Discovering the origin of matter with LXe $0\nu\beta\beta$ detectors: nEXO and beyond

Samuele Sangiorgio, LLNL
for the nEXO collaboration

TAUP 2023

Vienna, Aug 30, 2023

LLNL-PRES-853557

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

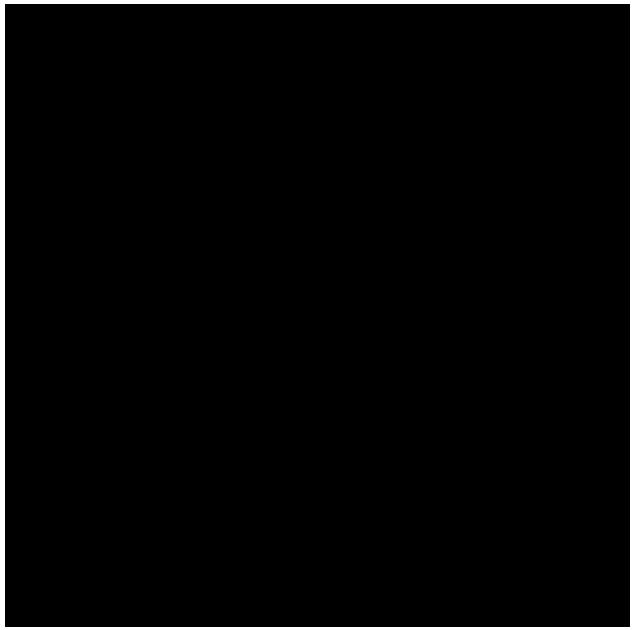
Lawrence Livermore National Laboratory

$0\nu\beta\beta$: a key to unlock new physics

Why does our Universe look like this…

Galaxies, stars, planets, life, all made only of matter

… and not like this?



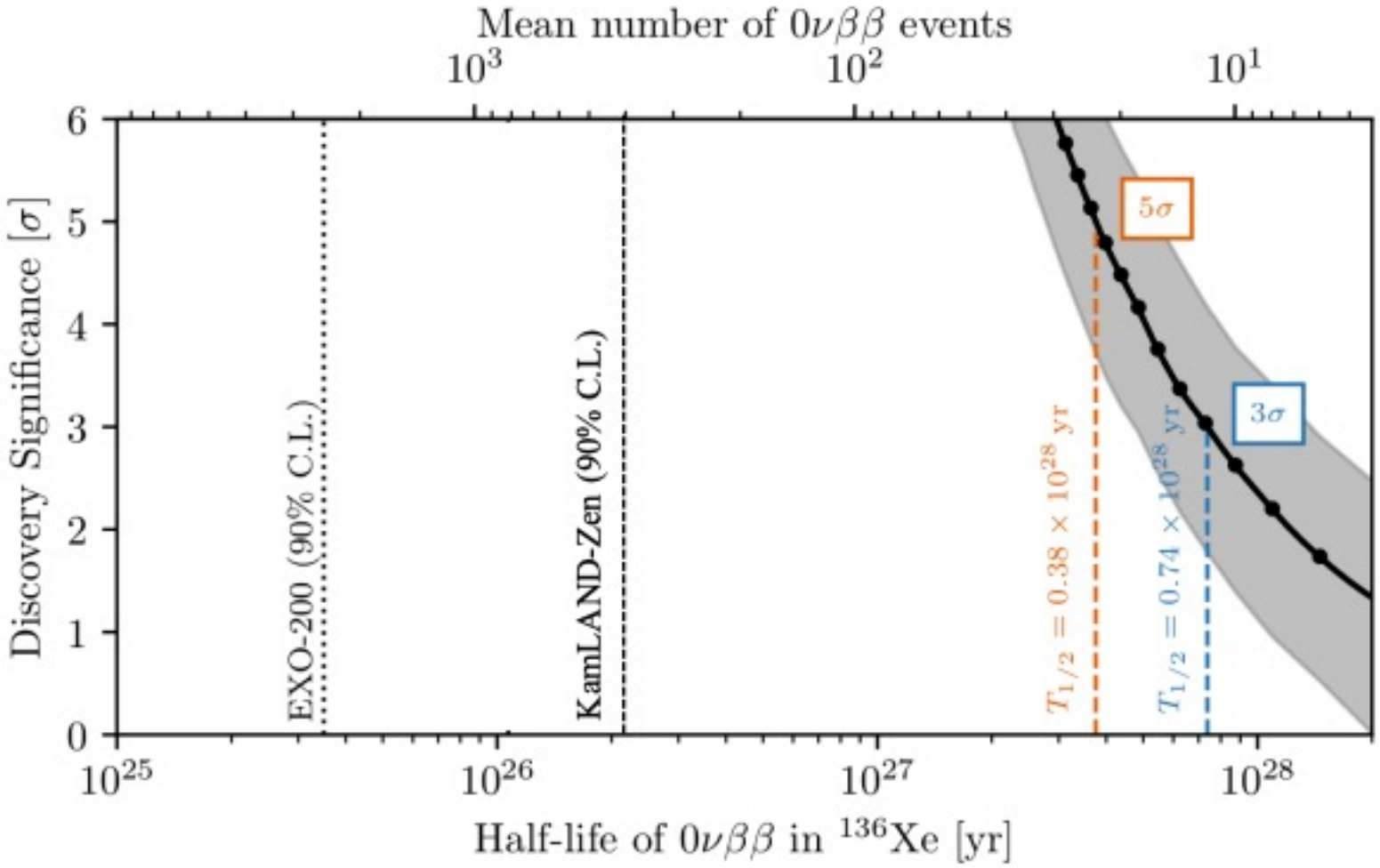
Empty Universe made only of left-over energy from matter-antimatter annihilation

- **What generated the matter/antimatter asymmetry?**
- **What physics is beyond the standard model?**
- **Is lepton number violated?**
- **Are neutrinos Majorana particles?**
- **What is the neutrino mass?**

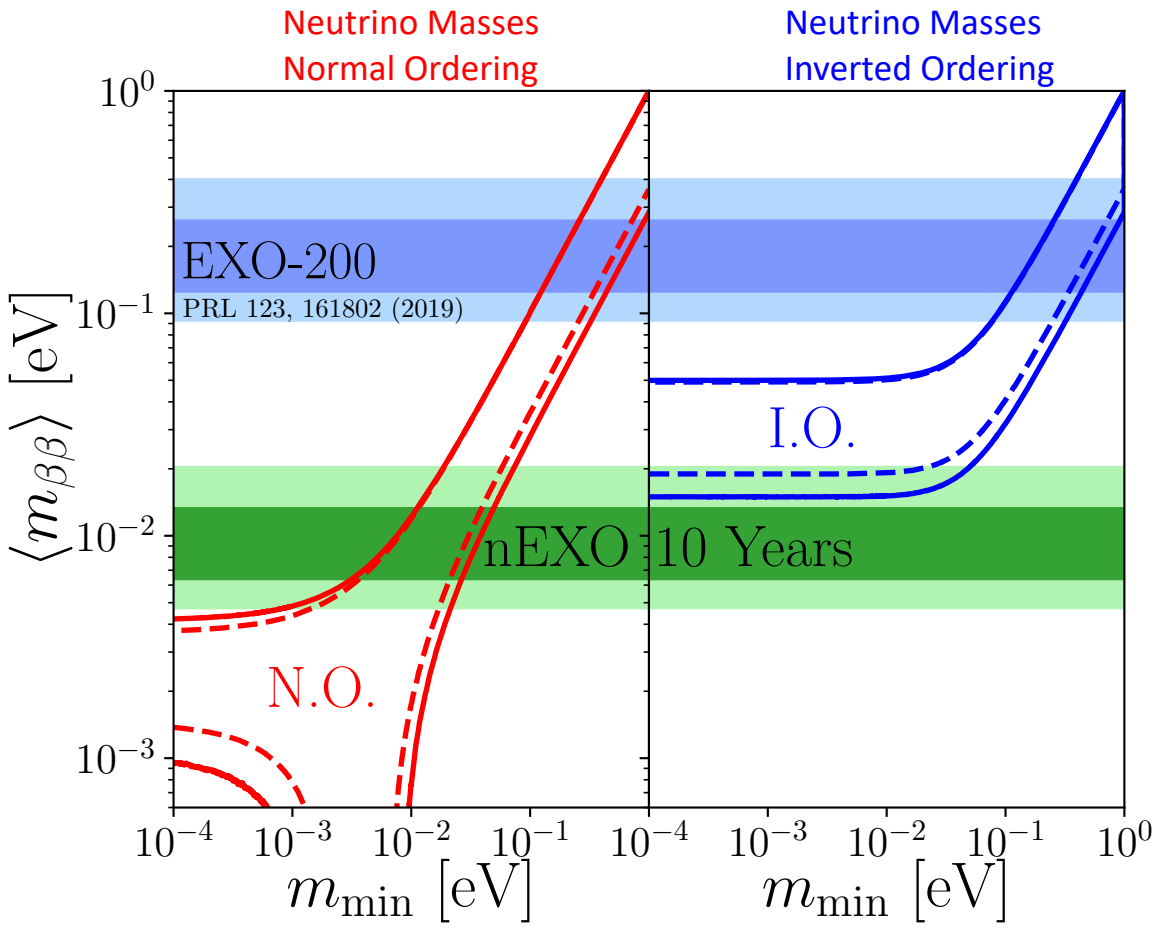
$0\nu\beta\beta$

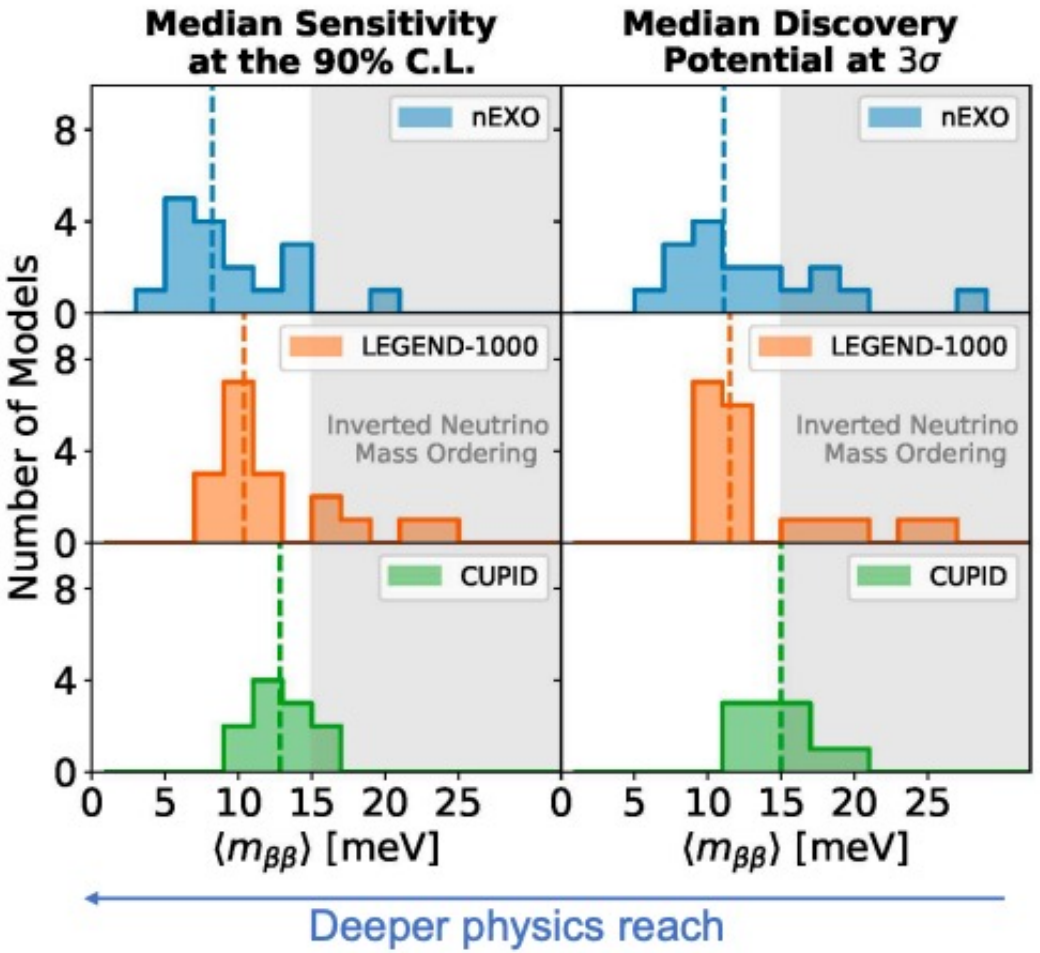
James Webb Telescope's First Deep Field
Image credit: NASA, ESA, CSA, STScI
https://webbtelescope.org/news/first-images

Discovering LNV across a large unexplored parameter space

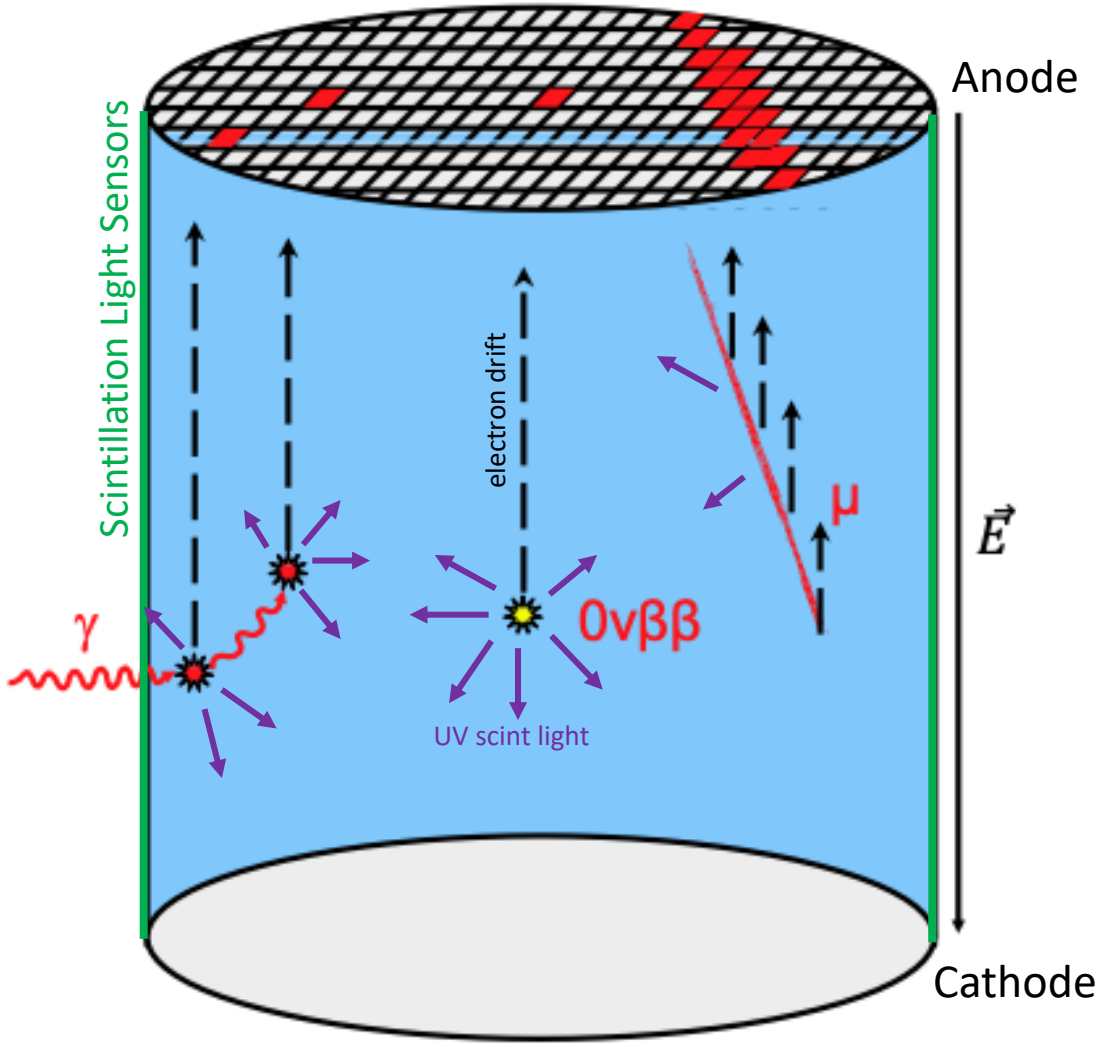


Majorana Neutrino Physics Reach of nEXO





0νββ Search in a LXe Time Projection Chamber (TPC)



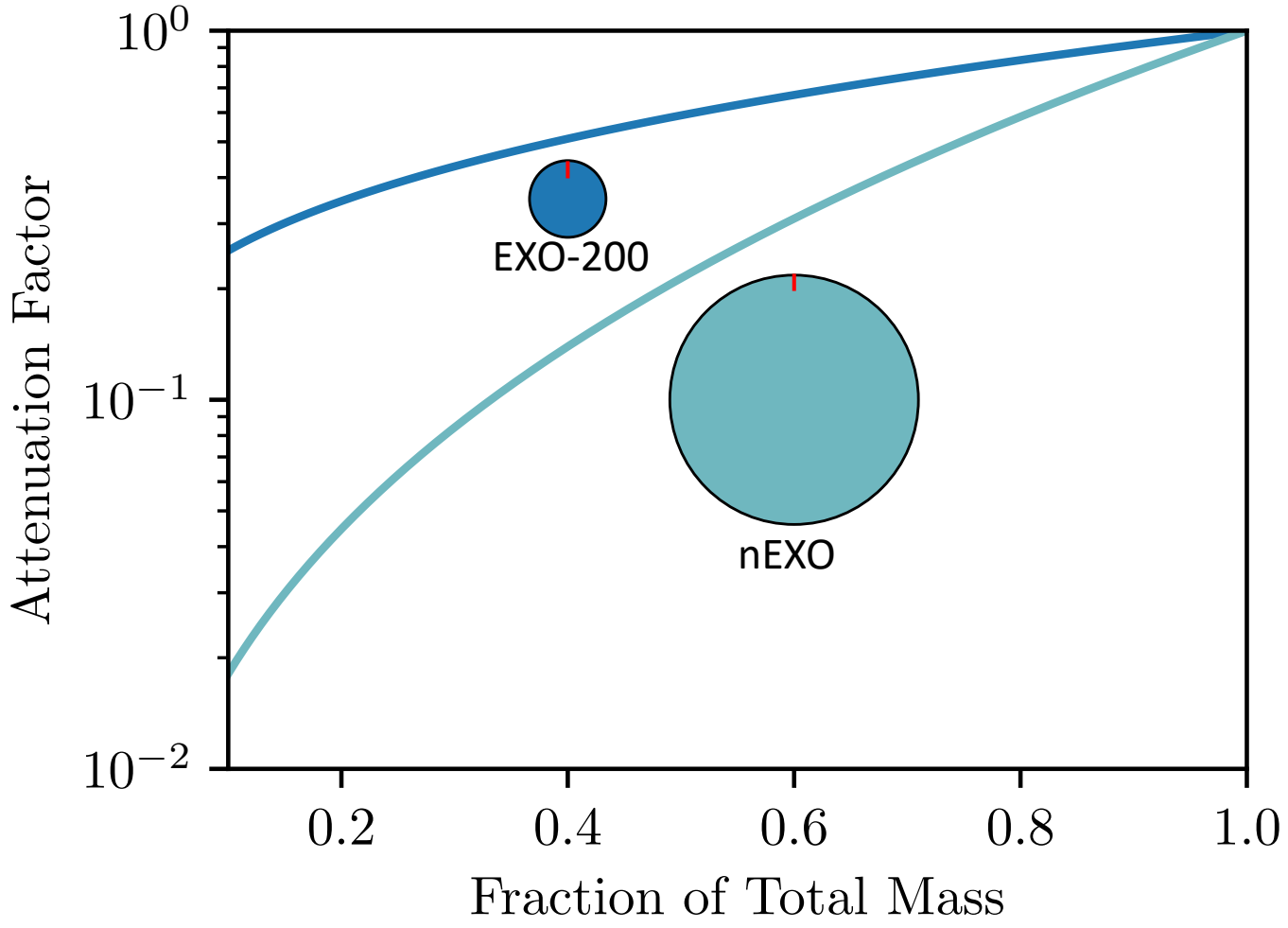
- Single phase LXe TPC measuring
  - Ionization
  - Scintillation
- Multi-parameter Event Reconstruction:
  - Energy (< 1% σE/E)
  - Position
  - Topology (SS vs MS)
- nEXO designed for 5 tonne of LXe enriched to 90% in the ^{136}Xe ββ isotope

Benefits of Homogenous Detector

- All backgrounds come from surrounding materials and surfaces
  → extremely quiet inner region

LXe mass (kg)	Diameter or length (cm)
5000	130
150	40
5	13

2.5 MeV γ attenuation length 8.7cm

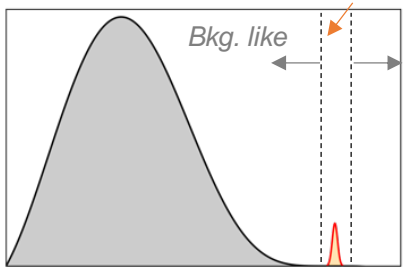


- Liquid xenon is continuously purified
- Discovery self-confirmation thru use of non-enriched xenon
- Intrinsically scalable

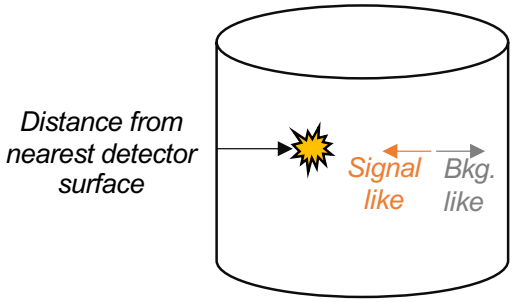
nEXO Signal and Background

- nEXO measures multiple parameters for each event to be able to robustly identify a 0νββ signal
- As a fully homogeneous detector, it precisely measures backgrounds in situ
  - No internal materials (other than Xe), making nEXO uniquely robust against unknown backgrounds

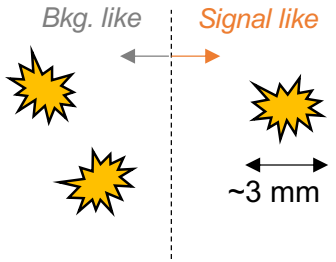
Energy:

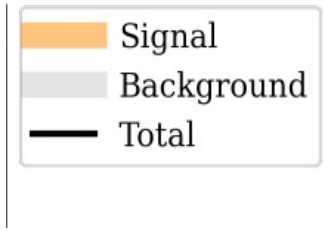


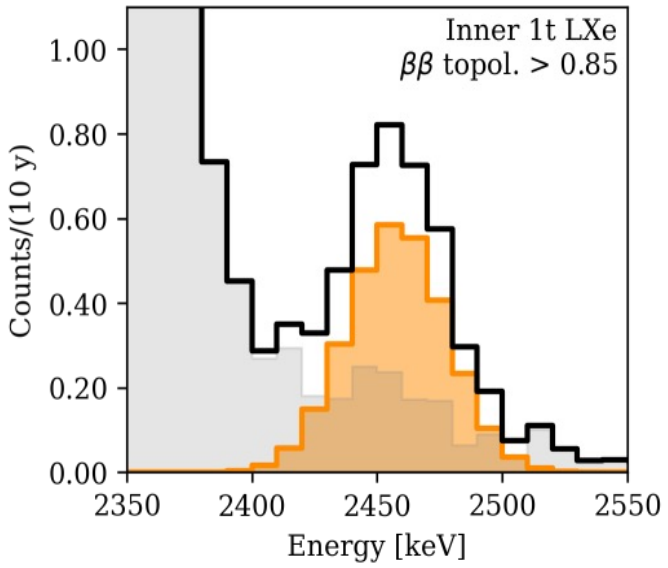
Standoff:

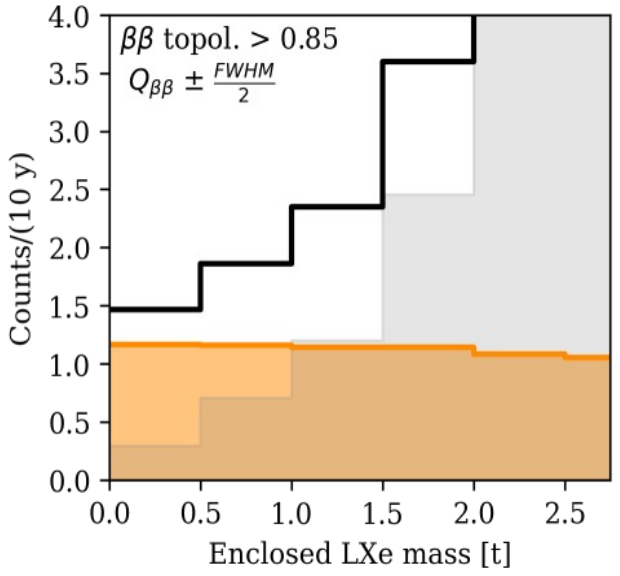


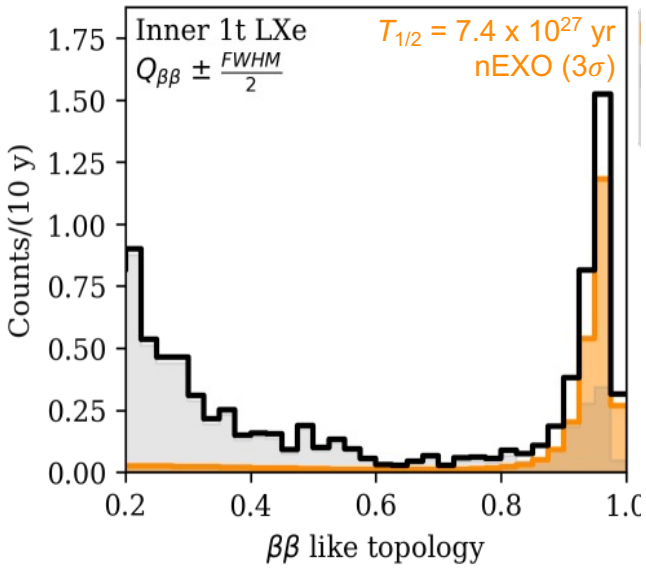
Topology:









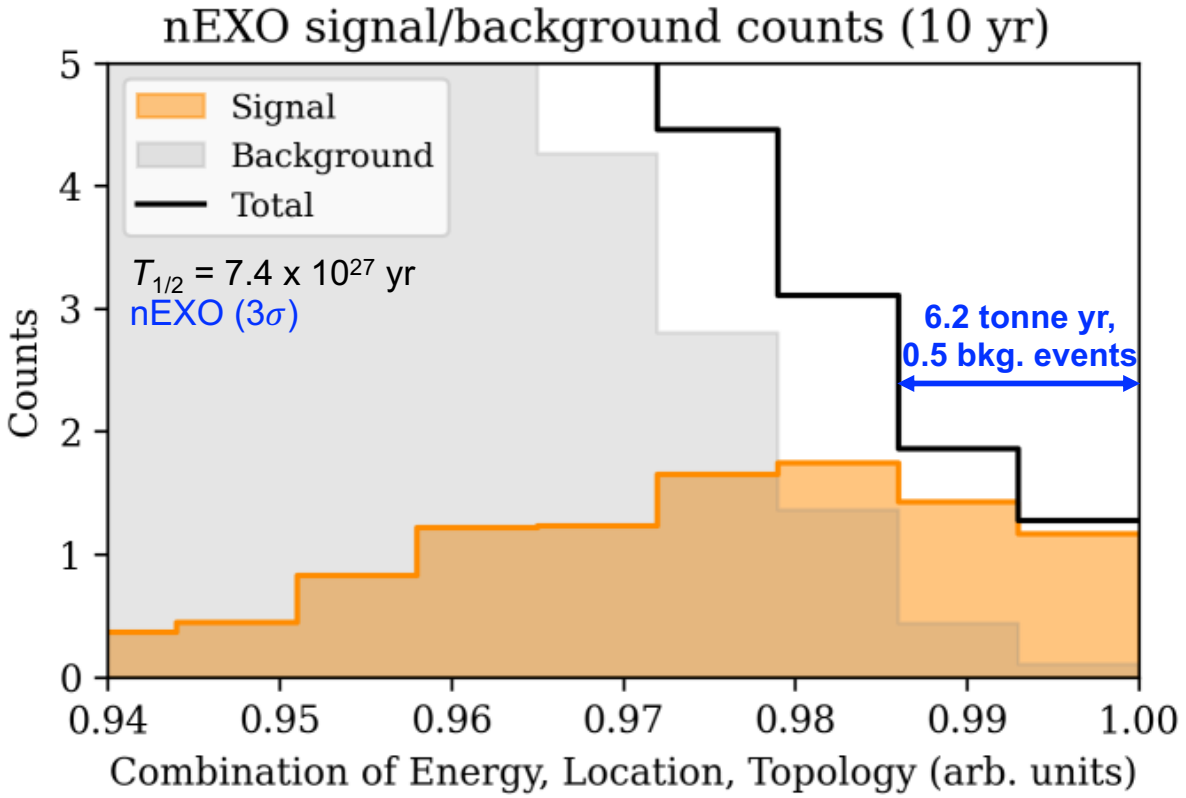


>>>>> Poster <<<<<
C. Hardy: Optimizing Energy Reconstruction for nEXO

nEXO Signal and Background

- Likelihood fit allows optimal weighting between signal and background combining energy, topology, and standoff over full 3D parameter space
  - Arranging the 3D bins into 1D, ordered by signal-to-background ratio, helps visualize the signal and background separation in nEXO

Combine energy, topology, and standoff (preserving correlations)

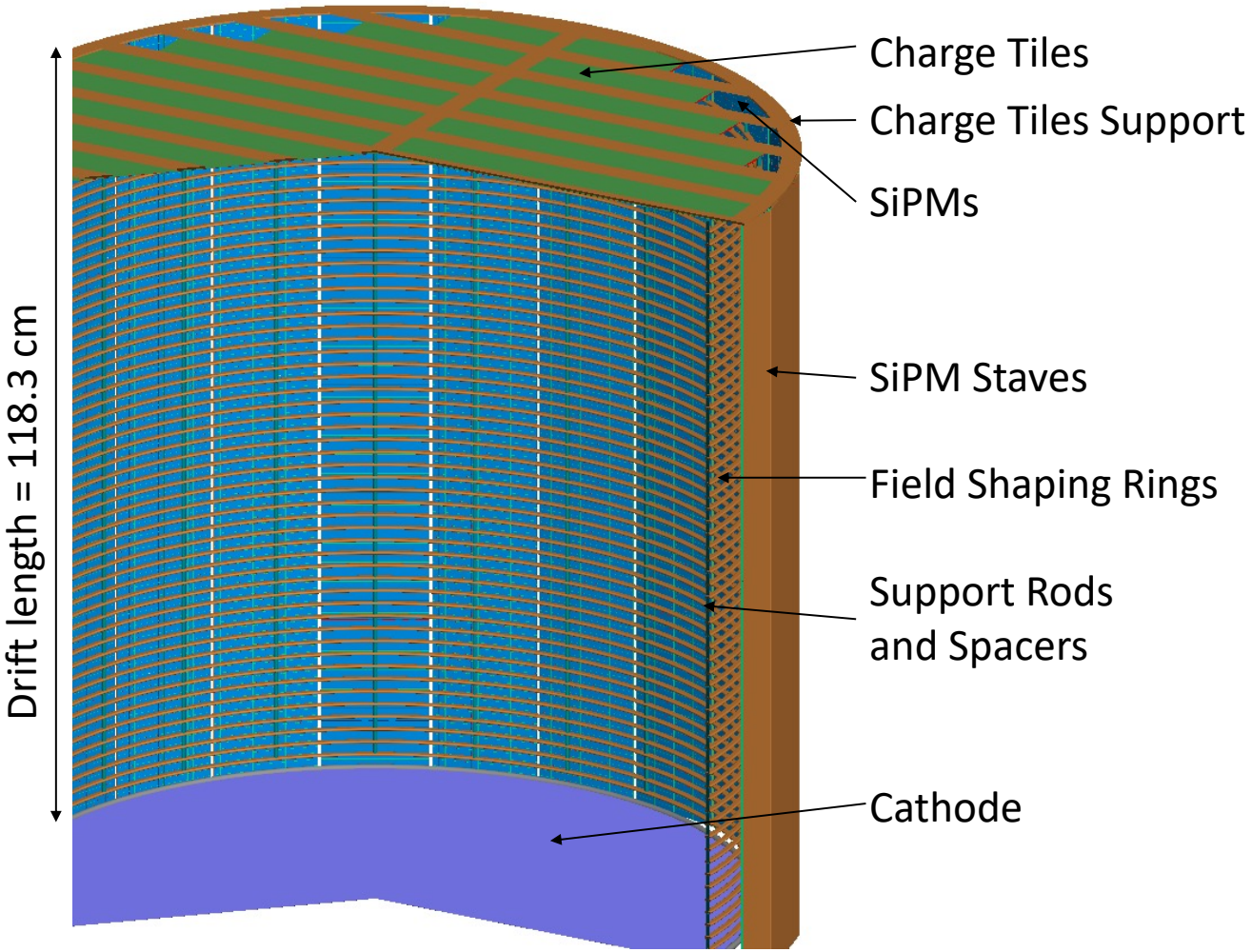


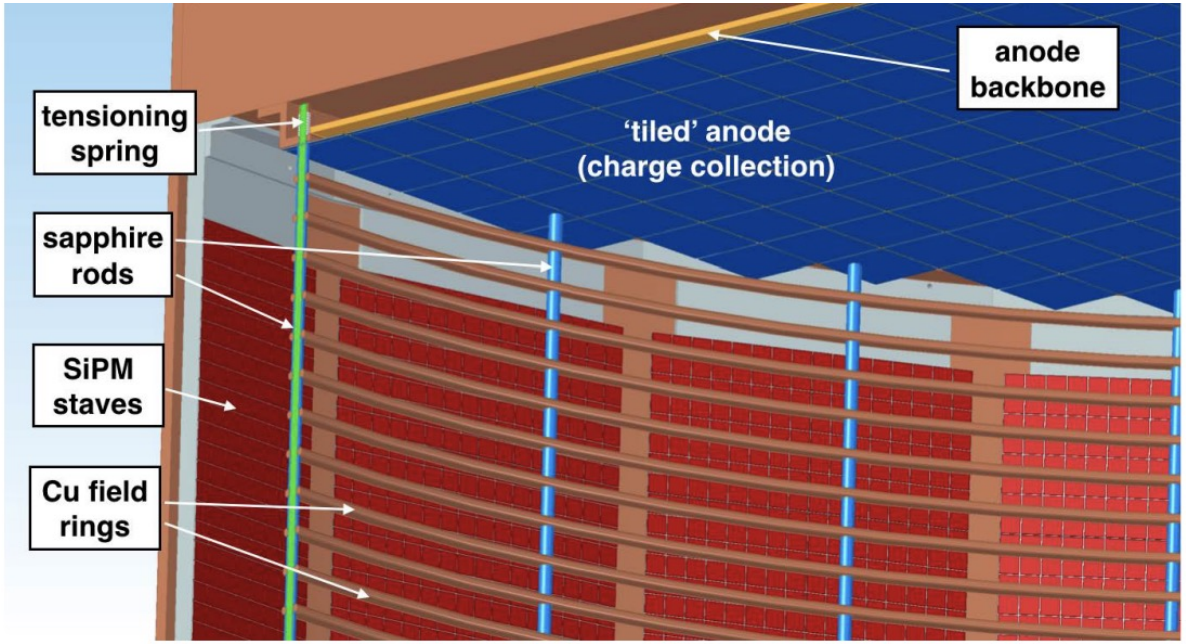
0 ← Background-like

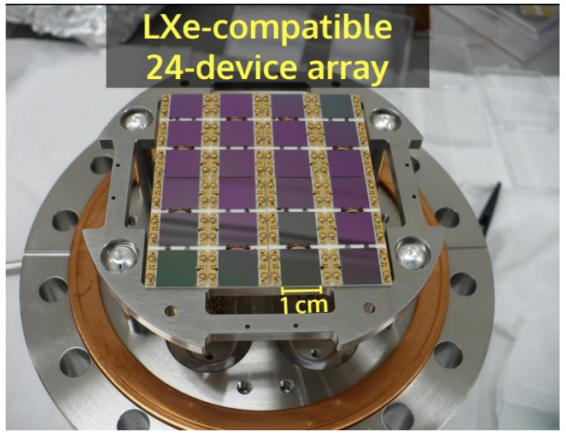
Signal-like → 1

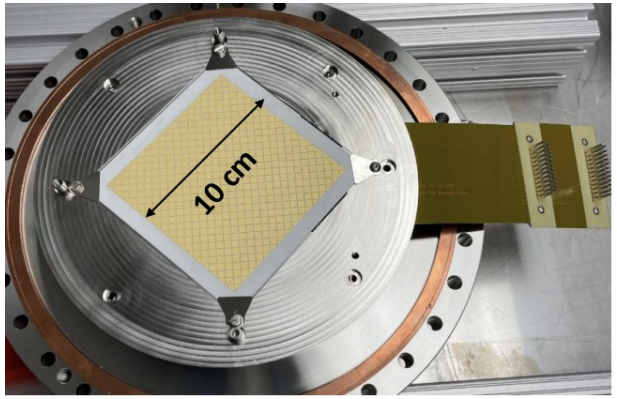
nEXO is a background free experiment in its full 3D parameter space

nEXO TPC Conceptual Design



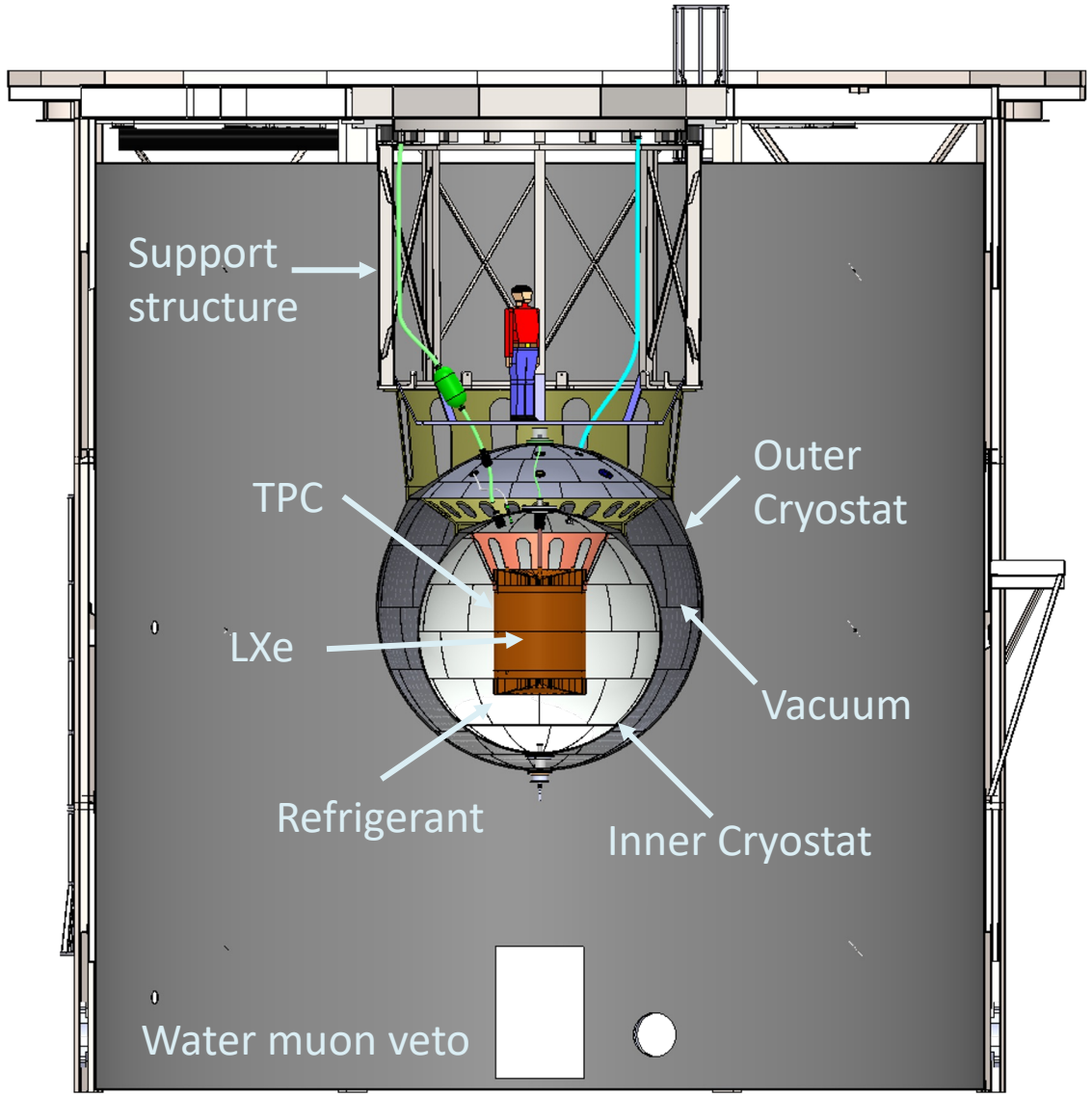






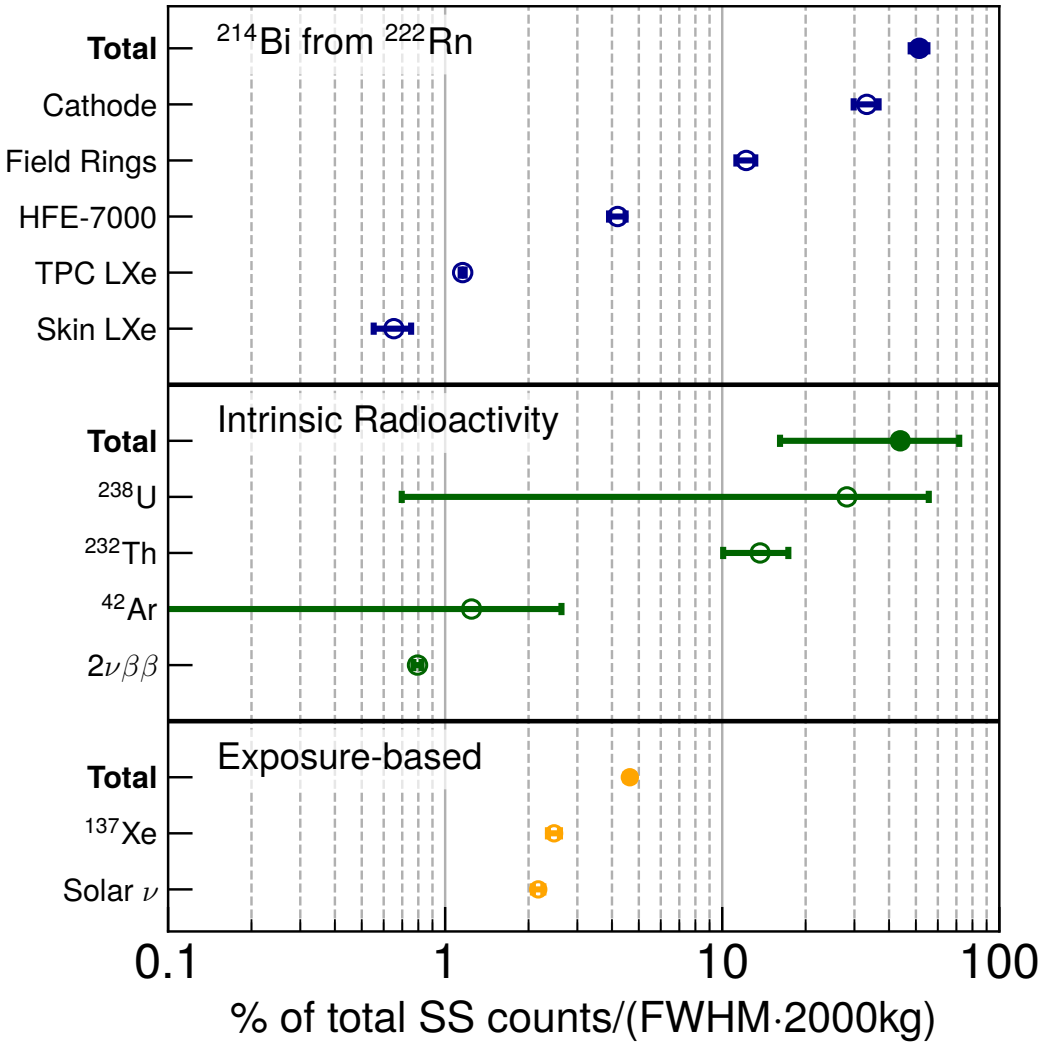
nEXO @ SNOLAB

- Depth: 6010 m.w.e.
- Layered shielding:
  - Water Cherenkov muon veto
  - Refrigerant (HFE)
- Advanced integration with SNOLAB facility



Backgrounds

- > ~95% of the background comes from gamma emissions from/on materials outside of the TPC LXe
- Background estimate from detailed MC simulations based on materials with measured radioactivity
  - Approach validated by EXO-200 experience



G. Adhikari, et al, J. Phys. G: Nucl. Part. Phys. 49, 015104 (2022)

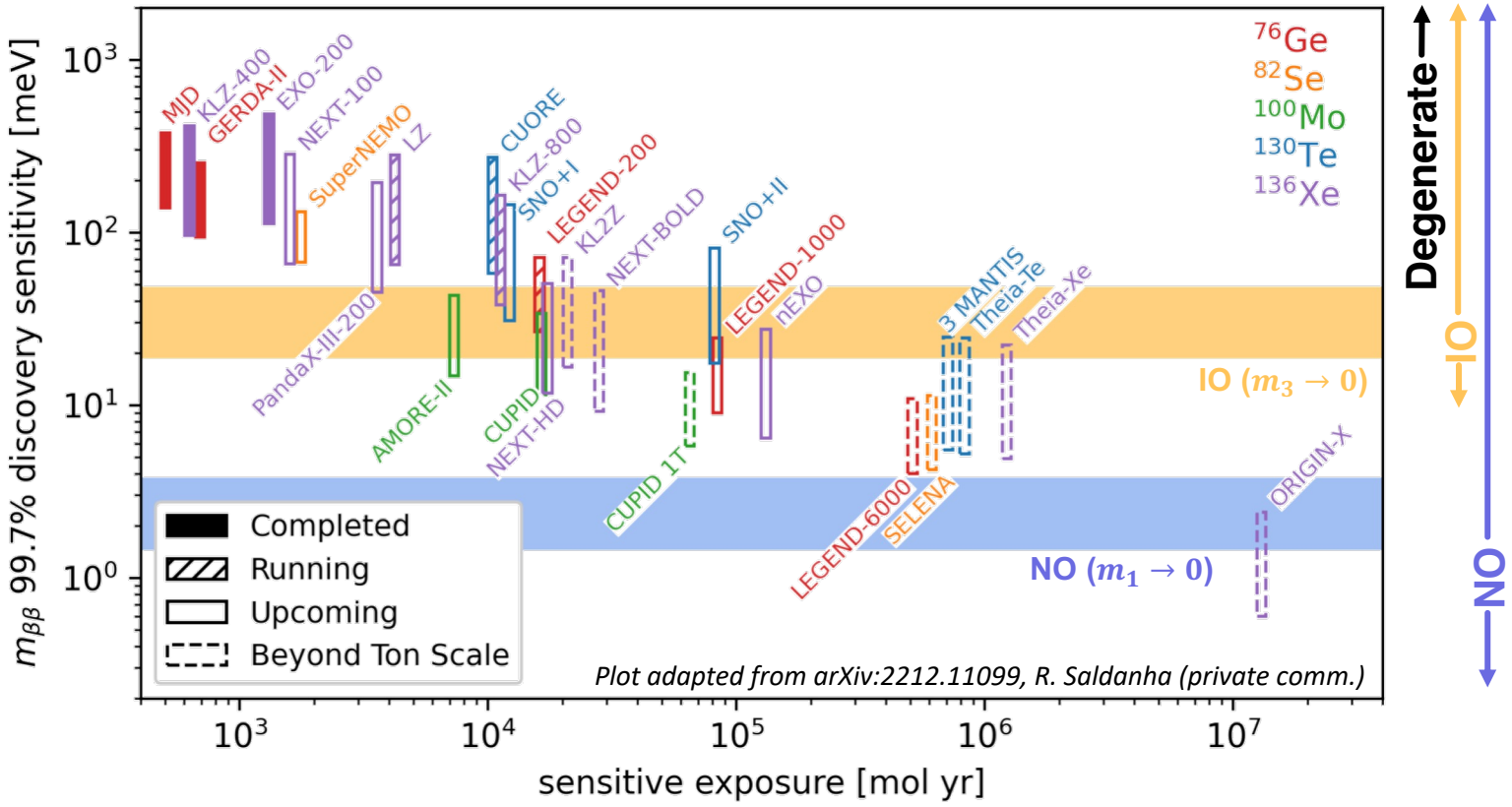
The Ultimate $0\nu\beta\beta$ Experiment: ORIGIN-X

- Xe TPC technology is inherently scalable
- Benefit of self-shielding

- **O**bserving **R**are **I**nteractions with a **GI**a**N**t **X**enon (ORIGIN-X) experiment: a ktonne Xe experiment for $0\nu\beta\beta$.

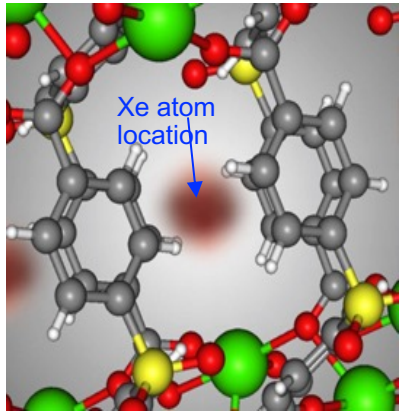
  A. Avasthi, et al, Phys. Rev. D 104, 112007 (2021)

- Xenon is present in the atmosphere at 87 ppb (~0.2 Gt total)
- Current production is a parasitic process in air liquefaction for steel industry
  → inelastic supply limited to 50-100 tons/year globally, subject to high volatility
  - Sufficient for nEXO
  - Limiting factor for much larger detectors

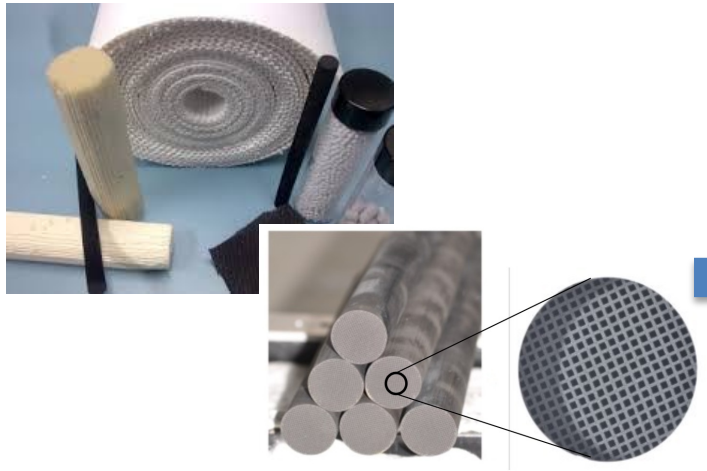


Not part of nEXO project

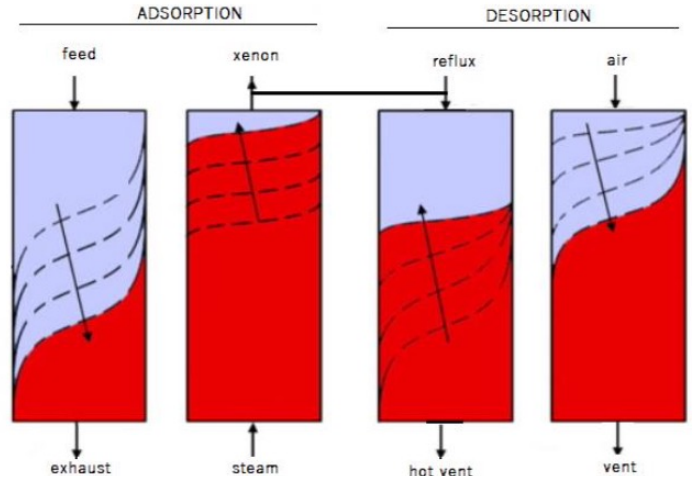
R&D at LLNL on Xenon Separation for Future kTonne Experiment



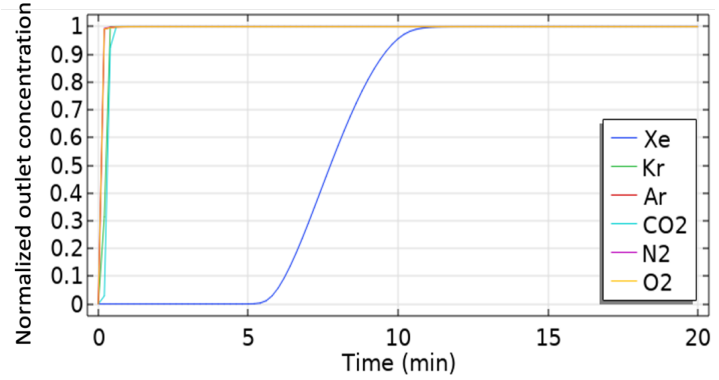
Highly-selective, stable Xe-adsorbing material



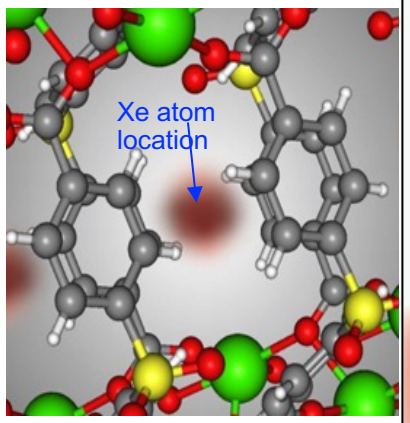
Embedded into a structured adsorbent



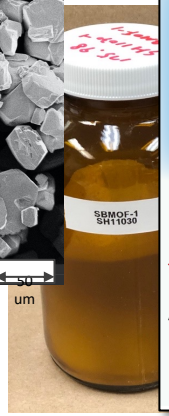
Rapid Intensified TSA Cycle



R&D at LLNL on Xenon Separation for Future kTonne Experiment



Highly-selective, stabl
Xe-adsorbing materia



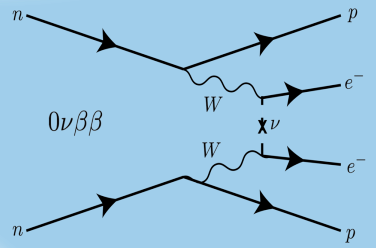
Workshop on Xenon Detector 0νββ Searches: Steps Towards the Kilotonne Scale

October 25-27 2023

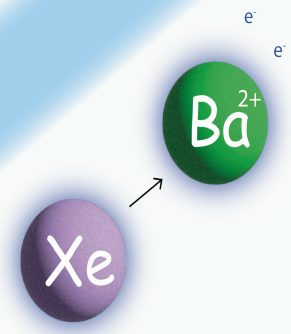
SLAC National Accelerator Laboratory

Contacts: krishan.mistry@uta.edu, rogersl@anl.gov

https://indico.slac.stanford.edu/event/8015

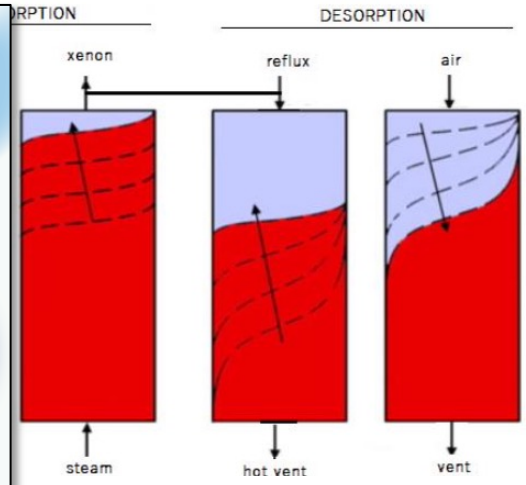


SLAC NATIONAL ACCELERATOR LABORATORY
Argonne NATIONAL LABORATORY
UTA
Lawrence Livermore National Laboratory

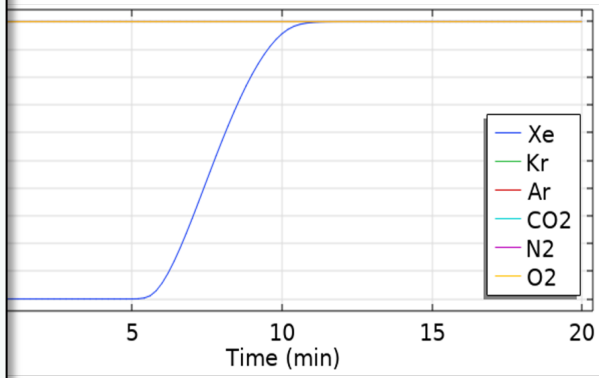


Workshop Topics

- Challenges towards a program reaching the kTonne scale
- Future light and charge readout
- Novel TPCs: additives, new concepts and more!
- Daughter tagging and ion transport
- Physics program of a kTonne detector



d Intensified TSA Cycle



Conclusions

- nEXO project officially started, preparations for DOE's CD-1 (conceptual design) review ongoing

- nEXO sensitivity arises from:
  - Homogenous/monolithic detector
  - Multiparametric analysis
  - Extensive radioassay campaign and material selection

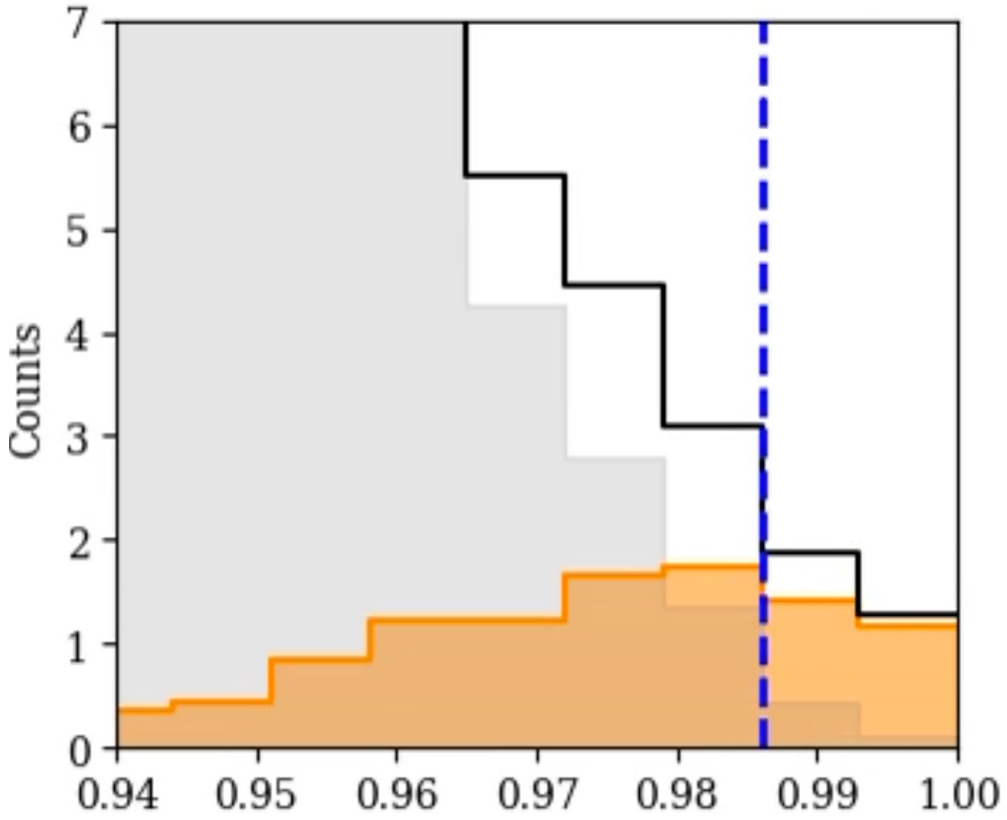
- Beyond nEXO, the ultimate $0\nu\beta\beta$ experiment may be feasible:
  - Leveraging Xe TPC scalability
  - R&D ongoing to address Xe acquisition challenges

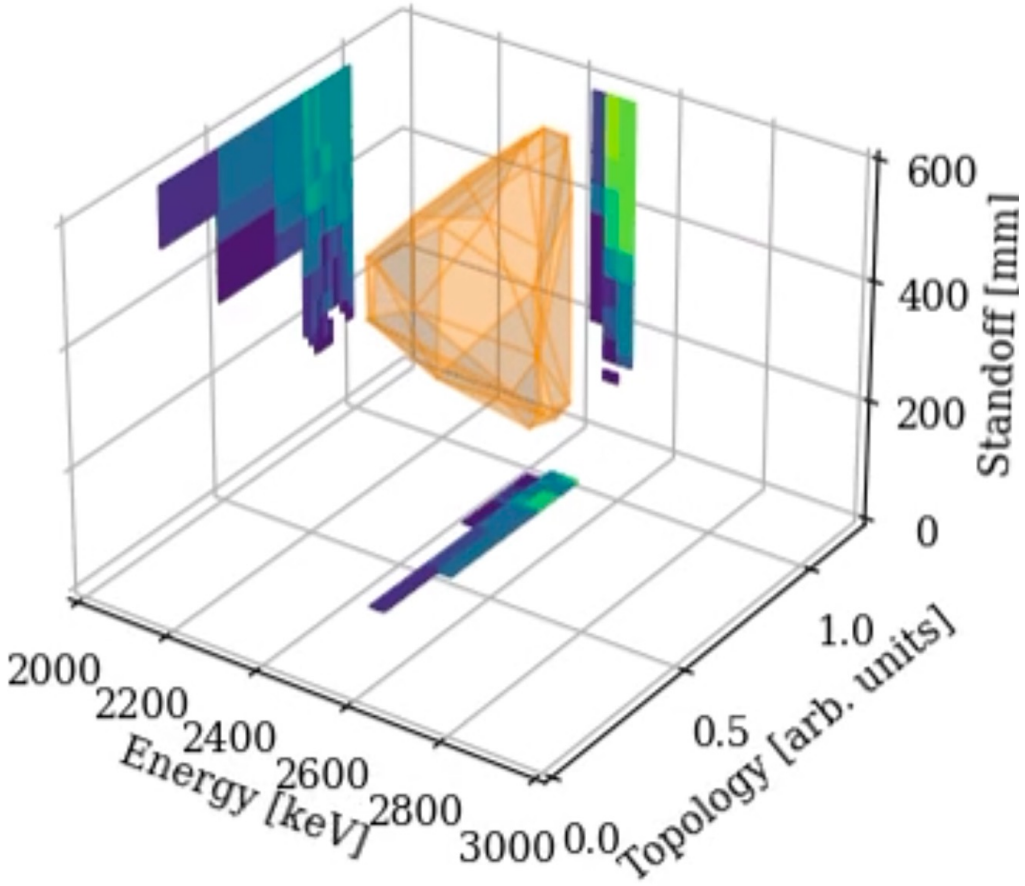
nEXO A worldwide effort of 9 countries, 33 institutions, ~200 collaborators

Disclaimer
This document was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor Lawrence Livermore National Security, LLC, nor any of their employees makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or Lawrence Livermore National Security, LLC. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or Lawrence Livermore National Security, LLC, and shall not be used for advertising or product endorsement purposes.

nEXO Signal and Background

- “Background free” region corresponds to a “simple” region in 3D (although correlations prevent any set of rectangular projections from fully capturing the signal/background separation)



Combination of Energy, Location, Topology (arb. units)

0 ← Background-like *Signal-like → 1*