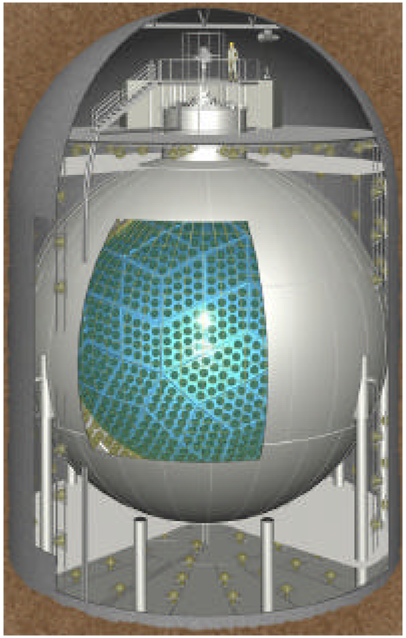
XX Rencontres in La Thuile
March 5-11, 2006

KamLAND
Present Status and Future Prospects

Kyo NAKAJIMA
(Tohoku University)

for the KamLAND collaboration

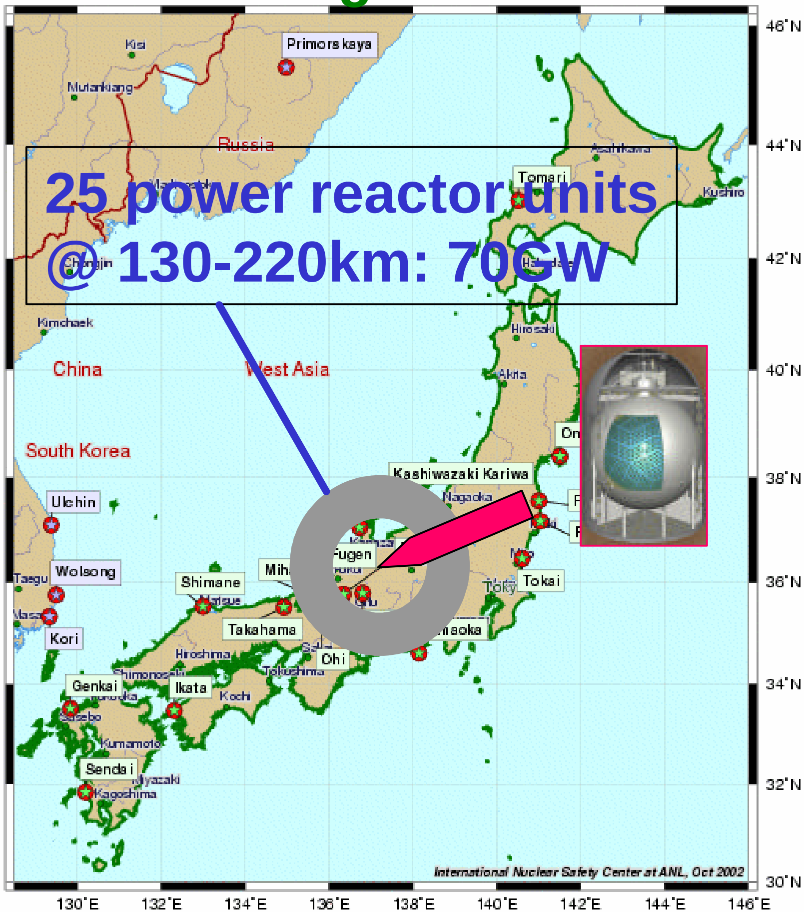


Contents

1. KamLAND Experiment
2. Reactor Neutrino Measurement
3. Search for Geoneutrinos
4. Prospects of Solar Neutrino Observation
5. Summary

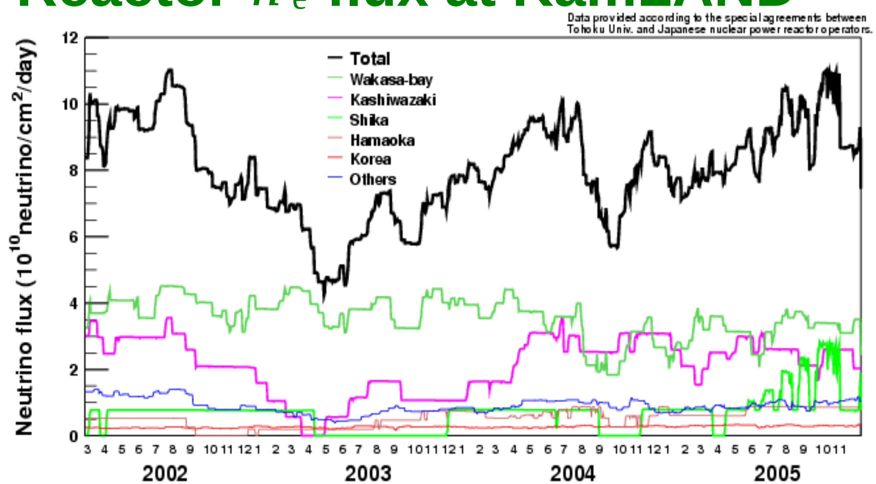
1-1. KamLAND Experiment

Limited range of baseline



- 1 kton Liquid Scintillator
  80% Dodecan, 20% Pseudocumene,
  1.52g/l PPO (? =0.78g/cm^3),
  49% Anthracene
- 1325 17” & 554 20” PMTs
  Photocathode coverage ~34%,
  500p.e./MeV @center

Reactor $\bar{n}_e$ flux at KamLAND



Sensitivity for ? *m*^{2}

$$L \sim 180\mathbf{km},\quad E_{\bar{n}_e} \sim 4\mathbf{MeV}$$

$$Þ \quad Dm^2 \sim 10^{-5}\,\mathbf{eV}^2$$

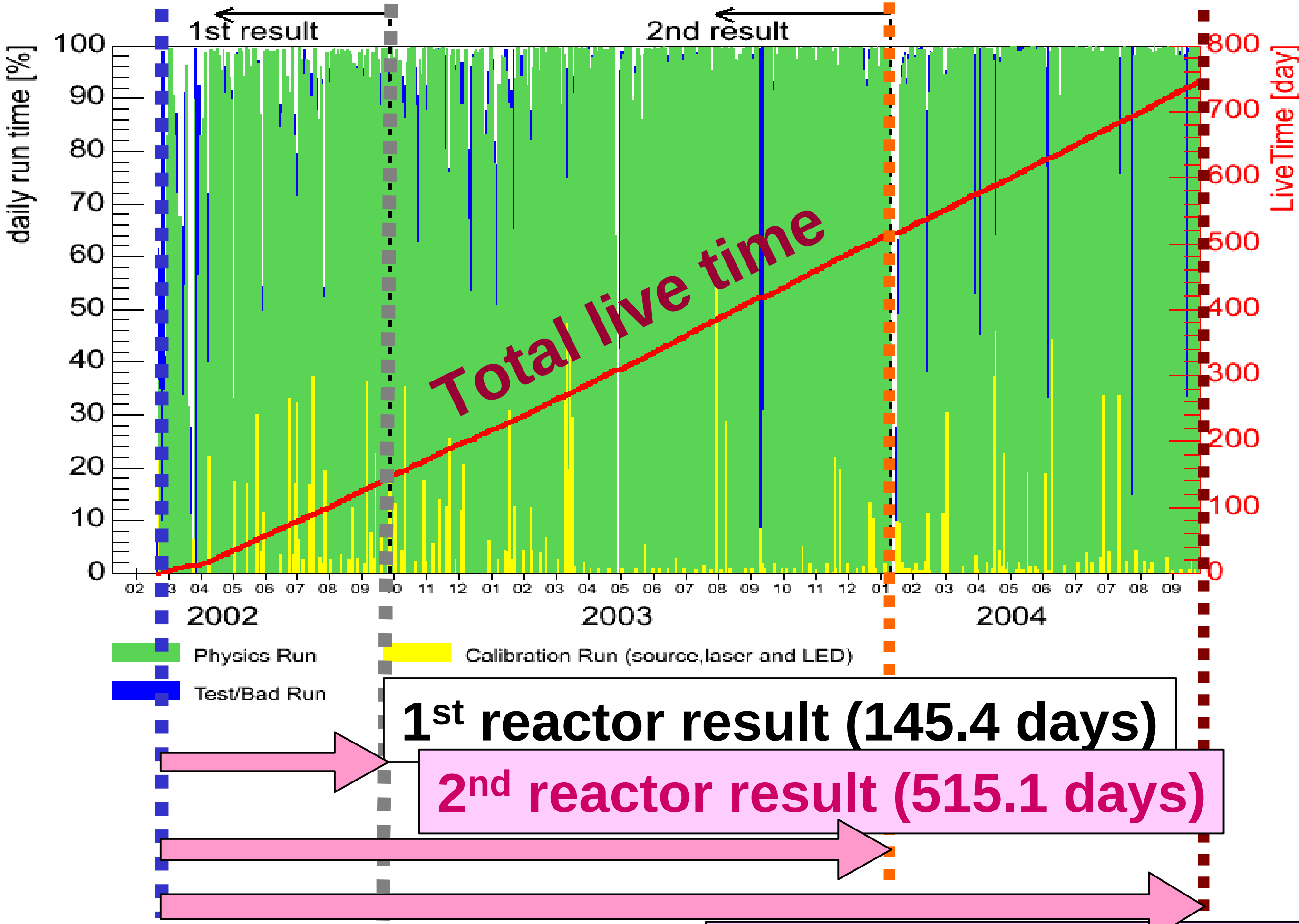
Other targets

- **Geoneutrino**
- **Solar neutrino etc**

1-2. Status of Data Taking

Since Jan. 2002

Detector activity



1st reactor result (145.4 days)

2nd reactor result (515.1 days)

1st geoneutrino result (749.1 days)

2-1. Event Selection

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

$n + p \rightarrow d + \gamma\,(2.2\,\text{MeV})$

1. Inverse beta-decay selection

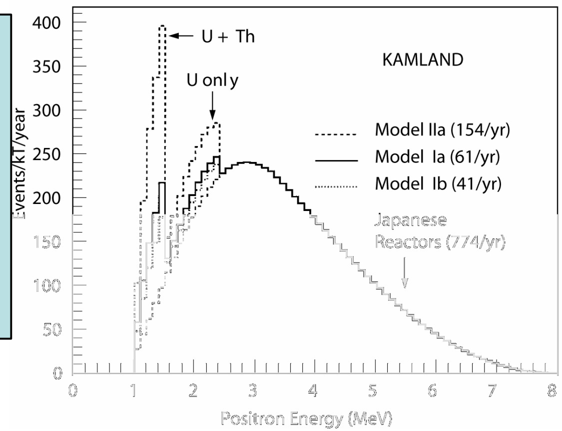
Geoneutrino

$0.9\,\text{MeV} < E_{prompt} < 2.7\,\text{MeV}$

$1.8\,\text{MeV} < E_{delayed} < 2.6\,\text{MeV}$

? R<1m

0.5μ s<? T<500μ s



Reactor neutrino

$2.6\,\text{MeV} < E_{prompt} < 8.5\,\text{MeV}$

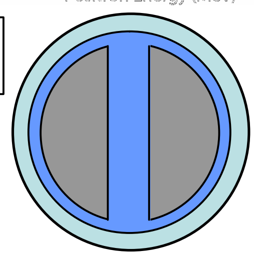
$1.8\,\text{MeV} < E_{delayed} < 2.6\,\text{MeV}$

? R<2m

0.5μ s<? T<1000μ s

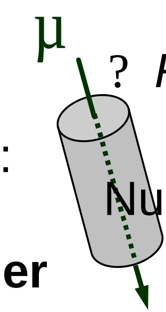
2. Fiducial selection

$R<5\text{m},\ X^2+y^2>1.44$ m



R<5.5m

3. Muon spallation event cut



? R_μ <3m

$^{12}C(?\ ,n)^{11}C$

? ^{11}B (ß $^+$)

etc.

Showering / bad:
? T_μ <2s,
entire volume

Well-tracked muon:
? T_μ <2s,
? R_μ <3m cylinder

2-2. Data Summary

Observed	258
Expected	365.2 ± 23.7
B.G.	17.8 ± 7.3

(>2.6MeV,766.3ton-yr)

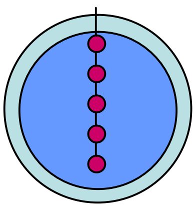
Background

a ’s from ^{210}Po (daughter ^{222}Rn)

Accidental	2.69 ± 0.02
9Li/8He	4.8 ± 0.9
Fast neutron	<0.89
^{13}C(a , n)^{16}O	10.3 ± 7.1
Total B.G. events	17.8 ± 7.3

Systematic uncertainty

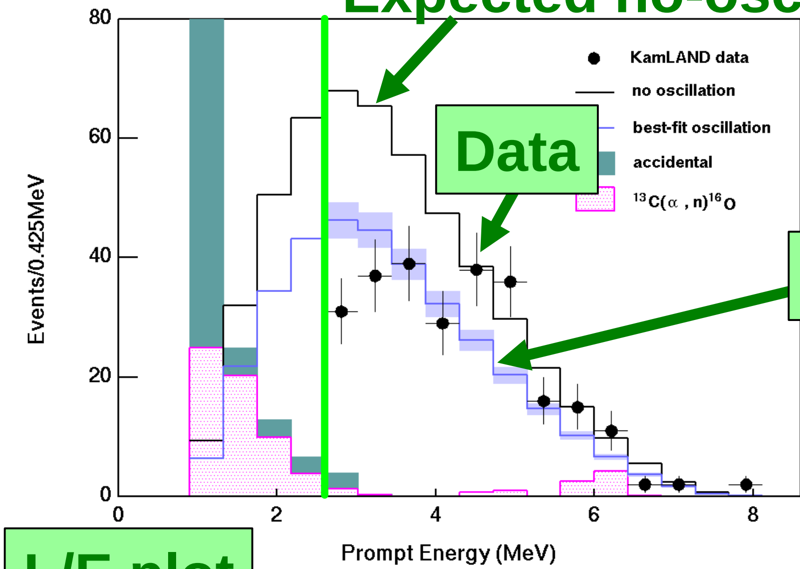
Fiducial volume: 4.7%



Systematic	%	Systematic	%
Total LS mass	2.1	Reactor power	2.1
Fiducial volume ratio	4.2	Fuel composition	1.0
Energy threshold	2.3	Neutrino spectra	2.5
Efficiency of cuts	1.6	Cross section	0.2
Live time	0.06		
Total systematic uncertainty	6.5%		

2-3. Spectrum Distortion

Expected no-oscillation



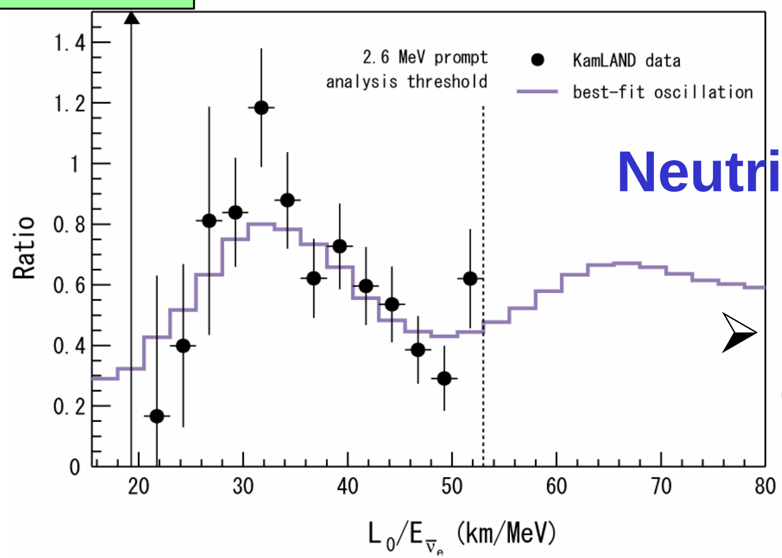
Data

Scaled no-oscillation

Neutrino disappearance at 99.998% C.L.

- Observed energy spectrum disagrees with no-oscillation shape at 99.6% C.L.

L/E plot



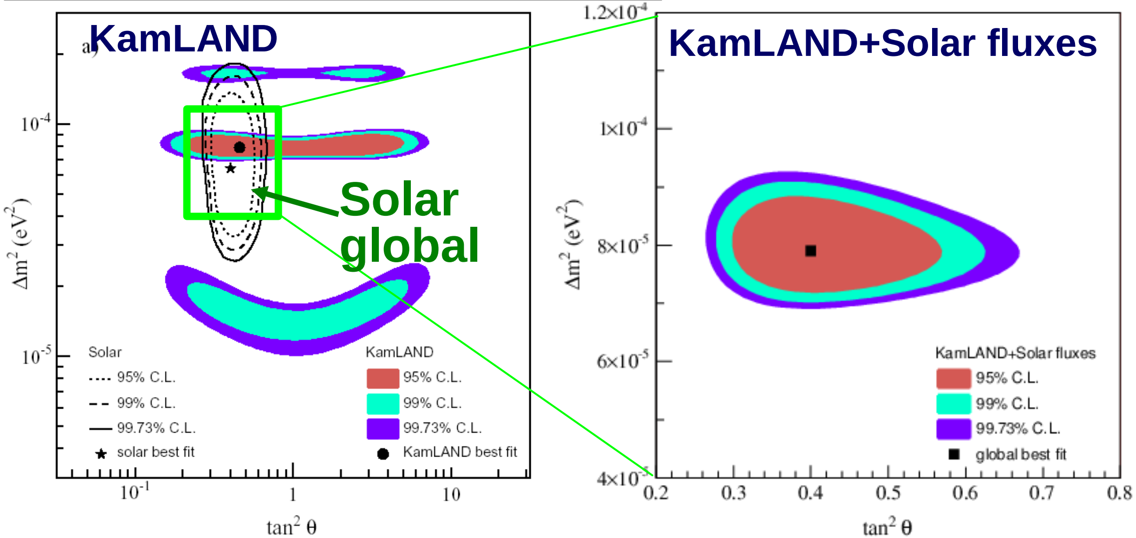
Neutrino oscillation $P_{ee} = 1 - \sin^2 2q \sin^2\left(1.27\Delta m^2 \frac{L}{E}\right)$

- Prefers the distortion expected from neutrino oscillation effects

L_0=180km

2-4. Oscillation Analysis

Oscillation parameters



$? m^{2} = 7.9^{+0.6}_{-0.5}$ ´ 10^{-5} eV^{2}
$\tan^{2} ? = 0.46$

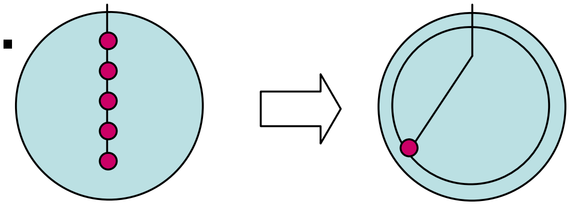
$\Delta m^{2} = 7.9^{+0.6}_{-0.5} \times 10^{-5}\ \mathrm{eV}^{2}$
$\tan^{2}\theta = 0.40^{+0.10}_{-0.07}$

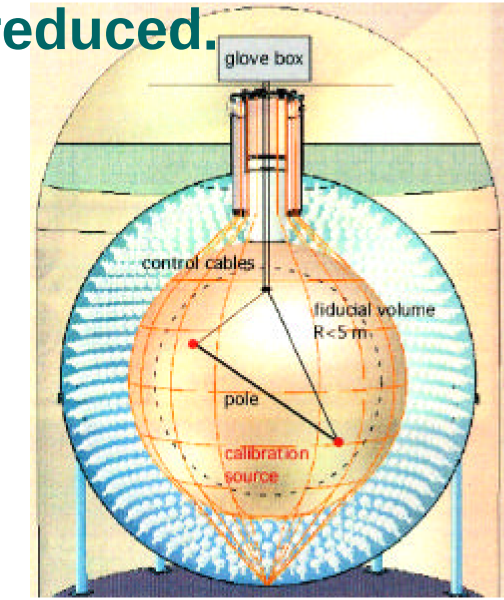
- Best-fit is in LMAI region.
- Determined ? m^2 precisely
- LMAII region is disfavored at 98.0% C.L.
  consistent with solar ? oscillations with LMA
- Lower ? m^2 region is disfavored at 97.5% C.L.

2-5. Future KamLAND Sensitivity

The total syustematic uncertainty will be reduced.

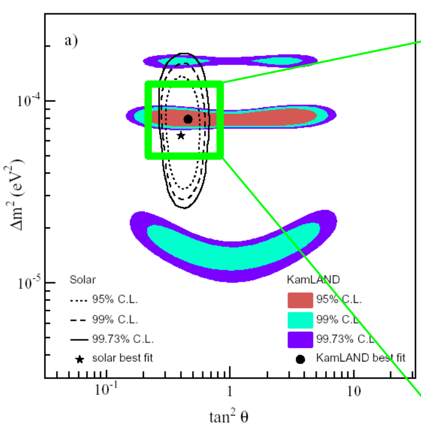
- **Expanding fiducial radius**
- **4p calibration in LS has been performed now.**

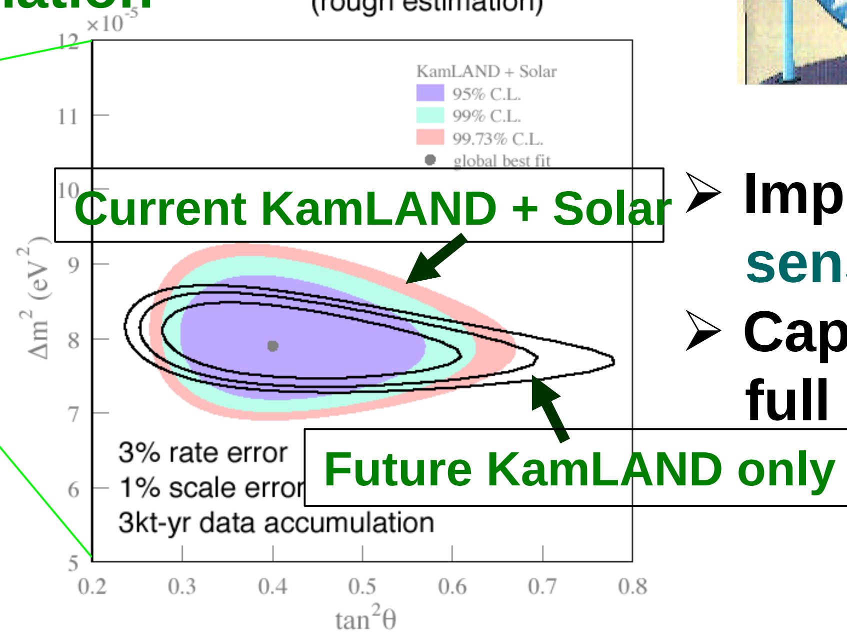




Optimistic estimation

(rough estimation)





- **Improvement of sensitivity of ? m²**
- **Capability to reject full mixing**

3-1. Geoneutrino

? $_e$'s from the ^{238}U and ^{232}Th decay chains and ^{40}K decay

$$^{238}\mathrm{U} \ ® \ ^{206}\mathrm{Pb} + 8\,^{4}\mathrm{He} + 6\,e^{-} + 6?_e + 51.7\ [\mathrm{MeV}]$$

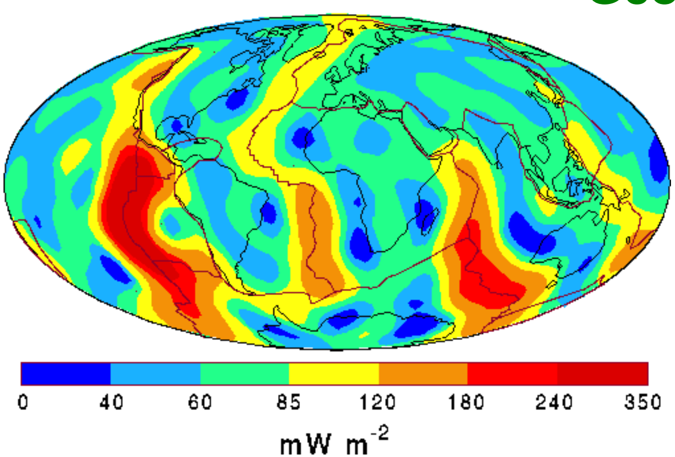
$$^{232}\mathrm{Th} \ ® \ ^{208}\mathrm{Pb} + 6\,^{4}\mathrm{He} + 4\,e^{-} + 4?_e + 42.7\ [\mathrm{MeV}]$$

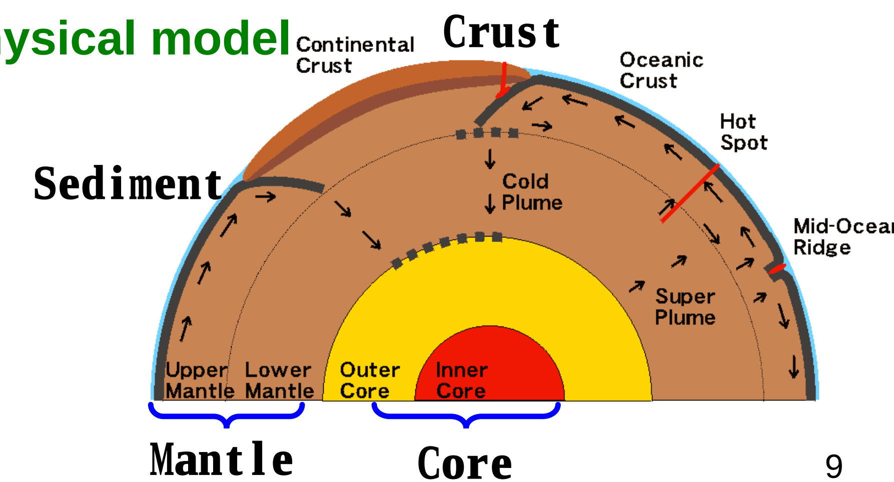
$$^{40}\mathrm{K} \ ® \ ^{40}\mathrm{Ca} + e^{-} + ?_e + 1.31\ [\mathrm{MeV}]$$

Heat flow

- Total power dissipated from the Earth : 44.2 or 31 TW
- On the basis of chondritic meteorites : radiogenic power is thought to be 19TW

Geophysical model



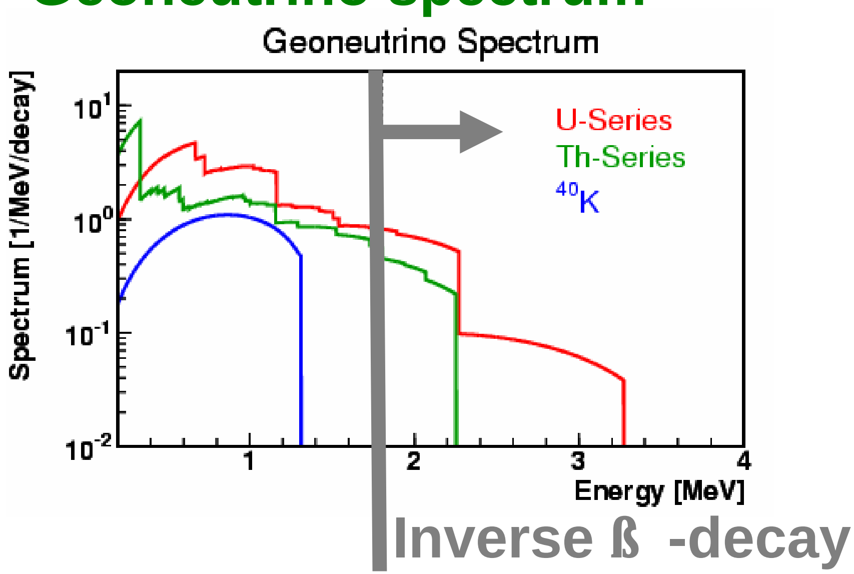


Th/U~3.9

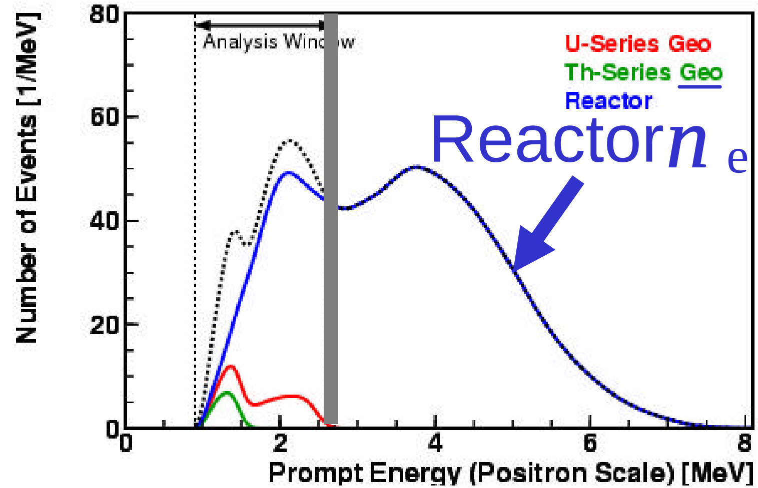
U and Th = 0

3-2. Geoneutrino Observation

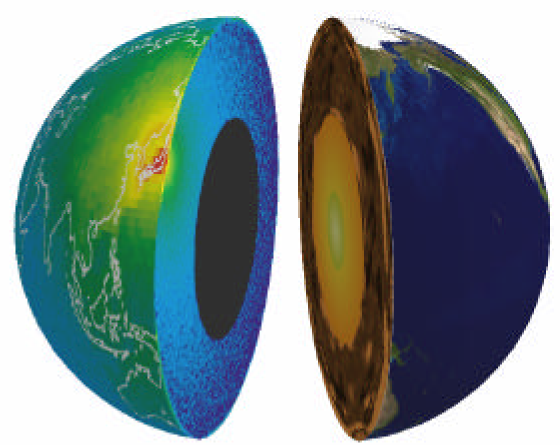
Geoneutrino spectrum



Observed energy spectrum



- Provide information for testing the models of the U and Th content and distribution in the Earth.

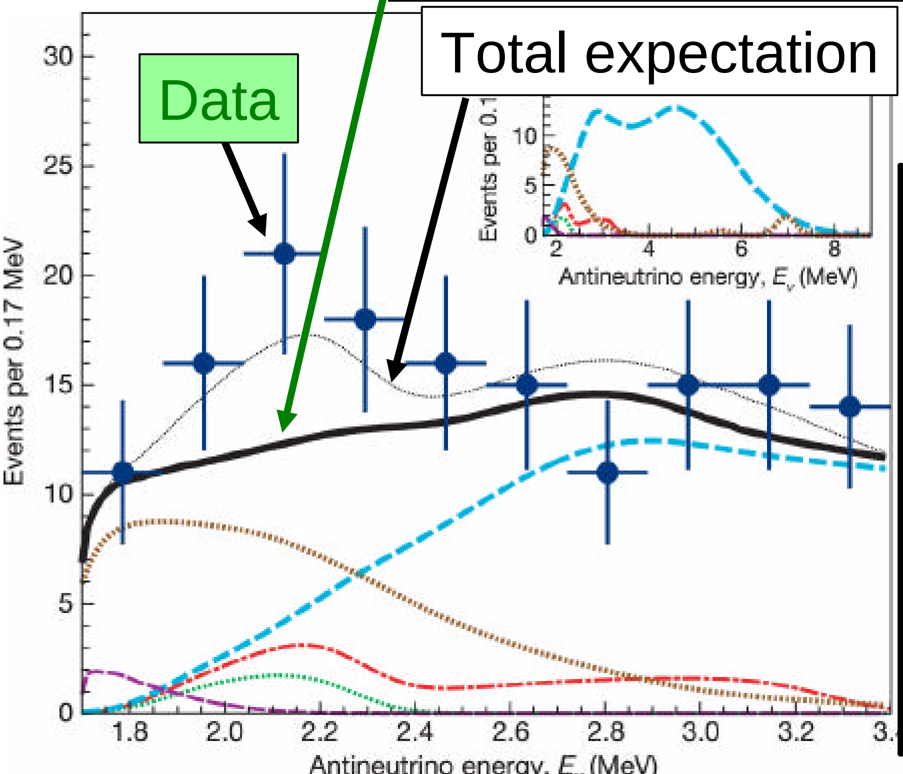


~50% of the total flux originates without 500km of KamLAND

3-3. Observed Energy Spectrum

March 7,2002 – Oct. 30,2004 (749.1 ± 0.5 days)

Total expectation excluding the geo-? ’s



a ’s from ^{210}Po (daughter ^{222}Rn)

Estimated BG.

Background	Events
Accidental	**2.38 ± 0.01**
^{13}C(a ,n)^{16}O	**42 ± 11**
Reactor ? e	**80.4 ± 7.2 (Long life)** **1.9 ± 0.2 (Short life)**
Total	**127 ± 13**

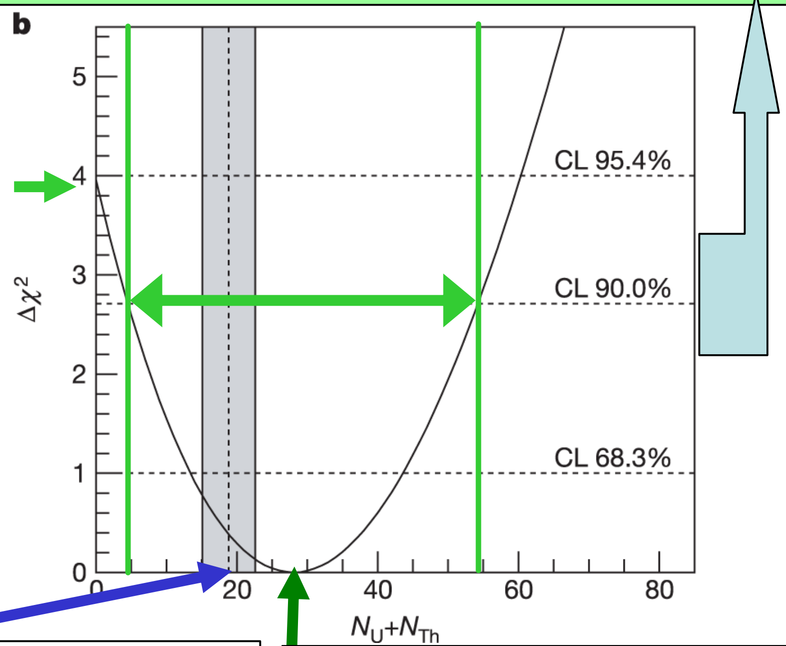
Observed events
152

25^{+19}_{-18} geoneutrino candidates from “rate only” analysis

3-4. Number of Detected Geoneutrinos

Confidence interval for the number of detected geoneutrinos
Assuming the mass ratio: Th/U=3.9

90% confidence interval for the total number of geoneutrino candidates: 4.5 to 54.2



Prediction by geophysical models: 19

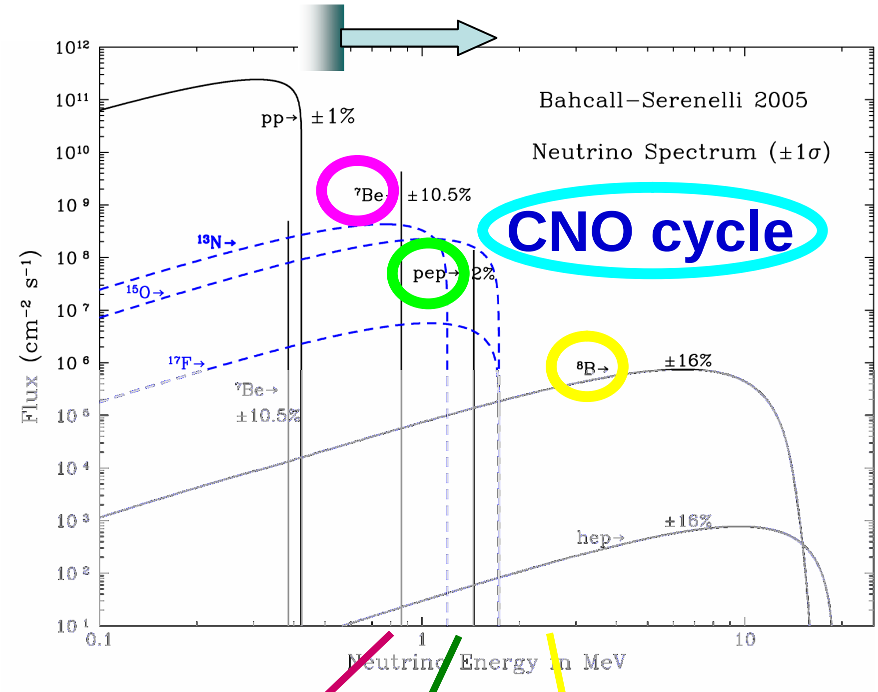
Central value for the total number of detected geoneutrinos with KamLAND: 28

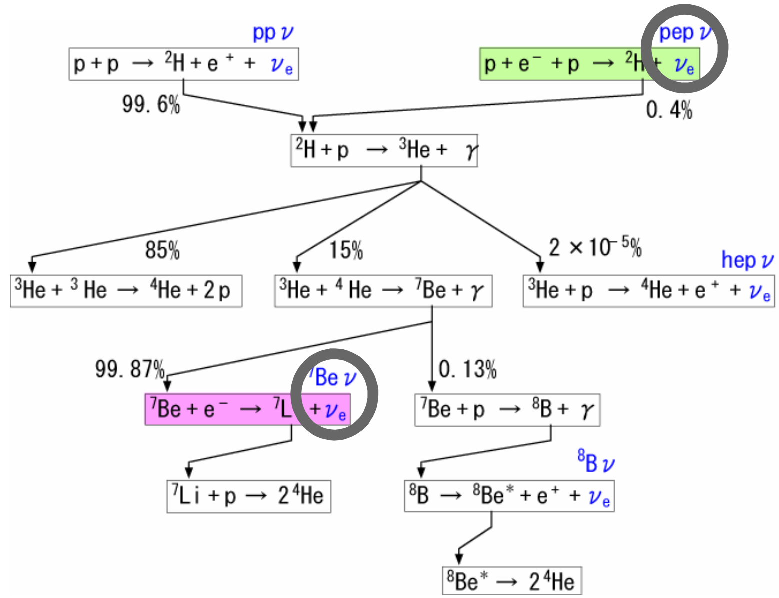
New method to explore the Earth was established.

4-1. Future Solar Neutrino Observation

Elastic neutrino-electron scattering $n_e + e^- \rightarrow n_e + e^-$

Solar neutrino flux

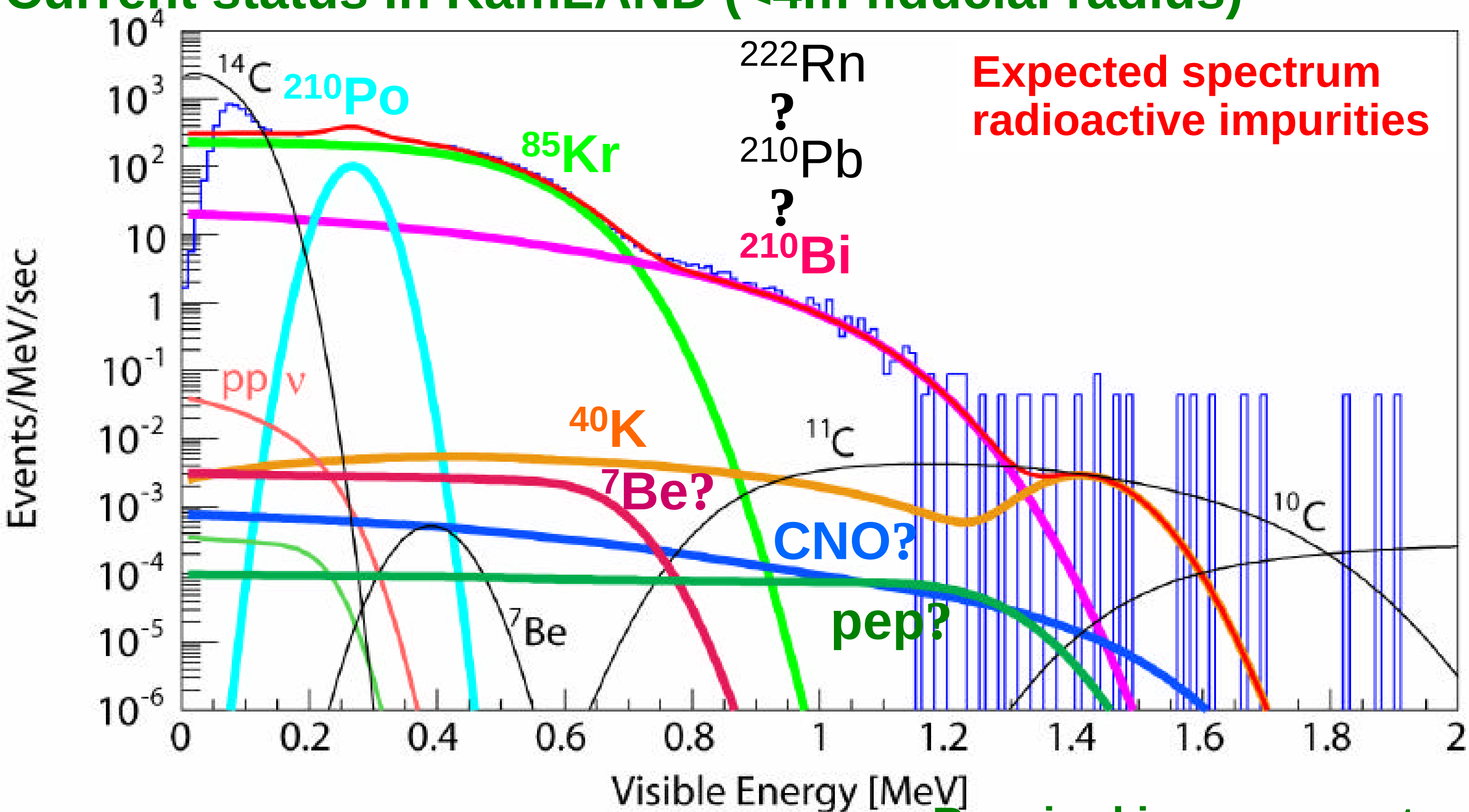




- ➢ **Verification of the MSW effect**
- ➢ **The first neutrino experiment by R. Davis et al.**
- ➢ **Verification of the SSM with low energy solar neutrinos**

4-2. Low Energy Spectrum

Current status in KamLAND (<4m fiducial radius)

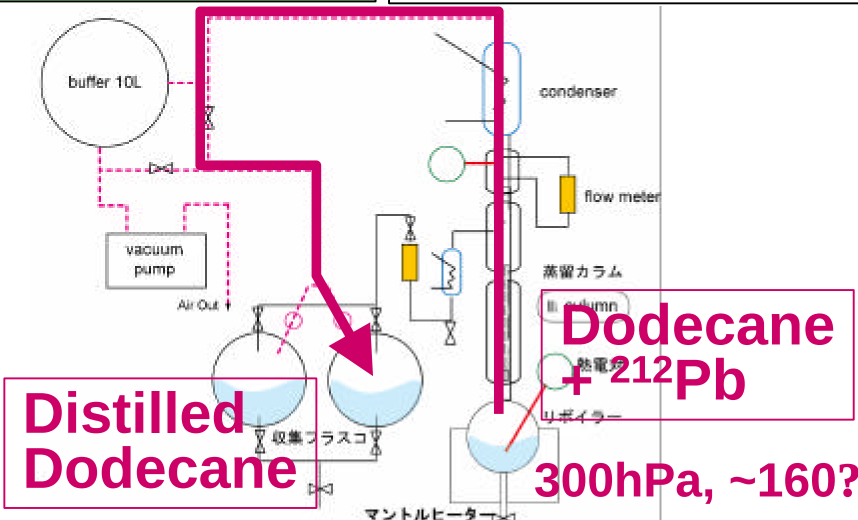


				Required improvement
^{85}Kr	~1 Bq/m^3	?	10^{-6} Bq/m^3	10^{-5}~10^{-6}
^{210}Bi-^{210}Po	10^{-20} g_{210Pb}/g	?	10^{-25} g_{210Pb}/g	10^{-4}~10^{-5}
^{40}K	<2.7x10^{-16} g_{40K}/g	?	10^{-18} g_{40K}/g	~10^{-2}

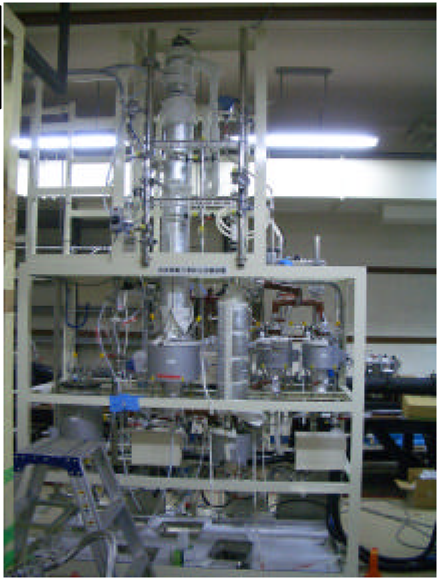
4-3. Purification of Liquid Scintillator

Distillation

Separation of substances based on differences in vapor pressures

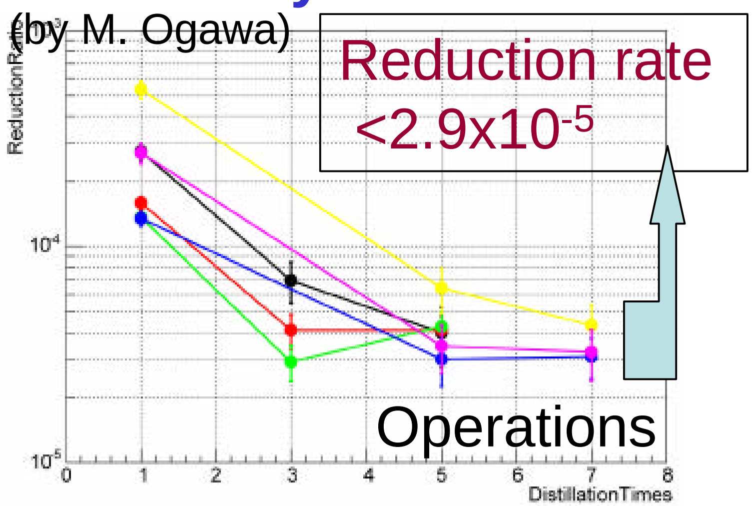


Test bench



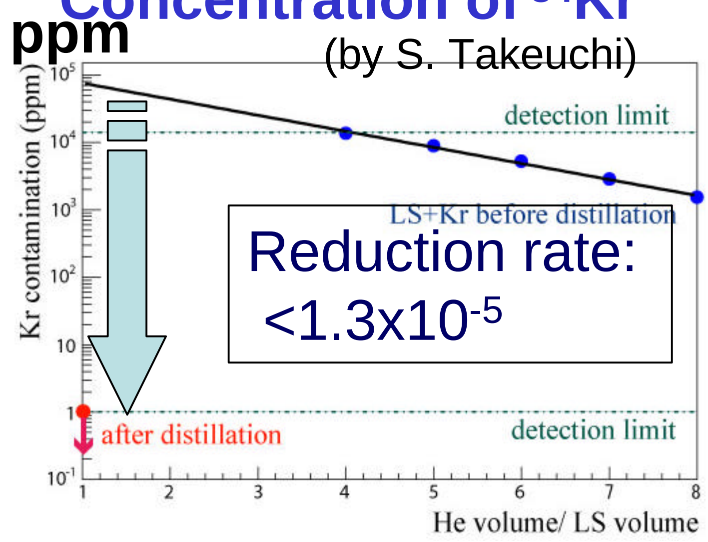
Ratio of decay rates of ^{212}Po

(by M. Ogawa)



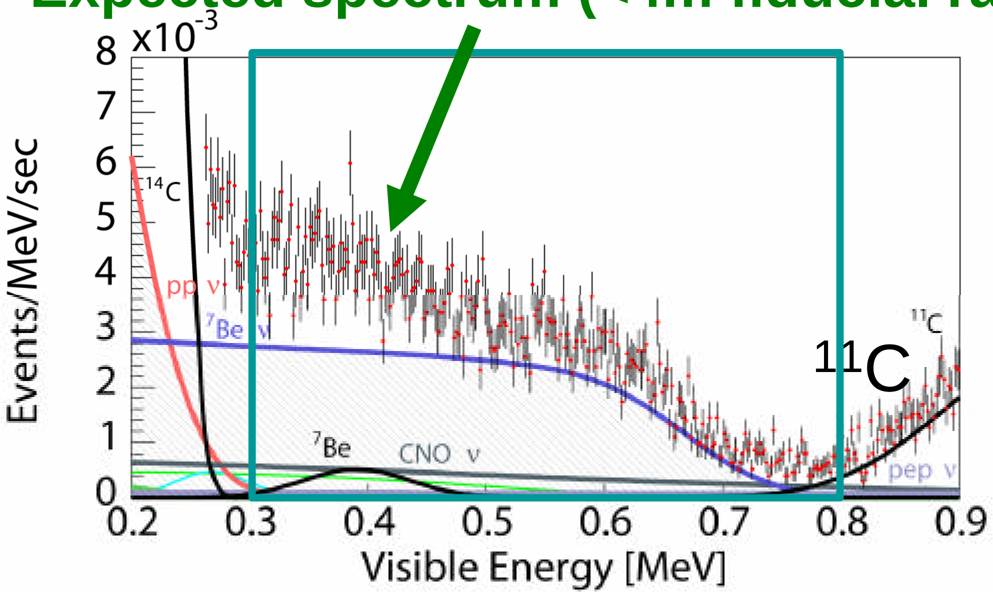
Concentration of ^{84}Kr

(by S. Takeuchi)



4-4. Expected Spectrum After Distillation

Expected spectrum (<4m fiducial radius, 100days)

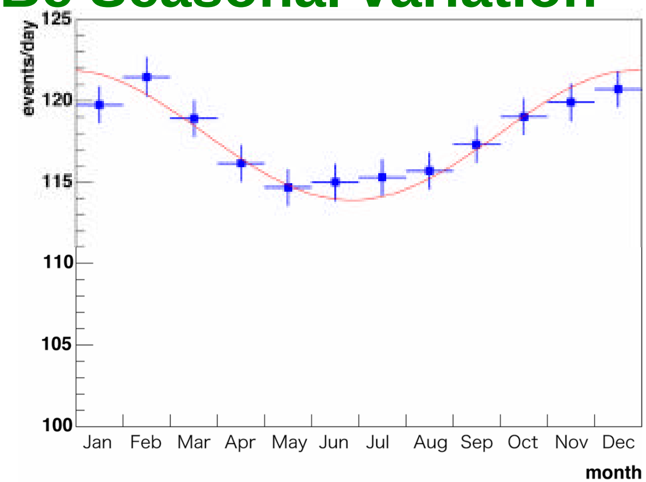


[Events/day/fiducial]

300keV< Evis <800keV

^{7}Be ν	**79.9** (No osc.)
^{210}Bi-^{210}Po	**2.0**
^{85}Kr	**7.6**
^{40}K	**2.3**

^{7}Be Seasonal variation

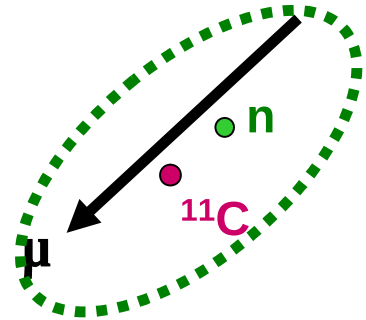


- Confirmation of solar neutrino signal
- Background estimation

4-5. Possibility of CNO + pep Observation
(After purification)

$^{12}C(?\ n)^{11}C\ ?\ ^{11}B$

(β^{+}, E_{max}=0.96MeV)

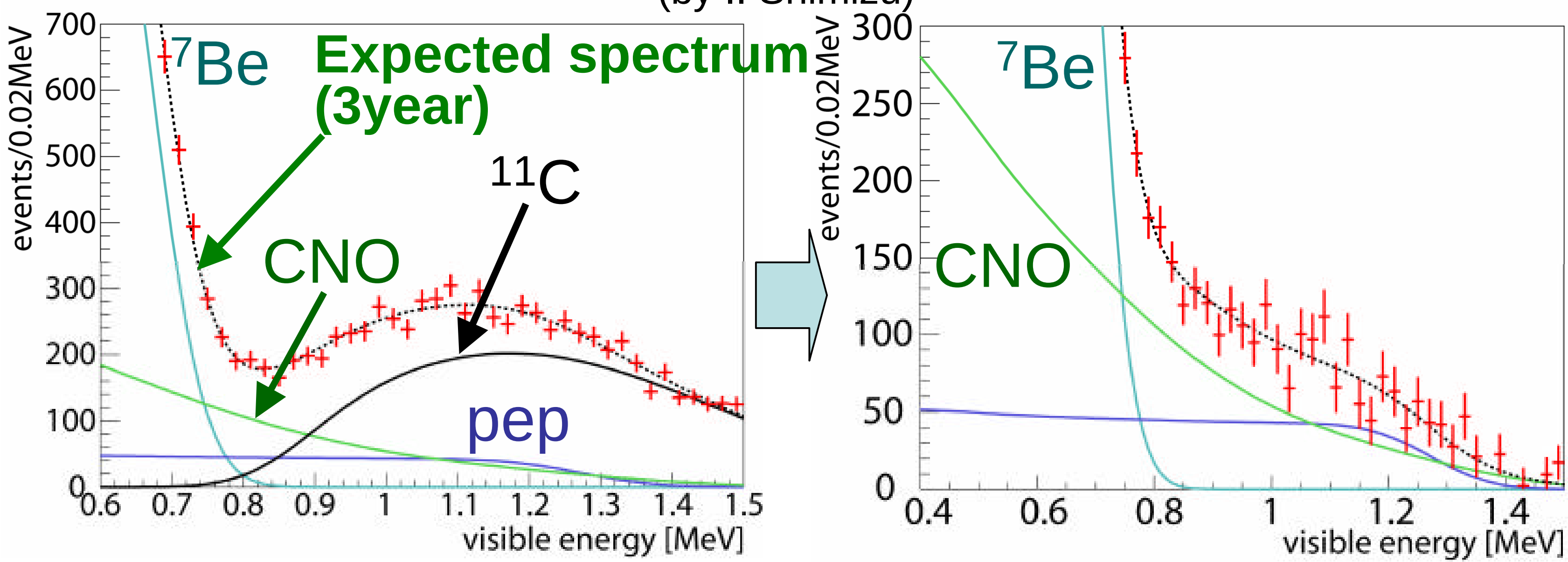


Galbiati et al., hep-ph/0411002

- **95% of ^{11}C produce neutrons**
  (measurable with KamLAND)

^{11}C rejection by neutron tagging
(Electronics upgrade is proposed)

(by I. Shimizu)



- **Possibility of the observation of the CNO cycle in the solar fusion reaction**

4-6. Tentative Schedule

2005	2006	2007	2008	2009

- R&D, Test
- Construction (Here)
- Purifi-cation
- Solar neutrino observation

Monitor system

New tunnel for the purification system

Summary

- With KamLAND 515.1 days data,
  - Reconfirmed the reactor neutrino disappearance at 99.998% C.L.
  - Evidence of spectrum distortion:
    rescaled null oscillation is excluded at 99.6% C.L.
  - Found the oscillation behavior in L_0/E plot
  - Determined ? m^2 precisely
- With KamLAND 749.1 days data,
  - First experimental investigation of geoneutrinos:
    4.5 - 54.2 at 90% C.L. interval consistent with geophysical models
  - Open neutrino geophysics
- ^{7}Be solar neutrino observation in KamLAND is coming soon.