An overview of the nEXO Experiment

Search for Neutrino-less Double Beta decay beyond 10^{28} years

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On behalf of the nEXO collaboration

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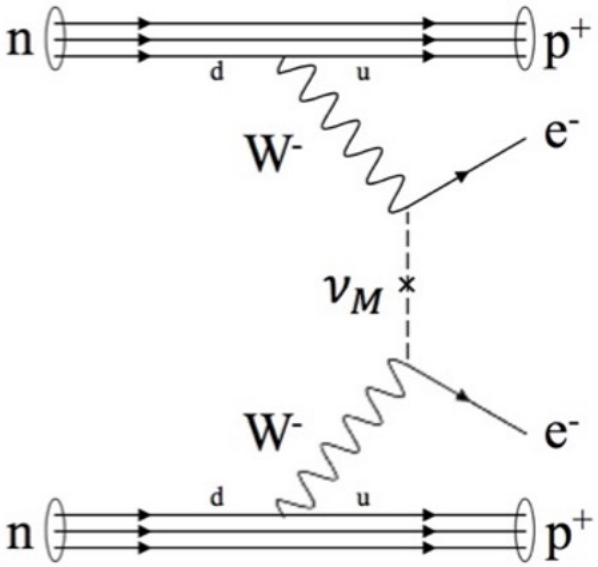
Neutrino-less Double Beta Decay

The observation of $0\upsilon\beta\beta$ decay would imply new physics beyond Standard Model, providing evidence for

- Lepton number violation
- Neutrinos being Majorana fermions

It would also offer possible explanations of

- The origin of neutrino mass
- The observed matter-antimatter asymmetry in the Universe

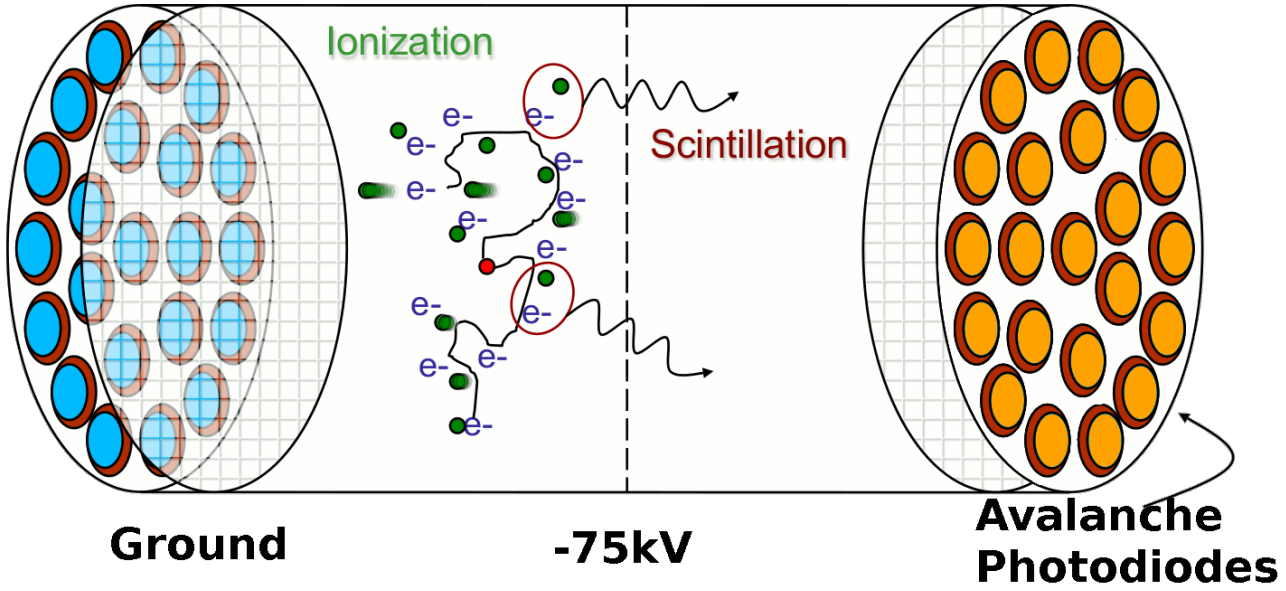


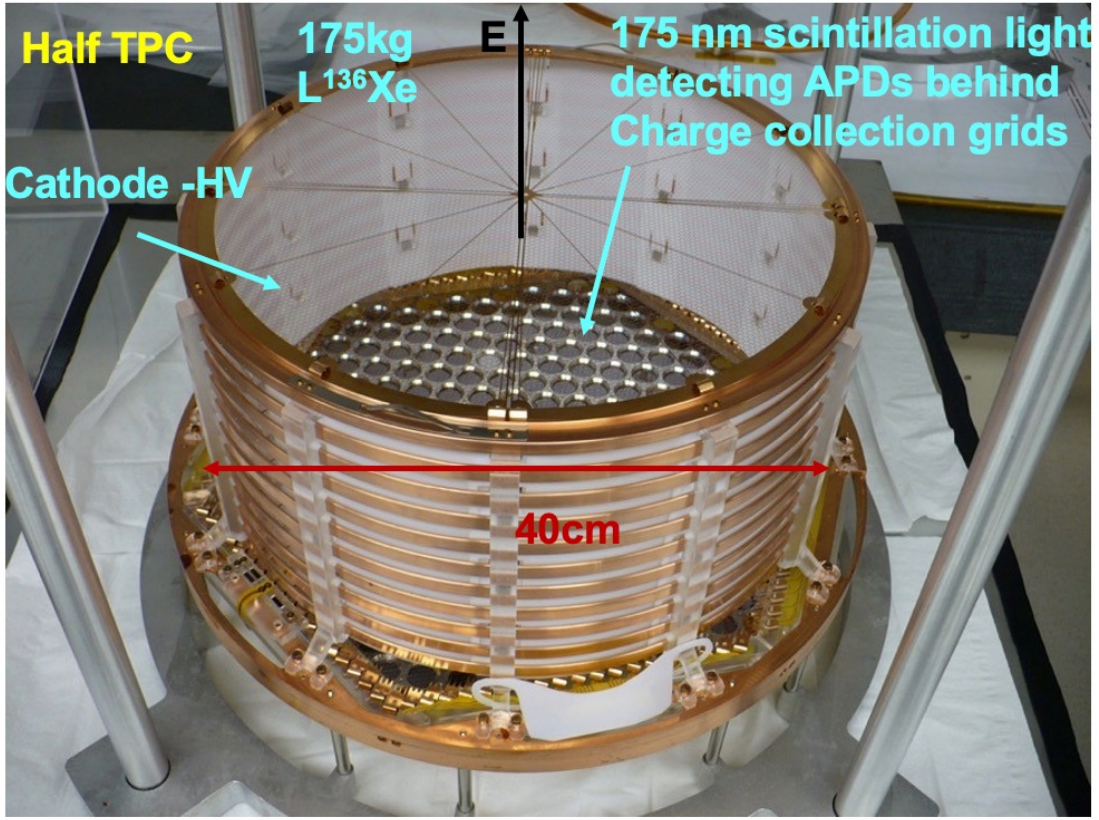
EXO-200 TPC

Liquid xenon time projection chamber searched for $0\upsilon\beta\beta$ in ^{136}Xe

- Used independent scintillation/ ionization measurement and full use of energy, position, topology to achieve 3D reconstruction for the expected MeV-scale energy deposits events
- Had effectiveness of self-shielding and low intrinsic background

The same principle will be used in nEXO



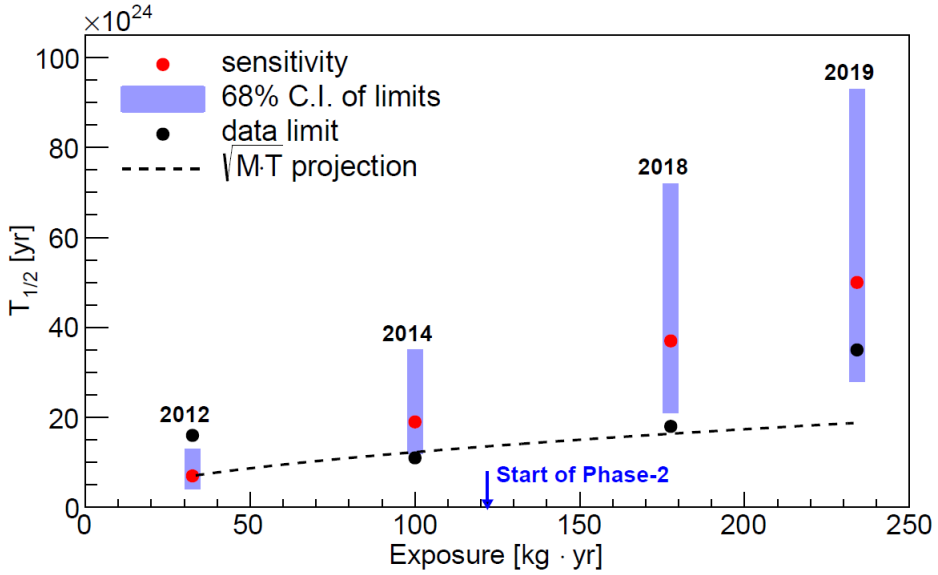


G. Anton et al. (EXO-200 Collaboration)
Phys. Rev. Lett. 123, 161802 – Published 18 October 2019

EXO-200 results for $0\nu\beta\beta$

First 100 kg-class experiment to take data

- Excellent background control, successfully predicted by the extensive material characterization program → This is essential for nEXO design.
- Scales linearly with exposure in two phases
- More papers on non-ββ decay physics



2012: Phys.Rev.Lett. 109 (2012) 032505
2014: Nature 510 (2014) 229-234
2018: Phys. Rev. Lett. 120, 072701 (2018)
2019: Phys. Rev. Lett. 123 (2019) 161802

Result

Phase I+II: 234.1 kg yr of ^{136}Xe exposure

Limit: $T_{1/2}^{0\nu\beta\beta} > 3.5\times10^{25}$ yr (90% CL)

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

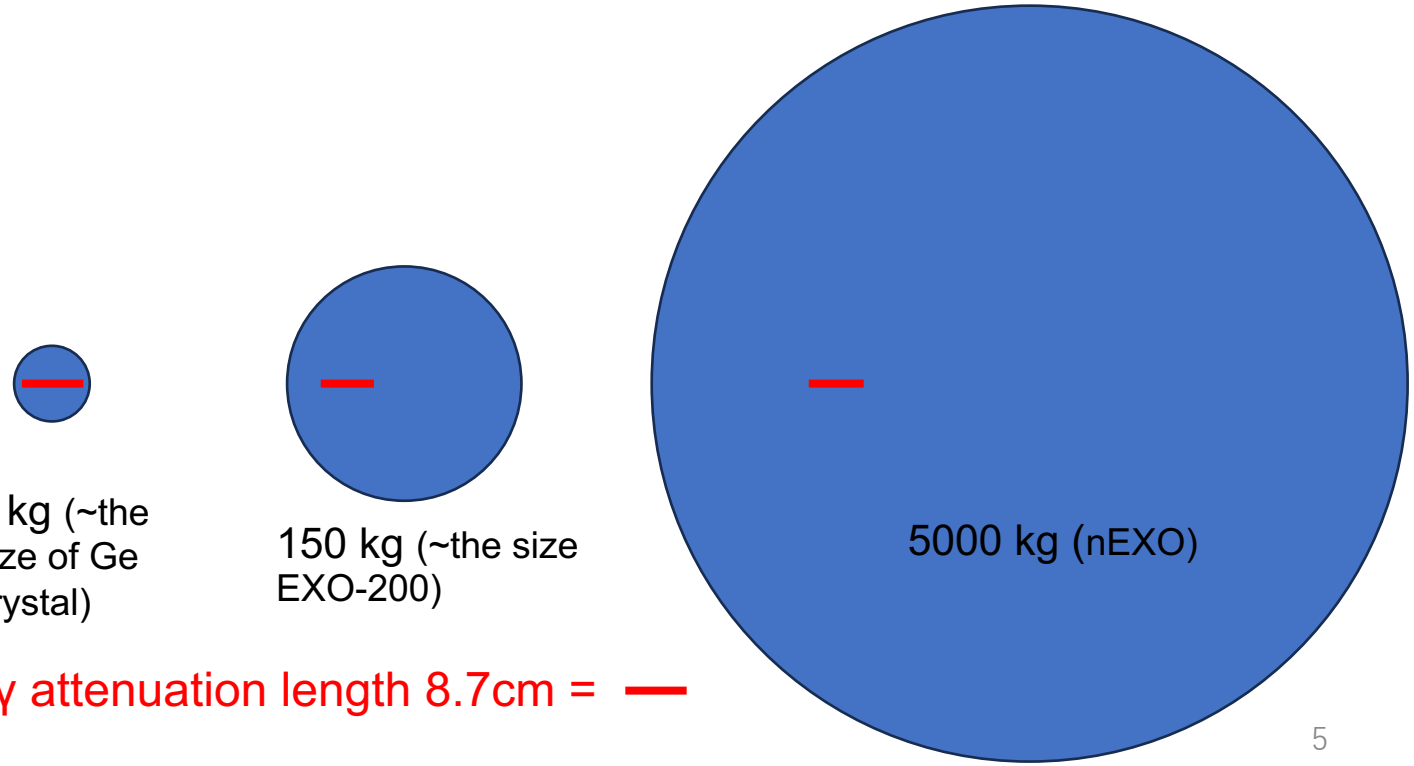
Sensitivity: 5.0×10^{25} yr

Ton-scale Monolithic/Homogeneous TPC

Expand the $T_{1/2}^{0\nu\beta\beta}$ sensitivity to new physics by 2 orders of magnitude

- Proved technology in EXO-200
- Scalable, re-purifiable, transferable enriched liquid xenon (LXe)
- Low radioactivity in LXe and strong self-shielding
- Better energy resolution (<1%) at $Q_{0\nu\beta\beta}$ of 2.5 MeV
- Independent readout of scintillation/ ionization to achieve full 3D event reconstruction
- Powerful background rejection

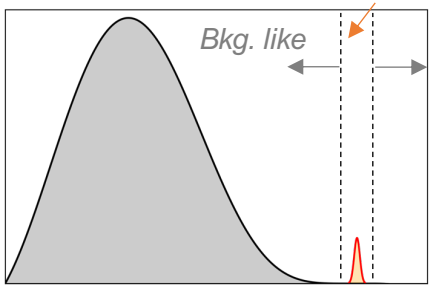
LXe Mass (kg)	Diameter or length (cm)
5000	130
150	40
5	13



Multi-parameter analysis

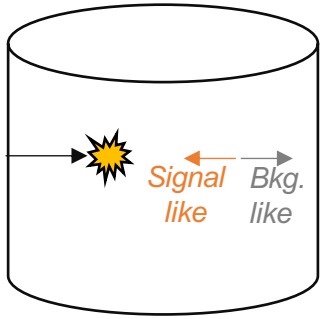
Multiple parameters of event are measured to robustly identify a 0νββ signal

Energy:



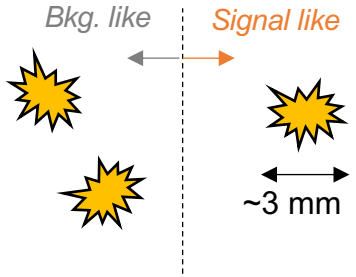
Location:

Distance from nearest detector surface ("standoff")

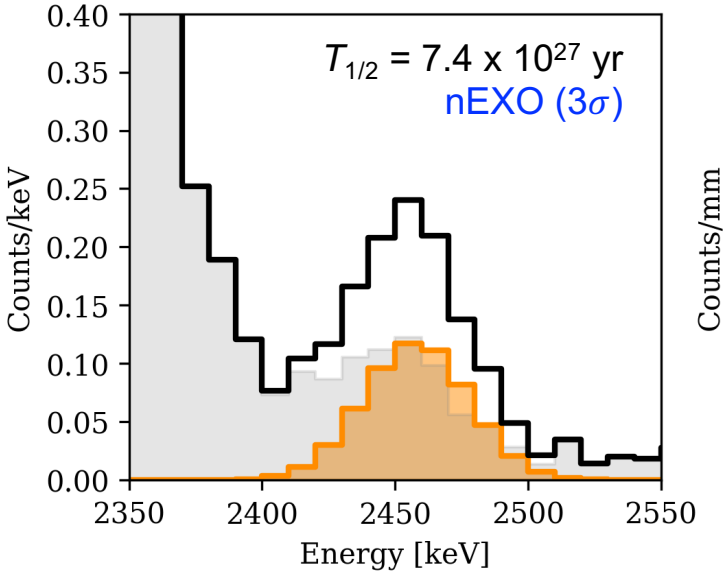


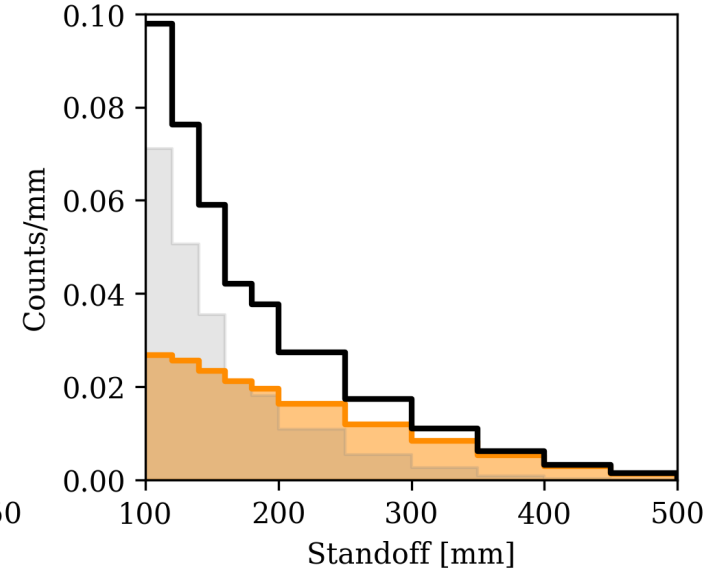
Topology:

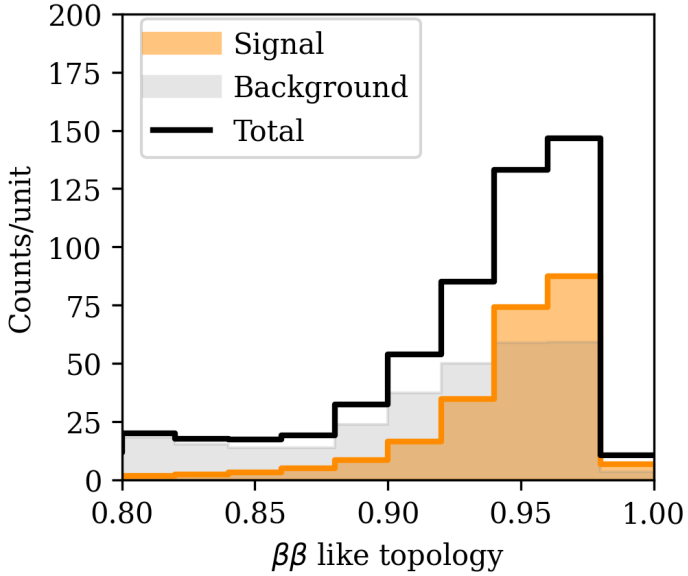
Distinguished by Deep Neural Network(DNN)



1D projections of simulated nEXO signal and backgrounds:

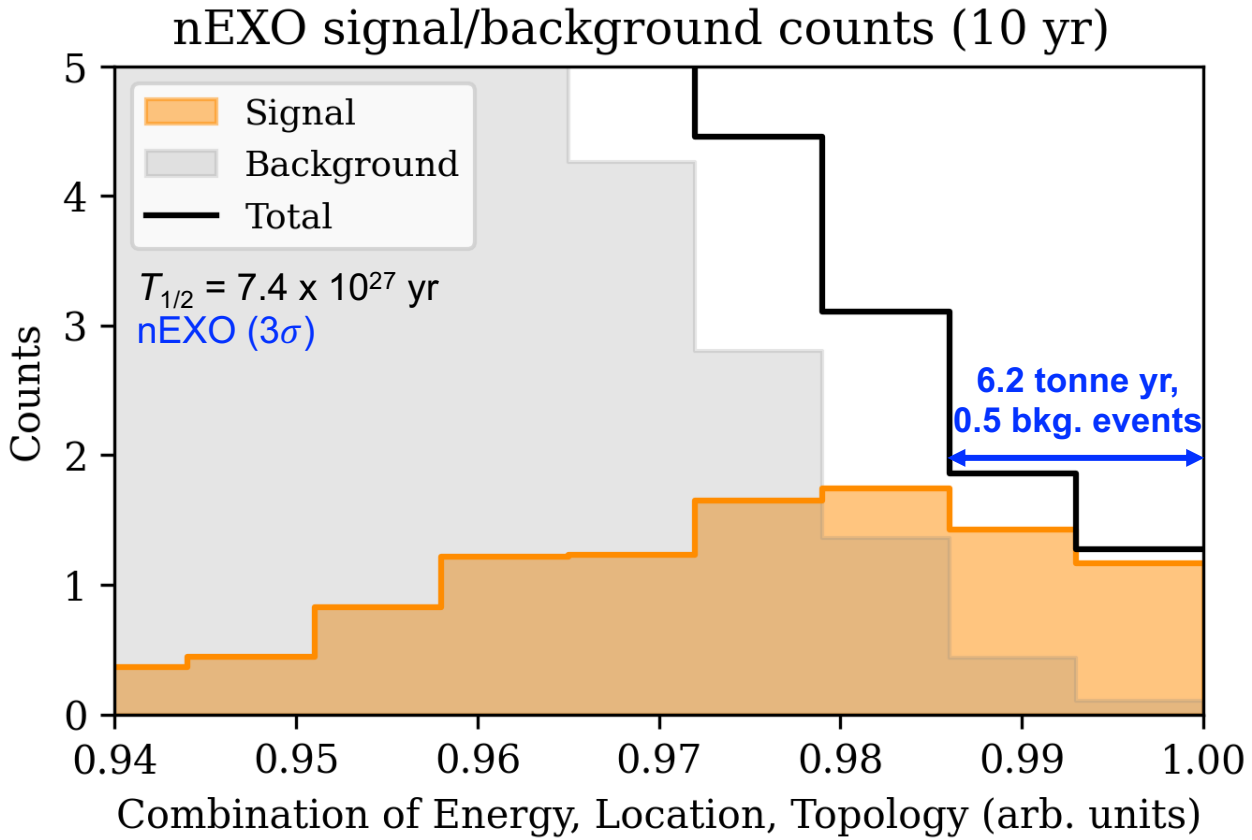






Arranging the 3D bins into 1D, ordered by signal-to-background ratio, helps visualize the signal and background separation in nEXO

Combine energy, topology, and standoff (preserving correlations)

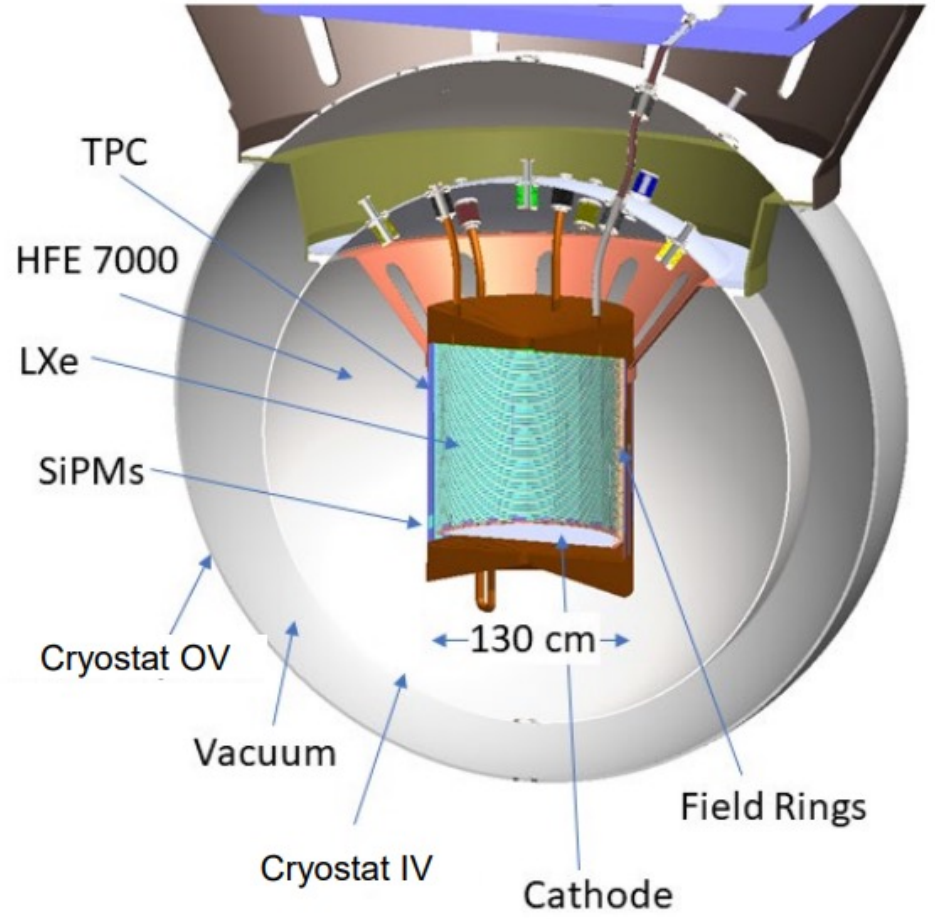


0 ← Background-like

Signal-like → 1

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

nEXO is an evolution from EXO-200, with specific R&D done over the last 10 years

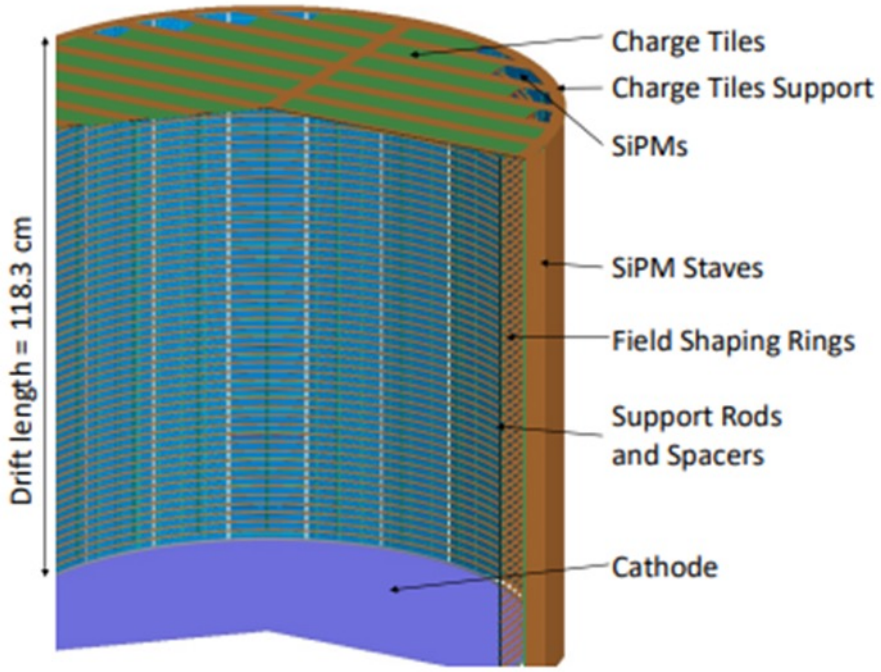


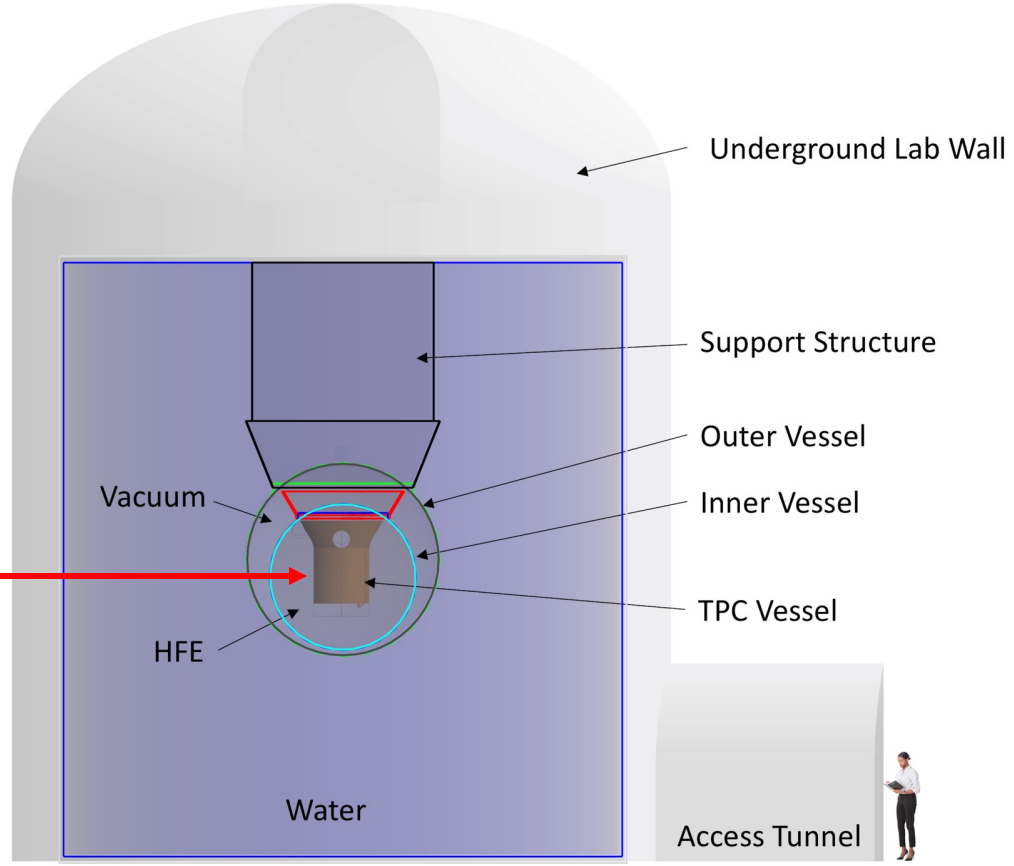
	EXO-200:	*nEXO:*	Improvements:
Vessel and cryostat	Thin-walled commercial Cu w/HFE	*Thin-walled electroformed Cu w/HFE*	Lower background
High voltage	Max voltage: 25 kV (end-of-run)	*Operating voltage: 50 kV*	Full scale parts tested in LXe prior to installation to minimize risk
Cables	Cu clad polyimide (analog)	*Cu clad polyimide (digital)*	Same cable/feedthrough technology, R&D identified 10x lower bkg substrate and demonstrated digital signal transmission
e^- lifetime	3-5 ms	*5 ms (req.), 10 ms (goal)*	Minimal plastics (no PTFE reflector), lower surface to volume ratio, detailed materials screening program
Charge collection	Crossed wires	*Gridless modular tiles*	R&D performed to demonstrate charge collection with tiles in LXe, detailed simulation developed
Light collection	APDs + PTFE reflector	*SiPMs around TPC barrel*	SiPMs avoid readout noise, R&D demonstrated prototypes from two vendors
Energy resolution	1.2%	*1.2% (req.), 0.8% (goal)*	Improved resolution due to SiPMs (negligible readout noise in light channels)
Electronics	Conventional room temp.	*In LXe ASIC-based design*	Minimize readout noise for light and charge channels, nEXO prototypes demonstrated in R&D and follow from LAr TPC lineage
Background control	Measurement of all materials	*Measurement of all materials*	RBC program follows successful strategy demonstrated in EXO-200
Larger size	>2 atten. length at center	*>7 atten. length at center*	Exponential attenuation of external gammas and more fully contained Comptons

nEXO Pre-Conceptual Design Report - arXiv.org" arXiv:1805.11142 [physics.ins-det]

nEXO TPC design

- Monolithic TPC with 5 tons of 90% enriched ^{136}Xe
- Light detection module: 4.6 m^2 of SiPMs with ASIC readout in LXe
- Charge detection module: Anode plane of modular charge tiles with ASIC readout in LXe
- Electron lifetime: 10 ms
- Electric field: 400 V/cm

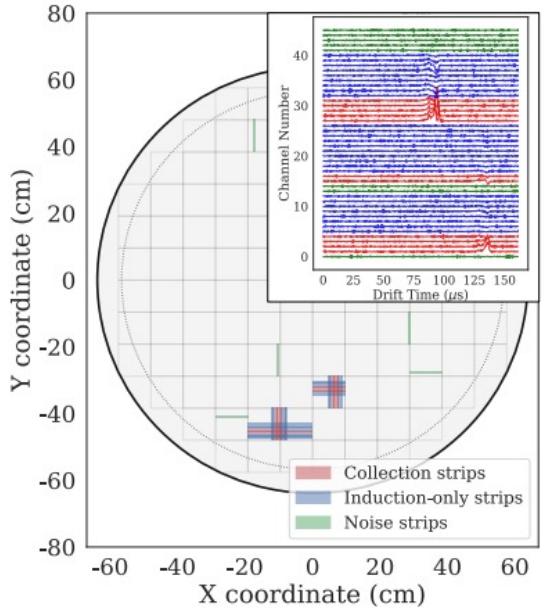




R&D-Charge detector

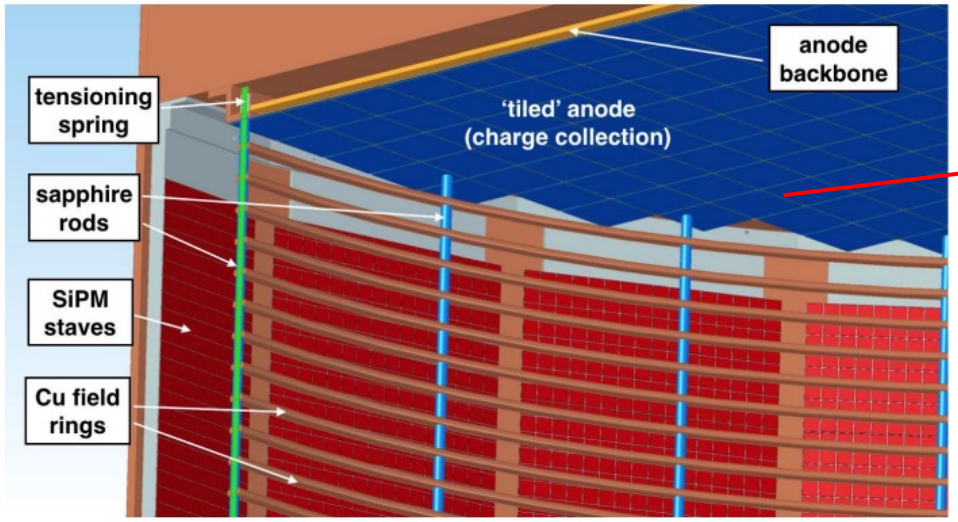
The design bases on full simulation of nEXO charge collection

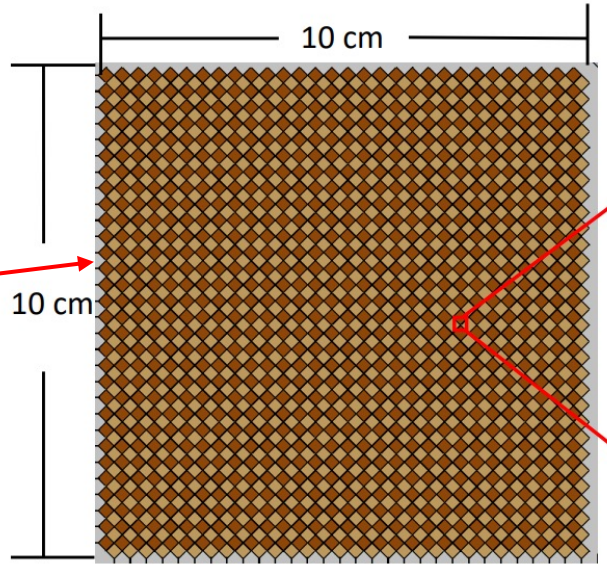
- Anode consists by crossed metallic strips of 10 cm long and 3 mm pitch
- The X/Y traces cross at 60 μm wide bridges separated by a thin dielectric layer



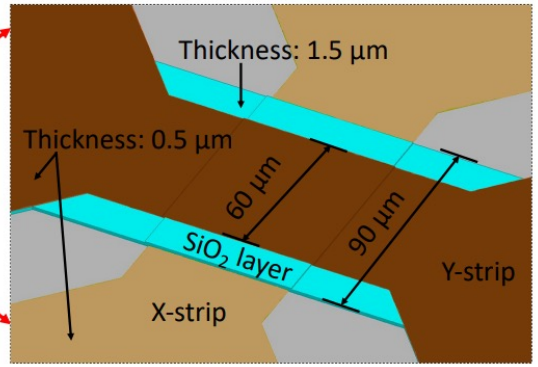
Prototype tiles are produced and test in LXe to character their performance

M. Jewell et al. (nEXO Collab) "Characterization of an ionization readout tile for nEXO," JINST 13 P01006 (2018)





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

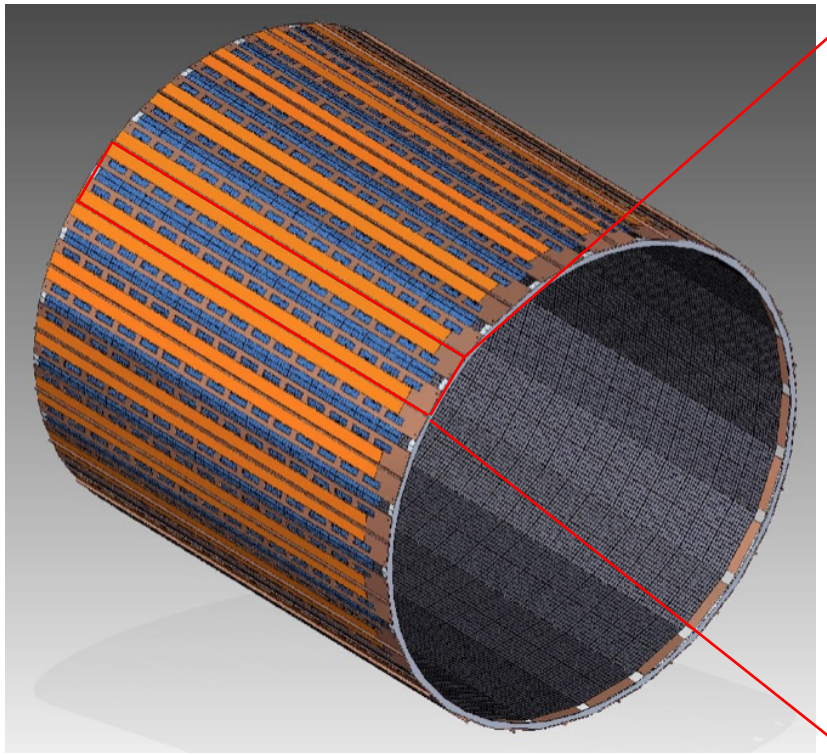


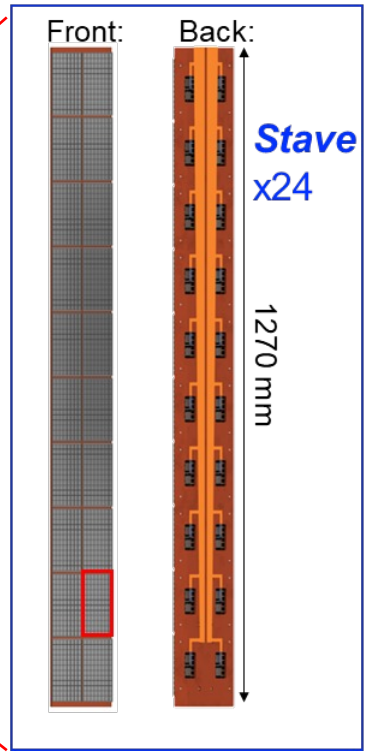
Z. Li et al. (nEXO Collab) "Simulation of charge readout with segmented tiles in nEXO," JINST 14 P09020 (2019)

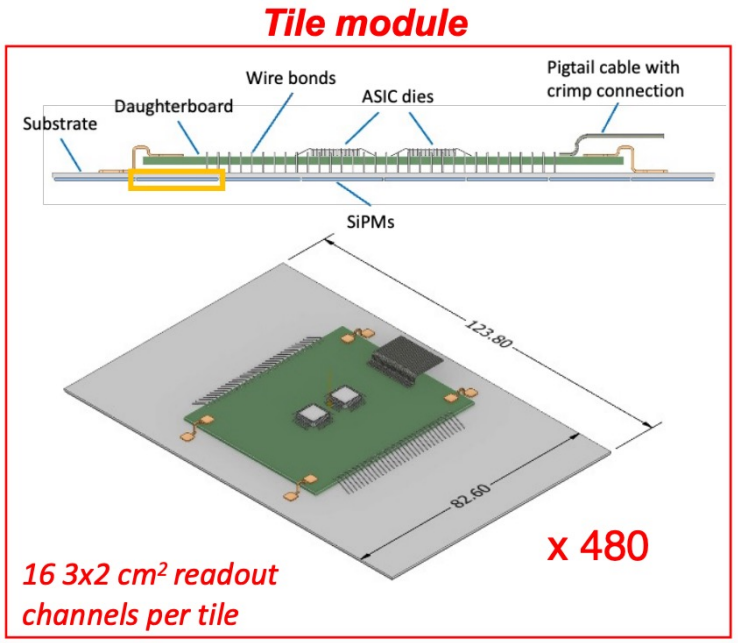
R&D-Photon detector

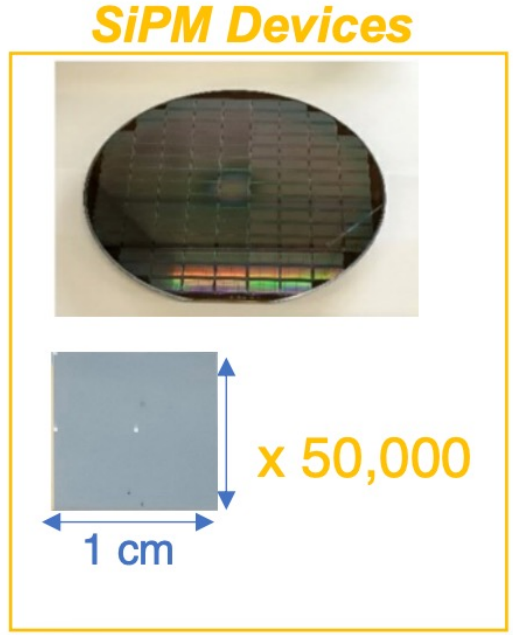
Photon Detector (PD) consists of vacuum ultraviolet(VUV) SiPMs

- 24 “staves” has 20 “tile modules” each
- Basic integrated element is “tile module” (96 cm^2) has 16 ASIC readout channels and 96 SiPMs
- Total ~46,000 SiPMs (1cm x 1cm)





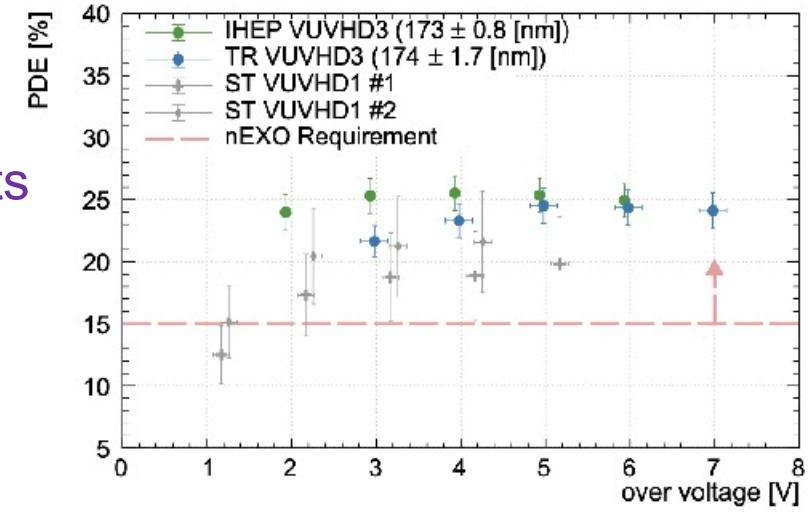




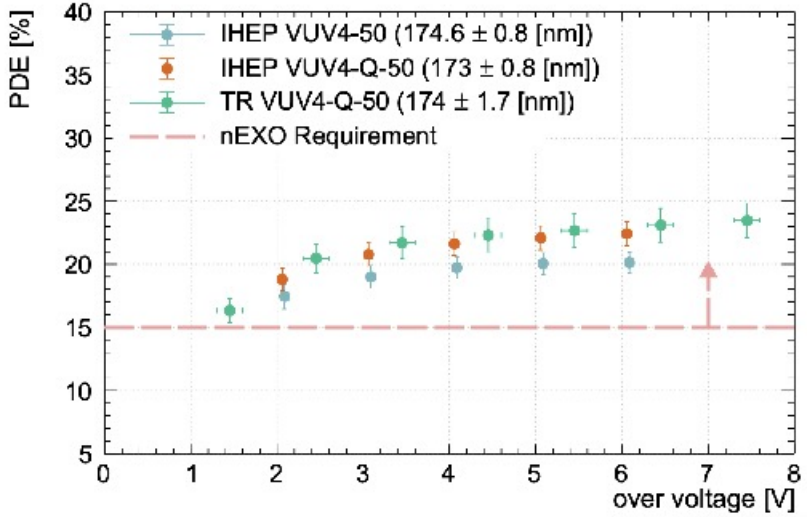
Performance of SiPMs

The SiPM devices from 2 vendors FBK(VUV-HD3) and Hamamastu (VUV4) meet the nEXO requirements

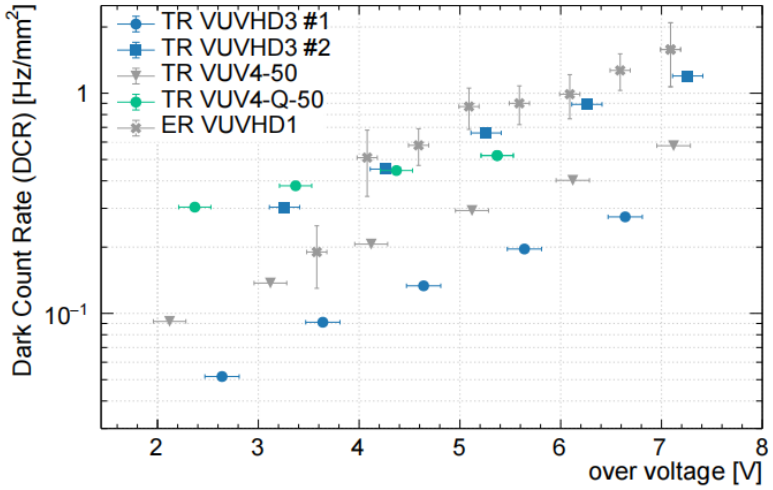
FBK VUV-HD3 PDE vs overvoltage



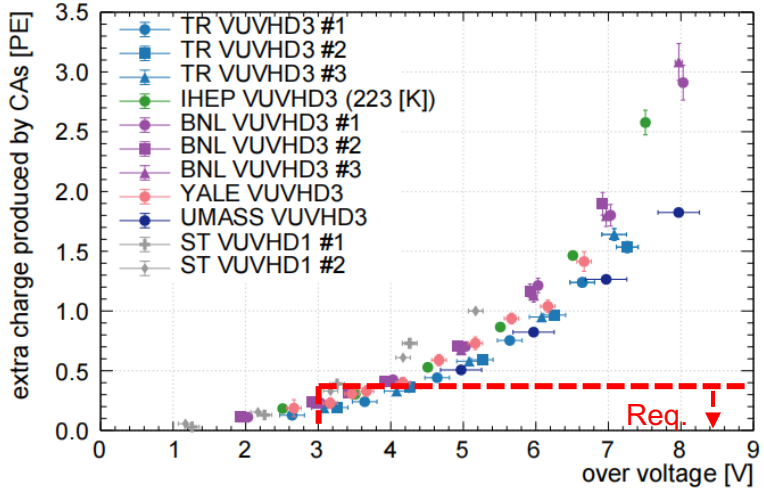
HPK VUV4 PDE vs overvoltage



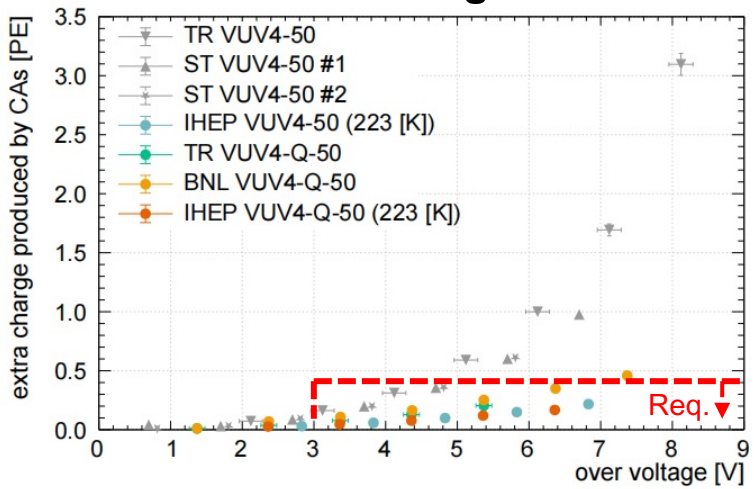
Dark noise rate vs overvoltage



FBK VUV-HD3 corr. avalanches vs overvoltage



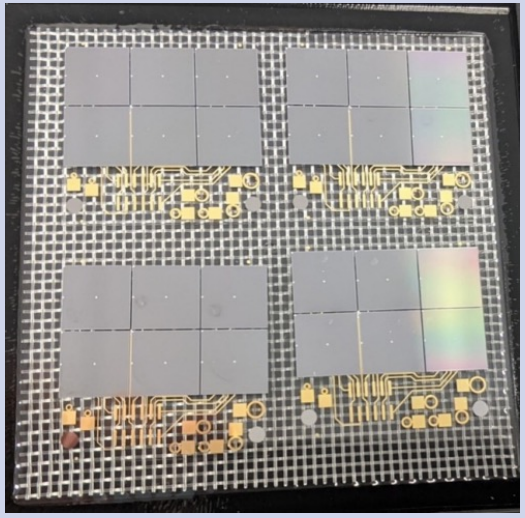
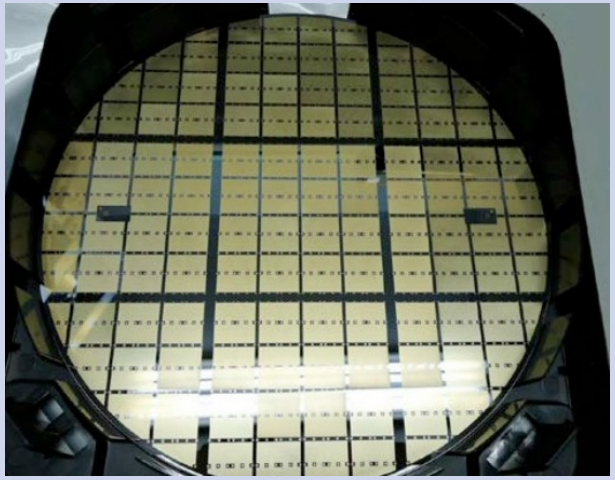
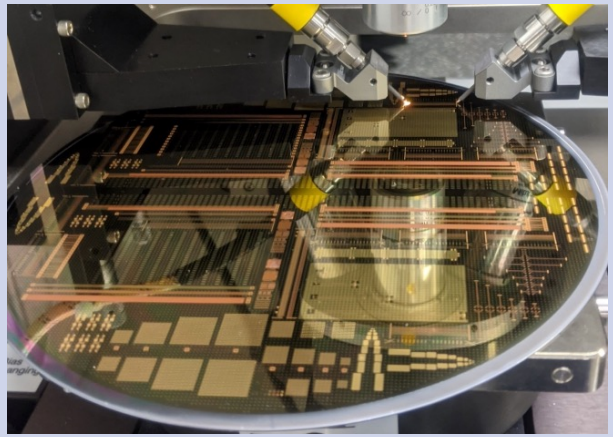
HPK VUV4 corr. avalanches vs overvoltage



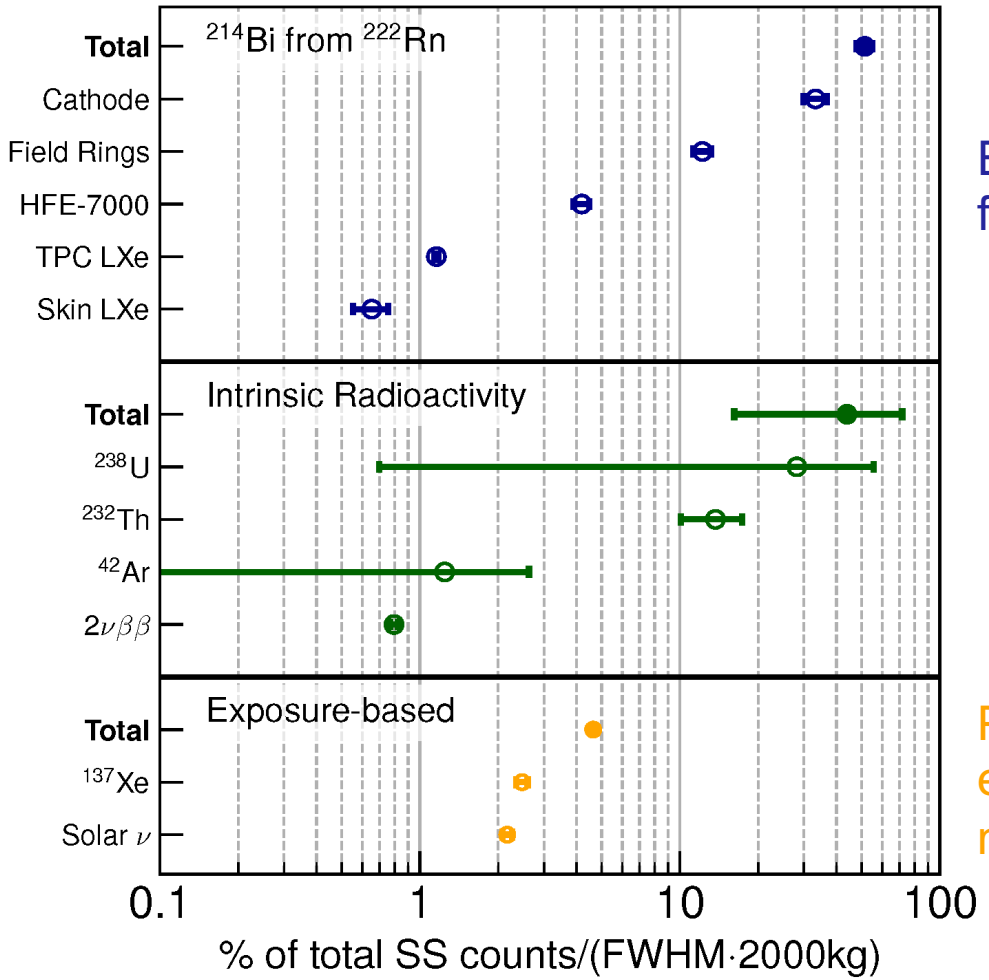
Gallina, G., Guan, Y., Retiere, F. *et al.* Performance of novel VUV-sensitive Silicon Photo-Multipliers for nEXO. *Eur. Phys. J. C* **82**, 1125 (2022).

Interposer technologies

3 concurrent technologies explored in parallel

USA Brookhaven National Laboratory	CHINA IHEP-IME	CANADA Sherbrooke-TRIUMF-IZM
Fabricated by Tecdia (USA) Silica substrate, passive 2 layers (1|1), TQV 	Fabricated by IHEP (China) Silicon substrate, passive 3 layers (1|2), TSV 	Fabricated by IZM (Germany) Silicon substrates, passive Up to 10 layers (4|2|4), TSV 

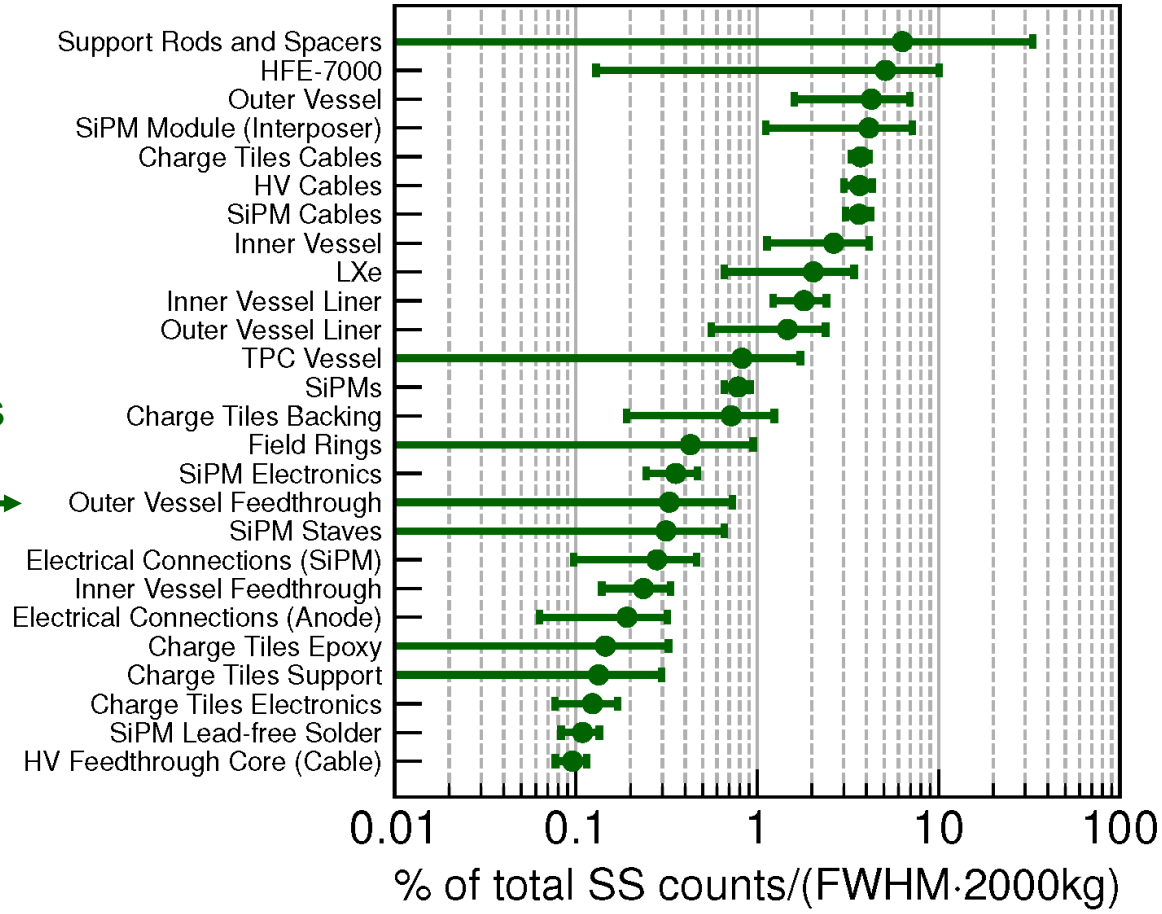
Background budget



Extrapolated from EXO-200

Radioassay measurements of materials

Predicted via external measurements



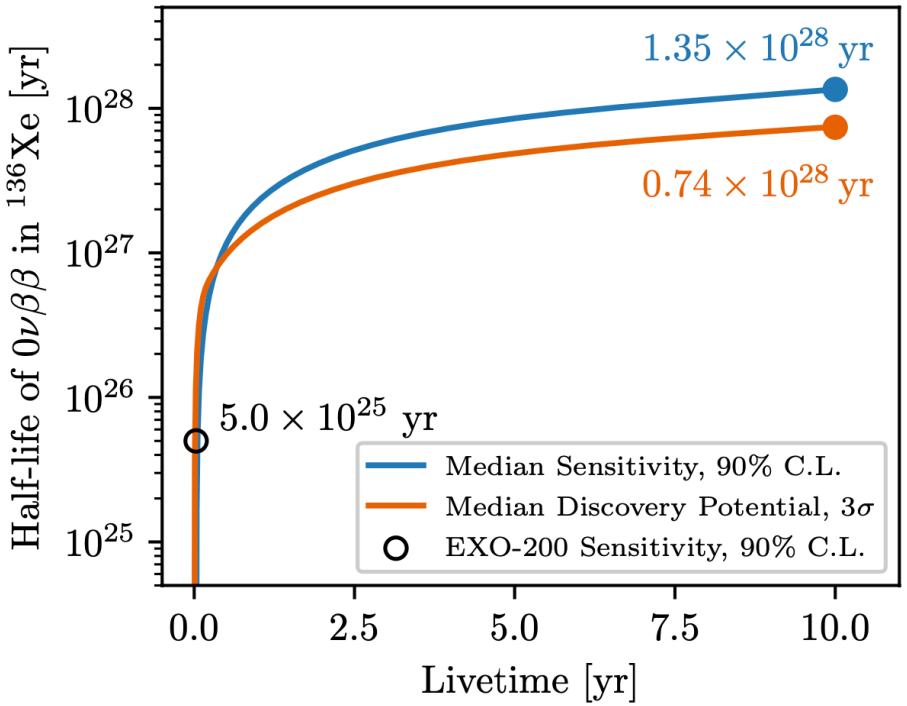
"nEXO Pre-Conceptual Design Report - arXiv.org" arXiv:1805.11142 [physics.ins-det]

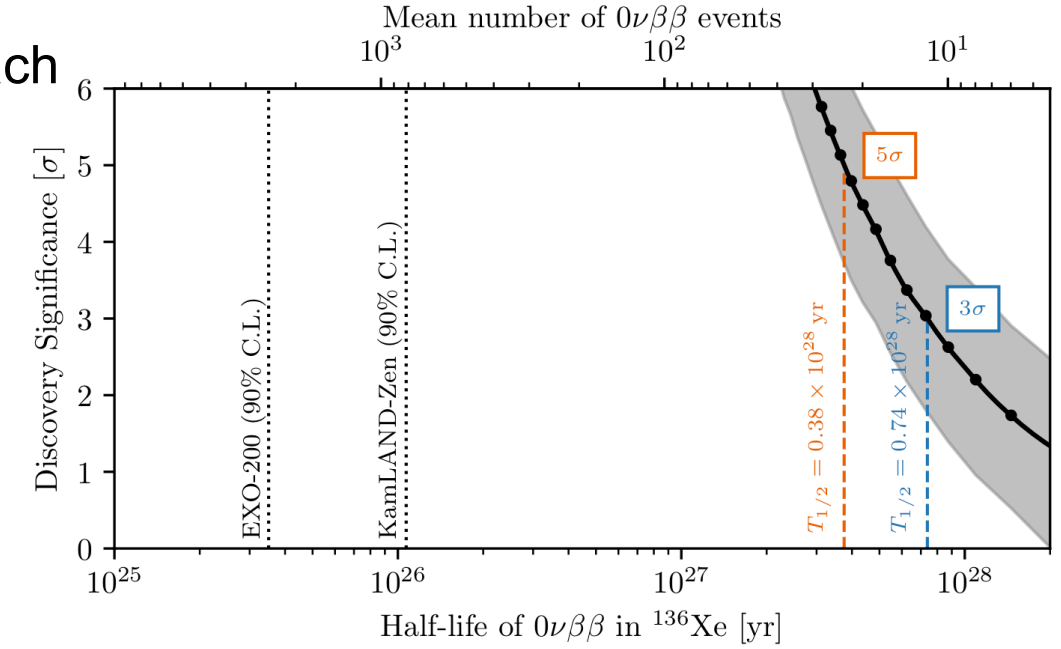
nEXO sensitivity and discover potential

nEXO will search $0\nu\beta\beta$ decay over a large, unexplored parameter space!

Assuming a 10 years livetime, nEXO is expected to reach

- Exclusion $T_{1/2}$ sensitivity of 1.35×10^{28} yrs at 90% CL
- Discover $T_{1/2}$ sensitivity of 0.74×10^{28} yrs at 3σ significance





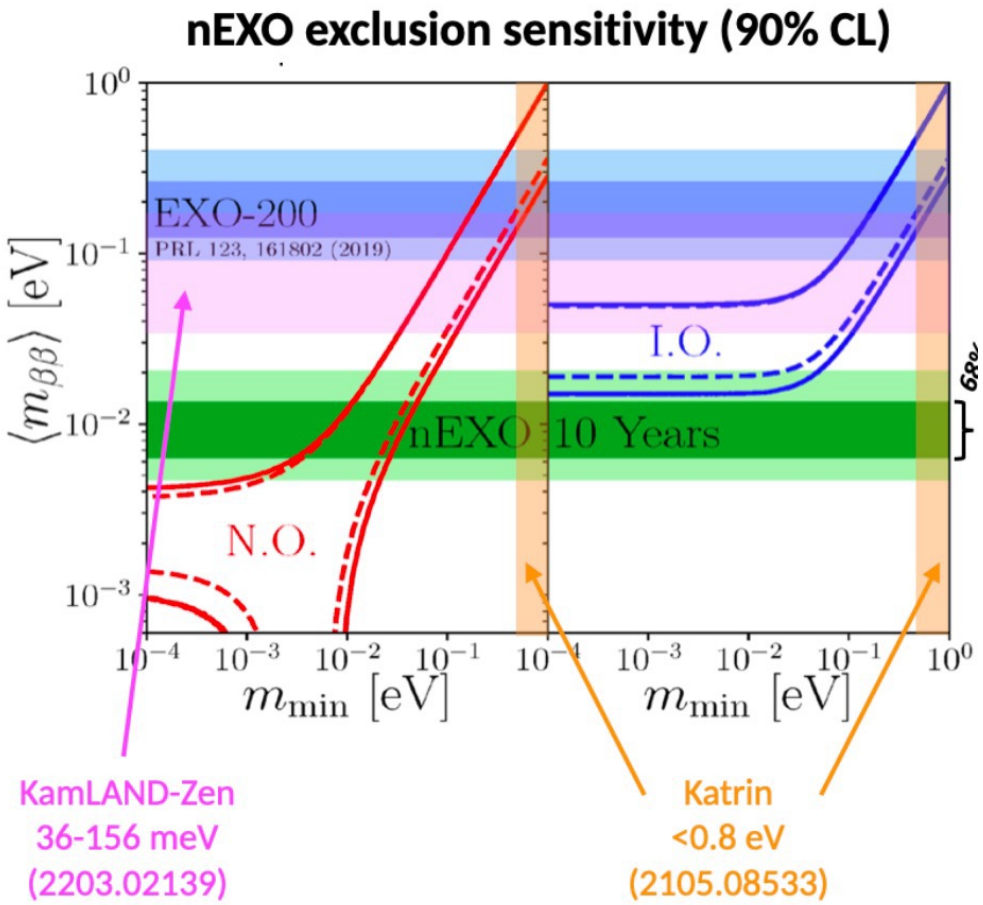
	Limit /Discovery sensitivity	Reference
EXO-200	0.35x10^{26}yr(90% CL)	PRL 123(2019) 161802
KamLAND-Zen	2.3x10^{26}yr(90% CL)	PRL. 130, 051001
nEXO	0.38x10^{28}(5σ) 0.74x10^{28}(3σ)	J.Phys.G: Nucl.Part.Phys. 49 (2022) 015104

G Adhikari et al 2022 J. Phys. G: Nucl. Part. Phys. 49 015104
DOI 10.1088/1361-6471/ac3631

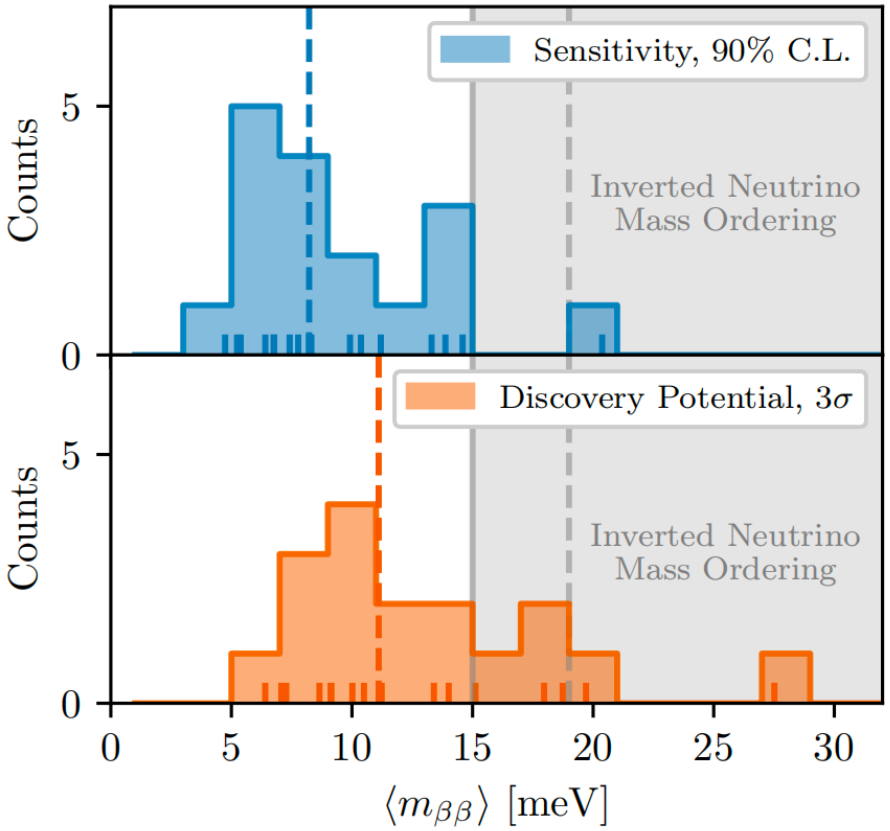
nEXO Majorana Mass Reach

nEXO completely explores the inverted mass ordering in almost all cases

$$\left(T_{1/2}^{0\nu}\right)^{-1} = \frac{\langle m_{\beta\beta}\rangle^2}{m_e^2} G^{0\nu} g_A^4 |M^{0\nu}|^2$$



Uncertainty in nuclear matrix elements



- nEXO 90% C.L sensitivity to Majorana Neutrino Mass : $m_{\beta\beta} \approx 4.7 - 20.3\ meV$
- nEXO 3σ discover sensitivity for the median NME model consider is $11.1 meV$

Summary

- nEXO is a 5 tons liquid xenon TPC detector to search the $0\upsilon\beta\beta$ decay process of ^{136}Xe.
- The projected sensitivity to half-life is 1.35×10^{28} yrs at 90% CL , nearly 2 orders of magnitude improvement compared to current limits.
- Sensitivity to Majorana neutrino mass of 4.7-20.3 meV, covering the entire inverted neutrino mass ordering.

nEXO: A world wide collaboration neutrino-less experiment

Thanks