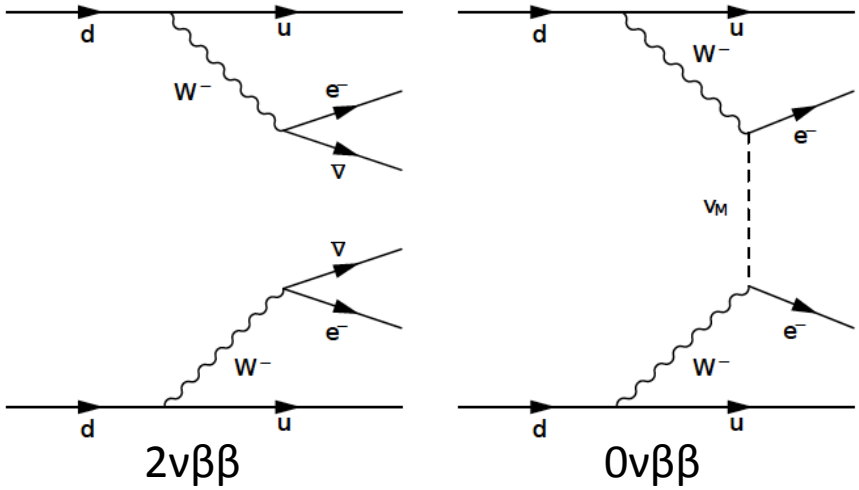
The EXO-200 Experiment

Heavy Quarks and Leptons – Virgina Tech – 5/23/16

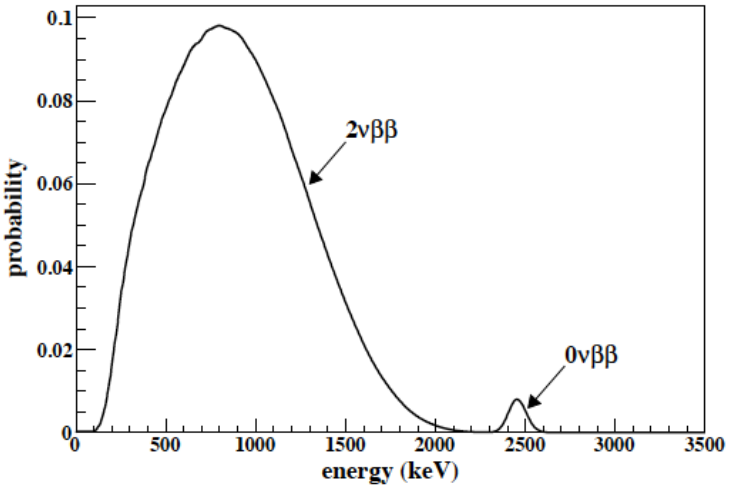
Manuel Weber

Double Beta Decay

The EXO-200 experiment is designated for the search of double beta decay, in particular the neutrinoless mode



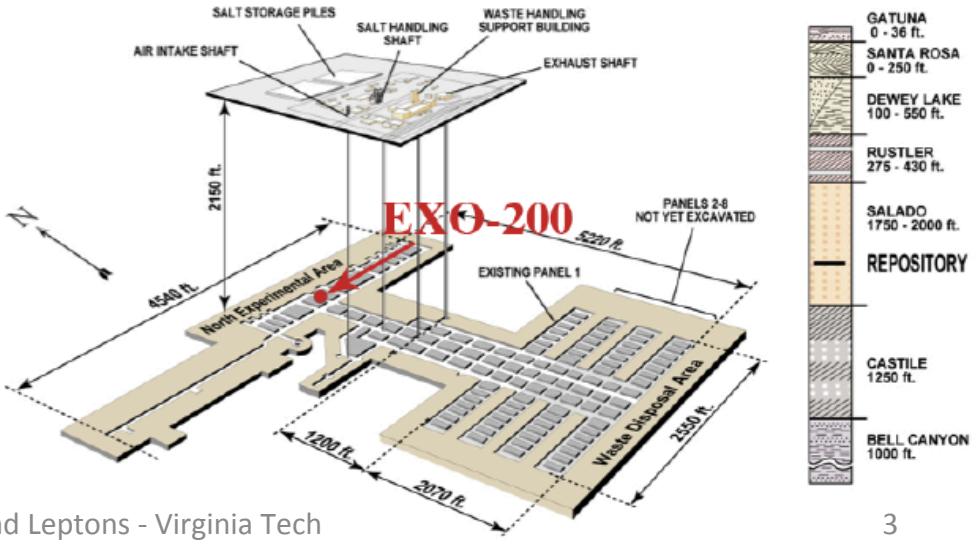
Two neutrino mode is a rare but allowed Standard Model process



Neutrinoless mode can only happen if neutrinos are massive Majorana particles. The observation of this decay allows to determine absolute mass scale

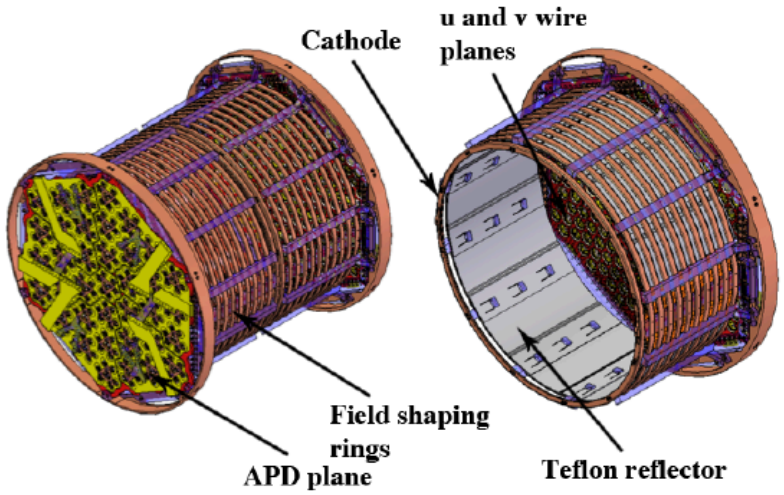
EXO-200

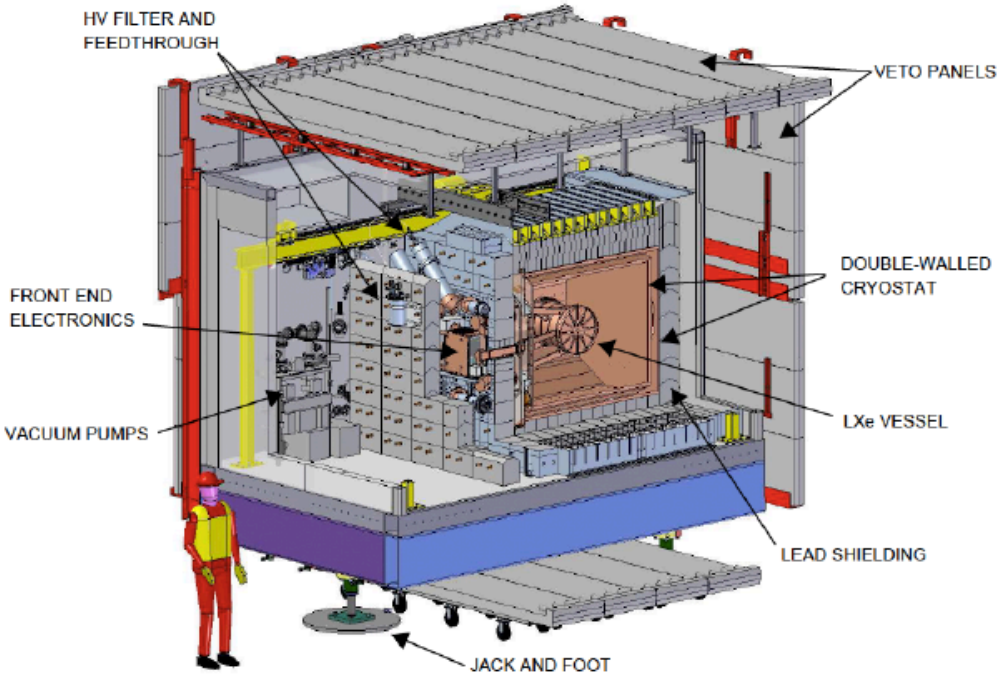
- Located at the Waste Isolation Pilot Plant, Carlsbad NM
  - 1585 m.w.e. overburden
  - Muon rate at this depth measured to be ~$3*10^{-7}$ $s^{-1}cm^{-2}sr^{-1}$
  - Low levels of U/Th (compared to rock) and Rn
- 200 kg of Xenon enriched to 80.6% in Xe-136
  - High Q-value above most γ backgrounds
  - Provides self shielding
  - Currently using ~100 kg as fiducial volume



EXO-200

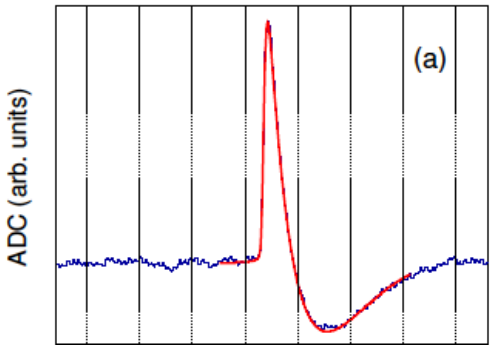
- Time Projection Chamber inside Cu cryostat
  - Split in two equal halves with common cathode
  - U- and V-wires for charge collection and APDs for light collection
  - All materials have been screen for radio-purity



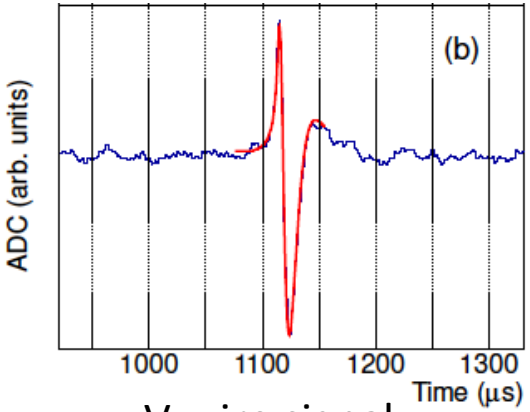


Signals in EXO-200

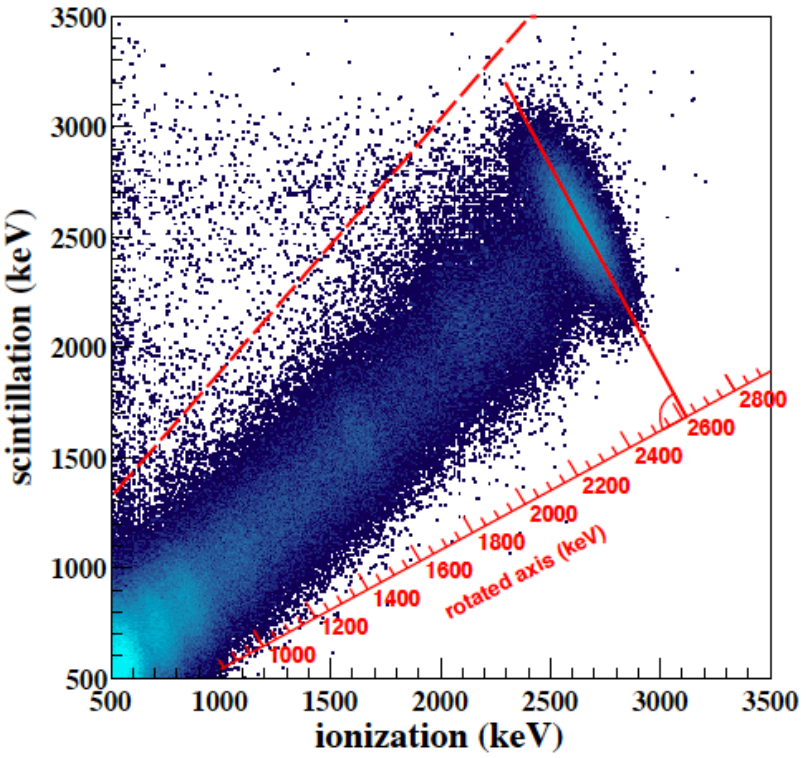
- Both charge and light signals are measured simultaneously
  - Linear combination yields better energy resolution due to anti-correlation
  - Rotation angle is measured as part of the detector calibration
- Single site vs multi site discrimination
  - Allows to better distinguish between signal and background



U-wire signal



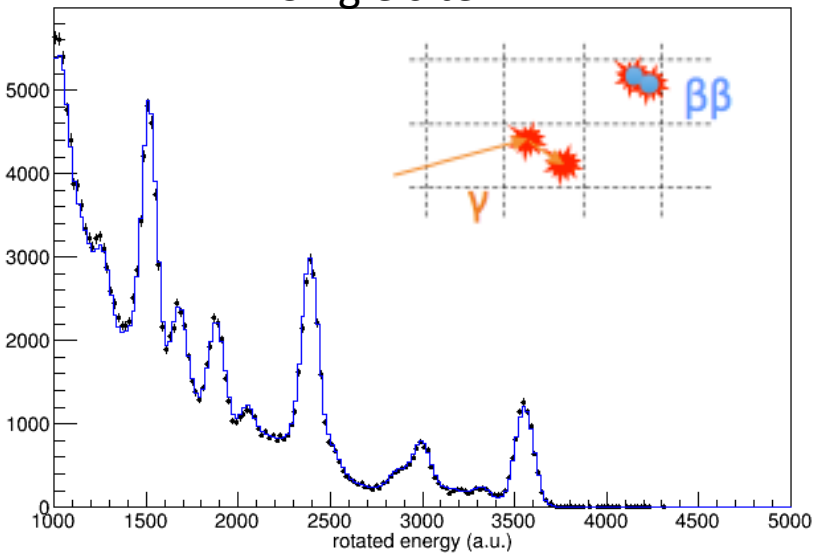
V-wire signal



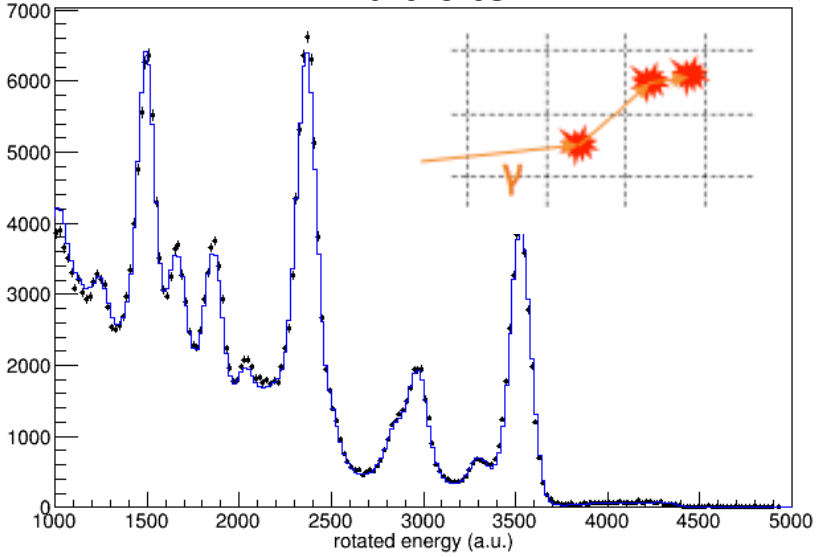
Detector calibration

- Calibration performed by placing radioactive sources in known locations around the detector
  - We use Cs-137, Co-60, Th-228 and Ra-226
  - Calibrations are performed on a weekly basis
  - All sources combined and fit to MC yielding calibration and resolution constants
- Source agreement allows to determine MC shape errors

Single site



Multi site



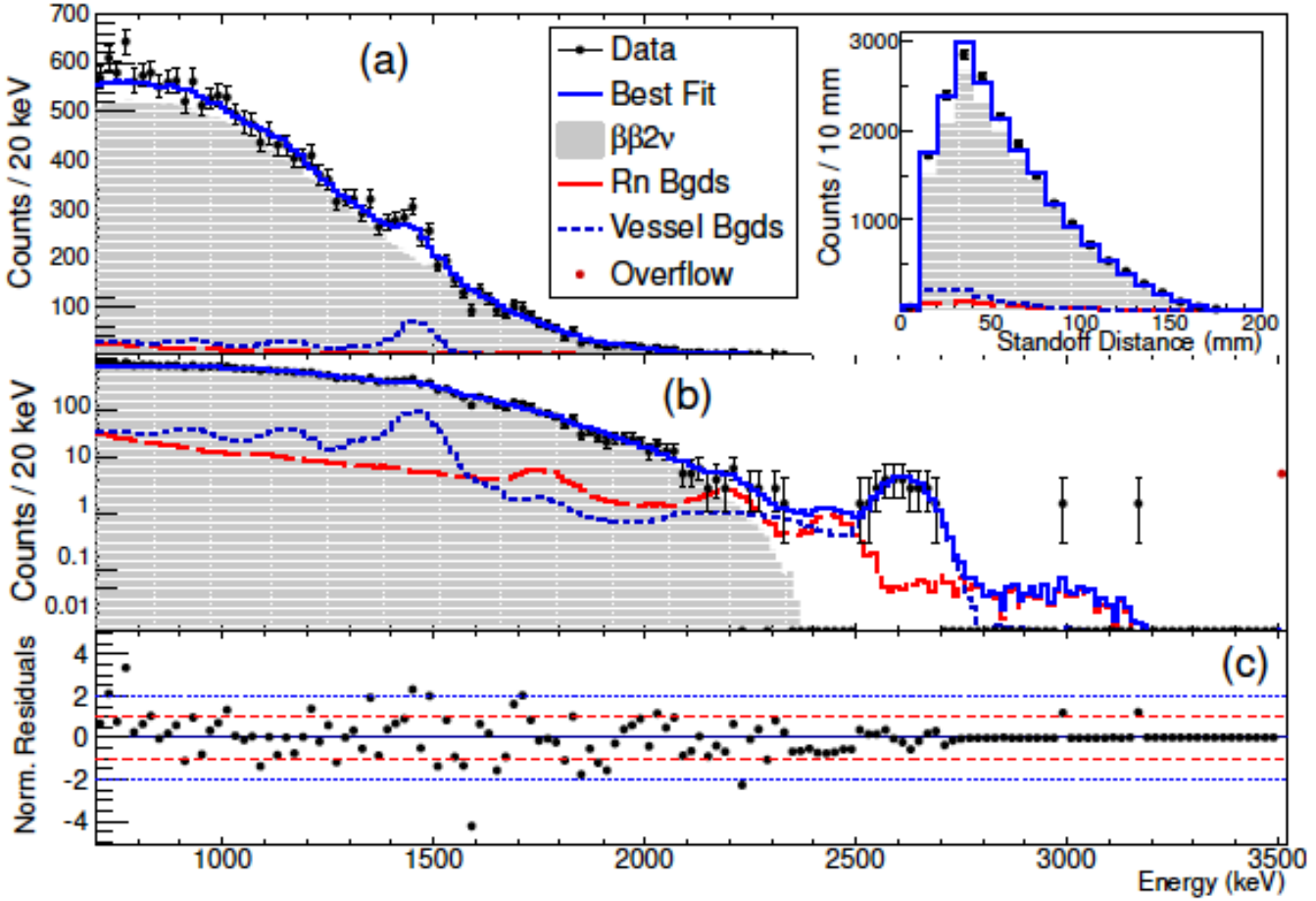
2νββ decay measurement

- In 2011 EXO-200 was the first experiment to measure double beta decay in Xe-136
  - Since then more data has been collected and the analysis has been improved substantially

- The most precise measurement of the 2νββ half-life up to date has been published in 2014
  - Total Xe-136 exposure of 23.14 kg yr
  - Measured half-lifetime: $2.165 \pm 0.016(\text{stat}) \pm 0.059(\text{sys}) \cdot 10^{21}$ yrs

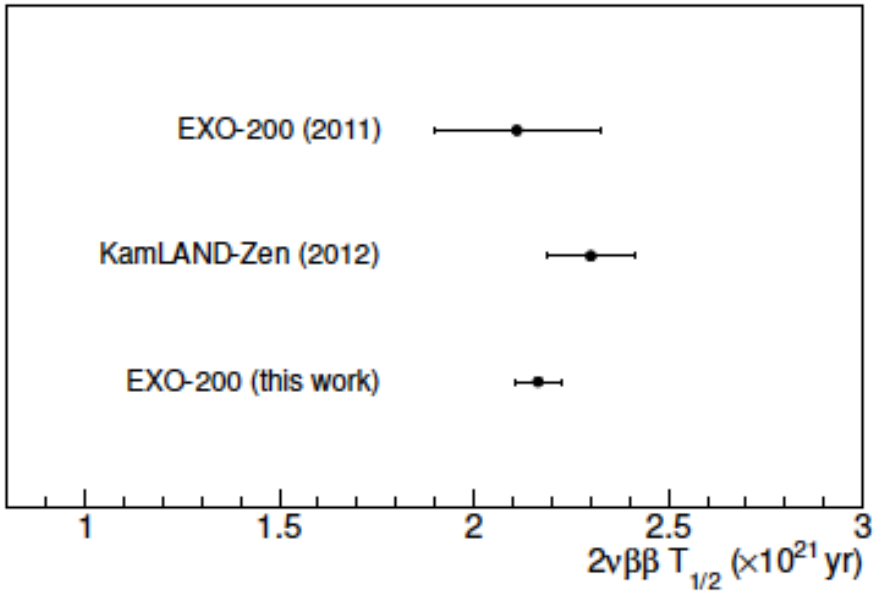
2νββ decay measurement

Final fit



2νββ decay measurement

Result in comparison and error balance



Discovery

PRL 107, 212501 (2011)

Confirmation

PRC 45, 045504 (2012)

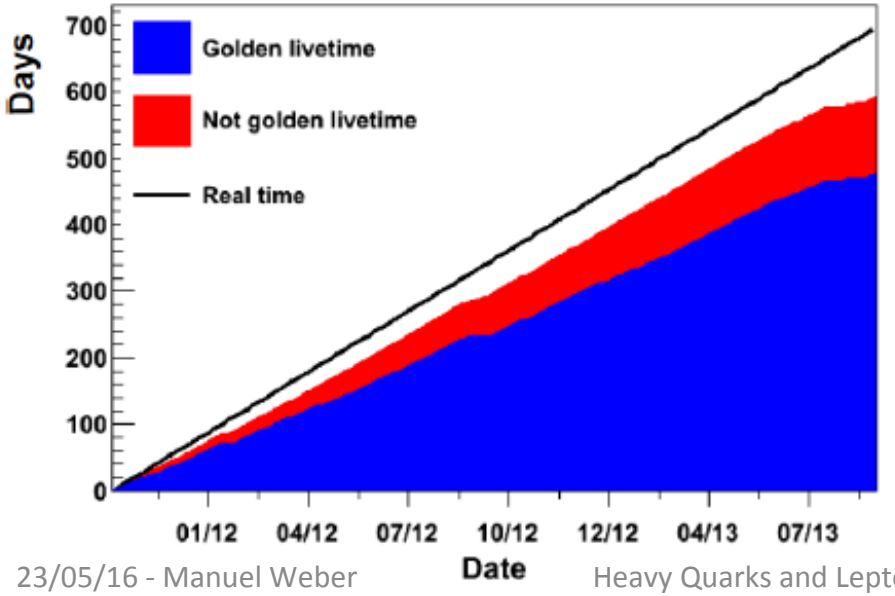
Precision measurement

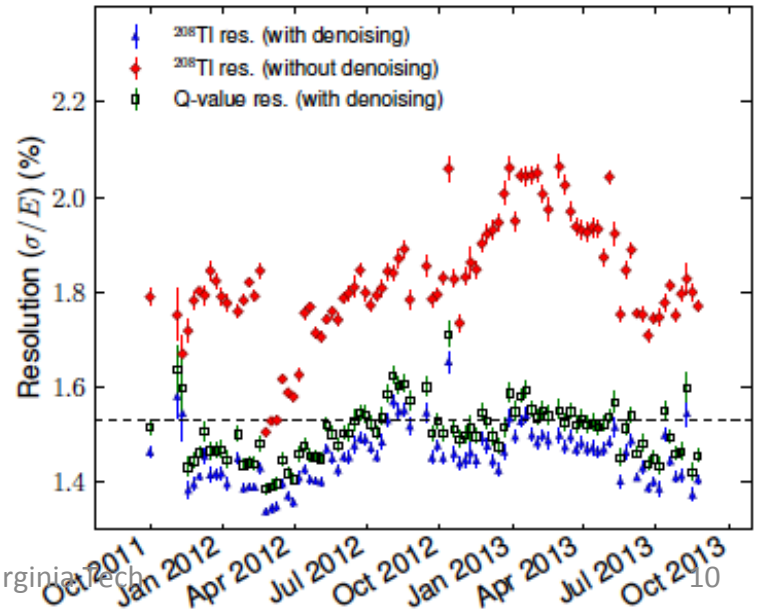
PRC 89, 015502 (2014)

Component	Error (%)
Systematic errors	2.60
SS/(SS+MS) Fraction	0.77
Backgrounds	1.3
Statistical	0.76
Total	2.83

0νββ decay search

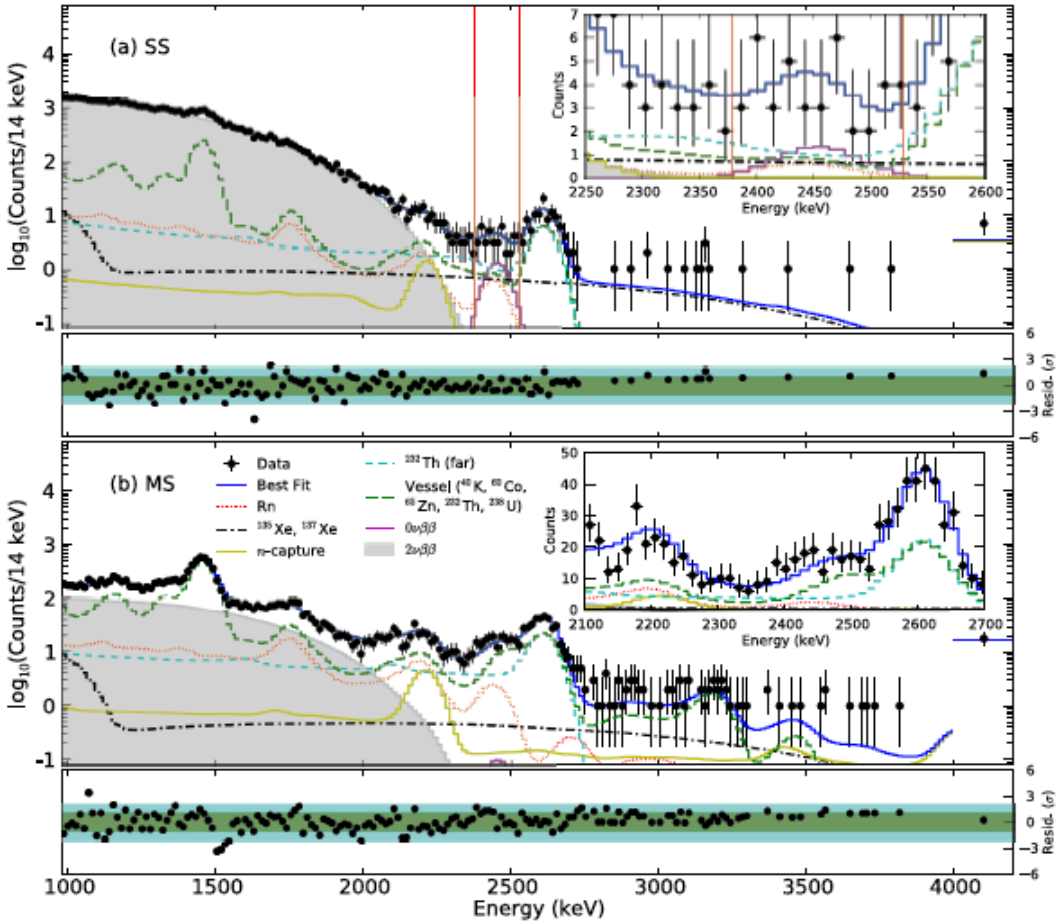
- First 0νββ decay search results presented in 2012 with the best limit at the time
- Since we have continued data taking (until Feb. 2014) and further improved the data analysis
  - 477.60 ± 0.01 effective days of data collection
  - Increased the fiducial volume for maximized exposure of 100.0 ± 3.4 kg yr
  - Introduced algorithm to reduce noise on the APD channel





0νββ decay search

Final fit: As for the 2νββ analysis, we fit simultaneously for SS and MS as well as standoff distance



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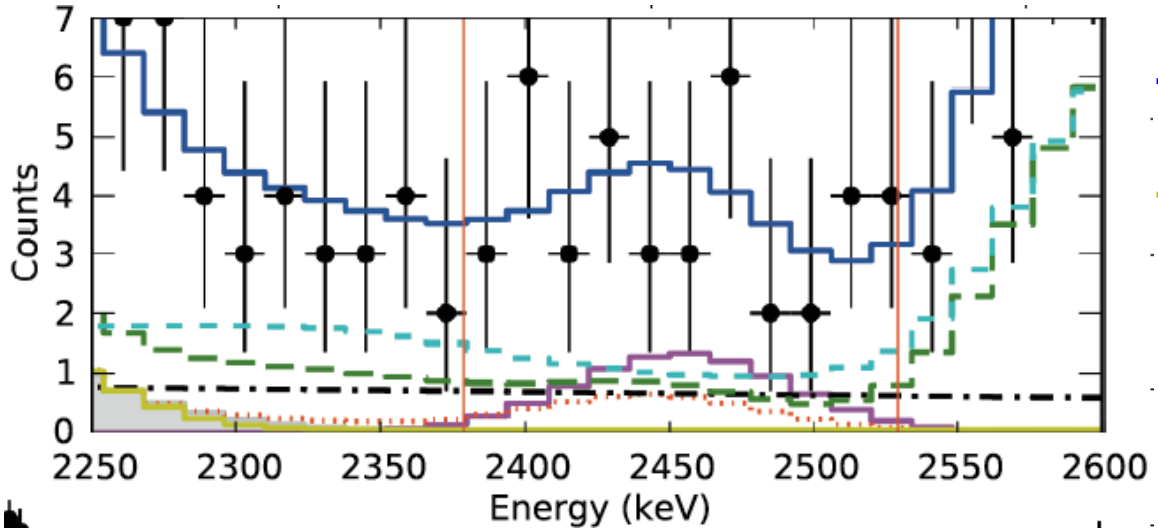


Background contribution in 2σ ROI:
31.1 ± 1.89(stat) ± 3.3(sys)

Source	Signal eff. (%)	Error (%)
Event selection	93.1	0.9
Partial reconstruction	90.9	7.8
Fiducial volume	-	3.4
Total	84.6	8.6

Source	Error (%)
Background shape distortion	9.2
Background model	5.7
Energy resolution variation	1.5
Total	10.9

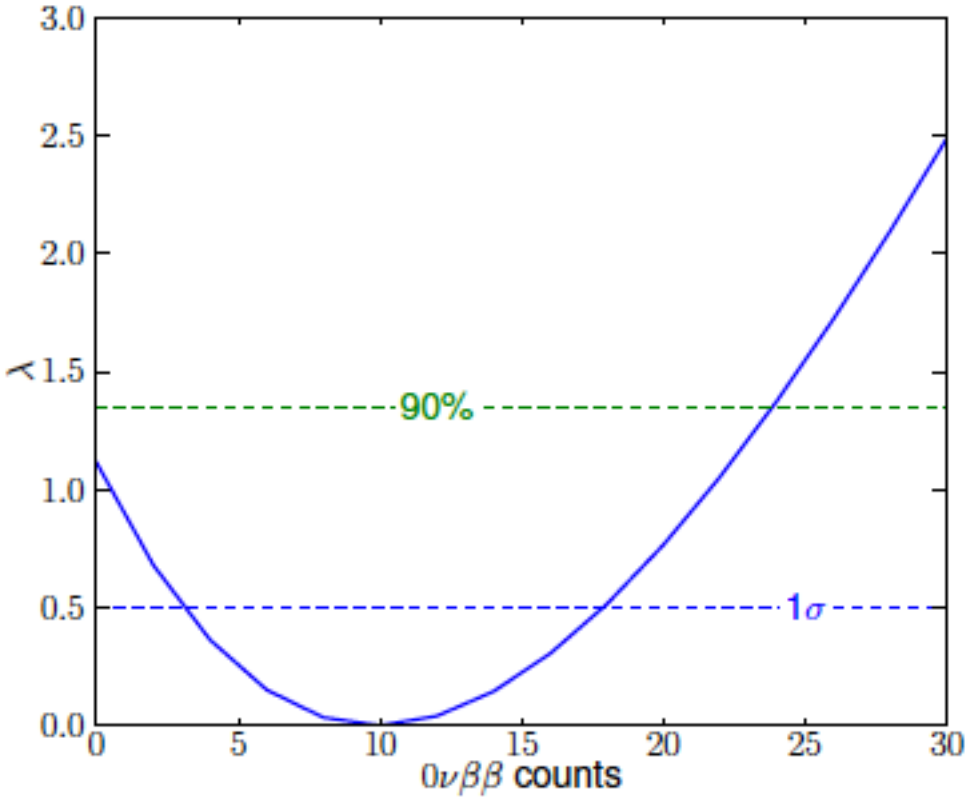
0νββ decay search

- Profile over the number of 0νββ decay gives an excess of 10 events which is compatible with background fluctuations at ~1.2σ

- Assuming background-only model the median 90% CL UL is >1.9•10^{25} yrs

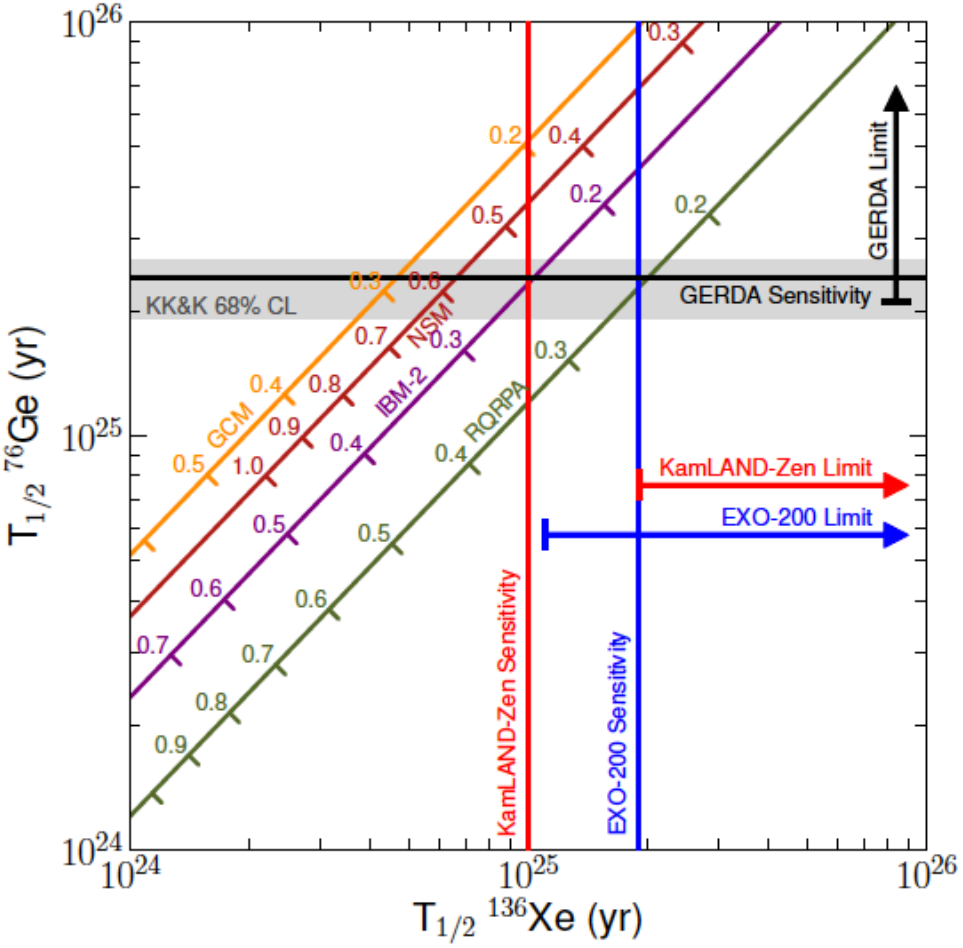
- The actual limit from the fit is >1.1•10^{25} yrs
  only ~1.5 "σ" from the median

- Upper Majorana neutrino mass limit: 190 – 450 meV



0νββ decay search

- Comparison to other 0νββ decay experiments



EXO-200:

Nature 520 (2014) 229

GERDA Phase I:

PRL, 111 (2013) 122503

KamLAND-Zen:

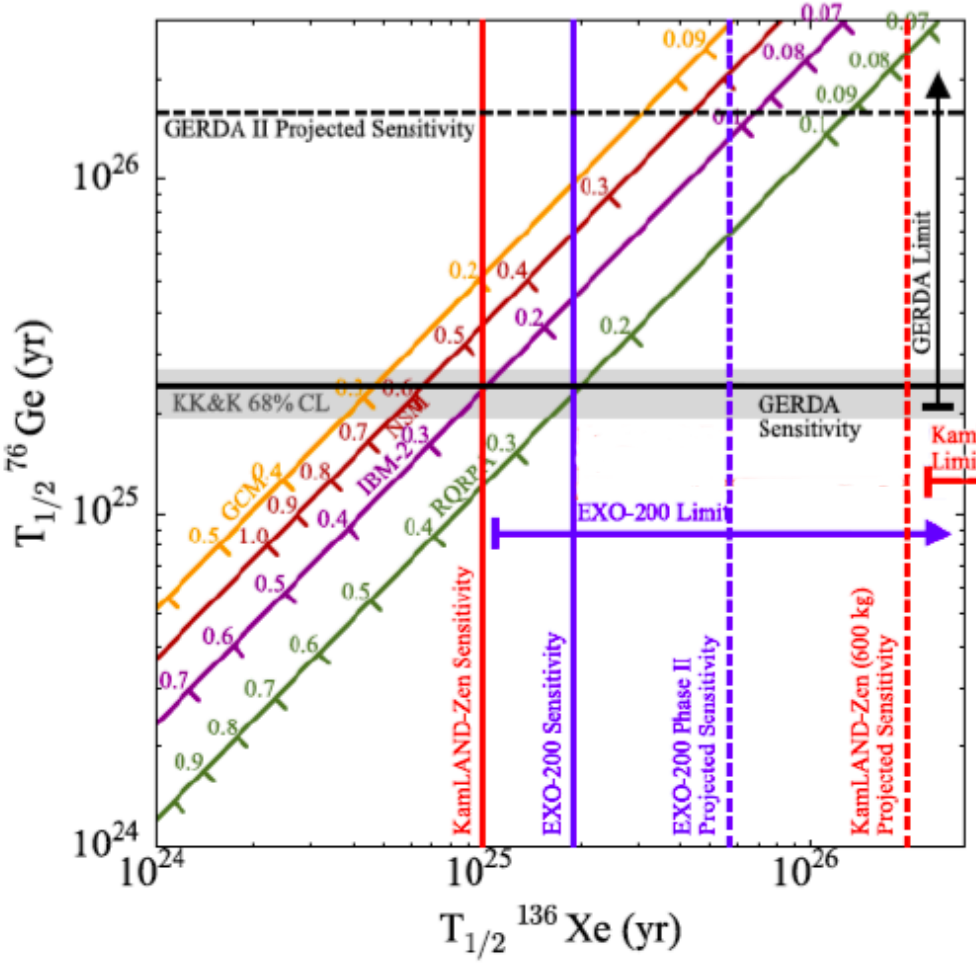
PRL, 110 (2013) 062502

KK&K Claim:

Mod. Phys. Lett. A21 (2006) 1547

0νββ decay search

- Comparison to other 0νββ decay experiments



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Other searches with EXO-200

- Search for Majoron-emitting modes of double-beta decay of ^{136}Xe with EXO-200
  Phys. Rev. D 90, 092004 (2014)
- Investigation of radioactivity-induced backgrounds in EXO-200
  Phys. Rev. C 92, 015503 (2015)
- Measurements of the ion fraction and mobility of alpha and beta decay products in liquid xenon using EXO-200
  Phys. Rev. C 92, 045504 (2015)
- Search for 2νββ decay of ^{136}Xe to the 0_1^+ excited state of ^{136}Ba with EXO-200
  Phys. Rev. C 93, 035501 (2016)
- Cosmogenics Backgrounds to 0νββ in EXO-200
  Published to JCAP
- First Search for Lorentz and CPT Violation in Double Beta Decay with EXO-200
  Phys. Rev. D 93, 072001 (2016)

Phase II

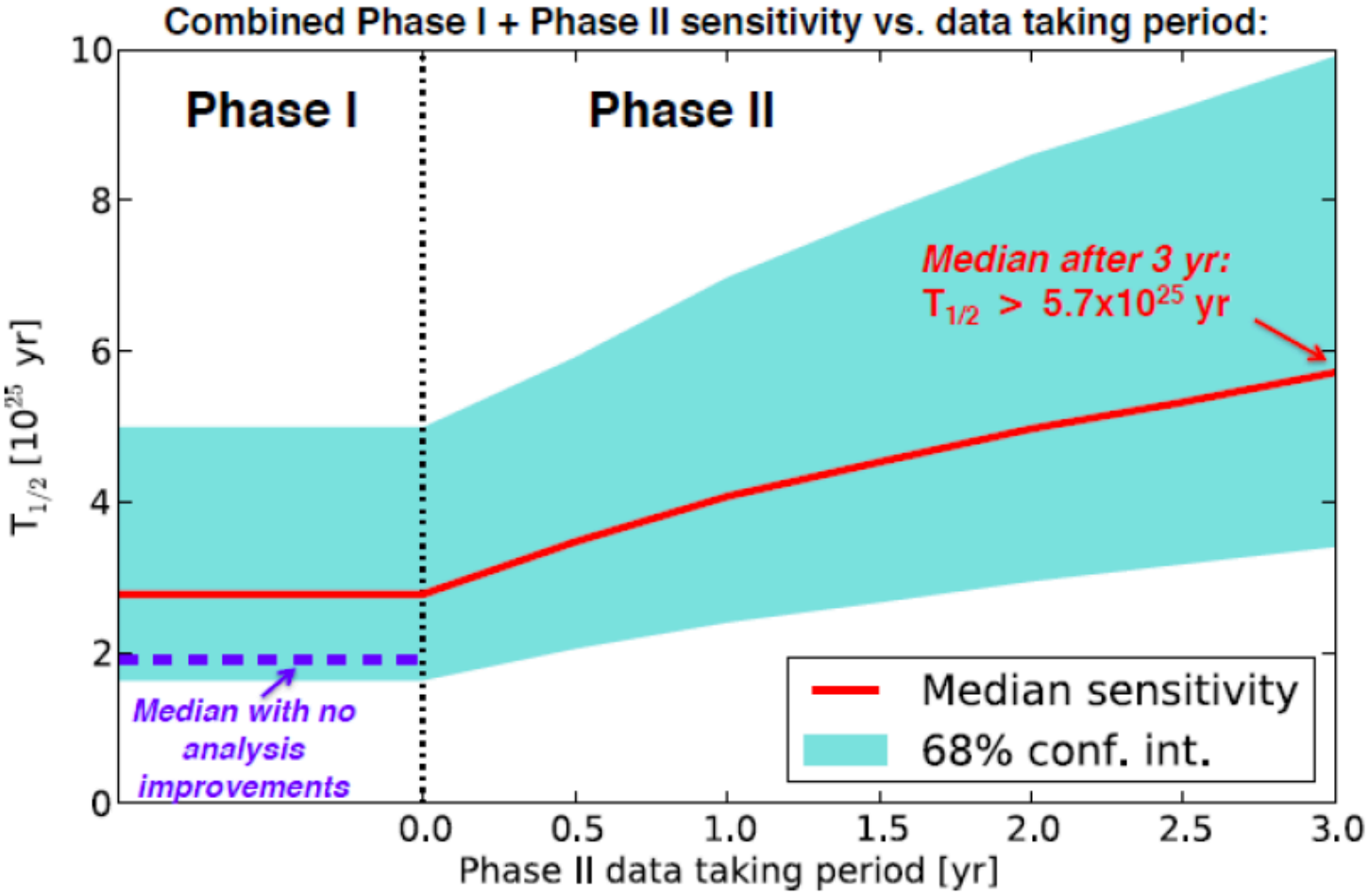
- In February 2014 an underground incident (not related to EXO-200) at WIPP forced us to suspend the operation of EXO-200

- Investigations of the incident made it impossible to continue running. By now we have regained access to the mine and a lot of people have worked hard to make the detector operational again

- In May 2015, DOE approved the restarts and continuation of data taking for another 3 years

Phase II

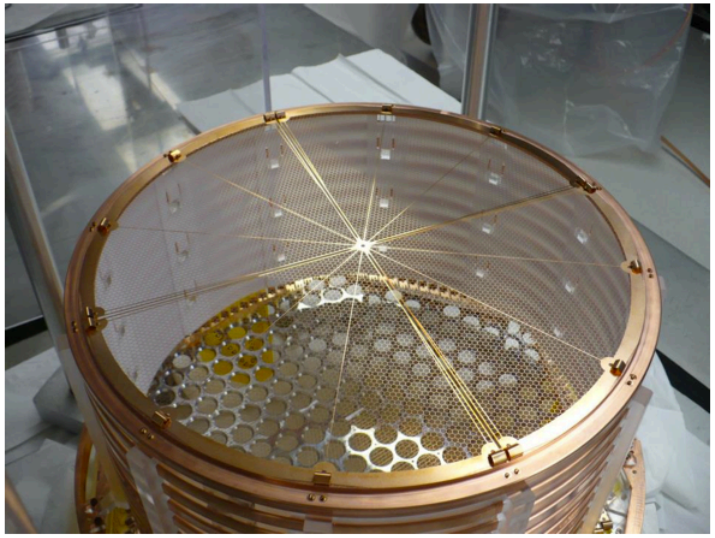
- Estimated sensitivity

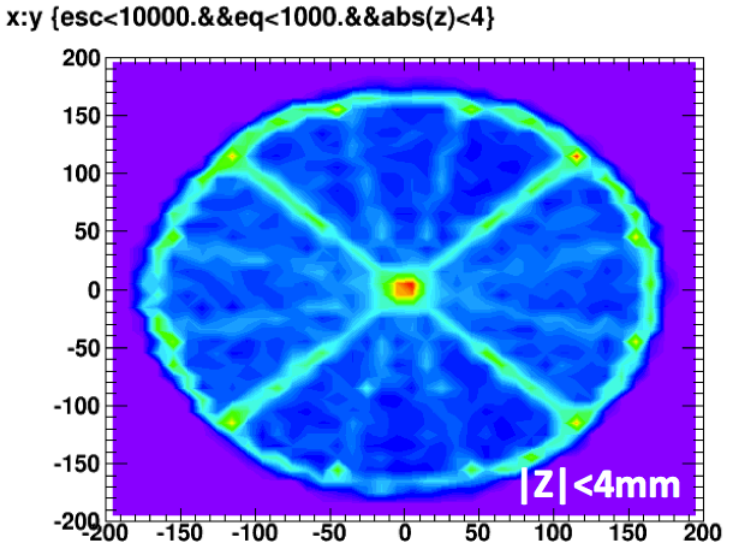


Phase II

- We have upgraded the readout electronics for the light channels and have taken first data to verify the condition of the detector

- First look at the data confirms improved energy resolution (approaching 1%) and detector is fully operational





Phase II

- We have also installed a “deradonator” system that flushes the gap between cryostat and lead shield with Rn-supressed air. This is expected to reduce far background further
- Analysis-wise an up to 70% reduction of γ background induced by neutron capture is possible
- More advanced analysis techniques using signal risetime information is expected to improve SS/MS discrimination
- All these improvements will reduce the major background components in the ROI, ^{232}Th (16 counts), ^{238}U (8.1 counts), ^{137}Xe (7 counts)

Summary

- EXO-200 was successfully operating and collected 2 years of low background data
- The unfortunate shutdown for almost 2 years gave the opportunity to improve analysis techniques and search for more exotic decays with the already collected data
- Some of the strongest results for 0νββ, 2νββ and Majoron-mediated decays were produced
- EXO-200 has successfully restarted operation in 2016. Hardware upgrades have been performed and improved energy resolution has been demonstrated

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Stay tuned for more news from EXO-200

The EXO-200 Collaboration

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Duke University, Durham NC, USA — PS Barbeau
IBS Center for Underground Physics, Daejeon, South Korea — DS Leonard
IHEP Beijing, People' s Republic of China — G Cao, W Cen, L Wen, J Zhao
ITEP Moscow, Russia — D Akimov, I Alexandrov, V Belov, A Burenkov, M Danilov, A Dolgolenko, A Karelin, A Kovalenko, A Kuchenkov, V Stekhanov, O Zeldovich
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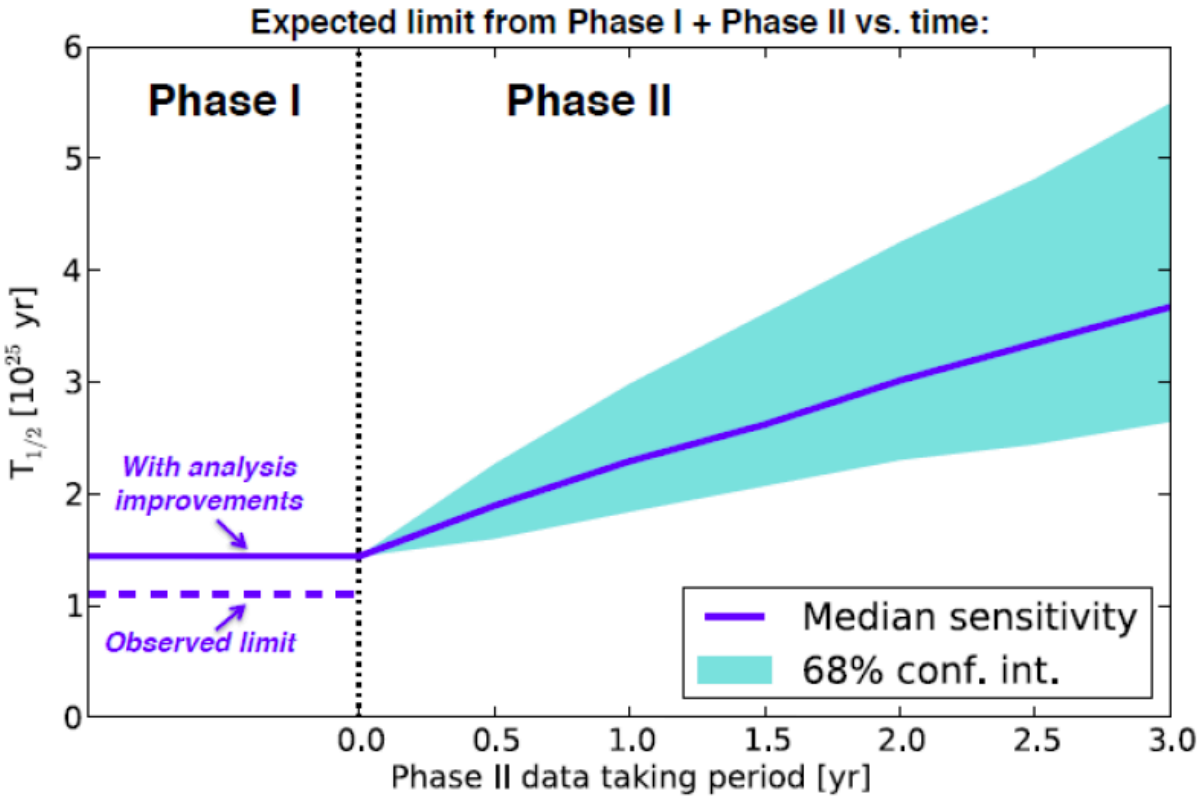
Stony Brook University, SUNY, Stony Brook, NY, USA — K Kumar, O Njoya, M Tarka
Technical University of Munich, Garching, Germany — W Feldmeier, P Fierlinger, M Marino
TRIUMF, Vancouver BC, Canada — J Dilling, R Krücken, F Retière, V Strickland

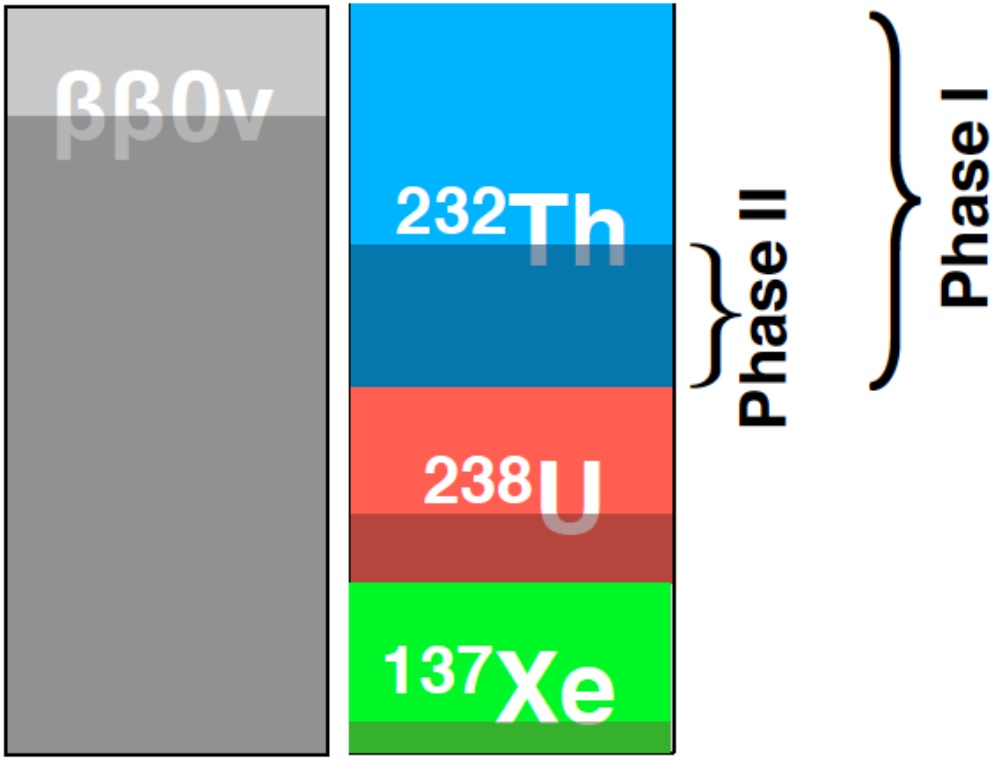
Back-up slides

Improvements that lead to higher S/B in ROI

- Energy Resolution reducing leakage of Th-232 backgrounds
- ~40% of U-238 activity assigned to Rn in air gap. Installation of deradonator
- Identification of Xe-136 neutron capture events. Removing ~70% of Xe-137 decay events
- Improved SS/MS discrimination using U-wire signal risetime

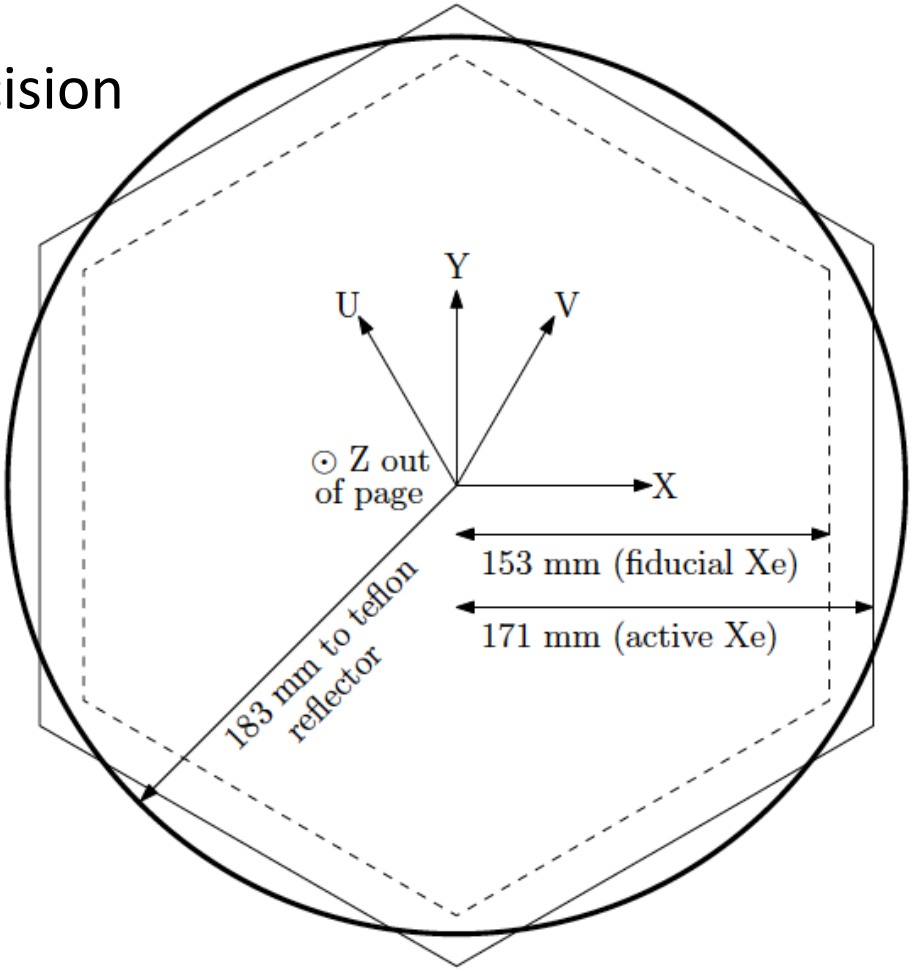


Schematic of background reduction:

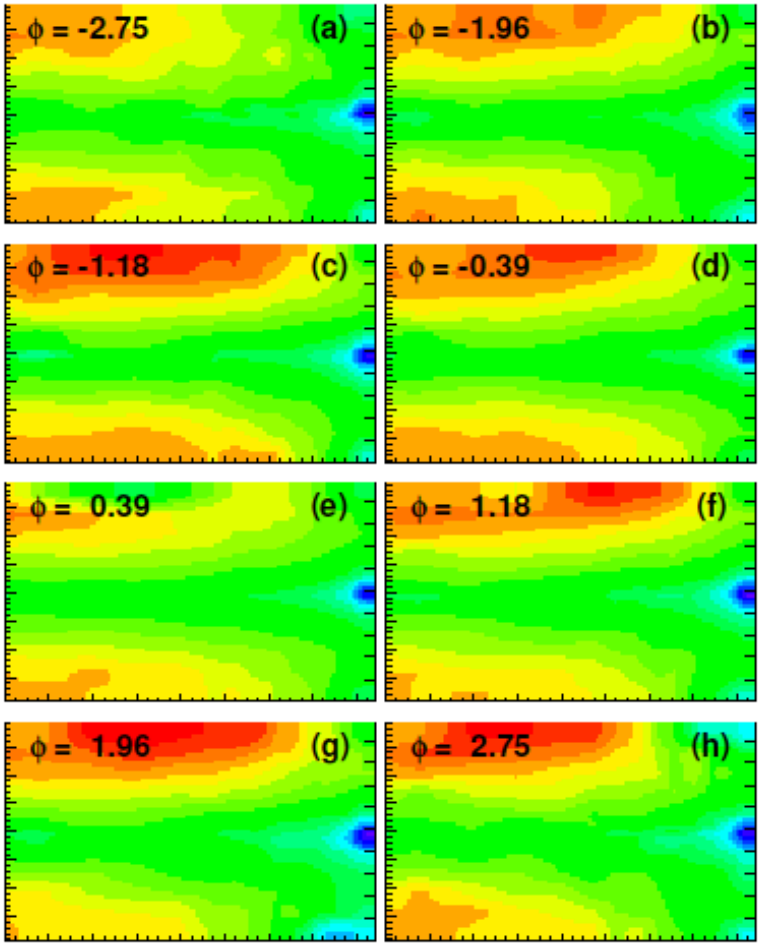


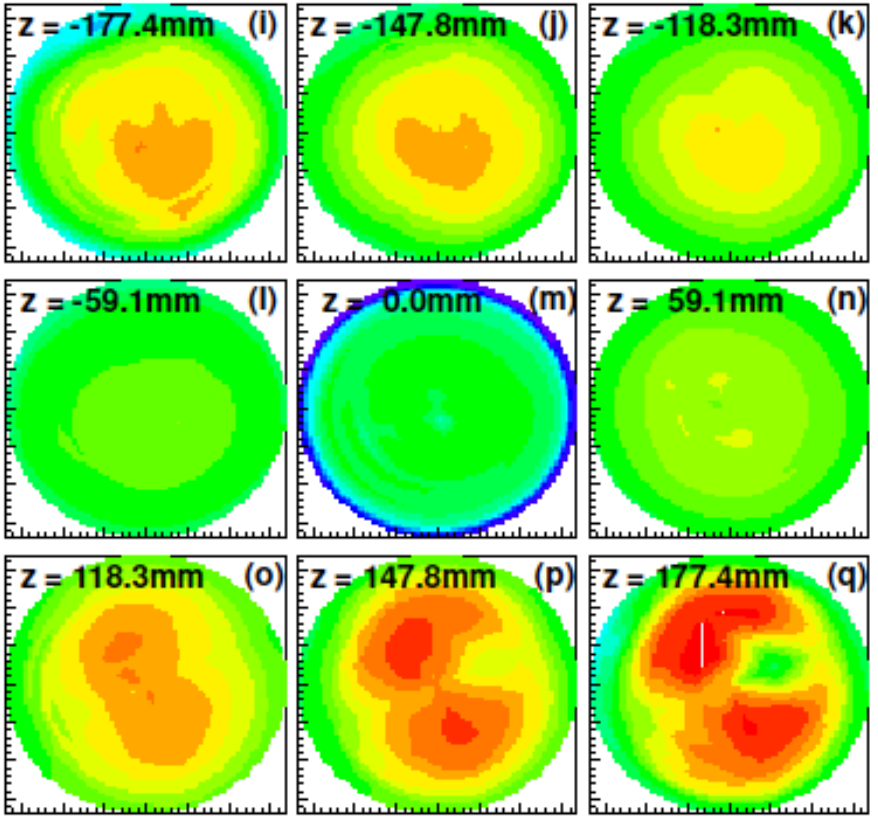
Fiducial volume used for precision measurement of 2νββ decay

There is enough statistics to allow for a smaller fiducial cut, improving background rejection and better understanding of detector performance

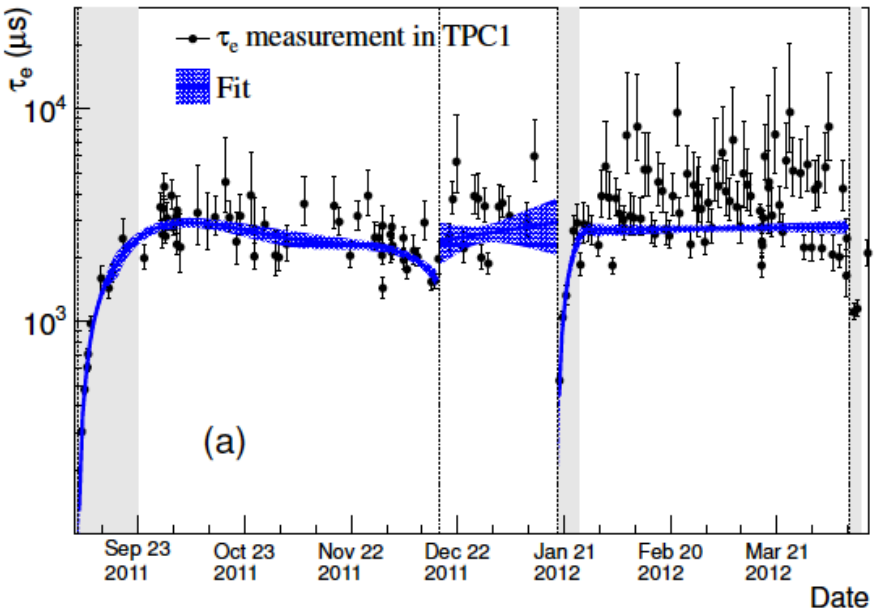


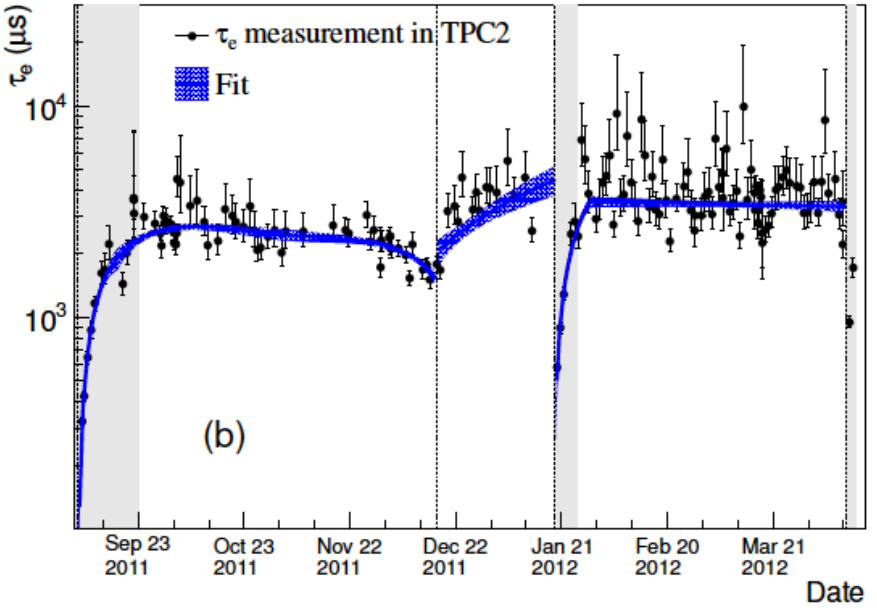
Lightmap


ϕ = -2.75 (a)
ϕ = -1.96 (b)
ϕ = -1.18 (c)
ϕ = -0.39 (d)
ϕ = 0.39 (e)
ϕ = 1.18 (f)
ϕ = 1.96 (g)
ϕ = 2.75 (h)

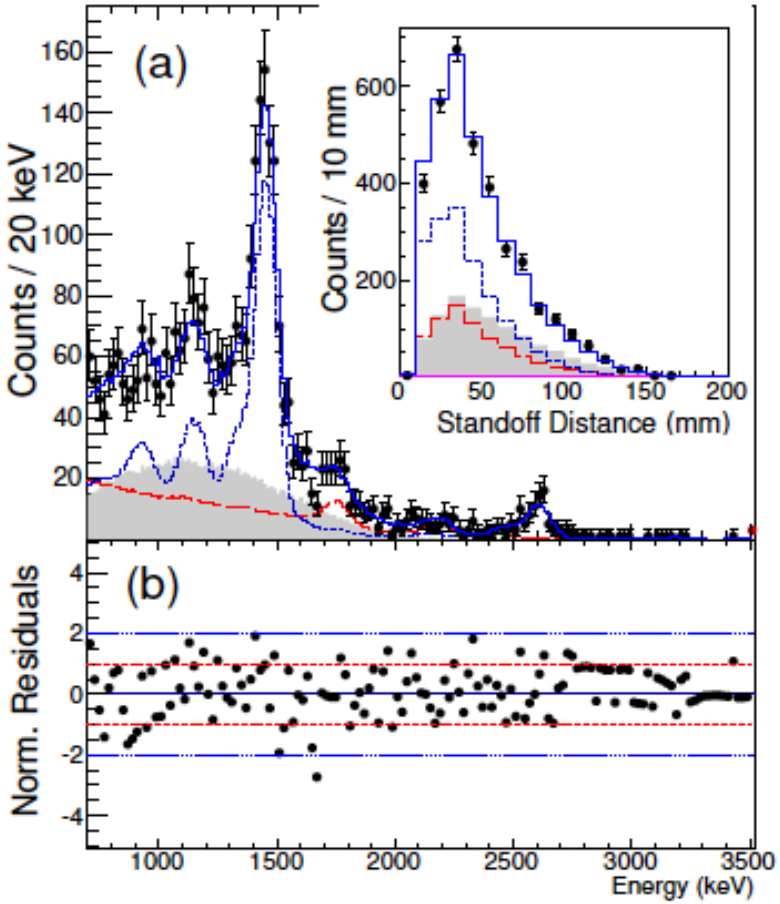

z = -177.4mm (i)
z = -147.8mm (j)
z = -118.3mm (k)
z = -59.1mm (l)
z = 0.0mm (m)
z = 59.1mm (n)
z = 118.3mm (o)
z = 147.8mm (p)
z = 177.4mm (q)

Purity

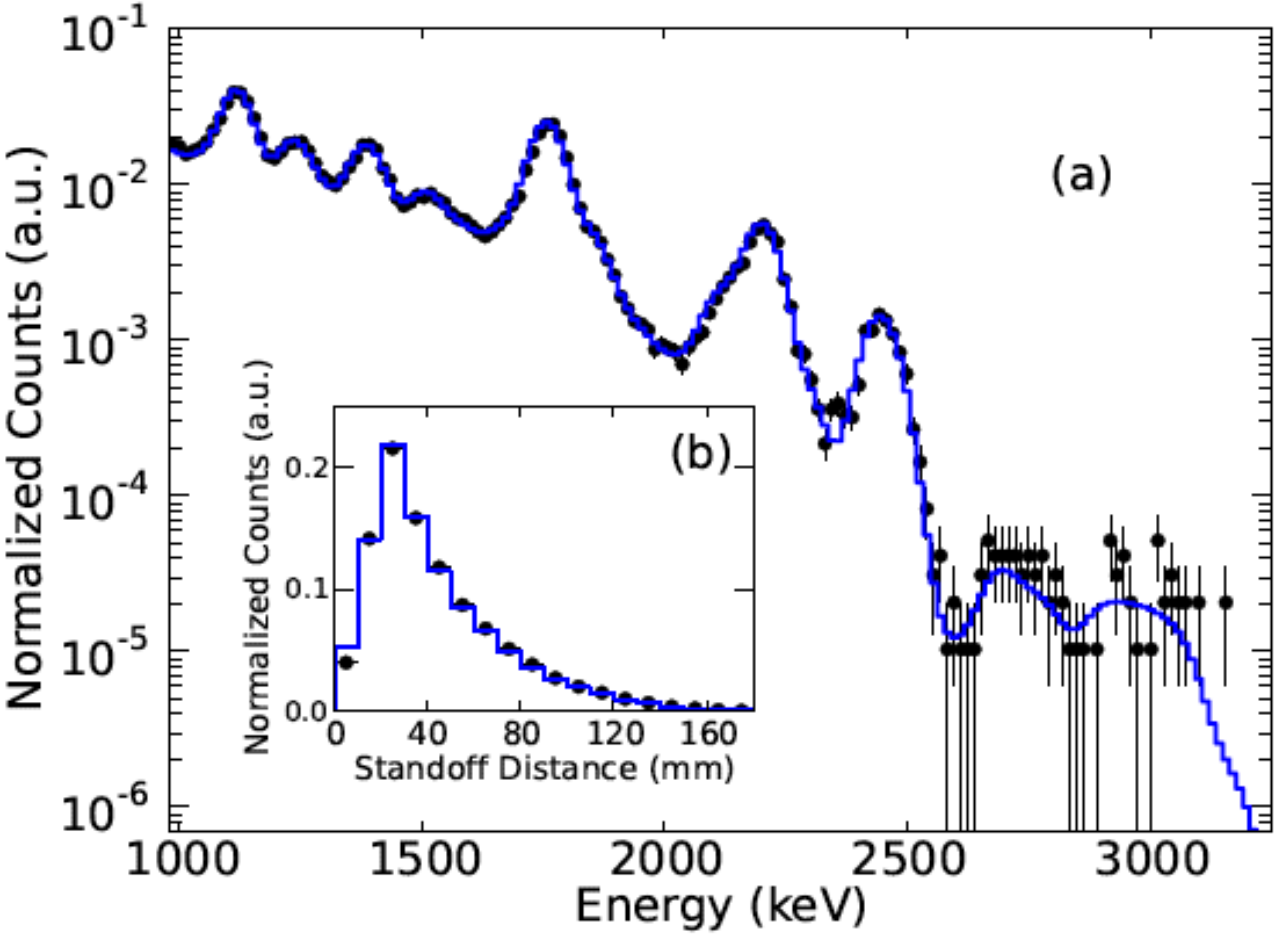

τ_e measurement in TPC1
Fit
τ_e (µs)
10^4
10^3
(a)
Sep 23 2011
Oct 23 2011
Nov 22 2011
Dec 22 2011
Jan 21 2012
Feb 20 2012
Mar 21 2012
Date


τ_e measurement in TPC2
Fit
τ_e (µs)
10^4
10^3
(b)
Sep 23 2011
Oct 23 2011
Nov 22 2011
Dec 22 2011
Jan 21 2012
Feb 20 2012
Mar 21 2012
Date

2νββ measurement MS fit



Calibrated Ra-226 spectrum



SS/MS ratio agreement