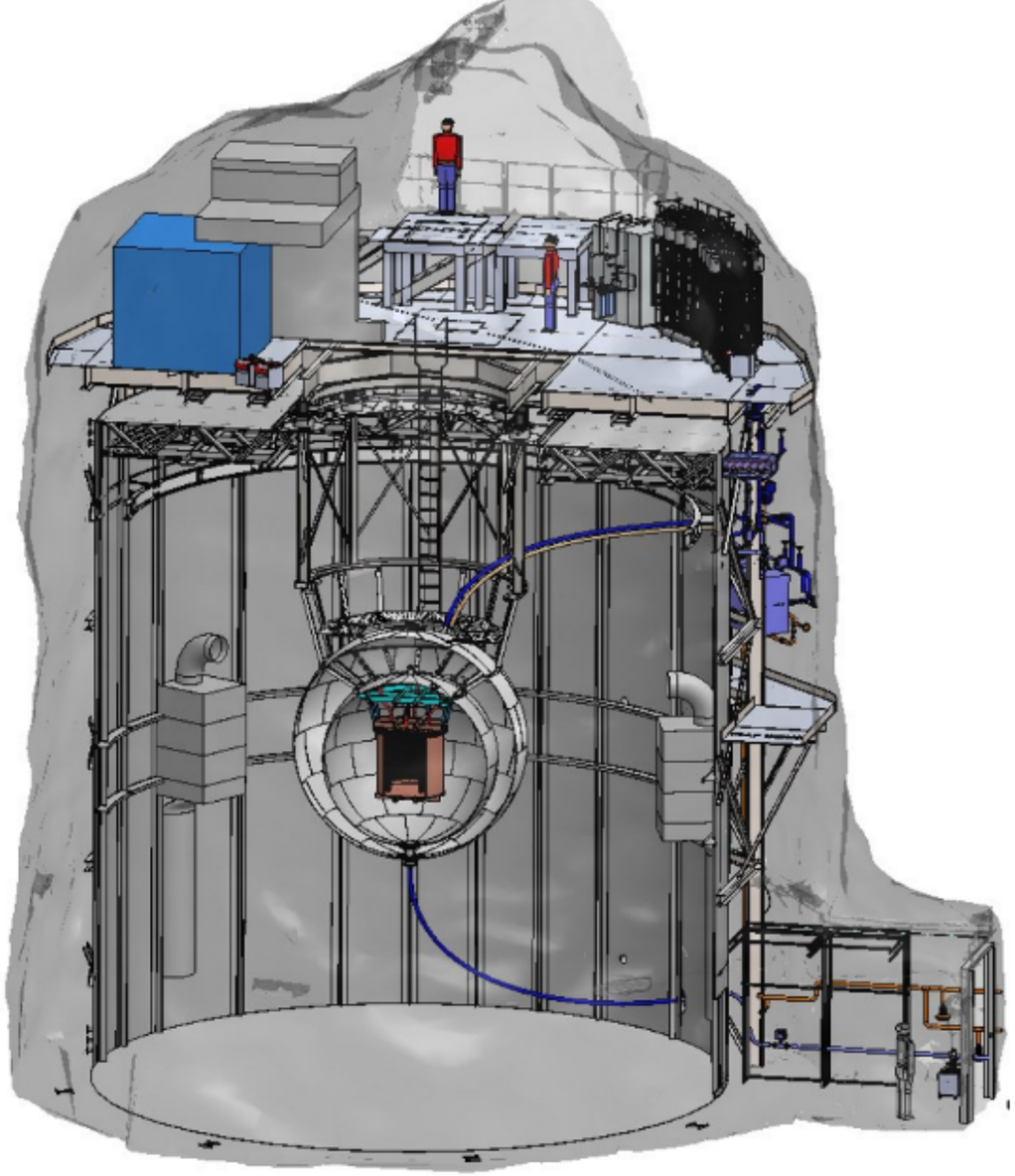
Xe TPCs for 0νββ

Perspectives from nEXO and XLZD

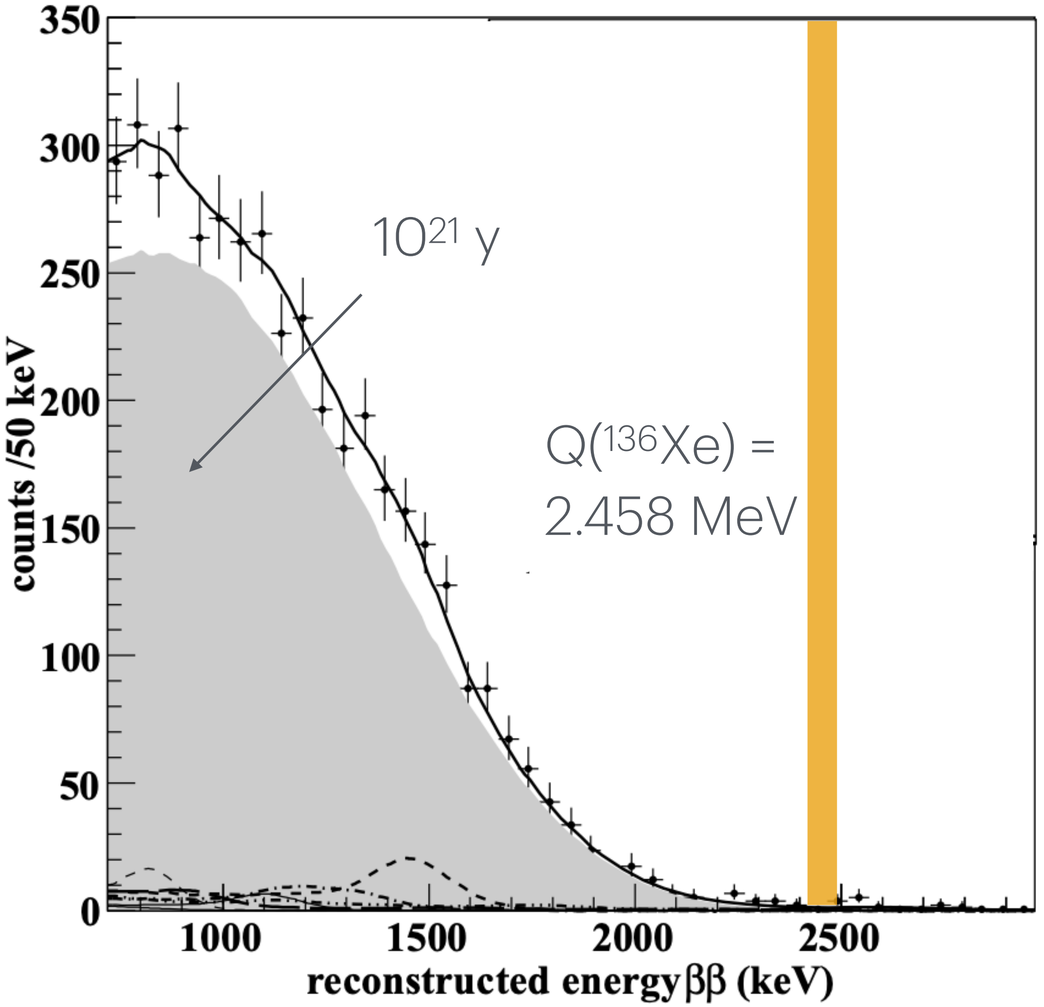
Erica Caden
Senior Research Scientist, SNOLAB
Adjunct Faculty, McGill & Laurentian Universities



Many thanks to Xe DBD Workshop series for the wealth of material
Nov 2025, Sep 2026

Low background liquid xenon (LXe) TPCs

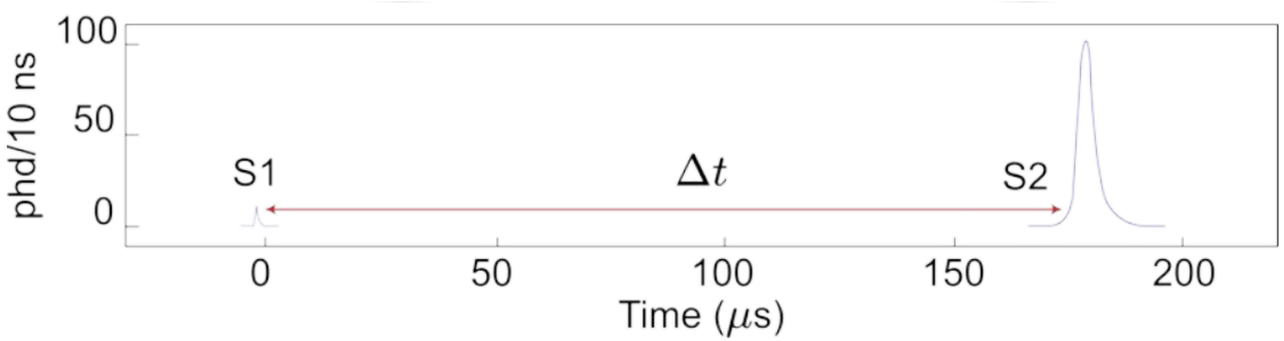
- LXe TPCs hold technological promise in rare event searches
  - Over the past 20 years, demonstrated scalable technology
- Today, several tonne-scale LXe TPCs are operational (XENONnT, LZ, PandaX-4T)
  - Dark Matter (WIMP-like) searches
  - Opportunistic searches: 2n, 0n DBD; 2EC; 0n QBD
- Larger ones are in the construction/design/proposal stage
  - Dark matter searches (PandaX-20T/40T, XLZD)
- nEXO was optimized for the search of 0νββ decay of ^{136}Xe
  - Can/should inform the design on next-gen experiments
  - Lots of signal, low intrinsic background, signal/bg ID

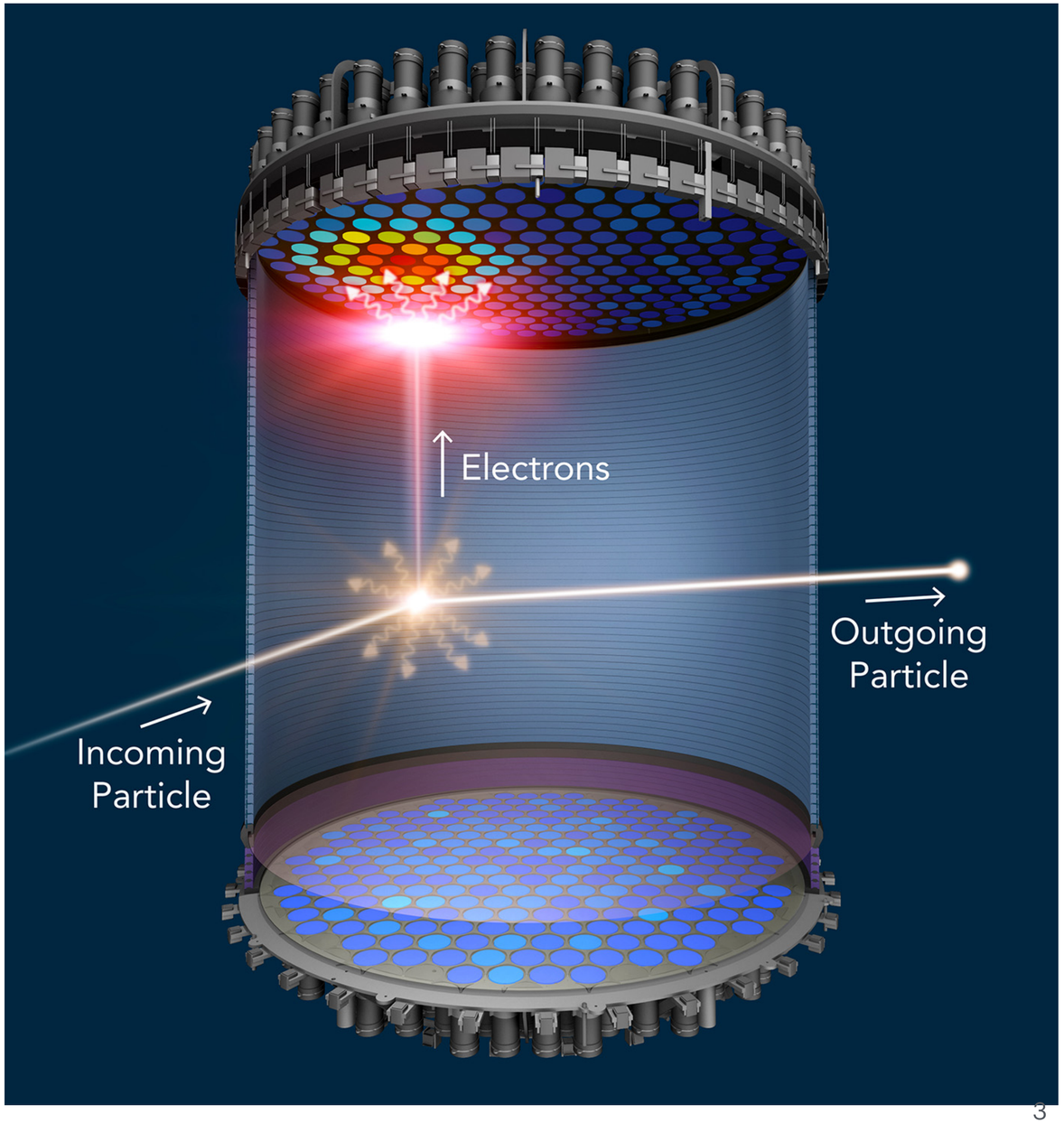


PRL 107.21 (2011): 212501.

TPCs

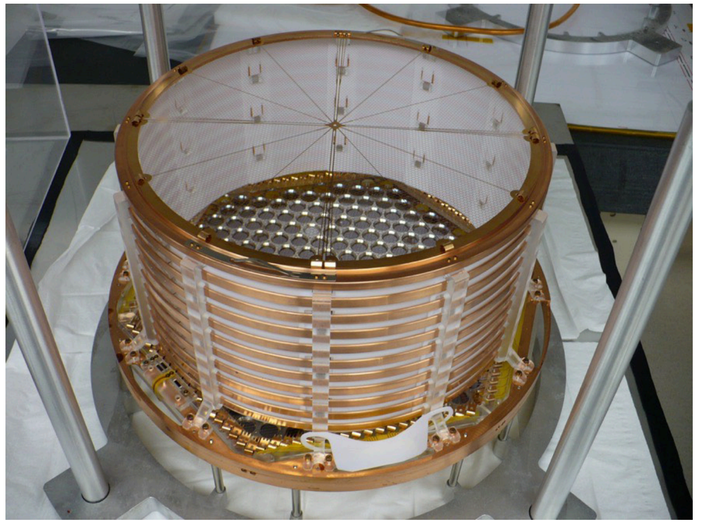
- Primary scintillation light (S1)
- Secondary signal induced from free charge (S2)
- 3D reconstruction allows for fiducialisation

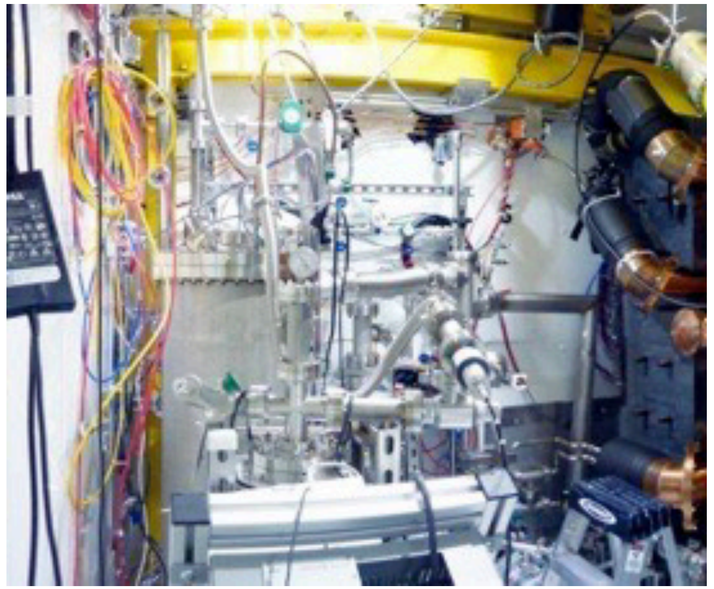


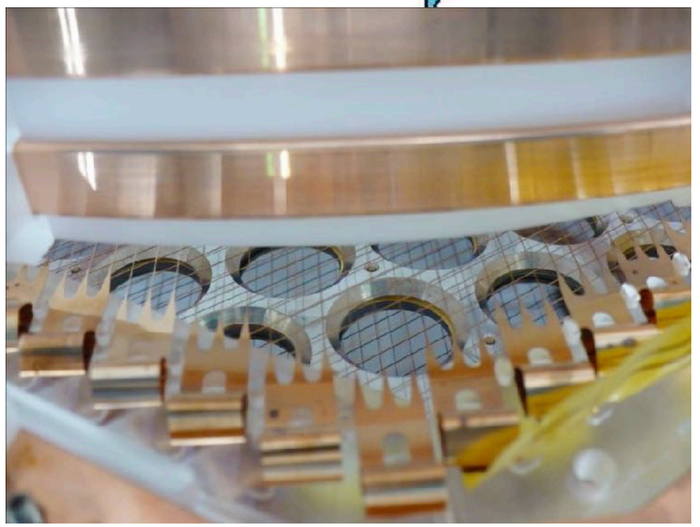


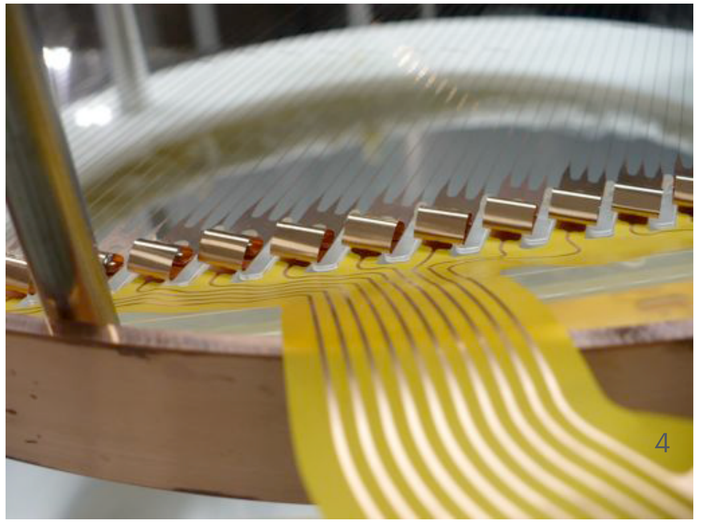
EXO-200 @ WIPP (2011-2018)

- 200 kg enriched LXe (80% ^{136}Xe) TPC
- Single phase
- Light readout with VUV-sensitive silicon LAAPDs
- Flat kapton cables
- Large Xe volume with the lowest background
  - Thin single vessel, low-radioactivity copper
  - Bulky double-vessel cryostat pushed far away, shielded by low-background, high density fluid
- Ultra-low bg design with HFE heat transfer fluid



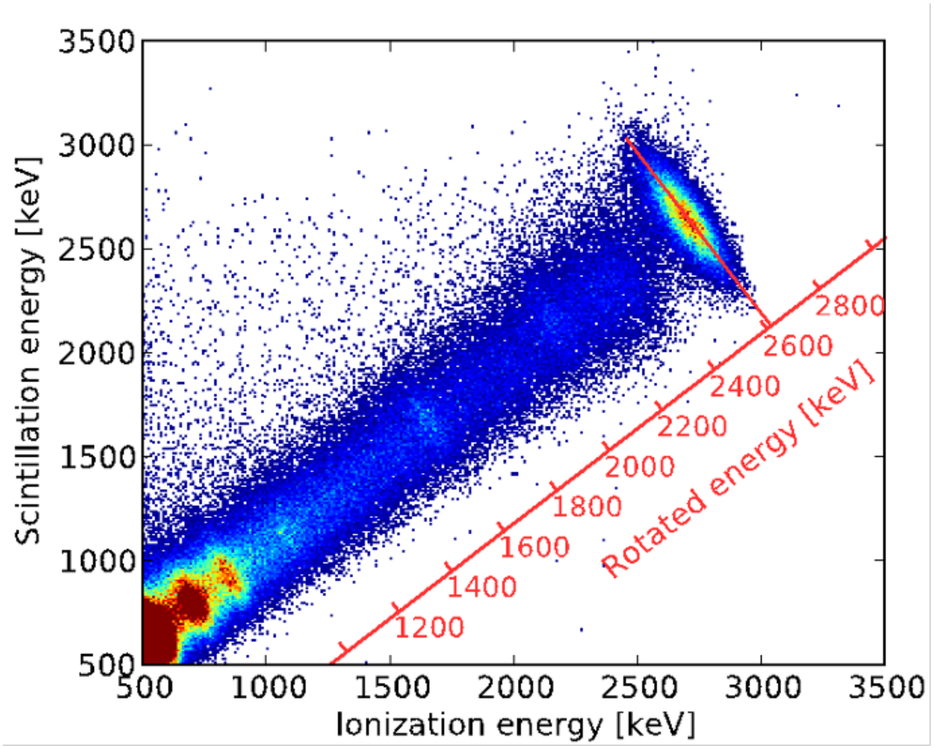




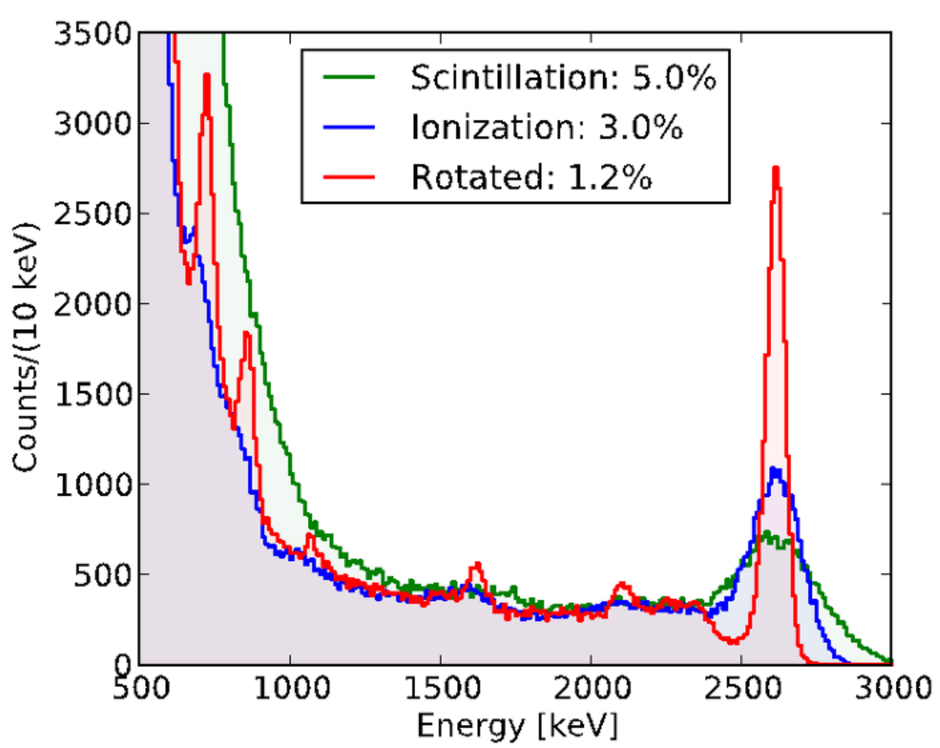


Energy measurement (EXO-200 data)

Scintillation vs. ionization, ^{228}Th calibration:



Reconstructed energy, ^{228}Th calibration:



Anti-correlation between scintillation and ionization in LXe known since early EXO R&D and now standard in LXe detectors [Phys Rev B 68 054201 (2003)]

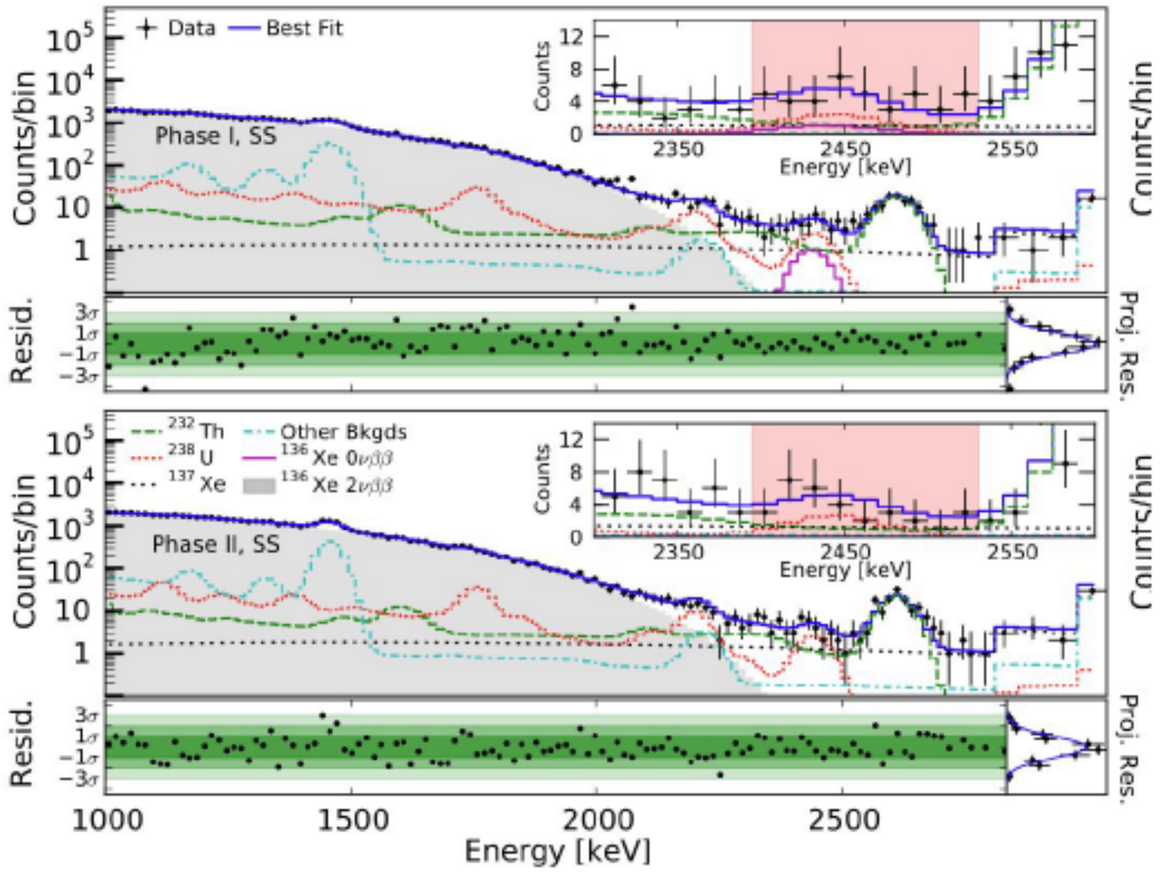
Rotation angle determined weekly using ^{228}Th source data (2615 keV), defined as angle which gives best rotated resolution

EXO-200 achieved ~ 1.15% energy resolution at the double-beta decay Q value in Phase II [PRL 123, 161802 (2019)]

LZ achieved <0.7% energy resolution in LXe [JINST 18 (2023) 04, C04007]

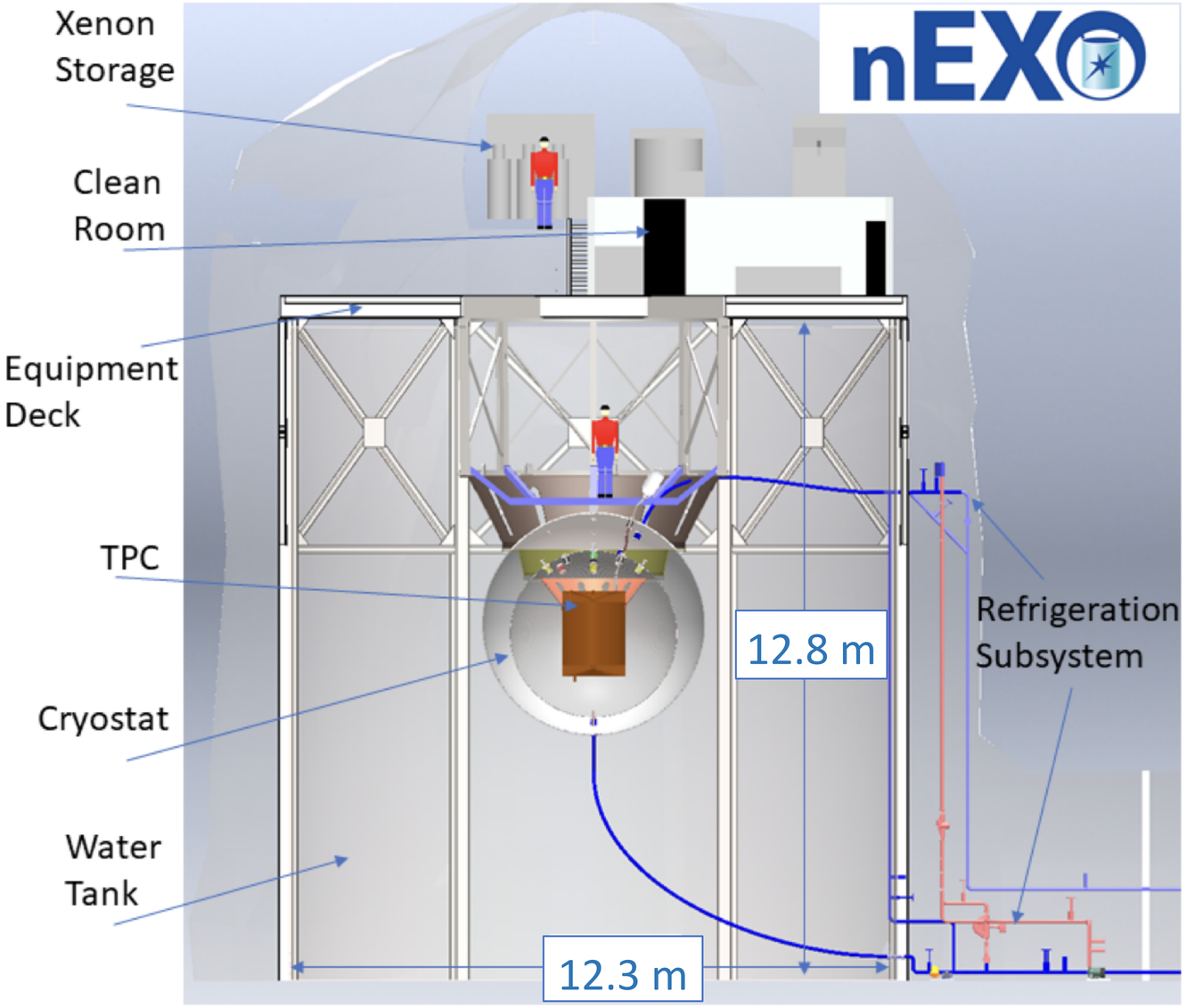
EXO-200 @ WIPP (2011-2018)

- **First measurement of ^{136}Xe 2νββ decay** (2011) (signal dominates)
- First sub-3% measurement of any 2νββ decay (2015)
- Very strong 0νββ decay measurement (2019) (matched design sensitivity)
- Best bound on ^{134}Xe 0νββ decay (2026)
- Lowest ^{222}Rn concentration in LXe (for a while)
- E&M background precisely predicted and controlled from radio assay + modeling (PRC 92, 015503, 2015)



[PRL 123, 161802 (2019)]

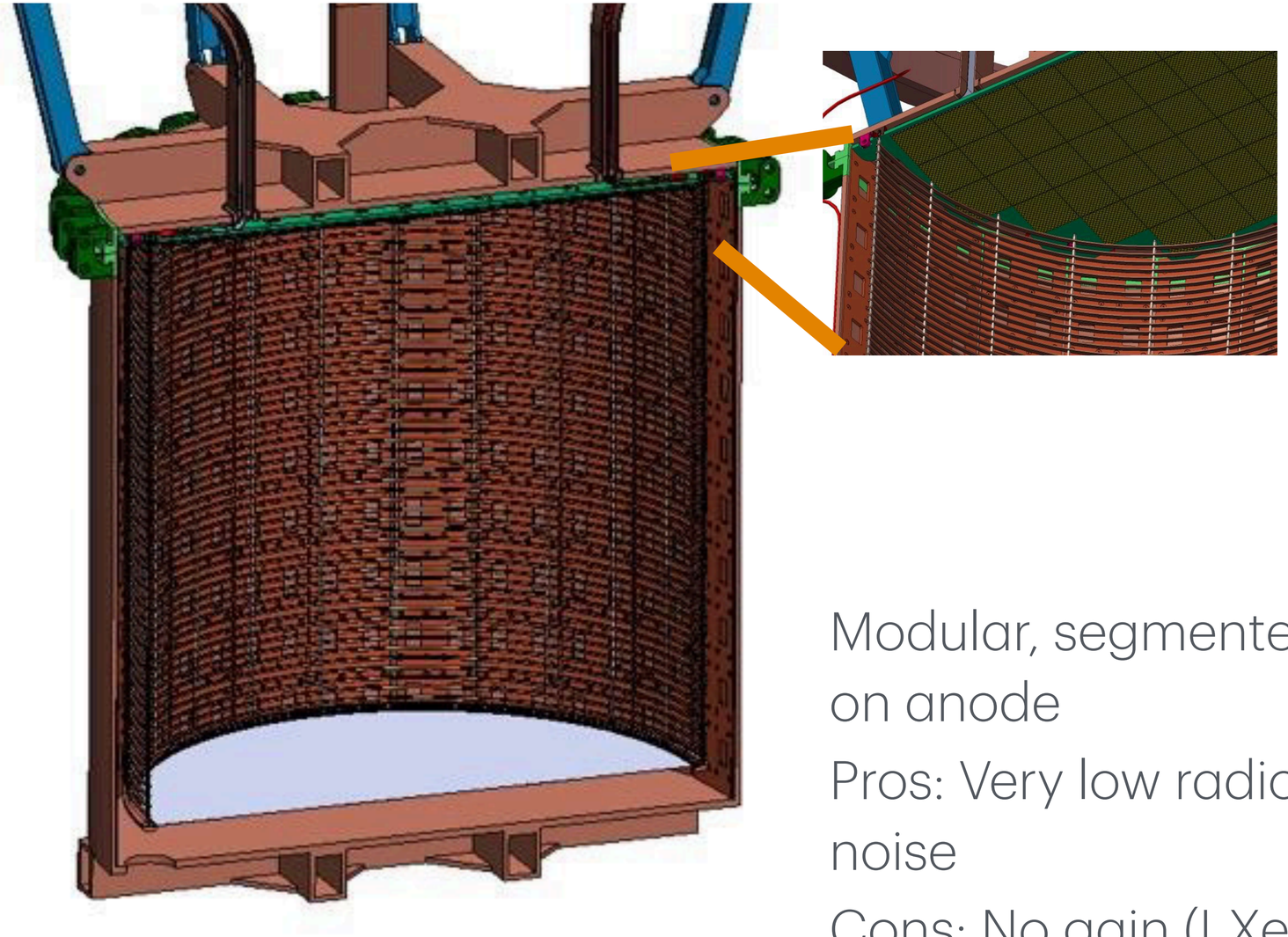
The nEXO detector design

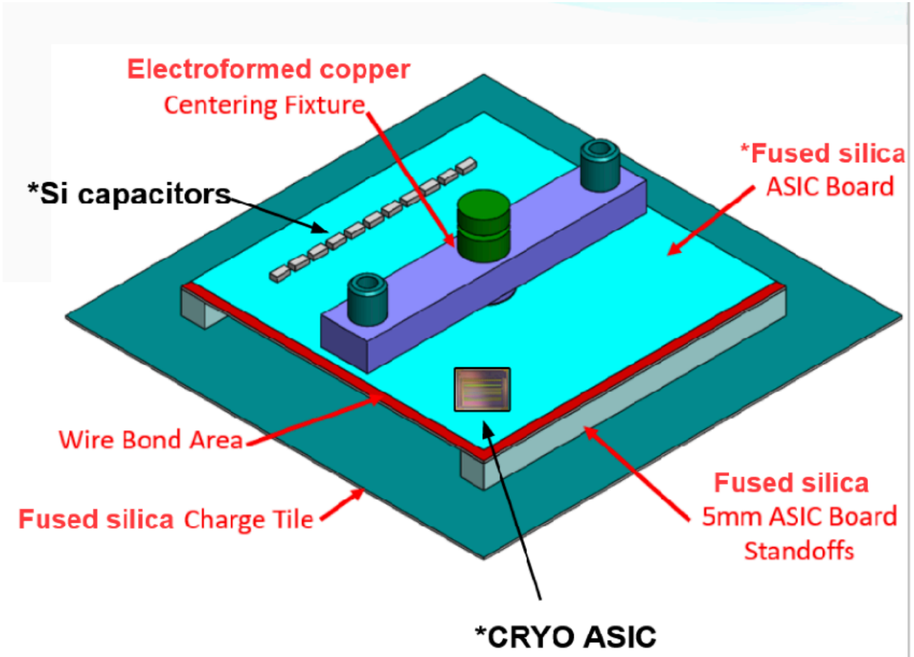


- 5-tonne single-phase liquid xenon Time Projection Chamber
- Enriched to 90% in ^{136}Xe
- Light readout with VUV-sensitive silicon SiPMs
- Thin electro-formed Cu vessel of the LXe
- Active Veto Water Shielding
- Extensive radio-assay program
- 2000 m overburden (@SNOLAB in Sudbury, ON)
- Designed for sensitivity to $T_{1/2} > 10^{28}$ y

nEXO Design:

Dual scintillation and ionization detector systems with cryogenic ASIC readout





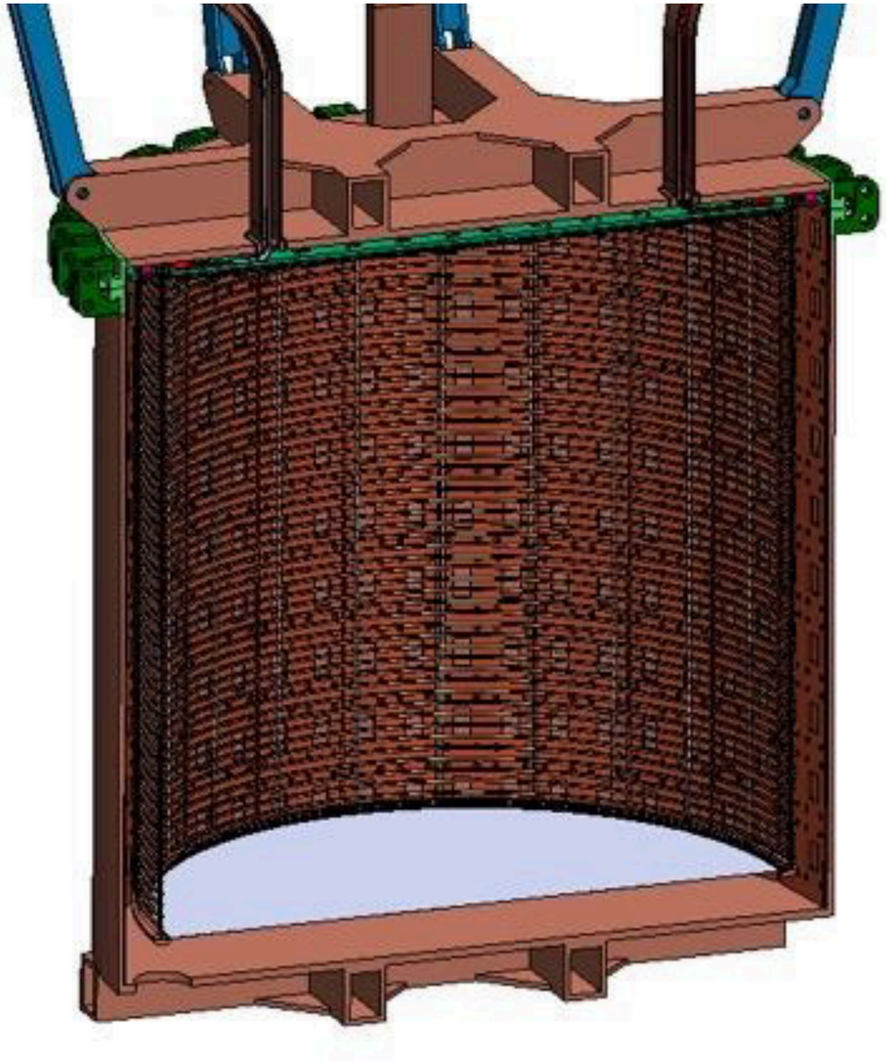
Modular, segmented, direct charge collection on anode

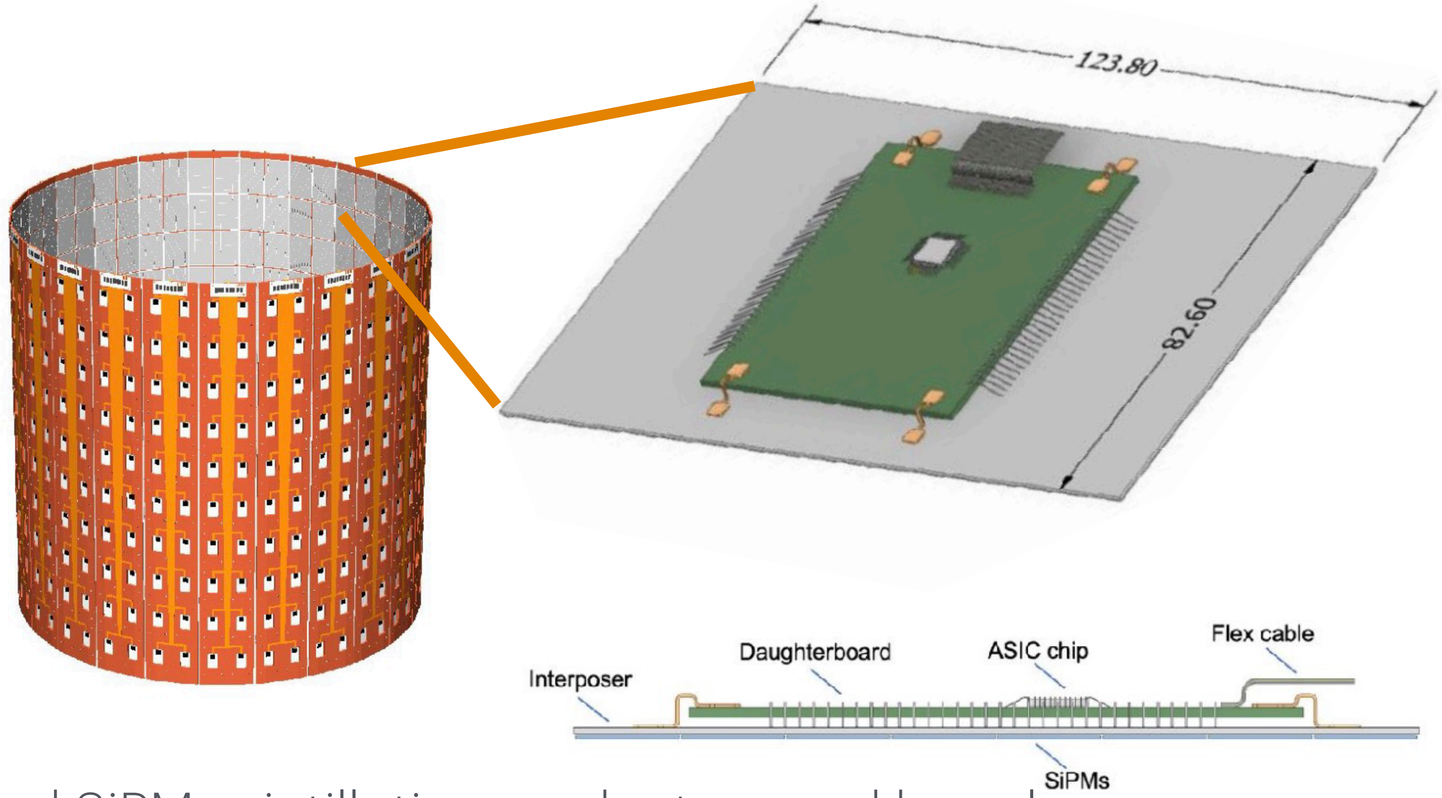
Pros: Very low radioactivity, Compact, Low noise

Cons: No gain (LXe single phase)

nEXO Design:

Dual scintillation and ionization detector systems with cryogenic ASIC readout





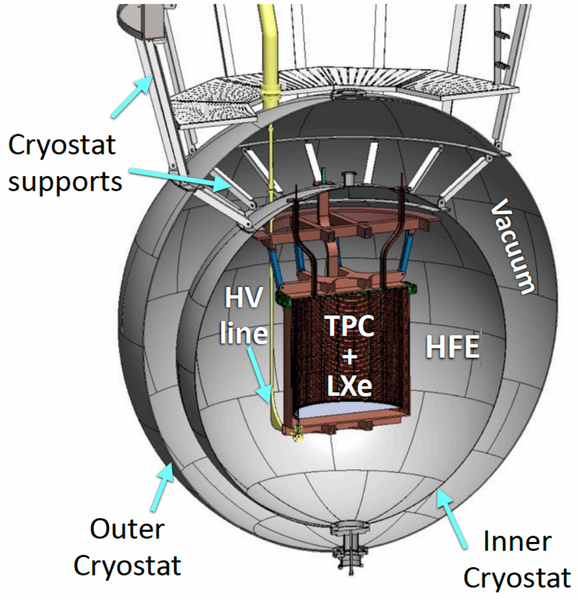
Tiled SiPM scintillation readout around barrel

Pros: Very low radioactivity, Compact, Low voltage,
Optically open TPC —> bg rejection

Risk: Novel technology compared to PMTs

Chemical Vapour Deposition Ni

- CVD Nickel produced by CVMR was used for the SNO 3He proportional counter tubes
- Produced through the MOND process with nickel carbonyl (extremely hazardous)
- Recently explored by nEXO for cryostat vessel [NIM A 1087, 171402 (2026)]
- Deposition rates can be as fast as 0.75 mm/hr, with achievable thickness over 5 cm
- The nEXO 2022 sensitivity calculation ($T_{1/2}$>1.35×10^{28} y) assumed cryostats made with carbon fiber composite (with a thin Ti liner)
  - 75 cm HFE buffer required (32 t)
- The 2024 nEXO Conceptual Design Report (CDR) featured a **CVD Nickel cryostat**, could reduce the HFE volume





Material	238U [uBq/kg]	232Th [uBq/kg]	40K [uBq/kg]	Yield Strength [MPa]
SS (XENONnT)	300 +/- 100	600 +/- 200	1600 +/- 600	200-240
Titanium (LZ)	< 90	230 +/- 20	< 540	170-310
CVD Nickel	**< 1.2***	**~0.3***	**~30**	**~400****

*Bulk contamination determined by ICP-MS (top of the chain)

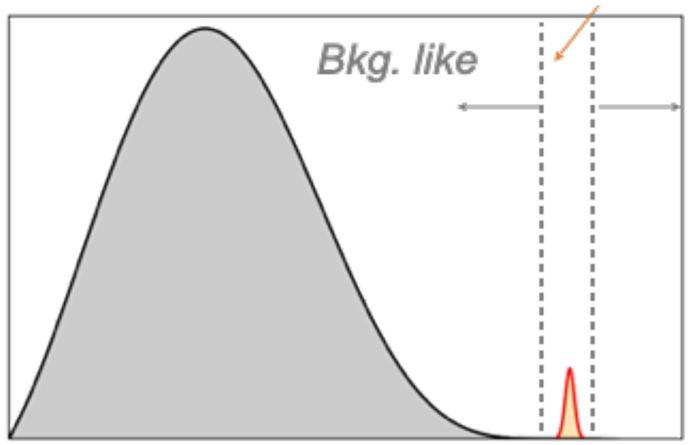
** Unwelded, Property Characterization of CVD Nickel, Masters Thesis, Patrice Bansa, University of Toronto

nEXO Design

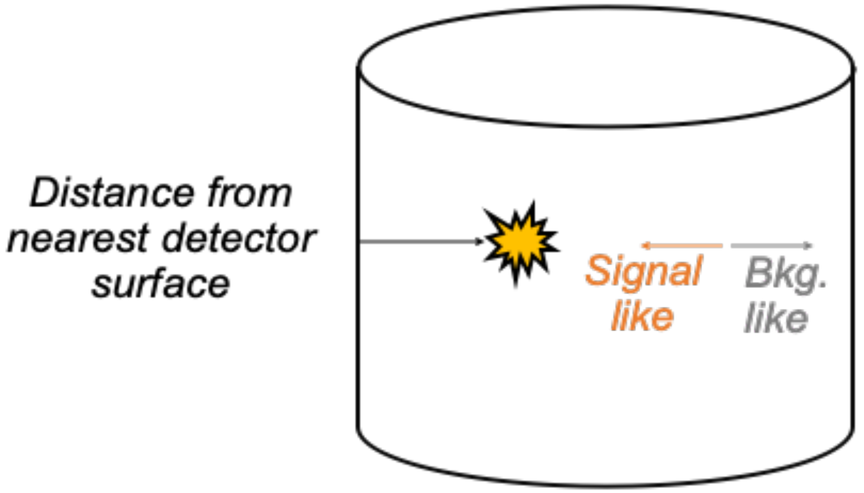
Detector **highly optimized** for 0νββ decay

- Meticulous care on mitigating detector radioactivity
- Particular focus on suppressing γ-ray background
- Such an optimization forces specific choices and compromises
- Environmental selection (depth, activation)

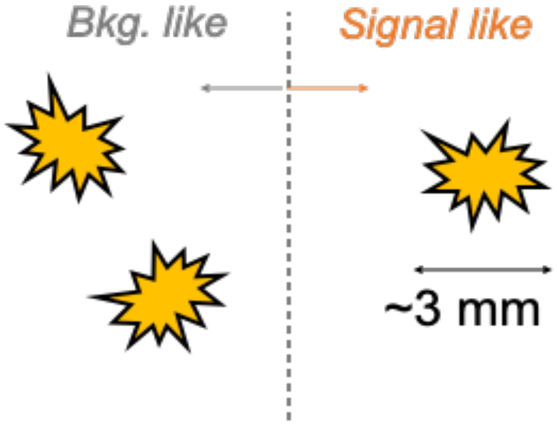
Energy: *Signal like*



Standoff:



Topology:



nEXO Sensitivity

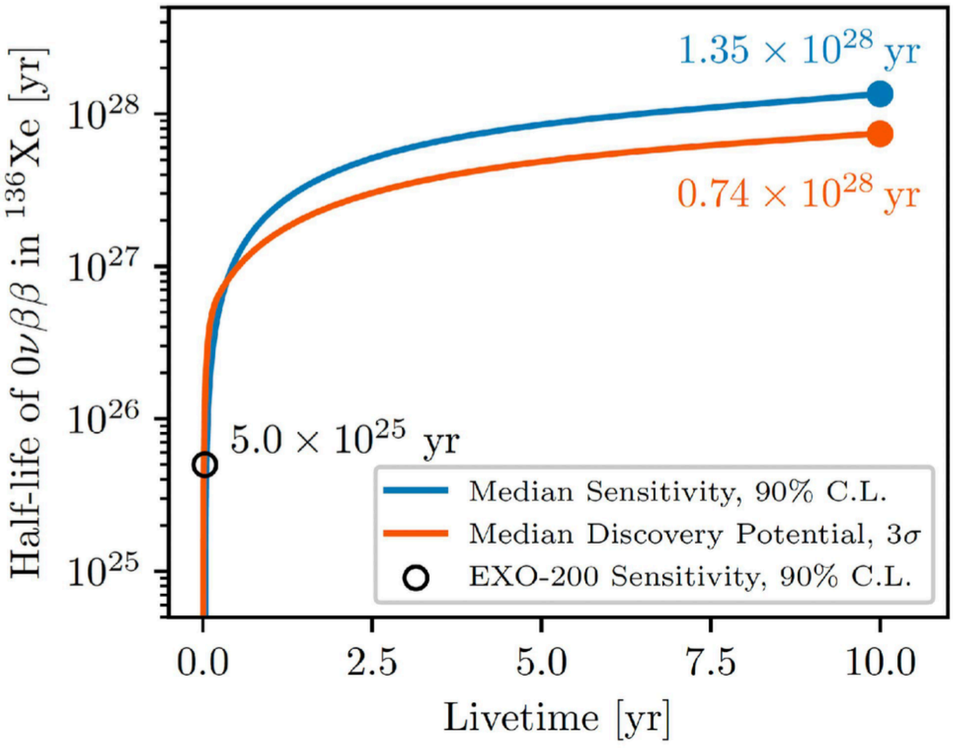
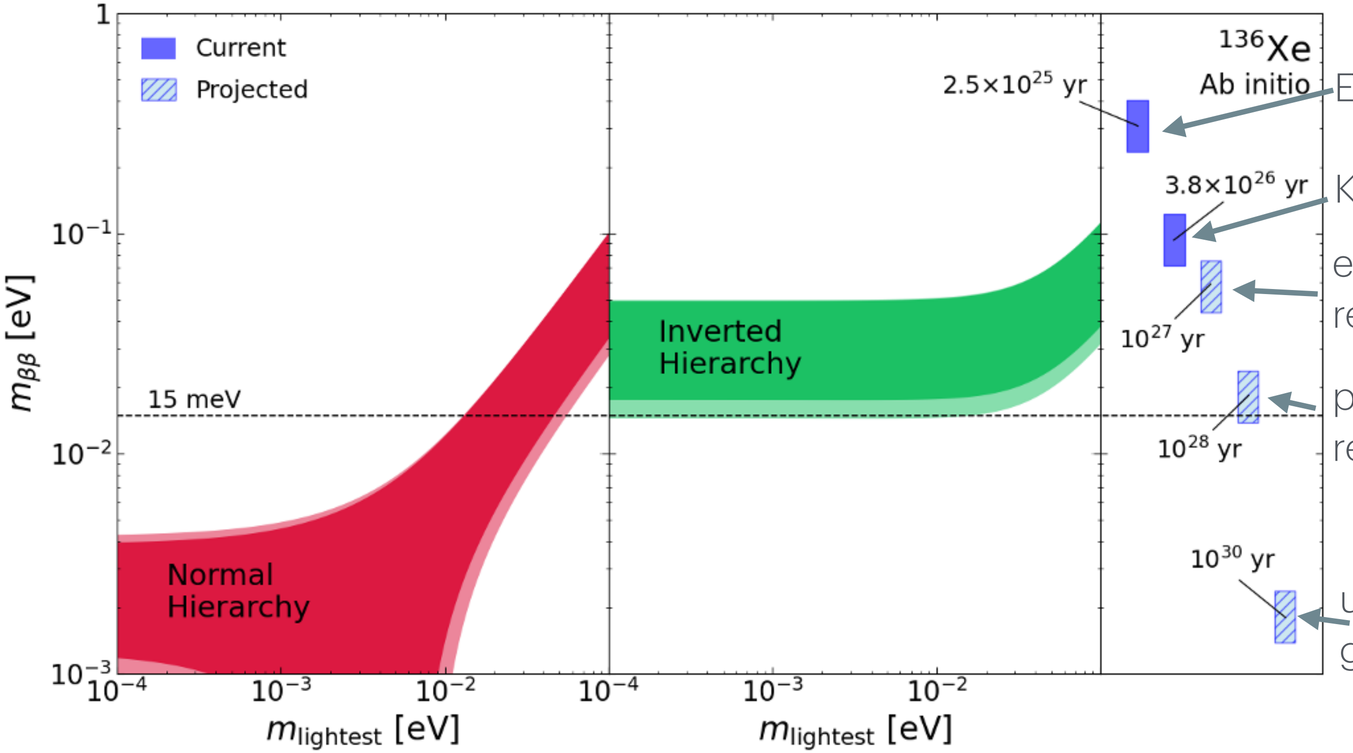


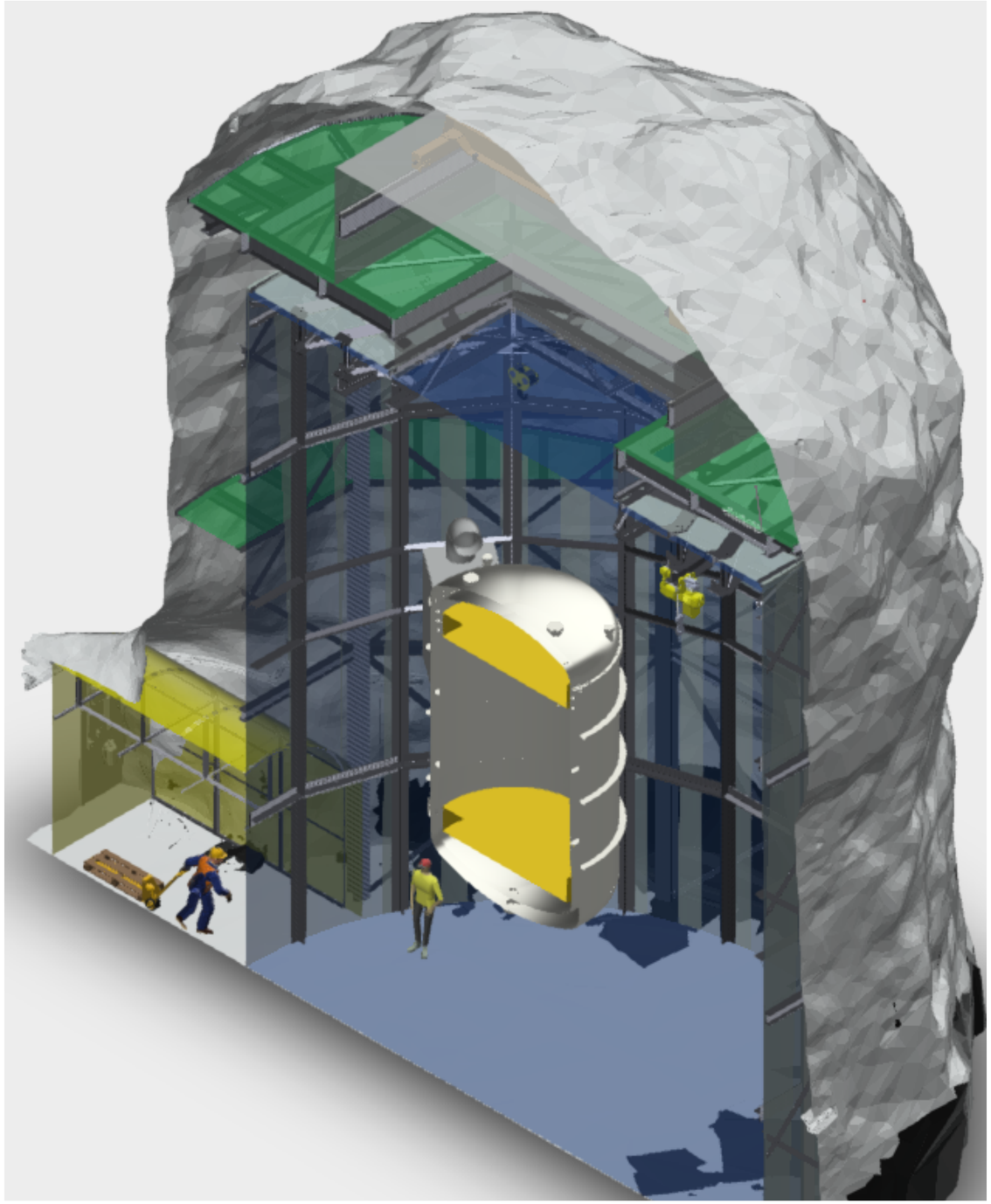
Figure courtesy to TRIUMF ab initio theory group



J. Phys. G 49 015104 (2022)

XLZD

- LXe dual phase TPC
- Merges demonstrated technologies of LZ and XENONnT
- Scientific Goal: Dark Matter AND 0νββ
- 60 t active mass (78t total) with possibility of 80t in optimistic scenarios

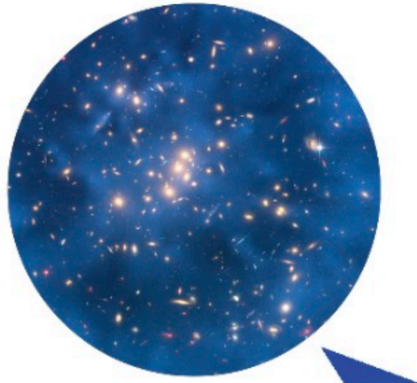


J. Phys. G: Nucl. Part. Phys. 52 (2025) 045102

Eur. Phys. J. C (2025) 85: 1192

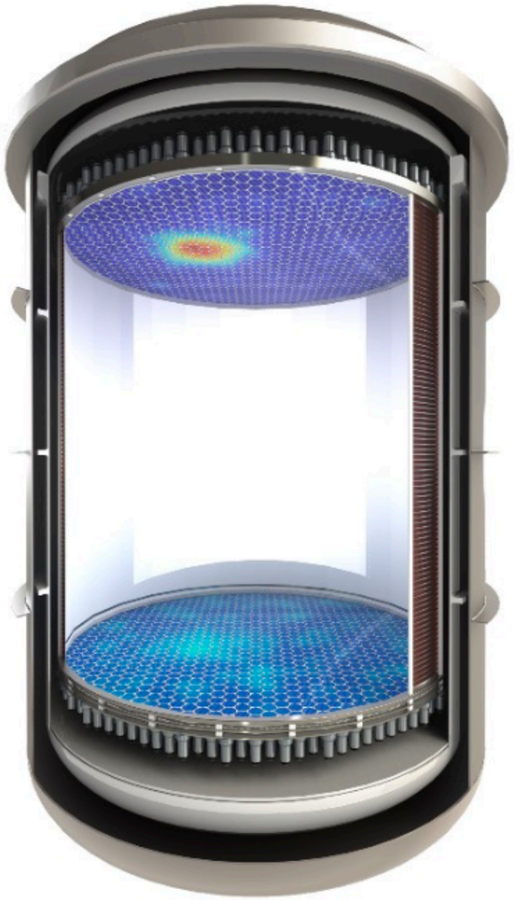
XLZD Science

Dark Matter
WIMPs
Sub-GeV
Inelastic
Axion-like particles
Planck mass
Dark photons



Supernovae
Early alert
Supernova neutrinos
Multi-messenger astrophysics





Neutrino nature
Neutrinoless double beta decay
Neutrino magnetic moment
Double electron capture



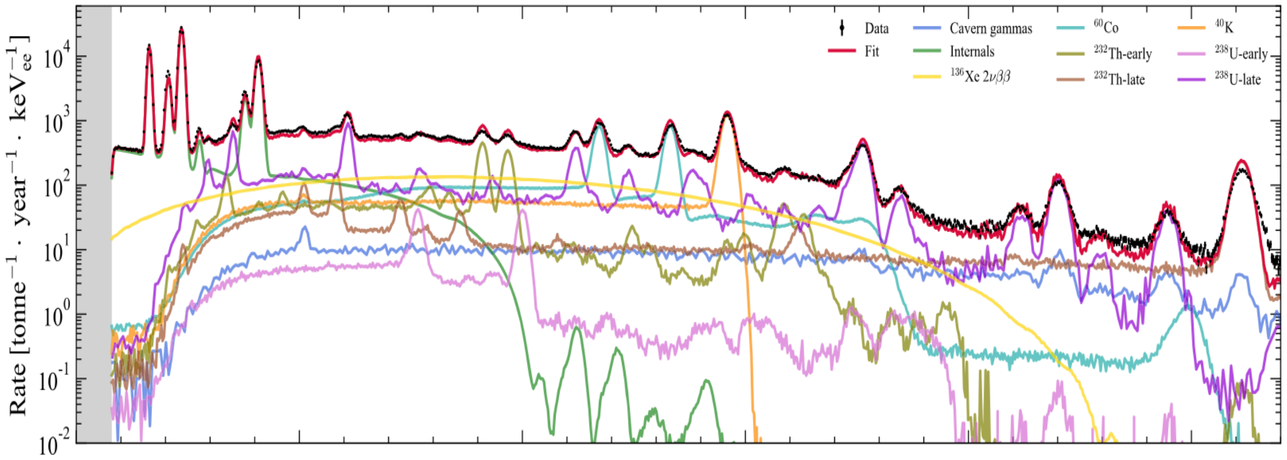
Sun
pp neutrinos
Solar metallicity
^{7}Be, ^{8}B, hep



Simultaneous 0νββ/WIMP optimization is non-trivial

WIMP-like DM searches optimize against:

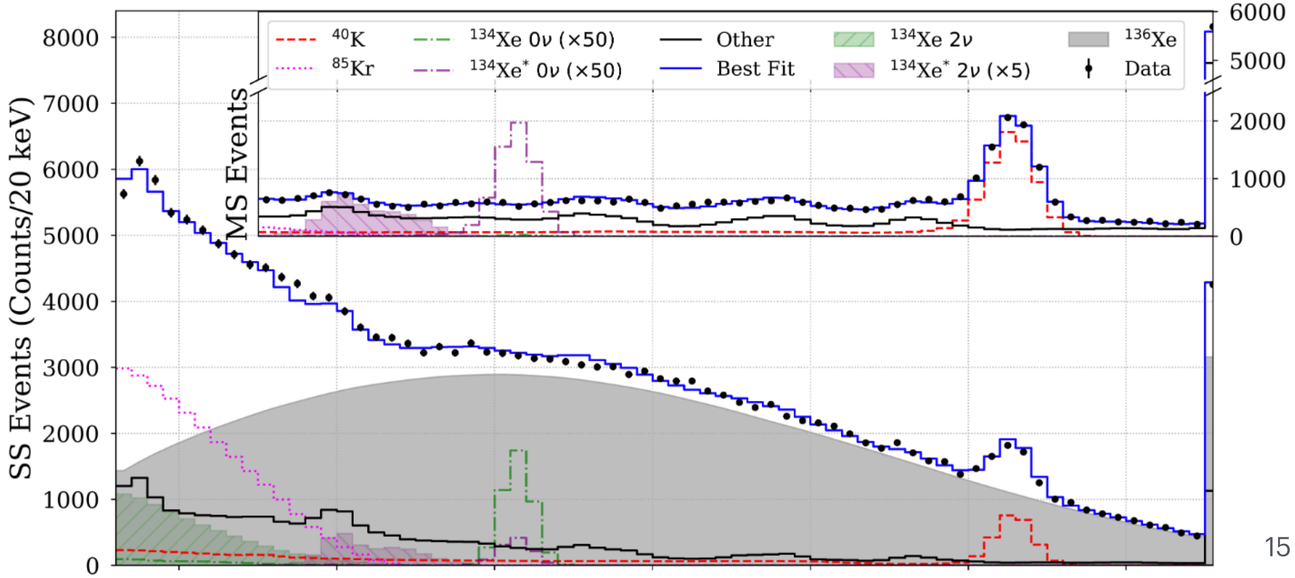
- Neutrons
- Low-energy X-rays, some βs
- Higher energy searches come with deep fiducial selection



LZ bg PRD 2023

0νββ decay searches optimize against:

- MeV gamma-rays (and betas)
- long-lived decay chains, neutron capture, activation products
- Tl-208, Bi-214, Co-60, (K-40)
- (n,γ) on Cu, F, Xe;



EXO-200 PRL 2026

EXPERIMENTAL STRATEGY

Baseline:

- Dual-phase xenon TPC with 60 tonnes of “active” mass of natural xenon, surrounded by a Skin Detector and an Outer Detector, 12 m water tank
- Fixed TPC diameter at 3 m, nominal height 3 m for 1x1 ratio at 60 tonnes
- Photosensors: 2- and 3-inch ultra-low-background VUV photomultipliers

Infrastructure designed to manage risks and opportunities:

- 80-tonne TPC (3m→4m height) to meet 0νββ goal of 10^{28} yr
- Early science & performance verification with smaller payloads is possible

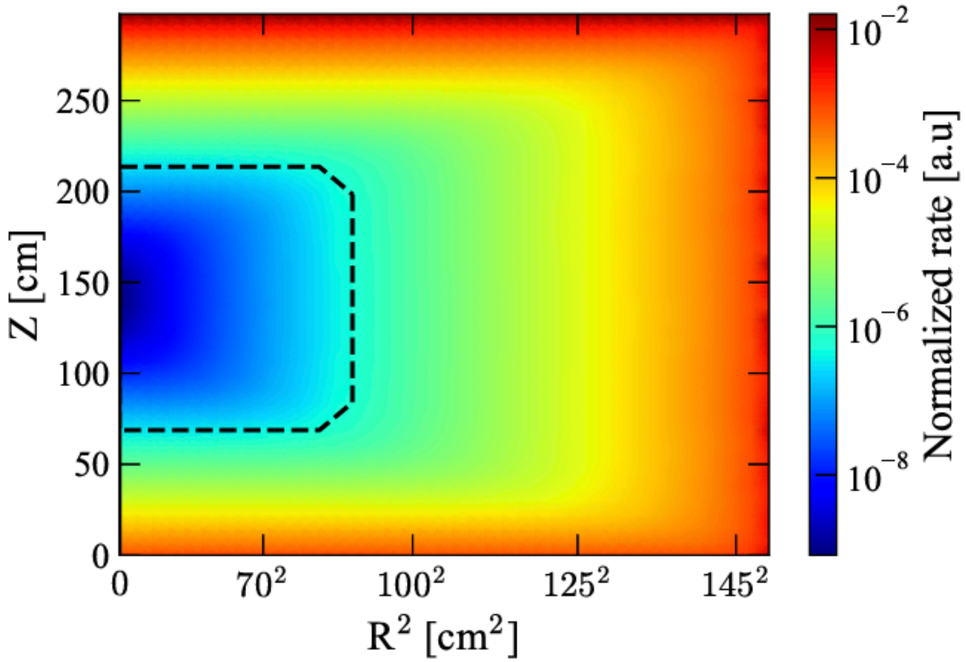
Community understands this technology:

- Many DM searches delivered over the last 20 years
- 0νββ decay searches now emerging from these experiments too

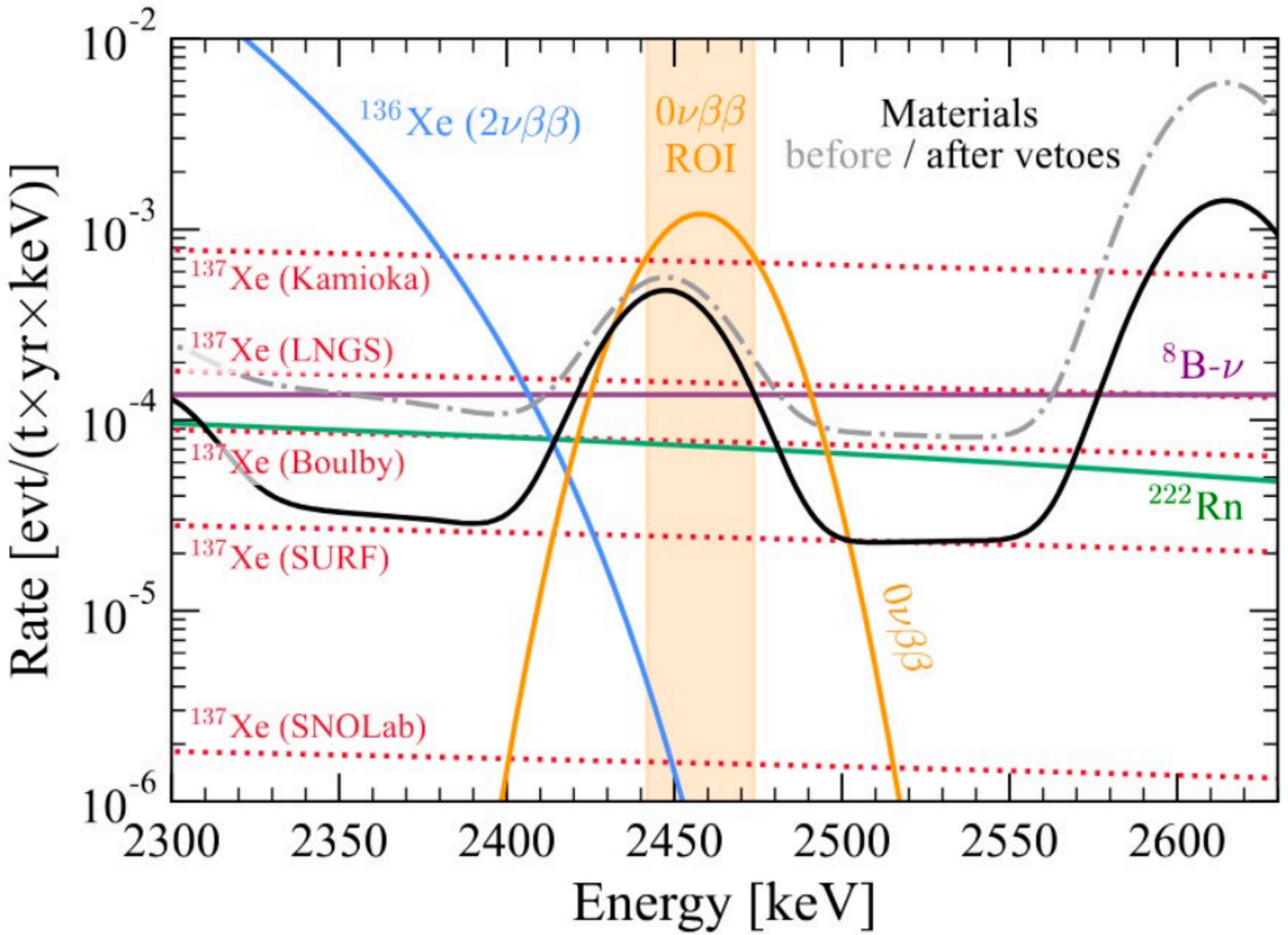




XLZD 0νββ - 2024 Studies

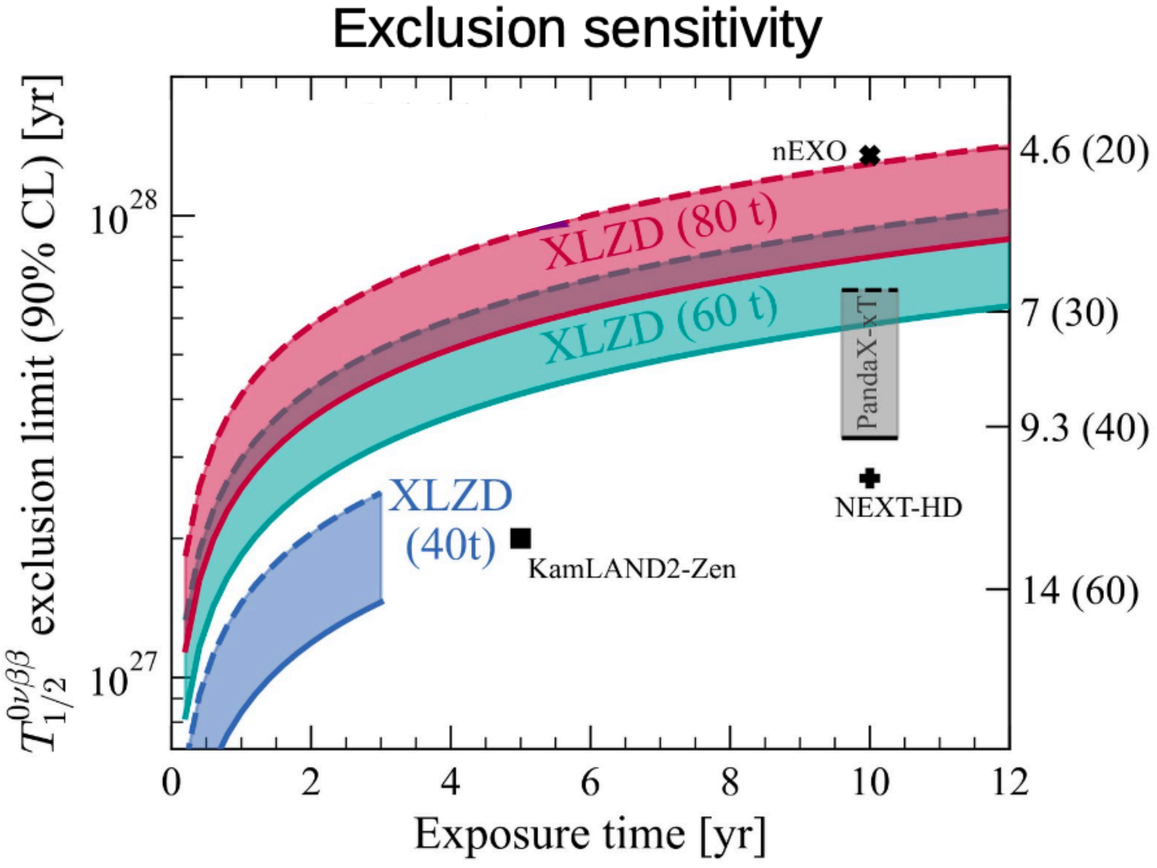


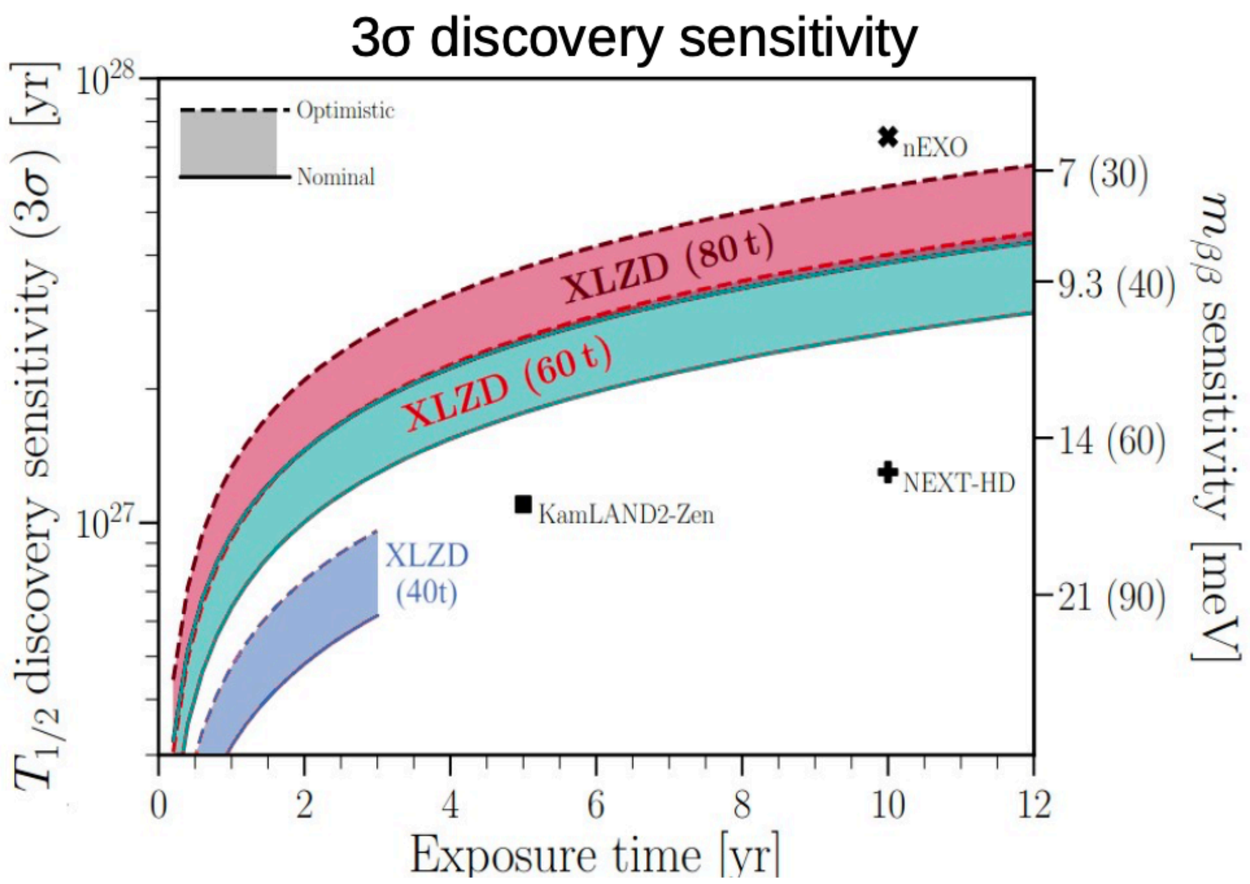
- External Xe shields the internal Xe from backgrounds (^{214}Bi γs)
- σ/E=0.65% @ $Q_{ββ}$
- ~3 mm position reconstruction



J. Phys. G: Nucl. Part. Phys. 52 (2025) 045102

XLZD 0νββ - 2024 Studies





XLZD - 2026 Studies

Granular bottom-up background model for more robust evaluation of sensitivity

G4 simulations for γ-ray propagation plus radioassay data

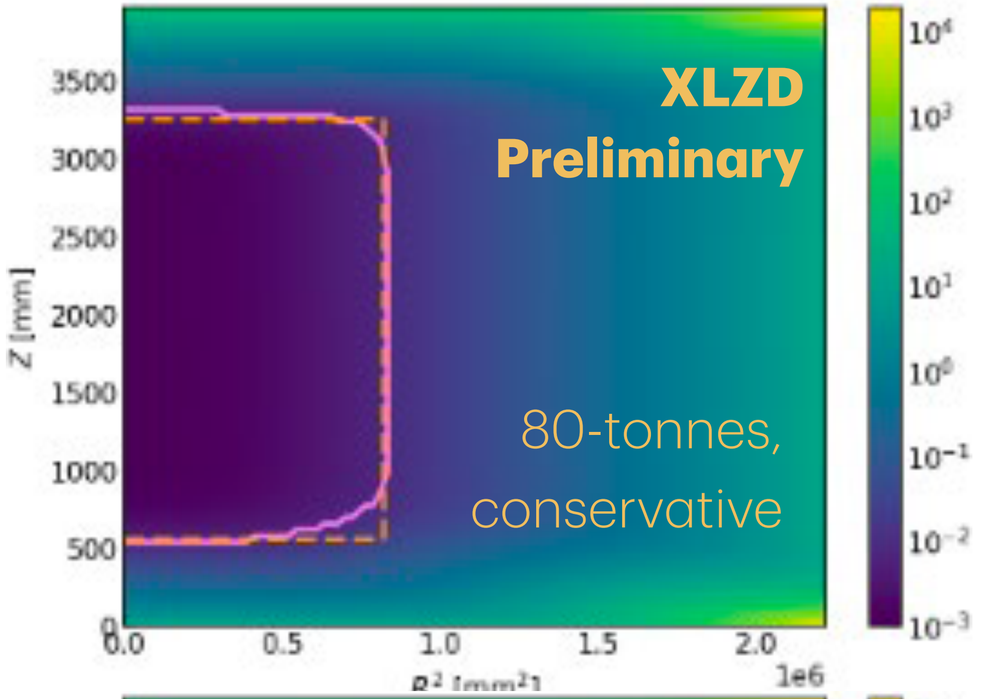
Modelling detector response

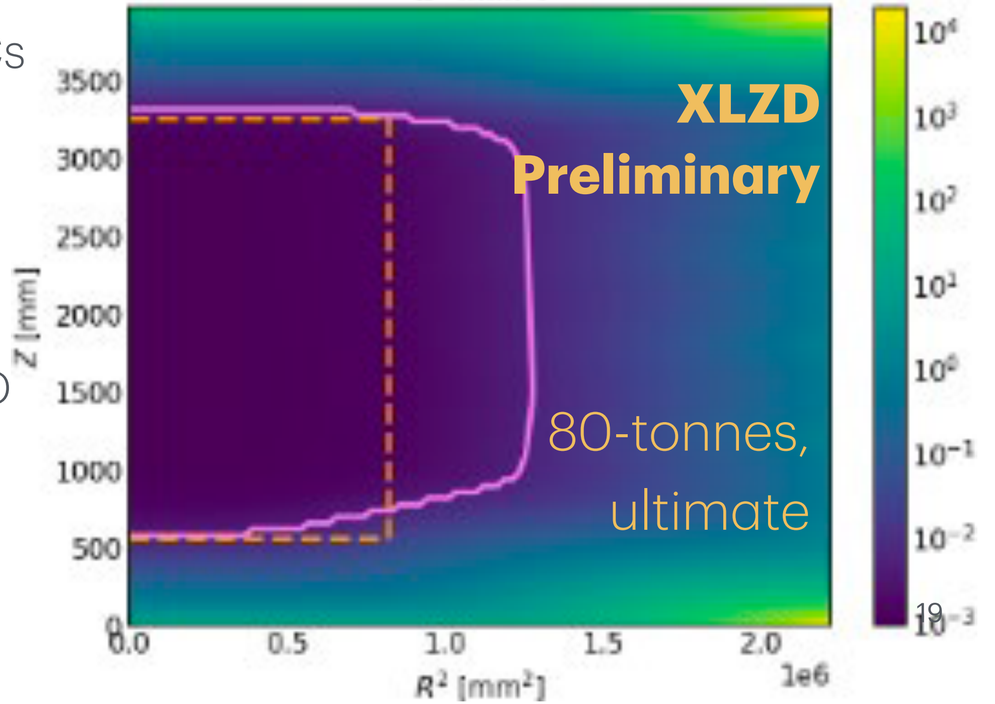
- σ/E = 0.65%
- 3-mm SS/MS resolution in z

Investigating sensitivity scenarios for 60-tonne and 80-tonne LXe-TPCs

- **Conservative:** assumes LZ cables, LZ Teflon, measured superinsulation, LZ titanium cryostat (≈ 2024 studies)
- **Improved:** nEXO cables, EXO-200 Teflon (10x improvement), 10x reduction in superinsulation
- **Ultimate:** above plus substantial improvement to cryostat (e.g. CVD nickel)

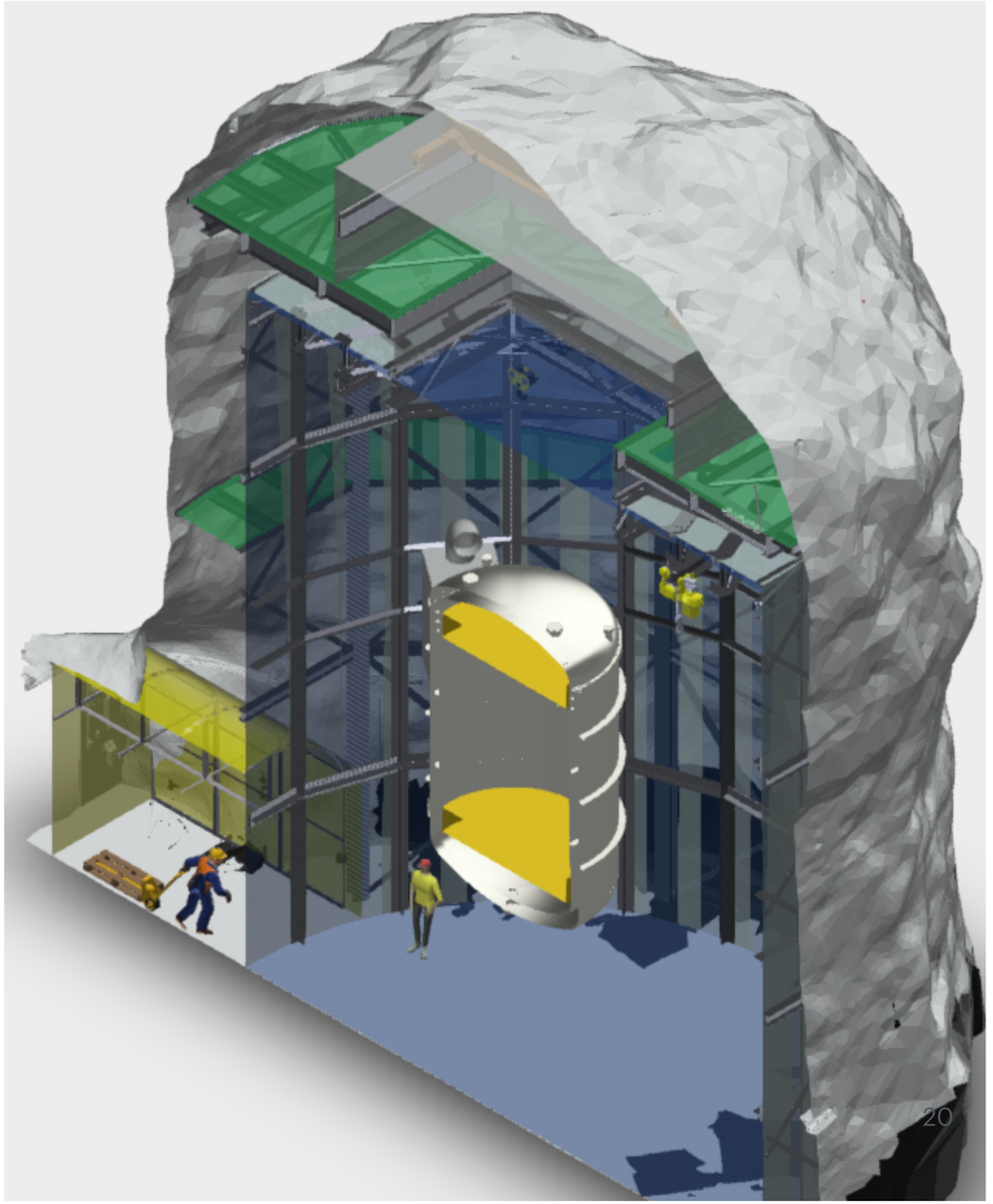
Preliminary conclusion: there is a path to 10^{28} years at 80 tonnes with judicious material selection

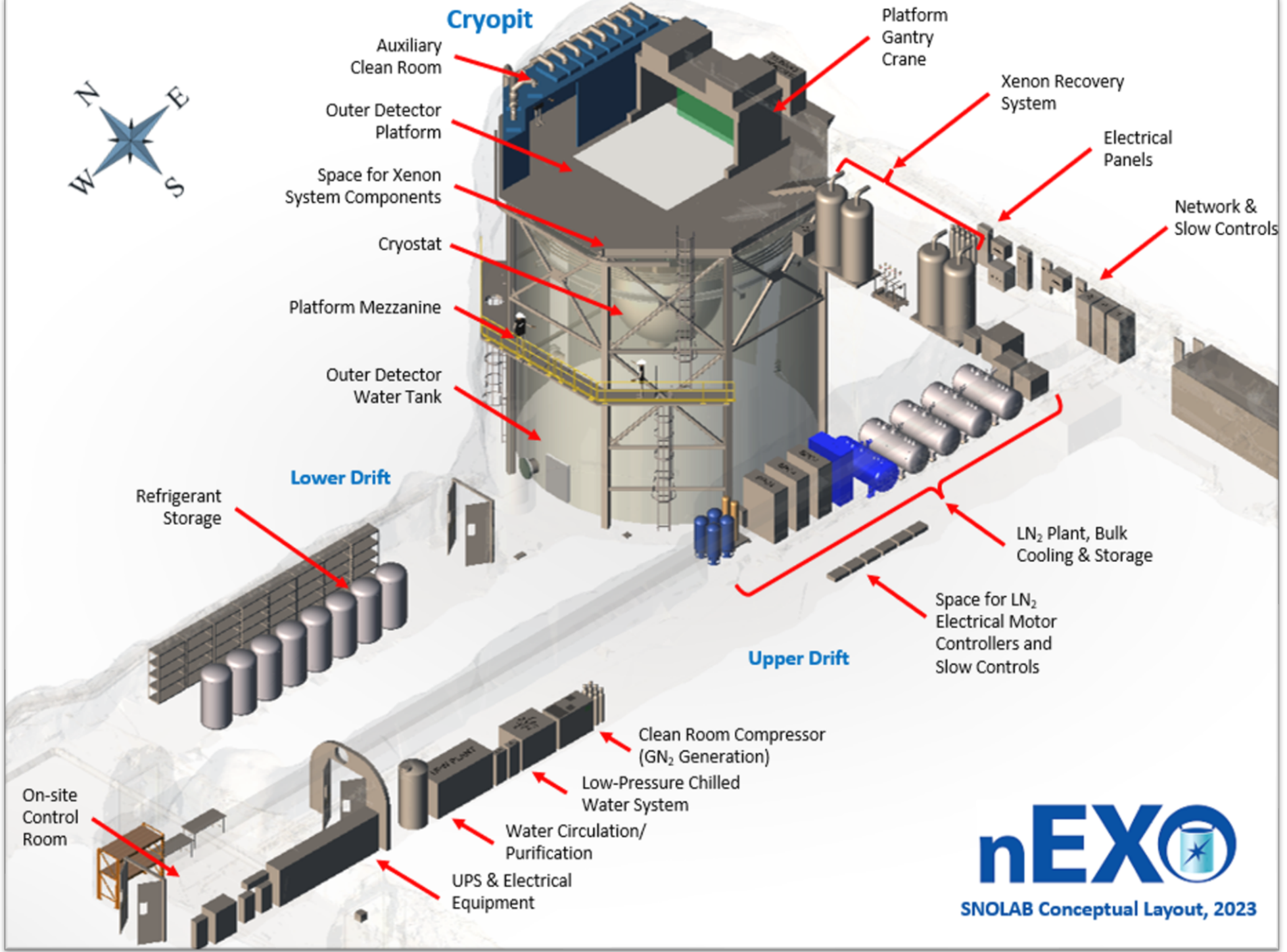




Xe TPCs for

- LXe TPCs hold technological promise in rare event searches
- EXO-200 provided great scientific results
  - Informed the design of nEXO
- nEXO was optimized for the search of 0νββ decay of ^{136}Xe
  - Can/should inform the design on next-gen experiments
- Today, several tonne-scale LXe TPCs are operational (XENONnT, LZ, PandaX-4T)
- XLZD merges demonstrated technologies of LZ and XENONnT
  - Scientific Goal: Dark Matter AND 0νββ
  - There is a path to $T_{1/2} > 10^{28}$ years at 80 tonnes with judicious material selection
- Much work remains in this area, where our strategy is still evolving within the collaboration**– join us if you want to contribute!**




Cryopit
Auxiliary Clean Room
Outer Detector Platform
Space for Xenon System Components
Cryostat
Platform Mezzanine
Outer Detector Water Tank
Platform Gantry Crane
Xenon Recovery System
Electrical Panels
Network & Slow Controls
Lower Drift
Refrigerant Storage
LN2 Plant, Bulk Cooling & Storage
Space for LN2 Electrical Motor Controllers and Slow Controls
Upper Drift
Clean Room Compressor (GN2 Generation)
Low-Pressure Chilled Water System
Water Circulation/ Purification
UPS & Electrical Equipment
On-site Control Room
N
E
S
W
nEXO
SNOLAB Conceptual Layout, 2023

Hydrofluoroethers (HFEs)

- HFEs are perfluorinated, engineered fluids (molecular masses in the 100s amu)
- HFE-7000 and -7200 are liquid at room temperature, all the way down to -100C
- Shown to be ultra-low radioactivity: ppq-level U, Th (quite refractory to impurities, purifiable)
- High density: 1.4 ÷ 1.8 g/cm3 —> excellent γ-ray shield
- Protonated —> neutron moderation
- nEXO HFE handling:
  - Cryogenics envisioned with recirculating HFE 7200 through an external HEX (cut cooldown time)
  - Volumetric (gear) pump
  - LN2 refrigeration



