Recent results from EXO-200

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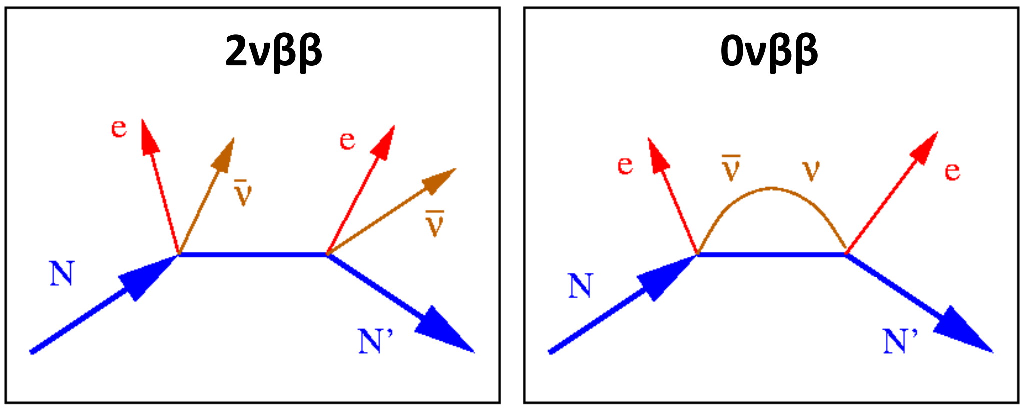
for the EXO-200 Collaboration

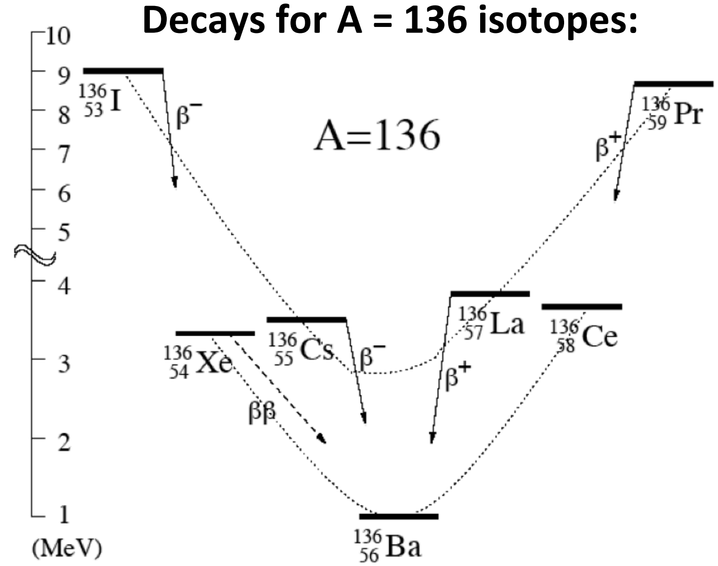
Introduction

- Nuclei for which β-decay is energetically forbidden can decay through a second-order transition ("double-beta decay")
- If ν is a Majorana particle ($\nu = \bar{\nu}$), then decay can proceed with no emitted neutrinos

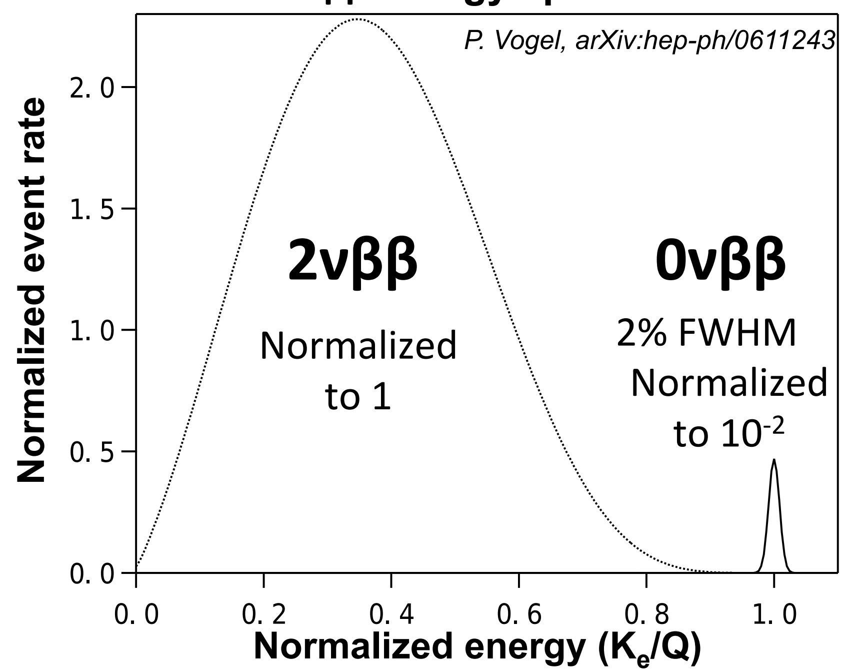


- Observation of 0νββ would provide:
  - A beyond the Standard Model, lepton-number violating process
  - Imply neutrinos are Majorana particles
  - Constrain neutrino mass scale

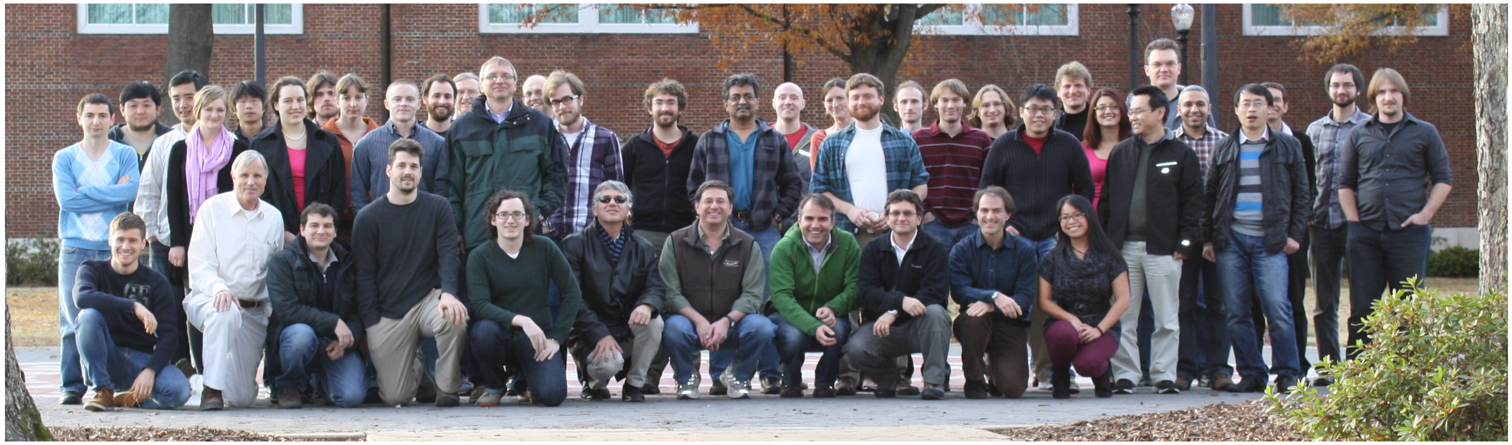
Decays for A = 136 isotopes:



ββ energy spectrum:



The EXO-200 Collaboration



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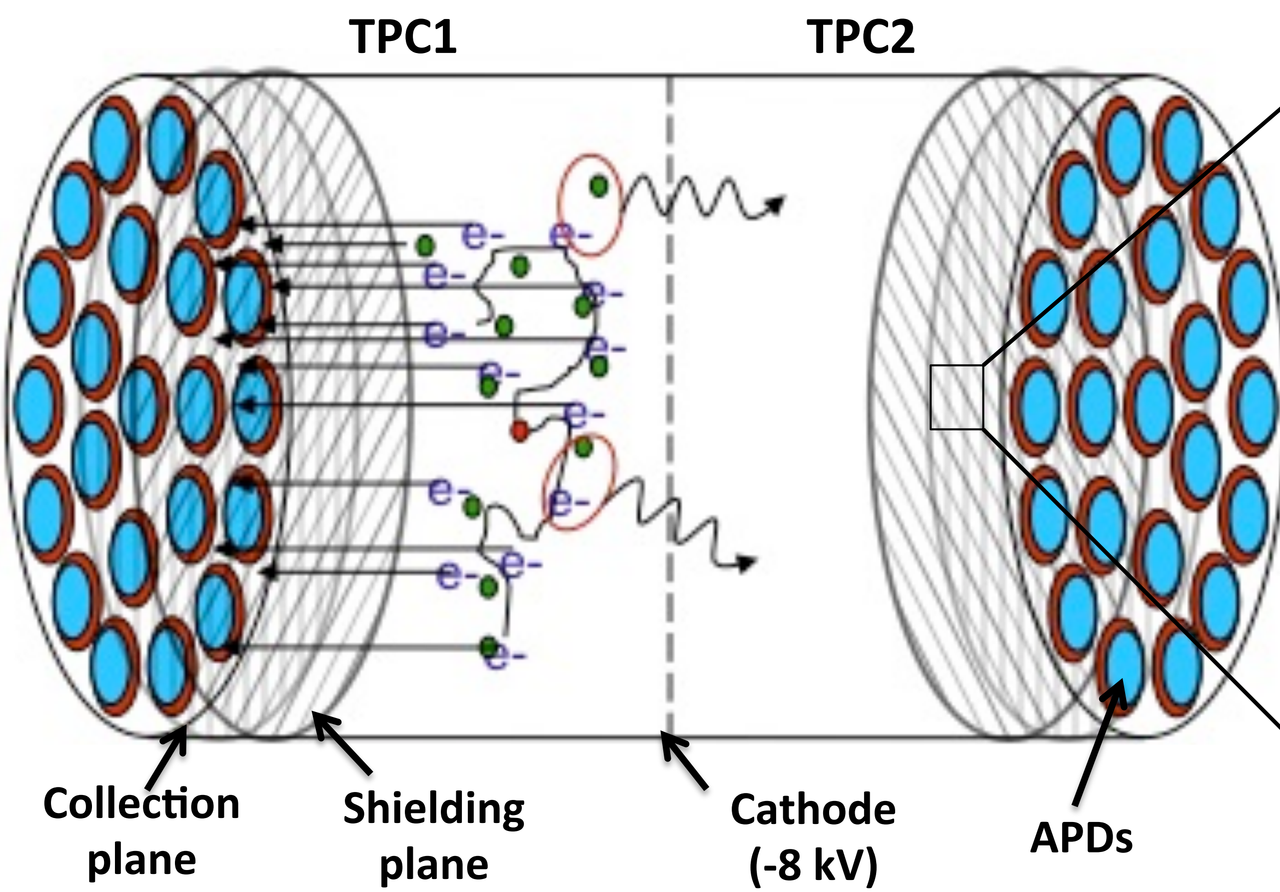
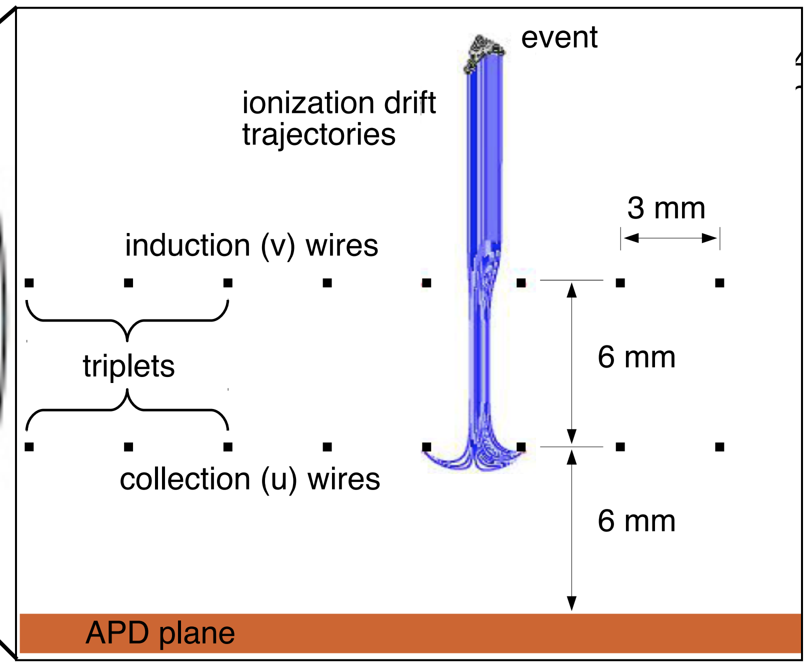
TRIUMF, Vancouver BC, Canada – J. Dilling, R. Krucken, F. Retière, V. Strickland

EXO-200 TPC

- EXO-200 consists of radiopure, dual time projection chambers (TPCs) sharing a central cathode (filled with ~150 kg LXe, enriched to 80.6% ^{136}Xe)
- Scintillation collected by avalanche photo-diodes (APDs) at interaction time
- Charge collection and shielding planes rotated to give X/Y position, Z from charge drift time



2D cross-section of collection grid:



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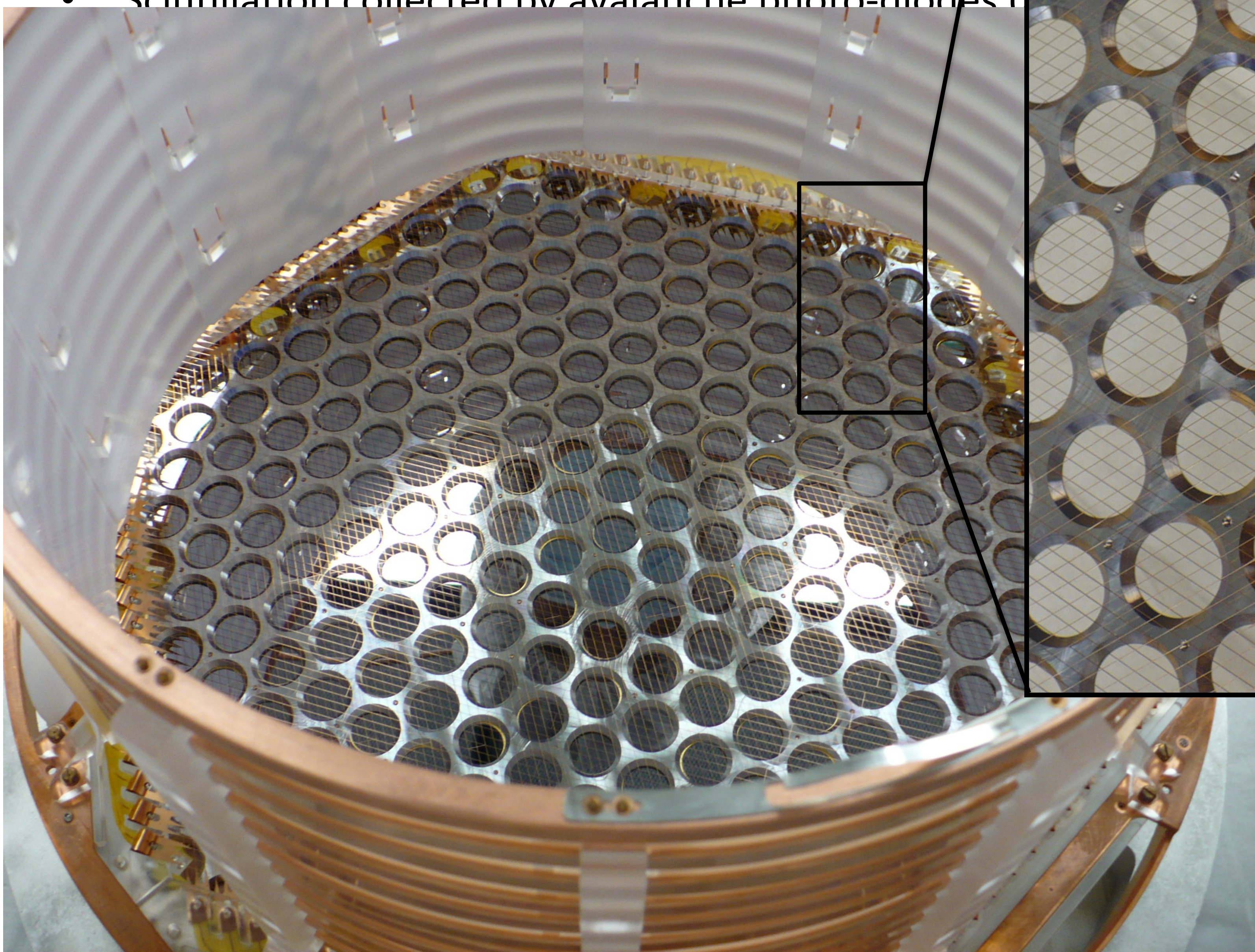
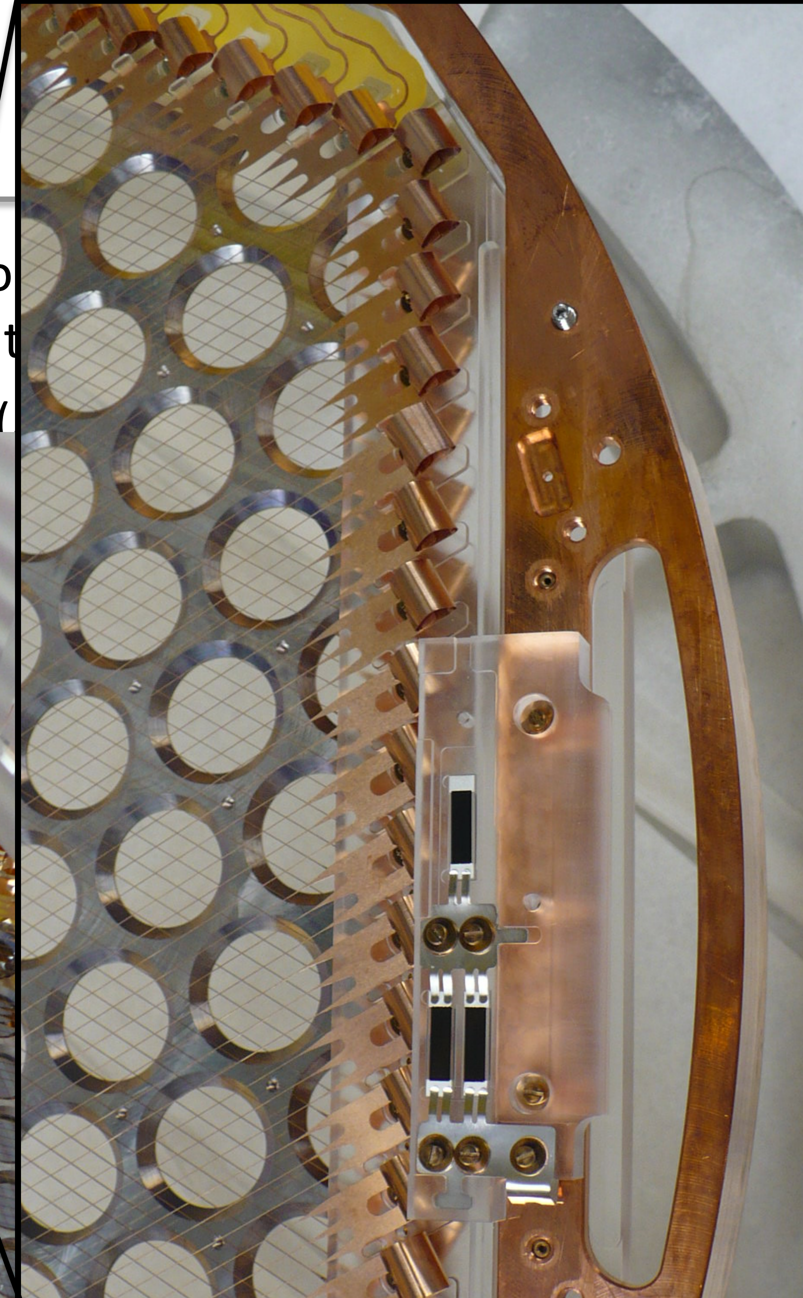
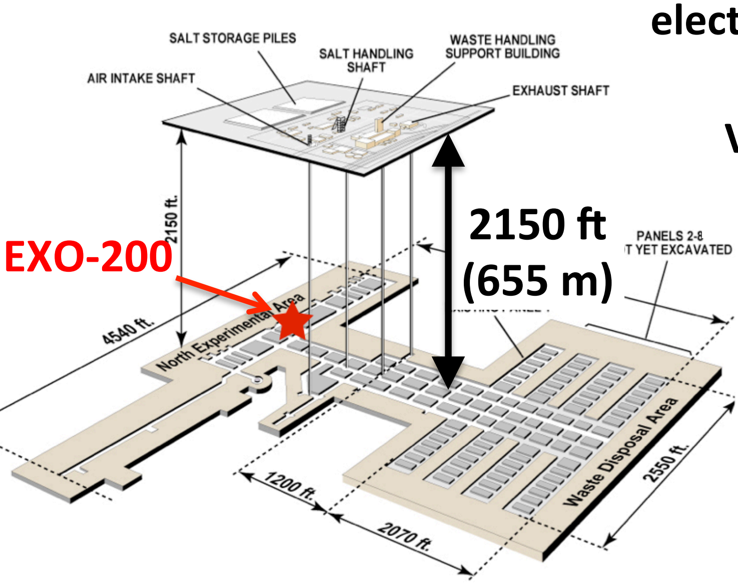




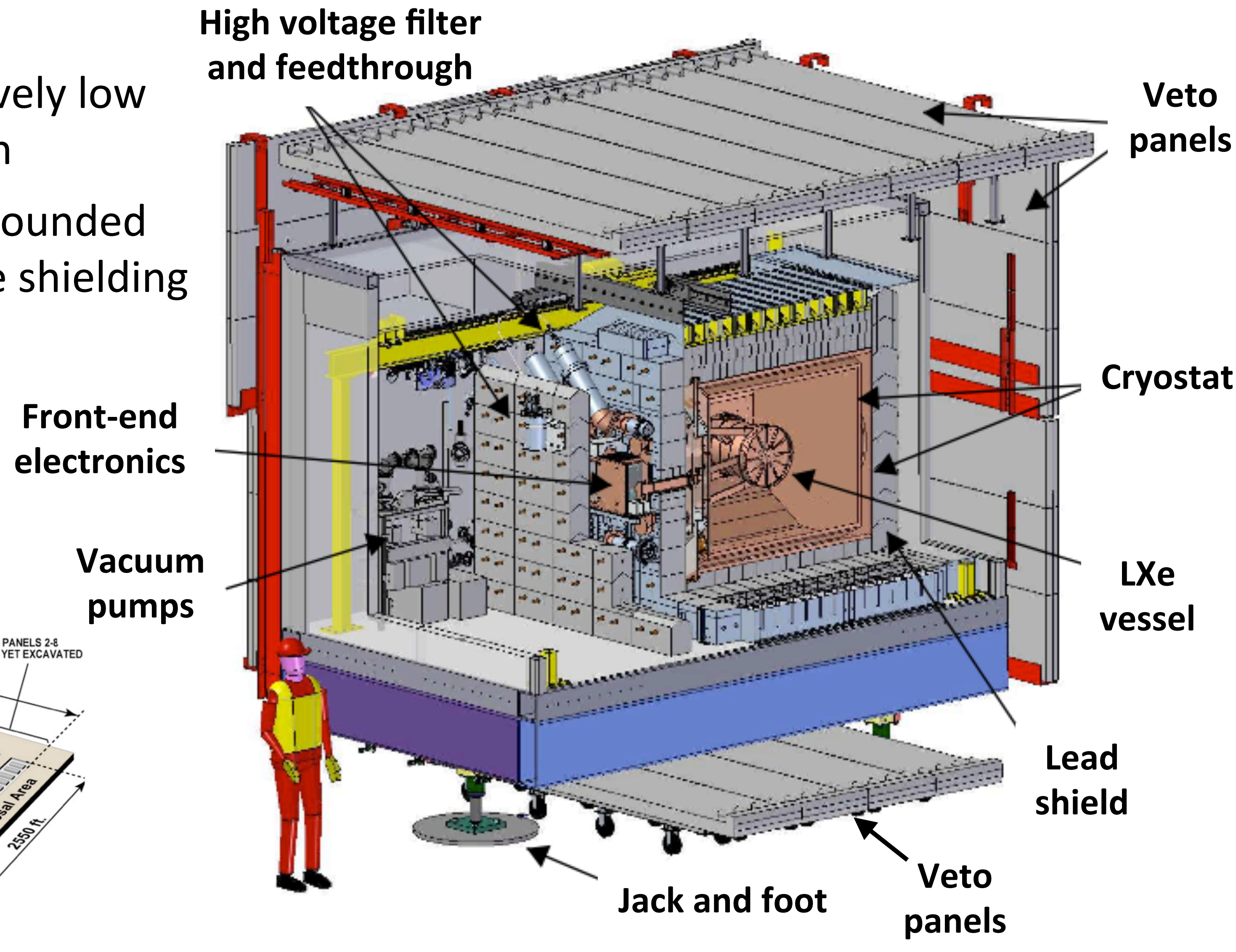
EXO-200 detector

- Detector installed at WIPP facility near Carlsbad, NM (~1600 mwe)
- Salt mine with relatively low levels of U/Th and Rn
- TPC additionally surrounded by active and passive shielding

WIPP Facility:



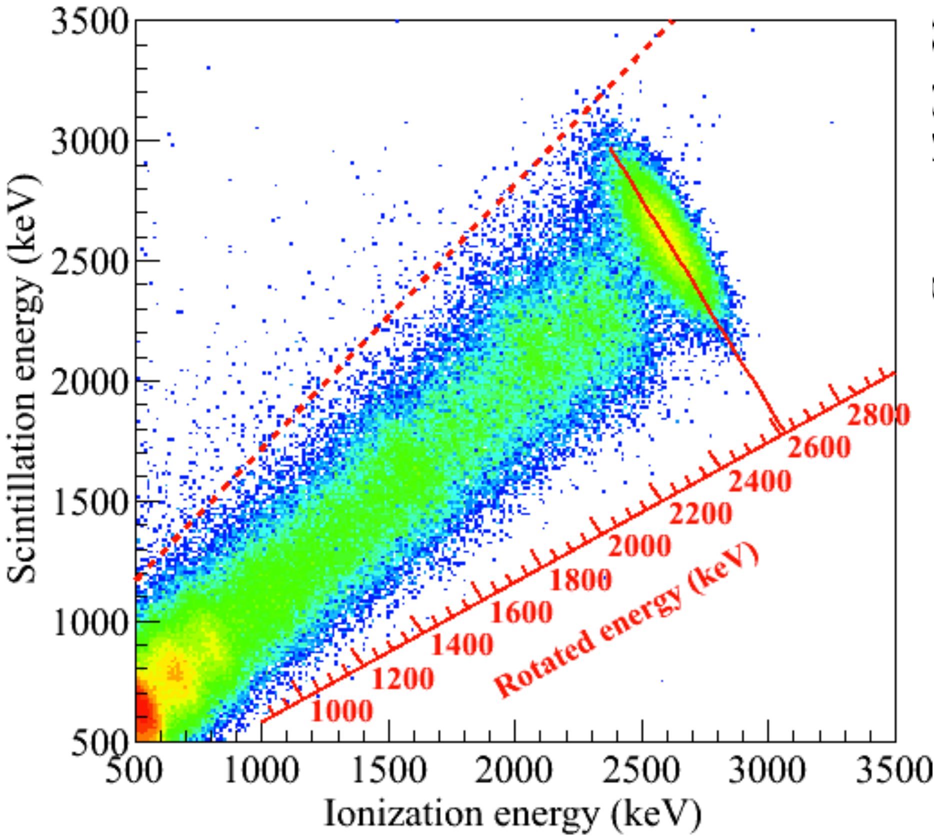
Detector schematic:



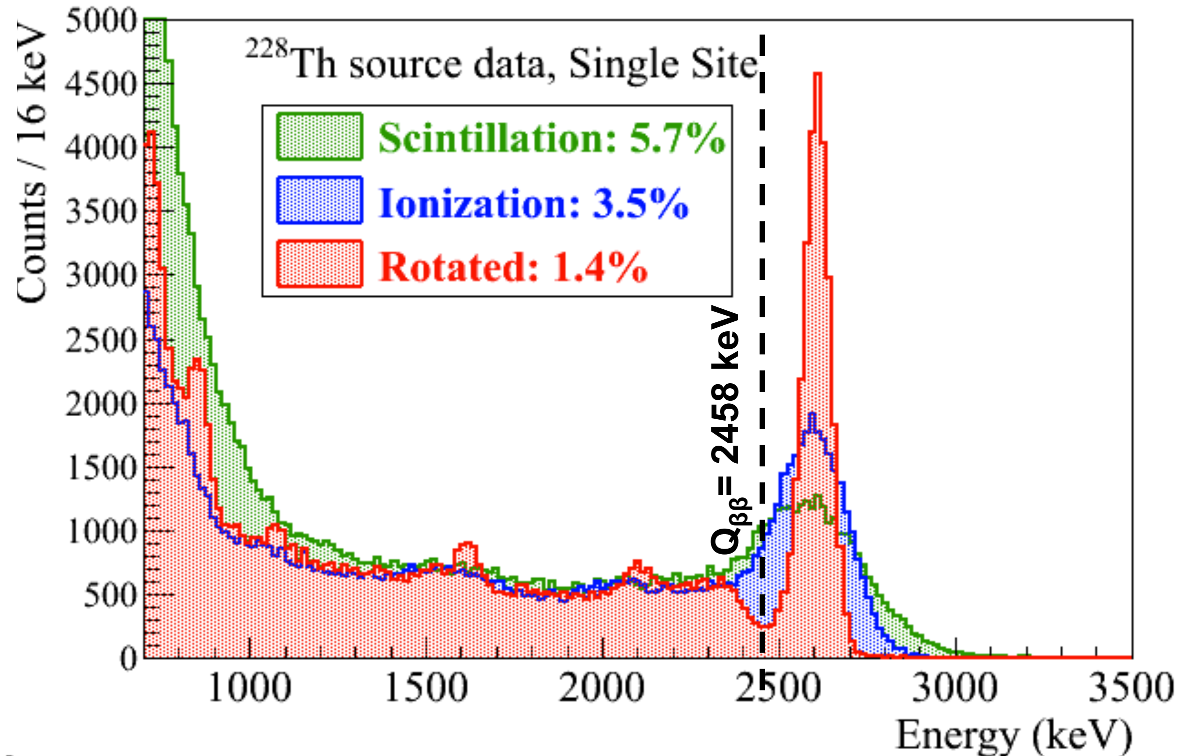
Energy reconstruction

- Reconstruct "rotated" energy measured in scintillation versus ionization plane
- Takes into account anti-correlation of charge and scintillation response to improve energy resolution
- Calibration performed with ^{60}Co, ^{137}Cs, ^{226}Ra, and ^{228}Th

Scintillation vs. Ionization, ^{228}Th calibration data:

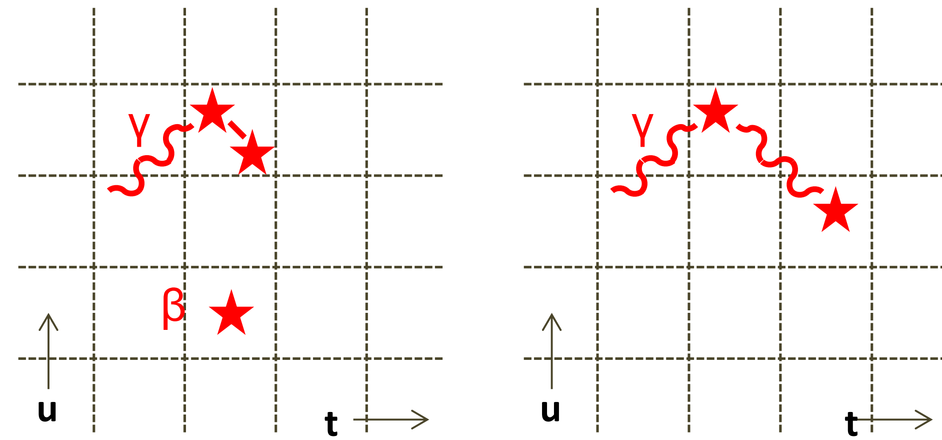


Reconstructed energy, ^{228}Th calibration data:

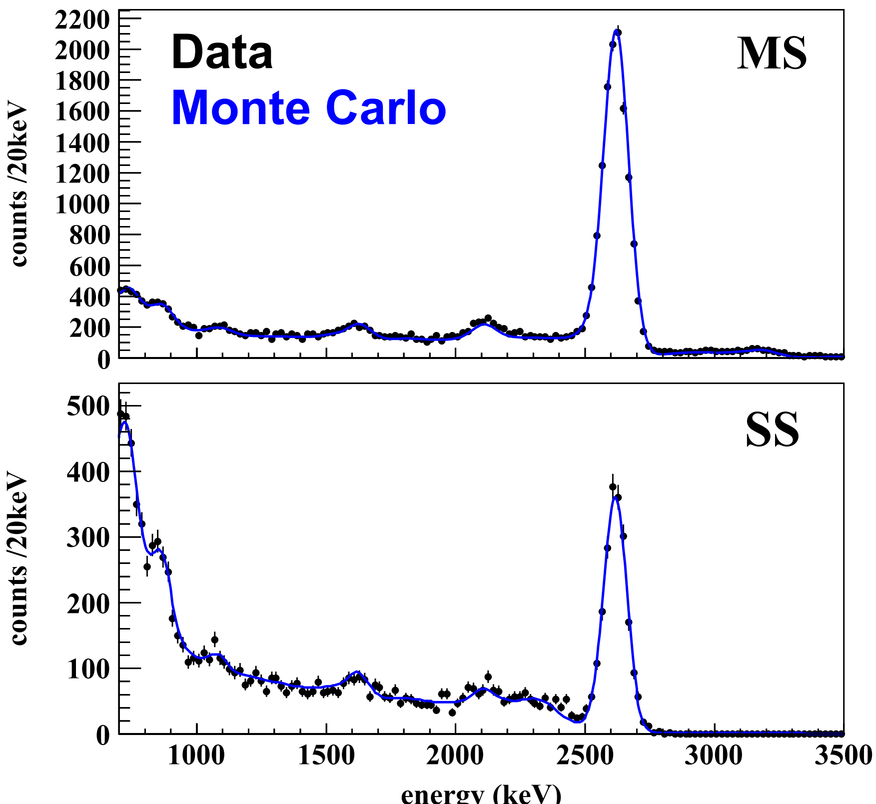


Background discrimination

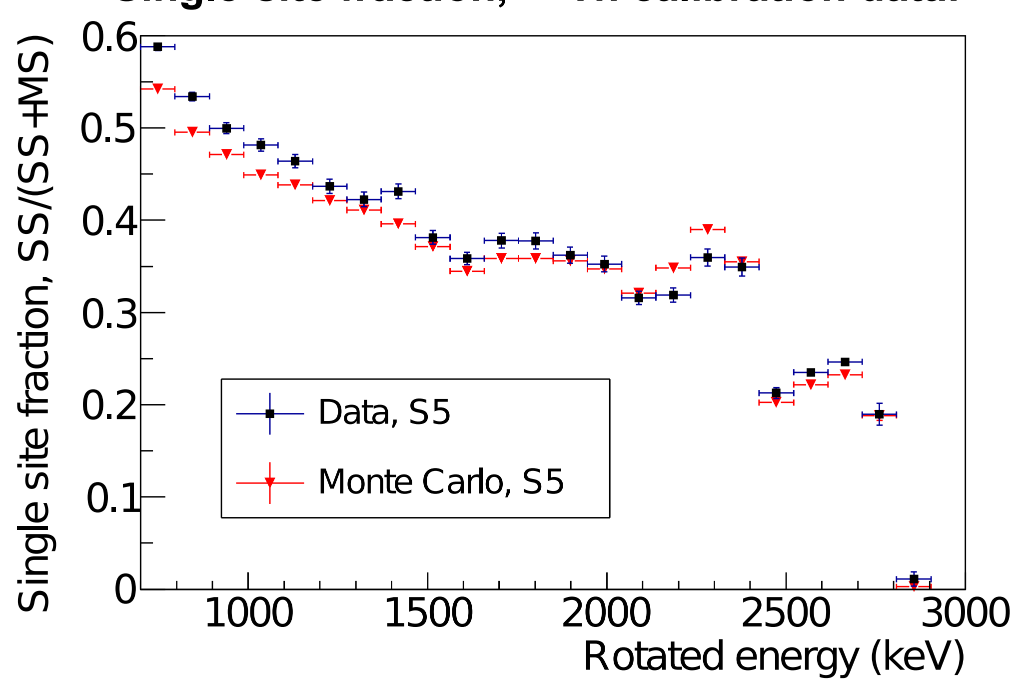
- Most backgrounds deposit energy at multiple locations (multi-site, MS), while signals deposited at single location (single-site, SS)
- Channel pitch is 9 mm in X/Y, Z resolution from timing is ~6 mm



Energy spectrum, ^{228}Th calibration data:



Single-site fraction, ^{228}Th calibration data:

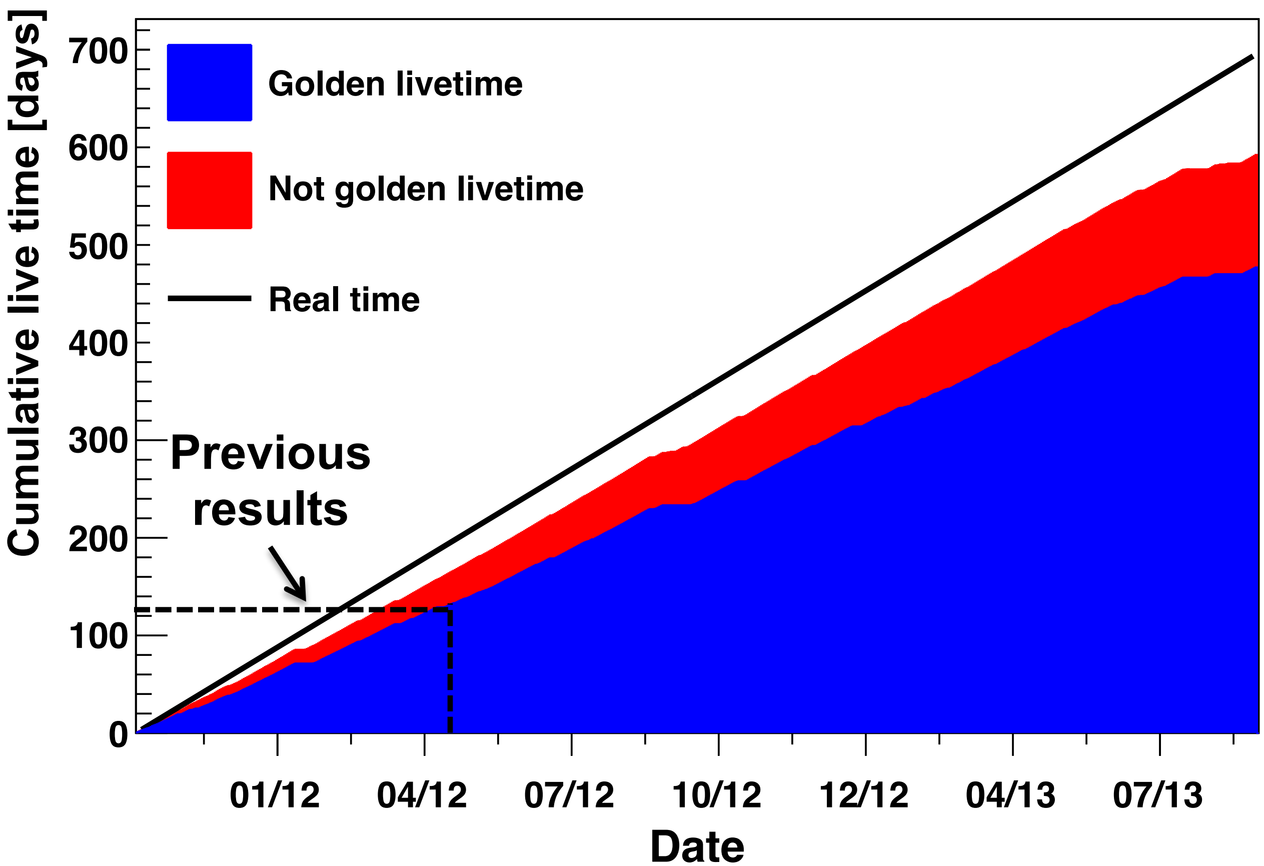


*Phys. Rev. C **89**, 015502, arXiv:1306.6106 (2013)*

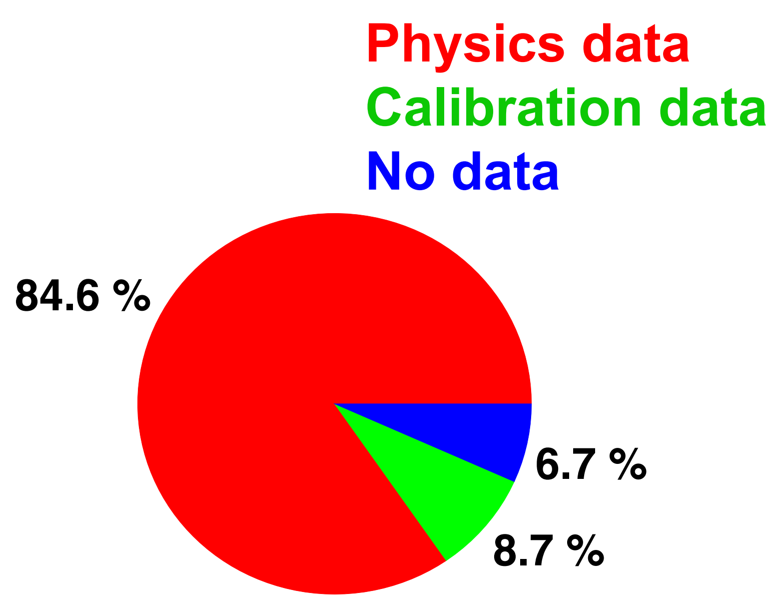
Run 2 data set

- Data analyzed in this work were taken between Oct. 2011 and Sept. 2013
- Total accumulated "Golden" data was 447.60 ± 0.01 days, corresponding to a ^{136}Xe exposure of 100 kg · yr

Run 2abc data taking vs. time:

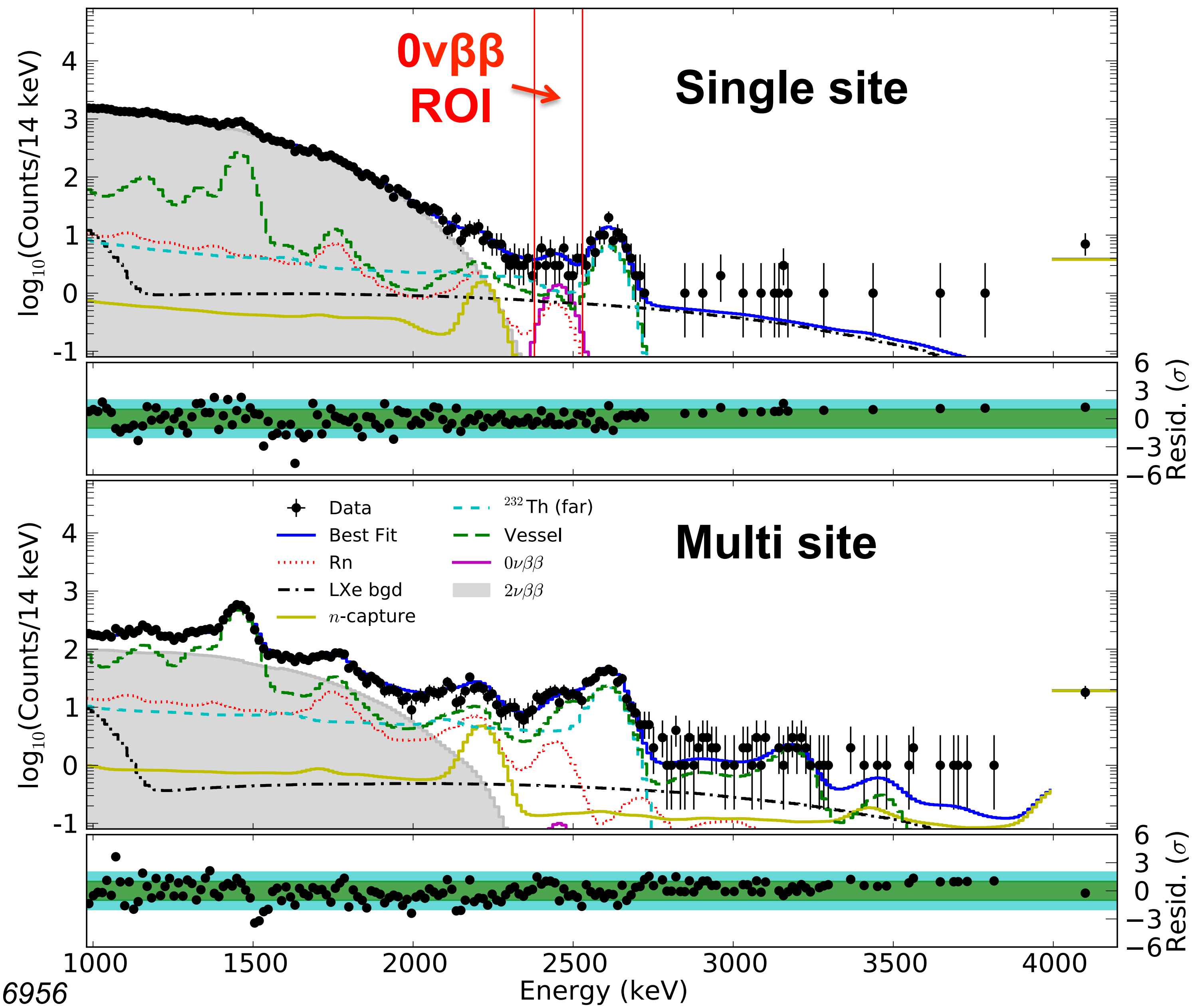


Data taking fraction:



0νββ results

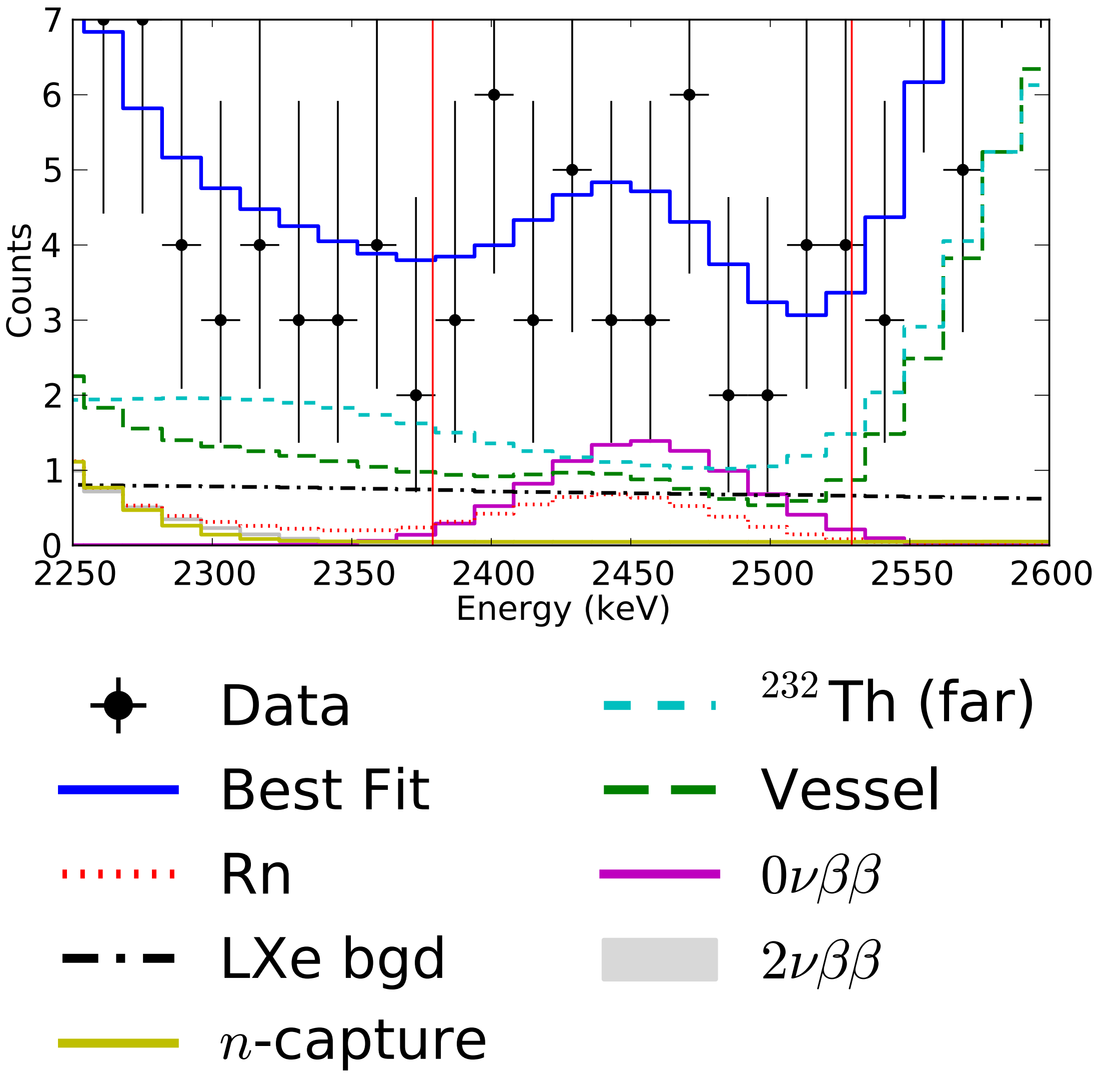
- Perform fit of observed spectrum from 980-9800 keV
- Multi-site data constrain backgrounds, while 0νββ ROI is in single-site data
- Fit also includes “standoff distance” from nearest TPC surface to better constrain backgrounds (suppressed here for clarity)



*Nature **510**, 229 (2014), arXiv:1402.6956*

0νββ results

Fit to single site spectrum near 0νββ ROI:



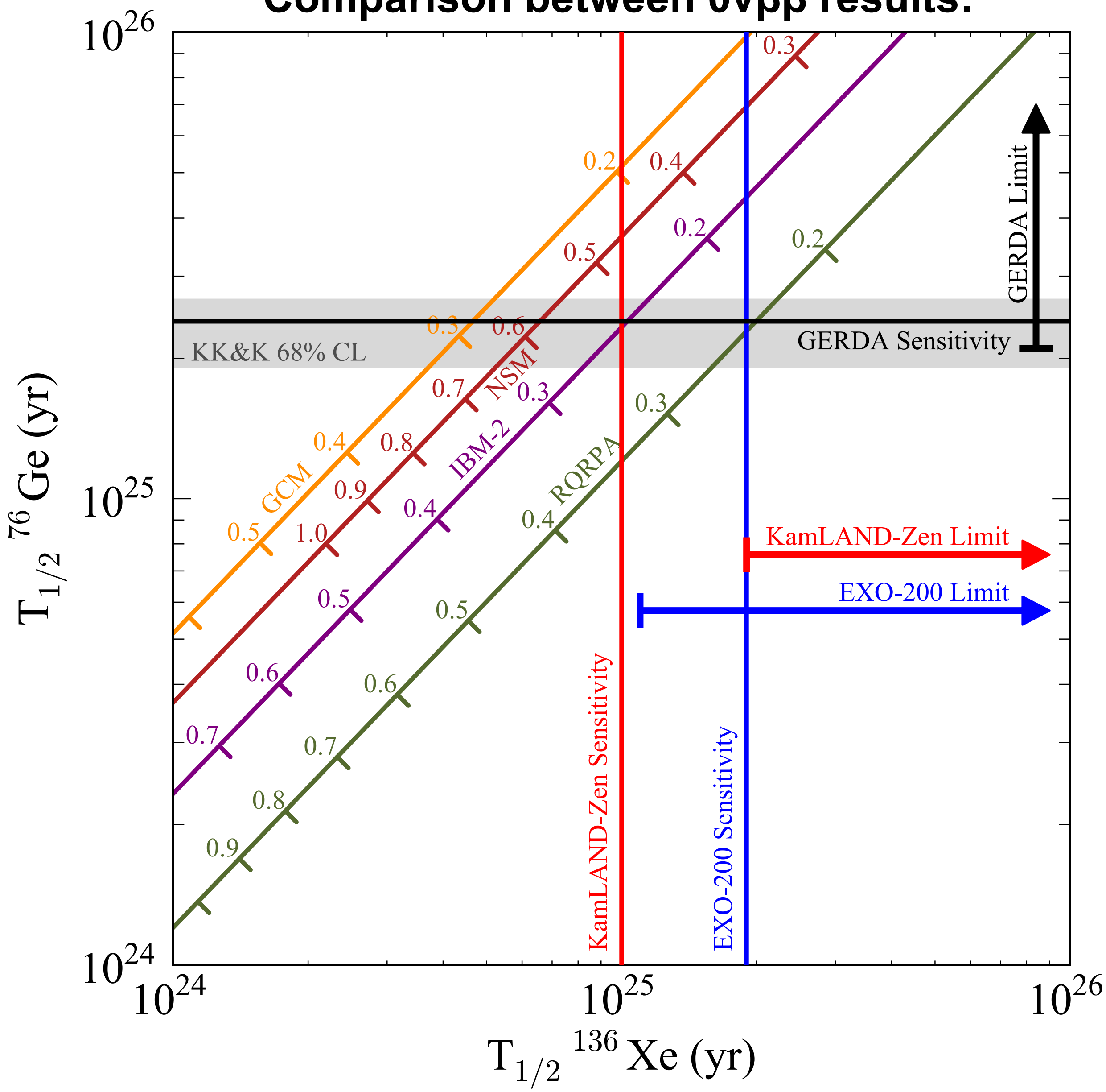
Backgrounds in ± 2σ ROI:	
Th chain	16.0
U chain	8.1
Xe-137	7.0
Total	31.1 ± 3.8

$T_{1/2}^{0\nu\beta\beta}$ > 1.1·10^{25} yr
$\langle m_{\beta\beta} \rangle$ < 190 - 450 meV
(90% C.L.)

*Nature **510**, 229 (2014), arXiv:1402.6956*

0νββ status

Comparison between 0νββ results:



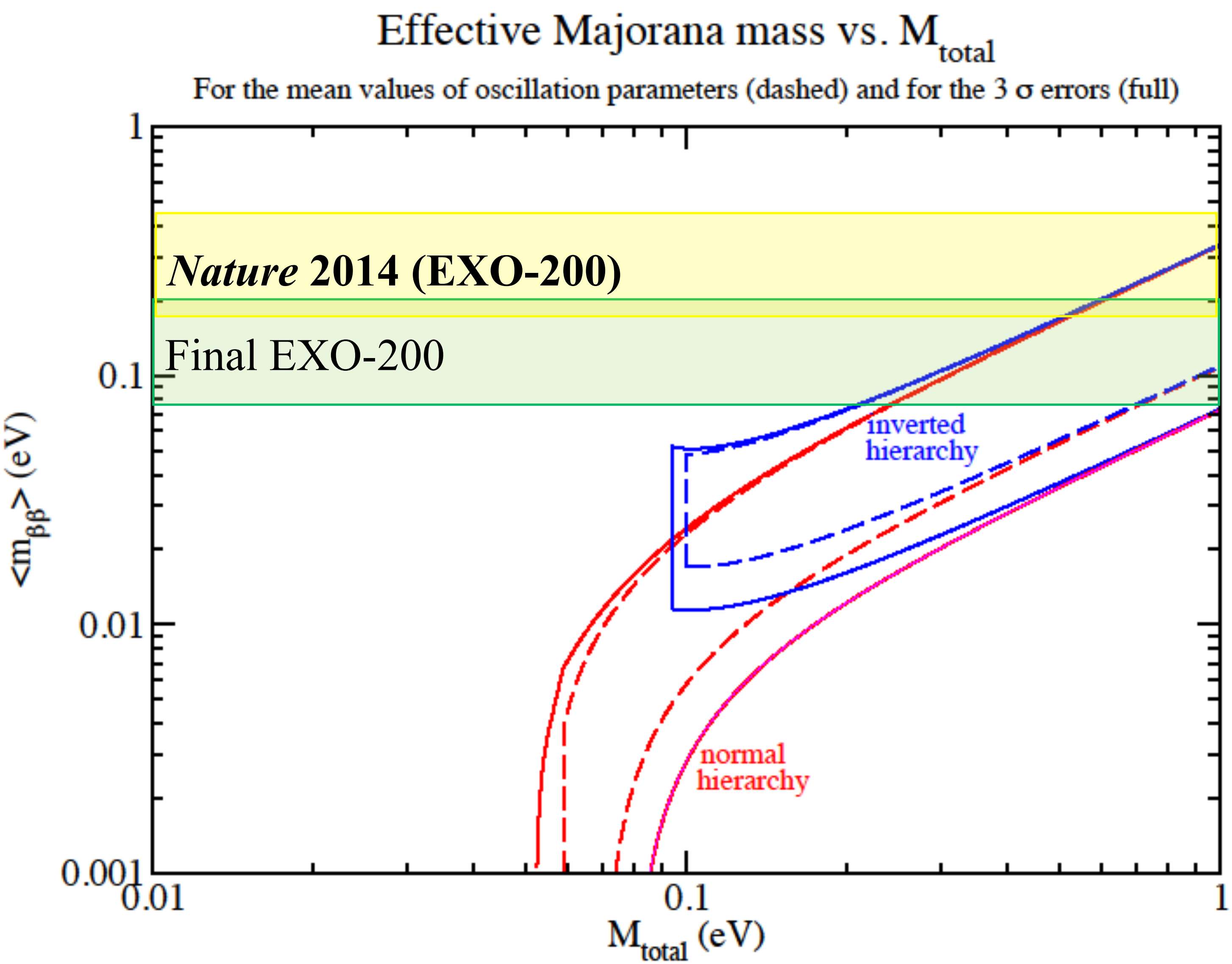
EXO-200:
Nature 510, 229 (2014)

GERDA Phase 1:
PRL 111 (2013) 122503

KamLAND-Zen:
PRL 110 (2013) 062502

KK&K Claim:
Mod. Phys. Lett., A21 (2006) 1547

Current and projected sensitivity



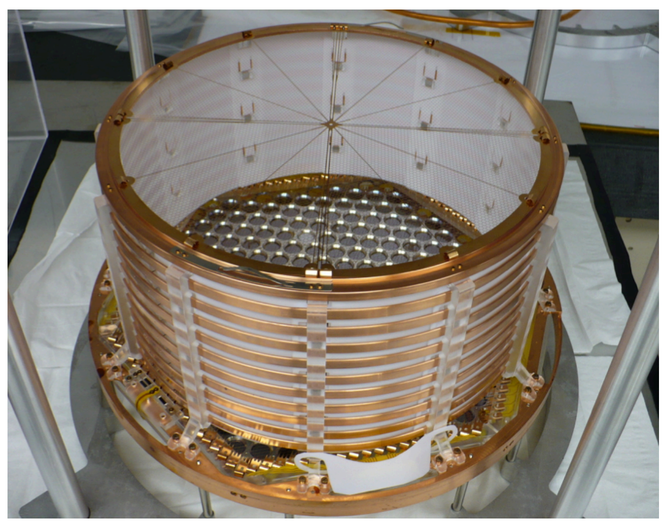
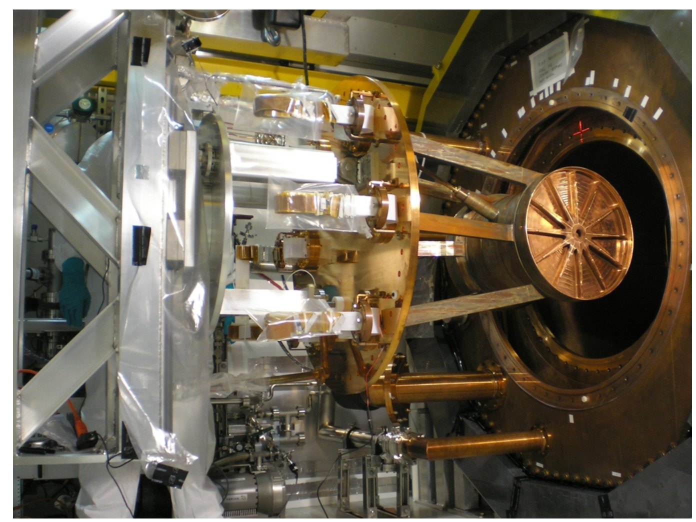
Final EXO-200: Assumes 2 years additional livetime with Rn removal

Upgrades to electronics to reduce APD noise are also planned

Data taking has stopped due to WIPP closure. Planned access to experimental site in Fall 2014.

Summary

- EXO-200 took 2 years of data between Oct. 2011 and Sept. 2013
- Search for $0\nu\beta\beta$ in full 2 year data set gave $T_{1/2}^{0\nu\beta\beta} > 1.1 \cdot 10^{25}$ yr (90% CL), and provides one of the most sensitive searches to date
- Data taking is currently stopped due to WIPP closure, but plan to upgrade the experiment and resume data taking in Fall 2014
- R&D for multi-tonne nEXO underway (see following talk)

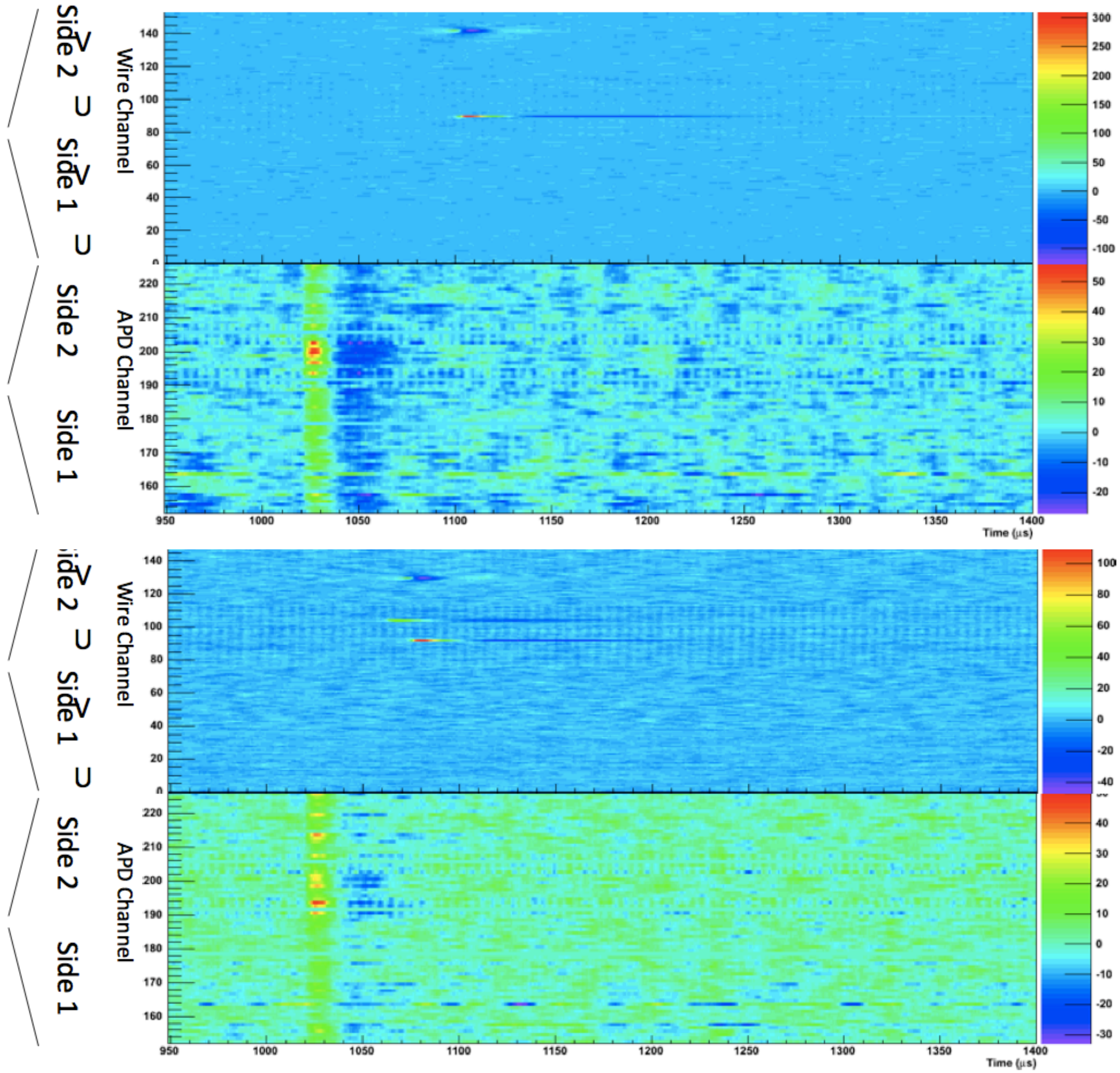




Event topology

Single site:

Charge readout
V: Induction
U: Collection

Light readout



Multi site:

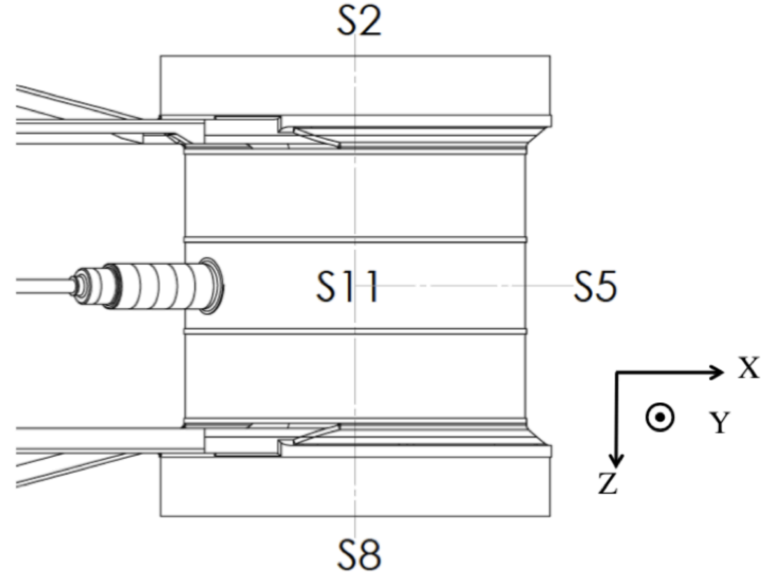
Charge readout
V: Induction
U: Collection

Light readout

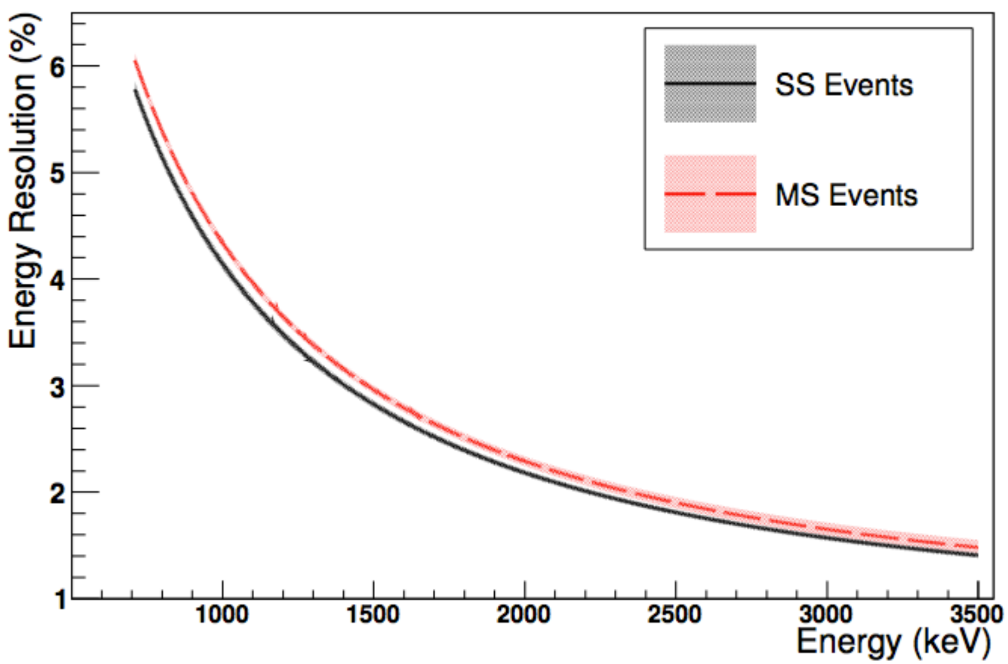
Calibration

- Calibrate in situ with 4 γ sources spread over energy range from 662-2615 keV (^{60}Co, ^{137}Cs, ^{226}Ra, and ^{228}Th)
- Calibrations taken 2-3 times per week with ^{228}Th position near cathode (S5), every few months with additional sources/locations

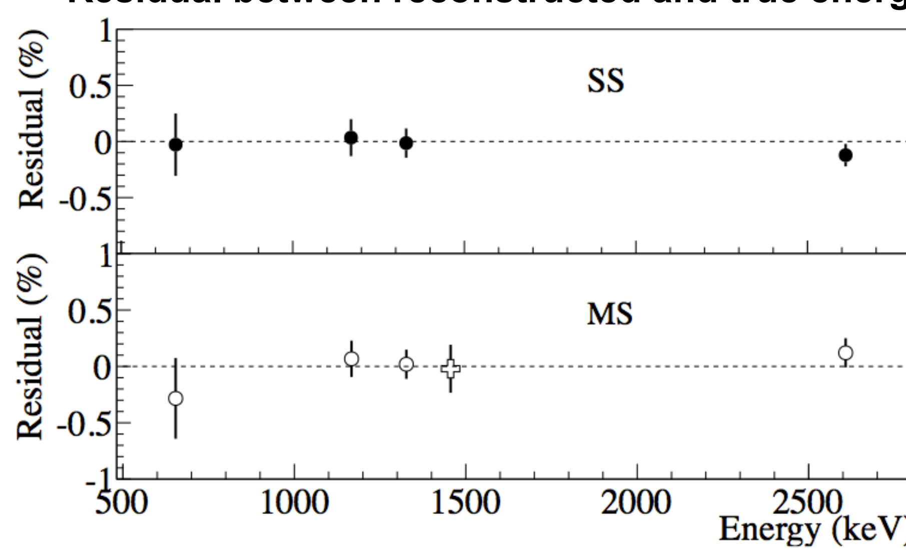
Calibration locations:



Relative resolution vs. energy:



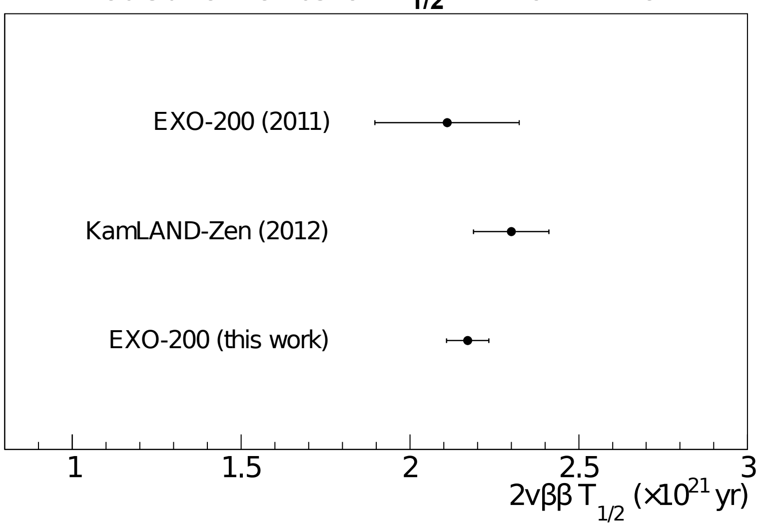
Residual between reconstructed and true energy:



2νββ half life (2013)

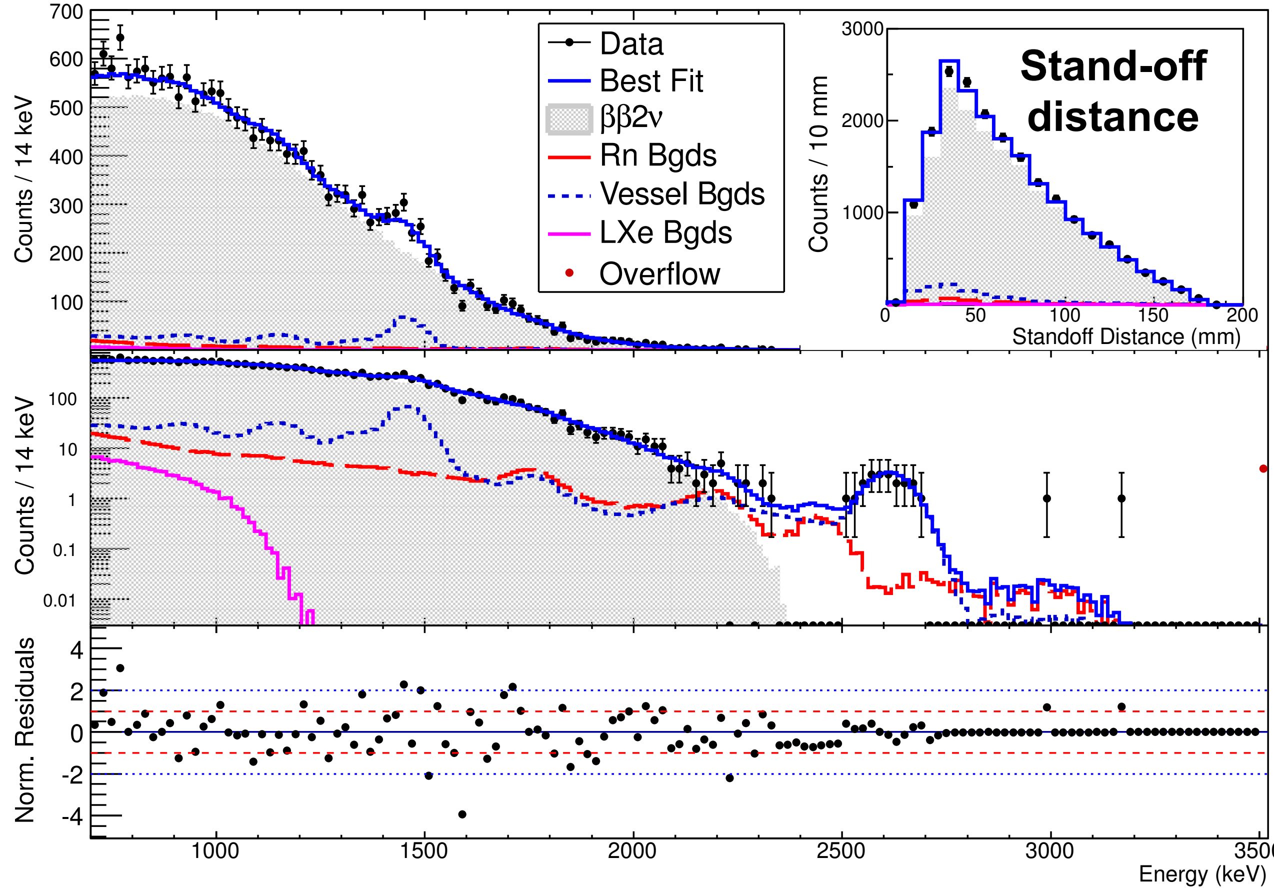
- Run 2a data set (previously analyzed in PRL **109**, 032505 [2012]) reanalyzed with improvements to event reconstruction and reduced fiducial volume uncertainty
- $T_{1/2}^{2\nu\beta\beta}$ measured with total relative uncertainty of 2.85 %
- Most precisely measured 2νββ half life of any isotope to date

Measurements of $T_{1/2}^{2\nu\beta\beta}$ for ^{136}Xe:



$T_{1/2}^{2\nu\beta\beta} = 2.172 \pm 0.017 \pm 0.060 \cdot 10^{21}$ yr
(stat.) (syst.)

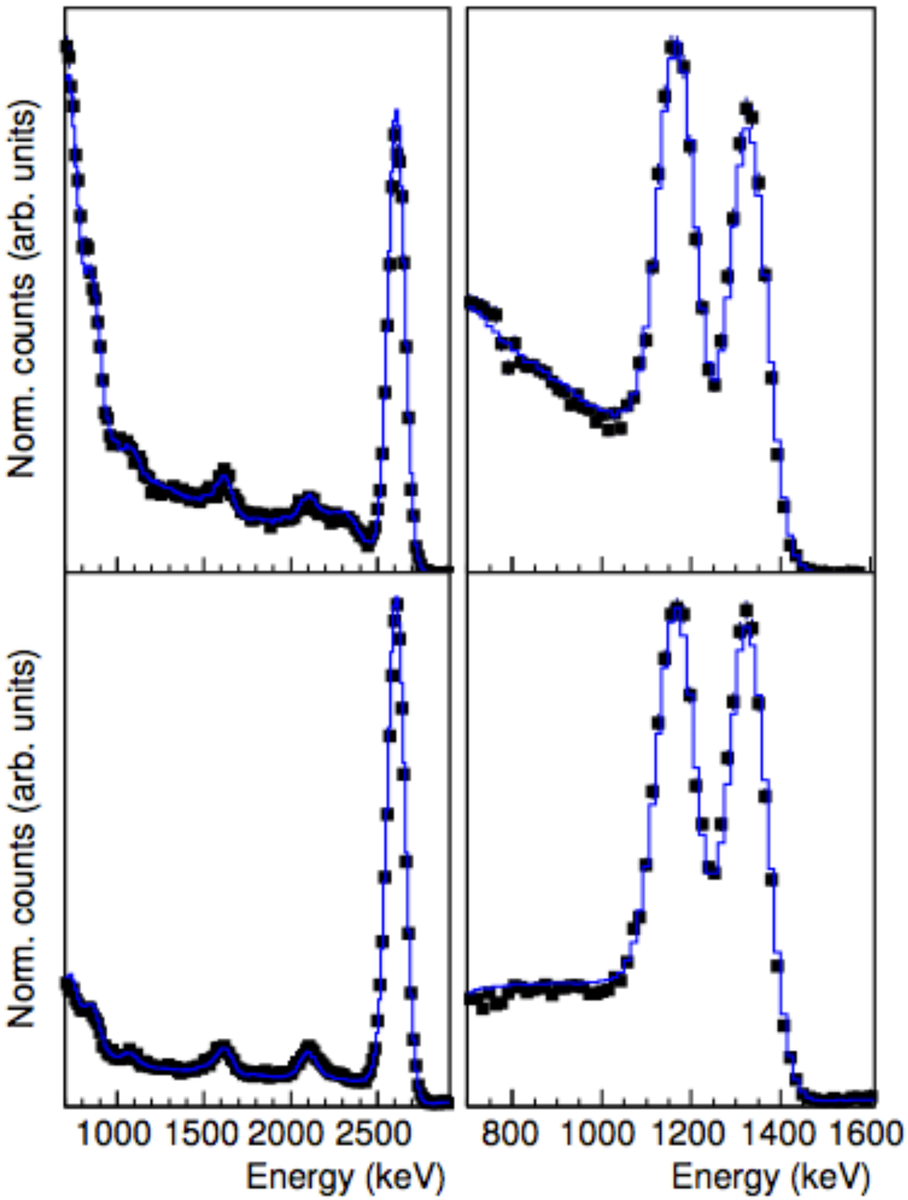
Single-site energy spectrum and fit:



*Phys. Rev. C **89**, 015502, arXiv:1306.6106 (2013)*

Source agreement

Source shape agreement:



Source rate agreement:

Source location	Source type	Absolute rate agreement (Data – (MC Sim))/Data [%]
S2 (anode)	^{228}Th	$3.5^{+0.8}_{-1.3}$
	^{60}Co	$2.4^{+0.4}_{-1.6}$
S5 (cathode)	^{228}Th	$1.1^{+1.0}_{-0.9}$
	^{60}Co	$-3.7^{+1.5}_{-1.2}$
S8 (anode)	^{228}Th	$-3.2^{+0.8}_{-0.9}$
	^{60}Co	$1.8^{+0.8}_{-1.1}$
S11 (cathode)	^{228}Th	$3.1^{+2.3}_{-2.7}$
	^{60}Co	$1.3^{+3.1}_{-4.0}$

- Excellent spectral shape agreement between data and MC for calibration with external Th and Co sources
- Absolute rate agreement with known source activities better than ~4%

Systematic errors

- Signal detection efficiency:

Source:	Signal efficiency [%]:	Relative error [%]:
Summary from PRC **89**, 015502 (2014)	93.1	0.9
Partial reconstruction	90.9	7.8
Fiducial volume/rate agreement		3.4
Total:	**84.6**	**8.6**

- ROI backgrounds:

Source:	Relative error [%]:
Background shape distortion	9.2
Choice of background model components	5.7
Variation of energy resolution over time	1.5
Total:	**10.9**

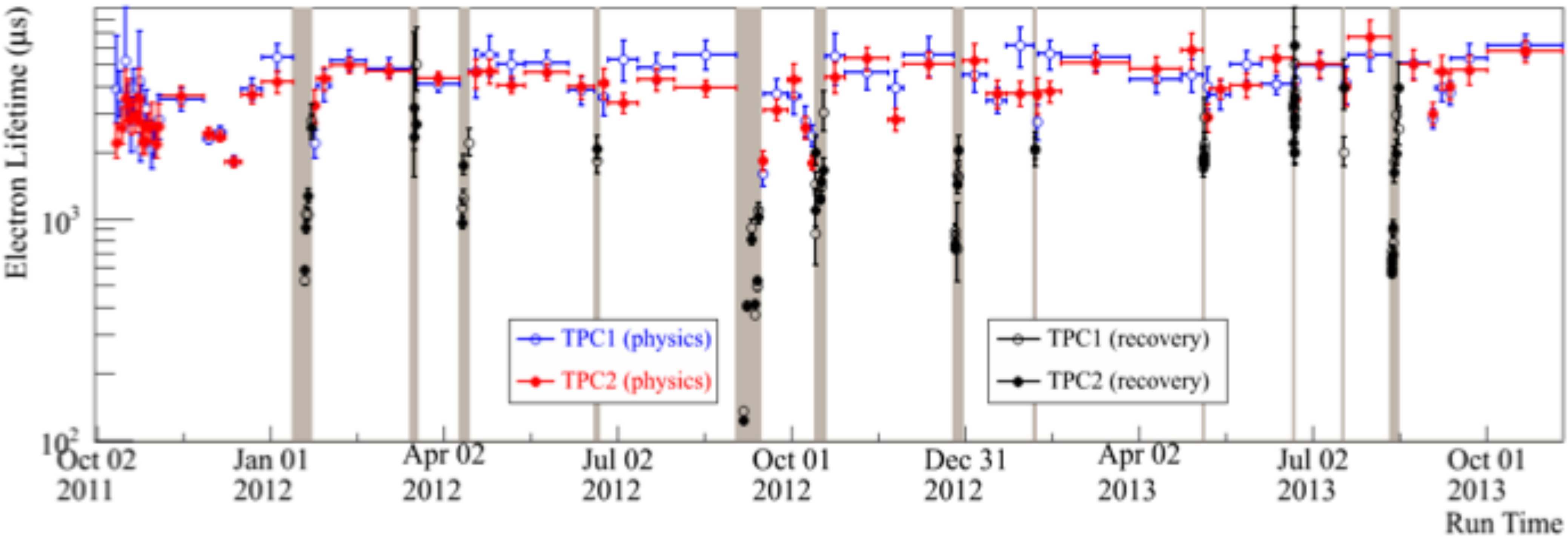
- Location of 0νββ ROI:

  Deviations between β and γ energy scale: $E_\beta = B^* E_\gamma \Longrightarrow$ $\boldsymbol{B = 0.999 \pm 0.002}$

- Single-site fraction error:

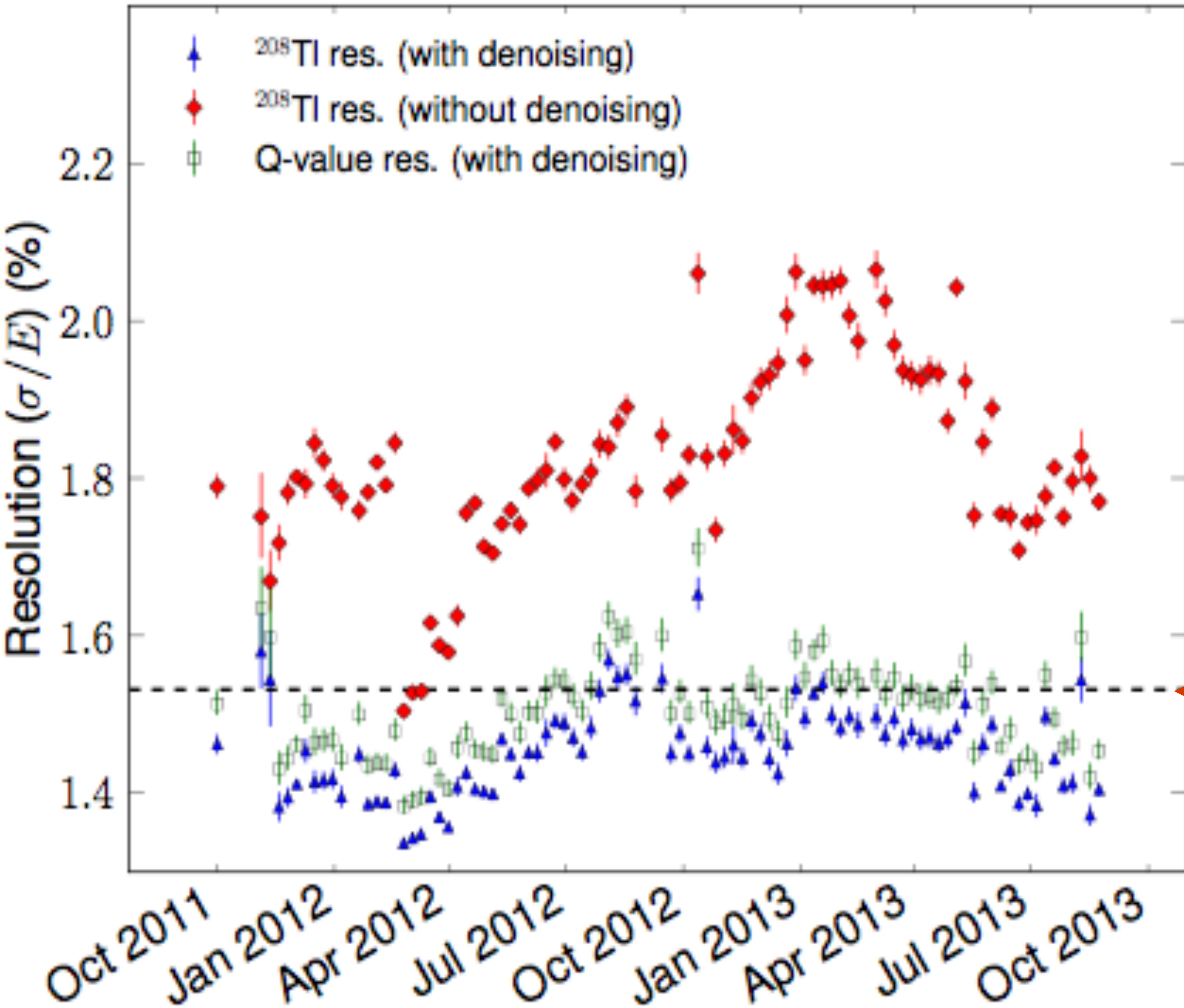
  Maximum deviation between data and simulation, averaged over all calibration sources:
  (Data – MC)/Data = 9.6%

Xe Purity over Run 2

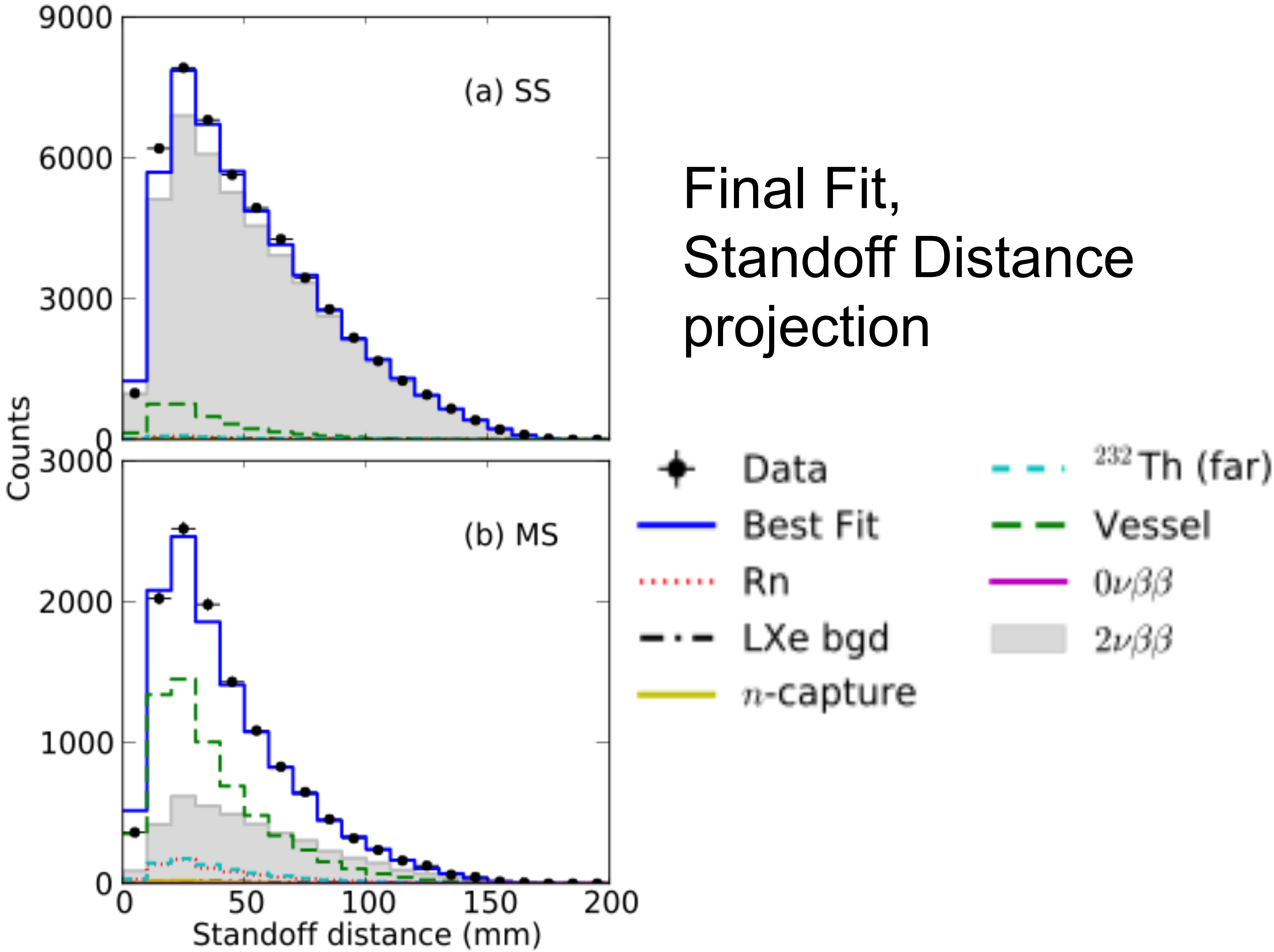


- Estimation based upon data from ^{228}Th source runs
- Purity strongly correlated with circulation pump speed
- At τ_e = 3 ms: drift time <110 μs, loss of charge: 3.6% at full drift length

APD Denoising



1.53 % in SS at 0νββ Q-value



Final Fit, Standoff Distance projection

Likelihood profile