Tonne-Scale ββ Overview and Future Large Scintillation Detectors

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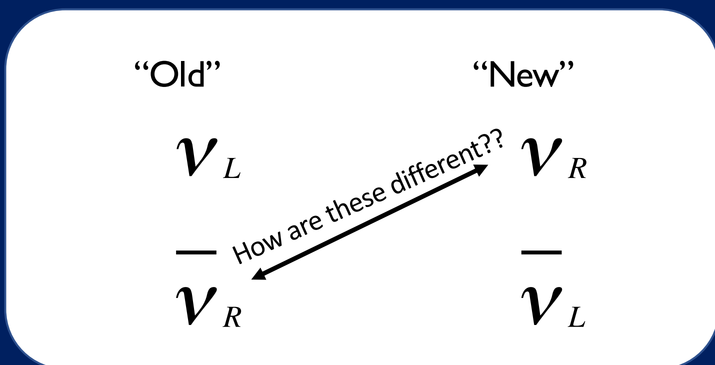
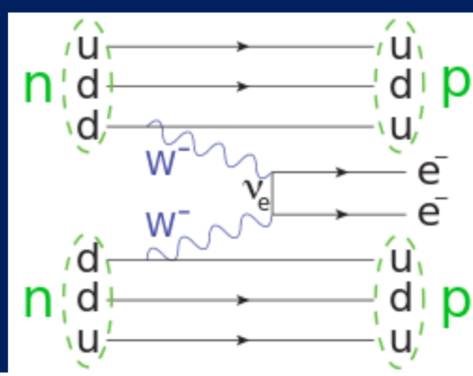
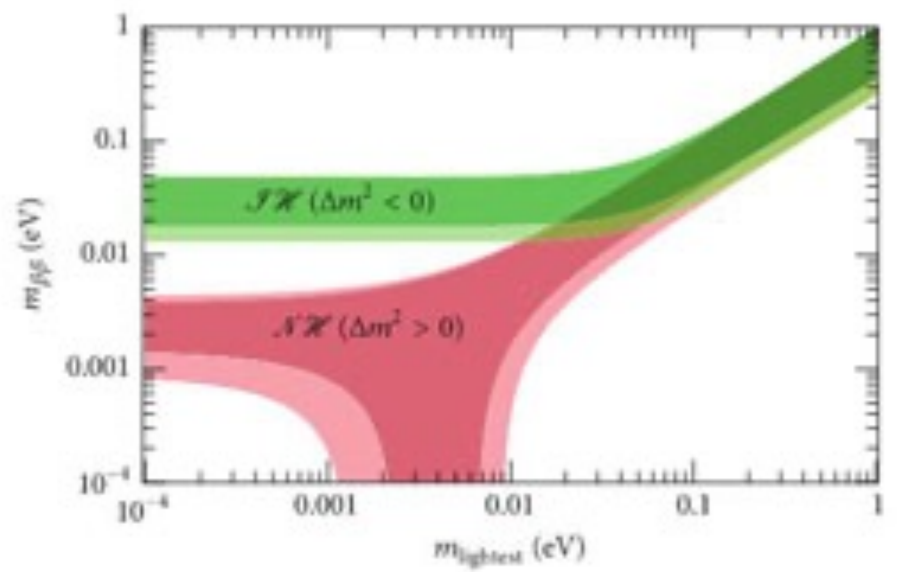
0νββ Decay

- Most critical, contextual question here at Snowmass







(a)

US Tonne-Scale Process

- $0\nu\beta\beta$ experiments are under the rubric of "nuclear physics"

REACHING FOR THE HORIZON

The 2015
LONG RANGE PLAN
for NUCLEAR SCIENCE

We recommend the timely development and deployment of a U.S.-led ton-scale neutrinoless double beta decay experiment.

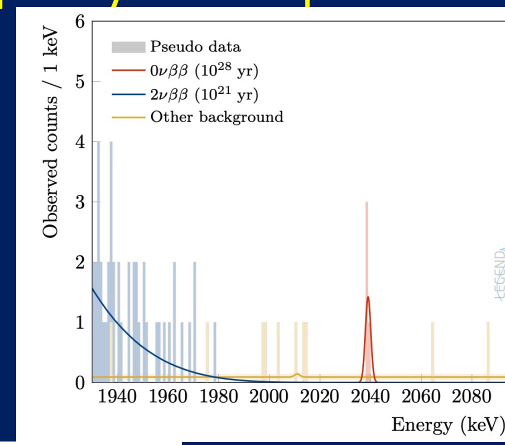
US Tonne-Scale Process

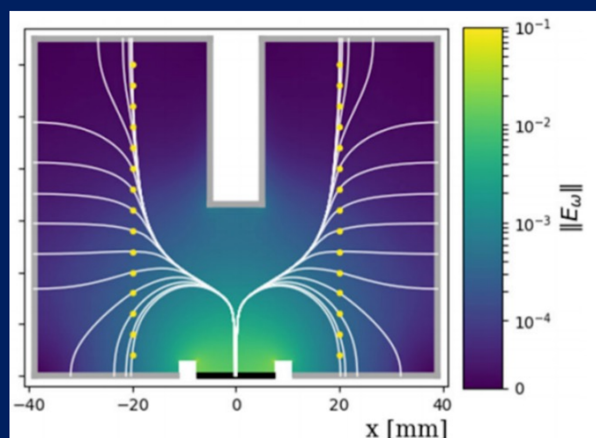
Since 2015

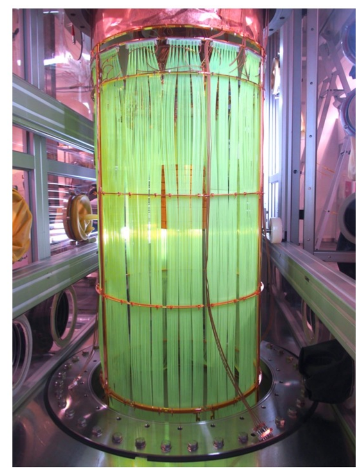
- R&D Review of many different programs
- Funding for several of these
- “Portfolio Review” of tonne-scale possibilities deemed ready, Summer 2021
  - LEGEND1000
  - nEXO
  - CUPID
- International Funding agency discussions in Fall of 2021
- Strong vocal support for a multi-isotope strategy
- Funding from DOE/NP typically quoted as “$200-$250 M”
- Full program will require significant international contributions

LEGEND1000

- Merger of GERDA and MAJORAN Collaboration for high-purity ^{76}Ge experiment
- LAr veto helps with cosmogenic and other backgrounds
- Excellent energy resolution
- New Ge technology for particle ID
- LEGEND200 (200 kg) already underway
- Zero background goal for 10^{28} y lifetime

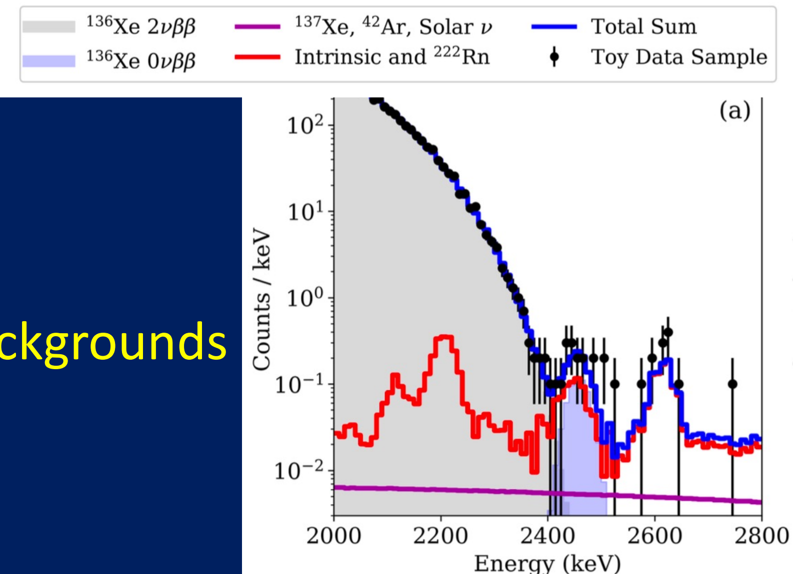


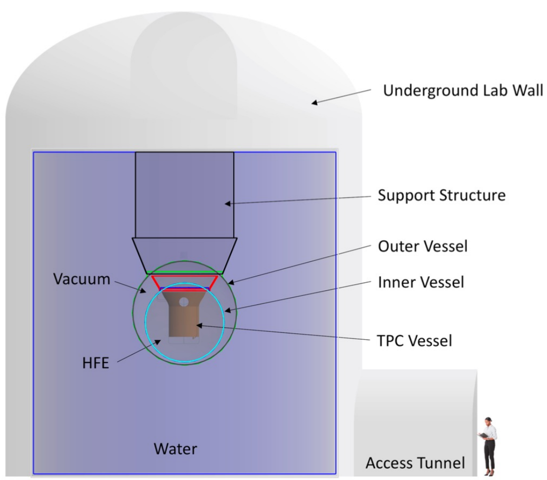


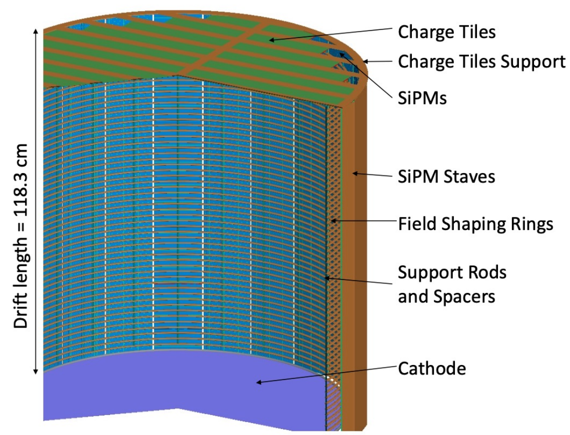


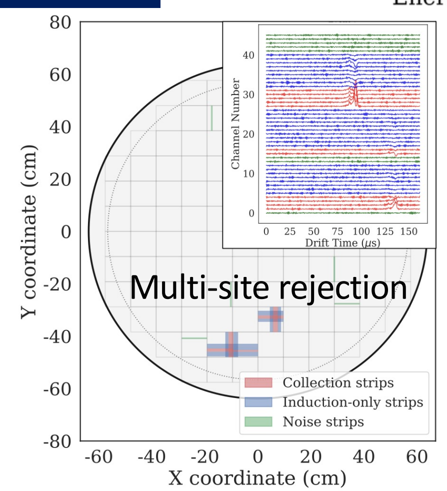
nEXO

- 5 tonne liquid ^{136}Xe TPC
- Builds on successful EXO-200[kg] detector
- Fiducialization, multi-site rejection, reduce backgrounds
- Final analysis is full multi-D likelihood fit
- Favored location SNOLAB



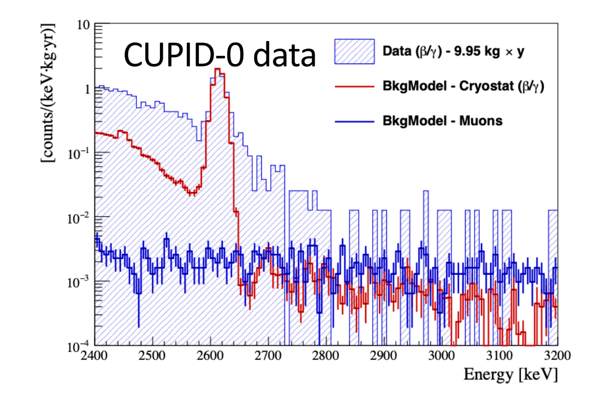


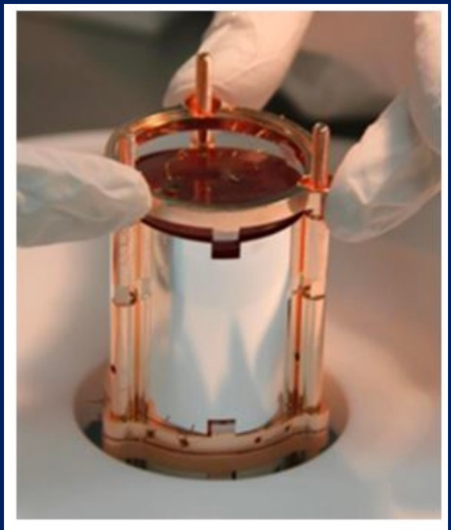


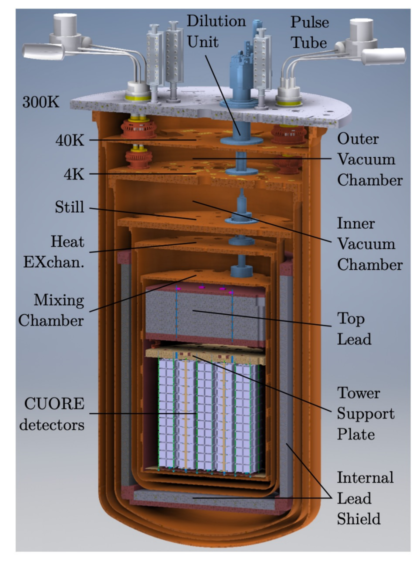


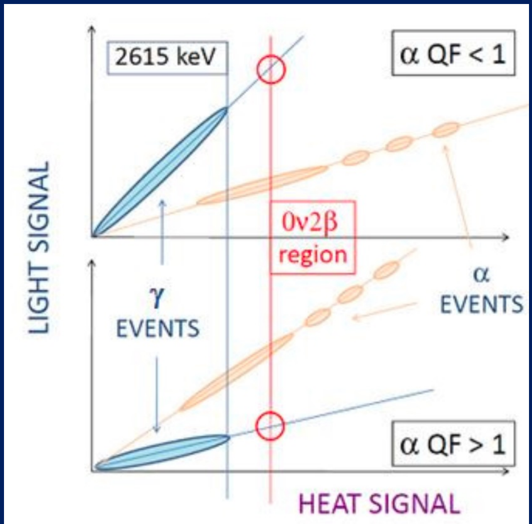
CUPID

- "CUORE+Particle ID" --> *scintillating* bolometers
- Bkgds rejected via heat/light ratio and high endpoint
- Initially 450 kg of ^{100}Mo; plan to move toward 1 tonne
- Re-use CUORE cryostat for big cost savings
- Located at LNGS







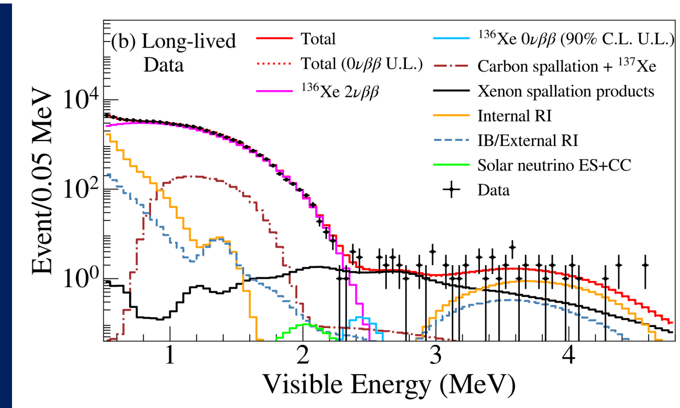


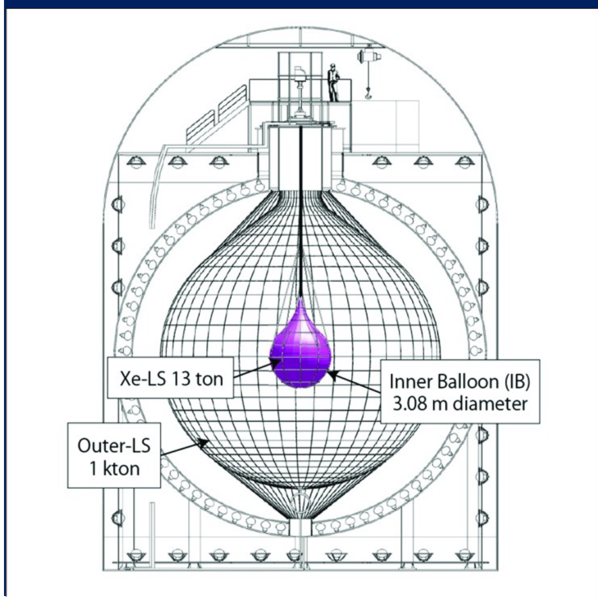
Liquid Scintillator Approaches

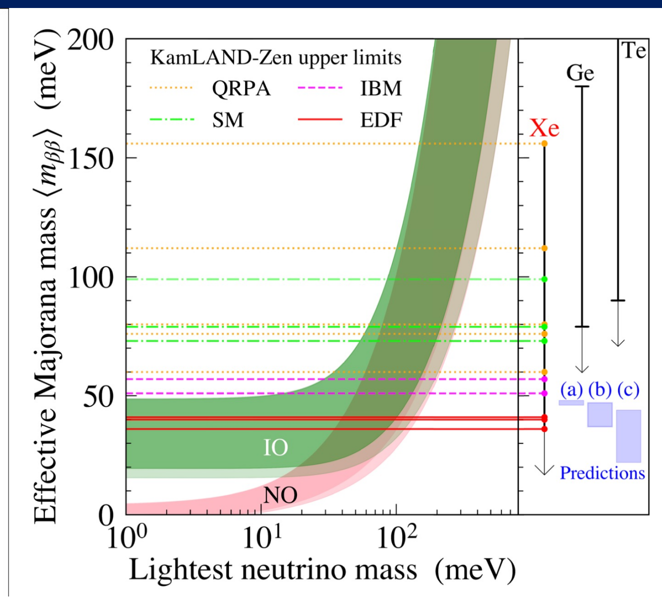
- Break the detector=isotope scaling rules
- (Many backgrounds stay fixed as isotopic mass goes up)
- (But this means solar neutrinos become a background source)
- Leverages large size to eliminate “external” backgrounds
- Broad program of “signal” physics (e.g. solar, reactor, supernova νs…)
- In some cases re-use existing large-scale detectors to save cost

KamLAND-Zen

- 745 kg ^{136}Xe gas dissolved in LS
- Fiducialization and ML approaches for PID
- Fast timing rejects coincident backgrounds
- Currently leading world in sensitivity

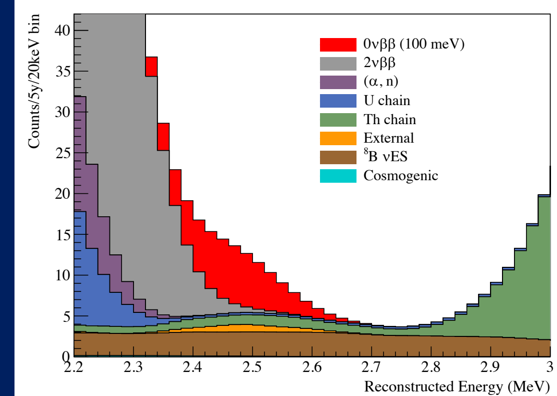


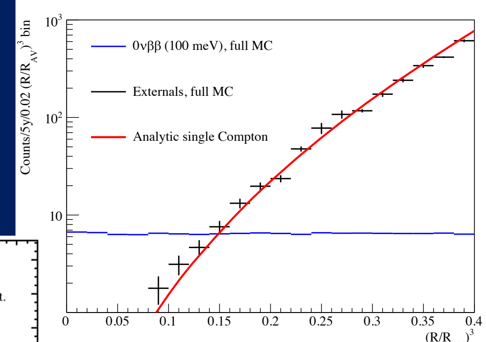


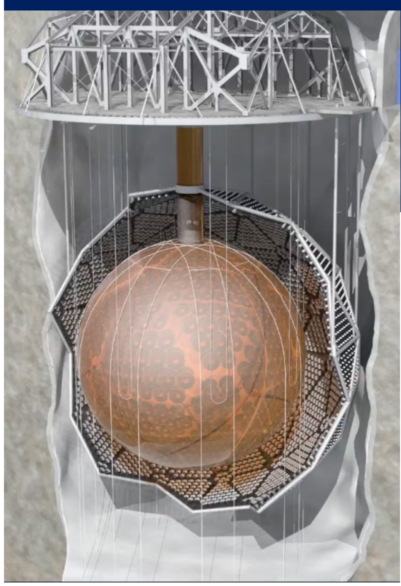


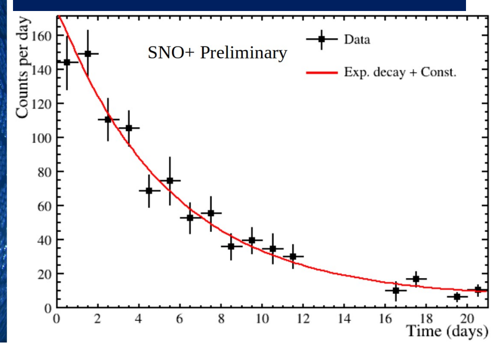
SNO+

- Goal is ~3% loading by mass of *natural* Te in LS
- Underground purification of Te to eliminate cosmics
- Re-uses SNO PMTs and electronics to save cost
- 0.5% level of Te already u/g, cooling down for years
- Te purification and loading plants commissioning now
- Solar and reactor neutrino physics ongoing with scintillator



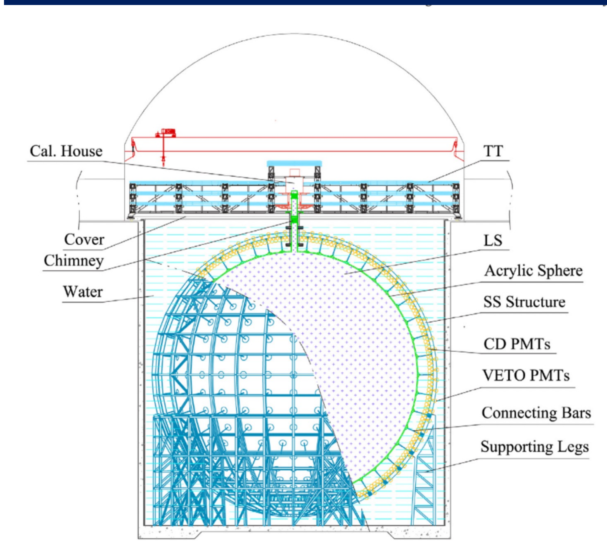


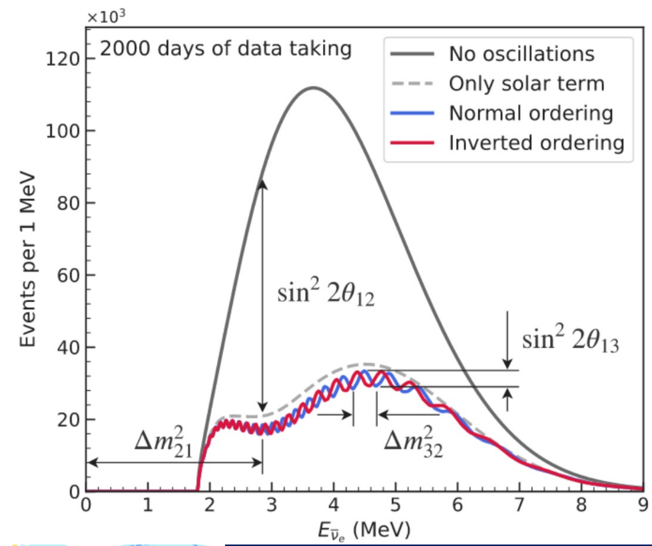




JUNO

- 20 kt of LAB-PPO with very high PMT coverage (80%)
- Reactor antineutrino measurement of MO at distance of ~50 km
- Also precision on θ_{12}, $\Delta m2_{12}$ to < 1%
- Also considering loading Te to do $0\nu\beta\beta$

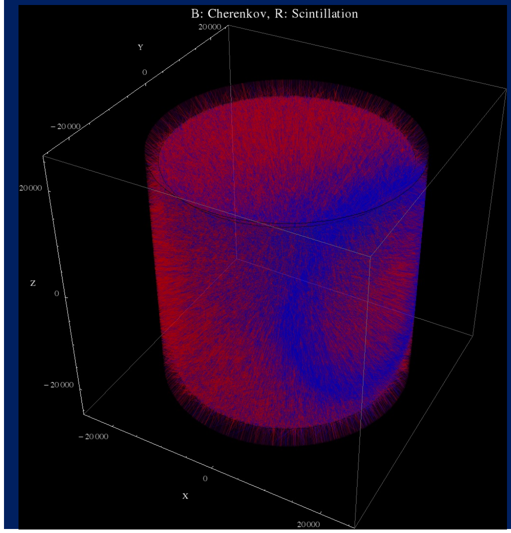


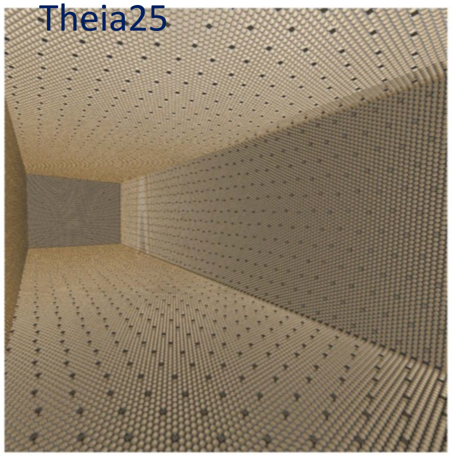


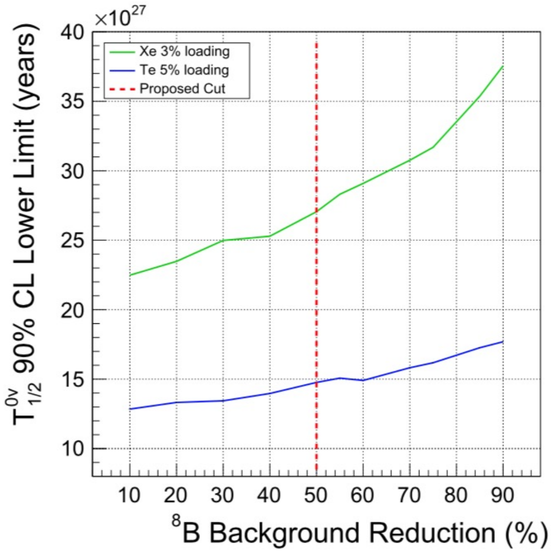
Theia

- Hybrid Cherenkov/scintillation detectors receiving a lot of interest
- 25 kt version could be DUNE Module 4 and broaden physics program
  - Solar neutrinos down to CNO or perhaps even below
  - Diffuse Supernova background νs
  - Long-baseline neutrinos
- At last Snowmass, detectors like this were just an idea
- Would require call for **new space** at SURF

Cherenkov light allows rejection of ^{8}B background







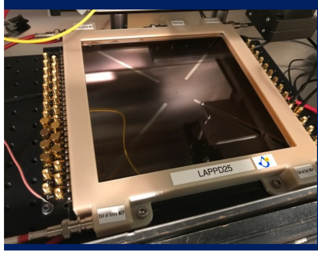
THEIA

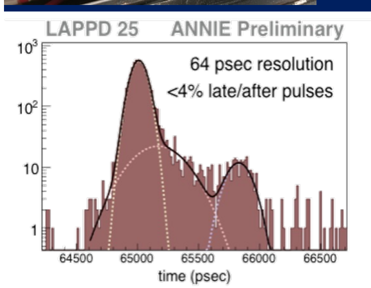
Multiple independent handles achieve:

- **90% purity for Chertons**
- **Little loss of scintons**

Many new technologies for discriminating “chertons” from “scintons”

LAPPDs

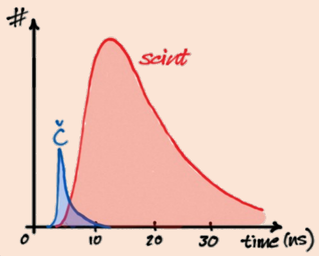




L. Pickard #551

Timing

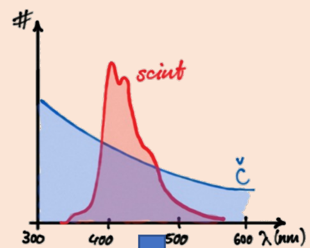
“instantaneous chertons” vs. delayed “scintons”
→ ns resolution or better



M. Wurm

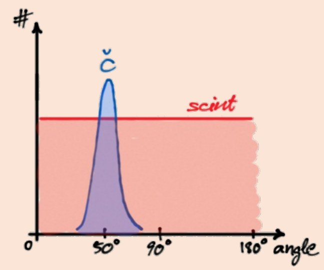
Spectrum

UV/blue scintillation vs. blue/green Cherenkov
→ wavelength-sensitivity

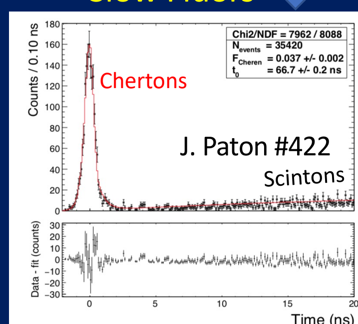


Angular distribution

increased PMT hit density under Cherenkov angle
→ sufficient granularity

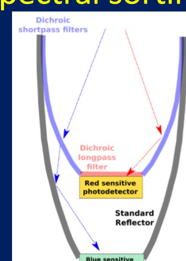


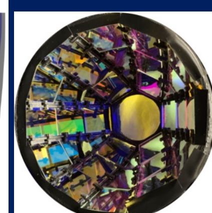
Slow Fluors

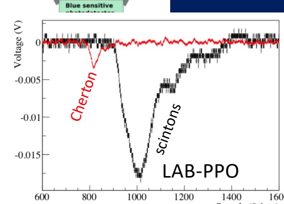


Biller, Leming, Paton NIMA 972 (2020) 164106

Spectral sorting--Dichroicons





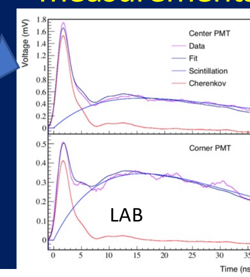


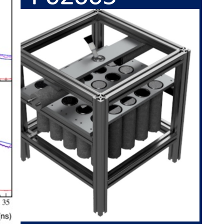
Kaptanoglu et al, PRD 101 (2020) 7, 072002

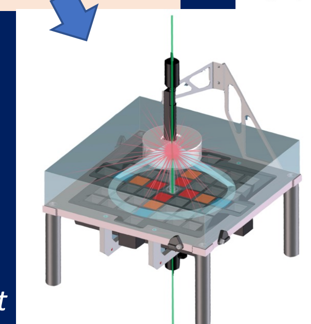
B. Land #472

FlatDot measurements

Gruszko et al, JINST 14 (2019) 02, P02005





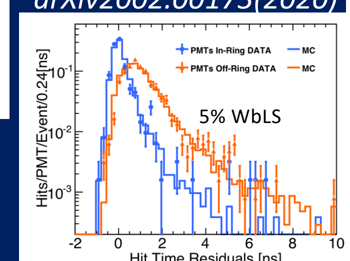


Caravaca et al, EPJC (2017) 77:811

J. Caravaca #490

CHESS Measurements

Caravaca et al, arXiv2002.00173(2020)

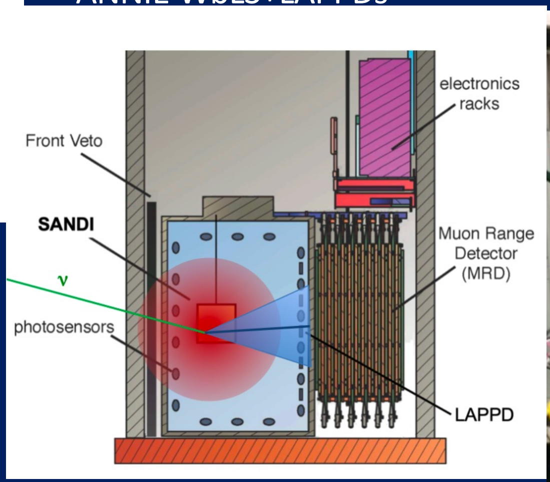


Hybrid Cherenkov/Scintillation Detectors

Existing and upcoming demonstrators:

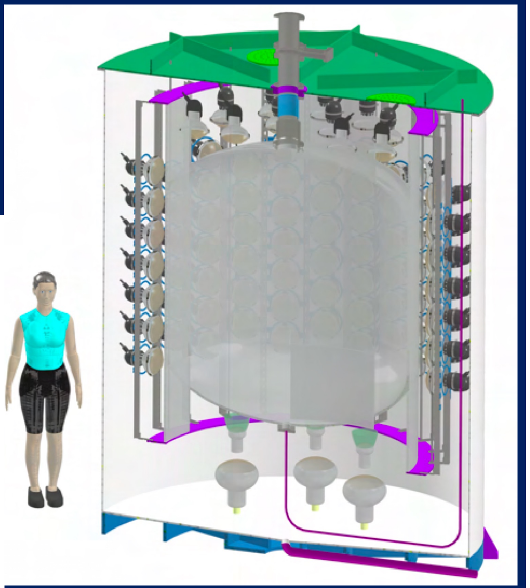
BNL 30 t WbLS

ANNIE WbLS+LAPPDs

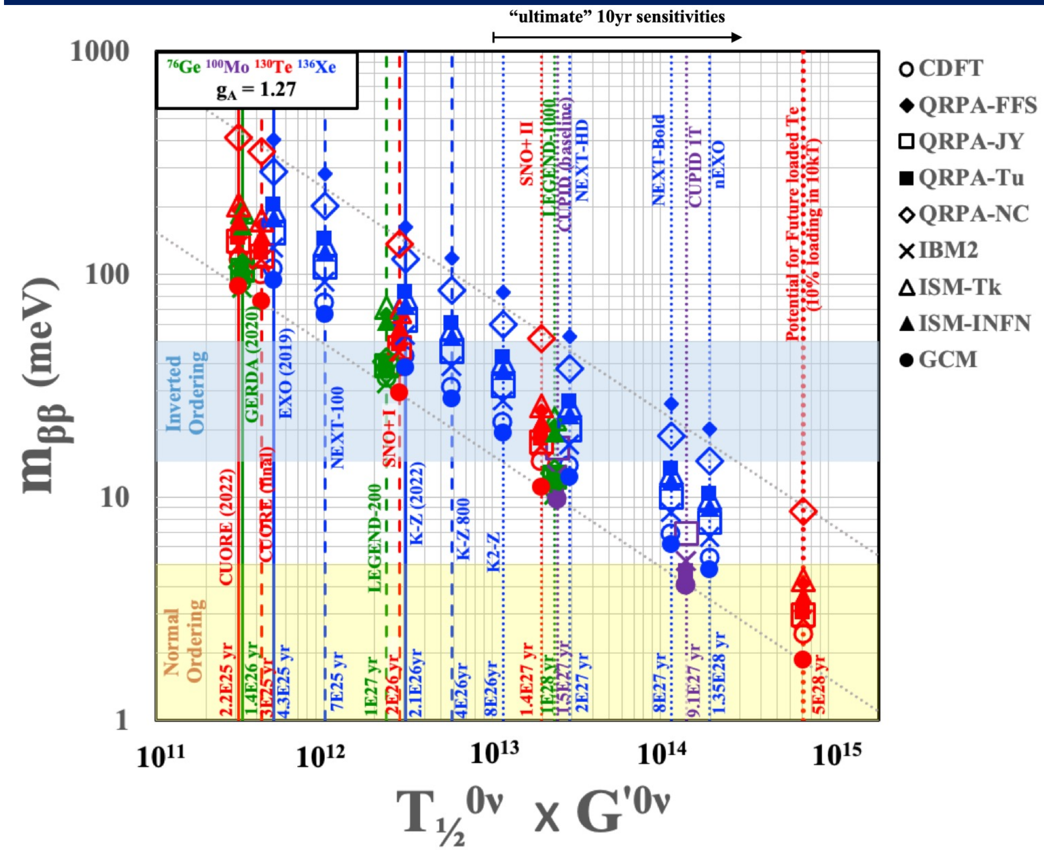


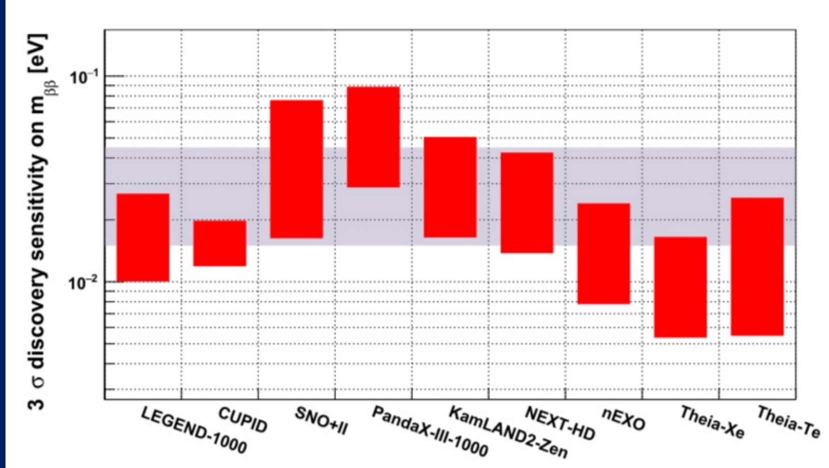
NuDOT

Eos



Sensitivity Comparisons





S. Biller