Sensitivity of nEXO experiment to ^{136}Xe $0\nu\beta\beta$

S. Sangiorgio, LLNL, *for the nEXO Collaboration*

Motivations

The nEXO collaboration is preparing a new estimate of the sensitivity of the experiment to $0\nu\beta\beta$ of ^{136}Xe. Focus on:

- Higher fidelity and details
- Increased simulation realism
- More advanced analysis

Improvements outlined were motivated by:

- Changes in detector design
- Updated measurements of input parameters
- EXO-200 analysis advancements
- Re-evaluation of previous simplifying assumptions

Introduction to the nEXO Experiment

Neutrinoless double-beta decay ($0\nu\beta\beta$) can only occur if neutrinos are Majorana particles. If observed, it will have profound impact on our understanding of the standard model and

nEXO: $0\nu\beta\beta$ in ^{136}Xe

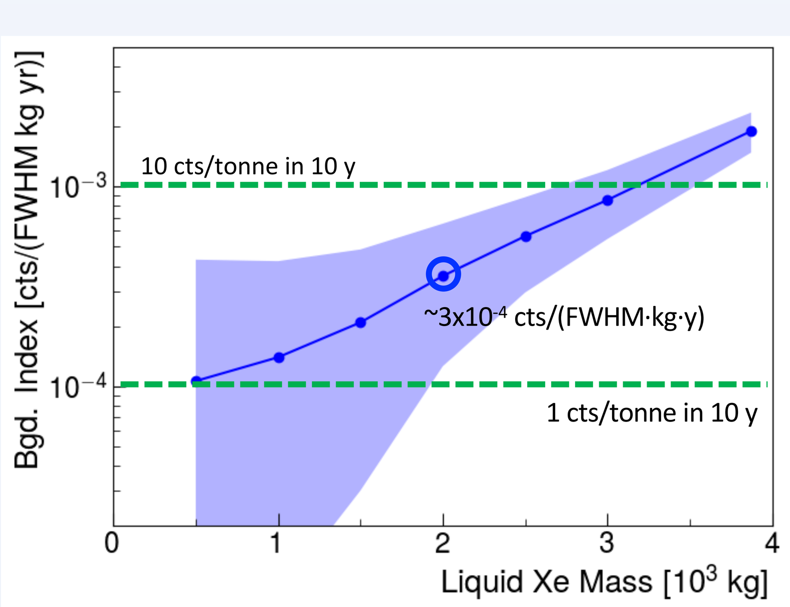
nEXO is the next generation of EXO-200 searching for $0\nu\beta\beta$ using a 5-tonne **time projection chamber** filled with enriched **liquid xenon** (LXe), and featuring:

- Energy resolution: $\sigma/E \leq 1\%$ (at Q-value)
- One drift volume: Fully active γ-ray attenuation and $0\nu\beta\beta$ decay event reconstruction detector volume
- SiPM surrounding barrel (optically open field cage)
- 6 mm charge tiles: improved background rejection

[1] S.Al Kharusi *et al.* (nEXO Collaboration), arXiv:1805.11142 (2018)

Previous nEXO Sensitivity (ca. 2017)

- **Predicted sensitivity of 9.2x10^{27} y,** two orders of magnitude above current limits for ^{136}Xe $0\nu\beta\beta$.
- Based on measured radioassay inputs
- Limited number of conservative assumptions and simplifications
- Rooted in EXO-200 analysis methodology to fully exploit multi-parameter capabilities provided by the TPC approach



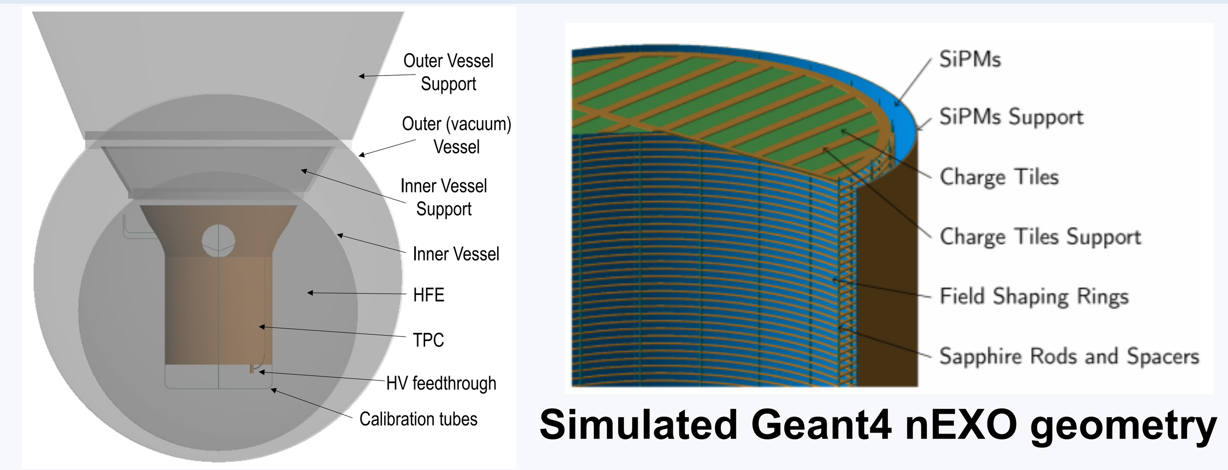
[2] J.B. Albert *et al.* (nEXO Collaboration), Phys. Rev. C 97, 065503 (2018)

Improvements in nEXO experiment modeling and analysis

Detector components and Geant4 model

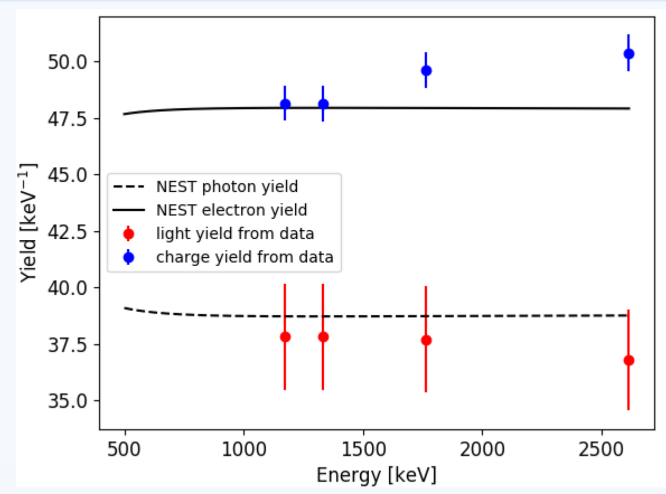
Additional components have been implemented into a comprehensive geometry of a custom Geant4 application. E.g. TPC support, OV support, calibration guide tubes.

Other components have been **updated** to reflect recent design changes. E.g. TPC height/diameter



Simulated Geant4 nEXO geometry

Detailed Event Simulations and Reconstruction



NEST vs EXO-200 data

[3] G. Anton *et al.* (EXO-200 Collaboration), Phys. Rev. C 101 (2020)

Detailed procedure for physics and detector simulations, followed by event reconstruction:

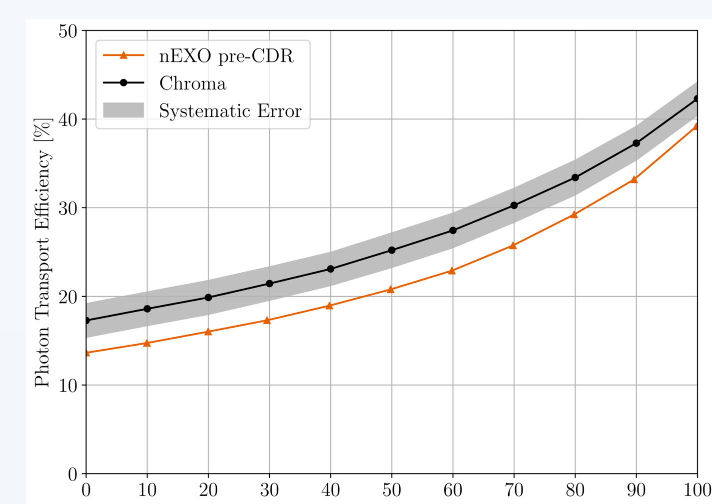
- Energy deposits evaluated by Geant4
- Thermal electrons and optical photons production as predicted by NEST
- Light and charge transport based on liquid xenon parameters and recent R&D results
- Designed electronics response
- Standoff distance computed from charge waveforms

GPU-based Model of Detector Light Response

Optical simulations performed with Chroma and cross-validated against Geant4. Updated optical properties are based on measurement or literature data.

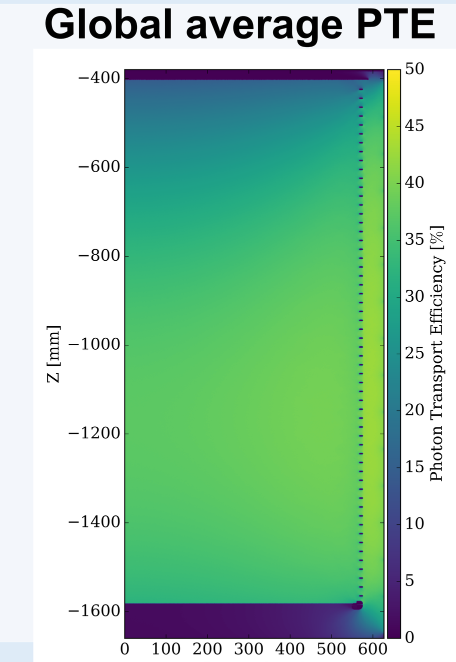
Predicted average **Light Collection Efficiency of 6.2–9.5%** at 80% reflectivity of field rings and cathode, with the range arising from the choice of SiPM.

[4] P. Nakarmi, et al, (nEXO Collaboration), JINST 15 (2020) 01
[5] G. Gallina, et al, (nEXO Collaboration), NIM A 940 (2019)
[6] A. Jamil, et al, (nEXO Collaboration), IEEE TNS 65 (2018) 11
[7] P. Lv, et al, (nEXO Collaboration), arXiv:1912.01841 (2019)
[8] J. Echevers, Neutrino 2020 poster #60
[9] A. Kumar, Neutrino 2020 poster #620



Sensitivity study for PTE

Global average PTE

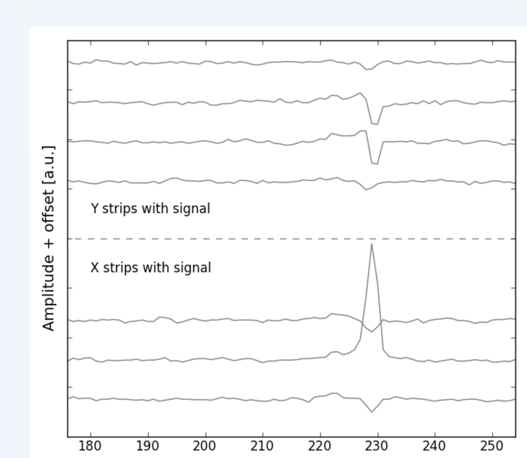


Event topology via Deep Neural Network

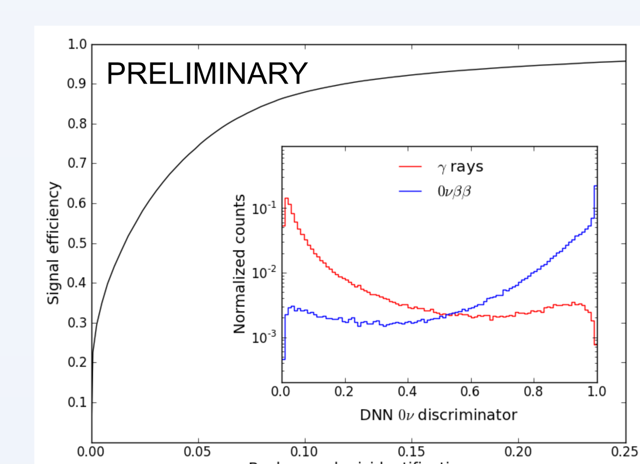
Detailed simulation of ionization propagation, including diffusion and electron lifetime, and of the detector electronics provides **realistic response**.

The LXe TPC technique and fine readout granularity allows powerful discrimination of signal events (single energy deposits) from backgrounds (multiple deposits), optimized through application of a deep neural network (DNN) trained on the simulated waveforms.

[9] Z. Li *et al* (nEXO Collaboration), JINST 14 no. 09, P09020 (2019)

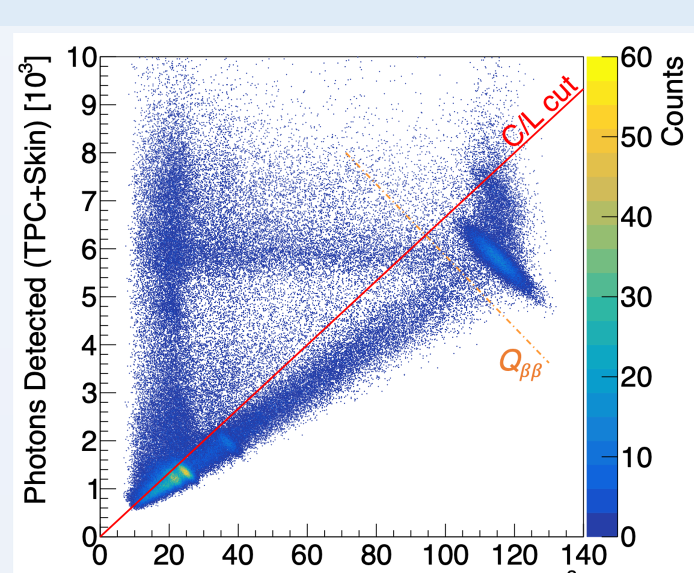


DNN sample input waveform



DNN performance

Accounting for Interaction in Skin Xe



nEXO features an **optically-open TPC field cage.** Outside of the TPC field cage, in the so-called skin LXe region, scintillations light is collected but the ionization signal goes undetected.

For events with energy deposited in both the TPC and LXe skin regions, the simulations account for both energy misreconstruction effects as well as enhanced background reduction via C/L cut.

Expected background reduction relative to simplified analysis [2]	
Detailed optically-open TPC analysis	5%
Perfect rejection of skin events	12%

[10] T. Stiegler, *et al*, (nEXO collaboration), *Event Reconstruction in a Liquid Xenon Time Projection Chamber with an Optically-Open Field Cage*, in preparation

Contact: samuele@llnl.gov

Material Selection and Radioassay

nEXO continued with its comprehensive plan of radioassay characterization and material selection.

Recent improvements include:

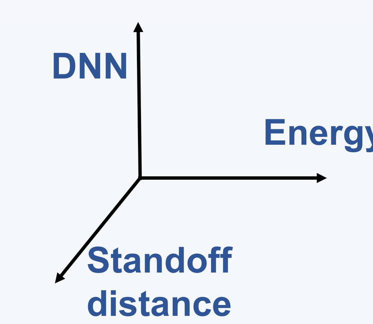
- New components or materials
- More precise or lower radioassay estimates
- Inclusion of additional background sources: ^{110m}Ag, ^{26}Al, ^{42}Ar
- Detailed tagging efficiency of Bi-Po from ^{222}Rn dissolved in LXe

[11] R. H. M. Tsang, Neutrino 2020 poster #84

Sensitivity Estimation Method

Rooted in the success of EXO-200 analyses, hypothesis testing is performed using a binned maximum-likelihood fit with 3 dimensions:

- Event energy
- Standoff-distance
- DNN $0\nu\beta\beta$ discriminator



The DNN discriminator is trained with uniform energy and spatial distribution, and thus disentangled from the other two fit dimensions. It provides a continuous variable to improve discrimination instead of counting the number of deposits.

Since the DNN provides good identification of decays accompanied by Brehmstralung emission, the signal detection efficiency is maximized, and sensitivity improvement expected at ~10%.

[12] G. Anton *et al.* (EXO-200 Collaboration), Phys. Rev. Lett. 123, 161802 (2019)

Conclusions

A second iteration on the estimation of the sensitivity of nEXO to $0\nu\beta\beta$ is in progress and incorporates multiple updates and refinements.

In addition to boosting confidence in nEXO's design and performance, these improvements are expected to yield a sensitivity similar if not better than the previous estimate of ~10^{28} y for the ^{136}Xe $0\nu\beta\beta$ half-life.

Acknowledgements

Support for nEXO comes from the the Office of Nuclear Physics of the Department of Energy and NSF in the United States, from NSERC, CFI, FRQNT, NRC, and the McDonald Institute (CFREF) in Canada, from IBS in Korea, from RFBR (18-02-00550) in Russia, and from CAS and NSFC in China.

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52 07NA27344. LLNL-POST-811646