EXO-200 latest results
Anthony Der Mesrobian-Kabakian for the EXO-200 collaboration
Mars 15th 2018
\[ ^{136}\text{Xe} \quad 0\nu\beta\beta \quad \text{– EXO-200} \]

- $0\nu\beta\beta$ in $^{136}\text{Xe}$
  - $^{136}\text{Xe} \rightarrow ^{136}\text{Ba}^{++} + 2e^-$, at $Q$-value = $2457.83 \pm 0.37$ KeV  \hspace{1cm} \textit{M. Redshaw et al., PRL 98, 053003 (2007)}

- $^{136}\text{Xe}$ \sim 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
  • 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: $\sigma/E(Q) = 1.38\%$
  - Phase 2: $\sigma/E(Q) = 1.23\%$, steady

- System to suppress radon in air gap
  - 5-15 Bq/m$^3 \rightarrow 0.55$ 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
Position discrimination

- $\beta\beta$ 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
Improved $\gamma$–background Rejection

• Additional discrimination in SS using spatial distribution and cluster size

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

• Size of individual cluster estimated from:
  • Pulse rise time (longitudinal direction)
  • Number of wires with collection signal (transverse)
Optimal $0\nu\beta\beta$ Discrimination

- Optimize SS discriminators into a more powerful one
  - Using a Boosted Decision Tree (BDT)

- Fitting $0\nu\beta\beta$ discriminators:
  - Energy
  - SS/MS
  - BDT $\rightarrow$ $\sim$15% sensitivity improvement
Tag neutron capture on $^{136}$Xe events using both veto panel and de-excitation prompt $\gamma$s information to suppress $^{137}$Xe $\beta$–decays ($T_{1/2} = 3.82$ min)

Veto same TPC half of the $\gamma$ signal for $5 \times T_{1/2} = 19.1$ min

- ~25% rejection
  - Phase 1: 7.0 cnts $\rightarrow$ 4.4 cnts
  - Exposure loss ~3%
Analysis approach

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

<table>
<thead>
<tr>
<th>Systematics</th>
<th>Phase I (%)</th>
<th>Phase II (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection efficiency</td>
<td>82.4 ± 3.0</td>
<td>80.8 ± 2.9</td>
</tr>
<tr>
<td>Shape differences</td>
<td>±6.2</td>
<td>±6.2</td>
</tr>
<tr>
<td>SS fraction</td>
<td>±5.0</td>
<td>±8.8</td>
</tr>
</tbody>
</table>

Phase 1

Single Site

Phase 2

Multi Site

Phase 2
Results

• Background model + data → maximum likelihood fit
• Combine Phase 1 + Phase 2 profiles

Phase 1

- Single Site

Phase 2

- Multi Site

• No statistically significant excess: null hypothesis ~ 1.5 σ
Energy of interest

- Background index: $(1.6 \pm 0.2) \times 10^{-3} / (\text{kg.yr.keV})$ (phase 1: $(1.5 \pm 0.3) \times 10^{-3}$)

- Component contributions
  - $^{232}\text{Th}$ reduction consistent with difference in resolution
  - $^{137}\text{Xe}$ rejection $\sim 25\%$

2018-03-15

EXO-200 Latest results, Rencontres de Moriond 2018
Sensitivity and limits

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

- Individual phase limits:

<table>
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<tr>
<th>Livetime</th>
<th>Exposure</th>
<th>Limit (90% CL)</th>
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<tbody>
<tr>
<td>Phase 1</td>
<td>596.7 d</td>
<td>$T_{1/2}^{0\nu\beta\beta} &gt; 1.0 \times 10^{25}$ yr</td>
</tr>
<tr>
<td>Phase 2</td>
<td>271.8 d</td>
<td>$T_{1/2}^{0\nu\beta\beta} &gt; 4.4 \times 10^{25}$ yr</td>
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</table>

Sensitivity of $3.7 \times 10^{25}$ yr

$T_{1/2}^{0\nu\beta\beta} > 1.8 \times 10^{25}$ yr

$\langle m_{\beta\beta} \rangle < 147 – 398$ meV

arXiv: 1707.08707

(90% CL)
Comparison with recent results in different isotopes

Current limits, $^{76}$Ge vs. $^{136}$Xe:

- GERDA Sensitivity
- KK&K 68% CL
- KamLAND-Zen Limit (Phase I+II)
- EXO-200 Sensitivity
- EXO-200 Projected Sensitivity (Phase I+II)

Current limits, $^{130}$Te vs. $^{136}$Xe:

- CUORE Sensitivity
- See M. Vignati’s talk
- CUORE Limit

2018-03-15
EXO-200 Latest results, Rencontres de Moriond 2018
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 $3.7 \times 10^{25}$ yr, improved by 2x

• On going EXO-200 Phase 2 running will continue to improve sensitivity
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Indiana University, Bloomington IN, USA — JB Albert, S Daugherty
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Thank you!
* $T_{1/2}^{2\nu\beta\beta} = 2.165 \pm 0.016 \text{ stat.} \pm 0.059 \text{ sys. } 10^{21} \text{ yrs}$

DOI: [10.1103/PhysRevC.89.015502](https://doi.org/10.1103/PhysRevC.89.015502)
\[ [T_{1/2}^{0\nu}]^{-1} = \frac{\langle m_{\beta\beta} \rangle^2}{m_e^2} G_{0\nu}^2 |M_{0\nu}|^2 \]
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.
WIPP Surface and Underground Facilities
nEXO sensitivity paper (arXiv:1710.05075)

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

5 Tons of Xe

The Ba tagging technique, that is not yet demonstrated, may provide an upgrade path, with ultimate sensitivity $\sim 4\times 10^{28}$ yr

**FIG. 10.** nEXO median sensitivity at 90% CL and 3$\sigma$ discovery potential as a function of the experiment livetime.

**FIG. 15.** Median exclusion sensitivity at 90% C.L. and 3$\sigma$ 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.