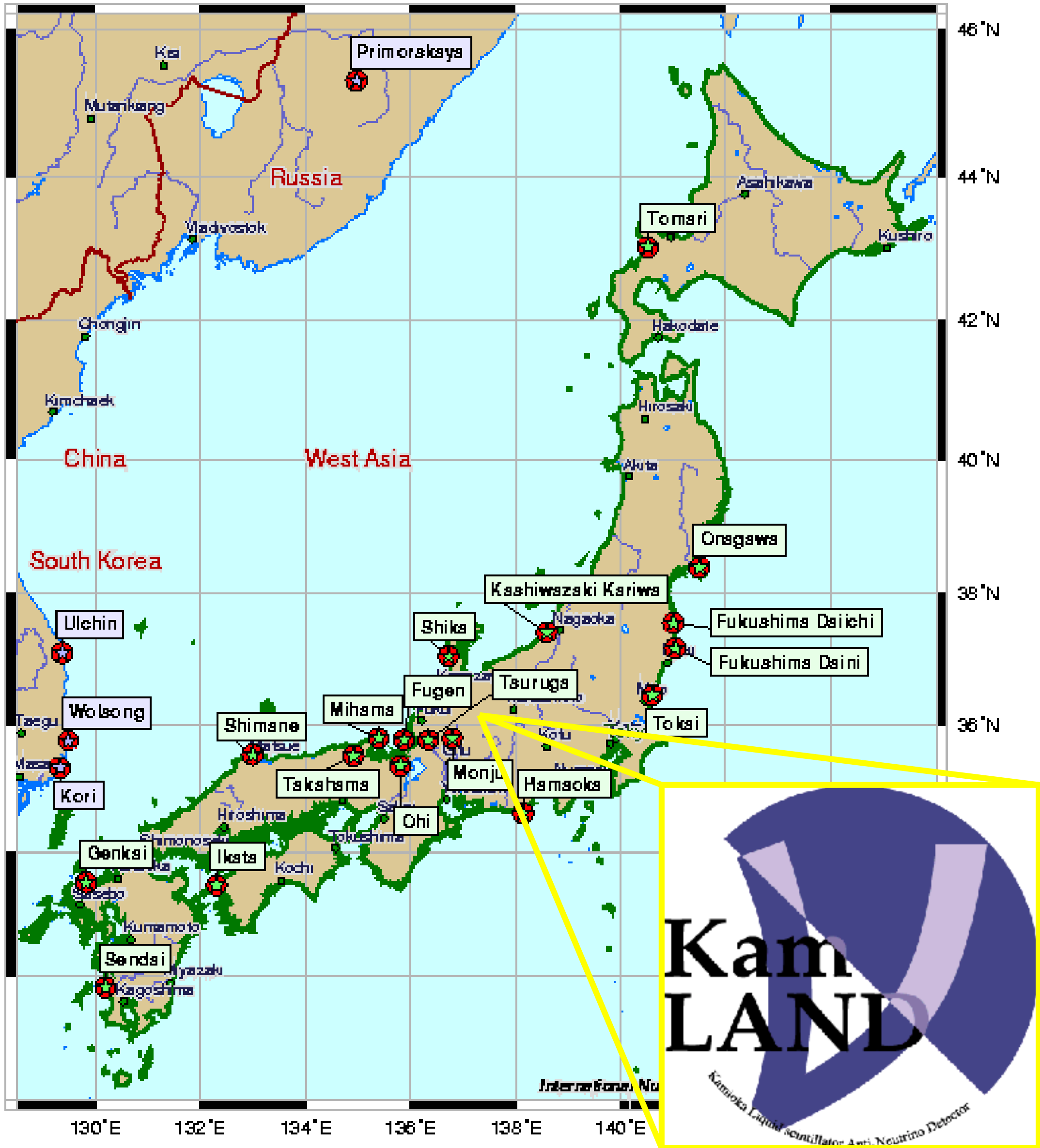
KamLAND:
A Brief Status Report

D. Markoff
North Carolina State University
Triangle Universities Nuclear Lab



***K**amioka*
***L**iquid-scintillator*
***A**nti-**N**eutrino*
***D**etector*

A long-baseline, neutrino oscillation experiment measuring the flux and energy spectrum of electron anti-neutrinos from near-by nuclear power reactors.

KamLAND Collaboration

G.A.Horton-Smith, R.D.McKeown, J.Ritter, B.Tipton, P.Vogel
California Institute of Technology
C.E.Lane
Drexel University
Y.-F.Wang
IHEP, Beijing
B.E.Berger, Y.-D.Chan, D.A.Dwyer, S.J.Freedman, B.K.Fujikawa, K.T.Lesko, K.-B.Luk, H.Murayama, D.R.Nygren, C.E.Okada, A.W.Poon, H.M.Steiner, L.A.Winslow
Lawrence Berkeley National Laboratory/U.C. Berkeley
S.Dazeley, S.Hatakeyama, M.Murakamki, R.C.Svoboda
Louisiana State University
J.Detwiler, G.Gratta, N.Tolich, Y.Uchida
Stanford University
K.Eguchi, S.Enomoto, K.Furuno, Y.Gando, J.Goldman, H.Hanada, H.Ikeda, K.Inoue, K.Ishihara, W.Ito, T.Iwamoto, T.Kawashima, H.Kinoshita, M.Koga, T.Maeda, T.Mitsui, M.Motoki, K.Nakajima, H.Ogawa, K.Oki, T.Sakabe, I.Shimizu, J.Shirai, F.Suekane, A.Suzuki, O.Tajima, H.Watanabe
Tohoku University
L.DeBraeckeleer, C.Gould, H.Karwowski, D.Markoff, J.Messimore, K.Nakamura, R.Rohm, W.Tornow, A.Young
Triangle Universities Nuclear Laboratory
J.Busenitz, Z.Djurcic, K.McKinney, 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
University of Tennessee

Reactor Neutrino Source

Site	Distance (km)	# of cores	P(ther.) (GW)	flux ($\bar{\nu}$ $cm^{-2} s^{-1}$)	Signal ($\bar{\nu}$/yr)
Japan					
Kashiwazaki	160.0	7	24.6	4.25×10^5	348.1
Ohi	179.5	4	13.7	1.88×10^5	154.0
Takahama	190.6	4	10.2	1.24×10^5	101.8
Hamaoka	214.0	4	10.6	1.03×10^5	84.1
Tsuruga	138.6	2	4.5	1.03×10^5	84.7
Shiga	80.6	1	1.6	1.08×10^5	88.8
Mihama	145.4	3	4.9	1.03×10^5	84.5
Fukushima-1	344.0	6	14.2	5.3×10^4	43.5
Fukushima-2	344.0	4	13.2	4.9×10^4	40.3
Tokai-II	294.6	1	3.3	1.7×10^4	13.7
Shimane	414.0	2	3.8	9.9×10^3	8.1
Onagawa	430.2	2	4.8	9.8×10^3	8.1
Ikata	561.2	3	6.0	8.4×10^3	6.9
Genkai	755.4	4	6.7	5.3×10^3	4.3
Sendai	824.1	2	3.3	3.5×10^3	2.8
Tomari	783.5	2	5.3	2.4×10^3	2.0
Korea					
Ulchin	~750	4	11.2	8.8×10^3	7.2
Wolsong	~690	4	8.1	7.5×10^3	5.2
Yonggwang	~940	6	16.8	8.4×10^3	6.9
Kori	~700	4	8.9	8.0×10^3	6.6
Total		69	175.7	1.34×10^6	1102

Total expected signal from reactors: (~80% duty factor) ≈ 2 events/day

Baseline is limited: 85.3% of signal has 140 km < L < 344 km

Average baseline distance <L>~ 190 km

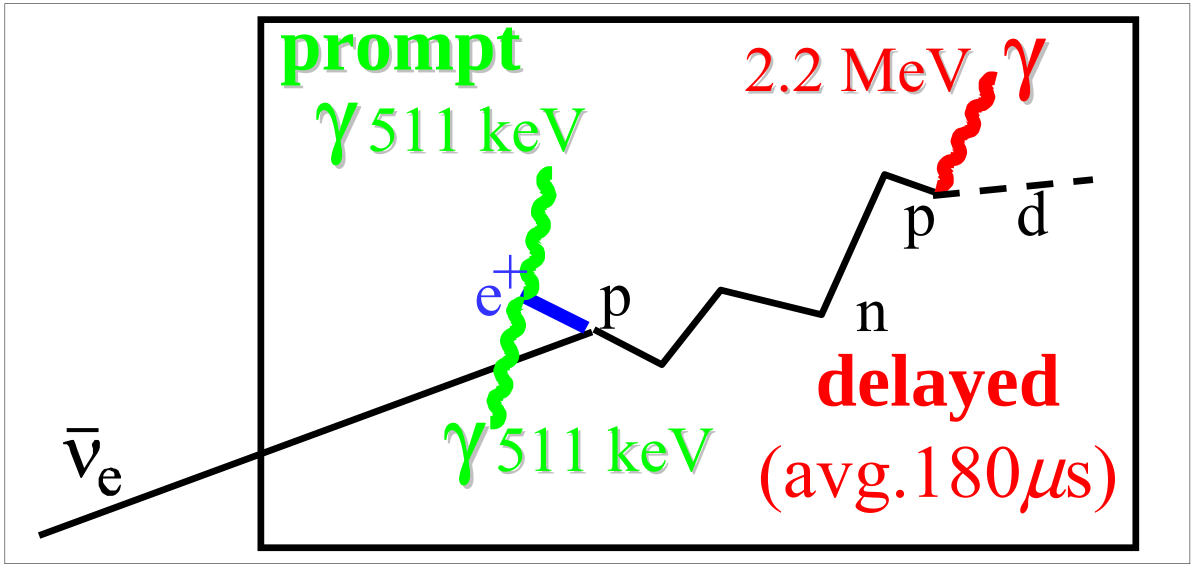
68 GWe power
4% world's manmade power
20% world's nuclear power

Inverse Beta Decay Signal

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

- Large(r) cross-section
- Specific signature

- **e^+ kinetic energy (<8 MeV)**
- **2 annihilation γs (0.5 MeV)**
- **neutron capture γ (2.2MeV)**



Neutrino energy measured from positron energy

$$E_{\bar{\nu}} \cong E_{e^+} + (M_n - M_p) + m_{e^+}$$

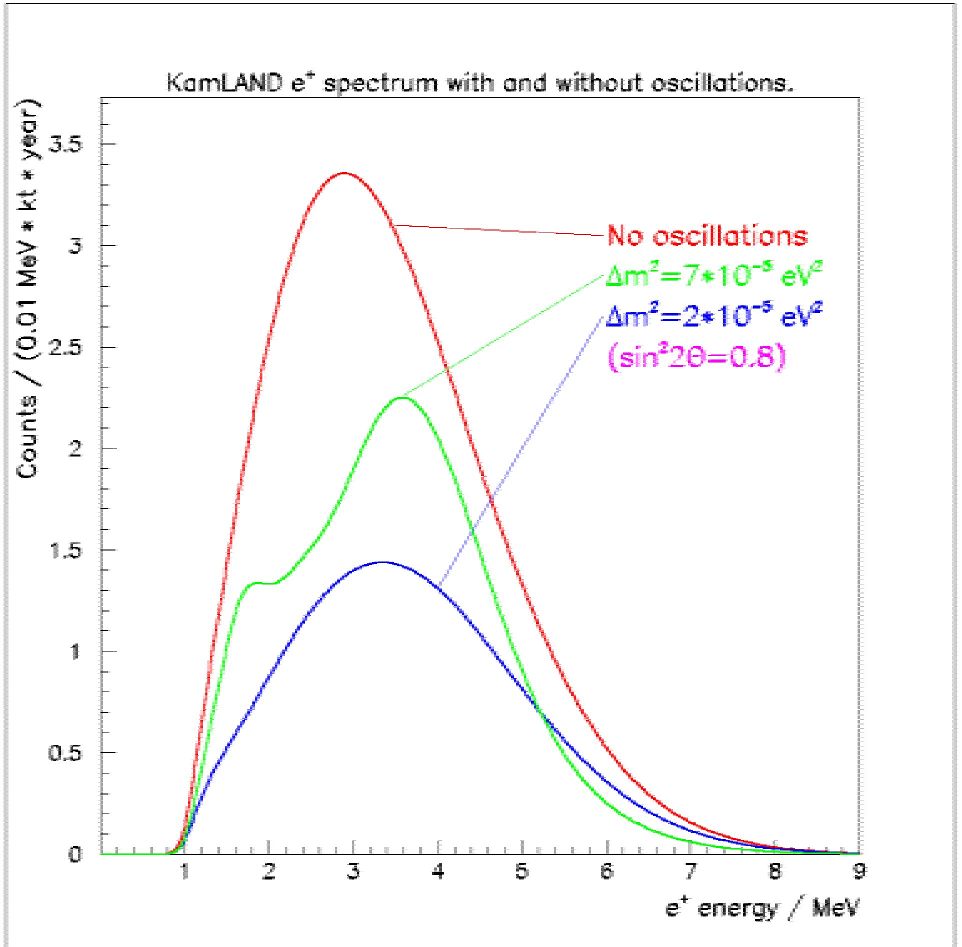
Positron Energy Spectrum

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

Δm^2 sensitivity to $7*10^{-6}$ eV^2

LMA-MSW solution

within reach <u>on the earth !</u>



KamLAND Detector Design

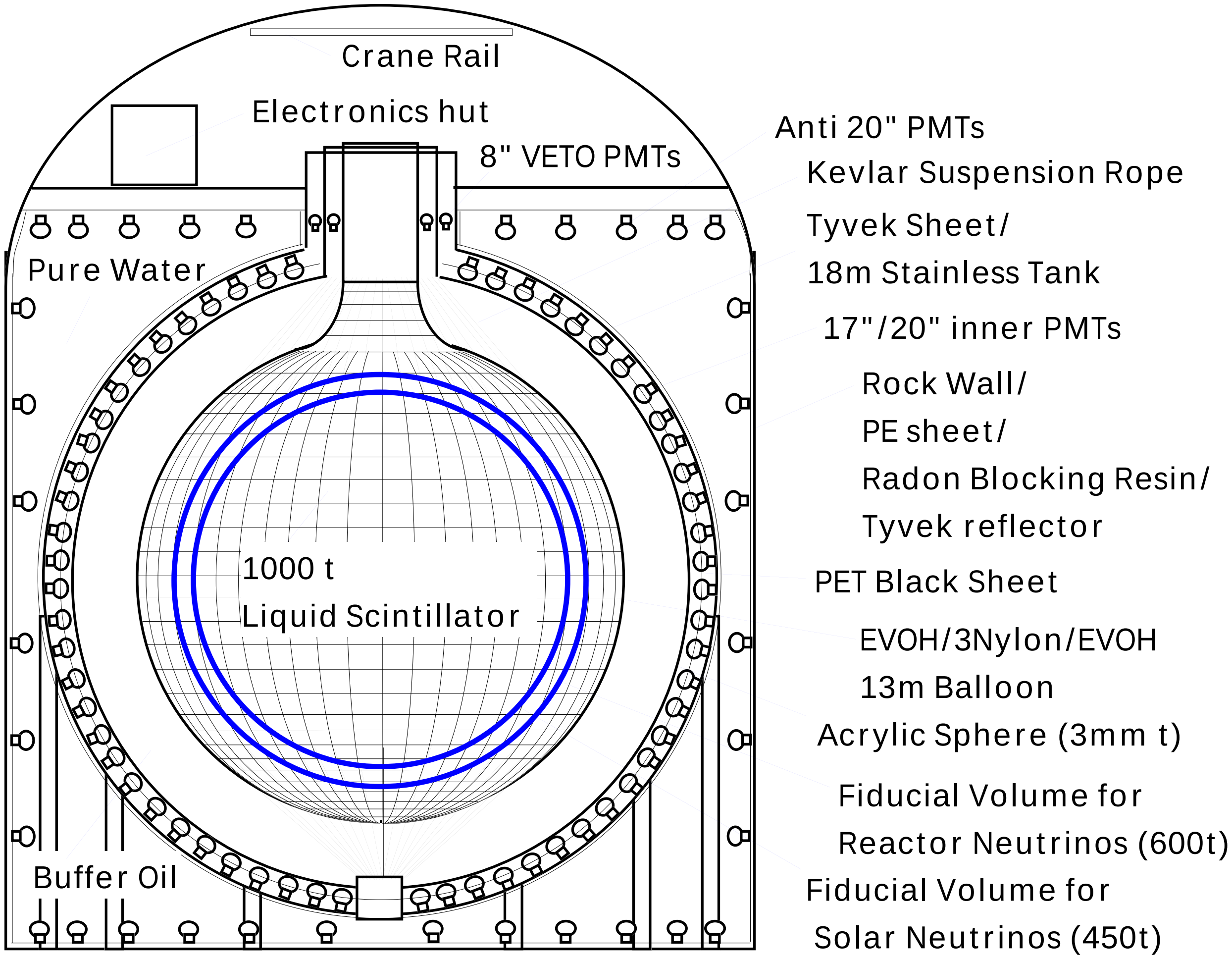
- Scintillator
  - 80% Paraffin Oil
  - 20% pseudocumine
  - 1.5 g/l PPO
- 30% photocathode coverage

  1325 fast 17″ PMTs
  544 large area 20″ PMTs

- Water Čerenkov veto detector

  225 large area 20″ PMTs

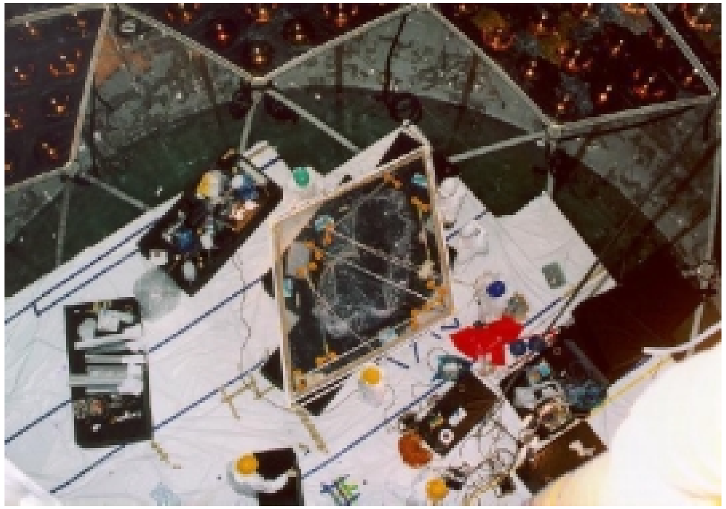
- Multi-hit, deadtime-less electronics



KamLAND Construction: Sphere

Steel Sphere Constructed
September-October 1999

KamLAND Construction: ID

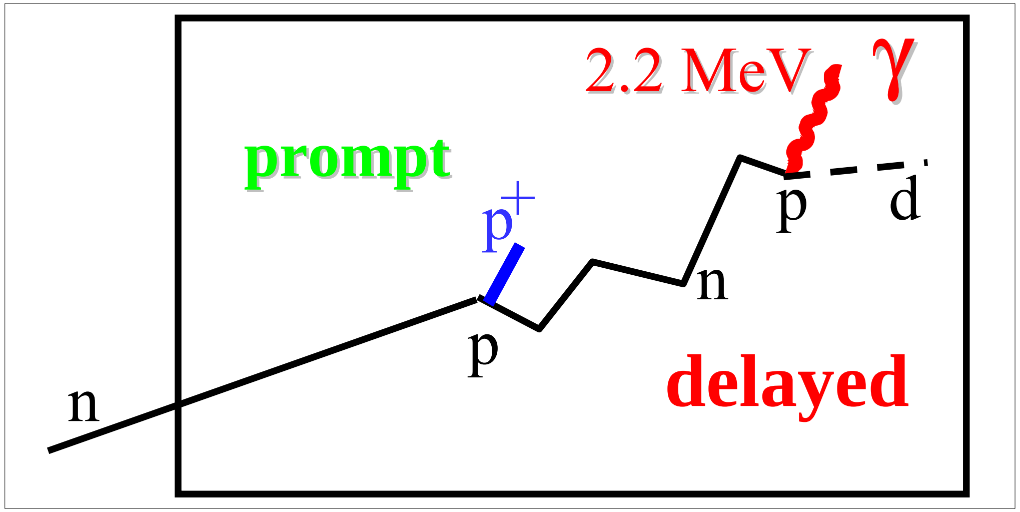


ID PMT Installation
Summer 2000
Completed September 28

Water Čerenkov Outer Detector

False neutrino signal from μ-induced spallation neutrons.

Prompt signal E > 1 MeV
Delayed signal Δt ~ 50-500 μs
Vertex distance Δr < 1 m



Veto muon induced events

tracking – spatial veto

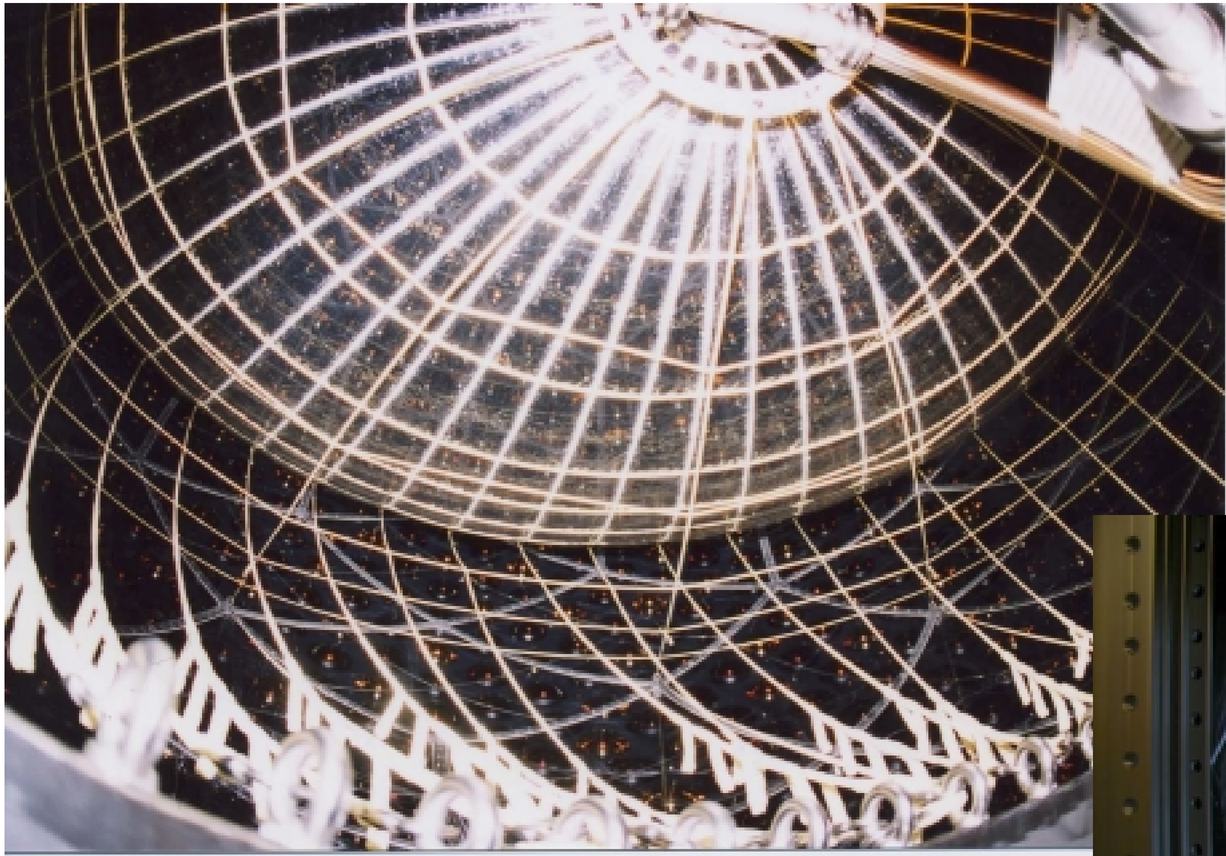
veto in time after muon signal

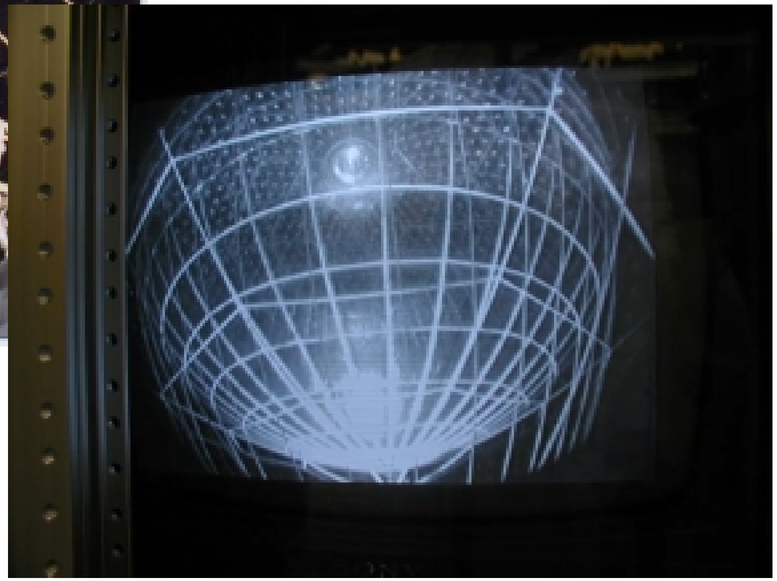
Passive neutron shield

KamLAND Construction: OD

OD PMT Installation
December 2000 to
April 2001

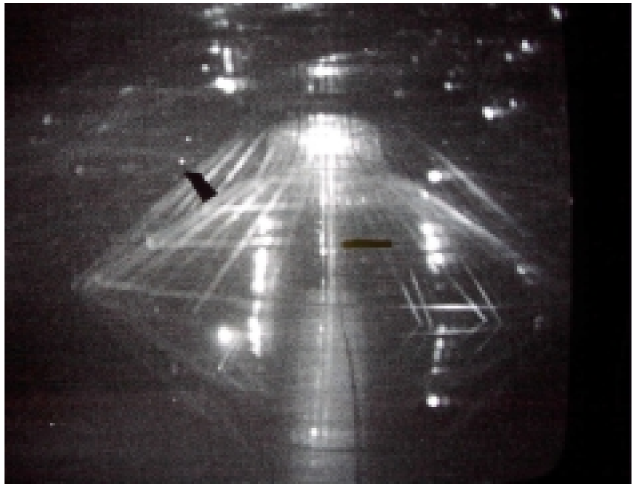
KamLAND Construction: Balloon





Balloon Installed and Tested
January-March 2001

KamLAND Construction: Filling

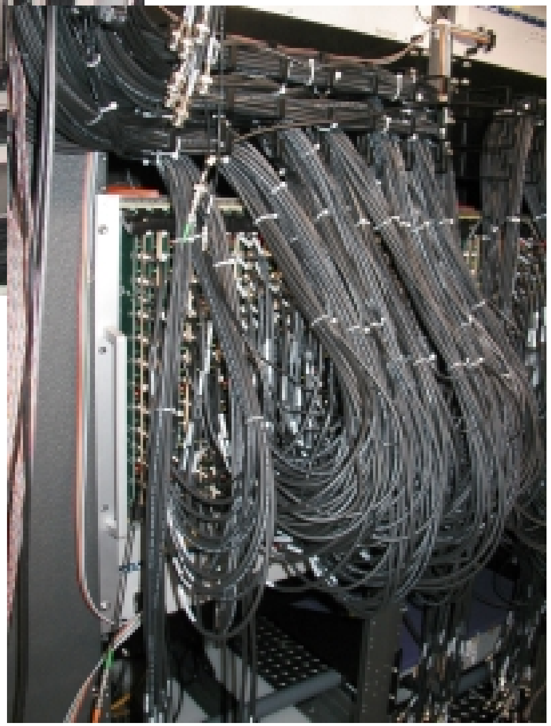


Oil and Scintillator Filling
Spring-Summer 2001
Completed September 24

KamLAND Construction

Cabling

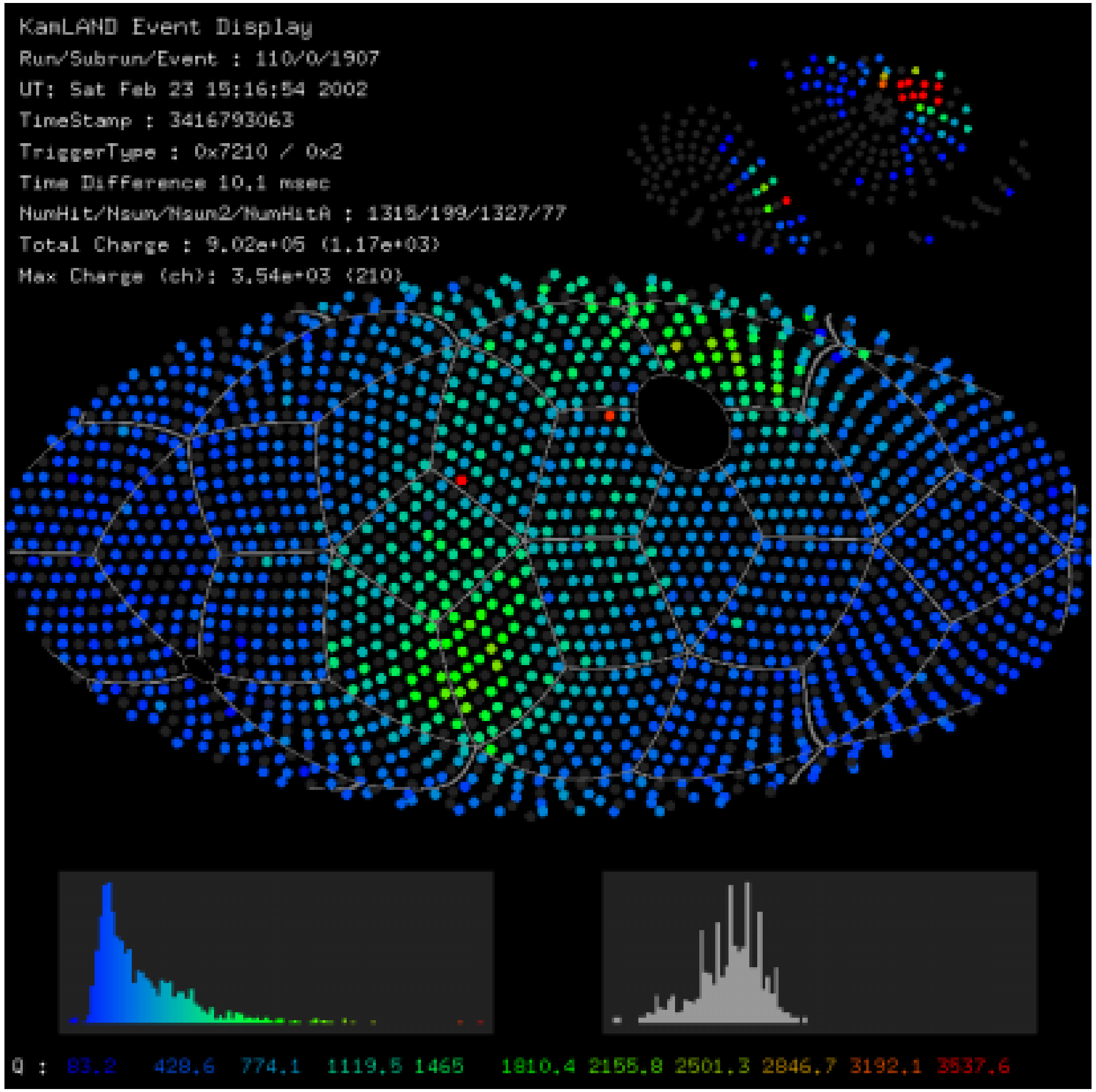
Infrastructure Completed
And Data Taking Begins
January, 2002



Front-End Electronics

Calibration Deck and Glovebox

KamLAND Data

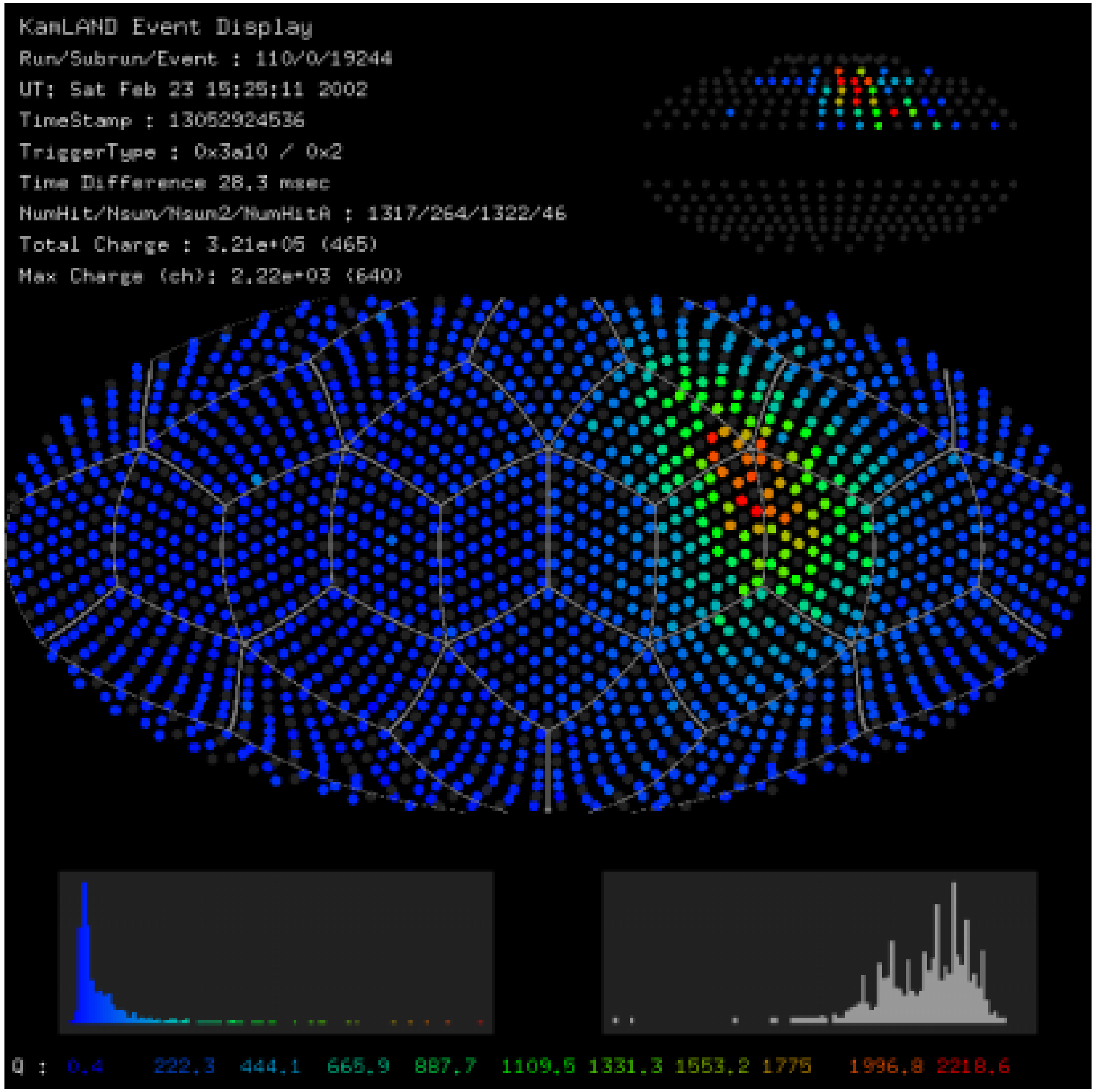


Event Display: through-going muon

Color is integrated pulse area

All tubes illuminated

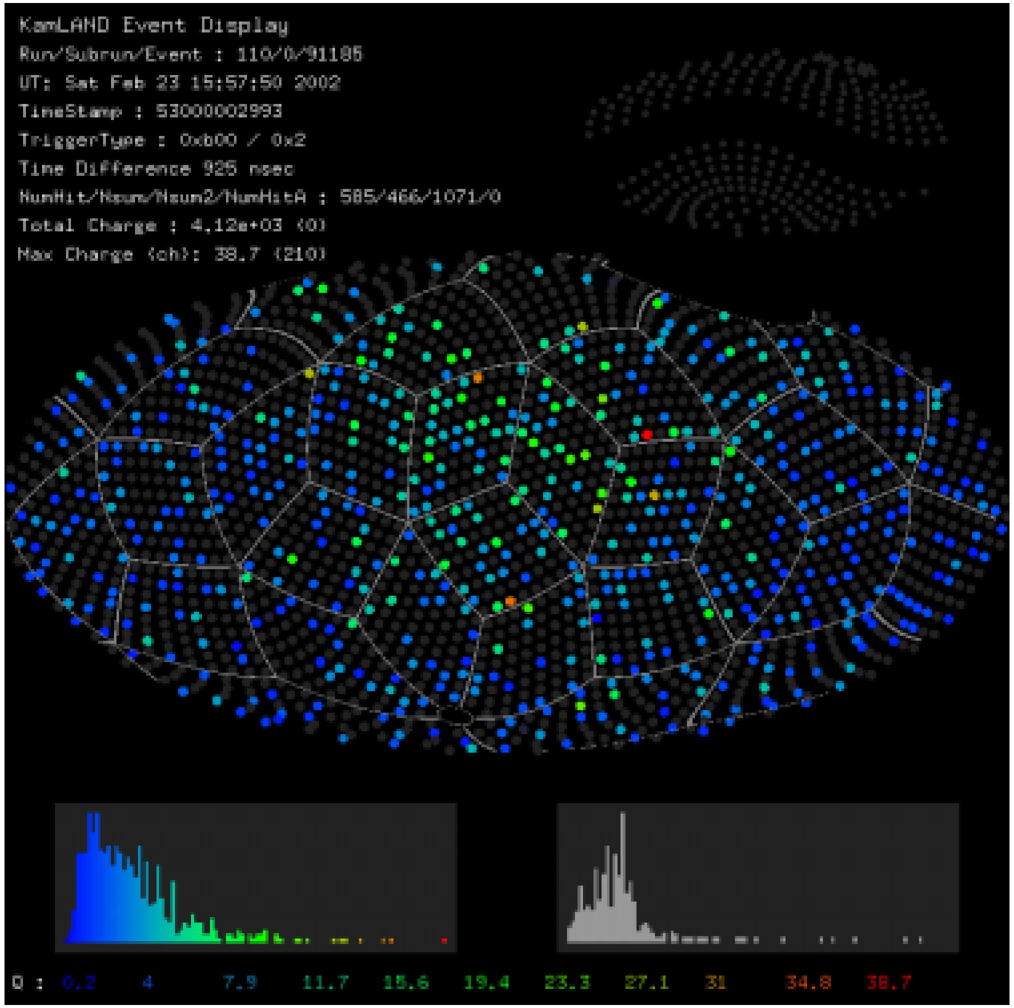
KamLAND Data



Stopped cosmic-ray muon

Color is integrated pulse area

KamLAND Data



Example of Michel electron following a muon.

Calibration

- Waveform data collected – convert charge and time information to event position and energy
- PMT calibration
  - Single photoelectron gain: peripheral LEDs
    - $G = 5 \times 10^6 \pm 6\%$
  - Large pulse height gain: UV laser
  - Timing: 500 nm dye laser
- The detector response is calibrated with radioactive sources
  - ^{60}Co (2505 keV sum from 2γ) and ^{65}Zn (1116 keV γ)
- Position obtained from vertex fit
- Light calibration study of scintillator
- Energy response depends on position

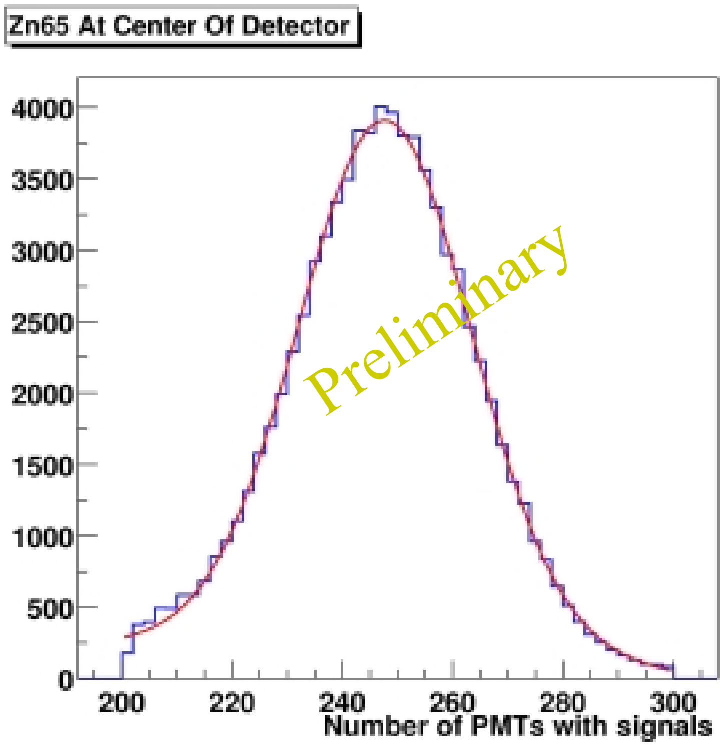
Light Yield Calibration

17″ PMTs Only

^{65}Zn : 1.115 MeV γ

σ/E = 6.5 %

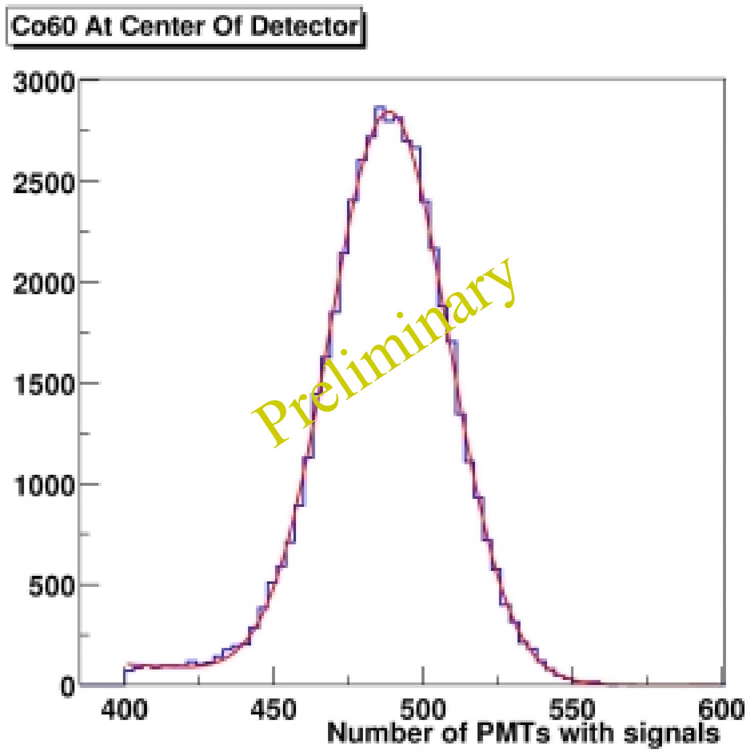
Light Yield 241 p.e./MeV



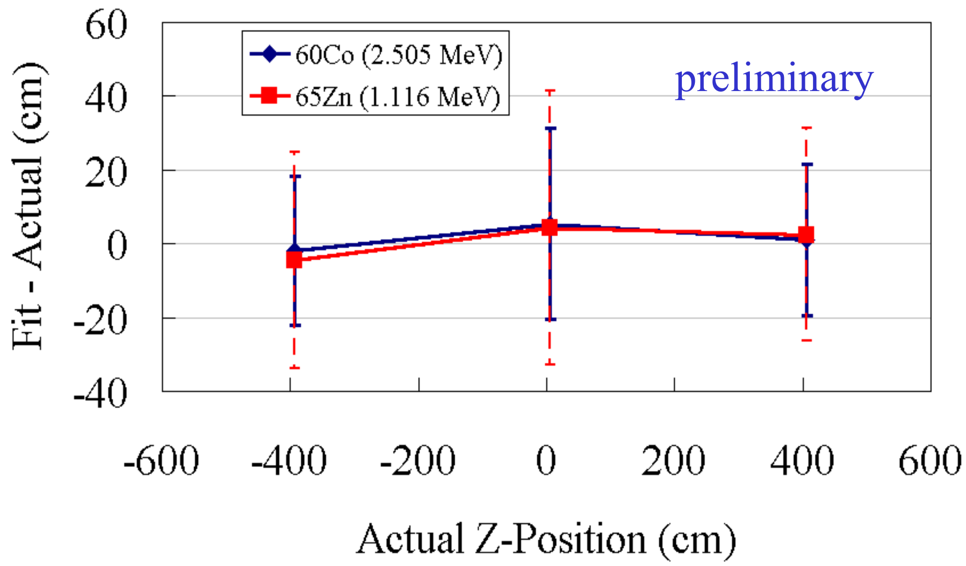
^{60}Co : 2.505 MeV γ

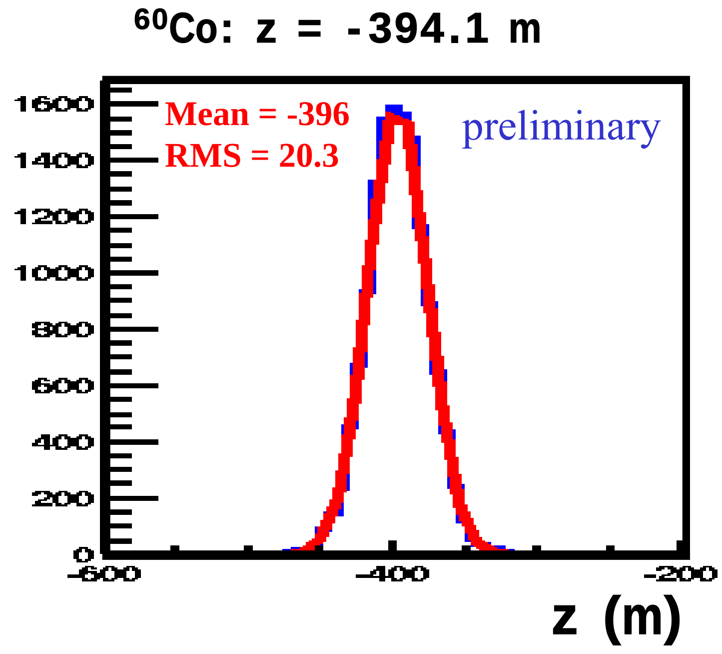
σ/E = 4.2%

Light Yield 239 p.e./MeV



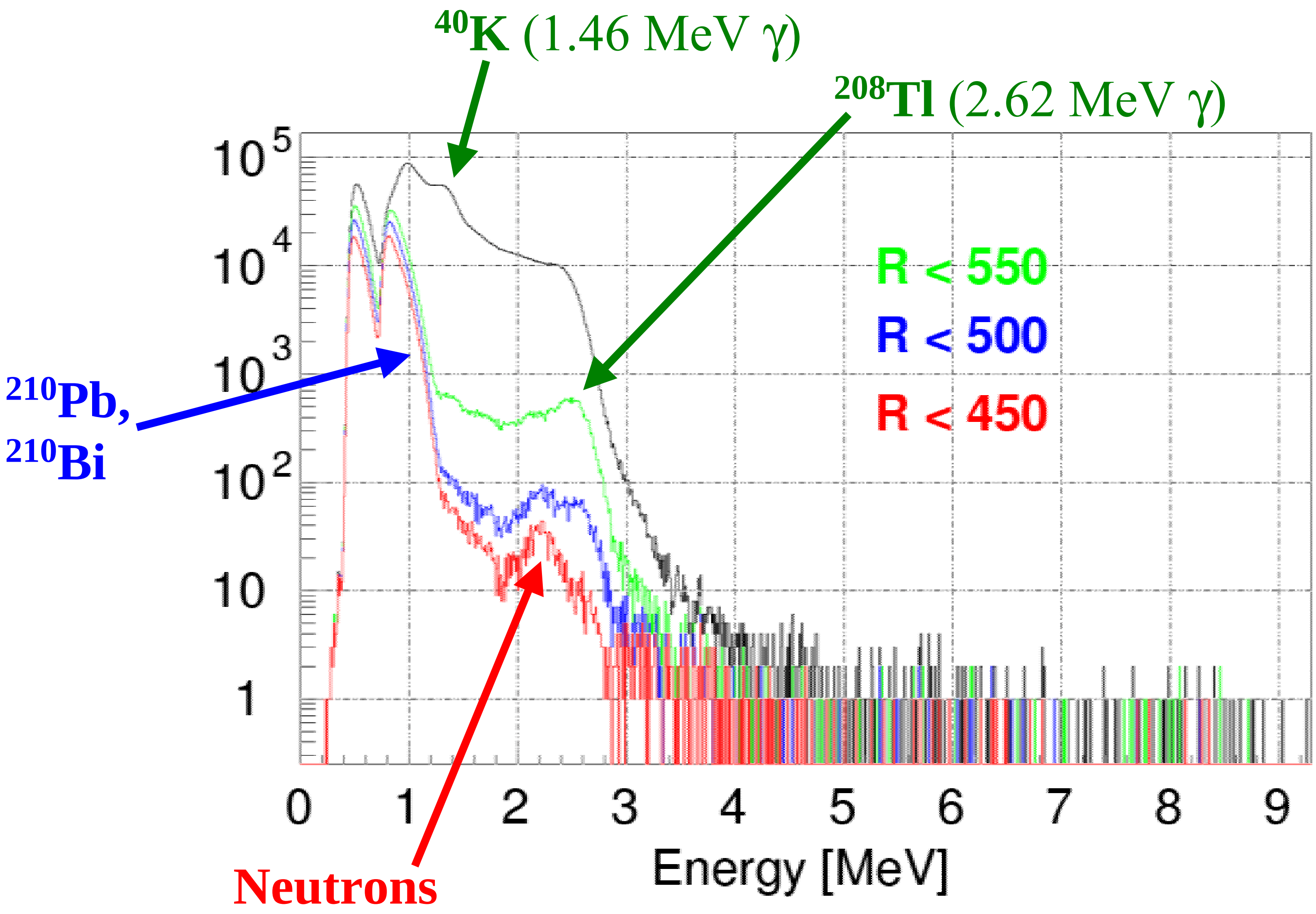
Position Calibration





Note: errors from statistical distribution.

Energy Spectrum: Fiducial Volume Cuts



Summary of Backgrounds

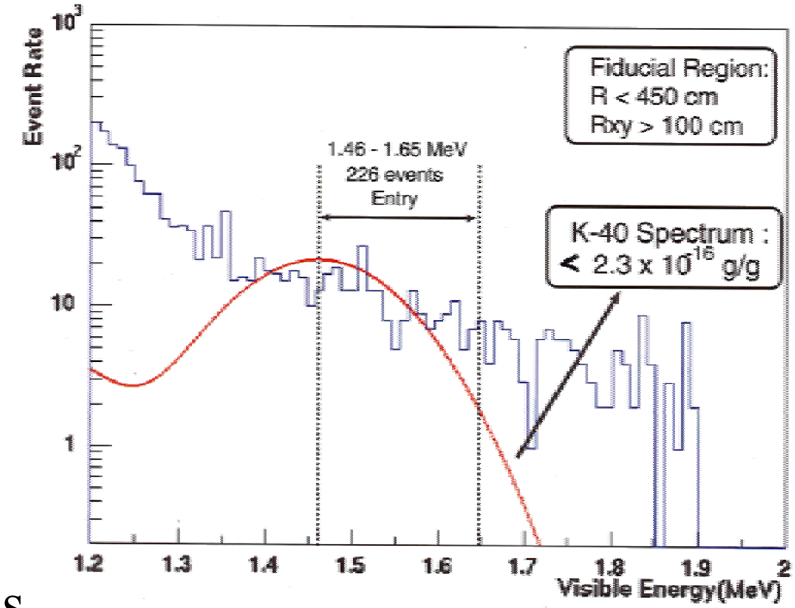
Most backgrounds peak near the balloon or near z-axis thermometer line

- radon decay products (^{214}Po, ^{214}Bi)
- external ^{40}K and ^{208}Tl

Energy spectra fits set limits on natural radiopurity contaminations (goal):

^{238}U $< 6.4 \times 10^{-16}$ g/g (10^{-14} g/g)
^{232}Th $< 1.8 \times 10^{-16}$ g/g (10^{-14} g/g)
^{40}K $< 2.3 \times 10^{-16}$ g/g (10^{-14} g/g)

(Consistent with neutron activation analysis on scintillator and with γ spectra surveys of detector materials.)

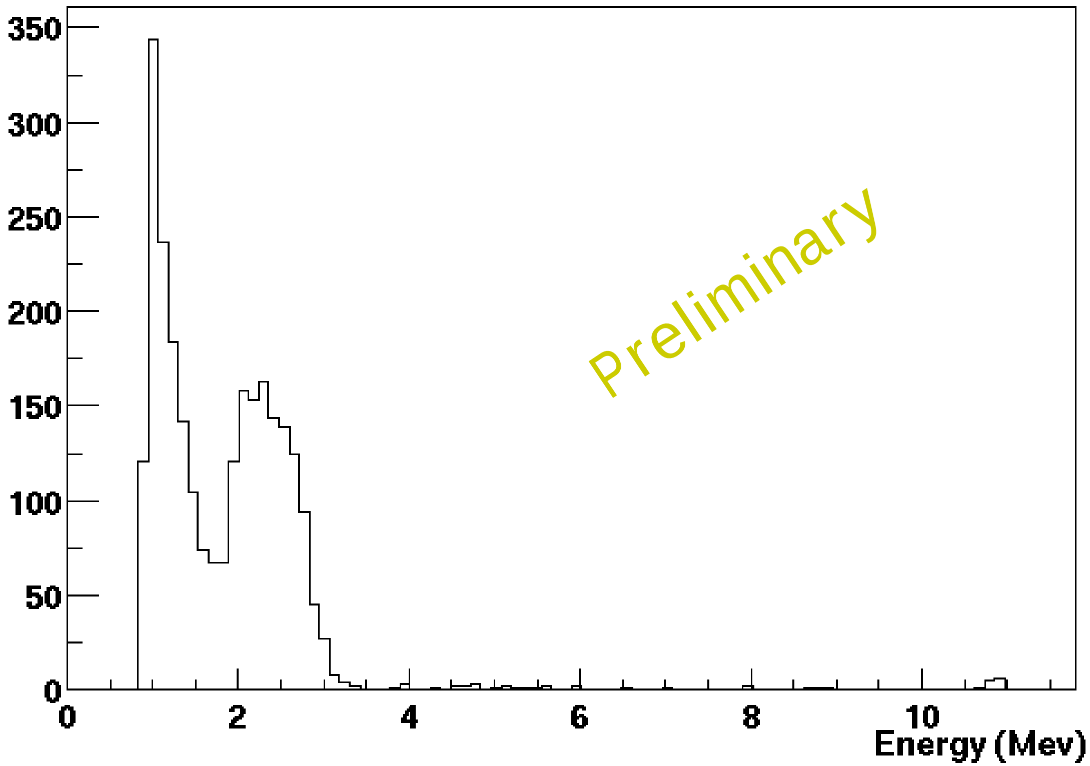


^{40}K limit fit

Fiducial volume cuts (< 5 m) reduce accidental coincidence rates to less than **6x10^{-4}/day.**

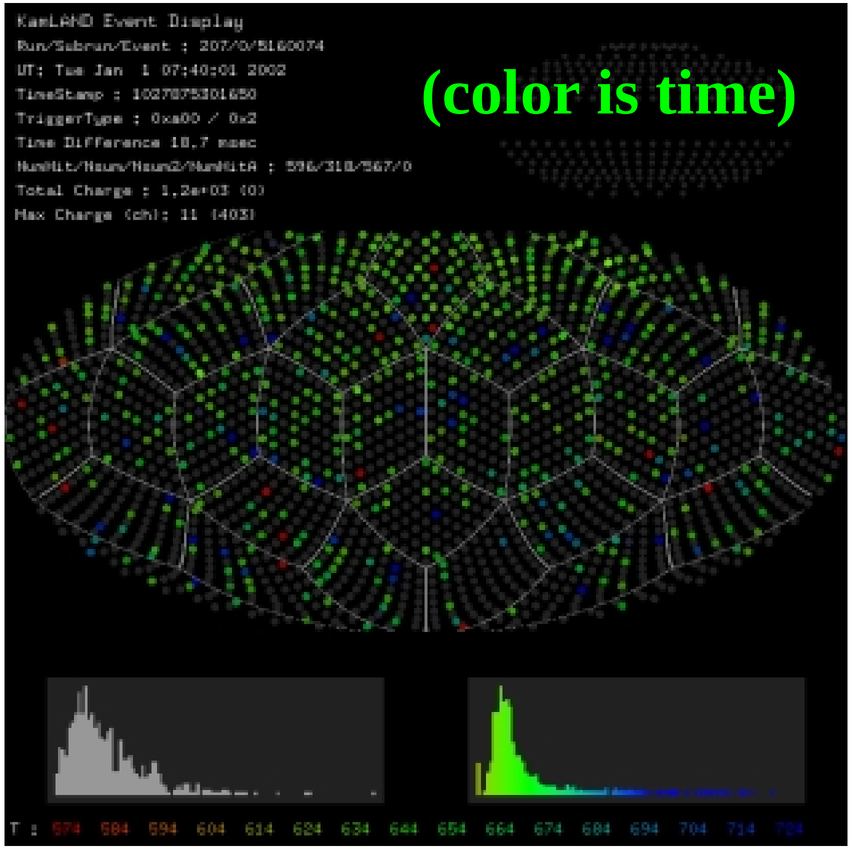
Radioactivity background is negligible for the reactor ν studies.

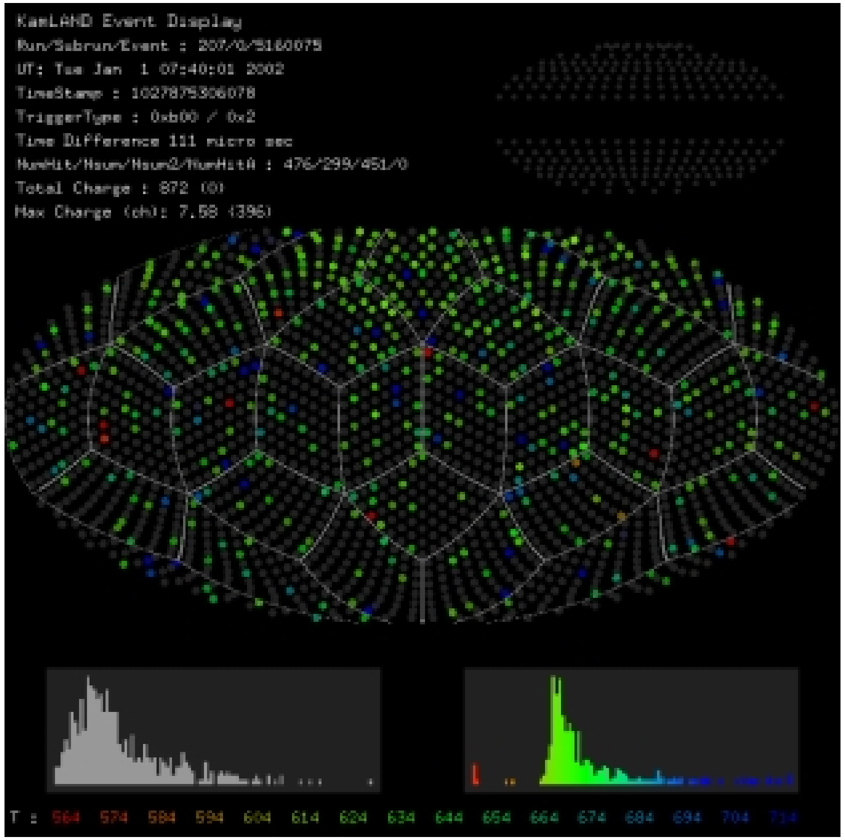
Energy Deposition of Cosmic-Ray Muon Events



- Using E calibration from source data, the peak is here at ≈ 2.3 MeV
- Identify n-capture events following μ events

Neutrino Event Candidate





Prompt (e^+) Signal
E = 3.20 MeV

Δt = 111 μs
ΔR = 34 cm

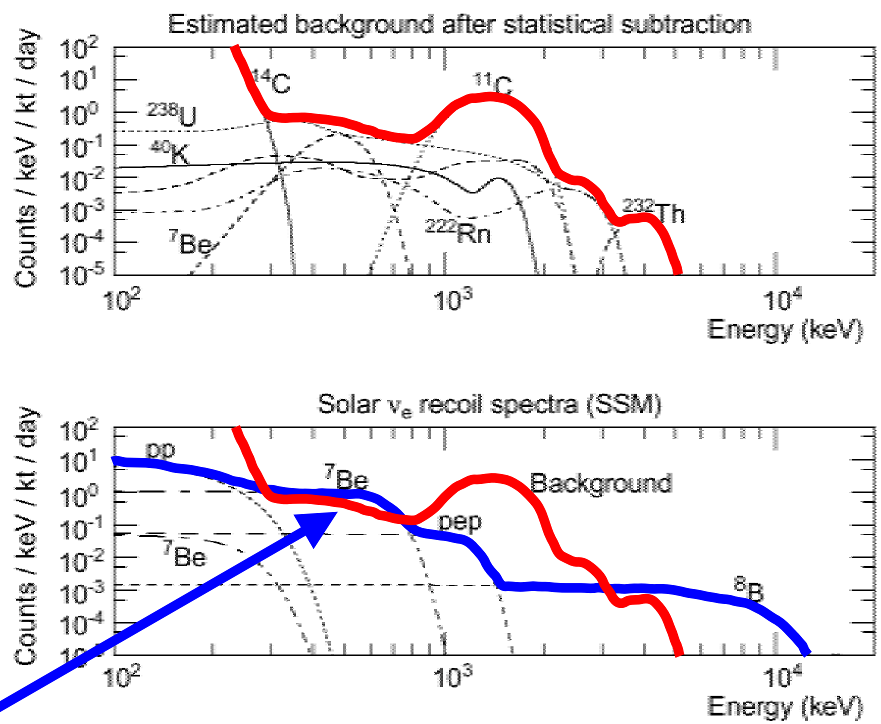
Delayed (neutron) Signal
E = 2.22 MeV

Looking toward the future: The Solar Neutrino Phase

- Goal: direct detection of
  ^{7}Be solar neutrinos

- Singles measurement:
  no coincidence signal

- Low backgrounds required!
- U/Th near required levels
- Reduction in low-energy
  backgrounds is needed



^{7}Be signal

Low-Energy Backgrounds:
Issues for the ^{7}Be Measurement

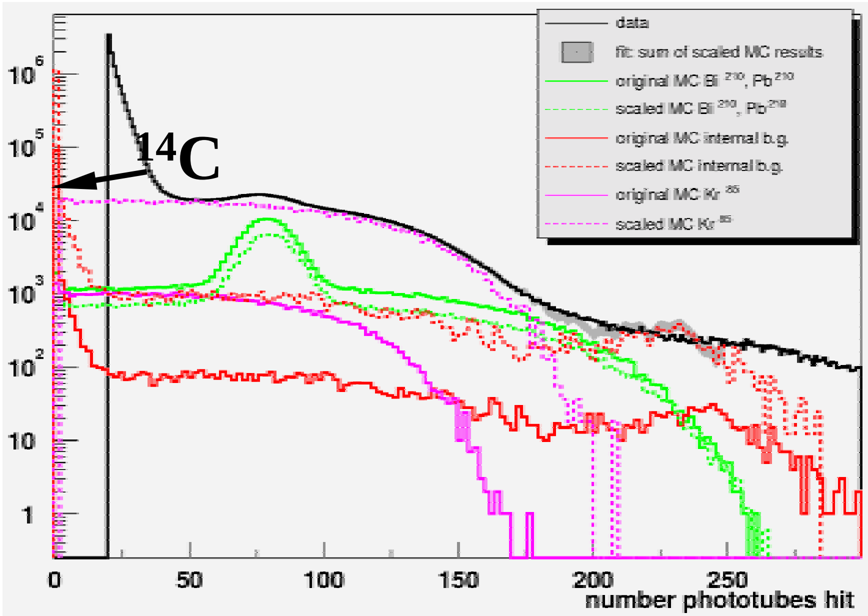
Radiopurity design goals and current limits:

^{238}U	10^{-16} g/g	$< 6.4 \times 10^{-16}$ g/g
^{232}Th	10^{-16} g/g	$< 1.8 \times 10^{-16}$ g/g
^{40}K	10^{-18} g/g	$< 2.3 \times 10^{-16}$ g/g

Dominant low-energy backgrounds are:

- ^{85}Kr (noble gas)
- ^{210}Pb, ^{210}Bi (metals) from Rn decays

Working on purification and eliminating leaks to remove contamination



Observed low-energy event spectrum and calculated backgrounds.

Summary

- Backgrounds and calibrations are sufficient for a successful reactor anti-neutrino oscillation measurement.
- Good quality data is now being collected.
- ^{7}Be solar neutrino measurement is within reach – reduction of low-energy background sources will be needed.
- Plans are underway to achieve this second phase.

The Completed Detector Looking Up