Search for neutrinoless double electron capture of ^{40}Ca with AMoRE experiment

Poster session 2 / 320

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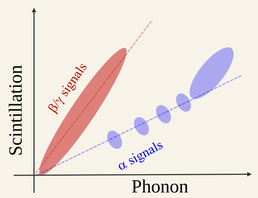
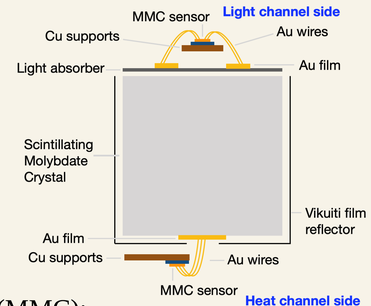
Introduction

- Neutrinoless double electron capture ($0\nu2EC$) is a lepton-number-violating process.
- Its observation would suggest Majorana nature of neutrinos.
- $0\nu2EC$ provides a complementary probe to $0\nu\beta\beta$ decay searches.
- ^{40}Ca, contained in $CaMoO_4$ crystal, is a promising isotope for this study.
- AMoRE-I provides a low-background cryogenic detector setup for rare-event searches.
- We investigated the $0\nu2EC$ in ^{40}Ca ($Q_{2EC} = 193.5$ keV) using live-time exposure of 7.32 kg·yr from the AMoRE-I experiment.

Detector Concept

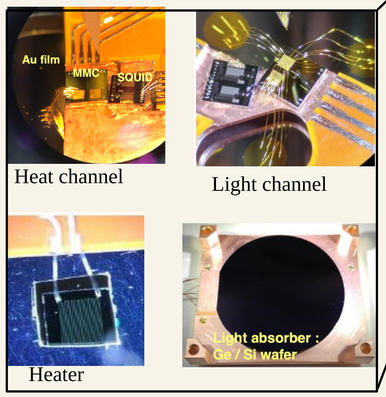
❖ Simultaneous read-outs of phonon and photon with scintillating calorimeters for α rejection.

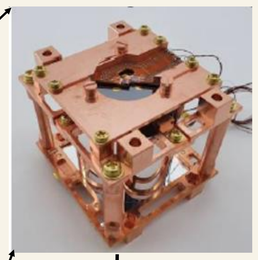


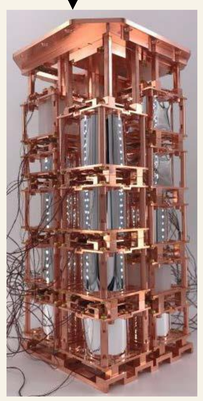


❖ Metallic Magnetic Calorimeter (MMC):

- Fast response: few ms rise-time for phonon at mK
- Good energy resolution ~10 keV at 2.6 MeV γ
- Wide dynamic range
- High linearity







❖ 18 Molybdate crystals:

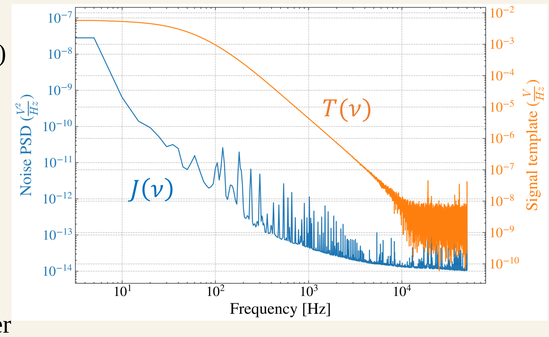
- 13 $^{40}Ca^{100}MoO_4$ (CMO) & 5 $Li_2{}^{100}MoO_4$

❖ The experiment was conducted at the Yangyang Underground Laboratory (Y2L), with ~700 m rock overburden, during 2020–2023 [1].

Data Analysis

❖Data trigger:

- r trigger (**Poster #446, Yoomin Oh**)



❖ Energy reconstruction:

- Optimal filter [2]

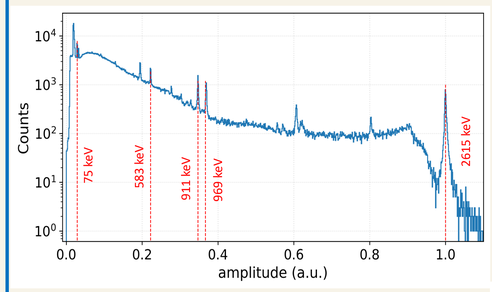
$$A = \frac{\sum_\nu S^*(\nu)\, T(\nu)/J(\nu)}{\sum_\nu |T(\nu)|^2/J(\nu)}$$

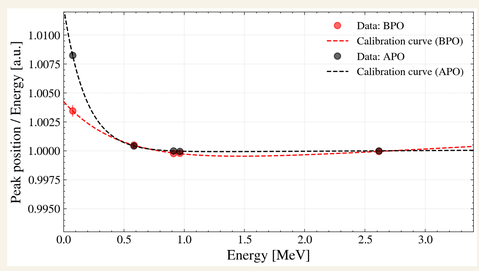
$S(\nu)$: event signal

- Baseline as drift correction parameter

❖Energy calibration

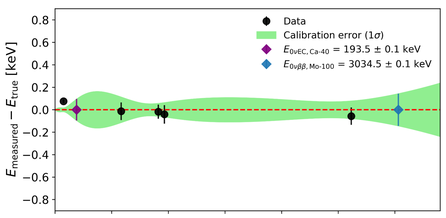
- First step: $\frac{A}{E} = p_0 + p_1 E$ using 583, 911, 969 & 2615 keV γ
- Second step: $\frac{A}{E} = p_0' + p_1' E + p_2 \exp(-p_3' E)$, using four γ rays + 75 keV Pb X-ray
- Bukin function $P(E, \mu, \sigma_p, \xi, \rho_l, \rho_r)$; better fit to the asymmetric peak shape [3]
- Discontinuous shift in the detector response after an unexpected power outage in November 2021. Hence data is divided into two groups: BPO & APO

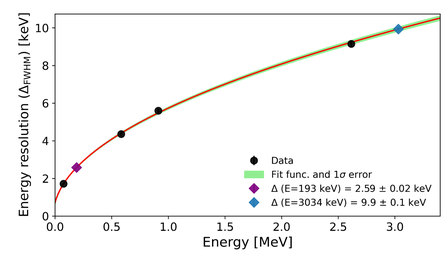




❖ROI estimation

- Offset between measured and true energy is minimized after 2nd calibration
- ER is modeled by using:
  - $\Delta_{FWHM}(E) = (a \times E^2 + b \times E + c)^{\frac{1}{2}}$
  - About 2.5 to 4 keV FWHM ER for most of the crystal detectors.

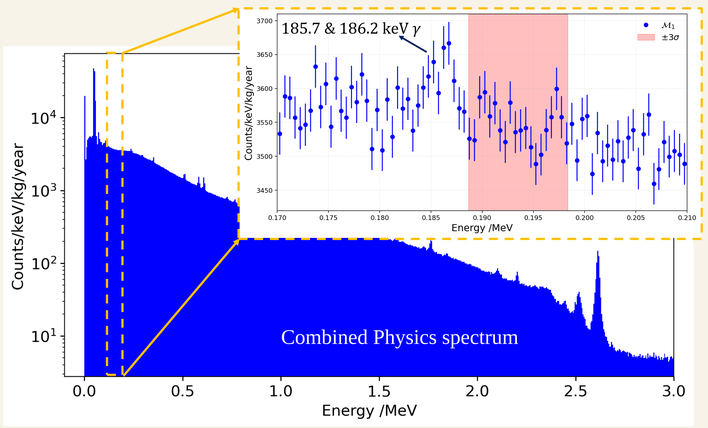




❖Event selection

1. Precut
   - Rejects non-physical signals
2. Anti-coincident cut
   - Applied to reject multi-site background events
   - There are 2 types: Multiplicity and muon veto cut

Limit on the $0\nu2EC$ half-life of ^{40}Ca

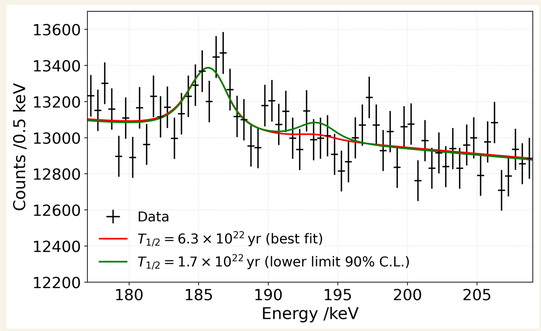


- Full-energy absorption detection efficiencies (ϵ_{cont}) for 2EC channels obtained by using GEANT4
- Total detection efficiency (ϵ) = 86-92% after considering all efficiencies (trigger efficiency & anti-coincident survival efficiency)
- Signal model per dataset:

$$S(E) = \frac{\Gamma\, \eta\, \epsilon\, N_A\, m \cdot t}{M_{CMO}}\, P(E, \mu, \sigma_p, \xi, \rho_l, \rho_r)$$

- Fit model: signal + 2 backgrounds; Gaussian priors for μ, σ_p, ξ, ρ_l, ρ_r and ϵ.

Results & Summary



- No statistically significant excess is observed.
- ^{40}Ca $0\nu2EC$ limit:
  - $T_{1/2}^{0\nu} > 1.7 \times 10^{22}$ yr at 90% C.L.
  - Median sensitivity: $2.0^{+0.8}_{-0.6} \times 10^{22}$ yr
- Strongest limit to date, improving the CRESST-II result [4]
  - $T_{1/2}^{0\nu} > 1.4 \times 10^{22}$ yr
- AMoRE-II projection [5]:
  - sensitivity $9^{+4}_{-3} \times 10^{22}$ yr, factor of 5 improvement than AMoRE-I

References: [1] A. Agrawal *et al.*, [AMoRE Collaboration], *Phys. Rev. Lett.* 134, 082501 (2025). [2] F. Toshi *et al.*, *Phys. Rev. D.* 109, 043035 (2024). [3] https://root.cern.ch/doc/master/classRooBukinPdf.html [4]. G. Angloher *et al.*, *J. Phys. G: Nucl. Part. Phys.* 43, 095202 (2016). [5] A. Agrawal *et al.*, [AMoRE Collaboration], *Eur. Phys. J. C* 85, 9 (2025)