Status and Results from EXO-200

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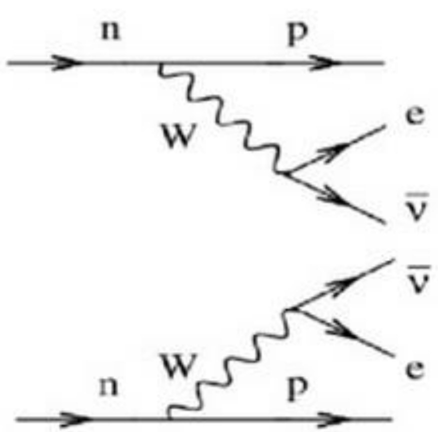
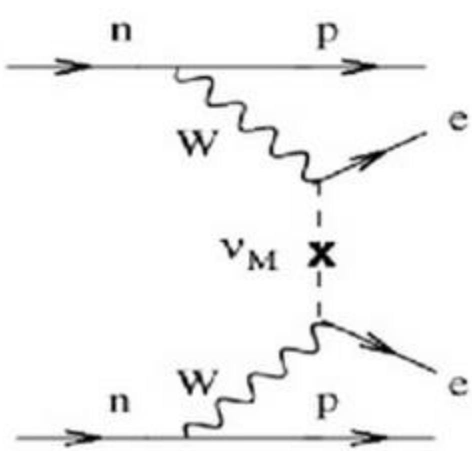
DPF 2013

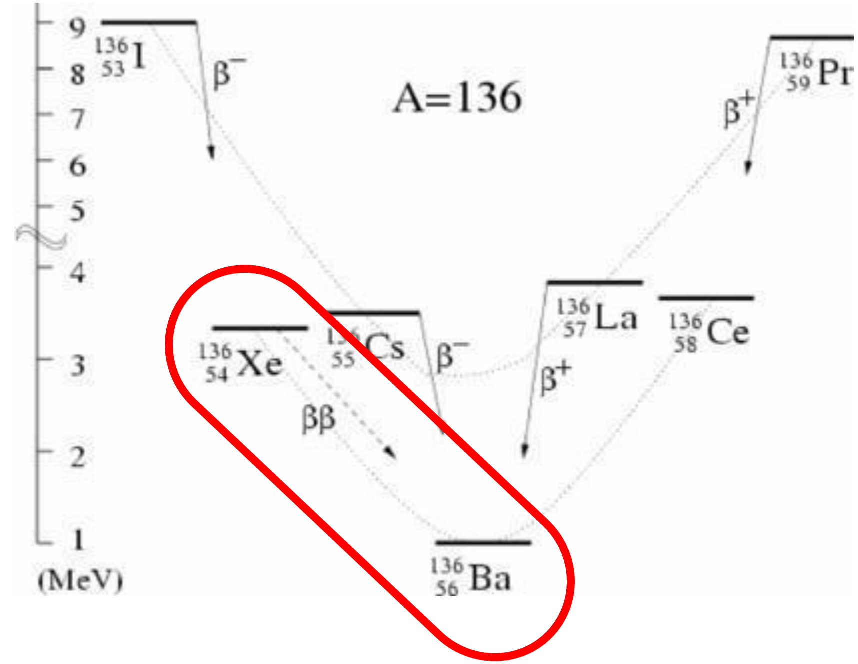
Neutrinoless Double Beta Decay

Two neutrino double beta decay



Neutrinoless double beta decay





2νββ: **2nd order process, only observable when single beta decay is highly suppressed. EXO-200 first to see in ^{136}Xe**

0νββ: **SM-forbidden process**

Possible New Physics

Observation of $0\nu\beta\beta$ would imply new physics concerning:

- ***Majorana nature of neutrinos***
- ***Neutrino mass scale***
- ***Lepton number conservation***

Advantages of ^{136}Xe

- Xenon isotopic enrichment is easier. Xenon is a gas & ^{136}Xe is the heaviest isotope.
- Xenon is "reusable". Can be repurified & recycled into new detector.
- Large monolithic detector. LXe is self shielding, rejection of Compton scatterings.
- Minimal cosmogenic activation. No long lived radioactive isotopes of Xe.
- Energy resolution in LXe can be improved. Scintillation light/ionization correlation.

… admits a novel coincidence technique. Background reduction by barium daughter tagging.

Goals of EXO-200

- **Use Time-Projection Chamber (TPC) detector, filled with 200 kg LXe, 80.6% enriched**

- **Observe 2vββ in ^{136}Xe**

- **Probe majorana mass range of 100-200 meV**

- **Demonstrate feasibility of a ton-scale experiment**

The EXO Collaboration

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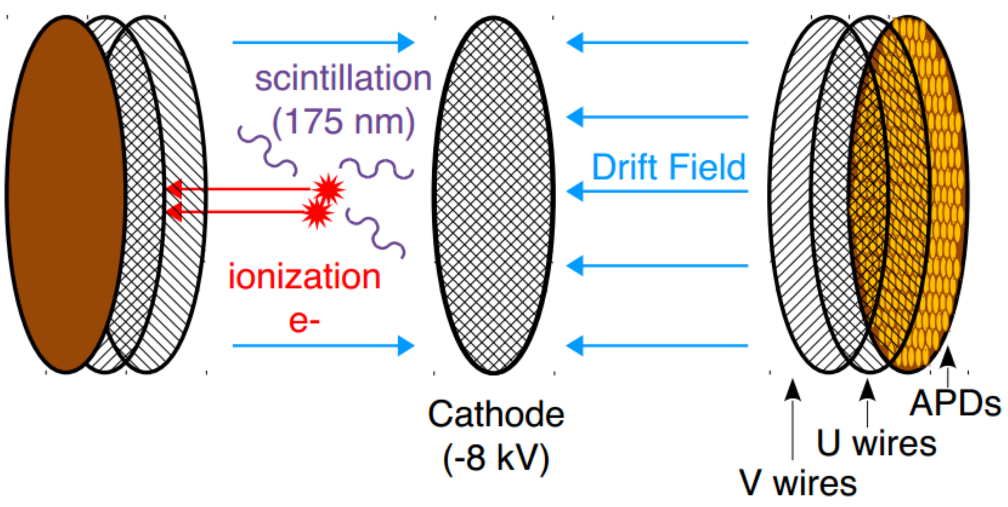
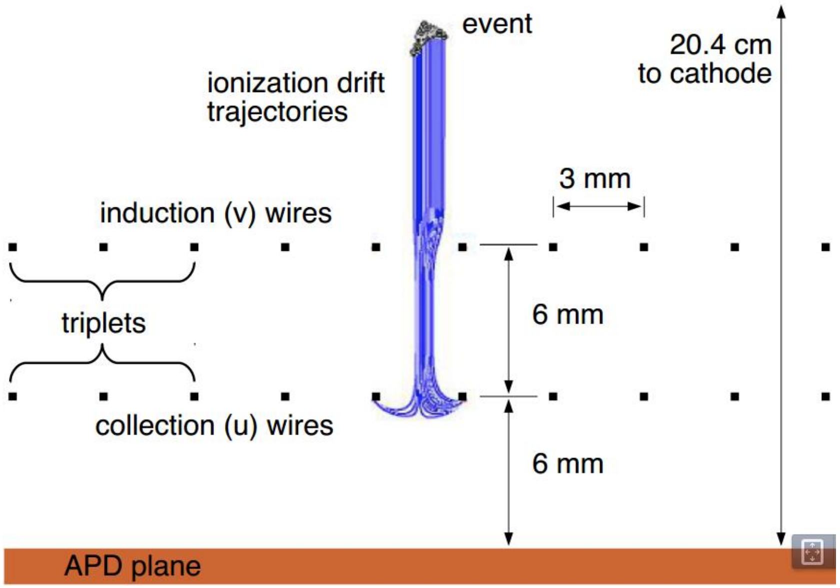
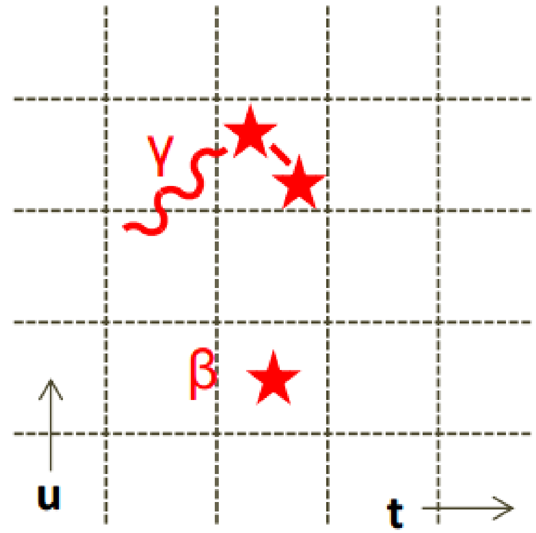
EXO-200 Detector

- Two TPCs with common cathode in middle
- APD planes observe prompt scintillation for drift time measurement.
- V-position given by induction signal on shielding grid.
- U-position and energy given by charge collection grid.

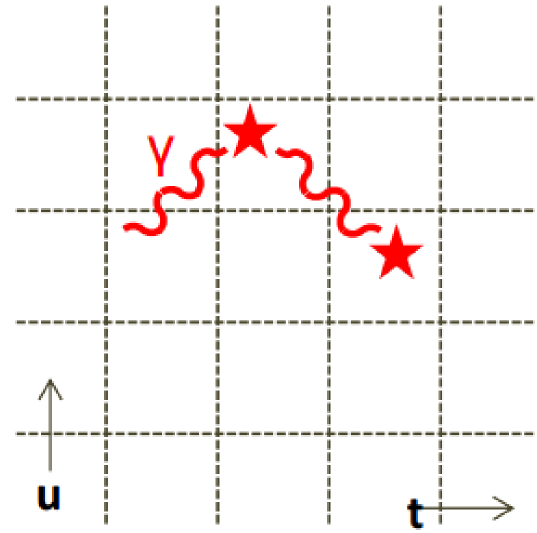




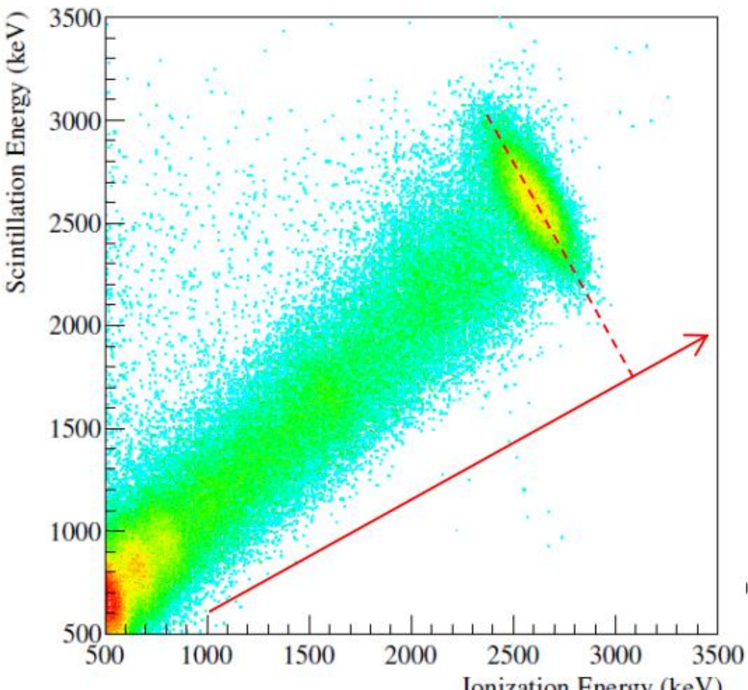
Single Site Events (SS)



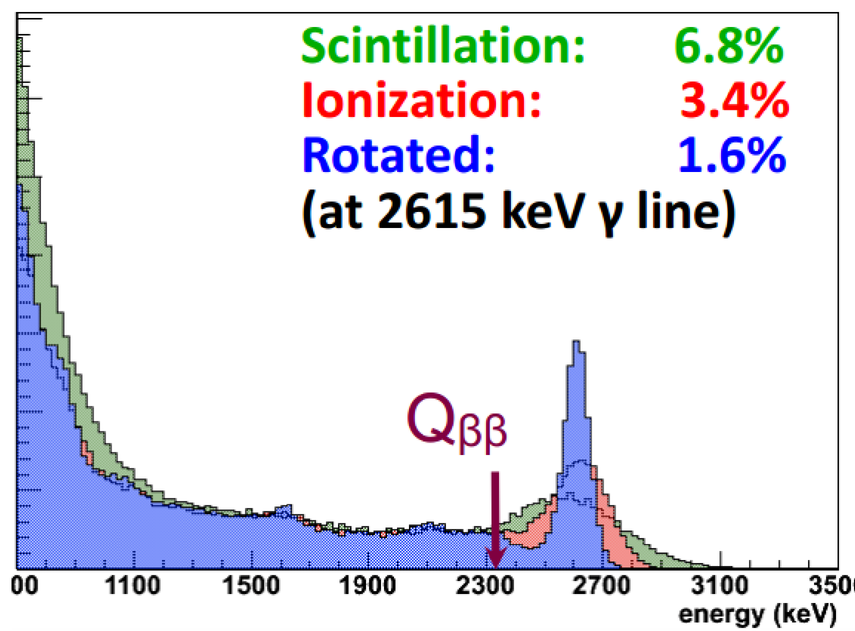
Multiple Site Events (MS)

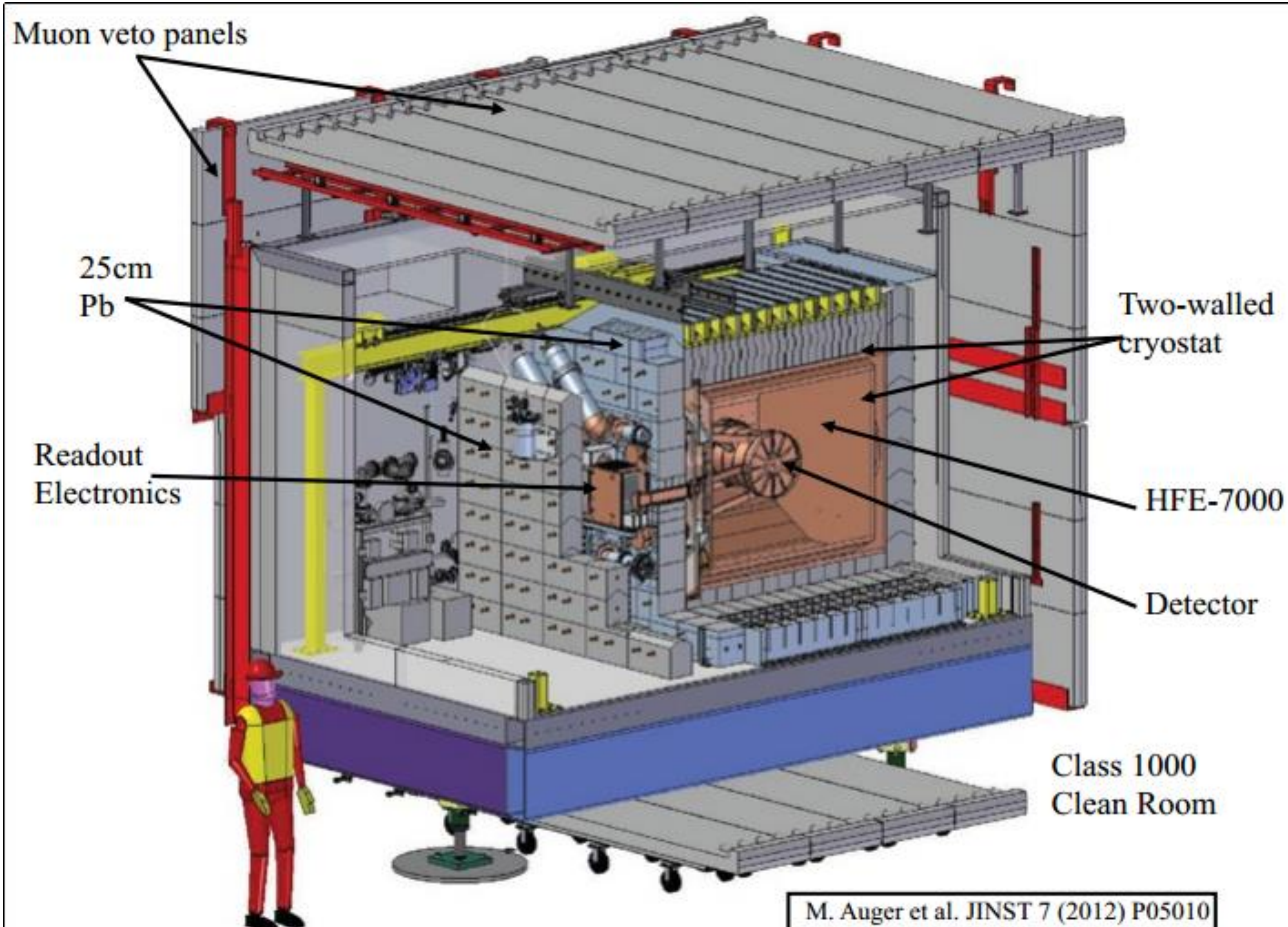


Anti-Correlation (Ioniz. vs Scint.)



Resolution





M. Auger et al. JINST 7 (2012) P05010
[arXiv: 1202.2192]

EXO-200 Installation Site: WIPP

Cleanrooms at WIPP drift

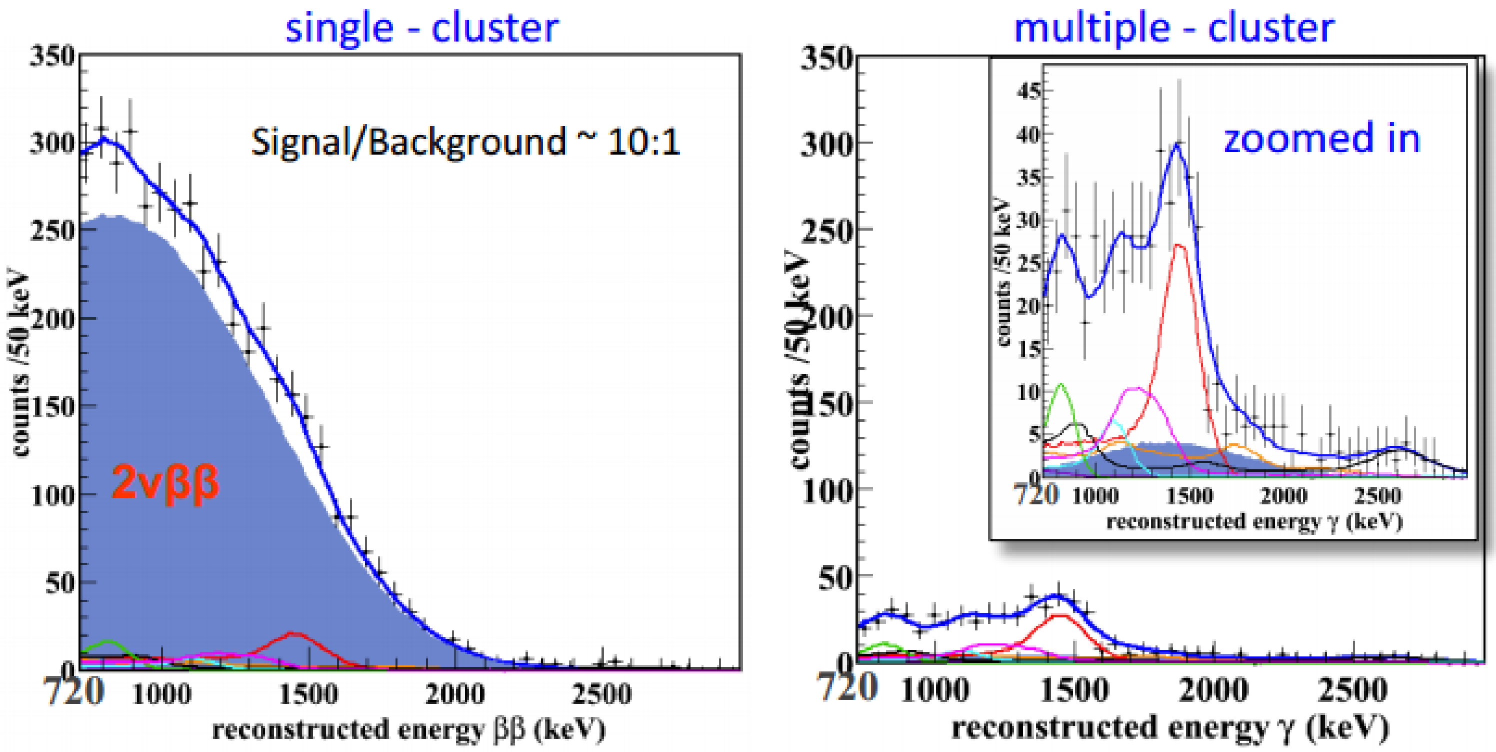
- **EXO-200 is installed at WIPP (Waste Isolation Pilot Plant), in Carlsbad, NM**
- **1600 mwe flat overburden (2150 feet, 650 m)**
- **U.S. DOE salt mine for radioactive waste storage**
- **Salt rock low activity relative to hard-rock mine**

EXO-200 Running

	Run 1 (2νββ Discovery)	Run 2a (0νββ limit)	Run 2a (this analysis)
Period	May 21, 11 – Jul 9, 11	Sep 22, 11 – Apr 15, 12	Sep 22, 11 – Apr 15, 12
Live Time	752.7 hr	2896.6 hr	3062.4 hr
Exposure	3.2 kg-yr	32.5 kg-yr	23.14 kg-yr
Publ.	PRL 107 (2011) 212501	PRL 109 (2012) 032505	arXiv:1306.6106 (Jun 2013)

- **Review previous two results**
- **Improvements made for this 2013 analysis**
- **Precision 2νββ measurement**

First observation of the 2νββ decay in ^{136}Xe



With first 31 live-days of data:

$T_{1/2}$ = (2.11 ± 0.04 stat ± 0.21 sys) · 10^{21} yr

[Ackerman et al Phys Rev Lett 107 (2011) 212501]

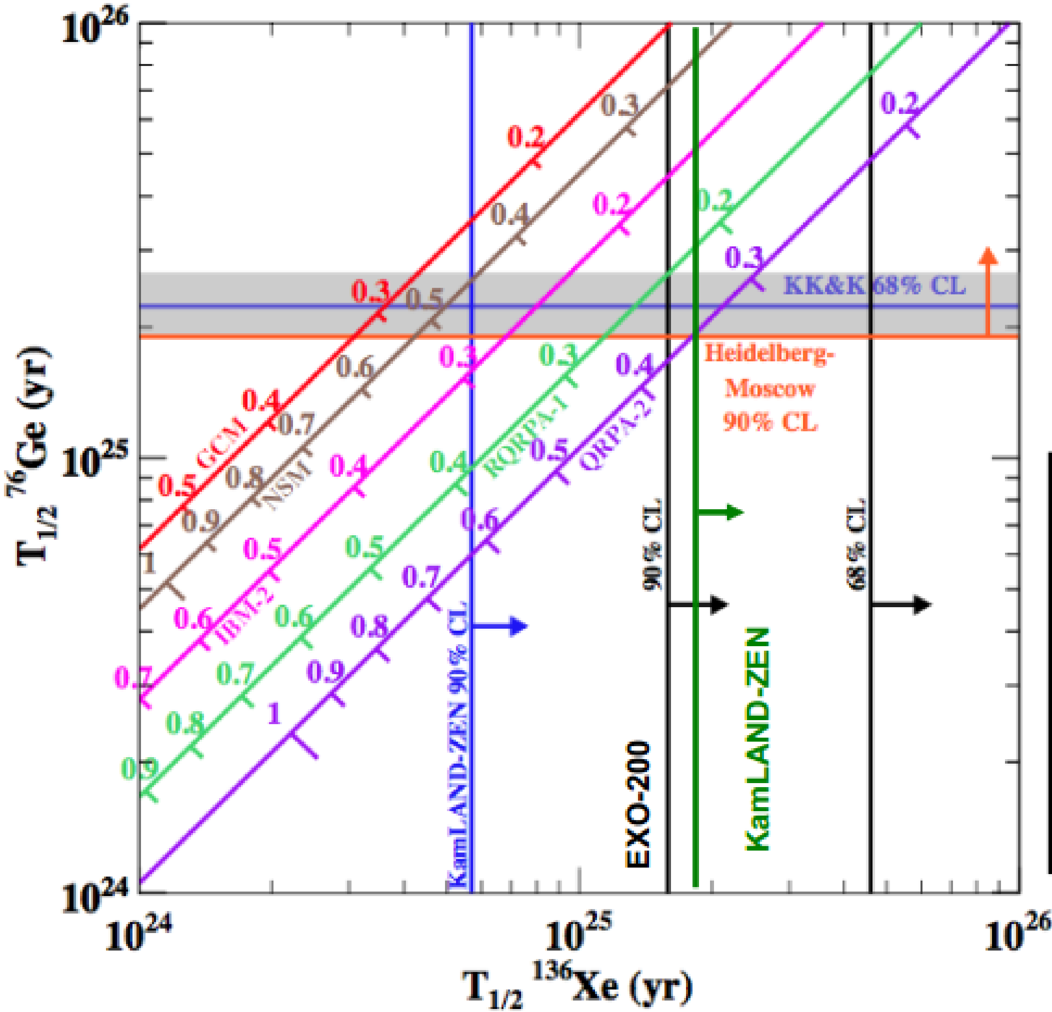
The slowest physics process ever directly observed in nature

Later confirmed by KamLAND-Zen

$T_{1/2}$=(2.38 ± 0.02stat ± 0.14sys)·10^{21} yr

[A.Gando et al. Phys Rev C 85 (2012) 045504]

Limits on $T_{1/2}^{0\nu\beta\beta}$ and $<m_{\beta\beta}>$



Interpret as lepton number violating process with effective Marojana mass 〈$m_{\beta\beta}$〉 :

$$\left(T_{1/2}^{0\nu\beta\beta}\right)^{-1} = G^{0\nu}\left|M_{nucl}\right|^2\langle m_{\beta\beta}\rangle^2$$

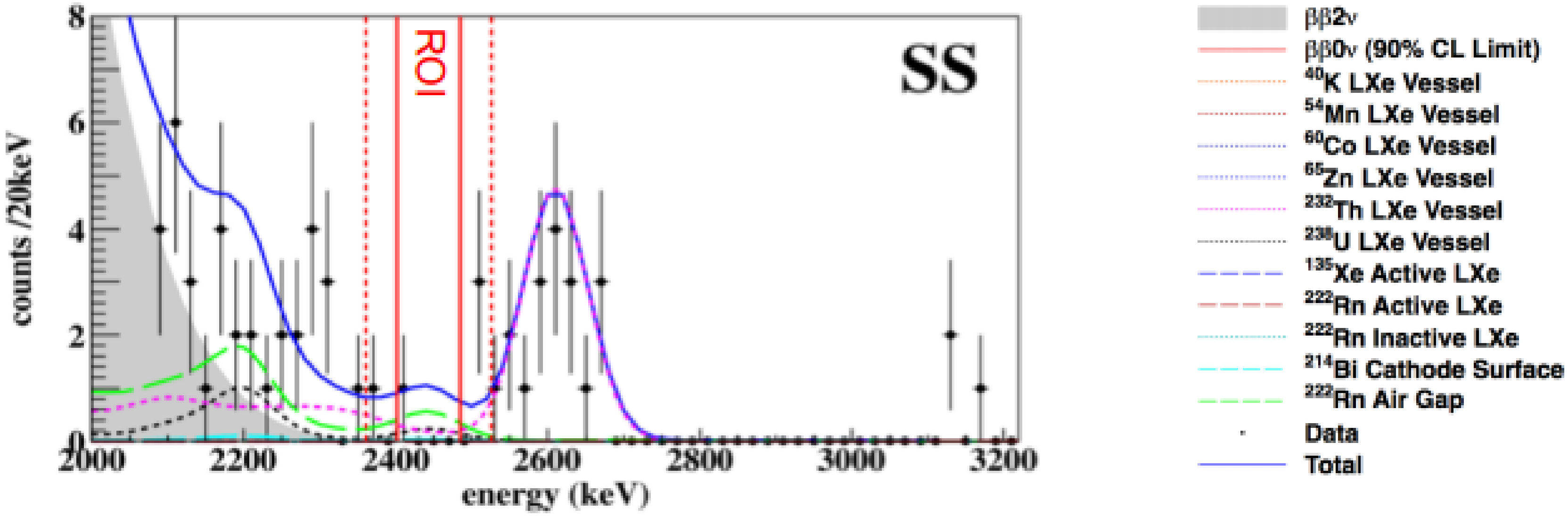
$T_{1/2}^{0\nu\beta\beta} > 1.6\cdot10^{25}$ yr

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

Phys.Rev.Lett 109 (2012) 032505 (arXiv:1205.5608)

KamLAND-ZEN
Phys.Rev.Lett. 110 (2013) 062502
(arXiv:1211.3863)

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 (kg^{-1}yr^{-1}keV^{-1})	$1.5\cdot10^{-3}$	± 0.1	$1.4\cdot10^{-3}$	± 0.1

EXO-200 goal:

40 cnts/2y in ±2σ ROI, 140 kg LXe

In this data 120 days, 98.5 kg: 4.6

Expected from the fit: 7.5
Observed: 5

Background within expectation

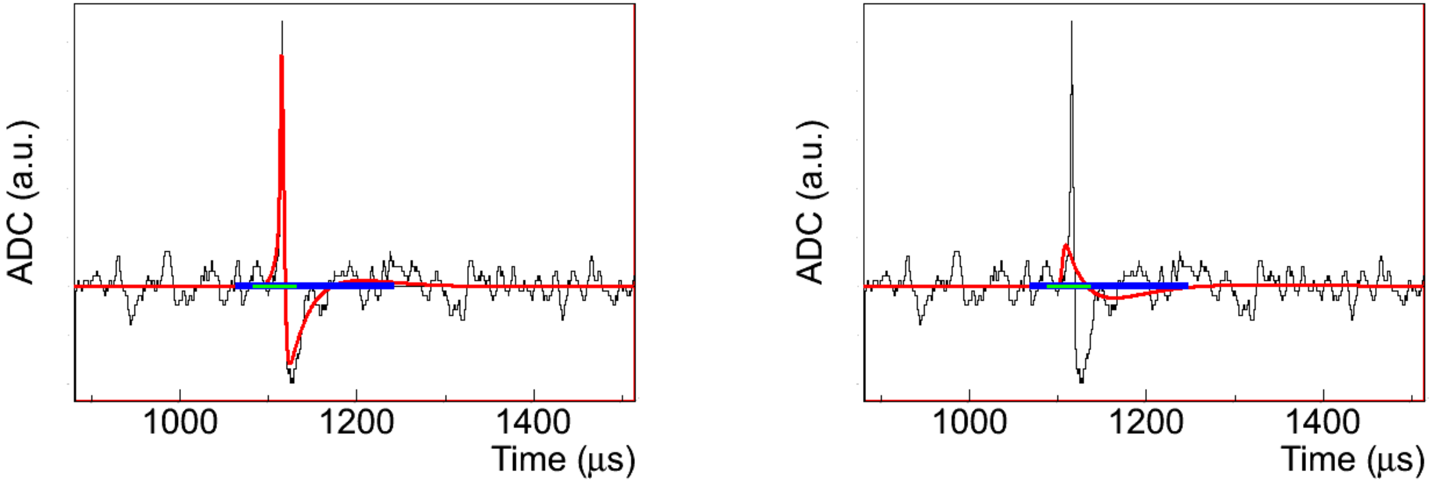
Since then

- Improved event reconstruction
- Improved and more detailed(geometry) Monte Carlo simulations
- More precise detector response calibration
- And other improvements

Induction Signals

- Identify Induction Signals on Collection Wires
- Mistakenly reconstructing as collection leads to SS/MS misclassification
- 77% induction rejection, with 99.9% collection efficiency

Fit to Induction and Collection Signal Models

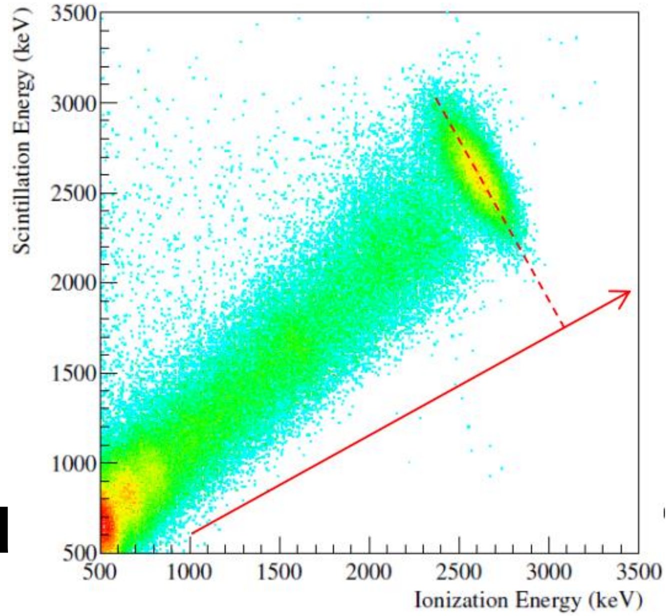


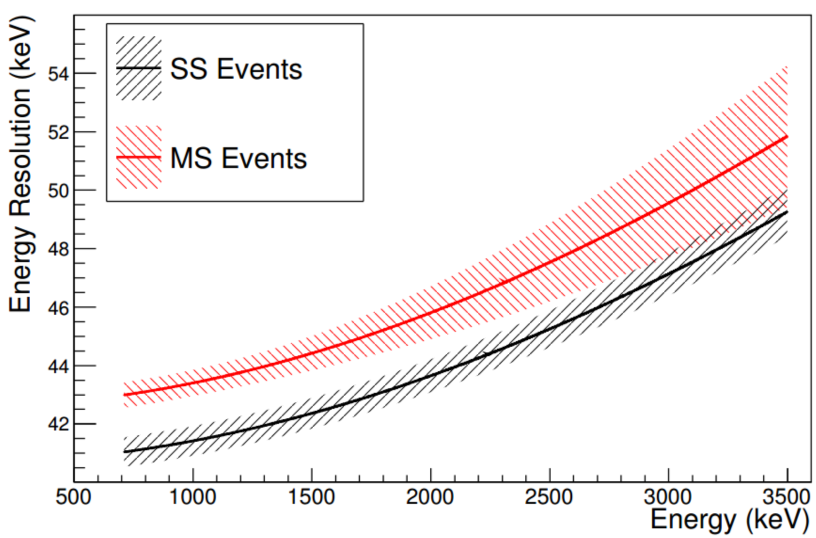
Corrections

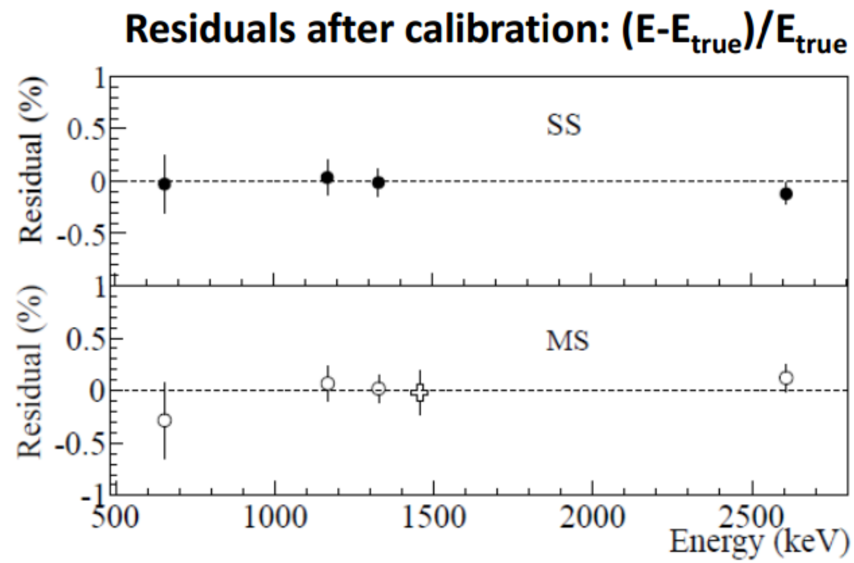
Optimal rotation angle measured weekly

New iterative approach developed to extract energy resolution curve

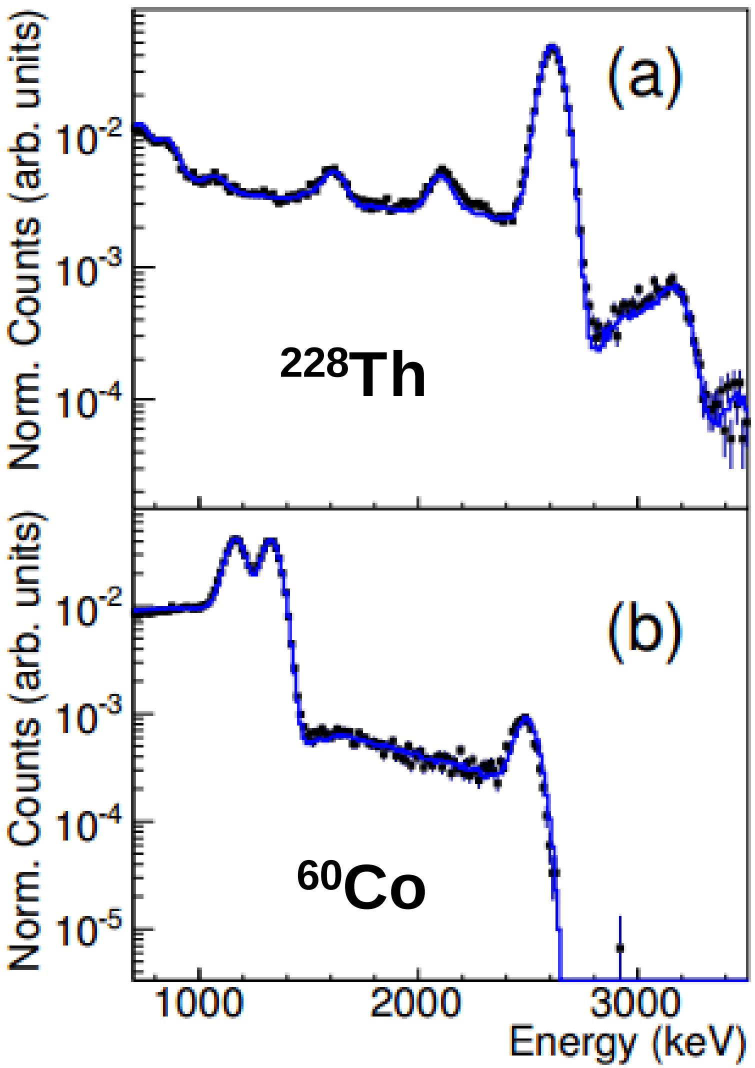
Time-averaged energy resolution used for final LB fit





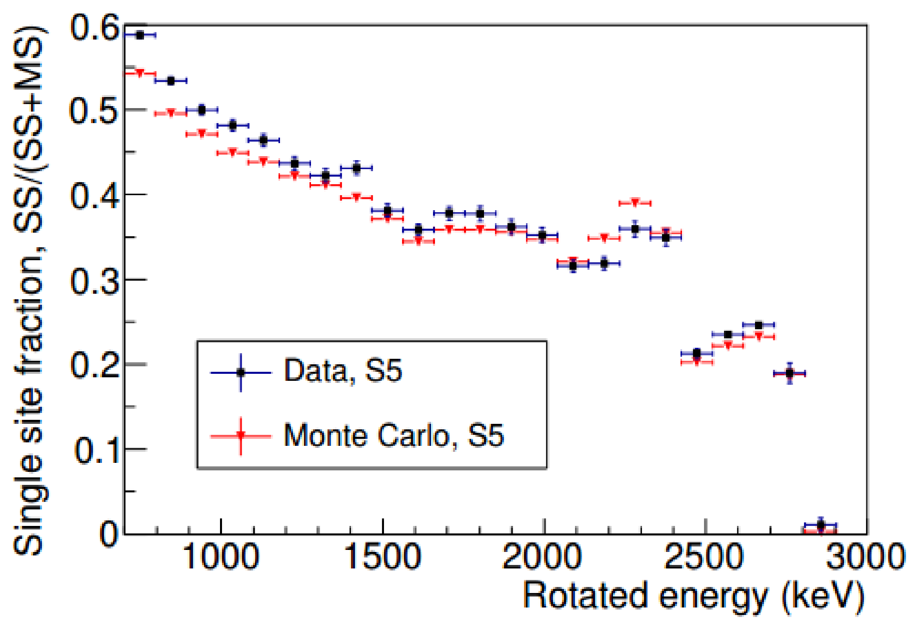


Source Agreement



Improved MC and event reconstruction

- **Source rate agreement to within 4% (9.4% in 0νββ analysis)**
- **Excellent spectral shape agreement**
- **Sufficient SS/MS agreement**



Fiducial Volume

Previous analysis: 79.4 kg of ^{136}Xe

This analysis: 66.2 kg of ^{136}Xe

$2\nu\beta\beta$ analysis is systematics-dominated

Chose smaller fiducial volume where detector response is better understood

Decrease related systematic uncertainties

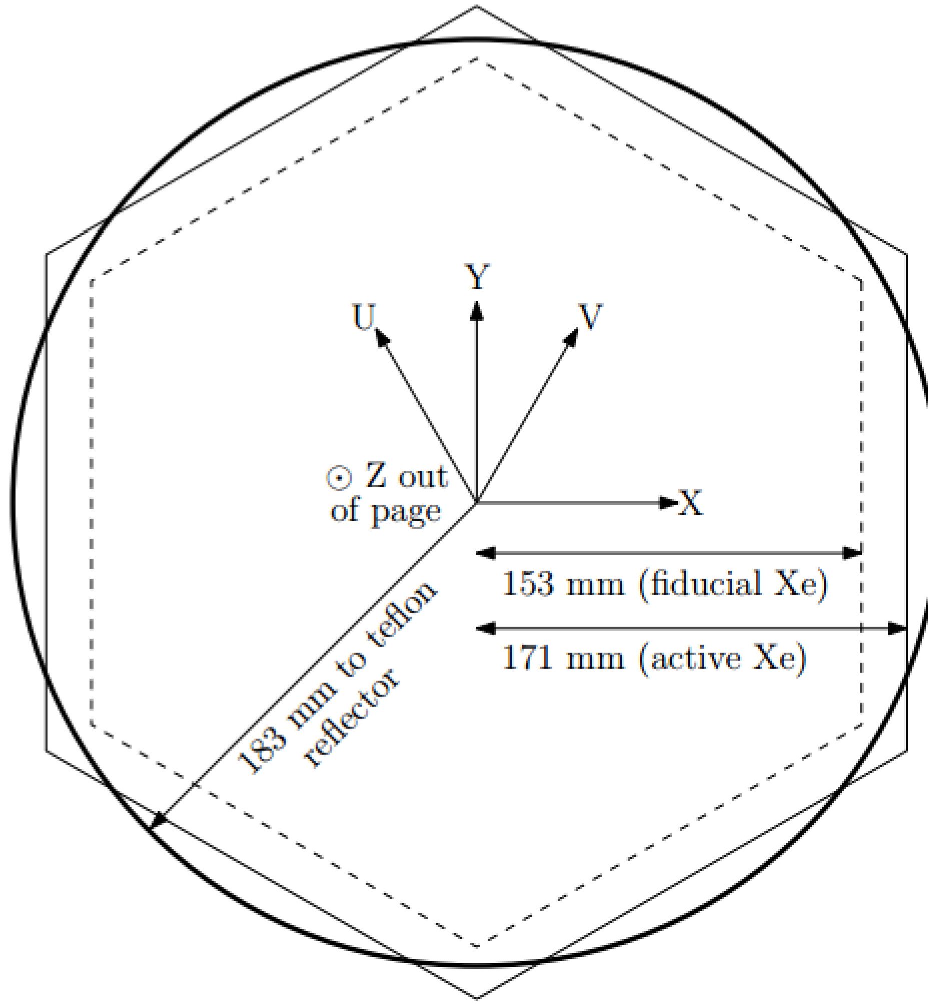
Fiducial Volume Cut

Hexagonal cut in U,V based on:

- **2νββ rate vs apothem**

Z cut based on:

- **Field non-uniformity near cathode**
- **Grid-efficiency correction due to V-Wire plane**

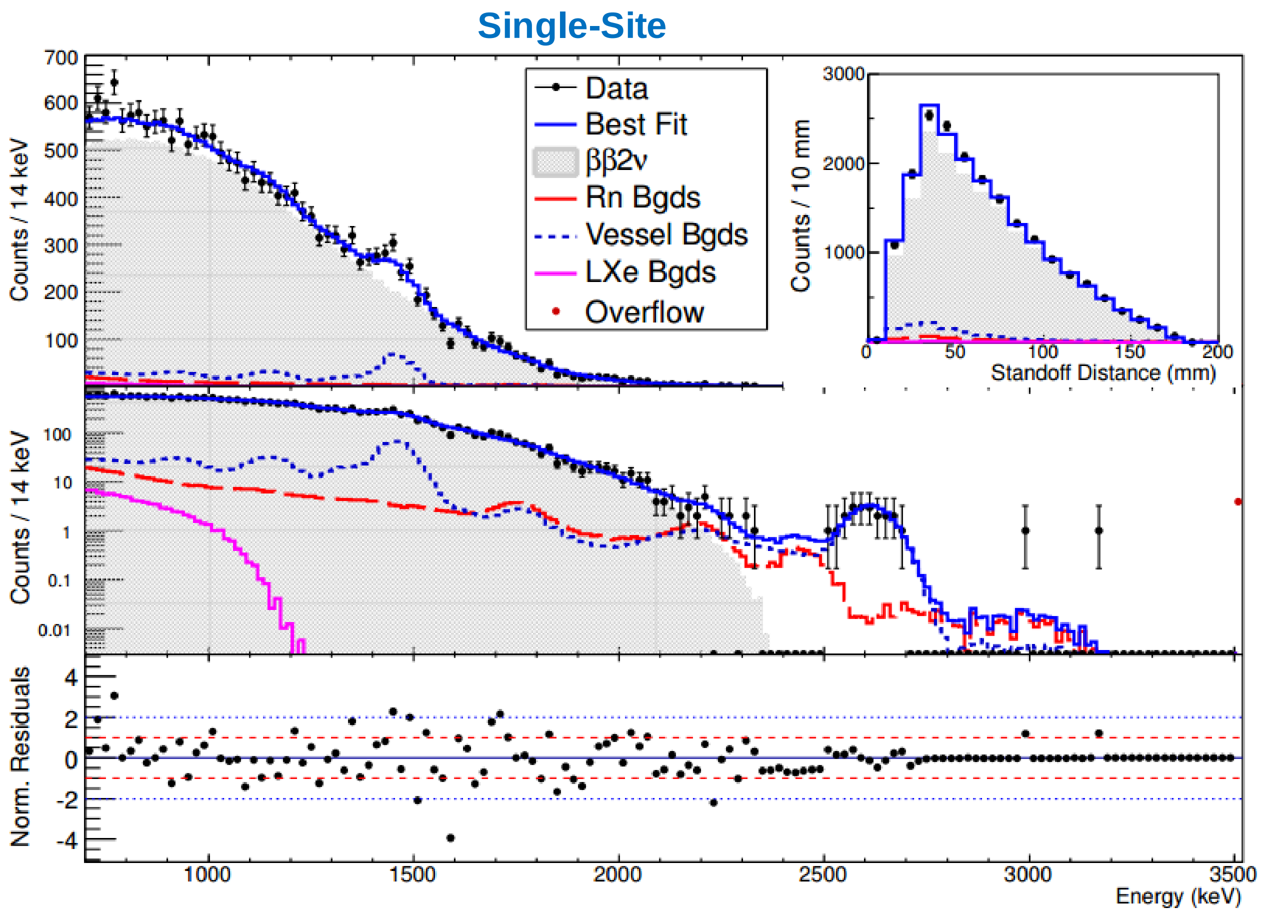


Standoff Fits

- Previously: simultaneously fit SS and MS event datasets using energy PDFs
- Now: added Standoff Distance as an additional fit dimension (PDFs are 2D, energy and standoff)

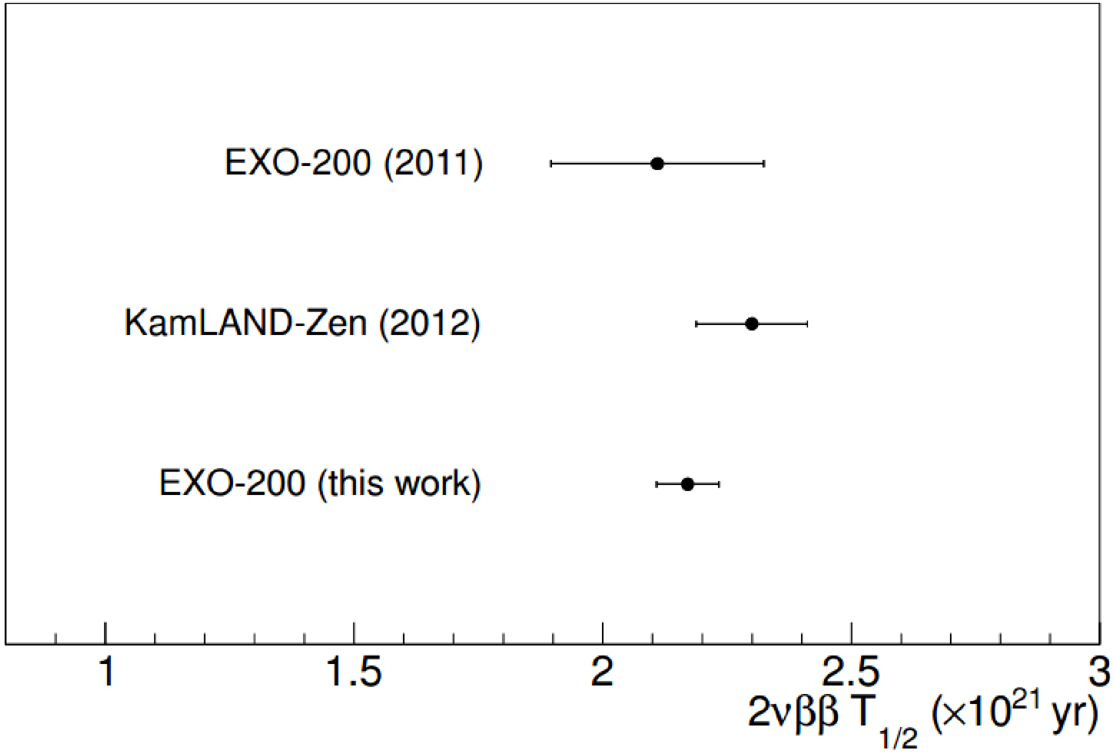
- Energy-only LB fit returns 2.4% less 2νββ counts than reported result
- SD improves background estimates (bkgd contribution on total error: 1.2% -> 0.83%)

Improved Measurement of $T_{1/2}^{2\nu\beta\beta}$



$T_{1/2}^{2\nu\beta\beta}$ = (2.172 ± 0.017(stat) ± 0.060(sys)) • 10^{21} years
Total relative uncertainty: 2.85%

Improved analysis of $T_{1/2}^{2\nu\beta\beta}$ submitted to PRC (arxiv:1306.6106)



This result is the most precisely measured half-life of any 2νββ decay process to date

Nuclide	$T_{1/2}^{2\nu\beta\beta}$ ± stat ± sys [y]	rel. uncert. [%]	$G^{2\nu}$ [10^{-21} y^{-1}]	$M^{2\nu}$ [MeV^{-1}]	rel. uncert. [%]	Experiment (year)
^{136}Xe	$2.172 \pm 0.017 \pm 0.060 \cdot 10^{21}$	±2.85	1433	0.0217	±1.4	EXO-200 (this work)
^{76}Ge	$1.84^{+0.09+0.11}_{-0.08-0.06} \cdot 10^{21}$	$^{+7.7}_{-5.4}$	48.17	0.129	$^{+3.9}_{-2.8}$	GERDA [39] (2013)
^{130}Te	$7.0 \pm 0.9 \pm 1.1 \cdot 10^{20}$	±20.3	1529	0.0371	±10.2	NEMO-3 [40] (2011)
^{116}Cd	$2.8 \pm 0.1 \pm 0.3 \cdot 10^{19}$	±11.3	2764	0.138	±5.7	NEMO-3 [41] (2010)
^{48}Ca	$4.4^{+0.5}_{-0.4} \pm 0.4 \cdot 10^{19}$	$^{+14.6}_{-12.9}$	15550	0.0464	$^{+7.3}_{-6.4}$	NEMO-3 [41] (2010)
^{96}Zr	$2.35 \pm 0.14 \pm 0.16 \cdot 10^{19}$	±9.1	6816	0.0959	±4.5	NEMO-3 [42](2010)
^{150}Nd	$9.11^{+0.25}_{-0.22} \pm 0.63 \cdot 10^{18}$	$^{+7.4}_{-7.3}$	36430	0.0666	$^{+3.7}_{-3.7}$	NEMO-3 [43](2009)
^{100}Mo	$7.11 \pm 0.02 \pm 0.54 \cdot 10^{18}$	±7.6	3308	0.250	±3.8	NEMO-3 [44](2005)
^{82}Se	$9.6 \pm 0.3 \pm 1.0 \cdot 10^{19}$	±10.9	1596	0.0980	±5.4	NEMO-3 [44](2005)

Looking Forward

- For the future $0\nu\beta\beta$ result, will have ~3x more data
- Further electronics upgrades
- Deradonator to remove ^{222}Rn from air around cryostat

R&D for nEXO, proposed ton-scale successor of EXO-200