Reactor anti-neutrino disappearance (with KamLAND)

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Lunchtime Seminar

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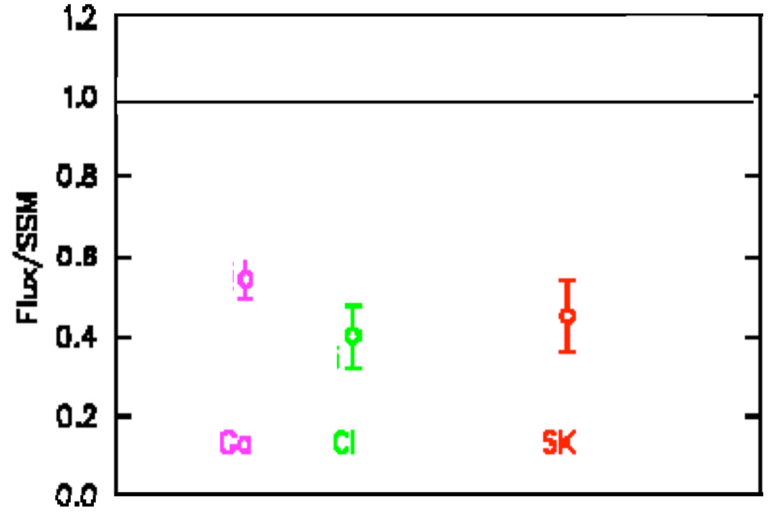
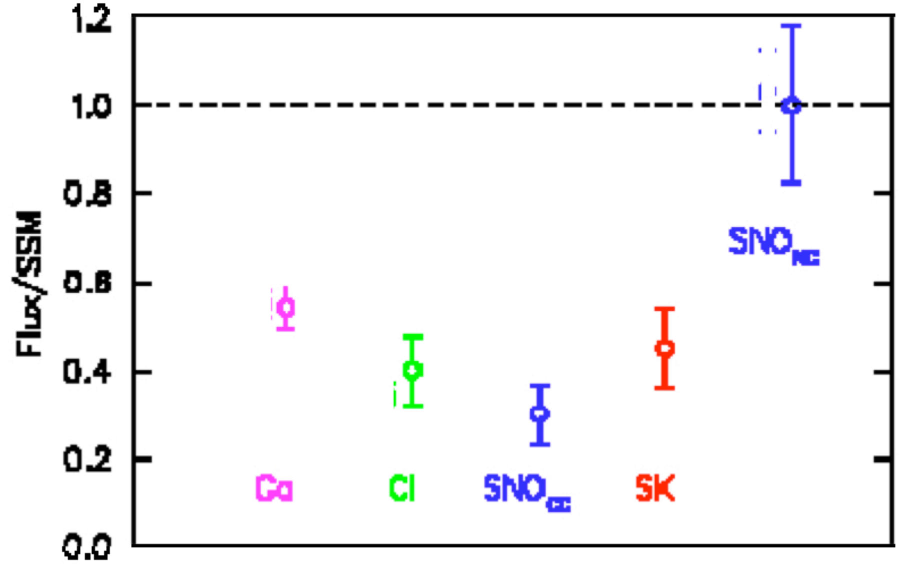
Solar Neutrino Problem

- Neutrino flux from sun to earth found at Cl / Ga and SuperK experiments ~1/2 of what expected from Standard Solar Model (SSM).
- But could SSM be wrong ?
- SNO confirmed that total flux (all flavours) arriving at earth agrees with SSM, but electron neutrinos only 1/3 of what expected.
- So electron neutrinos emitted in the sun arrive as a different flavour at earth



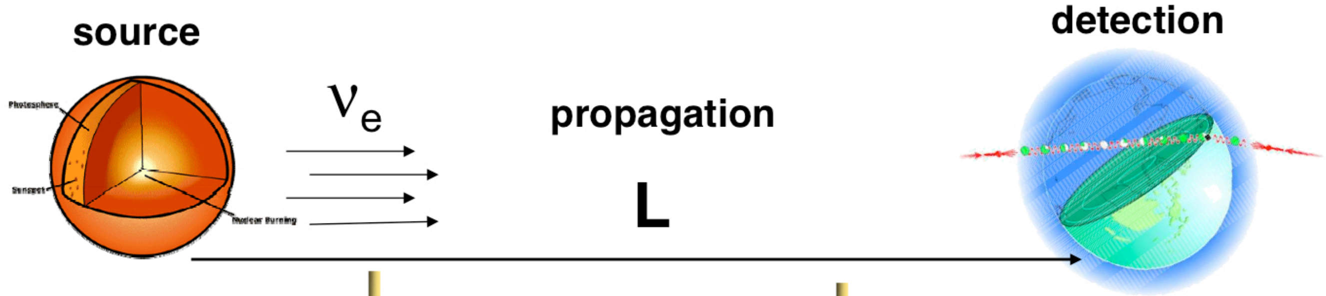


Neutrino Oscillations (?)

Neutrino Oscillations

Consider there are two types of objects,
Mass and Weak neutrino eigenstates.
These can be connected by a simple 2-d rotation :

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



The weak interaction produces neutrinos of a given flavor

$$|\nu(x_0)\rangle = |\nu_e\rangle$$
$$= c|\nu_1\rangle + s|\nu_2\rangle$$

The mass eigenstates Propagate at different velocities

$$|\nu(x)\rangle = c|\nu_1\rangle e^{i(Et-\vec{k}_1 \vec{x})}$$
$$+ \ s|\nu_2\rangle e^{i(Et-\vec{k}_2 \vec{x})}$$

Detection again via weak interaction

$$\nu_\mu N \to \mu^- X$$
$$\nu_e N \to e^- X$$

$$P(\nu_e \to \nu_\mu) = |<\nu_\mu | \nu(t)>|^2$$

Oscillation probability

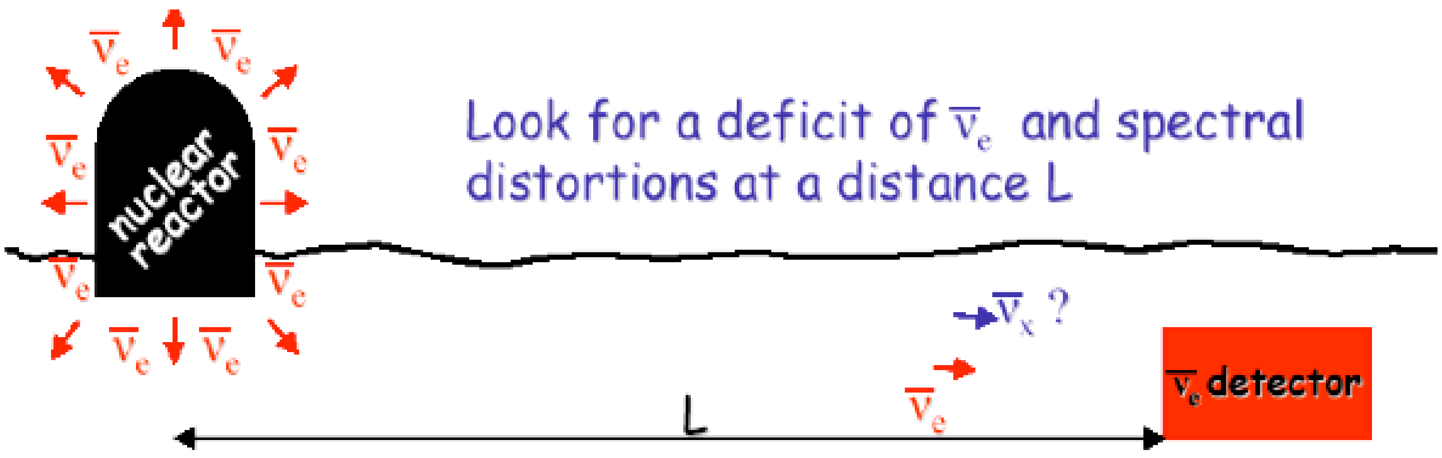
$$P_{\nu_e \to \nu_\mu}(L) = \sin^2(2\theta)\sin^2(1.27\frac{\Delta m^2(eV^2)}{E(GeV)}L(km))$$

Reactor Experiments

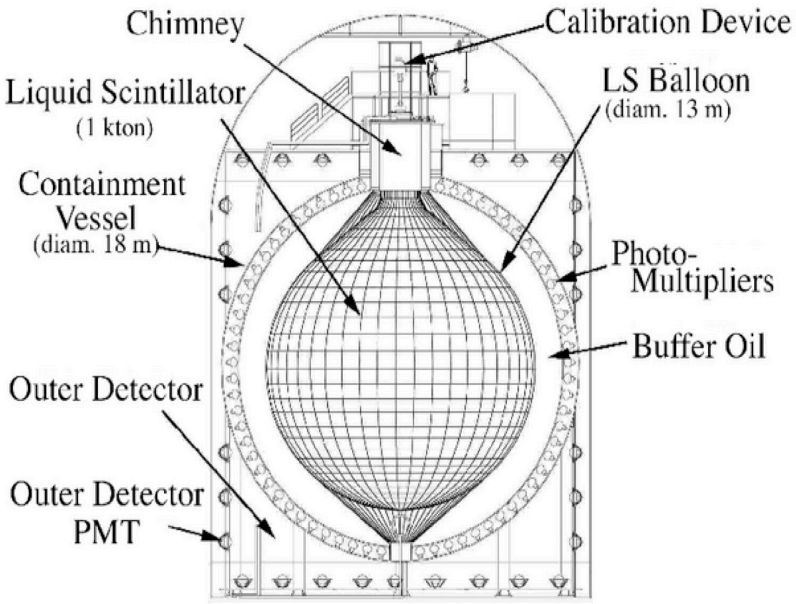
- Same principle holds for man-made neutrinos, but now well defined flux and L.
- Two methods :

Reactors	Accelerators
E ~ few MeV	E ~ few GeV
disappearance only	appearance possible
can probe v.small Δm^2	requires v.large L
fair $\sin^2 2\theta$ sensitivity	Produce μ and τ

- First detected neutrino (Reines, Cowan - 1953) came from a reactor (Savannah River)
- Nuclear reactors are very intense sources of $\bar{\nu}_e$ deriving from beta-decay of the neutron-rich fission fragments -> Yield ~ 6 $\bar{\nu}_e$ / fission at ~3MeV energy.



Kamioka Liquid scintillator Anti-Neutrino Detector



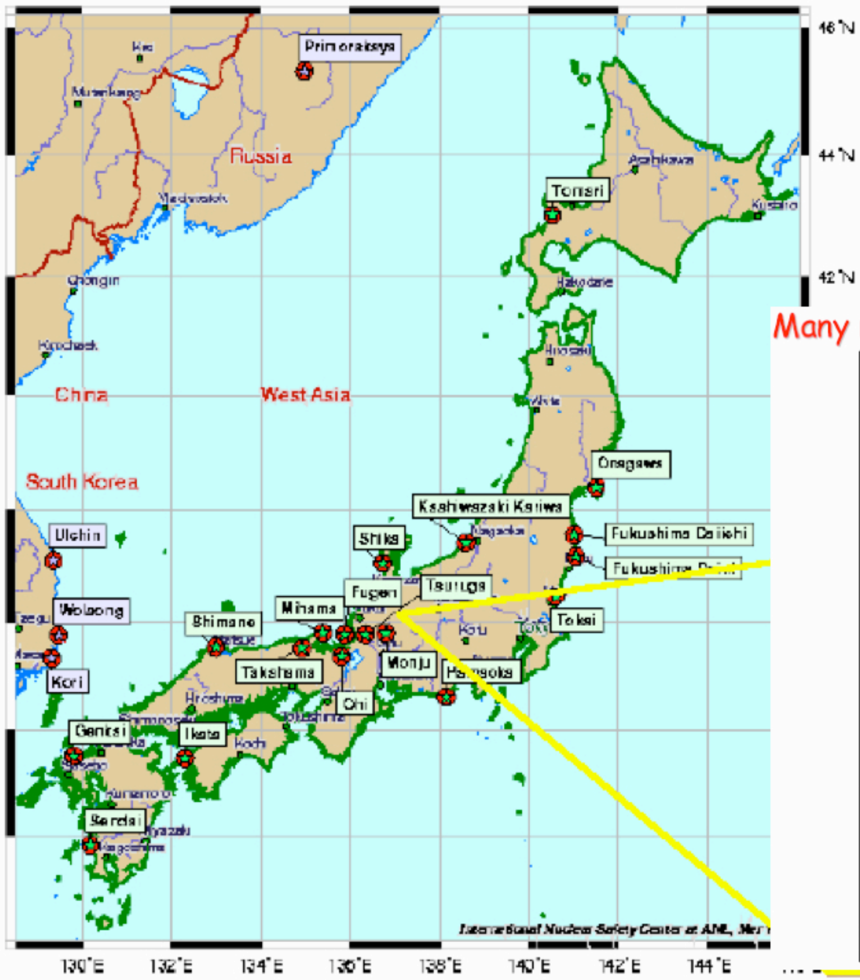
- 1 kton liq. Scintillator detector in the old Kamiokande cavern (1km undergr.) housed in a 13m diameter balloon.
- 1879 PMTs covering Inner Detector (ID)
- Outer Detector (OD) filled with ~3200 m^3 of pure water and 225 old Kamiokande PMTs to detect cosmic ray muons and absorb gamma rays and neutrons from surrounding rock radioactivity.
- Antineutrinos detected through inverse beta decay in LS
  Coincidence signal provides great handle over background.
- Energy / vertex calibration by inserting known radioactive sources.

KamLAND site

180 GW thermal power (~7% world's nuclear power) ~ 3.4e22 $\bar{\nu}_e$/ s

80% of total flux from baselines ~ 180 km.

Typical neutrino energies ~3MeV



Expected flux well defined (within ~1%) provided by Nuclear Power companies

Many reactors contribute to the antineutrino flux at KamLAND

	Site	Dist (km)	Cores (#)	P_{therm} (GW)	Flux ($cm^{-2}\,s^{-1}$)	Rate noosc* ($yr^{-1}\,kt^{-1}$)
Japan	Kashiwazaki	160	7	24.3	$4.1\cdot10^5$	254.0
	Ohi	179	4	13.7	$1.9\cdot10^5$	114.3
	Takahama	191	4	10.2	$1.2\cdot10^5$	74.3
	Tsuruga	138	2	4.5	$1.0\cdot10^5$	62.5
	Hamaoka	214	4	10.6	$1.0\cdot10^5$	62.0
	Mihama	146	3	4.9	$1.0\cdot10^5$	62.0
	Sika	88	1	1.6	$9.0\cdot10^4$	55.2
	Fukushima1	349	6	14.2	$5.1\cdot10^4$	31.1
	Fukushima2	345	4	13.2	$4.8\cdot10^4$	29.5
	Tokai2	295	1	3.3	$1.6\cdot10^4$	10.1
	Onagawa	431	3	6.5	$1.5\cdot10^4$	9.3
	Simane	401	2	3.8	$1.0\cdot10^4$	6.3
	Ikata	561	3	6.0	$8.3\cdot10^3$	5.1
	Genkai	755	4	10.1	$7.8\cdot10^3$	4.8
	Sendai	830	2	5.3	$3.4\cdot10^3$	2.1
	Tomari	783	2	3.3	$2.3\cdot10^3$	1.4
South Korea	Ulchin	712	4	11.5	$9.9\cdot10^3$	6.1
	Yonggwang	986	6	17.4	$7.8\cdot10^3$	4.8
	Kori	735	4	9.2	$7.5\cdot10^3$	4.6
	Wolsong	709	4	8.2	$7.1\cdot10^3$	4.3
Total Nominal		-	70	181.7	$1.3\cdot10^6$	803.8

*E_ν>3.4MeV (E_{prompt}>2.6MeV)

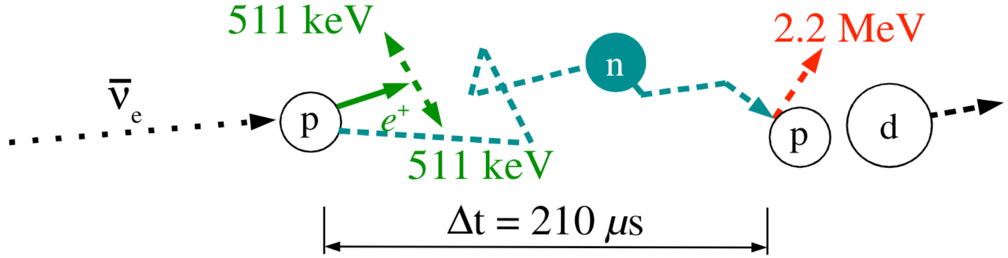
Detailed power and fuel Composition calculation used

From electrical power Japanese average fuel used

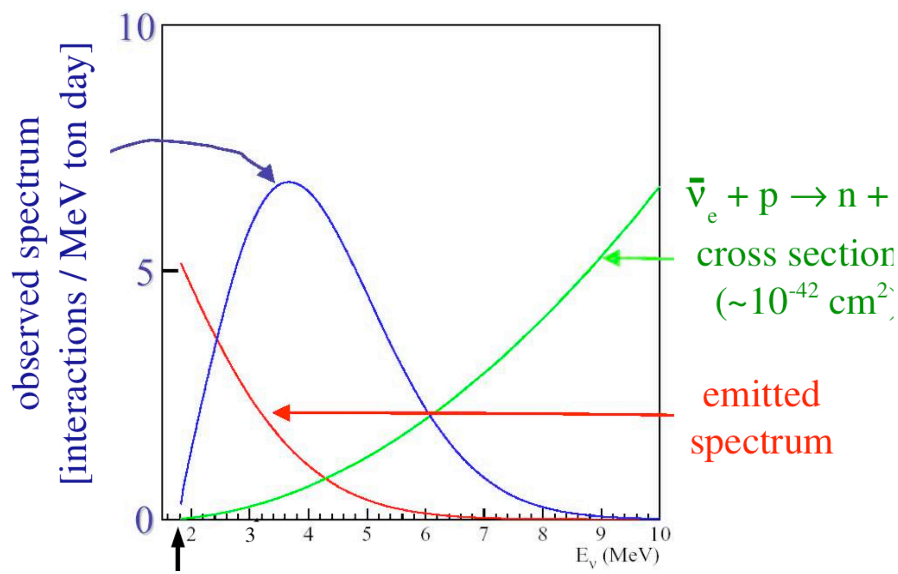
Detection Method

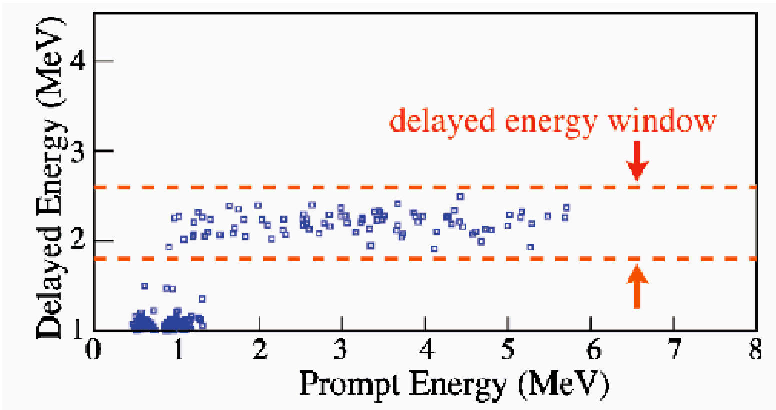
- Detection through inverse beta decay in LS
- Coincidence signal provides great handle over background
- Event locations are reconstructed from timing of PMT hits.

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



Coincidence signal: detect
- Prompt: e^+ energy + annihilation γ
- Delayed: **n**-capture γ





Selection Cuts

- Fiducial volume ($R < 5m$)
  - To avoid fast neutrons from rock.
- Time correlation ($0.5\ \mu sec < \Delta t < 660\ \mu sec$)
- Vertex correlation ($\Delta R < 1.6m$)
- Delayed Energy ($1.8\ MeV < E_{delay} < 2.6\ MeV$)
- Prompt Energy ($E_{prompt} > 2.6\ MeV$)
  - To avoid ambiguity with geoneutrinos

Total Efficiency : 78.3 ± 1.6 %

- Outer Detector veto (eliminate cosmic muon backgrounds)
  - Muons leave neutrons which can fake delayed signal
    - Veto detector for 2ms after muon in OD
  - Muons also create longer lived (>100ms) neutron emitters
    - Veto 3m cylinder cone around muon track for 2s
    - For high energy muons (>3GeV) veto entire detector for 2s

Results

Result using 145.1 days of data measures

54 events

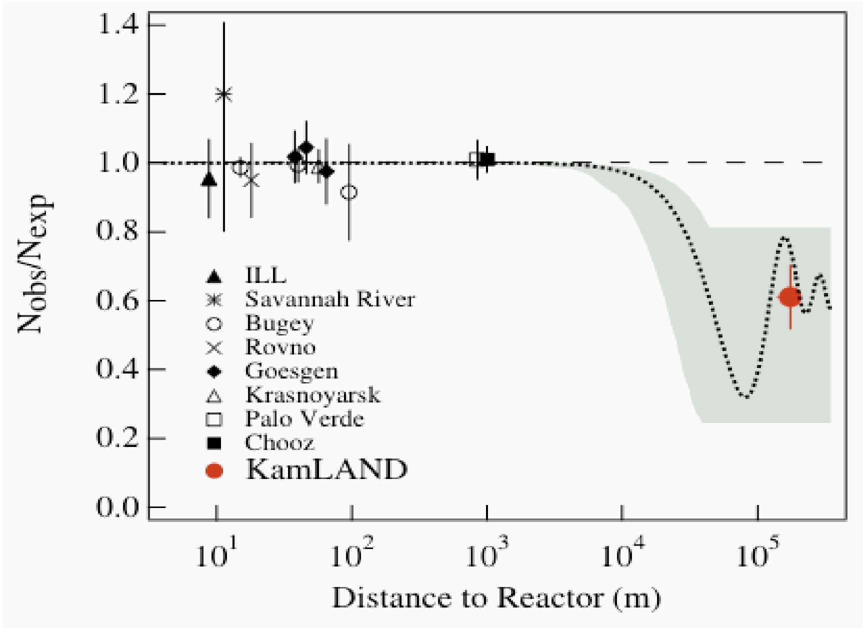
While the 'no oscillations' scenario predicts

86.8±5.6 events (1±1 bkgd)

Corresponding to

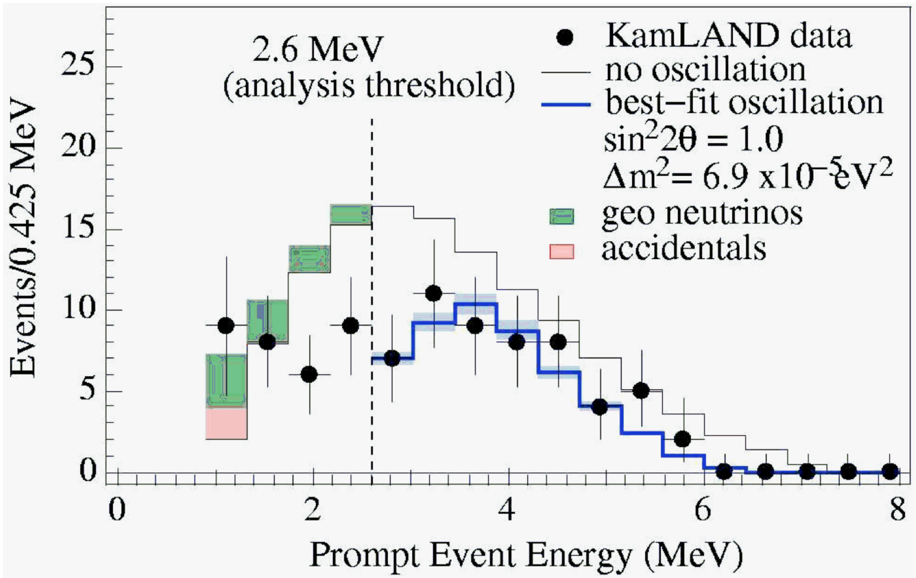
$$\frac{N_{\rm obs} - N_{\rm BG}}{N_{\rm expected}} = 0.611 \pm 0.085({\rm stat}) \pm 0.041({\rm syst}).$$

Which demonstrates reactor antineutrino disappearance at the 99.95% C.L.



By fitting the antineutrino spectrum the best-fit oscillation parameters can be extracted.

These exclude all solutions to the Solar Neutrino problem except the Large Mixing Angle solution (LMA).



Fit to oscillation parameters

Best fit parameters:

$\Delta m^2 = 6.9 \times 10^{-5}\ eV^2$

$\sin^2 2\theta = 1.0$

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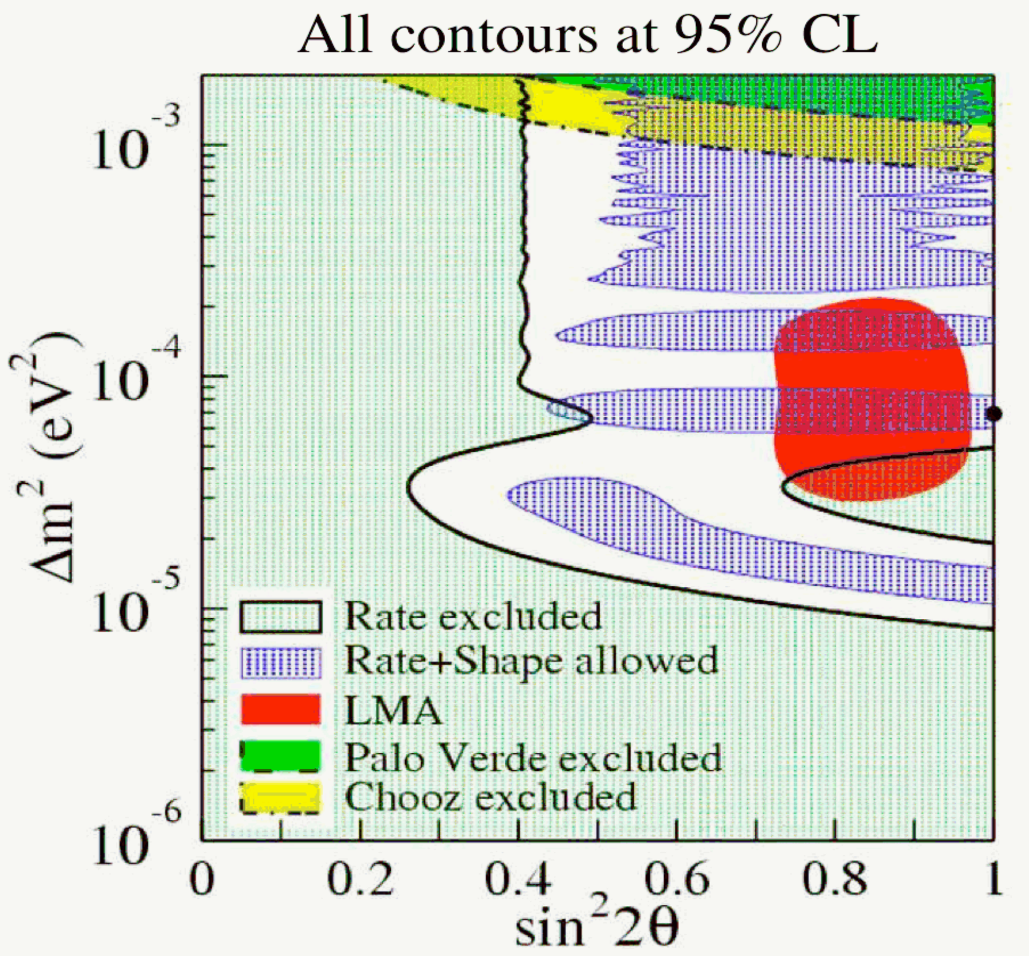

The END !

More on http://kamland.lbl.gov/