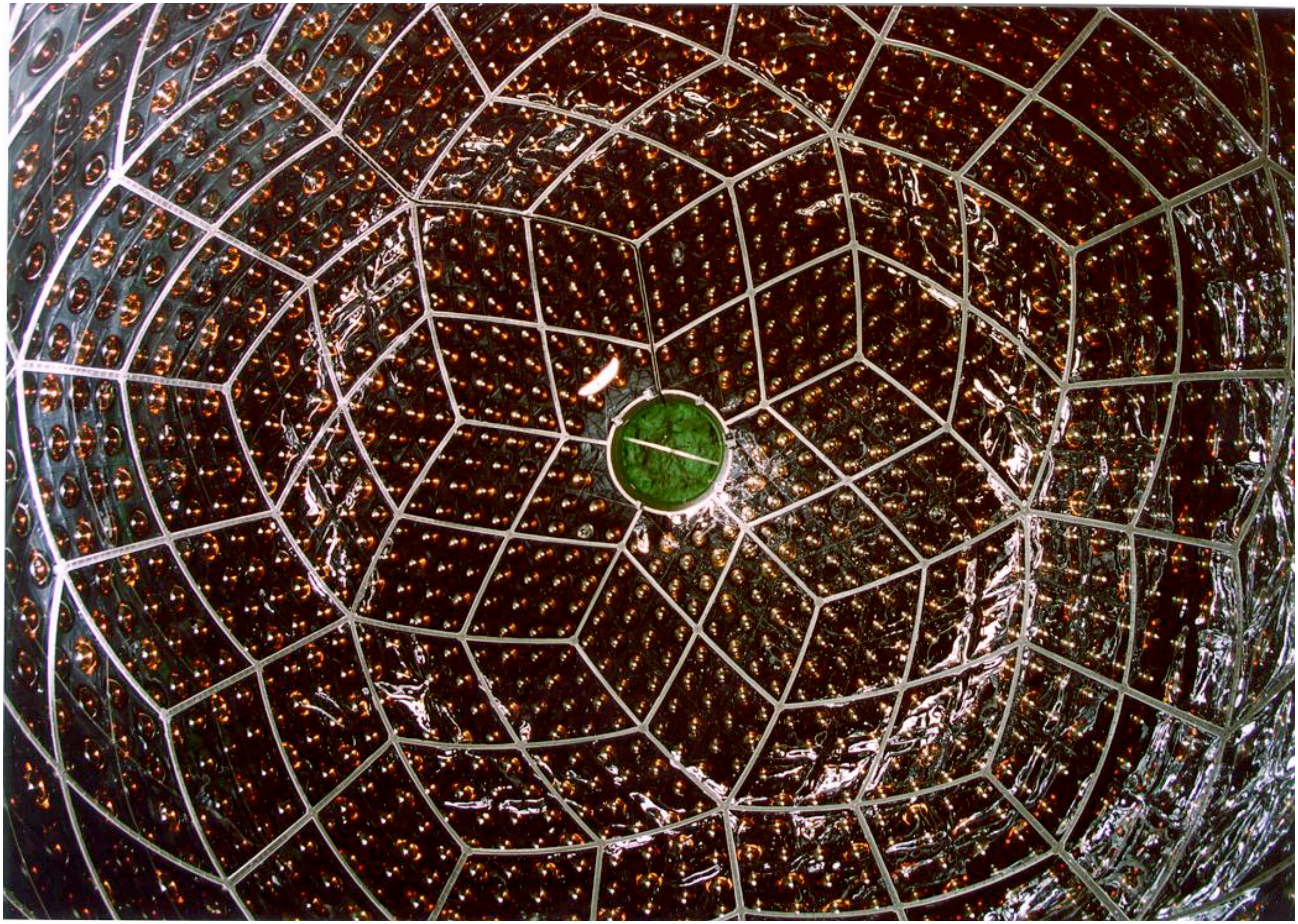
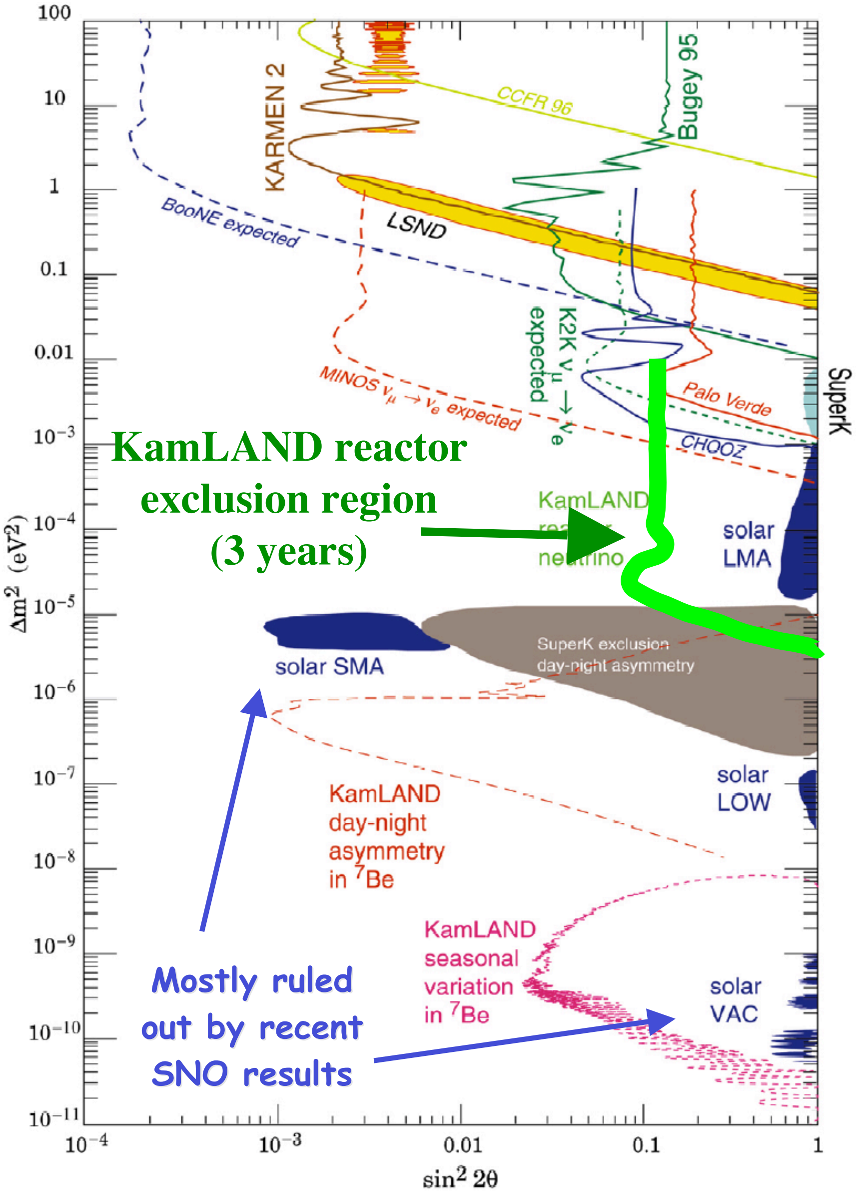
KamLAND



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
B.E.Berger, Y-D.Chan, M.P.Decowski, D.A.Dwyer, S.J.Freedman, Y.Fu, B.K.Fujikawa, K.M.Heeger, K.T.Lesko, K-B.Luk, H.Murayama, D.R.Nygren, C.E.Okada, A.W.Poon, H.M.Steiner, L.A.Winslow
LBNŁUC Berkeley
S.Dazeley, S.Hatakeyama, 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.Ikeda, K.Ikeda, K.Inoue, K.Ishihara, T.Iwamoto, T.Kawashima, Y.Kishimoto, M.Koga, Y.Koseki, T.Maeda, T.Mitsui, M.Motoki, K.Nakajima, H.Ogawa, K.Oki, K.Owada, I.Shimizu, J.Shirai, F.Suekane, A.Suzuki, K.Tada, O.Tajima, K.Tamae, H.Watanabe
Tohoku University
L.DeBraeckeleer, C.Gould, H.Karwowski, D.Markoff, J.Messimore, K.Nakamura, R.Rohm, W.Tornow, A.Young
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
University of Tennessee

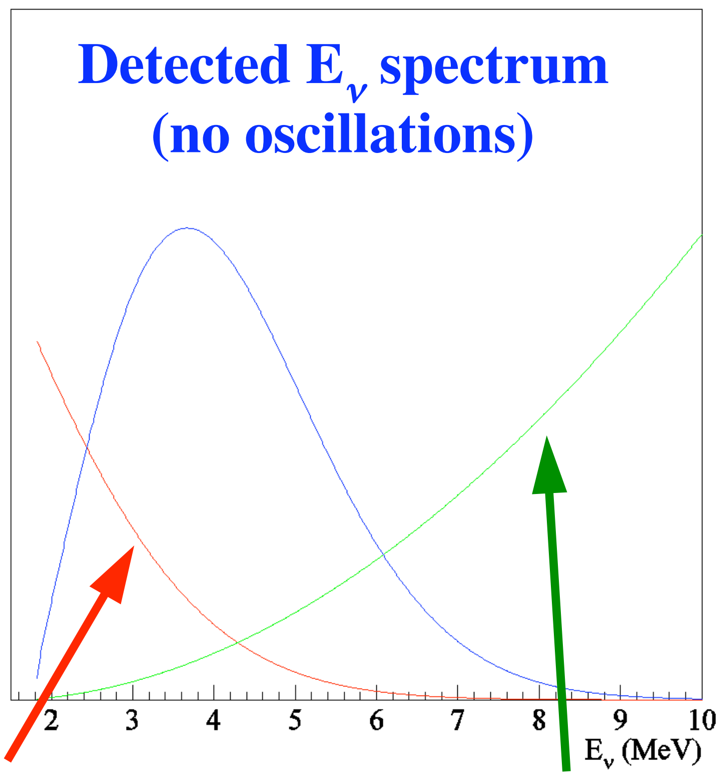
Introduction to KamLAND



- **Kam**ioka **L**iquid−Scintillator **A**nti**N**eutrino **D**etector
- 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

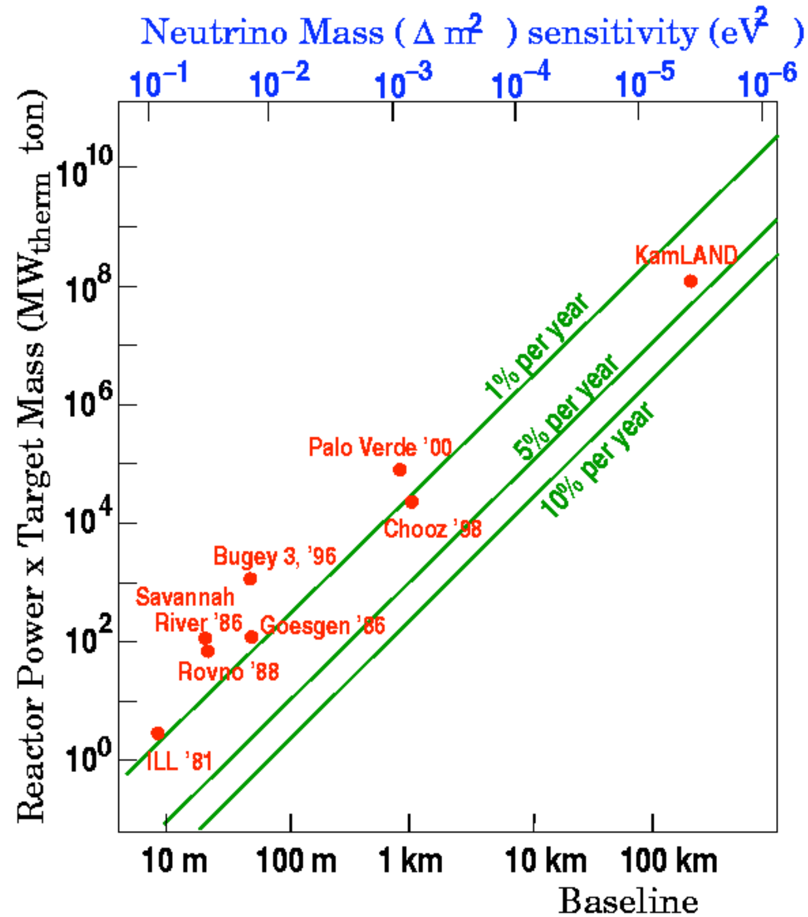
Introduction to KamLAND

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

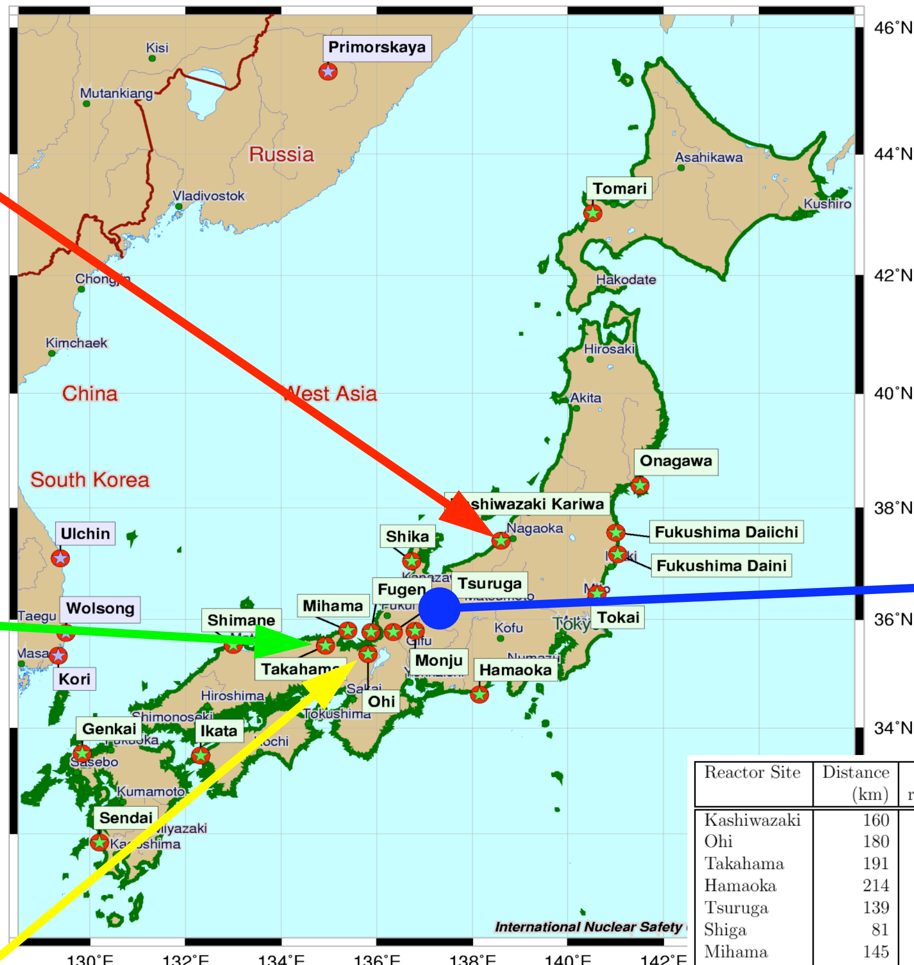


Reactor
ν_e spectrum

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



Introduction to KamLAND



KamLAND uses the entire Japanese nuclear power industry as a long−baseline source

KamLAND

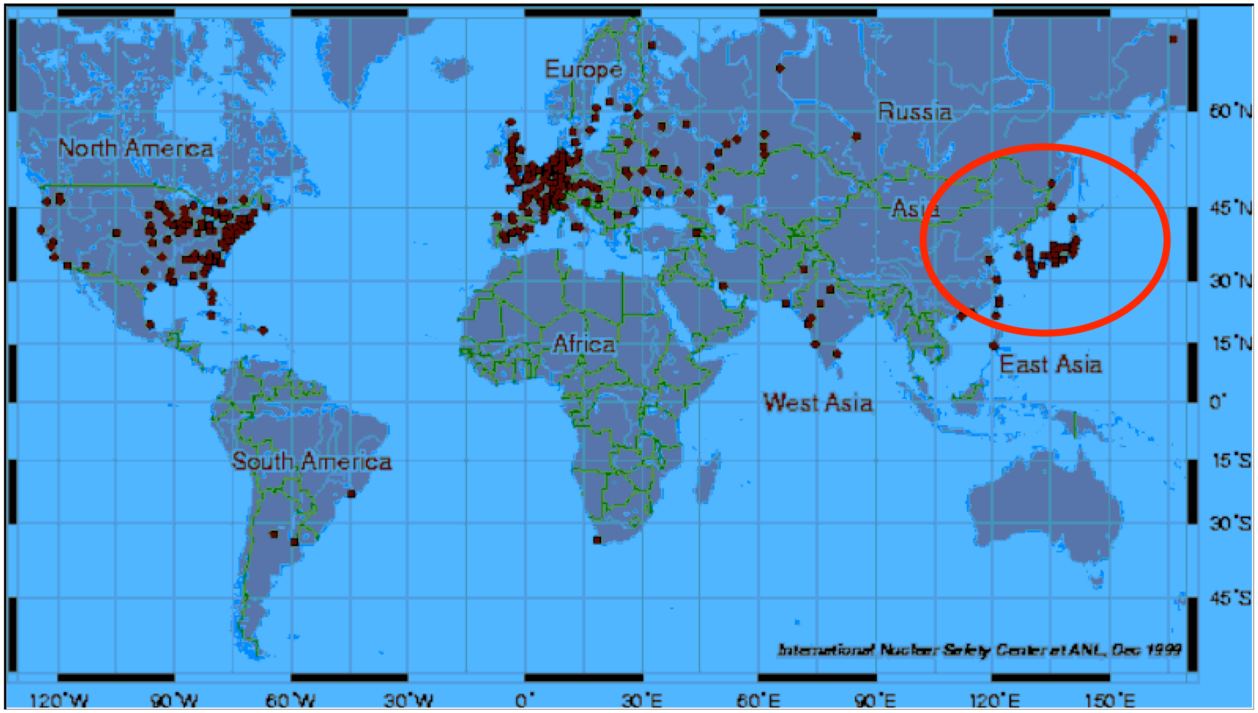
Reactor Site	Distance (km)	# of reactors	Therm. Power (max) (GW)	Max. Flux (10^5 $\bar{\nu}_e$ /cm^2/s)	Max.Event rate events/kt-year
Kashiwazaki	160	7	24.6	4.25	348
Ohi	180	4	13.7	1.90	154
Takahama	191	4	10.2	1.24	102
Hamaoka	214	4	10.6	1.03	84
Tsuruga	139	2	4.5	1.03	84
Shiga	81	1	1.6	1.08	89
Mihama	145	3	4.9	1.03	84
Fukushima-1	344	6	14.2	0.53	44
Fukushima-2	344	4	13.2	0.49	40
Tokai-II	295	1	3.3	0.17	14
Shimane	414	2	3.8	0.10	8
Ikata	561	3	6.0	0.08	7
Genkai	755	4	6.7	0.05	4
Onagawa	430	2	4.1	0.10	8
Tomari	784	2	3.3	0.02	2
Sendai	824	2	5.3	0.03	3
Total		51	130	13.1	1075

80% of flux from baselines 140−210 km

Introduction to KamLAND

The total electric power produced "as a by-product" of the ν_es is:

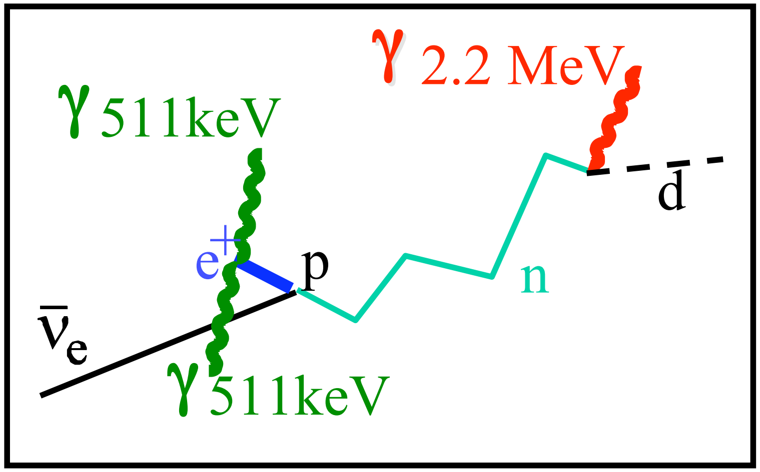
- **~60 GW or...**
- **~4% of the world's manmade power or…**
- **~20% of the world's nuclear power!**

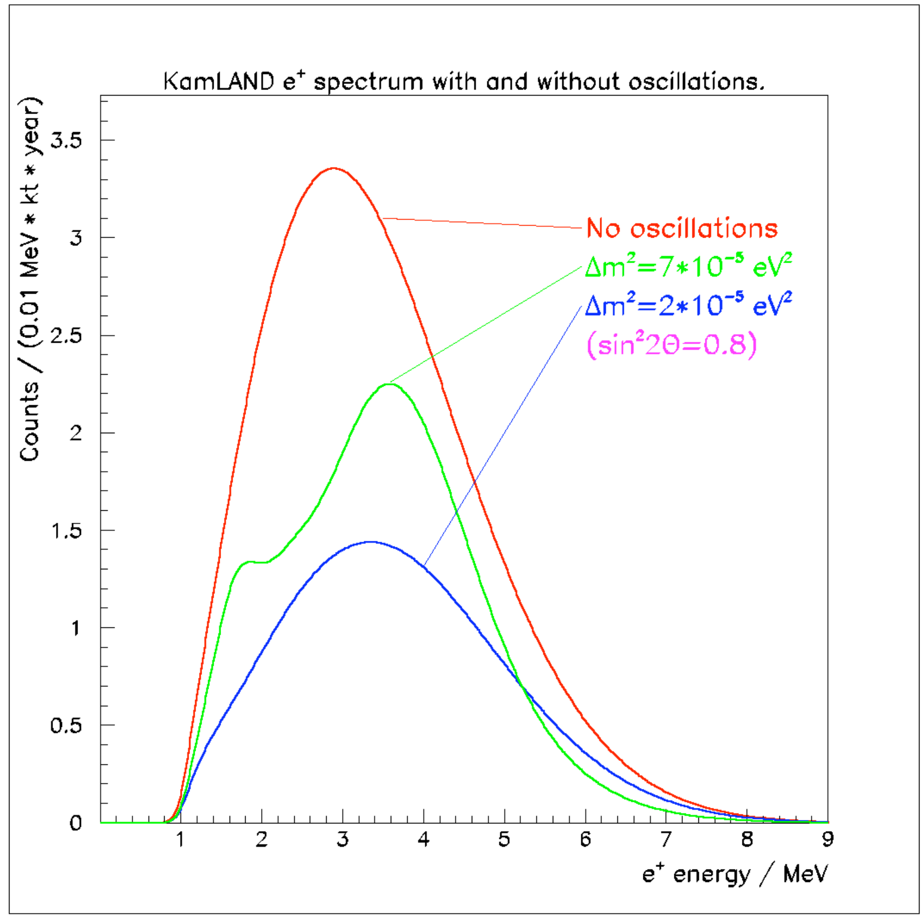


A large nuclear submarine parked as close as possible to shore in Toyama bay with reactors at full would produce a 10% excess in KamLAND

Introduction to KamLAND

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



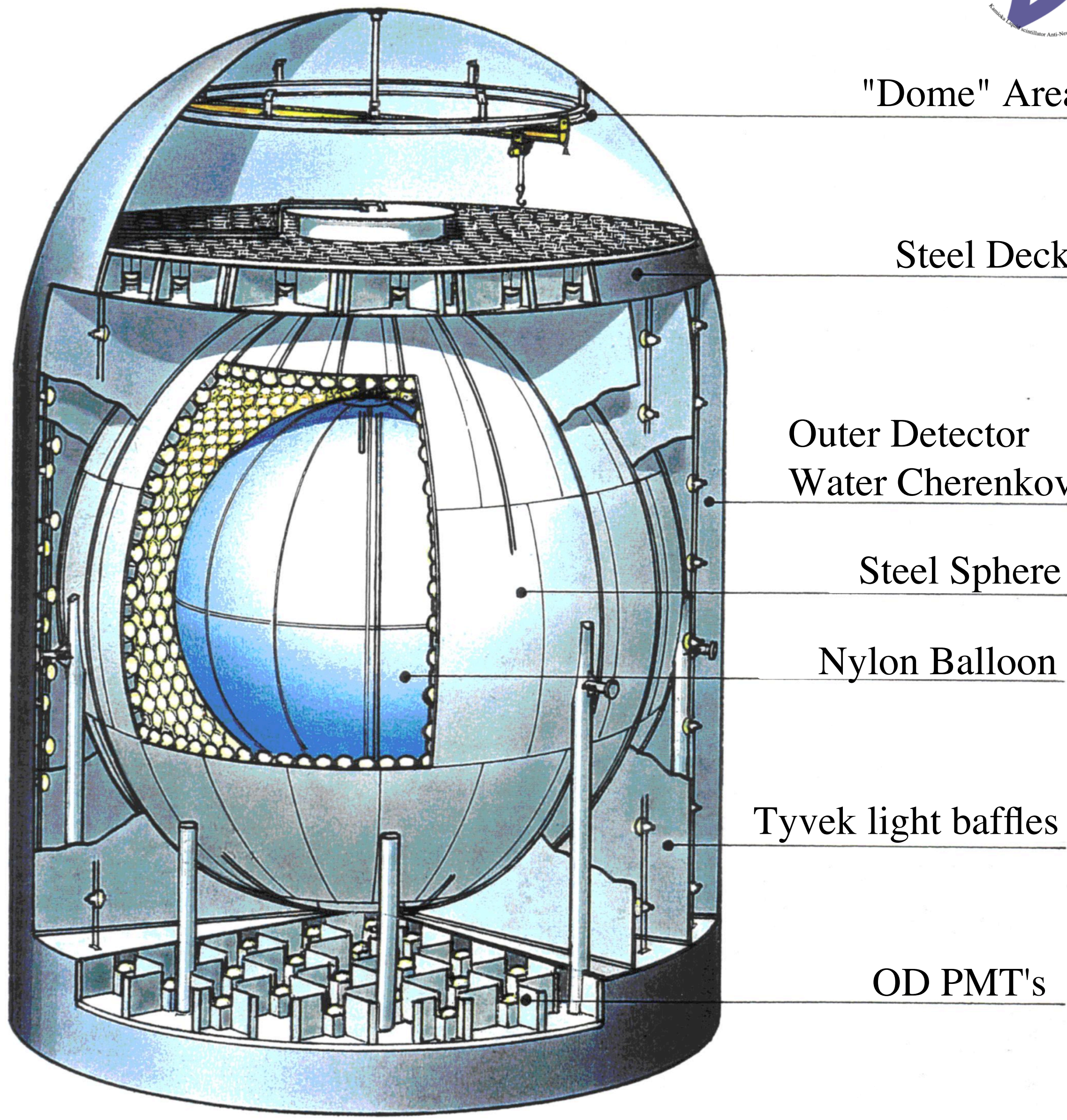


Coincidence signal: detect

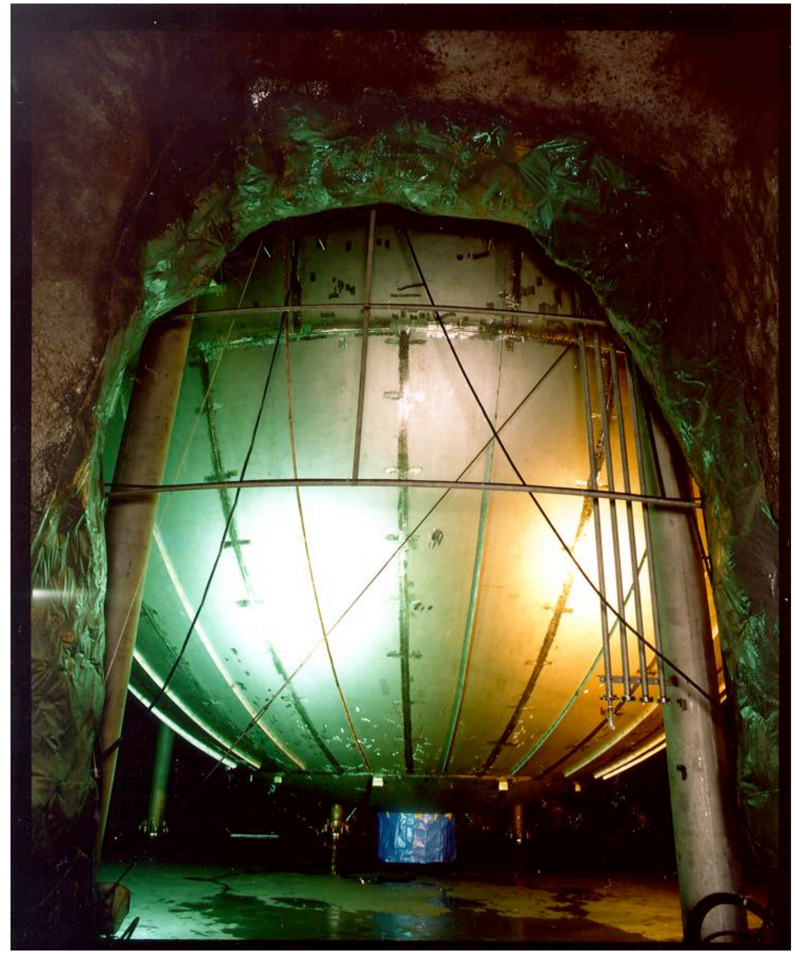
- Prompt: e^+ annihilation
- Delayed: **n** capture
  180 μs capture time

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 Čherenkov

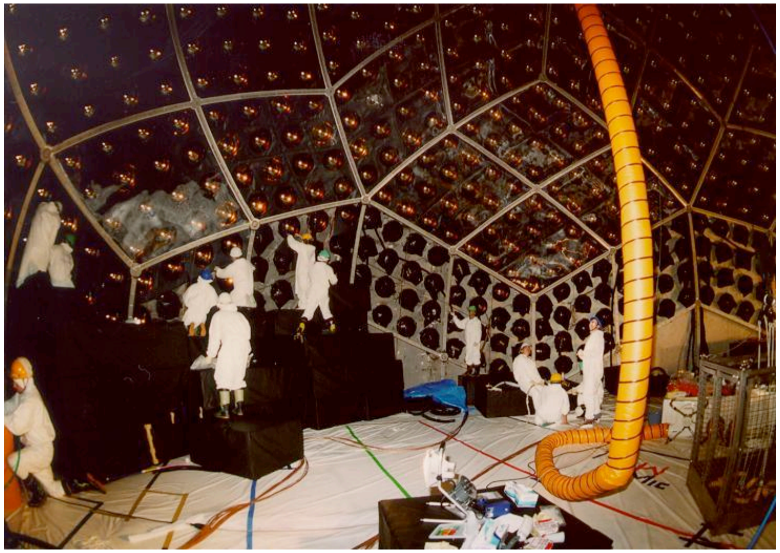


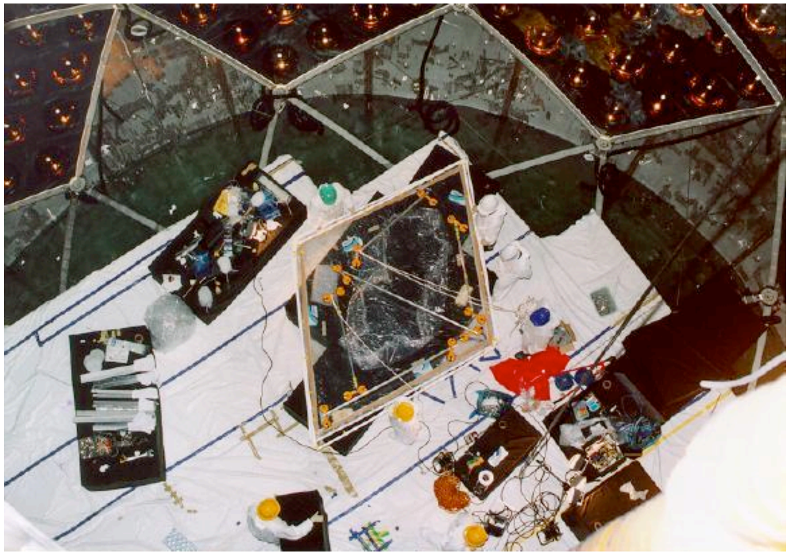
KamLAND Construction

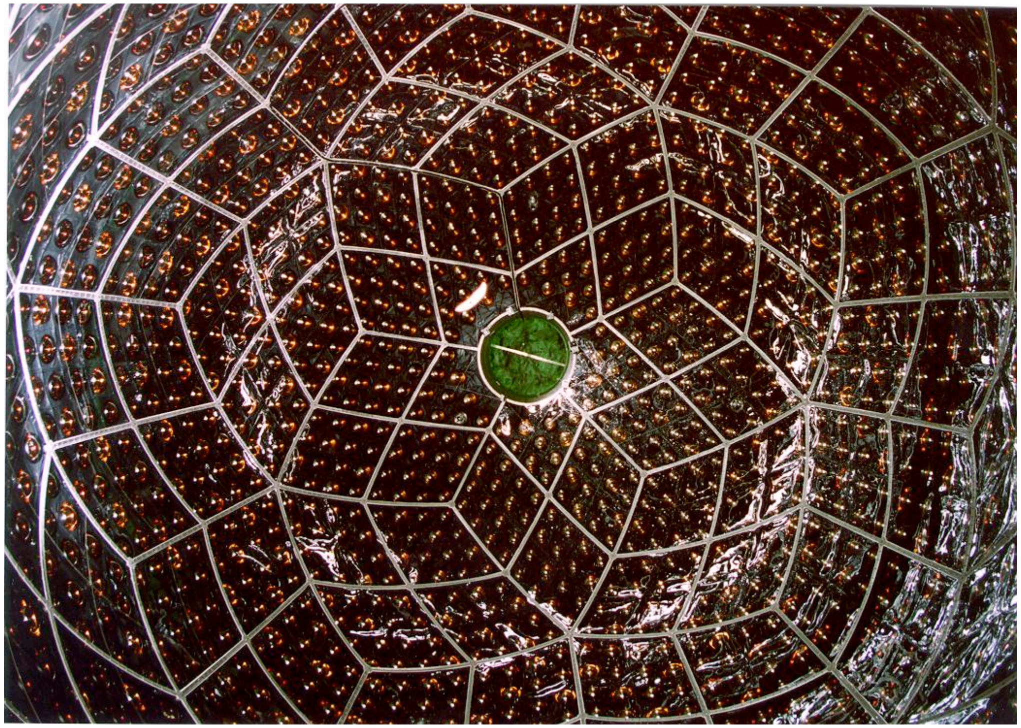


Steel Sphere Constructed
September−October 1999

KamLAND Construction

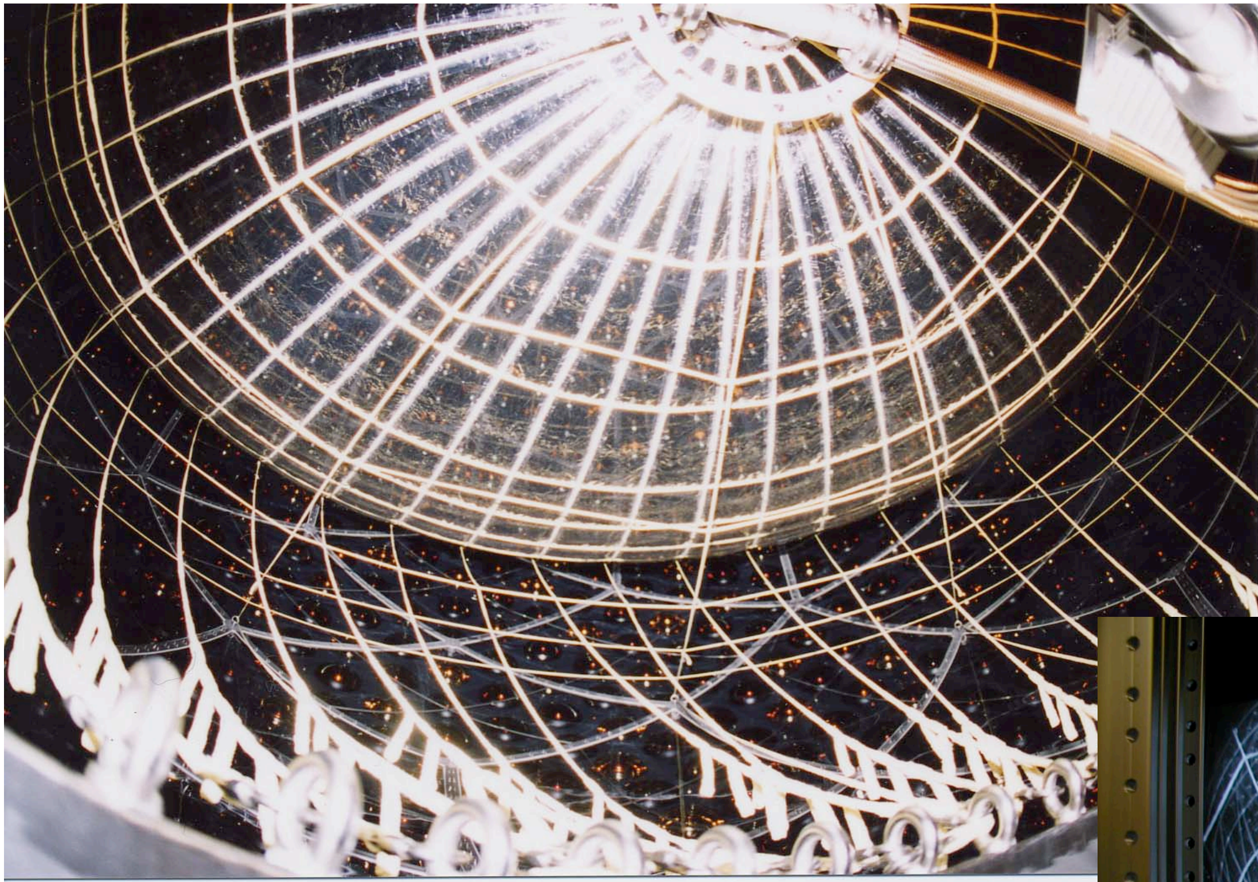


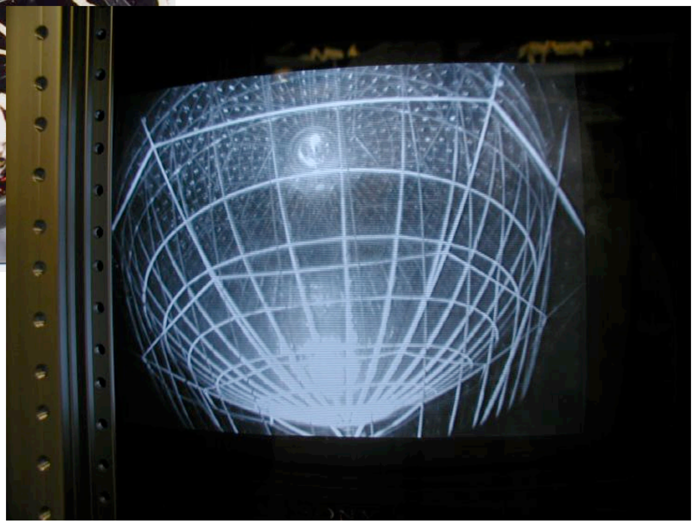




PMT Installation
Summer 2000
Completed September 28

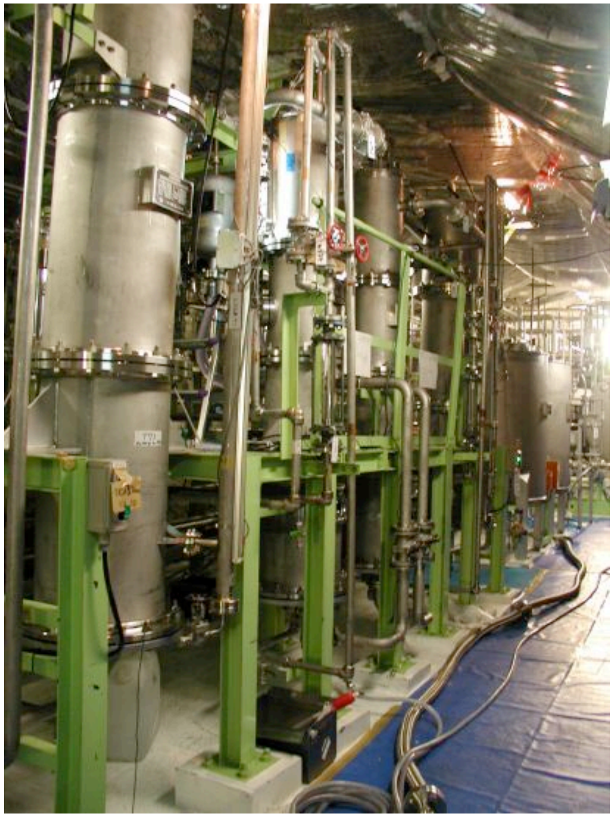
KamLAND Construction



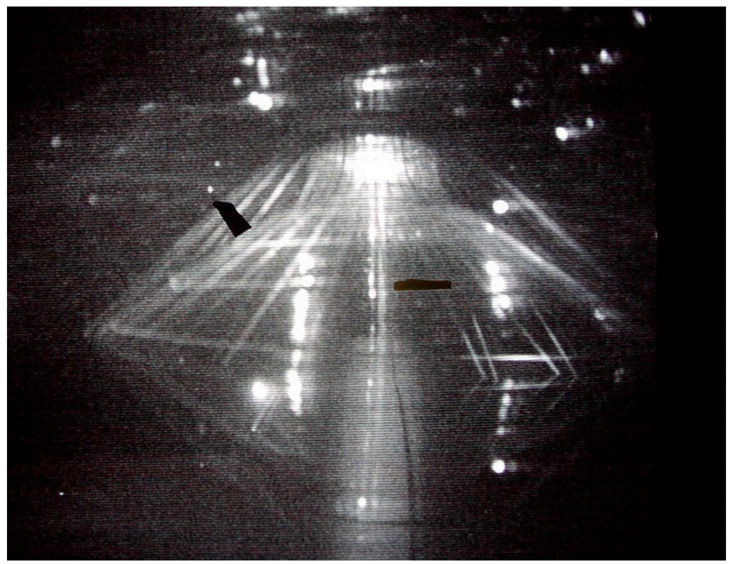


Balloon Installed and Tested
January−March 2001

KamLAND Construction



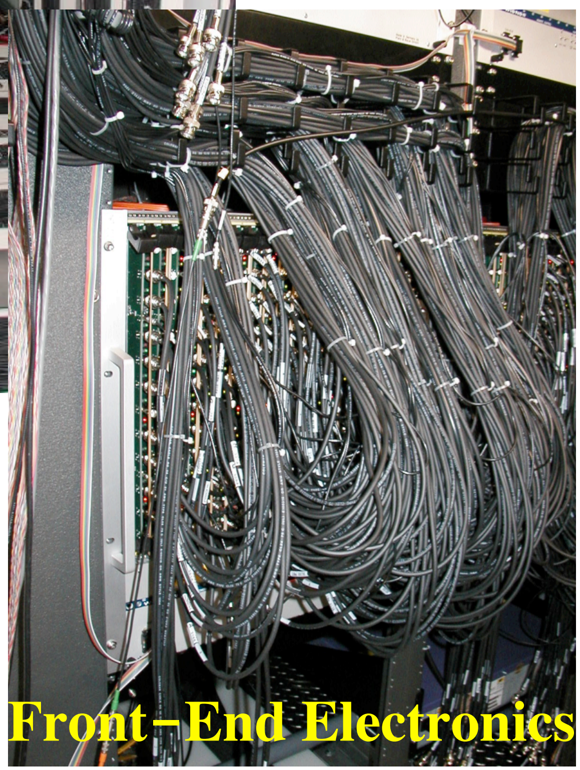
Oil and Scintillator Filling
Spring−Summer 2001
Completed September 24

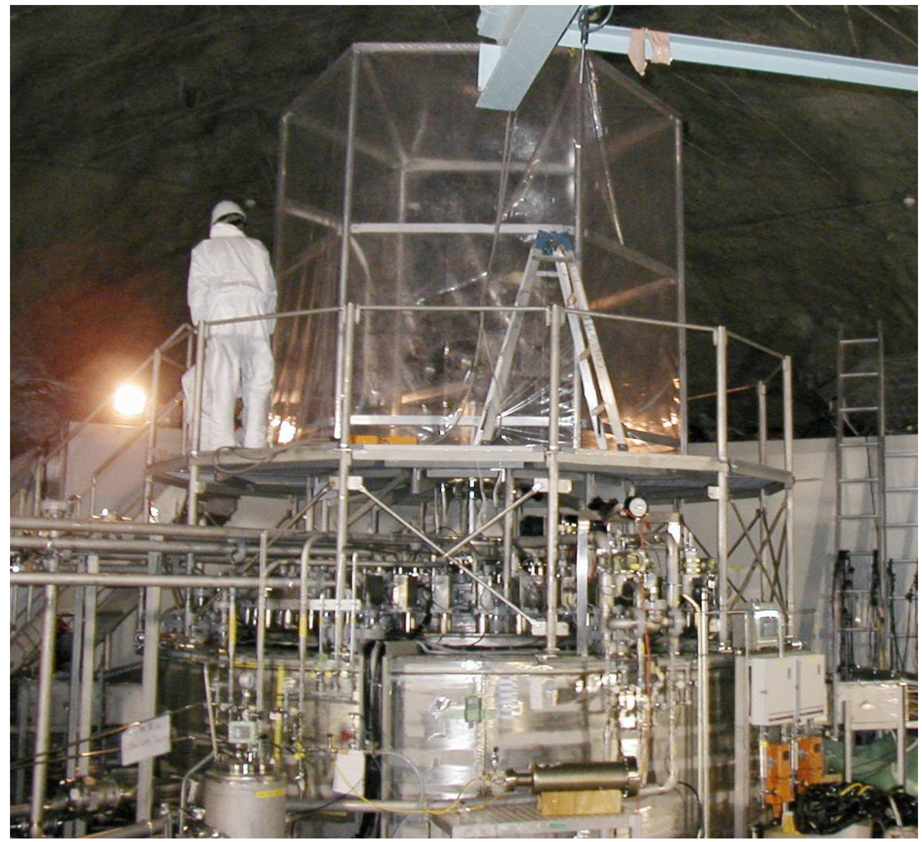


KamLAND Construction

Infrastructure Completed
January, 2002


Cabling


Front−End Electronics

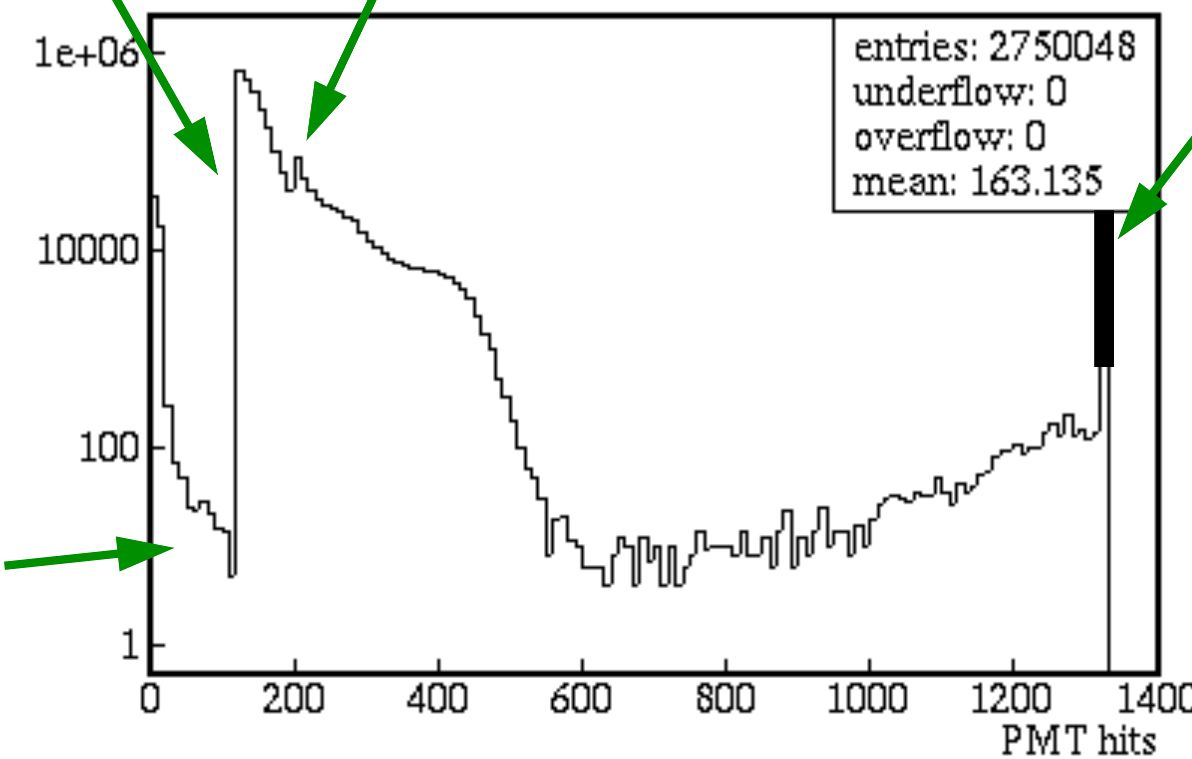

Calibration Deck and Glovebox

KamLAND Data

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

Singles threshold: 200 PMT's hit

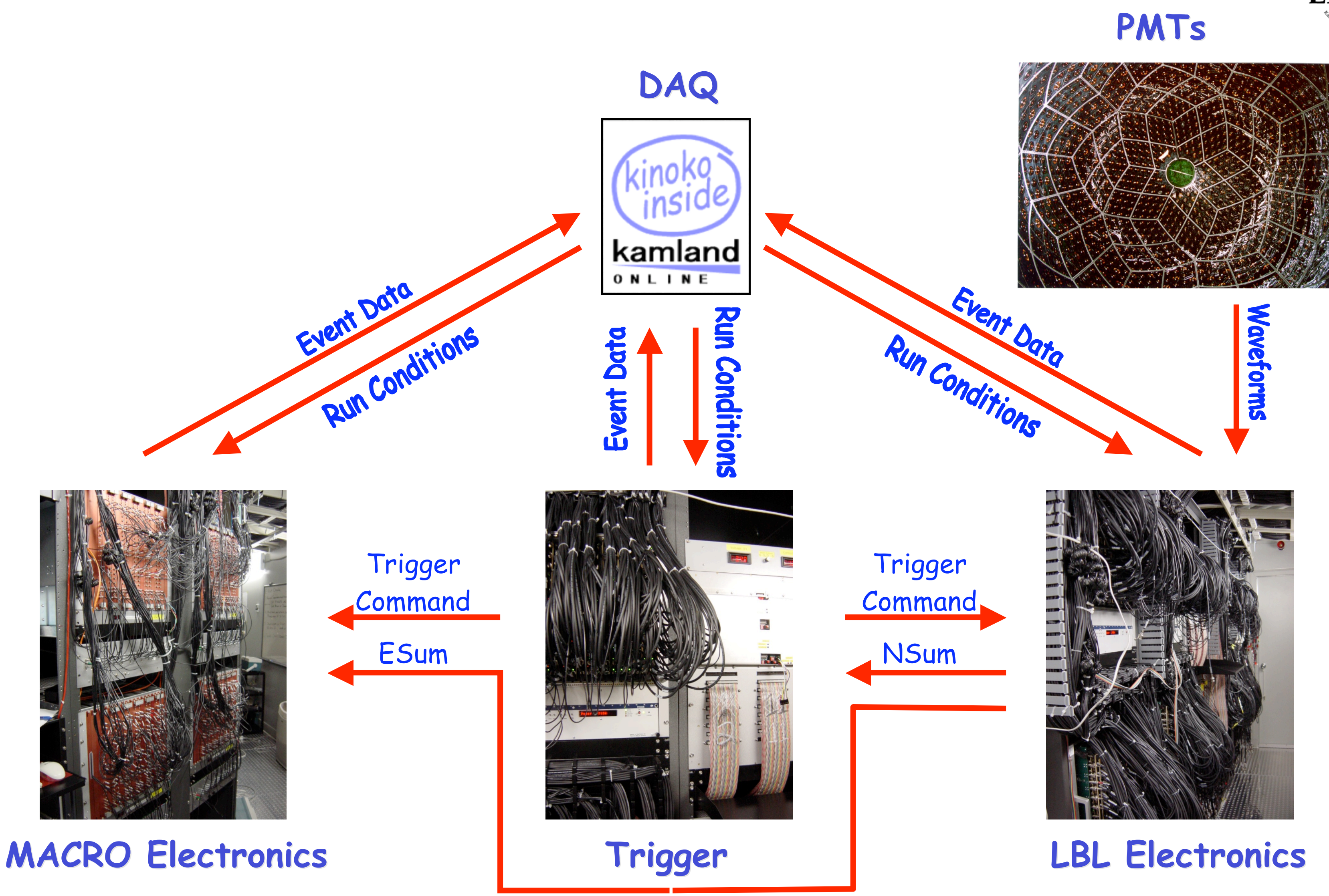
Muons: all tubes hit



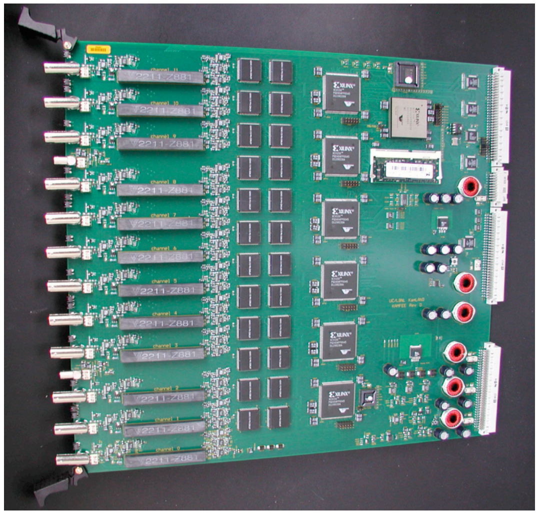
Calibration triggers

KamLAND Data Collection Started January 22, 2002

KamLAND Data



KamLAND Data

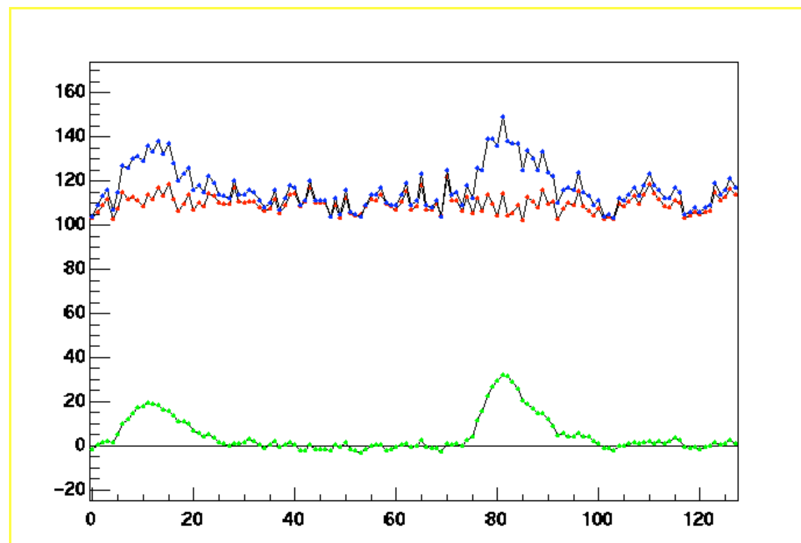


Waveforms are recorded using Analogue Transient Waveform Digitizers (ATWDs), allowing multi p.e. resolution

Blue: raw data
red: pedestal
green: pedestal subtracted

- 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

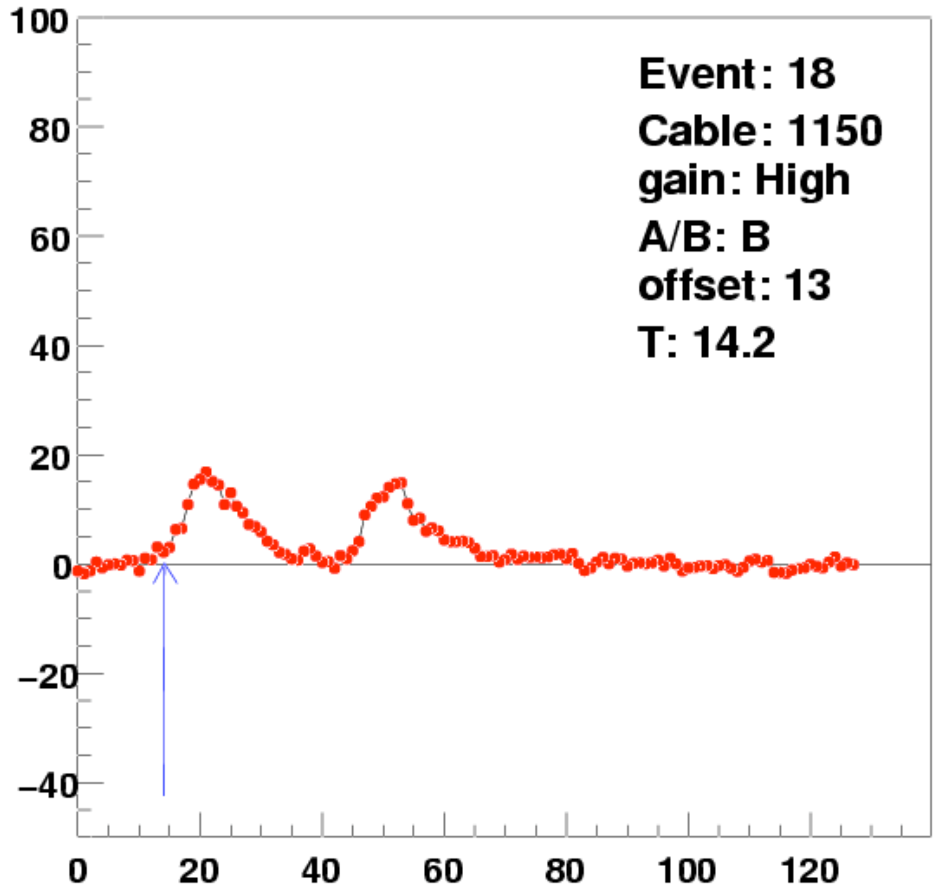
ADC counts (~120 µV)

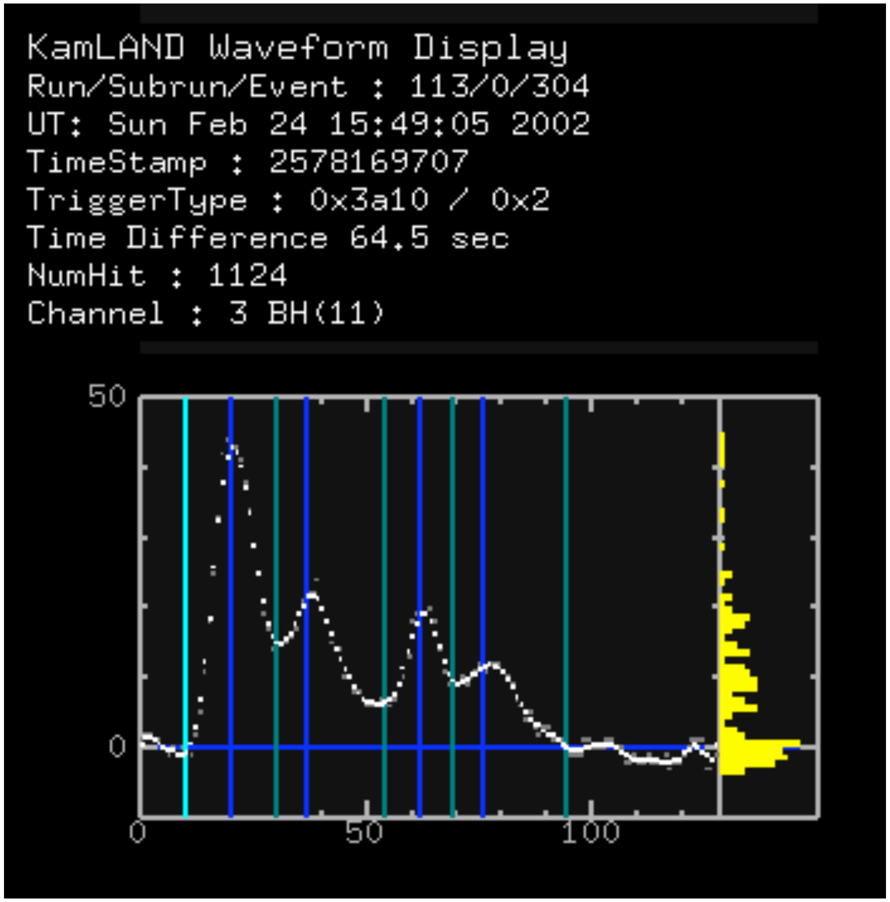


Samples (~1.5ns)

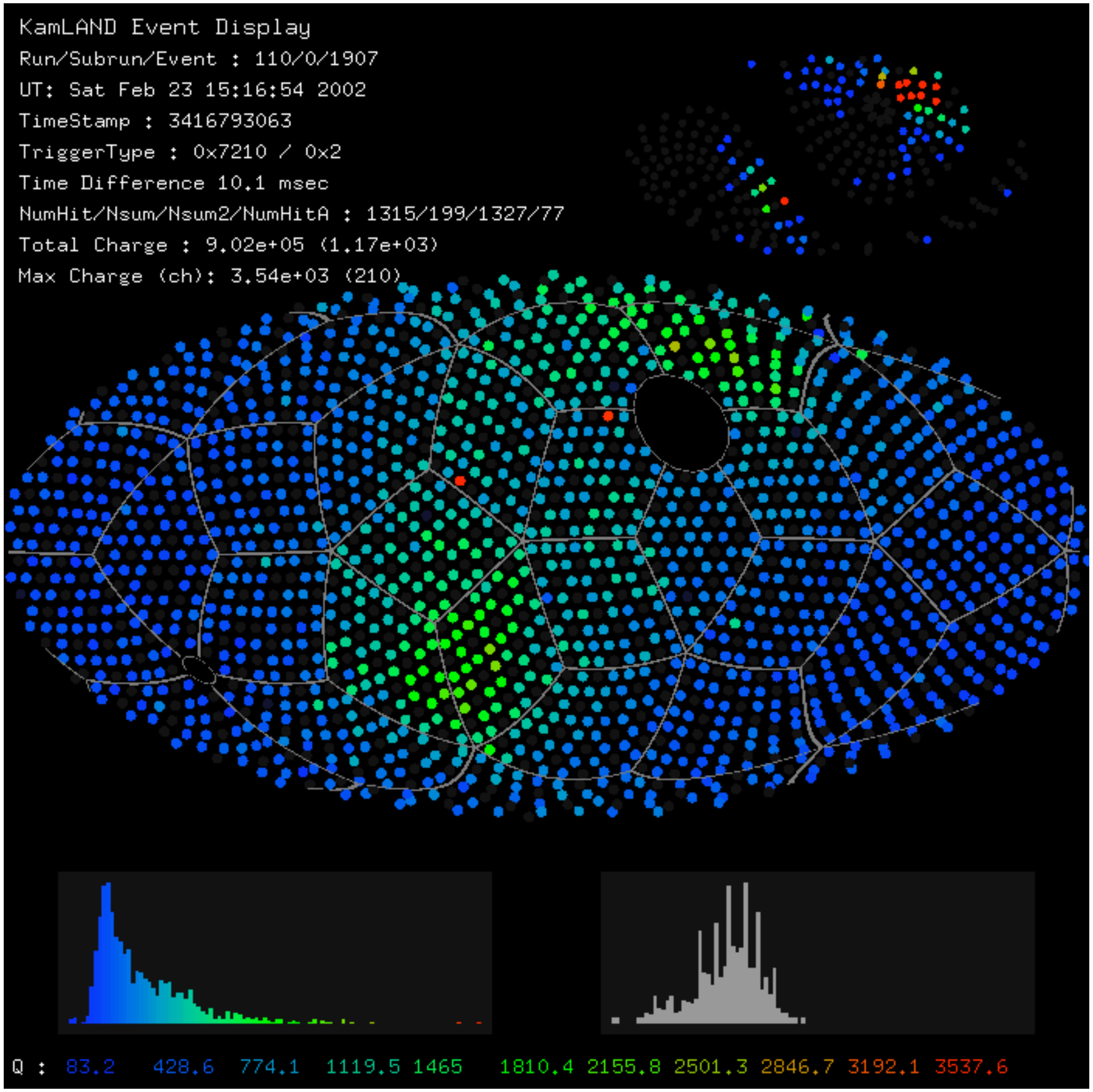
KamLAND Data

Converting **waveforms** into **time** and **charge** information





KamLAND Data

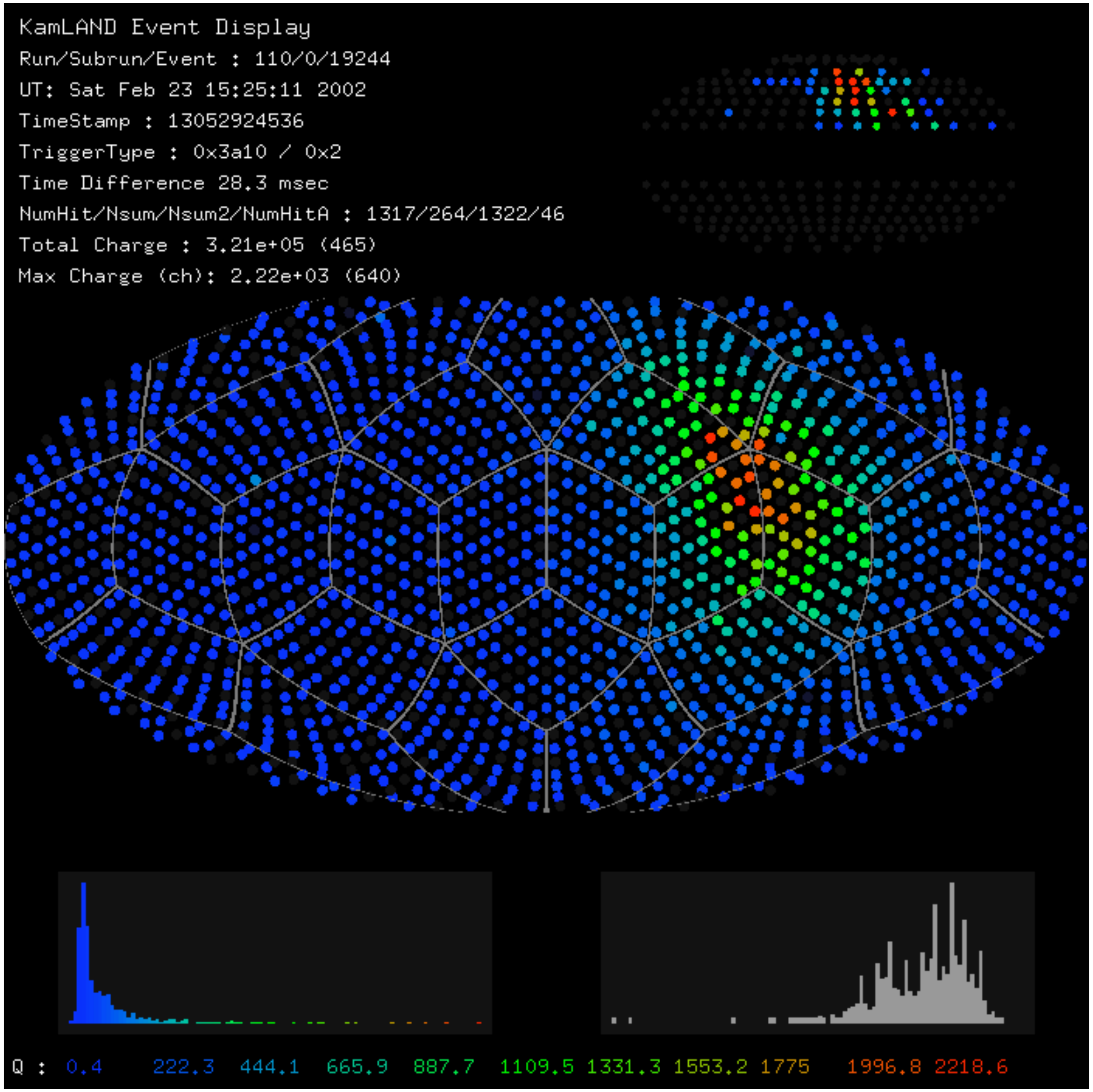


Event Display: through−going muon

color is pulseheight

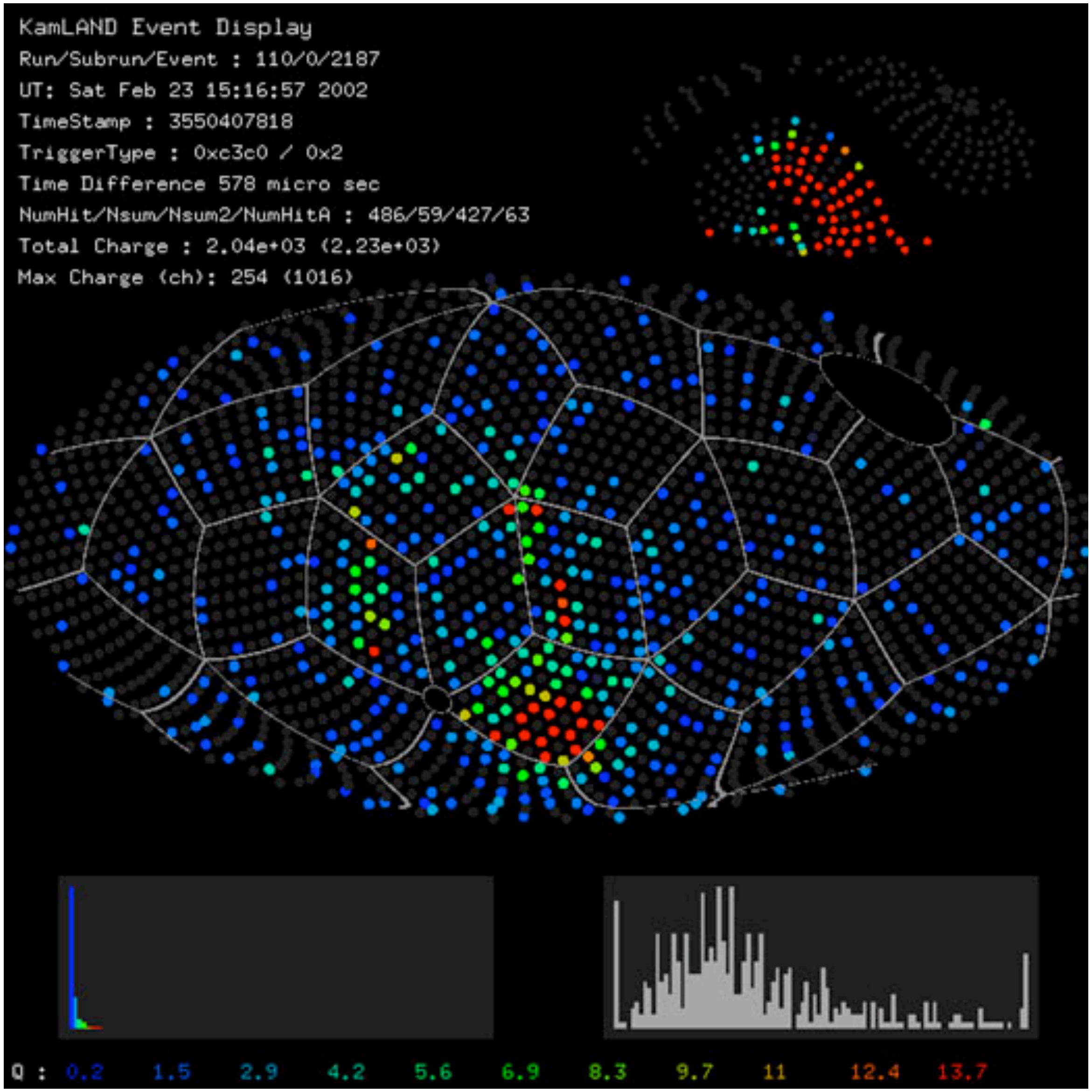
all tubes illuminated

KamLAND Data



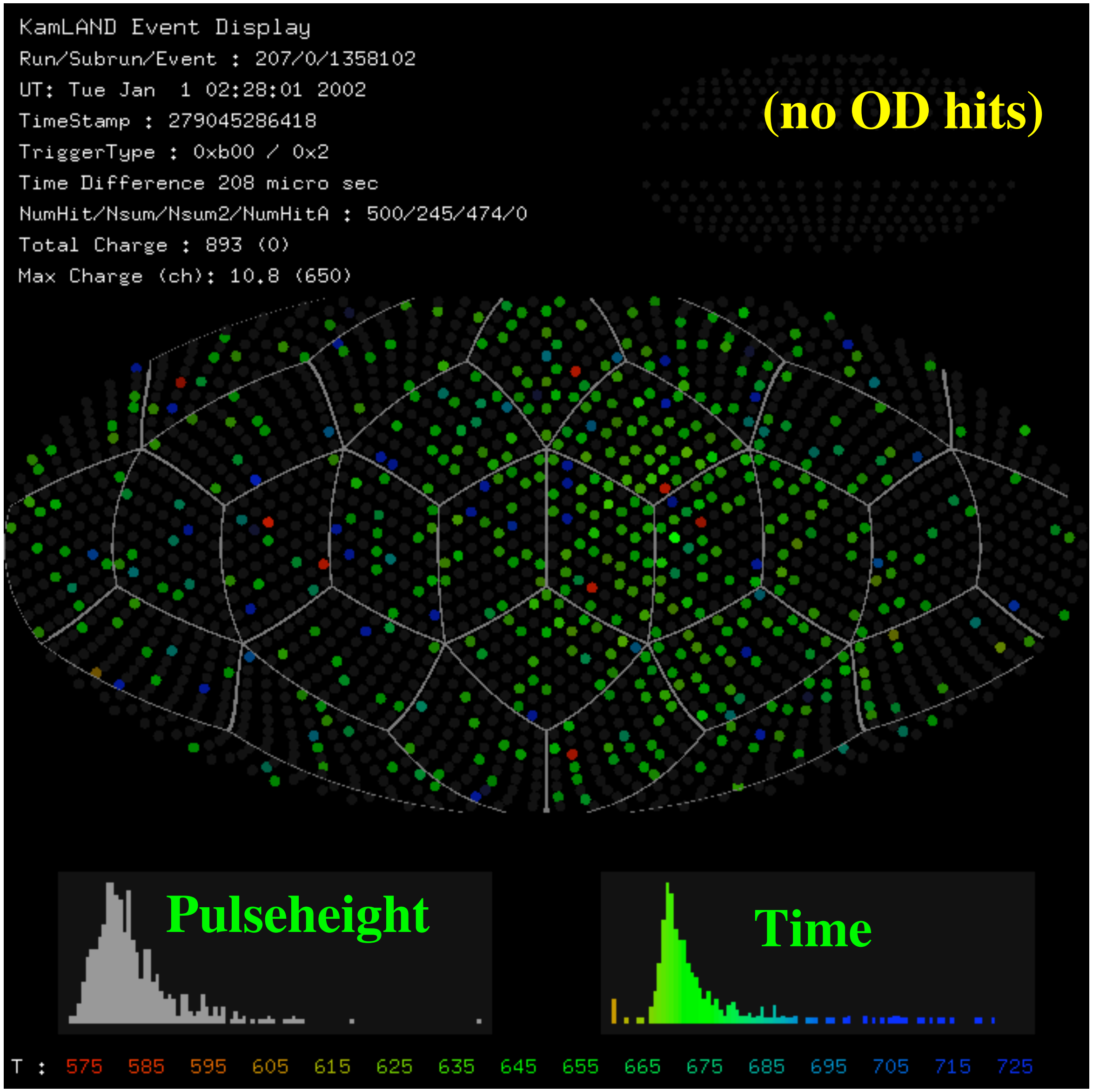
Stopped muon

KamLAND Data



Cerenkov ring from "corner clipper"

KamLAND Data



Low−energy event

color is time

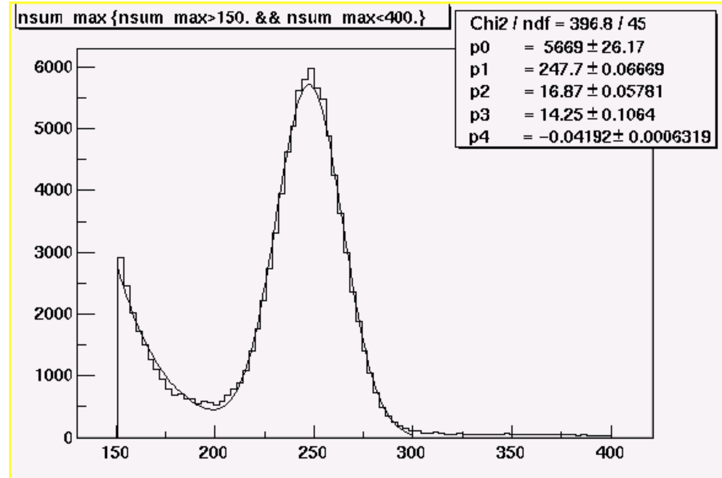
KamLAND Data

Converting **time** and **charge** information into event **position** and **energy**:

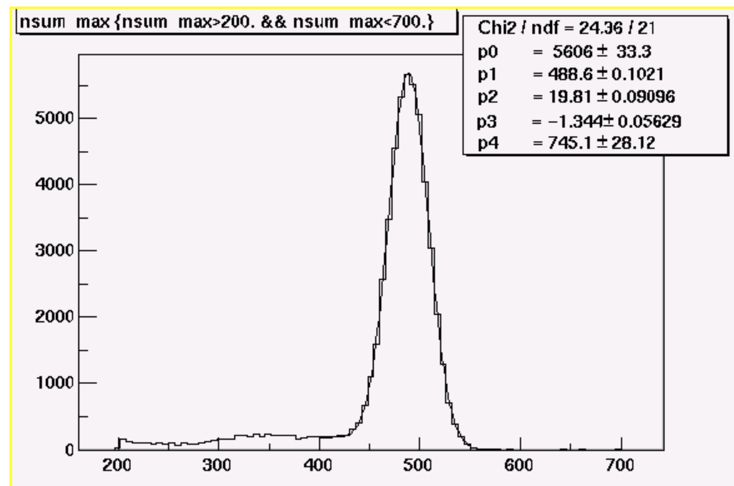
This requires calibration of the PMT's:
- Timing: done with a blue laser
- Gains: single photoelectron gains with LED's
  high pulseheight gains with UV laser

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



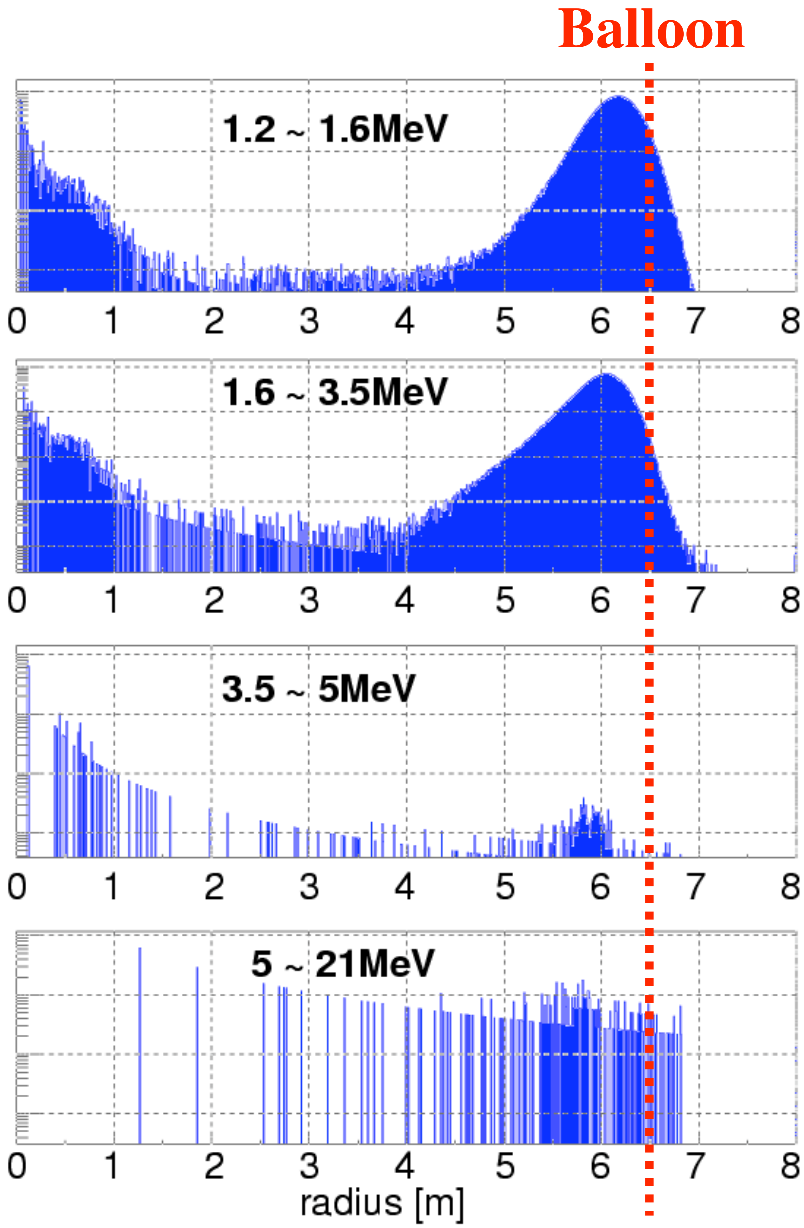
^{65}Zn (1.115 MeV γ)



^{60}Co (2.505 MeV γ+γ)

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

KamLAND Data



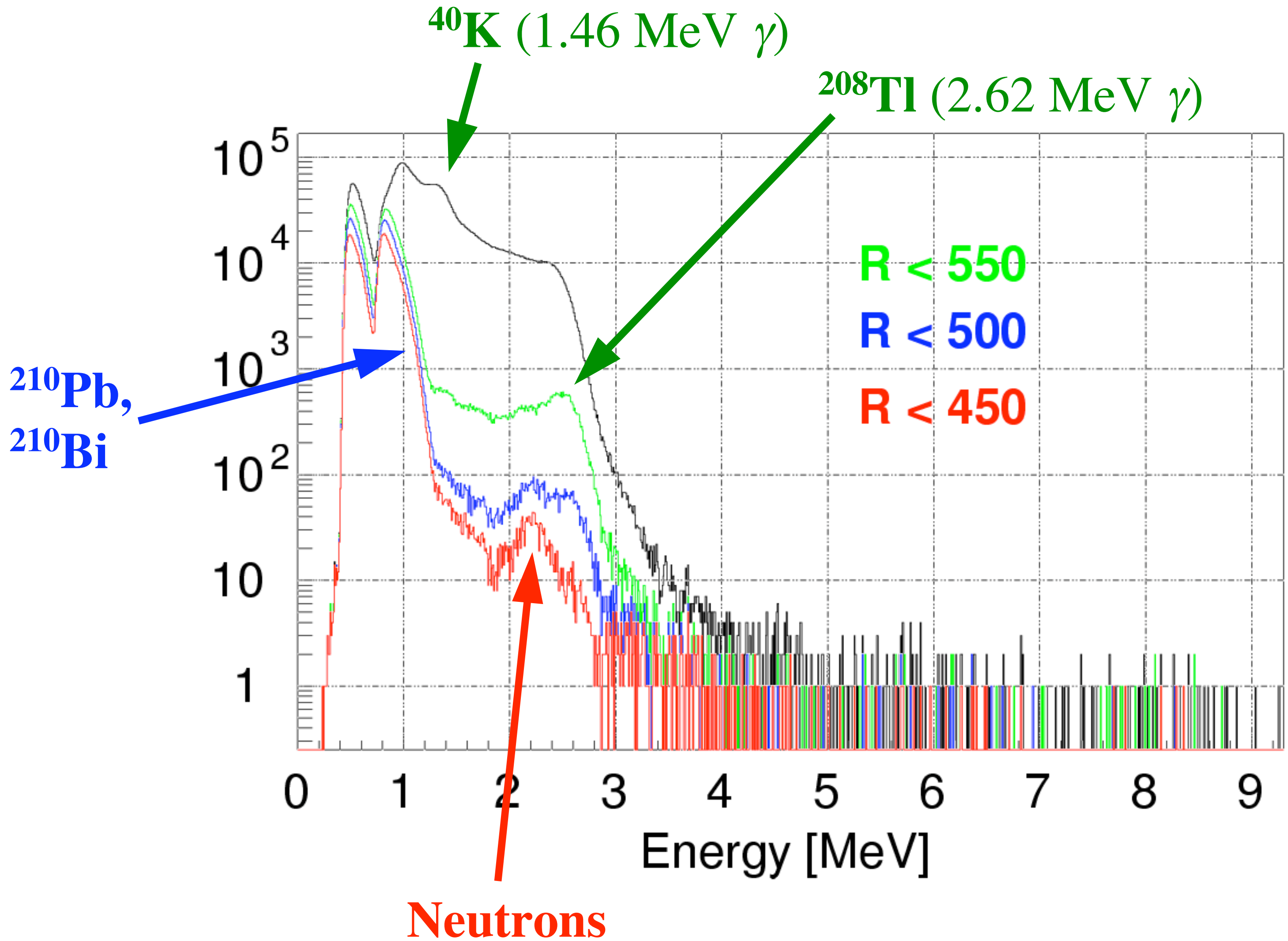
Reconstructed event position for different event energies

$1/R^2$ weight, log scale

Most backgrounds peak near the edge of the scintillator volume

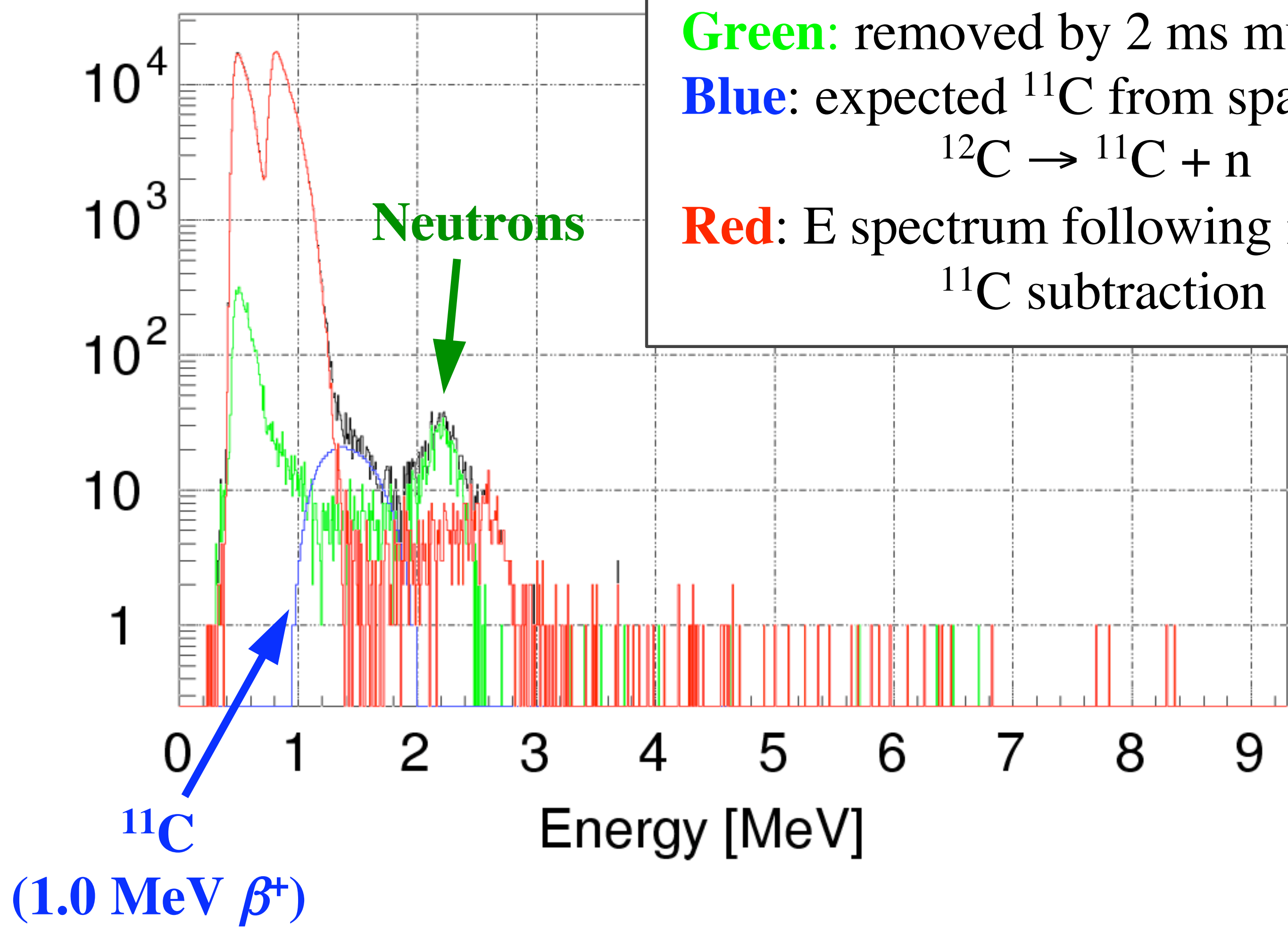
KamLAND Data

Effect of fiducial volume cuts on the energy spectrum



KamLAND Data

Muon−related backgrounds

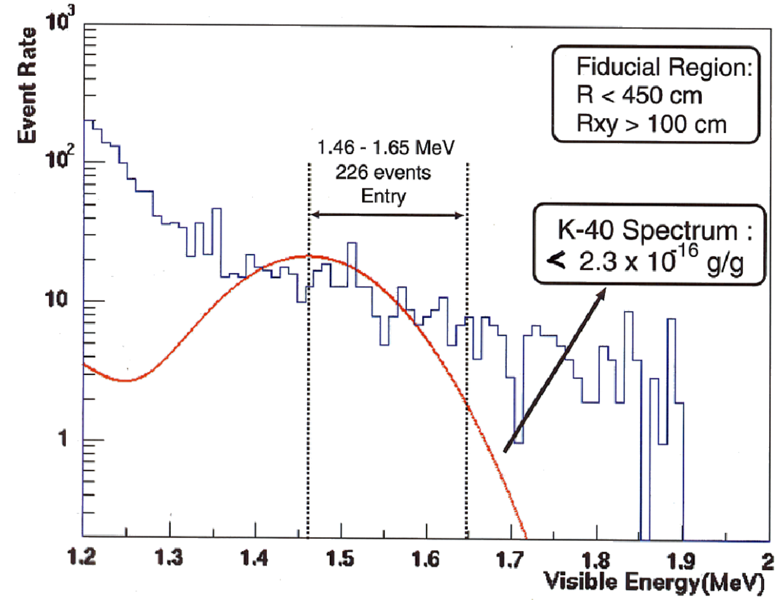


Black: 4.5 m fiducial volume cut
Green: removed by 2 ms muon veto
Blue: expected ^{11}C from spallation:
$^{12}C \rightarrow {}^{11}C + n$
Red: E spectrum following muon veto, ^{11}C subtraction

KamLAND Data

Background summary:

- Most backgrounds peak near the balloon
  - radon decay products (^{208}Tl, ^{210}Pb, ^{210}Bi)
  - ^{40}K
- Neutron rate and level of muon spallation products are consistent



^{40}K limit fit

- We can also set limits on certain contaminations:

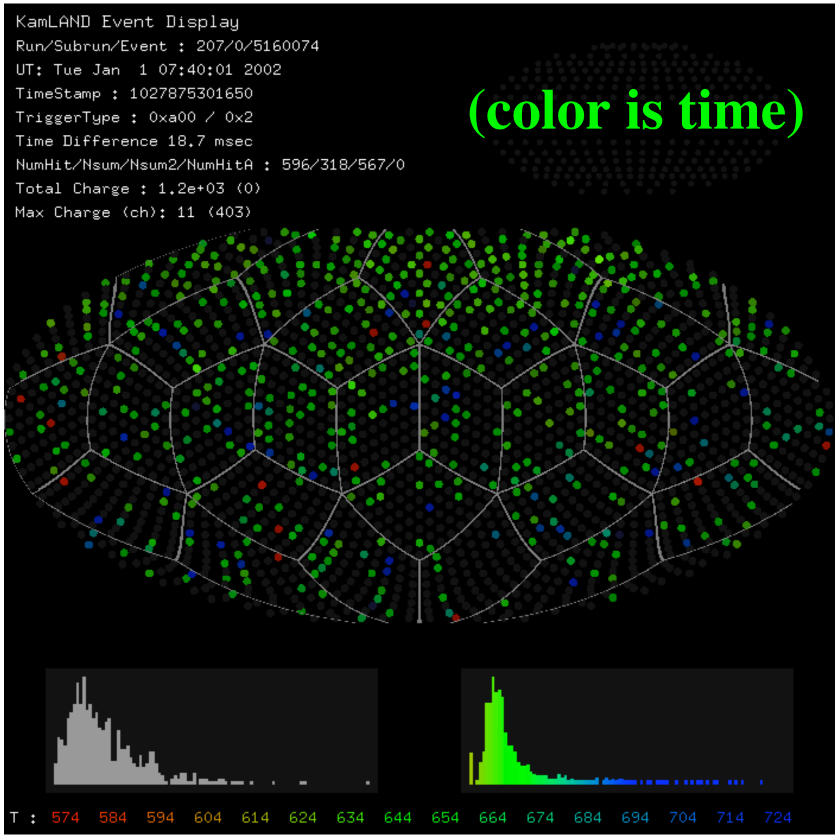
^{238}U	10^{-16} g/g	$< 6.4 \times 10^{-16}$ g/g
^{232}Th	10^{-16} g/g	$< 1.8 \times 10^{-16}$ g/g
^{40}K	10^{-18} g/g	$< 2.3 \times 10^{-16}$ g/g

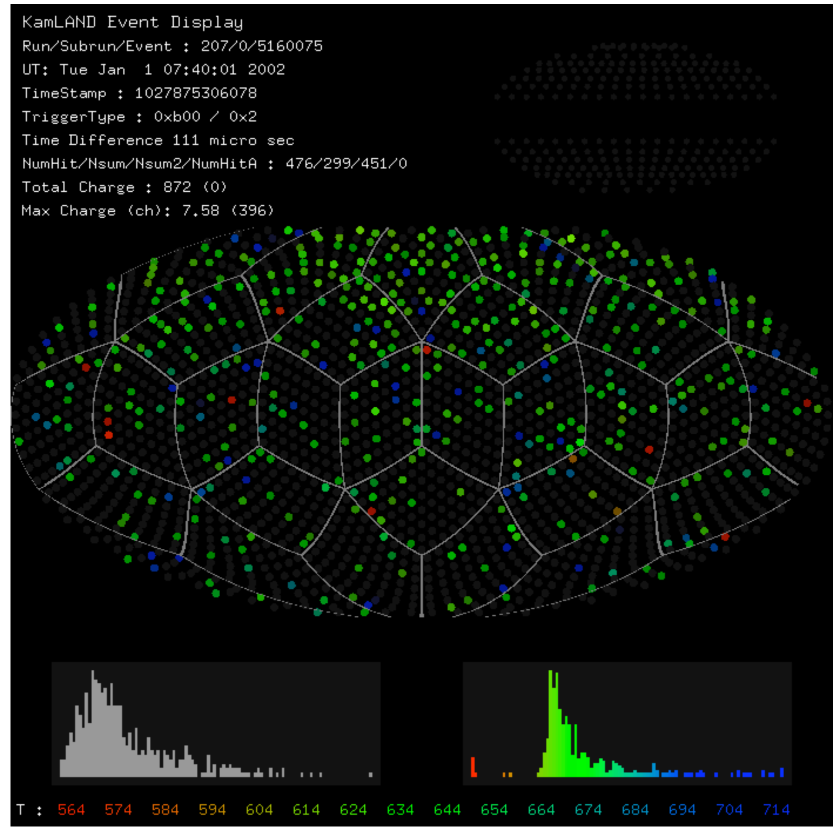
- background rates tolerable for reactor experiment

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

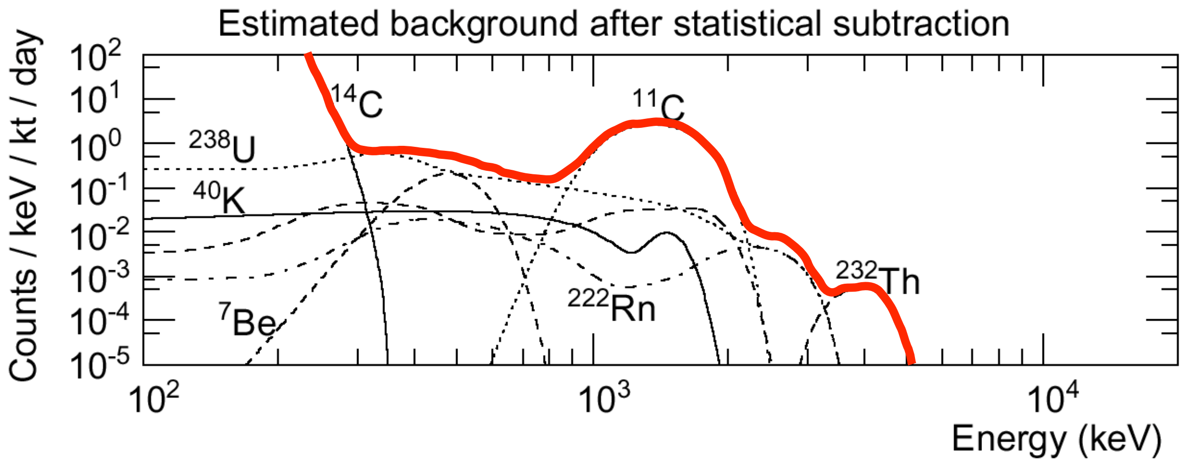
Summary

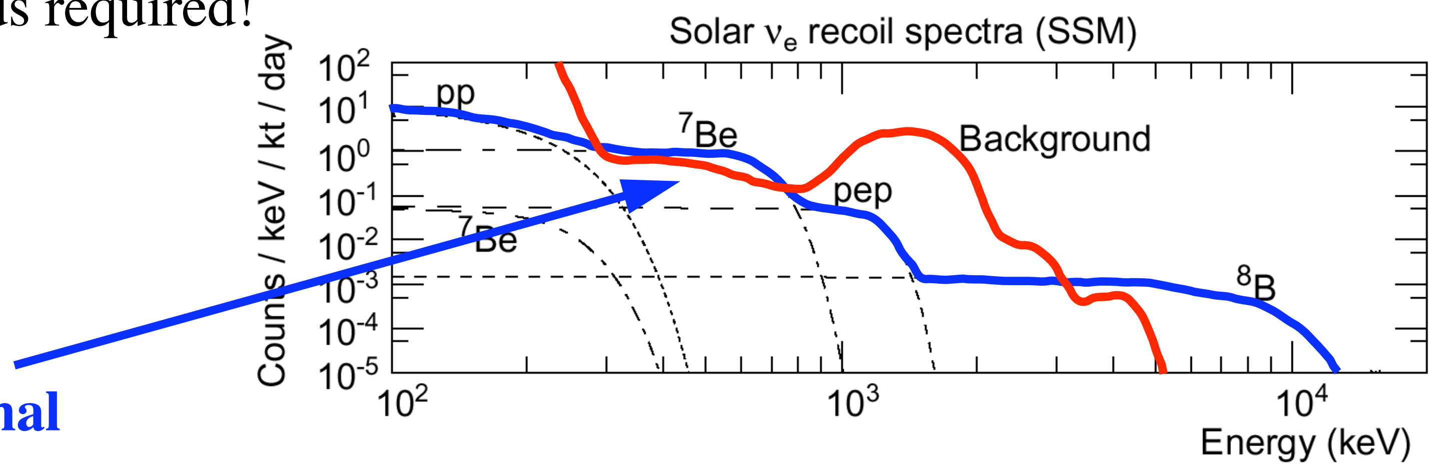
- KamLAND is making rapid progress
- background levels are acceptable for the reactor experiment,
  we are working to reduce them to allow lower energy thresholds
- stay tuned for interesting physics results
- Longer−term future: KamLAND solar neutrino experiment

Solar Neutrinos at KamLAND

(KamLAND proposal)

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

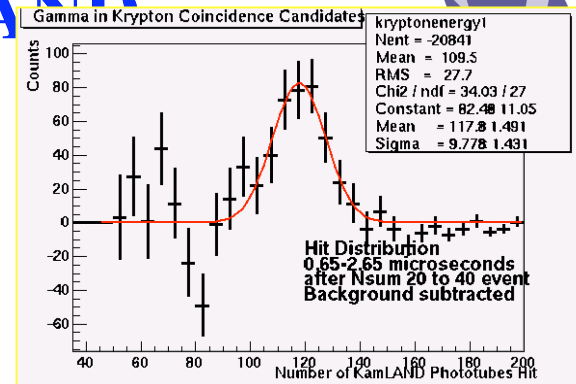




Solar Neutrinos at KamLAND

- Radiopurity design goals vs. measurements:

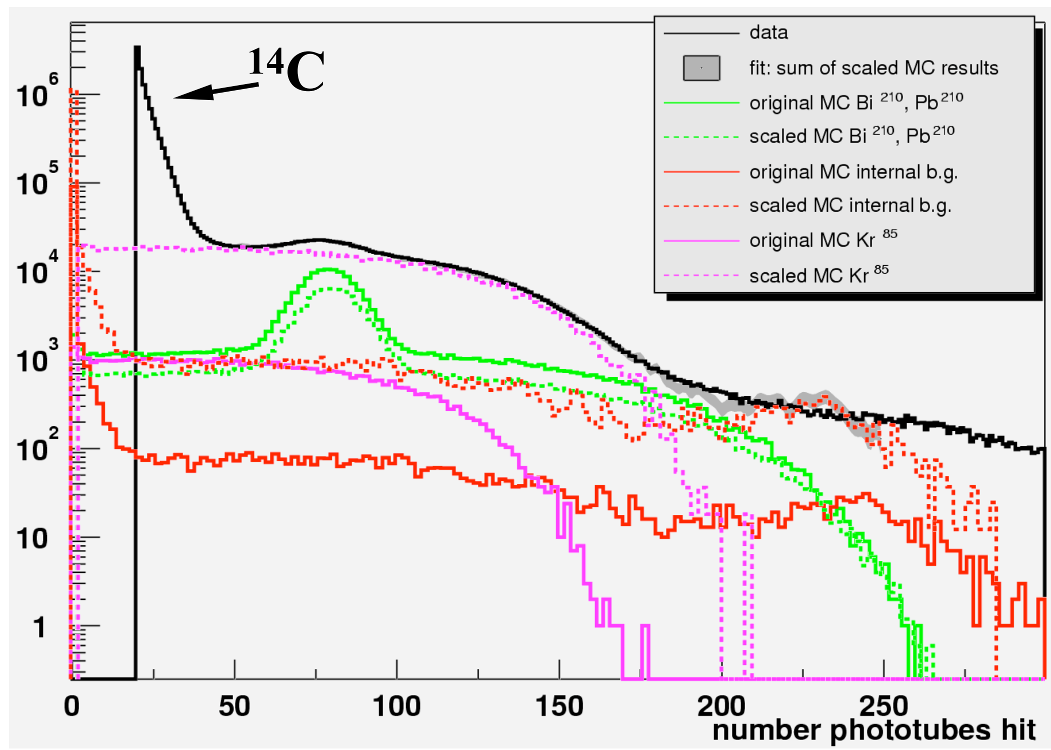
^{238}U	10^{-16} g/g	$< 6.4 \times 10^{-16}$ g/g
^{232}Th	10^{-16} g/g	$< 1.8 \times 10^{-16}$ g/g
^{40}K	10^{-18} g/g	$< 2.3 \times 10^{-16}$ g/g



^{85}Kr coincidence measurement

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

- Working on purification and eliminating leaks to remove such contamination



Observed low−energy event spectrum