Toward Sensitivity to the Neutrino Hierarchy with Quantum Calorimetry

Rare Processes and Precision Frontier Town Hall Meeting

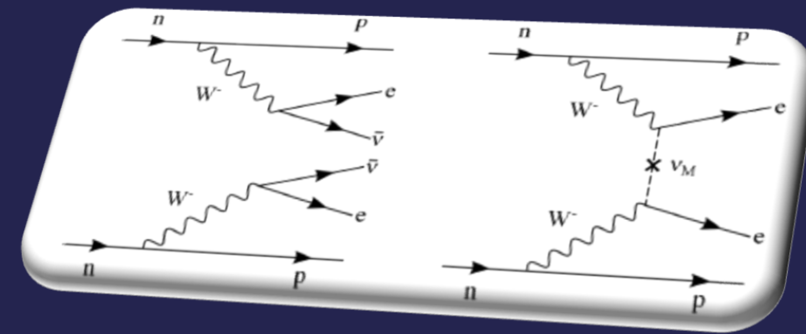
RF4: Baryon and Lepton Number Violating Processes

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

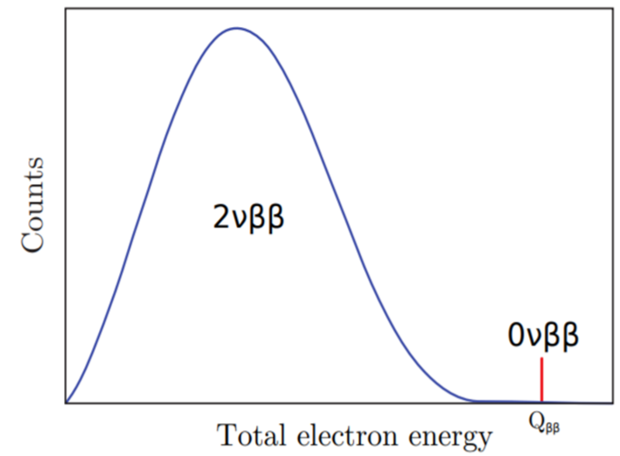
LOI for Topical Groups: NF5; NF3, RF4, CF1, IF1, IF2, UF03, IF7

Physics and Motivation



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

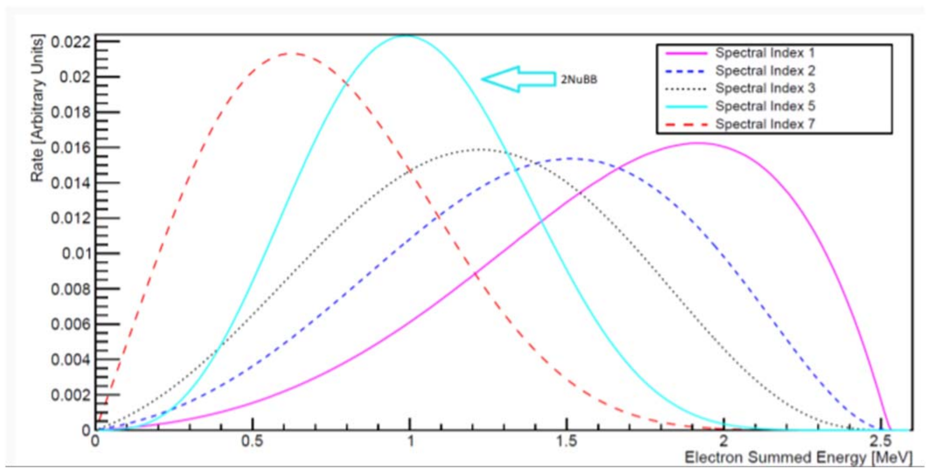
- Neutrinoless double-beta decay as mediated by Majorana neutrinos
- 1-Ton isotope experiment: sensitivity to the normal hierarchy



arXiv:1601.07512v2

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



C. Davis (2018)

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: $T_{1/2}$> 8×10^{27} years (3σ)**, $m_{\beta\beta}$>4-7 meV (NH)

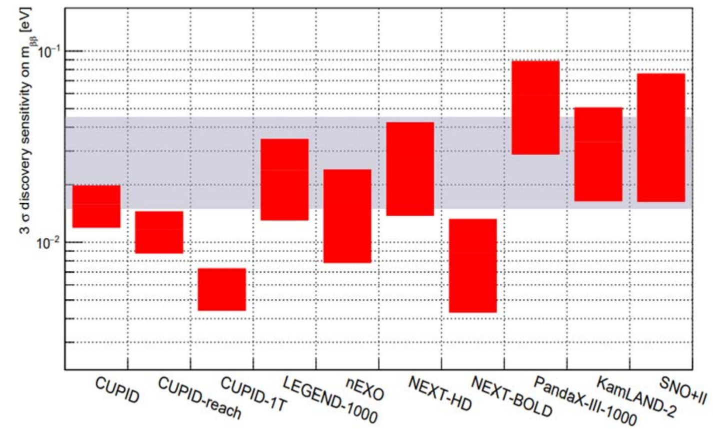
Requirements

- **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:***
    - **~1900 kg of Li_2MoO_4**, few keV thresholds possible
  - ***Light detectors:***
    - **~6200 units, 68 kg of Ge** (or 29 kg of Si)
    - O(10 eV) threshold, active γ 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

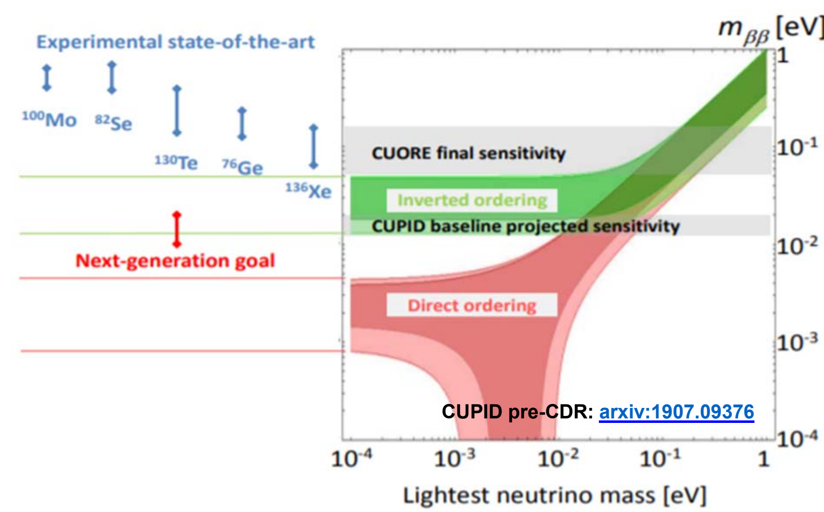


CUPID pre-CDR: exactly what we could start building today: 10^{-4} counts/keV/kg/yr

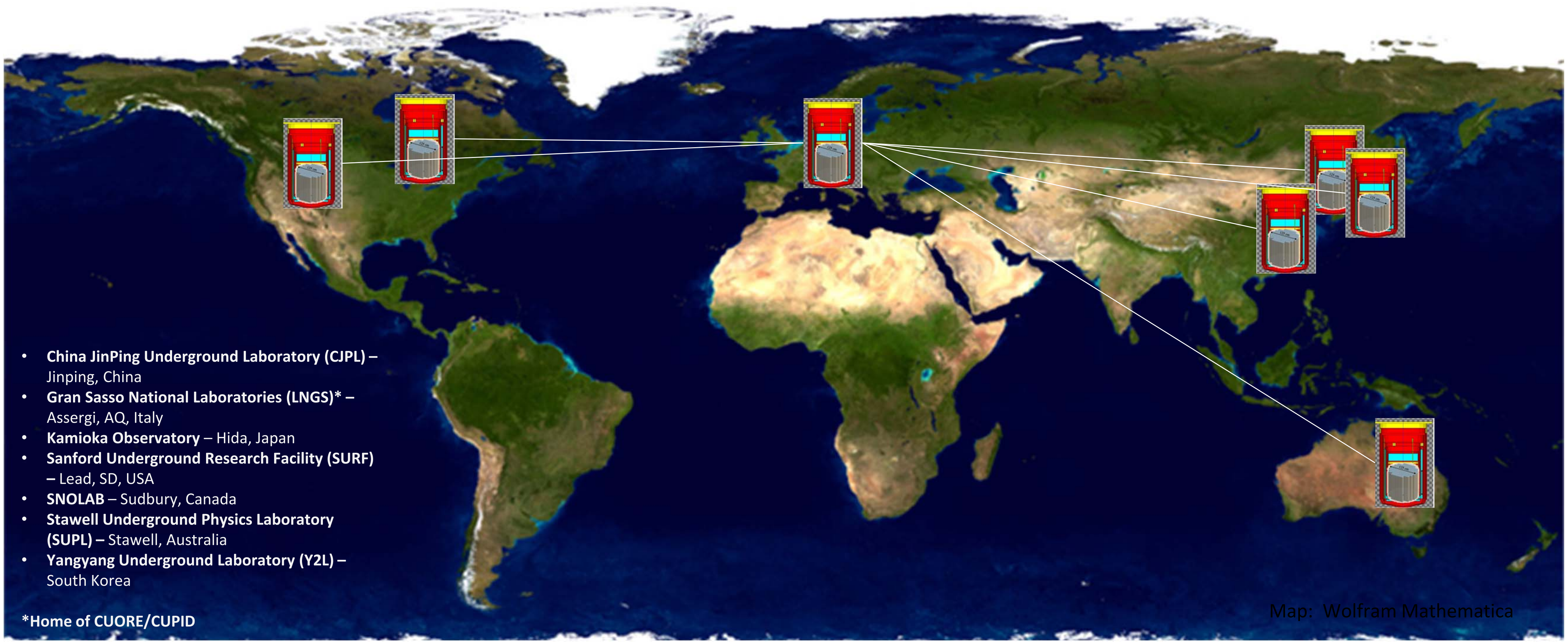
CUPID reach: assume improvement at reach before construction: $2\cdot10^{-5}$ counts/keV/kg/yr

CUPID 1Ton: new, 4 times larger (in volume) cryostat, 1 ton 100Mo : $5\cdot10^{-6}$ counts/keV/kg/yr

M. Pavan, CUPID Project Update 13 July 2020



From CUPID to CUPID-1T: Multi-Site Possibilities



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 γ 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 γ 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)

NF5: Neutrino Properties
NF3: BSM Neutrinos
RF4: B-L Violating Processes
CF1: Particle-like DM
IF1: Quantum Sensors
IF2: Photon Detectors
UF03: Underground Detectors
IF7: Electronics/ASICS

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)