The KamLAND Collaboration

G.A. Horton-Smith, R.D. McKeown, J. Ritter, B. Tipton, P. Vogel

California Institute of Technology
C. E. Lane, T. Miletic

Drexel University
Y. F. Wang

IHEP, Beijing
T. Taniguchi

KEK


LBNL UC Berkeley
S. Dazeley, S. Hatakeyama, R. C. Svoboda

Louisiana State University
J. Detwiler, G. Gratta, N. Tolich, Y. Uchida

Stanford University

Tohoku University

TUNL
J. Busenitz, Z. Djurcic, K. McKinny, D.-M. Mei, A. Piepke, E. Yakushev

University of Alabama
P. Gorham, J. Learned, J. Maricic, S. Matsuno, S. Pakvasa

University of Hawaii
B. D. Dieterle

University of New Mexico
M. Batygov, W. Bugg, H. Cohn, Y. Efremenko, Y. Kamyshkov, Y. Nakamura

Jason Detwiler

DPF 2002
Introduction to KamLAND

- **Kamioka Liquid–Scintillator AntiNeutrino Detector**

- **KamLAND** is a neutrino oscillation experiment that uses a terrestrial source of neutrinos to investigate the solar neutrino problem.

- **KamLAND** is a long–baseline experiment to study the disappearance of electron antineutrinos ($\bar{\nu}_e$).

- **Liquid Scintillator** allows us to probe lower neutrino energies than water Čherenkov detectors.
Introduction to KamLAND

KamLAND is part of a tradition of experiments that detect neutrinos from nuclear power plants.

Detected $E_\nu$ spectrum (no oscillations)

$\nu_e + p \rightarrow e^+ + n$

Reactor $\nu_e$ spectrum

Cross section for $\nu_e + p \rightarrow e^+ + n$

Jason Detwiler
KamLAND uses the entire Japanese nuclear power industry as a long-baseline source.

80% of flux from baselines 140–210 km

<table>
<thead>
<tr>
<th>Reactor Site</th>
<th>Distance (km)</th>
<th># of reactors</th>
<th>Therm. Power (max) (GW)</th>
<th>Max. Flux (10^9 $\nu_e$/cm²/s)</th>
<th>Max. Event rate events/kt-year</th>
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<td>Total</td>
<td>51</td>
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<td>130</td>
<td>13.1</td>
<td>1075</td>
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</table>
Introduction to KamLAND

The total electric power produced “as a by-product” of the $\nu_e$ s is:

- $\sim 60$ GW or...
- $\sim 4\%$ of the world’s manmade power or...
- $\sim 20\%$ of the world’s nuclear power!

A large nuclear submarine parked as close as possible to shore in Toyama bay with reactors at full would produce a 10% excess in KamLAND
Introduction to KamLAND

Neutrino oscillations change both the rate and energy spectrum of the detected events.

Coincidence signal: detect
- Prompt: $e^+$ annihilation
- Delayed: $n$ capture
  180 $\mu$s capture time

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Introduction to KamLAND

- 1 kton liquid scintillator
  - 80% paraffin oil
  - 20% pseudocumene
  - 1.5 g/L PPO

- Paraffin outside the nylon balloon
  - radon barrier

- 1879 PMT's
  - 1325 17" – fast
  - 544 20" – efficient
  - 34% coverage

- 225 Veto PMT's
  - Water Čerenkov

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KamLAND Construction

Steel Sphere Constructed
September–October 1999
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PMT Installation
Summer 2000
Completed September 28
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Balloon Installed and Tested
January–March 2001
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Oil and Scintillator Filling
Spring–Summer 2001
Completed September 24
KamLAND Construction

Infrastructure Completed
January, 2002
KamLAND Data Collection Started January 22, 2002

KamLAND Data

Coincidence, prescale, "history" threshold: 120 PMT's hit

Singles threshold: 200 PMT's hit

Muons: all tubes hit

Calibration triggers

entries: 2750048
underflow: 0
overflow: 0
mean: 163.135

PMT hits
KamLAND Data
KamLAND Data

Waveforms are recorded using Analogue Transient Waveform Digitizers (ATWDs), allowing multi p.e. resolution

- The ATWDs are self launching with a threshold ~1/3 p.e.
- Each PMT is connected to 2 ATWDs, reducing deadtime
- Each ATWD has 3 gains (20, 4, 0.5), allowing a dynamic range of ~1mV to ~1V

Blue: raw data
red: pedestal
green: pedestal subtracted
KamLAND Data

Converting waveforms into time and charge information

Event: 18
Cable: 1150
gain: High
A/B: B
offset: 13
T: 14.2

KamLAND Waveform Display
Run/Subrun/Event : 113/0/304
UT: Sun Feb 24 15:49:05 2002
TimeStamp : 2578169707
TriggerType : 0x3a10 / 0x2
Time Difference 64.5 sec
NumHit : 1124
Channel : 3 BH(11)
KamLAND Data

Event Display: through-going muon

color is pulseheight

all tubes illuminated
KamLAND Data

Stopped muon
KamLAND Data

Cerenkov ring from “corner clipper”
KamLAND Data

Low-energy event

color is time
KamLAND Data

Converting time and charge information into event position and energy:

This requires calibration of the PMT's:
- Timing: done with a blue laser
- Gains: single photoelectron gains with LED's, high pulseheight gains with UV laser

The detector response as a whole is calibrated with radioactive sources

The position is obtained from a vertex fit
The energy response depends on position

(Note: these are old calibration plots, not valid for current running conditions)
KamLAND Data

Reconstructed event position for different event energies

$1/R^2$ weight, log scale

Most backgrounds peak near the edge of the scintillator volume
KamLAND Data

Effect of fiducial volume cuts on the energy spectrum

$^{40}\text{K} (1.46 \text{ MeV } \gamma)$

$^{208}\text{Tl} (2.62 \text{ MeV } \gamma)$

$^{210}\text{Pb}$, $^{210}\text{Bi}$

Neutrons

$R < 550$

$R < 500$

$R < 450$
KamLAND Data

Muon-related backgrounds

- **Black**: 4.5 m fiducial volume cut
- **Green**: removed by 2 ms muon veto
- **Blue**: expected $^{11}$C from spallation: $^{12}$C → $^{11}$C + n
- **Red**: E spectrum following muon veto, $^{11}$C subtraction

$^{11}$C (1.0 MeV $\beta^+$)

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KamLAND Data

Background summary:

- Most backgrounds peak near the balloon
  - radon decay products ($^{208}\text{Tl}$, $^{210}\text{Pb}$, $^{210}\text{Bi}$)
  - $^{40}\text{K}$

- Neutron rate and level of muon spallation products are consistent

- We can also set limits on certain contaminations:
  $^{238}\text{U}$ $10^{-16}$ g/g $< 6.4 \times 10^{-16}$ g/g
  $^{232}\text{Th}$ $10^{-16}$ g/g $< 1.8 \times 10^{-16}$ g/g
  $^{40}\text{K}$ $10^{-18}$ g/g $< 2.3 \times 10^{-16}$ g/g

- Background rates tolerable for reactor experiment

Now we can add event coincidence and look for neutrinos...
KamLAND Data
Neutrino Candidate

Prompt Signal
E = 3.20 MeV
Δt = 111 µs
ΔR = 34 cm

Delayed Signal
E = 2.22 MeV
Summary

- KamLAND is making rapid progress

- background levels are acceptable for the reactor experiment, we are working to reduce them to allow lower energy thresholds

- stay tuned for interesting physics results

- Longer-term future: KamLAND solar neutrino experiment
Solar Neutrinos at KamLAND

- Goal: direct detection of $^7\text{Be}$ solar neutrinos
- Singles measurement: no coincidence signal
- Low backgrounds required!

$^7\text{Be}$ signal
Solar Neutrinos at KamLAND

- Radiopurity design goals vs. measurements:
  \[ ^{238}\text{U} \quad 10^{-16} \text{g/g} \quad < 6.4 \times 10^{-16} \text{g/g} \]
  \[ ^{232}\text{Th} \quad 10^{-16} \text{g/g} \quad < 1.8 \times 10^{-16} \text{g/g} \]
  \[ ^{40}\text{K} \quad 10^{-18} \text{g/g} \quad < 2.3 \times 10^{-16} \text{g/g} \]

- Dominant low-energy backgrounds are:
  - \(^{85}\text{Kr}\)
  - \(^{210}\text{Pb}, ^{210}\text{Bi}\) (from Rn decays)

- Working on purification and eliminating leaks to remove such contamination

\(^{85}\text{Kr}\) coincidence measurement

Observed low-energy event spectrum