Toward Sensitivity to the Neutrino Hierarchy with Quantum Calorimetry

Rare Processes and Precision Frontier Town Hall Meeting
RF4: Baryon and Lepton Number Violating Processes
October 2, 2020, 13:38-13:45 PM Eastern

Danielle H. Speller (JHU), Yury Kolomensky (UCB/LBL), Lindley Winslow (MIT) on behalf of the CUPID Group of Interest

LOI for Topical Groups: NF5; NF3, RF4, CF1, IF1, IF2, UF03, IF7
Physics and Motivation

Motivation: The discovery of lepton number violation through the observation of neutrinoless double-beta decay

- Neutrinoless double-beta decay as mediated by Majorana neutrinos
- 1-Ton isotope experiment: sensitivity to the normal hierarchy

Secondary Studies

- Tri-nucleon decays for B-violation
- Majoron and CPT violation searches
- Charge conservation studies
- Solar axion searches
- Low-mass WIMP searches
- Searches for fractionally charged particles
- Solar neutrinos
- Other studies
The CUPID 1T Concept: Target Design Goals for a Ton Scale Cryogenic Bolometer

**CUPID-1T Concept: Based on Baseline Experience from CUORE & CUPID**

**Hallmarks**
- 1000 kg of $^{100}$Mo in a new cryostat and/or multiple facilities worldwide, with 4x volume of CUORE
- Sensitivity: $T_{1/2} > 8 \times 10^{27}$ years (3$\sigma$), $m_{\beta\beta} > 4$-7 meV (NH)

**Requirements**
- Reduction in the background compared to CUPID (x20)
- Readout for O(10k) crystal array

**Potential Expansions**
- Large volume cryogenic facilities in multiple UG labs worldwide
- Possible detector parameters:
  - Main detectors:
    - $\sim$1900 kg of Li$_2$MoO$_4$, few keV thresholds possible
  - Light detectors:
    - $\sim$6200 units, 68 kg of Ge (or 29 kg of Si)
    - O(10 eV) threshold, active $\gamma$ and surface veto
  - Could also deploy specialized towers, e.g. SuperCDMS style DM detectors

**Possible Target Timeline: Construction in late 2020's, Commissioning early 2030's**
From CUPID to CUPID-1T: Multi-Site Possibilities

- China Jinping Underground Laboratory (CJPL) – Jinping, China
- Gran Sasso National Laboratories (LNGS)* – Assergi, AQ, Italy
- Kamioka Observatory – Hida, Japan
- Sanford Underground Research Facility (SURF) – Lead, SD, USA
- SNOLAB – Sudbury, Canada
- Stawell Underground Physics Laboratory (SUPL) – Stawell, Australia
- Yangyang Underground Laboratory (Y2L) – South Korea

*Home of CUORE/CUPID

Map: Wolfram Mathematica
CUPID Collaboration R&D & Schedule

Ongoing R&D for CUPID (independent of 1T concept)

- Development of TDR for CUPID
- Detector readout technologies to mitigate technical risks
  - Core competence: NTD sensors
  - Cryogenic electronics, multiplexing solutions: synergy with QIS
  - High-performance sensors (TES)
- Readiness to deploy a ton-scale experiment
  - Development of US-based vendors for LMO crystals
  - Participation in LMO pilot experiments at Modane and LNGS
  - Isotopic enrichment of $^{100}$Mo, $^{130}$Te, TeO$_2$ crystal production
  - Cryogenic operations, in-situ calibration schemes
- Verification of cosmogenic backgrounds in TeO$_2$ and LMO
  -Muon veto in CUORE

R&D for CUPID-1T (Current and potential new directions)

- Superconducting coating of crystals to enhance PSD capabilities (CROSS @ Canfranc)
- Active $\gamma$ veto (synergy with low-mass DM experiments)
- High-speed superconducting sensors (TES, MKID)
- Multiplexed readout (synergy with CMB)
- Cryogenic CMOS ASIC developments (synergy with QIS); support for ~10K channels in one (or more) cryostat(s)
- Physics/Sensitivity Simulations

Schedule – Ongoing R&D for CUPID through

Discussion – Whitepaper
Joint Efforts, Common Datasets, and Desired Outcomes

Key Joint R&D Efforts & Joint Datasets:

- Active $\gamma$ veto (synergy with low-mass DM experiments – CF1)
- Development of high-speed superconducting sensors (TES, MKID) – DM experiments, QIS (IF1, IF2)
- Multiplexed readout systems (IF1, IF7)
- Cryogenic CMOS ASIC developments (synergy with QIS); support for ~10K channels in one (or more) cryostat(s) (IF1, IF2, IF7, UF03)
- Radiopurity and shielding efforts (UF03)
- Physics/Sensitivity Simulations (NF5, NF3)
- Common frameworks for matrix elements (NF5, NF3)
- Common event generators (NF5, NF3)

Desired outcomes for Snowmass 2021:

- Strengthened collaboration between NP and HEP
- Focus on the development of scalability of quantum sensor arrays with robust multiplexing techniques
Key Takeaways

• Discussion of a ton-scale quantum calorimeter now feasible and necessary through convergence of technological capabilities and fundamental physics questions

• New paradigms for detector morphology – possible distribution of towers in laboratories worldwide. New opportunities to host – discussion welcome

• Important connections to QIS via deployment of SQUID-based quantum sensors in large fundamental physics searches, taking advantage of key capabilities in below SQL noise performance and multiplexing (i.e. scaling)