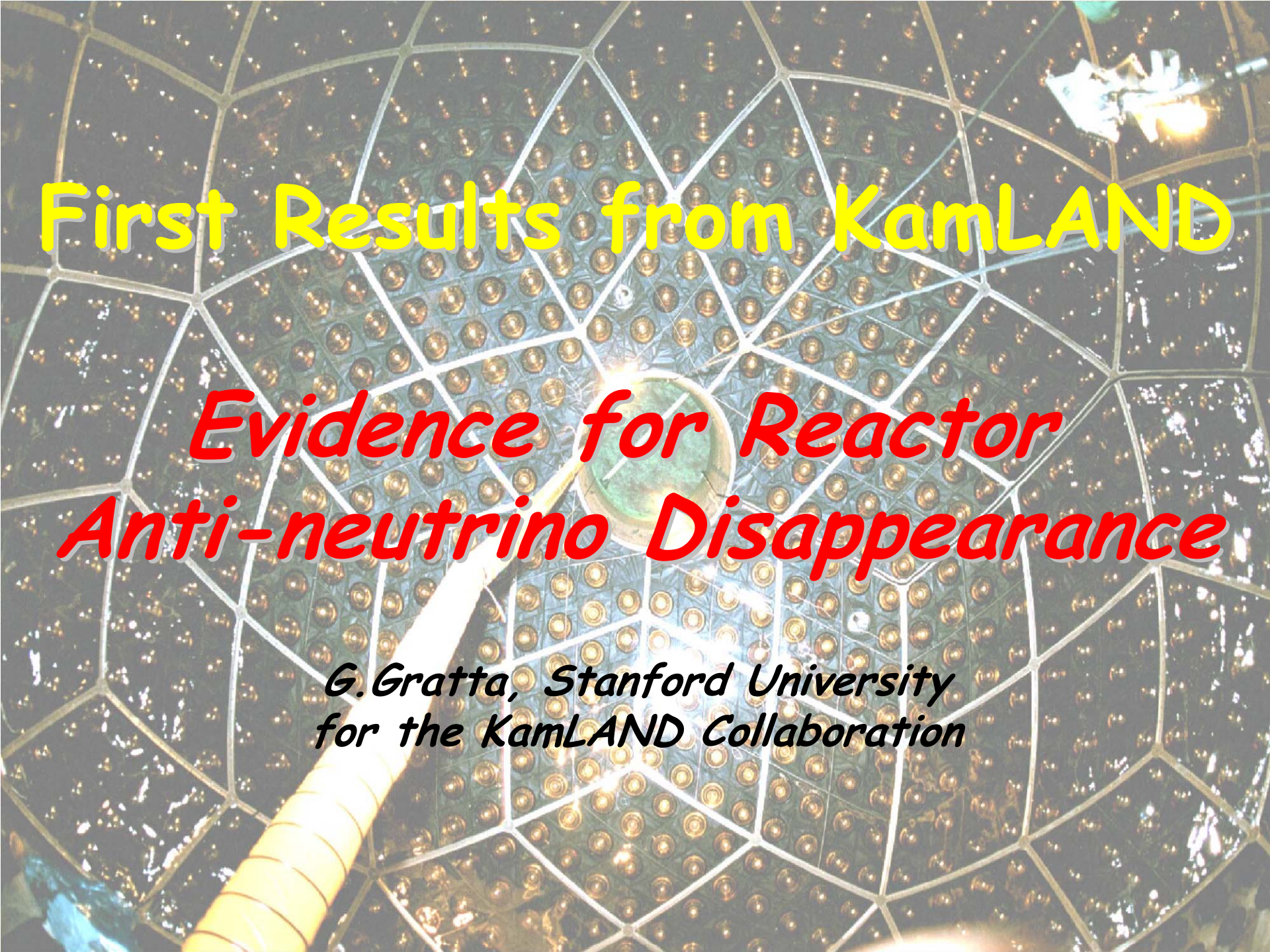
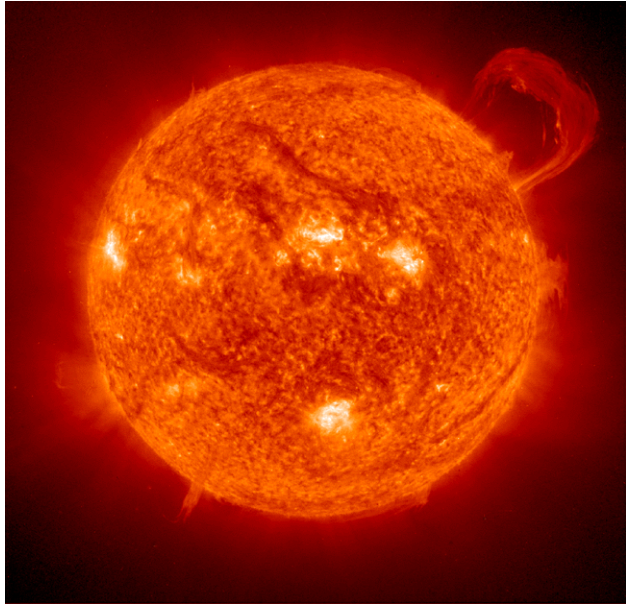


First Results from KamLAND

Evidence for Reactor Anti-neutrino Disappearance

G.Gratta, Stanford University
for the KamLAND Collaboration

ν_e are abundant by-products of nuclear fusion in the sun



$p + p \rightarrow {}^2H + e^+ + \nu_e + 0.42MeV$ "pp" 99.75%

$p + e^- + p \rightarrow {}^2H + \nu_e + 1.44MeV$ "pep" 0.25%

${}^2H + p \rightarrow {}^3He + \gamma + 5.49\ MeV$

86% ${}^3He + {}^3He \rightarrow \alpha + 2p + 12.86MeV$

14% ${}^3He + \alpha \rightarrow {}^7Be + \gamma + 1.59MeV$

"hep" 2.4*10^{-5} ${}^3He + p \rightarrow \alpha + e^+ + \nu_e$

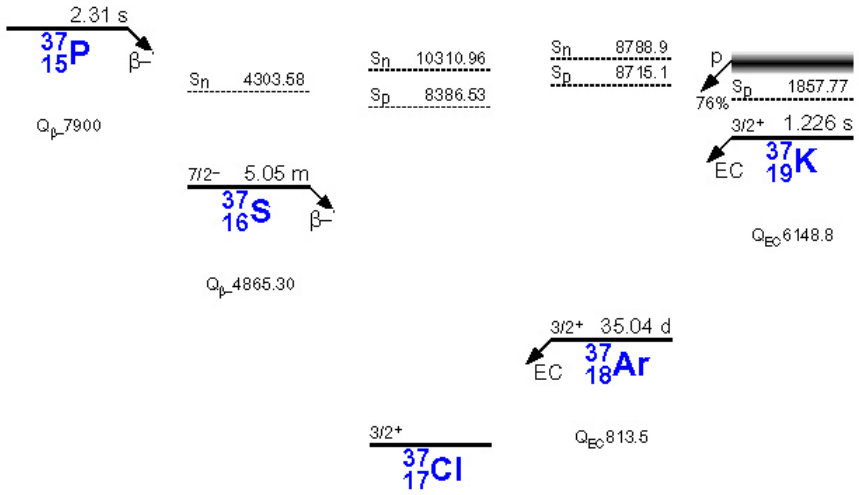
"^{7}Be" 99.89% ${}^7Be + e^- \rightarrow {}^7Li + \gamma + \nu_e + 0.8617MeV$

0.11% ${}^7Be + p \rightarrow {}^8B + \gamma + 0.14MeV$

${}^7Li + p \rightarrow \alpha + \alpha + 17.35MeV$

"^{8}B" 0.11% ${}^8B \rightarrow {}^8Be + e^+ + \nu_e + 14.6MeV$

${}^8Be \rightarrow \alpha + \alpha + 3MeV$



Homestake Mine, Lead SD
1400 m underground

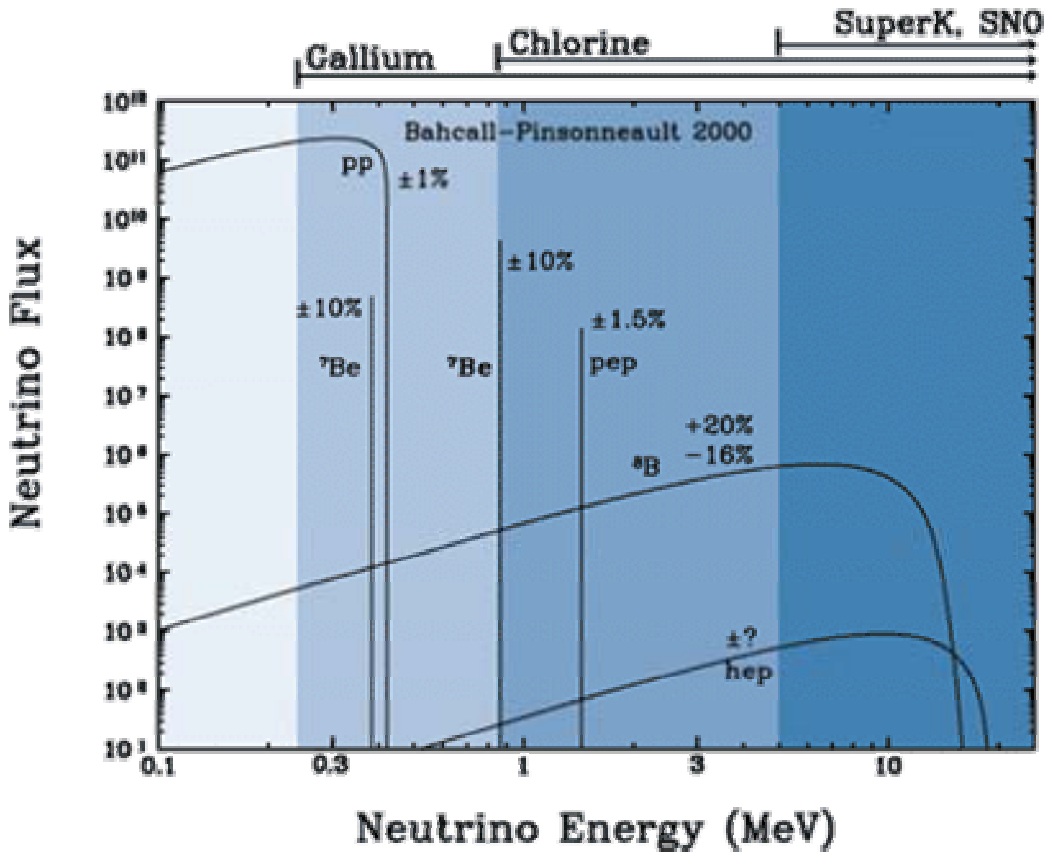
615 tons of perchloroethilene
(C_2Cl_4)

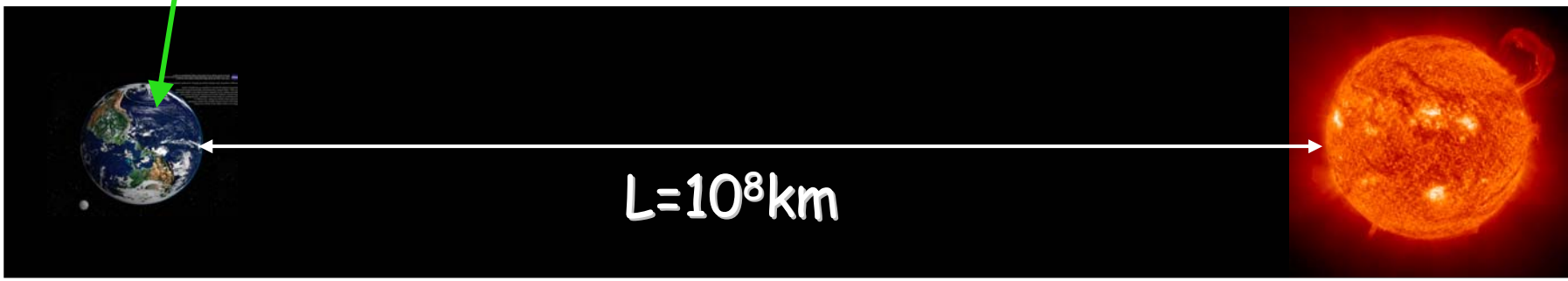
$2.2*10^{30}$ atoms of ^{37}Cl
^{36}Ar or ^{38}Ar added to the fluid as carrier gas

Data taken continuously since 1967 (!)

3 types of experiments detecting solar neutrinos

- Chlorine: $^{37}Cl+\nu_e=^{37}Ar+e^-$
  1 exp running >30 yrs (US)
- Gallium: $^{71}Ga+\nu_e=^{71}Ge+e^-$
  3 exp (Russia, Italy)
- Cerenkov: $e^-+\nu_e=e^-+\nu_e$
  3 exp (Japan, Canada)

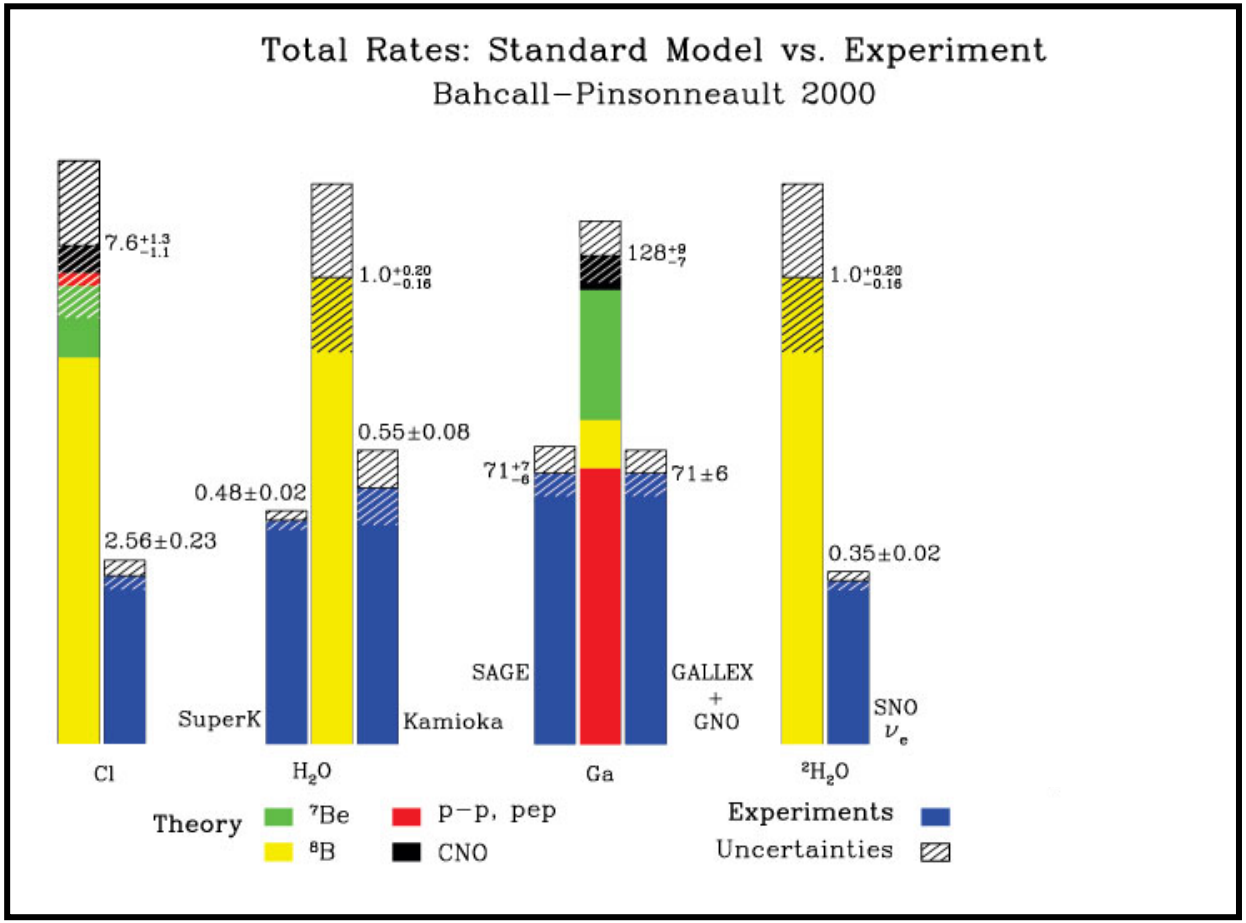




Conclusion':

We do not see enough vs !

- *do we understand the sun well enough ?*
- *are vs playing tricks ?*



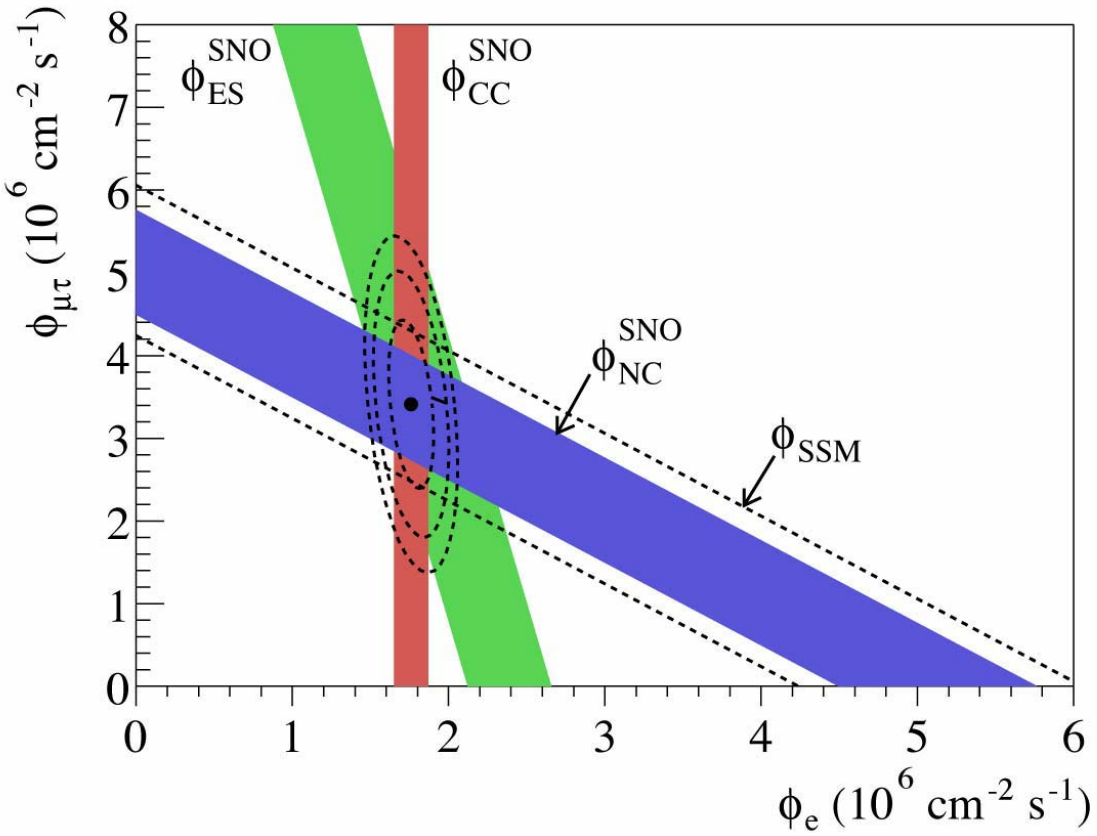
"It starts to be really interesting ! It would be nice if all this will end with something unexpected from the point of view of particle physics. Unfortunately it will not be easy to demonstrate this, even if nature works this way..." B.Pontecorvo, 1972

SNO: 1 kton of D_2O

$$\nu_x + e^- \rightarrow \nu_x + e^-$$

$$\nu_e + e^- \rightarrow \nu_e + e^-$$

sensitive to a ν_e, ν_x mix



$$\nu_e + {}^2H \rightarrow \nu_x + p + n$$

equally sensitive to all neutrinos

$$\nu_e + {}^2H \rightarrow p + p + e^-$$

sensitive to ν_e only

For 2 flavors this simplifies:

$$U = \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix}$$

Only one mixing parameter θ

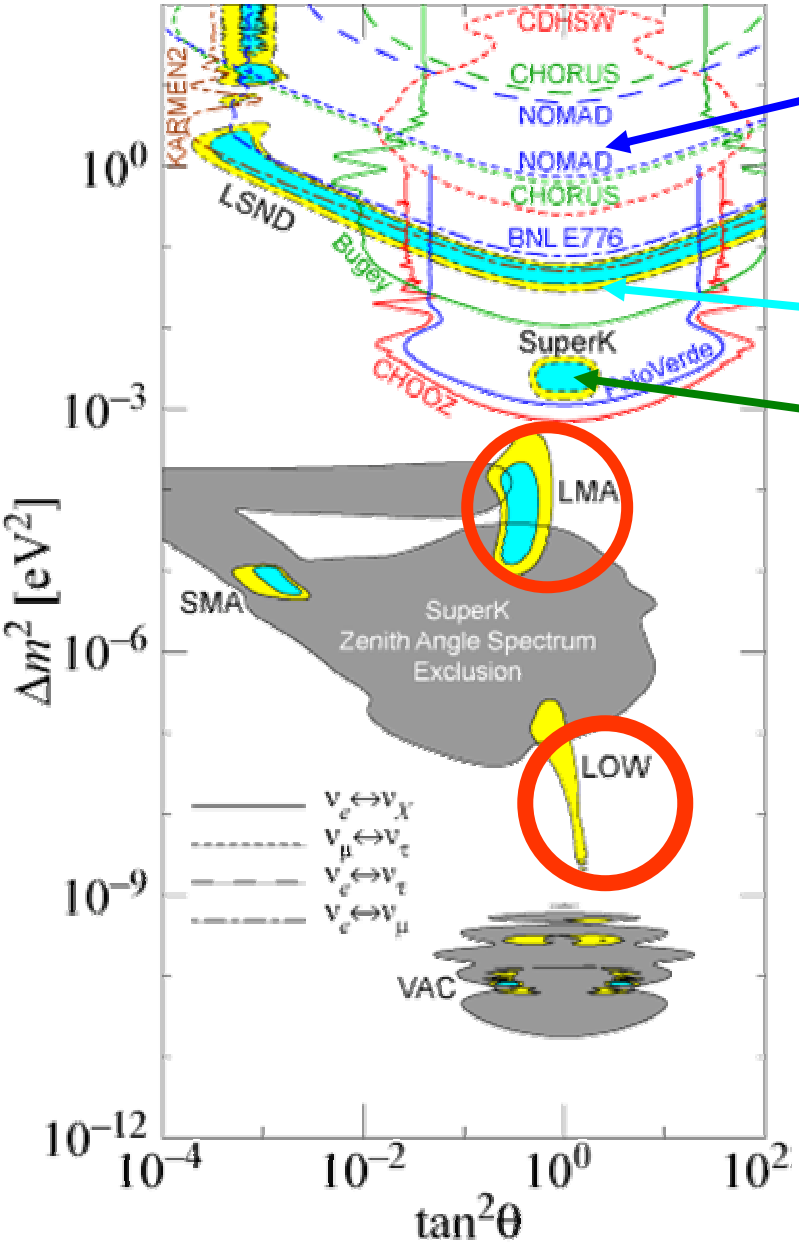
$$P(\nu_e \rightarrow \nu_\mu, L) = \sin^2 2\theta \ \sin^2 \frac{1.3\Delta m^2 L}{E}$$

$m_1^2 - m_2^2$ [eV²]

[km]

[MeV]

Neutrino oscillations ➡ $m_\nu \neq 0$



Excluded regions from other experiments

Possible oscillations from LSND

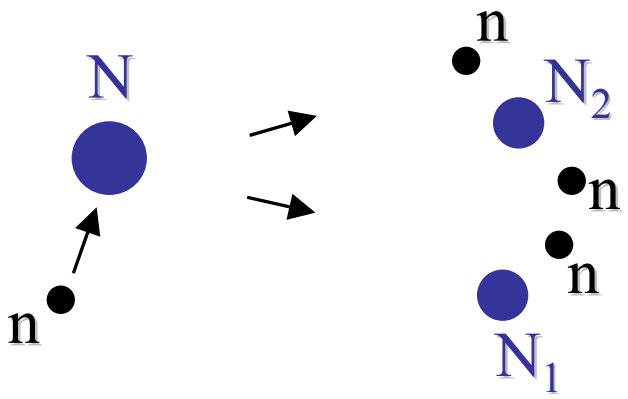
Oscillations from "atmospheric neutrinos"

If the correct interpretation is that neutrinos oscillate only two solutions are compatible with all solar data

All of this is very interesting…

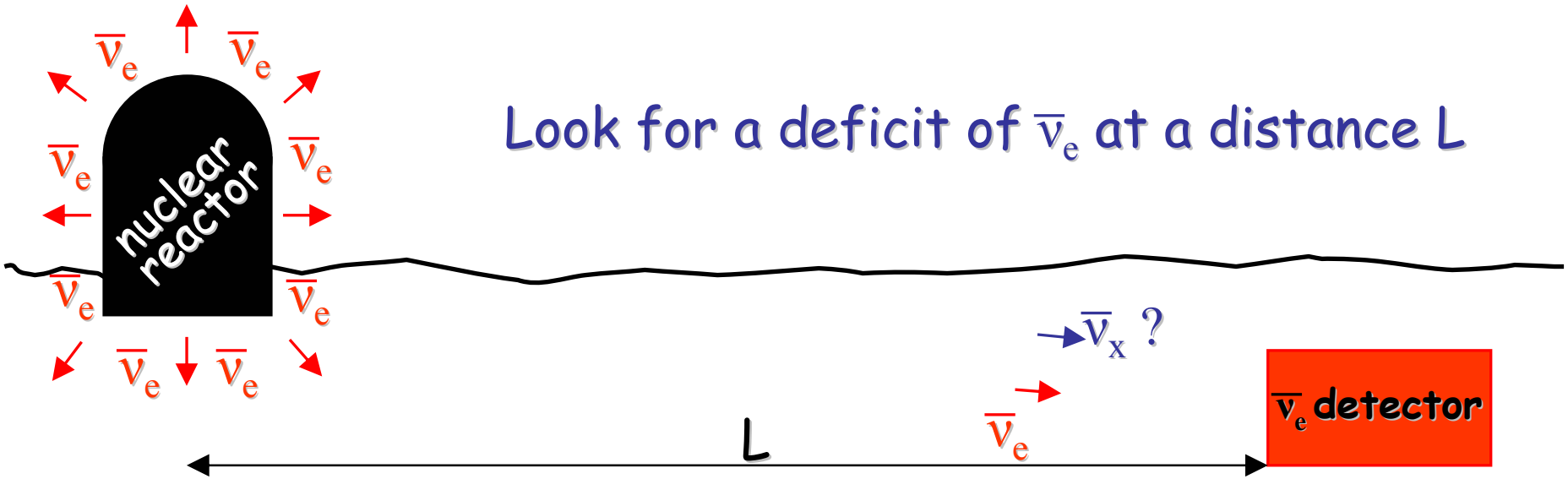
…but wouldn't it be great if we could reproduce it with with artificial means ?

Nuclear reactors are very intense sources of ν_e deriving from beta-decay of the neutron-rich fission fragments

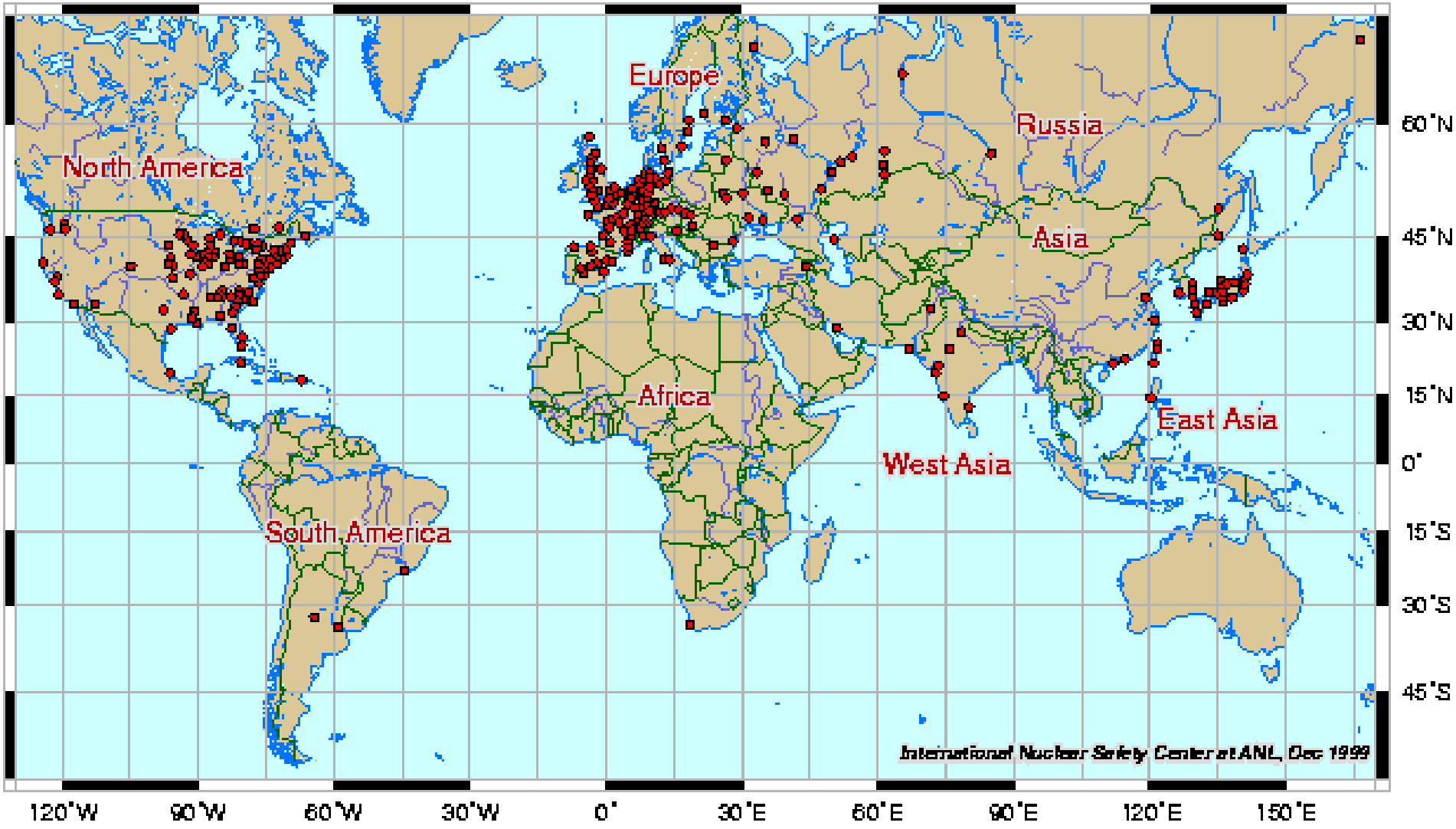


N_1 and N_2 still have too many neutrons and decay

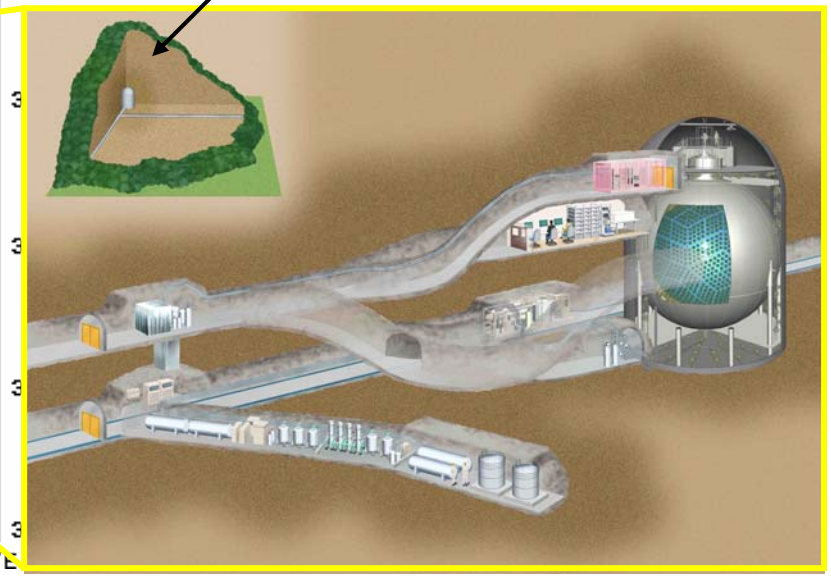
$$N_2 \rightarrow N_3 + e^- + \nu_e$$



Need to think regionally: large concentration of nuclear power plants exist in Europe, eastern US and Japan

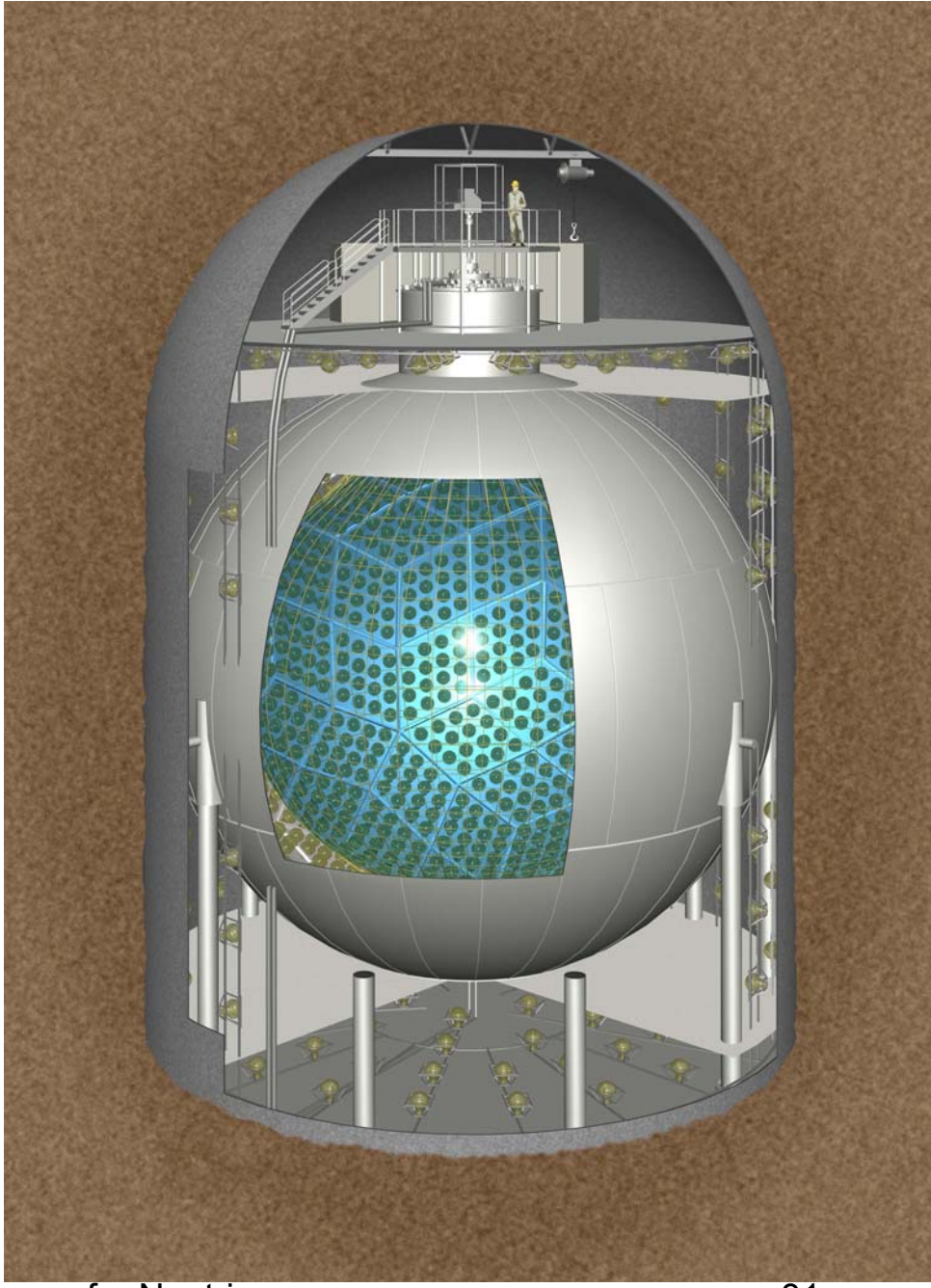


~1 km high
Mt Ikenoyama



KamLAND: the ultimate reactor neutrino oscillation experiment

- 1 kton liq. Scint. Detector in the Kamioka cavern
- ~1300 17" fast PMTs
- ~700 20" large area PMTs
- 30% photocathode coverage
- H_2O Cerenkov veto counter
- Multi-hit deadtime-less electronics
- Δm^2 sensitivity $7*10^{-6}$ eV^2 LMA-MSW solution within reach <u>on the earth !</u>



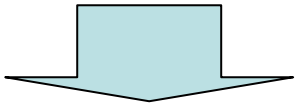
The total electric power produced "as a by-product" of the νs is:

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

Total expected signal from reactors in 1 kton: ≈2 ev/day

Expected S/N ratio ≈ 20
@ 10^{-14} U, Th, ^{40}K contamination in the scintillator

Since reactors produce $\bar{\nu}_e$ while the sun produces ν_e the equivalence of solar neutrino oscillations with what can be observed with the KamLAND reactor experiment rests on the validity of CPT

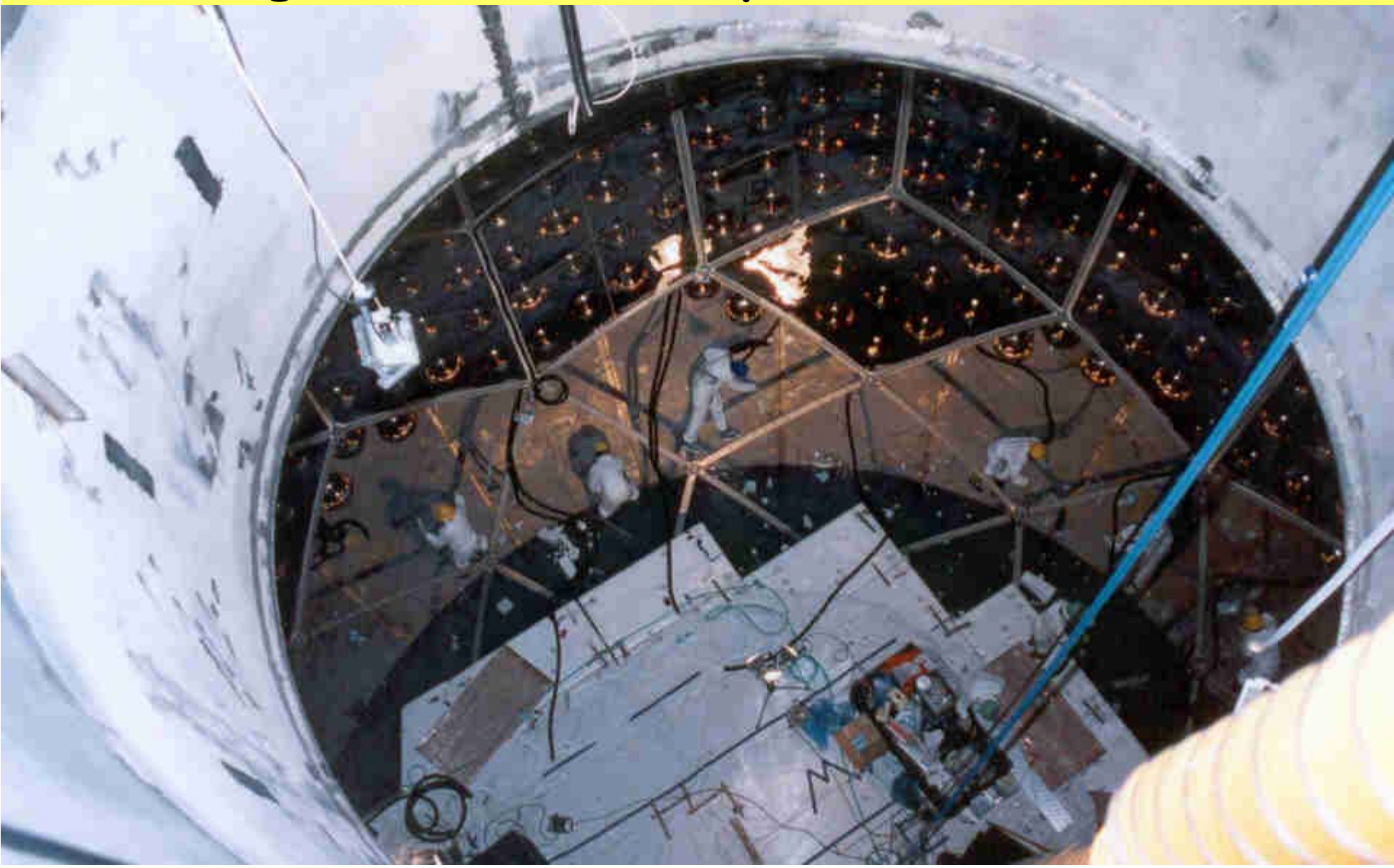


An unexpected oscillation pattern in KamLAND could be an indication of CPT violation

KamLAND: neutrino physics on a shinkansen

- Summer 2000 — PMT installation
- Winter 2000-01 — Veto counter installation
- Feb 2001 — Balloon insertion
- Mar-Apr 2001 — Balloon inflation and test
- Apr-May 2001 — Plumbing for fill
- Jun-Sept 2001 — Fill MO and LS
- Aug-Sept 2001 — Eng. runs with Macro Elec.
- Sept 2001 — FEE/DAQ/Trigger int. (LBL)
- end Sept 2001 — First data taking with FEE
- Jan 22, 2002 — Begin Data Taking
- Dec 6, 2002 — First Physics Paper (hep-ex/0212021)

Cleaning the KamLAND sphere (Summer 2000)



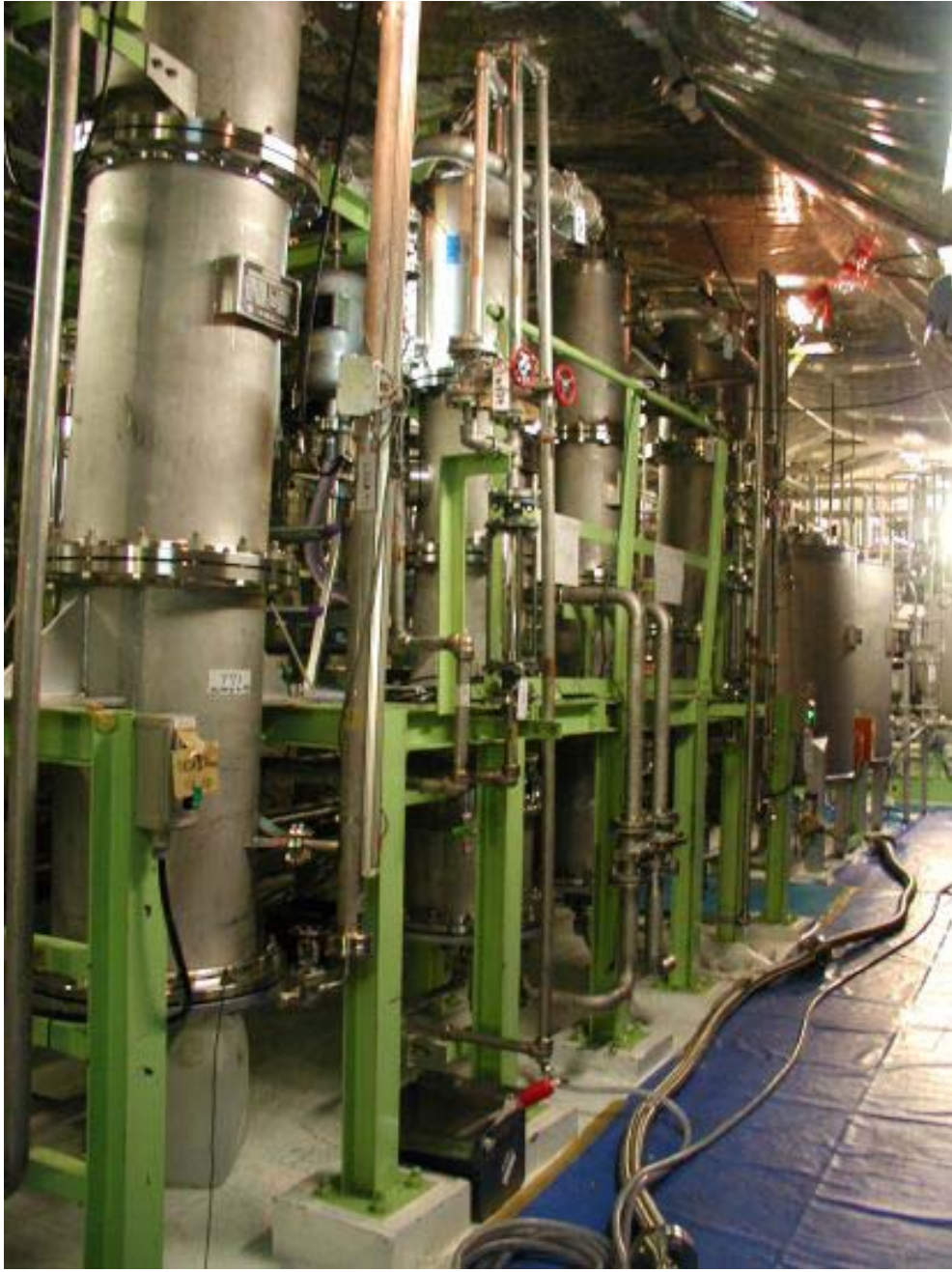
Installing 17" and 20" PMTs in KamLAND (Summer 2000)

Scintillator is a blend of 20% pseudocumene and 80% dodecane

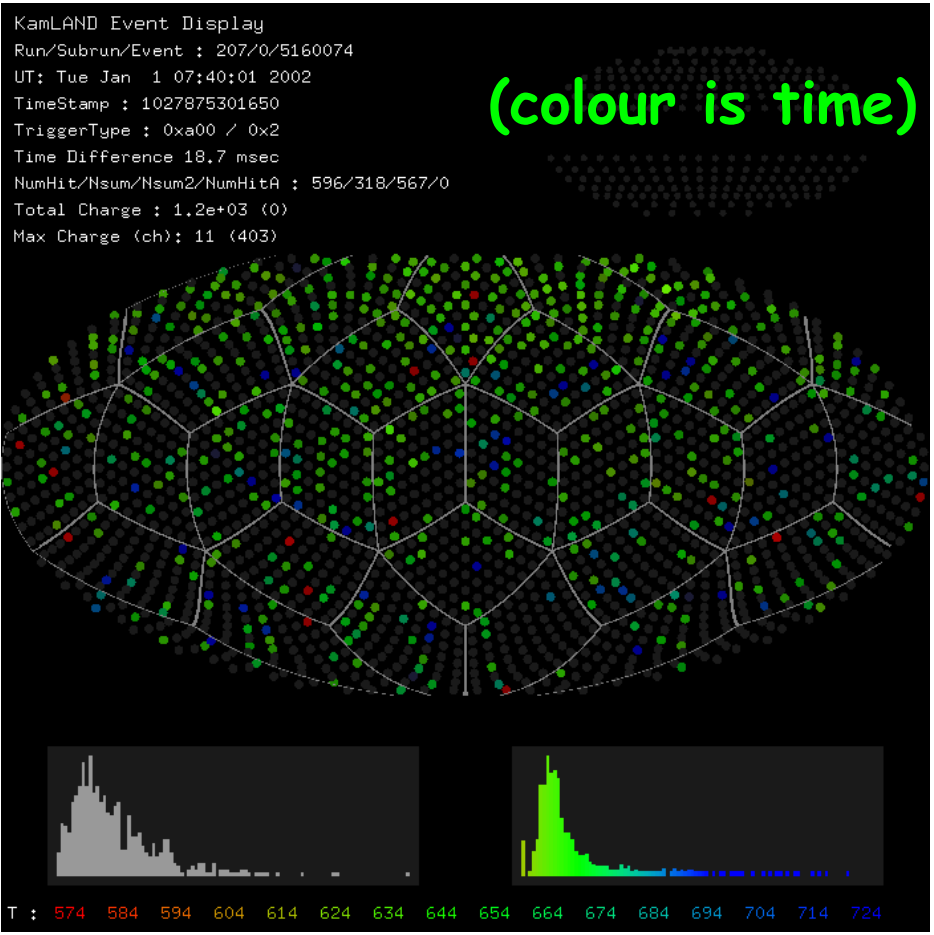
Different density paraffines are used to tune the density of buffer to 0.995 of that of the scintillator

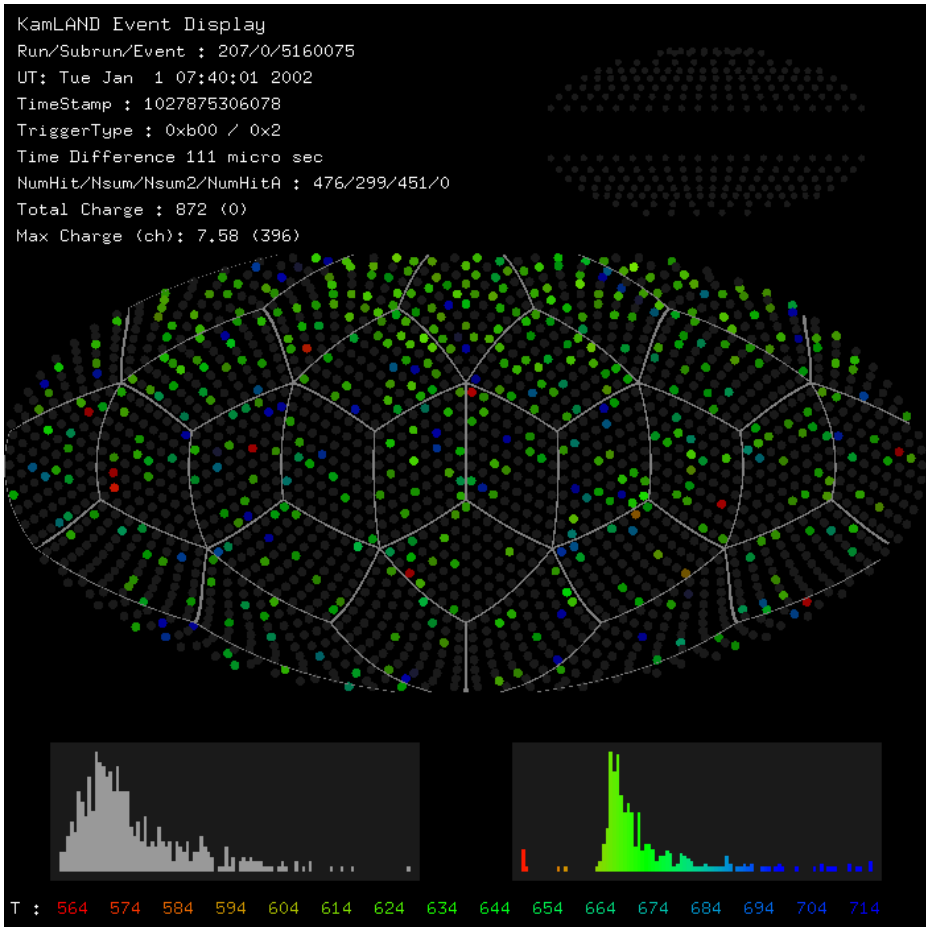
PPO concentration is 1.5 g/l of the final scint.

During blending the liquids are pre-purified.



Anti-Neutrino Candidate





Prompt Signal
E = 3.20 MeV

Δt = 111 μs
ΔR = 34 cm

Delayed Signal
E = 2.22 MeV

Observed Event Rates with $E_{prompt} > 2.6$ MeV

Data	54 events
Expected	86.8 ± 5.6 events
Total Background	0.95 ± 0.99 events
accidental	*0.0086 ± 0.0005*
^{9}Li/^{8}He	*0.94 ± 0.85*
fast neutron	*< 0.5*

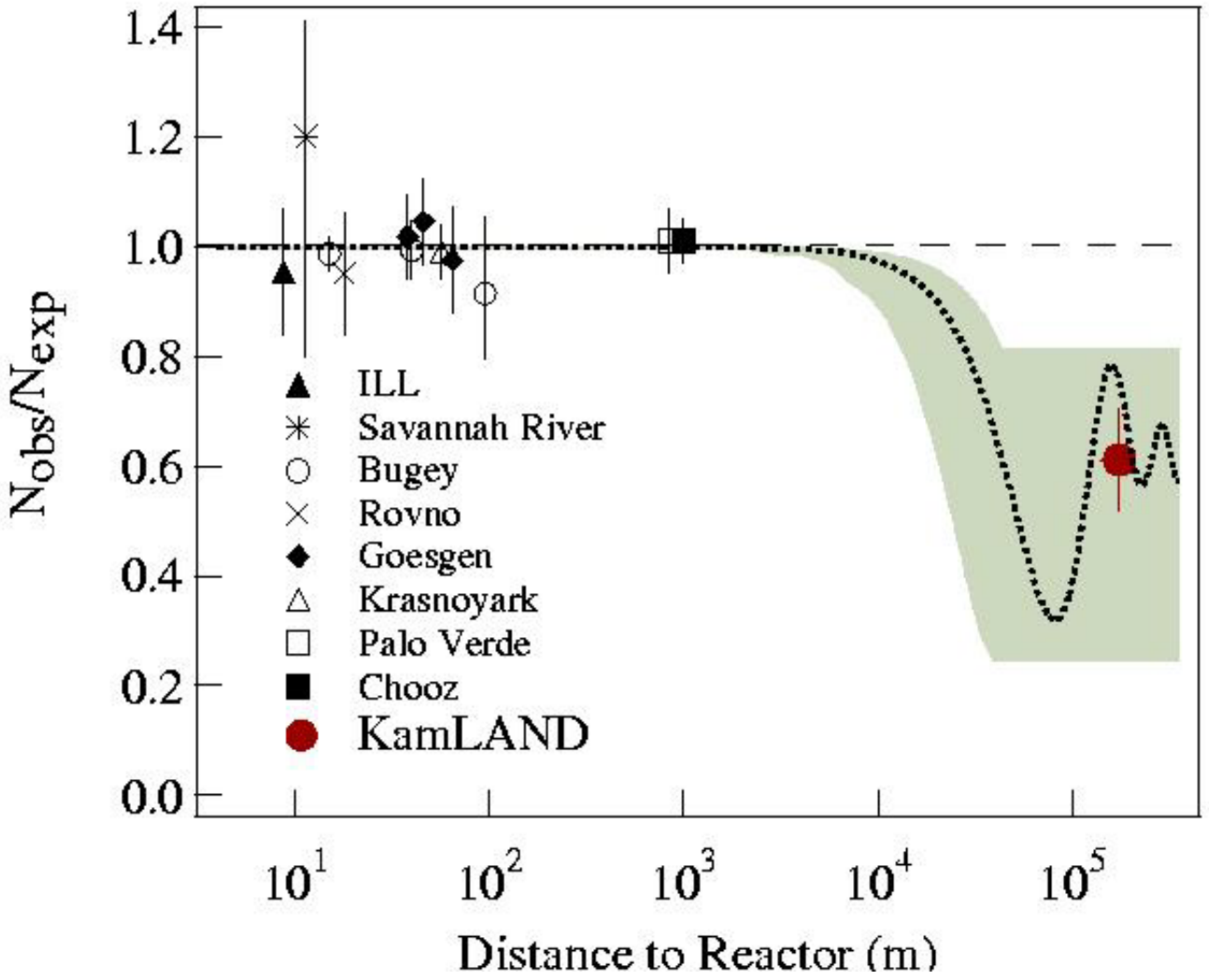
Evidence for Reactor $\bar{\nu}_e$ Disappearance

for $E_\nu > 3.4$ MeV

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

Inconsistent with $1/R^2$ flux dependence at 99.95 % C.L.

After 30 years of work reactor neutrinos finally are unmasked !

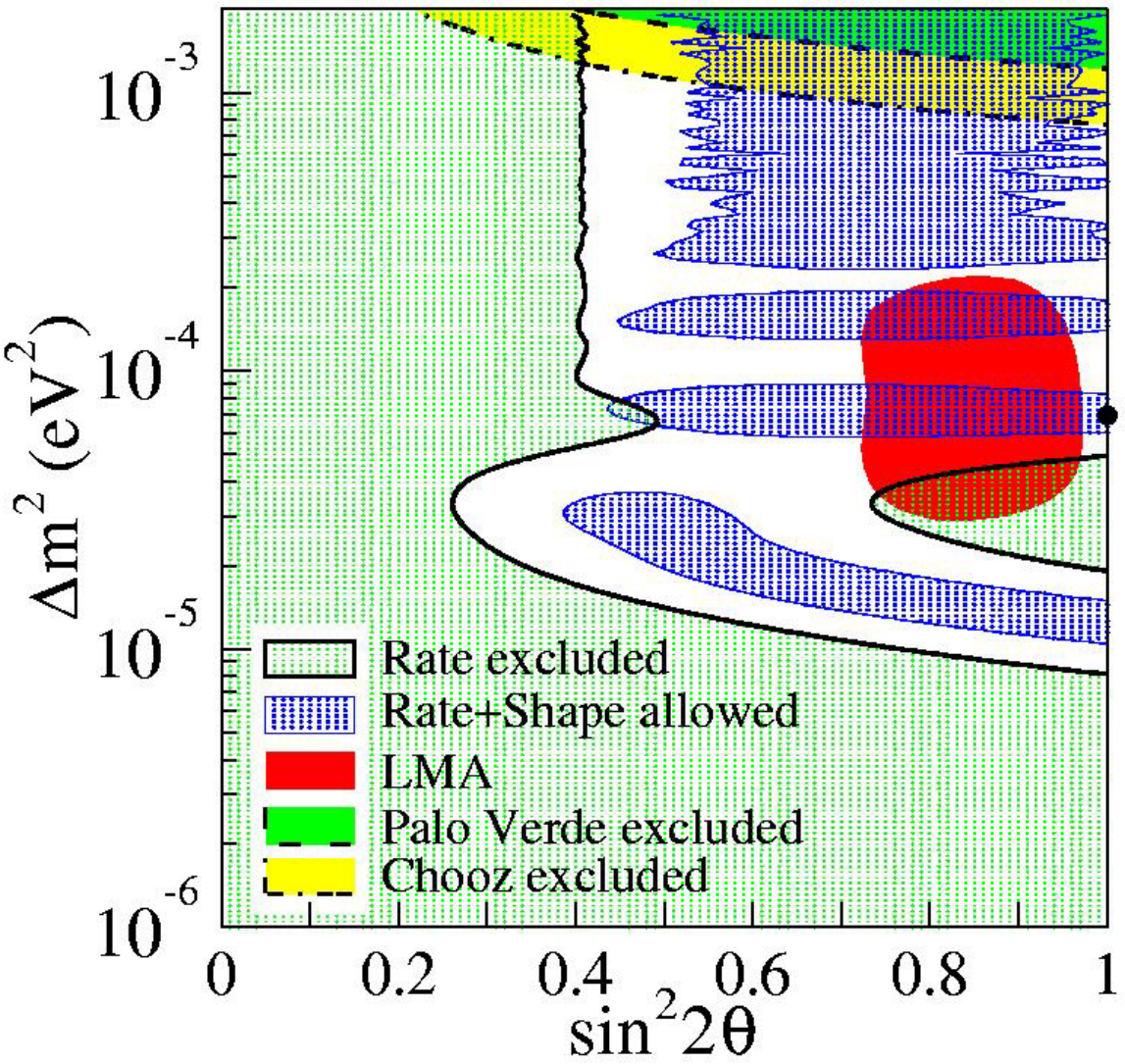


Fit to Oscillations for E_{prompt} > 2.6 MeV

Best fit :

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

$\sin^2 2\theta = 1.0$



Conclusions:

KamLAND observes a >4 sigma deficit of reactor anti-neutrinos

Assuming that CPT is conserved the interpretation of this result in terms of oscillations is smack in the middle of the LMA-MSW solution: The solar neutrino puzzle is now completely understood: we can reproduce it on Earth !

We can move on and use neutrinos to do solar physics !

More precision data on oscillation and many other phenomena is on the way… stay tuned !