Recent Results From EXO-200

$$^{136}Xe \rightarrow {}^{136}Ba^{++} + 2e^{-} + (2\bar{\nu}_e)$$

Kevin O'Sullivan

^{136}Xe is an Excellent Candidate for Double Beta Decay Search

Can be both the source and the detector. Noble liquids are common as radiation detectors.

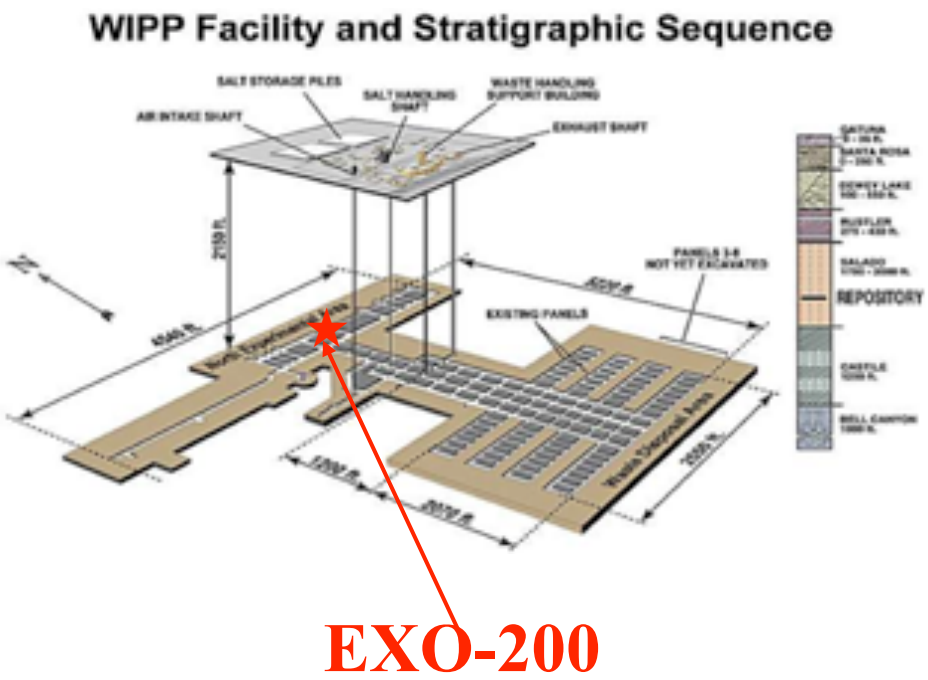
Enrichment is easier. EXO has 200 kg of xenon enriched to 80.6% in ^{136}Xe.

Monolithic detector. LXe is self shielding, surface contamination minimized.

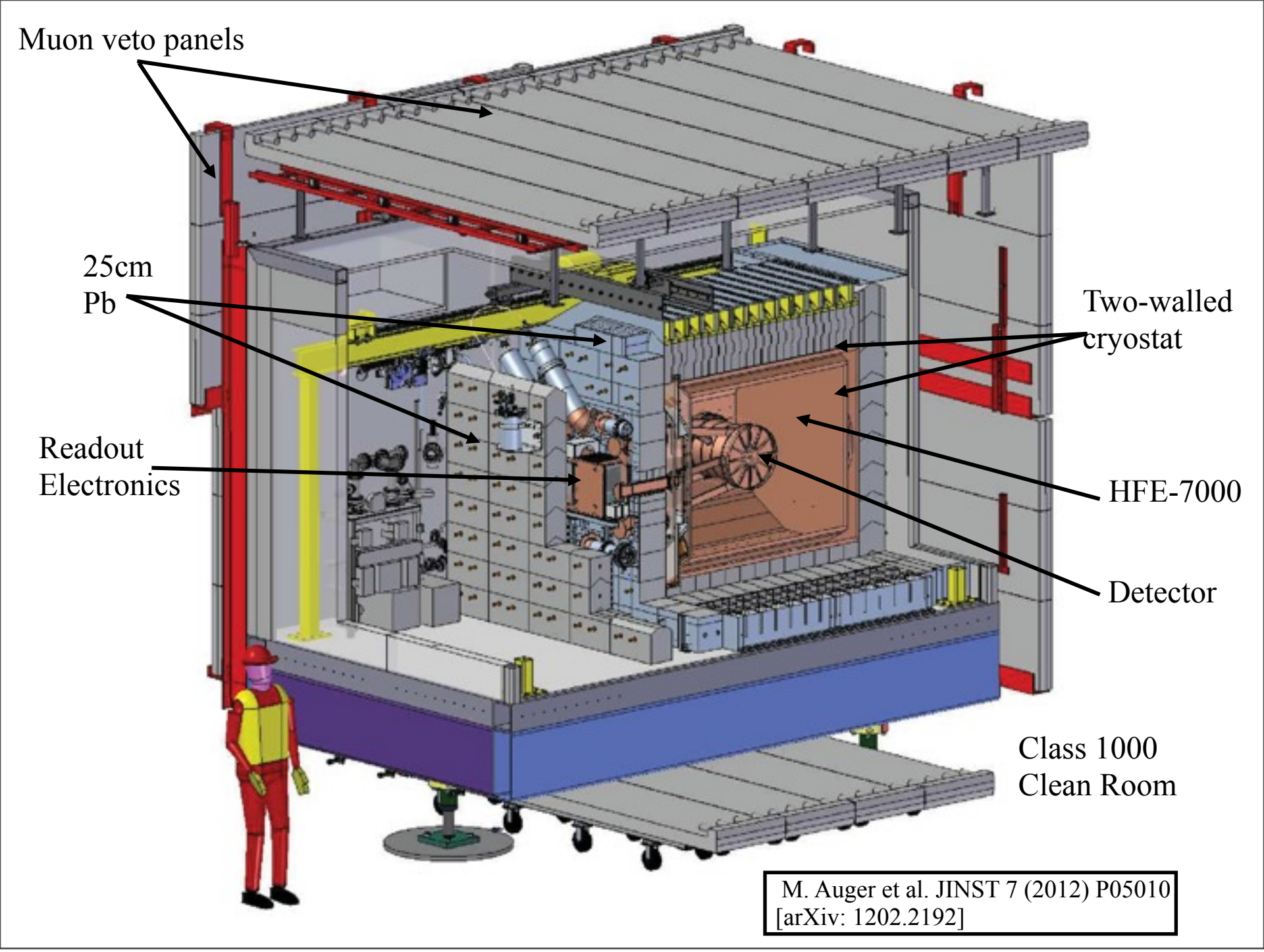
Minimal cosmogenic activation. No long lived radioactive isotopes of Xe.

There are no crystals to grow. The Xe can be re-purified over the course of the experiment.

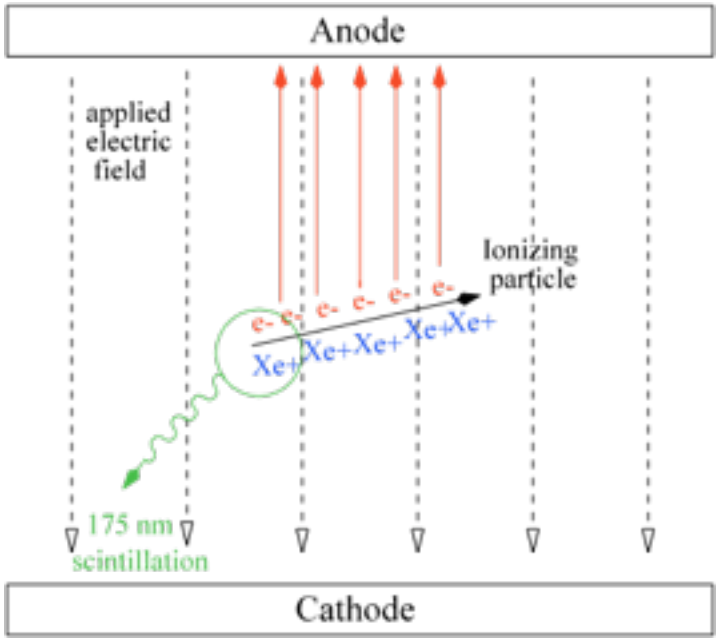
EXO-200 Installation Site: WIPP



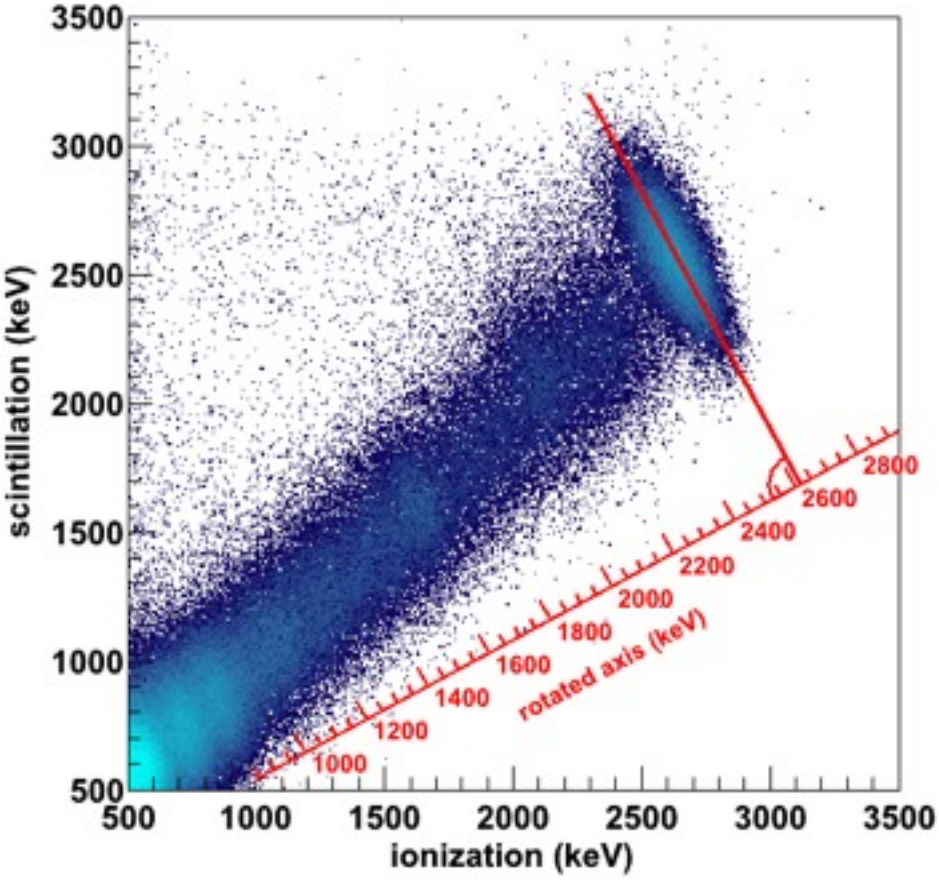
- EXO-200 is installed at WIPP (Waste Isolation Pilot Plant), near Carlsbad, NM
- 1600 mwe flat overburden (2150 feet, 650 m)
- U.S. DOE salt mine for radioactive waste storage
- Salt “rock” low activity relative to hard-rock mine


Muon veto panels
25cm
Pb
Readout
Electronics
Two-walled
cryostat
HFE-7000
Detector
Class 1000
Clean Room
M. Auger et al. JINST 7 (2012) P05010
[arXiv: 1202.2192]

Measuring Energy In Liquid Xenon



Ionizing radiation in liquid xenon creates Xe^+-e^- pairs and Xe^*, some of the Xe^+ and Xe^* undergo recombination and emit 175nm photons

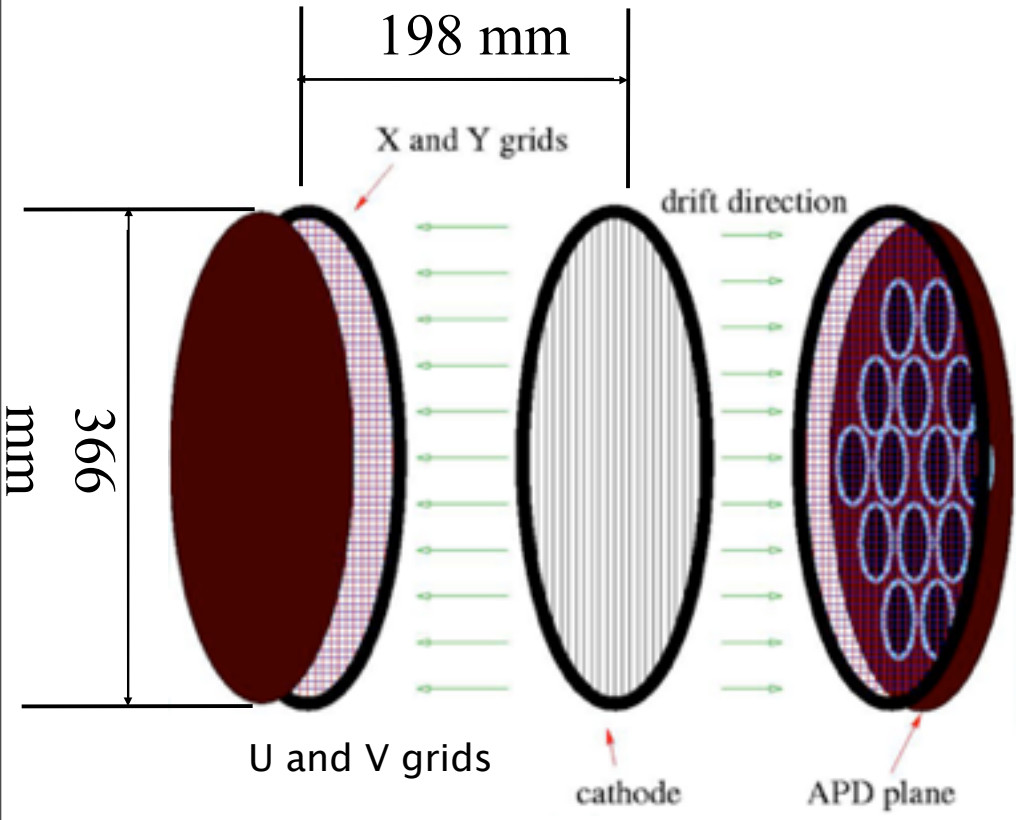


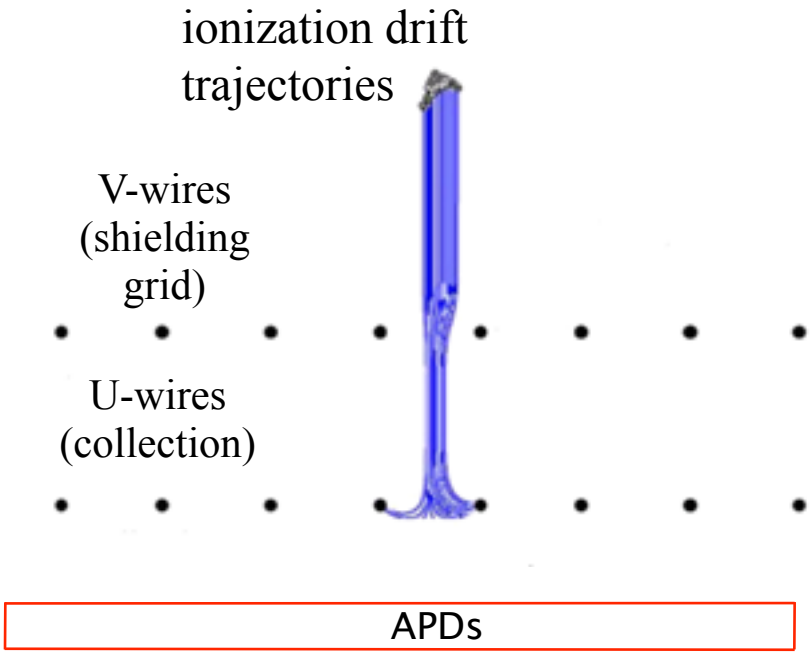
Energy Resolution (σ/E) at 2615 keV:

- Charge Only: 3.6%
- Scintillation Only: 6.8%
- Combined: 1.6%

See *Phys. Rev.* B **68** 054201 (2003)

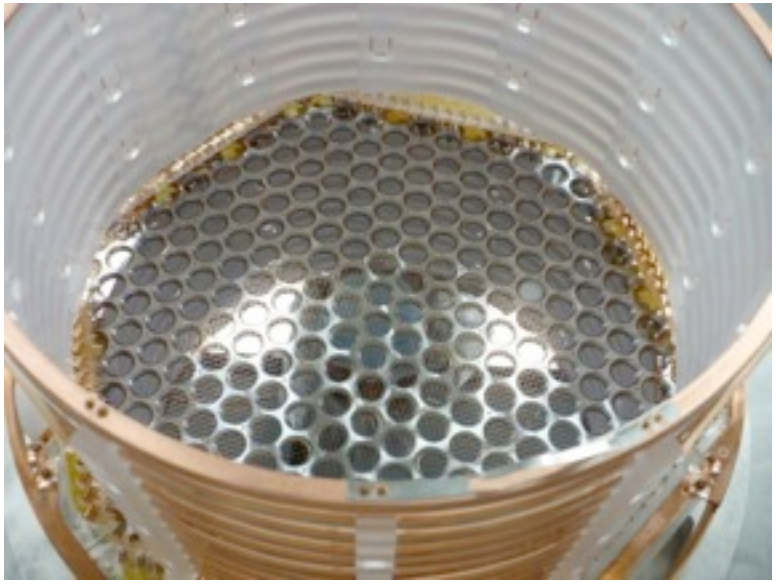
EXO-200 Time Projection Chamber (TPC)

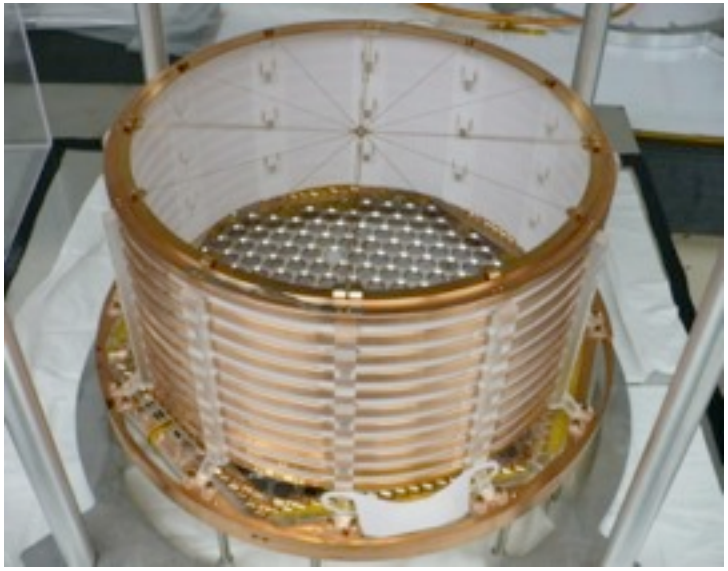


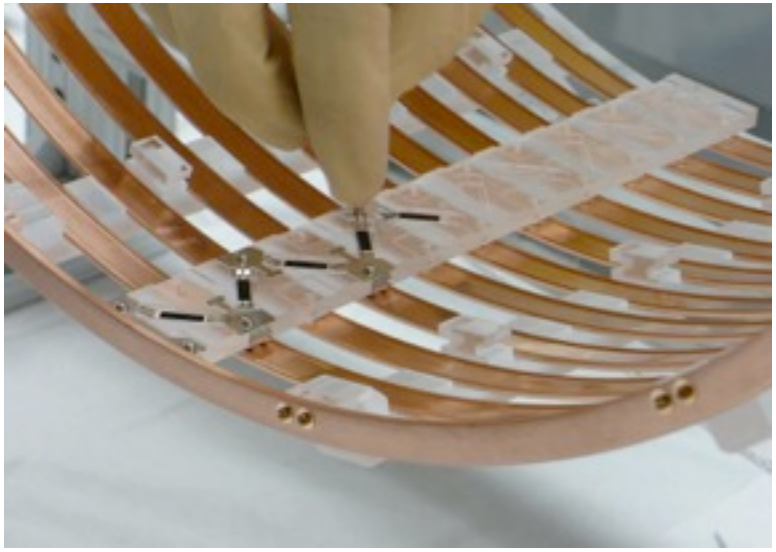


- Two TPC modules with common cathode in the middle.
- APD array observes prompt scintillation for drift time measurement.
- V-position given by induction signal on shielding grid.
- U-position and energy given by charge collection grid.

LXe TPC





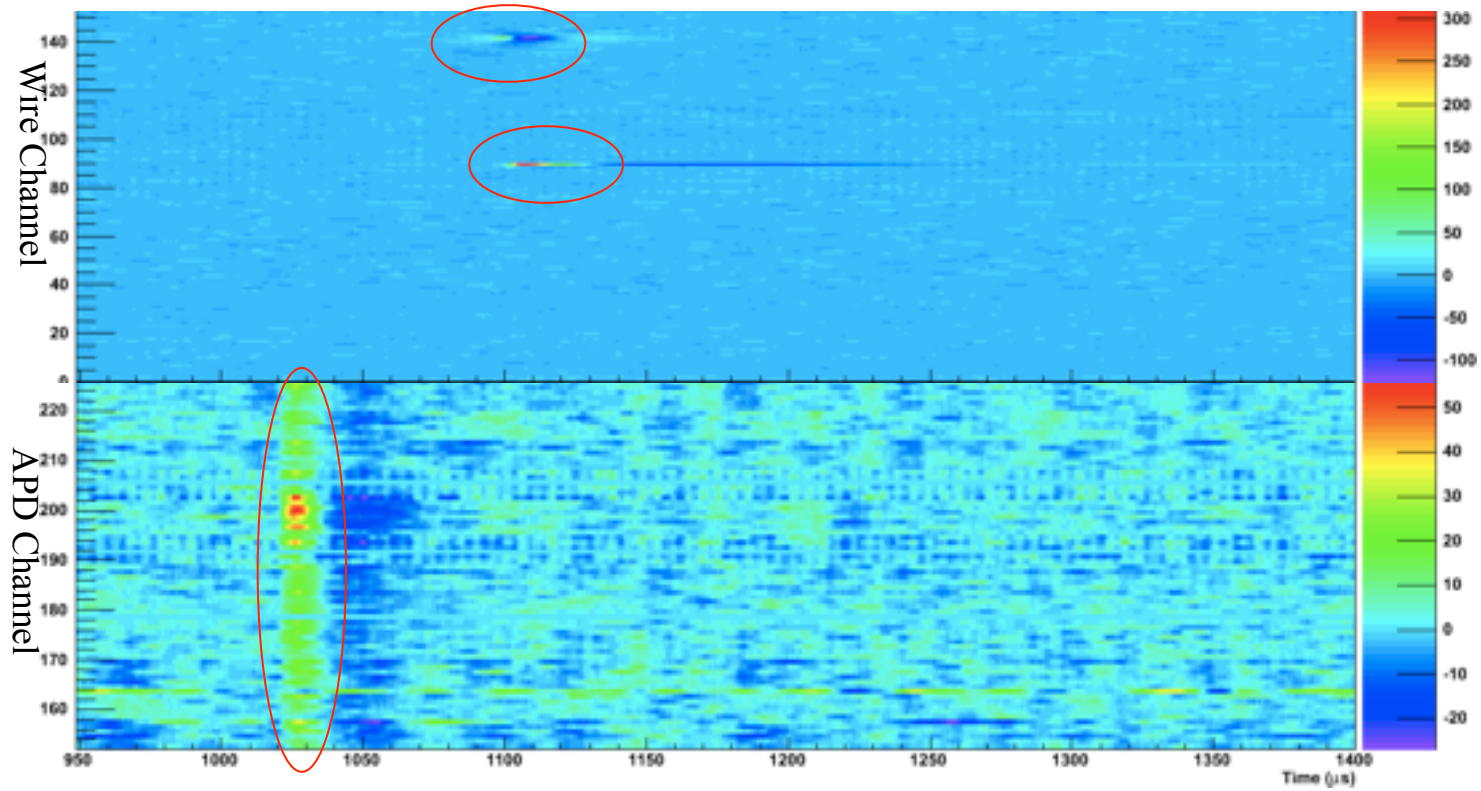


An Energy Deposit in EXO-200

Charge readout

V: Induction
U: Collection

Light readout

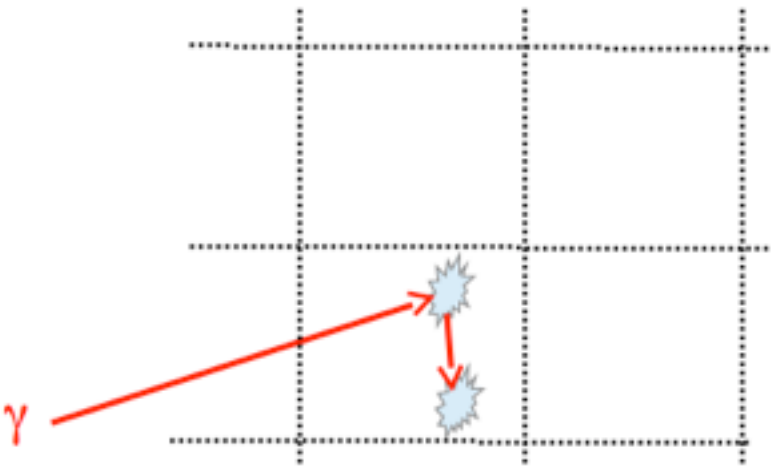


Scintillation light is seen at both sides. The light is more diffuse on side 1 and more localized on side 2, where the event occurred.

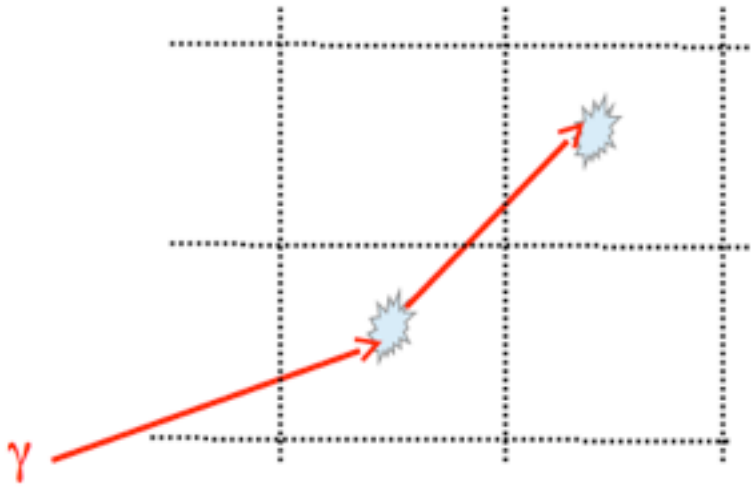
The light signal always precedes both charge signals. The induction (V) signal precedes the collection (U) signal.

Single Site Vs. Multi Site Events

Single Site

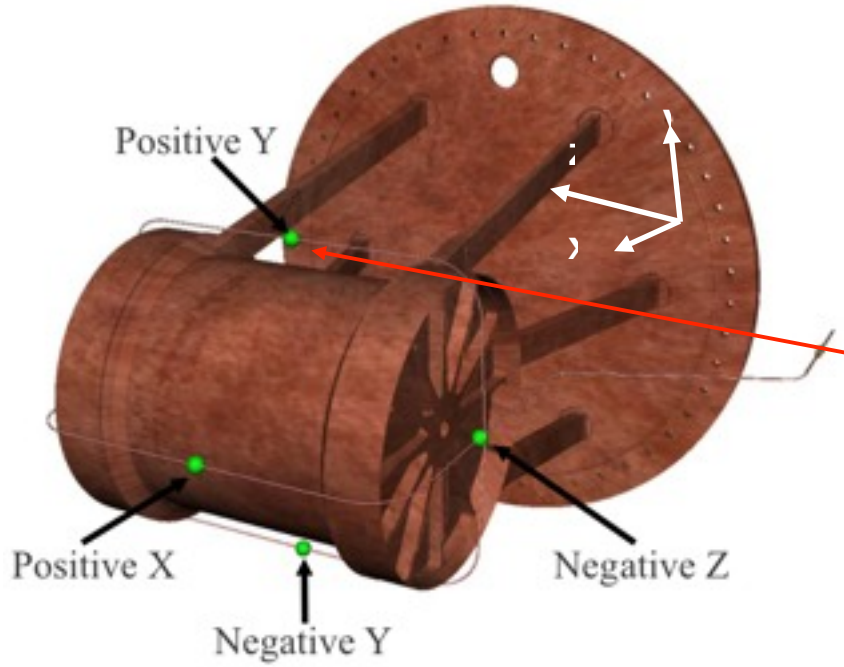


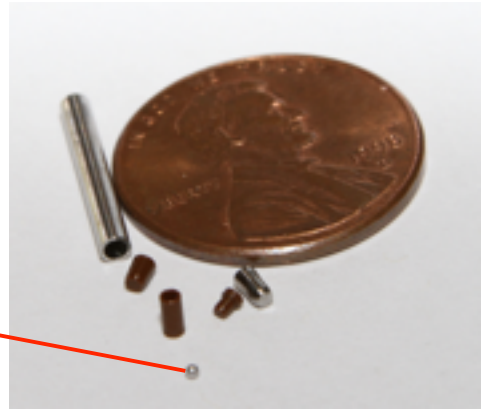
Multi Site



- The TPC can differentiate events with one charge deposit (SS) from events with several (MS)
- ββ-Decays are predominantly single site
- => This can be used to reject backgrounds
- This is limited by the granularity of the wires

Calibration Source Run



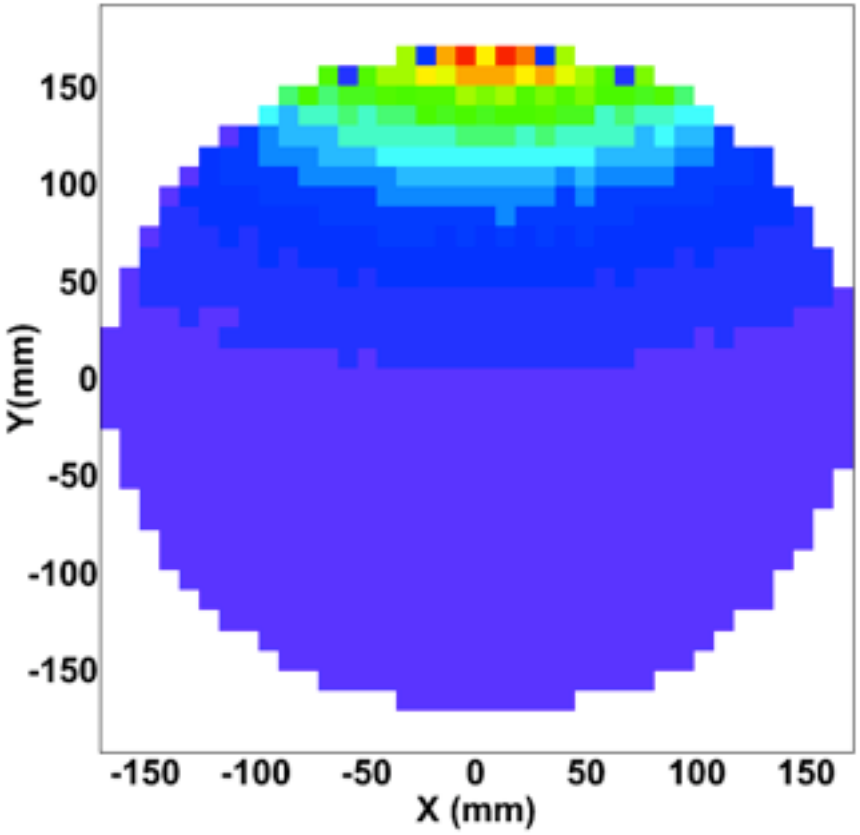


Sources:

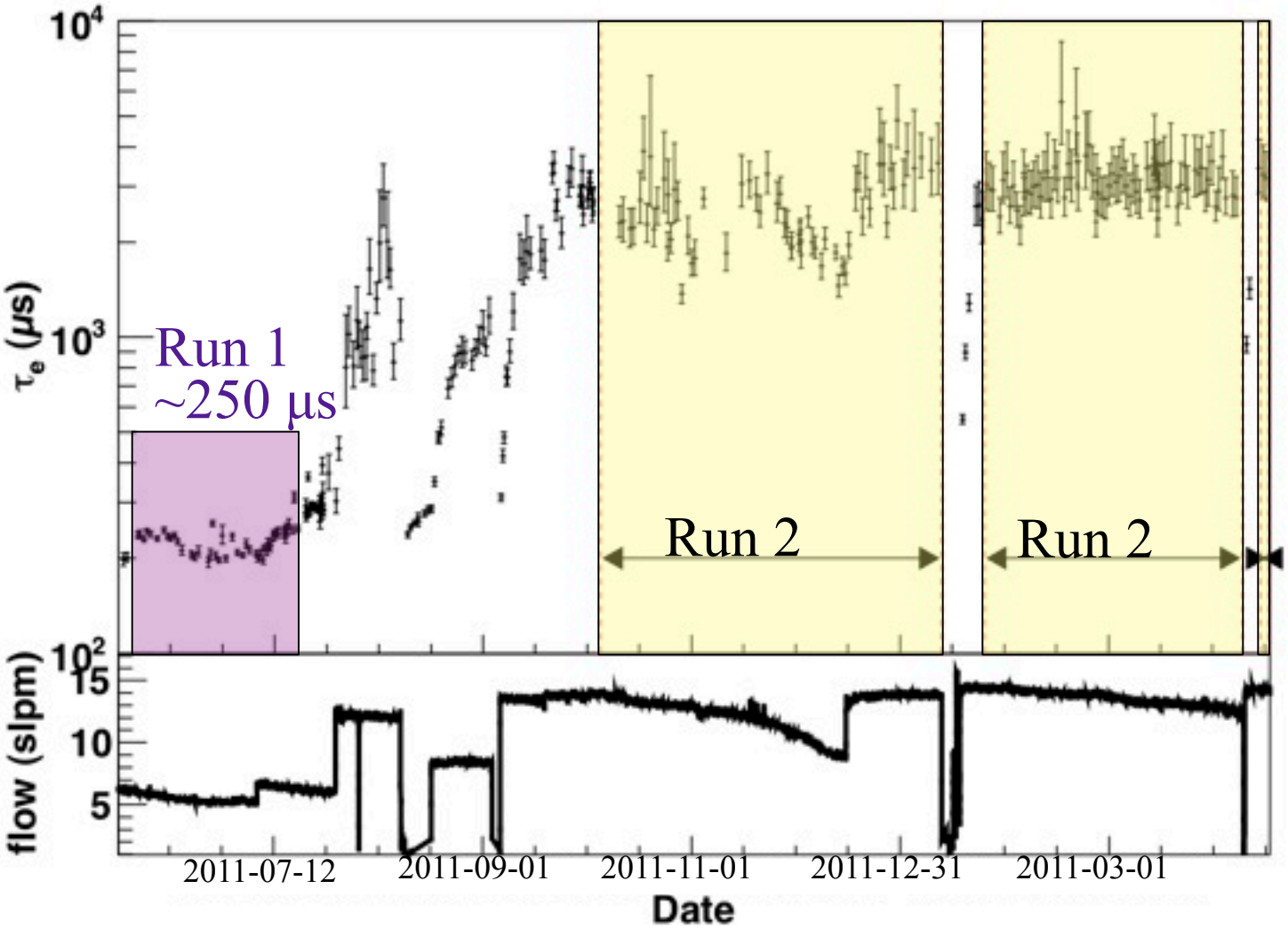
^{137}Cs, ^{60}Co, ^{228}Th

Various calibration sources can be brought to several positions just outside the detector

X-Y distribution of events clearly shows excess near the source location

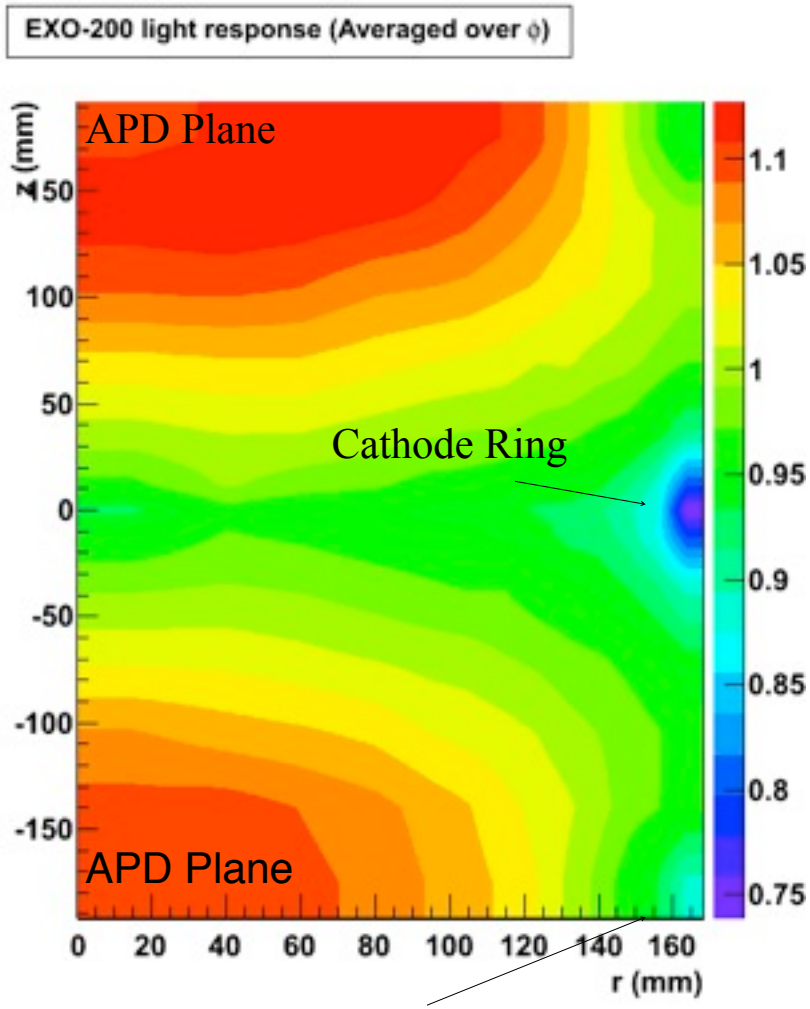


Electron Lifetime



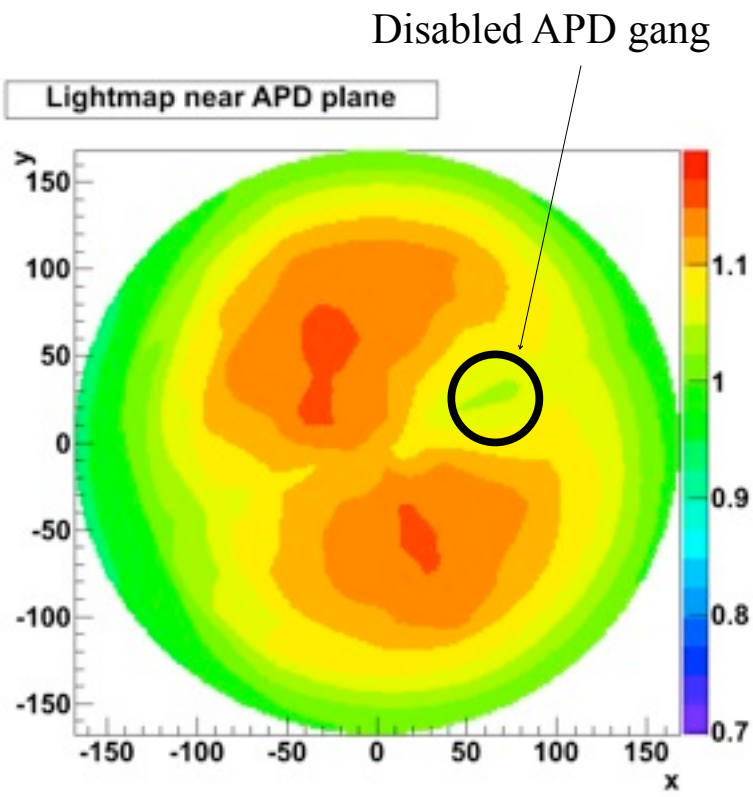
•Recirculation rate increased to 14 slpm, leading to τ_e = 3 ms:
•max. drift time=116 µs
•loss of charge is 3.8% at full drift length

Correcting for light response

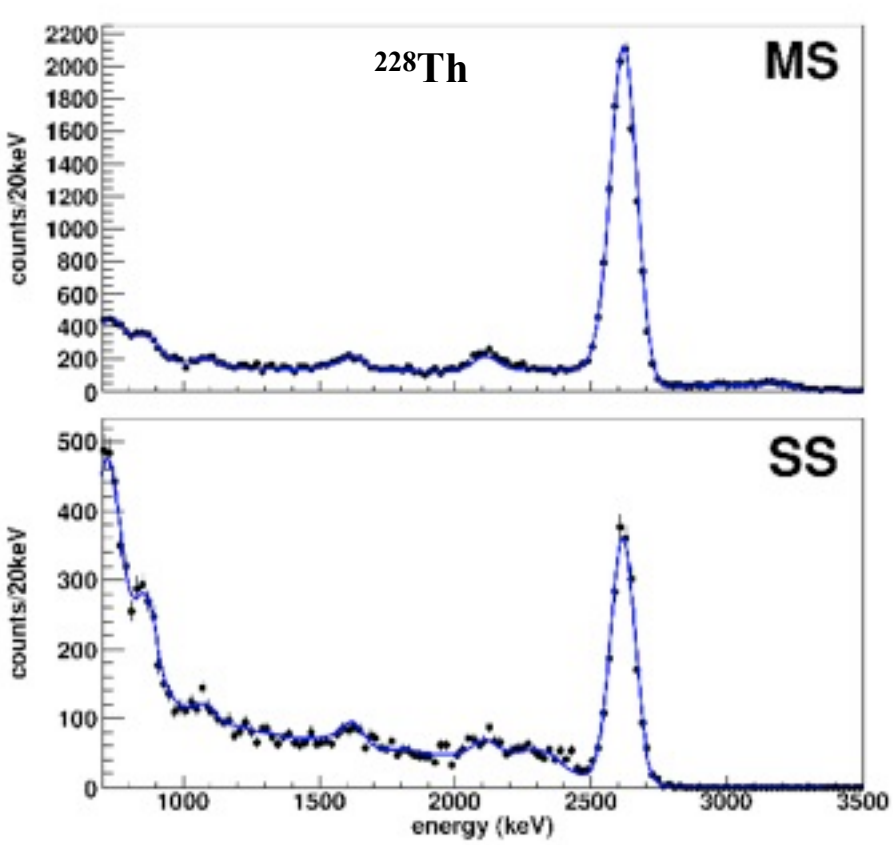


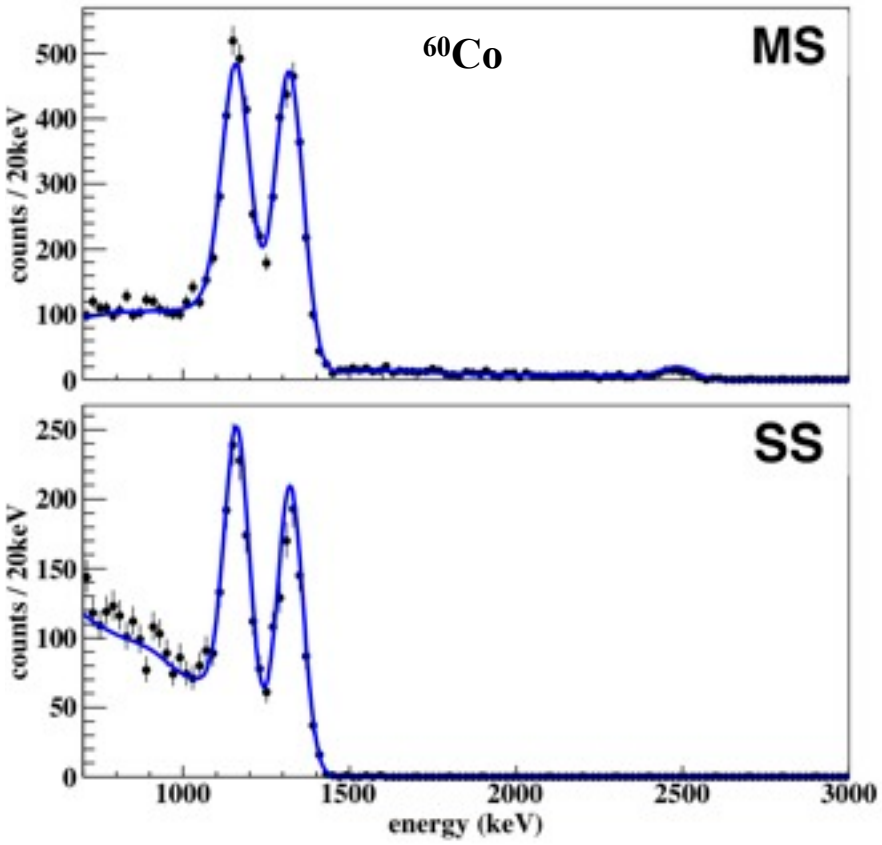
Use full absorption peak of 2615 keV gamma from ^{208}Tl to map light response in TPC

Linearly interpolate between 1352 voxels



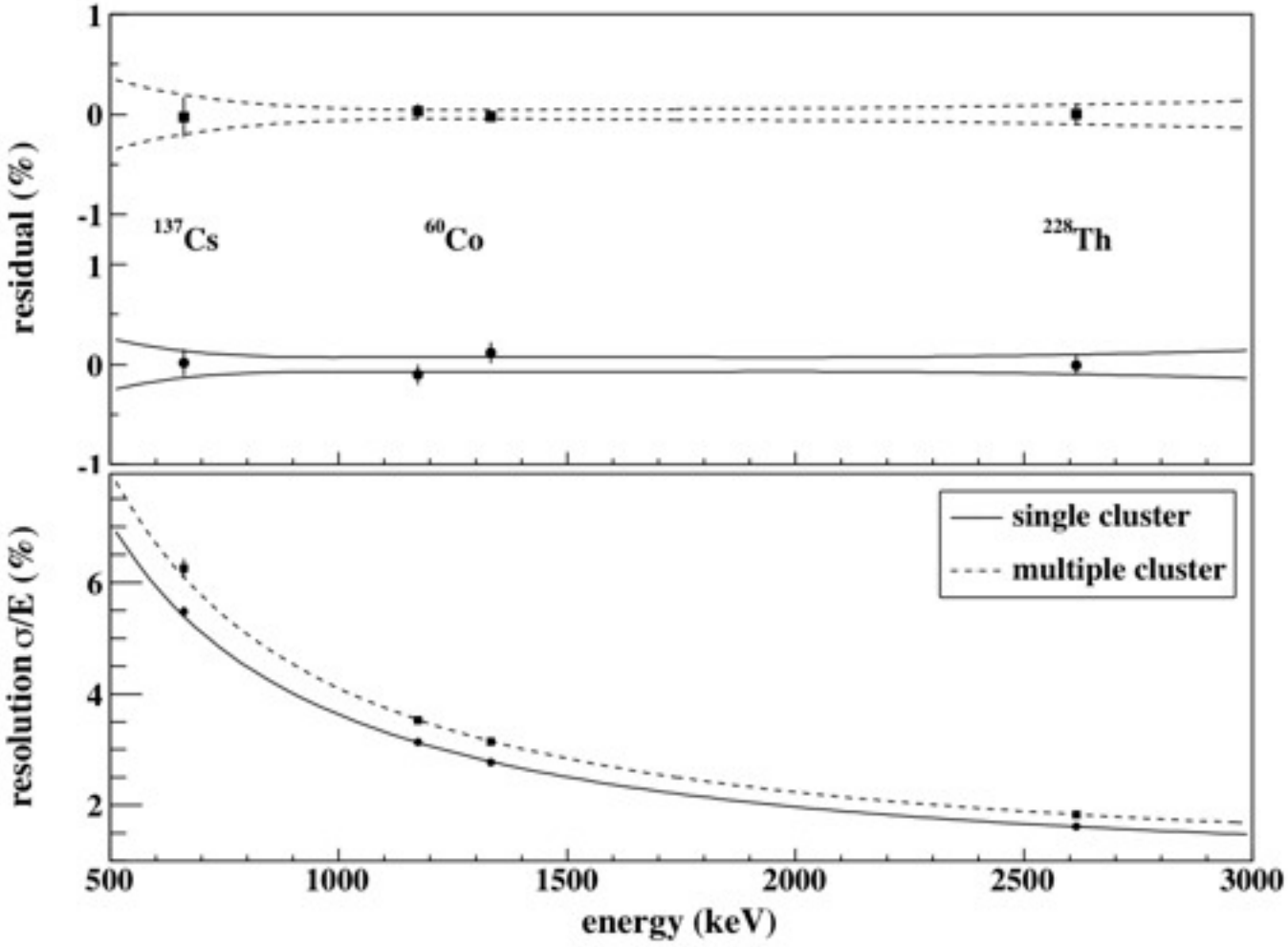
Calibration Source Spectral Agreement





- Multi site (MS) and single site (SS) data (black points) are compared to model (blue curves)
- Single site fraction agrees to within 8.5%
- Can measure source activities to within 9.4%

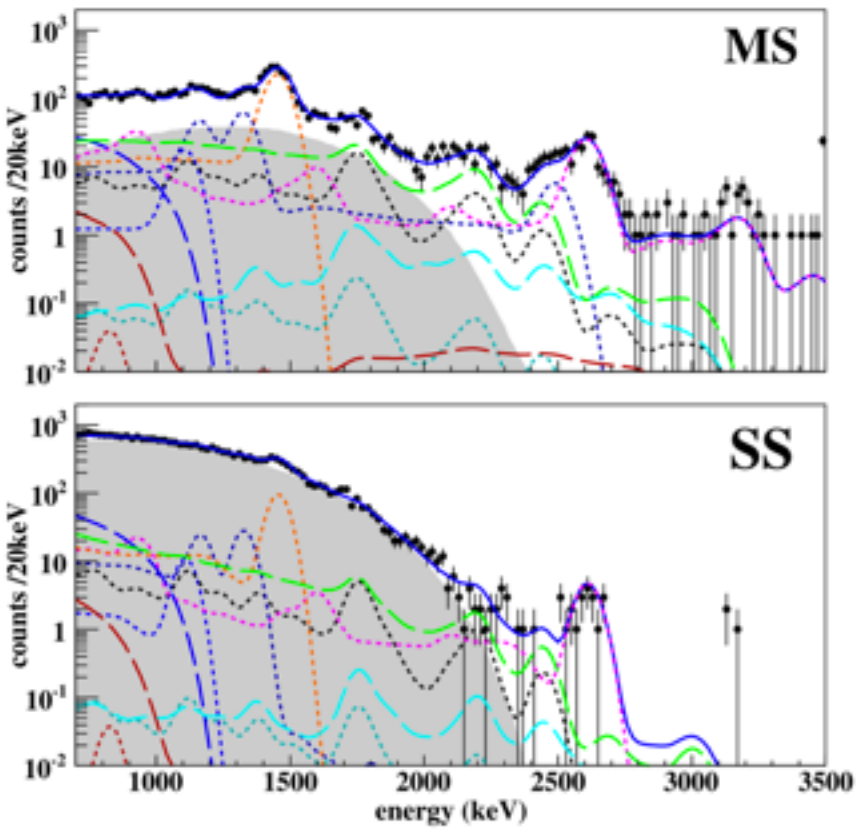
Calibrations



- Energy calibration residuals uncertainties constrained to be less than 0.1%
- Energy resolution at the Q-value (2458 keV) is 1.67% (1.84%) in the SS (MS) spectrum

Low background data

Maximum likelihood fit

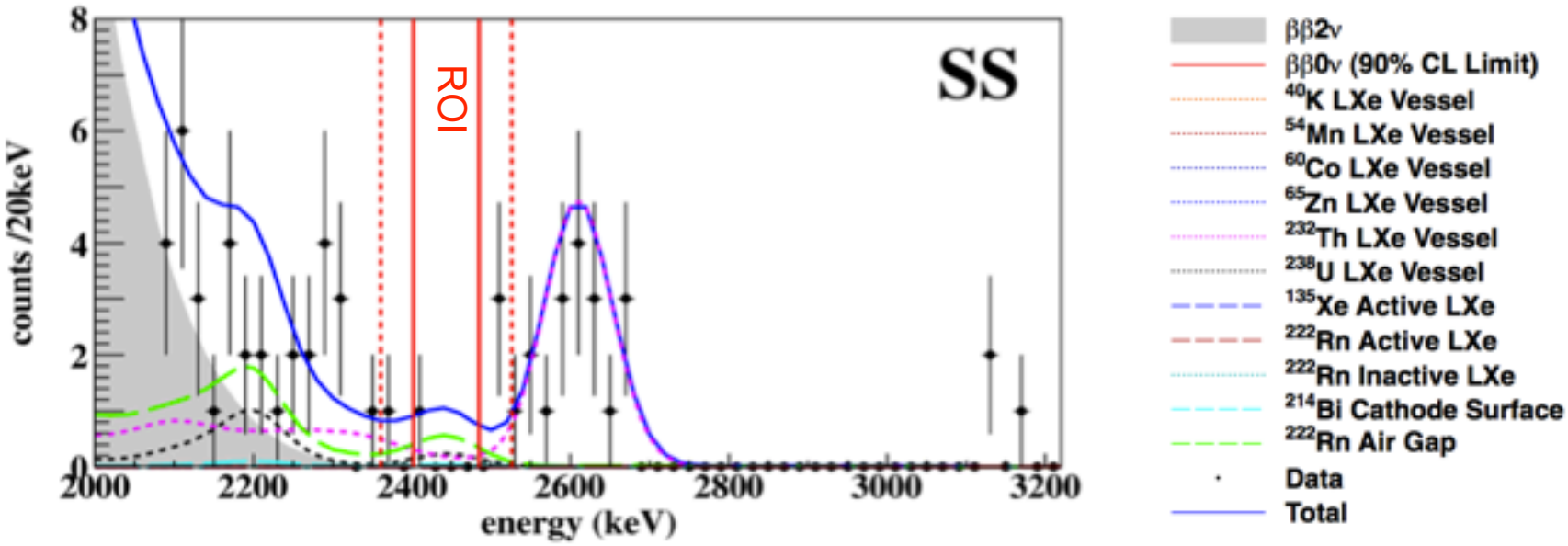


- Trigger fully efficient above 700 keV
- Low background run livetime:
  120.7 days
- Active mass:
  98.5 kg LXe (79.4 kg ^{136}LXe)
- ^{136}Xe exposure:
  26.2 kg·yr
- Total dead time (vetos): 8.6%
- Various background PDFs fitted along with 2νββ and 0νββ PDFs

$T_{1/2}^{2\nu\beta\beta}$ (^{136}Xe) = (2.23 ± 0.017 stat ± 0.22 sys)·10^{21} yr

(In agreement with previously reported value by EXO-200 and KamLAND-ZEN collaborations)

Background counts in ±1,2 σ ROI



	Expected events from fit			
	±1 σ		±2 σ	
^{222}Rn in cryostat air-gap	1.9	±0.2	2.9	±0.3
^{238}U in LXe Vessel	0.9	±0.2	1.3	±0.3
^{232}Th in LXe Vessel	0.9	±0.1	2.9	±0.3
^{214}Bi on Cathode	0.2	±0.01	0.3	±0.02
All Others	~0.2		~0.2	
Total	4.1	±0.3	7.5	±0.5
Observed	1		5	
Background index b ($kg^{-1}yr^{-1}keV^{-1}$)	$(1.5\pm 0.1)\cdot 10^{-3}$		$(1.4 \pm 0.1)\cdot 10^{-3}$	

EXO-200 background goal :
40 cnts/2y in ±2σ ROI,
140 kg LXe

In this data 120 days,98.5 kg, this would be: 4.6

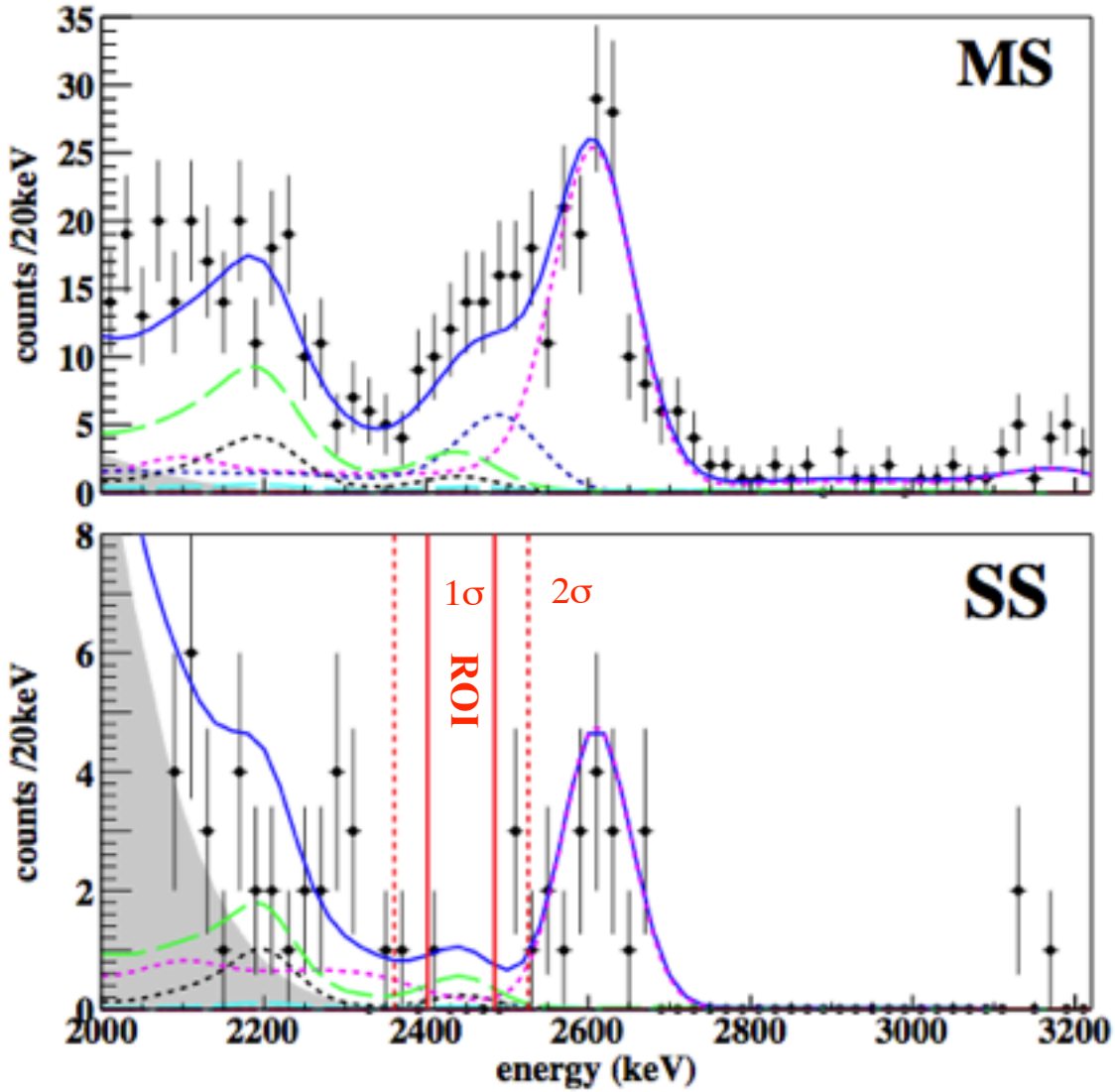
Expected from the fit: 7.5

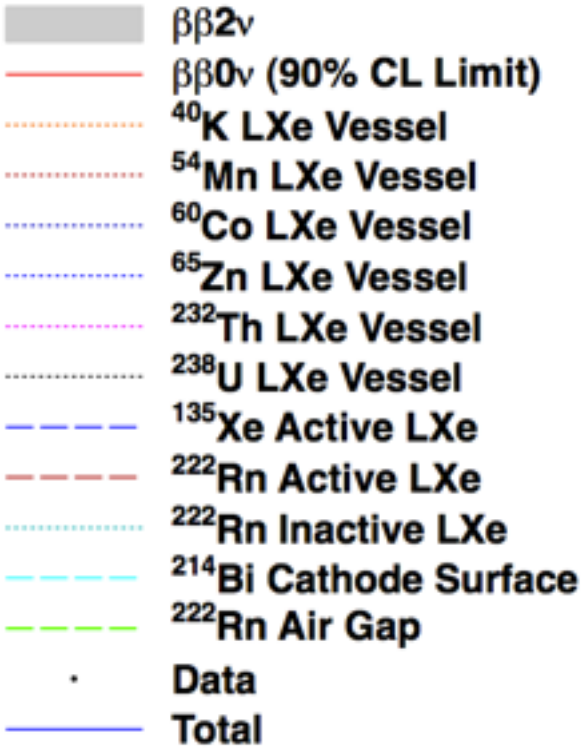
Observed: 5

Background within expectation

Low Background Spectrum

Zoomed around 0νββ region of interest (ROI)



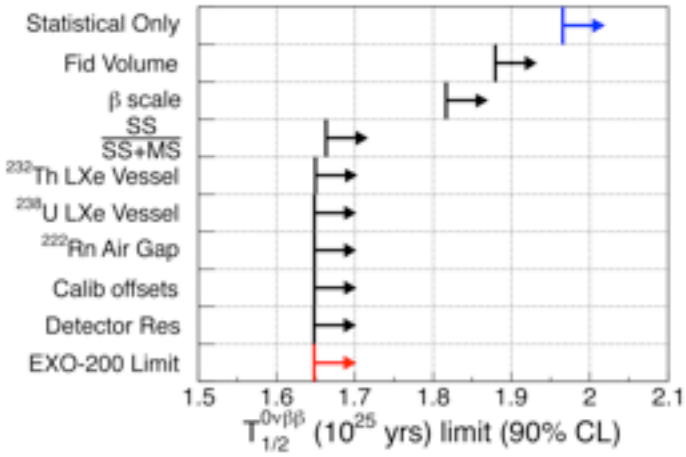


Profile likelihood fit to entire SS and MS spectra to extract limits for $T_{1/2}^{0\nu\beta\beta}$

No 0ν signal observed

$T_{1/2}^{0\nu\beta\beta}$ (^{136}Xe) > $1.6 \cdot 10^{25}$ yr (90% C.L.) [PRL 109 (2012) 032505]

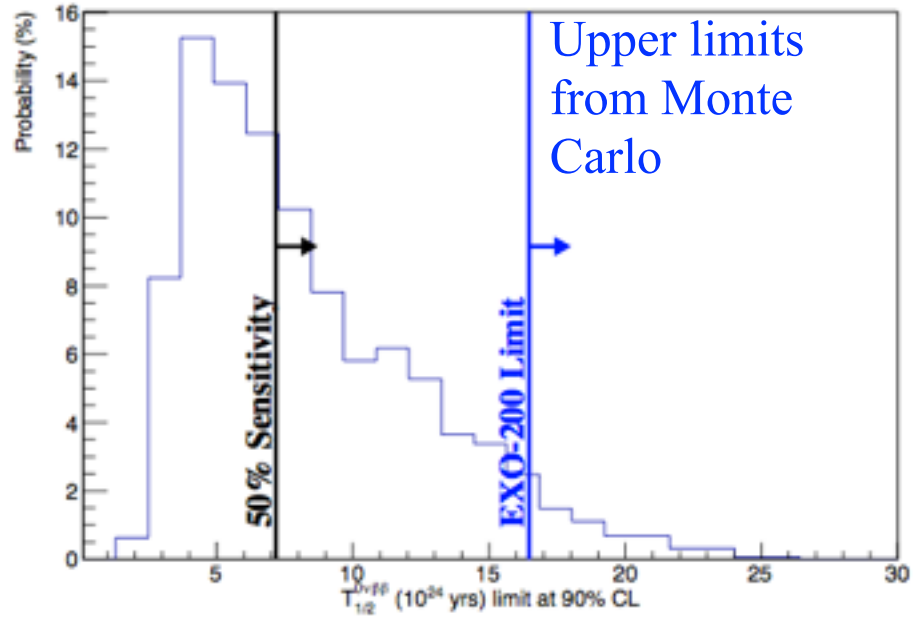
Systematics and sensitivity



Error breakout: expected 90% CL limit given absolute knowledge (0 error) of a given parameter or set of parameters

Term	%
Fiducial Volume	12.34
β scale	9.32
SS / (SS + MS)	0.93
^{232}Th LXe Vessel	0.11
^{238}U LXe Vessel	0.04
^{222}Rn Air Gap	0.04
Calibration offsets	0.04

Distribution of $0\nu\beta\beta$ $T_{1/2}$ 90% CL

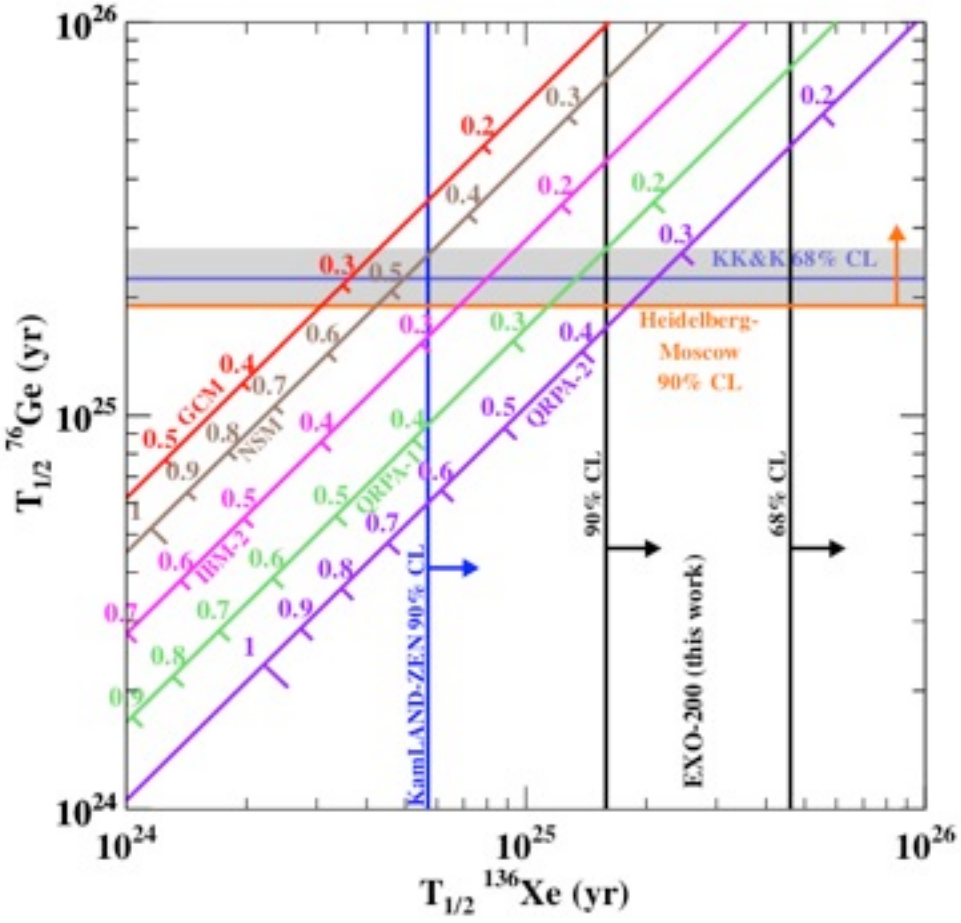


From estimated background, expect to quote a 90% CL upper limit on $T_{1/2}$:

$\geq 1.6 \times 10^{25}$ yr 6.5% of the time

$\geq 7 \times 10^{24}$ yr 50% of the time

Limits on 0νββ



$T_{1/2}^{0\nu\beta\beta}$ (^{136}Xe) > $1.6 \cdot 10^{25}$ yr

$\langle m_{\beta\beta} \rangle$< 140–380 meV (90% C.L.)

90% C.L. limit compared with recent ^{136}Xe constraint (KamLAND-ZEN) >2.5 factor improvement.

EXO-200 contradicts Klapdor-Kleingrothaus and Krivosheina claim at the 90% C.L. for most matrix element calculations.

Future Improvements

- New Radon purge for the air gap between Pb and Cryostat (potential factor of 2 background reduction)

- Further improvements of 3D reconstruction and multiplicity assignment for background reduction

- Energy resolution improvements on the horizon, such as reduction in electronics noise.

- More statistics….

Summary

- $T^{0\nu}_{1/2} > 1.6 \text{ X } 10^{25}$ years for ^{136}Xe
- One of only two isotopes with a half-life limit > 10^{25} years! (the other being ^{76}Ge)
- This limit is in conflict with the claim evidence in ^{76}Ge for most matrix element models
- Several possible ways to improve upon current result in the future

The EXO Collaboration

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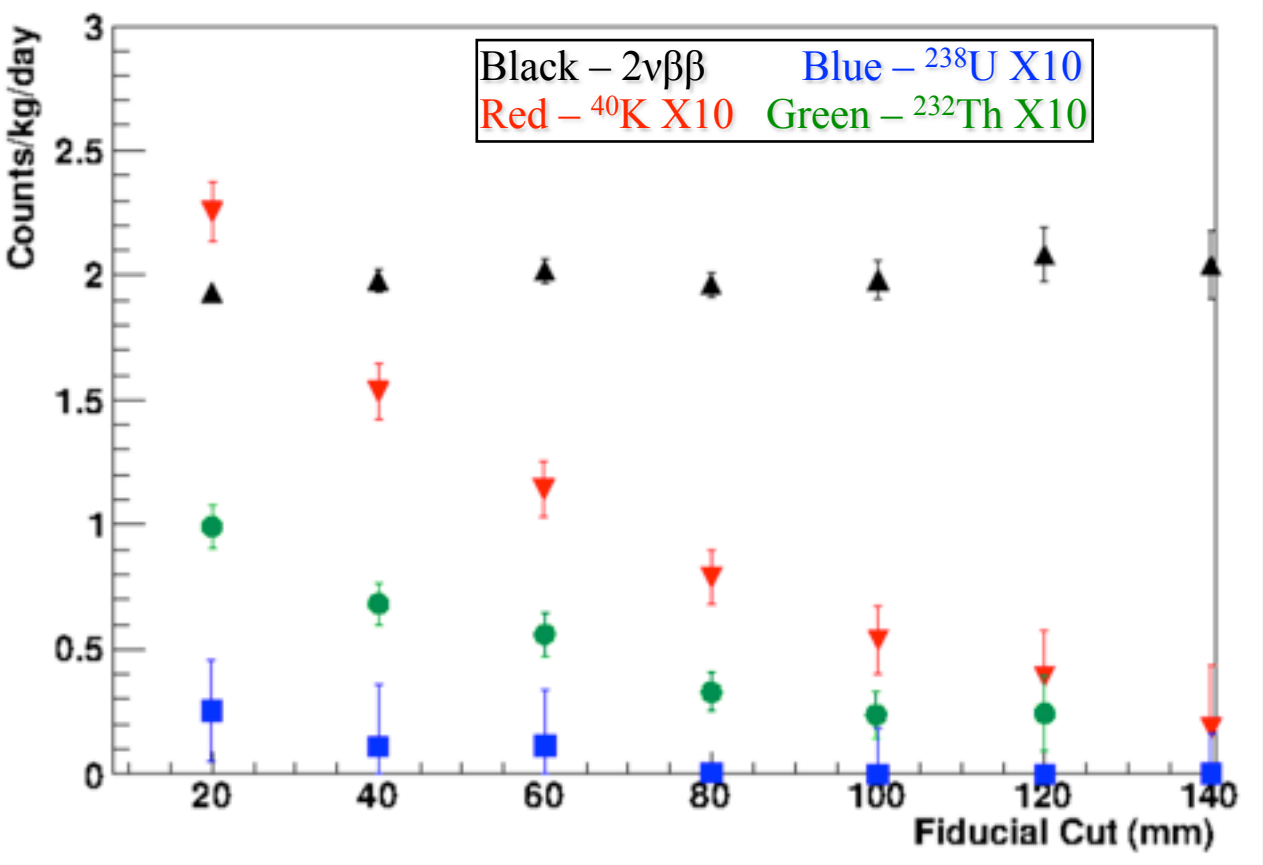
Back Up Slides

Spatial distributions



2νββ rate does not change with fiducial volume

Background gammas rates drop towards the inside of the detector

Events in the ±1,2σ ROIs: statistics is too low to conclude on their parent distribution