KamLAND

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KamLAND

- Large underground detector
  - 1000t of LS
  - 1000m underground
  - 34% coverage
    - 17” PMTs … 1325
    - 20” PMTs … 544
  - Water Cherenkov OD
Physics Targets of KamLAND

- solar neutrino (0.4 MeV)
- geo neutrino (1.0 MeV)
- reactor neutrino (2.6 MeV)
- supernova neutrino (8.5 MeV)

**Neutrino Detection by Electron Scattering**
- Solar neutrino: $\nu_x \rightarrow e^-$
- Geo neutrino: $\nu_x \rightarrow e^-$

**Anti-neutrino Detection by Inverse Beta-Decay**
- Reactor neutrino: $\bar{\nu}_e \rightarrow e^+ + p$ mean capture time $\sim 200 \mu$sec on proton
- Supernova neutrino: $\bar{\nu}_e \rightarrow e^- + n$ delayed decay

Prominent processes include:
- $\gamma$ prompt decay
- $\gamma$ delayed decay
• Latest published data
  – Data Set: March 9, 2002 ~ May 12, 2007

\[ \Delta m_{12}^2 = 7.58 \times 10^{-5} \text{ eV}^2 \]

\[ \tan^2 \theta_{12} = 0.47 \]
Geo-$\nu$ Physics

- Latest published results
  - Data Set: March 9, 2002 ~ May 12, 2007

$\nu p \rightarrow e^+ n$
Before May 12, 2007

Large BG

- $^7\text{Be} \nu: ^{85}\text{Kr}, ^{210}\text{Bi} (^{210}\text{Pb} \text{ daughter})$
- $^8\text{B} \nu: ^{208}\text{Tl} (^{232}\text{Th} \text{ series})$

$10^{-5} \sim 10^{-6}$ reduction

Fiducial R < 4 m
Liquid Scintillator Purification

- Method:
  - **Distillation** against Bi, Tl, K, (U, Th, …)
  - **Ultra-pure N₂ purge** against Kr, (Ar, …)

- Purification system
  in Kamioka mine in 2006
Liquid Scintillator Purification

- Purification
  - 1\textsuperscript{st} : April 17 ~ August 1, 2007
    - $V_{\text{purified}} = 1699\text{ m}^3$
  - 2\textsuperscript{nd} : June 19, 2008 ~ Feb. 9, 2009
    - $V_{\text{purified}} = 4856\text{ m}^3$

In the 1\textsuperscript{st} purification, purified LS was fed from the top. In the 2\textsuperscript{nd} one, purified LS was firstly fed from the top, then from the bottom to control balloon weight made by fine film.
During the purification

LS boundary wend down.

Top filling in the early stage of the 2\textsuperscript{nd} purification.
Waiting time after the 2\textsuperscript{nd} purification (I)

Waiting for $^{210}\text{Bi}$ to decay out and for system to be stable.

Waiting time for system to be stable
Present Status of KamLAND

• Data has been acquired.
  – Accumulating events.

• A new fitter has been developed.
  – Improvement of vertex and energy resolution in low energy region

• Energy calibration with sources.
  – Light and energy relation

• Investigating systematic in detail.
  – Event reconstruction error estimation
  – Cutting efficiency estimation
What’s expected: Solar-$\nu$ (I)

Huge BG reduction

Waiting time for system to be stable: 2/9/09

the end of 2nd purification: 2/9/09

$\nu e^- \rightarrow \nu e^-$
What's expected: Solar-$\nu$ (II)

$^8$B $\nu$ became measurable
$\leftarrow \sim 3$MeV

MC data

$^{208}$Tl reduction by purification

Expected $^{208}$Tl subtraction by $\alpha + \beta$ delayed coincident
($^{212}$Bi $\rightarrow ^{208}$Tl $\rightarrow ^{208}$Pb (Br=36%))

$\nu e^- \rightarrow \nu e^-$

Visible Energy (MeV)
What’s expected: Solar-$\nu$ (III)

- Thanks to lower BG in low energy region, we measure $^7$Be- and $^8$B- $\nu$.

Expectation:
- $^7$Be $\nu$ error = 10\text{~}13\%
- $^8$B $\nu$ error = $\sim$10\%

assuming 2y runtime

Assuming 2y runtime
What’s expected: Geo $\nu$

13\(^{13}\text{C}(\alpha, n)^{16}\text{O}\) BG is reduced.
(Less than 1/10)

Reactor $\nu$ “BG” (~1/2)

“Discovery” of Geo-$\nu$ in 2y (!?)
5$\sigma$ significance could be achieved in next 2y assuming present condition
What’s expected: Reactor-ν

2.4y data (Up to Oct., 2009)

Stat~50% increase $P_{\text{reactor}} \sim 50\%$
What’s expected: Reactor $\nu$ (II)

- Feature in these years
  - Lower operation rate (~1/2)
  - A new reactor (Shika II)

Better limit on uncorrelated flux will be obtained.

Error~1/2

Or we can see some unknown anti-$\nu$ sources.

Accumulating lower flux data

Expected error
New Electronics

• Multiple events rejection with large RAM

$\text{Board installation} \rightarrow \text{Almost completed}$

$\text{DAQ software development} \rightarrow \text{Starting}$
Benefit of New Electronics

\( ^{8}\text{B} \nu \) threshold: \(~3\text{MeV} \rightarrow ~2\text{MeV}\)

- Example: Lower \( E_{\text{th}} \) of \( ^{8}\text{B} \nu \) tagging by multiple n after \( \mu \)

- \( ^{10}\text{C} \) tagging by multiple n after \( \mu \)

- MC data

- \( ^{8}\text{B} \) solar \( \nu_{e} \)
- \( ^{208}\text{Tl} \)
- \( ^{10}\text{C} \)
- \( ^{11}\text{C} \)

\( ^{208}\text{Tl} \beta+\gamma, \ Q=5.0\ \text{MeV} \)

Ex. \( ^{8}\text{B} \nu \)
Further more in KamLAND

ββ0ν experiment in KamLAND!!
KamLAND with $^{136}$Xe

400kg $^{136}$Xe

Ultra low BG environment in KL
KamLAND with $^{136}\text{Xe}$ (II)

- $^{136}\text{Xe}$ 2ν
- 400 × 5 kg·years

$<m_\nu> = 0.15$ eV (min KKDC)

$T_{1/2} \ (0\nu) = 9.8 \times 10^{25}$ y
$T_{1/2} \ (2\nu) = 1.0 \times 10^{22}$ y

- $t_{\text{balloon}} = 25$ μm, $R_{\text{balloon}} = 1.7$ n
- $^{232}\text{Th},^{238}\text{U} = 10^{-13}$ g/g

$^{10}\text{C} \ 95\% \ tag$
Summary

• KamLAND and its published results
• Purification toward solar $\nu$
• Status after purification
• Physics prospects of current and near future KamLAND
  – Solar-, reactor-, geo- $\nu$, …
  – *Keep your eyes on KamLAND!*
Power Reactors

86% of ν events from ~180 km

Kamioka

~ 180 km baseline

Number of Events [year/kt]

Distance from Kamioka [km]
What’s expected: $\theta_{13}$

Latest published data

$(\sin \theta_{12}, \sin \theta_{13})$

- (0.36, 0.00)
- (0.23, 0.10)
- (0.16, 0.20)
- (0.10, 0.30)
What’s expected: $\theta_{13} (\text{II})$

**Latest published data**

- $\sin^2 \theta_{12}$
- $\sin^2 \theta_{13}$

**Ratio**

\[
\text{Ratio} = \frac{\text{observed } \bar{\nu}_e \text{ spectrum}}{\text{expected no-oscillation spectrum}}
\]
$\theta_{12}$ and $\theta_{13}$

KamLAND (Rate + Shape + Time)
$\theta_{13}$ by Global analysis

SNO updated results

Phase 1 & 2

Phase 3

$^{210}\text{Bi}$ Leaching from Balloon (?)

- Pb can stick on a surface.
  - It is observed by $^{212}\text{Pb}$ in tests experiments.
    - Especially SiO$_2$
    - Other materials, such as the balloon film

- There is a flow in KL, which is observed by $^{210}\text{Bi}$ (daughter of $^{210}\text{Pb}$).