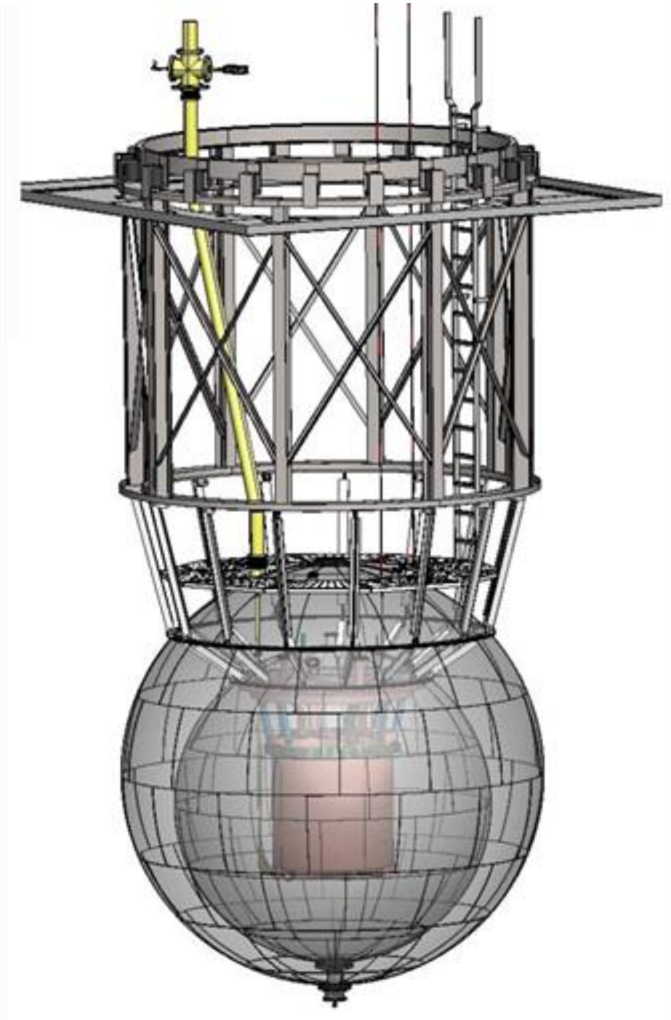
Searching for neutrinoless double decay with the **nEXO** experiment

Lin Si, On behalf of the nEXO collaboration

6/10/2025, CIPANP, Madison

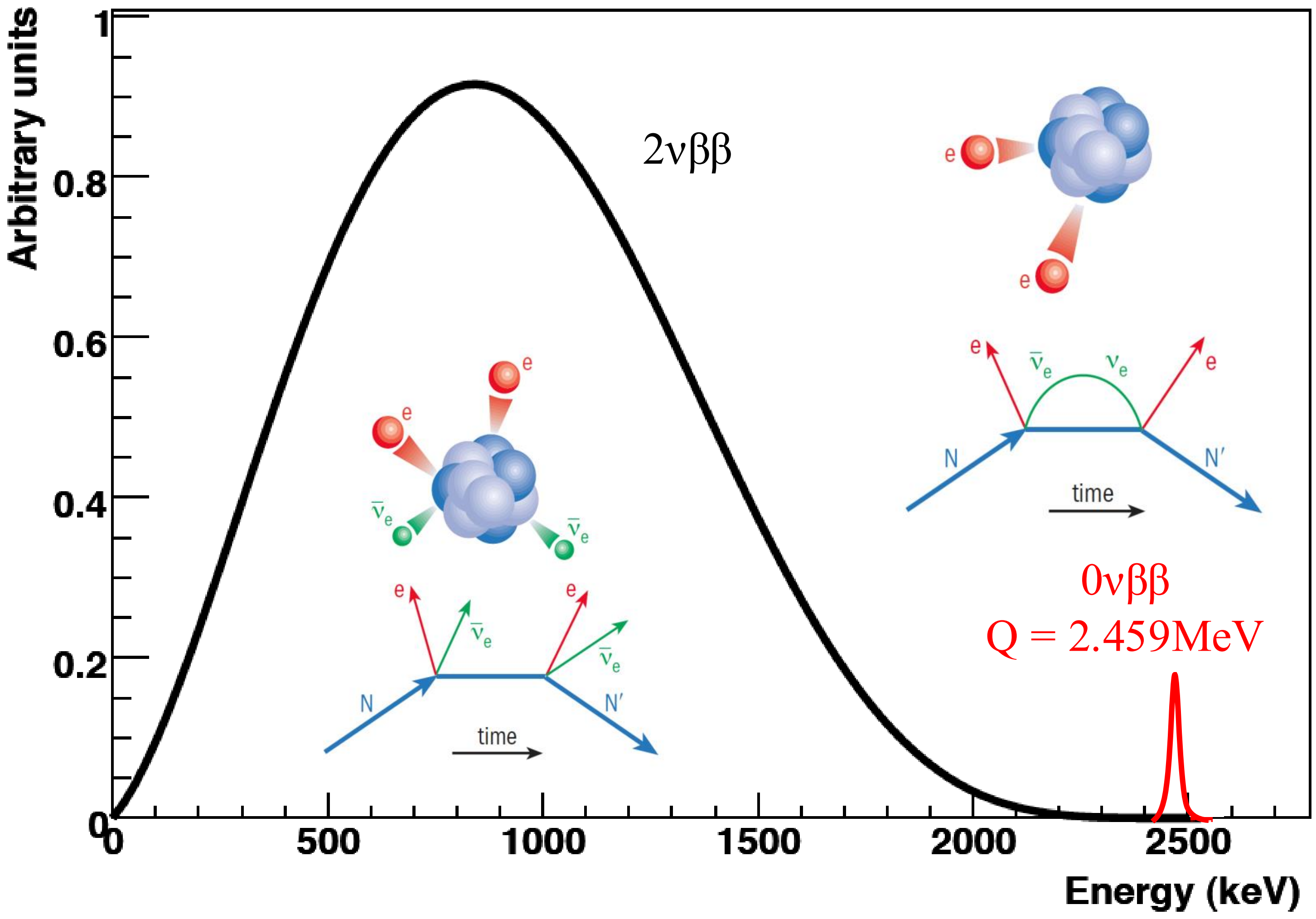
Outline

- Neutrinoless Double Beta Decay
- nEXO Experiment
- SiPM array studies in Lxe
- ASIC testing for charge readout



Neutrinoless Double Beta Decay

- **Confirm Neutrino Majorana Nature**
  Detect neutrinoless double beta decay ($0\nu\beta\beta$) to prove neutrinos are their own antiparticles.
- **Probe Lepton Number Violation & Matter Dominance**
  $0\nu\beta\beta$ (ΔL = 2) could explain the observed matter-antimatter asymmetry in the Universe.
- **Neutrino Mass**
  If $0\nu\beta\beta$ is observed, effective neutrino mass can be constrained to the ~10meV scale



Neutrinoless Double Beta Decay

Candidate	Q(MeV)
$^{48}Ca \rightarrow {}^{48}Ti$	4.271
$^{76}Ge \rightarrow {}^{76}Se$	2.040
$^{82}Se \rightarrow {}^{82}Kr$	2.995
$^{96}Zr \rightarrow {}^{96}Mo$	3.350
$^{100}Mo \rightarrow {}^{100}Ru$	3.034
$^{110}Pd \rightarrow {}^{110}Cd$	2.013
$^{116}Cd \rightarrow {}^{116}Sn$	2.802
$^{124}Sn \rightarrow {}^{124}Te$	2.228
$^{130}Te \rightarrow {}^{130}Xe$	2.533
$^{136}Xe \rightarrow {}^{136}Ba$	2.458
$^{150}Nd \rightarrow {}^{150}Sm$	3.367

Multiple experiment with different isotopes

- Q-value and phase space
- Half-life
- Nuclear matrix element
- Experimental practical challenges

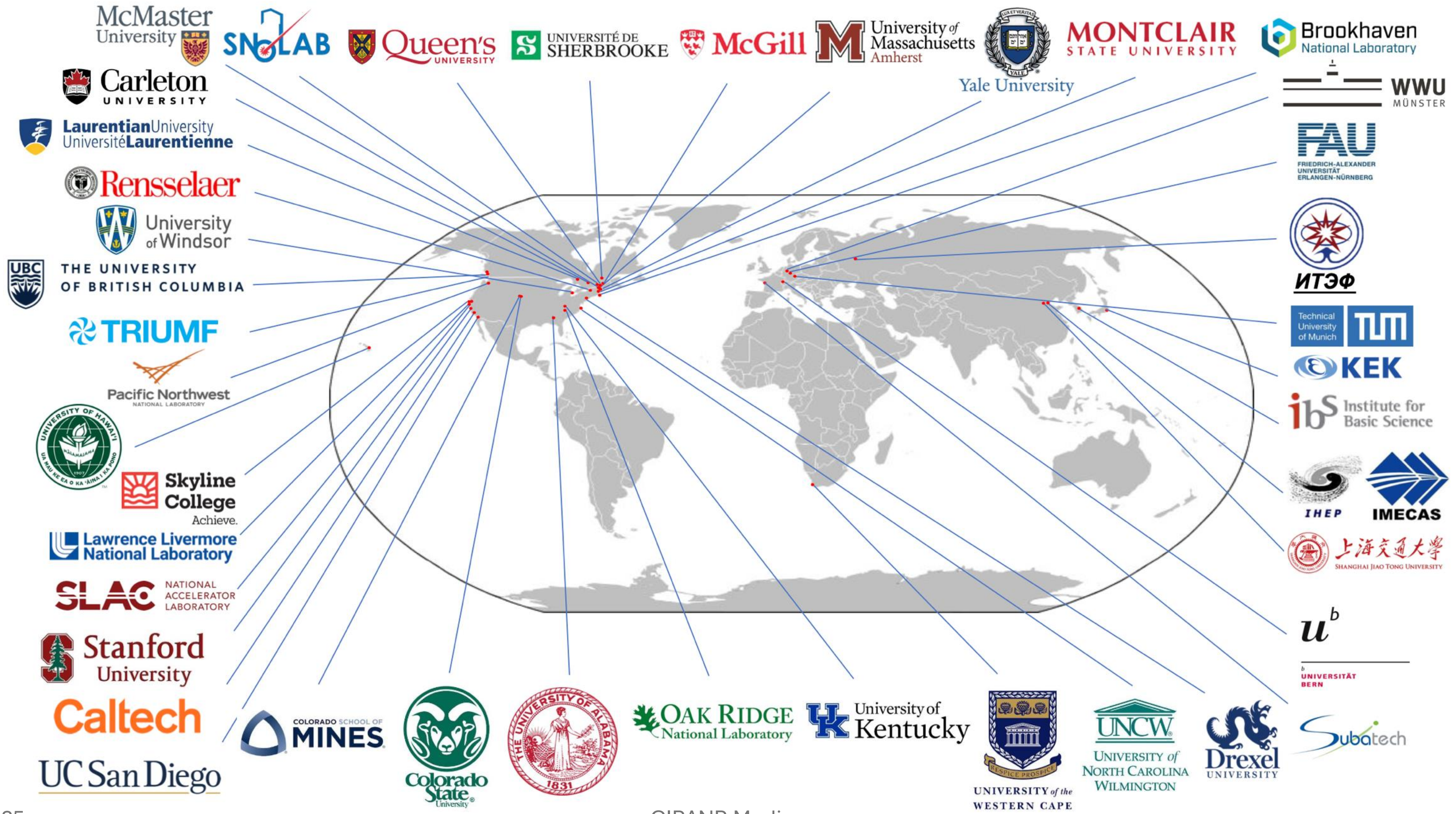
Motivations for using multiple isotopes

- Enable different detection techniques
- Mitigate risks from unknown γ transitions
- Distinct $2\nu\beta\beta$ backgrounds
- Nuclear matrix elements are uncertain and model-dependent

Isotope of choice for nEXO: ^{136}Xe

- High Q value: 2.4578 MeV
- Few radioactive backgrounds
- Noble element: good detector material

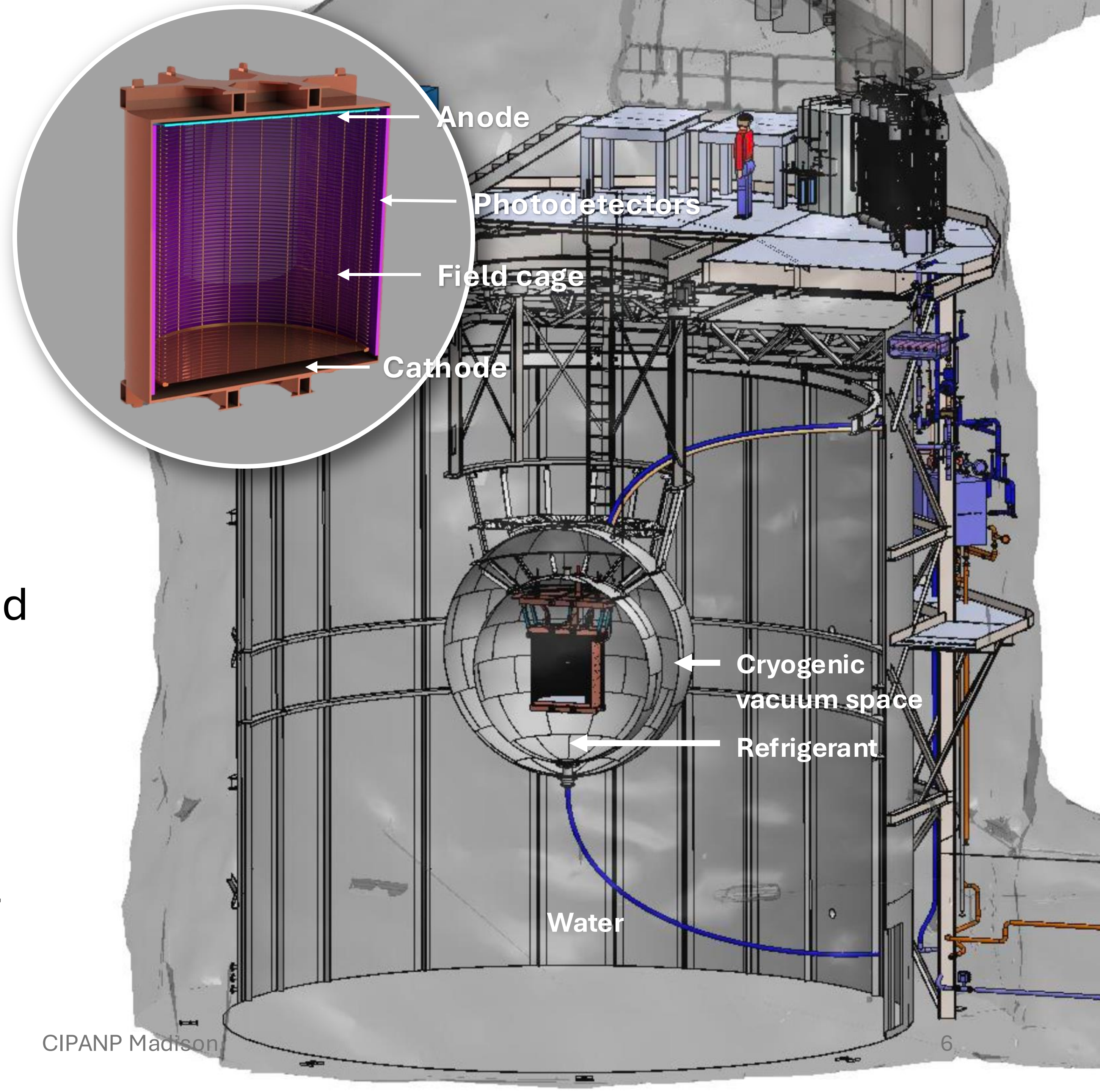
nEXO Collaboration



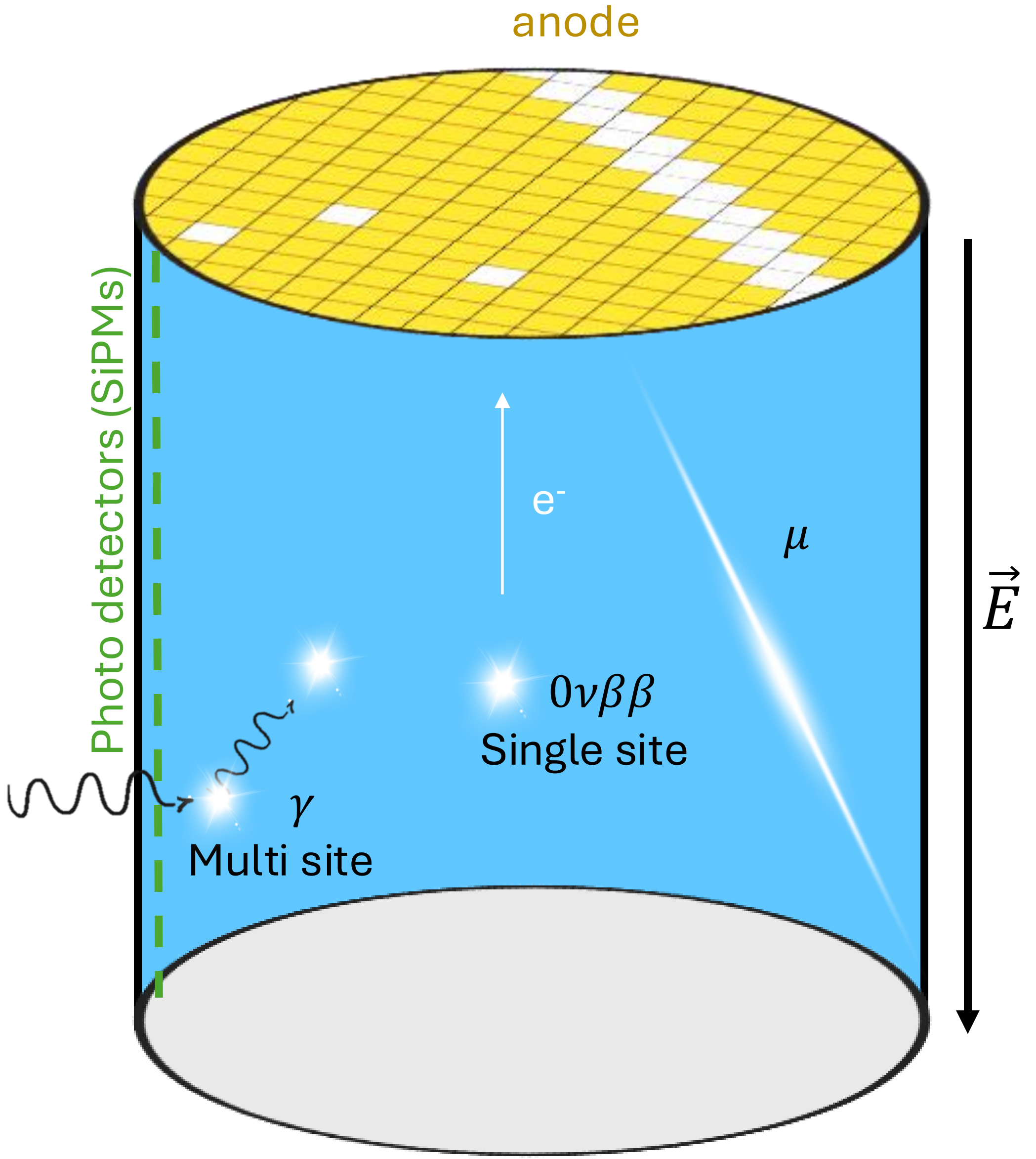
nEXO Experiment

Next-gen $0\nu\beta\beta$ detector

- Single phase Time Projection Chamber(TPC) with 1.3 m drift length
- 5 tonnes of liquid xenon enriched to 90% in ^{136}Xe
- Underground at SNOLAB, Large overburden 2 km
- Active water veto outer detector

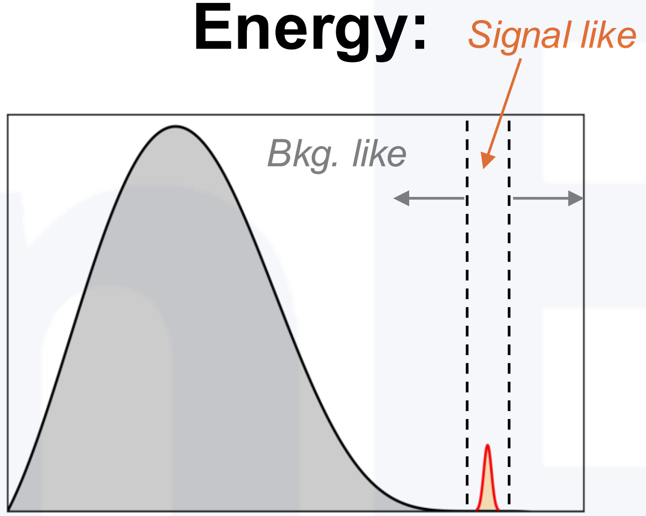


Signal Detection in nEXO TPC

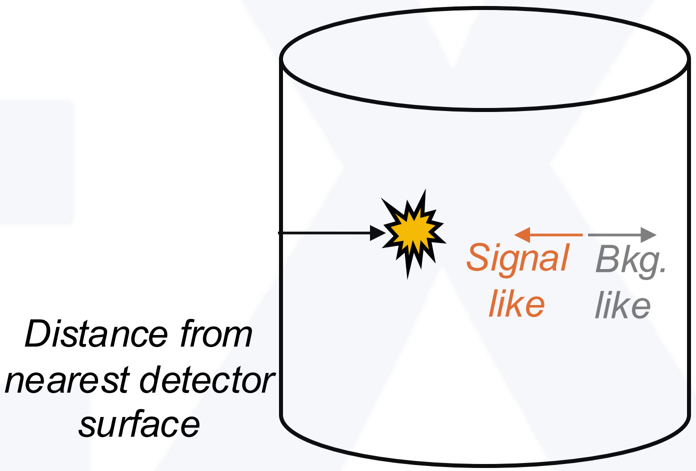


Multi-dimensional likelihood analysis

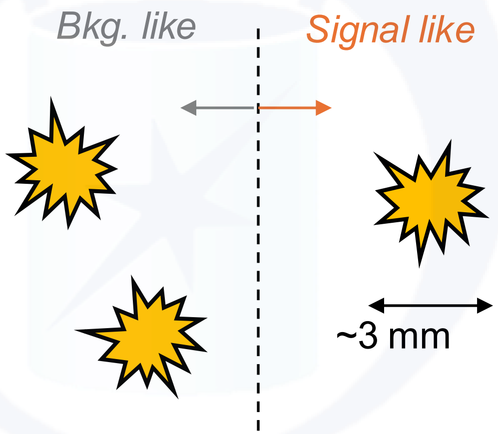
Energy:



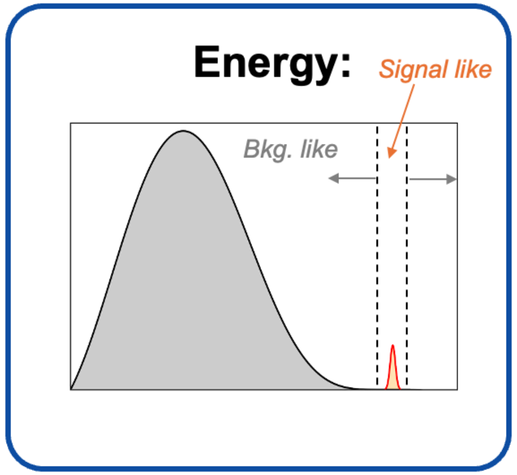
Standoff:



Topology:

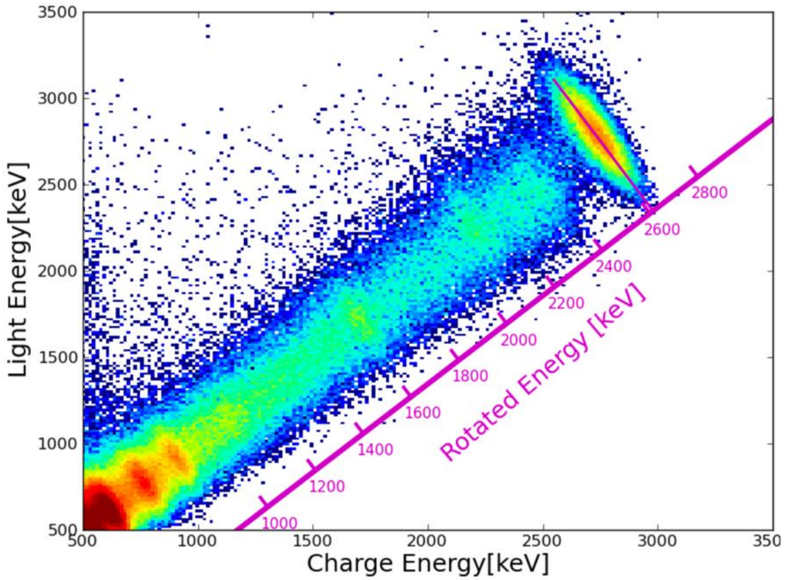


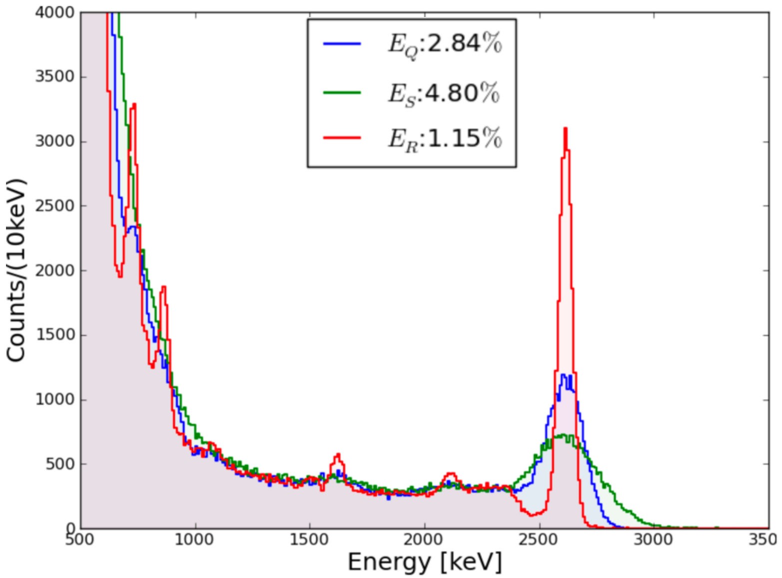
Multi-dimensional likelihood analysis



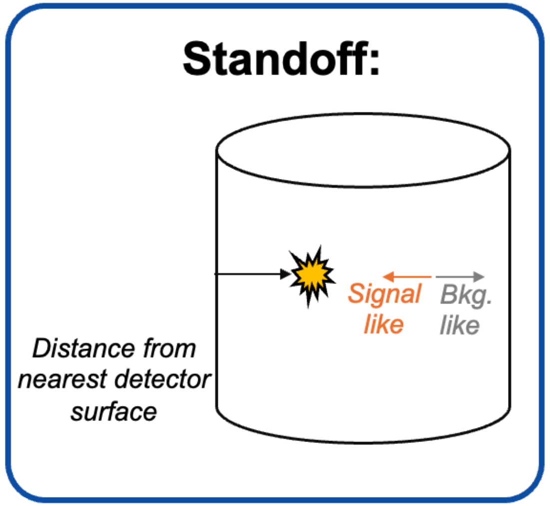
- Signal: mono-energetic peak at Q-value
- Better energy resolution → better signal-background separation
- Energy reconstructed using combined charge and light
- EXO-200 achieved significant improvement with rotation
- **nEXO target resolution: 0.8% at Q-value**

^{228}Th EXO-200 data

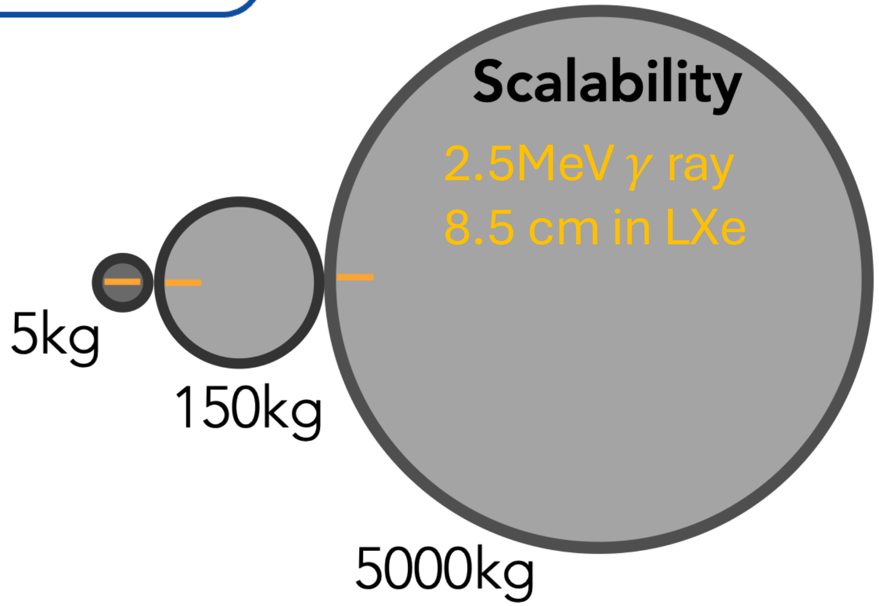




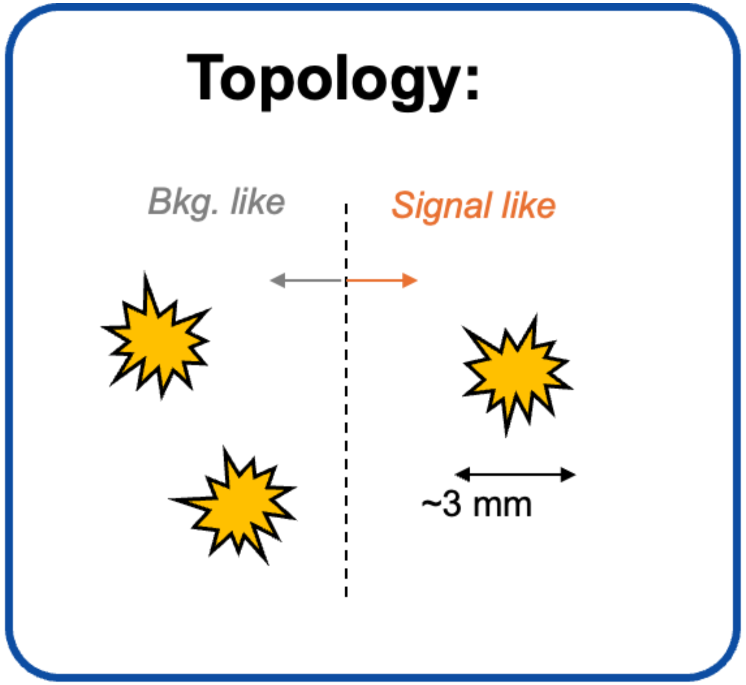
Multi-dimensional likelihood analysis



- Signal: uniformly distributed in LXe
- Environmental BKG enter from detector surfaces
- 2.5 MeV $\gamma \rightarrow$ mean free path ≈ 8.5 cm in LXe
- Larger detectors → stronger self-shielding
- **Reduces environmental BKG in the inner detector**



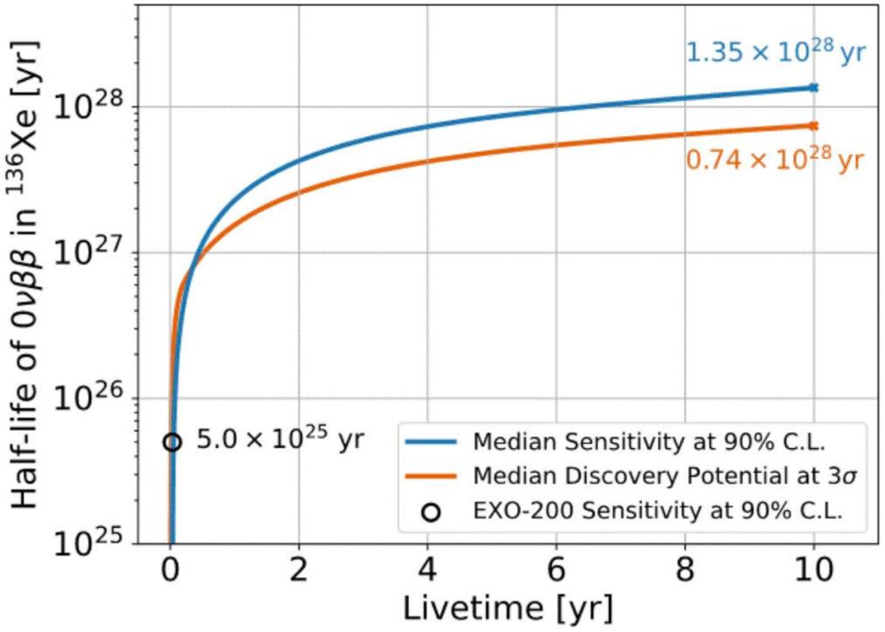
Multi-dimensional likelihood analysis



Single-site vs. multi-site discrimination

- $0\nu\beta\beta$ signal: single-site energy deposition
- γ backgrounds: often produce multi-site scattering
- Segmented anode: 3 mm pitch cross strips
- Allows identification of spatially separated deposits
- Improves signal–background separation

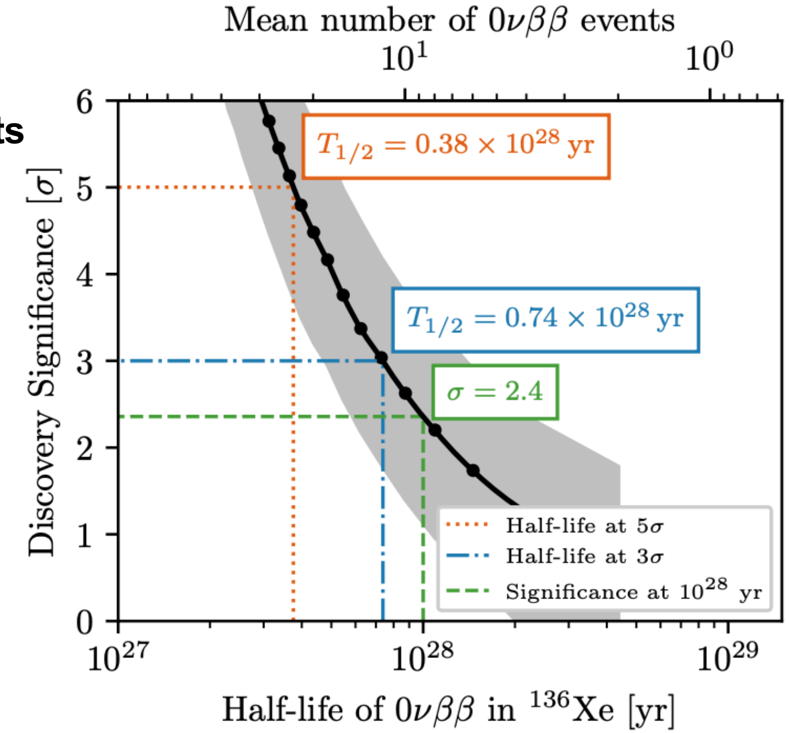
Projected Sensitivity of nEXO



Current $T_{1/2}$ limits: > 10^{26} yrs

→ Next generation experiments **> 10^{28} yrs** → tonne scale!

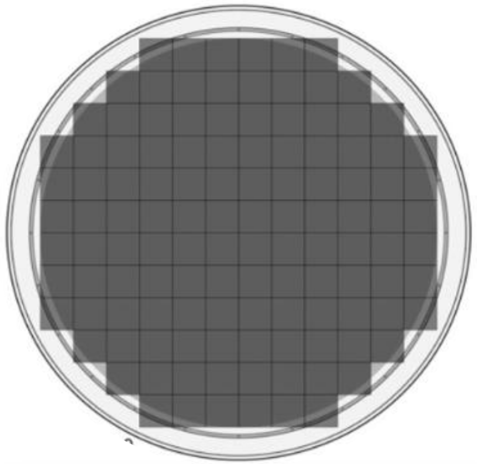
Existing limits ($\sim10^{26}$ yr)

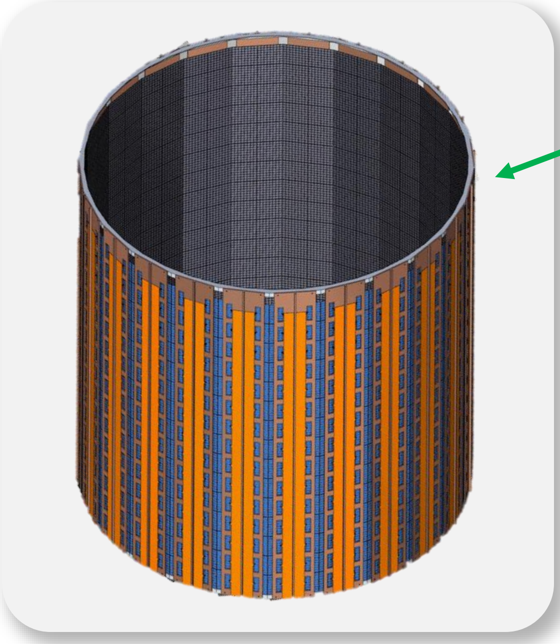


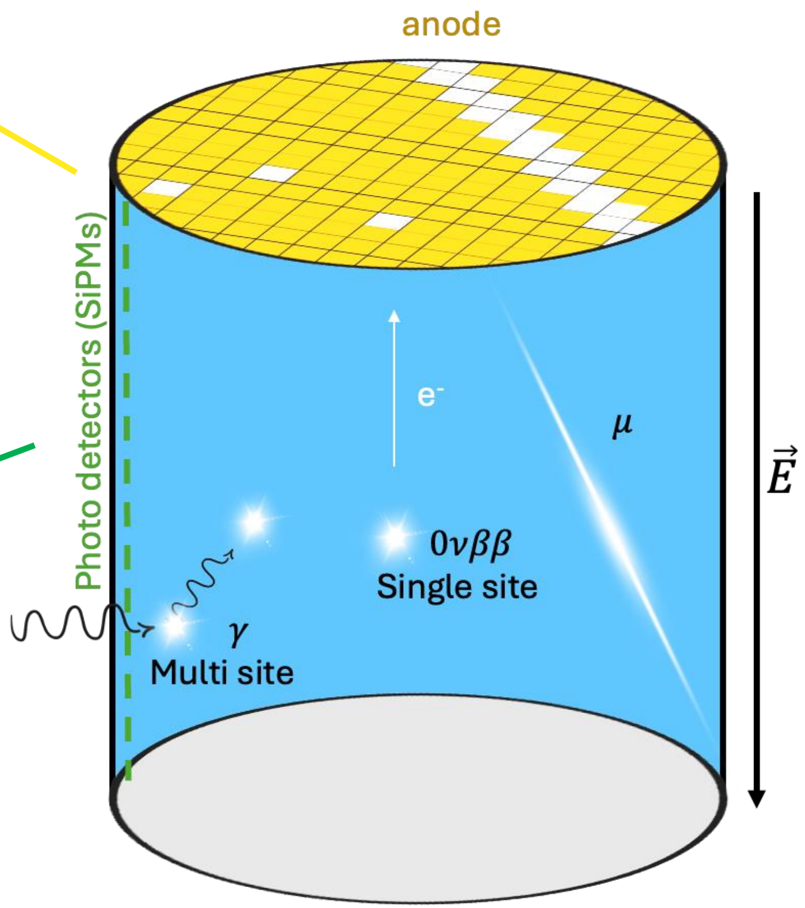
- nEXO is a discovery experiment, which will search for $0\nu\beta\beta$ with half-life sensitivity approximately 2 orders of magnitude beyond existing experiments
- If observed, nEXO will provide compelling evidence of a discovery:

  Measures multiple parameters, fully homogeneous, can replace ^{136}Xe with ^{nat}Xe for a control experiment

Instrumentation R&D







Ionization charge

- Gridles segmented modular tiles (charge tiles)
- Top of the detector

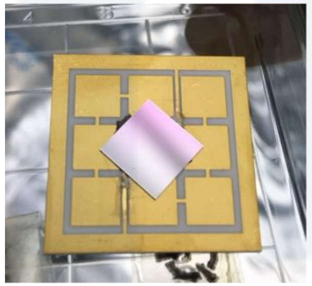
Scintillation light

- Silicon Photomultipliers (SiPMs)
- Barrel of TPC

Light Signal

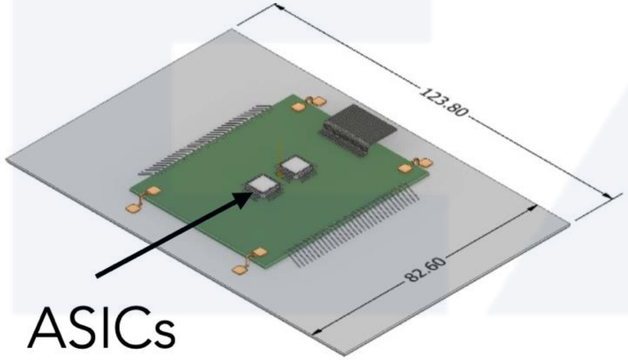
4.6 m² of Silicon Photomultipliers (SiPMs)

~46,000 1cm × 1 cm VUV sensitive SiPMs
7680 channels



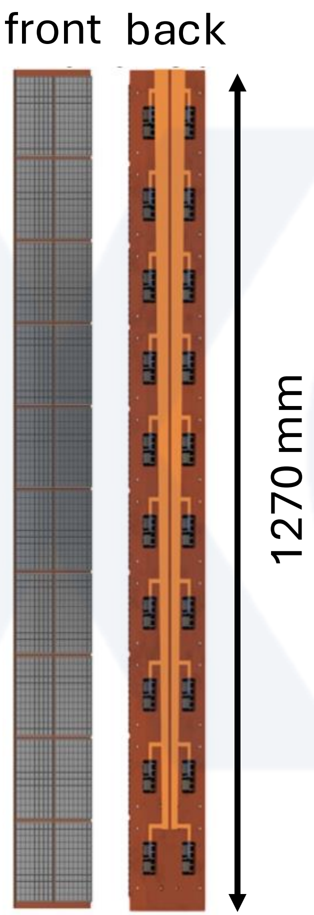
SiPM 1 × 1 cm²

SiPM Modules:
Each SiPM is 1 cm × 1 cm



tile

light Tiles:
Each tile contains 96 SiPMs



stave

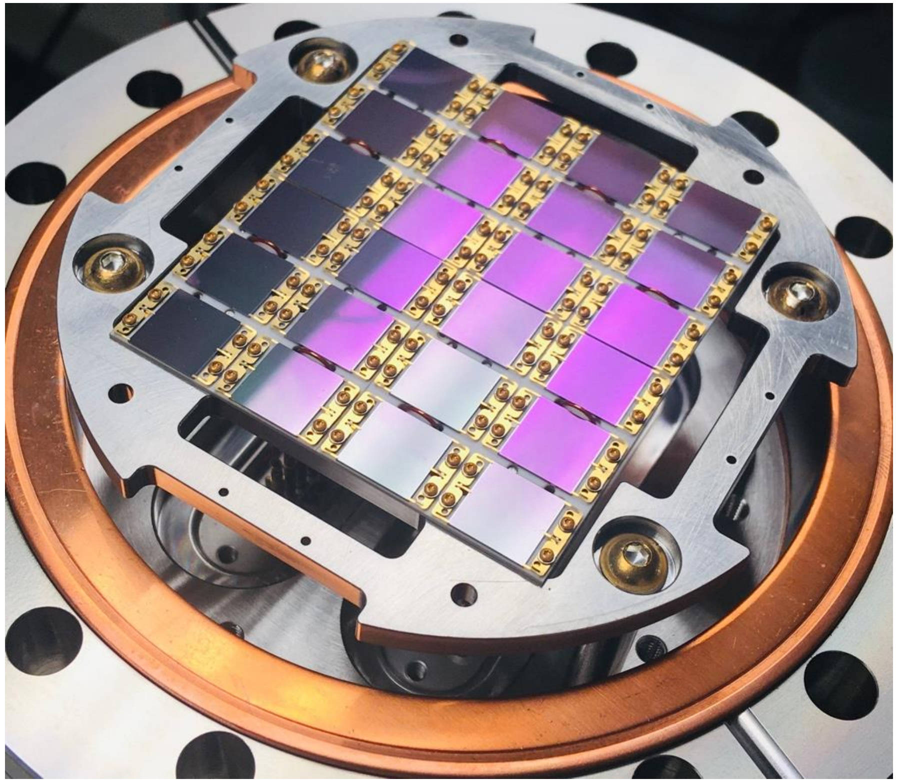
Stave assembly:
20 tiles form one stave

Photon detection system

Full photon detection system:
24 staves around the TPC barrel

Light Signal

Stanford TPC installation(R&D with 24 SiPMs)
early measurements and study how the array behaves in LXe



SiPMs array
(use different preamp for nEXO)

Multiple SiPM candidates are meeting nEXO requirements

Gallina, G., et al. "Performance of Novel VUV-Sensitive Silicon Photo-Multipliers for nEXO." The European Physical Journal C 82, no. 12 (December 13, 2022): 1125

properties under investigation in R&D:

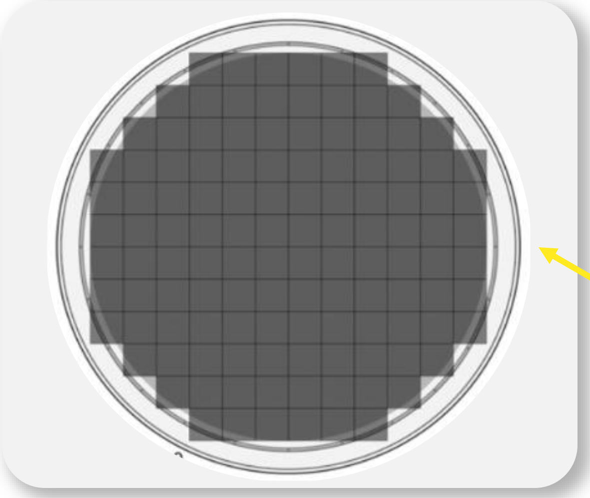
- dark rate
- photodetection efficiency
- correlated avalanches
- overvoltage/temperature dependence

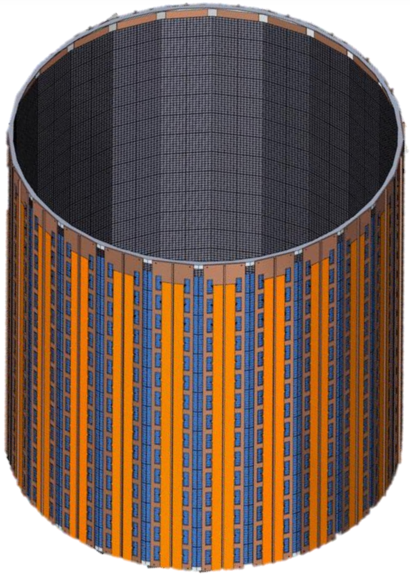
Light Signal

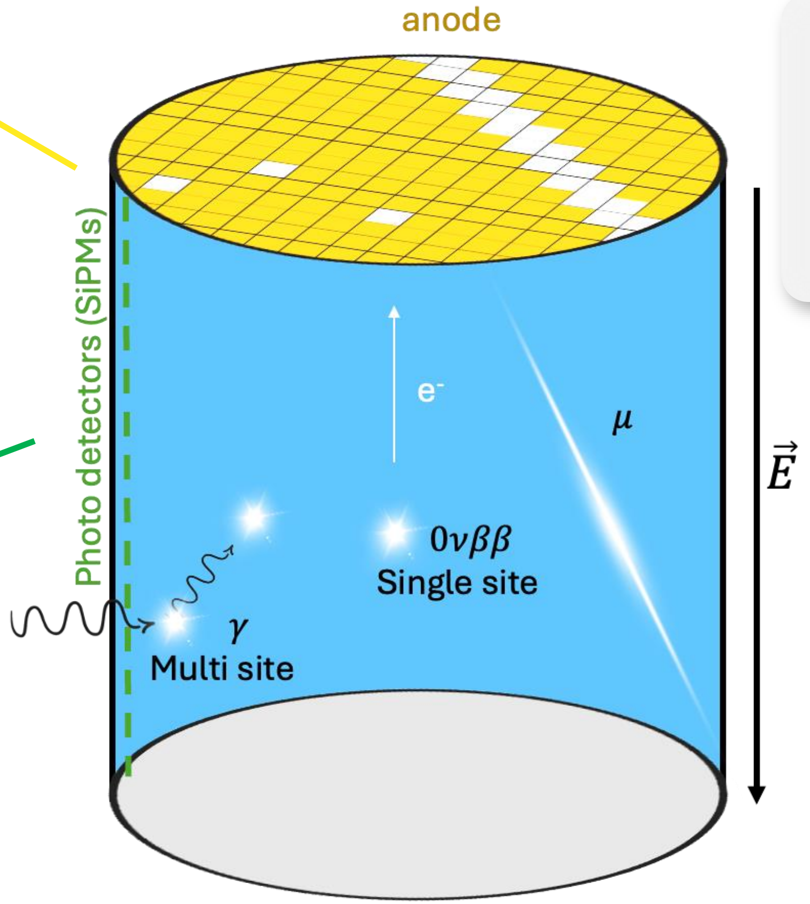
Stave test chamber McGill:

- All hardware for 30 cm x 60 cm area cryogenic prototype stave test in place.
- Assembly progressing well.
- First vacuum end of Feb. 2025
- First cooldown May 2025
- First SiPM tile test August 2025

Signal Detection in nEXO TPC







Ionization charge

- Gridles segmented modular tiles (charge tiles)
- Top of the detector

Scintillation light

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- Barrel of TPC

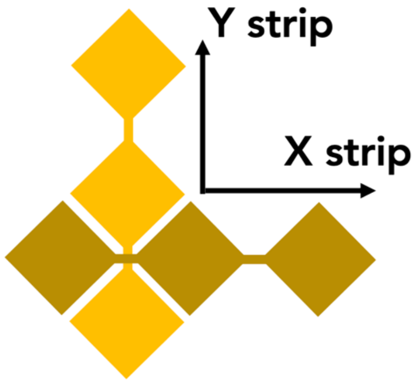
Charge Signal

nEXO full assembly of the charge readout: 120 tiles

Modular Charge Tile Structure

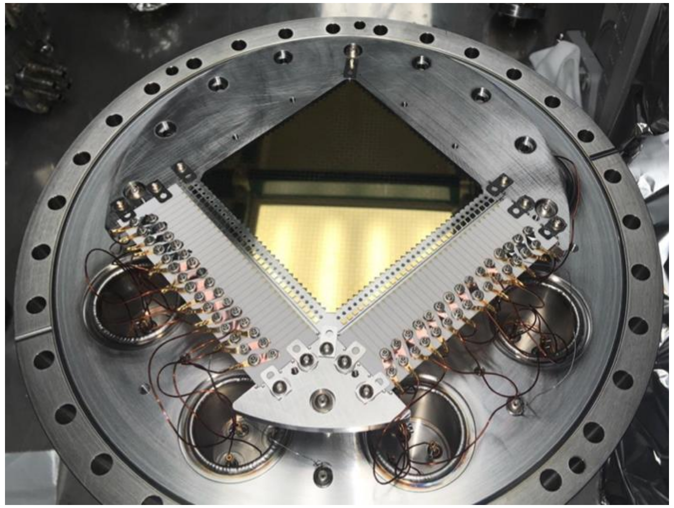
- Each tile: 10 cm × 10 cm
- X and Y strips for 2D charge reconstruction
- Each strip: 16 squares for charge collection

the charge tile will first be tested externally with dedicated electronics to validate its performance



Squares daisy chained

Modular Anode Plane: 32 perpendicular strips



Charge Tile Testing Setup with External Electronics

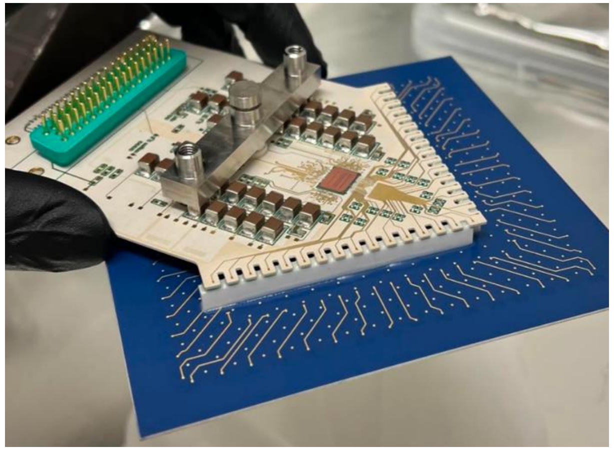
Charge Signal

Charge integrating analog circuits have noise contributors often dominated by **capacitance** of the collecting electrode

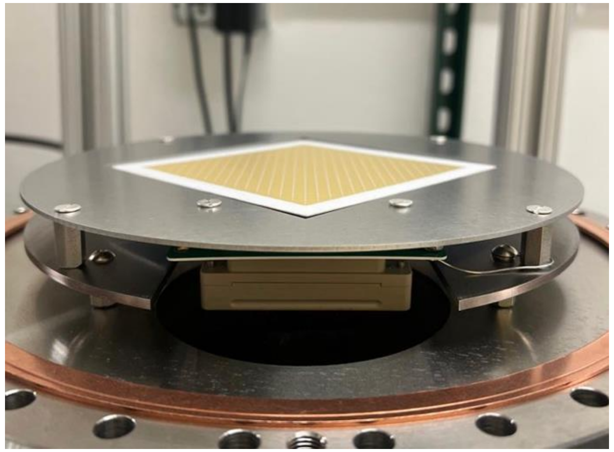
- Long cabling introduces a lot of capacitance
- Place the amplifier/digitizer as close to the electrode as possible

nEXO has strict **radiopurity** requirements and assays every material that goes into the detector

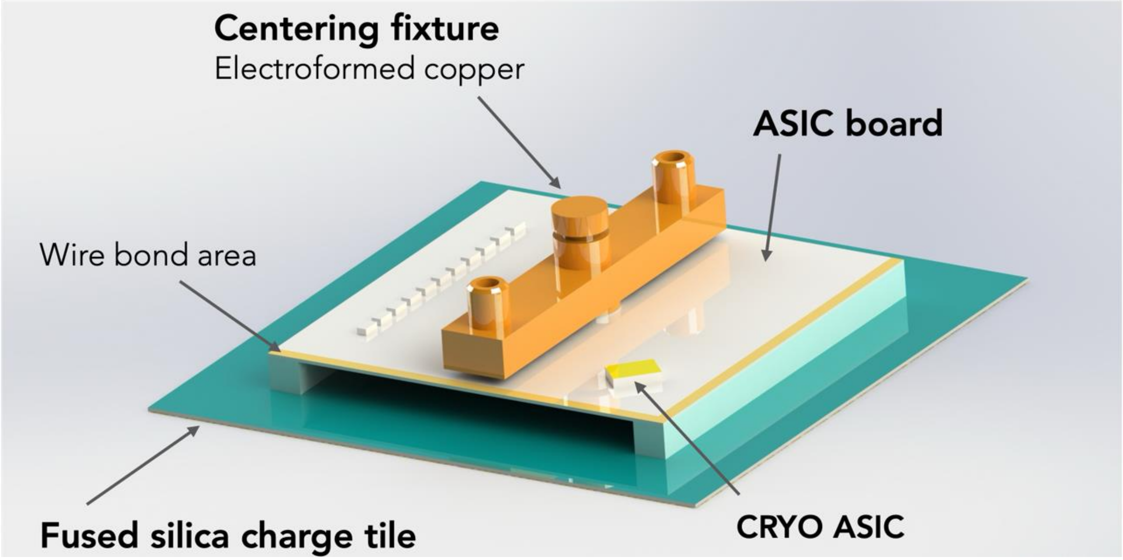
- ~3840 channels implies lots of cable mass if every channel gets a cable up to the surface



Prototype Module at Stanford Lab



Full Module Connected to Flange



Amplifier & Digitizer Directly Connected to Modular Charge Tiles

Next step

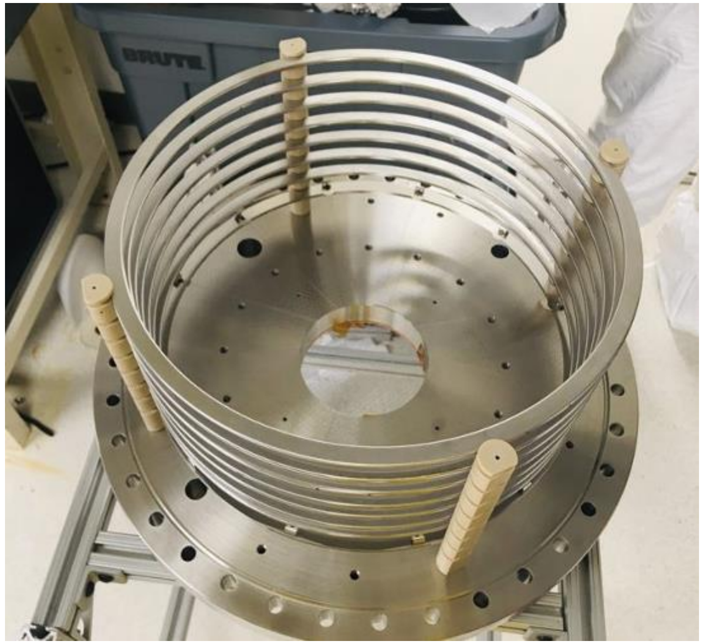
nEXO requires 120 charge tiles
how multiple tiles behave together

- Wide TPC can accommodate four charge tiles
- Key study areas:

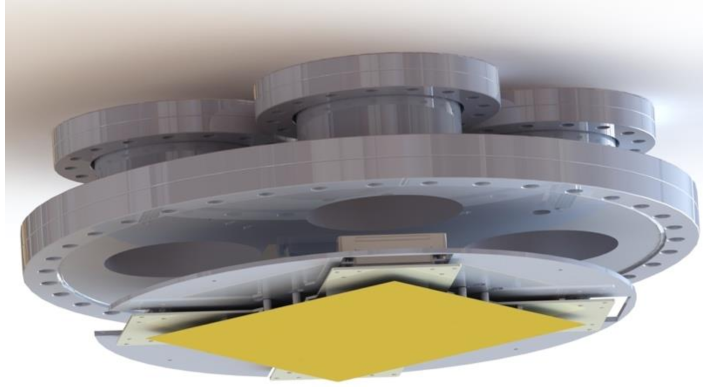
Multi-tile testing
Large SiPM array performance
Cross-talk between tiles
Energy resolution improvements

- Technical Specs:

Drift length: 13cm
Inner diameter: 35.25 cm
Total mass: 64 kg xenon



Wide TPC
capable of holding four charge tiles



Experimental setup for multiple tile

Conclusion

nEXO is a next-generation experiment designed to search for neutrinoless double beta decay in **5 tonnes of enriched liquid xenon**.

It features a **fully homogeneous detector**, measuring energy, position, and topology of every event.

nEXO aims for a **half-life sensitivity beyond 10^{28} years**, with **ultra-low background and multi-dimensional analysis**.

Our R&D focuses on:

- **SiPM-based light detection**
- **Charge readout tiles** (low-noise ASICs, integrated electronics)
- A **64-kg LXe test TPC** to validate full system integration and performance

Thank you