2021/06/08
CAP: Neutrino Symposium

Current Status of the nEXO Experiment

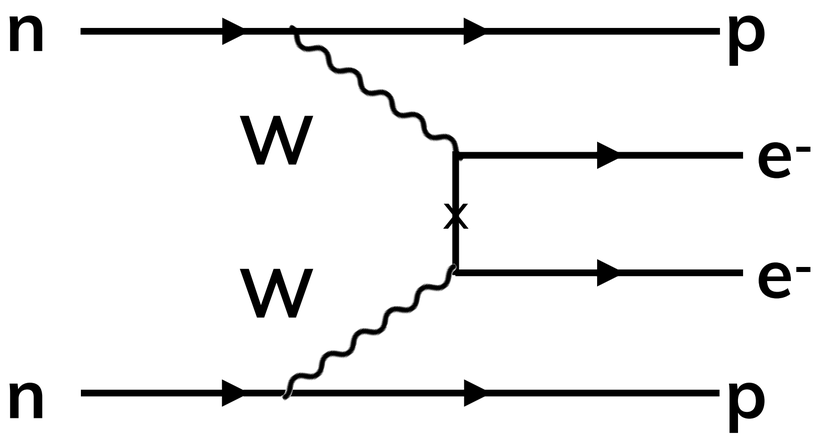
Erica Caden, (she/her)
on behalf of nEXO-Canada
Research Scientist

Neutrinoless Double Beta Decay

Neutrinoless Double Beta Decay

- Observation of 0νββ always implies new physics:
  - Majorana Neutrinos
  - Lepton number violation
  - Probe new mass mechanism up to GUT scale
  - Help explain observed cosmic baryon asymmetry

- Neutrino Masses have to be non-zero for 0νββ to be possible
  - The distinction between Dirac and Majorana particles is only observable for particles of non-zero mass

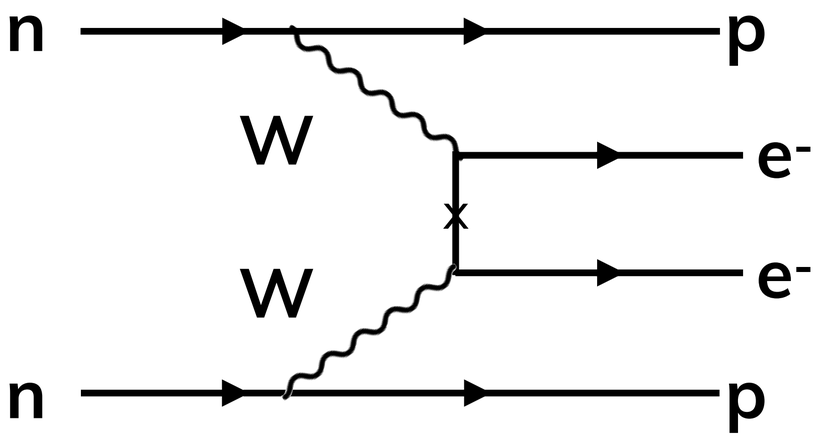


Neutrinoless Double Beta Decay

$$[T_{1/2}^{0\nu}]^{-1} = \Gamma^{0\nu} = G^{0\nu} \mid M^{0\nu} \mid^2 < m_{\beta\beta} >^2$$

- The effective Majorana neutrino mass may be extracted from the decay rate
- $G^{0\nu}$: Phase Space Factor
- $M^{0\nu}$: Nuclear Matrix Element
- For virtual exchange of light Majorana neutrinos, the decay rate depends on the effective neutrino mass:

$$< m_{\beta\beta} > = \sum_i U_{ei} m_i$$

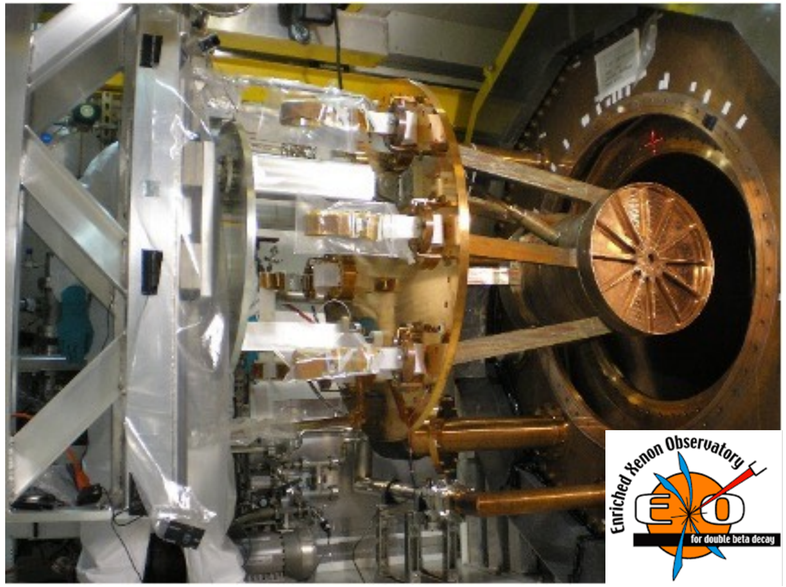


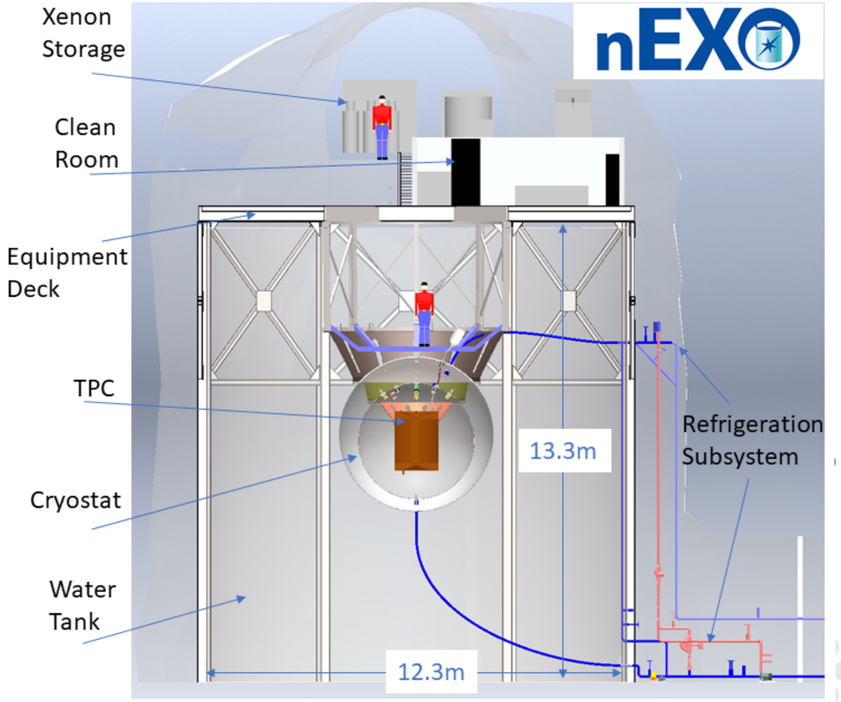
nEXO: 5-tonne Liquid Xenon Time Projection Chamber

Searching for 0νββ in ^{136}Xe with liquid Xe TPC

EXO-200:

- EXO-200 First 100-kg class ββ experiment
- 175 kg liquid-Xe TPC with ~80% ^{136}Xe
- WIPP Mine in NM, USA
- Decommissioned in Dec 2018
- End-of-run Calibration campaign informs nEXO Design



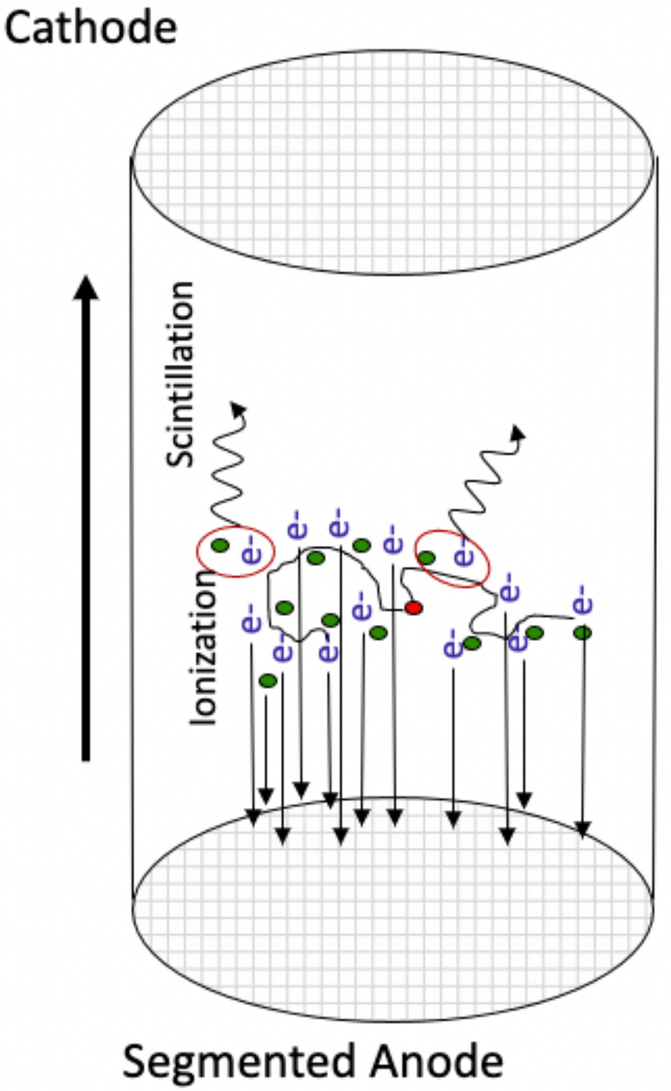


nEXO:

- Next-generation liquid-Xe TPC
- 5-tonne enriched in ^{136}Xe at ~90%
- Designed to go beyond $T_{1/2}$~10^{28} years
- Preferred location: SNOLAB Cryopit
- Design of detector and components are advanced
- **DOE Decision on funding 0νββ projects anticipated this year**

Liquid Xe TPCs

- Liquid Xe is Source and Detection Medium
- Monolithic detector structure -> excellent background rejection
- Cryogenic electronics in LXe
- Active self-shielding
- Detection of scintillation light and secondary charges
  - Good energy resolution
  - Particle ID
  - Event Topology

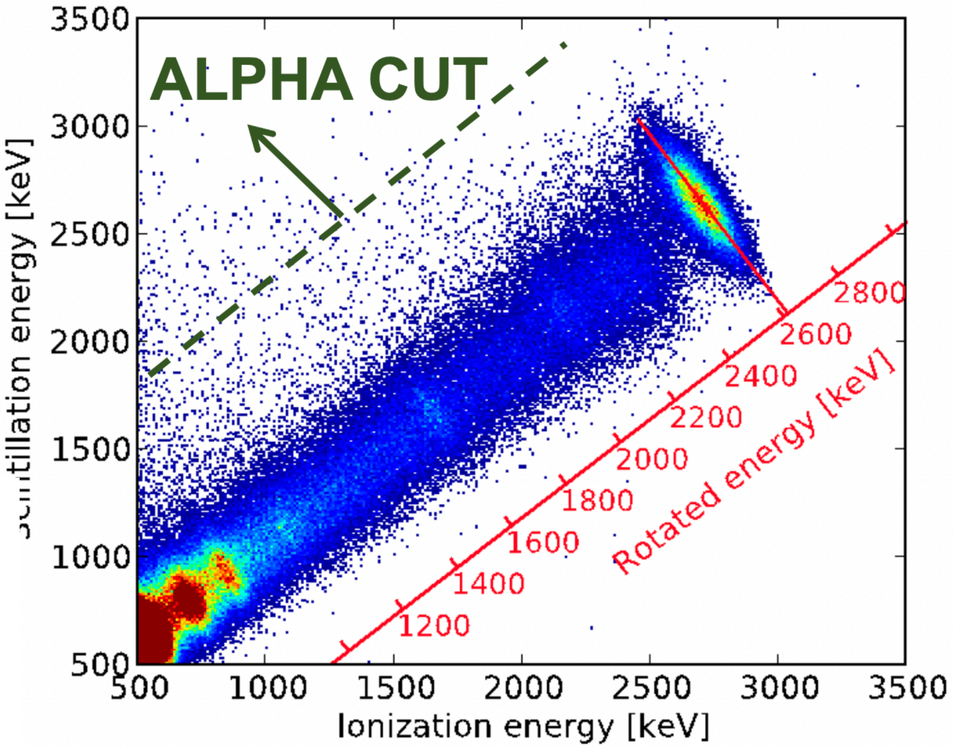


Energy, Position, & Multiplicity

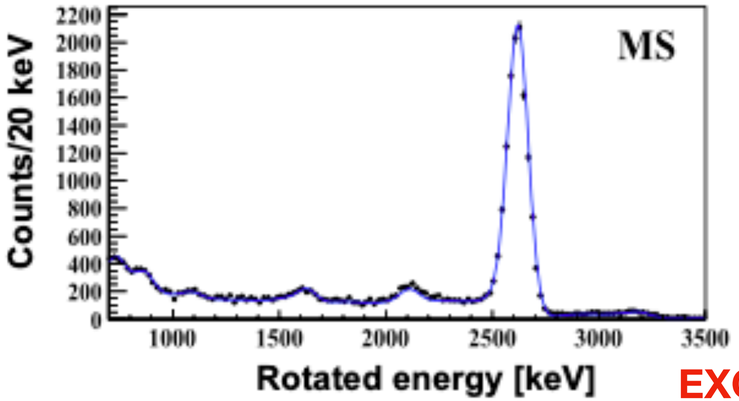
- Anti-correlation between scintillation and ionization energies in LXe [PRB 68, 054201 (2003)]
- Rotation angle determined using ^{228}Th source data
- EXO-200 achieved 1.15% energy resolution at 0νββ Q-value (2458 keV) [PRL 123, 161802 (2019)]
- Position and Multiplicity reconstruction allow for background measurement and reduction

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

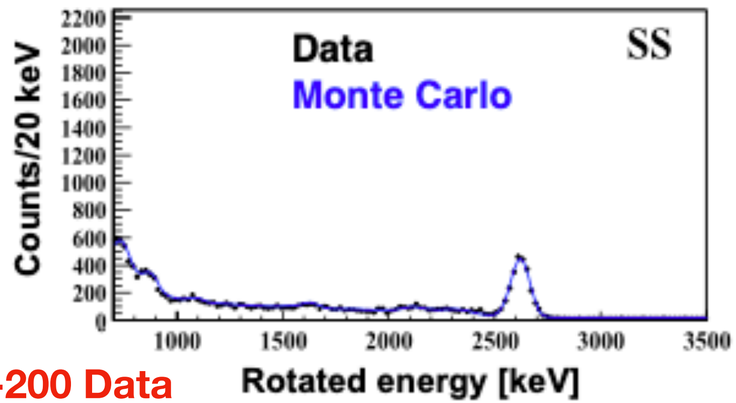
EXO-200 Data



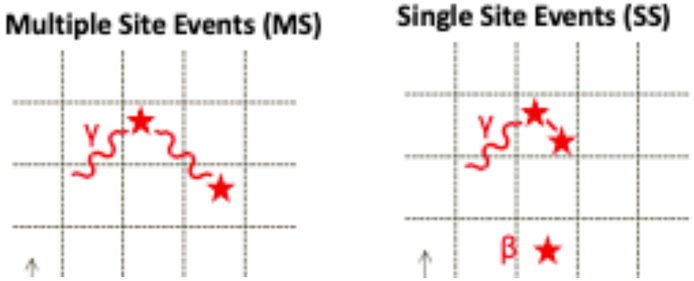
^{228}Th calibration data, MS:



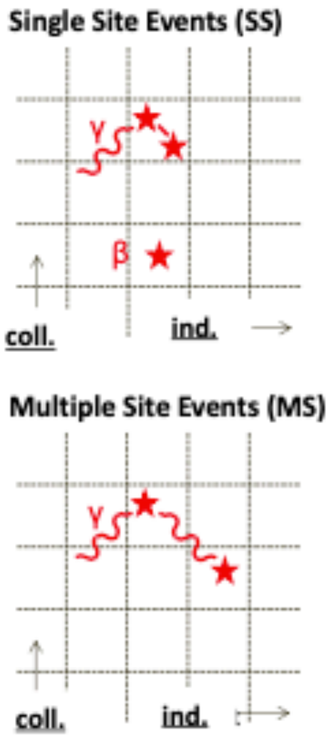
^{228}Th calibration data, SS:

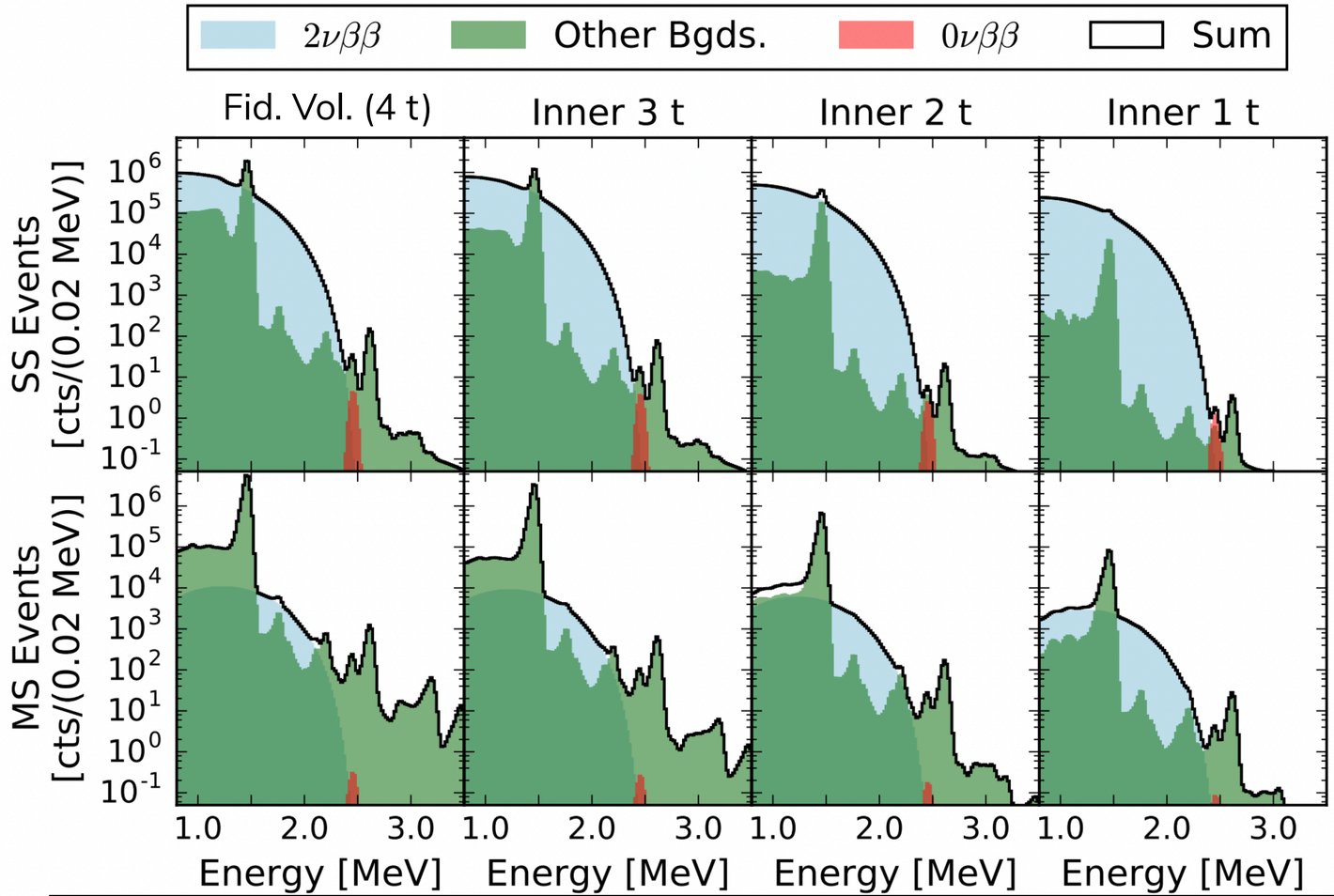


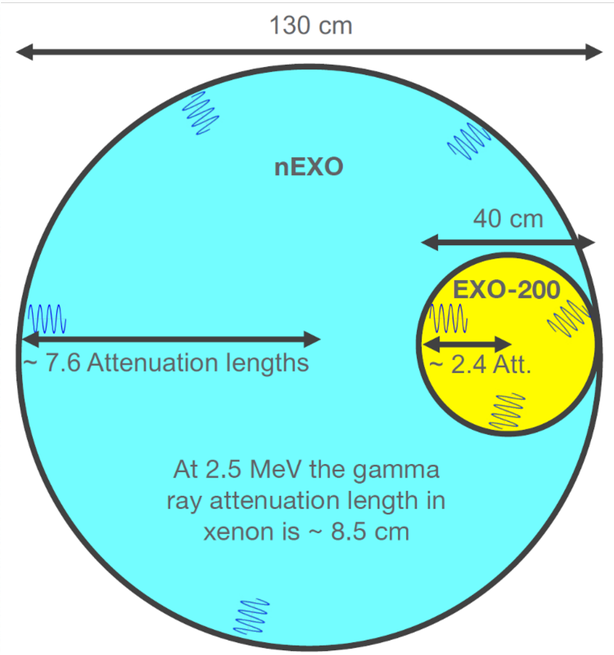
EXO-200 Data



nEXO Discovery Potential



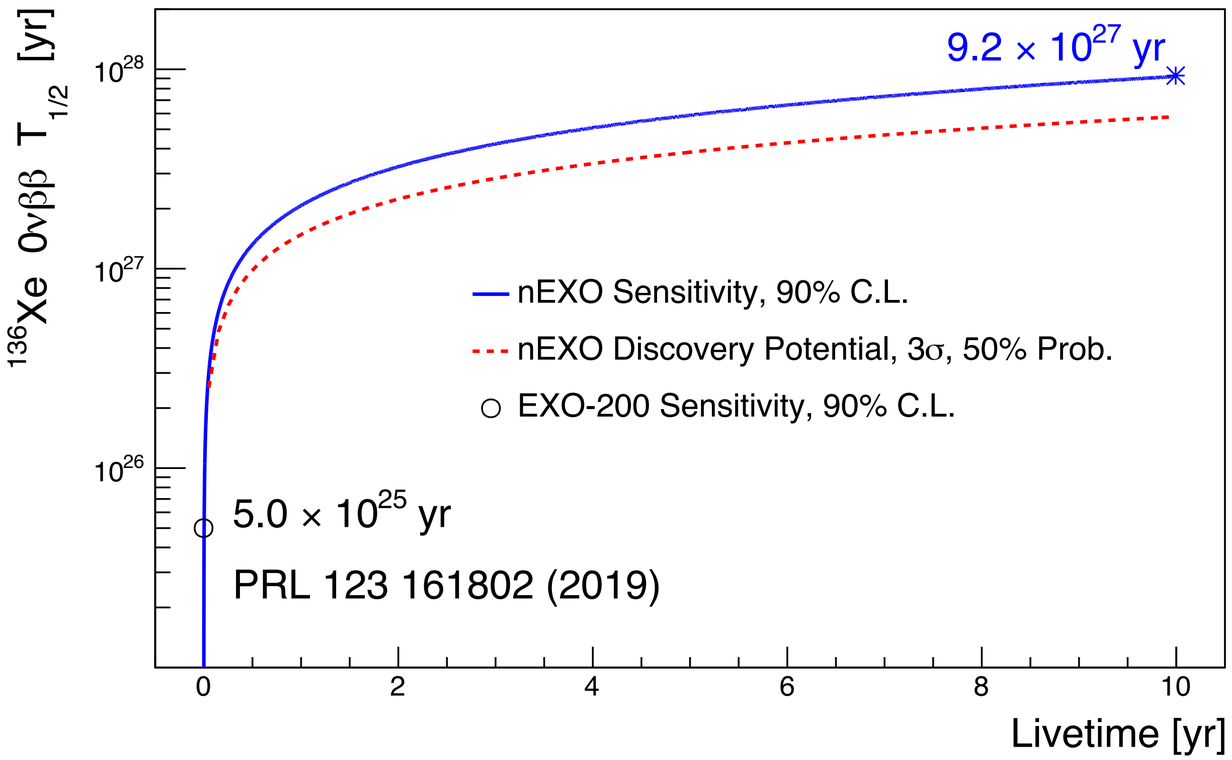


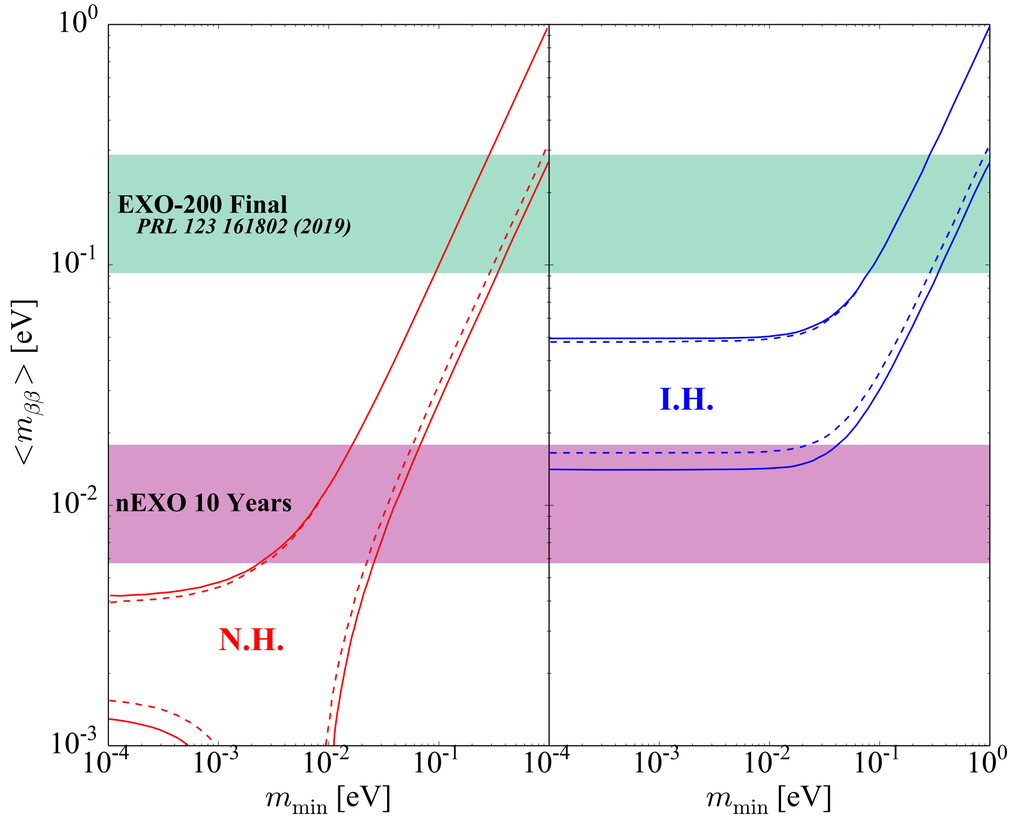


nEXO 10 year discovery potential: $T_{1/2}=5.7\times10^{27}$y (3σ)

[Phys. Rev. C. 97 065503 (2018)]

nEXO Sensitivity





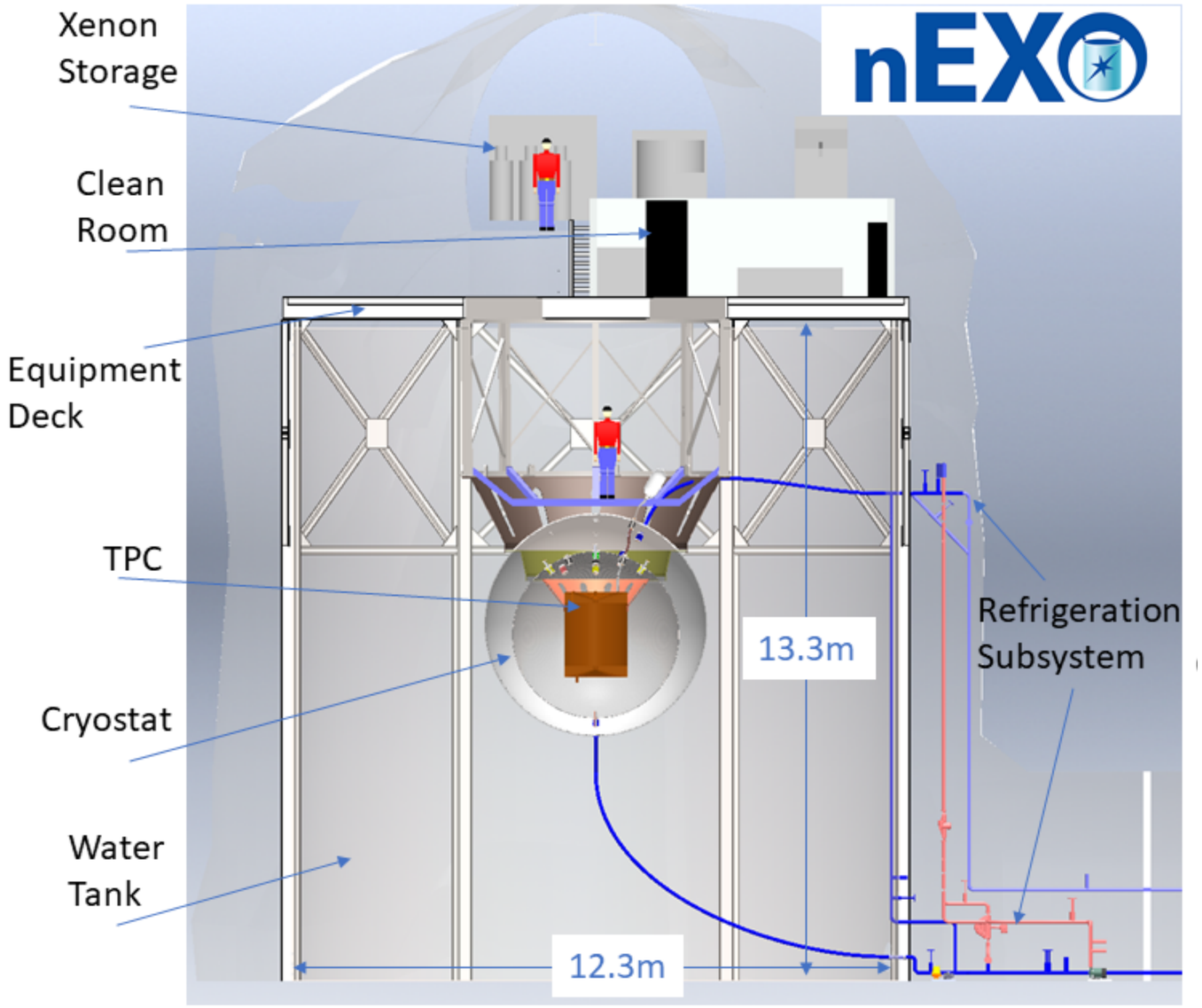
New sensitivity study coming out soon, reflecting advances in the design and understanding of nEXO's performance through R&D

[Phys. Rev. C. 97 065503 (2018)]
[Phys. Rev. Let 123, 161802 (2019)]

The nEXO Detector

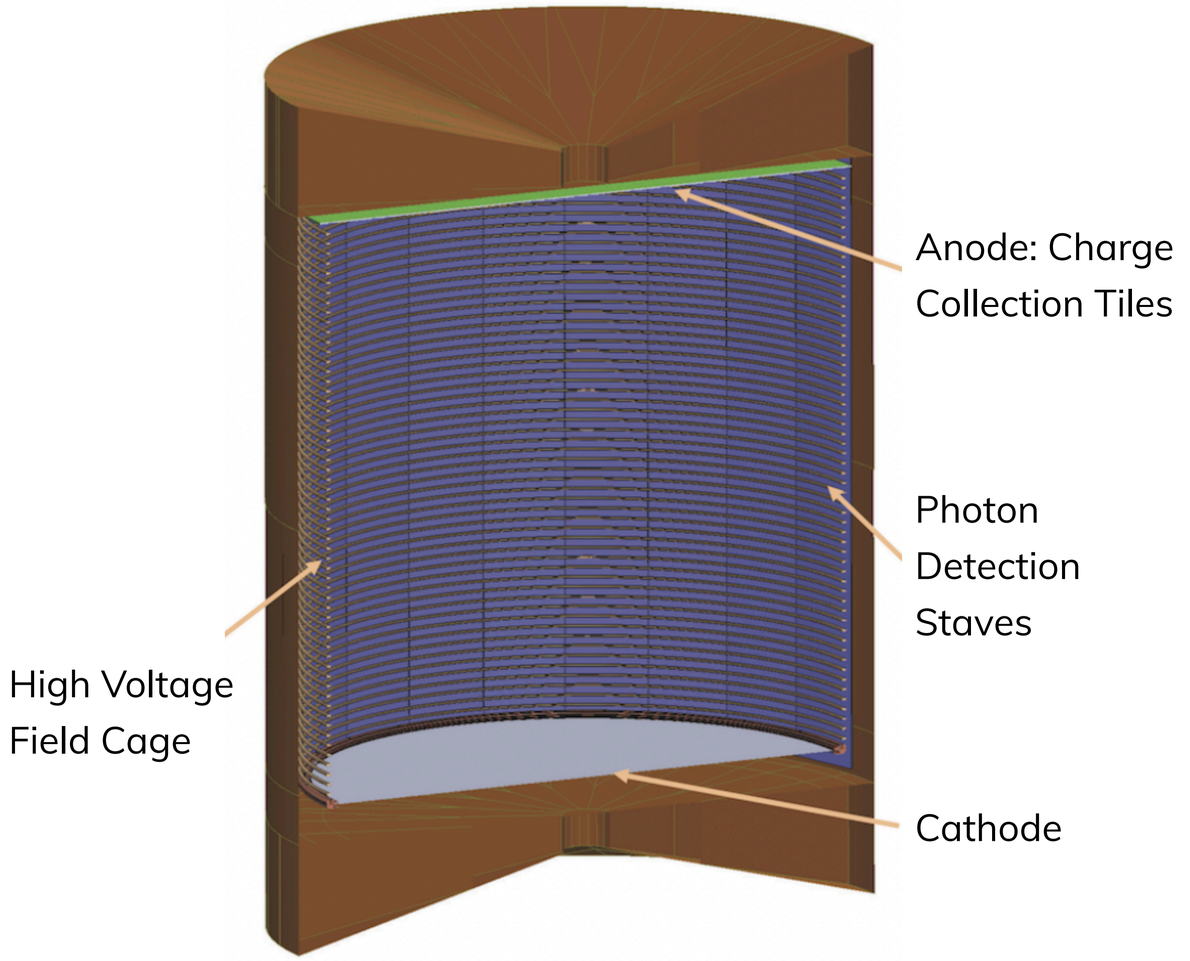
Canadian PIs take on leading roles in nEXO project:

- Photon sensor infrastructure
- External calibration sources
- Outer detector
  - Water Shield
  - Muon Veto
- SNOLAB facility
- Rn Emanation
- LXe HV tests
- Radioactive background control
- Simulation



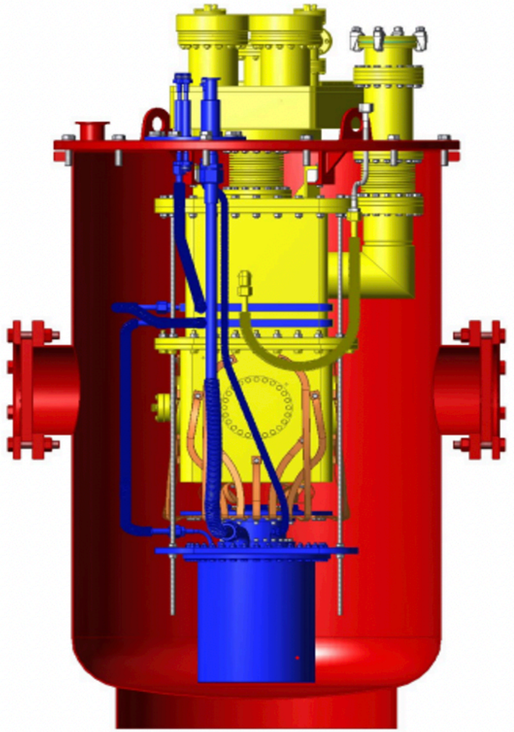
The nEXO TPC

- Next generation 0νββ detector
- 5 t liquid Xenon TPC, 28x EXO-200 volume
- SiPM for 175nm scintillation light detection, ~4.5m^2 array in LXe
- Tiles for charge read out in LXe
- In-cold electronics inside TPC in liquid Xe
- 3D event reconstruction
- Combine charge and light readout: anticipated σ/E of 1% at Q-value (2458 keV)



EXO-100: Cryogenic facility with TPC setup to perform high voltage test in liquid xenon

- Successfully commissioned the cryostat and HV setup
- First run of condensing and recovering Xe done in Dec. 2020
- Promising results came out from HV test done in Xe gas
- Coming soon: HV tests in LXe



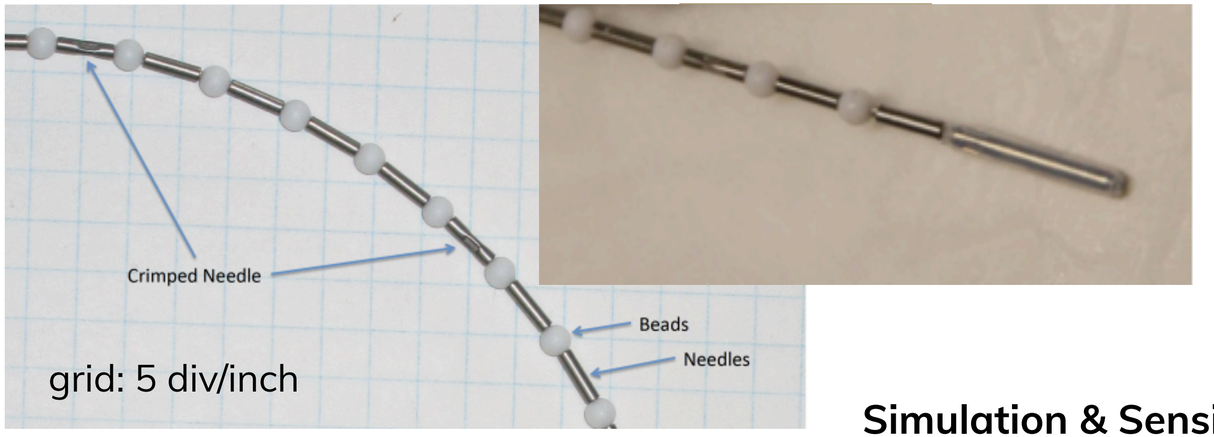
Schematic diagram of EXO-100
Yellow: Inner chamber for detector in LXe
Blue: Liquid nitrogen tank with exhaust lines
Red: Outer insulation vacuum vessel

Laurentian University
Université Laurentienne

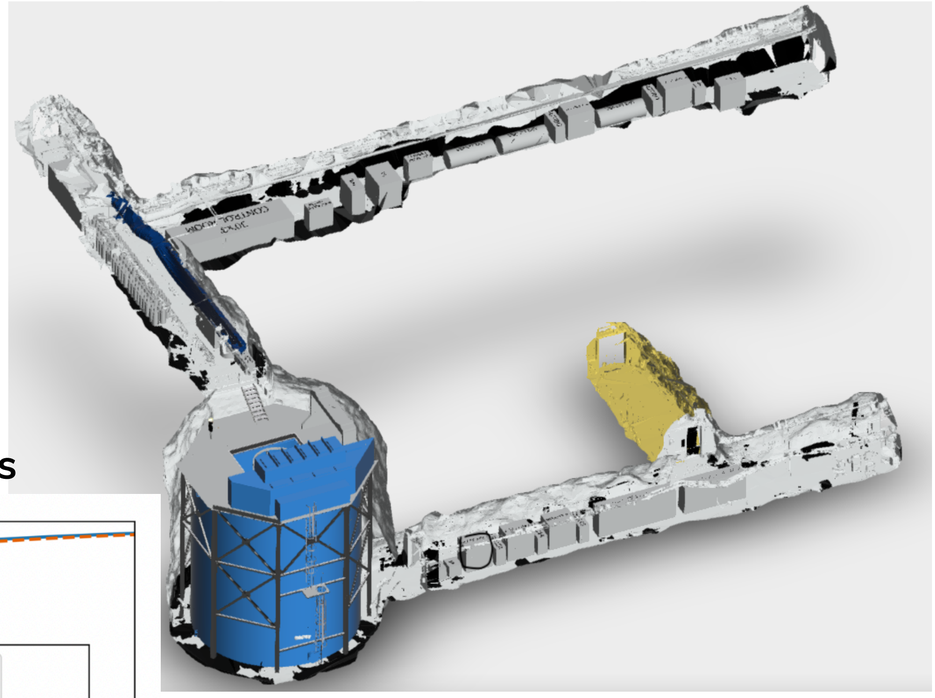
SNOLAB

SNOLAB

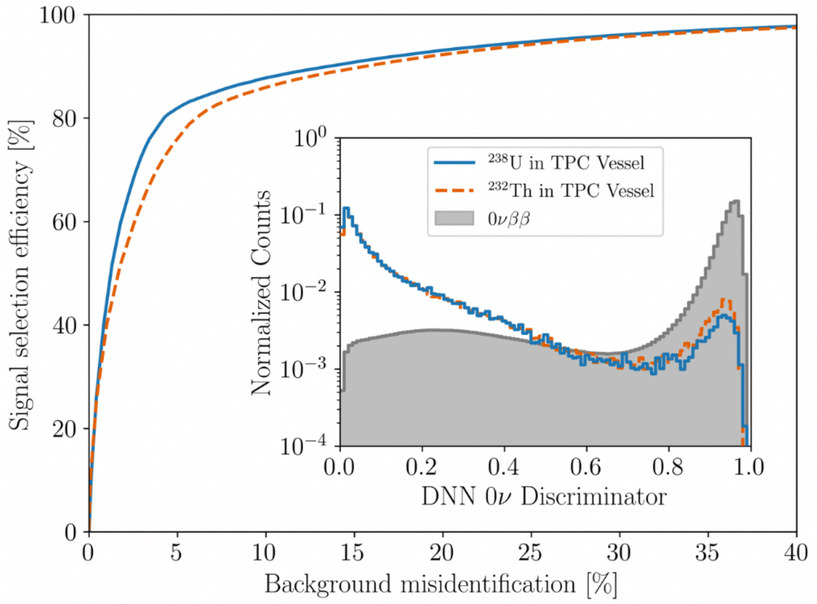
Calibration Source Development



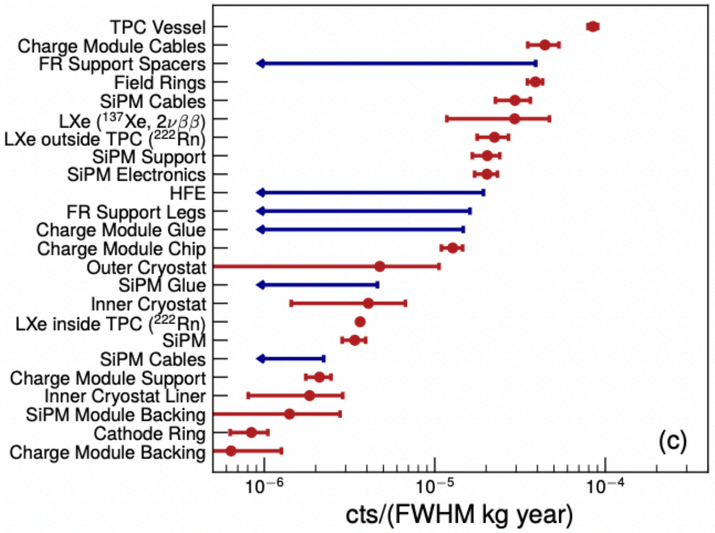
Design Layout and Project Management Support



Simulation & Sensitivity Studies



Radioactive Background Control

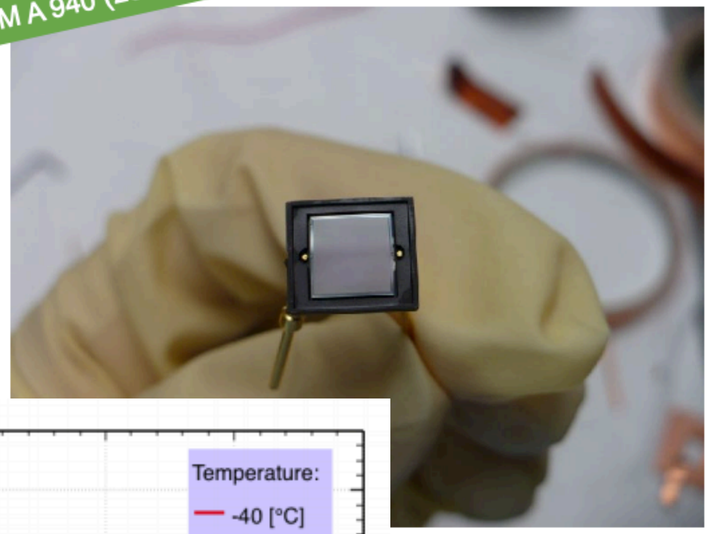


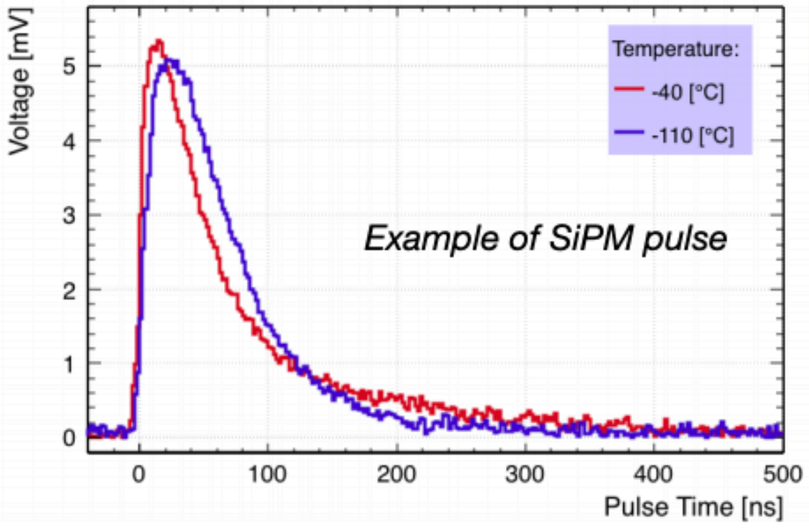
Test Facility to Characterize PMTs

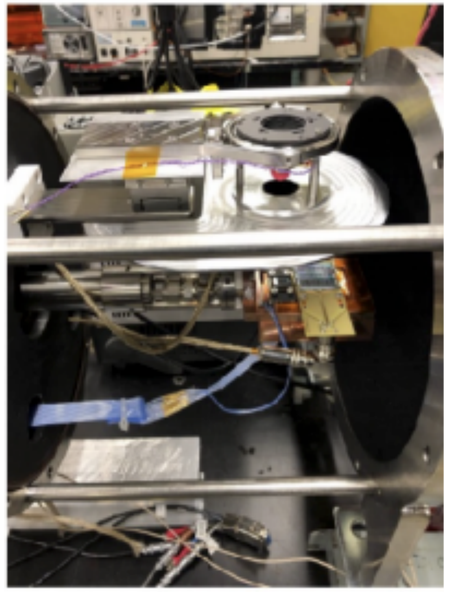
Silicon PhotoMultiplier Testing

NIM A 940 (2019)

Hamamatsu VUV4 MPPC







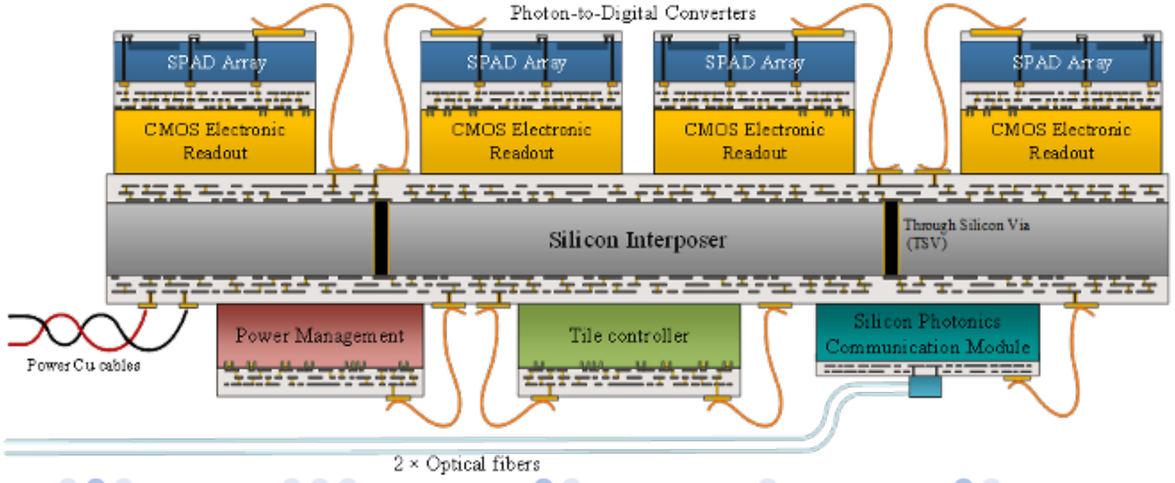
- Testing in vacuum at LXe temps
- CW VUV light source with monochrometer
- Improvements in pumping/ baking to eliminate residual water film

Requirement	Hamamatsu VUV4	FBK HD3
Photo-Detection Efficiency (>15%)	19 ± 3%	27 ± 5%
Correlated Avalanches (<0.2 @ >3V OV)	0.15 @ 3V	0.17 @ 3V
Dark Counts (<50 Hz/mm^2)	0.2 Hz/mm^2 @ 4V	0.2 Hz/mm^2 @ 4V

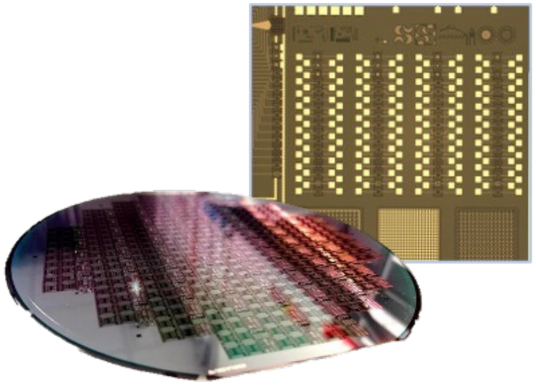
Publication Forthcoming!

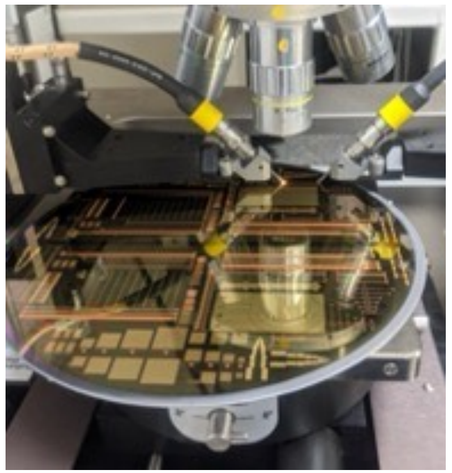
Beyond analog SiPMs for light readout

- Photon-to-digital converter (PDC): a digital SiPM
- U. de Sherbrooke/TRIUMF is developing a PDC based system optimized for noble liquid experiments
  - PDC and tile controller
  - Silicon interposer for tile integration
  - Readout electronics status
- 1st version of PDC readout fully functional



- SPAD array layer
  - Fabrication at Teledyne DALSA
  - VUV enhancement at Lawrence Berkeley Nat. Lab (MI supported)
- System integration
  - Large scale silicon interposer
  - Optical Integration Module

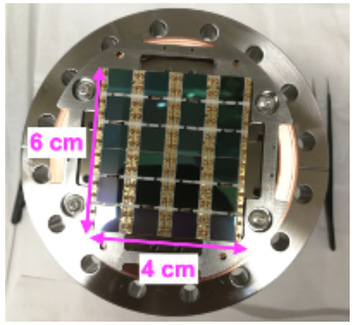


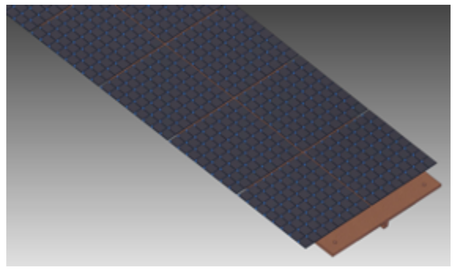


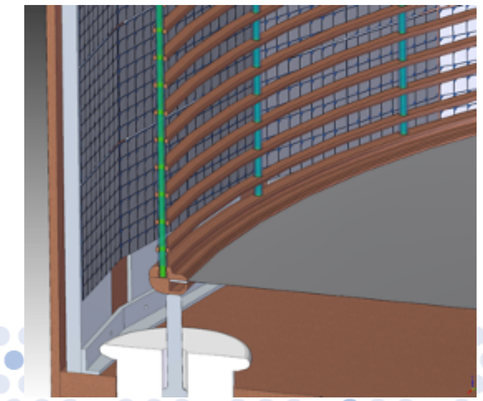
McGill UNIVERSITY

SNOLAB

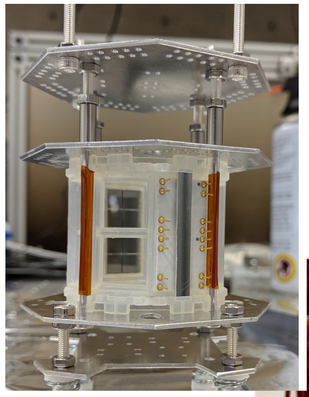
Characterization of Integrated SiPM Modules

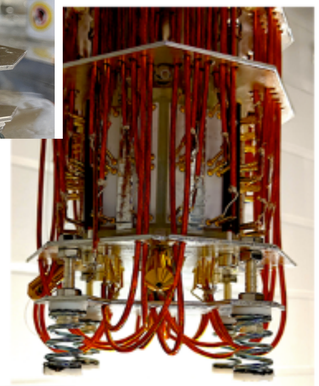


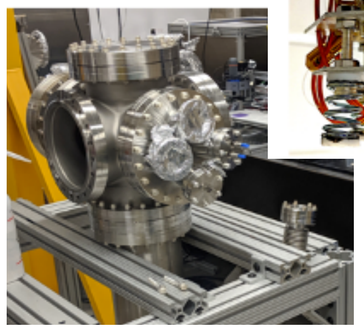




LOLX
Light-only Liquid Xenon



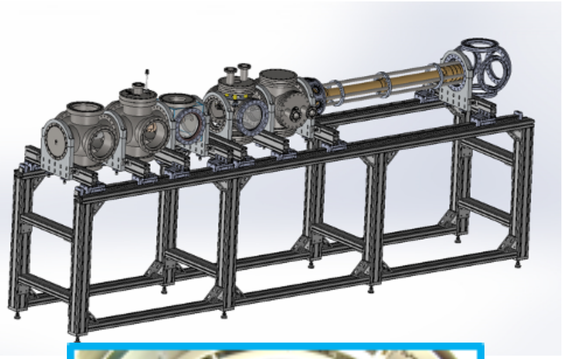




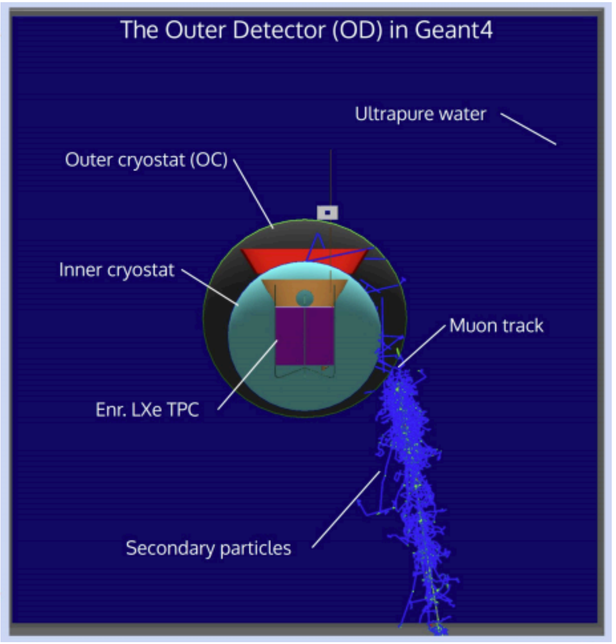
With Carleton & TRIUMF

Ba-ion Tagging

- Radio-Frequency Funnel
- Laser ablation ion source
- Multi-reflection time-of-flight mass spectrometer (MR TOF)

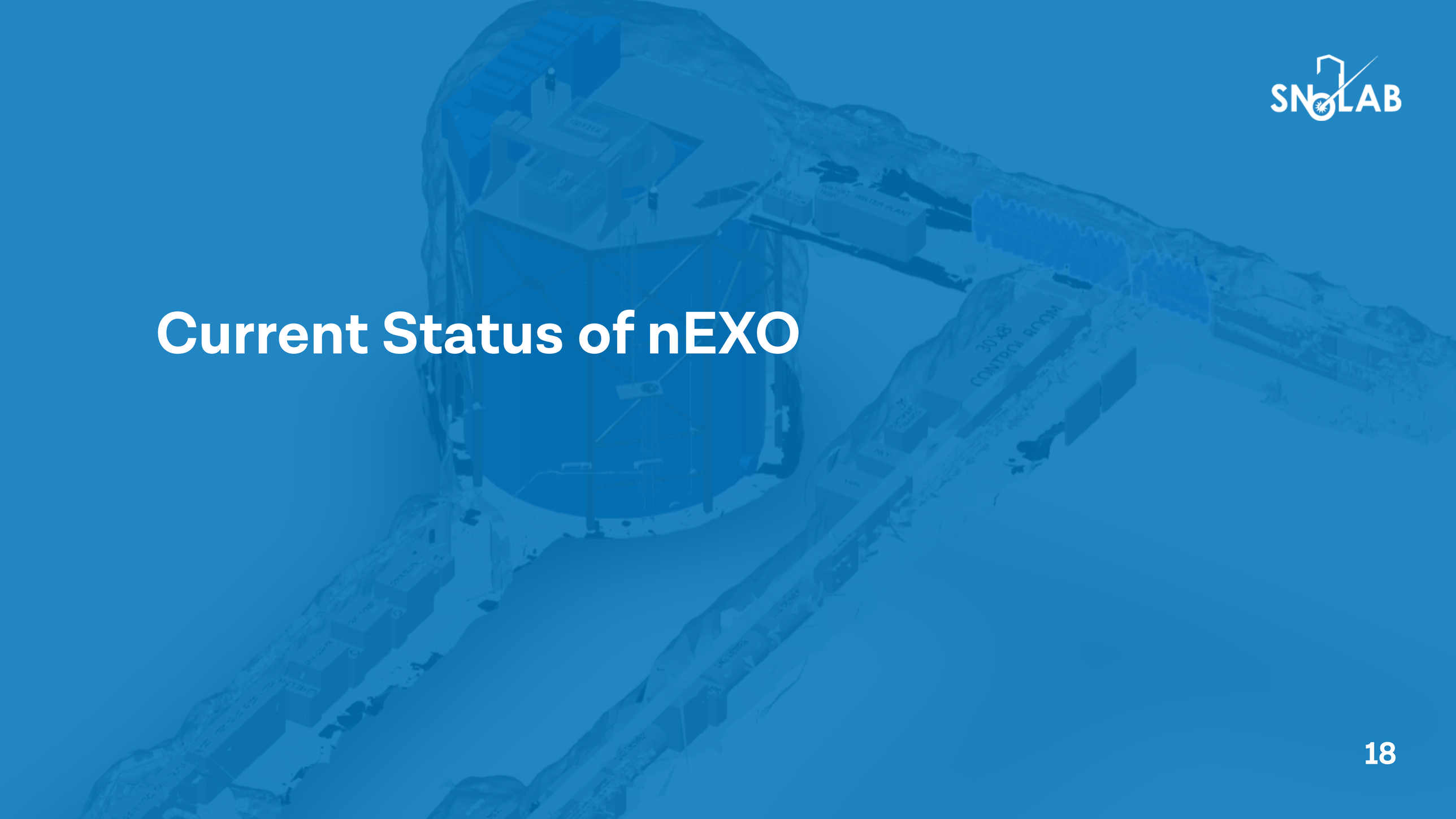


Outer Detector

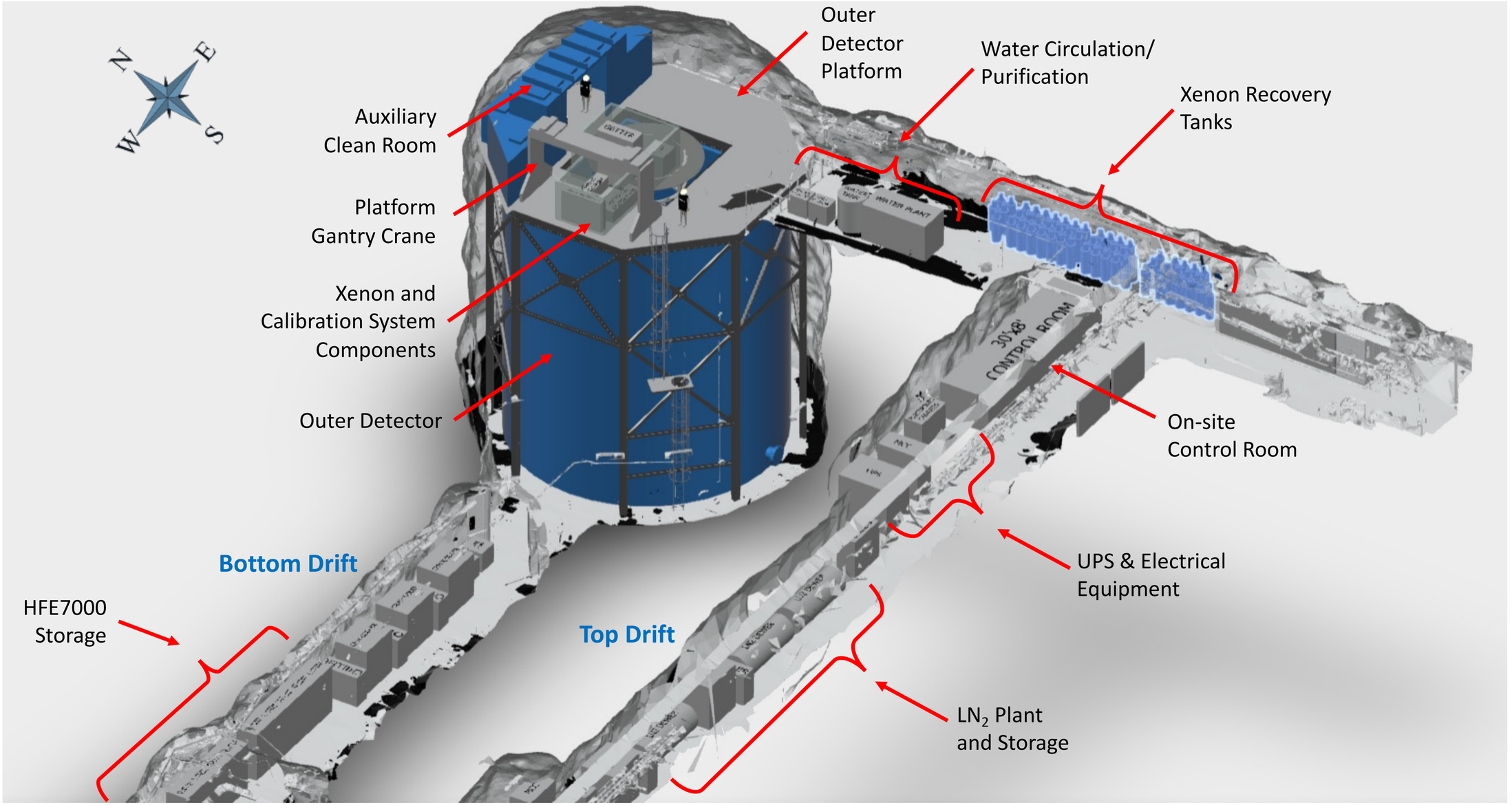


- Tagging muons increases detector efficiency
- Moving Geometry to Chroma

Current Status of nEXO



nEXO at SNOLAB



Other nEXO Talks this Congress

M2-6: Integrated photon-sensor tests for nEXO
- *L Darroch (McGill)*
- *07 June 2021 13:15 ET*

W2-7: Barium extraction from Xe Gas and identification for nEXO
- *C Chambers et al (McGill)*
- *09 June 2021 12:45 ET*

W2-6: The characterization of a spatially resolved multi-element laser ablation ion source
- *K Murray et al (McGill)*
- *09 June 2021 13:05 ET*

R1-8: The Light-only Liquid Xenon experiment - Status and Updates
- *S Al Kharusi (McGill)*
- *10 June 2021 12:15 ET*

R3-6: High Voltage Breakdowns in Liquid Xenon
- *M Elbeltagi (Carleton)*
- *10 June 2021 16:00 ET*

R3-6: Nuisance Processes in p-on-n SiPMs
- *G Gallina (TRIUMF)*
- *10 June 2021 16:05 ET*

Poster-81: Study of External Crosstalk in Light-only Liquid Xenon (LoLX) experiment
- *M Patel (Simon Fraser)*
- *09 June 2021 13:47 ET*

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Yale University
Brookhaven National Laboratory
FAU Friedrich-Alexander Universität Erlangen-Nürnberg
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Rensselaer
Technical University of Munich
UBC The University of British Columbia
u b Universität Bern
TRIUMF
Pacific Northwest National Laboratory
ibs Institute for Basic Science
Skyline College
IHEP
Lawrence Livermore National Laboratory
IMECAS
SLAC National Accelerator Laboratory
Subatech
Stanford University
Drexel University
Caltech
UNCW University of North Carolina Wilmington
UC San Diego
Colorado School of Mines
Colorado State University
The University of Alabama 1831
Oak Ridge National Laboratory
University of Kentucky
University of the Western Cape


Mike Heffner
Seth Thibado
nEXO
22
Collaboration Meeting Dec 2020

Summary

- nEXO its a discovery focused 0νββ experiment
- Observation of 0νββ always means new physics!
- Development of nEXO is well advanced
- nEXO is anticipated to be located at SNOLAB
- nEXO's projected sensitivity probes large fraction of parameter space in NH
  - beyond $T_{1/2}$~10^{28} y
  - 5.7meV < $\langle m_{\beta\beta} \rangle$ < 17.7meV
  - Improved Sensitivity Study coming soon
- **US DOE has scheduled a DBD portfolio review in July 2021**
- **We welcome new collaborators to join our search for 0νββ!**