Results from EXO-200

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Excellence Cluster ‘Universe’

for the EXO-200 collaboration

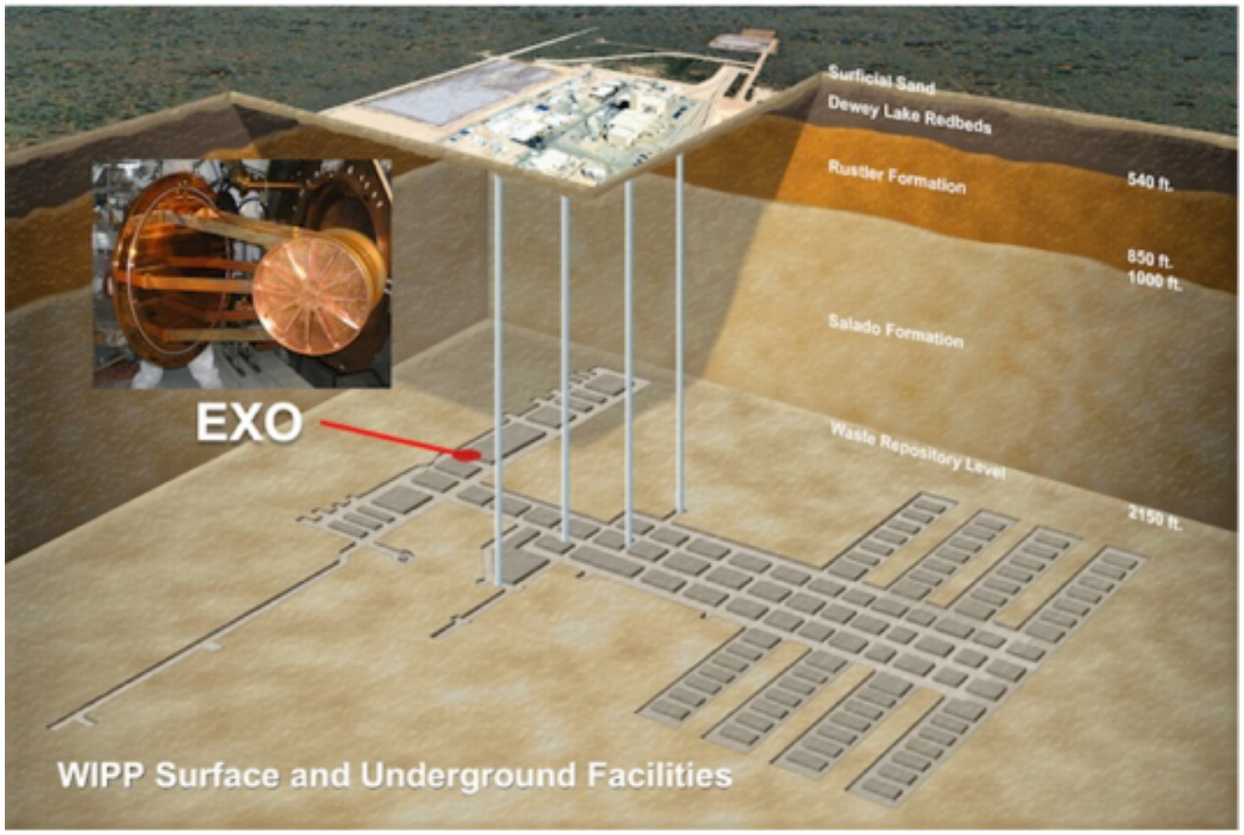
ALSO SEE:

EXO-200 and nEXO Posters (# 93 - 100) in Session II

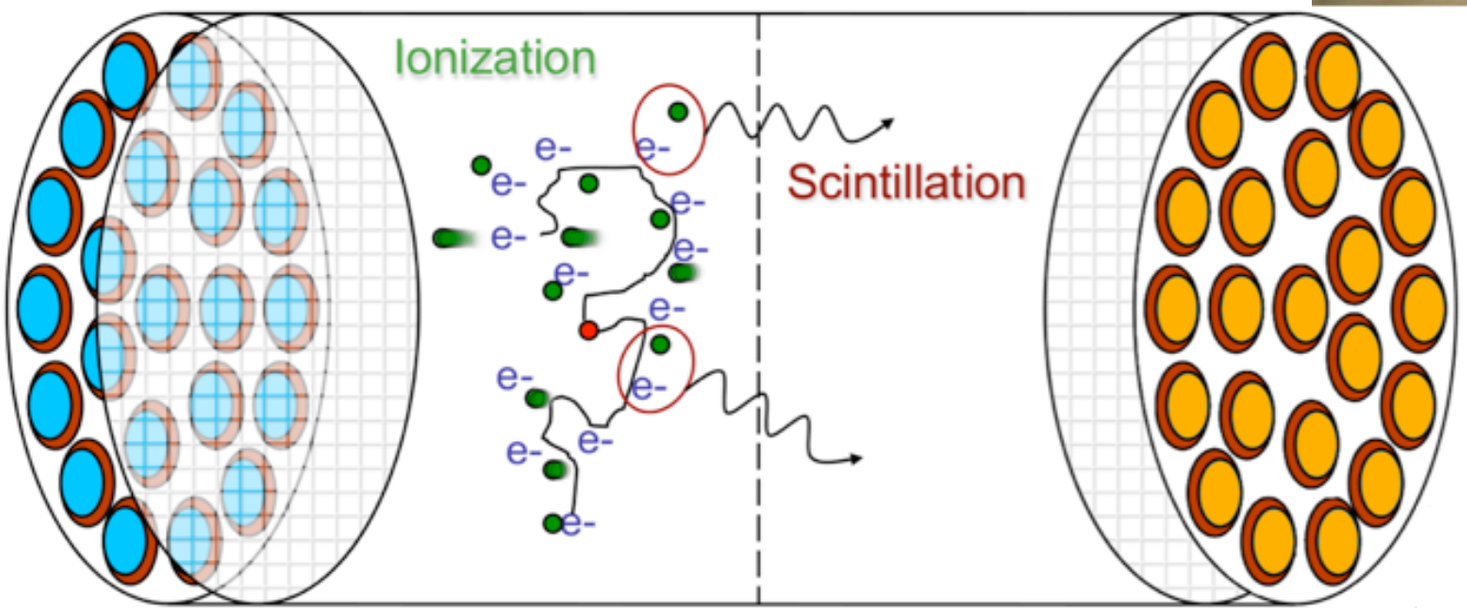
Neutrino 2014, Boston, USA
6 June 2014

EXO Enriched Xenon Observatory

- Liquid Xe Time Projection Chamber (TPC)
- Enriched ^{136}Xe to 80.6%
- Q-value 2458 keV



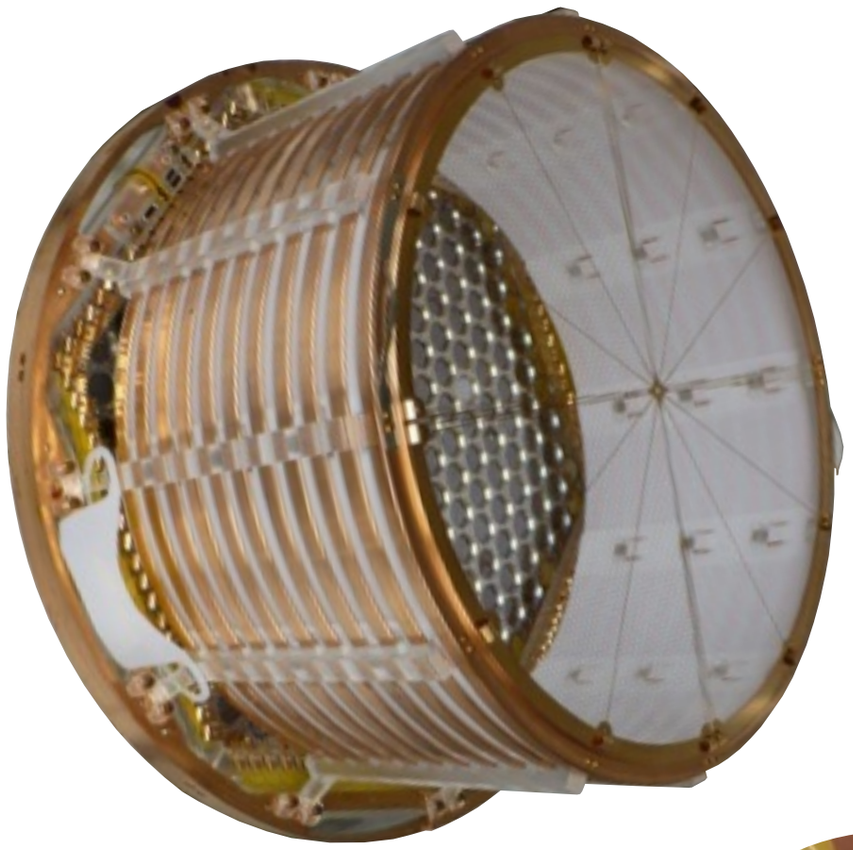
-8 kV



Avalanche Photo Diodes

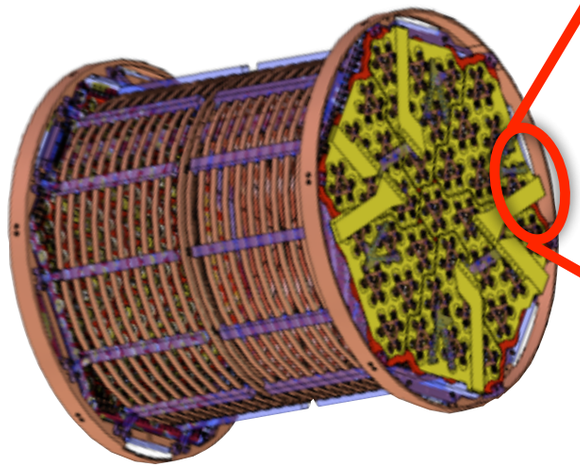
- Located at Waste Isolation Pilot Plant (WIPP) in Carlsbad, NM, USA
- 1585 meters water equivalent

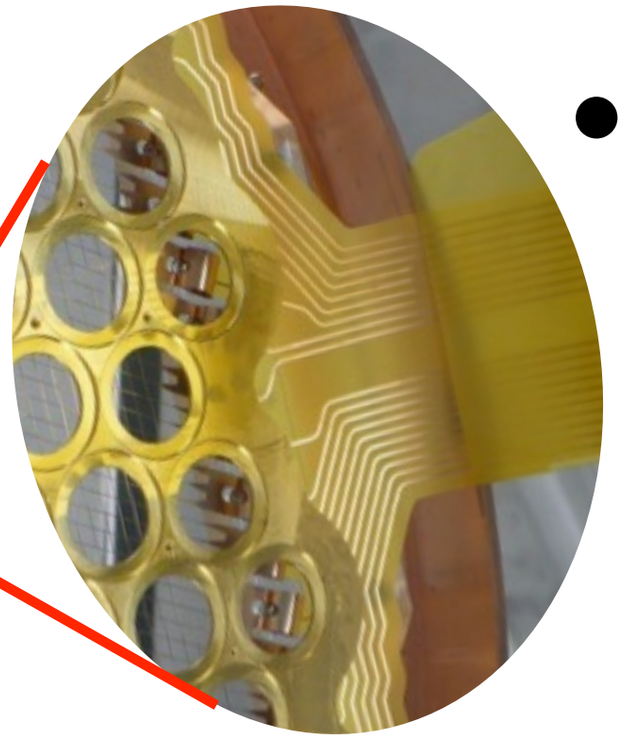
The EXO-200 TPC

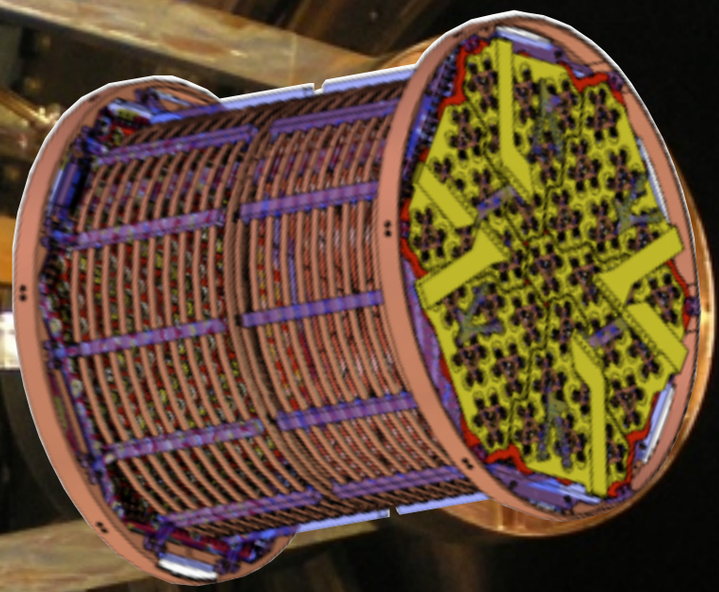


Two almost identical halves reading **ionization** and 178 nm **scintillation**, each with:

- 38 U triplet wire channels (charge)
- 38 V triplet wire channels, crossed at 60^{o} (induction)
- 234 large area avalanche photodiodes (APDs, light in groups of 7)
- All signals digitized at 1 MS/s, ±1024 μs around trigger (2 ms total)
- Drift field 376 V/cm







EXO-200 detector: JINST 7 (2012) P05010
Characterization of APDs: NIM A608 68-75 (2009)
Materials screening: NIM A591, 490-509 (2008)

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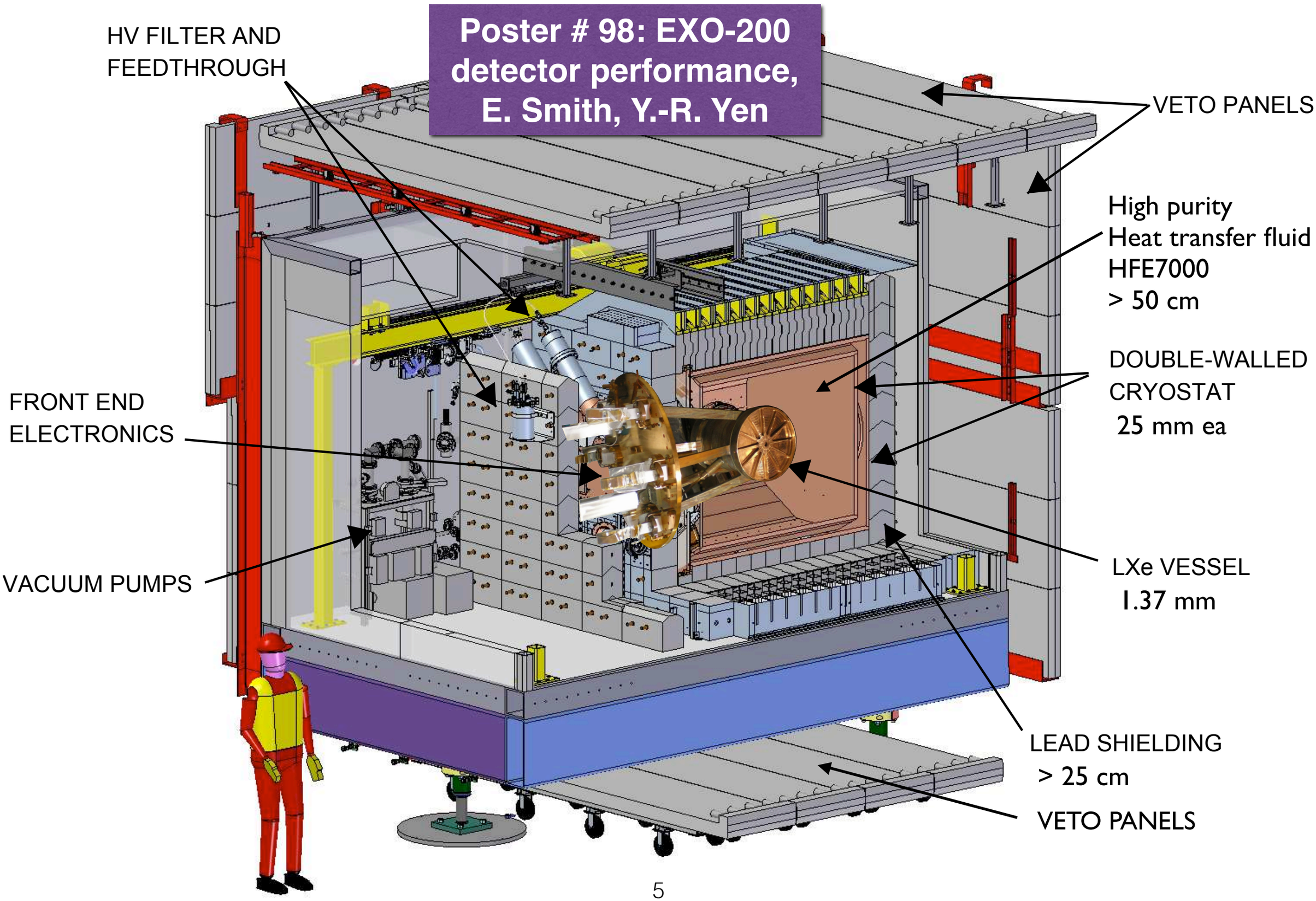
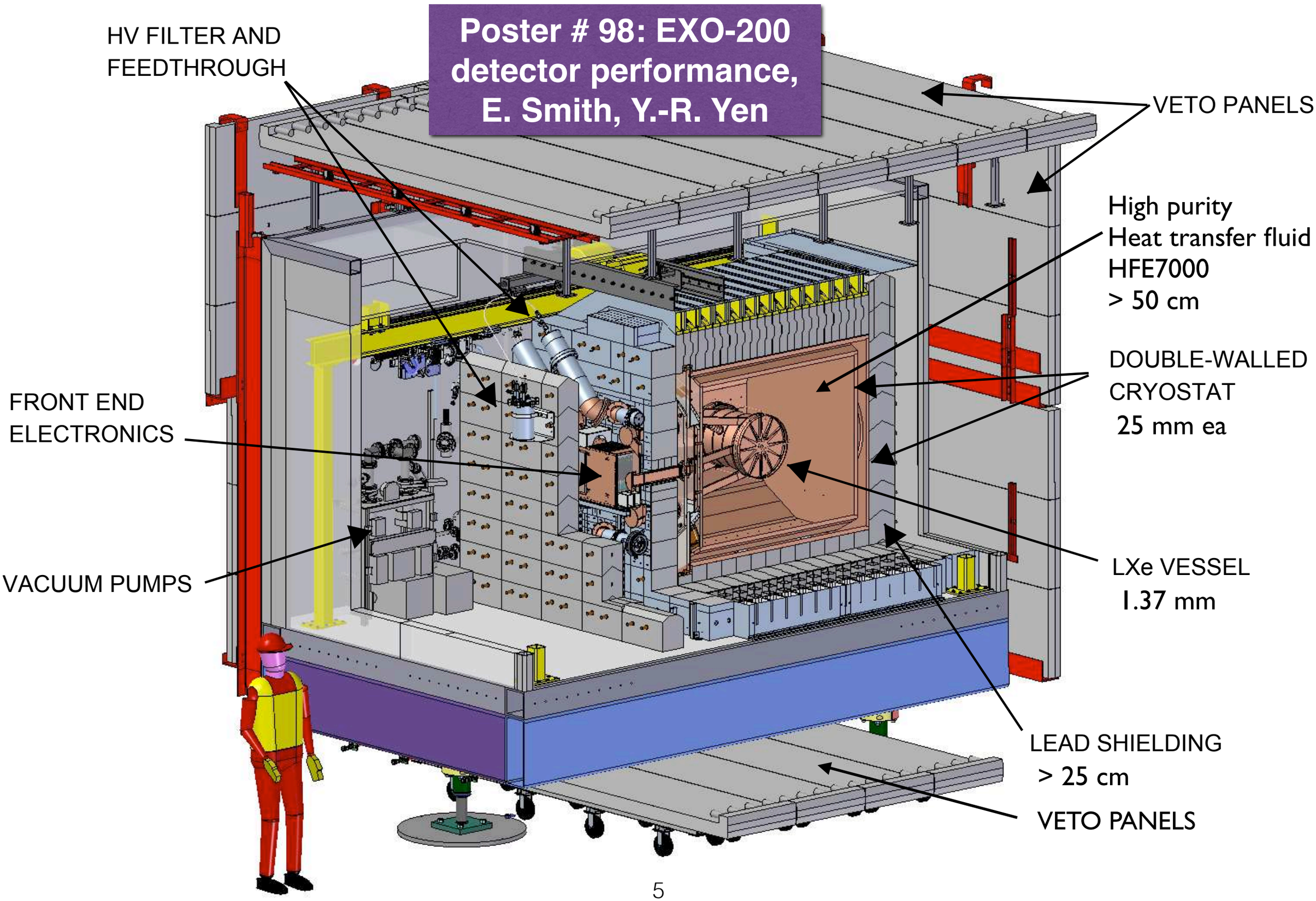
The EXO-200 Detector

Poster # 98: EXO-200 detector performance, E. Smith, Y.-R. Yen



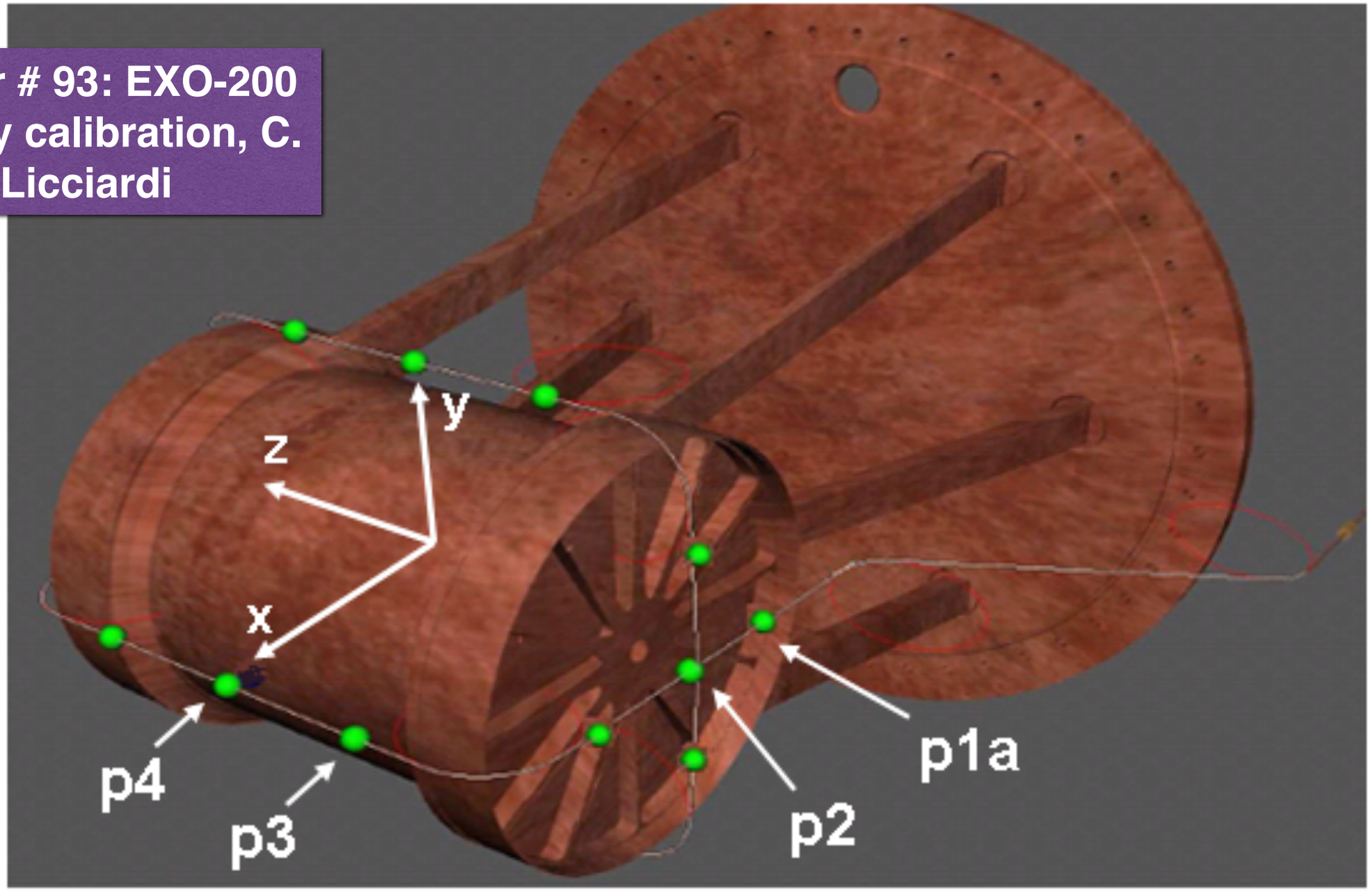
The EXO-200 Detector

Poster # 98: EXO-200 detector performance, E. Smith, Y.-R. Yen



Calibration

Poster # 93: EXO-200 Energy calibration, C. Licciardi



- Primary calibration - 2615 keV line from ^{228}Th source (deployed at least 2 times weekly)
- Periodic (every ~3 months) campaigns with ^{228}Th, ^{60}Co, ^{226}Ra, and ^{137}Cs, used also for systematics studies

Event reconstruction

1. Event position

2. Event multiplicity

3. Energy measurement

V-wire signals

U-wire signals

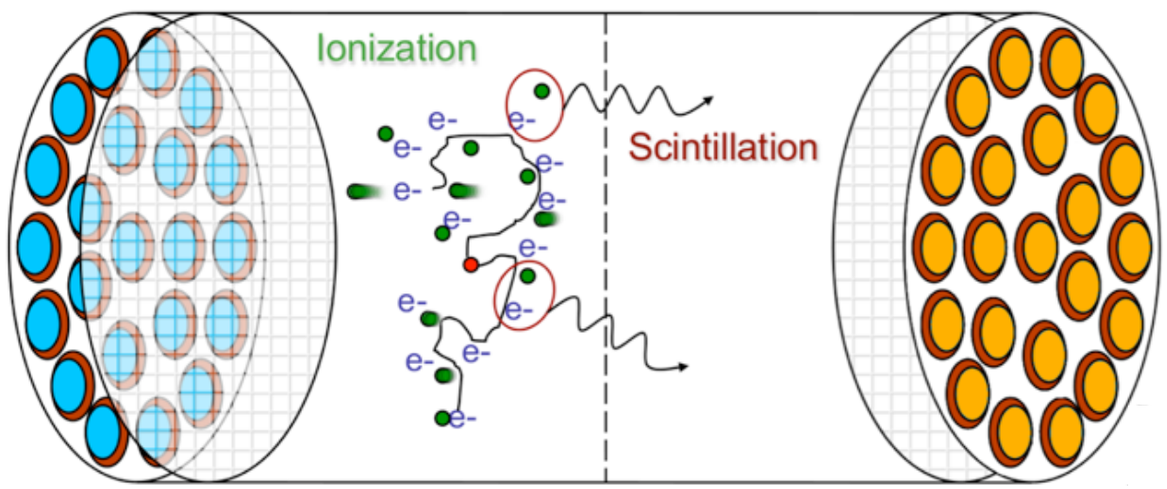
Charge clusters

Linked

APD signals

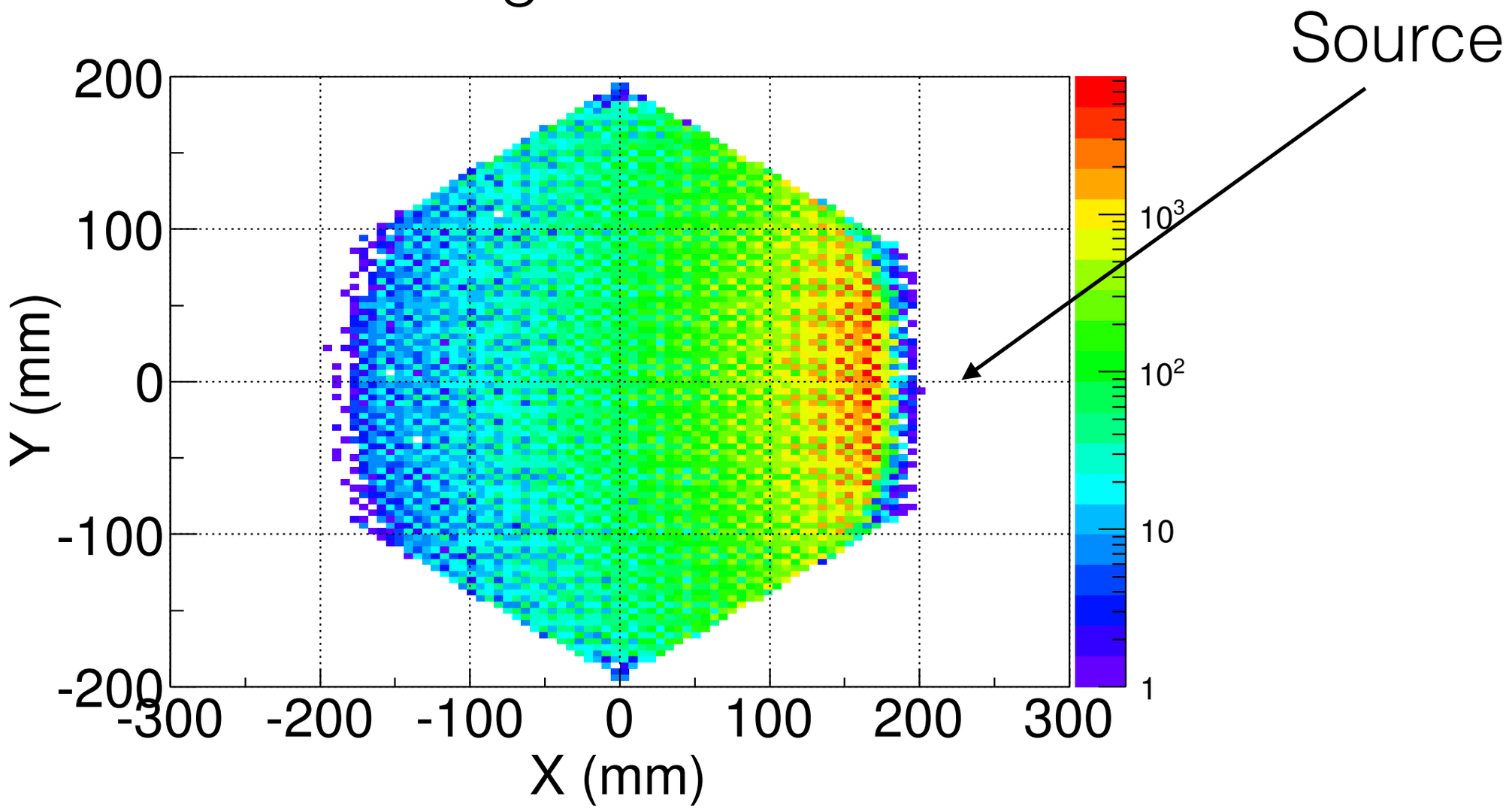
Scintillation clusters

Poster # 100: EXO-200 Event reconstruction, R. MacLellan



Position/multiplicity reconstruction

Combine signals into “clusters”



Uncertainty, 2.4 (1.2) mm U (V) + 1.5 mm shift (taken as systematic error), Z (0.5 mm), measured using internal decays on the cathode

Total error in fiducial volume due to position reconstruction: **1.73%**

Position/multiplicity reconstruction

Background measurement/reduction

Events with **> 1** charge cluster: multi-site (MS) events

Event with **1** charge cluster: single-site (SS) events

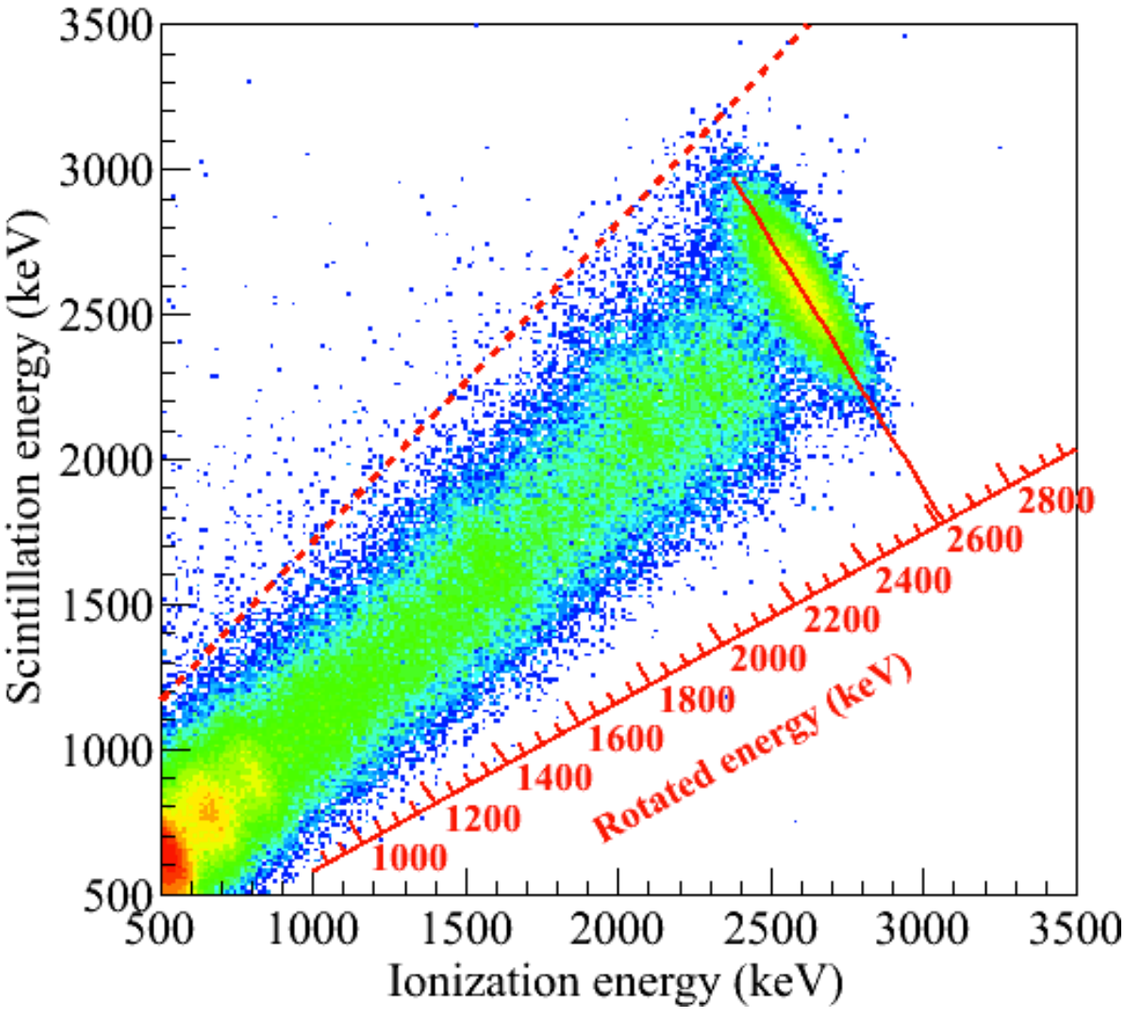
0νββ: ~90% SS

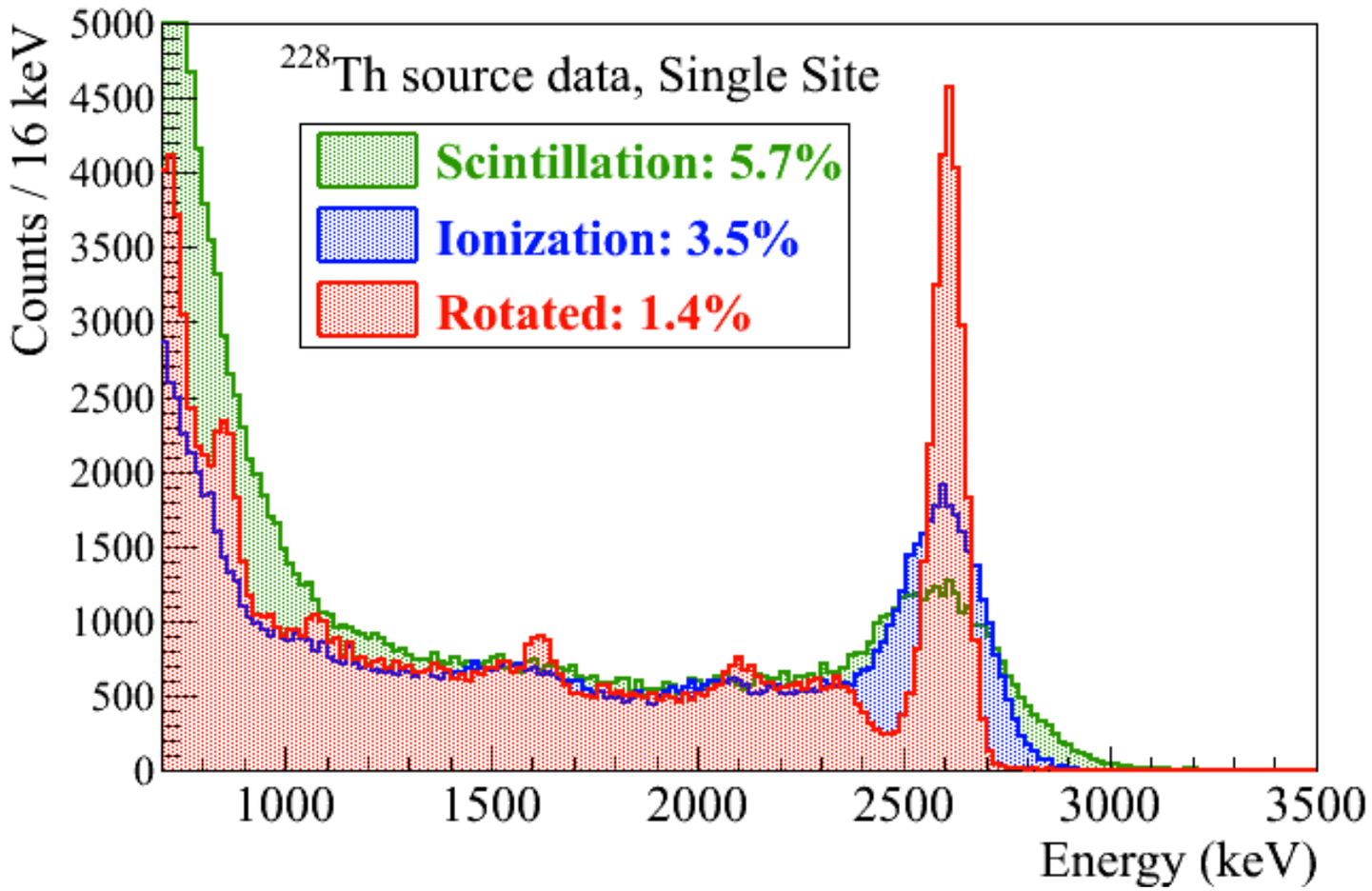
γs: ~30% SS at 0νββ Q-value

But we don't throw MS events away! Use them in the fit to help predict background…

Energy measurement

Combination of charge and light





'Rotation angle' determined weekly using ^{228}Th source data, defined as angle which gives best 'rotated' resolution

Energy resolution is dominated by APD noise (more on this later)

Previous results (Run 2a)

Most precise measurement of the 2νββ half-life

$T_{1/2}^{2\nu\beta\beta} = 2.165 \pm 0.016(\text{stat}) \pm 0.059(\text{sys}) \times 10^{21}$ yr

PRC 89, 015502 (2014)

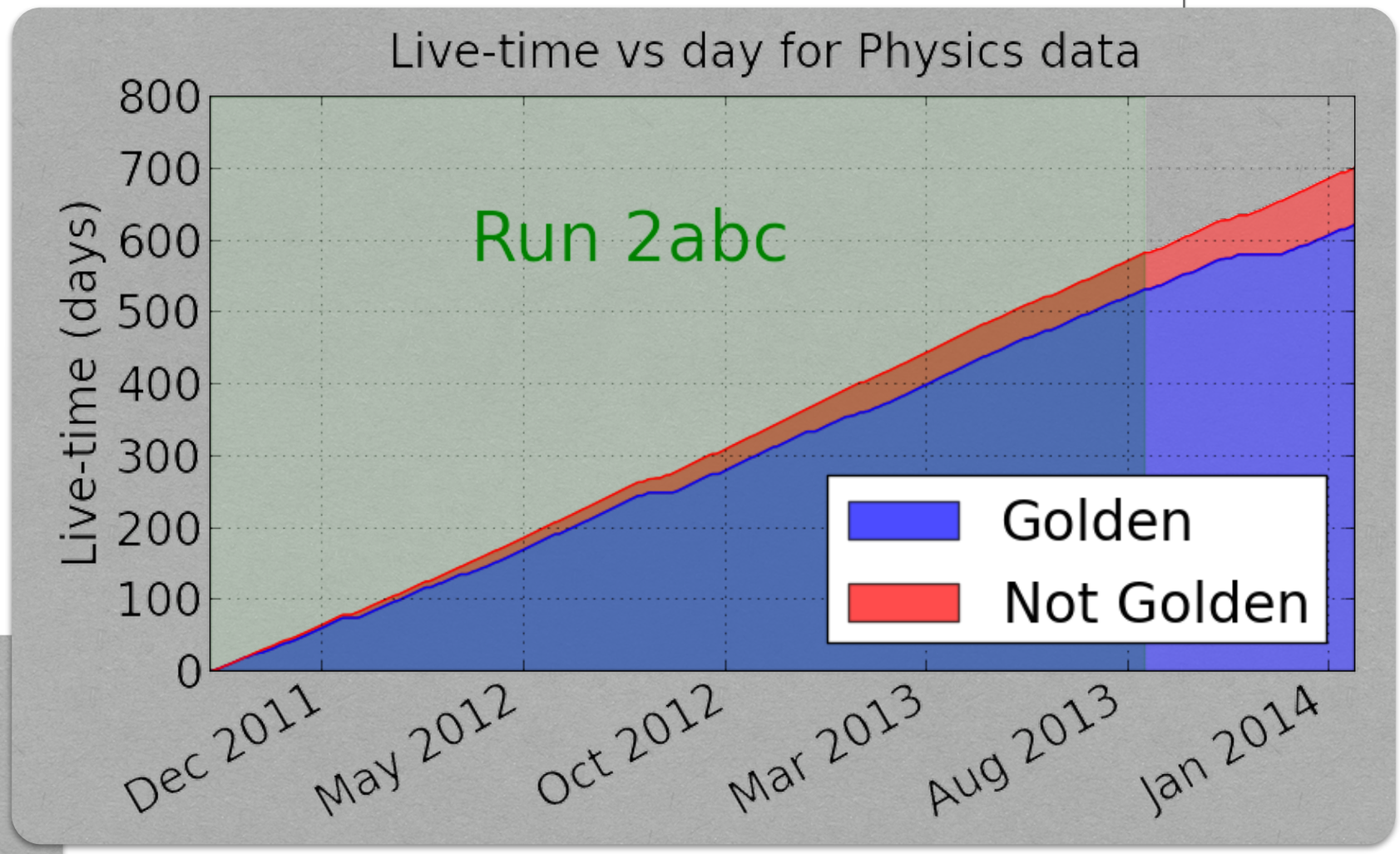
2νββ Sig-to-Bgd ratio:
11: 1

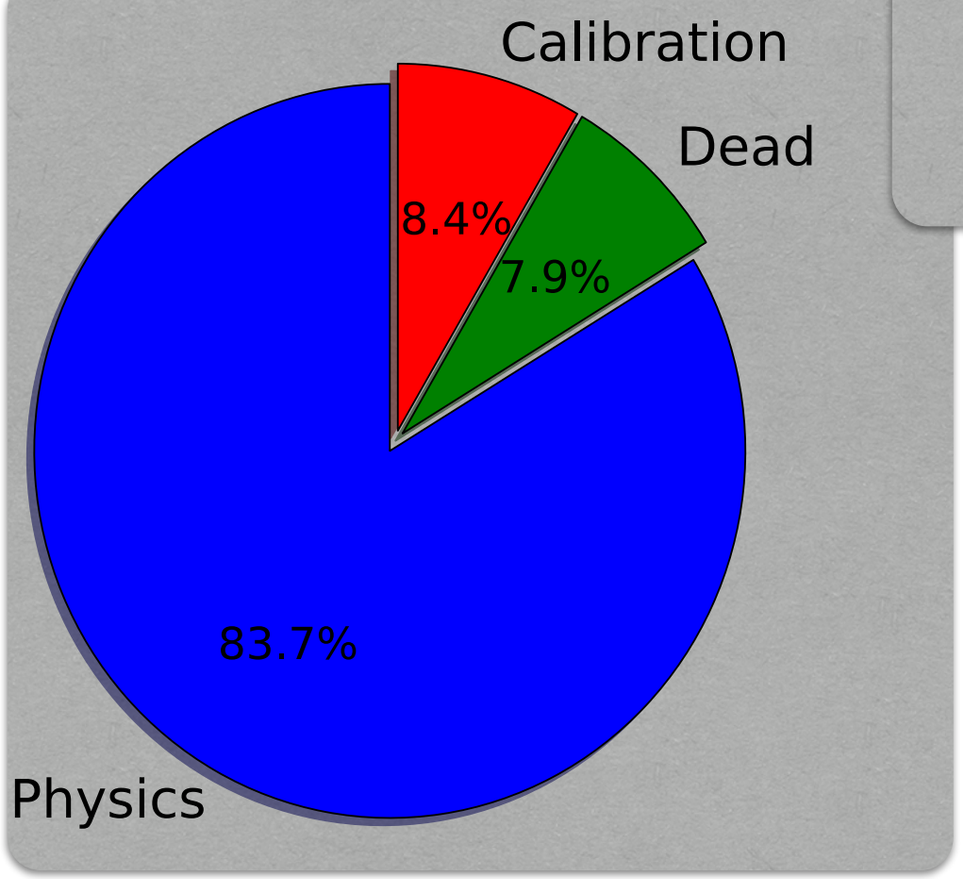
Inner 40% Fiducial Volume:
19: 1

Above reference includes analysis details

Recent results (Run 2)

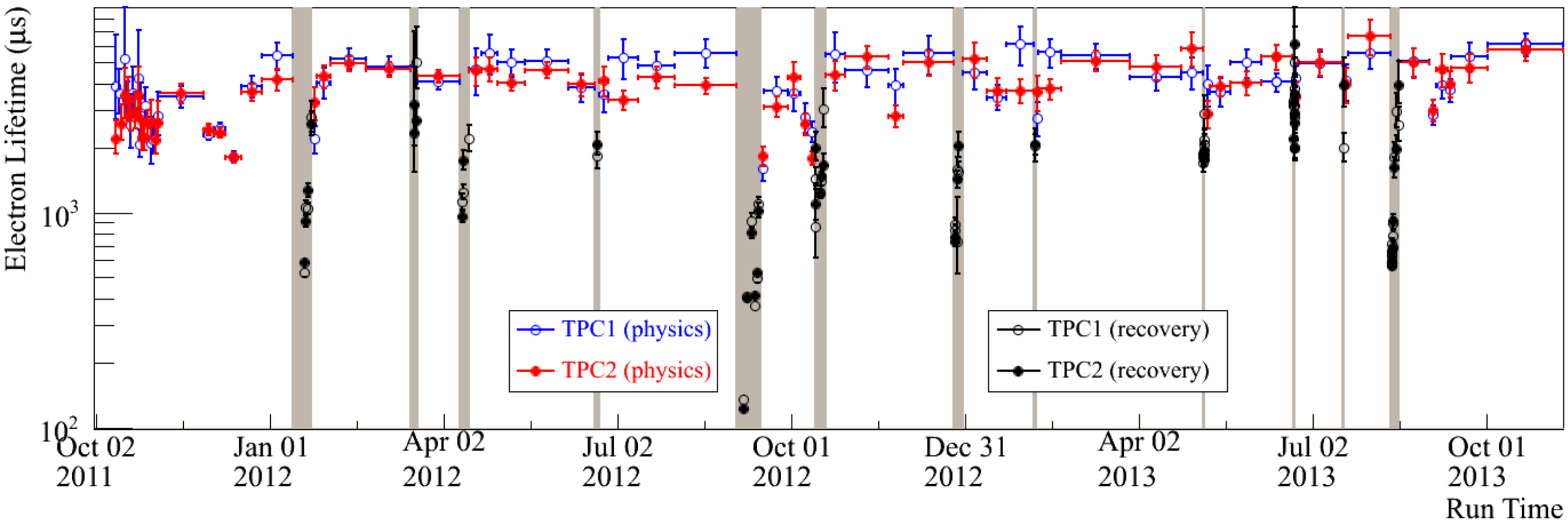
nature
(12 June 2014, online 4 June)
doi:10.1038/nature13432





Accumulation of "Golden" data
447.60 ± 0.01 days livetime
(100 kg·yr, 736 mol·yr ^{136}Xe exposure)
(6 Oct 2011- 1 Sep 2013)

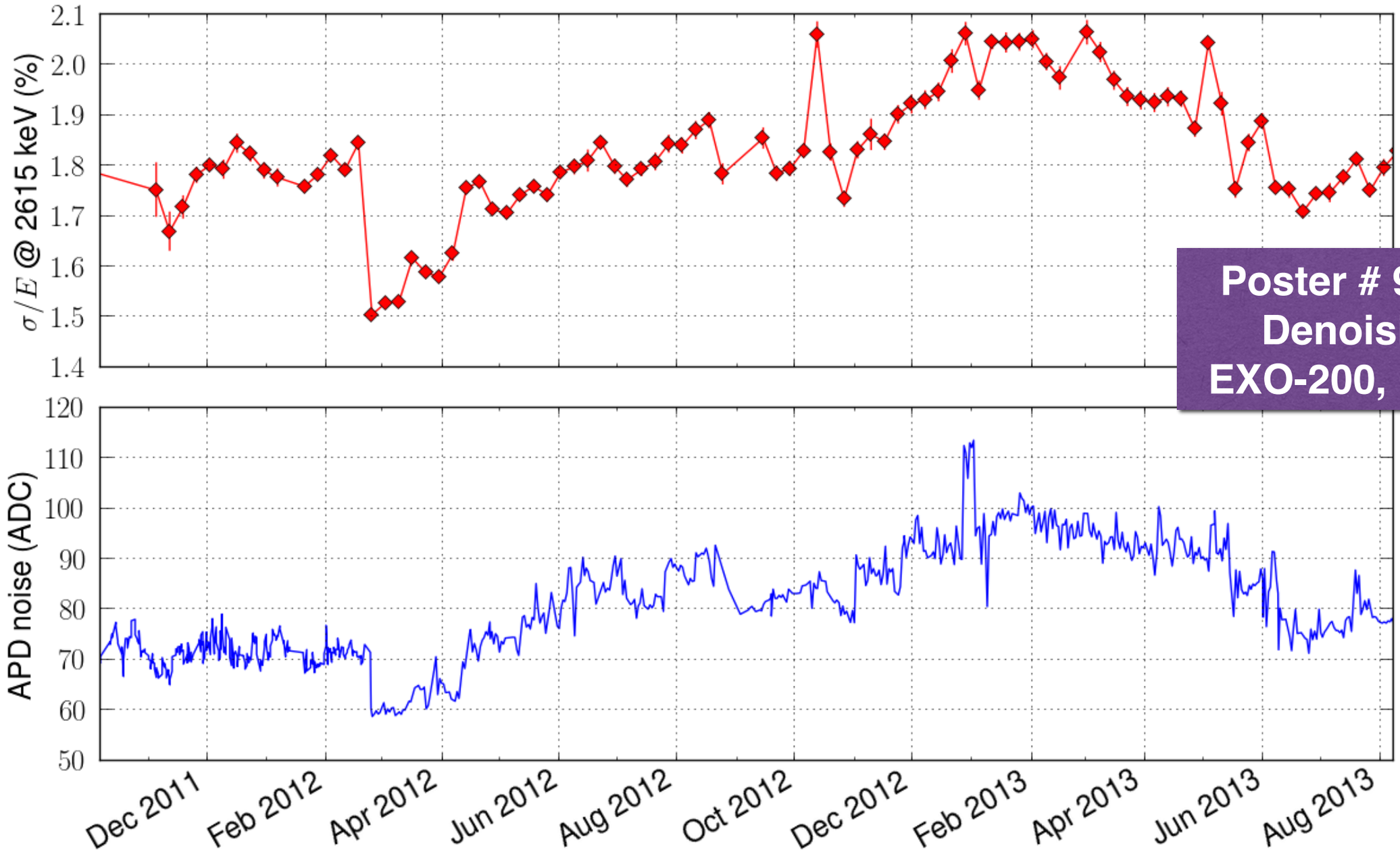
Xe Purity over Run 2



- 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

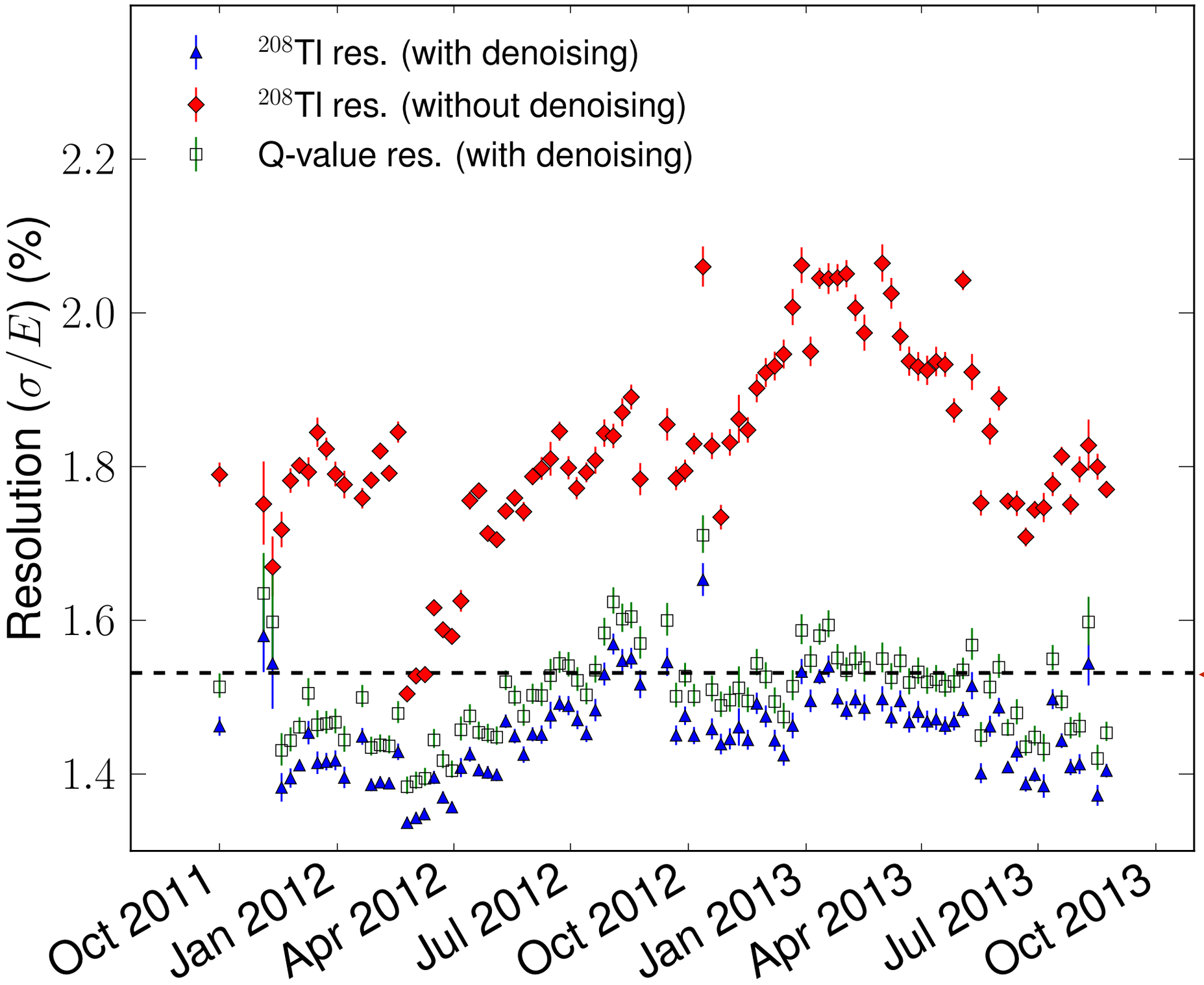
Problem: Noise and resolution is dependent on the varying (correlated) noise of the APDs



Poster # 97: APD Denoising in EXO-200, C. Davis

(Current) solution: Find the optimum combination of APD signals *per event,* given position and noise

APD Denoising

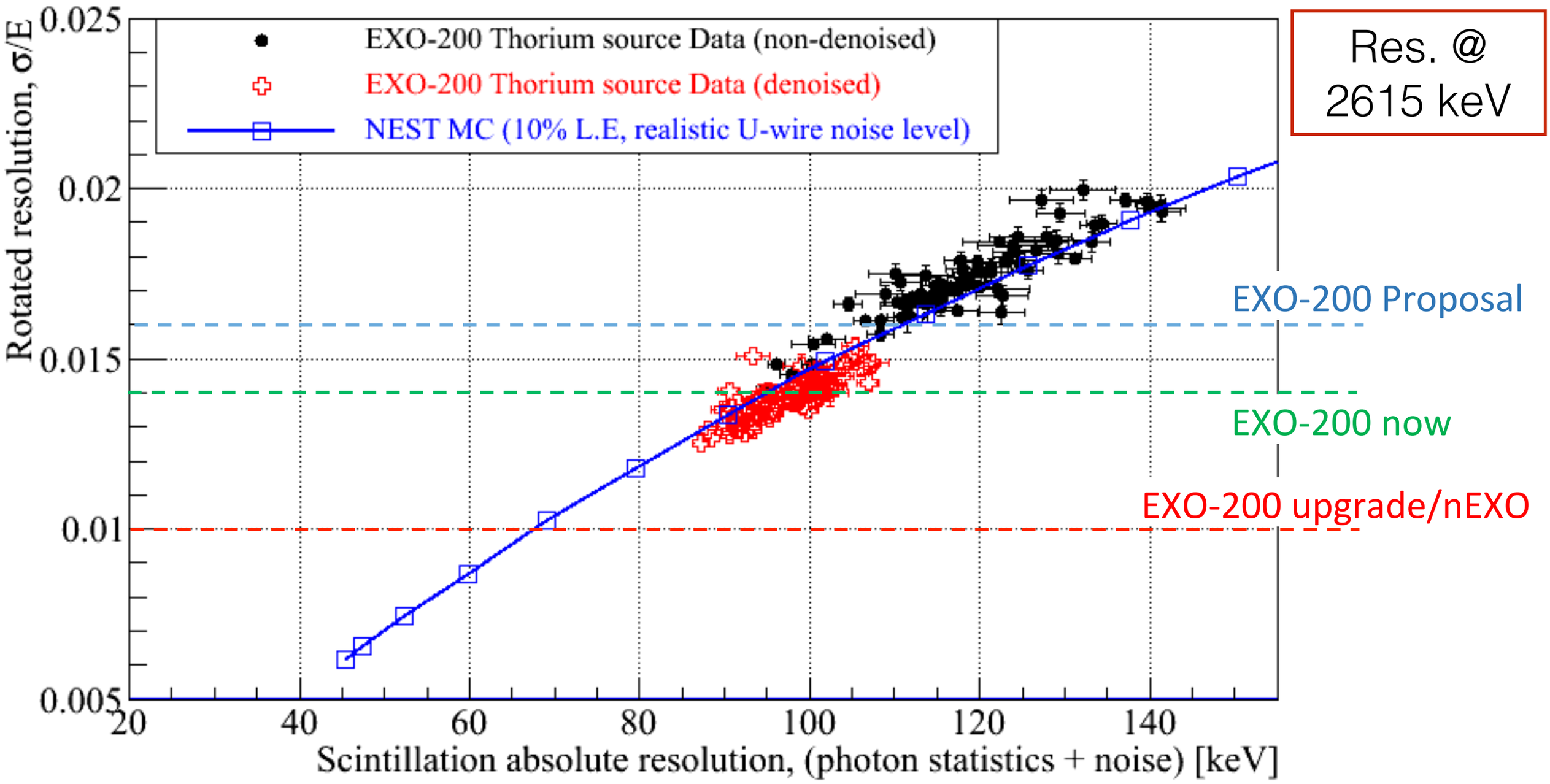


Poster # 97: APD Denoising in EXO-200, C. Davis

1.53 % in SS at 0νββ Q-value

APD Denoising

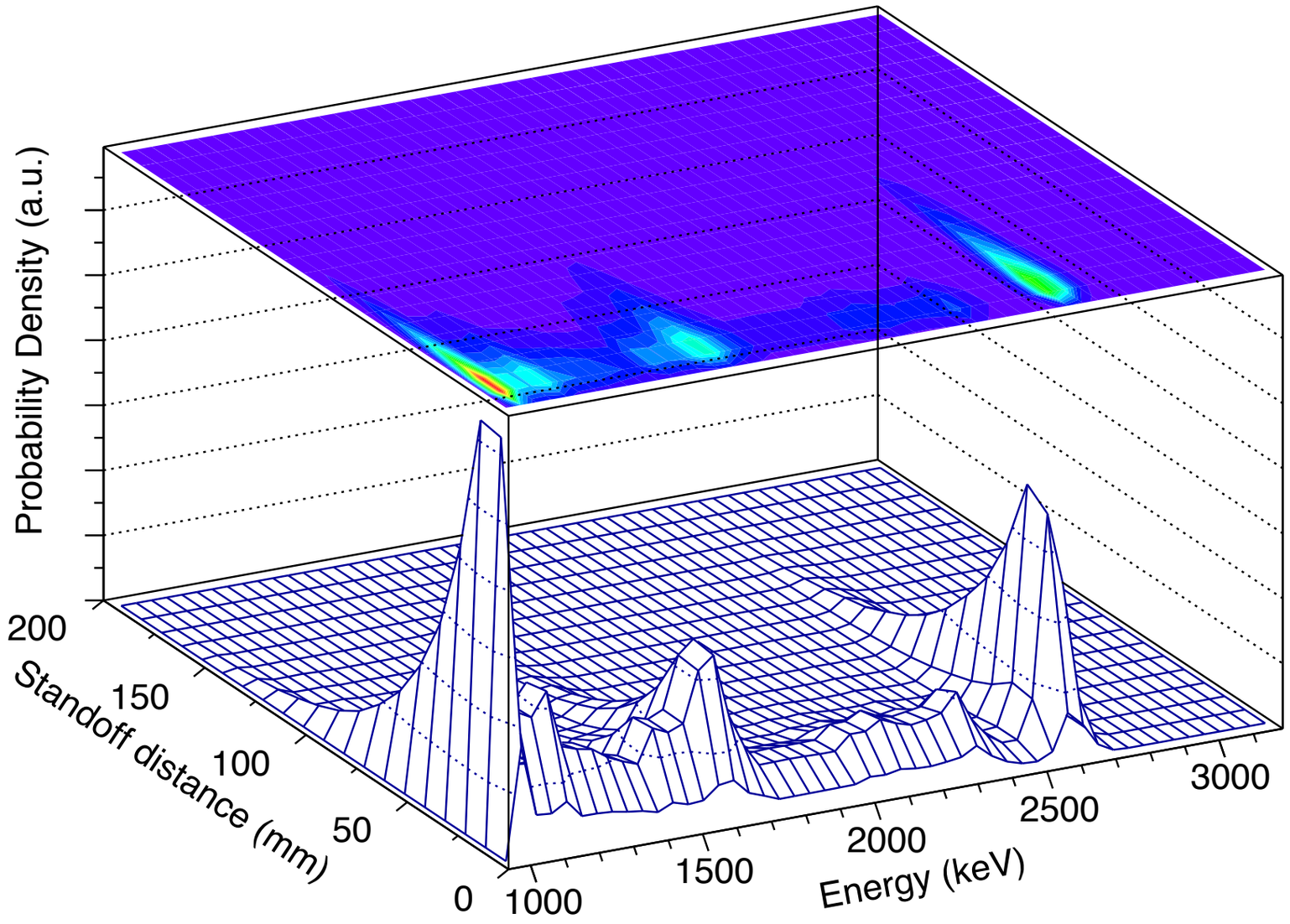
Future: Upgrade of APD readout electronics to improve noise characteristics



NEST: http://nest.physics.ucdavis.edu/

Extracting physics results

Background model + Data → (Maximum Likelihood Fit) → Physics Results



^{232}Th PDF in Cu TPC Vessel (SS)

- Variables
  - Energy
  - Position (standoff distance)
- Multiplicity
  - SS
  - MS

Systematic errors

- 0νββ 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**

- Region-of-interest (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:

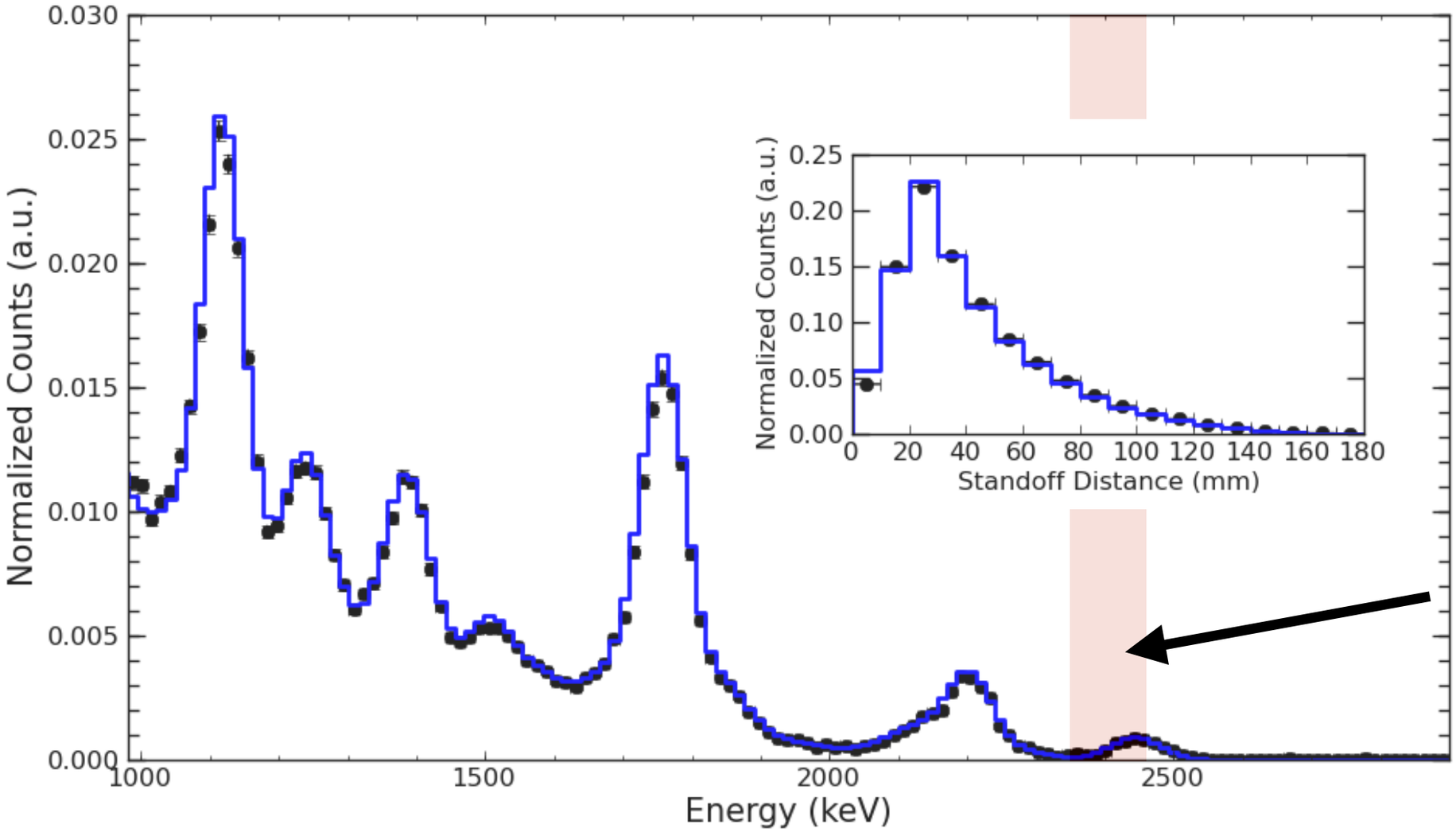
"β-scale" allowed to float in fit

  - Deviations between β and γ energy scale: $E_\beta = B \cdot E_\gamma \implies \boldsymbol{B = 0.999 \pm 0.002}$

- Single-site fraction error: **9.6%**

SS/MS fraction allowed to vary within this error in fit

Systematic errors agreement with simulation

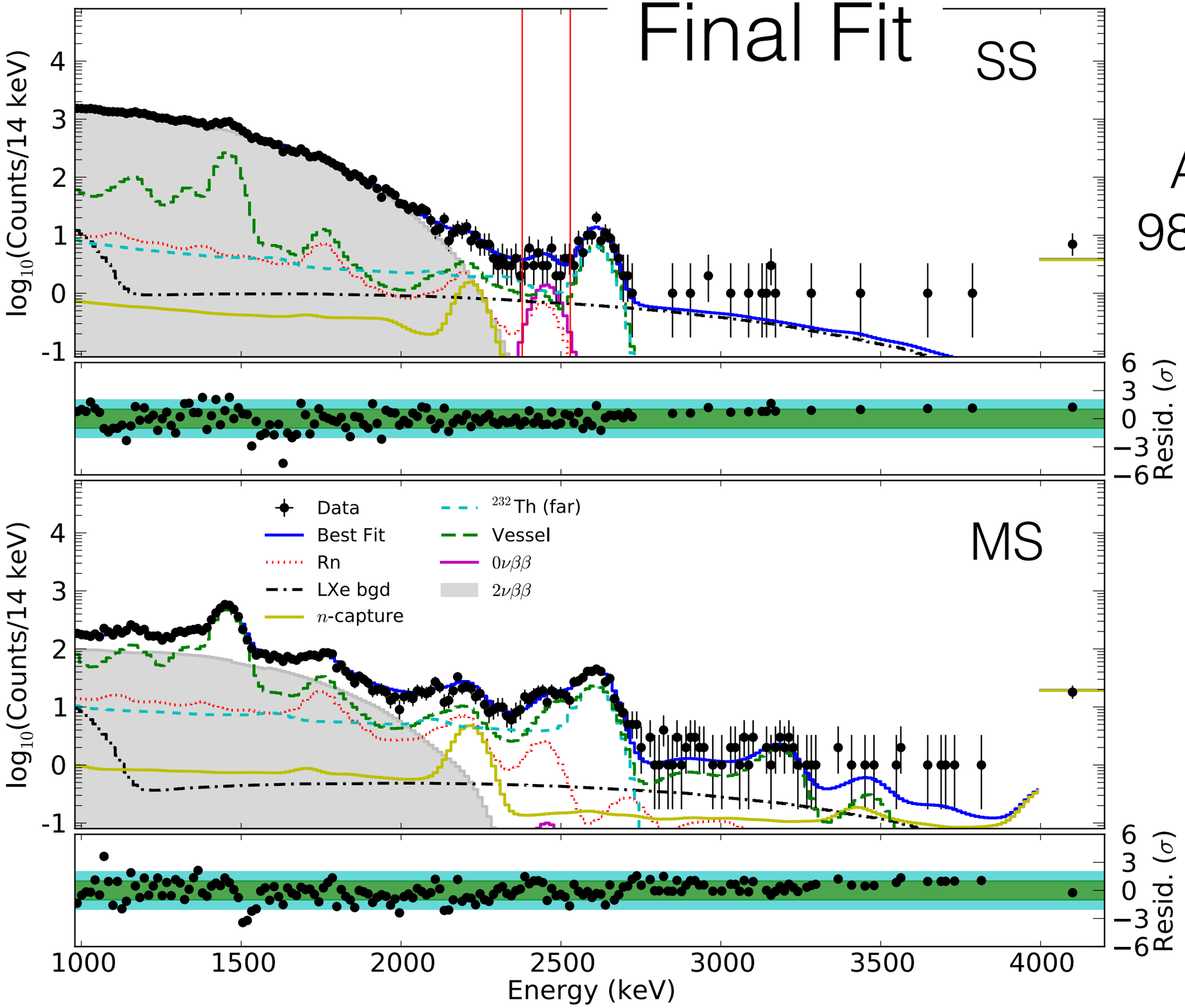


Determine how systematics issues affect background estimates in the ROI.

Allowed background in ROI (red region) to float within this error with respect to the rest of the energy spectrum.

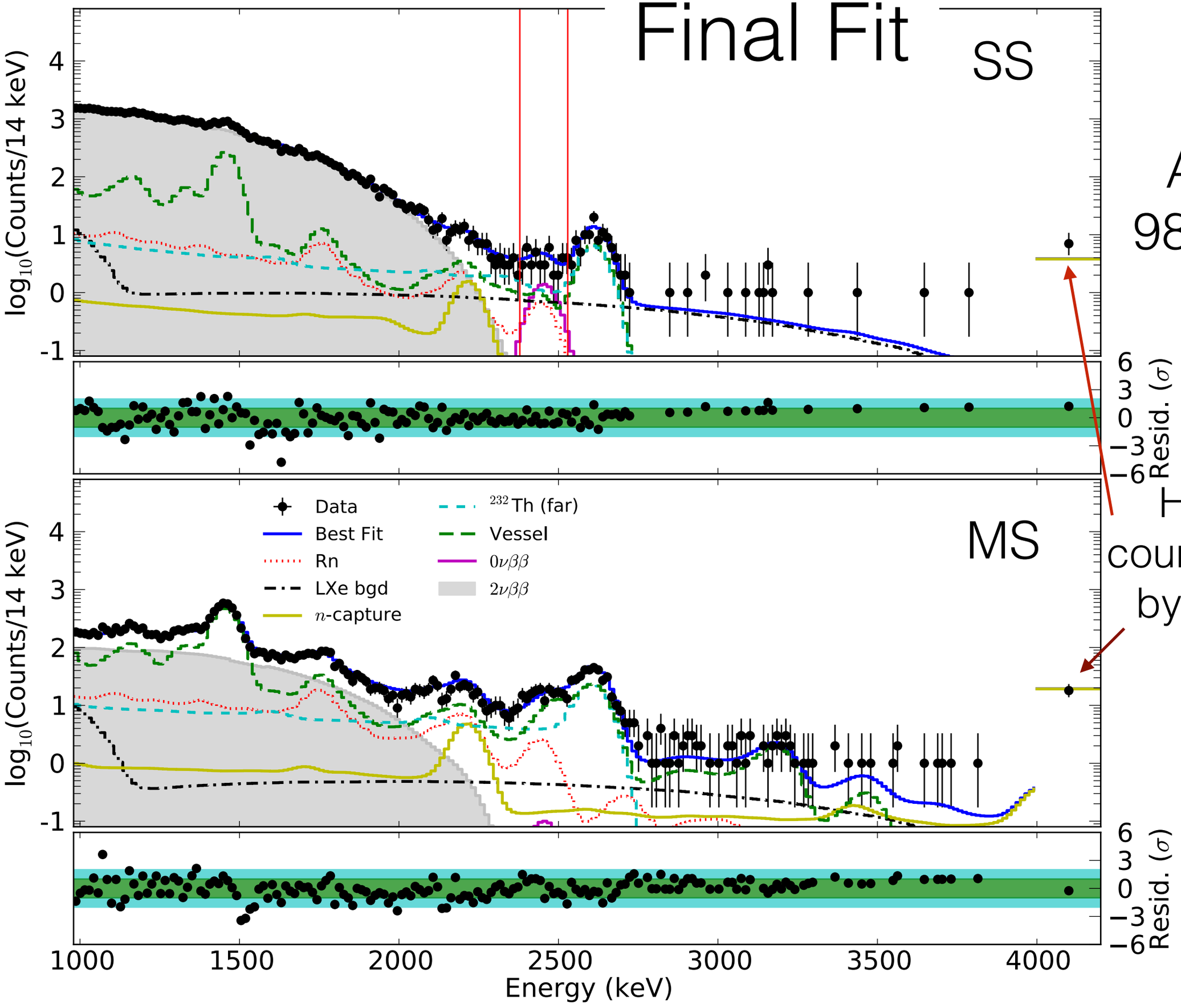
^{226}Ra source data, single-site: example distribution comparison used to estimated systematics (also used ^{228}Th, ^{60}Co, ^{137}Cs sources)

Final Fit



Analysis:
980 to 9800
keV

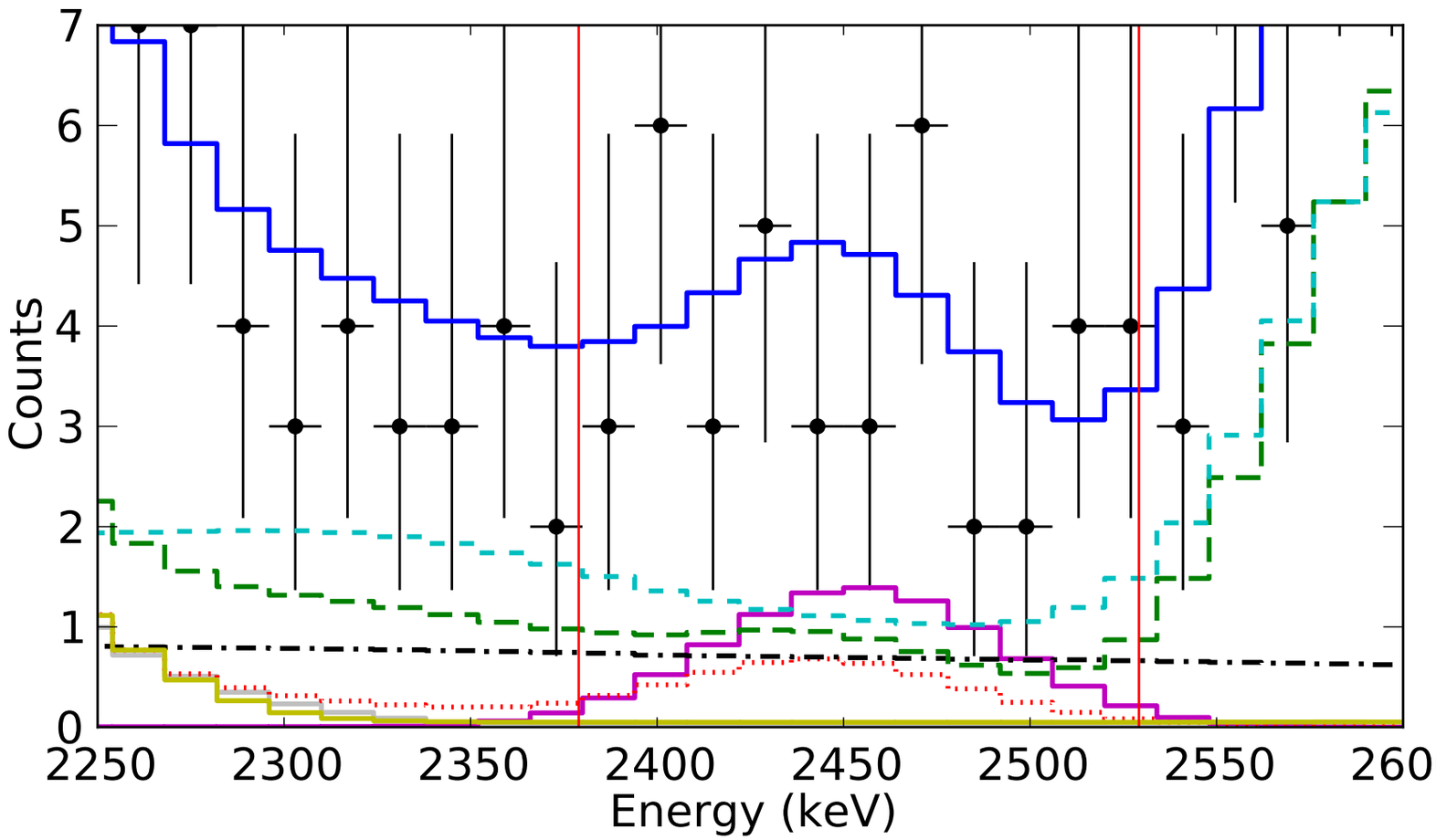
Final Fit



Analysis: 980 to 9800 keV

High-energy counts dominated by μ-produced neutrons

Looking for 0νββ



Backgrounds in ± 2σ ROI	
Th-228 chain	16.0
U-232 chain	8.1
Xe-137	7.0
Total	**31.1 ± 3.8**

Data
Best Fit
Rn
LXe bgd
n-capture
^{232}Th (far)
Vessel
$0\nu\beta\beta$
$2\nu\beta\beta$

From profile likelihood:

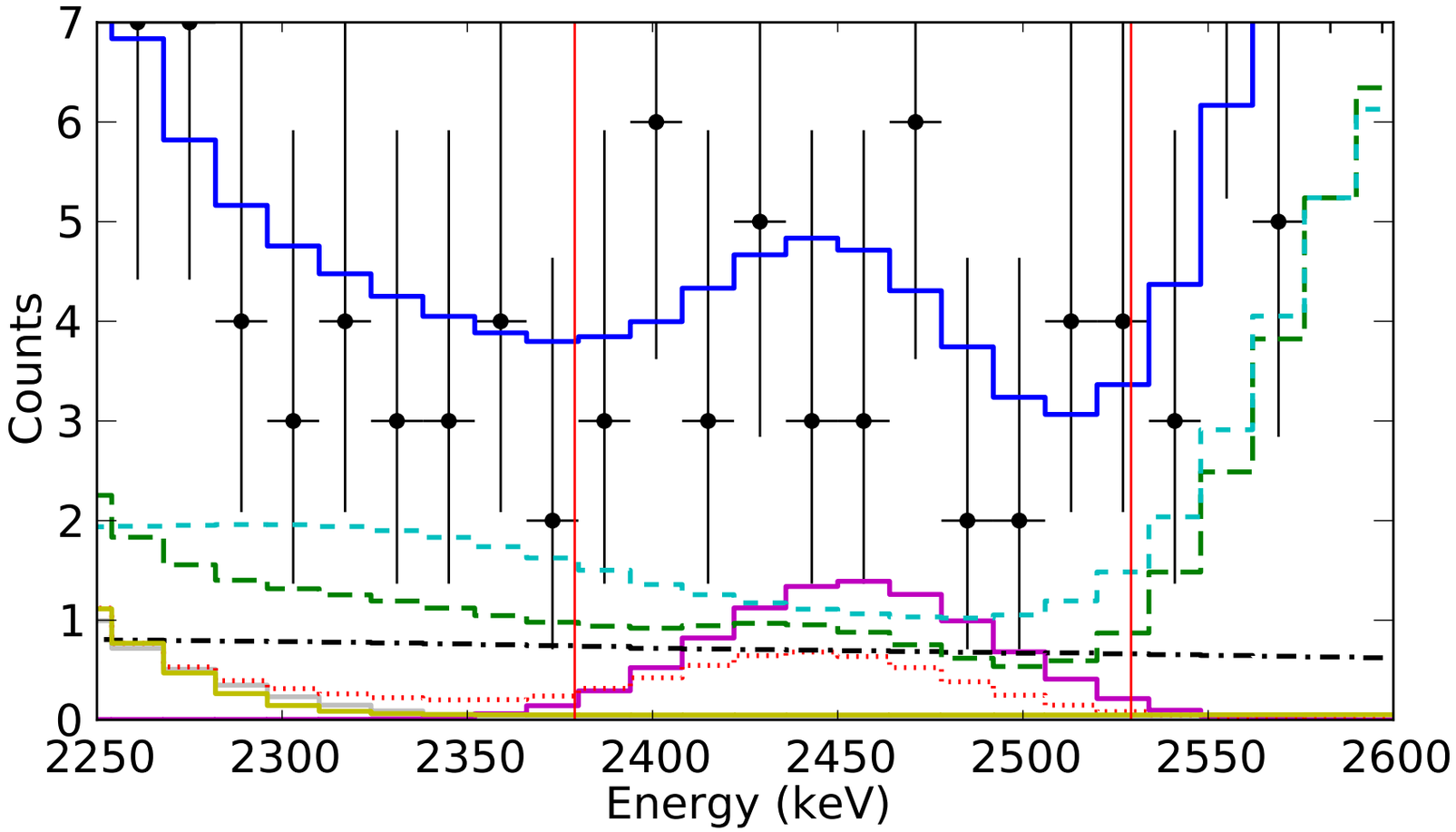
$T_{1/2}^{0\nu\beta\beta} > 1.1 \cdot 10^{25}$ yr

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

(90% C.L.)

***Nature* (2014)**
doi:10.1038/nature13432

Looking for 0νββ



Backgrounds in ± 2σ ROI	
Th-228 chain	16.0
U-232 chain	8.1
Xe-137	7.0
Total	**31.1 ± 3.8**

consistent with activation estimates from muon-veto-tagged data

Data
Best Fit
Rn
LXe bgd
n-capture
^{232}Th (far)
Vessel
$0\nu\beta\beta$
$2\nu\beta\beta$

From p

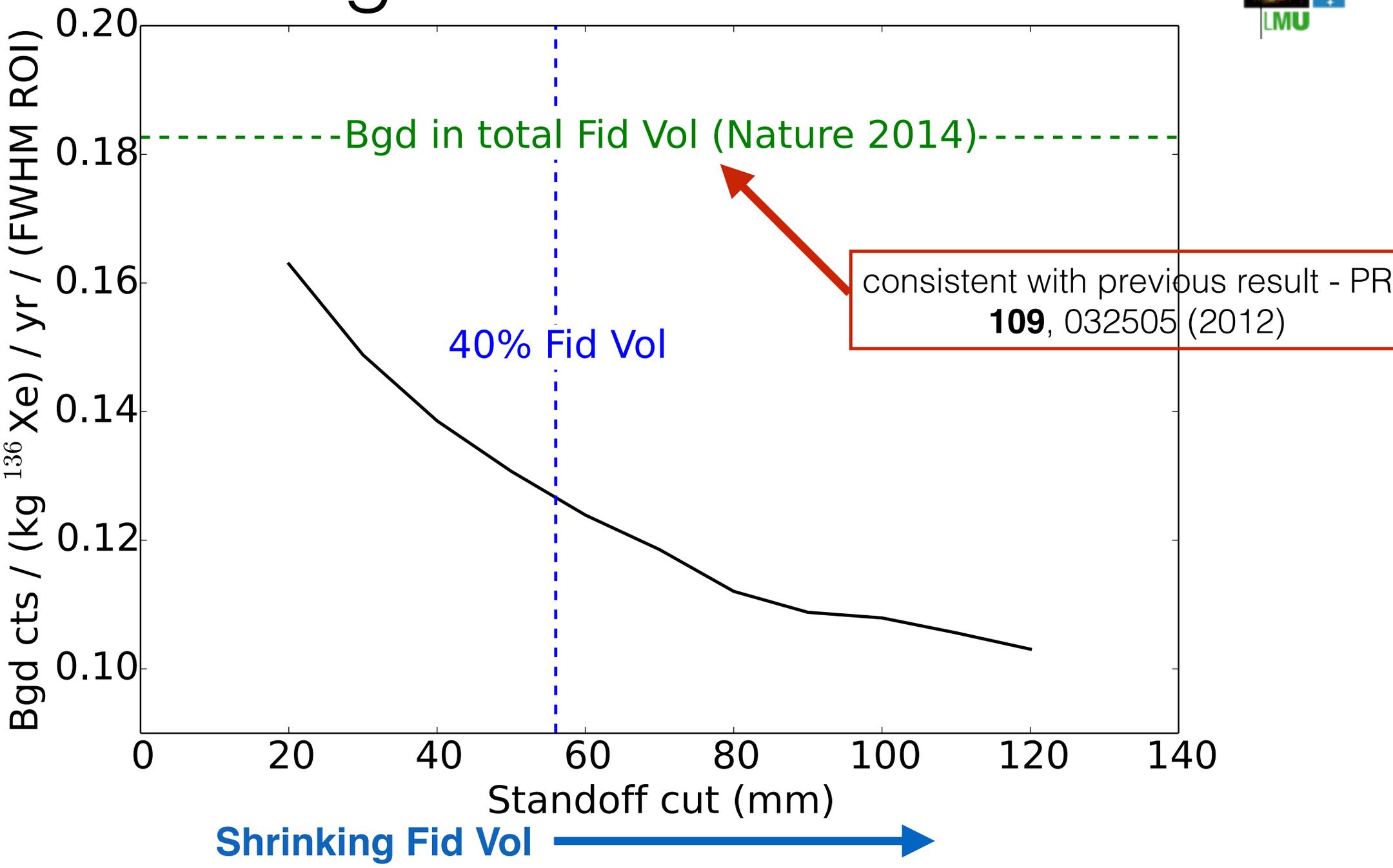
$T_{1/2}^{0\nu\beta}$ [illegible]

$\langle m_{\beta\beta} \rangle$ < 190 – 450 meV
(90% C.L.)

***Nature* (2014)**
doi:10.1038/nature13432

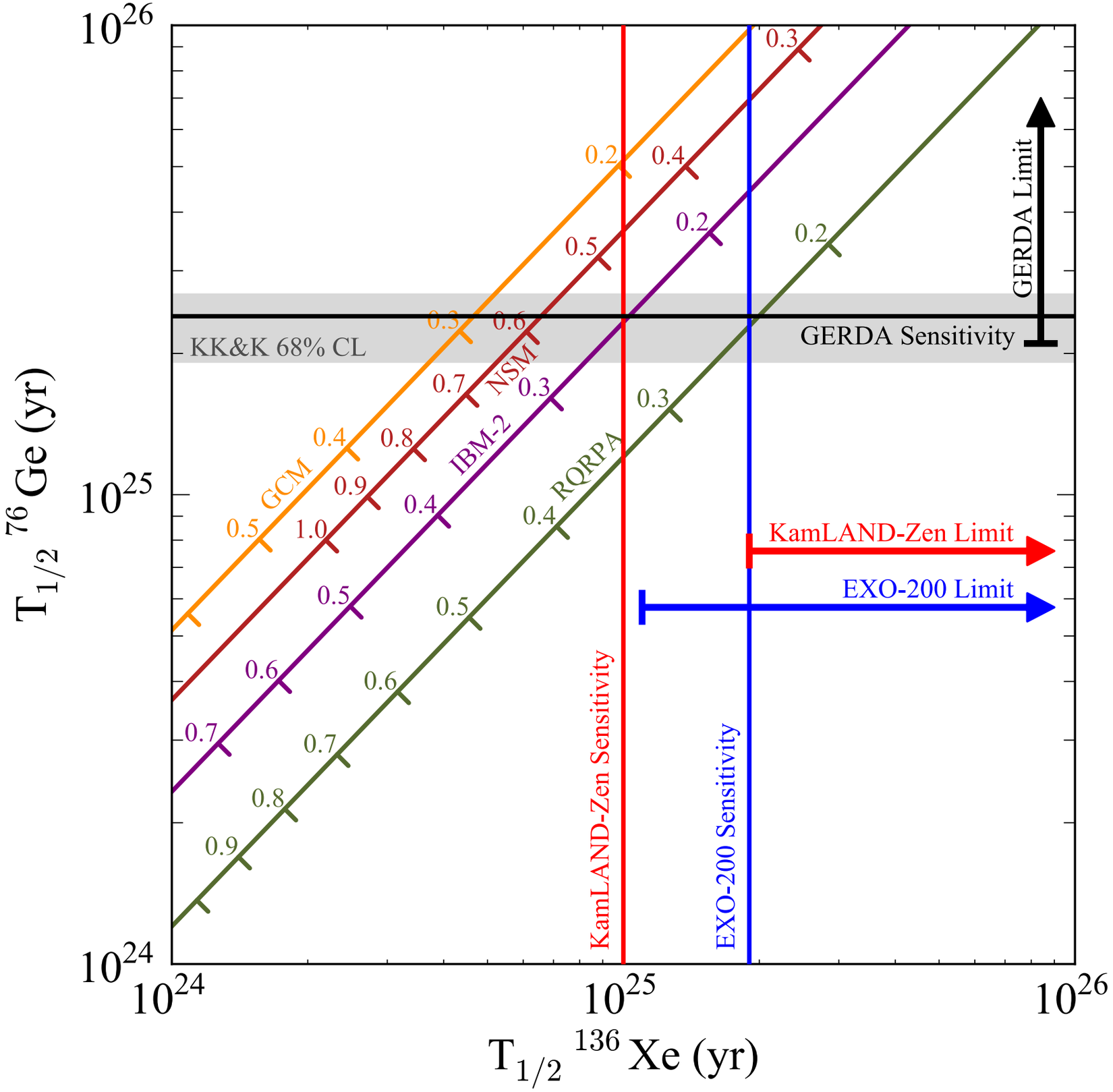
Poster # 96: Cosm. neutron bgds for EXO-200, J. Albert

Backgrounds in the ROI



30% reduction of background index in inner 40% fiducial volume (reduction limited by size of TPC)

0νββ status comparison



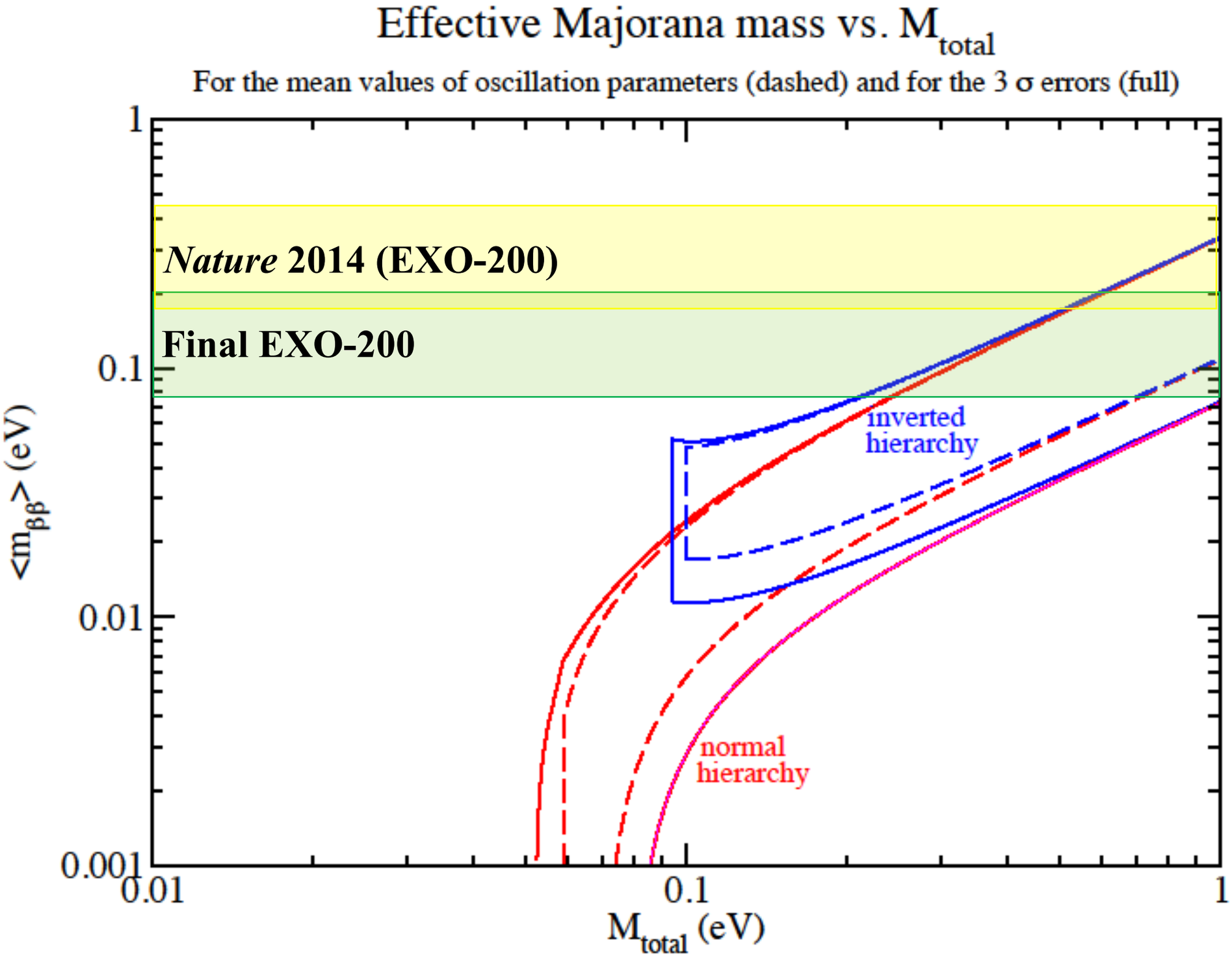
EXO-200:
***Nature* (2014),**
doi:10.1038/nature13432

GERDA Phase 1:
PRL 111 (2013) 122503

KamLAND-Zen:
PRL 110 (2013) 062502

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

Sensitivity outlook



EXO-200 ultimate sensitivity (90%CL):
2 years additional livetime with Rn removal

Current EXO-200 status

- **WIPP events:**
  - **5 Feb 2014** - Fire in WIPP underground
  - **13-14 Feb 2014** - underground access, including with EXO-200 members: "… amount of soot in the project area … **extensive but recoverable**."
  - **14 Feb 2014, ~23:00** - Airborne radiological event

DOE Accident Inv. Rep., Mar 2014

- **EXO-200 status:**
  - Was taking (source) data **during above events**. Network/control access has continued.
  - **In late February, once date of next access was no longer clear:** With remote system access, Xe was successfully recovered (as designed), TPC/Cryostat was warmed

- **Outlook**, "…reassure our commitment to make access to the unique underground environment at WIPP available to the scientific community." - DOE
  - Must still be verified that northern air circuits free of contamination, hoist/ground control operations must return to normal, etc.
  - " … **access in the Autumn time frame**…."

Summary

- EXO-200 is among the most sensitive 0νββ experiments, achieving 100 kg·yr of ^{136}Xe exposure. Substantial improvements in understanding systematics, improving energy resolution have been recently achieved.
- Data taking is currently halted due to WIPP closure, planned access in Fall 2014:
  - Planned deployment of new electronics, deradonator
- nEXO plans to take advantage of the scalability of LXe in a next-generation experiment.
  See L. Winslow's talk and:

nEXO Posters:
 # 94 The nEXO Experiment: L. Wen
 # 95 Ba tagging for nEXO: B. Fairbank
 # 98 EXO-200 detector performance, lessons for nEXO: E. Smith, Y.-R. Yen
 # 99 Radio assay for nEXO: D. Auty

$T_{1/2}^{0\nu\beta\beta} > 1.1 \cdot 10^{25}$ yr

Sensitivity: $1.9 \cdot 10^{25}$ yr

$\langle m_{\beta\beta} \rangle < 190 - 450$ meV (90% C.L.)

***Nature* (2014)**
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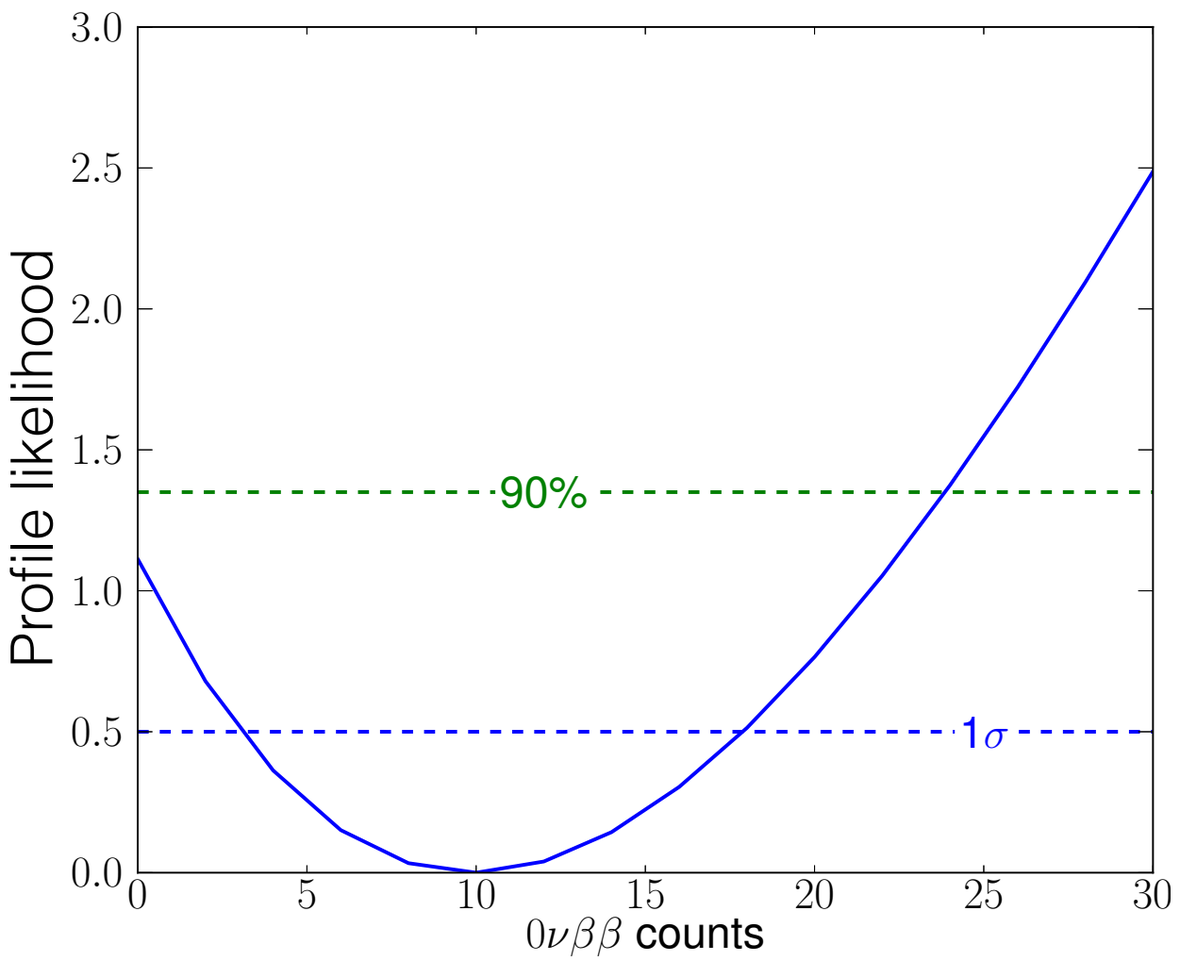

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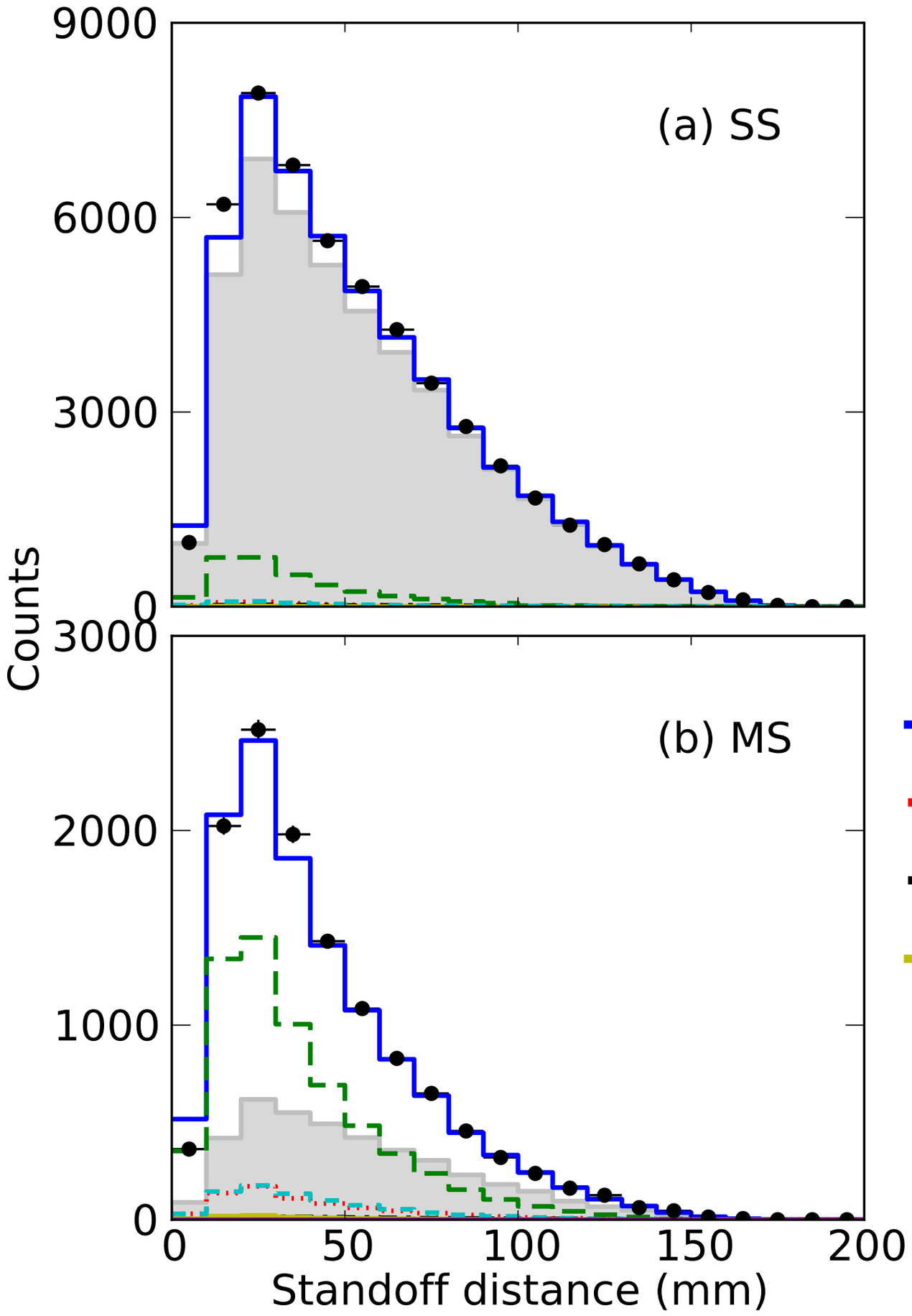
Technical University of Munich, Garching, Germany - W. Feldmeier, P. Fierlinger, M. Marino
TRIUMF, Vancouver BC, Canada – J. Dilling, R. Krucken, F. Retière, V. Strickland

Extra slides

Final Fit, Standoff Distance projection



Data
Best Fit
Rn
LXe bgd
n-capture
^{232}Th (far)
Vessel
$0\nu\beta\beta$
$2\nu\beta\beta$