nEXO: a Next Generation Neutrinoless Double Beta Decay Experiment

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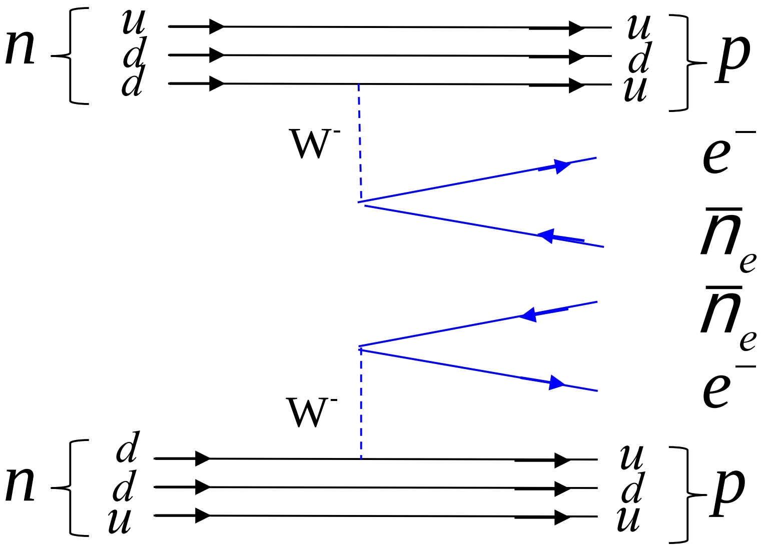
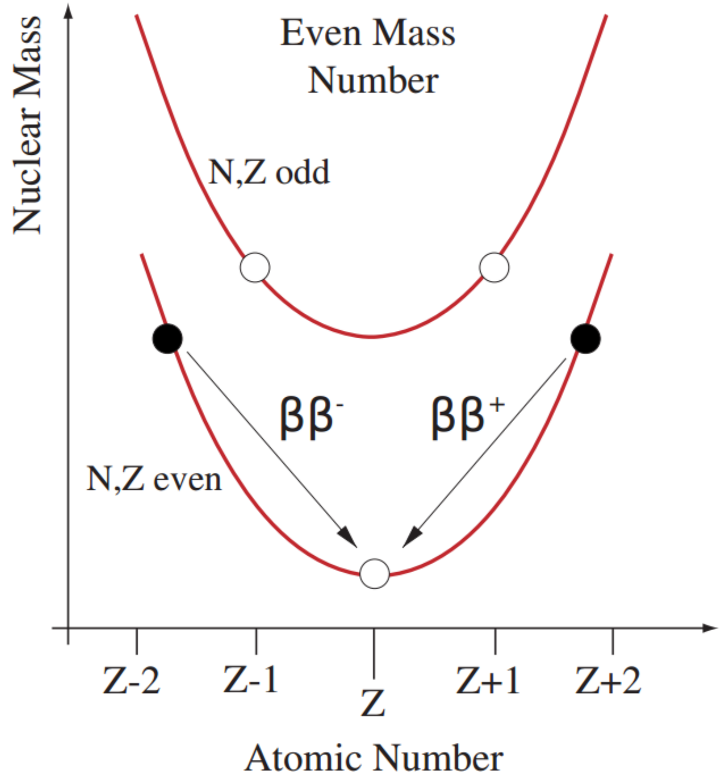
Double Beta Decay (2νββ)

$$^{136}\mathrm{Xe} \longrightarrow \, ^{136}\mathrm{Ba} + 2\,\mathrm{e}^- + 2\,\overline{\nu_\mathrm{e}}$$

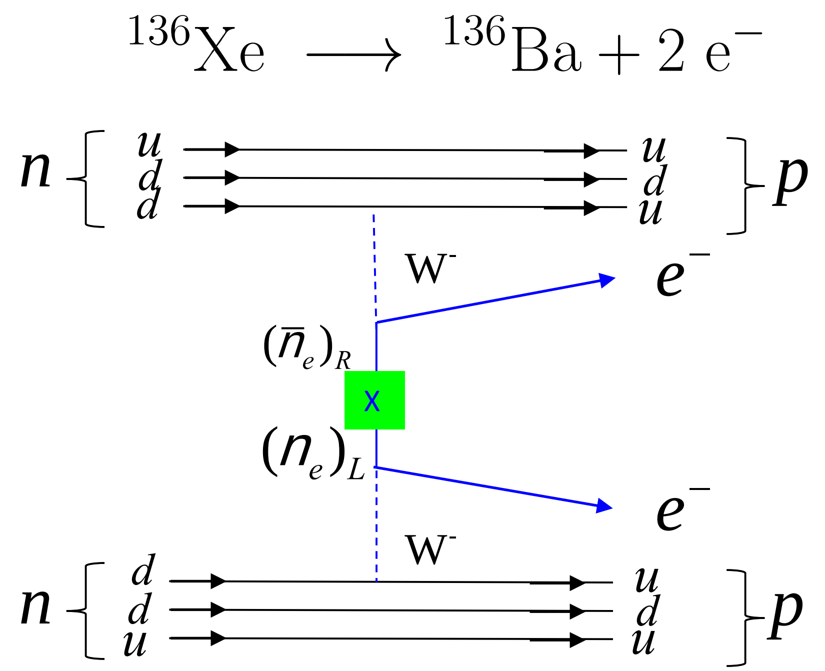


Observed! 2nd order weak interaction leads to long lifetime.

$$T^{2\nu}_{1/2}(^{136}\mathrm{Xe}) = 2.1 \times 10^{21}\ \mathrm{yr}$$



Neutrinoless Double Beta Decay (0νββ)



Requires Baryon-Lepton Number Violation!

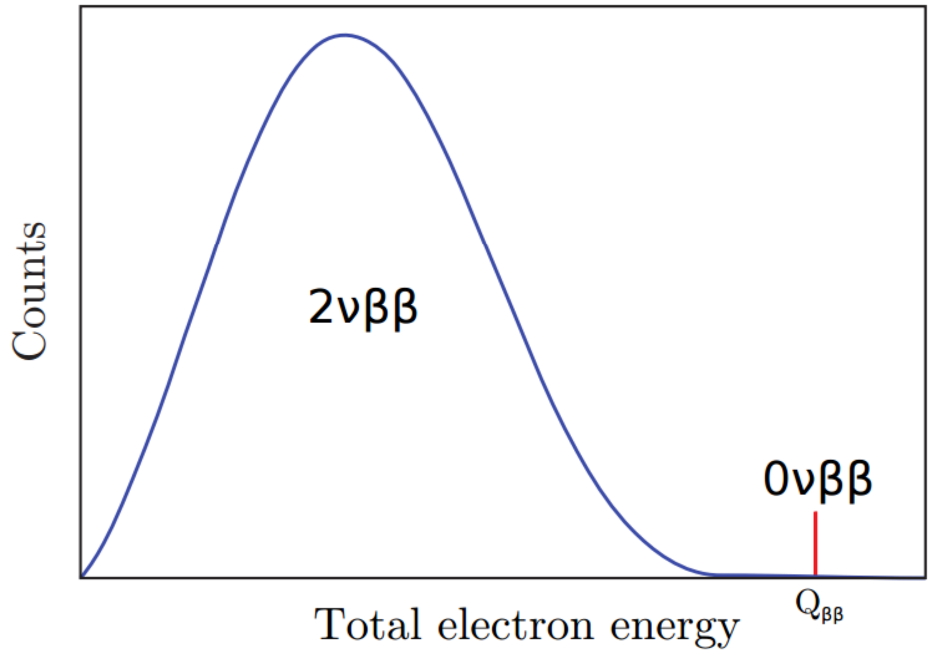
Should occur if the neutrino is a Majorana particle

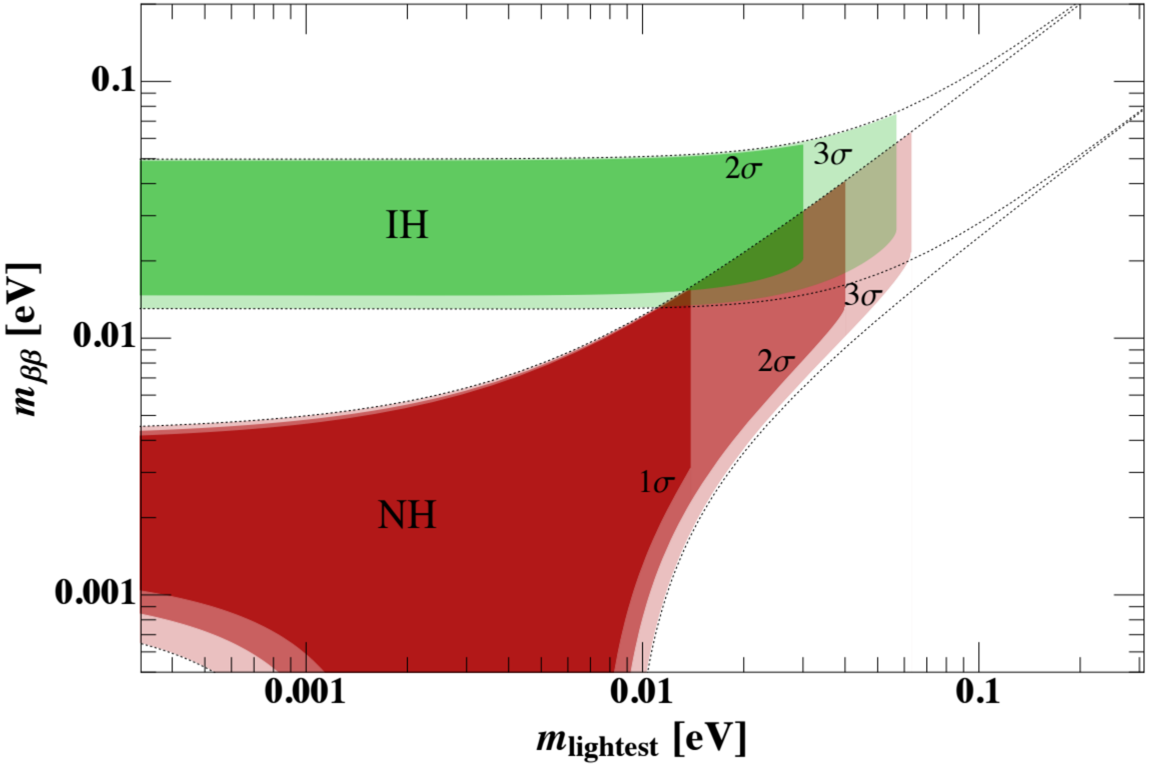
Isotope	isotopic abundance (%)	$Q_{\beta\beta}$ [MeV]
^{48}Ca	0.187	4.263
^{76}Ge	7.8	2.039
^{82}Se	9.2	2.998
^{96}Zr	2.8	3.348
^{100}Mo	9.6	3.035
^{116}Cd	7.6	2.813
^{130}Te	34.08	2.527
^{136}Xe	8.9	2.459
^{150}Nd	5.6	3.371

Key for experiments:

- High $Q_{\beta\beta}$
- High isotopic abundance or easily enriched
- Detector scalability

Neutrinoless Double Beta Decay (0νββ)



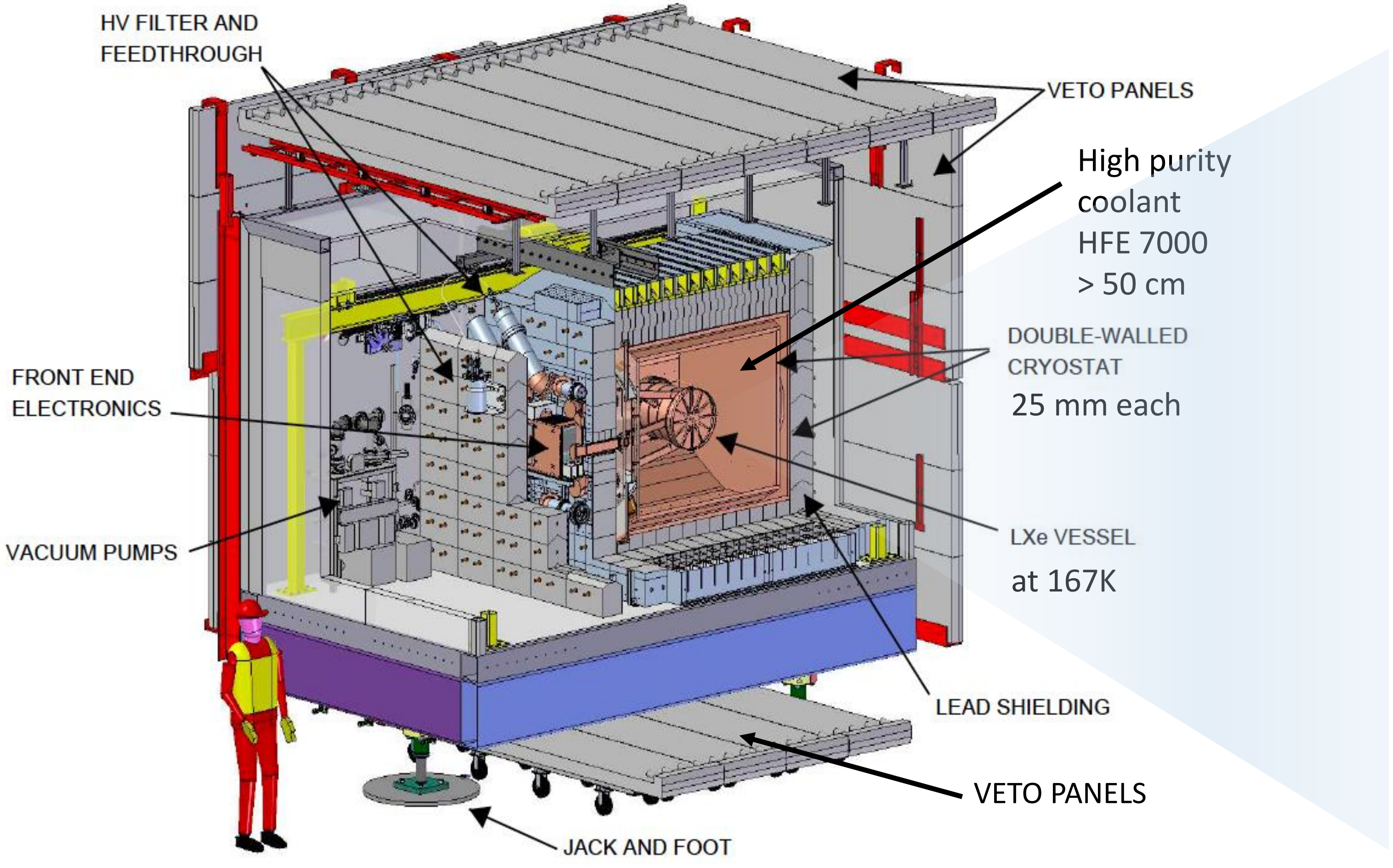


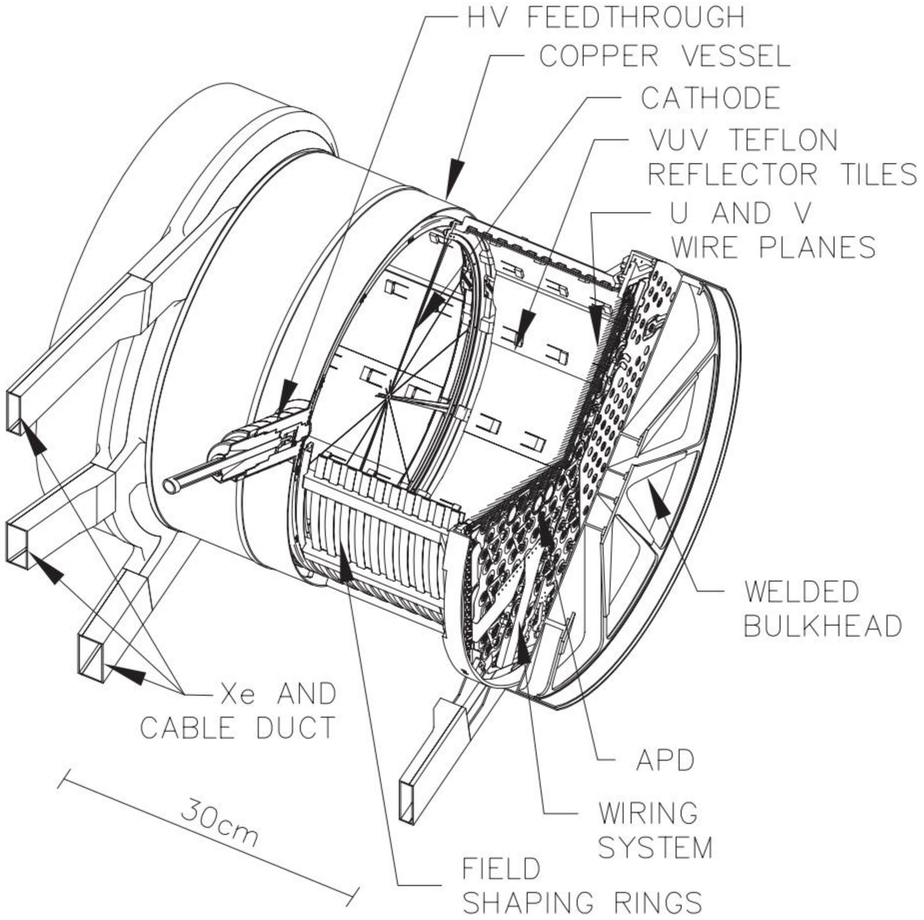
$$T^{0\nu}_{1/2} = \frac{1}{G_{0\nu}(Q,Z) \times |M_{0\nu}|^2} \times \frac{m_e^2}{m_{\beta\beta}^2}$$

$$m_{\beta\beta} \equiv |U_{e1}^2\, m_1 + U_{e2}^2\, m_2 + U_{e3}^2\, m_3|$$

$$m_{\beta\beta} \leq \frac{m_{\mathrm{e}}}{\mathcal{M}\, \sqrt{G_{0\nu}\, t^{1/2}}}$$

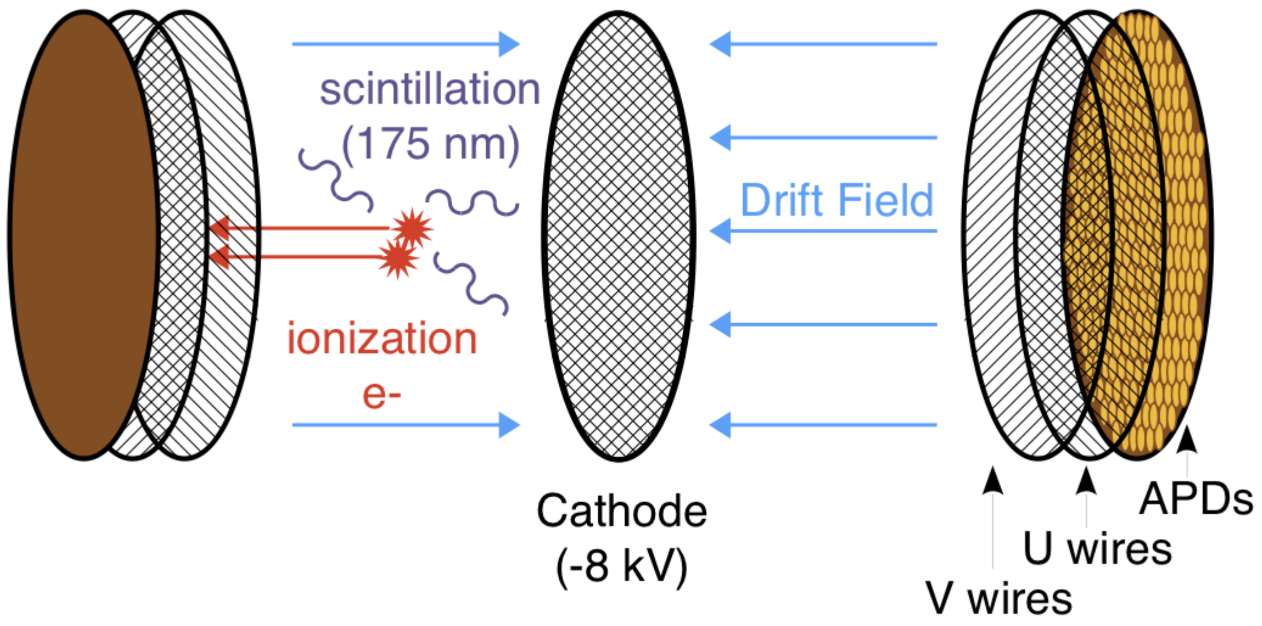
EXO-200



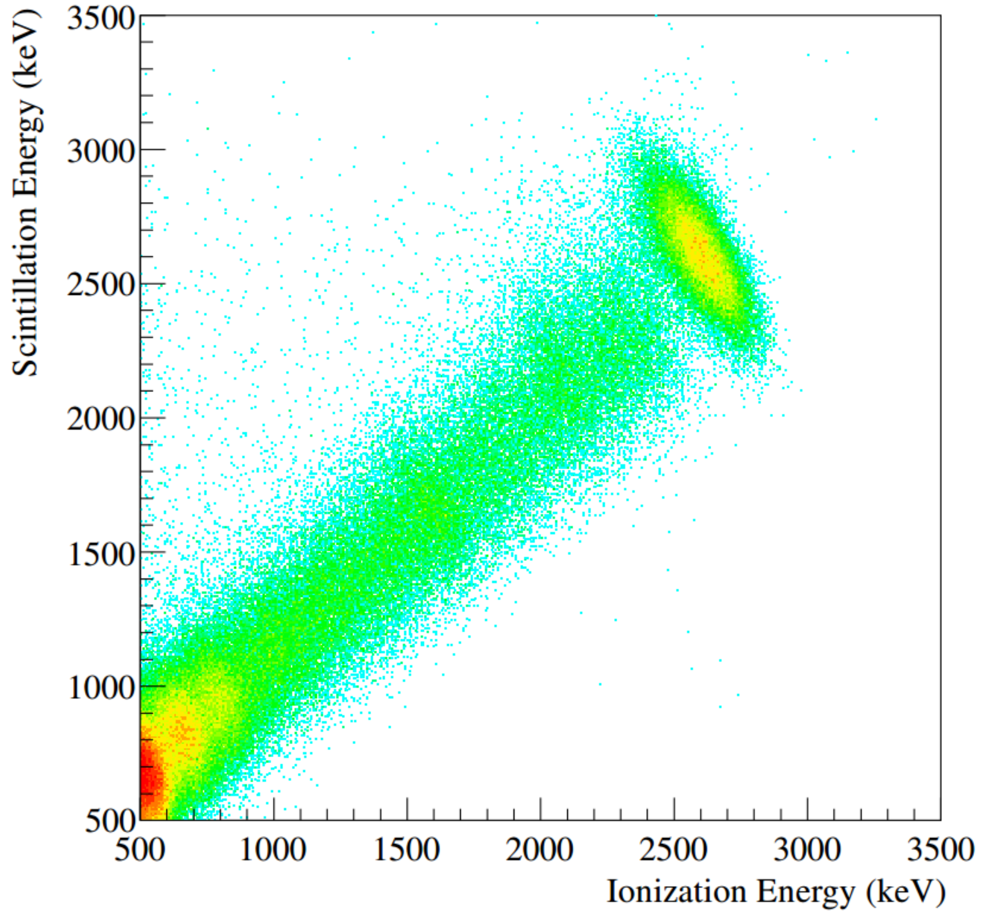


Located at the Waste Isolation Pilot Plant (WIPP)

EXO-200

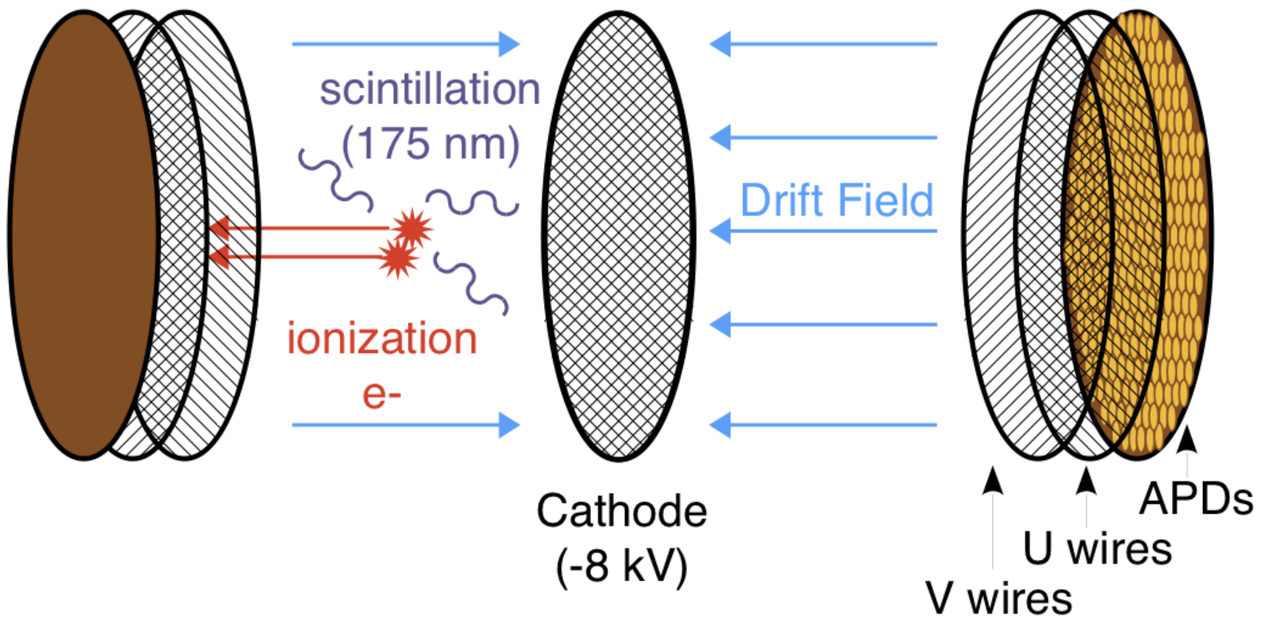


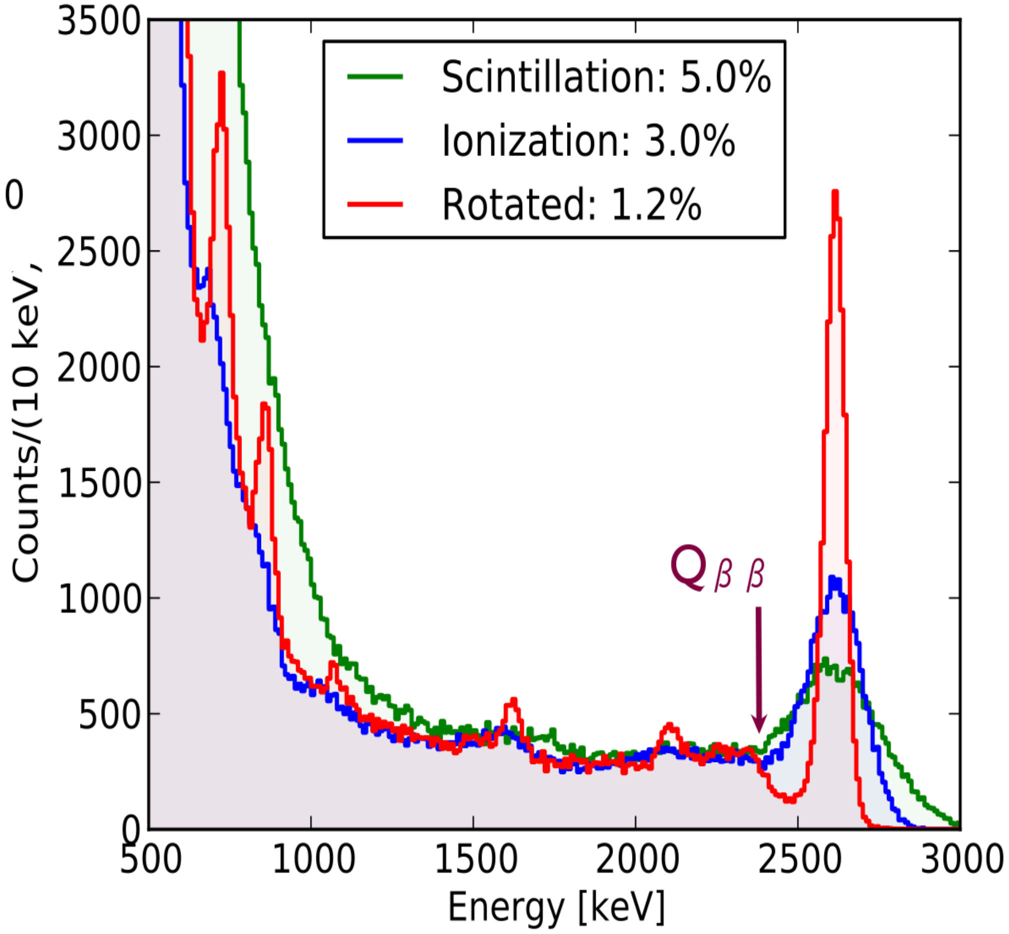
- Scintillation light collected by avalance photo-diodes (APDs) located on the ends of the TPC.
- Charge induces a signal on V-wires, is collected on U-wires.
- Scintillation timing information combined with U and V wire signals allows for 3-D reconstruction.
- Anti-correlation between scintillation and charge is used to obtain superior energy resolution.



Events from a ^{228}Th calibration source.

EXO-200





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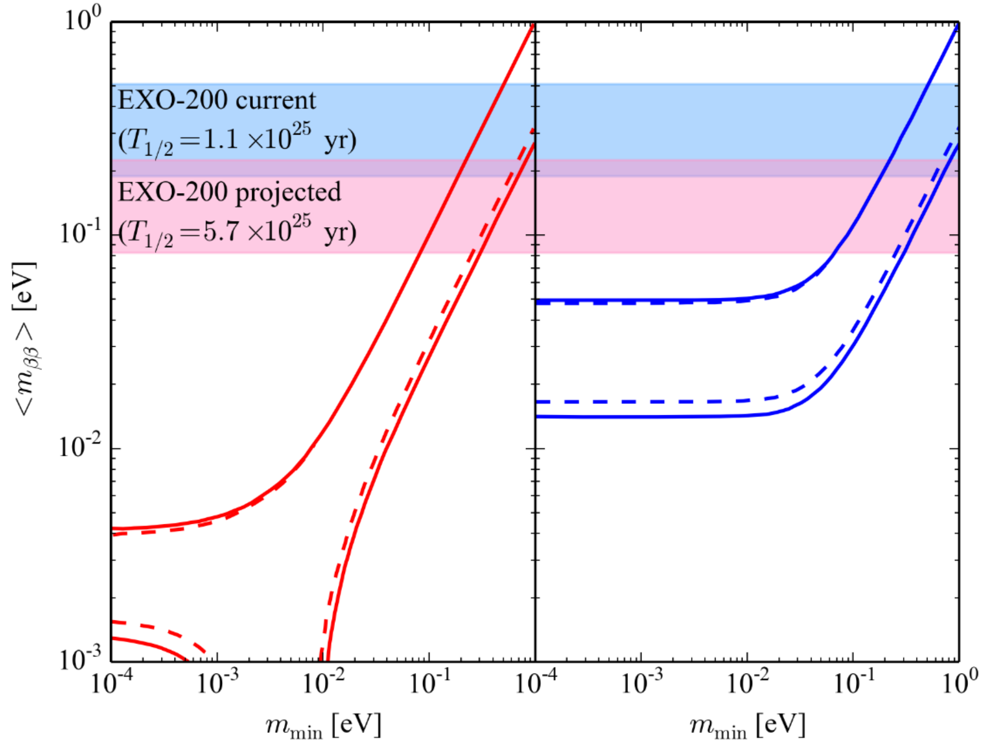
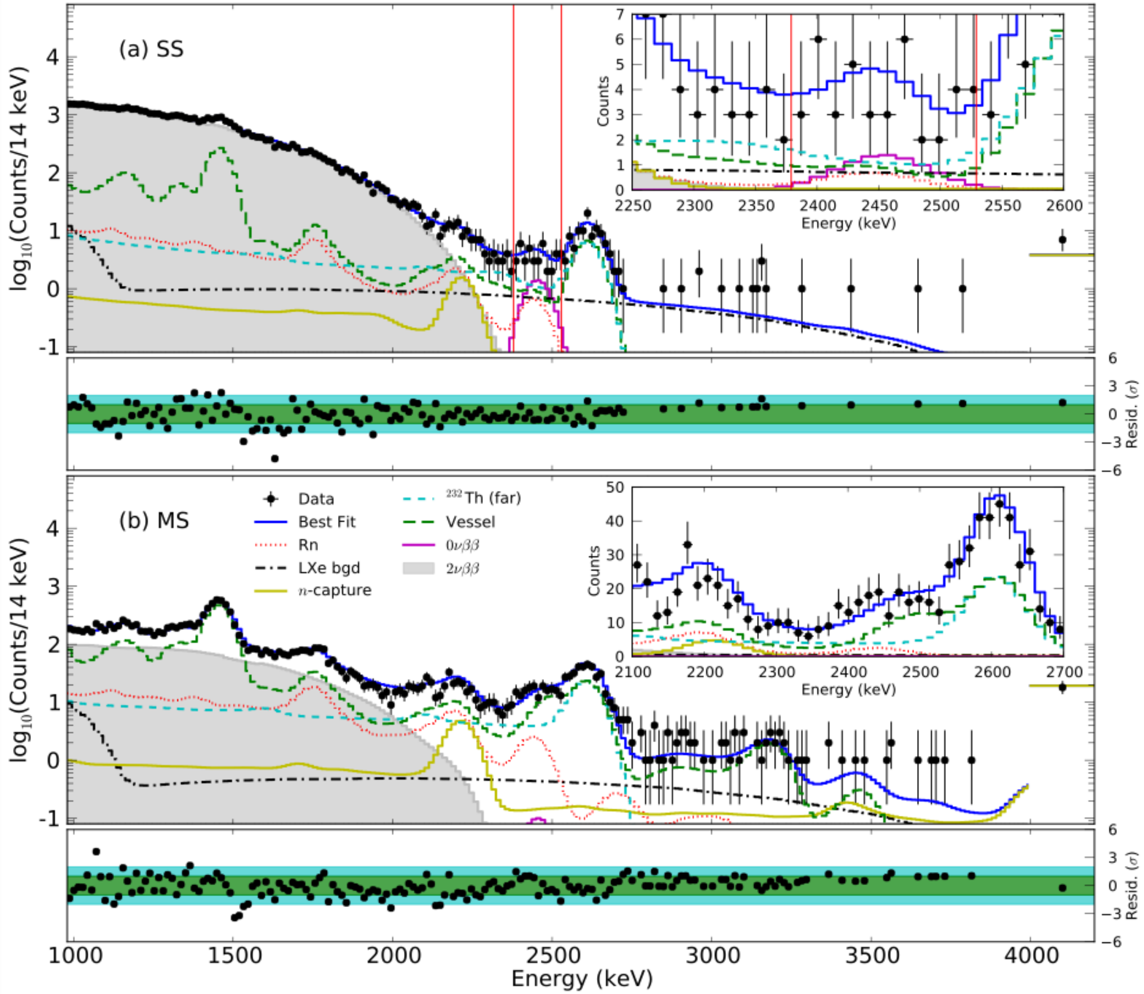
EXO-200 – Phase 1 Results



Updated Analysis with new data underway!

Nature (2014) doi:10.1038/nature13432



$$T_{1/2}^{0\nu\beta\beta} > 1.1\times10^{25}\,\mathrm{yr}$$

$$\langle m_{\beta\beta}\rangle < 190-450\,\mathrm{meV}$$

Scaling Up to Multi-ton

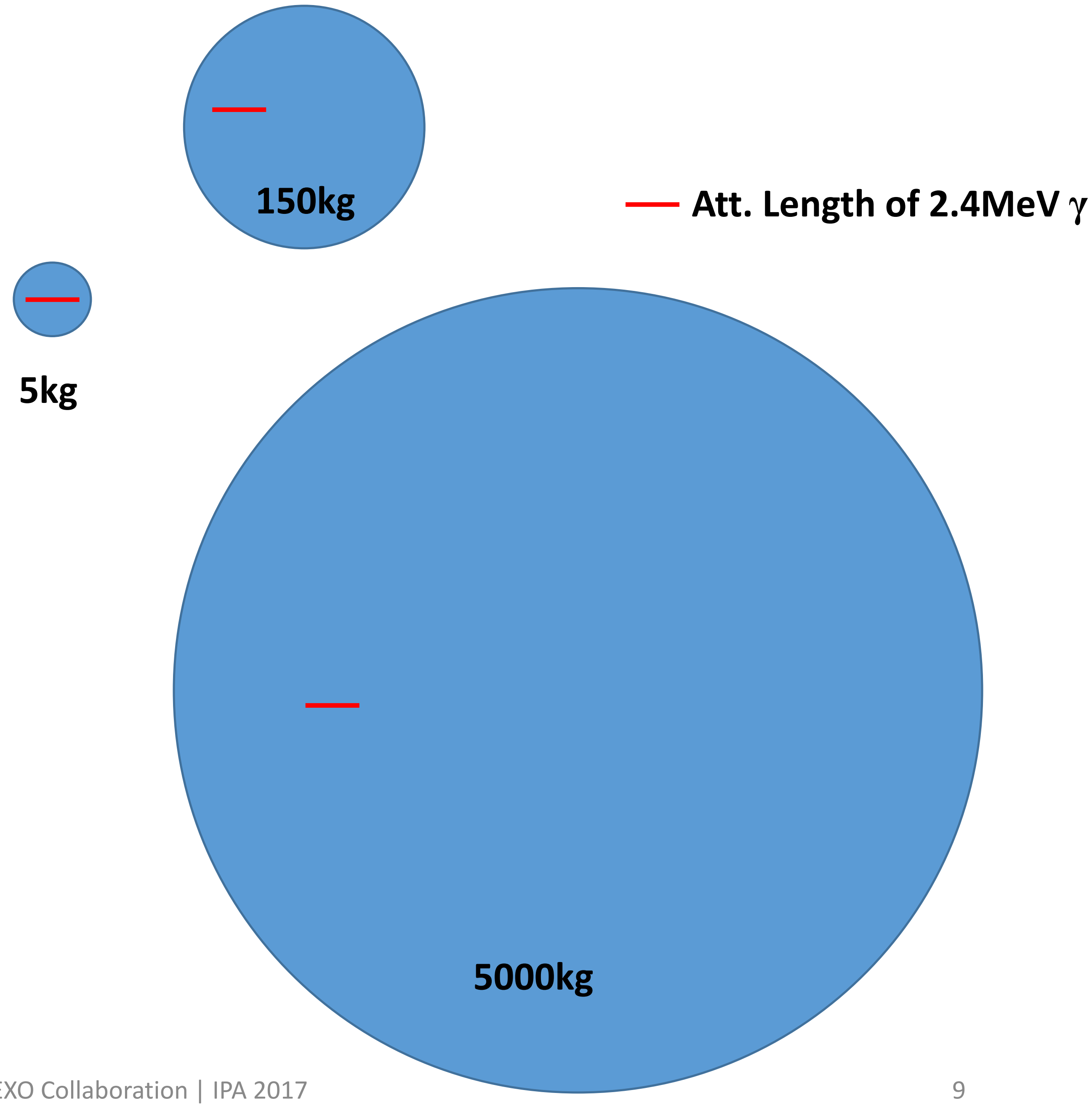
- EXO-200 has demonstrated the effectiveness of LXe in the search for 0νββ. What's the next step?

- A single monolithic detector has several advantages over multiple lower-mass detectors:

  - Improved ability to detect Compton scatter events.

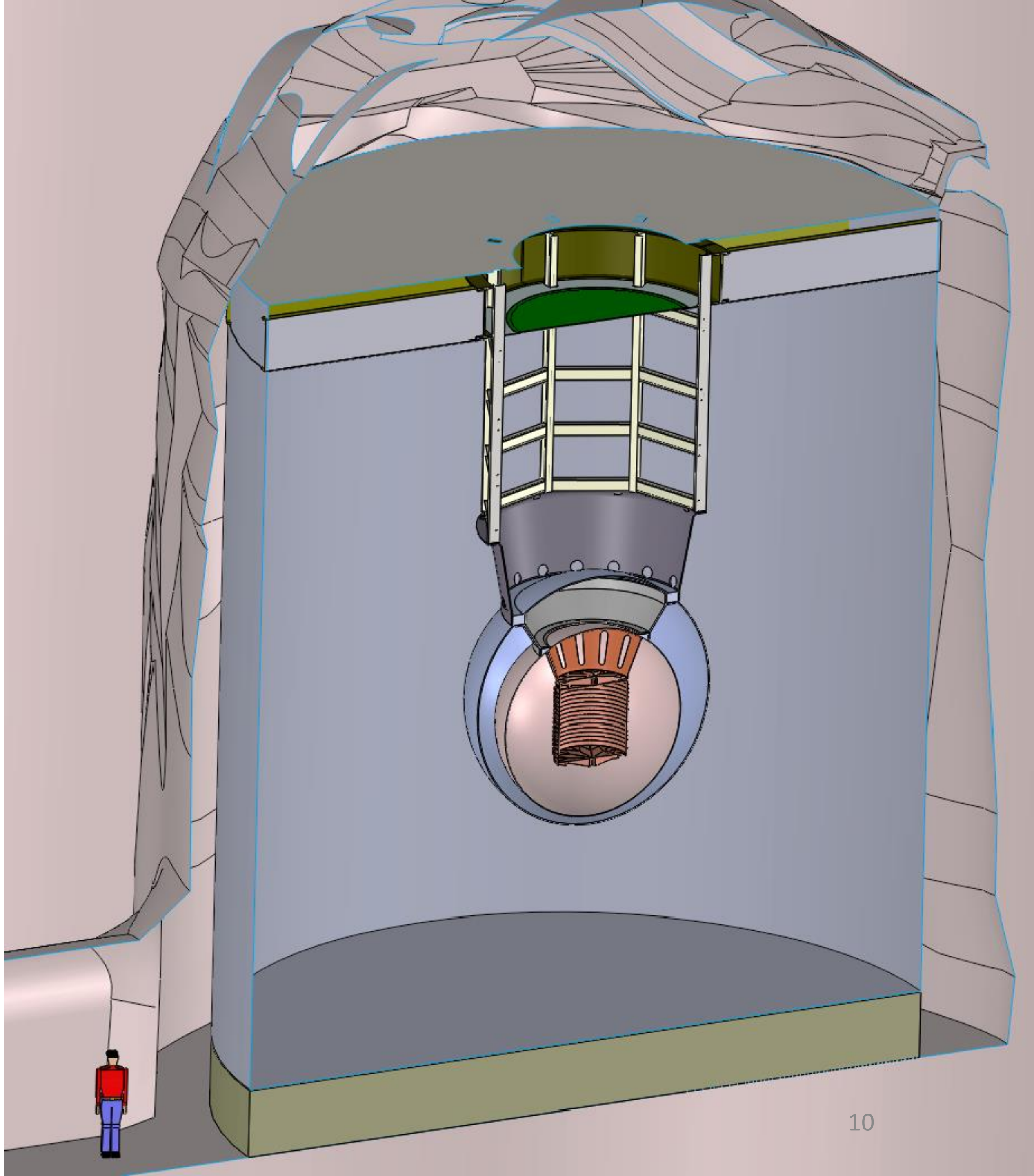
  - Self-shielding screens out nearly all external gamma rays from inner volume.

- Not just a calorimeter! Larger volume improves signal-background separation power of spatial variables.



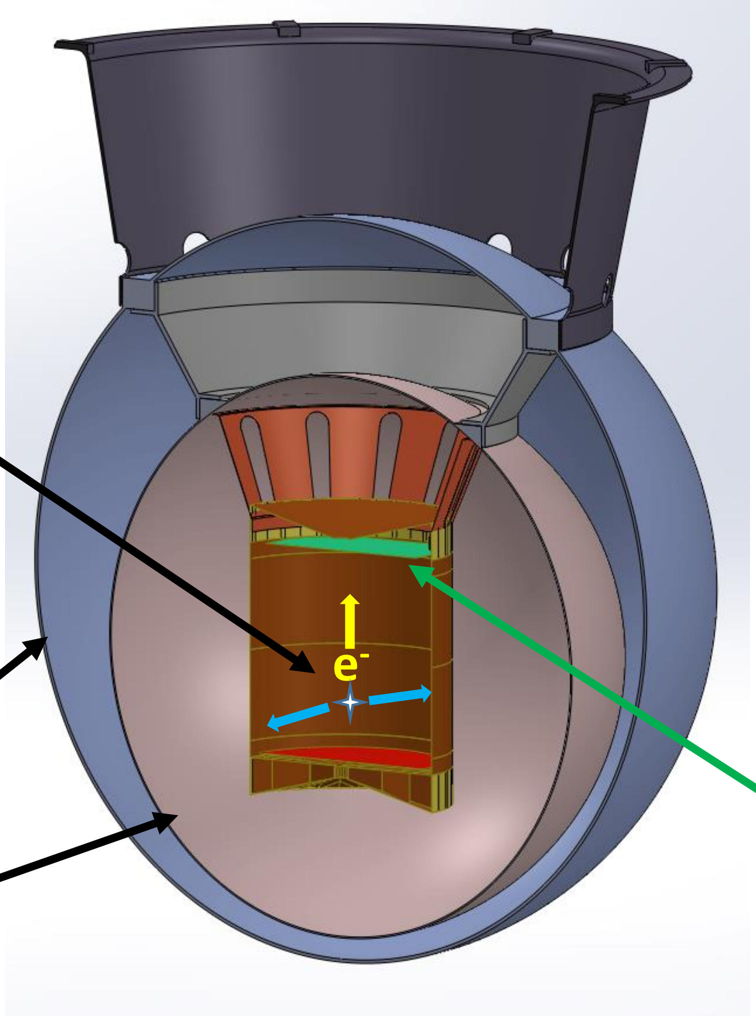
The next EXO (nEXO)

- Next generation dectector based on EXO-200 LXe TPC technique.
- Currently proposed location in the SNOLAB cryopit at a depth of 6010 m.w.e.
- Defining parameters
  - 5000 kg total Xe mass (3474 kg fiducial)
  - 90% enrichment
  - $\sigma_E \leq 1\%$ (58 keV FWHM at the Q-value)
  - 1.25 m drift region
  - 380 V/cm drift field
  - 4 m^2 of SiPM coverage

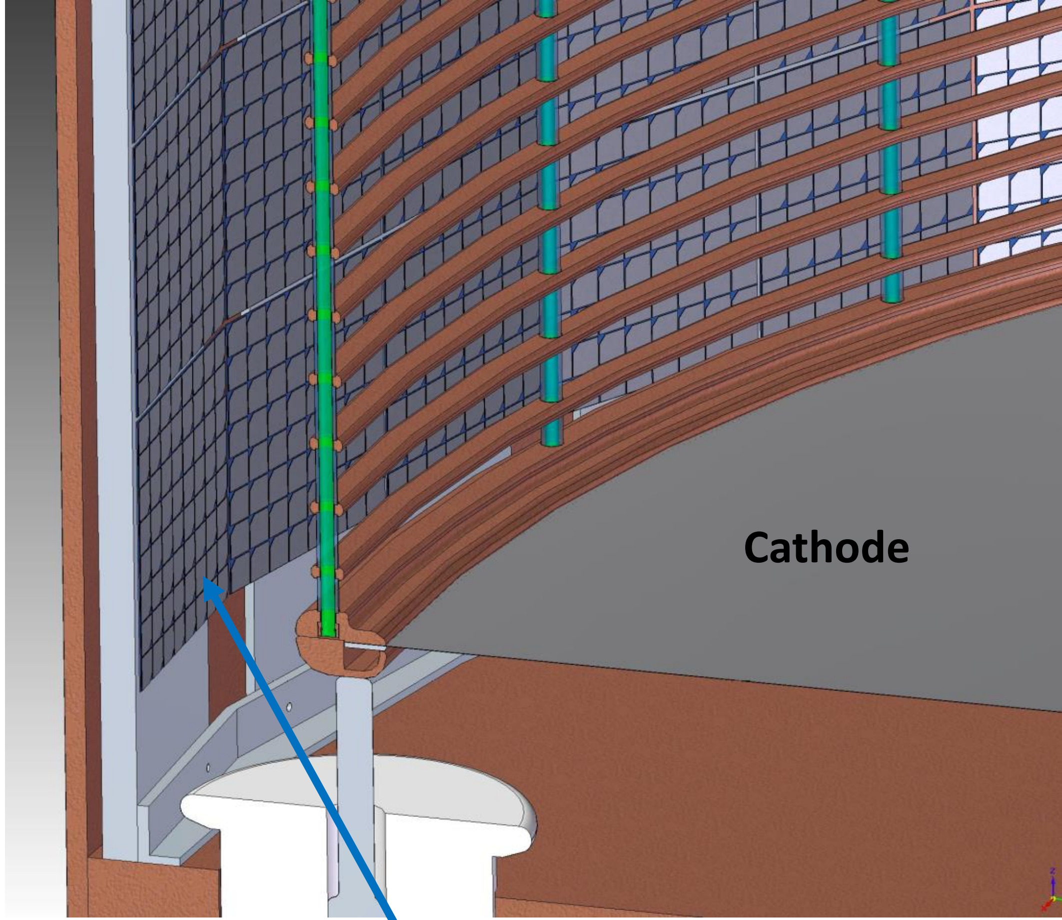


nEXO

Single TPC design



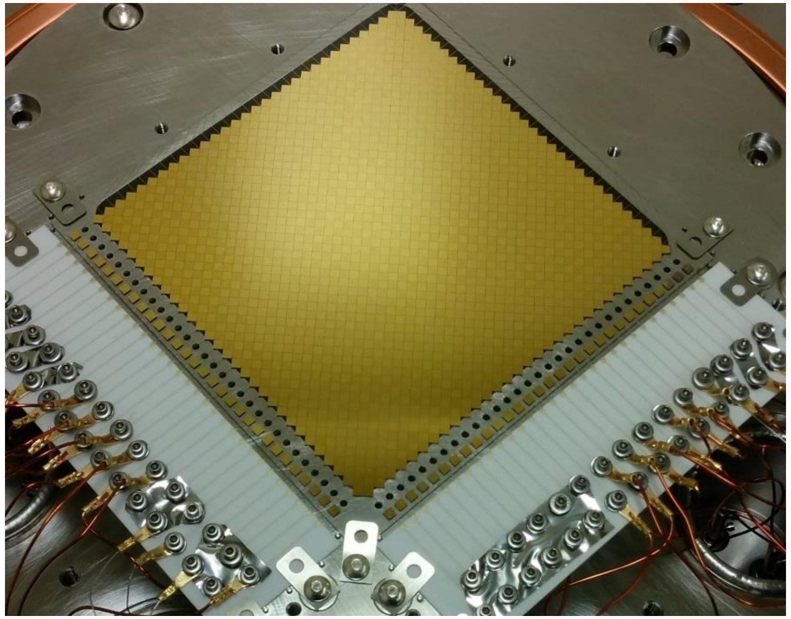
Carbon Fiber Cryostats



Charge collection pads on the anode

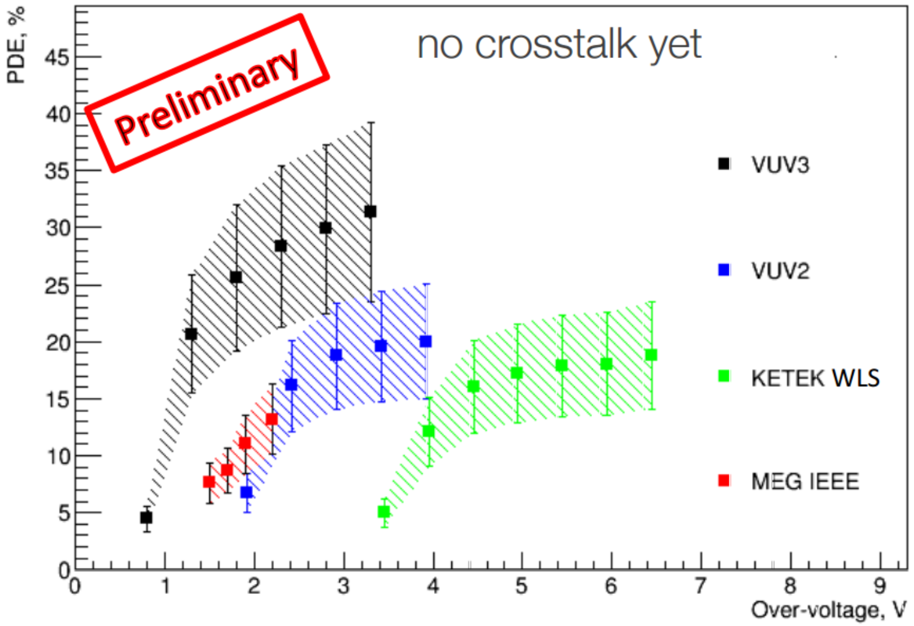
SiPM line the outer wall

R & D Efforts

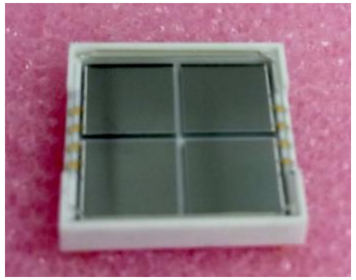


Charge readout pads

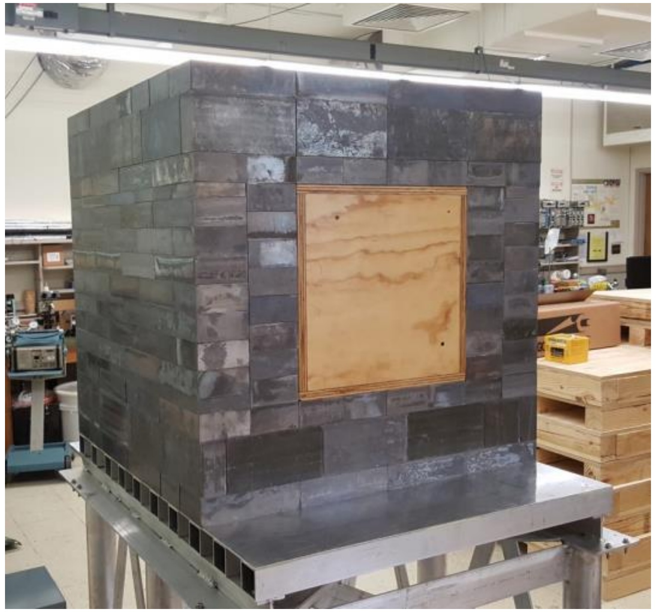
- Metal strips on quartz substrate.
- Tested in Lxe
- 3 mm pitch



Si PM VUV Readout



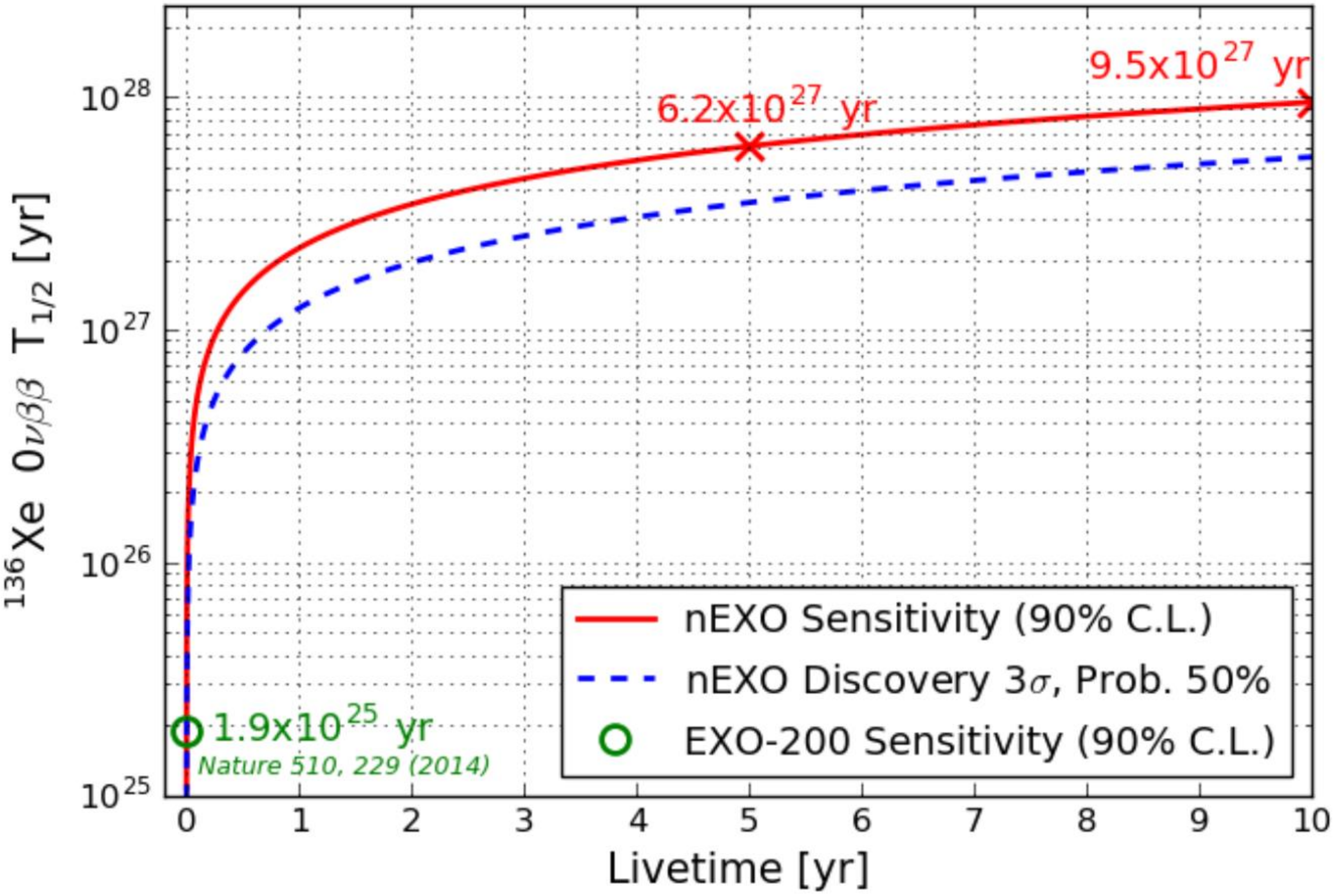
R & D Efforts



Ge-IV test assembly

- Radioassay
  - Inductively Coupled Plasma Mass Spectroscopy (ICPMS)
  - Above ground Ge counting
  - Neutron Activation Analysis (NAA)
  - Underground Ge counting at SURF (in development)
- Cold Electronics
- High Voltage
- Calibration Techniques – external gamma sources insufficient for interior of the detector!
  - Inelastic neutron scattering
  - Internal calibration sources (Rn-220)
- Xenon purification – larger drift region will require higher purity

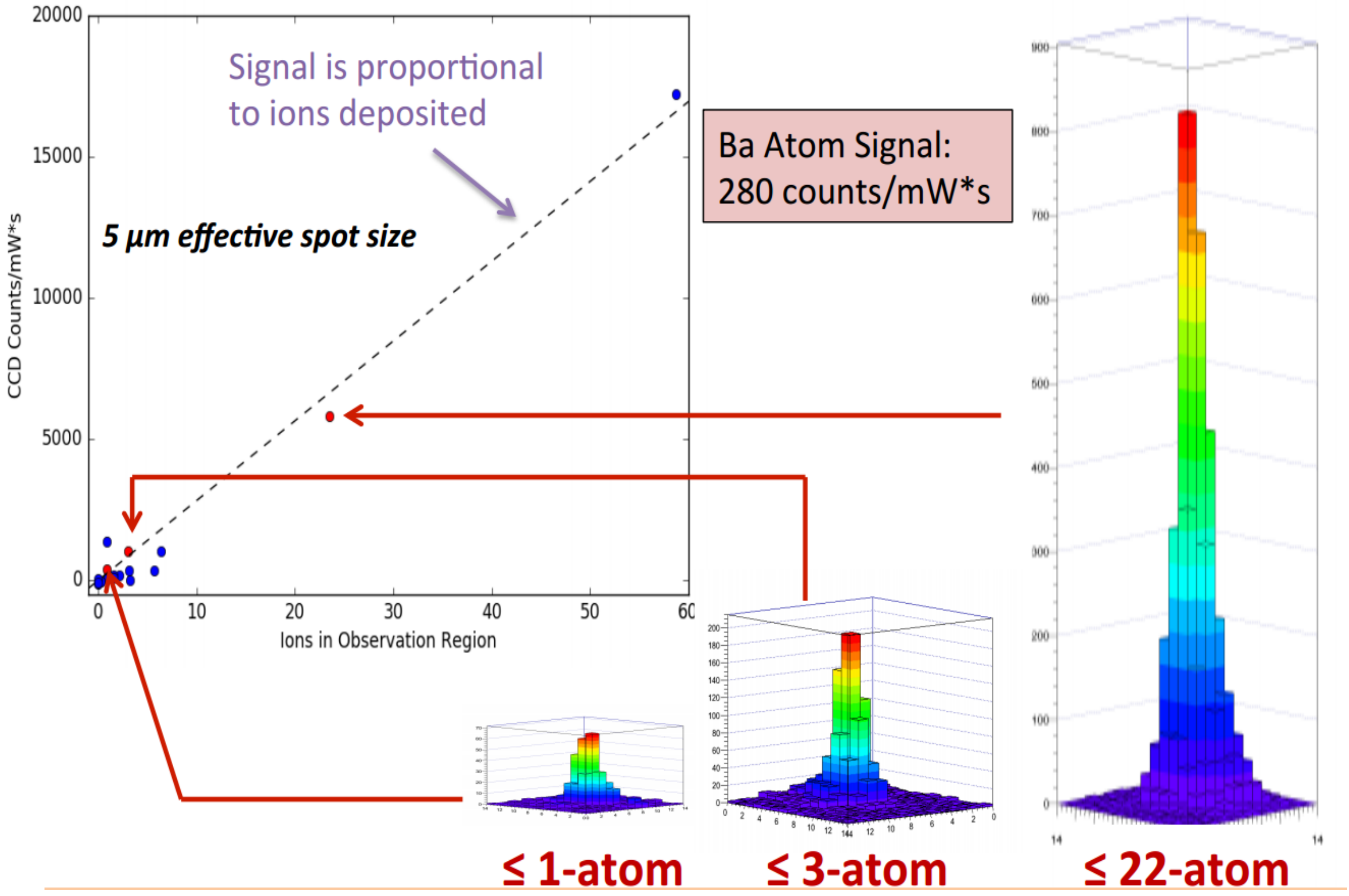
nEXO – Sensitivity



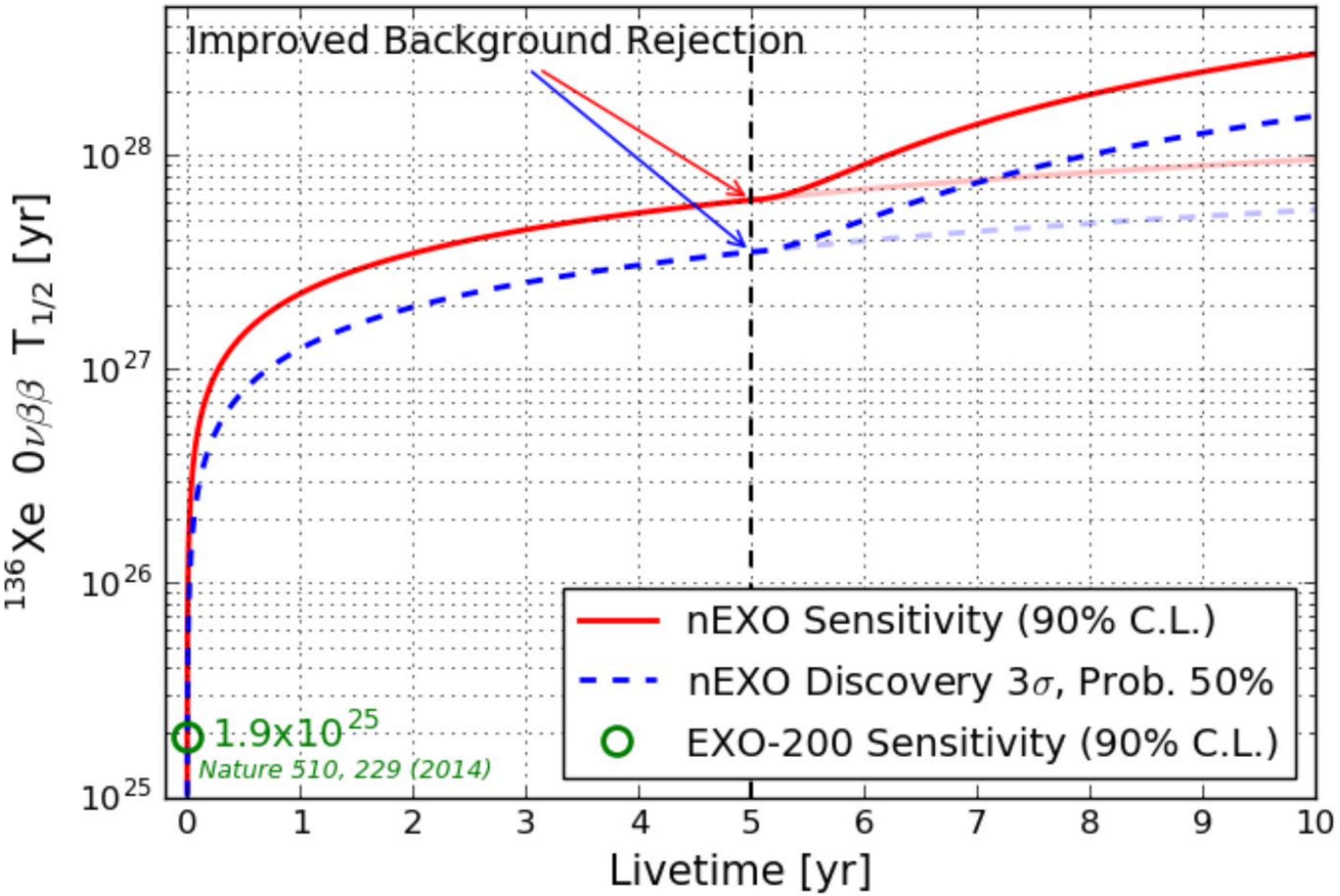
(Nearly) Background Free – Ba Tagging

$$^{136}\mathrm{Xe} \longrightarrow \boxed{^{136}\mathrm{Ba}} + 2\ \mathrm{e}^-$$

- Phased in upgrade could provide ability to 'tag' the end state Ba2+ ion from candidate 0νββ events.
- Only background event possible would be from end spectrum 2νββ events (greatly suppressed by energy resolution).
- Difficult engineering challenge, but the idea now appears feasible.

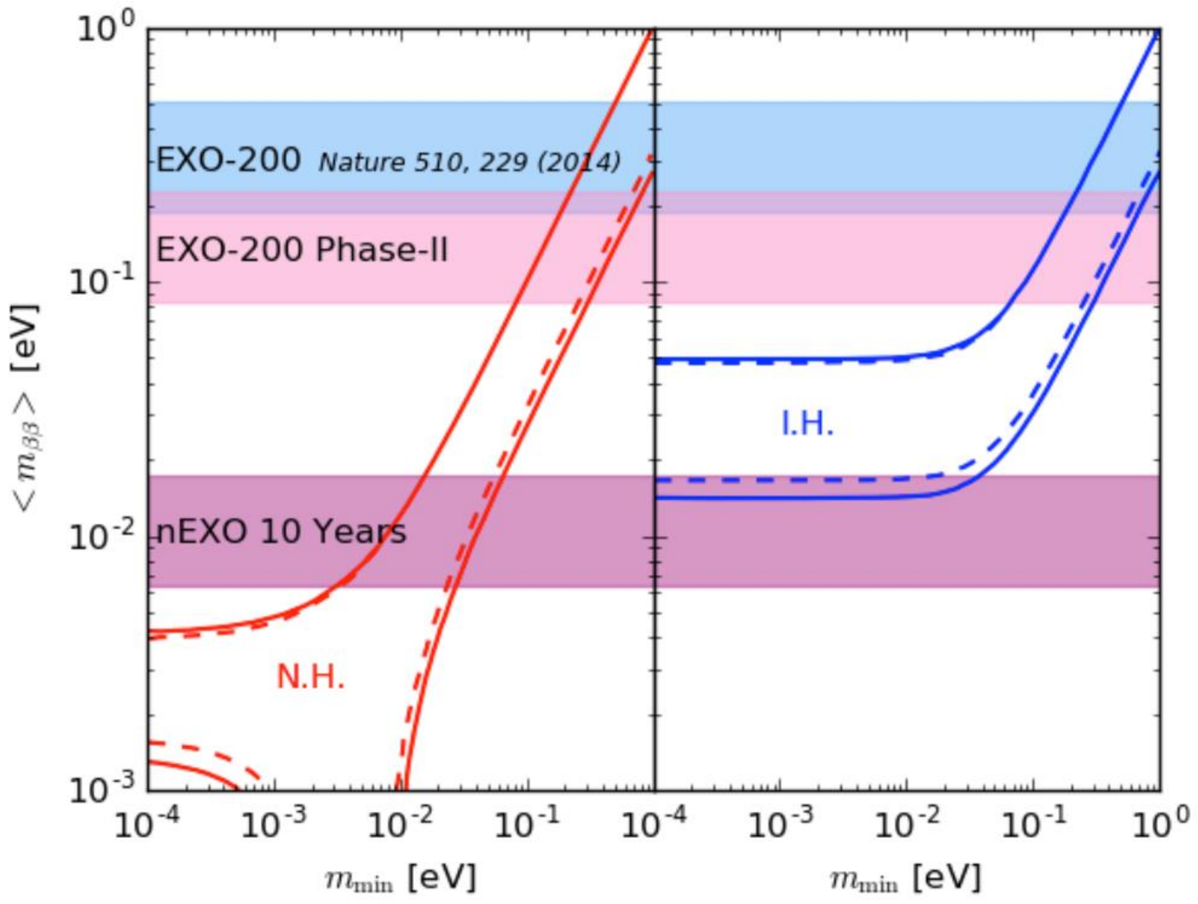


nEXO – Sensitivity (phased in Ba Tagging)

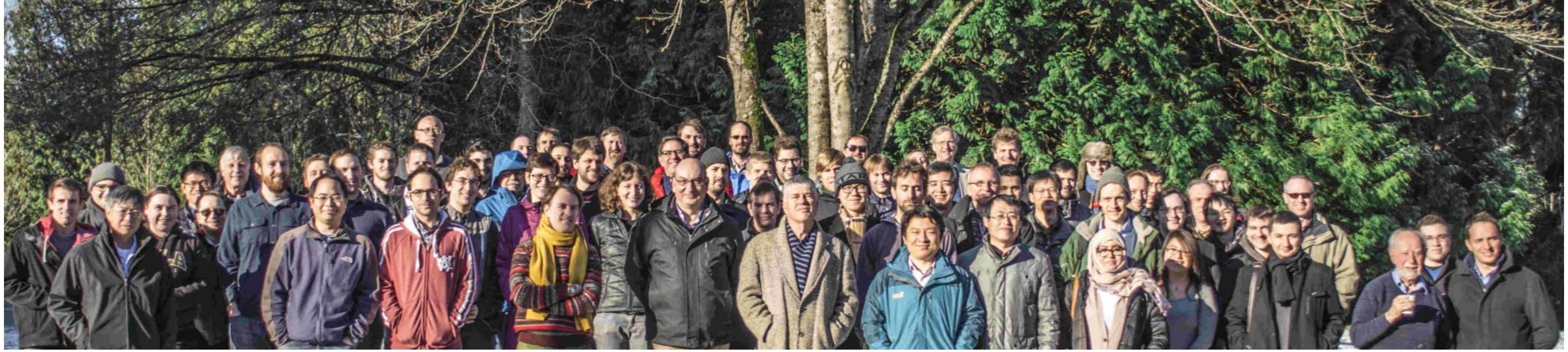


Summary

- $0\nu\beta\beta$ is the most sensitive probe for confirming if the neutrino is Majorana in nature.
- EXO-200 demonstrates that a multi-ton scale Lxe experiment holds great potential for discovering this process.
- R & D progressing rapidly!



The nEXO Collaboration



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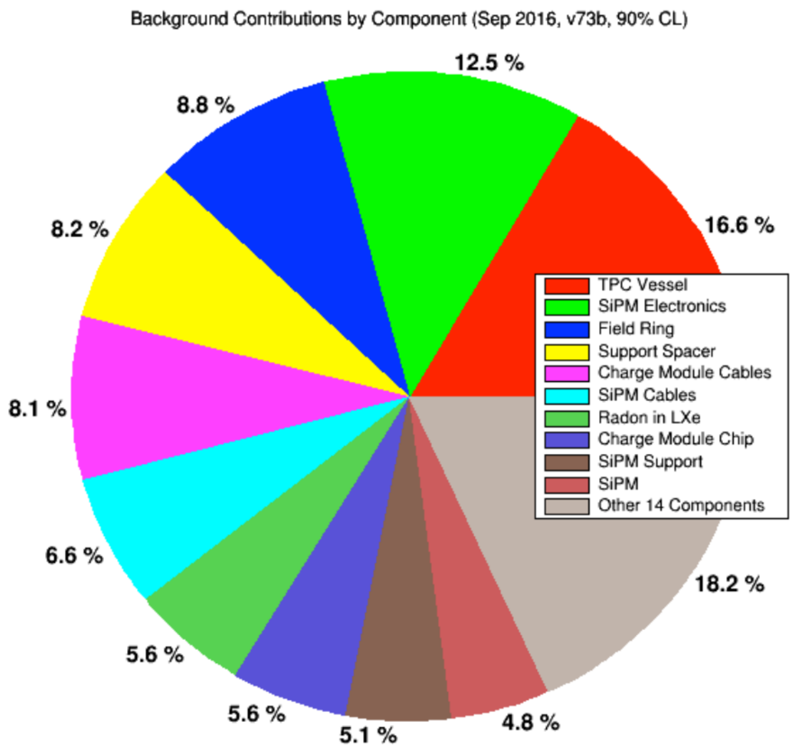
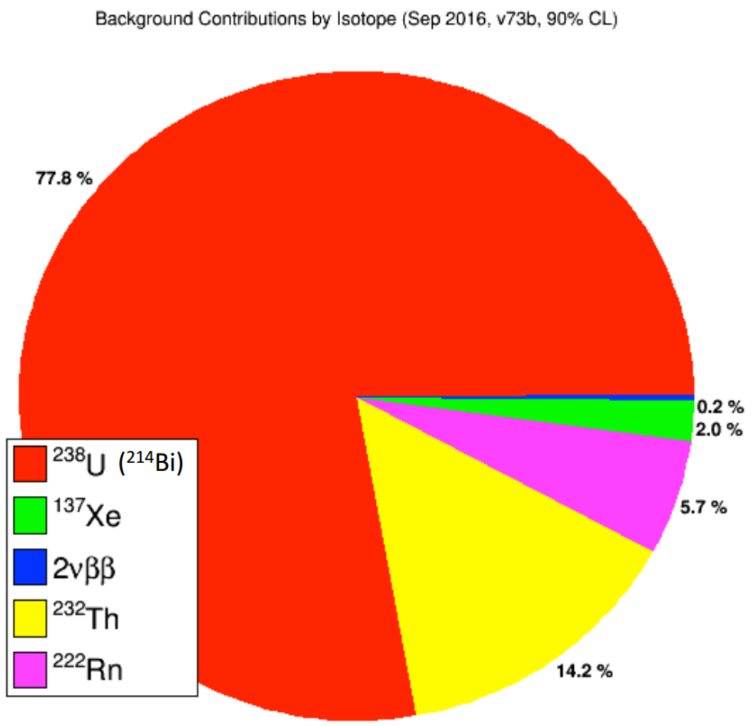
Auxiliary Slides

Background in ROI





Conservative energy resolution goal is 1% at the Q-value