A high sensitivity search for anti-neutrino's from the sun and other sources at KamLAND

Hiroshi Ogawa
Tohoku University
2/16,2004
10th ICEPP symposium, Hakuba

Contents

- KamLAND experiment
- Summary of reactor neutrino observation
- Search for electron anti-neutrino from the sun
- Future plan
- Summary

KamLAND Collaboration

- **Tohoku University:** K.Eguch, S.Enomoto, K.Furuno, J.Goldman, H.Hanada, H.Ikeda, K.Ikeda, K.Inoue, K.Ishihara, W.Itoh, T.Iwamoto, T.Kawaguchi, T.Kawashima, H.Kinoshita, Y.Kishimoto, M.Koga, Y.Koseki, T.Maeda, T.Mitsui, M.Motoki, K.Nakajima, M.Nakajima, T.Nakajima, H.Ogawa, T.Sakabe, I.Shimizu, J.Shirai, F.Suekane, A.Suzuki, K.Tada, O.Tajima, T.Takayama, K.Tamae,H.Watanabe
- **University of Alabama:** J.Busenitz, Z.Djurcic, K.McKinny, D-M.Mei, A.Piepke, E.Yakushev
- **LBNL Berkeley:** B.E.Berger, Y.D.Chan, M.P.Decowski, D.A.Dwyer, S.J.Freedman, Y.Fu, B.Fujikawa, K.M.Heeger, K.T.Lesko, K-B.Luk, H.Murayama, D.R.Nygren, C.E.Okada, A.W.Poon, H.M.Steiner, L.A.Winslow
- **California Institute of Technology:** G.A.Horton-Smith, R.D.McKeown, J.Ritter, B.Tipton, P.Vogel
- **Drexel University:** C.E.Lane, T.Miletic

- **University of Hawai Manoa:** P.W.Gorham, G.Guilian, J.G.Leanned, J.Maricic, S.Matsuno, S.Pakvasa
- **Louisiana State University:** S.Dazeley, S.Hatakeyama, M.Murakami, R.C.Svoboda
- **University of New Mexico:** B.D.Dieterle, M.DiMauro
- **Stanford University:** J.Detwieler, G.Gratta, K.Ishii, N.Tolich, Y.Uchida
- **University of Tennessee:** M.Batygov, W.Bugg, H.Cohn, Y.Efremenko, Y.Kamyshkov, A.Kozlov, Y.Nakamura
- **TUNL/ NCSU:** L.De Braeckeleer, C.R.Gould, H.J.Karwowski, D.M.Markoff, J.A.Messimore, K.Nakamura, R.M.Rohm, W.Tornow, A.R.Young
- **IHEP Beijing:** Y-F.Wang

KamLAND experiment

KamLAND : Kamioka Liquid scintillator Anti-Neutrino Detector

Physics Motivation

→ **Reactor electron anti-neutrinos**

Geo electron anti-neutrinos

→ **Solar anti-neutrinos**

7Be solar neutrinos

Other anti-neutrino sources

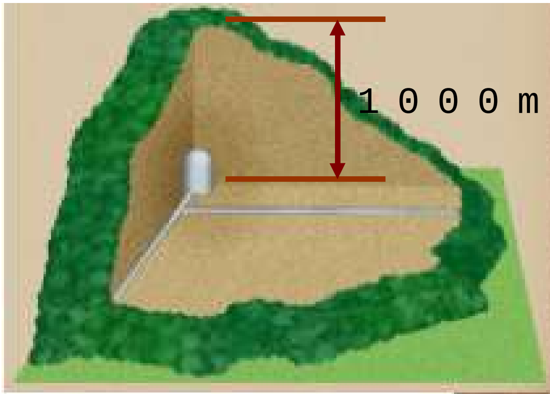
- **SN neutrinos**
- **Relic neutrinos**

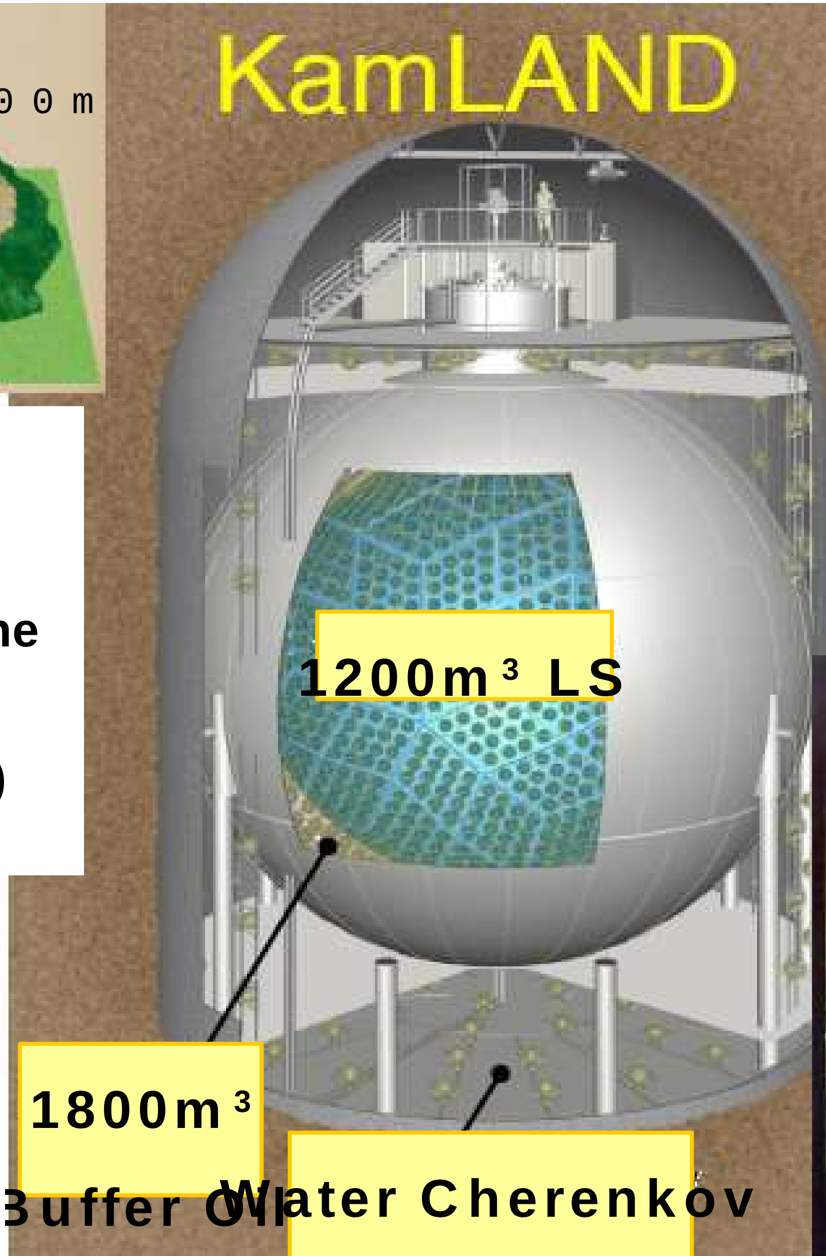
KamLAND advantage:

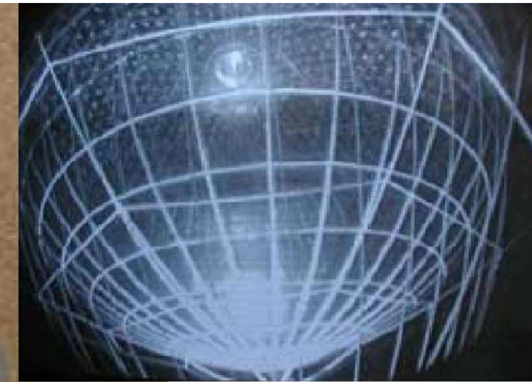
high energy resolution

low threshold ~0.9MeV

~0.3MeV (in the future)







LS

80% dodecane

20% pseudocumene

(1,2,4

Trimethylbenzene)

1.52g/l PPO

(2,5-

Diphenyloxazole)

$8{,}000 photons/MeV$

$\lambda \sim 10 m$

34% photo-coverage

50% isoparaffin

1325 17"

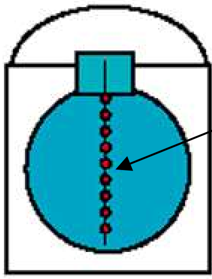
photo-tubes

22% photo-

coverage

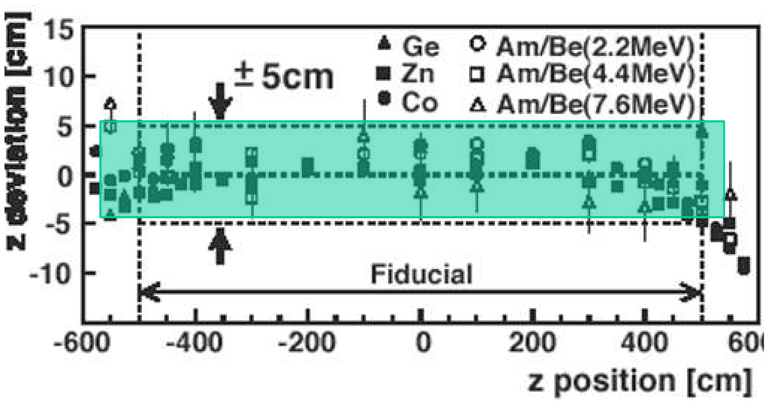
- Vertex & energy calibration

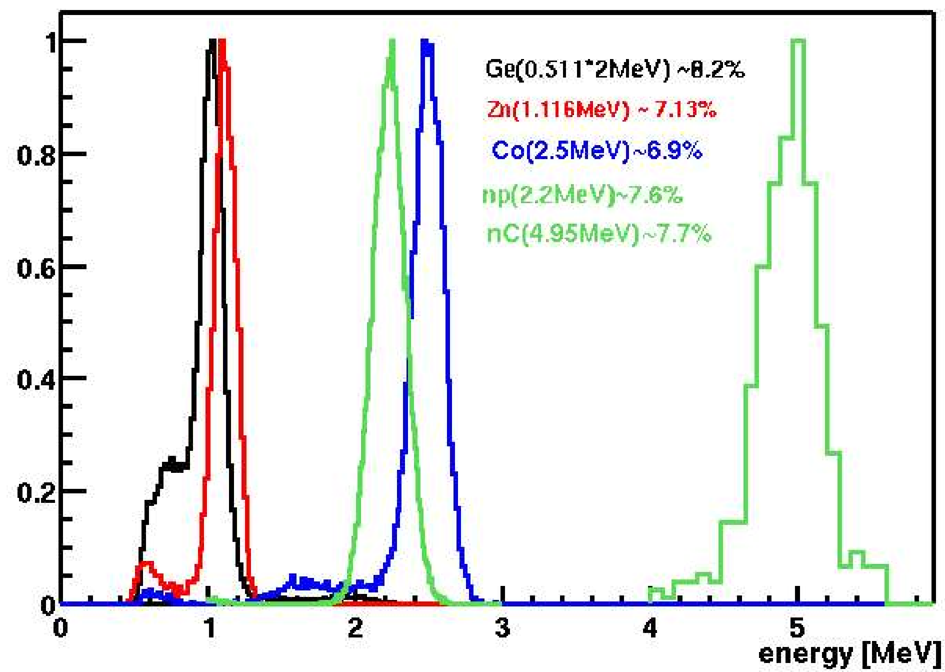
with radioactive sources



^{68}Ge : 1.012 MeV (γ + γ) ^{65}Zn : 1.116 MeV (γ)

^{60}Co : 2.506 MeV (γ + γ) AmBe : 2.20 , 4.40, 7.6 MeV (γ)

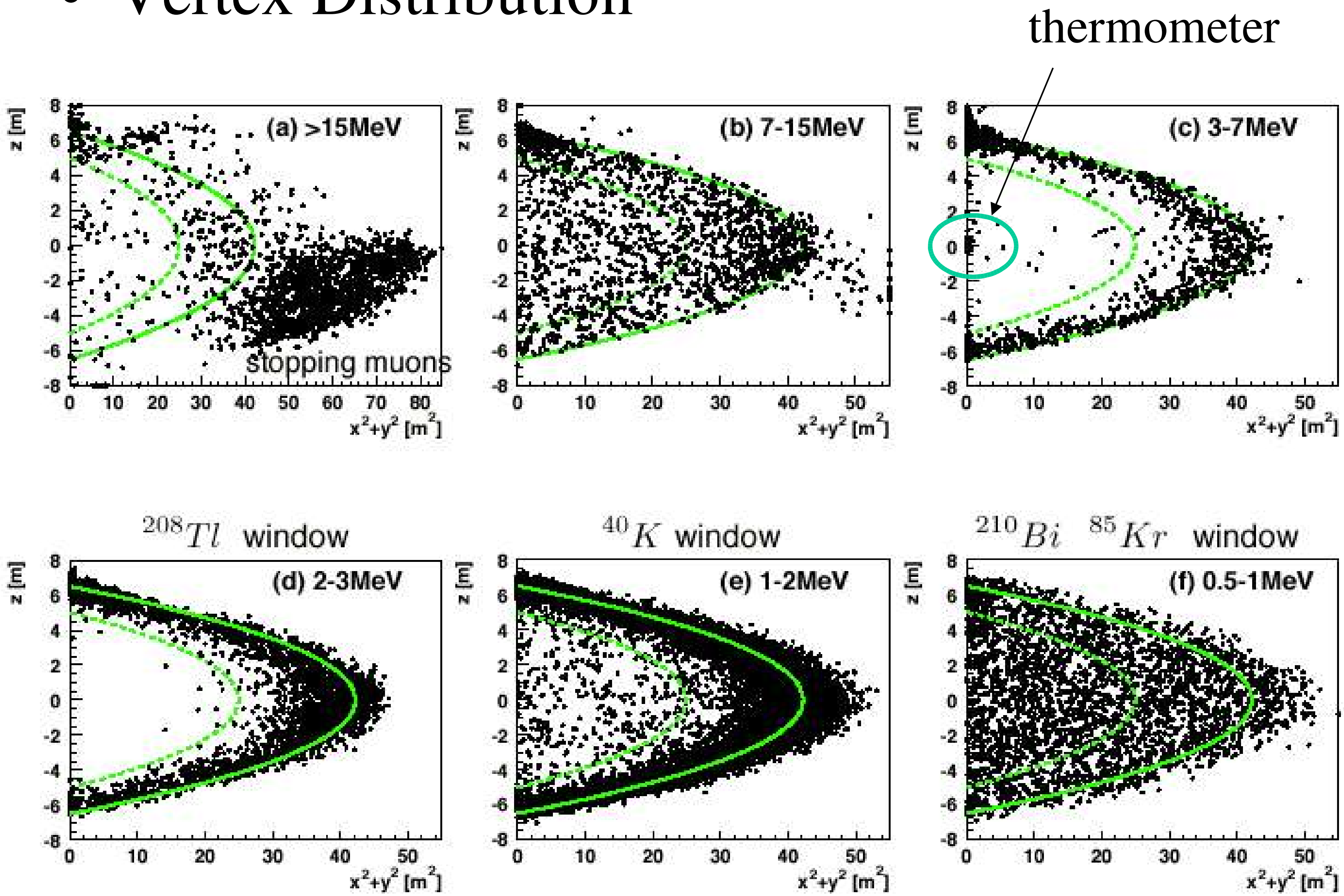




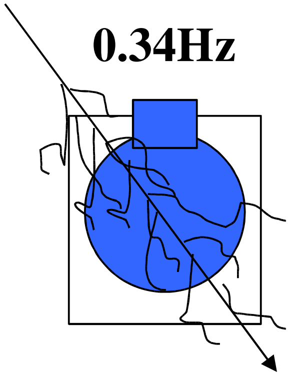
σ_{xyz} = 30cm/ ?E

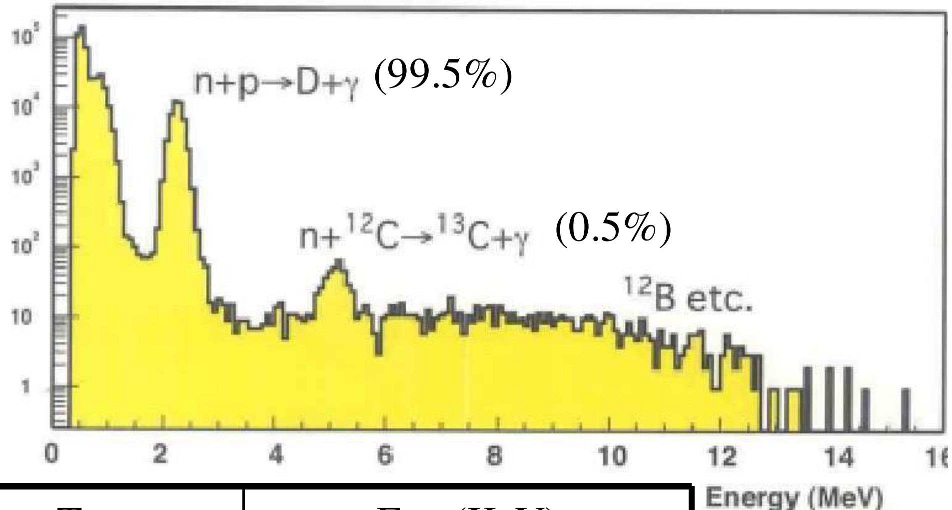
ΔE/E~7.5%/ ?E,
Light Yield~300 p.e./MeV

- Vertex Distribution



- Spallation events after muon





BG of neutrino event

^{9}Li & ^{8}He

energy calibration

p capture (2.224MeV)

^{12}C capture (4.947MeV)

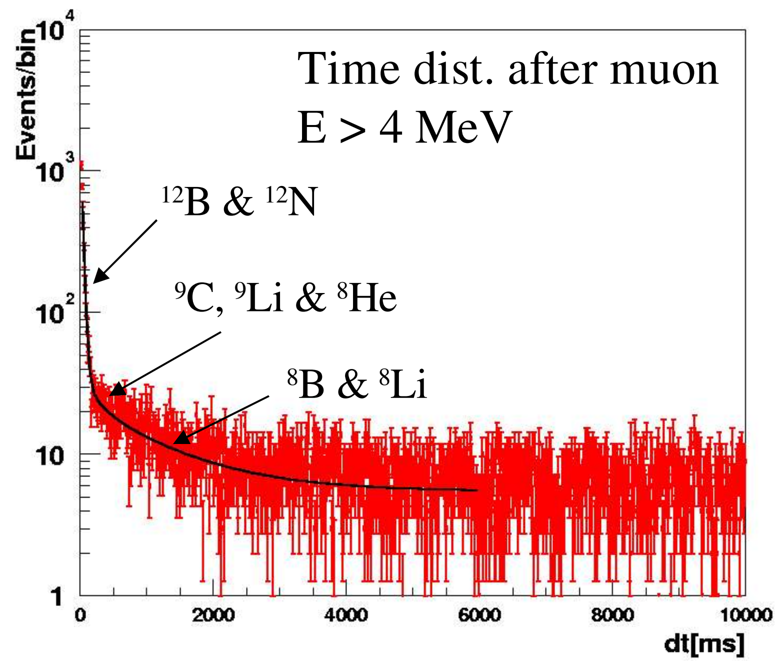
^{12}B beta decay

vertex calibration

p capture

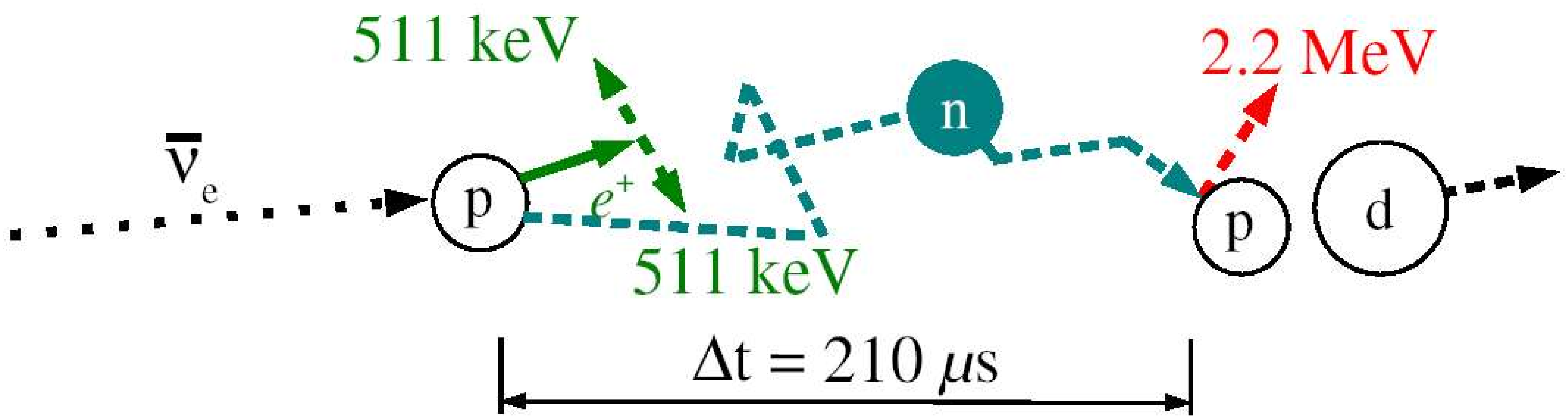
^{12}B beta decay

Isotopes	$T_{1/2}$	E_{max} (KeV)
^{12}B	20.2 ms	13369(β^-)
^{12}N	11.0 ms	17338(β^+)
^{11}Li	8.5 ms	20610(β^-)
^{9}Li	173.8 ms	13606(β^- n) ←
^{8}He	119.0 ms	10653(β^- n) ←
^{9}C	126.6 ms	16498(β^+)
^{8}Li	838.0 ms	16006(β^-)
^{6}He	806.7 ms	3508(β^-)
^{8}B	770.0 ms	17979(β^-)



- $\bar{\nu}_e$ detection in liquid scintillator

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



prompt part : e^+

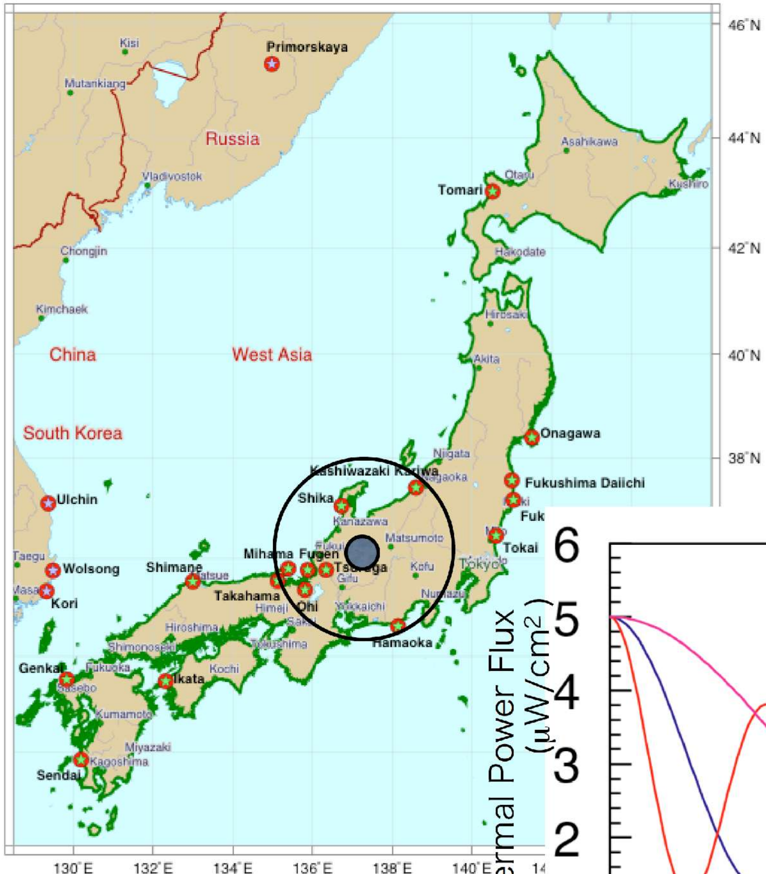
$$E_{vis} = E_{\nu e} - (\Delta m_{np} + m_e) - T_n(\theta) + 2m_e$$
$$= E_{\nu e} - 0.782\text{MeV} - T_n(\theta)$$

delayed part : γ (2.2MeV)

Reduce the background Powerfully !

Summary of reactor neutrino observation

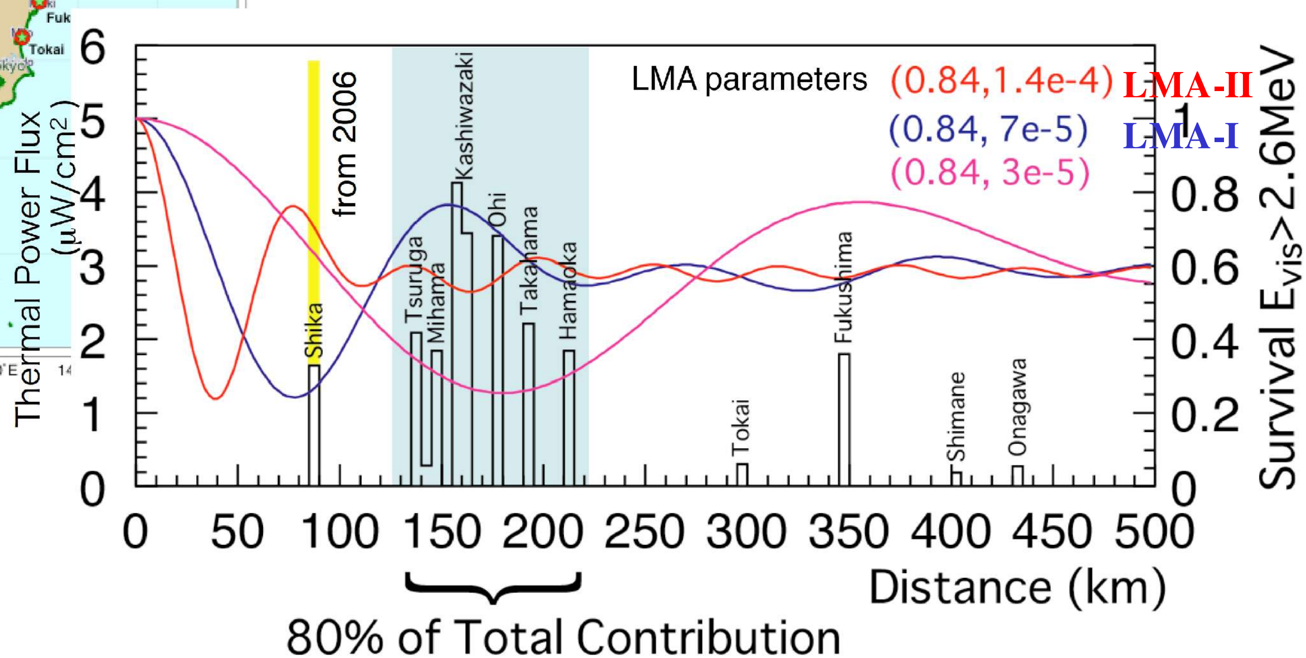
- Kamioka location



70 GW (7% of world total) is generated at 130-240 km distance from Kamioka.

Reactor neutrino flux, $\sim 5 \times 10^6/cm^2/sec$ requires O(kiloton) underground detector.

There is a former Kamiokande cavity at 1000 m (2700 mwe) underground.



~97% from Japan
~2.5% from Korea

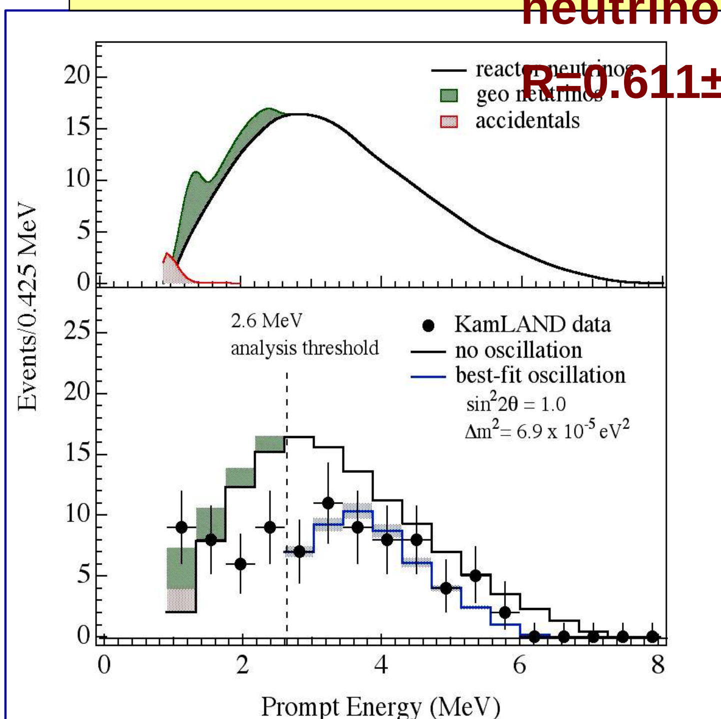
- # Reactor neutrino analysis result

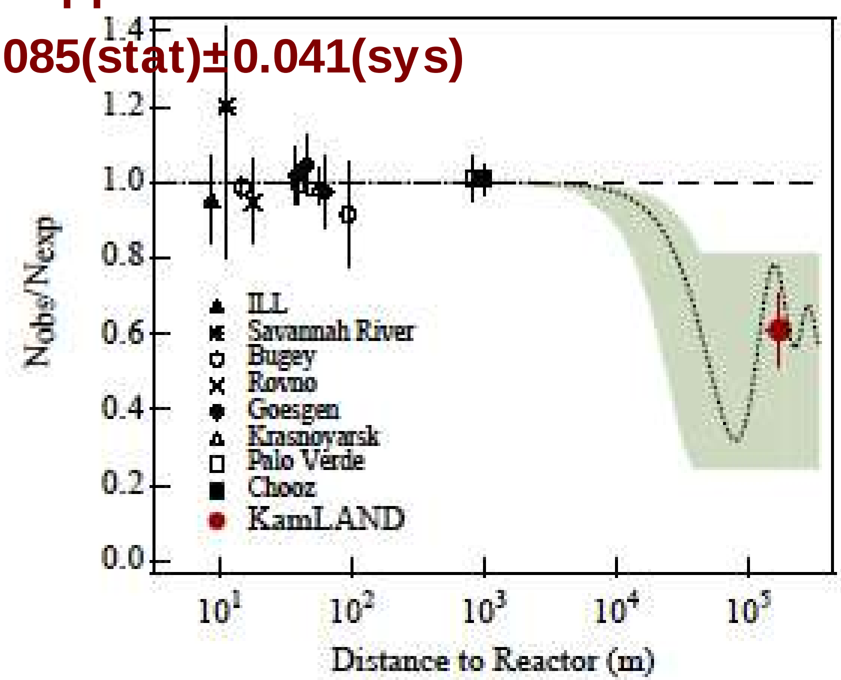
4 Mar. – 6 Oct. 2002   145.1 live days (162 ton-year exposure)

Analysis threshold	**2.6MeV**	**0.9MeV**
Expected signal	**86.8±5.6**	**124.8±7.5**
BG	**1±1**	**2.9±1.1 (+9 geo neutrino)**
Observed	**54**	**86**

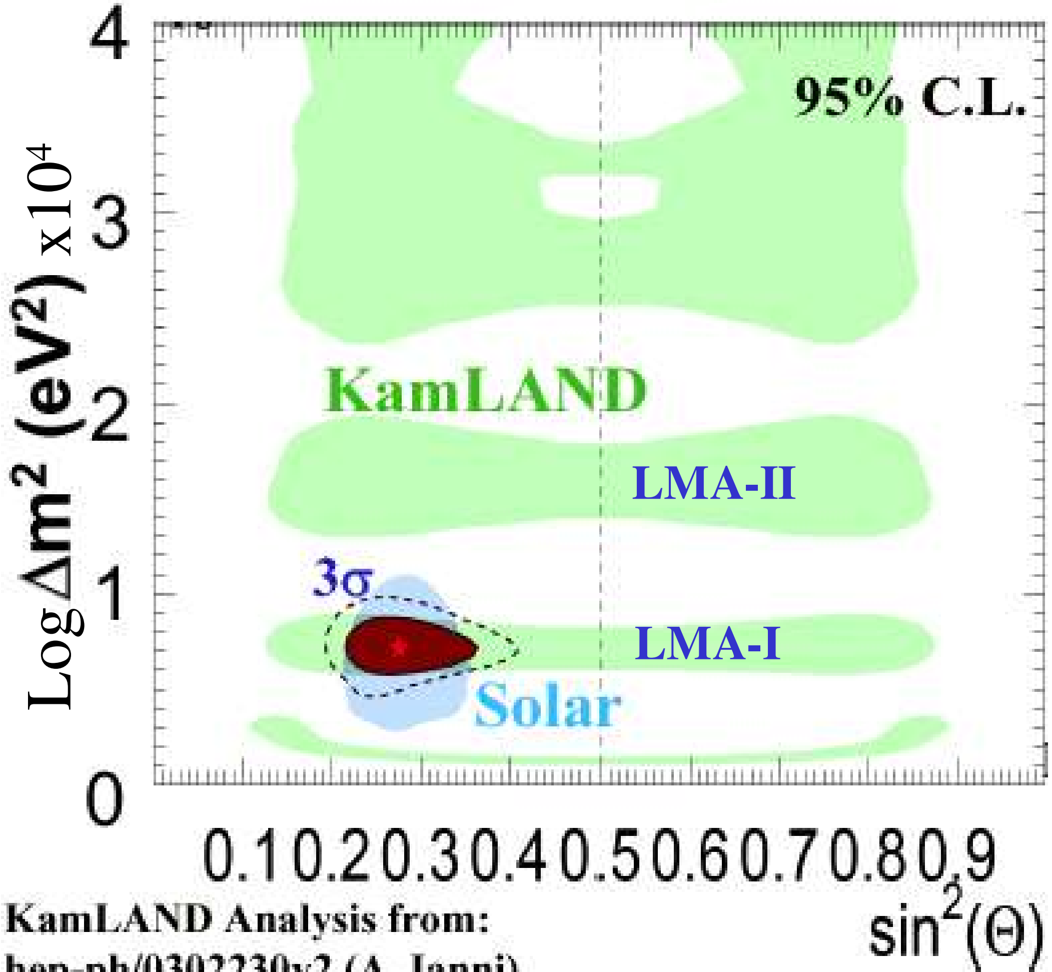
neutrino disappearance 99.95C.L.

R=0.611±0.085(stat)±0.041(sys)





Oscillation parameters from solar neutrino and KamLAND experiments



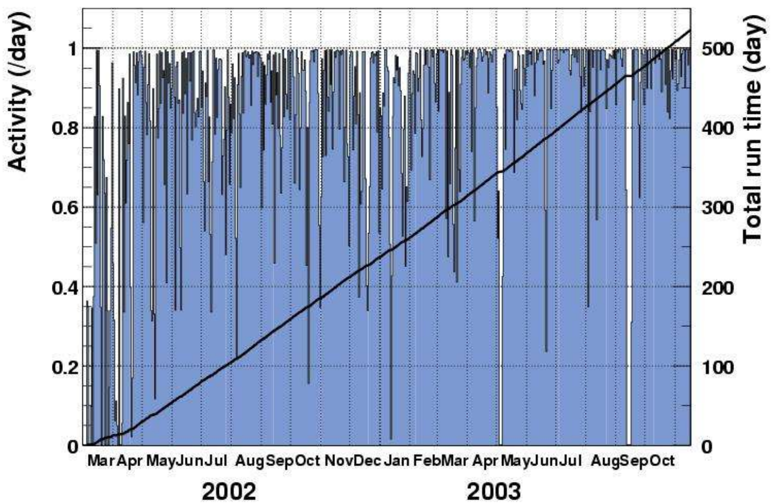
KamLAND Analysis from:
hep-ph/0302230v2 (A. Ianni)

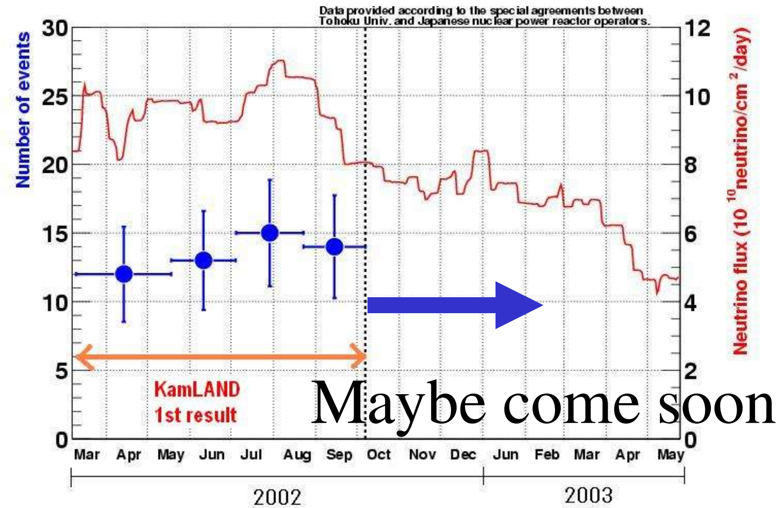
- Solar neutrino: Combined analysis of Homestake, GALLEX+GNO, SAGE, SK and SNO
- Agree with KamLAND contour
- Solar + KamLAND Best fit:
  - $\sin^2\theta=0.28$ ($\tan^2\theta=0.38$)
  - $\Delta m^2 = 7.2\times 10^{-5}$ eV^2

M. Nakahata
Noon 04 Feb. 11-15, 2004,
International Workshop on Neutrino Oscillations and their Origin;
Tokyo, Japan

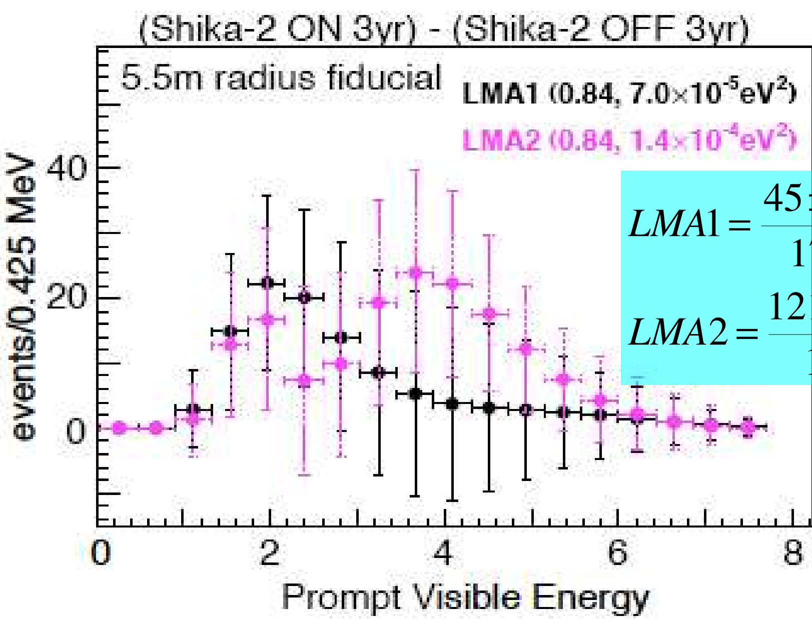
- Future

Analysis data update : seasonal variation





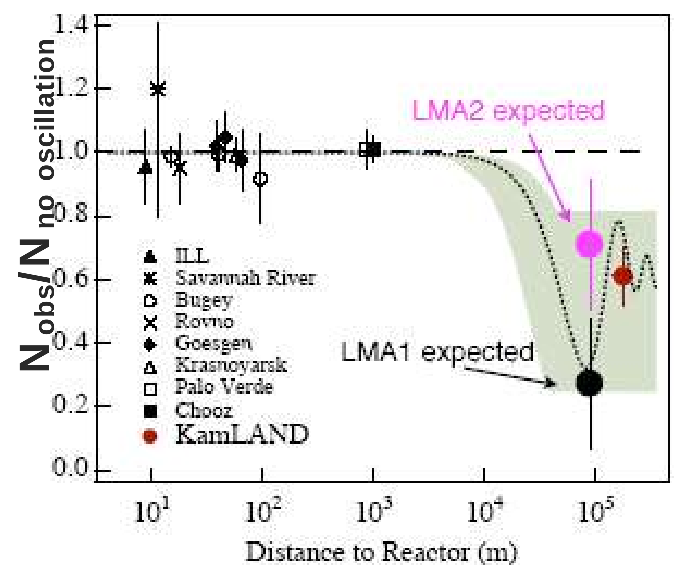
Shika2 reactor will work at 88km –2006 : LMA1 or LMA2



$$LMA1 = \frac{45 \pm 37}{173}$$

$$LMA2 = \frac{121 \pm 36}{173}$$

Oscillatory pattern may be seen as an evidence for oscillation.



Search for electron anti-neutrino from the sun

- How to make solar anti-neutrino

ν_e with a non-zero transition magnetic moment can evolve into $\bar{\nu}_\mu$, $\bar{\nu}_\tau$ while propagating through intense magnetic fields in the sun.

$$i\frac{d}{dt}\begin{pmatrix}\nu_e\\ \nu_\mu\\ \bar{\nu}_e\\ \bar{\nu}_\mu\end{pmatrix}=\begin{pmatrix}\frac{G}{\sqrt{2}}(2N_e-N_n) & \frac{\Delta m^2}{4E}\sin 2\theta & 0 & \mu B\\ \frac{\Delta m^2}{4E}\sin 2\theta & -\frac{G}{\sqrt{2}}N_n+\frac{\Delta m^2}{2E}\cos 2\theta & -\mu B & 0\\ 0 & -\mu B & -\frac{G}{\sqrt{2}}(2N_e-N_n) & \frac{\Delta m^2}{4E}\sin 2\theta\\ \mu B & 0 & \frac{\Delta m^2}{4E}\sin 2\theta & -\frac{G}{\sqrt{2}}N_n+\frac{\Delta m^2}{2E}\cos 2\theta\end{pmatrix}\begin{pmatrix}\nu_e\\ \nu_\mu\\ \bar{\nu}_e\\ \bar{\nu}_\mu\end{pmatrix}$$

(green oval) : MSW effect

(red oval) : spin-flavor presession

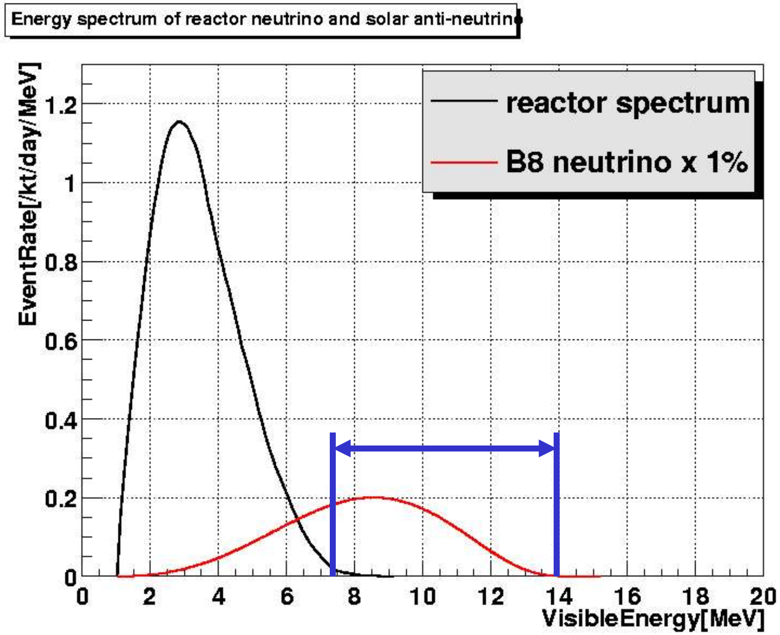
$\mu_\nu = 3\text{x}10^{-19}\mu_B(m_\nu/\text{eV})$ extension of SM

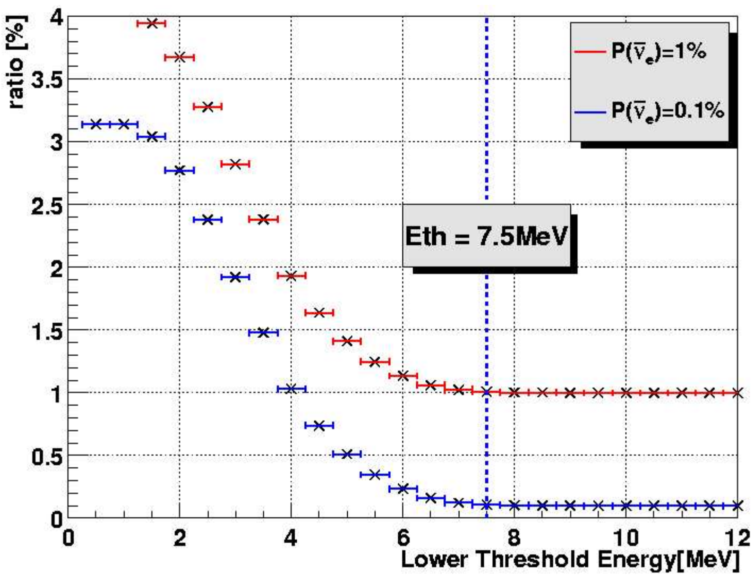
$\mu_\nu < 1\text{x}10^{-10}\mu_B$ MUNU experiment

conversions : $\nu_{eL} \rightarrow \bar{\nu}_{\mu R} \rightarrow \bar{\nu}_{eR}$ or $\nu_{eL} \rightarrow \nu_{\mu L} \rightarrow \bar{\nu}_{eR}$

⟶ depend to magnetic field model

- Energy region for solar anti-neutrino





Avoid BG by reactor

Near of the ^{8}B neutrino endpoint

$7.5 < E_{e+} < 14\text{MeV}$

$$8.3 < E_{\bar{\nu}_e} < 14.8 MeV$$

- Event selection

Data: 4. Mar. – 1. Dec. 2002

Livetime: 185.5 days

Event selection criteria

spallation cut t < 2sec for $dQ>10^6$ p.

t < 2sec, dr(from muon

for $dQ>10^6$ p.e.

dead time 11.5%

vertex cut R_p < 550 cm, R_d < 550 cm

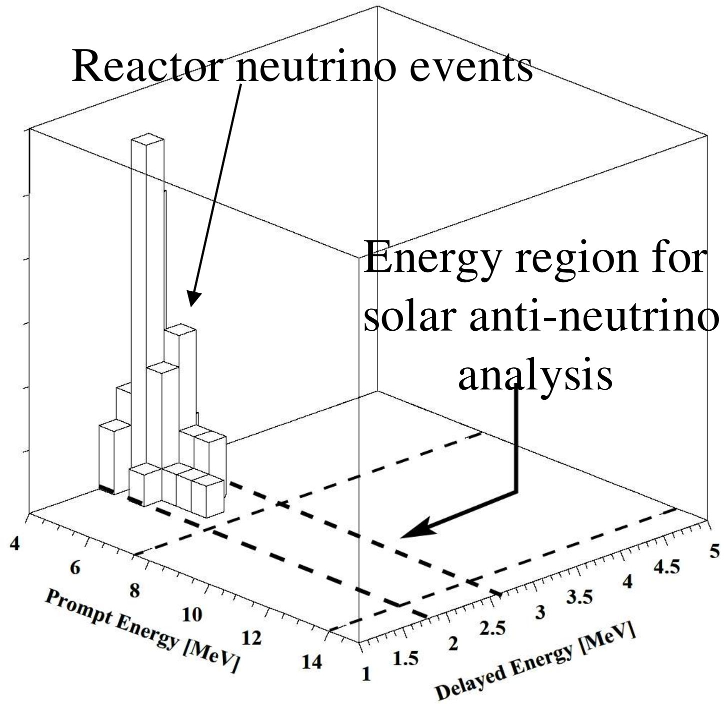
vertex correlation dL < 160 cm

timing correlation 0.5 < dt < 660μs

energy cut delayed: 1.8< E < 2.6MeV

detection efficiency 84.1%

energy cut prompt: 7.5 < E < 14.0 MeV



No observed event !

- Systematic errors

Detection efficiency (ε) : 1.6 %

space correlation R<550cm, dL<160cm : 1.6%
time correlation $0.5 < dt < 660$ μs : 0.4%
delayed energy $1.8 < E_d < 2.6$ MeV : 0.1%

Cross section (σ) : 0.2 %

Number of target proton : 4.3 %

total volume error 1171 +/- 25 m^3 : 2.2%
fiducial volume ratio R<550 cm : 3.7%

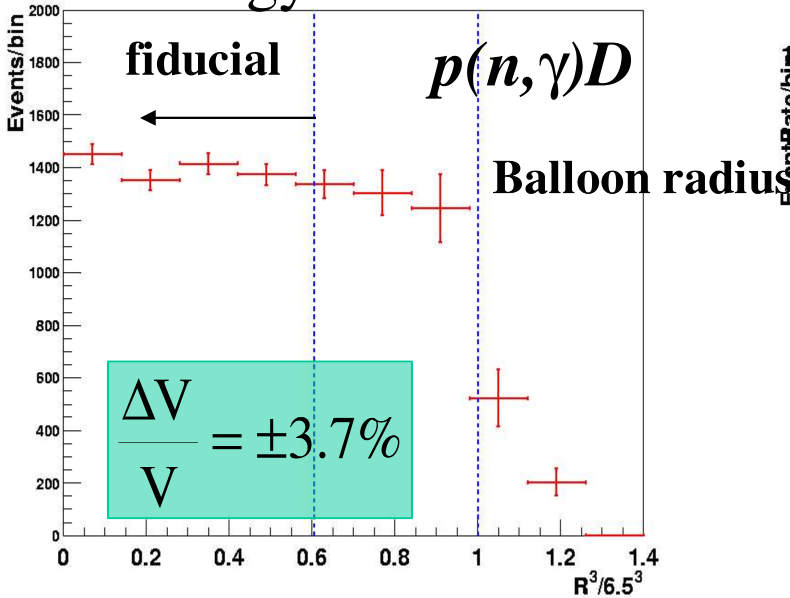
Energy threshold : 4.3 %

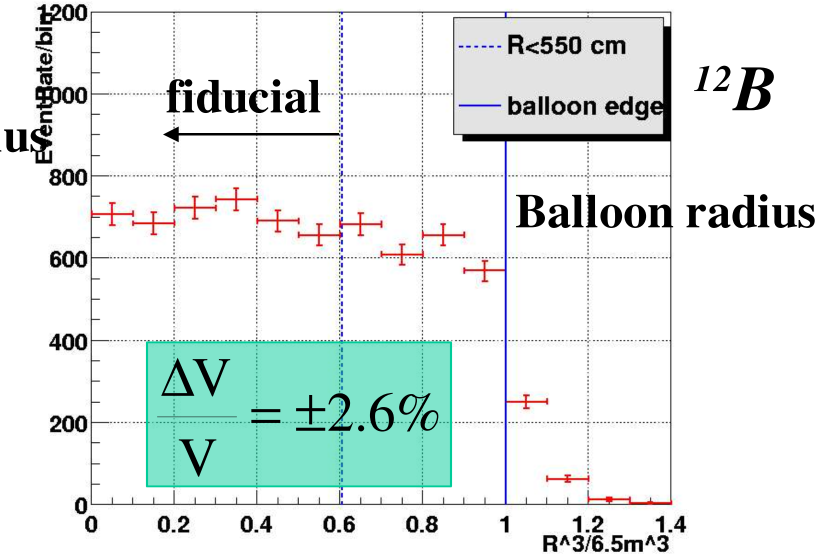
energy calibration is done by ^{12}B beta decay

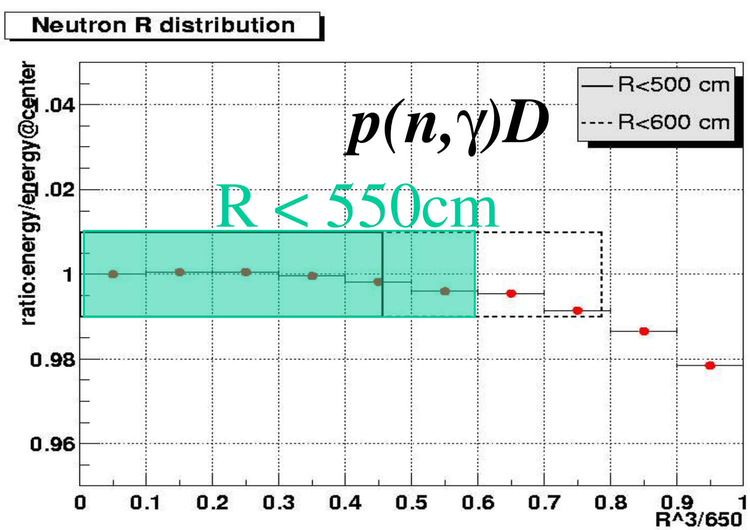
Livetime (T) : 0.07 %

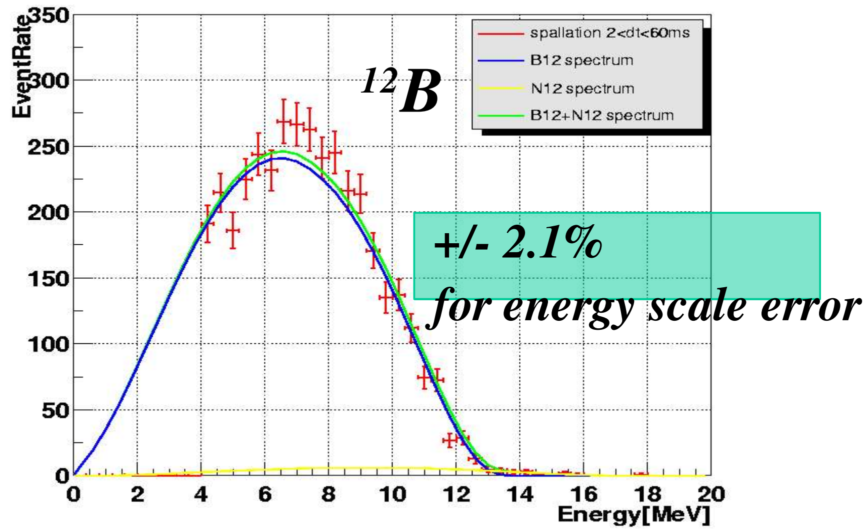
Total : 6.3 %

Vertex & energy calibration with muon spallation









Assuming ^{8}B neutrino shape : 4.3% error @ 7.5MeV threshold

- Expected background

?

Reactor neutrino	: 0.2 +/- 0.2
Ep > 7.5MeV, LMA region	
Atmospheric neutrino	: 0.001
T.K. Gaisser Phys. Rev. Lett. 1985	
Fast neutron	: 0.3 +/- 0.2
OD inefficiency 8% + passing rock event	
Accidental coincidence	: 0.02
pick up the off-timing events 1 < dt < 10 sec	
^{8}He & ^{9}Li	: 0.6 +/- 0.2
Total	: 1.1 +/- 0.4

- The $\bar{\nu}_e$ flux over the energy range

8.3-14.8 MeV (7.5 – 14 MeV for E_p)

N_{signal}=1.58 : using the Feldman-Cousins method
G.J.Feldman & R.D.Cousins, Phys. Rev. D57,3873(1998)

$$\Phi_{\bar{\nu}_e} = \frac{N_{signal}}{\bar{\sigma} \times \bar{\varepsilon} \times T \times \rho_p \times f_v}$$

$\bar{\sigma} = 6.88 \times 10^{-42}\ \mathrm{cm}^2$

$\bar{\varepsilon} = 0.841$

$T = 1.60 \times 10^7\ s$

$\rho_p \times f_v = 4.61 \times 10^{31}$: [illegible]

$< 3.7 \times 10^{2}\ \mathrm{cm^{-2}s^{-1}}$ (90% C.L.)

Normalize to ^{8}B solar neutrino flux

[illegible] 25% of [illegible]

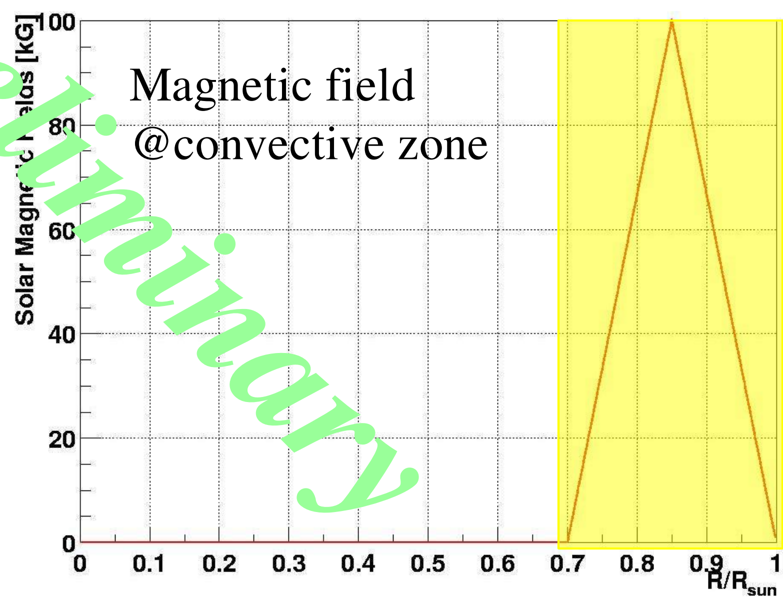
$5.05\ ^{+1.01}_{-0.81} \times 10^{6}\ \mathrm{cm^{-2}s^{-1}}$ ([illegible])

Neutrino conversion probability < 2.8×10^{-4} (90% C.L.)

X30 improvement of the previous best measurement !

hep-ex/0310047

- Interpretation by spin-flavor precession



J.Pulido, hep-ph/0106201

B_{core}<2MG

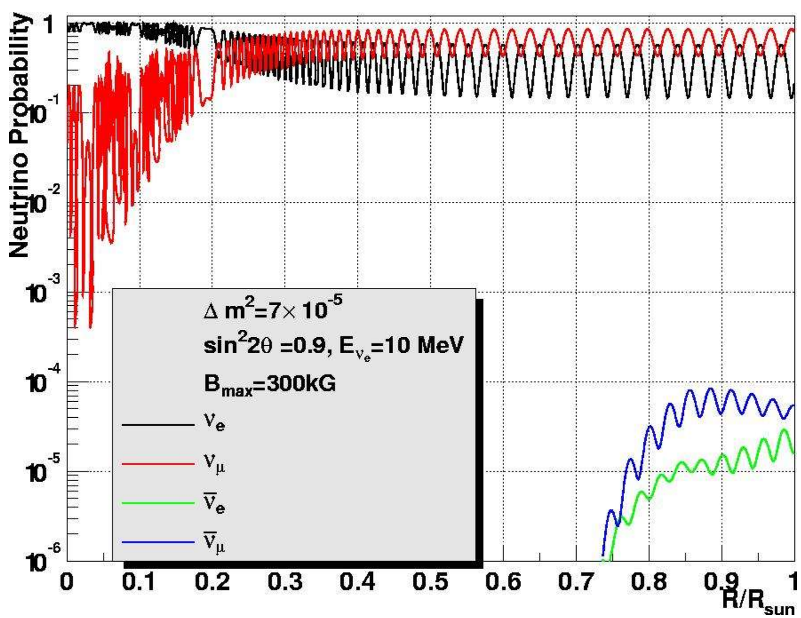
S.Chandrasekar & E.Fermi, Astrophys.J.188(1953)116

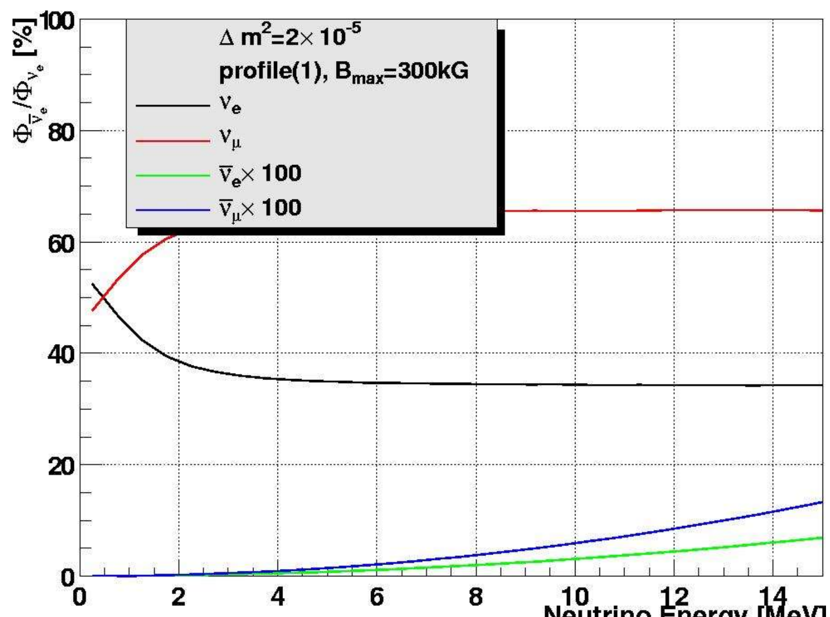
B_{core}<7MG

A.Friedland & A.Gruzinov, astro-ph/0211377

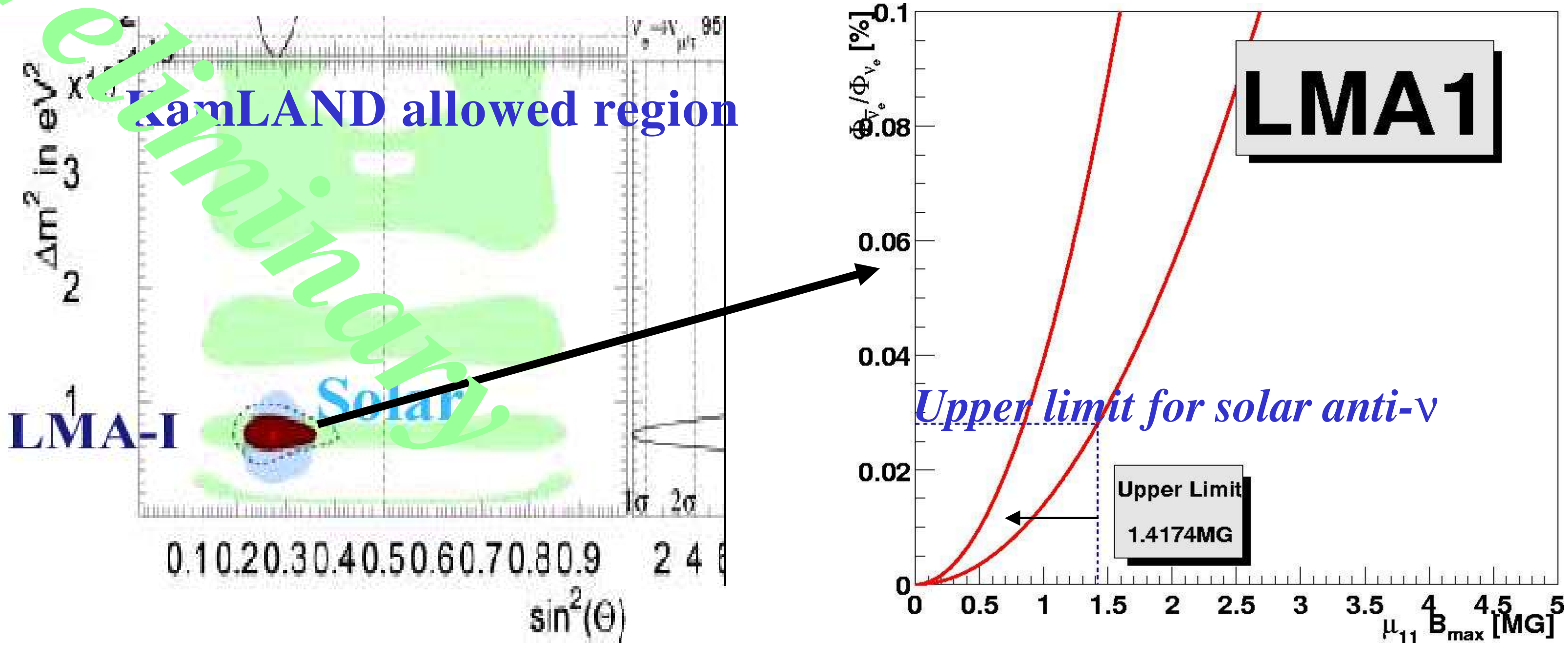
$B_{convective}$<300kG

H.M.Antia et. Al., astro-ph/0005587





Analysis region for oscillation parameter : LMA-I



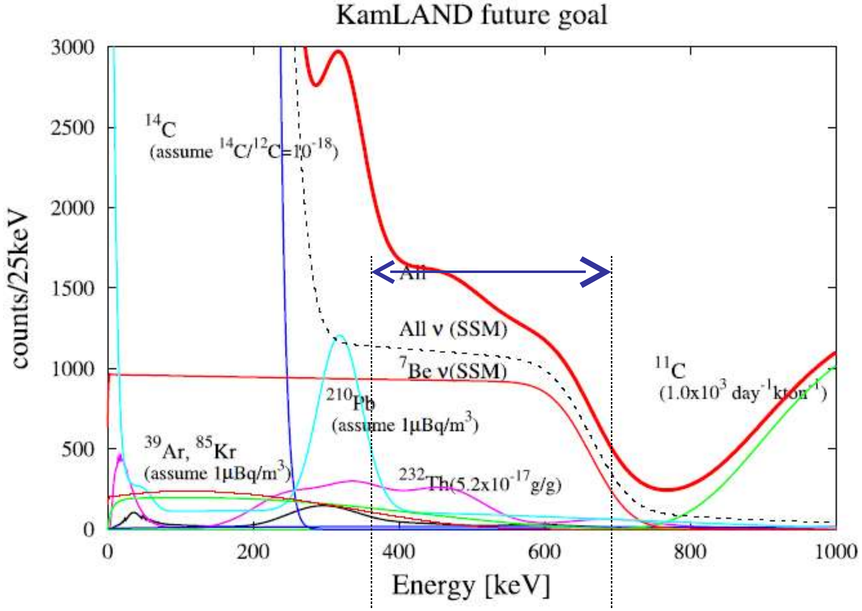
Neutrino conversion probability $\nu_e \rightarrow \bar{\nu}_e <$ 2.8×10⁻⁴ (90% C.L.)

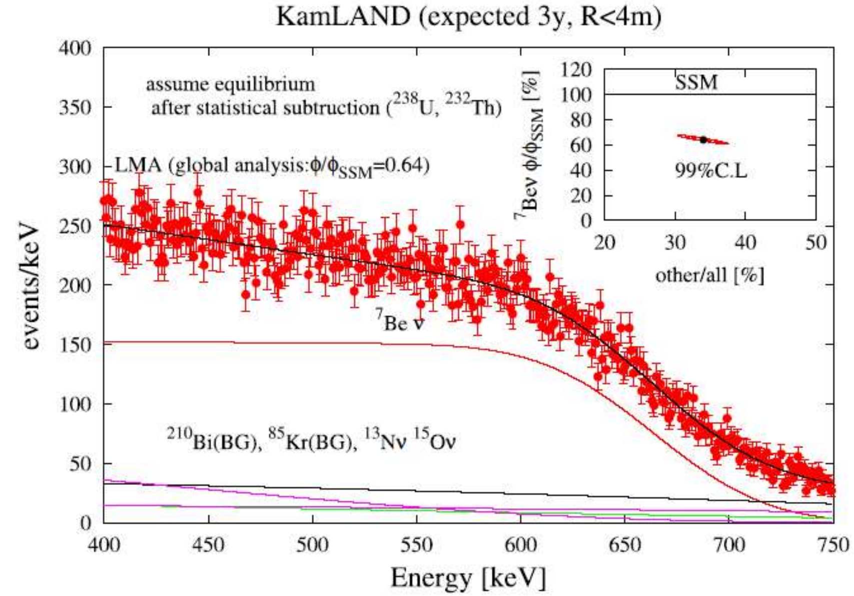
$$\mu_\nu B_{max} < 1.4 \times 10^{-5} \mu_B \, G$$

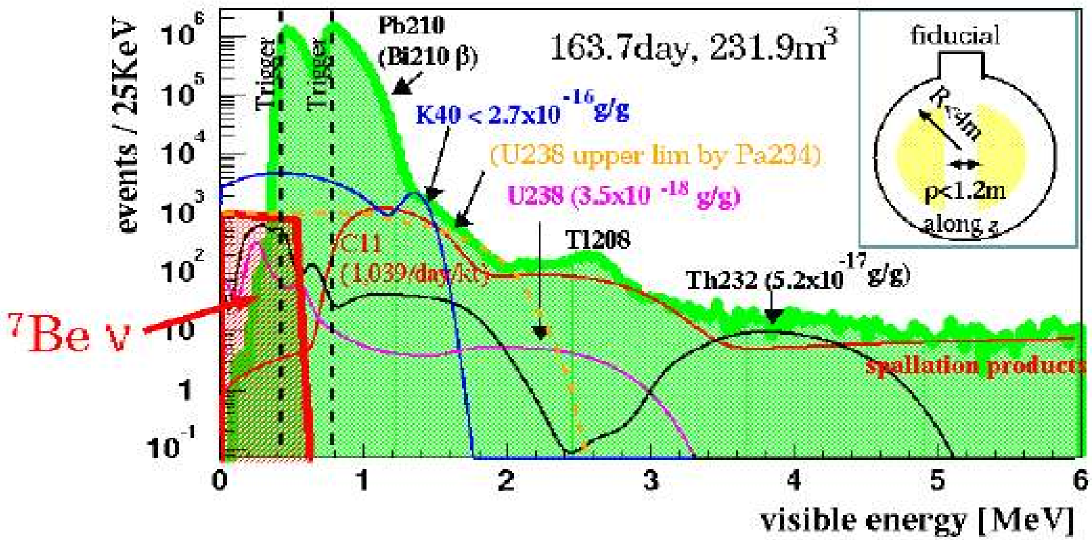
$\mu_\nu < 4.7 \times 10^{-11} \mu_B$ (B_{max}=300kG)

Future study

- ^{7}Be solar neutrino detection







We need the purification

- How reduce the impurity?

Background	now	goal
^{238}U(by Bi-Po)	3.5×10^{-18}g/g	**OK!!**
^{238}U(by ^{234}Pa)	O(10^{-15}g/g)(Max.)	10^{-18}g/g
^{232}Th (by Bi-Po)	5.2×10^{-17}g/g	**OK!!**
^{40}K	2.7×10^{-16}g/g(max.)	$< 10^{-18}$g/g
^{210}Pb	$\sim 10^{-20}$g/g	5×10^{-25}g/g $\sim 1\mu$Bq/m^3
^{85}Kr, ^{39}Ar	^{85}Kr =0.7Bq/m^3	1μBq/m^3
^{222}Rn (after purification)	^{238}U $= 3.5 \times 10^{-18}$g/g $= 3.3 \times 10^{-8}$Bq/m^3	**OK!!** (1μBq/m^3)
^{222}Rn (during purification)		1mBq/m^3 ^{210}Pb $= 0.5\mu$Bq/m^3 after decay

For ^{85}Kr & ^{39}Ar : nitrogen purge system update

For ^{210}Pb & ^{40}K : water extraction update
distillation

For Rn protection : acryl cover for system
main guard + fresh air blow

Summary

KamLAND has observed an evidence for reactor neutrin

at ~180km distance with 99.95% C.L.

$$R = 0.611 \pm 0.085 \pm 0.041$$

Assuming CPT invariance, only the LMA solution is com

deficit.

We got a anti-neutrino flux upper limit in the energy range 8.3 – 14.8 MeV

$< 3 \times 10^{2}\ cm^{-2} s^{-1}$ (90% C.L.)

This corresponds to **2.8×10^{-4}** for BP2000 ^{8}B neutrino flux

We start R&D for detection ^{7}Be solar neutrinos on KamLAND!