EXO-200 latest results

Anthony Der Mesrobian-Kabakian for the EXO-200 collaboration

Mars 15th 2018

^{136}Xe $0\nu\beta\beta$ – EXO-200

- $0\nu\beta\beta$ in ^{136}Xe
  - ^{136}Xe $\rightarrow$ ^{136}Ba^{++} + 2e^{-}, at Q-value = 2457.83 ± 0.37 KeV   *M. Redshaw et al., PRL 98, 053003 (2007)*
- ^{136}Xe ~9% natural abundance
- Xe both used as the source and the detection medium
- Liquid xenon (LXe) Time Projection Chamber (TPC)
  - 3D reconstruction of energy depositions
- Monolithic detector provides excellent background rejection capabilities

TPC

- EXO-200 consists of a radiopure TPC filled with enriched LXe (80.6%)
- Located at Waste Isolation Pilot Plant (WIPP) in Carlsbad, NM, USA
- High voltage applied between cathode and anodes (opposite ends)
- Two measurements of energy deposited in event
  - Scintillation light, by large avalanche photo-diodes (APDs)
 - Ionization charge, by 2 wire grids (induction and collection)
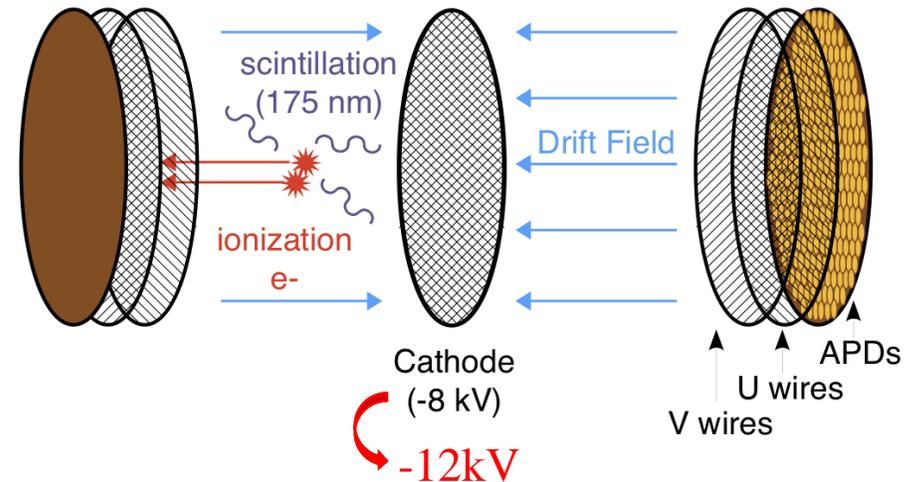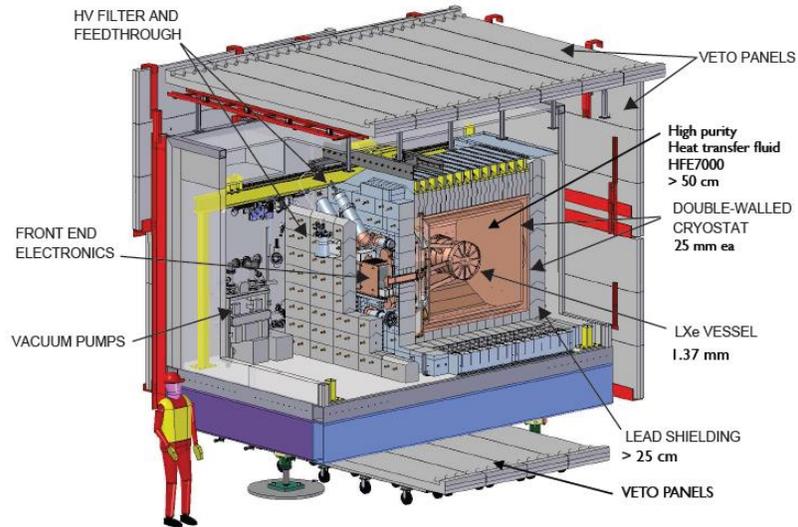
Phase 1

- Sep 2011 to Feb 2014
  - Total live time 596.7 days

- Selected physics results
  - Most precise $2\nu\beta\beta$ measure
    - *Phys. Rev. C 89, 015502 (2013)*
  - Stringent $0\nu\beta\beta$ search
    - *Nature 510, 229 (2014)*
    - Sensitivity $T_{1/2}^{0\nu\beta\beta} > 1.9 \times 10^{25}$ yr (90% CL)

Phase 2

- Access regained in 2015 after stop imposed by WIPP accidents

- Jan to May 2016
  - Hardware upgrades (next slide)

- HV raised by 50% in May 2016
  - Live time 271.8 days
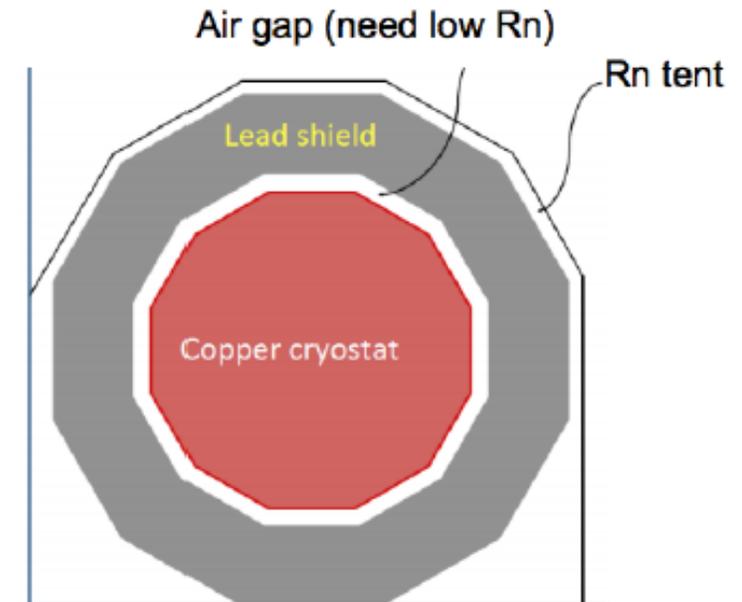
- Physics results: this talk
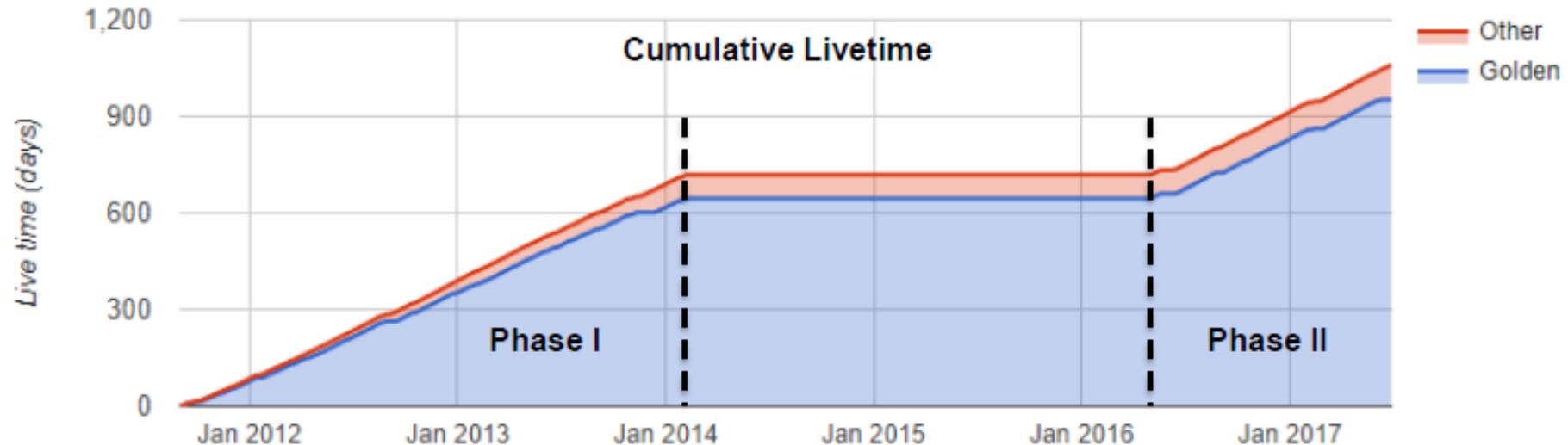
Detector upgrades

- Front end readout electronics
  - Reduce APD readout noise

- Increase of HV
  - -8 kV → -12 kV

- Effect in energy resolution:
  - Phase 1: σ/E(Q) = 1.38%
  - Phase 2: σ/E(Q) = 1.23%, steady

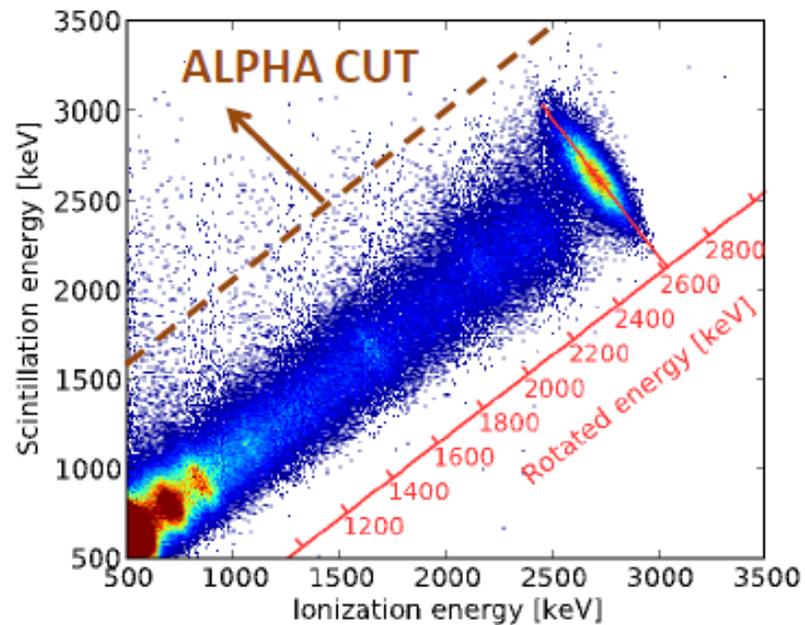^{228}Th calibration
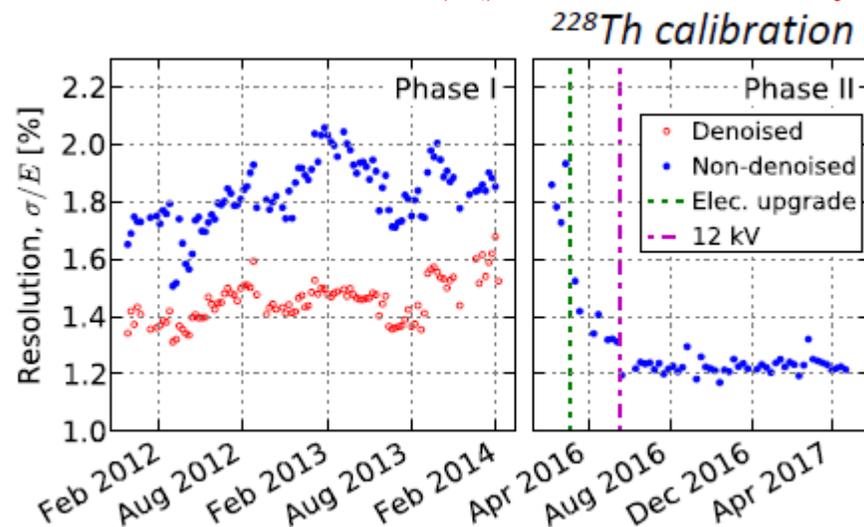
- System to suppress radon in air gap

EXO-200 Clean Room Module 1

- 5-15 Bq/m^3 → 0.55 Bq/m^3
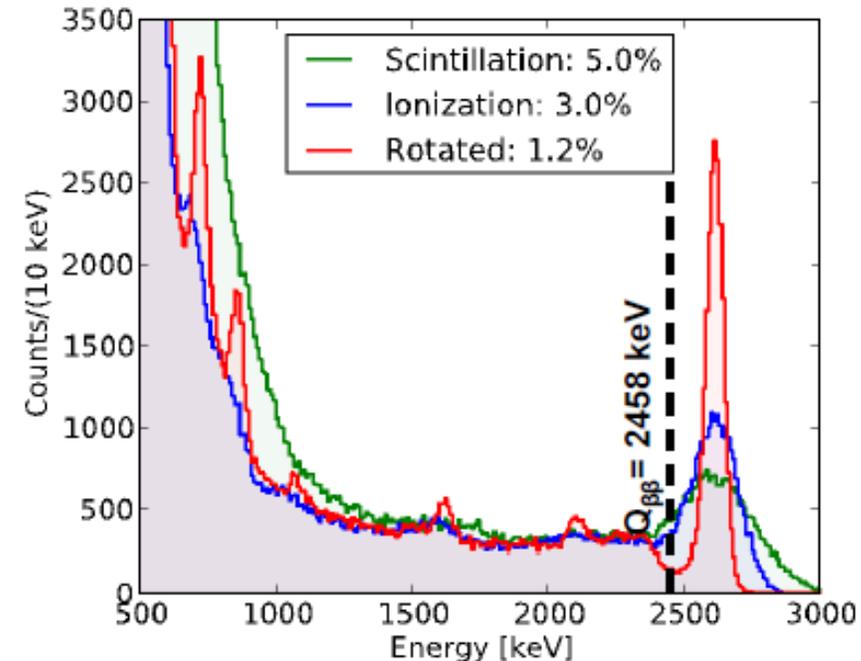- Direct air sampling shows radon levels reduced in the gap by > 10x

Energy

- Rejection of α particles (vs β/γ) using light/charge ratio
- Using anti-correlation between charge and scintillation response
  - "Rotated" energy provides optimal resolution in the energy of interest

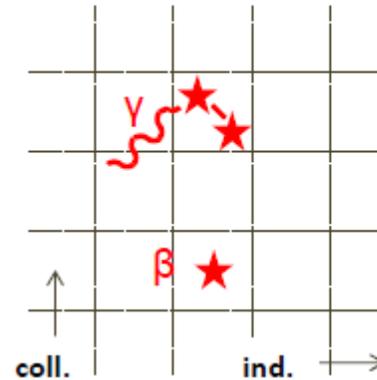**Scintillation vs. ionization, ^{228}Th calibration:**
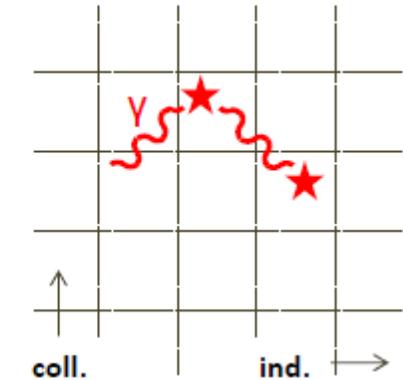
Reconstructed energy, ^{228}Th calibration:

Position discrimination

- ββ deposits energy at single location

- Channel pitch is 9 mm in X/Y,
  Z (time) resolution is ~6 mm

- SS fraction is ~20% in the energy of interest

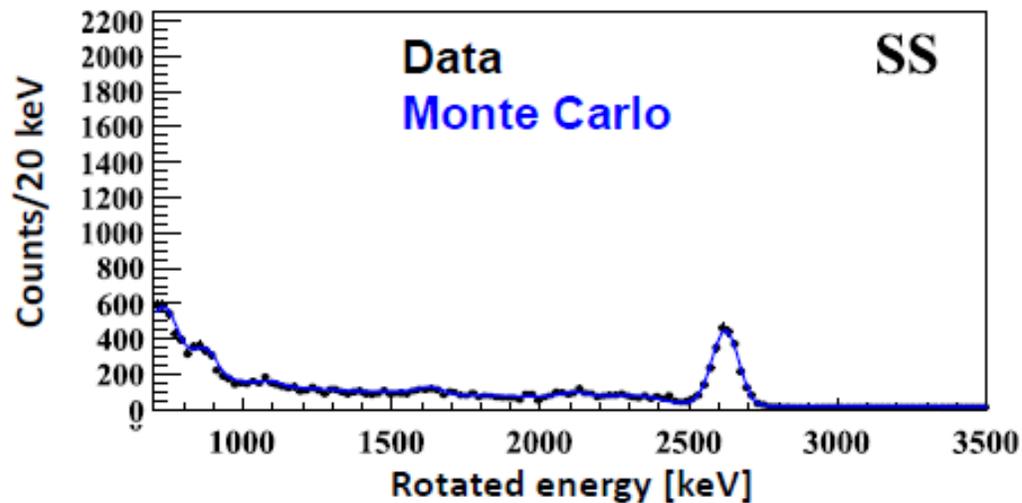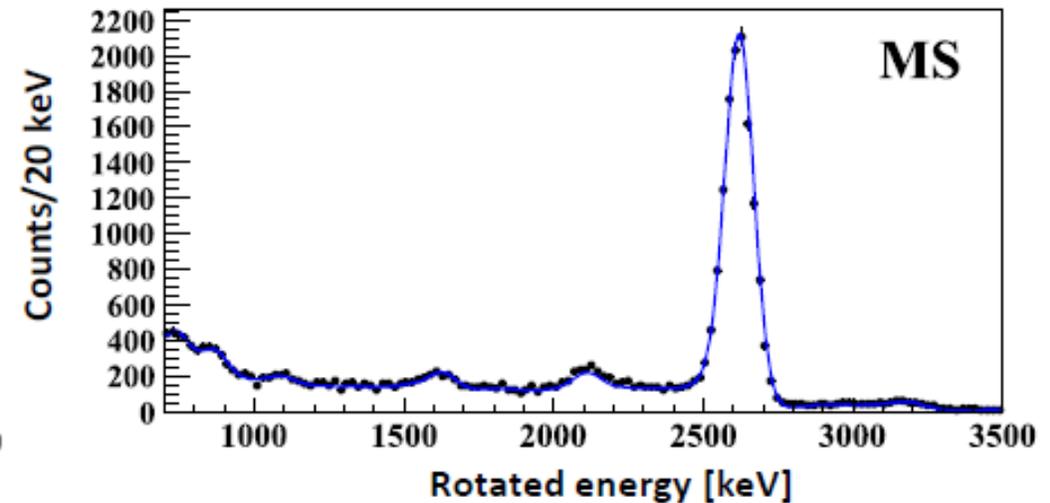**Single Site Events (SS)**

Multiple Site Events (MS)

Energy spectrum, ^{228}Th calibration data, SS:

Data
Monte Carlo
SS

Energy spectrum, ^{228}Th calibration data, MS:
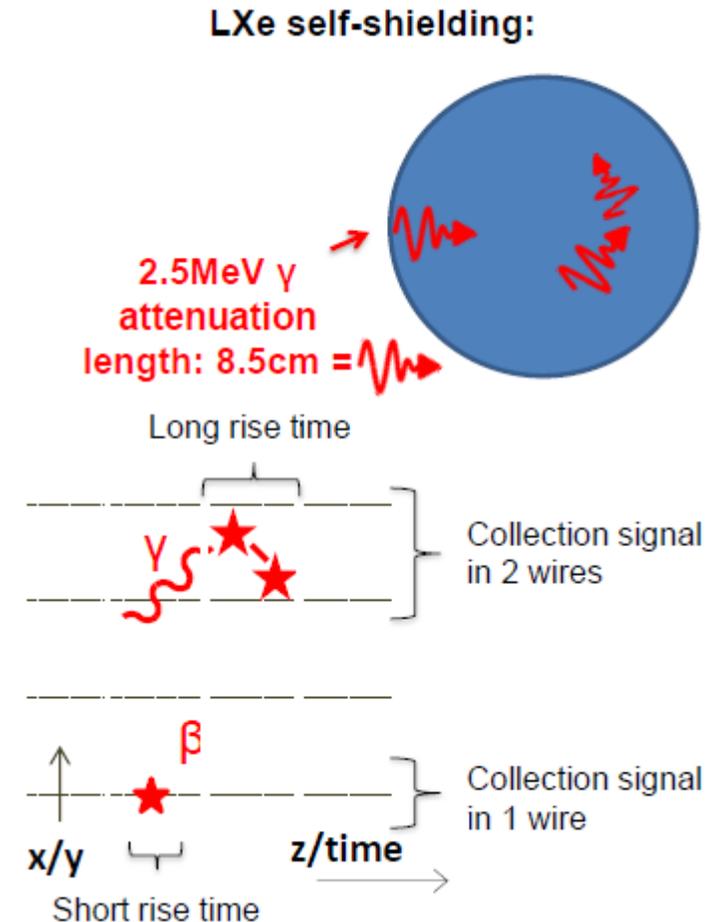
MS

Improved γ–background Rejection

- Additional discrimination in SS using spatial distribution and cluster size

- Entering γ–rays rate is exponentially reduced by LXe self-shielding, provides independent measurement of γ–backgrounds
  - Standoff-distance

- Size of individual cluster estimated from:
  - Pulse rise time (longitudinal direction)
  - Number of wires with collection signal (transverse)

LXe self-shielding:

2.5MeV γ attenuation length: 8.5cm =

Long rise time

γ

Collection signal in 2 wires

β

x/y   z/time

Short rise time

Collection signal in 1 wire

Optimal 0νββ Discrimination

- Optimize SS discriminators into a more powerful one
  - Using a Boosted Decision Tree (BDT)
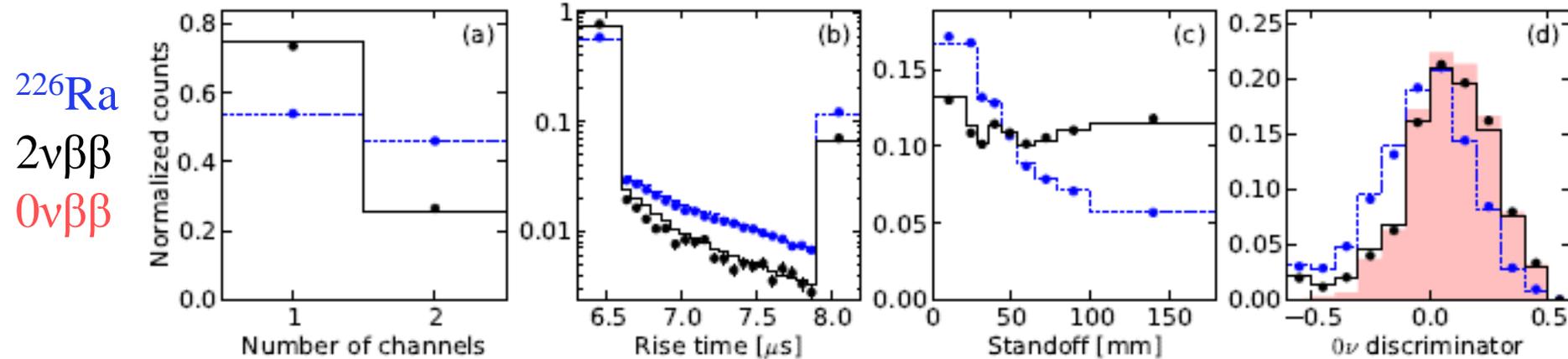
- Fitting 0νββ discriminators:
  - Energy
  - SS/MS
  - BDT → ~15% sensitivity improvement

^{137}Xe β–decay Veto

Nature **510**, 229 (2014)

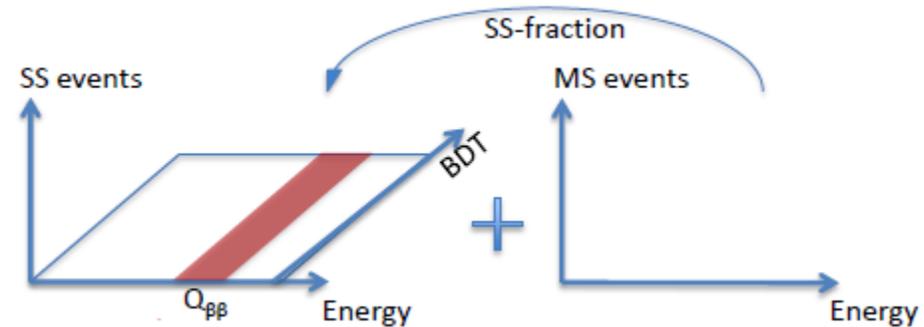| Backgrounds in Q ± 2σ:	
Th chain	16.0
U chain	8.1
Xe-137	7.0
Total	31.1 ± 3.8

JCAP **1604**, 029 (2016)

Muon veto coincident MS data:

^{1}H capture line

^{136}Xe(n,γ) capture line
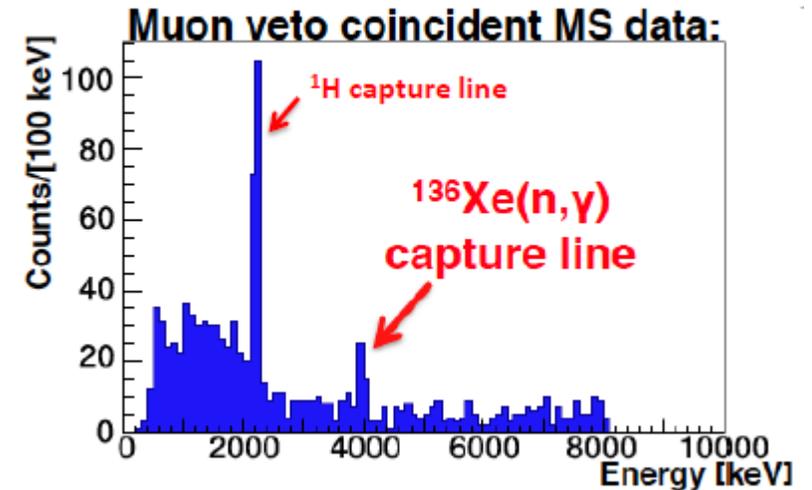
- Tag neutron capture on ^{136}Xe events using both veto panel and de-excitation prompt γs information to suppress ^{137}Xe β–decays ($T_{1/2}$ = 3.82 min)

- Veto same TPC half of the γ signal for 5x$T_{1/2}$ = 19.1 min
  - ~25% rejection
    - Phase 1: 7.0 cnts → 4.4 cnts
  - Exposure loss ~3%

Analysis approach
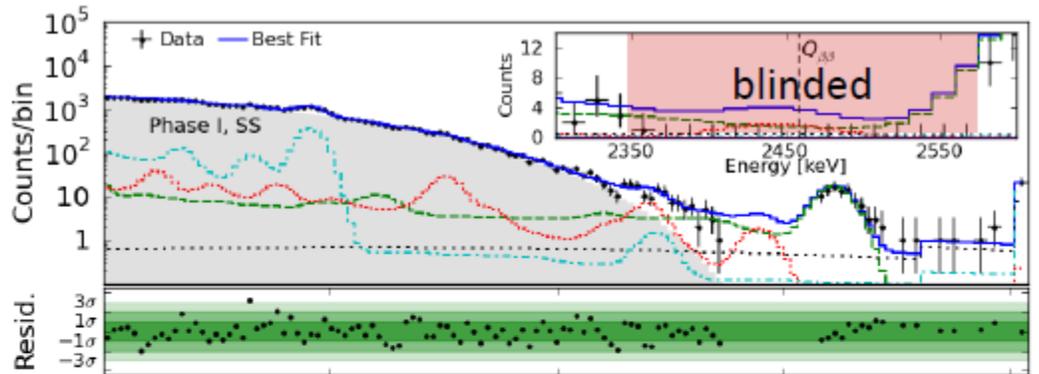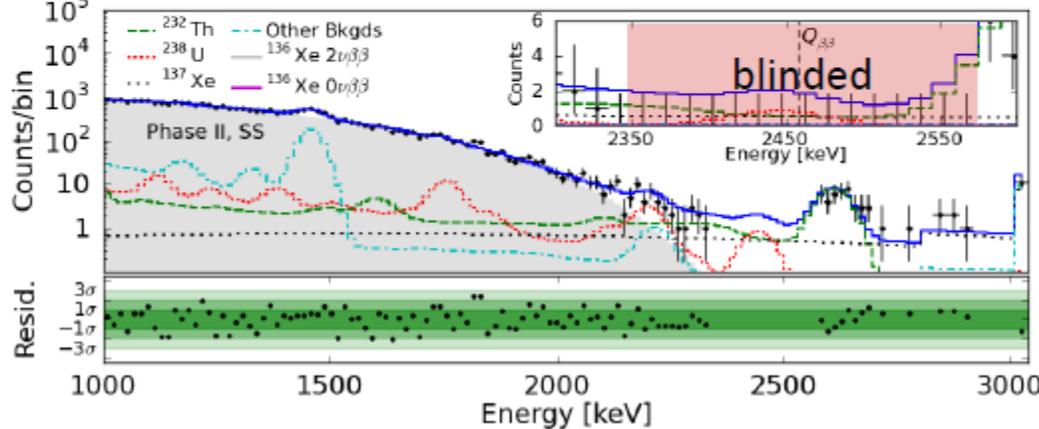
- Blind analysis
- Background model + data → maximum likelihood fit
- Combine Phase 1 + Phase 2 profiles

Phase 1

Single
Site

Phase 2

Phase 1
Multi
Site
Phase 2

Systematics	Phase I (%)	Phase II (%)
Detection efficiency	82.4 ± 3.0	80.8 ± 2.9
Shape differences	±6.2	±6.2
SS fraction	±5.0	±8.8
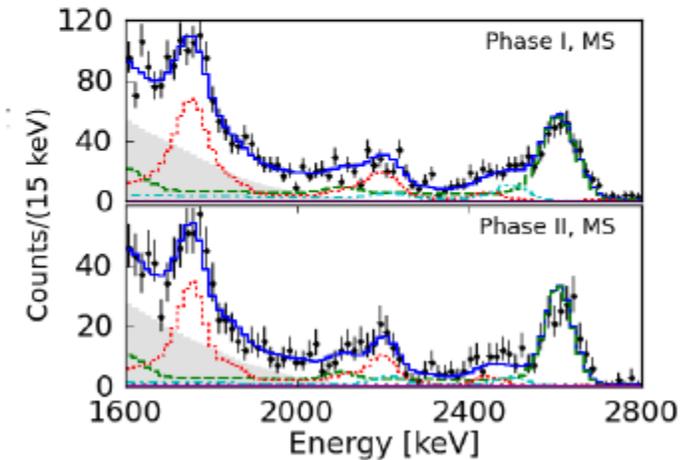
Results

- Background model + data → maximum likelihood fit

- Combine Phase 1 + Phase 2 profiles

Phase 1

Single Site

Phase 2

Phase 1 Multi Site Phase 2
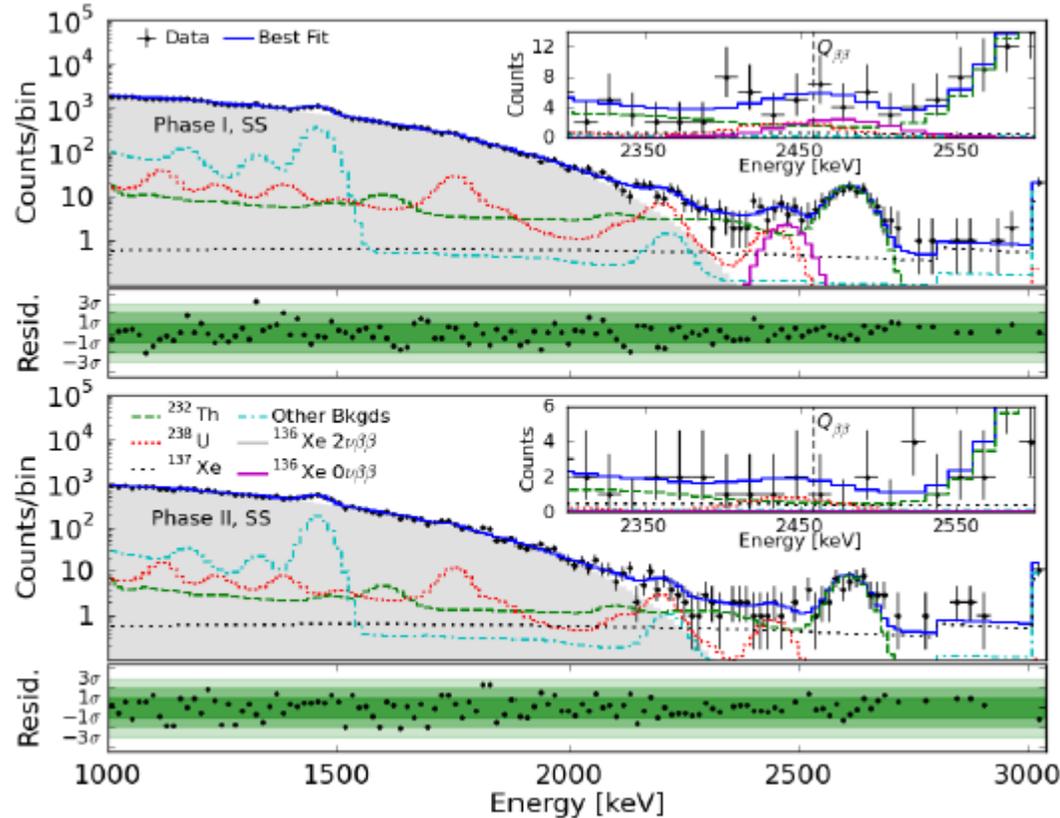
Systematics	Phase I (%)	Phase II (%)
Detection efficiency	82.4 ± 3.0	80.8 ± 2.9
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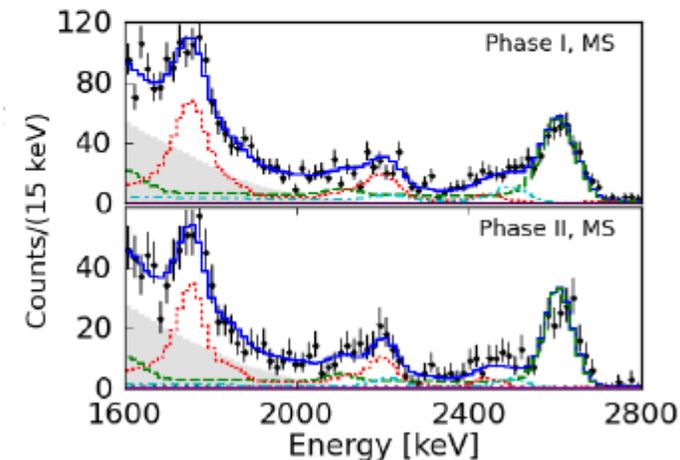
- No statistically significant excess: null hypothesis ~ 1.5 σ

Energy of interest
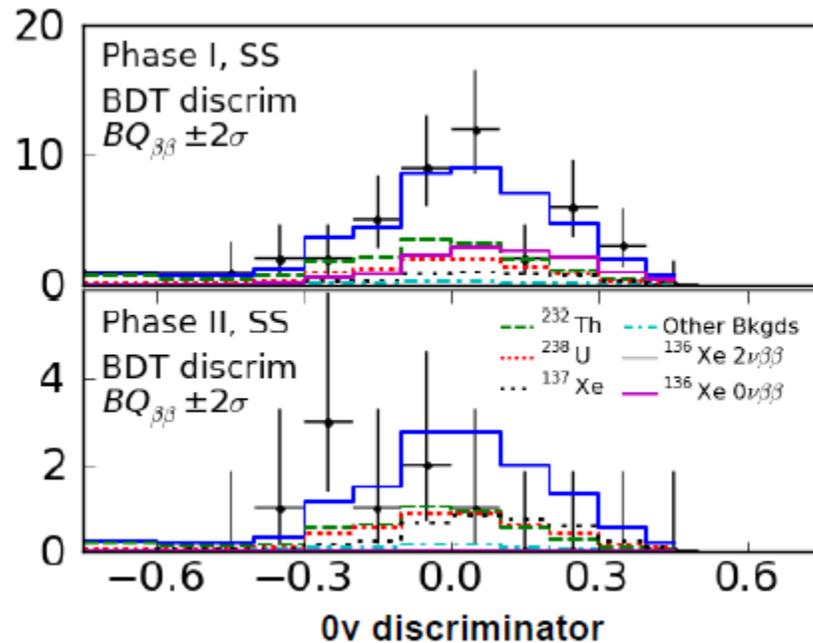
Contributions to BQ±2σ	Phase I (cts)	Phase II (cts)
^{232}Th	15.8	4.8
^{238}U	9.4	4.2
^{137}Xe	4.4	3.6
Total	**30.7±6.0**	**13.2±1.4**
Data	*43*	*8*

- Background index: $(1.6 \pm 0.2) \times 10^{-3}$ / (kg.yr.keV)   (phase 1: $(1.5 \pm 0.3) \times 10^{-3}$)
- Component contributions
  - ^{232}Th reduction consistent with difference in resolution
  - ^{137}Xe rejection ~25%

Sensitivity and limits

- Combined analysis:
  - Total exposure = 177.6 kg.yr

$$\text{Sensitivity of } 3.7\text{x}10^{25} \text{ yr}$$
$$T_{1/2}^{0\nu\beta\beta} > 1.8\text{x}10^{25} \text{ yr}$$
$$\langle m_{\beta\beta} \rangle < 147 - 398 \text{ meV}$$

(90% CL)

arXiv: 1707.08707

- Individual phase limits:

	Livetime	Exposure	Limit (90% CL)
Phase 1	596.7 d	122.0 kg.yr	$T_{1/2}^{0\nu\beta\beta} > 1.0\text{x}10^{25}$ yr
Phase 2	271.8 d	55.6 kg.yr	$T_{1/2}^{0\nu\beta\beta} > 4.4\text{x}10^{25}$ yr

Comparison with recent results in different isotopes
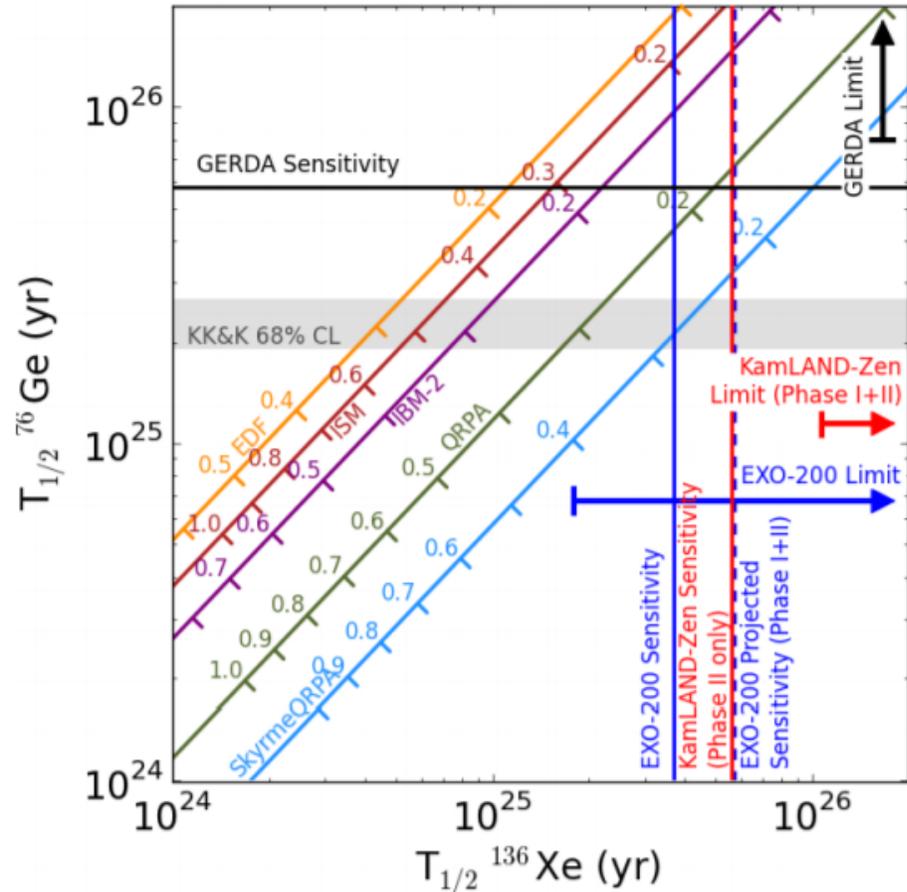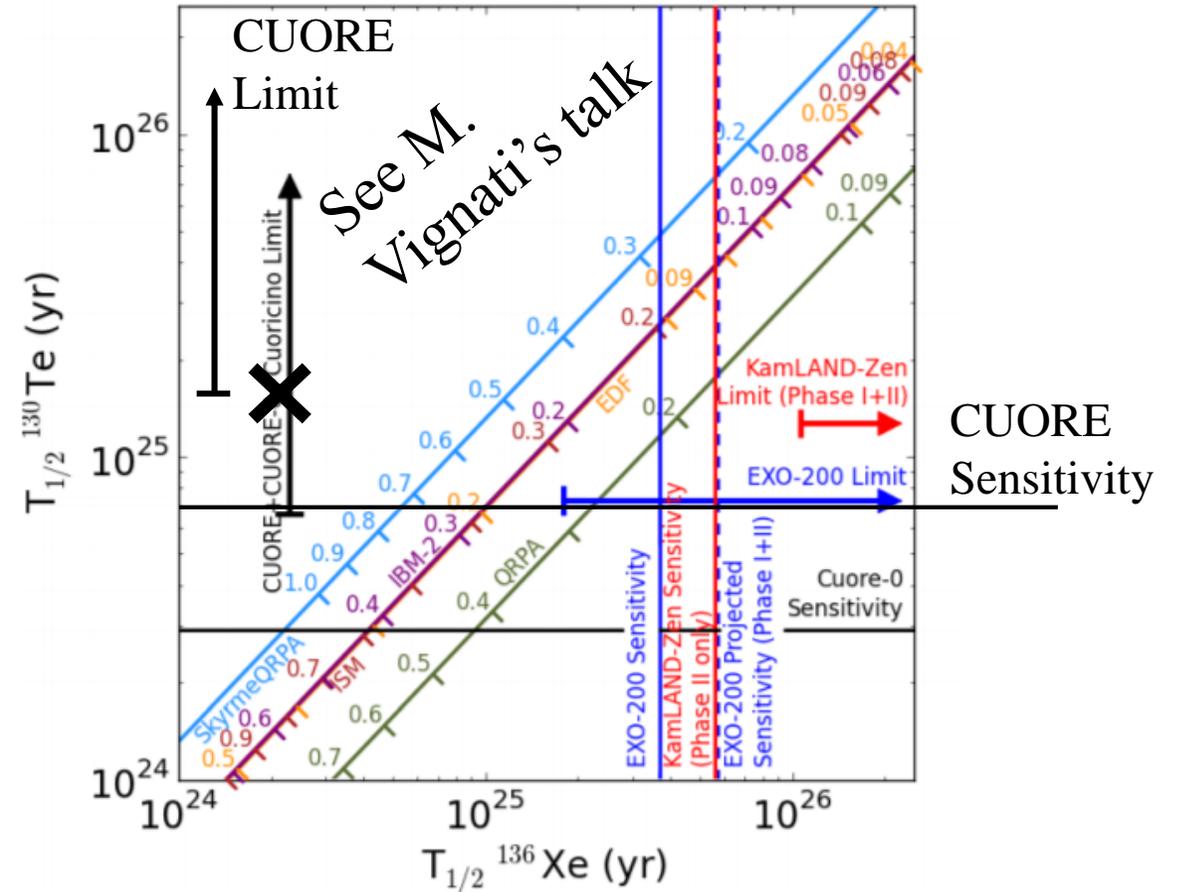
Summary

- New EXO-200 data results show no statistically significant $0\nu\beta\beta$ excess
  - $T_{1/2}^{0\nu\beta\beta} > 1.8 \times 10^{25}$ yr (90% CL)
  - $\langle m_{\beta\beta} \rangle < 147 - 398$ meV
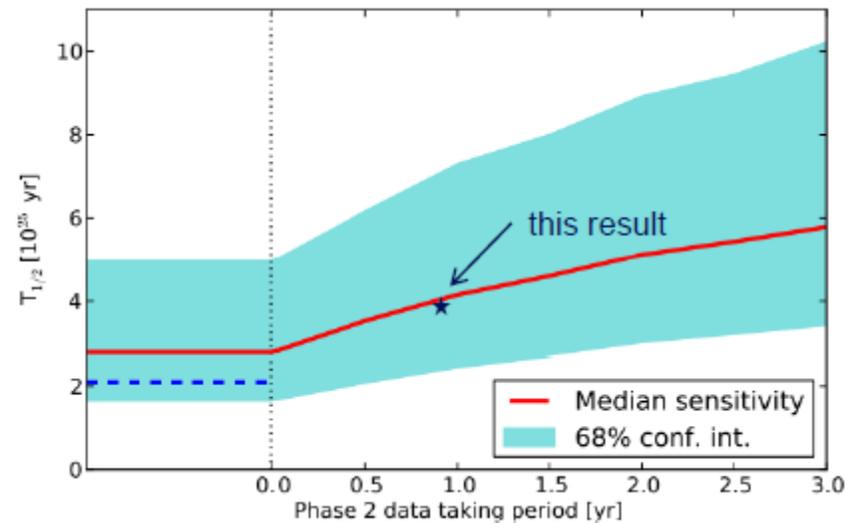- EXO-200 sensitivity to $0\nu\beta\beta$ of 3.7×10^{25} yr, improved by 2x

- On going EXO-200 Phase 2 running will continue to improve sensitivity

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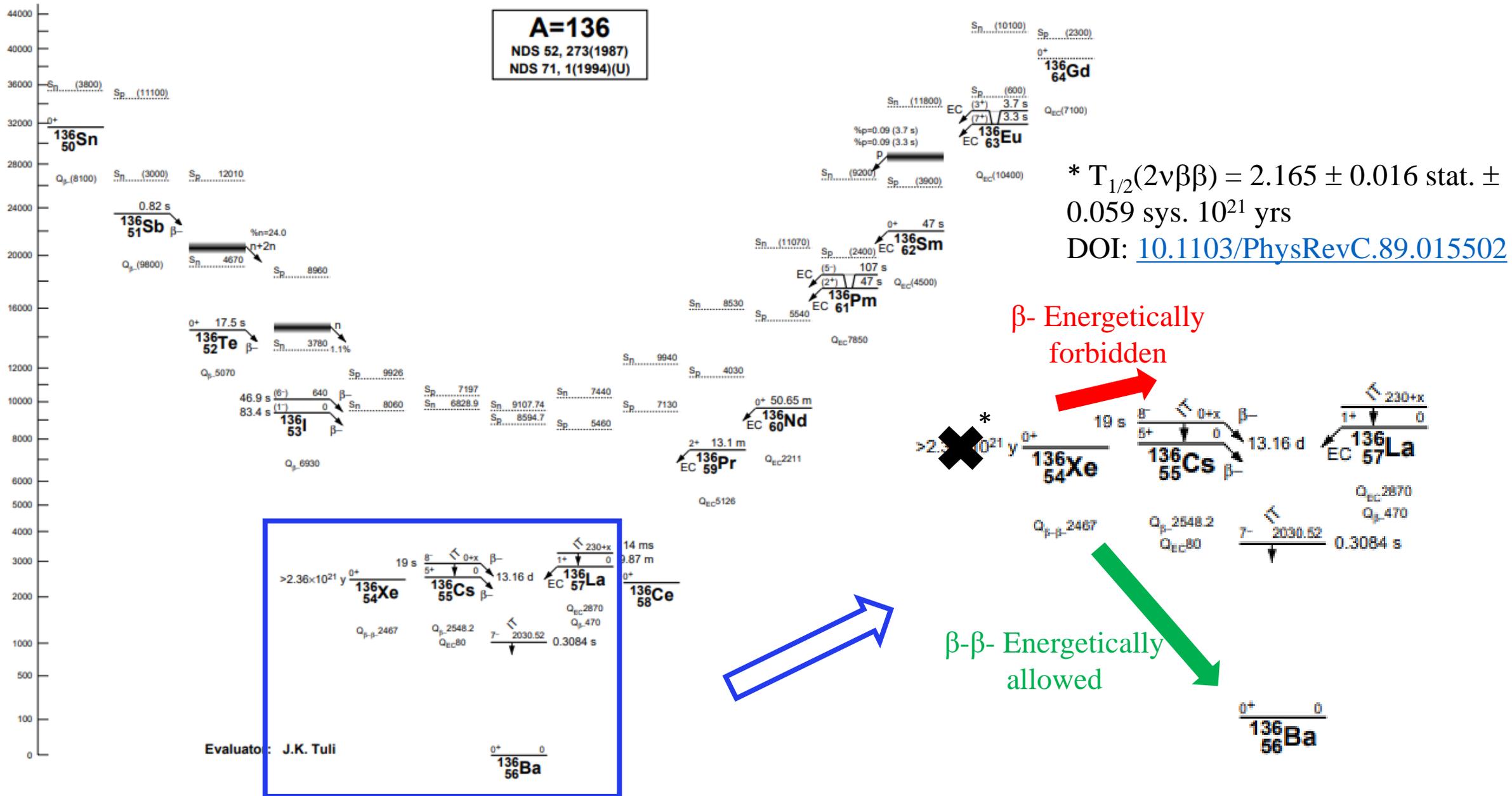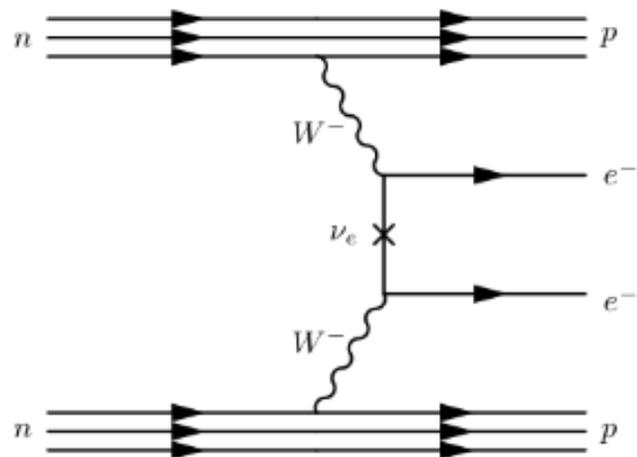
The EXO-200 Collaboration

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Yale University, New Haven CT, USA — Z Li, D Moore, Q Xia

Thank you!

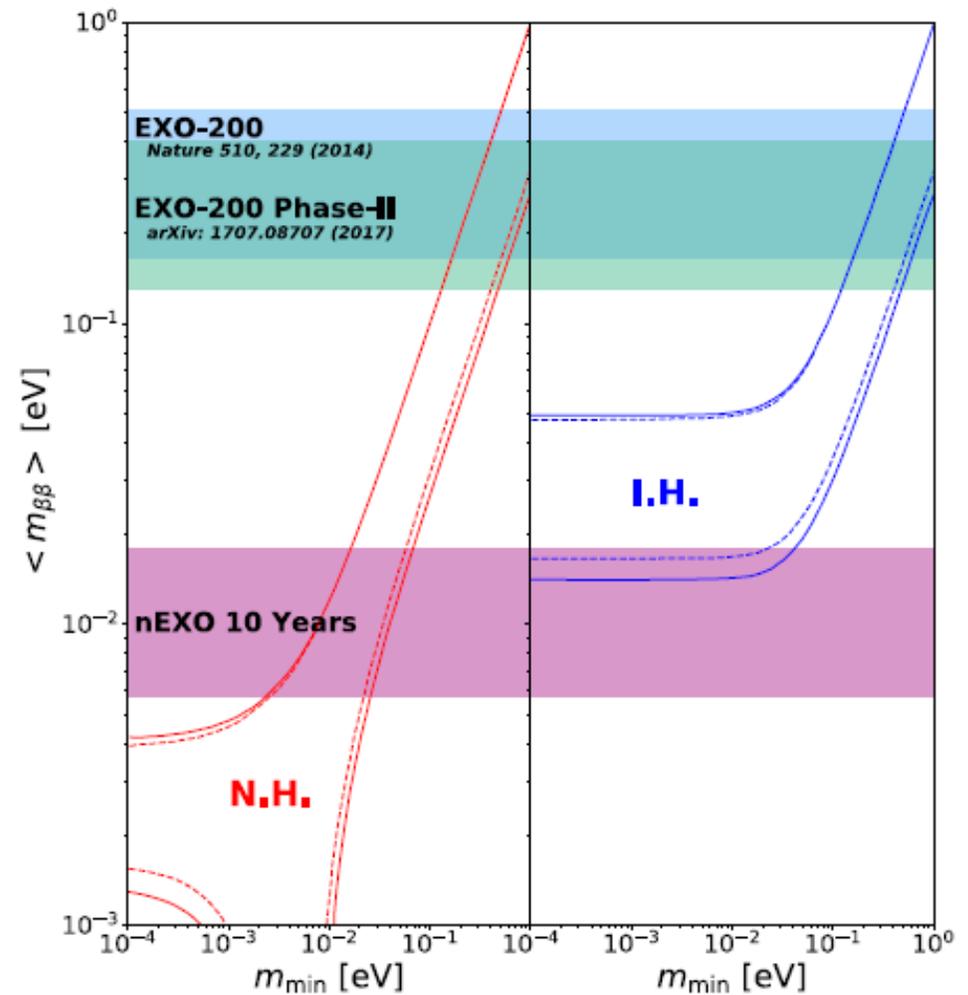EXO-200 Latest results, Rencontres de Moriond 2018

$* \; T_{1/2}(2\nu\beta\beta) = 2.165 \pm 0.016 \; \text{stat.} \pm 0.059 \; \text{sys.} \; 10^{21} \; \text{yrs}$
DOI: [10.1103/PhysRevC.89.015502](#)

β- Energetically forbidden

β-β- Energetically allowed

$$[T^{0\nu}_{1/2}]^{-1} = \frac{\langle m_{\beta\beta}\rangle^2}{m_e^2} G^{0\nu} |M^{0\nu}|^2$$

HV FILTER AND FEEDTHROUGH

VETO PANELS

High purity Heat transfer fluid HFE7000 > 50 cm

DOUBLE-WALLED CRYOSTAT 25 mm ea

FRONT END ELECTRONICS

LXe VESSEL 1.37 mm

VACUUM PUMPS

LEAD SHIELDING > 25 cm

VETO PANELS

Charge readout

V: Induction
U: Collection

Side 2: V, U
Side 1: V, U

Light readout

Side 2
Side 1

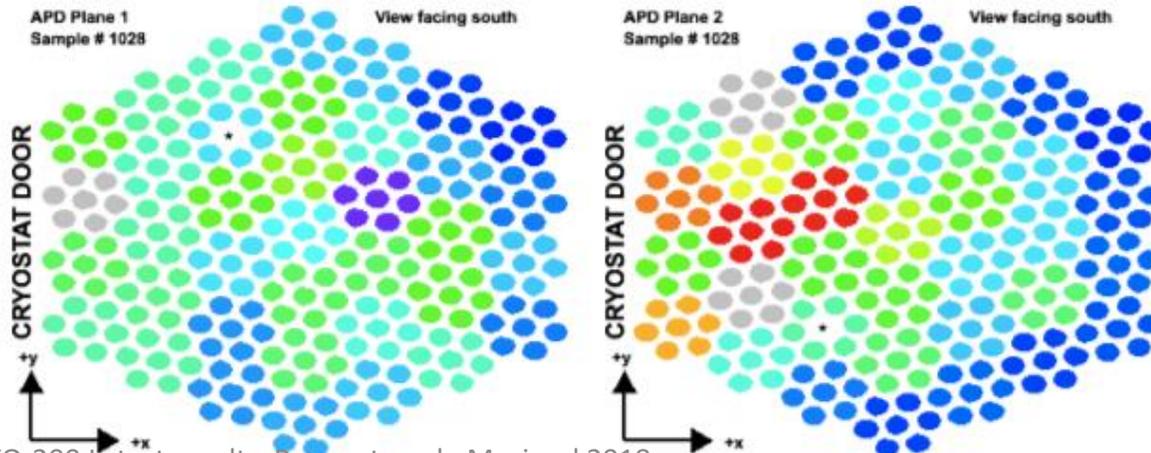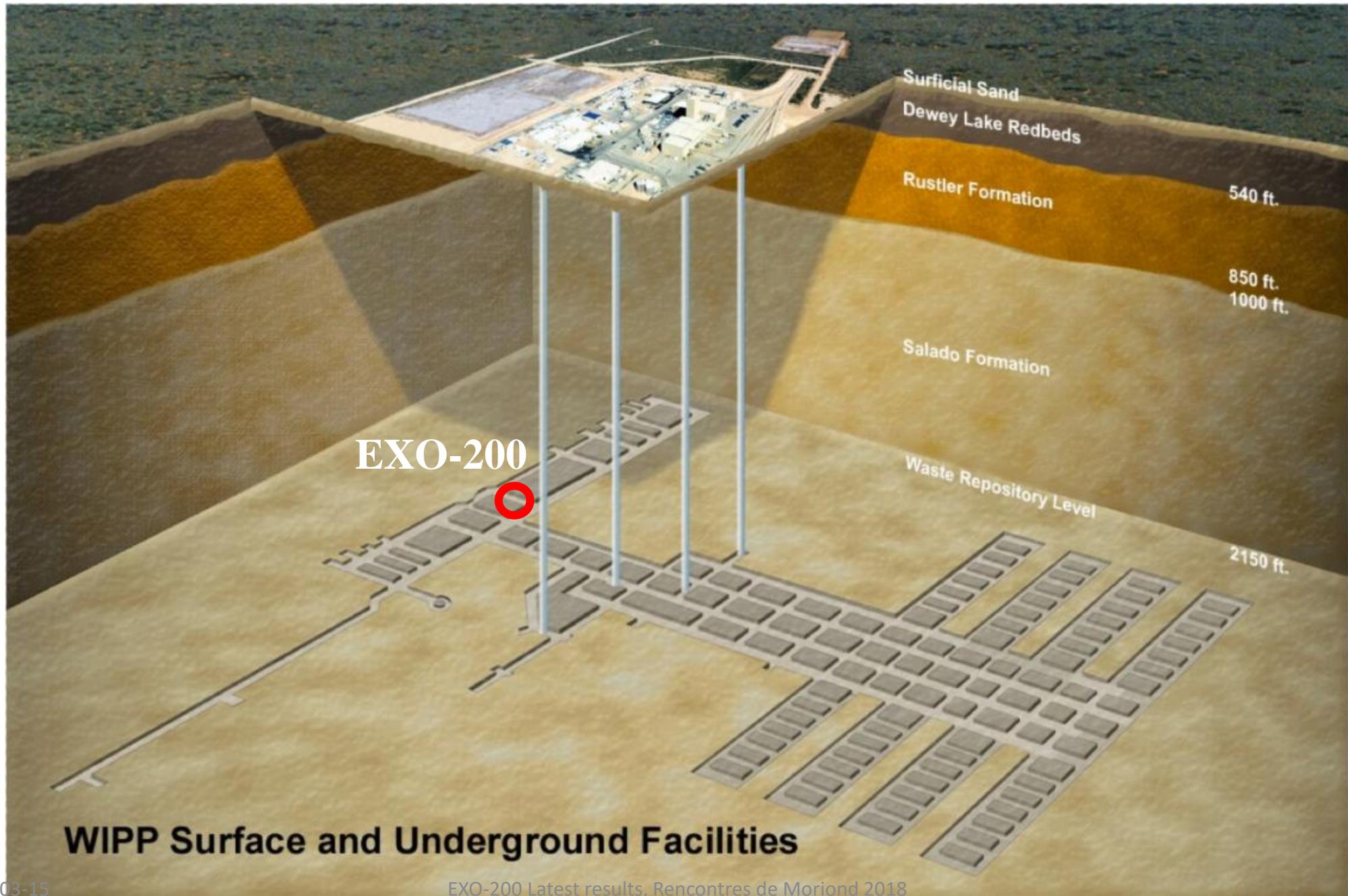Wire Channel
APD Channel
Time (μs)

one sample

A single-site energy deposition in EXO-200

Scintillation light is seen at both sides. The light is more diffuse on side 1 and more localized on side 2, where the event occurred.

The light signal always precedes both charge signals. The induction (V) signal precedes the collection (U) signal.

APD Plane 1
Sample # 1028
View facing south
CRYOSTAT DOOR

APD Plane 2
Sample # 1028
View facing south
CRYOSTAT DOOR

EXO-200

Surficial Sand
Dewey Lake Redbeds
Rustler Formation   540 ft.
                           850 ft.
                           1000 ft.
Salado Formation
Waste Repository Level
                           2150 ft.

WIPP Surface and Underground Facilities

nEXO sensitivity paper (arXiv:1710.05075)
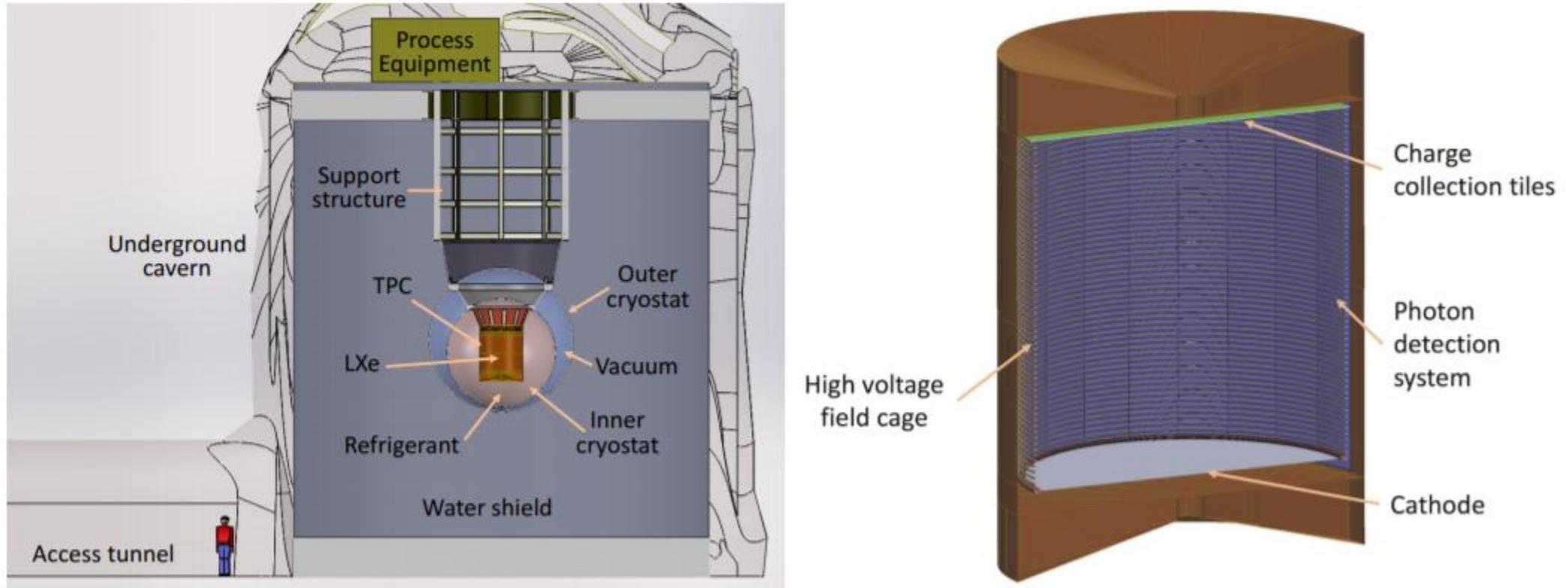
5 Tons of Xe

FIG. 1. Engineering design rendering of the nEXO experiment concept, for concreteness drawn in the SNOLAB cryopit (left). Cross-section of the TPC (right).

nEXO sensitivity paper (arXiv:1710.05075)

The Ba tagging technique, that is not yet demonstrated, may provide an upgrade path, with ultimate sensitivity ~4x10^{28} yr
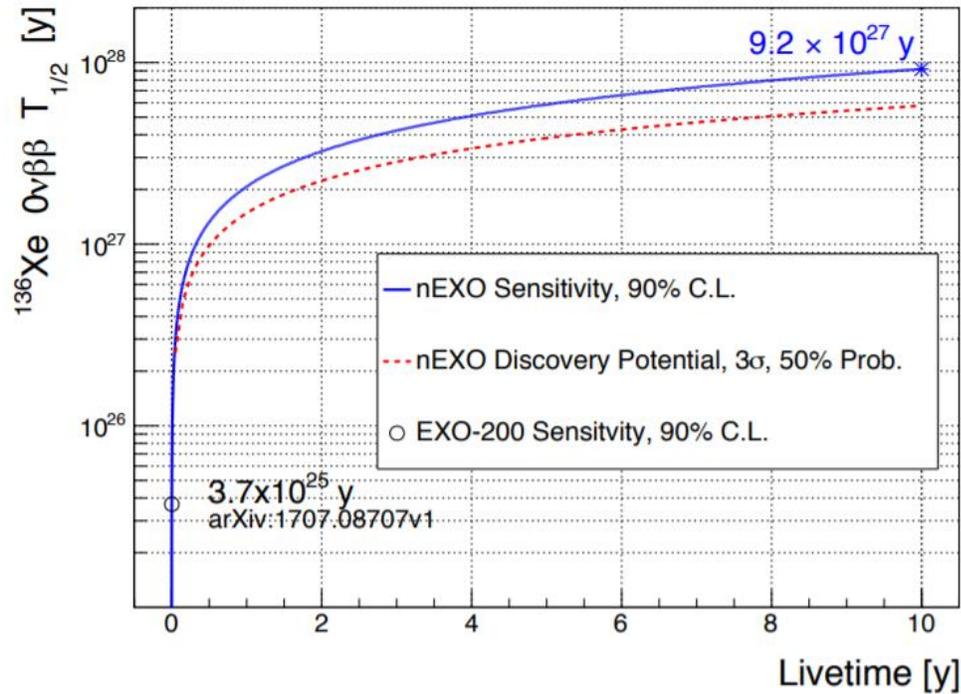

FIG. 10. nEXO median sensitivity at 90% CL and 3σ discovery potential as a function of the experiment livetime.
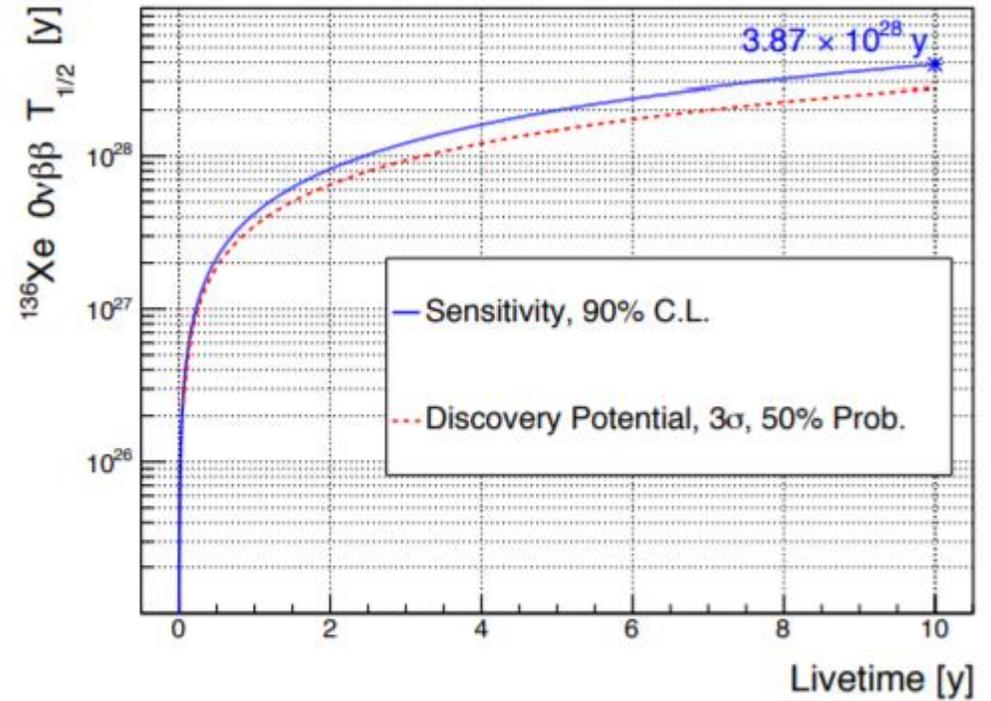
FIG. 15. Median exclusion sensitivity at 90% C.L. and 3σ discovery potential to the $0\nu\beta\beta$ half-life of a nEXO-like experiment under a background consisting only of the $2\nu\beta\beta$ component.