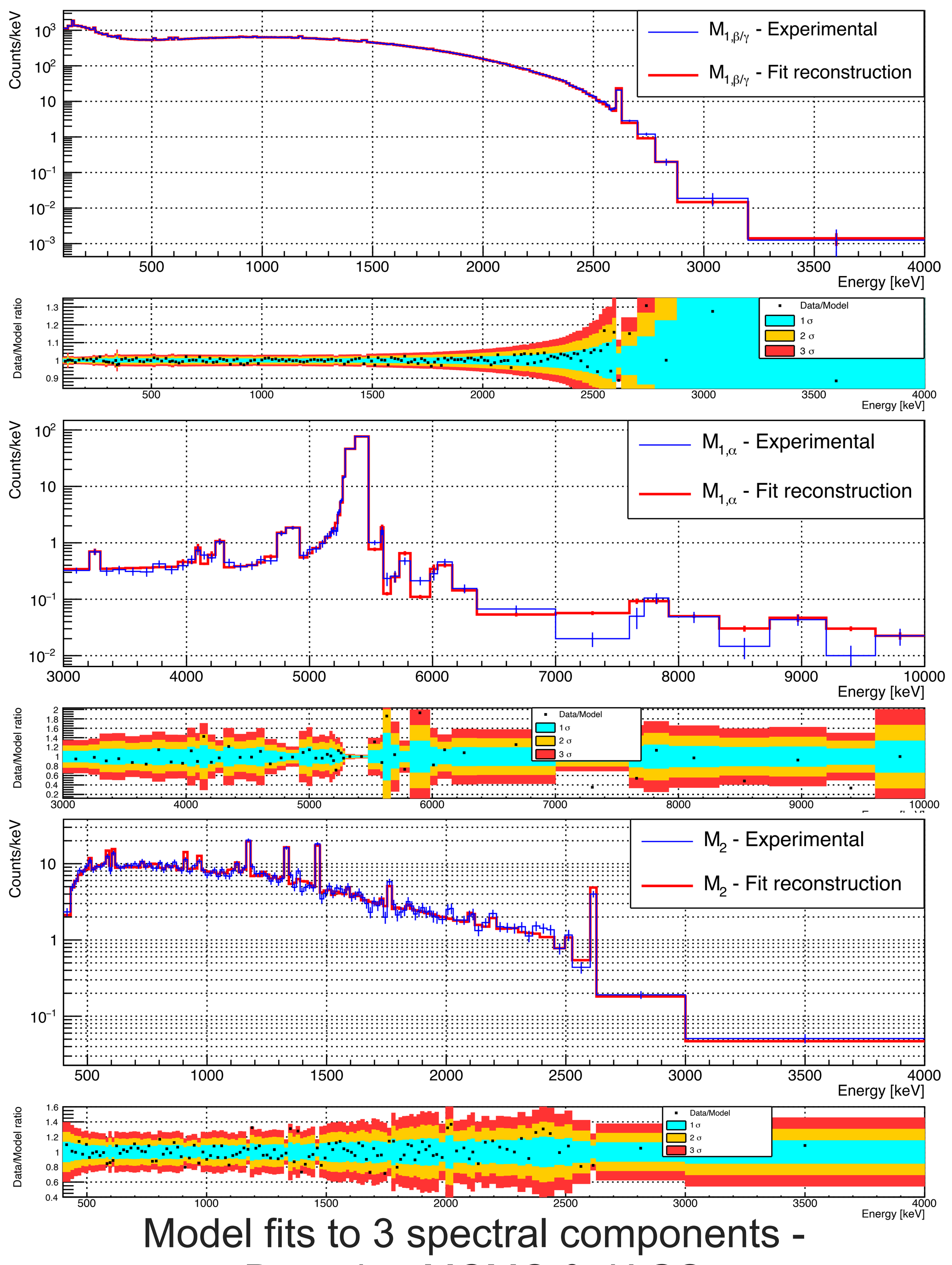
67 total sources included in fit

Data modeled against 3 simulated spectra: M1 γ/β, M1 α's, and M2 γ/β

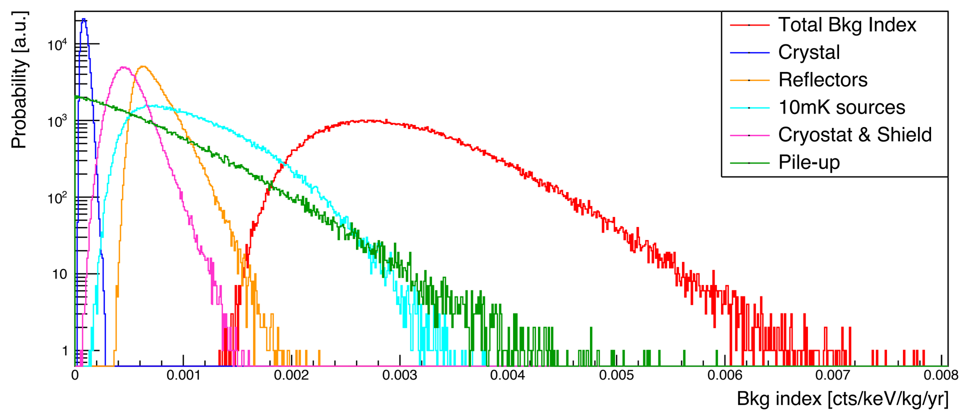


Multiplicity 1 (M1) has energy deposition only in single crystal

Multiplicity 2 (M2) has energy shared across two crystals



Model fits to 3 spectral components - Bayesian MCMC & JAGS



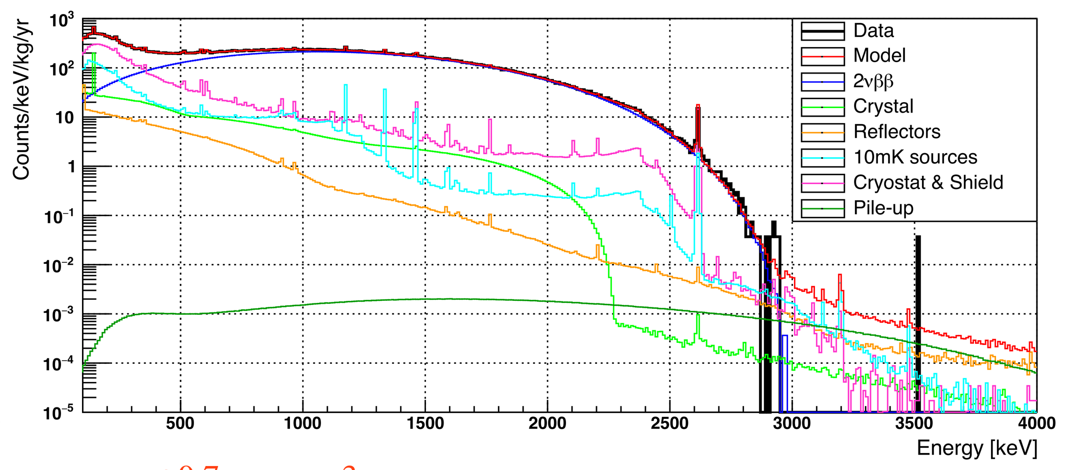
Posteriors of background model components grouped by location

The crystal contamination is extremely low

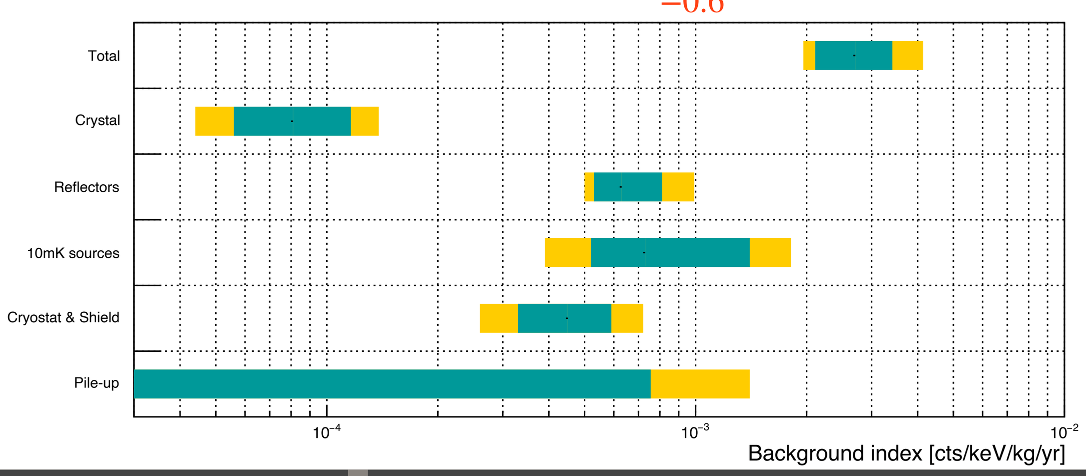
Background model components overlaid with M1 data

Dominant contribution from 2νββ decay clearly visible

Validated with ^{56}Co data - accurate activity



$b = 2.7^{+0.7}_{-0.6} \times 10^{-3}$ counts/keV/kg/yr

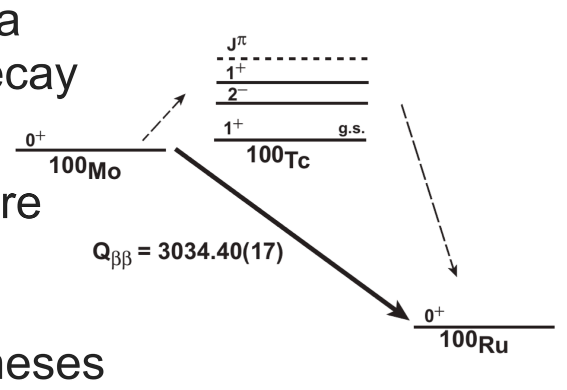


Contributions to BI from various components

Sampled from mode of posteriors with smallest 68.3% (green) and 90% (yellow) c.i.

2νββ Decay and Spectral Shape

The isotope ^{100}Mo has a relatively "fast" 2νββ decay half-life



Two common models are higher state dominant (HSD) and single state dominant (SSD) hypotheses

$$T_{1/2}^{2\nu} = \left(G_{2\nu} \cdot g_{A,eff}^4 \cdot \left|M_{2\nu}\right|^2\right)^{-1}$$

Modification to decay rate proposed [6,7]

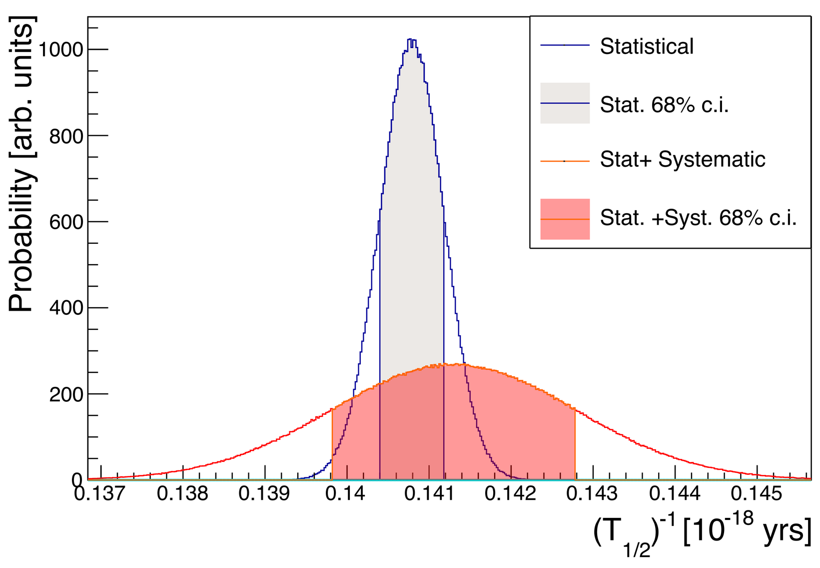
Decay rate expressed in terms of phase space factors (G's) and nuclear matrix elements (M's)

Spectral shape parameters (ξ's) allow for probes of g_A

HSD recovered if all ξ terms = 0

$$\frac{d\Gamma}{dE} = g_{A,eff}^4 \left|M_{GT-1}\right|^2 \left(\frac{dG_0}{dE} + \xi_{3,1}\frac{dG_2}{dE} + \frac{1}{3}\xi_{3,1}^2\frac{dG_{22}}{dE} + \left(\frac{1}{3}\xi_{3,1}^2 + \xi_{5,1}\right)\frac{dG_4}{dE}\right)$$

$$\xi_{3,1} = M_{GT-3}/M_{GT-1} \qquad \xi_{5,1} = M_{GT-5}/M_{GT-1}$$



Background model favors SSD over HSD

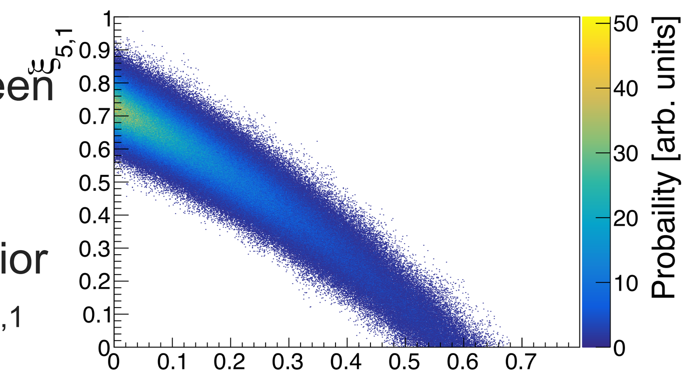
Run fit with modified model

Systematics via Toy Monte-Carlo

One of the most precise 2νββ decay half-life measurements [8]

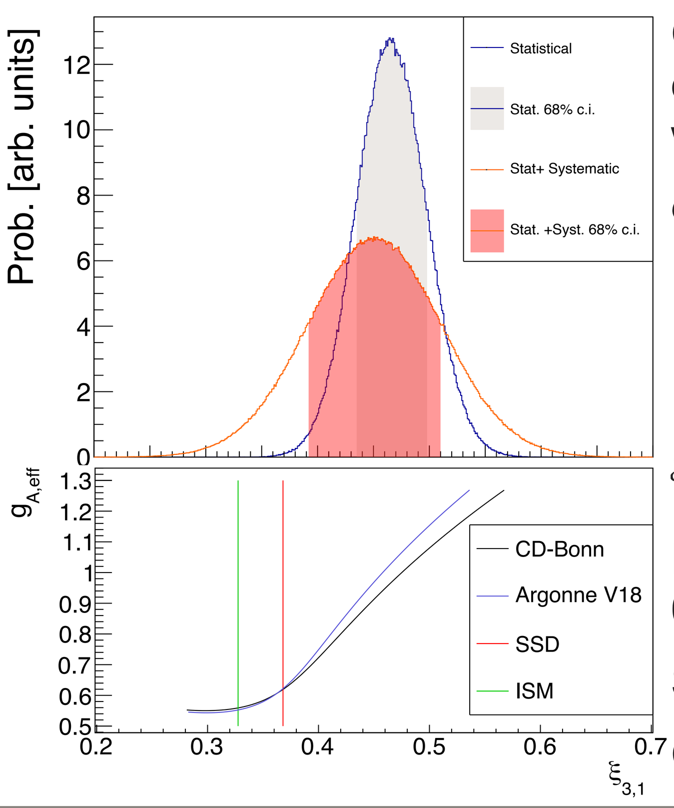
Strong anti-correlation between spectral shape parameters

Use Gaussian prior on ratio of $\xi_{5,1}/\xi_{3,1}$



Ratio computable from low-energy state terms (M_{GT-3} & M_{GT-5}):

- pn-QRPA: 0.364 – 0.368 (depending on g_{Aeff})
- ISM: 0.349
- SSD: 0.367



CD-Bonn & Argonne V-18 to derive g_{Aeff} or compute directly with ISM [8,9]

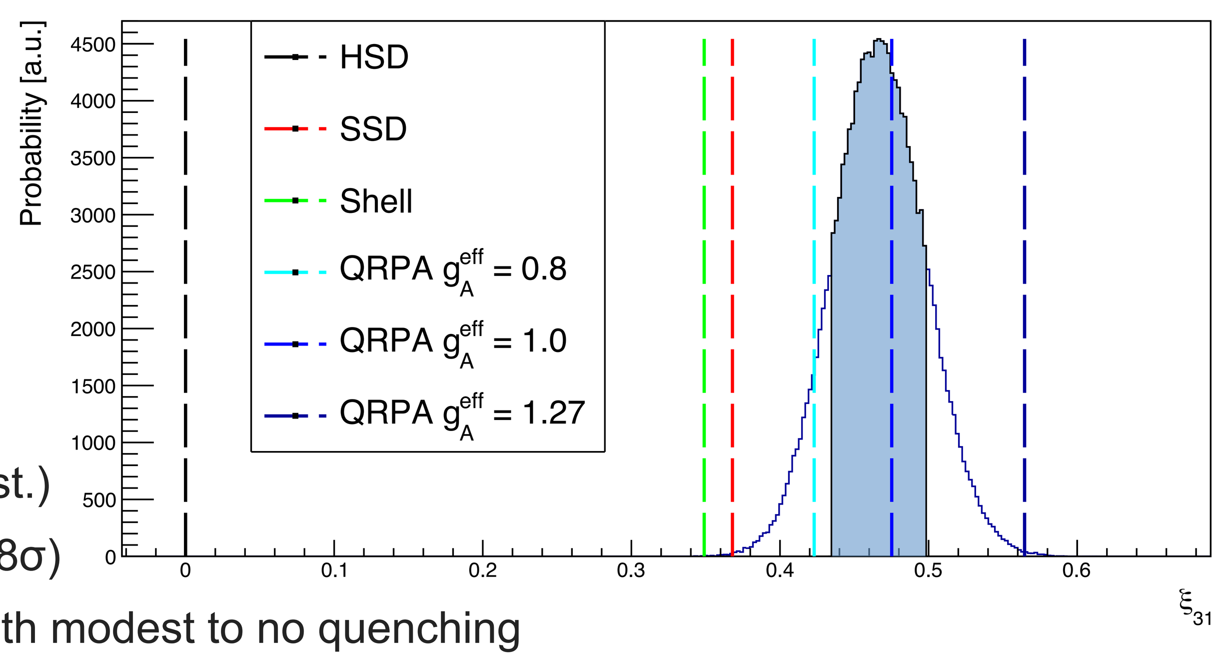
$$G = G_0 + \xi_{3,1}G_2 + \frac{\xi_{3,1}^2 G_{22}}{3} + \left(\frac{\xi_{3,1}^2}{3} + \xi_{5,1}\right)G_4$$

$$g_{A,eff}^4 = \frac{\xi_{3,1}^2}{T_{1/2}^{2\nu} \cdot M_{GT-3}^2 \cdot G} \quad \text{(ISM)}$$

Posterior of $\xi_{3,1}$: 0.45 ± 0.03 (stat.) ± 0.05 (syst.)

Significantly disfavors HSD (8σ)

Compatible with pn-QRPA with modest to no quenching



Summary of Results

0νββ Decay

$T_{1/2}^{0\nu} > 1.8 \times 10^{24}$ yr (90 % c.i.)

$m_{\beta\beta} < [0.28 - 0.49]$ eV (90 % c.i.)

Excited States

$T_{1/2}^{0\nu \to 0_1^+} > 1.2 \times 10^{23}$ yr (90 % c.i.)

$T_{1/2}^{0\nu \to 2_1^+} > 2.1 \times 10^{23}$ yr (90 % c.i.)

$T_{1/2}^{2\nu \to 0_1^+} = \left(7.5 \pm 0.8\ (\text{stat})^{+0.4}_{-0.3}\ (\text{syst})\right) \times 10^{20}$ yr

$T_{1/2}^{2\nu \to 2_1^+} > 4.4 \times 10^{21}$ yr (90 % c.i.)

Background Model

$b = 2.7^{+0.7}_{-0.6} \times 10^{-3}$ counts/keV/kg/yr

2νββ Decay & Spectral Shape

$T_{1/2}^{2\nu} = (7.07 \pm 0.02\ (\text{stat.}) \pm 0.11\ (\text{syst.})) \times 10^{18}$ yr

$\xi_{3,1} = 0.45 \pm 0.03$ (stat.) ± 0.05 (syst.)

$g_{A,eff} = 1.11 \pm 0.03$ (stat.) ± 0.05 (syst.) ISM

$g_{A,eff} = 1.0 \pm 0.1$ (stat.) ± 0.2 (syst.) pn-QRPA

CUPID-Mo successfully demonstrated scintillating bolometer technology for use in CUPID

Most precise 2νββ decay half-life in ^{100}Mo and first of its type spectral shape and $g_{A,eff}$ result

Upcoming results on ^{56}Co detector response for escape peaks vs. primary photo peaks

References

1. *The CUPID-Mo experiment for neutrinoless double-beta decay: performance and prospects*, **EPJC 80, 44 (2020)**
2. *CUPID pre-CDR*, **arXiv:1907.09376**
3. *Final results on the 0νββ decay half-life limit of ^{100}Mo from the CUPID-Mo experiment*, **EPJC 82, 1033 (2022)**
4. *New measurement of double-β decays of ^{100}Mo to excited states of ^{100}Ru with the CUPID-Mo experiment*, **Phys. Rev. C 107, 025503 (2023)**
5. *The background model of the CUPID-Mo 0νββ experiment*, **EPJC 83, 675 (2023)**
6. *Improved description of the 2νββ-decay and a possibility to determine the effective axial-vector coupling constant*, **Phys. Rev. C 97, 034315 (2018)**
7. *Angular Distributions of Emitted Electrons in the Two-Neutrino ββ Decay*, **Universe 7(5), 147 (2021)**
8. *Measurement of the 2νββ Decay Rate and Spectral Shape of ^{100}Mo from the CUPID-Mo Experiment*, **Phys. Rev. Lett. 131, 162501 (2023)**
9. *See thesis by L. Imbert for more:* **https://theses.hal.science/tel-04266831**