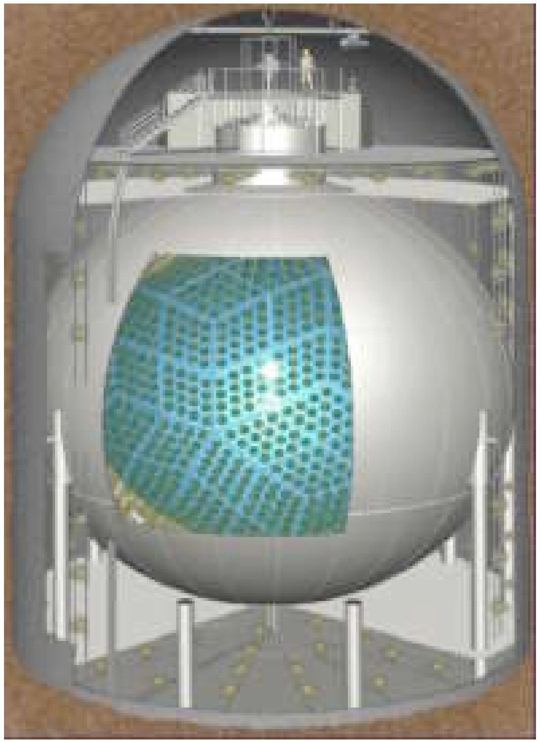
Brown Journal Club (APJC)

KamLAND - FIRST RESULTS

(My thanks to Alan Poon, LBL for providing many of slides)

See also http://kamland.lbl.gov



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http://gaitskell.brown.edu

Only In Japan ….

- Aggressively pursuing underground neutrino physics !
  - Kamiokande / Super-K / KamLAND
- “Small” island with >50% nuclear electricity generation
- Reporting results within 1 year of turn on
  - Reporting data from March 4 -> Oct 6, 2002
    (145 days live, 30 Hz raw trigger)
    54 events $\overline{n}_e$

2-Flavor Neutrino Oscillation

Mass states (ν_M)

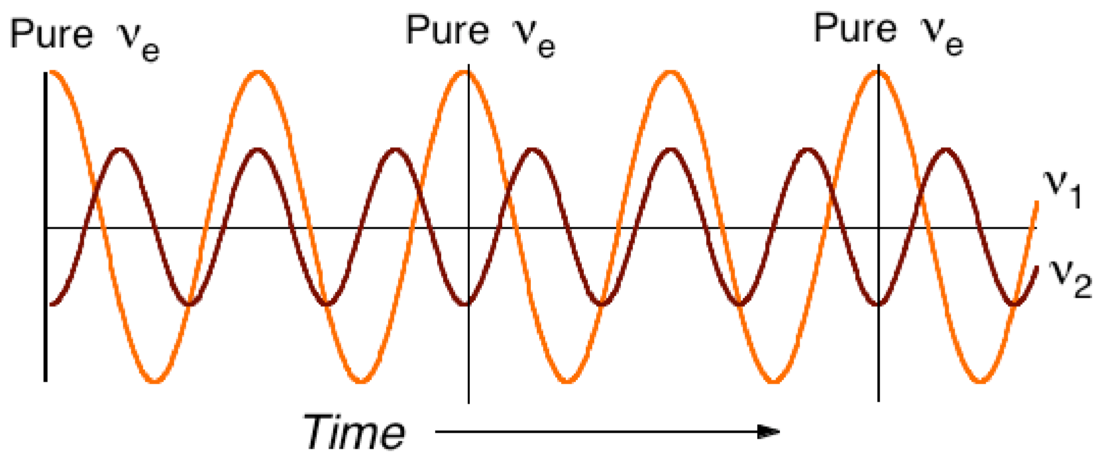
mass: m_1, m_2

Weak states (ν_W)

(participate in weak interactions)

$$\begin{pmatrix} \nu_e \\ \nu_\mu \end{pmatrix} = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \end{pmatrix}$$

ν_1 ν_2 ν_e ν_μ

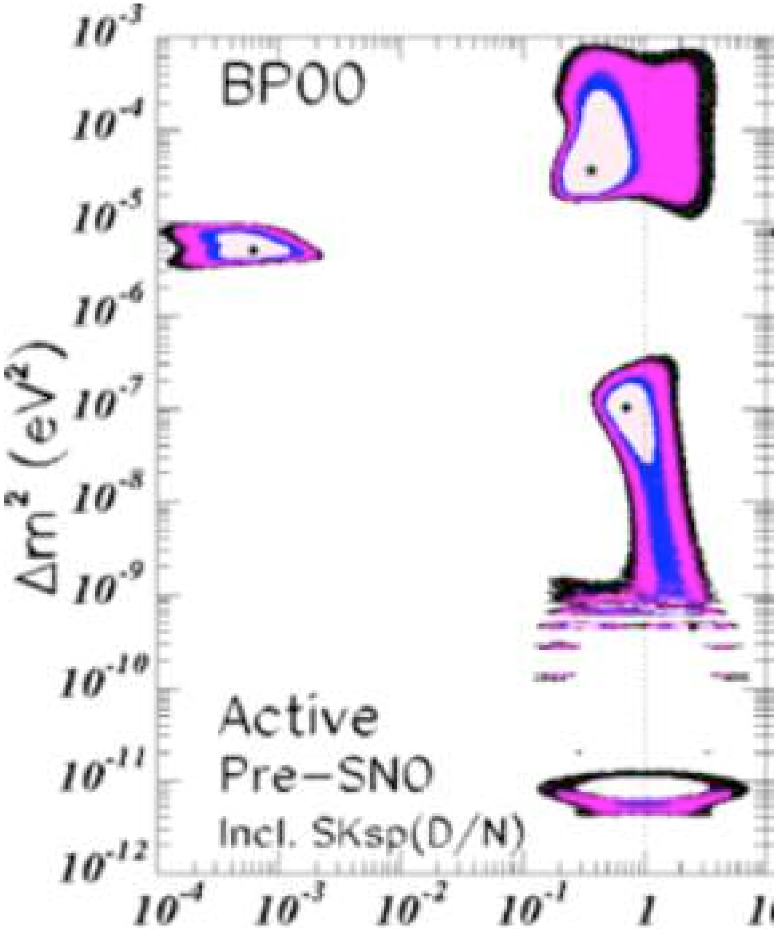


$$P(\nu_e \to \nu_e) = 1 - \sin^2 2\theta \sin^2\left(1.27 \frac{\Delta m^2_{[\mathrm{eV}^2]}\, L_{[\mathrm{m}]}}{E_{[\mathrm{MeV}]}}\right) \quad \text{where } \Delta m^2 = m_2^2 - m_1^2$$

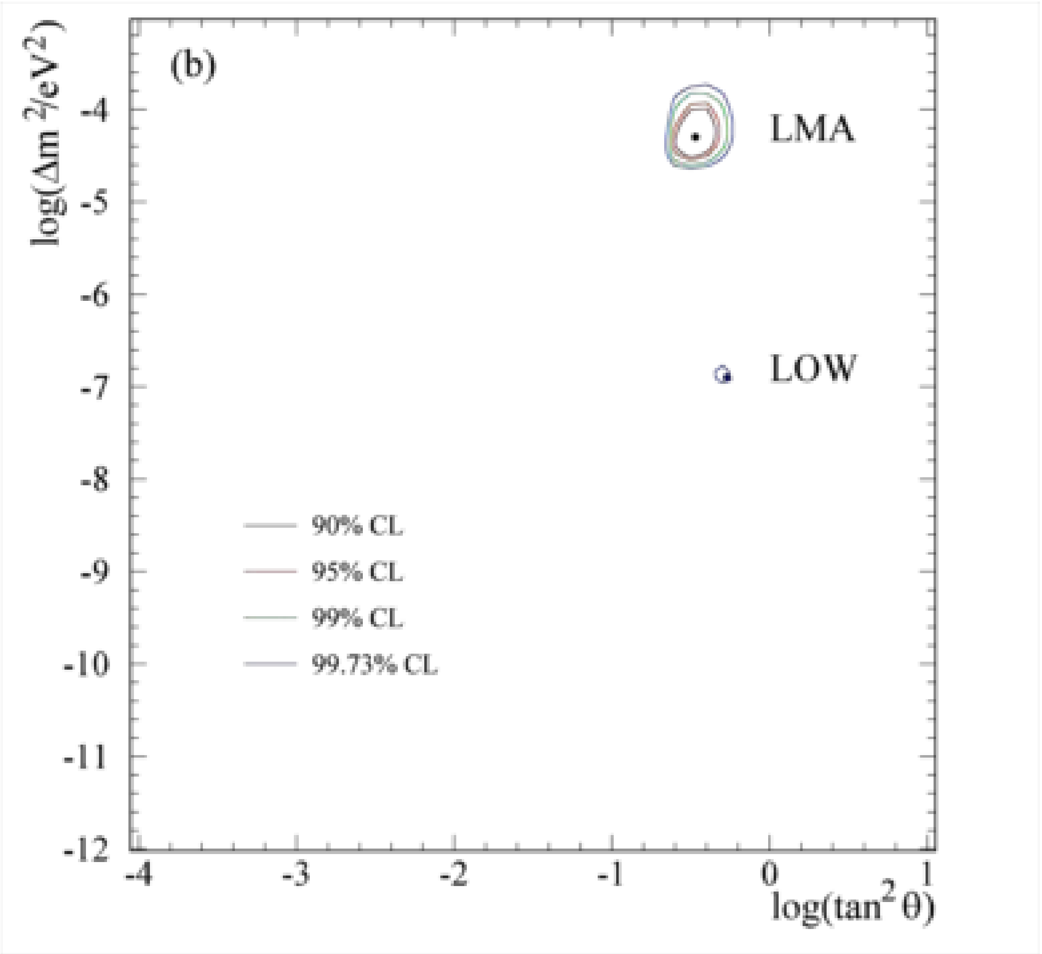
Note: May also have resonant flavor conversion in matter —
Mikheyev-Smirnov-Wolfenstein (MSW) effect

Rapidly Moving Field…. What did SNO Contribute?

Pre-SNO (circa. early 2001)



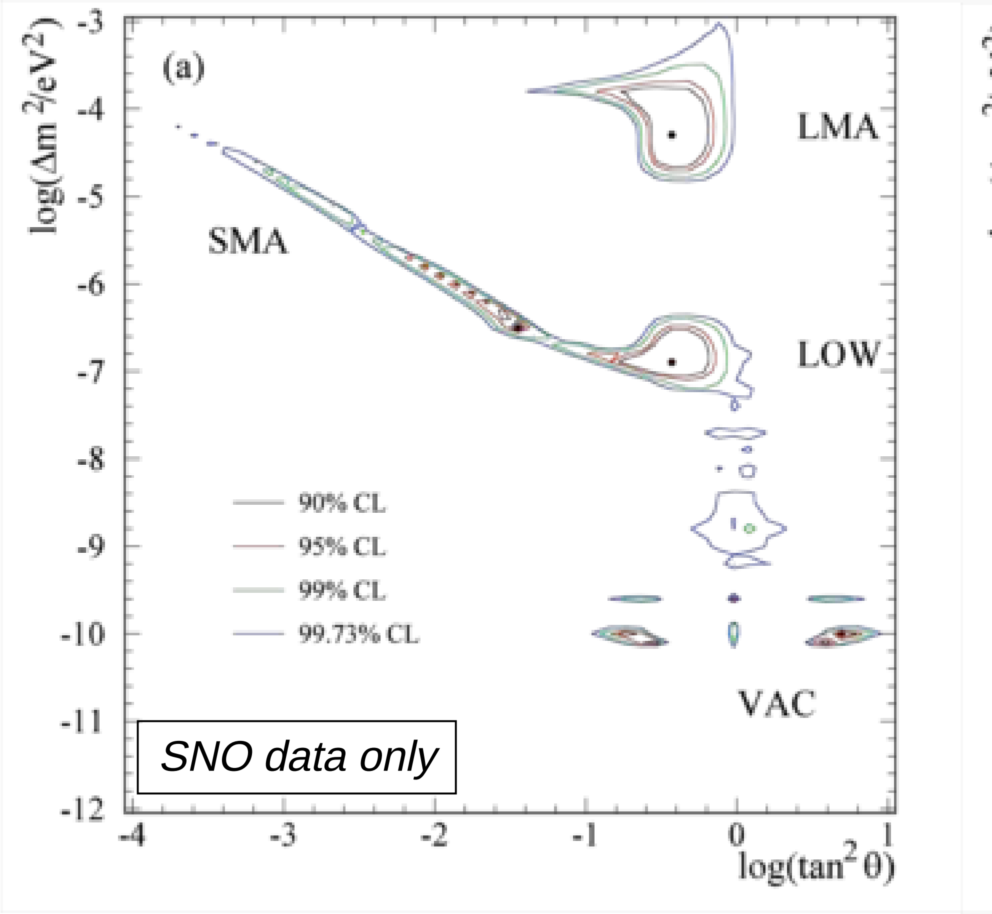
Now

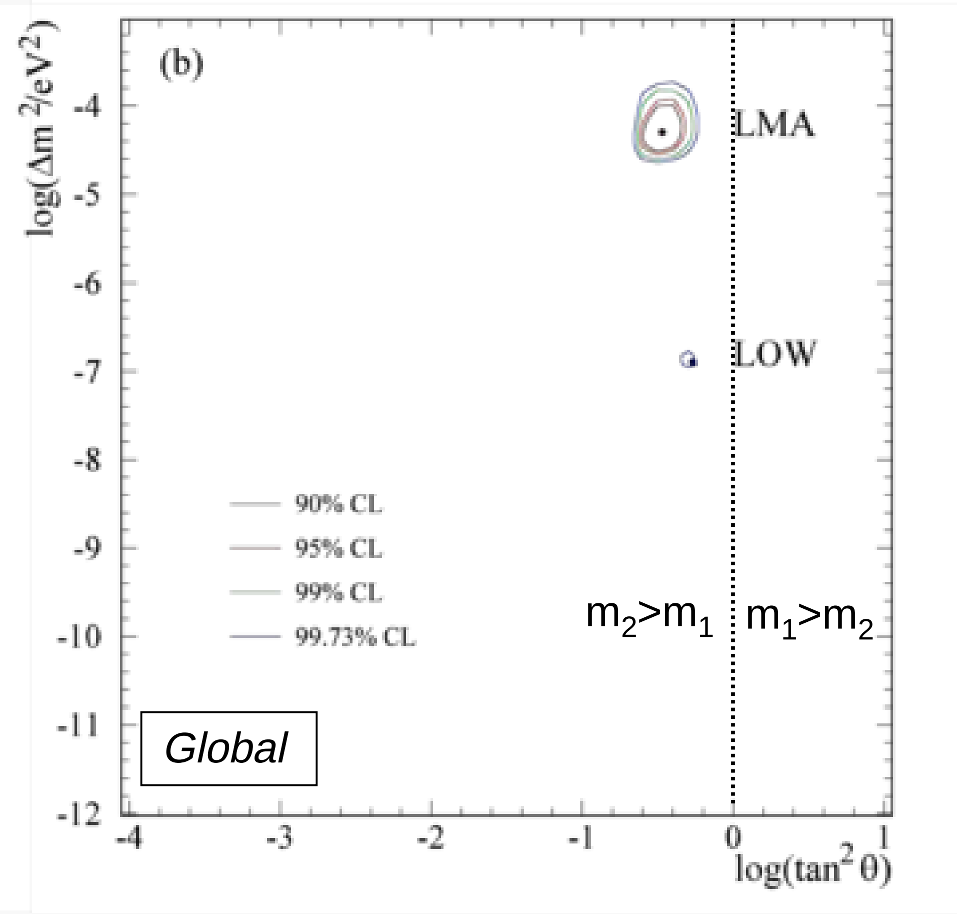


Bahcall, Gonzalez-Garcia, Pena-Garay (2001)

Global Solar n Analysis

Inputs:
- ^{37}Cl, latest Gallex/GNO, new SAGE, SK 1258-day day & night spectra
- SNO day spectrum (total: CC+NC+ES+background)
- SNO night spectrum (total: CC+NC+ES+background)
- ^{8}B floats free in fit, hep n at 1 SSM

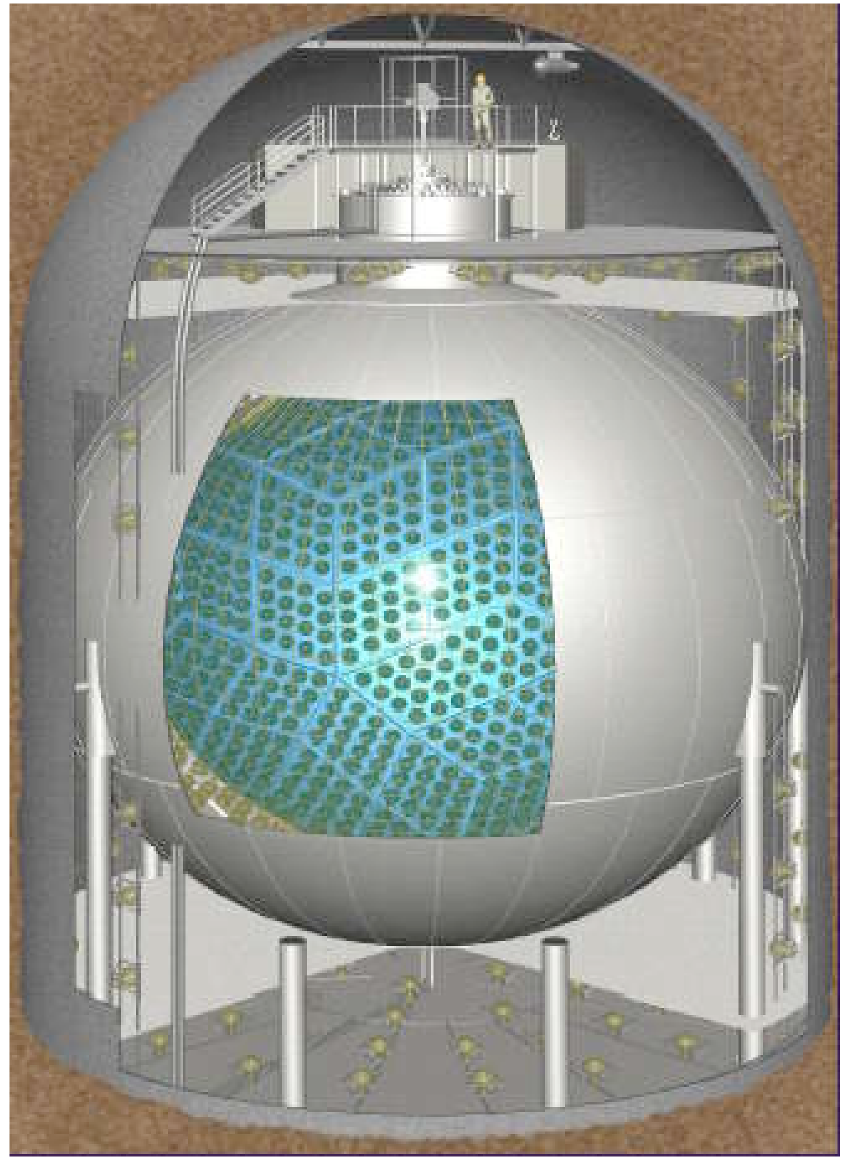




KamLAND

Kamioka Liquid scintillator Anti-Neutrino Detector (KamLAND)

(Kamioka, Gifu Prefecture, Japan)
Æ reactor n @ “right” baseline for directly testing the currently favored LMA region



1 kt liquid scintillator as target

$$\bar{n}_e + p \text{ Æ } n + e^+$$

2x coincidence

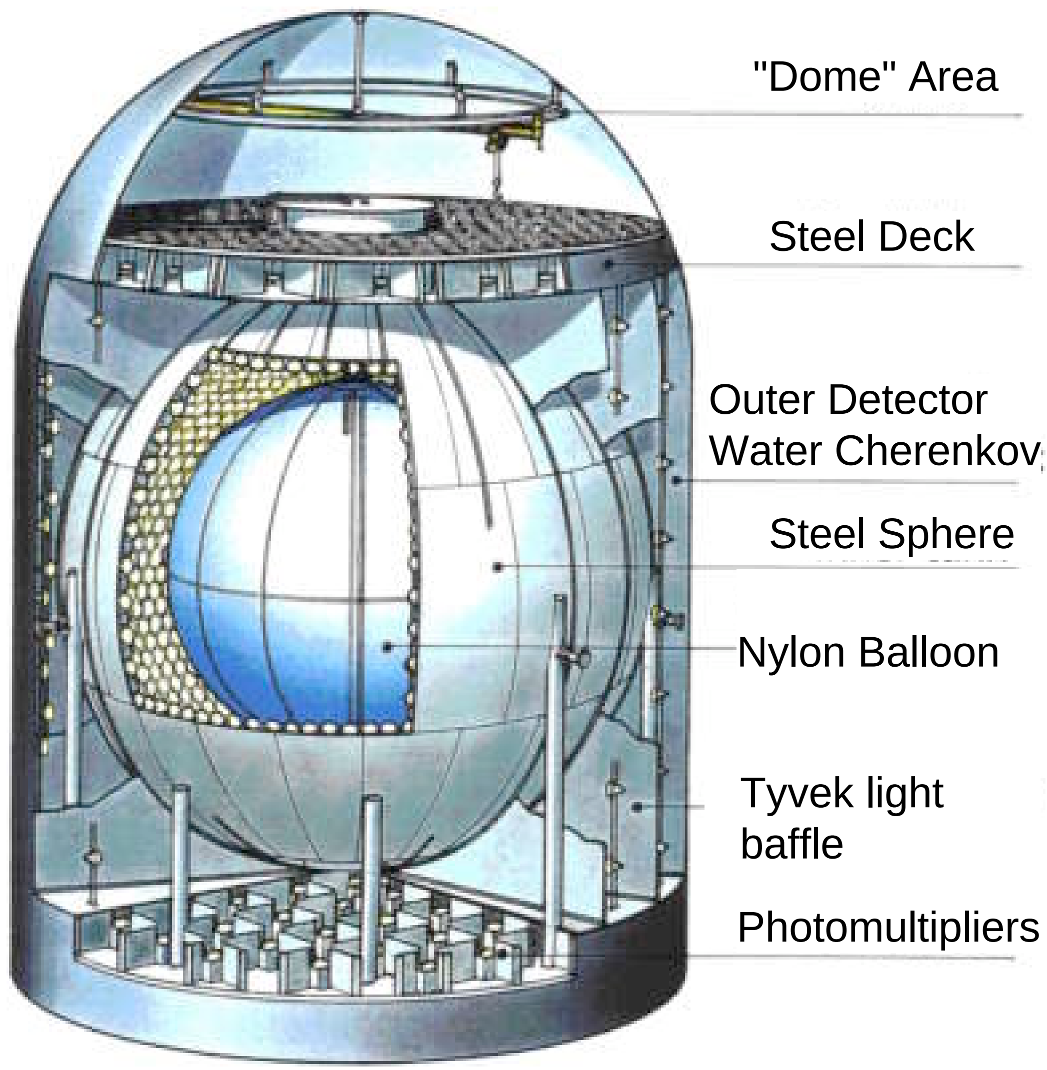
$$e^+ + e^- \text{ Æ } 2g$$

$$n + p \text{ Æ } d + g\,(2.2 \text{ MeV})$$

(inverse b decay)

The KamLAND Detector

- 1 kton liquid scintillator
  - 80% mineral oil
  - 20% pseudocumine
  - 1.5 g/L PPO
  - r =0.78 g/cm^3
- Mineral oil outside
  - nylon balloon
  - radon barrier
  - r =0.76 g/cm^3
- 1879 PMT's
  - 1325 17"
  - 544 20”
- 225 Veto PMT's
  - Water Cherenkov



Long Baseline - Reactor Distribution

51 reactors in Japan,

Dominated (80% flux) by 26 reactors in distance band 138-214 km
i.e. <L> ~ 180 km +/- 22%

One reactor 88 km (7%)
Rest > 295 km

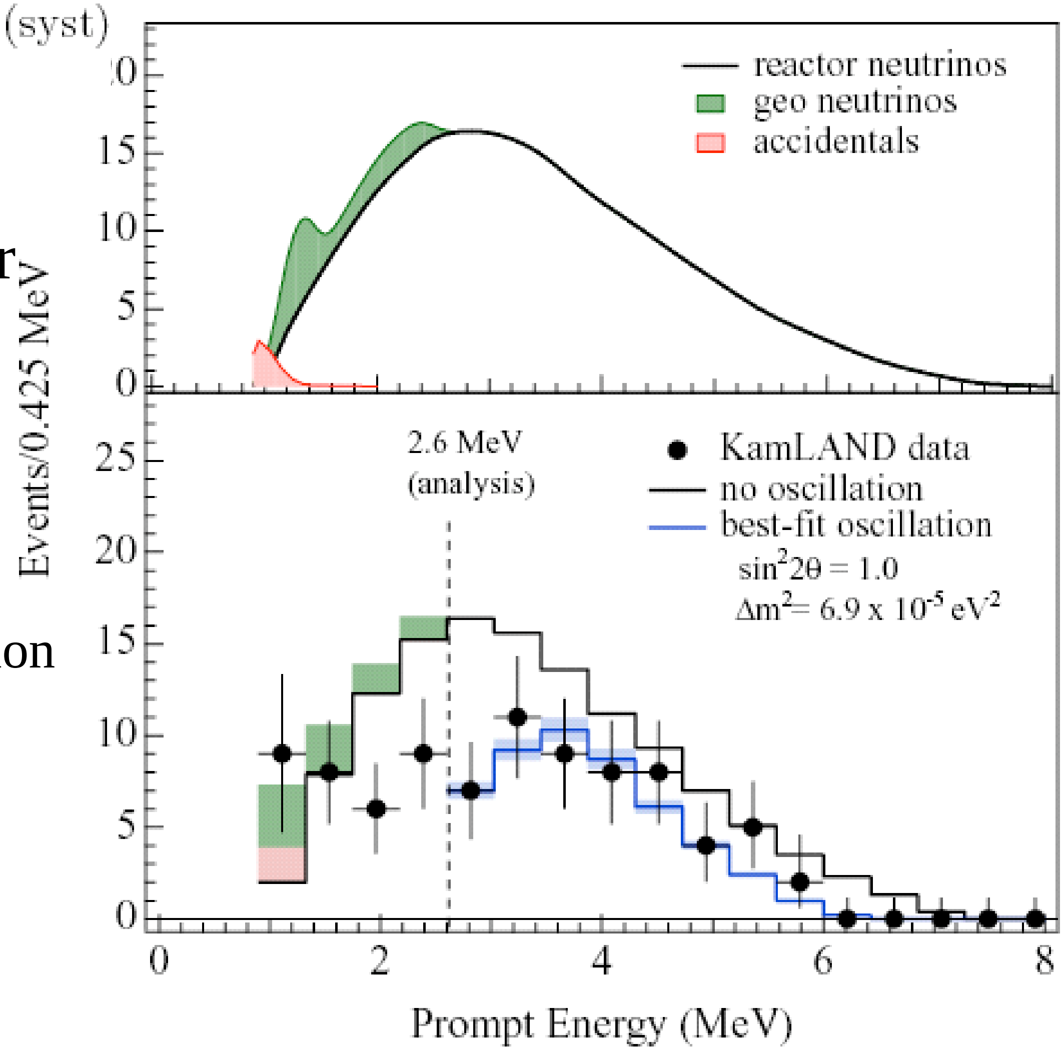
Korean Reactors (2.5%)
ROW (0.7%)

KamLAND - New results

$$\frac{N_{obs} - N_{BG}}{N_{expected}} = 0.611 \pm 0.085(\text{stat}) \pm 0.041(\text{syst})$$

- 408 ton fiducial
- 54 events in final sample after cuts
  - Expected 87+/-6 for no osc
- B/G E>2.6 MeV 1+/-1
  - Dominated by 9Li/8He cosmogenics - delayed n emission
  - Lower energies Geo n #~9

FIG. 5: Upper panel: Expected reactor $\bar{\nu}_e$ energy spectrum with contributions of $\bar{\nu}_{geo}$ (model Ia of [6]) and accidental backround. Lower panel: Energy spectrum of the observed prompt events (solid circles with error bars), along with the expected no oscillation spectrum (upper histogram, with $\bar{\nu}_{geo}$ and accidentals shown) and best fit (lower histogram) including neutrino oscillations. The shaded band indicates the systematic error in the best-fit spectrum. The vertical dashed line corresponds to the analysis threshold at 2.6 MeV.



KamLAND - Cuts

- Cuts
  - – Fiducial Volume (R<5 m) for both prompt & delayed
  - – Time correlation (prompt & delayed) 0.5-660 us
  - – Vertex correlation (dR<1.6 m)
  - – 1.8 MeV < $E_{delayed}$ < 2.6 MeV
  - – $R_{delayed}$ > 1.2 m from central axis
    - (LS Thermometers are radioactive!)
- Total ~78.3% x fid vol (408 ton) for primary defined by 1

KamLAND - Error budget

TABLE I: Background summary.

Background	Number of events
Accidental	0.0086 ± 0.0005
$^{9}Li/^{8}He$	0.94 ± 0.85
Fast neutron	< 0.5
Total B.G. events	0.95 ± 0.99

TABLE II: Estimated systematic uncertainties (%).

Total LS mass	2.13	Reactor power	2.05
Fiducial mass ratio	4.06	Fuel composition	1.0
Energy threshold	2.13	Time lag	0.28
Efficiency of cuts	2.06	ν spectra [8]	2.48
Live time	0.07	Cross section [11]	0.2
Total systematic error			6.42%

KamLAND - L/E

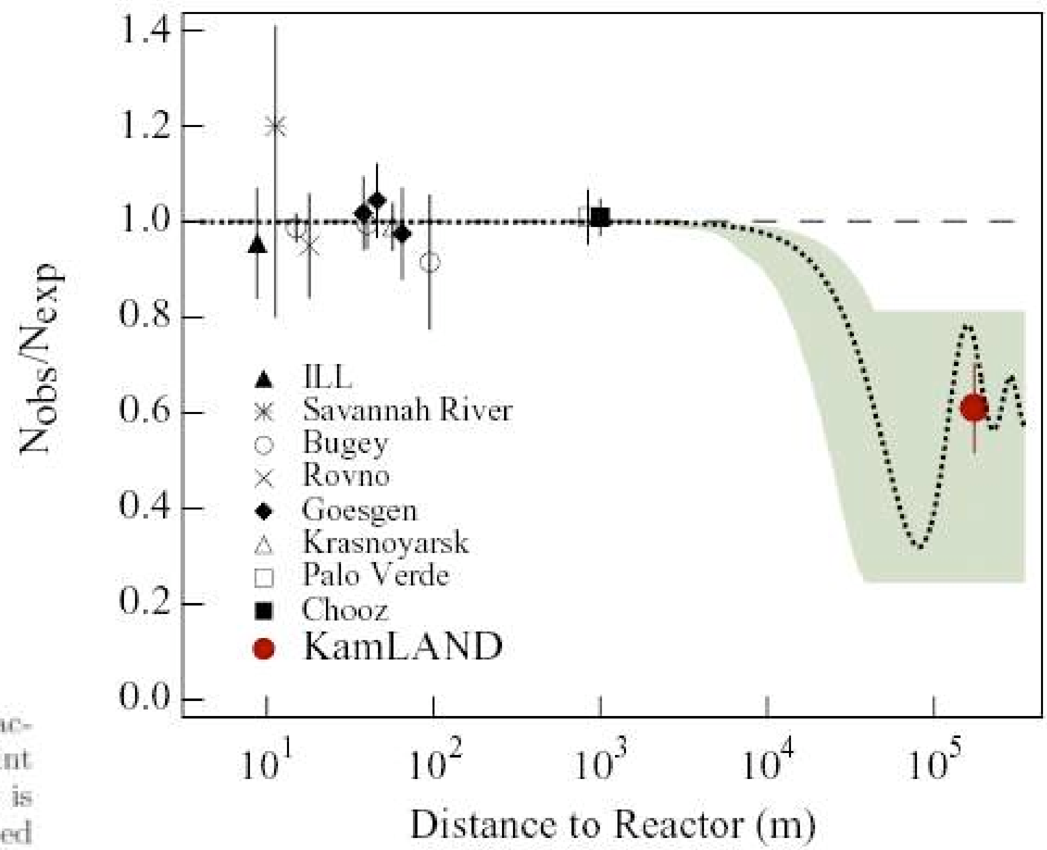


FIG. 4: The ratio of measured to expected $\bar{\nu}_e$ flux from reactor experiments [12]. The solid dot is the KamLAND point plotted at a flux-weighted average distance (the dot size is indicative of the spread in reactor distances). The shaded region indicates the range of flux predictions corresponding to the 95% C.L. LMA region found in a global analysis of the solar neutrino data [13]. The dotted curve corresponds to $\sin^2 2\theta = 0.833$ and $\Delta m^2 = 5.5 \times 10^{-5}$ eV^2 [13] and is representative of recent best-fit LMA predictions while the dashed curve shows the case of small mixing angles (or no oscillation).

KamLAND - Allowed / excluded

- Simple 2-n osc & CPT

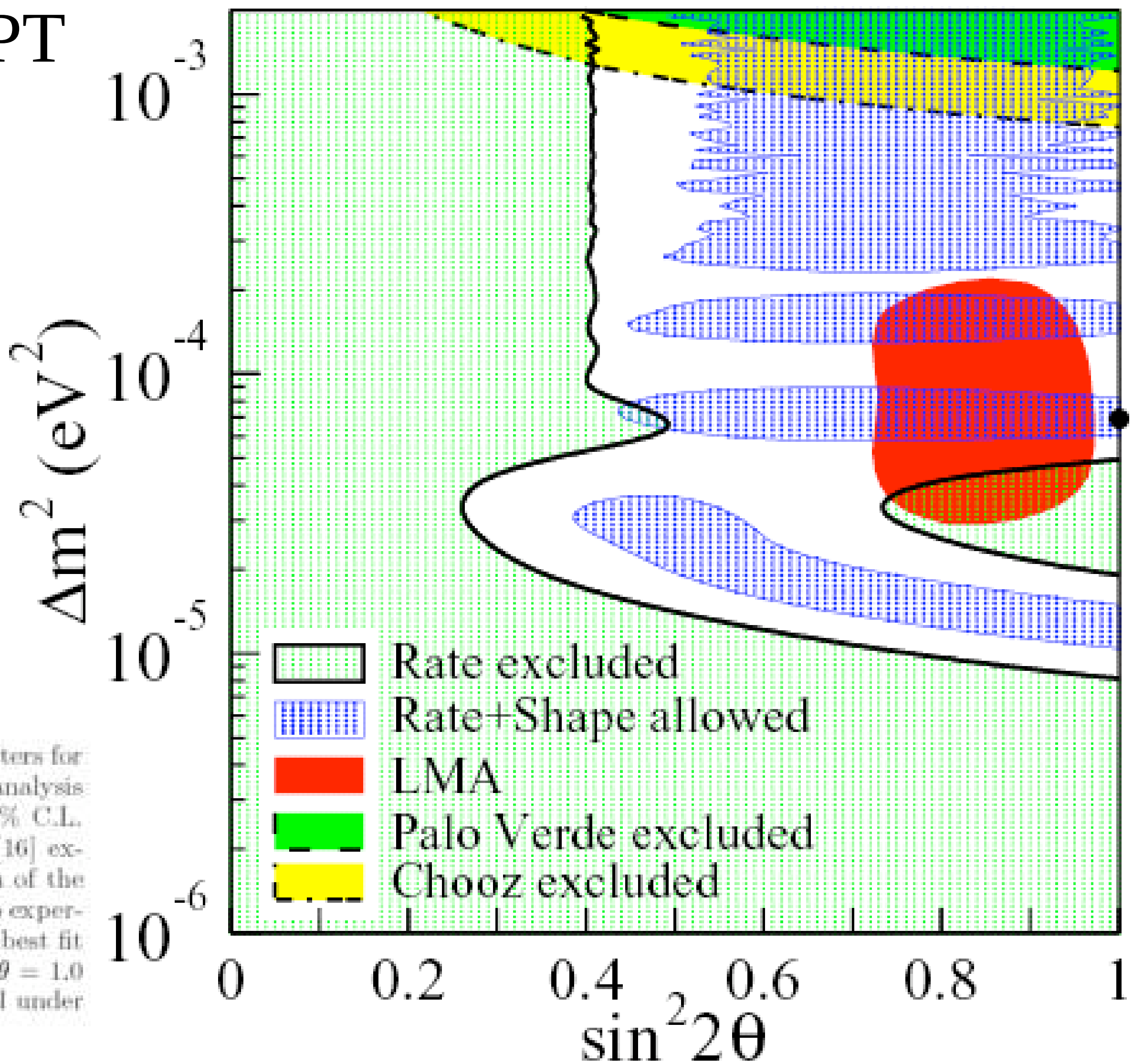


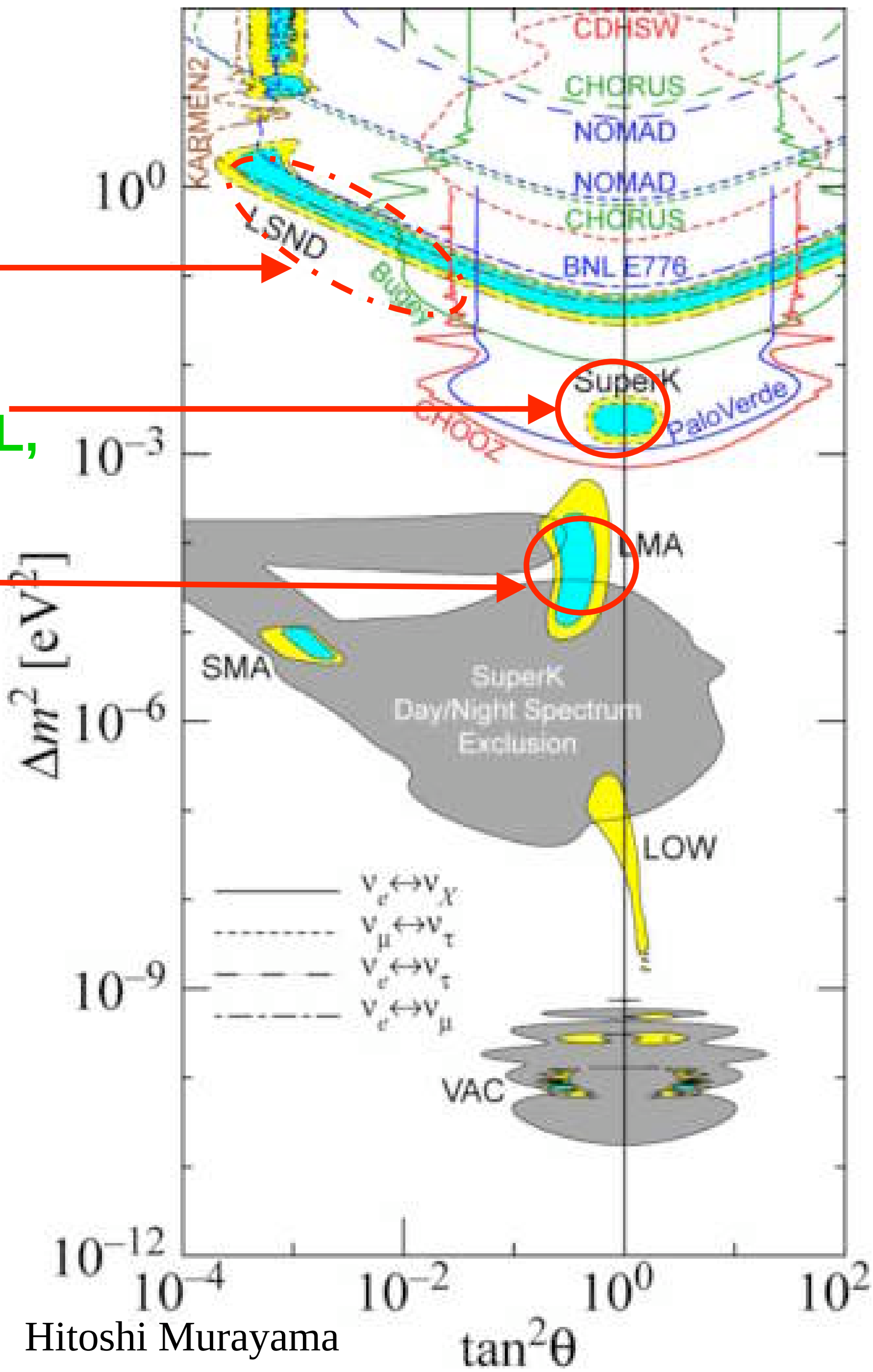
FIG. 6: Allowed regions of neutrino oscillation parameters for the rate analysis and the combined rate and shape analysis from KamLAND at 95% C.L. At the top are the 95% C.L. excluded region from CHOOZ [15] and Palo Verde [16] experiments, respectively. The 95% C.L. allowed region of the 'Large Mixing Angle' (LMA) solution of solar neutrino experiments [13] is also shown. The thick dot indicates the best fit to the KamLAND data in the physical region: $\sin^2 2\theta = 1.0$ and $\Delta m^2 = 6.9 \times 10^{-5}$ eV^2. All regions look identical under $\theta \leftrightarrow (\pi/2 - \theta)$ except for the LMA region.

n After April 2002

Accelerator n
MiniBoone

Atmospheric n
MINOS, K2K, LBL, Off-axis expt.

Solar n
SNO
KamLAND
Borexino



Hitoshi Murayama 2001

Outstanding Issues

- Precision determination of parameters, 3 family mixing
- Absolute n mass scale
- Sterile neutrinos?
- Modifications to Standard Model
- Origins of n mass
- CP violation in neutrino sector?