CURRENT STATUS & FUTURE PROSPECTS OF KAMLAND-ZEN

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On behalf of the KamLAND-Zen Collaboration
7/31/2019
DPF 2019, Northeastern University
NEUTRINOS

- Seesaw Mechanism explain the low mass of neutrinos: Combine Dirac and Majorana masses

\[
\mathcal{L} \sim -\frac{1}{2} \begin{pmatrix} \bar{\nu}_L & \bar{\nu}_R \end{pmatrix} \begin{pmatrix} 0 & m_D \\ m_D & m_M \end{pmatrix} \begin{pmatrix} \nu_L^c \\ \nu_R \end{pmatrix} \Rightarrow m_\nu = \frac{m_D^2}{m_M}, m_N = m_M
\]

- Search for double beta decay

SM process

BSM process
DOUBLE BETA DECAY SPECTRUM

- Schematic view of energy spectrum of $2\nu\beta\beta$ and $0\nu\beta\beta$

- $0\nu\beta\beta$ only creates a mono-energetic peak at the $Q$-value of the nuclei
MOTIVATION

- Lepton Number Violation explains Leptogenesis
  \(0\nu\beta\beta\)'s introduce Lepton Number Violation
  Explain matter-antimatter asymmetry

- Multiple choices for possible isotopes
  KamLAND is using \(^{136}\text{Xe}^\):
  (1) Noble gas
  (2) High Q-value, \(Q = 2459\) keV
  (3) Centrifugal enrichment possible
  (4) Easy to scale, loaded 3% by weight
KAMLAND-ZEN APPARATUS

- LS mini-balloon is added 90% enriched $^{136}\text{Xe}$

- Zen-400
  - Period 1: 320kg started at 2012
  - Period 2: 380kg started at 2014

- Zen-800
  - 745 kg started in Jan, 2019
  - Data taking in progress
CURRENT RESULT

- **Zen-400 conclusion:**
  1. No signal for $0v\beta\beta$
  2. Approaching the Inverted Hierarchy region
  3. First experiment to reach (corresponding to 61-165 meV)

  $$T_{1/2}^{0\nu\beta\beta} > 1.07 \times 10^{26} \text{ yrs}$$

- **Zen-800 goal:**
  1. Begin probing the Inverted Hierarchy region
  2. Target sensitivity of 40 meV

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PRL117, 082503 (2016)
ANALYSIS OF ZEN-400

- All data of 2νββ & major backgrounds
- Expect 0νββ shown with 90% C.L.
- Significant 110mAg contamination
- Large external background
### BACKGROUND SUMMARY

- **Backgrounds in region of interest 2.3 ~ 2.7 MeV**
- **Within 1m-radius spherical volume**

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**Residual radioactivity in Xe-LS**

| **214$^{Bi}$ ($^{238}$U series)** | 0.23 ± 0.04 | 0.25 | 0.028 ± 0.005 | 0.03 |
| **208$^{Tl}$ ($^{232}$Th series)** | -          | 0.001 | -          | 0.001 |
| **$^{110m}$Ag** | -          | 8.5 | -          | 0.0   |

**External (Radioactivity in IB)**

| **214$^{Bi}$ ($^{238}$U series)** | -          | 2.56 | -          | 2.45 |
| **208$^{Tl}$ ($^{232}$Th series)** | -          | 0.02 | -          | 0.03 |
| **$^{110m}$Ag** | -          | 0.003 | -          | 0.002 |

**Spallation products**

| **$^{10}$C** | 2.7 ± 0.7 | 3.3 | 2.6 ± 0.7 | 2.8 |
| **$^{6}$He** | 0.07 ± 0.18 | 0.08 | 0.07 ± 0.18 | 0.08 |
| **$^{12}$B** | 0.15 ± 0.04 | 0.16 | 0.14 ± 0.04 | 0.15 |
| **$^{137}$Xe** | 0.5 ± 0.2 | 0.5 | 0.5 ± 0.2 | 0.4 |

*Phys. Rev. Lett. 117 (2016) no.8, 082503*
REDUCTION OF $^{110m}$Ag

- After 1.5 years purification
- 95% reduction of $^{110m}$Ag
# BACKGROUND $^{214}\text{Bi}$

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**CUT $^{214}$Bi-$^{214}$Po Decays**

- $^{214}$Bi-$^{214}$Po is vetoed by a delayed coincidence tag. This cut removes $(99.95\pm0.01\%)$ of $^{214}$Bi-$^{214}$Po decays.
- Major background at bottom of balloon
- Zen-800 is bigger and cleaner
Cosmic muons and their spallation products are potential backgrounds

Muon rate \( \sim 0.333 \text{Hz} \)
SPALLATION NEUTRONS

- Spallation Neutrons
  Capture time = 220 $\mu$s
  Use coincidence cut to reduce neutrons

- Spectra of the events following muons in
  $150 \leq T < 1000\mu$s
  $4150 \leq T < 5000\mu$s
### BACKGROUND $^{10}$C

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SPALLATION ISOTOPIES

- Spallation Isotopes
  Major problem $^{10}$C, with lifetime $T\sim20s$
  Use machine learning to separate from signal events
  (More details in Aobo’s talk)
FUTURE PLAN - KLZ2

- Winston Cones
- Better PMT & More transparent LS => Light collection resolution 4% to 2%
- New electronics in progress
- Goal: (almost) finish probing the IH region
COLLABORATION

- Japan
  - Tohoku University, RCNS
  - University of Tokyo, Kavli IPMU
  - Osaka University
  - Tokushima University
  - Kyoto University

- US
  - Massachusetts Institute of Technology
  - Boston University
  - University of Washington
  - University of California Berkeley
  - University of Tennessee
  - Triangle University Nuclear Laboratory
  - Virginia Polytechnic Institute
  - Virginia State University
  - University of Hawaii

- Netherland
  - Nikhef, University of Amsterdam

※ Second affiliation is not listed.
Timeline of KamLAND-Zen from 2011 to present

2011
- MIB production
- 400 phase 1
- 320 kg

2012
- LS purification
- Recovery from fire

2013
- LS purification

2014
- 400 phase 2
- 380 kg

2015
- OD refurbishment
- MIB production

2016
- Welding improvement
- MIB production

2017
- MIB production

2018
- LS purification
- Xenon installation

2019
- Zen 800
- 745 kg