# nEXO and LXe TPCs for $0\nu\beta\beta$

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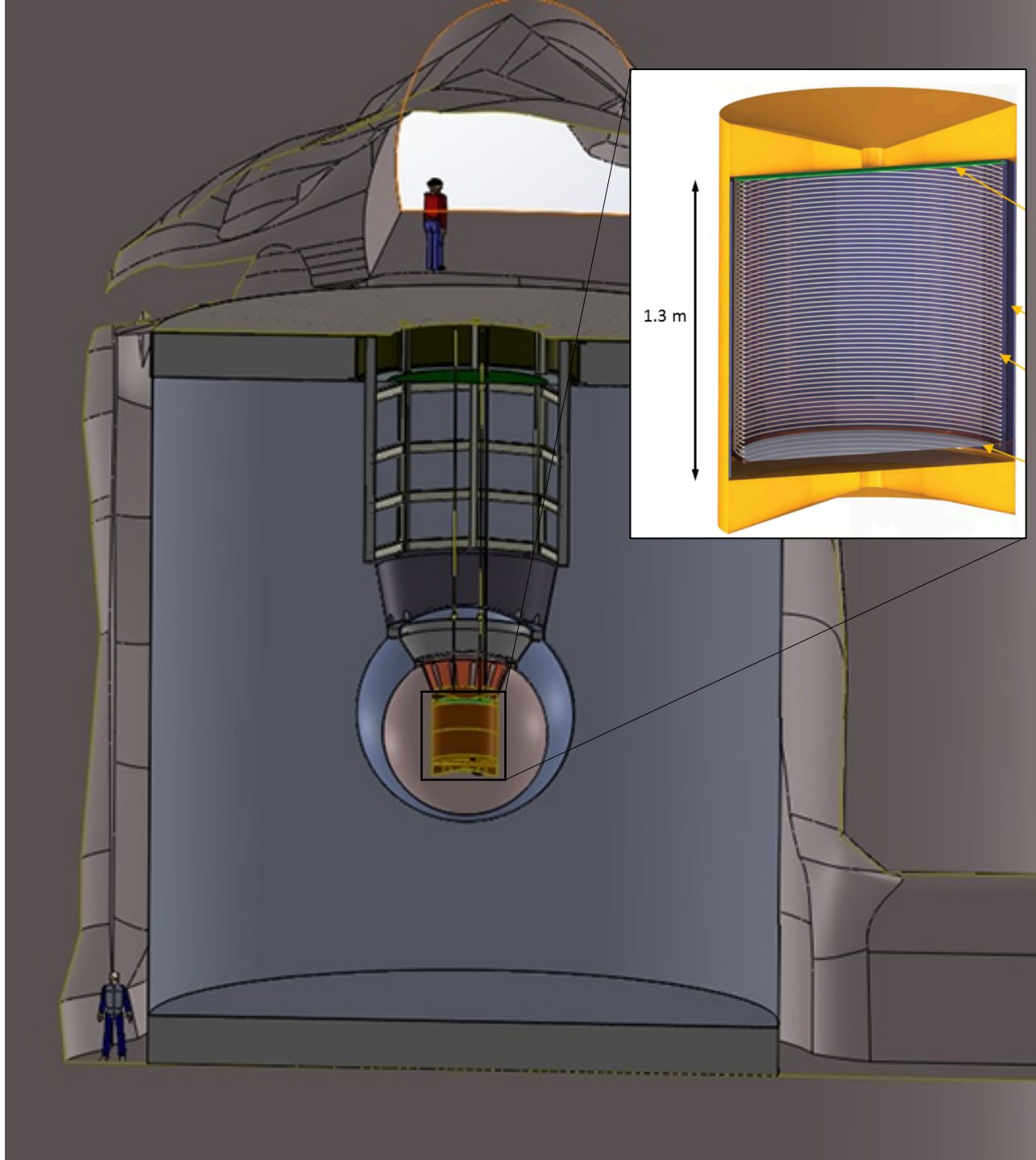
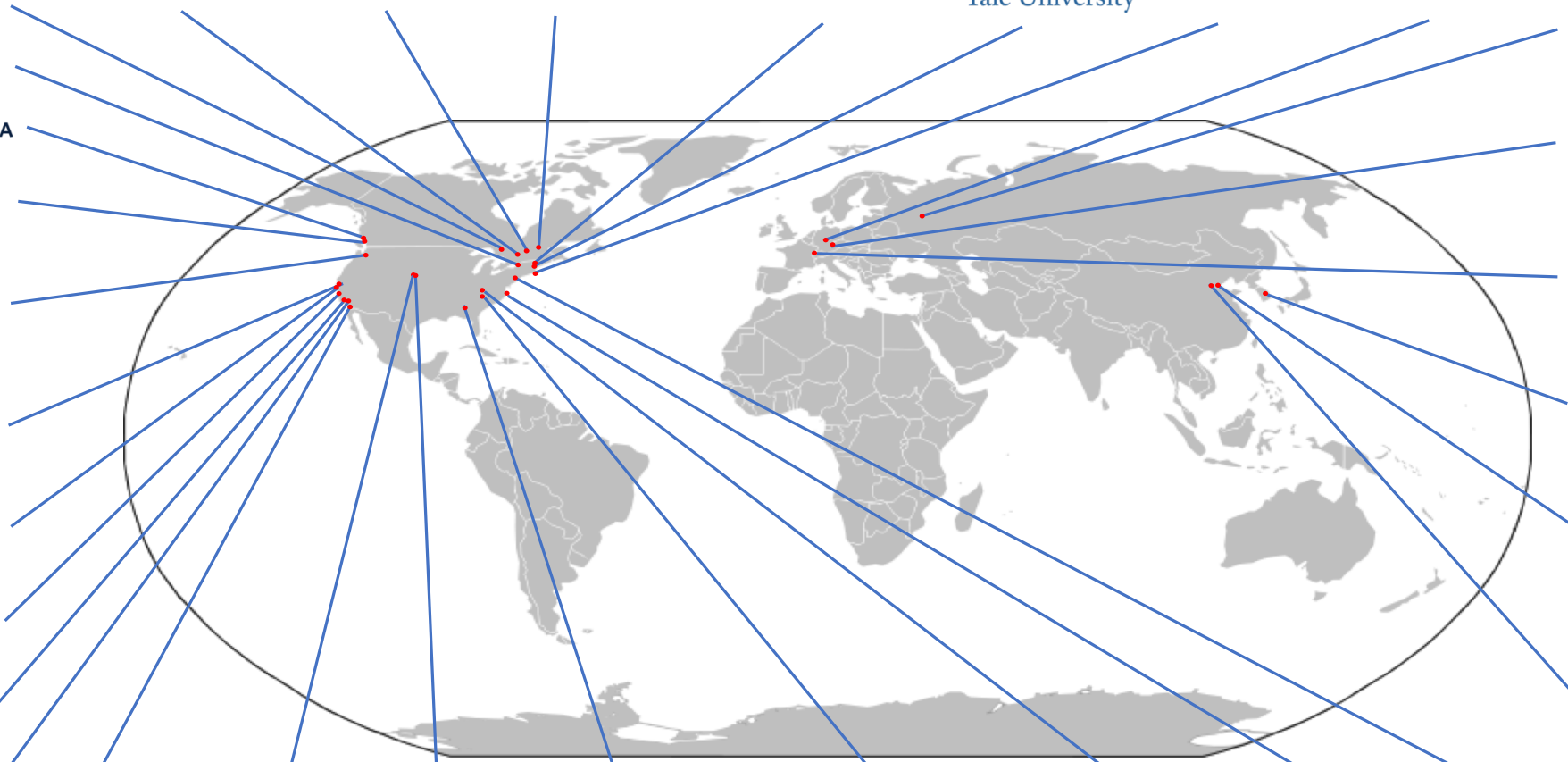
*for the nEXO collaboration*

SNOWMASS Mini Workshop: 0nubb Experiment

*August 5, 2020*




Laurentian University
Université Laurentienne
Carleton University
McGill
Université de Sherbrooke
UMass Amherst
Yale University
Brookhaven National Laboratory
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Friedrich-Alexander Universität Erlangen-Nürnberg
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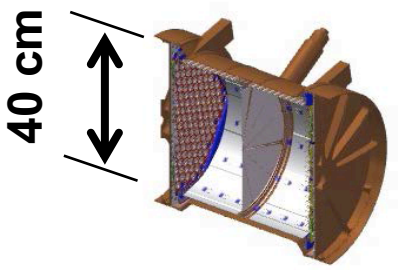
UC San Diego
Colorado School of Mines
Colorado State University
The University of Alabama
Oak Ridge National Laboratory
University of Kentucky
UNCW University of North Carolina Wilmington
Drexel University

# EXO-200 and nEXO

- Large LXe TPC can enable the exposure and low background needed for multi-ton scale $0\nu\beta\beta$ searches
- Multi-parameter detector allows measurement of background and signal in single, homogeneous volume

**EXO-200**



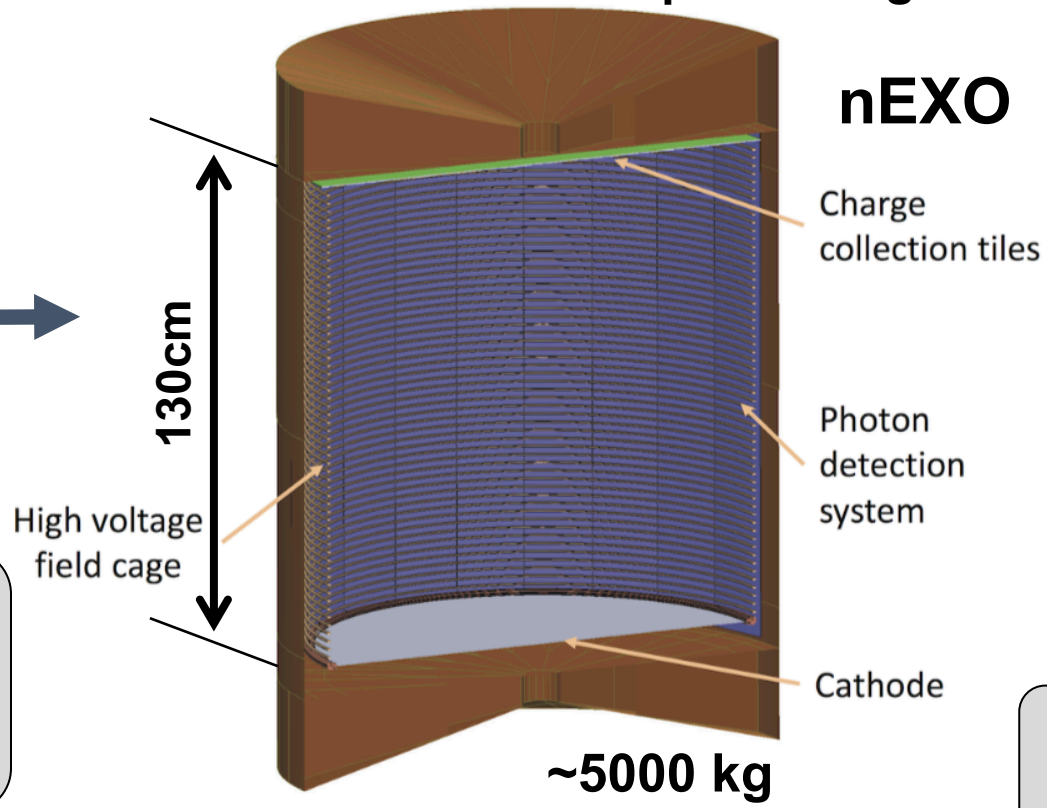

**~150 kg**

*Operated 2011-2018 @ WIPP*

*Reached sensitivity of* $T_{1/2} = 5 \times 10^{25}$ *yr*

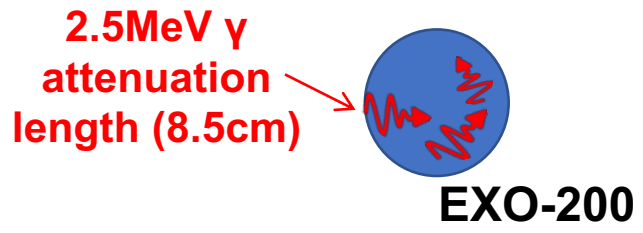
*Phys. Rev. Lett. 123, 161802 (2019), arXiv:1906.02723*

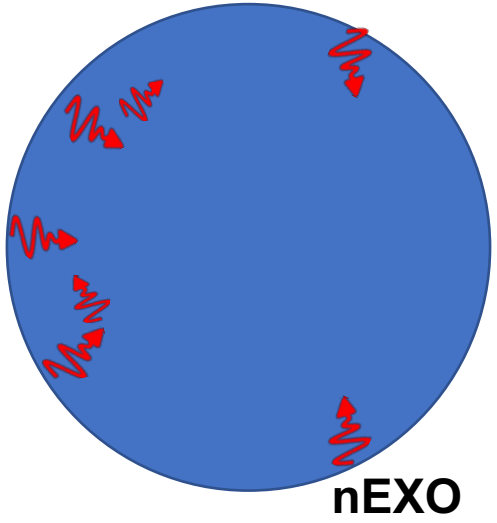
**nEXO detector conceptual design:**




**~5000 kg**

**Self-shielding:**




*nEXO reaches required backgrounds for ton-scale by taking full advantage of self-shielding*

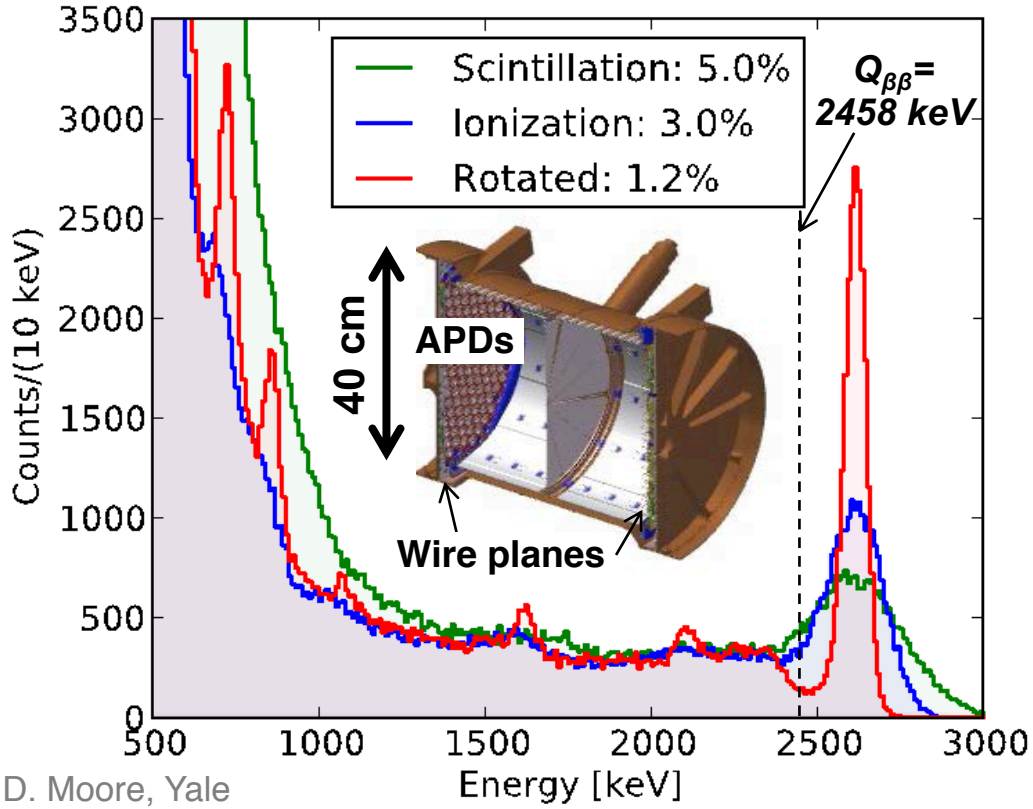
*nEXO projected sensitivity* $T_{1/2} \sim 10^{28}$ *yr in 10 years of operation*

*Phys. Rev. C 97, 065503 (2018), arXiv:1710.05075*

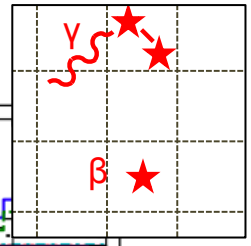
# EXO-200

- Single phase LXe TPC (~150 kg, enriched to 80% $^{136}$Xe), ran from 2011-2018
- Topological discrimination and $\sigma$ = 1.2% energy resolution

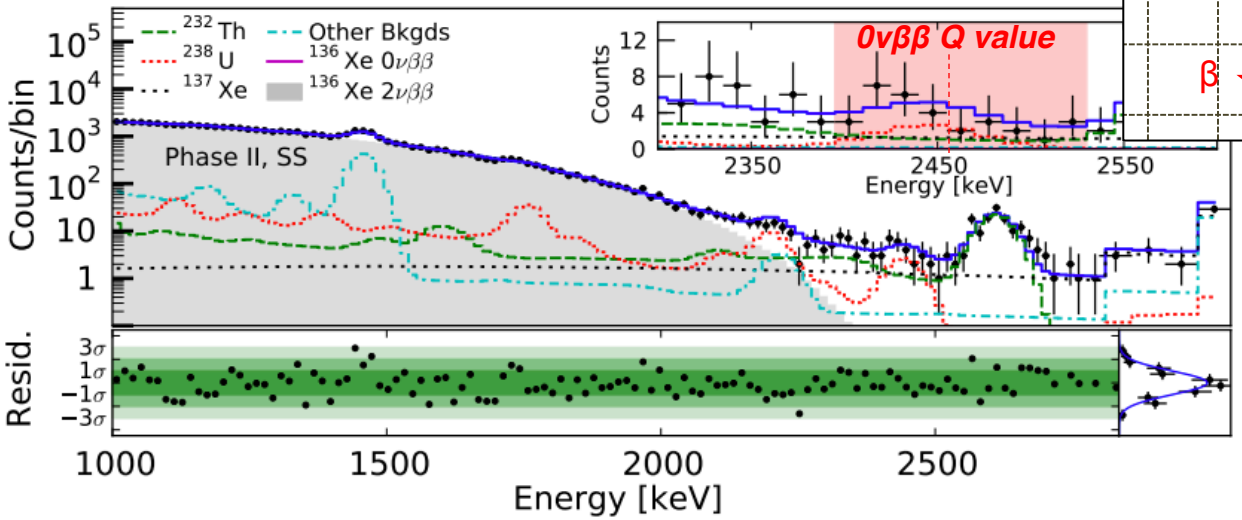
**Reconstructed energy, $^{228}$Th calibration:**




*Signal-like:*

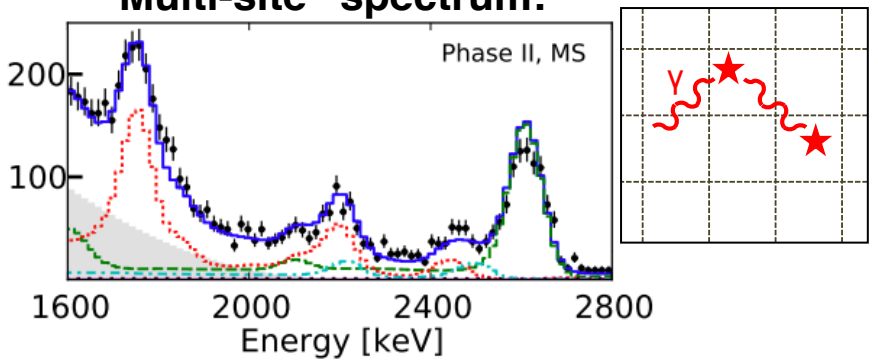



**"Single-site" spectrum:**




*Background-like:*

**"Multi-site" spectrum:**







*Results from complete exposure (234 kg yr):*

**$T_{1/2}^{0\nu\beta\beta}$ > 3.5 ·10$^{25}$ yr (Phase 1+2)**

*median sensitivity = 5.0 ·10$^{25}$ yr*

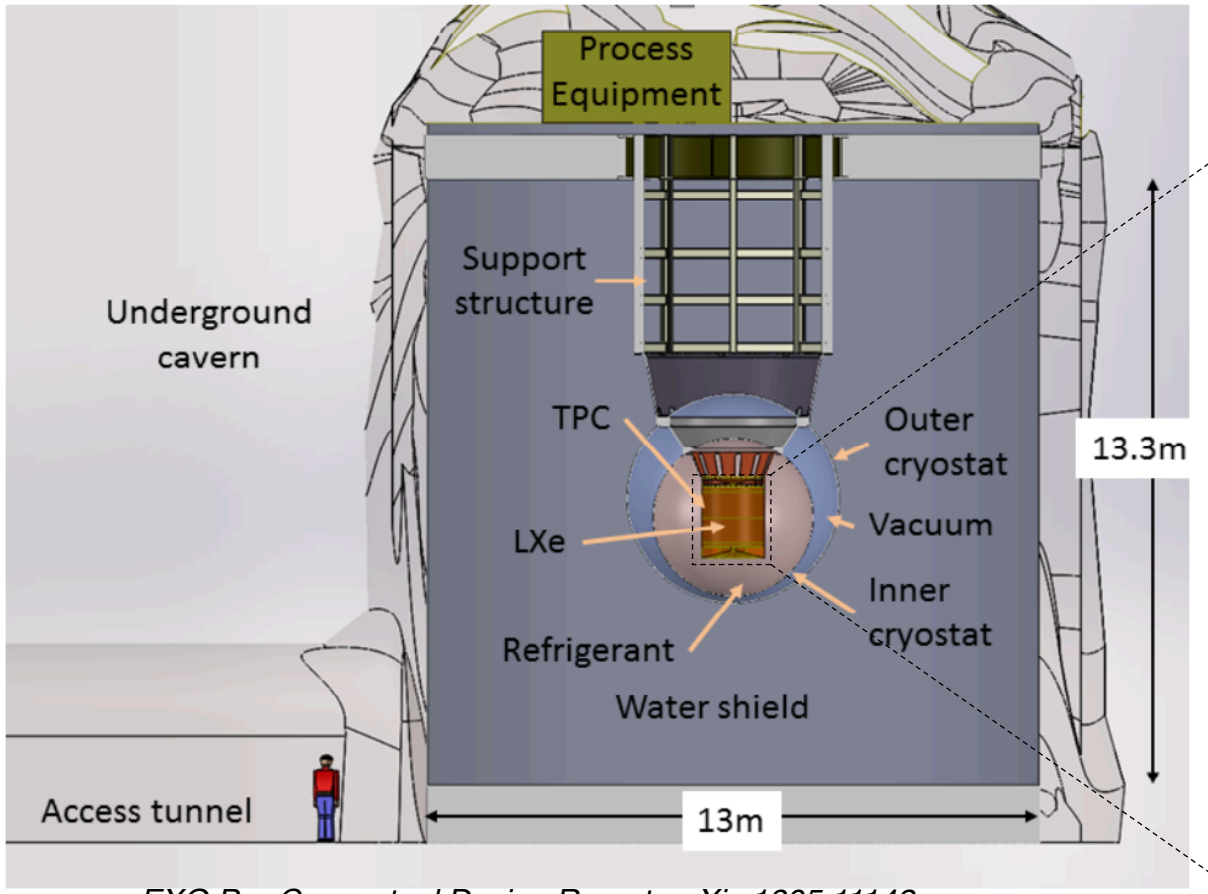
**$\langle m_{\beta\beta} \rangle$ < 93 - 286 meV**

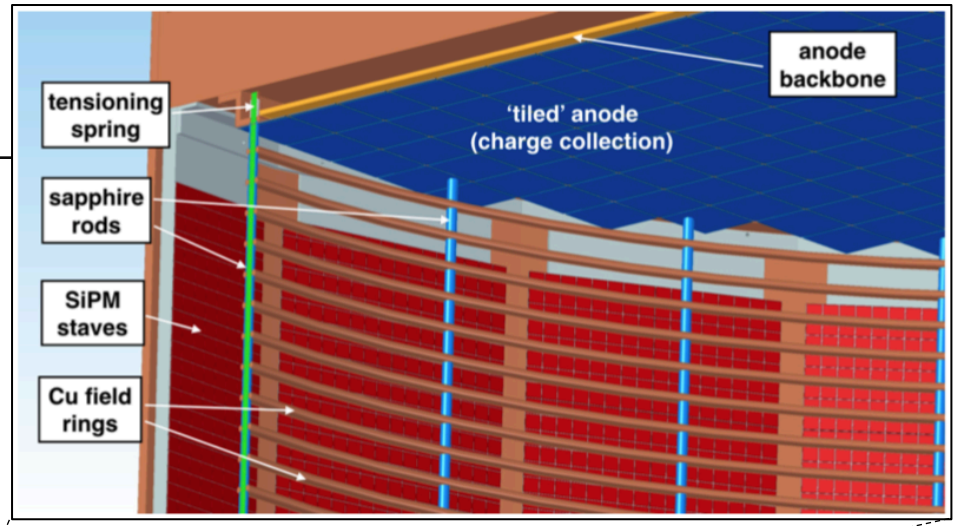
*PRL 123, 161802 (2019), arXiv:1906.02723*
*PRL 120, 072701 (2018), arXiv:1707.08707*
*Nature 510, 229 (2014), arXiv:1402.6956*

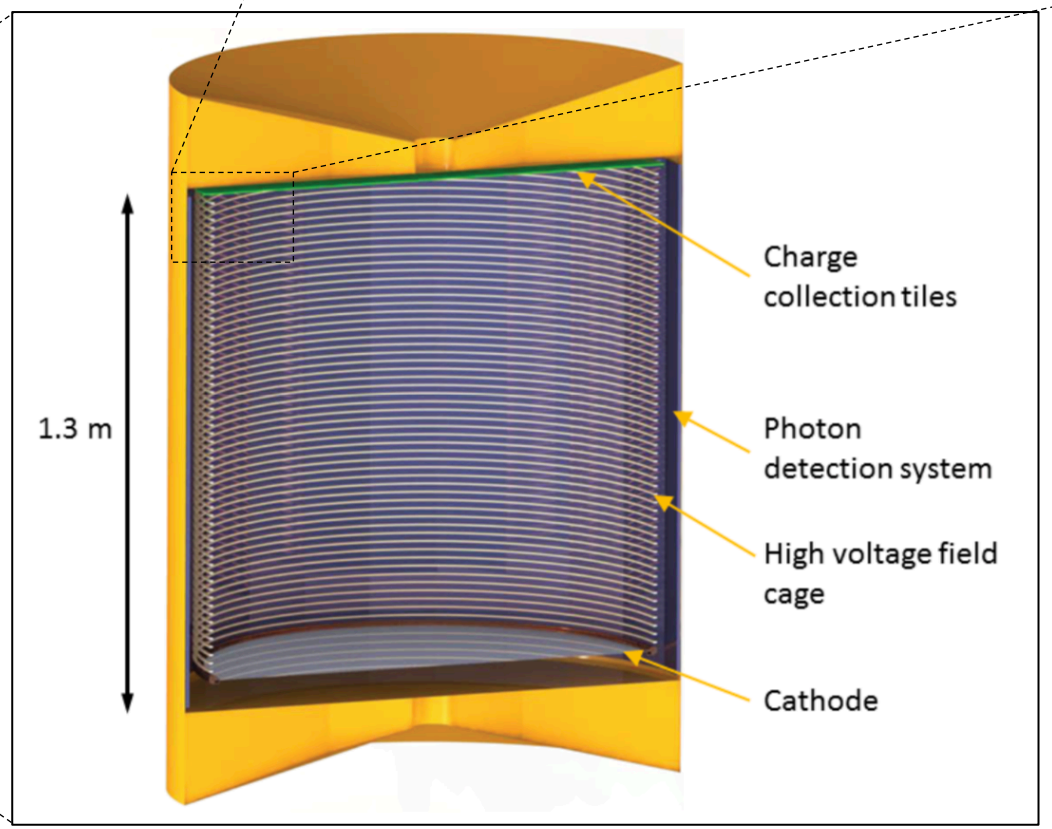
# nEXO Conceptual Design

- nEXO provides a multi-ton scale extension of the single-phase LXe TPC technology demonstrated for $0\nu\beta\beta$ in EXO-200

**Conceptual design in SNOlab Cryopit:**



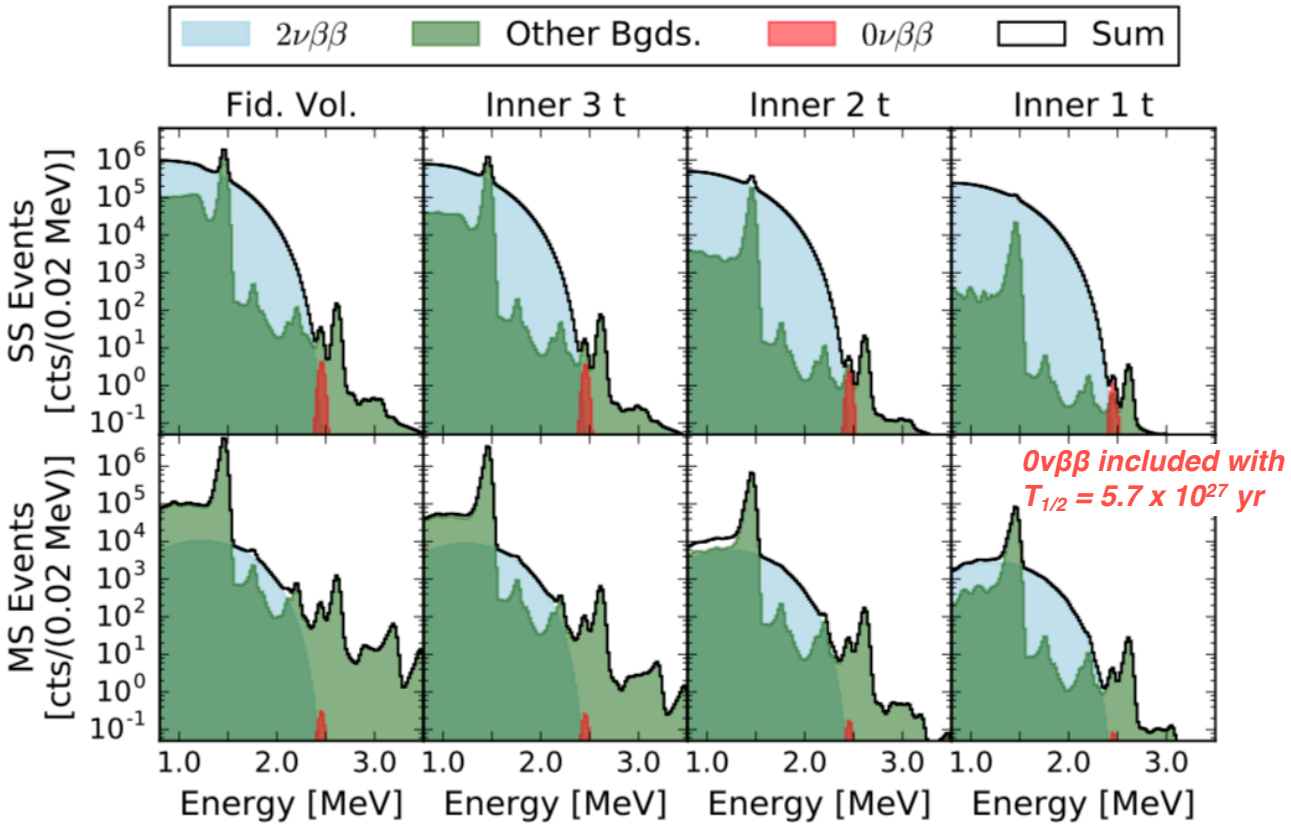

*nEXO Pre-Conceptual Design Report, arXiv:1805.11142*

# nEXO Sensitivity

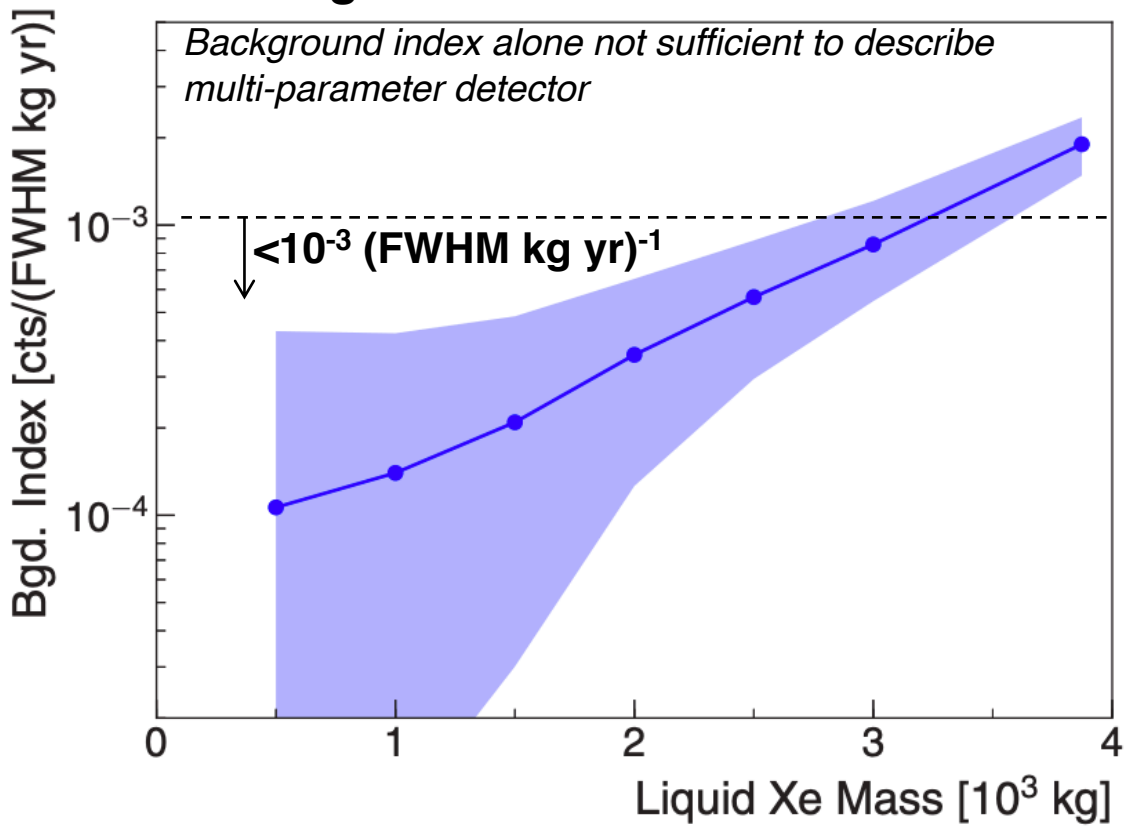
- Sensitivity projections based on direct measurements of material radiopurity and detailed detector simulation (same procedure validated in EXO-200)
- Detailed description of pre-conceptual design and sensitivity:

*Phys. Rev. C 97, 065503 (2018), arXiv:1710.05075*
*nEXO Pre-Conceptual Design Report, arXiv:1805.11142*

**Simulated nEXO spectra (full detector volume):**

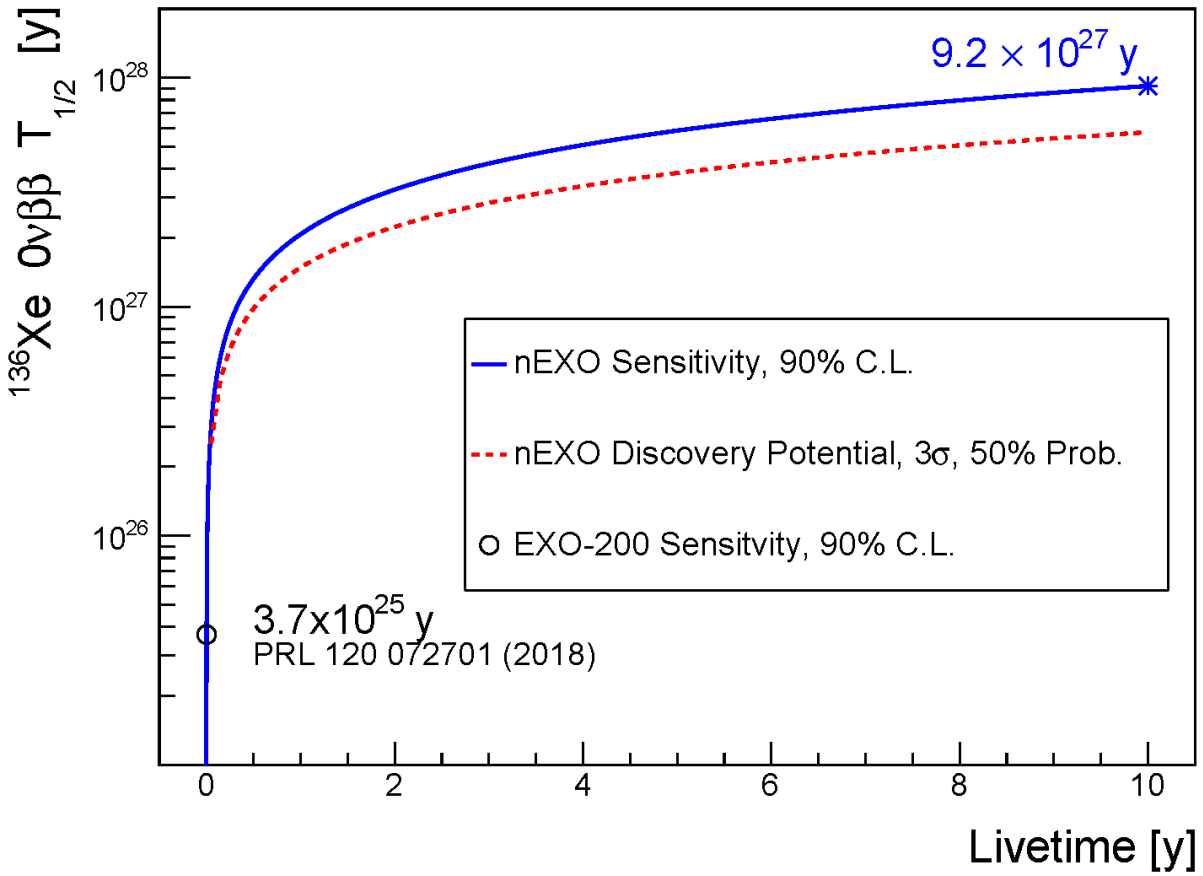



**Background index vs. central mass:**



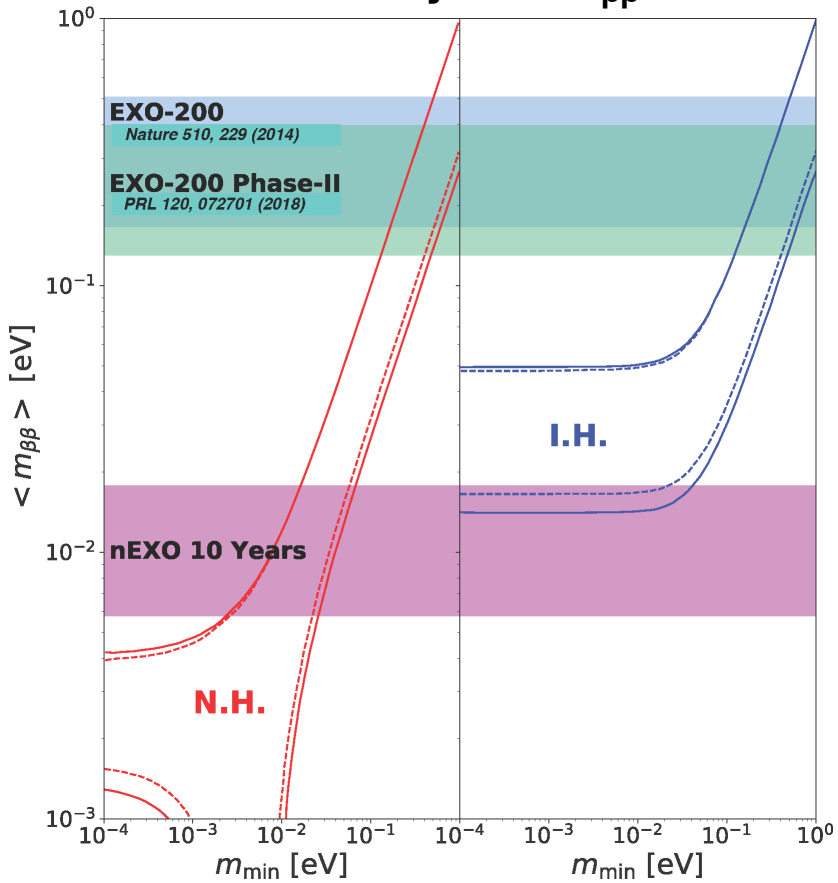
# nEXO Sensitivity

**Projected half-life sensitivity vs. livetime:**




*Phys. Rev. C 97, 065503 (2018), arXiv:1710.05075*

**Sensitivity to $\langle m_{\beta\beta} \rangle$**



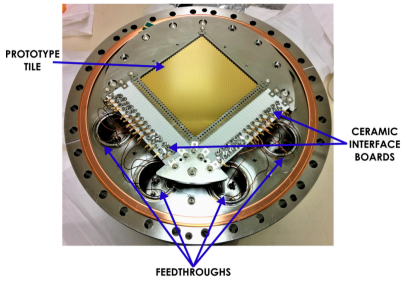

- *Assumes $g_A = g_A^{free} = -1.27$*
- *Bands indicate the envelope of various NME calculations:*
  - *EDF: T.R. Rodríguez and G. Martínez-Pinedo, PRL 105, 252503 (2010)*
  - *ISM: J. Menendez et al., Nucl Phys A 818, 139 (2009)*
  - *IBM-2: J. Barea, J. Kotila, and F. Iachello, PRC 91, 034304 (2015)*
  - *QRPA: F. Šimkovic et al., PRC 87 045501 (2013)*
  - *SkyrmeQRPA: M.T. Mustonen and J. Engel PRC 87 064302 (2013)*

# nEXO R&D

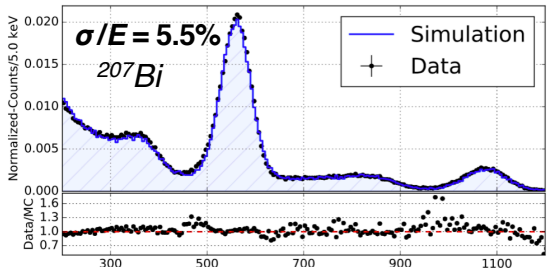
## Charge detection:

- nEXO anode concept consists of ~150 10cm x 10cm charge "tile modules"

**Photo of prototype tile:**




**Measured energy spectrum:**

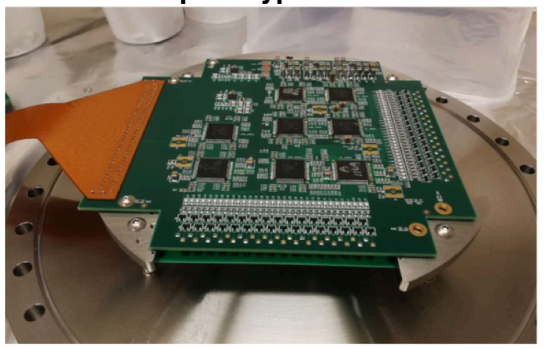



*JINST 13 P01006 (2018), arXiv:1710.05109*
*JINST 14 P09020 (2019), arXiv:1907.07512*

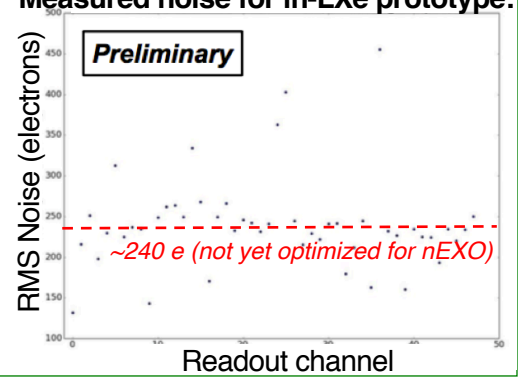
## In-LXe electronics:

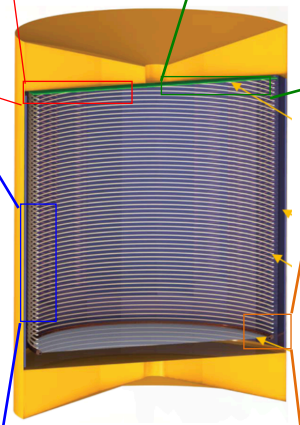
- Cold electronics will be used to avoid long readout wires, allowing noise <200 *e* per channel

**Photo of prototype electronics:**



**Measured noise for in-LXe prototype:**

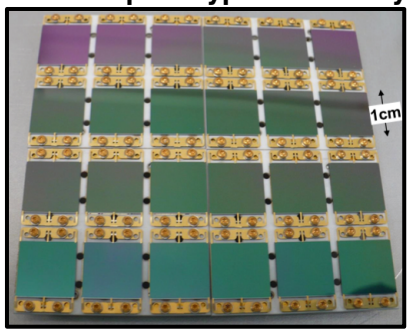


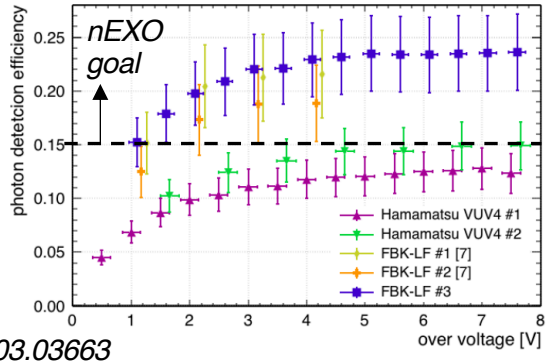

## Light detection:

- Scintillation light collected by ~4.5 m$^2$ of VUV sensitive SiPMs, in ultra low-background modules

**Photo of prototype SiPM array:**




**VUV Photon Detection Efficiency (PDE):**

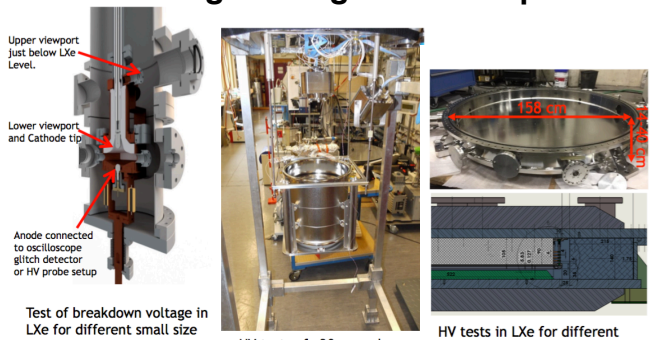



*NIM A 940, 371 (2019), arXiv:1903.03663*
*IEEE Trans. Nucl. Sci. 65 (2018), arXiv:1806.02220*

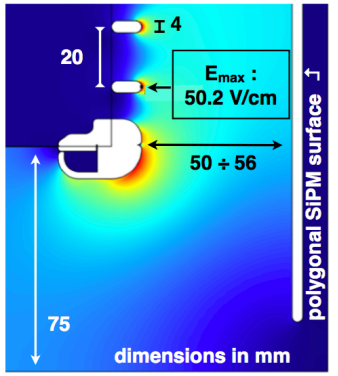
## High voltage design:

- nEXO HV components tested at full-scale prior to installation to ensure operating field of 400 V/cm

**nEXO high-voltage R&D setups:**




**Simulation of cathode:**



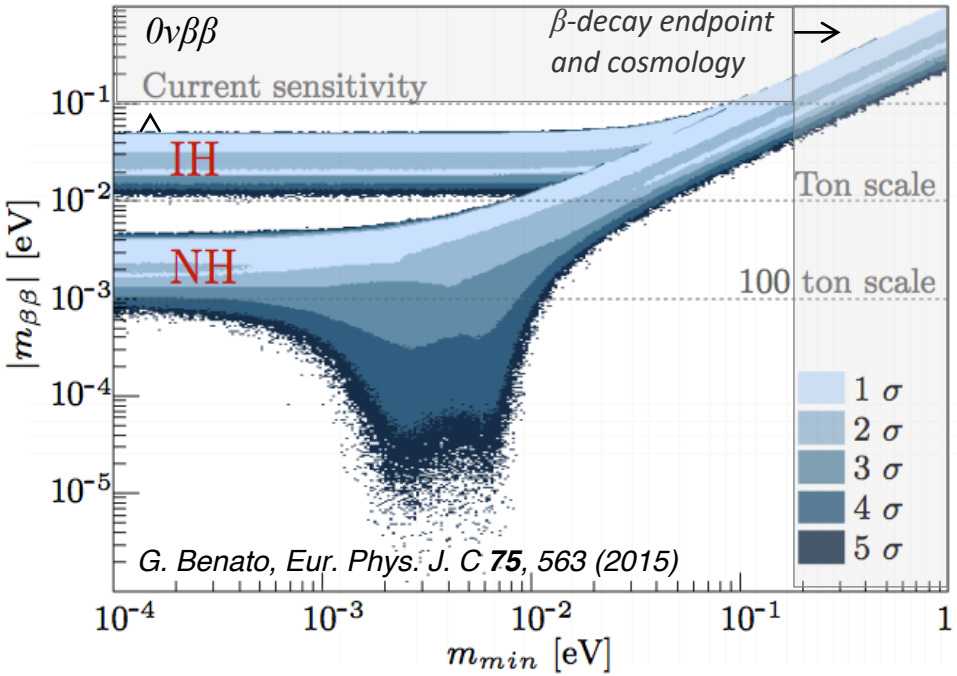
# nEXO Summary

- EXO-200 was the first 100 kg-class experiment to run and demonstrated the power of a large, homogeneous LXe TPC for $0\nu\beta\beta$
- Scaling this technology to the ton-scale (nEXO) allows substantial increase in sensitivity as LXe TPCs begin to take advantage of self-shielding at MeV-scale energies
- The nEXO conceptual design is mature and documented by the pre-CDR document (arXiv:1805.11142) and a detailed sensitivity analysis (PRC 97, 065503 [2018], arXiv:1710.05075)
- Hardware R&D is ongoing and has demonstrated key features required for the conceptual design
  - Beyond nEXO, substantial additional improvement may be possible (see, e.g., following talk by W. Fairbank on Ba tagging)

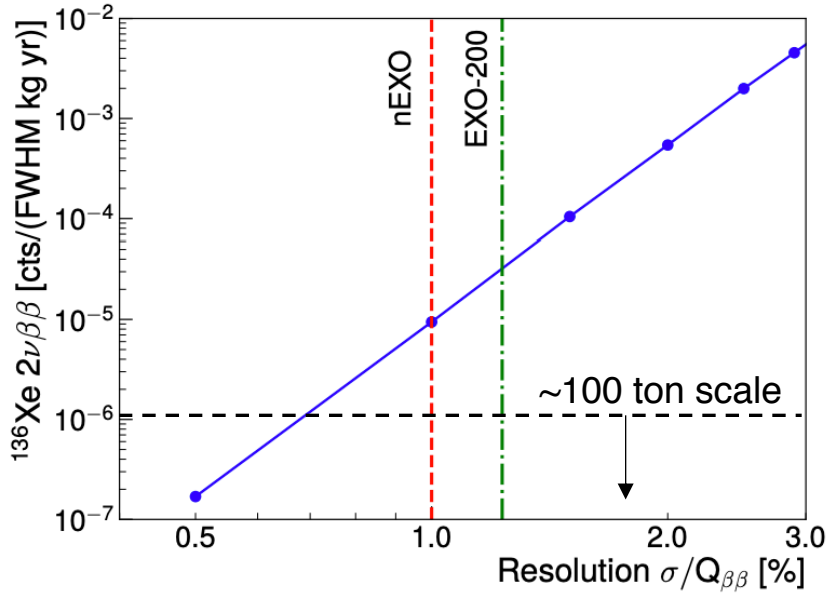
# LXe TPCs beyond nEXO

- Larger experiments will be required to study $0\nu\beta\beta$ in detail, or to probe the remaining parameter space allowed in the normal mass ordering ($T_{1/2}$ sensitivity ~$10^{30}$ yrs)
- A ~100 ton LXe TPC would require linear dimensions of ~3.5 m (2.5x larger than nEXO)
- Irreducible background from $2\nu\beta\beta$ requires $\sigma \lesssim 0.7\%$ energy resolution, continued improvement for in-LXe backgrounds (especially Rn)

**Majorana mass parameter space:**




$2\nu\beta\beta$ **background vs resolution:**




*Phys. Rev. C 97, 065503 (2018), arXiv:1710.05075*

**Technical challenges requiring R&D:**

- Isotope procurement
- Improved resolution
  - Light collection efficiency -> 10%
  - Low noise, pixelated charge readouts
- Liquid phase Xe purification (electronegatives)
- Removal of noble gas impurities (primarily Rn)
- High-voltage operation up to cathode biases of ~150 kV