Searches for neutrinoless double beta decay with $^{136}\text{Xe}$

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0νββ with $^{136}$Xe

- 0νββ provides the most sensitive probe of the Majorana nature of neutrinos
- Observation of 0νββ would demonstrate lepton number violation
- $^{136}$Xe provides an attractive isotope for 0νββ searches:
  - Chemically inert -> “easy” purification and enrichment
  - Natural abundance ~9%
  - No long lived cosmogenic activation
  - Can be incorporated into a variety of detector technologies
  - May be possible to identify $^{136}$Ba daughter (R&D in EXO, NEXT)
- Large detectors (multi-ton scale) under development

Current and future $^{136}$Xe experiments:

*Chemically inert -> “easy” purification and enrichment*

*Natural abundance ~9%*

*No long lived cosmogenic activation*

*Can be incorporated into a variety of detector technologies*

*May be possible to identify $^{136}$Ba daughter (R&D in EXO, NEXT)*

*Large detectors (multi-ton scale) under development*
EXO-200

- Liquid xenon time projection chamber (~150 kg, enriched to 80% $^{136}$Xe)
- Topological discrimination and $\sigma = 1.3\%$ energy resolution
- Taking data since 2011:
  - Phase I: Sept 2011 – Feb 2014 (~100 kg yr)
  - Phase II: May 2016 - present (~200 kg yr with upgrades, projected)
- Phase 1 results:
  \[ T_{1/2}^{0\nu\beta\beta} = 2.172 \pm 0.017 \pm 0.060 \cdot 10^{21} \text{ yr} \]
  \[
  (\text{stat.}) (\text{syst.})
  \]
  \[ T_{1/2}^{0\nu\beta\beta} > 1.1 \cdot 10^{25} \text{ yr} \]
  \[ \langle m_{\beta\beta} \rangle < 190 - 450 \text{ meV} \]

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  - First Phase 2 results in summer 2017
nEXO

- Next-generation detector scales LXe TPC technology to multi-ton scale
- Large reduction in backgrounds in central region due to “self-shielding”
- Detailed detector simulation provides projected sensitivity of $T_{1/2} = 6.7 \times 10^{27}$ yr (90% CL, 10 yr run)

Projected sensitivity:

$1^{3}Xe \ 0\nu\beta\beta \ T_{1/2}$

Livetime [yr]

10$^{26}$ 10$^{27}$ 10$^{28}$

nEXO Sensitivity (90% C.L.)
nEXO Discovery 3$\sigma$, Prob. 50%
KamLAND-Zen

• Currently ~400 kg $^{136}$Xe loaded into liquid scintillator in balloon in KamLAND

• Began acquiring data in Sept 2011 (Phase 1, ~90 kg yr)

• Repurified scintillator and acquired data in 2014-2015 (Phase 2, ~500 kg yr)

• Phase 1+2 results:

\[
T_{1/2}^{2
\nu\beta\beta} = 2.21 \pm 0.02 \pm 0.07 \cdot 10^{21} \text{ yr (stat.) (syst.)}
\]

\[
T_{1/2}^0\nu\beta\beta > 1.1 \cdot 10^{26} \text{ yr (Phase 1+2)}
\]

\[
\langle m_{\beta\beta}\rangle < 61 - 165 \text{ meV}
\]


• Currently installing lower background balloon, fill with 750 kg $^{136}$Xe (KLZ-800)
KamLAND2-Zen

• KamLAND-Zen 800 plans to reach sensitivity to $\langle m_{\beta\beta} \rangle \sim 50$ meV

• To improve further requires better energy resolution ($2\nu\beta\beta$ background), and continued improvement in radiopurity

• R&D in progress towards KamLAND2-Zen (goal of $\sigma_E \sim 2\%$, $\langle m_{\beta\beta} \rangle \sim 20$ meV)

• Light yield improvements:
  • LAB-based liquid scintillator (x1.4)
  • High QE PMTs (x1.9)
  • PMT coverage (x1.8)

• Backgrounds:
  • Scintillating balloon
  • New methods for LS purification (e.g. molecular sieve)
  • Pressurized Xe loaded scintillator

Talk by J. Shirai, Neutrino 2016
NEXT-100

- High pressure gas TPC with \(\sim 100\) kg \(^{136}\)Xe
- Best energy resolution for Xe detectors \((\sigma \sim 0.3\% \text{ in small prototypes})\)
- Excellent topological background rejection
- To begin operation at Canfranc in 2018
- Expect to reach median sensitivity:
  \[T_{1/2}^{0\nu\beta\beta} = 2.8 \cdot 10^{25} \text{ yr}\]
  \[\text{JHEP05 159 (2016), arXiv:1511.09246}\]
- “NEXT-ton” could extend to ton scale

**Schematic of NEXT-100 detector**

**Topological discrimination requiring 2 “blobs”**: 
PandaX 200

- High pressure gas TPC to be installed at Jinping in ~2019 (~200 kg $^{136}$Xe)
- Will use Micromegas detectors to directly collect electrons
- Initial detectors will have $\sigma \sim 1\%$ with ~1mm spatial resolution
- Projected sensitivity: $T_{1/2}^{0\nu\beta\beta} = 10^{26}$ yr (3 year run)

PandaX 1k

• PandaX ultimately plans for 5 copies of PandaX-200 in large water shield

• R&D towards “Topmetal” CMOS pixel charge sensors (goal $\sigma \sim 0.3\%$)

•Projected sensitivity: $T_{1/2}^{0\nu\beta\beta} = 10^{27}$ yr

Projected sensitivity vs live time (90% CL):

- PandaX-III, 200 kg Module
- PandaX-III, 1T, Multiple Modules

Concept for PandaX 1k:
Ba “tagging”

- Xe (gas/liquid) detectors may allow the daughter Ba atom to be spectroscopically identified
- High efficiency Ba “tagging” would eliminate all non-ββ backgrounds
- R&D ongoing by EXO and NEXT collaborators using several techniques

Single atom spectroscopy in SXe:

Resonance Ionization spectroscopy:

Single Molecule Fluorescence Imaging:

≤ 1 Ba atoms


Summary

- Experiments using $^{136}$Xe provide some of the most sensitive techniques for searching for $0\nu\beta\beta$

- These homogenous, gas and liquid phase detectors will be scaled to the ton scale and beyond in the coming years

- Such detectors may be the first to identify this lepton number violating process!

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**Constraints on $m_{\beta\beta}$:**

- KamLAND-Zen ($^{136}$Xe), Current
- IH, Next-gen
- NH

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**Background vs. exposure:**

- Current
- Next-gen
- KamLAND-Zen
- KamLAND-Zen 800
- KamLAND2-Zen
- PandaX 200
- PandaX 1k
- NEXT 1.5k
- nEXO

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*arXiv:1705.02996*