KamLAND double beta decay experiment using $^{136}$Xe

( KamLAND-Zen )

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KamLAND

BO
50% dodecane
50% isoparaffin

\[ \frac{\rho_{LS}}{\rho_{BO}} = 1.0004 \]

1,200 m$^3$ LS

1,800 m$^3$ Buffer Oil

Water Cherenkov Outer Detector

\[ \rho = 0.78 \text{ g/cm}^3 \]
8,000 photons/MeV
\[ \lambda \sim 10 \text{ m} \]

34% photo-coverage with 1,325 17” and 554 20” photo-tubes

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Summary of KamLAND

- 1998-2001: construction
- 2002: data-taking start
- We got some results
  - reactor anti-neutrino observation
  - neutrino deficit at ~175km base
  - spectral distortion
  - precise oscillation parameters measurement
- Geo neutrino detection
  - 2009~: KamLAND is running for $^7$Be solar neutrino observation after the LS distillation
  - 2011~: Xe phase
Reactor Anti-Neutrino

LMA2

~2005

~2007

Precise oscillation
Parameter measurement

2 cycle

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Geo Neutrino observation

Radio active nuclei produce heat

\[ ^{238}\text{U} \rightarrow ^{206}\text{Pb} + ^{8}_{\text{He}} + 6\text{e}^{-} + 6\overline{\nu}_{\text{e}} + 51.7\text{MeV} \]
\[ ^{232}\text{Th} \rightarrow ^{208}\text{Pb} + ^{6}_{\text{He}} + 4\text{e}^{-} + 4\overline{\nu}_{\text{e}} + 42.7\text{MeV} \]
\[ ^{40}\text{K} \rightarrow ^{40}\text{Ca} + \text{e}^{-} + \overline{\nu}_{\text{e}} + 1.31\text{MeV} \]

Terrestrial heat flow \( 31\sim44\text{TW} \)

Contribution of radioactive nuclei \~20\text{TW} \)
( U series 8TW / Th series 8TW / \(^{40}\text{K} 4\text{TW} \) )

from Crust + Mantle
-- based on Chondrite model (BSE model)

Upper crust of land
U:2. 8ppm / Th: 10.7ppm


No radiogenic heat from the core
Th/U ratio \~3.7

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Geo Neutrino observation

- preliminary result (K. Inoue, Neutrino2010)

  data set: March 9, 2002 ~ November 4, 2009

  total exposure: $3.49 \times 10^{32}$ target–proton–years

  841 candidates in 0.9 - 2.6 MeV

BG total: $729.4 \pm 32.3$

- reactor $\bar{\nu}_e$: $484.7 \pm 26.5$
- $^{13}$C$(\alpha, n)^{16}$O: $165.3 \pm 18.2$
- accidental: $77.4 \pm 0.1$
- $9^\text{Li}$: $2.0 \pm 0.1$
- atm. $\nu +$ fast n: $< 2.8$

rate - only analysis: $111^{+45}_{-43}$ events

Null signal exclusion 99.55%

(rate - only hypothesis test)
Rate-Shape-time analysis

0 signal is rejected at $99.997\%$CL. (>4σ) (rate-shape-time $\Delta\chi^2$)

# of geo-ν events

$10^6_{-28}^{+29}$

$4.3_{-1.1}^{+1.2} \times 10^6$ /cm$^2$/sec

$38.3_{-9.9}^{+10.3}$ TNU

corresponds to 16TW (for U+Th)
Consistent with the model prediction
7Be neutrino observation

LS was purified by the distillation system (2007 and 2008)

Installed new electronics – for $^{13}$C($\alpha$,n) background reduction (on going)

Data-taking continue (to March 2011)
KamLAND Zen experiment
(KamLAND zero neutrino Double Beta decay)

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Advantage for $\beta\beta$ experiment on KamLAND

- KamLAND has
  - huge volume: 1,200m$^3$ Liquid Scintillator
  - Ultra low radioactivity
  - Low threshold: (It will be $E_{th} = \text{few} 100\text{keV}$)
  - established distillation technique
  - experience of balloon development
  - new electronics (from 2009)

  **mach advantage for $0\nu\beta\beta$ experiment!**

- Disadvantage

  Current Energy Resolution:
  
  \[ \Delta E = \frac{6.2\%}{\sqrt{E(\text{MeV})}} \quad (34\% \text{ photo coverage}) \]

  This is enough on earlier stage!
KamLAND-Zen project

Merit of using $^{136}$Xe on KamLAND

<table>
<thead>
<tr>
<th>Nucleas</th>
<th>$T^{0\nu}_{1/2}$ (50 meV)</th>
<th>$T^{2\nu}_{1/2}$ measured (year)</th>
<th>Nat. Abundane (%)</th>
<th>Q-value (keV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{136}$Xe$\rightarrow^{136}$Ba</td>
<td>$4.55 \times 10^{26}$</td>
<td>$&gt;10^{22}$</td>
<td>8.9</td>
<td>2476</td>
</tr>
</tbody>
</table>

- Available the Isotopic enrichment (>90%)
- Purification method was established
- Solubility to LS > 3%, easy extracted
- Slow $2\nu\beta\beta$ ($T^{2\nu}_{1/2} >10^{22}$ years)
- Small $T^{0\nu}/ T^{2\nu}$ ratio

* Basic idea by R.S. Raghavan

KamLAND-Zen project

1st phase enriched Xe 400kg
- R=1.7m balloon
- V=20.5m³, S=36.3m²
- LS : C₁₀H₂₂(81.8%) + PC(18%) + PPO + Xe (~2.5wt%)
- \( \rho_{LS} : 0.78\text{kg/ℓ} \)
- high sensitivity with low cost

Tank opening (2013 or 2015)

2nd phase enriched Xe 1000kg
- R=2.3m balloon
- V=51.3m³, S=66.7m²
- improvement of energy resolution
  (brighter LS, higher light concentrator)
Developments of system for 400kg Xe phase

1. Xe gas loading/ extraction system

2. New electronics - MOGURA

System will be ready in December 2010

3. Enriched Xe

- We have 190kg 90% enriched Xe gas
- Purchase 210kg more to March 2011 (400kg total)

4. Mini Balloon Φ3.4m

Handling and pressurized test by water (80μm film, June 2010)

More R&D
- ultra low contamination films
  U/Th/^{40}K \sim 10^{-13}g/g
- more thin film \sim 25μm

MIB will be delivered to March 2011

Background study using KamLAND MC (GEANT4)

Major BG
(1). $^{136}\text{Xe}$ 2νββ
(2). spallation isotopes: $^{10}\text{C}$, $^{11}\text{Be}$ => 1/10 using new electronics help
(3). $^8\text{B}$ solar neutrinos <4.9 events/d/kton on KamLAND
(4). from Mini Balloon (MIB) material: $^{208}\text{Tl}$, $^{214}\text{Bi}$ => vertex cut,

Simulated Energy Spectrum at KamLAND

Assumed
- 400kg 90% enriched Xe loaded LS
- MIB contamination (238U, 232Th, 40K)
  = (10^{-12}, 10^{-12}, 10^{-11})[g/g]
- neutrino effective mass $m_{\nu} < 150\text{meV}$ (the lower limit of the current claimed detection)
- $T_{1/2}(2\nu\beta\beta) > 10^{22}\text{y}$
- $T_{1/2}(0\nu\beta\beta) > 1.14\times10^{24}\text{y}$
- $^{10}\text{C}$ 90% tag, $^{214}\text{Bi}$ 66% tag

Summary of BG and signal in signal region

<table>
<thead>
<tr>
<th>Source</th>
<th>Total</th>
<th>$^{136}\text{Xe}\ 0\nu$</th>
<th>$^{208}\text{Tl}$</th>
<th>$^{214}\text{Bi}$</th>
<th>$^{10}\text{C}$</th>
<th>$^{11}\text{Be}$</th>
<th>$^8\text{B}$</th>
<th>Total</th>
<th>$^{136}\text{Xe}\ 2\nu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Events/year</td>
<td></td>
<td></td>
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<tr>
<td>2.08±0.15</td>
<td>1.86±0.13</td>
<td>2.40±0.30</td>
<td>3.09±0.01</td>
<td>0.26±0.03</td>
<td>1.52±0.03</td>
<td>9.35±0.23</td>
<td>18.08±0.02</td>
<td>18.08±0.02</td>
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</tbody>
</table>
observable = \left[ T_{1/2}^{0\nu} \right] = G^{0\nu} | M^{0\nu} |^2 | m_{\beta\beta} |^2

Target sensitivity of the 400kg phase is \sim 60\text{meV}

2 years on 100% fiducial vol. @90% enrichment

Target sensitivity of the 2nd phase is \sim 25 \text{meV} with 5 years.
summary

- KamLAND is running for reactor, Geo, 7Be solar (to 2011)
- KamLAND have ability to do $0\nu\beta\beta$ experiment
- KamLAND-Zen project will start using 400kg 90% enriched Xe from May 2011
- Target sensitivity on 400kg Phase $\sim 60\text{meV} \ @ 2\text{years}$
- Planning Xe1000 phase (from 2013 or 2015: depend on funding)

Thank you!