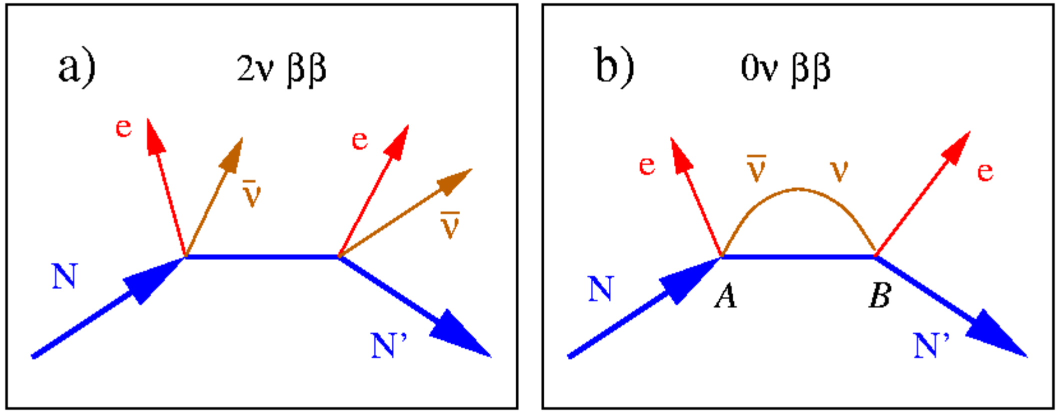
EXO-200: Results and Plans for Phase-II

Igor Ostrovskiy

for the EXO-200 collaboration

Double beta decay

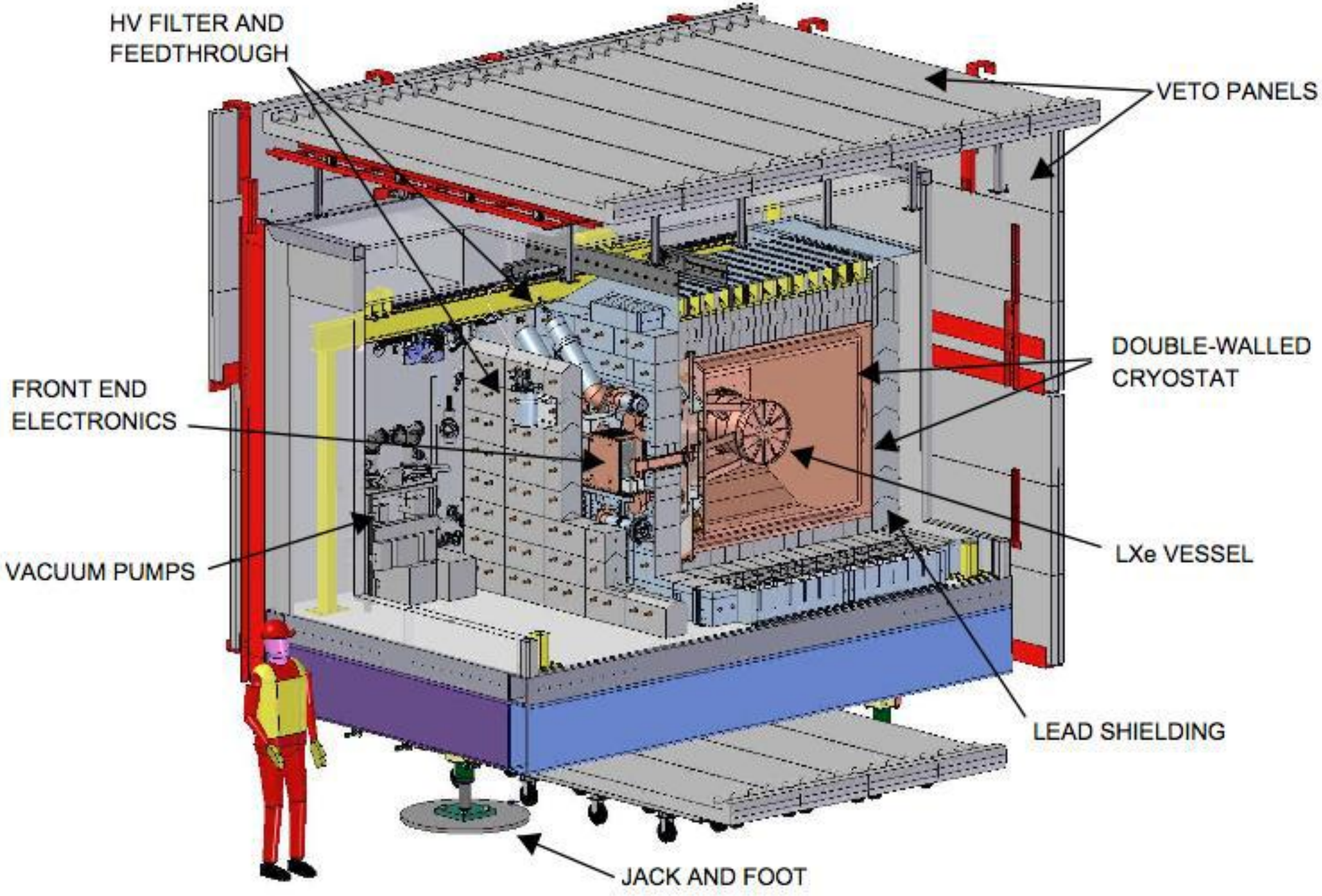
- ***Two-neutrino*** mode is a Standard model process observed for several isotopes, but is extremely rare
- ***Neutrinoless*** mode violates lepton number conservation
  - can only happen if neutrinos are **massive Majorana** particles
  - provides information about **absolute mass** scale
  - has never been observed*
- Main goal of EXO-200 is to search for the neutrinoless mode



* a controversial discovery claim exists by a sub-group of Heidelberg-Moscow collaboration [H.V. Klapdor-Kleingrothaus and I.V. Krivosheina Mod. Phys. Lett., A21 (2006) 1547]

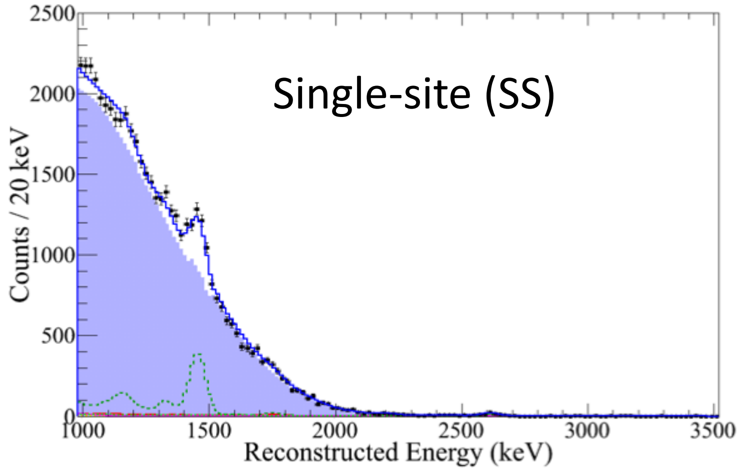
EXO-200

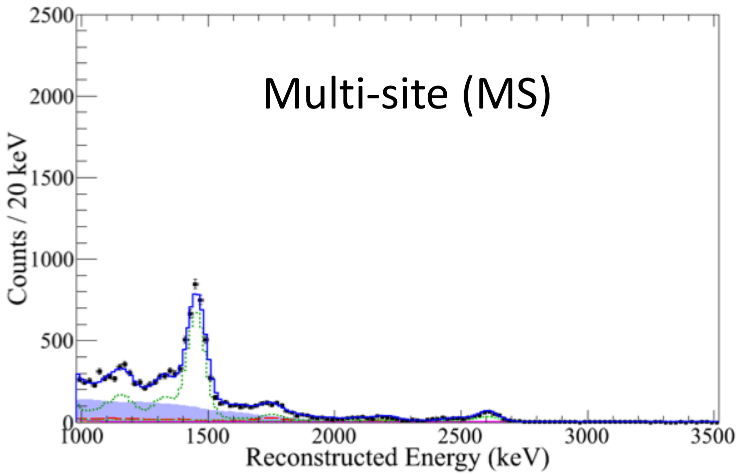
- ~200 kg of Xe enriched to 80.6% in ^{136}Xe
  - ~175 kg in liquid phase inside a cylindrical Time Projection Chamber
  - ~100 kg current fiducial mass
- Located at 1585 m.w.e. in the Waste Isolation Plant near Carlsbad, NM
  - Muon rate reduced to the order of 10^{-7} Hz /cm^2 /sr
  - Salt has inherently lower levels of U/Th (<100 ppb), compared to rock
  - Low levels of Rn (~20 Bq/m^3)
- Carefully selected radioactively clean materials, rigorous cleaning procedures, detector installation inside class 1000 clean room
  - Goal of **40 counts/2 yrs** in 2σ 0nu energy window (assuming 140 kg LXe, 1.6% resolution)
  - M. Auger et al., **JINST 7 (2012)** P05010 and D.S. Leonard et al., **NIM A 591 (2008)** 490


HV FILTER AND
FEEDTHROUGH
VETO PANELS
DOUBLE-WALLED
CRYOSTAT
FRONT END
ELECTRONICS
LXe VESSEL
VACUUM PUMPS
LEAD SHIELDING
JACK AND FOOT

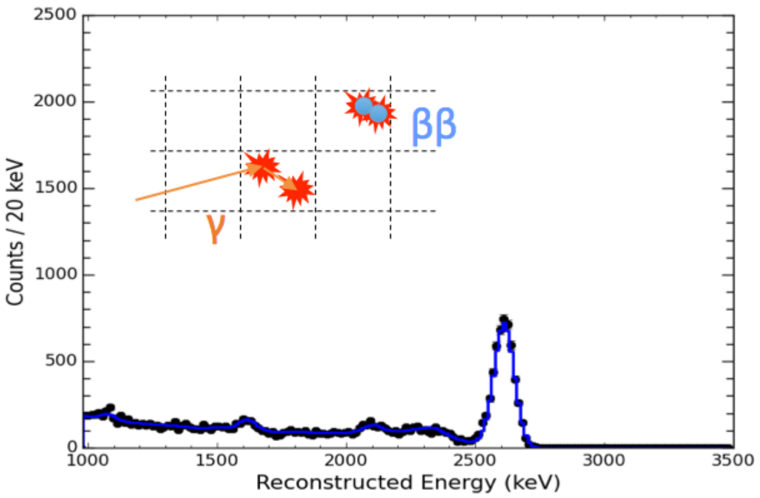
Single- vs. Multi-site events

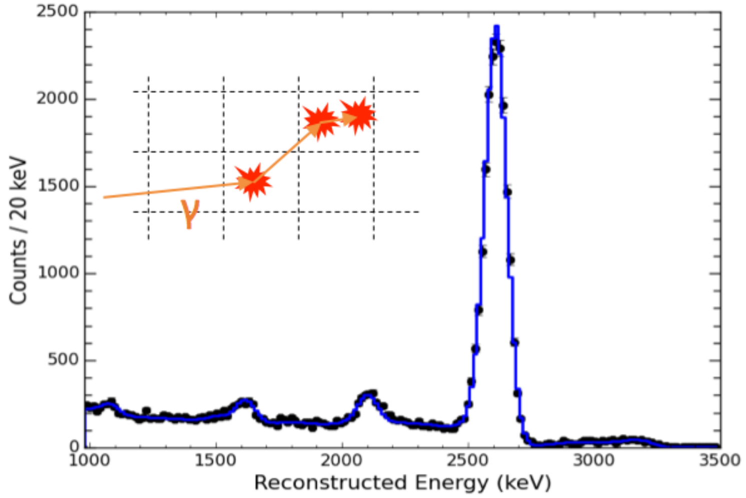
Low Background Data





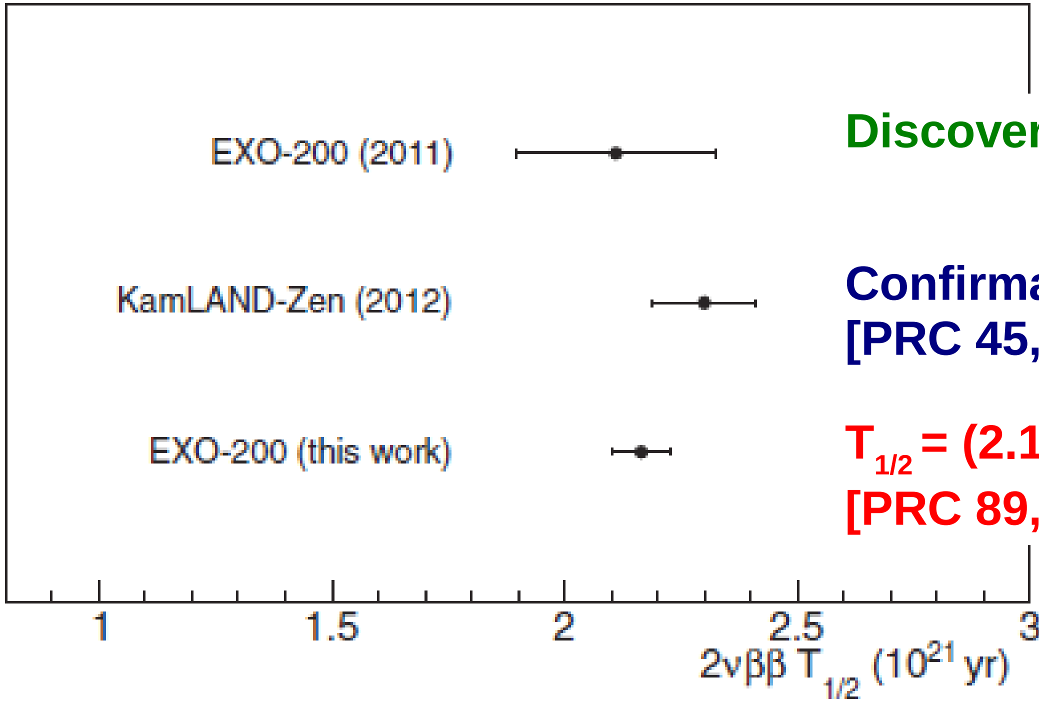
^{228}Th Calibration Source





Very useful in identifying gamma backgrounds!

Two-neutrino result



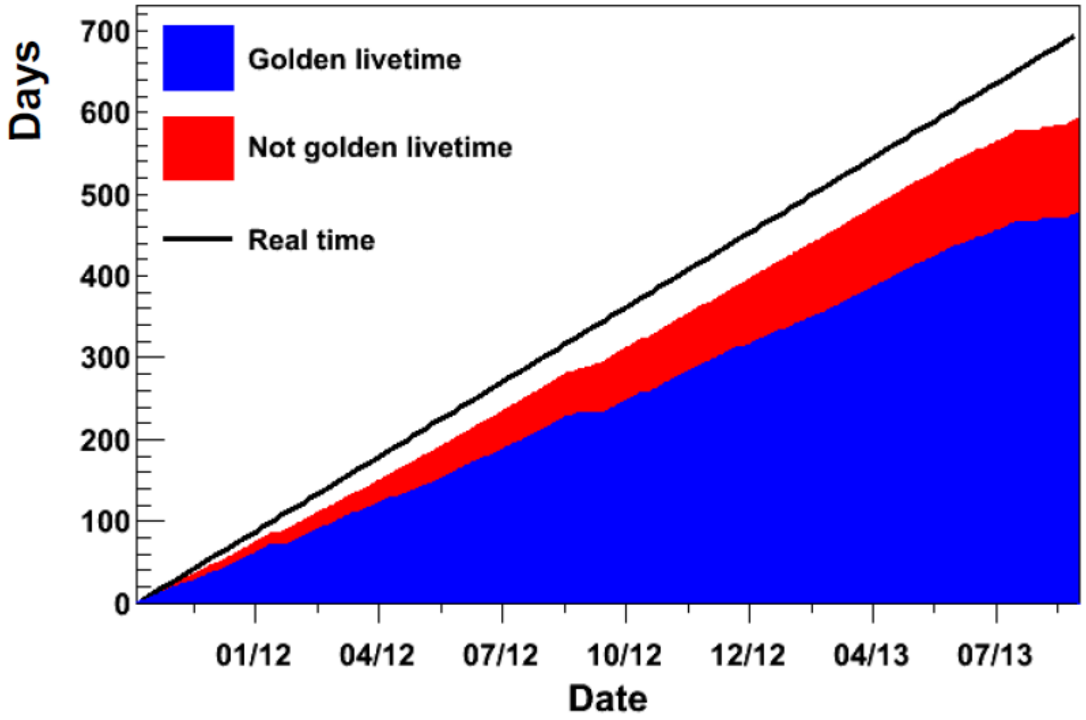
Discovery [PRL 107, 212501 (2011)]

Confirmation by KamLAND-Zen [PRC 45, 045504 (2012)]

$T_{1/2}$ = (2.165 ± 0.016^{stat} ± 0.059^{sys})·10^{21} yr [PRC 89, 015502 (2014)]

EXO-200 **discovered** the 2ν mode in ^{136}Xe and provided the **most accurate** measurement of a 2ν half-life among all isotopes

Dataset for neutrinoless analysis



- **477.60±0.01** live days collected between 10/2011 and 09/2013
- Larger fiducial volume to maximize exposure
- **100.0±3.4** kg·yr ^{136}Xe

Systematics budget

- Signal detection efficiency:

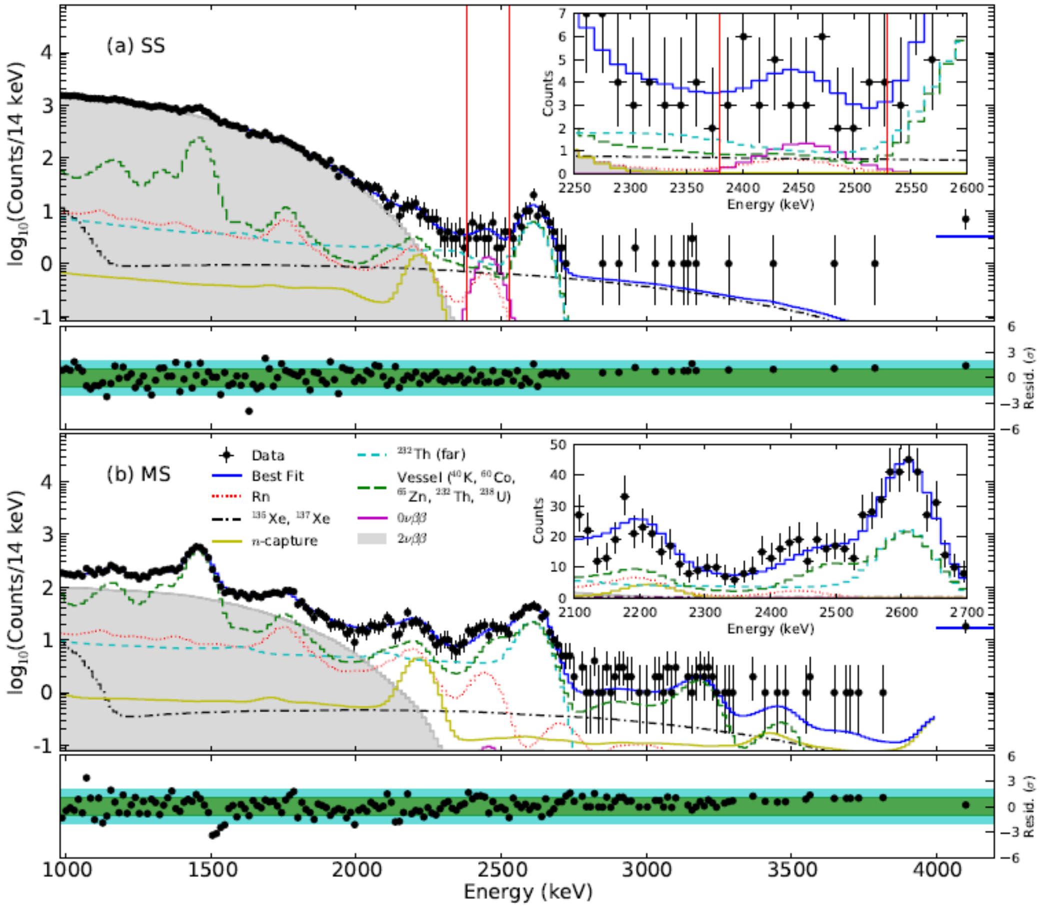
Source:	Signal efficiency [%]:	Relative error [%]:
Summary from 2-nu	93.1	0.9
Partial reconstruction	90.9	7.8
Fiducial volume		3.4
Total:	**84.6**	**8.6**

- 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**

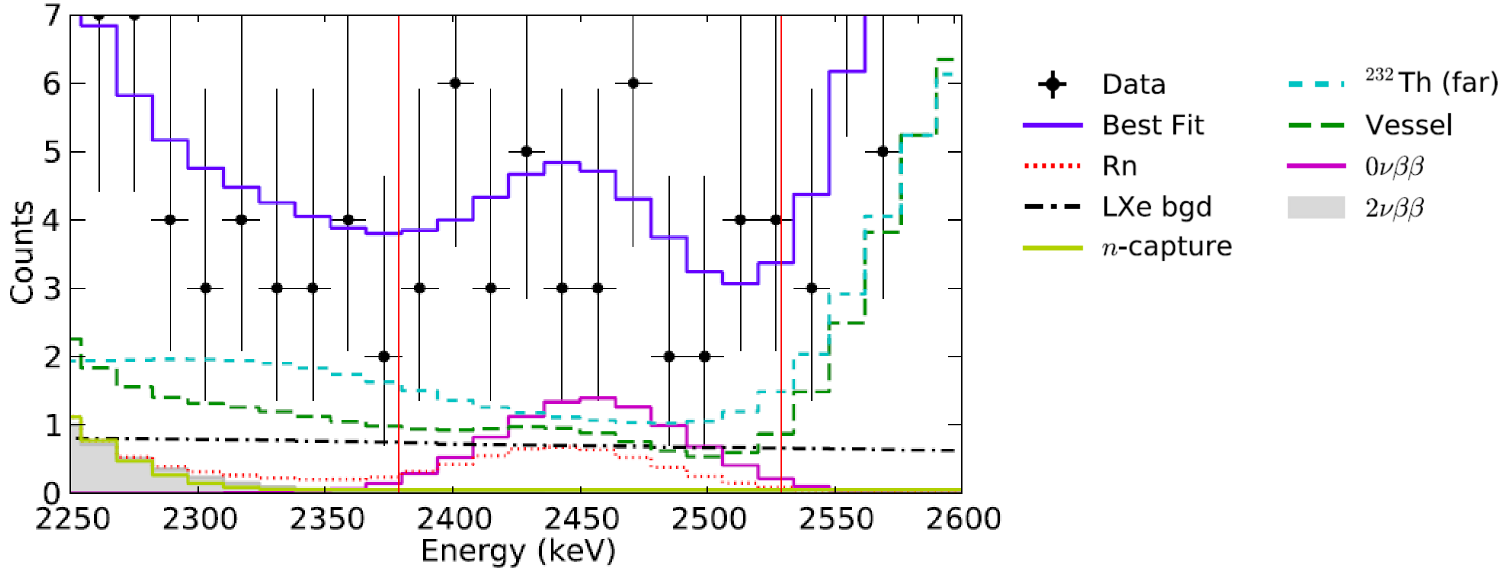
- Deviation between β and γ energy scale ($E_\beta = B \cdot E_\gamma$): ***B* = 0.999 ±0.002**
- Single-site fraction error: **(Data – MC)/Data = 9.6%**

Final fit



Projections on energy axes (fit also includes position information)

Single-site zoom-in



2σ ROI breakdown for major backgrounds

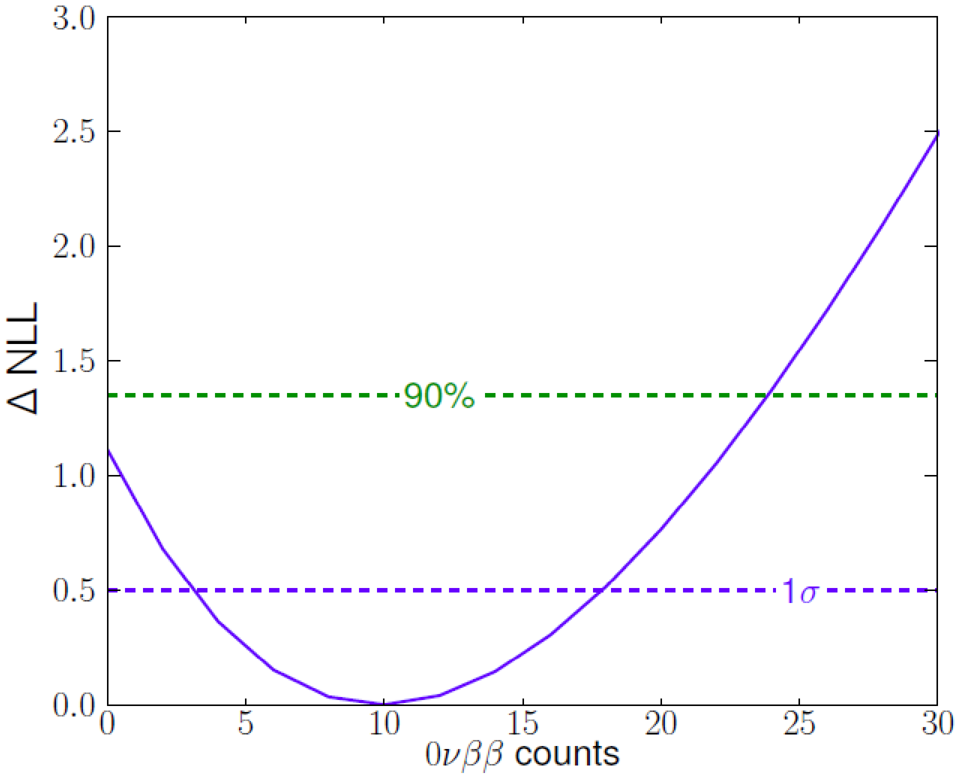
	Events	BI, 1e-3 /kg/yr/keV*
Th-232	**16.0**	
U-238	**8.1**	
Xe-137	**7.0**	
Total	**31.1±1.89(stat)±3.3(syst)**	**1.7±0.2**

*normalized to total exposure (124 kg*yr).

^{136}Xe exposure is 100 kg·yr

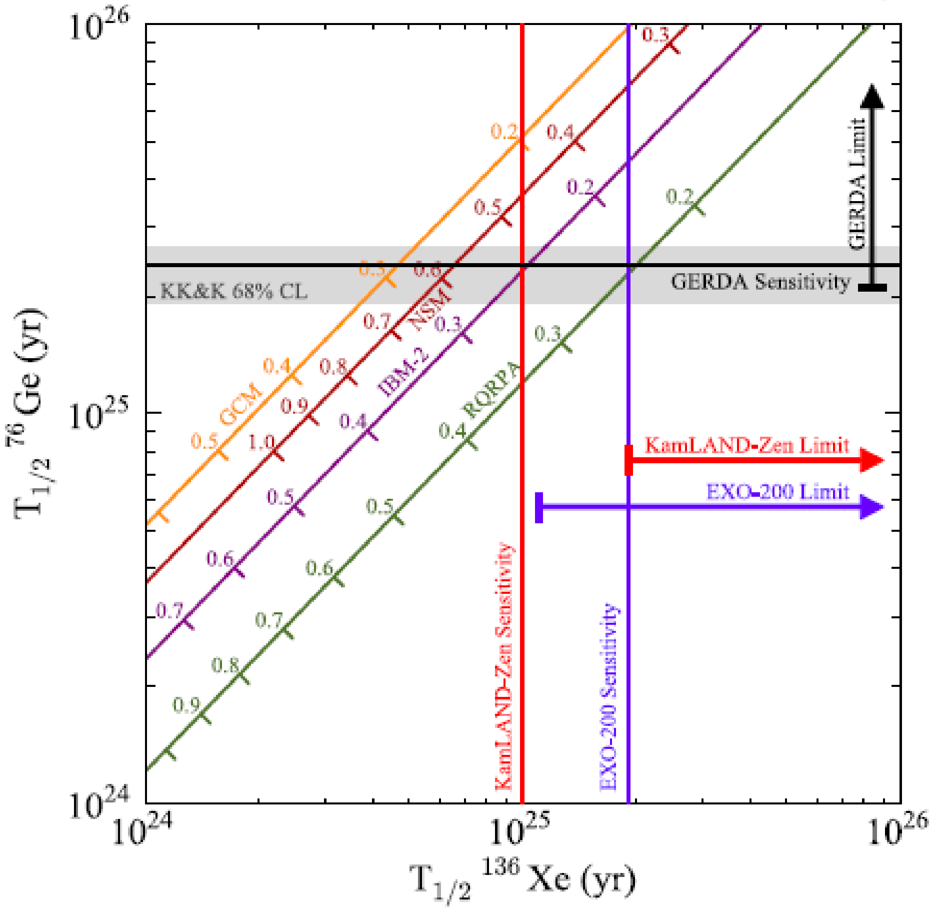
Compare to p.3

90% C.L. Limit



- The event excess is compatible with background fluctuation at **~1.2σ**
- Median 90% C.L. U.L. limit assuming adequate “background-only” model: **>1.9e25 yrs**
- Limit from the fit to the actual data: **>1.1e25 yrs**
- ~1.5 “σ” away from the median
  - 14% of signal-free toys have limits worse than this

Context



EXO-200:
Nature 510 (2014) 229

GERDA Phase 1:
PRL 111 (2013) 122503

KamLAND-Zen:
PRL 110 (2013) 062502

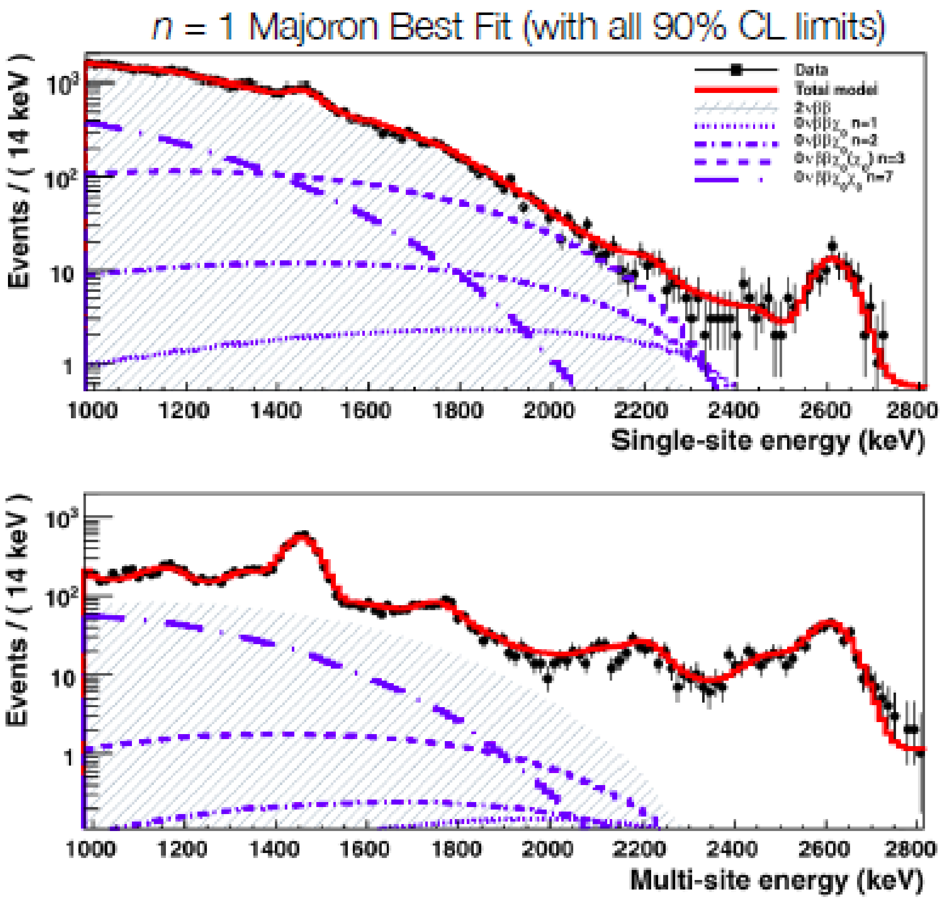
KK&K Claim:
Mod. Phys. Lett., A21 (2006) 1547

Other physics: Majoron-mediated decays

$$(A, Z) \rightarrow (A, Z+2) + 2e^- + \chi_0$$
$$(A, Z) \rightarrow (A, Z+2) + 2e^- + 2\chi_0$$

← Massless or light boson ("Majoron")

- Originally described as Goldstone boson of lepton number symmetry breaking
- Possible dark matter candidates; speculated to be involved in other astrophysical processes
- Characteristic spectral shape that can be searched for in EXO-200
- No stat. significant evidence was found. Limits on coupling constants among strongest to date
- **PRD 90, 092004 (2014)**



Other recent EXO-200 papers

- **J.B. Albert et al. “Measurements of the ion fraction and mobility of alpha and beta decay products in liquid xenon using EXO-200”**
  - ***arXiv:1506.00317 (Jun 2015), submitted to Phys. Rev. C.***
- **J.B. Albert et al. "Investigation of radioactivity-induced backgrounds in EXO-200"**
  - ***Phys. Rev. C 92 (2015) 015503***

EXO-200: Plans for Phase II

- Following the WIPP accidents on Feb 2014, access to the underground was discontinued and EXO-200 has stopped collecting data
- The access is largely restored by now and EXO-200 is making preparations to restart data-taking
- In May 2015, a panel of experts reviewed the case for continuation of EXO-200. Following the review, DOE has approved the restart and collection of 3 more years of data in June 2015
- Current plan is to restart by the end of the year

Expected improvements in Phase-II

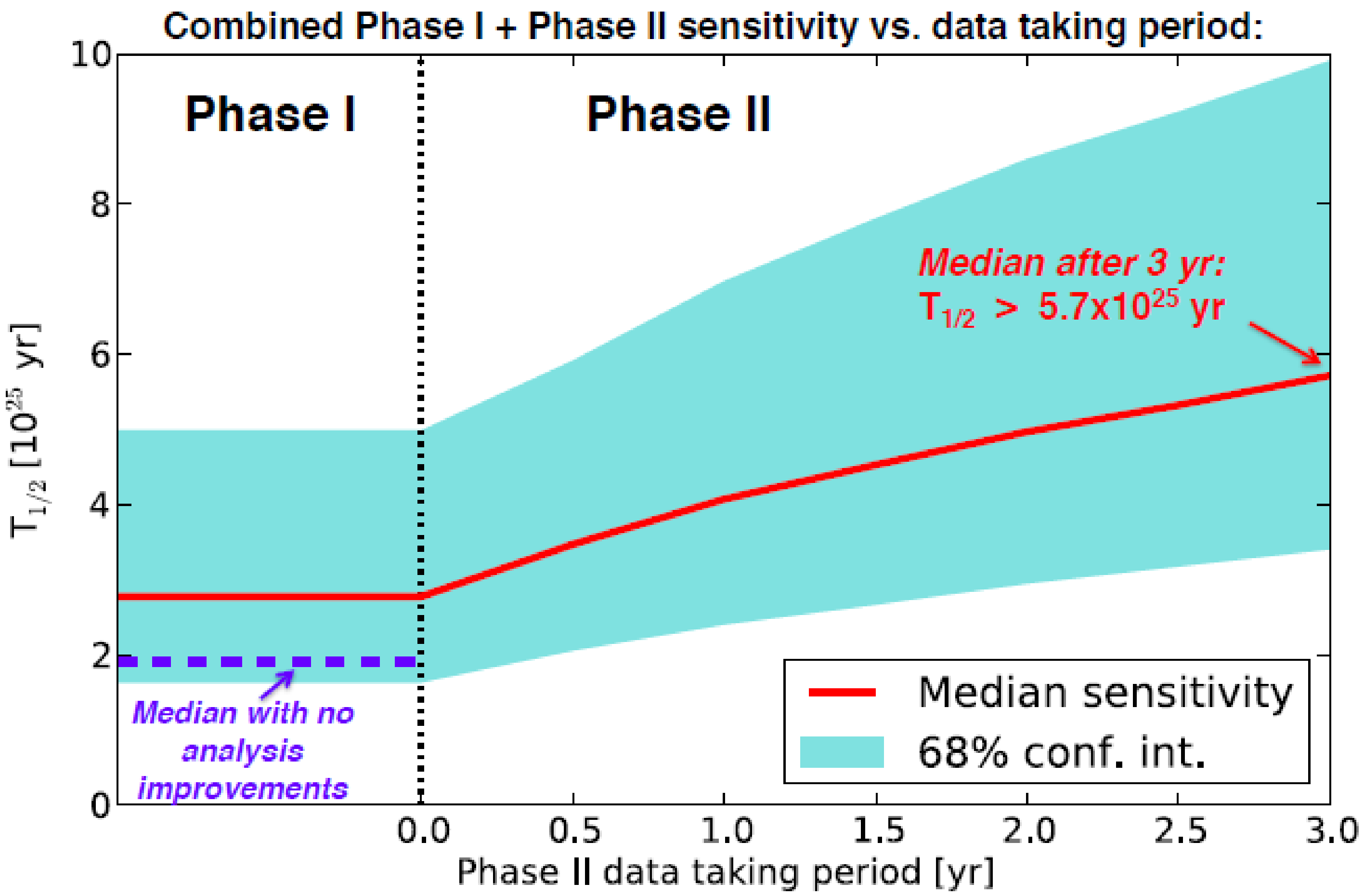
Analysis

- Reduce ^{137}Xe background with a new veto cut for events consistent with ^{136}Xe neutron capture γs. **Up to 70% possible reduction**
- Using pulse rise time and U-wire induction signals to improve SS/MS discrimination. Simple 1D cut already **moves 40% of γs, while only 15% of signal, from SS to MS**. More could be possible with continuous variable

Hardware

- Electronics upgrade to reduce noise in the light channel. Expected to decrease the **energy resolution at Q-value from ~1.5% to ~1%**
- "Deradonator" system to flush the air gap between cryostat and lead shield with Rn-suppressed air. Expected to **remove or reduce "remote" U background**

Estimated sensitivity



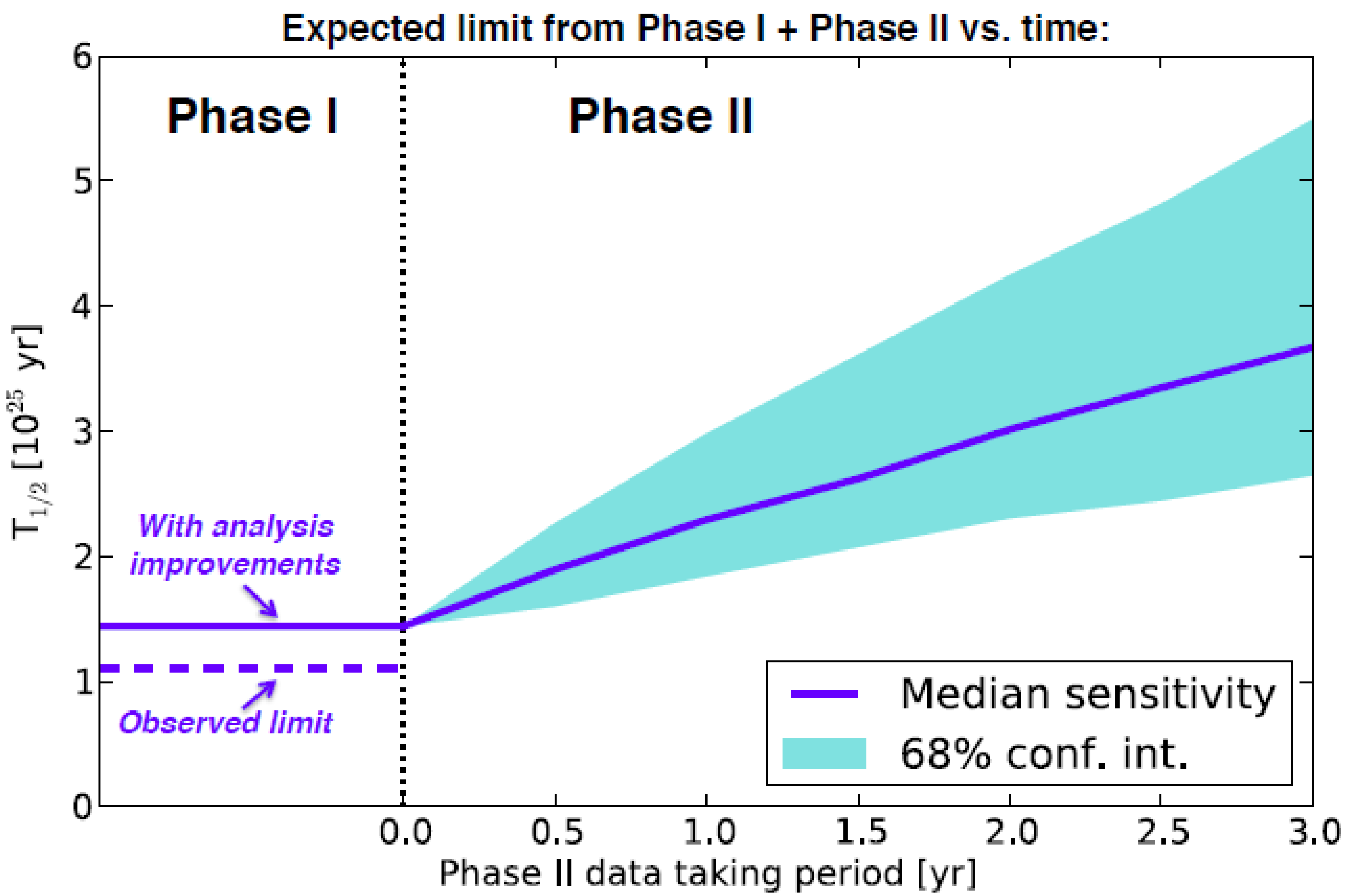
Summary

- EXO-200 has already produced one of the strongest results for neutrinoless, two-neutrino, and Majoron-mediated decays
- The experiment is currently preparing for Phase-II
- Phase-II is expected to improve sensitivity to neutrinoless decay by up to a factor of 3, compared to Phase-I (assuming 3 years of data-taking and stated hardware and analysis improvements)

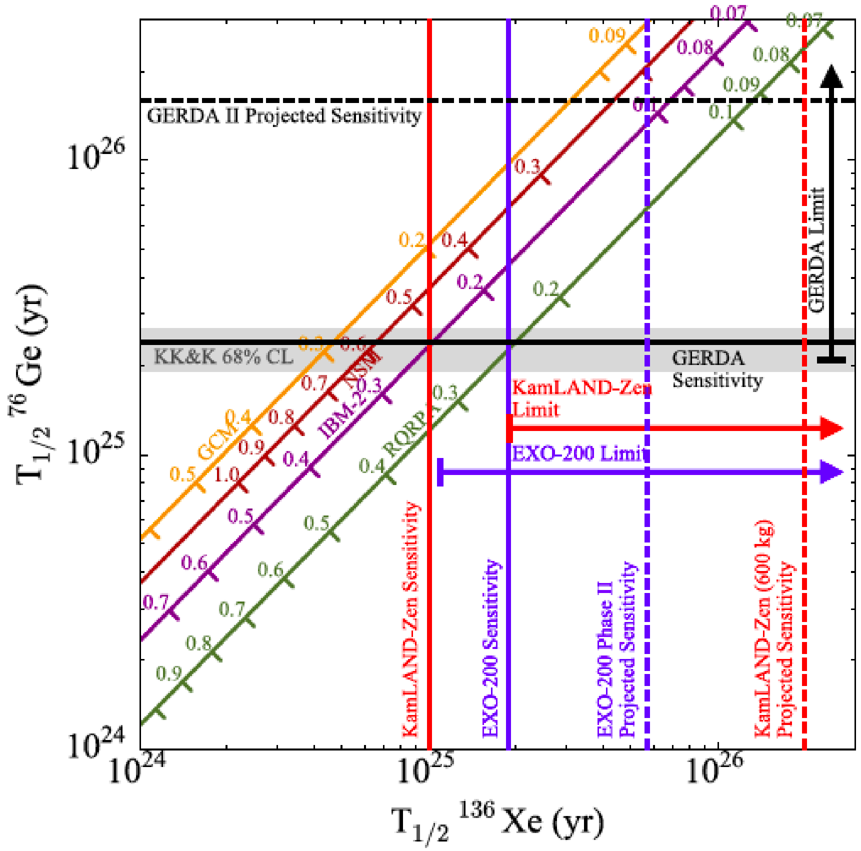
The EXO-200 Collaboration

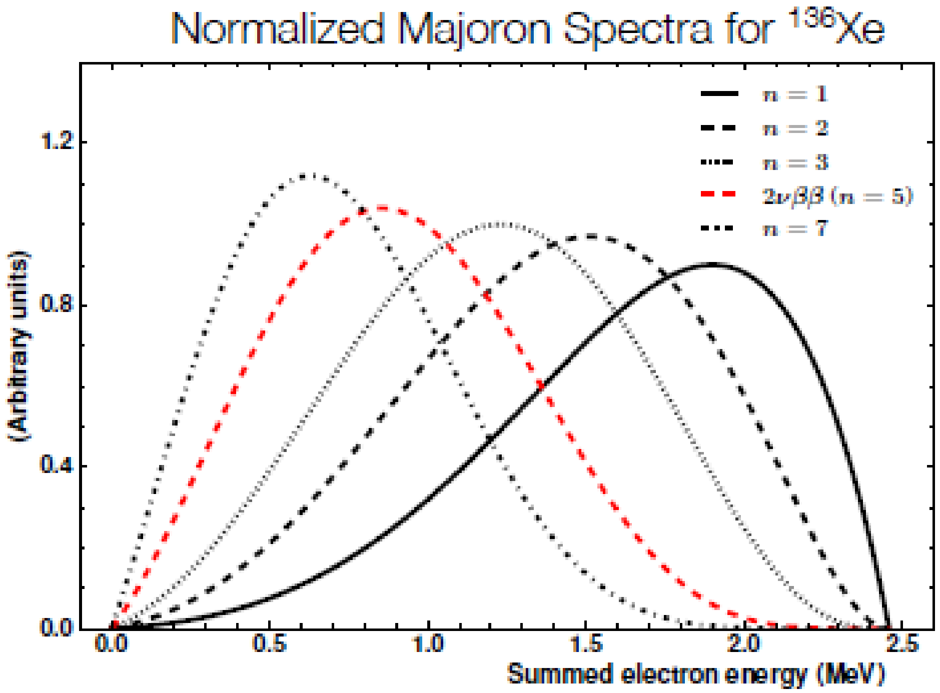
University of Alabama, Tuscaloosa AL, USA — D Auty, T Didberidze, M Hughes, A Piepke, R Tsang
University of Bern, Switzerland — S Delaquis, R Gornea†, J-L Vuilleumier
University of California, Irvine, Irvine CA, USA — M Moe
California Institute of Technology, Pasadena CA, USA — P Vogel
Carleton University, Ottawa ON, Canada — M Dunford, R Gornea, K Graham, C Hargrove, R Killick, T Koffas, C Licciardi, D Sinclair
Colorado State University, Fort Collins CO, USA — C Chambers, A Craycraft, W Fairbank Jr, T Walton
Drexel University, Philadelphia PA, USA — MJ Dolinski, YH Lin, E Smith, Y-R Yen, T Winick
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
University of Illinois, Urbana-Champaign IL, USA — D Beck, M Coon, J Walton, L Yang
Indiana University, Bloomington IN, USA — JB Albert, S Daugherty, TN Johnson, LJ Kaufman, J Zettlemoyer
Laurentian University, Sudbury ON, Canada — B Cleveland, A DerMesrobian-Kabakian, J Farine, B Mong, U Wichoski
University of Maryland, College Park MD, USA — C Hall
University of Massachusetts, Amherst MA, USA — S Feyzbakhsh, S Johnston, J King, A Pocar
McGill University, Montreal PQ, Canada — T Brunner
SLAC National Accelerator Laboratory, Menlo Park CA, USA — M Breidenbach, R Conley, T Daniels, J Davis, A Dragone, K Fouts, R Herbst, A Johnson, K Nishimura, A Odian, CY Prescott, PC Rowson, JJ Russell, K Skarpaas, M Swift, A Waite, M Wittgen
University of South Dakota, Vermillion SD, USA — R MacLellan
Stanford University, Stanford CA, USA — R DeVoe, D Fudenberg, G Gratta, M Jewell, S Kravitz, D Moore, I Ostrovskiy, A Schubert, K Twelker, M Weber
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

†Now at Carleton University


Expected limit from Phase I + Phase II vs. time:
Phase I
Phase II
With analysis improvements
Observed limit
Median sensitivity
68% conf. int.
$T_{1/2}$ [10^{25} yr]
Phase II data taking period [yr]
0
1
2
3
4
5
6
0.0
0.5
1.0
1.5
2.0
2.5
3.0

Comparison between ^{136}Xe and ^{76}Ge:

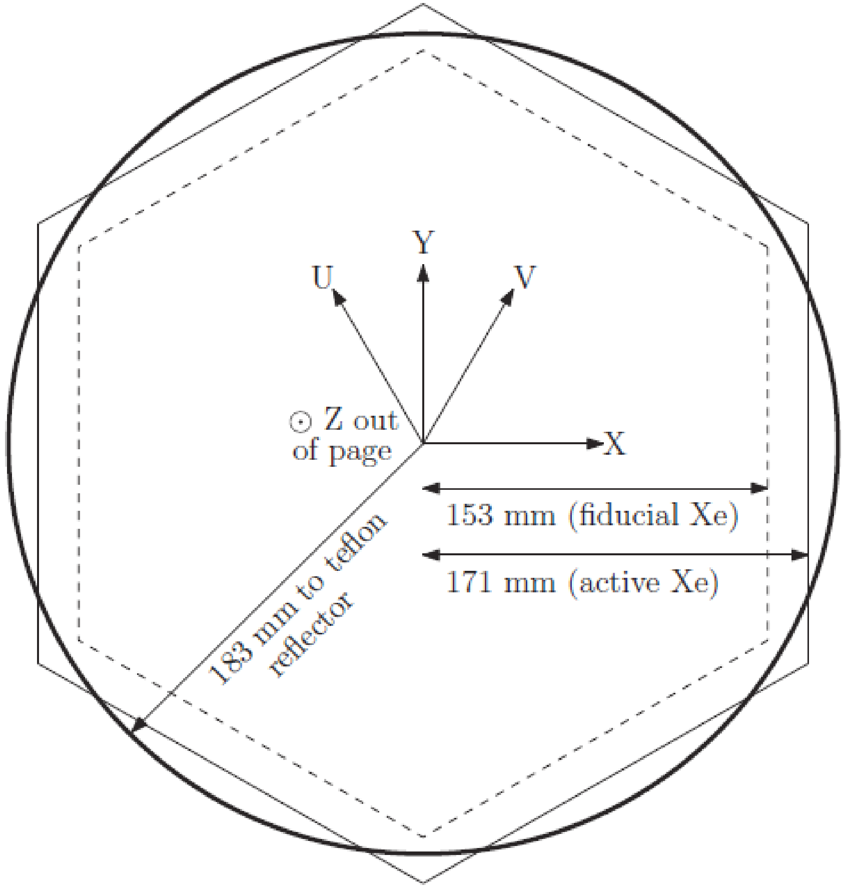



Normalized Majoron Spectra for 136Xe
n = 1
n = 2
n = 3
2νββ (n = 5)
n = 7
(Arbitrary units)
0.0
0.4
0.8
1.2
0.0
0.5
1.0
1.5
2.0
2.5
Summed electron energy (MeV)

Measurement of two-neutrino mode half-life

- 2ν measurement is not limited by statistics, so we used a strict fiducial cut to leave only the best-modeled core volume – 66.2 kg of ^{136}Xe

Component	Error (%)
Normalization	2.6
SS fraction	0.77
Backgrounds	1.3
Statistical	0.76
Total	**2.83**



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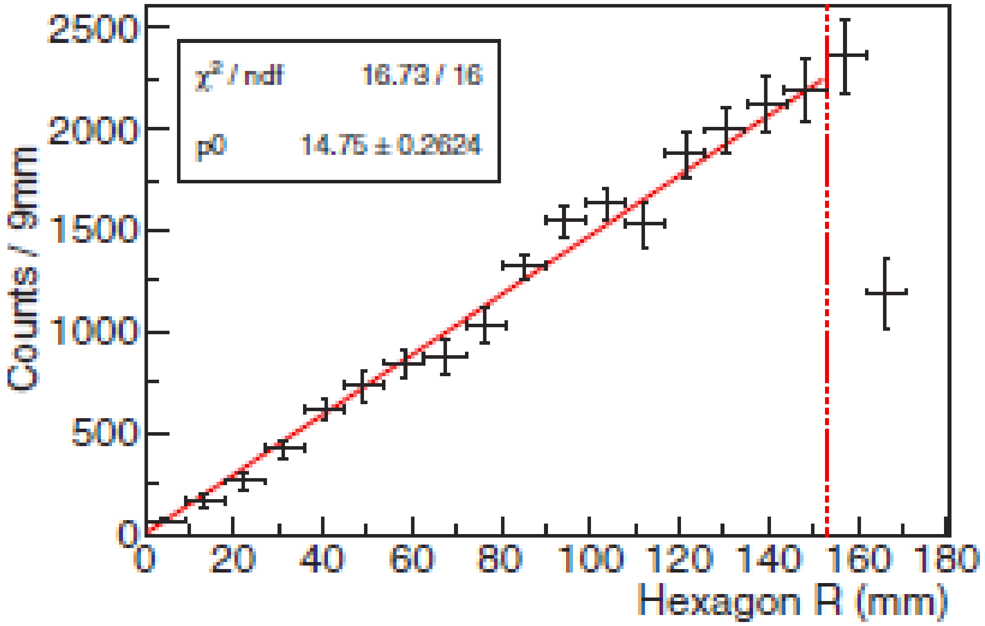

Rate of 2ν decay vs. apothem