KamLAND (Anti-Neutrino Status)

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KamLAND Collaboration

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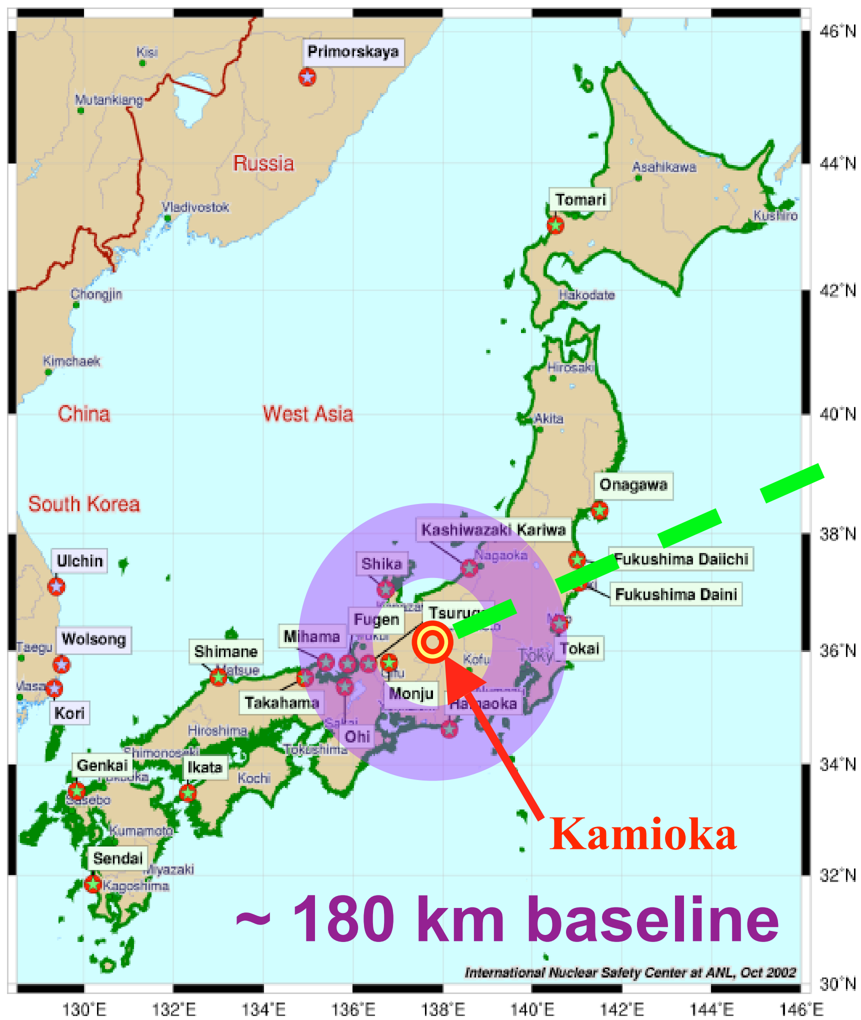
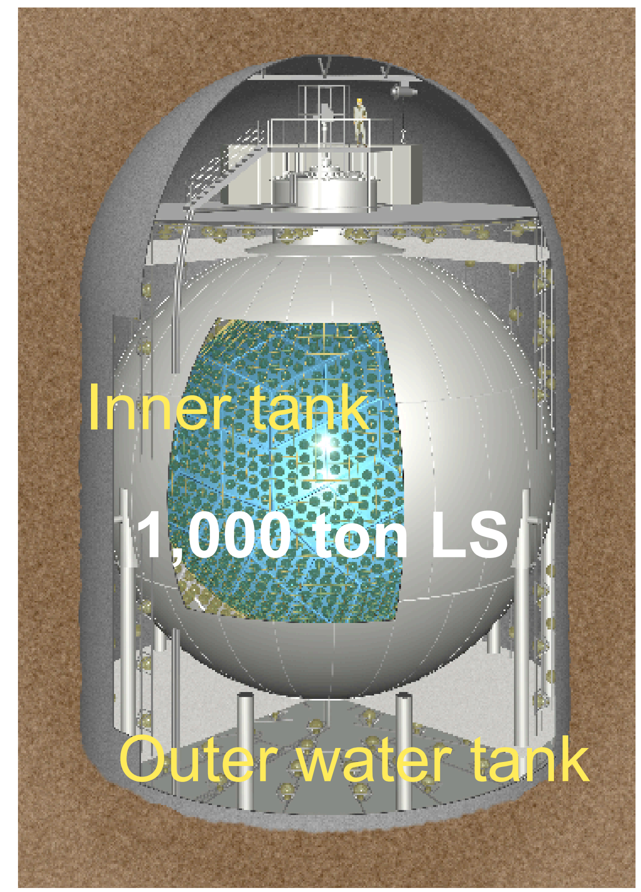
KamLAND

Kamioka Liquid Scintillator Anti-Neutrino Detector





34% photo-coverage with
1325 17" and 554 20" PMTs

2 flavor neutrino oscillation

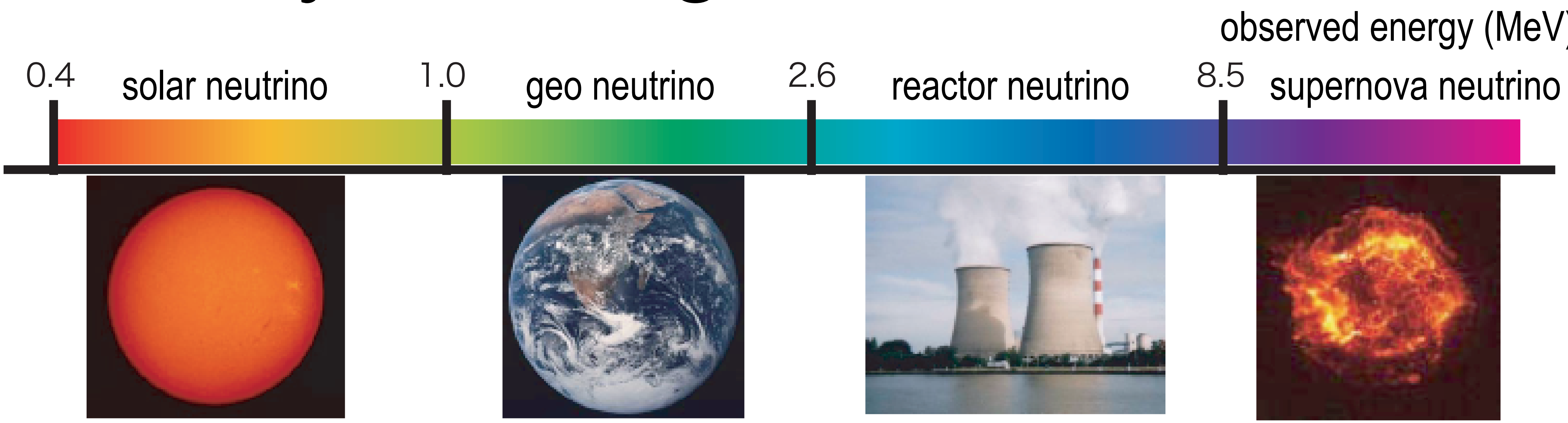
$$P(\nu_e \rightarrow \nu_e) = 1 - \sin^2 2\theta \sin^2\left(\frac{1.27\Delta m^2[\mathrm{eV}^2]l[m]}{E[\mathrm{MeV}]}\right)$$

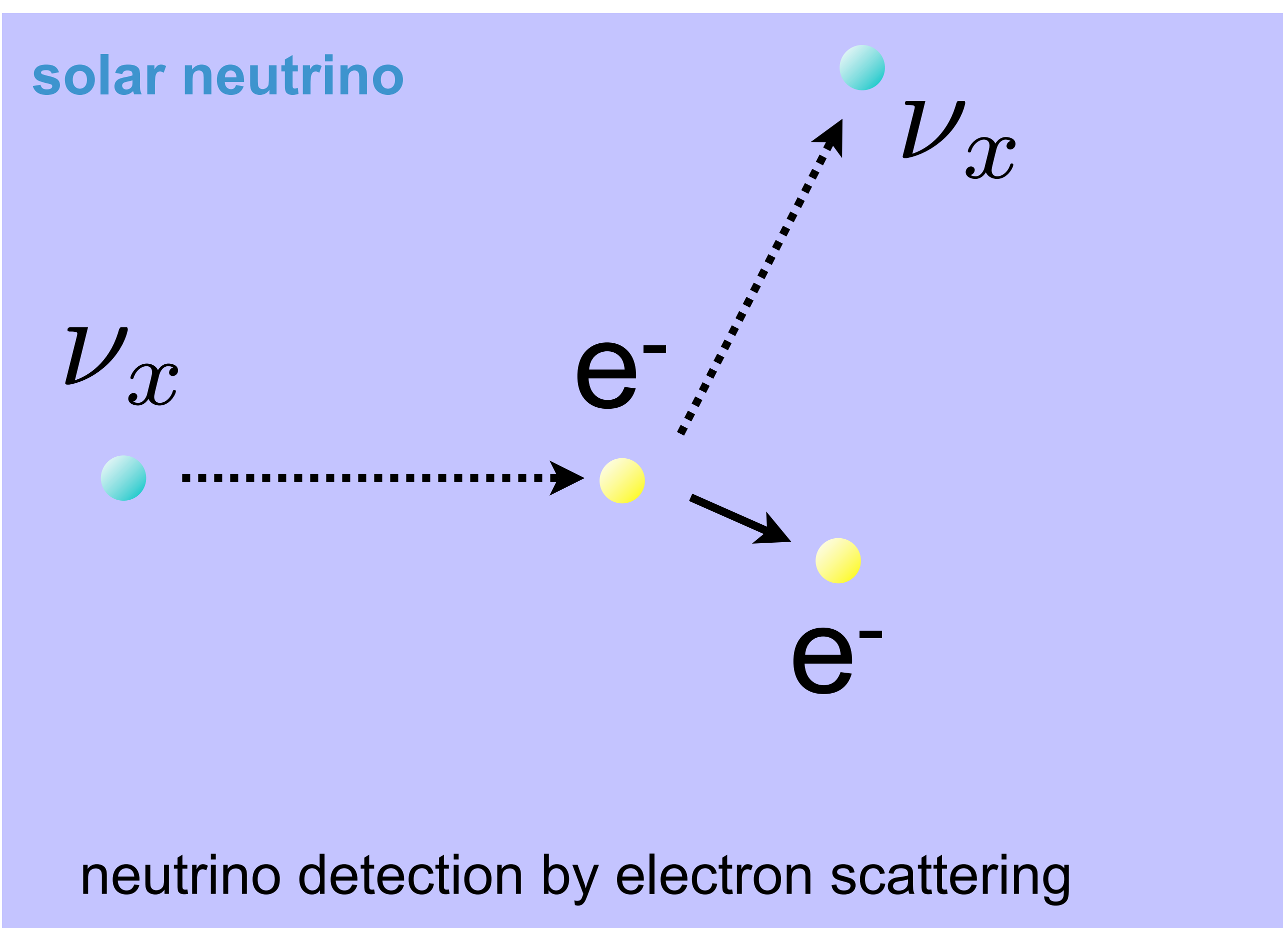
most sensitive region

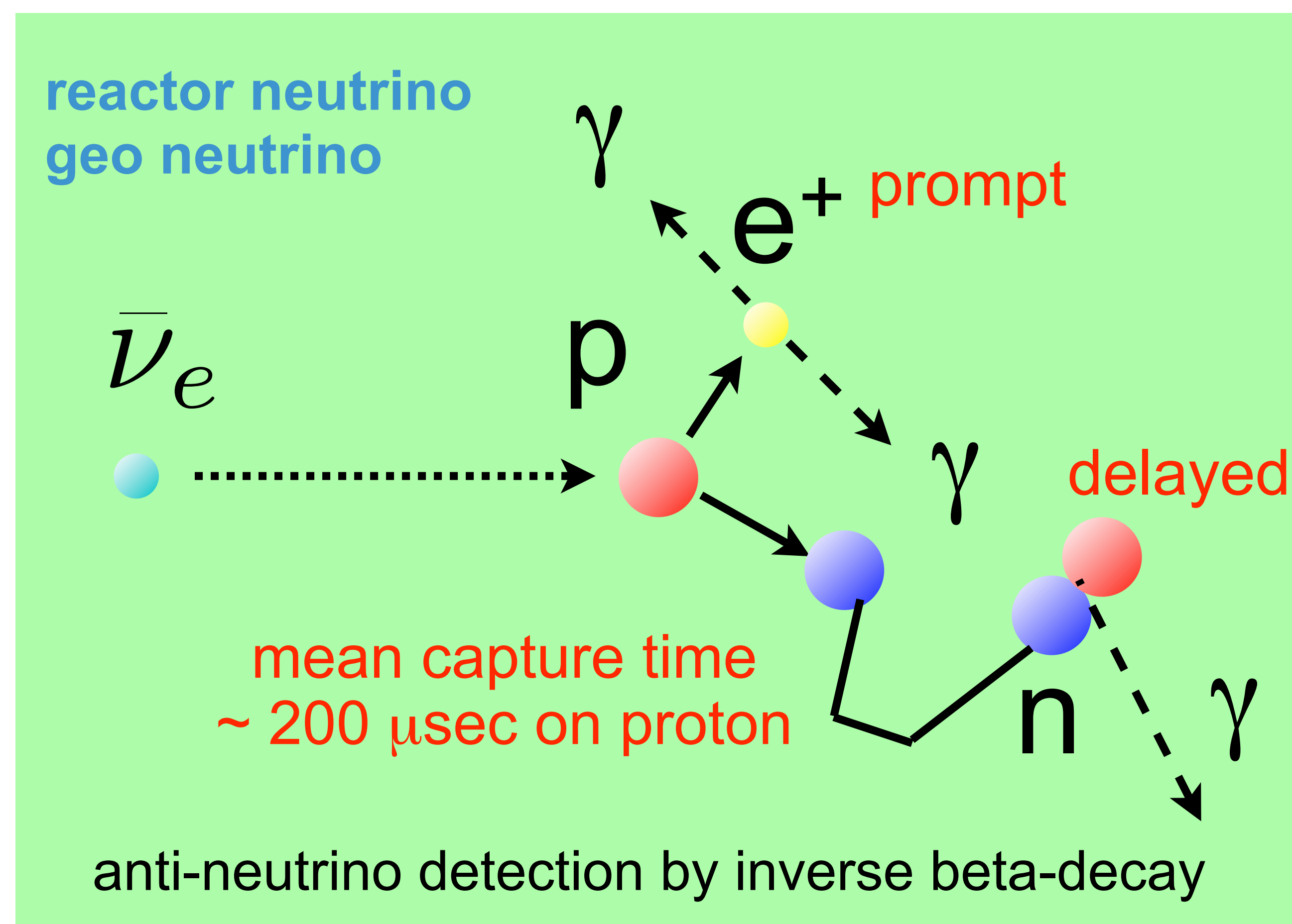
$$\Delta m^2 = (1/1.27)\cdot(E[\mathrm{MeV}]/L[m])\cdot(\pi/2)$$
$$\sim 3\times 10^{-5}\mathrm{eV}^2$$

reactor neutrino : sensitive to LMA solution

Physics Target in KamLAND







Reactor and Geo Neutrino Analysis

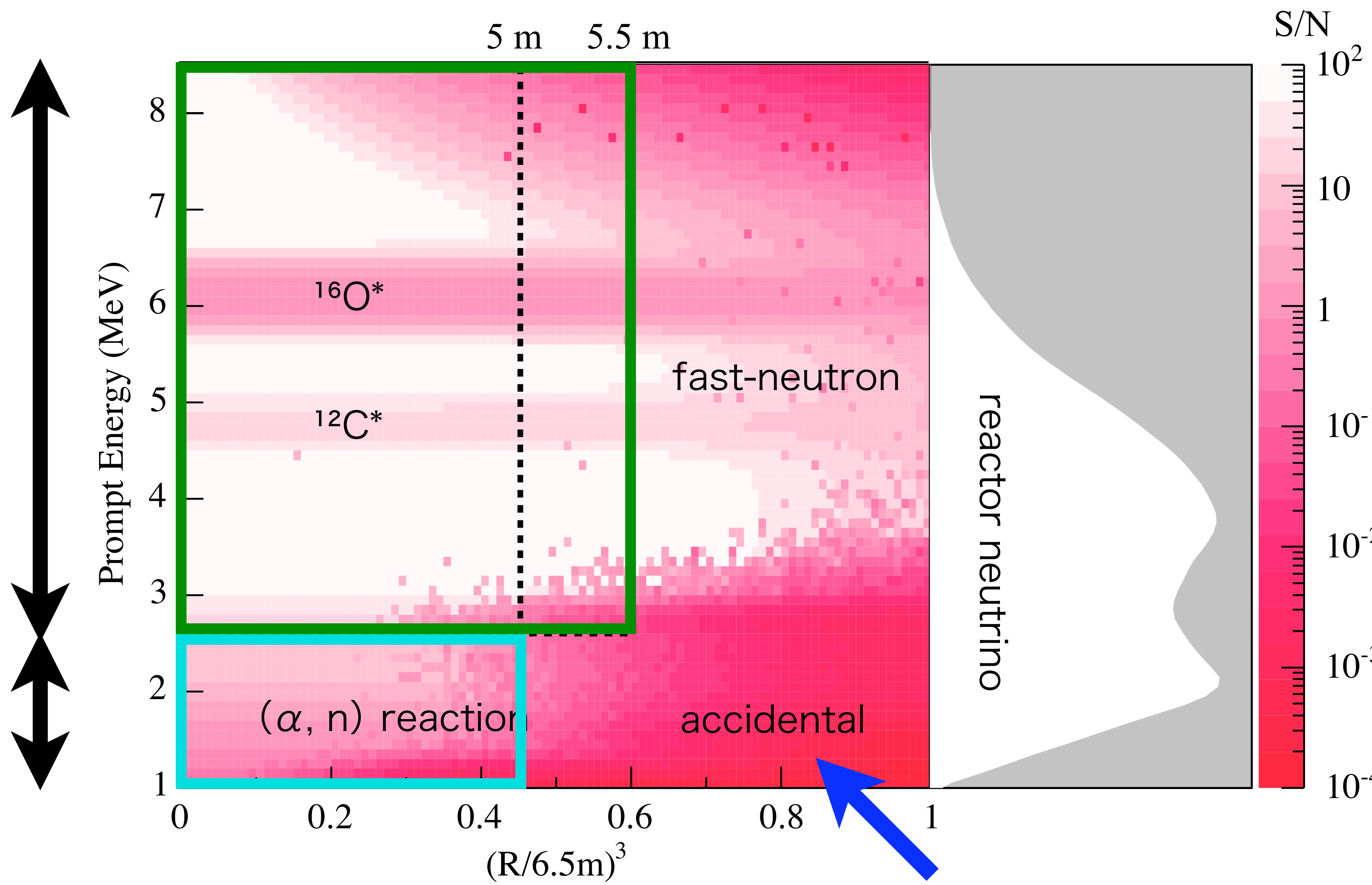
previous result

separated analysis window for reactor and geo neutrinos

reactor neutrino
(2.6 - 8.5 MeV, R 5.5 m)

geo neutrino
(0.9 - 2.6 MeV, R 5.0 m)

S / B ratio map (energy v.s. radius)



large accidental B.G.
caused by external γ-rays

Analysis improvement

(1) efficient accidental background rejection

(2) combined analysis of reactor and geo neutrinos

Anti-Neutrino Event Selection

(a) Accidental B.G. discrimination

discriminator based on 5 parameters (E_d, ΔR, ΔT, R_p, R_d)

$$L_{ratio} = f_{\bar{\nu}} / (f_{\bar{\nu}} + f_{accidental})$$

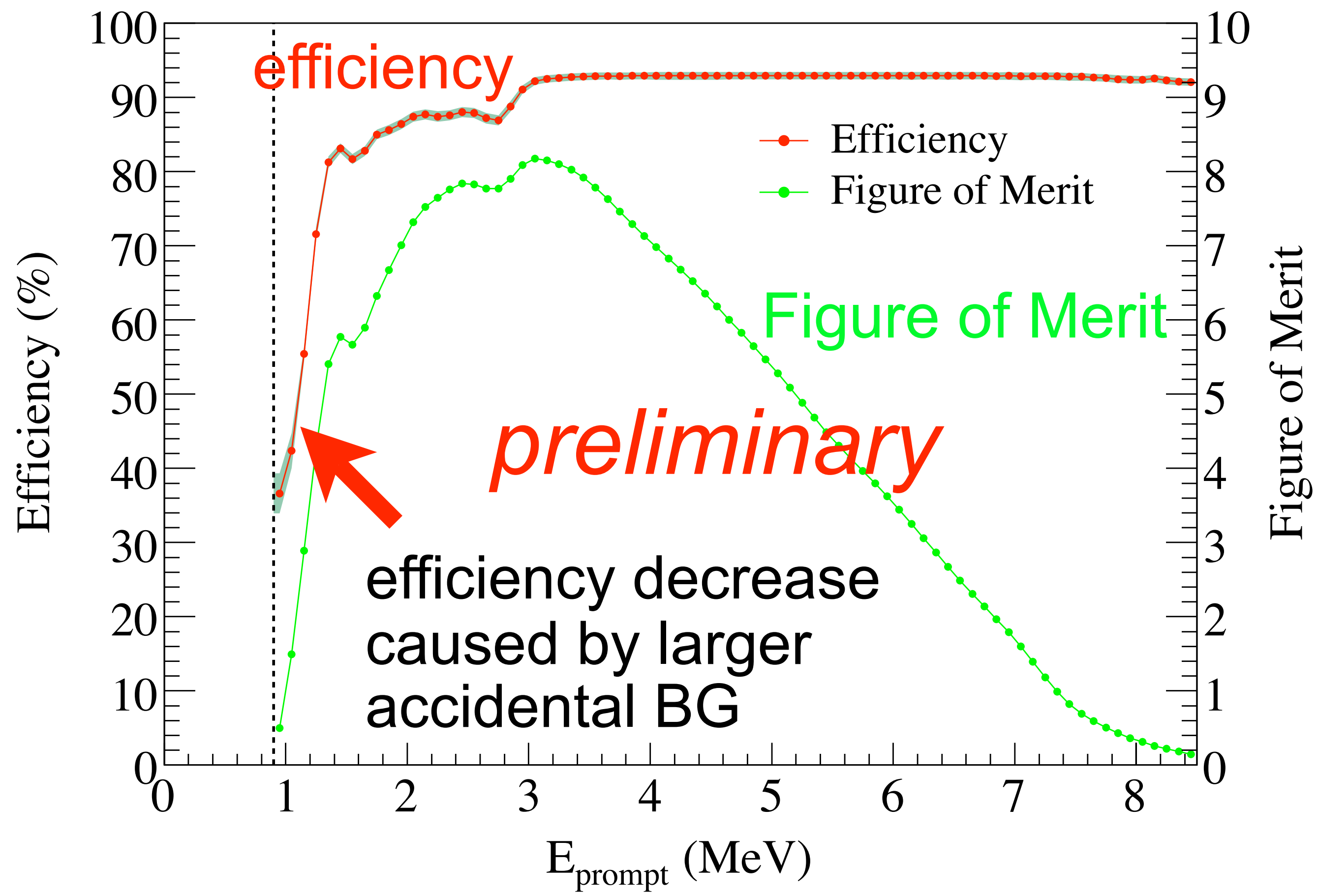
f : PDF

Selection : Maximize "Figure of Merit" $\frac{S}{\sqrt{S + B_{accidental}}}$

(b) μ spallation cut

- $\Delta T_\mu > 2$ s after showing μ ($\Delta Q > 10^6$ p.e.)
- $\Delta T_\mu > 2$ s or $\Delta L > 3$ m after non-showering μ

Detection efficiency



2.2 < E_{prompt} < 2.3 MeV

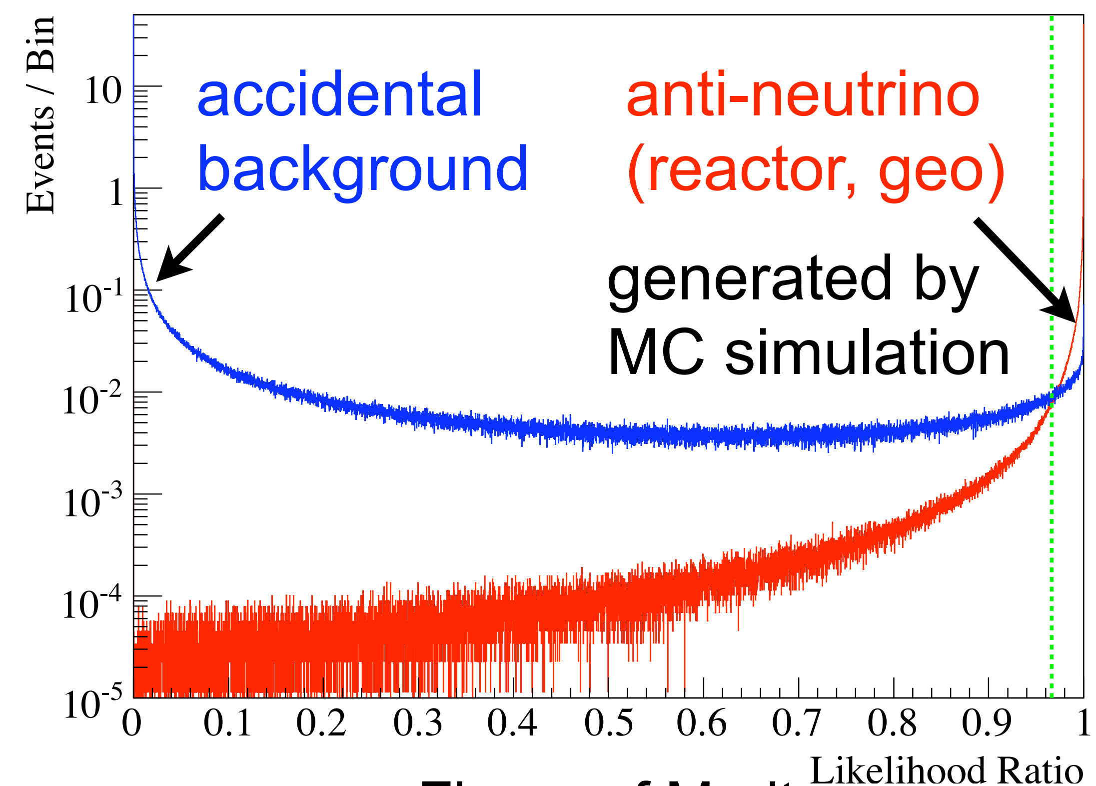
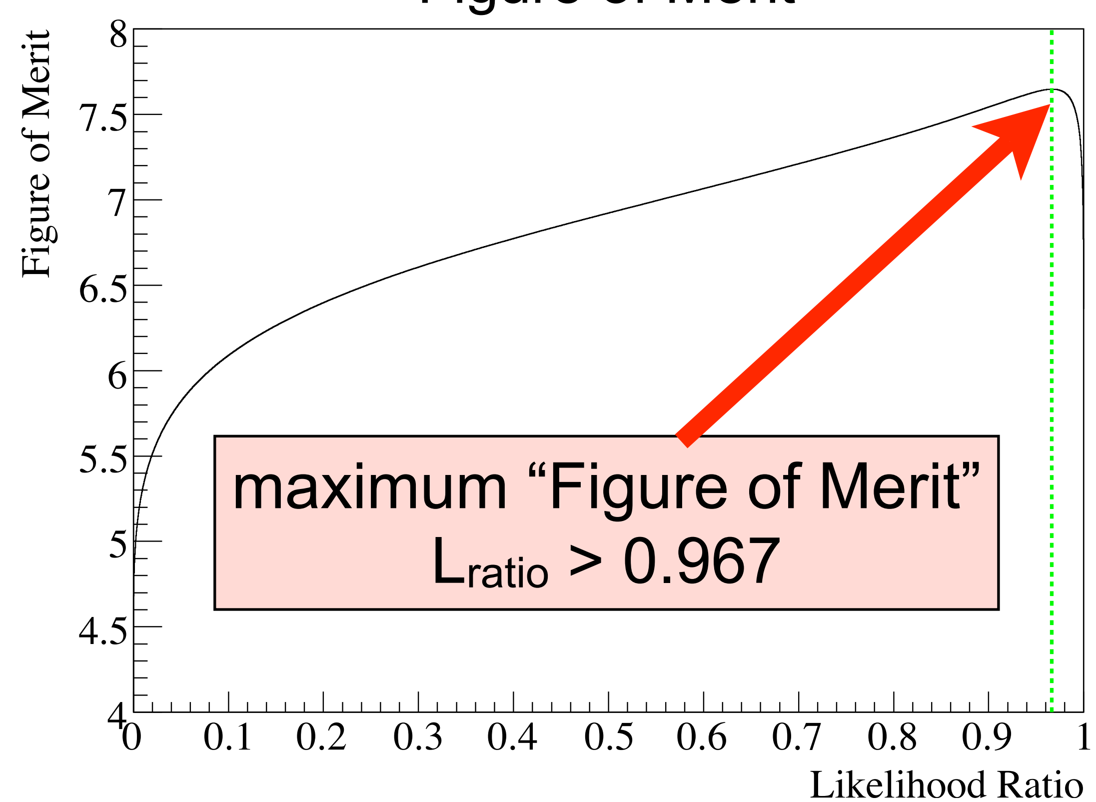


Figure of Merit



Systematic Uncertainty

"full volume" calibration lowered the fiducial volume error

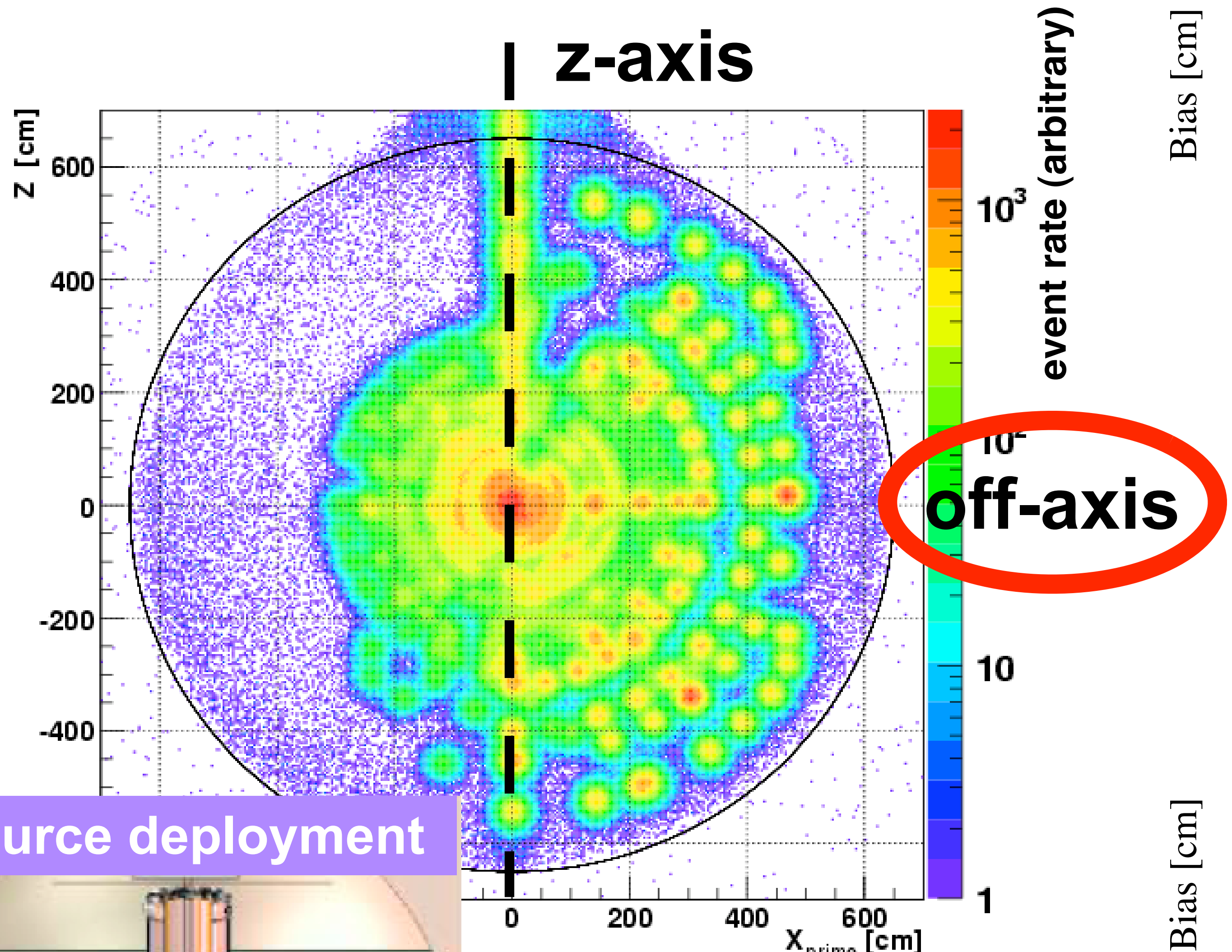
(4.7% in previous analysis)

preliminary

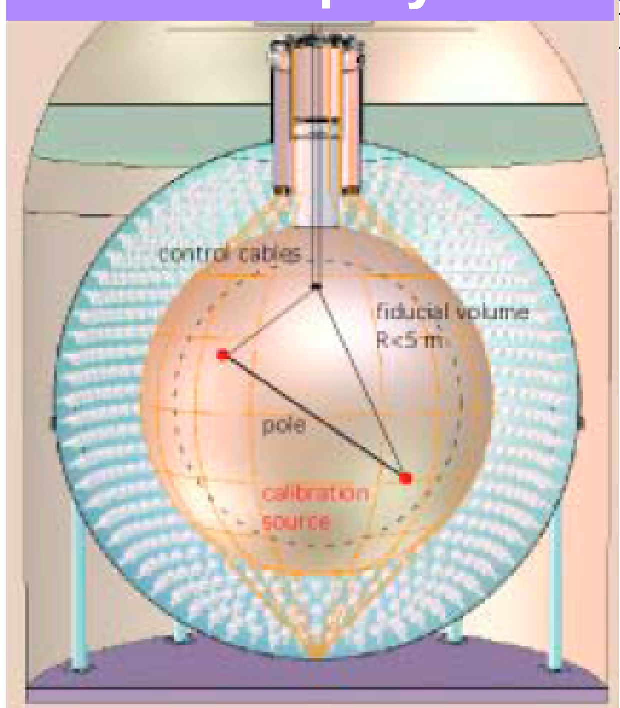
Detector related		Reactor related	
Fiducial volume	1.8%	$\bar{\nu}_e$ spectra	2.4%
Energy scale	1.5%	Reactor power	2.1%
L-selection eff.	0.6%	Fuel composition	1.0%
OD veto	0.2%	Long-lived nuclei	0.3%
Cross section	0.2%	Time lag	0.01%
	2.4%		3.4%

Total systematic uncertainty : 4.1%

Full Volume Calibration



source deployment

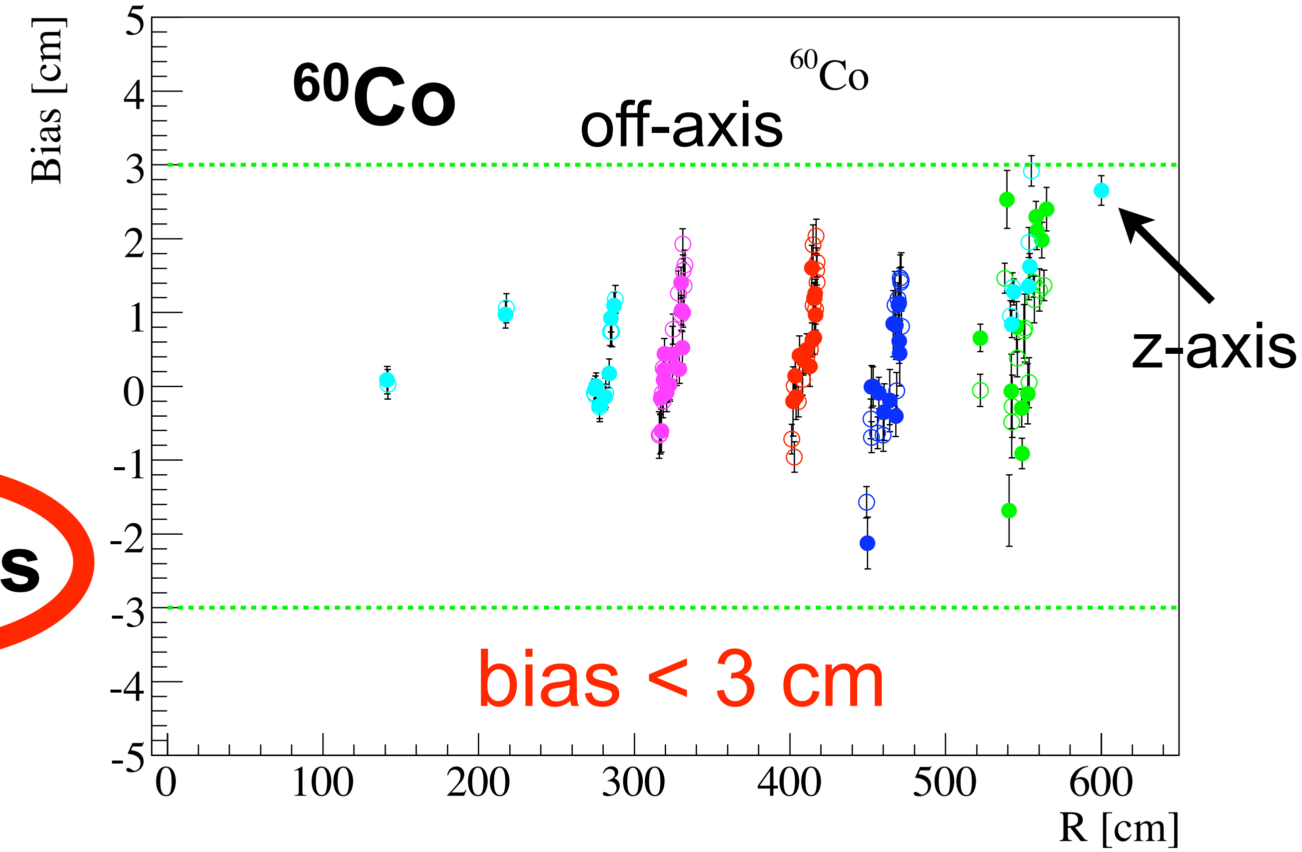


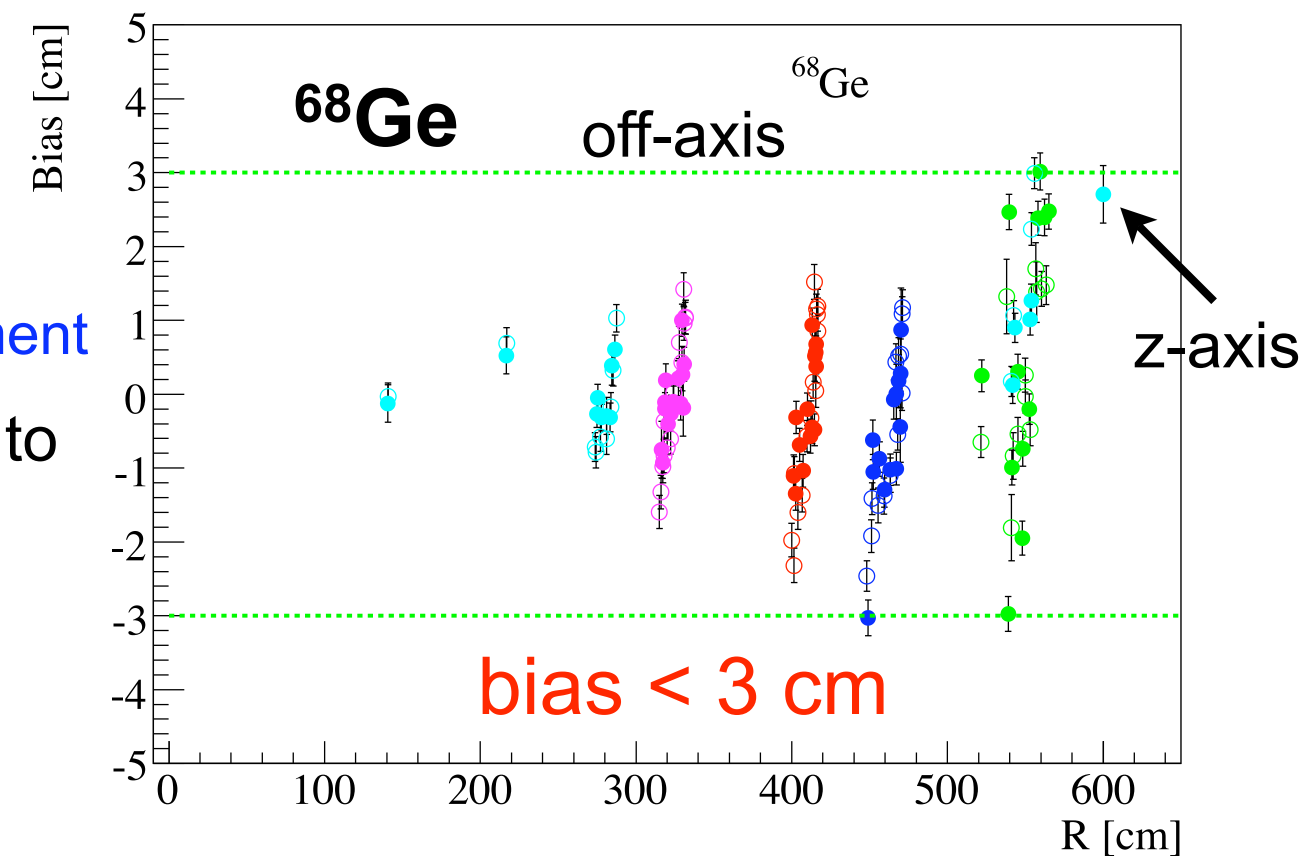
"4pi calibration" system for the off-axis source deployment

bias < 3 cm corresponds to 1.8% volume uncertainty

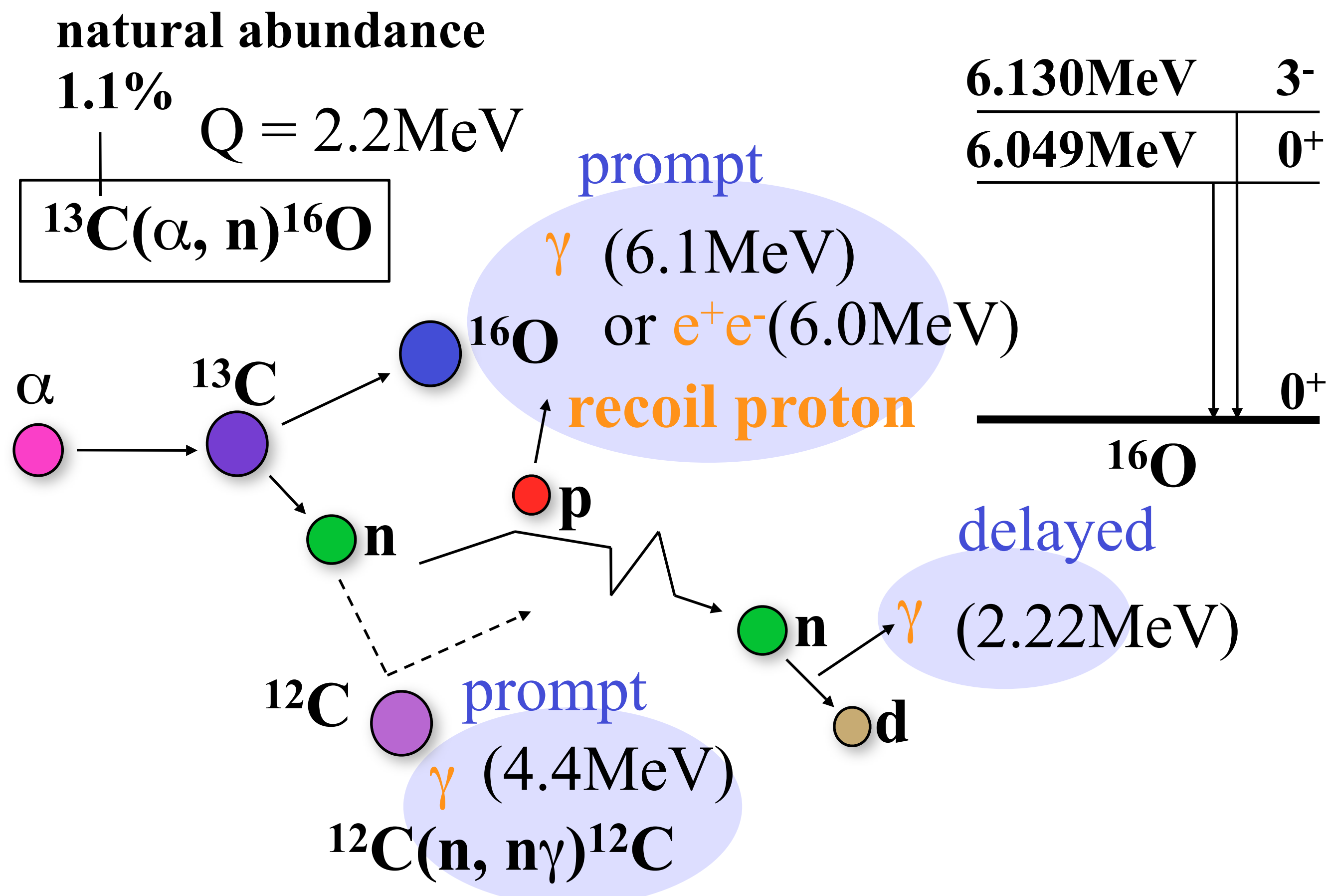
↓

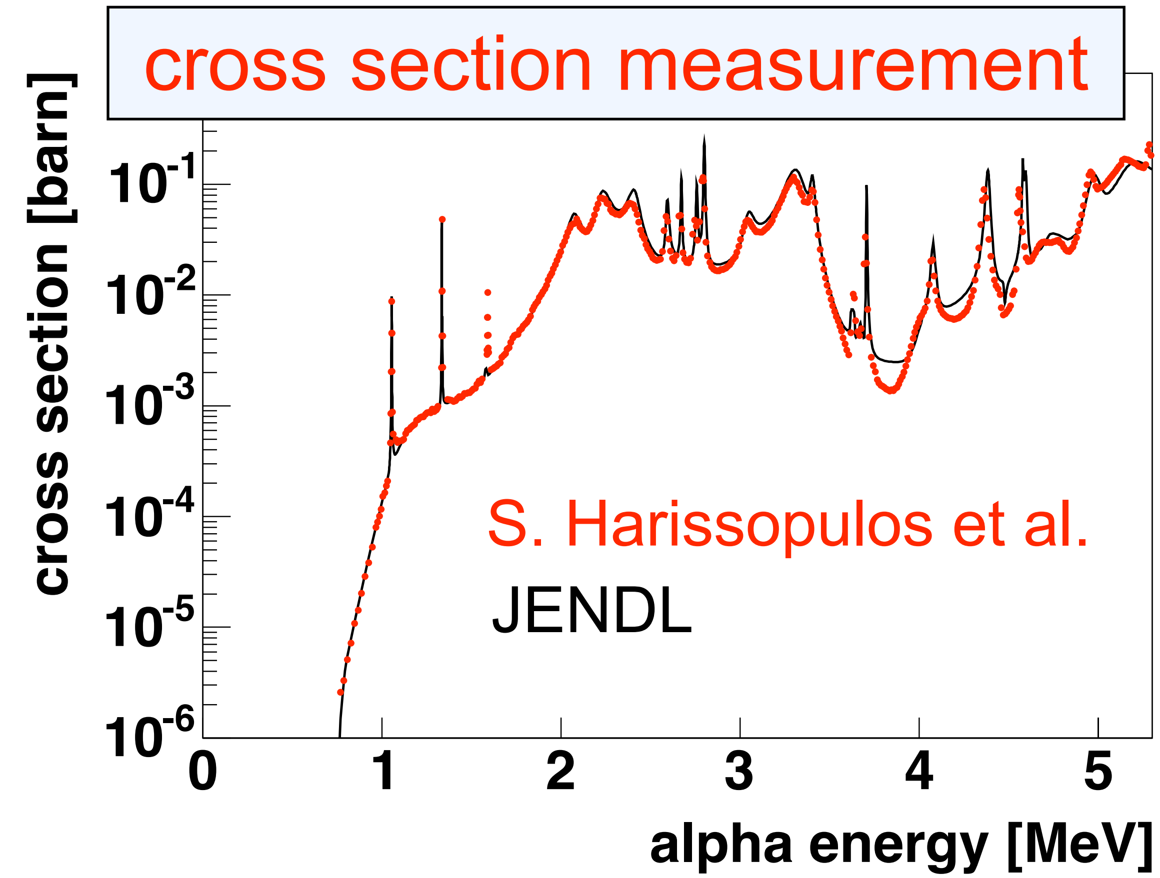
cross-checked by $^{12}B/^{12}N$ uniformity

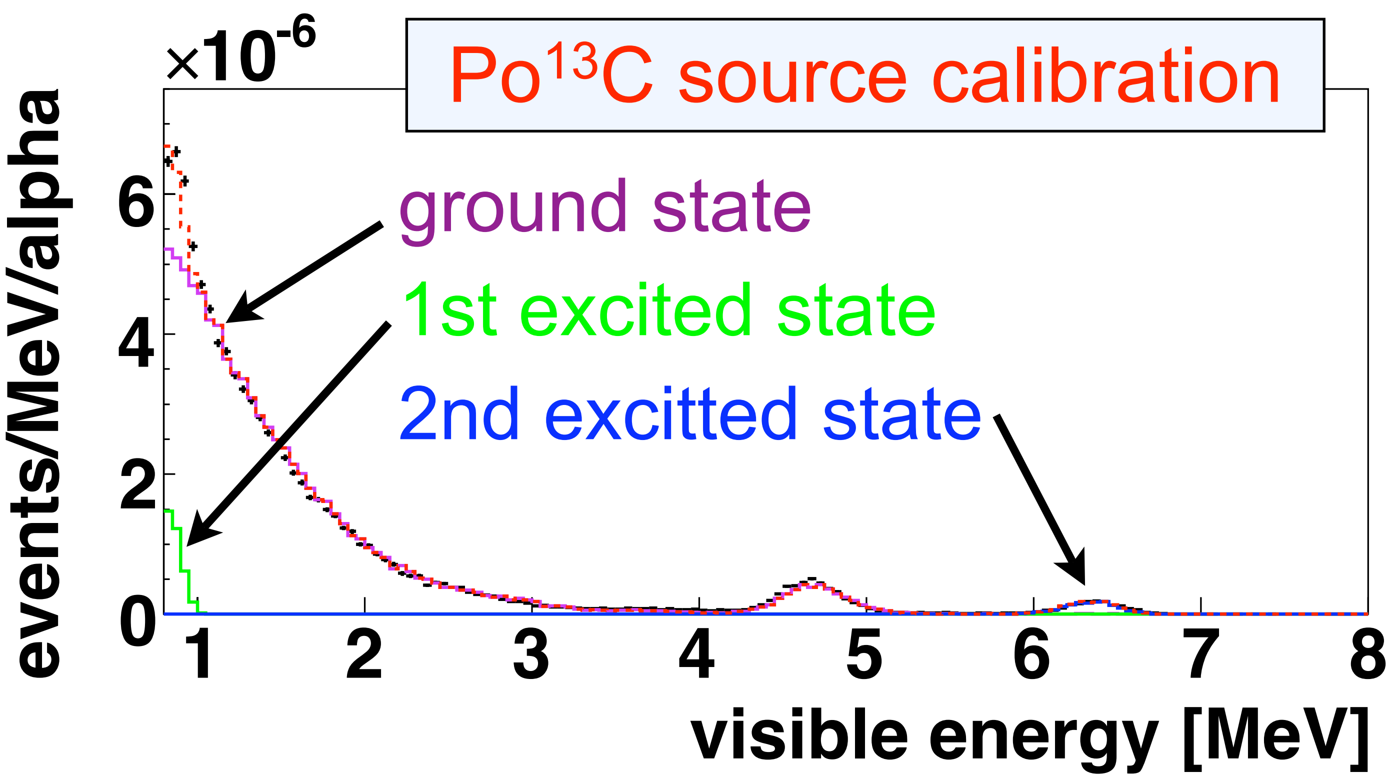




(α, n) Background Estimation







neutron yield difference < 4%

(α, n) background estimation

163.3 ± 18.0 events for ground state

18.7 ± 3.7 events for excited state

Estimation uncertainty

11% for ground state

20% for excited state

Rate Analysis above 2.6 MeV

“Reactor” rate analysis
(2.6 MeV threshold)

No osci. expected 1549

Background 63

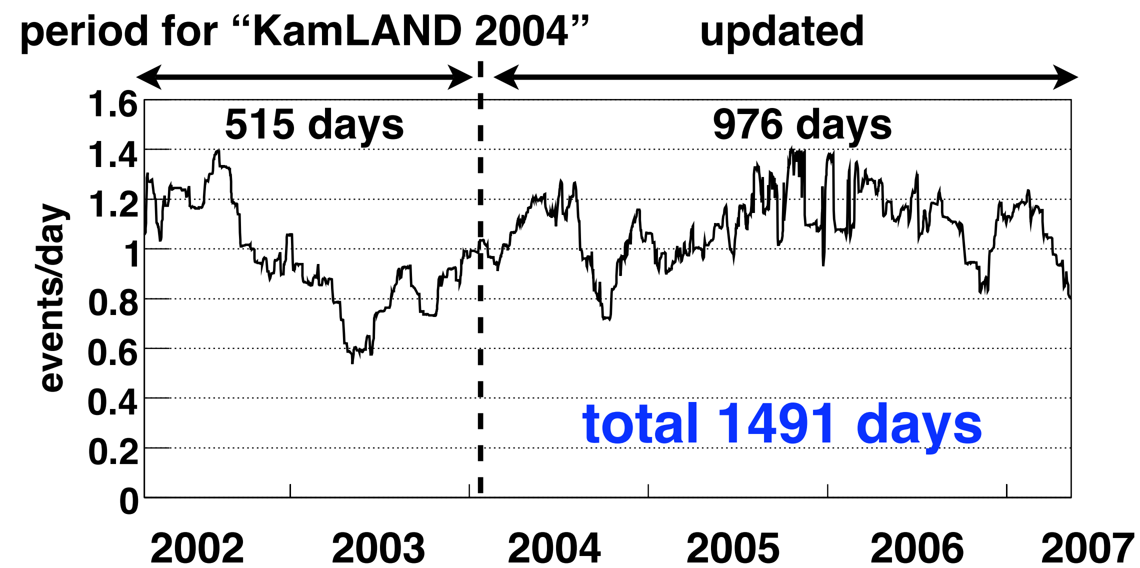
(see Poster Sessions : Ichimura and Minekawa et al.)

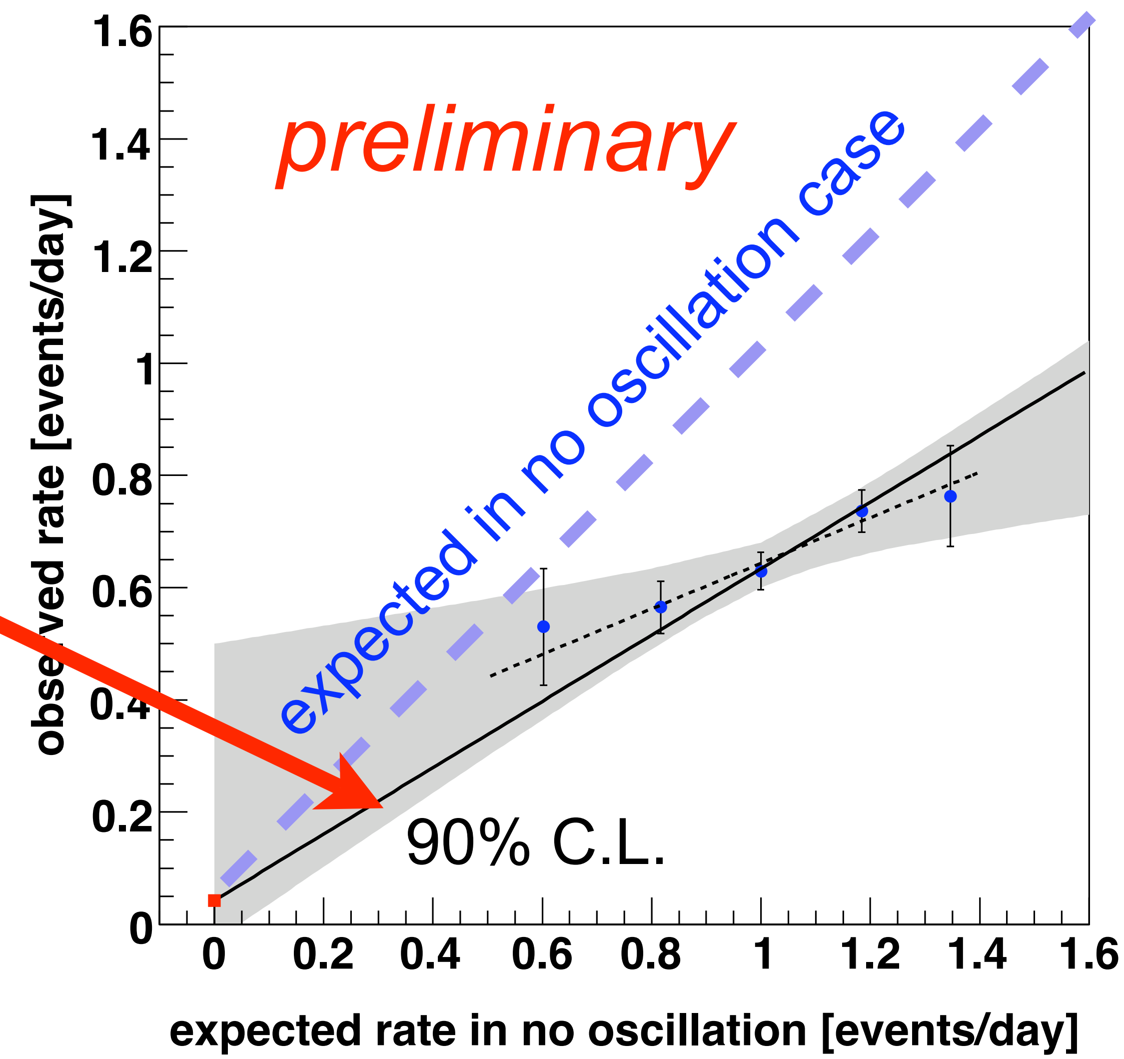
Observed events 985

Ratio = (obs. - B.G.) / No osci.

0.594 ± 0.020(stat) ± 0.026(syst)

8.5σ disappearance significance





Fit constrained through B.G. expected

χ^2 / ndf = 3.1 / 4

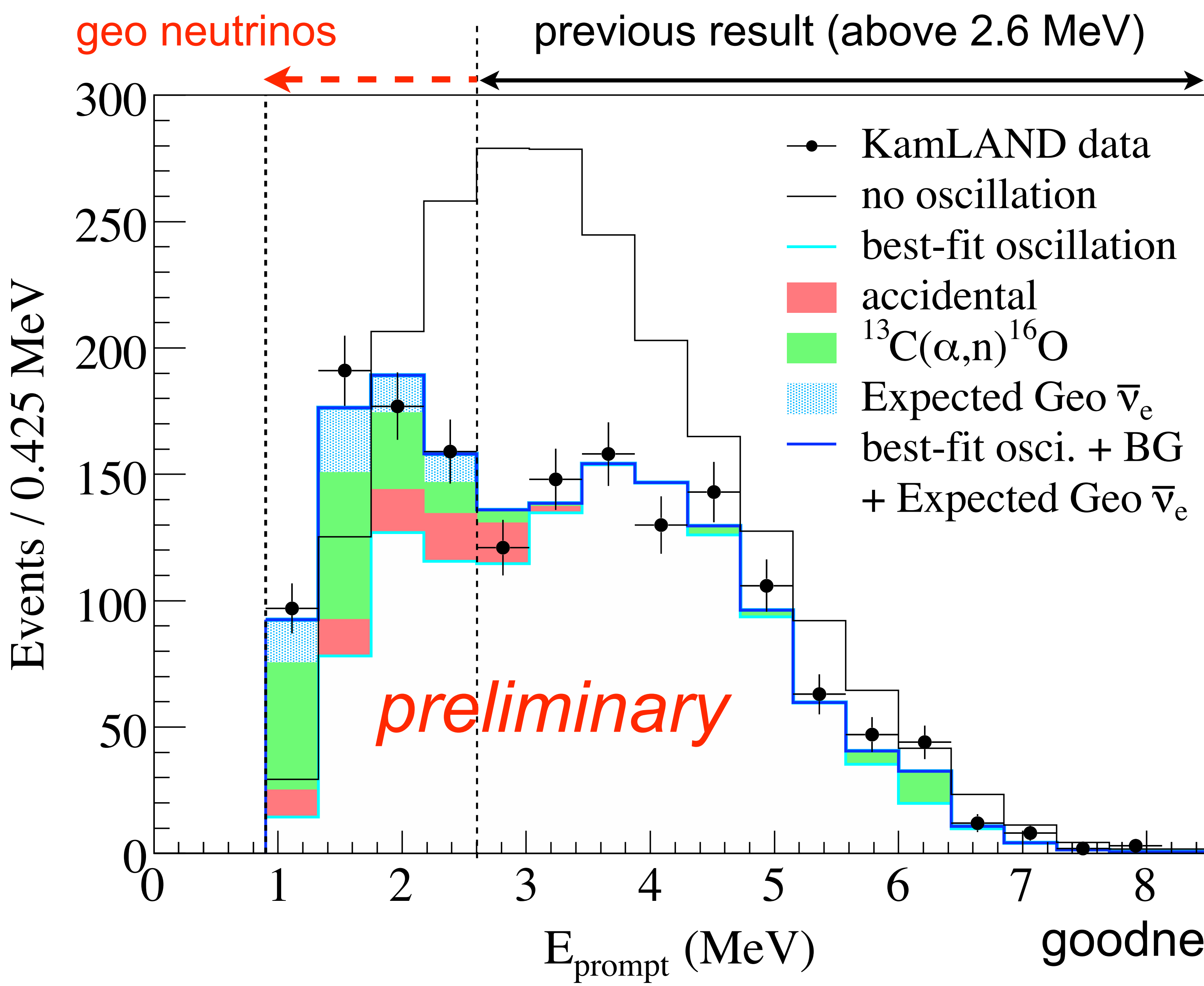
Fit with a horizontal line

χ^2 / ndf = 11.8 / 4

(1.9% C.L.)

Energy Spectrum above 0.9 MeV

exposure : 2881 ton-year (3.8 × 766 ton-year for "KamLAND 2004")



"Geo + Reactor" combined analysis

No osci. expected	**2178**
Background (w/o geo neutrino)	**276**
(Ichimura and Minekawa et al.)	
Observed events	**1609**

best-fit

$(\tan^2\theta, \Delta m^2)$
$= (0.56, 7.58 \times 10^{-5}\ eV^2)$

free parameter : geo neutrinos
(U, Th) = (39.3, 29.4) events

goodness of fit using equal probability bins

best-fit χ^2 / ndf = 21.0 / 16 (18.0% C.L.)

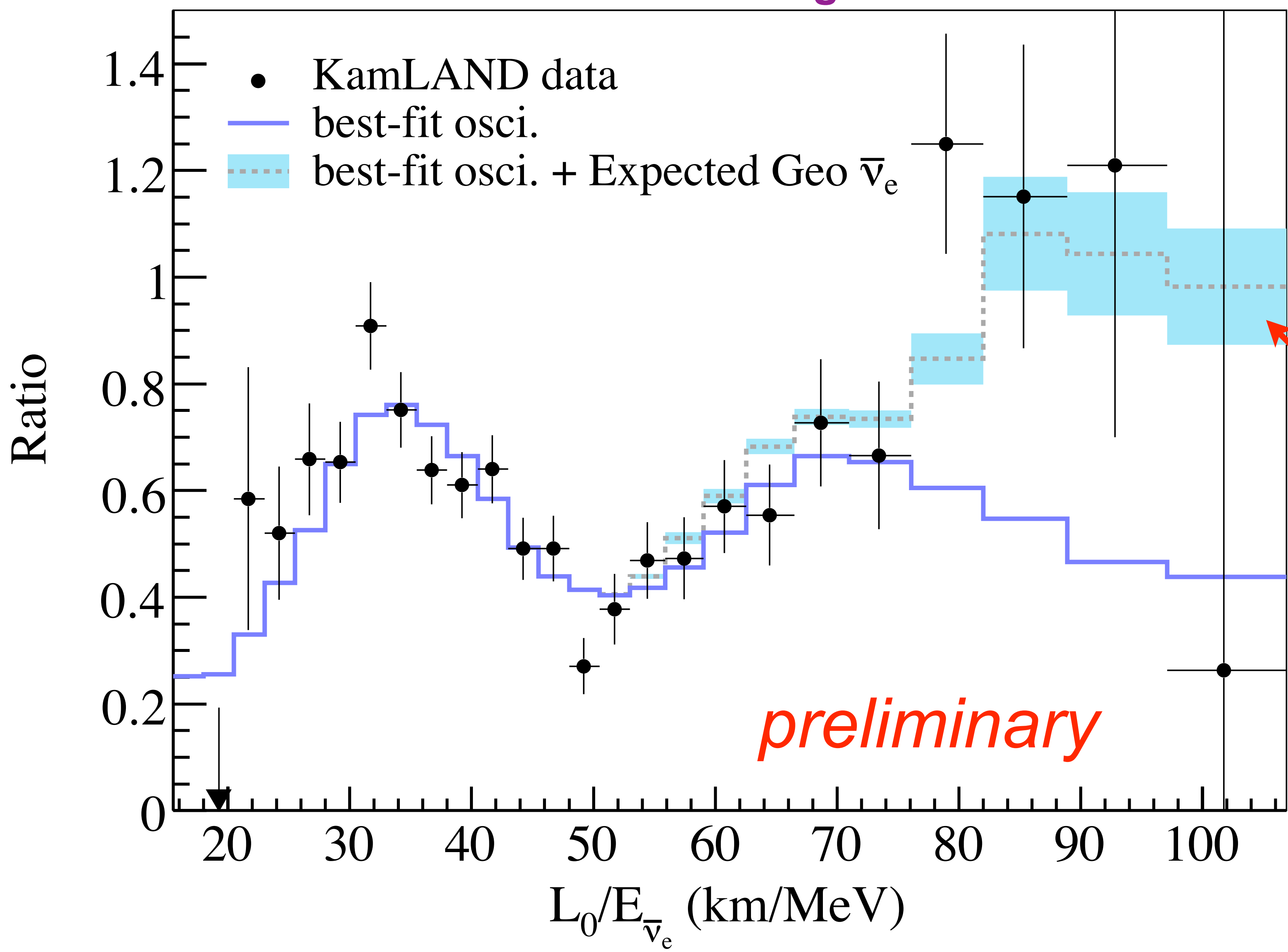
no osci. χ^2 / ndf = 63.9 / 17

Scaled no oscillation spectrum is excluded at 5.2σ

L/E plot

Ratio = (observed - B.G.) / (no osci. expected)

w/o geo neutrino



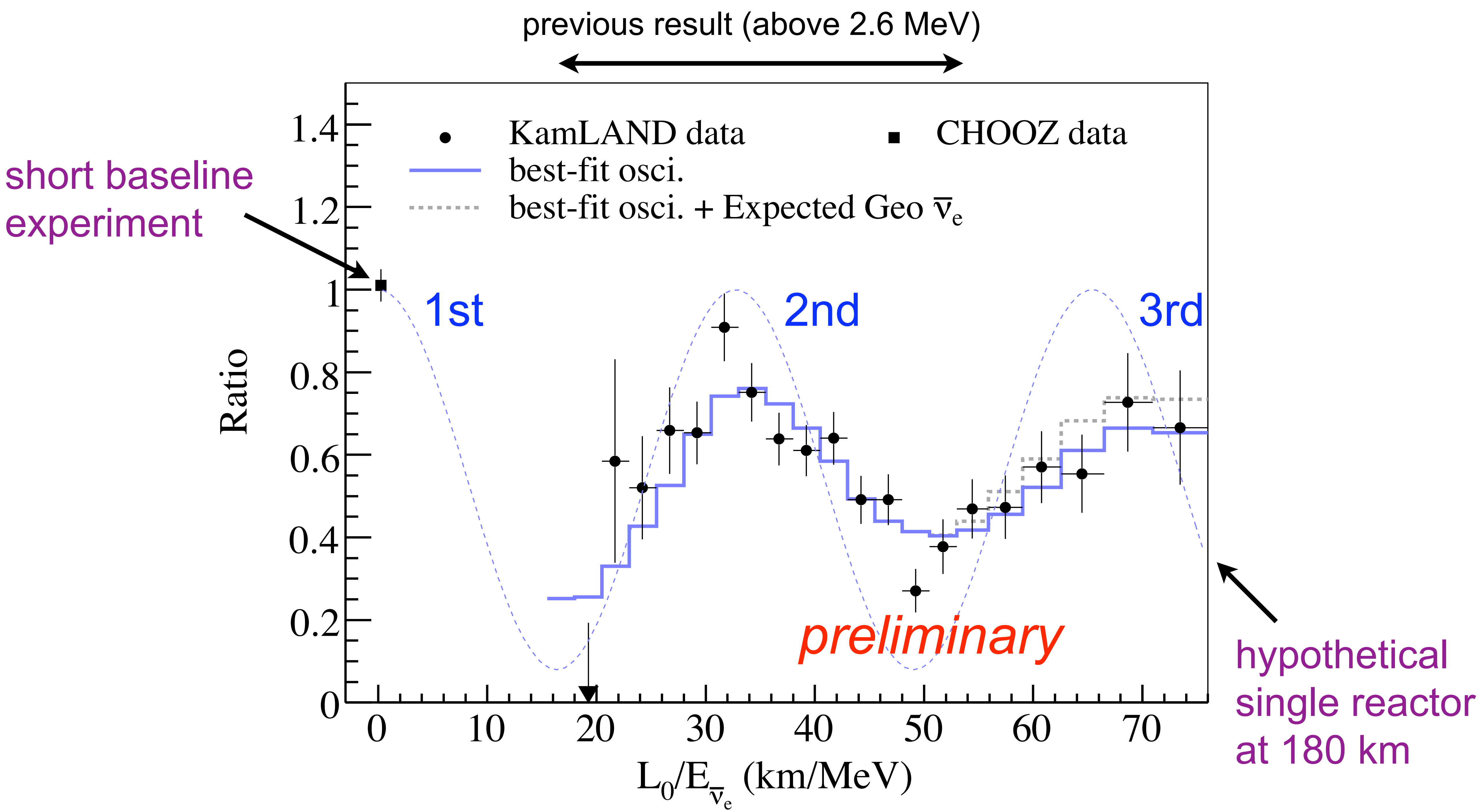
consistent with geo neutrino expectation from an earth model

20% geo neutrino flux uncertainty (a claim based on the geology)

L_0 : a fixed baseline (180 km)

Distortion effect is clearly illustrated by L/E plot

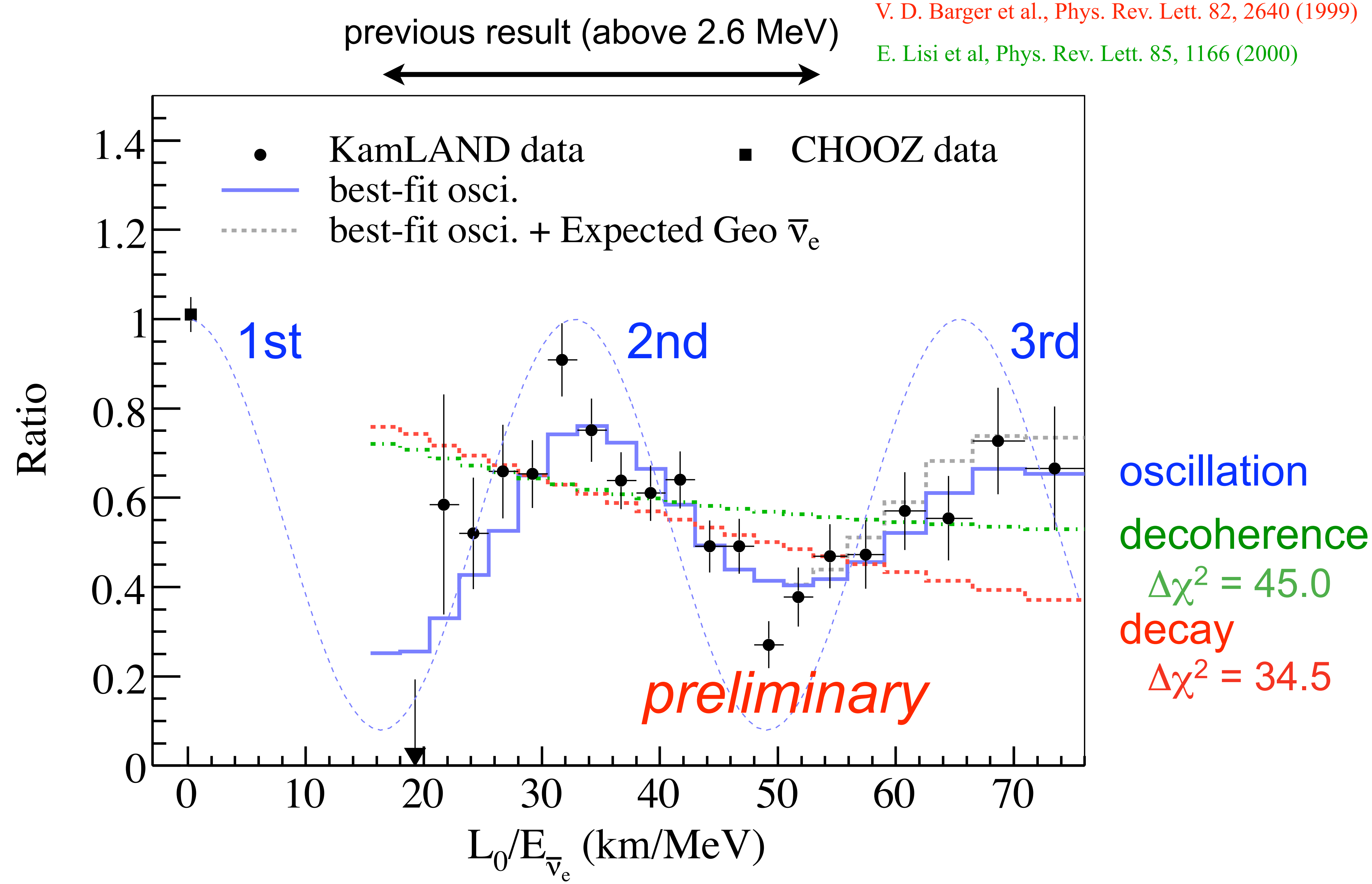
Neutrino Oscillation



KamLAND covers the 2nd and 3rd maximum

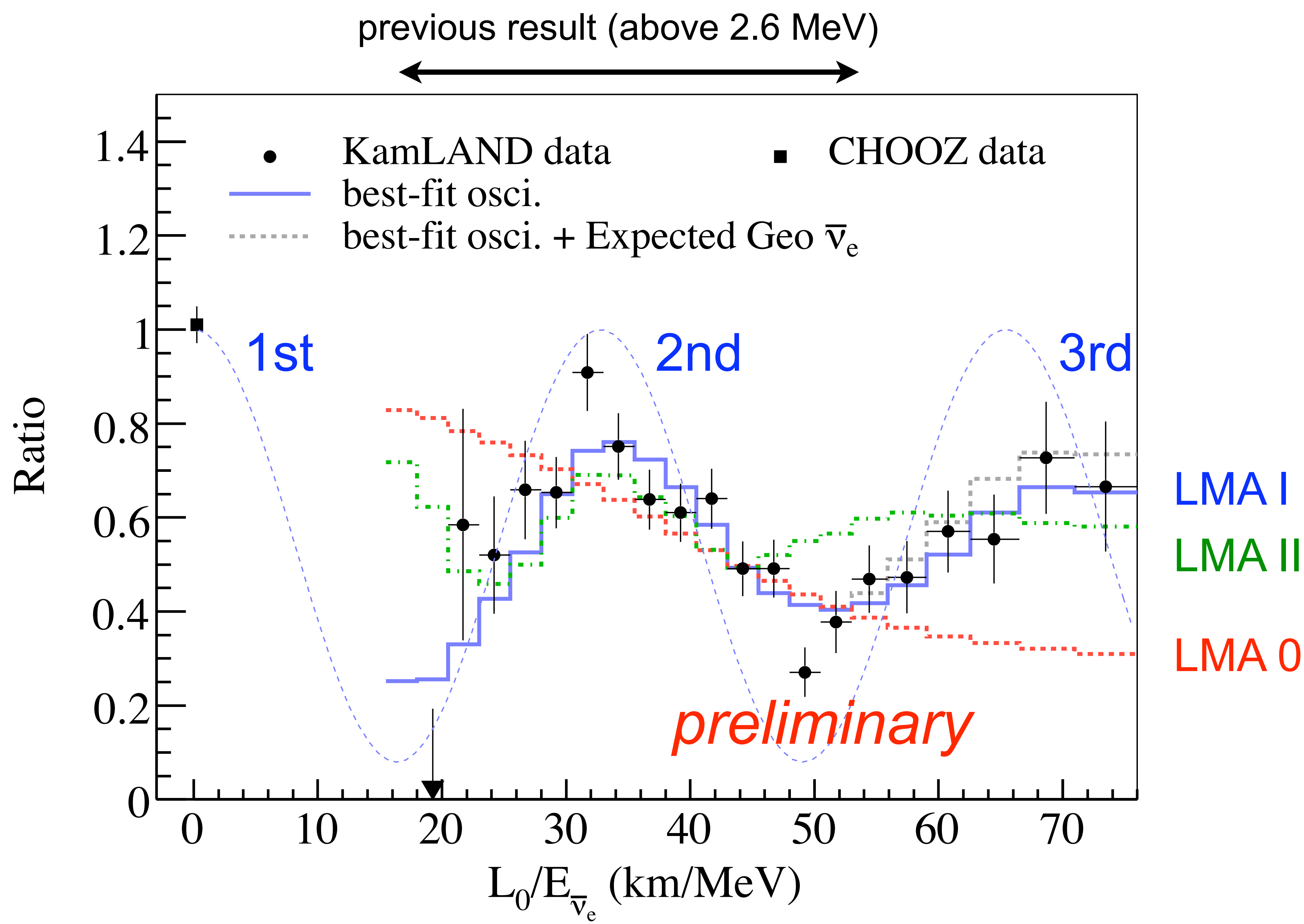
→ **characteristic of neutrino oscillation**

Alternate Hypothesis



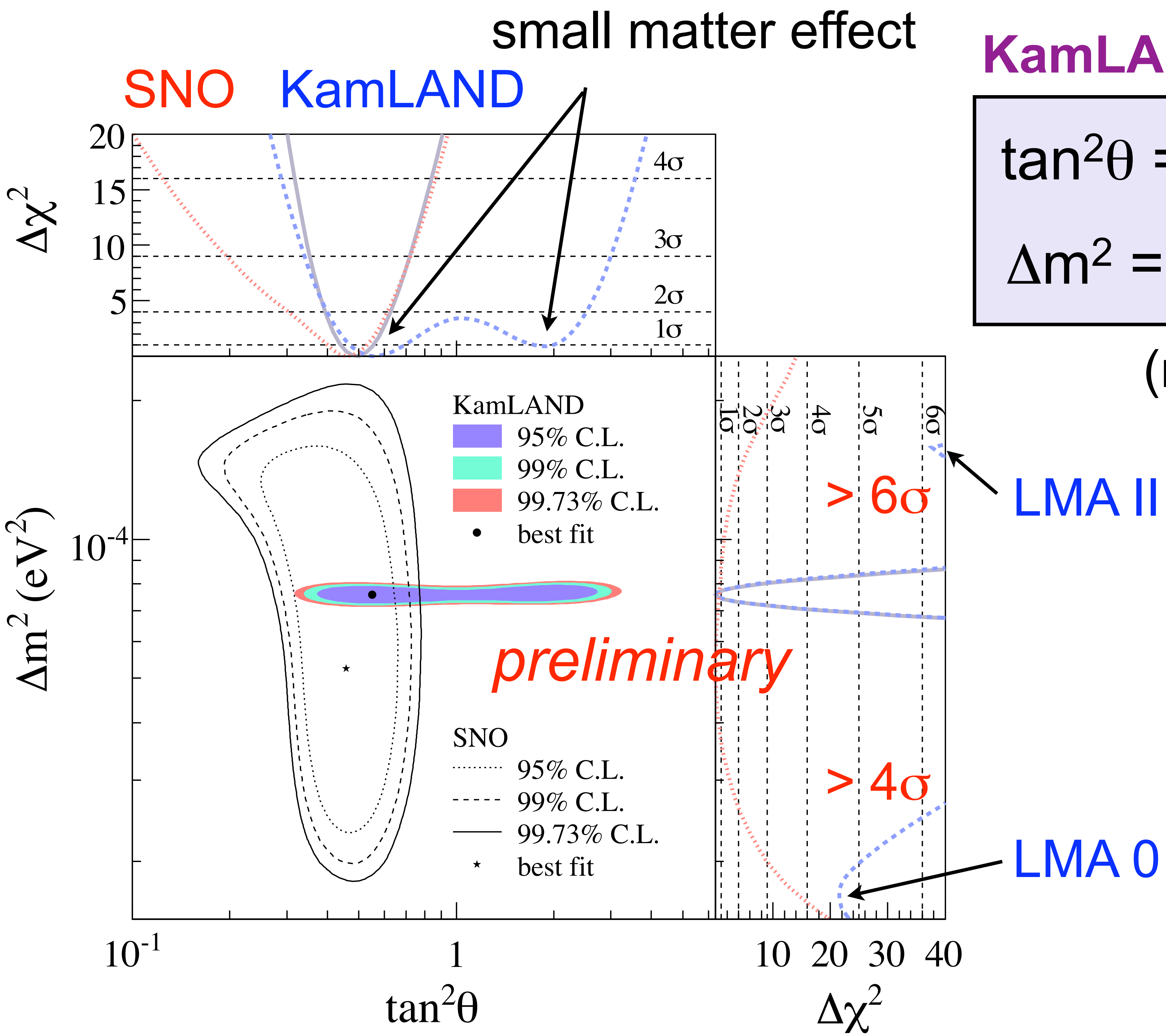
best model is neutrino oscillation

Alternate Wavelength



LMA 0 and LMA II are disfavored at more than 4σ

Oscillation Parameters



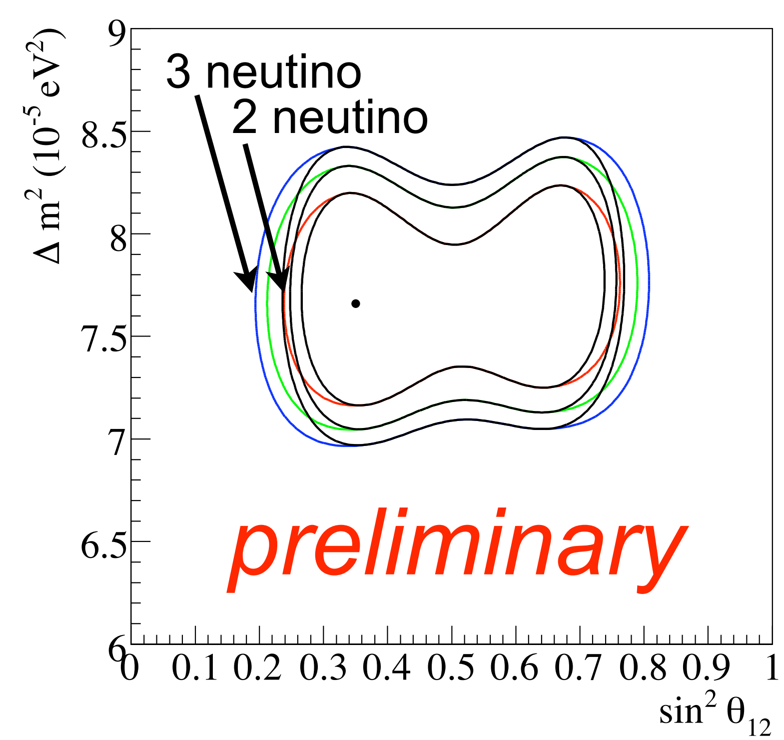
KamLAND only

$$\tan^2\theta = 0.56^{+0.14}_{-0.09}$$

$$\Delta m^2 = 7.58^{+0.21}_{-0.20} \times 10^{-5}\ \mathrm{eV}^2$$

(marginalized error)

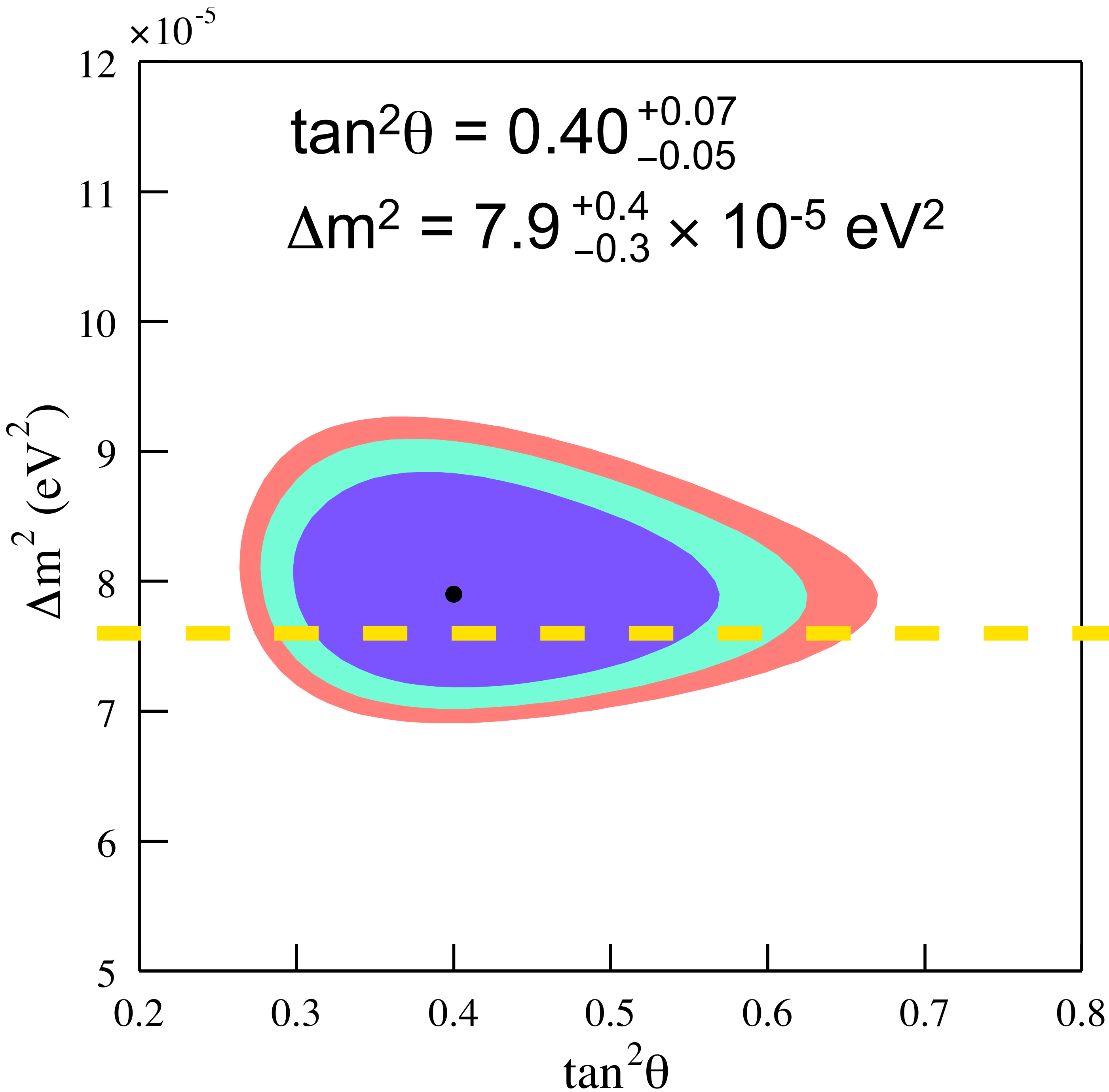
3 neutrino effect



same result for Δm^2

Precise measurement of Δm^2

KamLAND 2004



This result

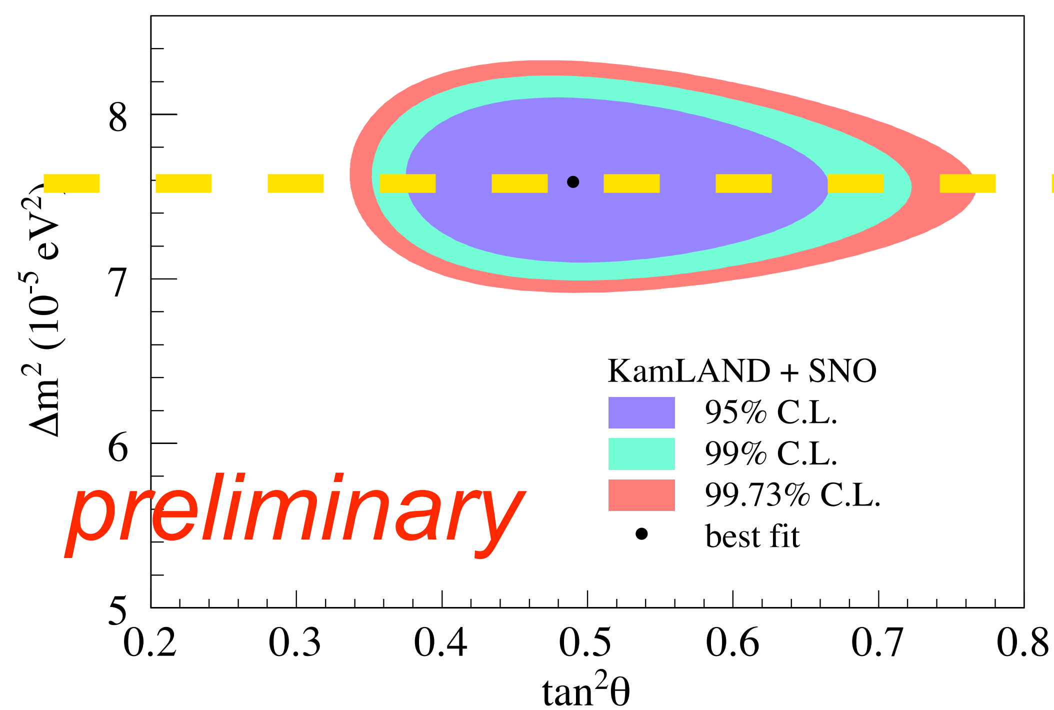
KamLAND + SNO

$\tan^2\theta = 0.49^{+0.07}_{-0.05}$

$\Delta m^2 = 7.59^{+0.20}_{-0.21} \times 10^{-5}$ eV^2

Δm^2 : systematic uncertainty 2.0%

dominated by linear energy scale uncertainty

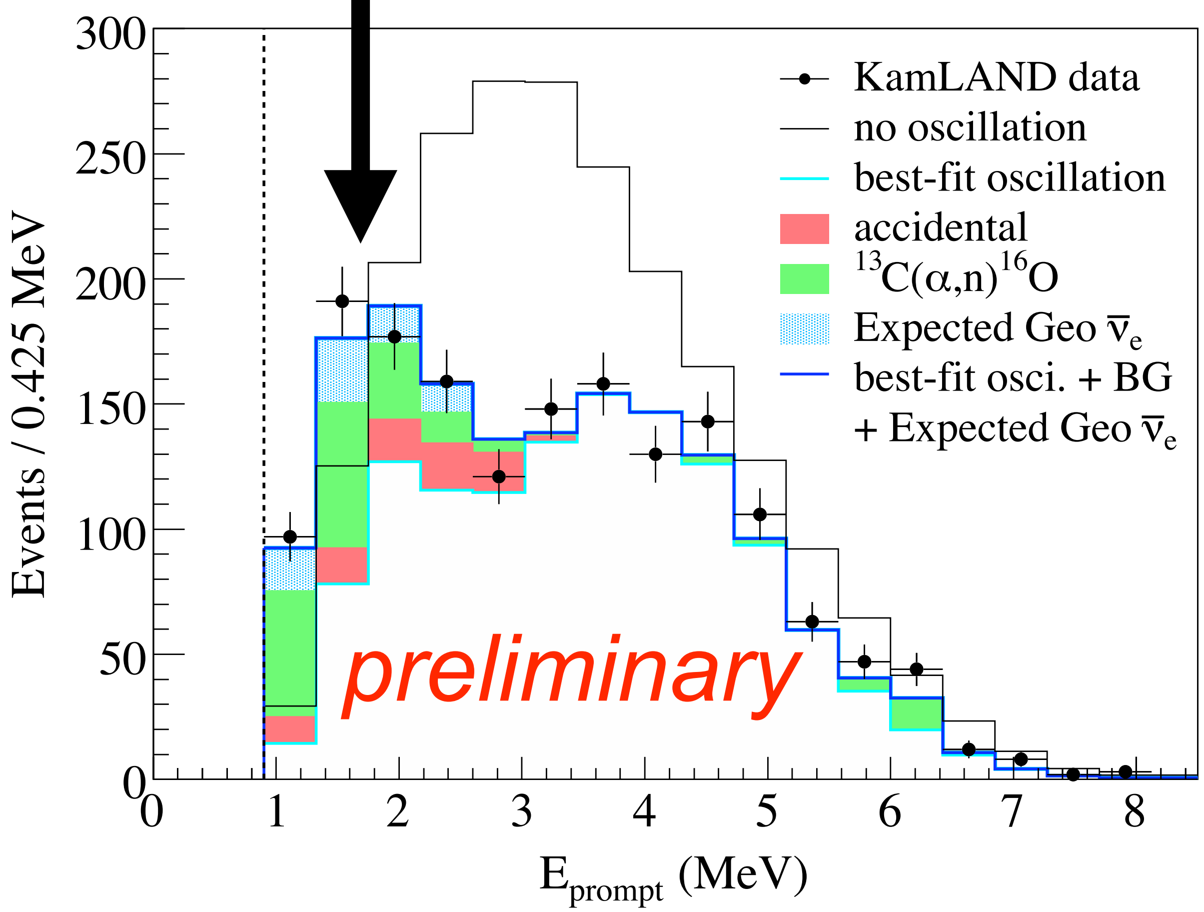


Δm^2 is measured at 2.8% precision by KamLAND

Geo Neutrino Estimation

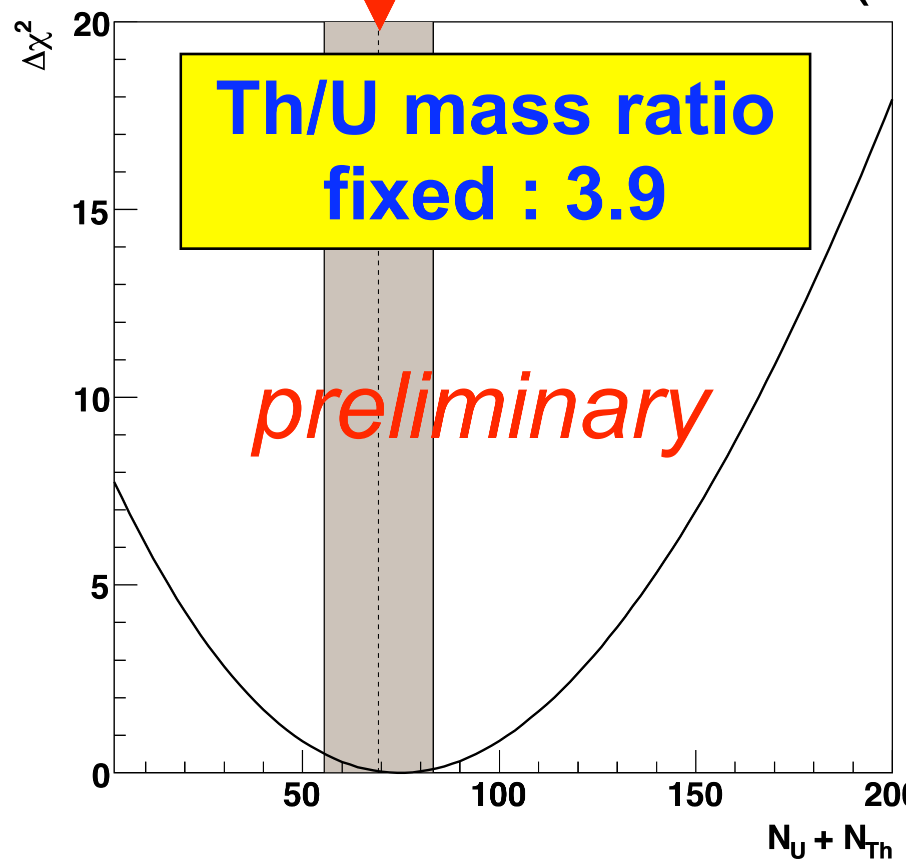
Analysis : KamLAND (rate + shape + time) + SNO

geo neutrinos (U, Th)



model expected

69.3 events (36.5 TNU)



Reference model (16 TW)

U : 56.2 event (28.9 TNU)

Th : 13.1 event (7.6 TNU)

U+Th = $74.9^{+27.3}_{-27.2}$ event

$39.4^{+14.4}_{-14.3}$ TNU

(previous result : $57.4^{+32.0}_{-30.0}$ TNU)

TNU (Terrestrial Neutrino Unit) = events/10^{32} target-proton/year

Summary

- KamLAND improved sensitivity to $\overline{\nu}_e$ observation.

data-set : 766 ton-yr → 2881 ton-yr
E threshold : 2.6 MeV → 0.9 MeV
syst. uncertainty : 6.5% → 4.1%

(α, n) B.G. uncertainty :
32% → 10% (ground state)
100% → 20% (excited state)

- In the reactor neutrino analyses, we showed

- Oscillatory shape including 2nd and 3rd maximum
- Exclusion of LMA II and 0 at more than 4σ C.L.
- Precise measurement of oscillation parameters.

KamLAND only $\tan^2\theta = 0.56^{+0.14}_{-0.09}$ $\Delta m^2 = 7.58^{+0.21}_{-0.20} \times 10^{-5}\ \mathrm{eV}^2$

KamLAND + SNO $\tan^2\theta = 0.49^{+0.07}_{-0.05}$ $\Delta m^2 = 7.59^{+0.20}_{-0.21} \times 10^{-5}\ \mathrm{eV}^2$

- Geo neutrino flux is measured with better precision.