

Prospects for ${}^7\text{Be}$ Solar Neutrino Detection with KamLAND

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Outline

- Neutrino Oscillation Measurement with Reactor Anti-neutrinos
- Solar Neutrinos
- Solar Neutrino Measurement and Background
- Liquid Scintillator Purification

Neutrino Oscillations in Vacuum

- The weak interaction neutrino eigenstates may be expressed as superpositions of definite mass eigenstates

$$|\nu_l\rangle = \sum_{i=1}^3 U_{li} |\nu_i\rangle$$

- The electron neutrino survival probability can be estimated as a two flavor oscillations:

$$P_{\nu_e \rightarrow \nu_e}(L) = 1 - \sin^2 2\theta_{12} \sin^2 \left(\frac{\pi L}{L_{osc}} \right), \quad L_{osc} = \frac{4\pi E_{\nu_e}}{\Delta m_{12}^2}$$

Reactor Anti-Neutrinos



- KamLAND was designed to measure reactor anti-neutrinos.
- 80% of total flux baseline 140-210km.

KamLAND Detector

Electronics Hut

Steel Sphere, 8.5m radius

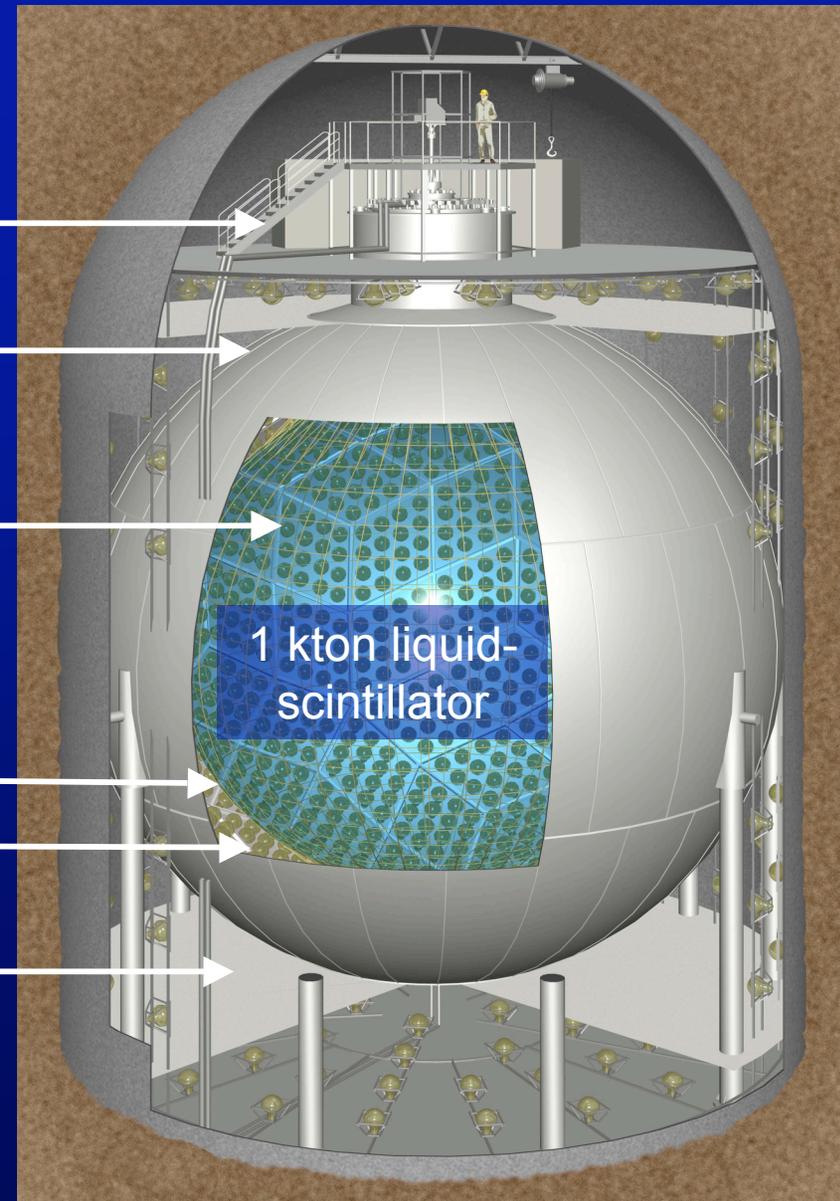
Inner detector
1325 17" PMT's
554 20" PMT's
34% coverage

Transparent balloon, 6.5m radius

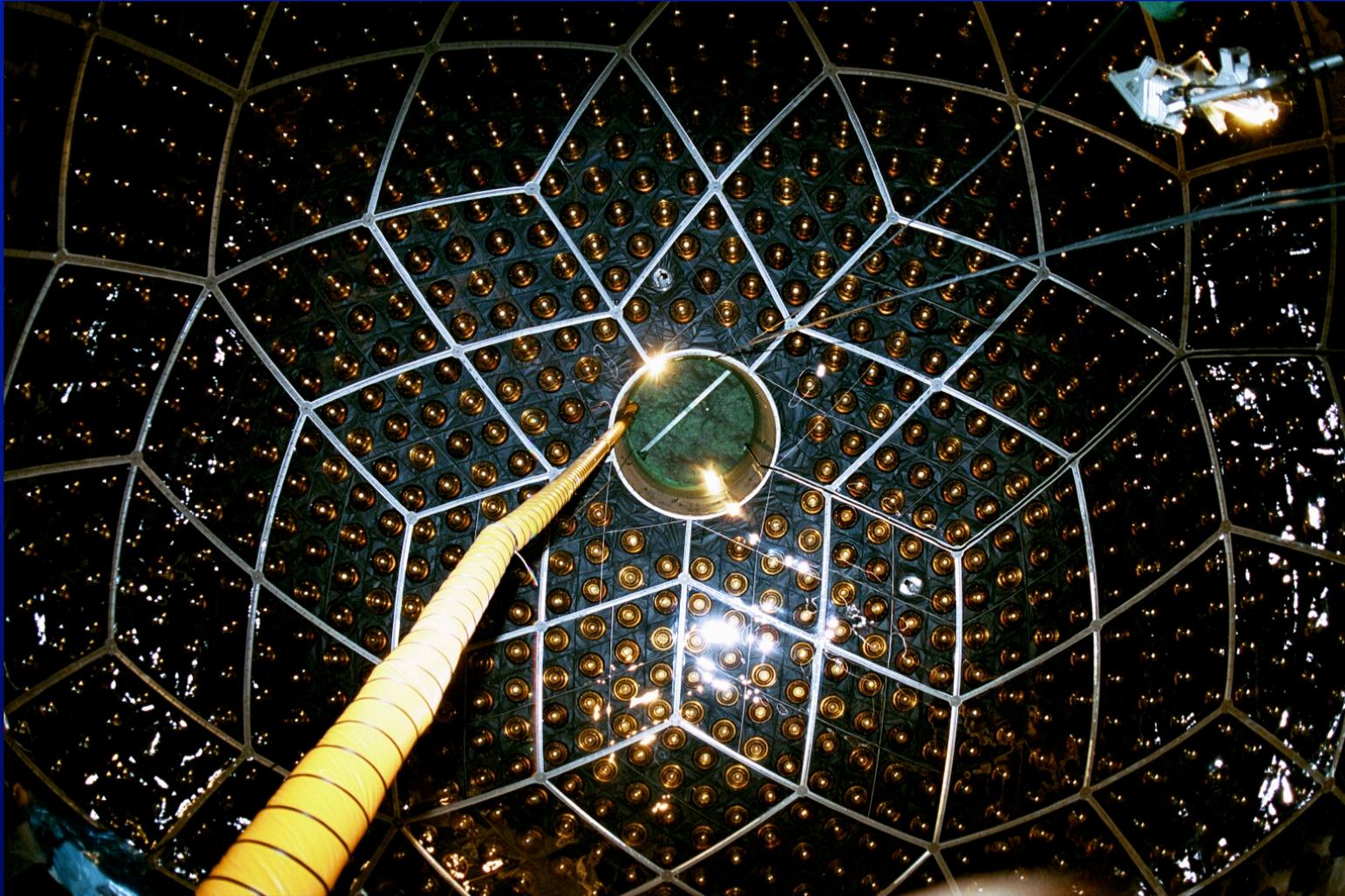
Buffer oil

Water Cherenkov outer detector
225 20" PMT's

1km Overburden



Inside the Detector

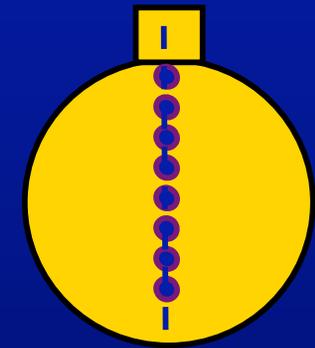
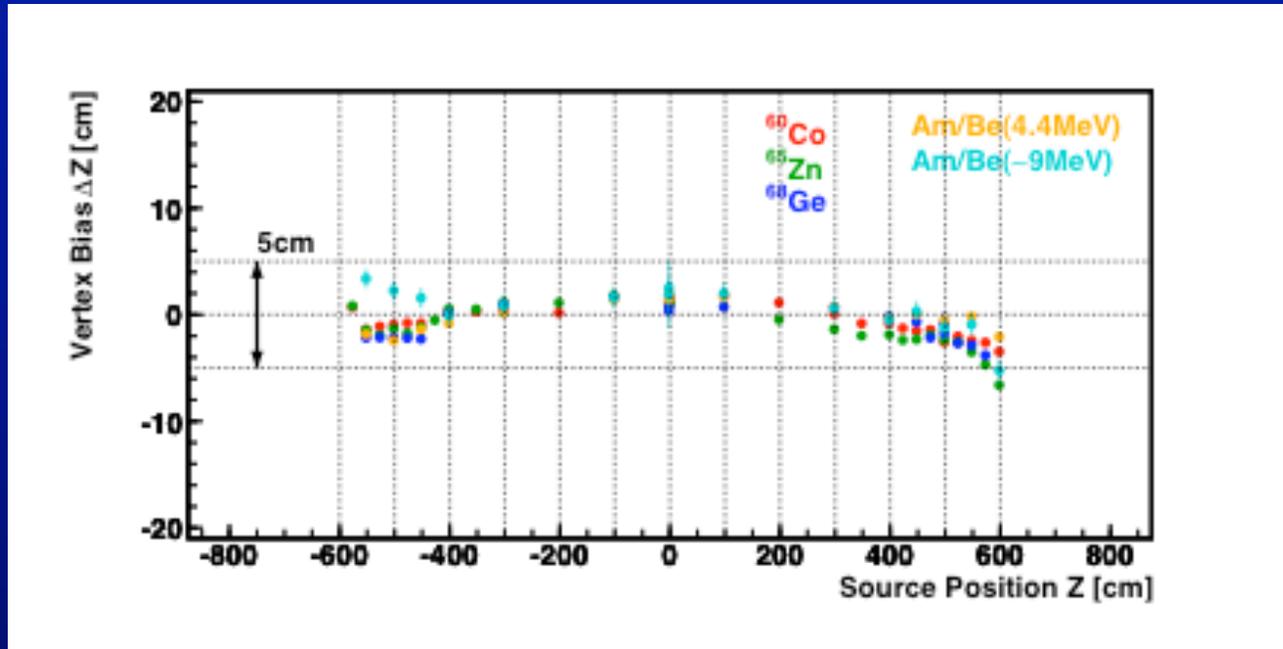


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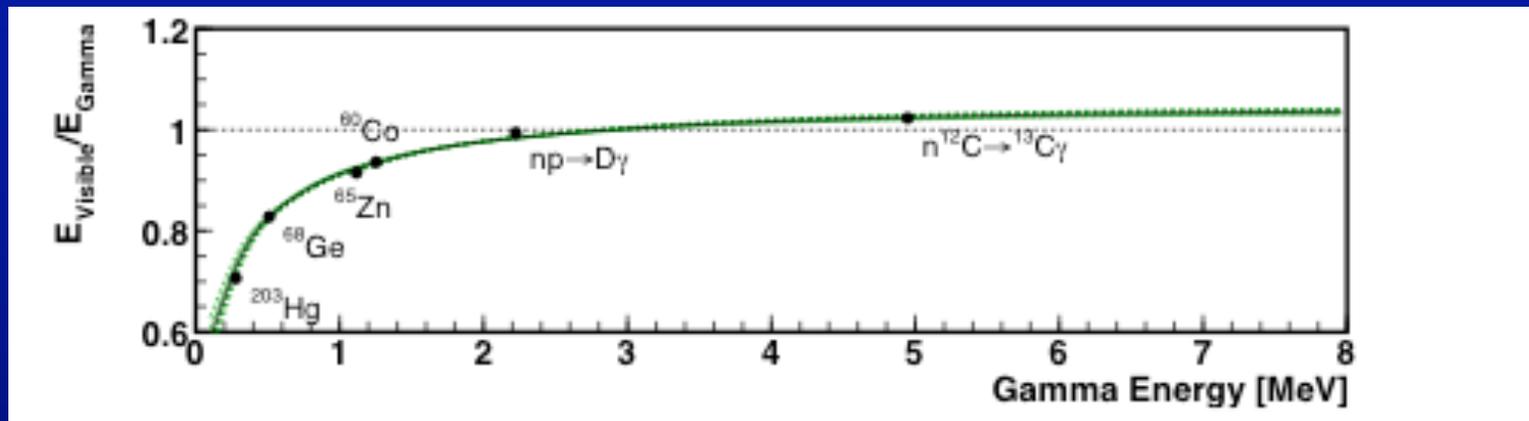
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Determining Event Vertices



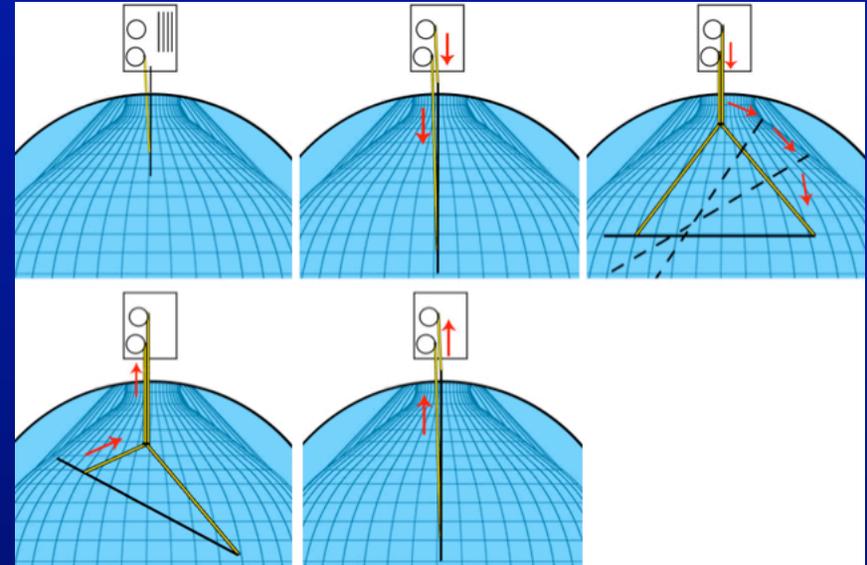
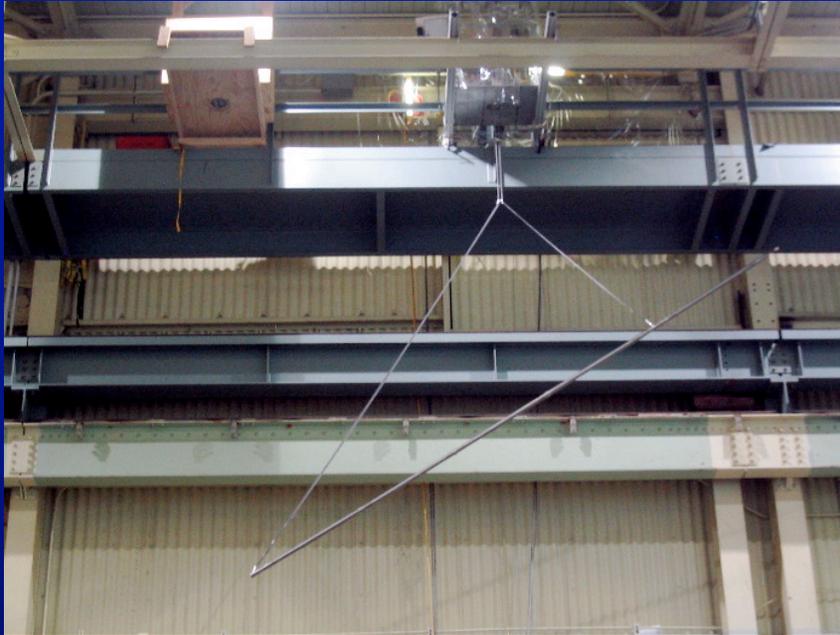
- Vertex determined using the photon arrival times at PMTs.
- Calibrated using sources deployed down the center of the detector.
- New vertex finding algorithm is under development to improve the performance for lower energy events.

Determining Event Energies



- The “visible” energy is calculated from the amount of photo-electrons correcting for spatial detector response.
- The “real” energy is calculated from the visible energy correcting for Cherenkov photons and scintillation light quenching.

4π Calibration



4π off-z-axis calibration device is under development.

Detecting Anti-neutrinos with KamLAND

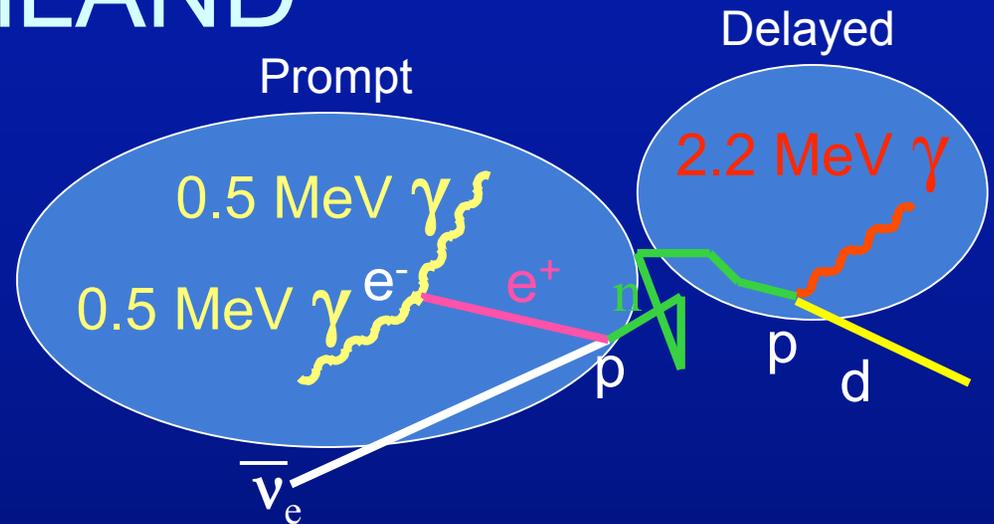
- KamLAND (**K**amioka **L**iquid scintillator **A**nti-**N**eutrino **D**etector)

- Inverse beta decay



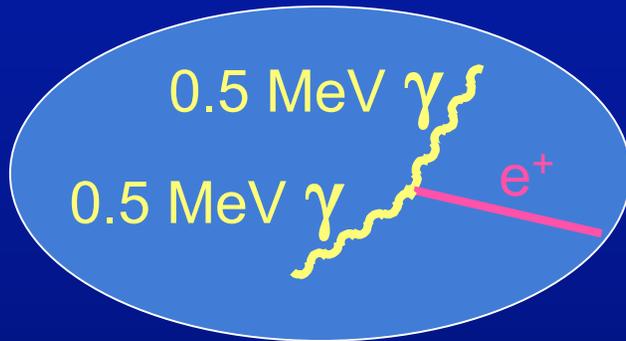
$$E_\nu \sim T_e + 1.8\text{MeV}$$

- The positron loses its energy then annihilates with an electron.
- The neutron first thermalizes then gets captured on a proton with a mean capture time of $\sim 200\mu\text{s}$.



Selecting Reactor Anti-neutrino Events

Prompt

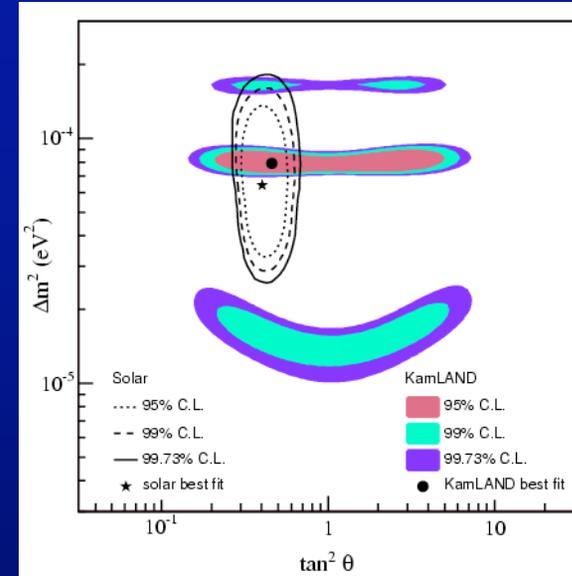
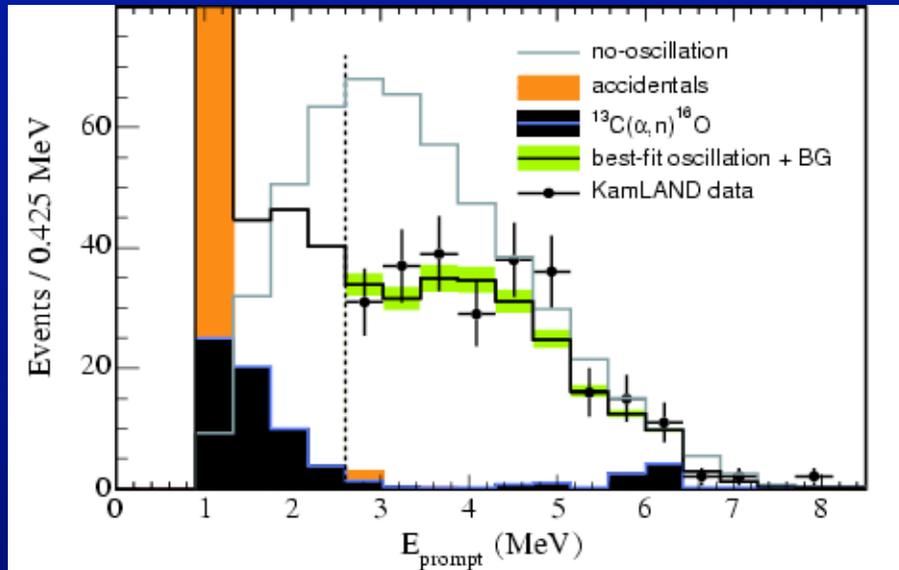


Delayed



- $\Delta r < 2\text{m}$
- $0.5\mu\text{s} < \Delta T < 1000\mu\text{s}$
- $2.6\text{MeV} < E_p < 8.5\text{MeV}$
- $1.8\text{MeV} < E_d < 2.6\text{MeV}$
- Veto after muons
- $R_p, R_d < 5.5\text{m}$

Reactor Neutrino Oscillation Measurement Result

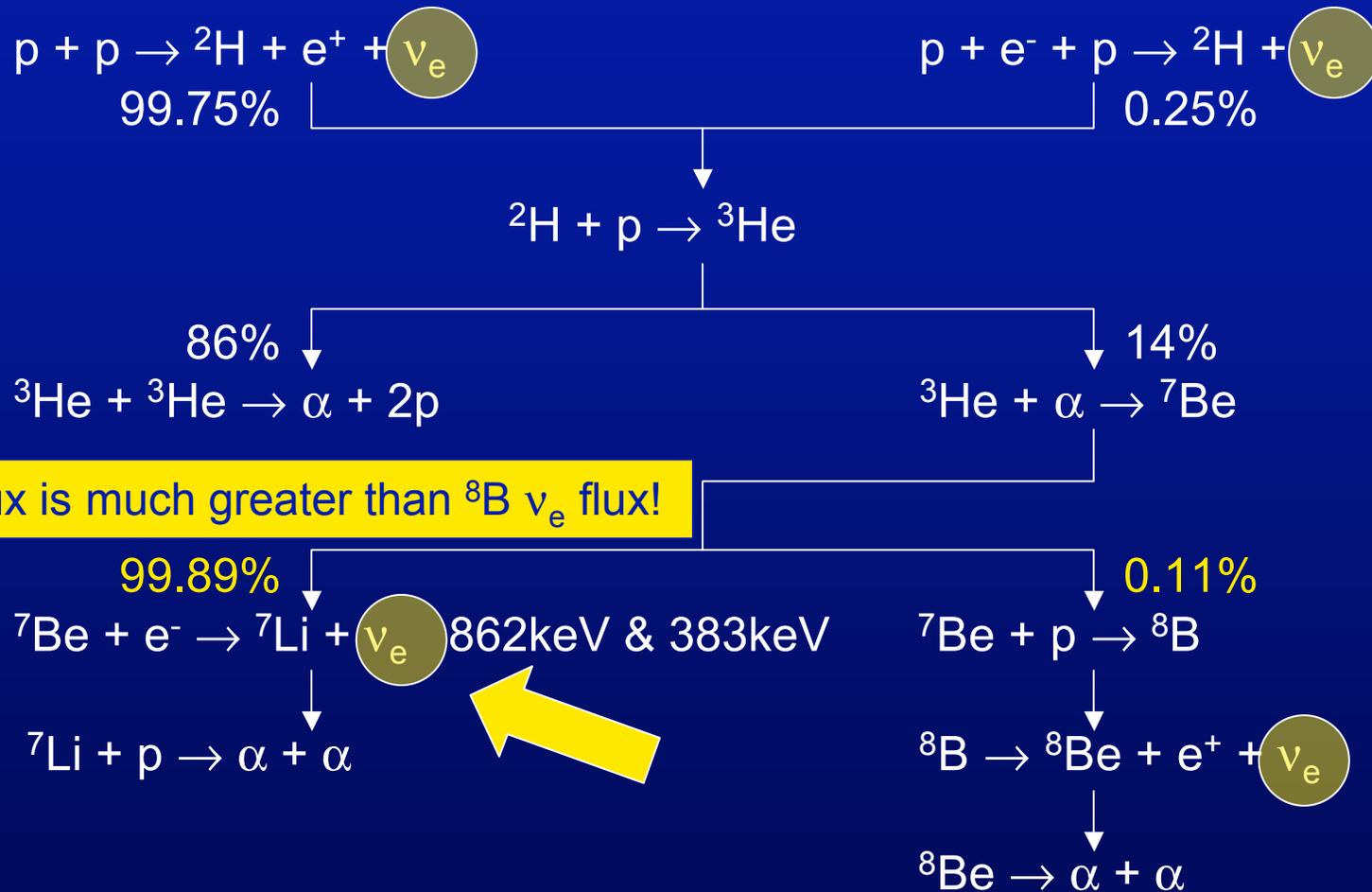


- KamLAND saw an anti-neutrino disappearance and a spectral distortion.
- KamLAND result combined with solar experiments precisely measured the oscillation parameters.

$$\tan^2 \theta_{12} = 0.40^{+0.10}_{-0.07}$$

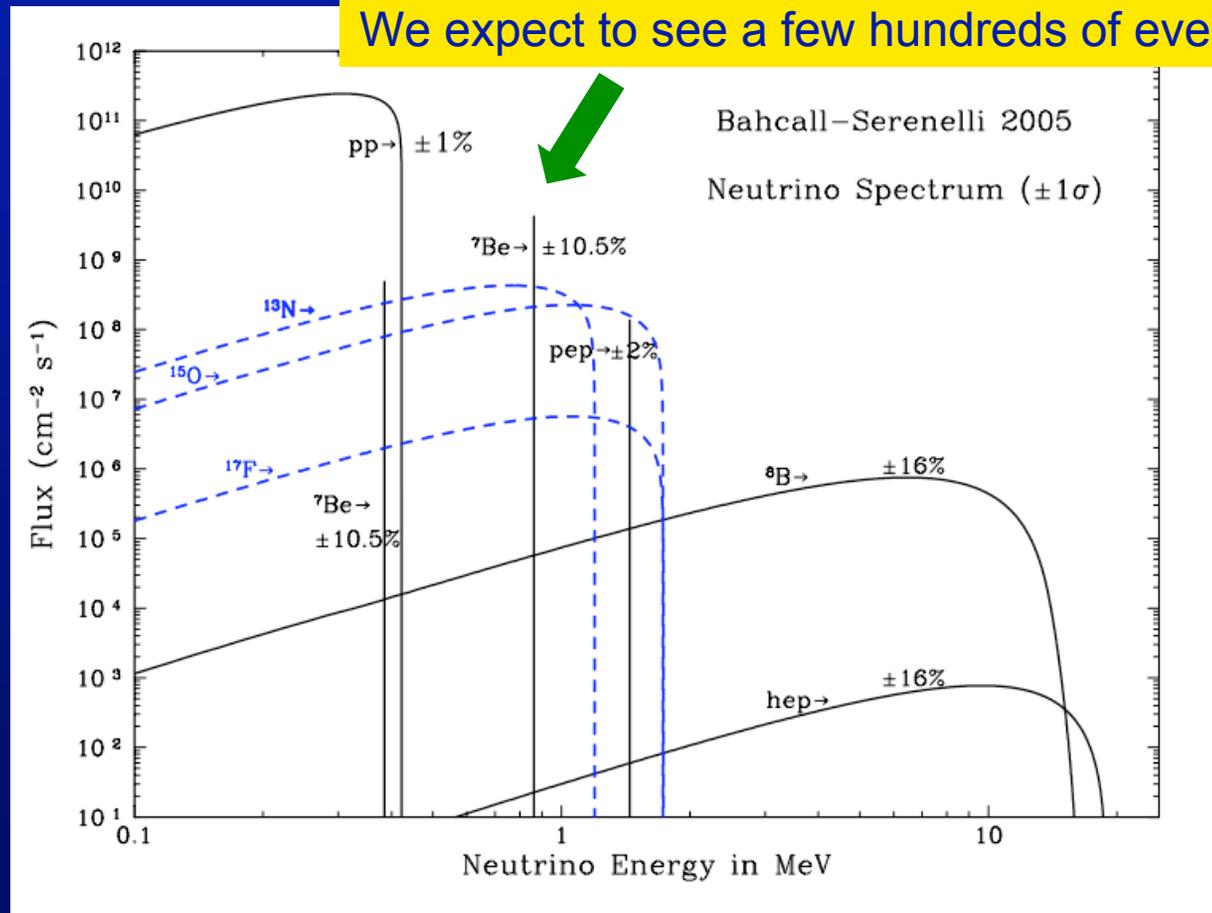
$$\Delta m_{12}^2 = 7.9^{+0.6}_{-0.5} \times 10^{-5} \text{ eV}^2$$

Solar Neutrinos from the p-p Chain Reactions



Solar Neutrino Spectrum

We expect to see a few hundreds of events per day.



Solar Neutrino Flux at the surface of the Earth with no neutrino oscillations. Uses the solar model, BS05(OP).

MSW Effect

- ν_e 's experience MSW effect in the Sun.

$$P_{\nu_e \rightarrow \nu_e}(L) = 1 - \sin^2 2\theta_m \sin^2 \left(\frac{\pi L}{L_m} \right)$$

$$\tan 2\theta_m \equiv \tan 2\theta_{12} \left(1 + \frac{L_{osc}}{L_0} \sec 2\theta_{12} \right)^{-1}$$

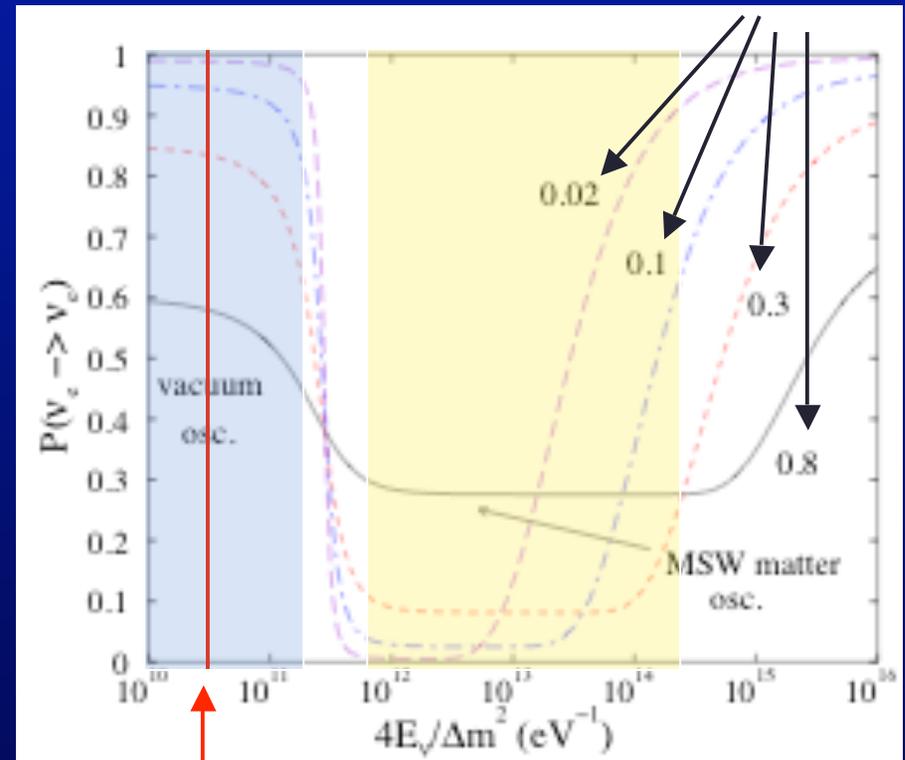
$$L_0 = \frac{2\pi}{\sqrt{2}G_F N_e}$$

$$L_m \equiv L_{osc} \left[1 + 2 \cos 2\theta_{12} \frac{L_{osc}}{L_0} + \left(\frac{L_{osc}}{L_0} \right)^2 \right]^{-\frac{1}{2}}$$

- For ${}^7\text{Be}$ ν_e 's,

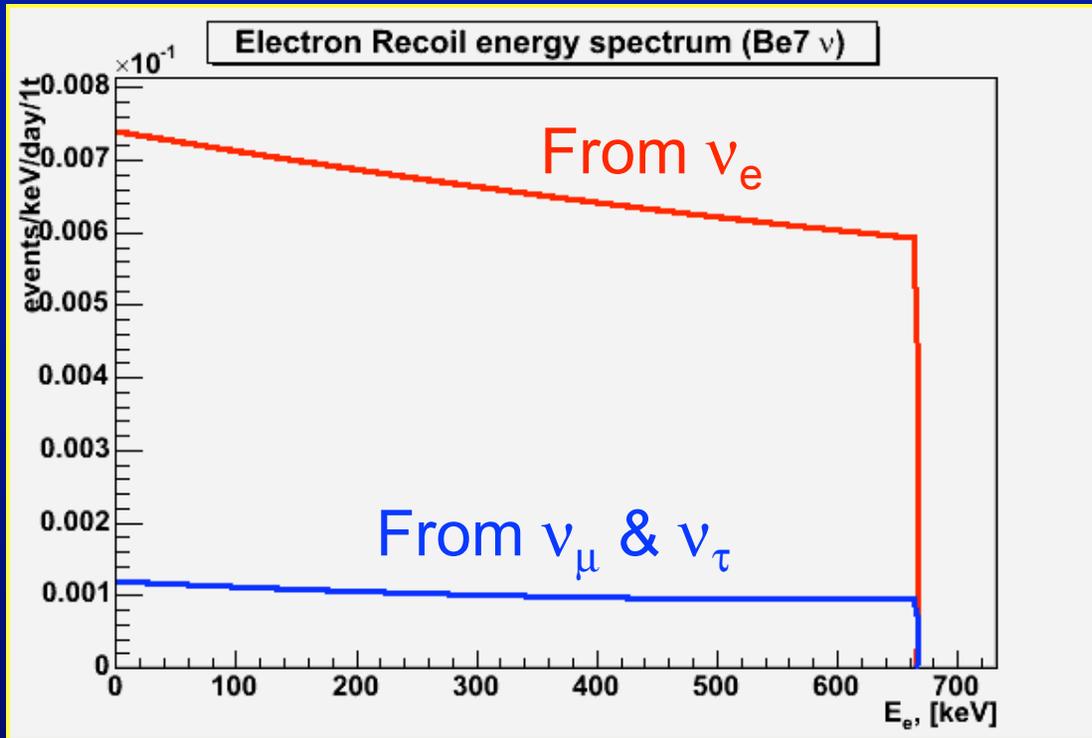
$$P_{\nu_e \rightarrow \nu_e}(L) \sim 1 - \frac{1}{2} \sin^2 2\theta_{12}$$

Possible $\sin^2 2\theta$



For $E_\nu = 862\text{keV}$ & $\Delta m^2 = 7.9 \times 10^{-5} \text{eV}^2$

${}^7\text{Be}$ Solar Neutrino Detection



*Detection resolution is not included.

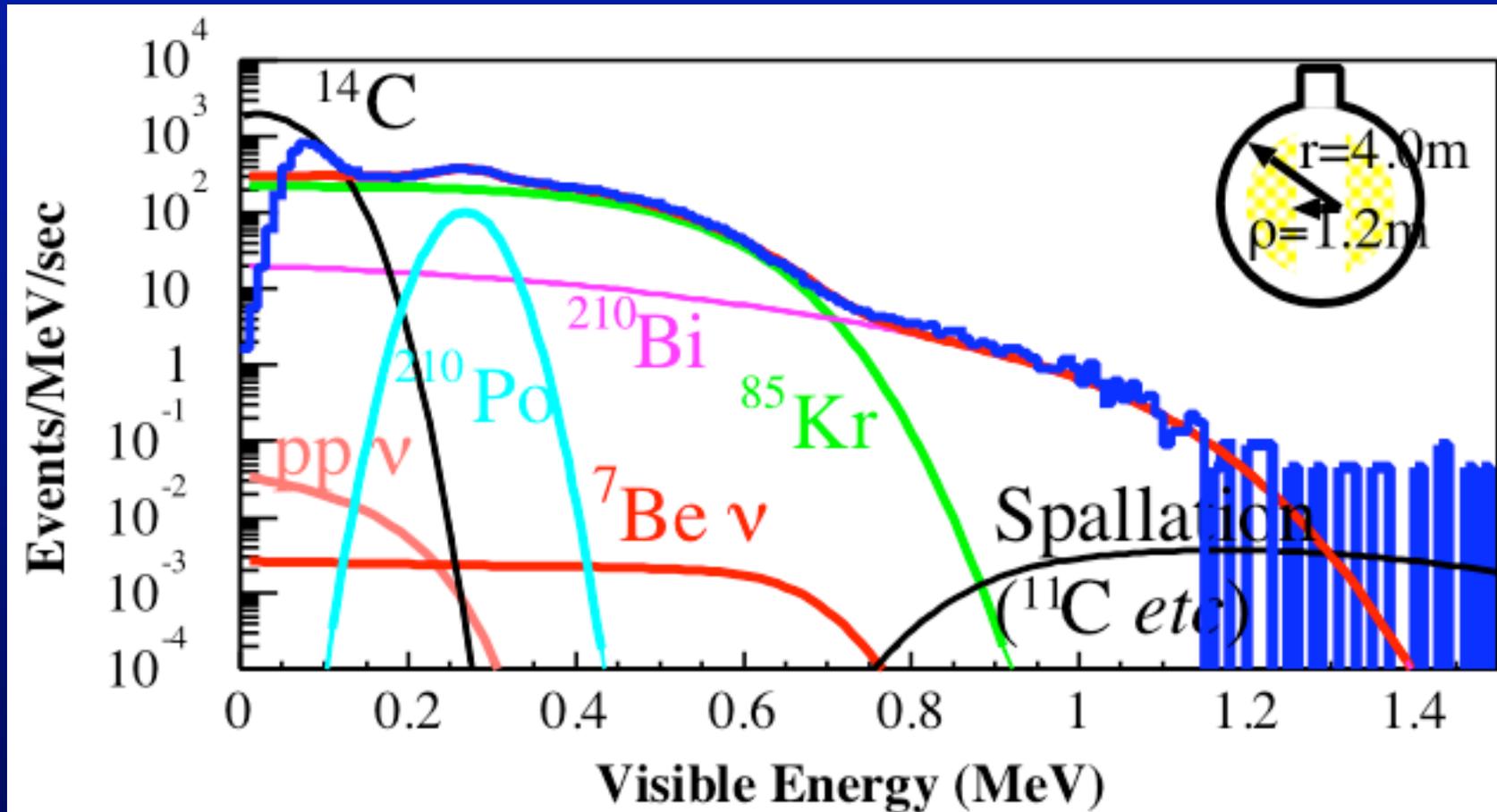
- Solar ν scatters off e^- .
- The electron recoil energy is

$$E_e \leq \frac{2E_\nu^2}{2E_\nu + m_e}$$

Irreducible Radioactivity

- γ 's (1.46MeV) from ^{40}K in the balloon
- γ 's (2.6MeV) from ^{208}Tl decay in the surrounding rocks
- ^{14}C throughout the detector (less than $\sim 200\text{keV}$)
- ^{11}C from cosmic muons (more than 700keV)
- Most of the ^{40}K and ^{208}Tl background is removed with fiducial volume cut.
- Most of the ^{14}C and ^{11}C background is removed with energy cut.

Current Reducible Radioactivity in KamLAND



After fiducial volume cut is applied

Current Radioactivity Levels in the Liquid Scintillator and Reduction Goals

	Current Level	Reduction Goal
^{238}U	$3.5 \times 10^{-18} \text{ g/g}$	OK
^{232}Th	$5.2 \times 10^{-17} \text{ g/g}$	OK
^{40}K	$2.7 \times 10^{-16} \text{ g/g}$	10^{-18} g/g
^{85}Kr	0.7 Bq/m^3	$1 \mu\text{Bq/m}^3$
^{210}Pb	10^{-20} g/g	$5 \times 10^{-25} \text{ g/g}$

Removal of ^{222}Rn

- Distillation removed ^{222}Rn by a factor of 10^5 after dissolving ^{222}Rn in $\sim 100\text{ml}$ of liquid scintillator.
- A detector that can measure very low amount of ^{222}Rn is under development.

Removal of ^{210}Pb

- Since decay rate of ^{210}Pb is low, we study with ^{212}Pb .
- Most of Pb is ionic, but some is organic.
- Heating breaks the covalent bonds of organic Pb.
- Heating and distillation reduced the ^{212}Pb activity in a few liters of liquid scintillator by a factor of 10^4 to 10^5 after spiking it with ^{220}Rn increasing the ^{212}Pb activity by a factor of 10^4 .
- Adsorption by silica gel also reduced the ^{212}Pb concentration by a factor of 20.

Removal of ^{40}K

- Distillation reduced the ^{40}K concentration in PPO by a factor of 10^2 .

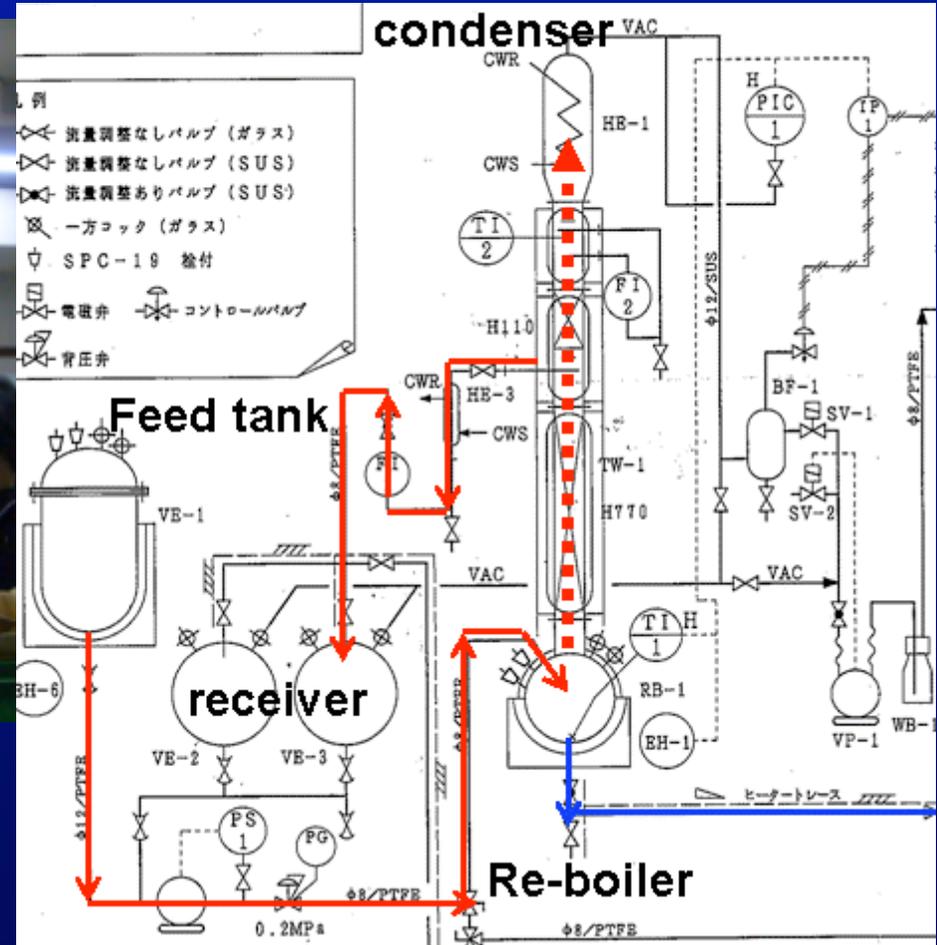
Removal of ^{85}Kr

- ^{85}Kr is produced in nuclear reactors.
- Noble gas bubbling is under investigation.
- Distillation achieved $^{\text{nat}}\text{Kr}$ reduction by a factor of 10^6 after dissolving $^{\text{nat}}\text{Kr}$ in 80ml of liquid scintillator.
- A system to do inline monitoring of $^{\text{nat}}\text{Kr}$ levels during purification is under development.

Test Distillation Tower



- Test distillation tower can run at a few L/hr.
- Actual distillation tower will purify the liquid scintillator at 2m³/hr.



Purification System Construction



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Summary

- Neutrino oscillation parameters have been measured precisely by KamLAND with reactor anti- ν 's and by solar experiments.
- ${}^7\text{Be}$ ν detection and testing the solar model is one of the KamLAND's next goals.
- According to the best fit neutrino oscillation parameters, we expect that ${}^7\text{Be}$ ν 's experience mainly just vacuum neutrino oscillations, and almost no MSW effect.
- KamLAND needs to reduce current background significantly.
- Background reduction studies are under way, and look promising.