New Geo-neutrino Measurement with KamLAND

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for the KamLAND collaboration

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Brief history

$$^{238}\mathrm{U} \rightarrow ^{206}\mathrm{Pb} + 8\alpha + 6\mathrm{e}^- + 6\bar{\nu}_\mathrm{e} + 51.7\,\mathrm{MeV}$$

$$^{232}\mathrm{Th} \rightarrow ^{208}\mathrm{Pb} + 6\alpha + 4\mathrm{e}^- + 4\bar{\nu}_\mathrm{e} + 42.7\,\mathrm{MeV}$$

$$^{40}\mathrm{K} \rightarrow ^{40}\mathrm{Ca} + \mathrm{e}^- + \bar{\nu}_\mathrm{e} + 1.311\,\mathrm{MeV}\,(89.28\%)$$

$$^{40}\mathrm{K} + \mathrm{e}^- \rightarrow ^{40}\mathrm{Ar} + \nu_\mathrm{e} + 1.505\,\mathrm{MeV}\,(10.72\%)$$

Possibility of using neutrinos to study the Earth was first suggested by Marx, Markov and Eder in 1960's.

Despite of the importance of direct measurement of the terrestrial heat source for understanding evolution and dynamics of the Earth, there was no realistic detector to observe geo-neutrinos.

5 Big Questions:

McDonough in Neutrino 2008

- What is the Planetary K/U ratio?
  planetary volatility curve
- Radiogenic contribution to heat flow?
  secular cooling
- Distribution of reservoirs in mantle?
  whole vs layered convection
- Radiogenic elements in the core??
  Earth energy budget
- Nature of the Core-Mantle Boundary?
  hidden reservoirs

KamLAND in Japan, low background and large liquid scintillator detector, first established the method to detect geo-neutrinos in 2005 and further improved its precision in 2008.

Borexino in Italy joined the game and results from the different geological point is added in 2010.

Now, we enter the era to obtain geophysical information from geo-neutrino measurements at different geological locations.

Background

In the past publications, major backgrounds were
Non-ν: ^{13}C (^{210}Po α, n)^{16}O , accidental
Reactor-ν.

KamLAND has performed intensive purification of the liquid scintillator, and the dominant background at lower energy, ^{13}C (^{210}Po α, n)^{16}O, has been reduced. And uncertainty of the cross section is well-controlled by the in-situ calibration.

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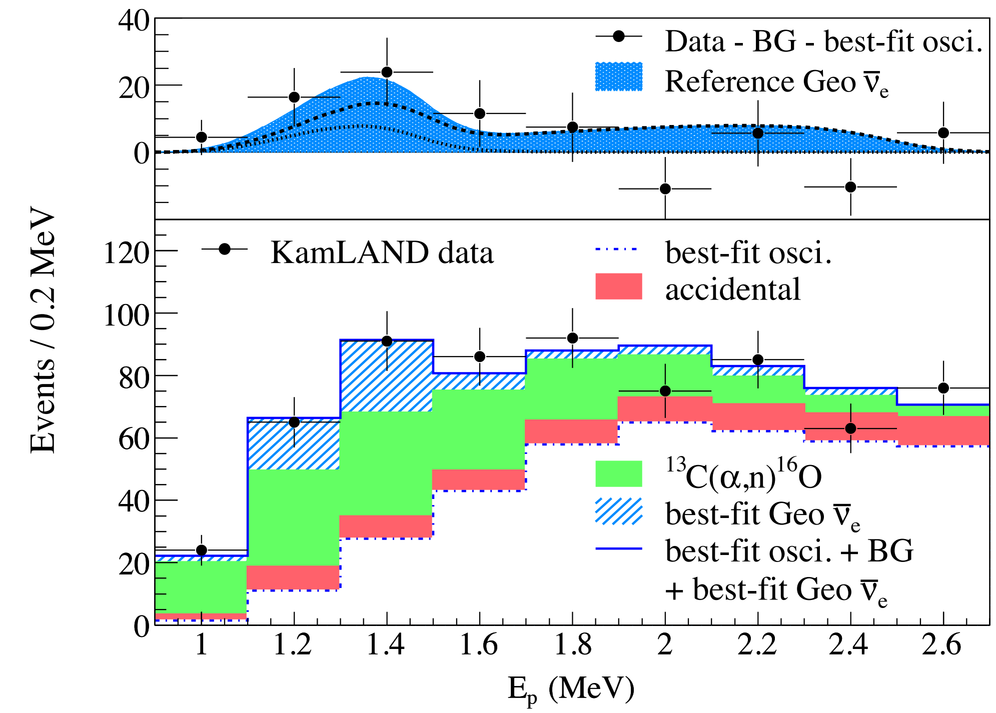
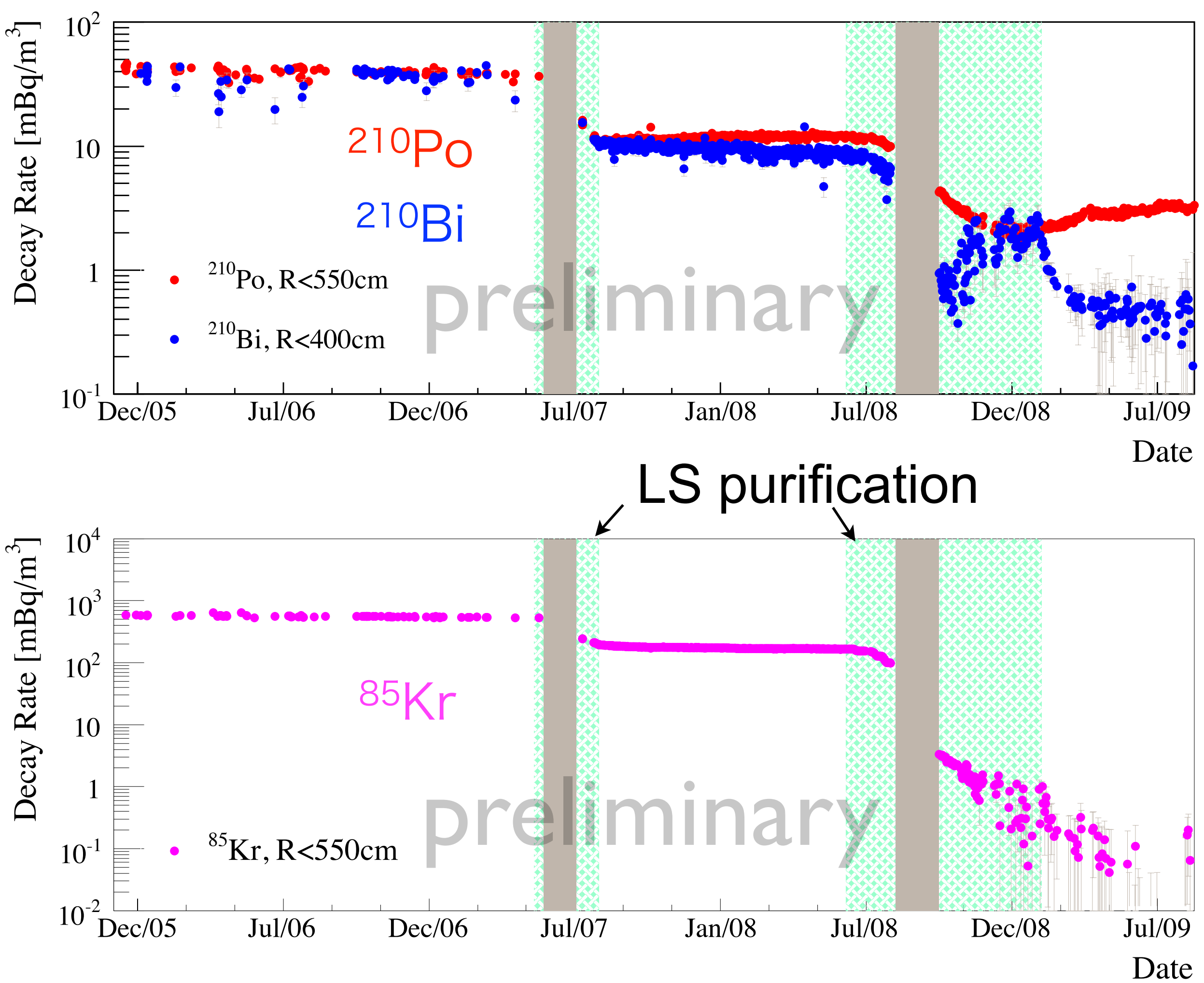
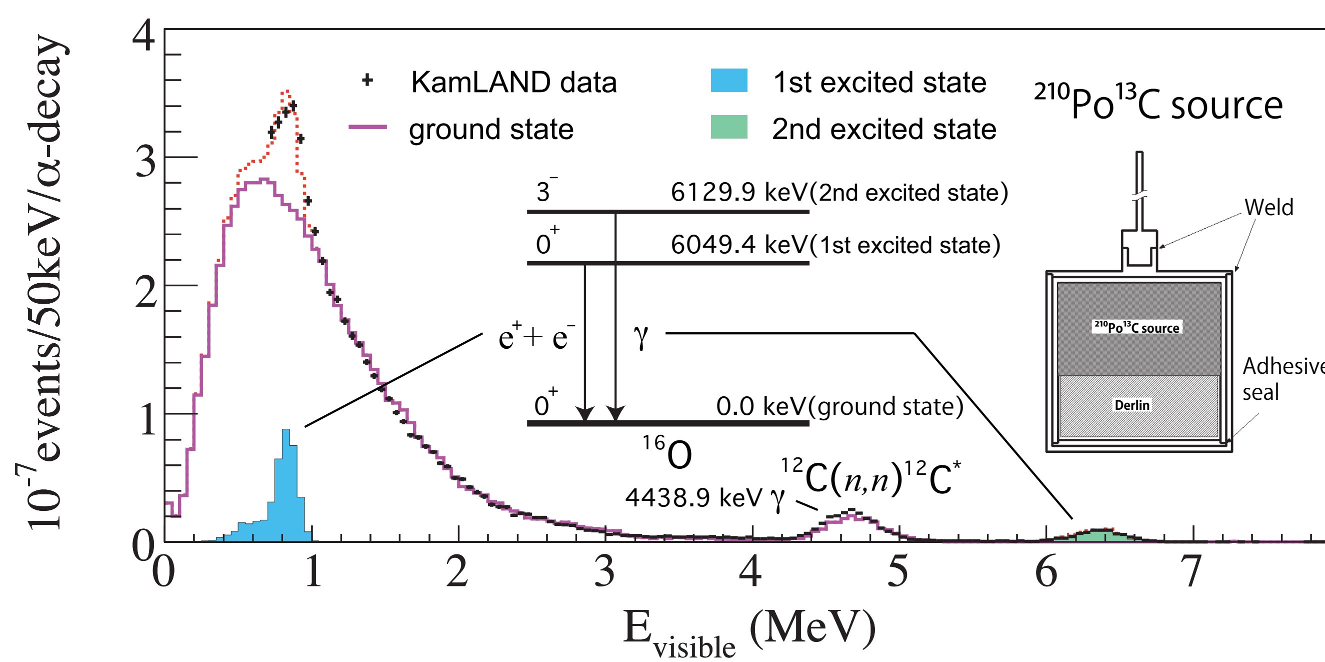




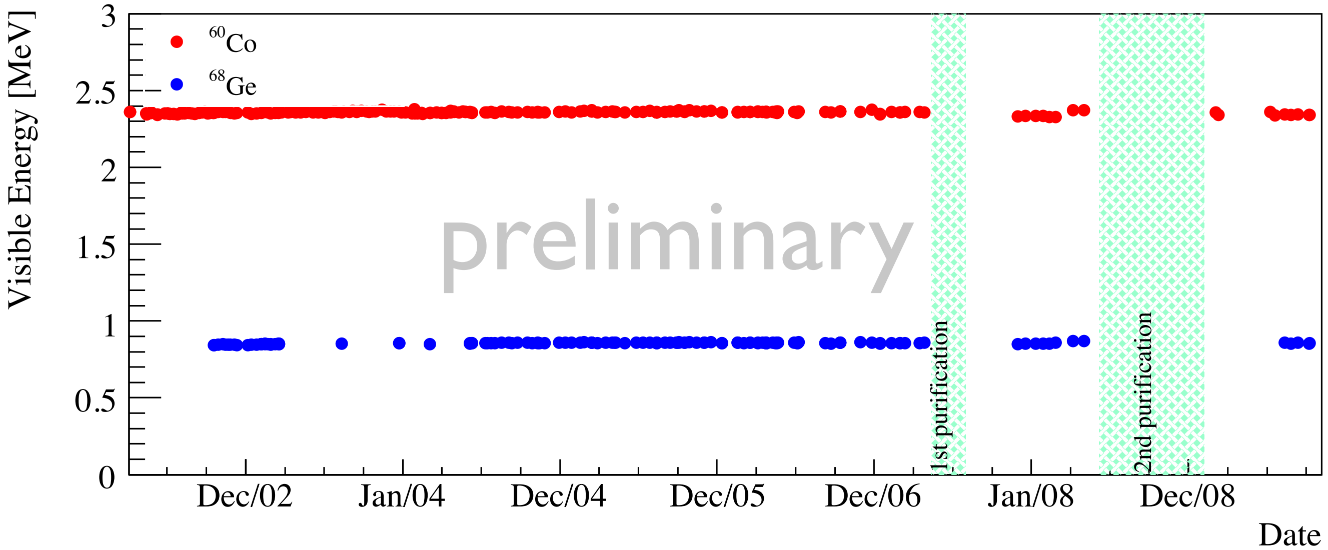
in-situ calibration with $^{210}Po^{13}C$ source



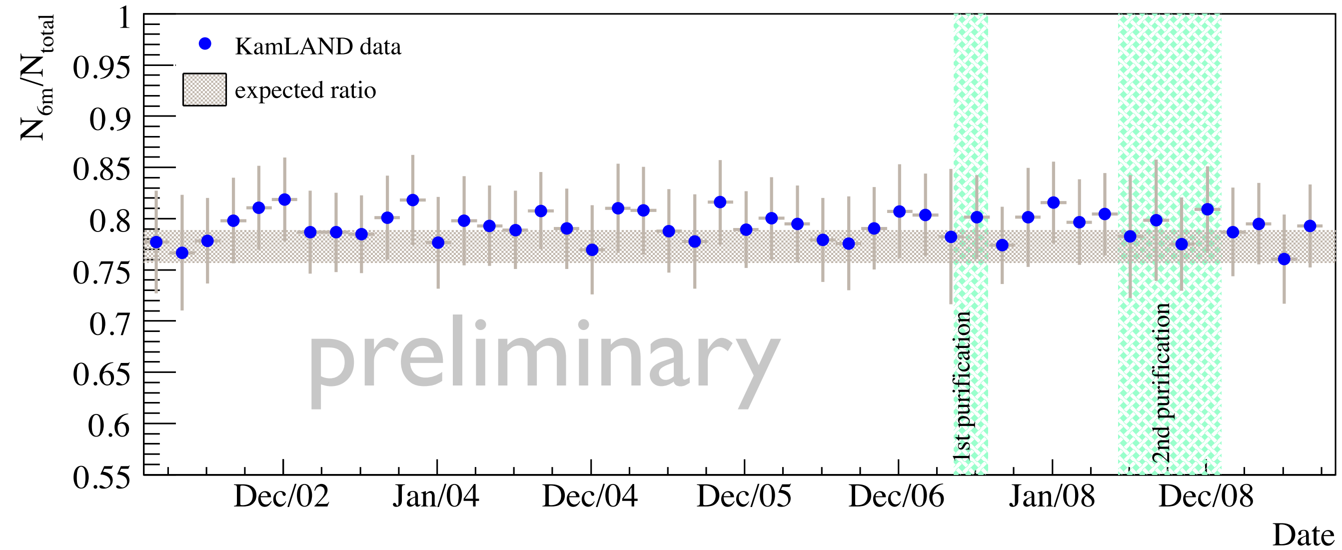
uncertainty of the cross section to the ground state is 11%.

Calibrations

^{60}Co/^{68}Ge energy deviation vs time

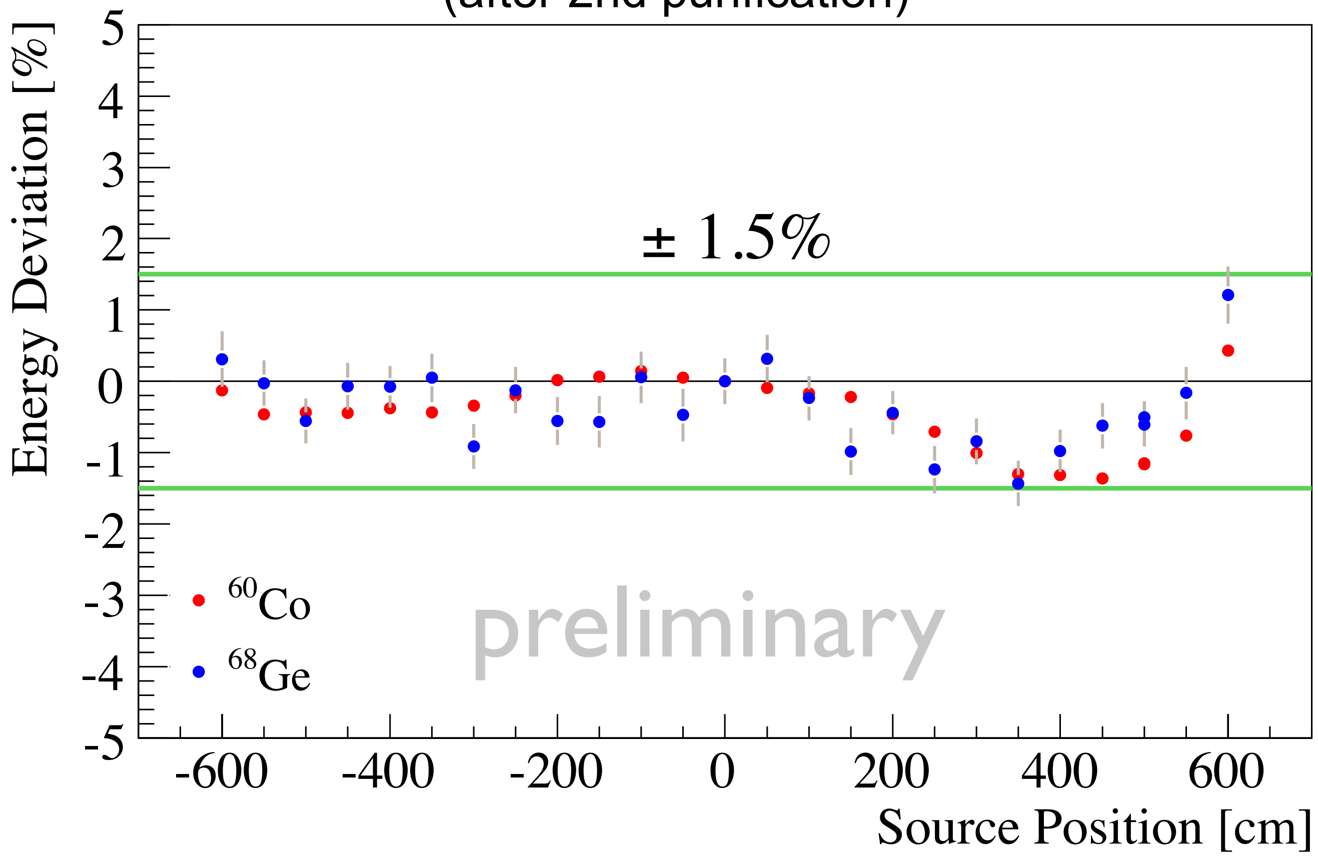


^{12}B N_{6m}/N_{total} vs time

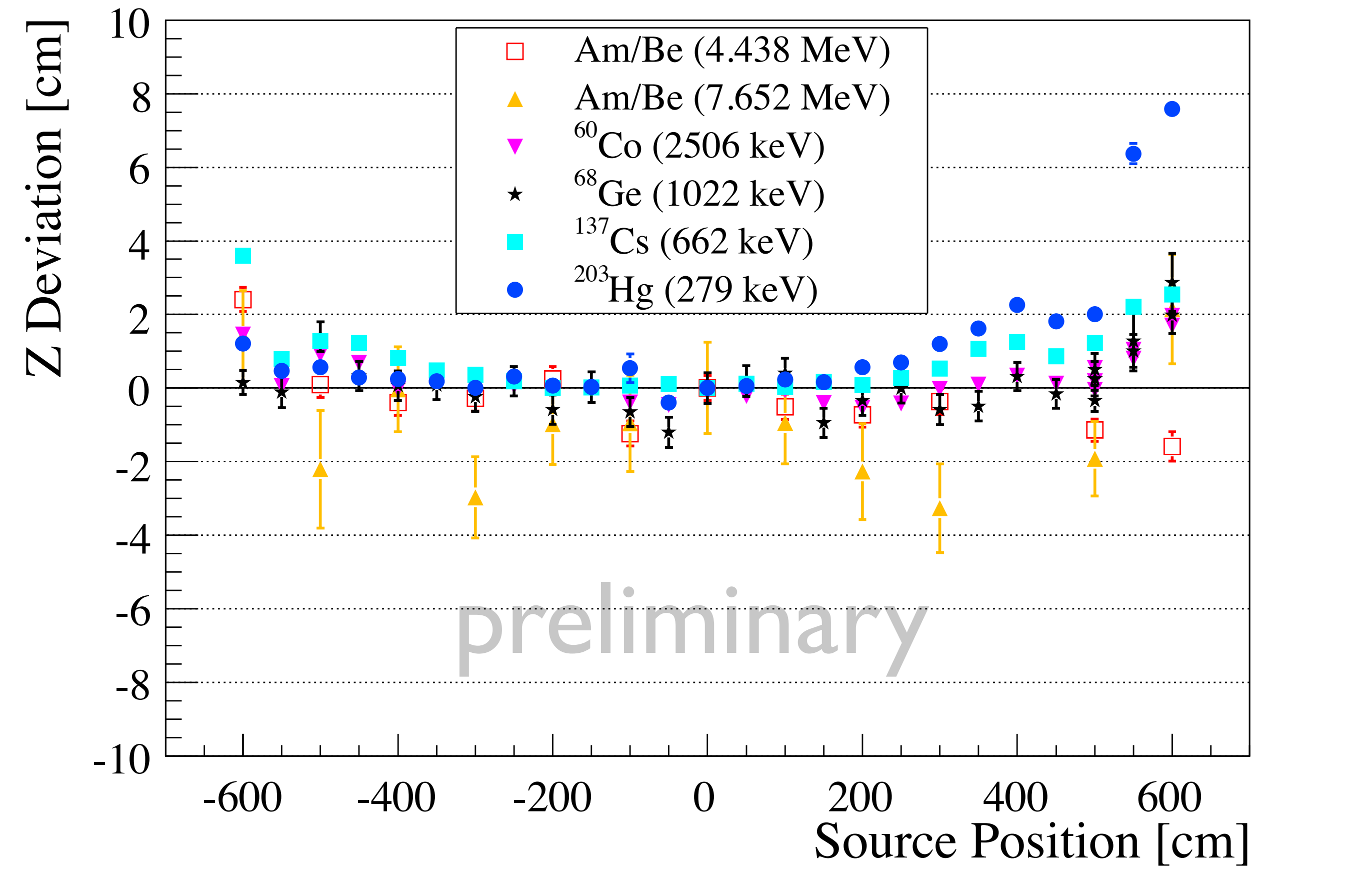


^{60}Co/^{68}Ge energy deviation vs Z

(after 2nd purification)

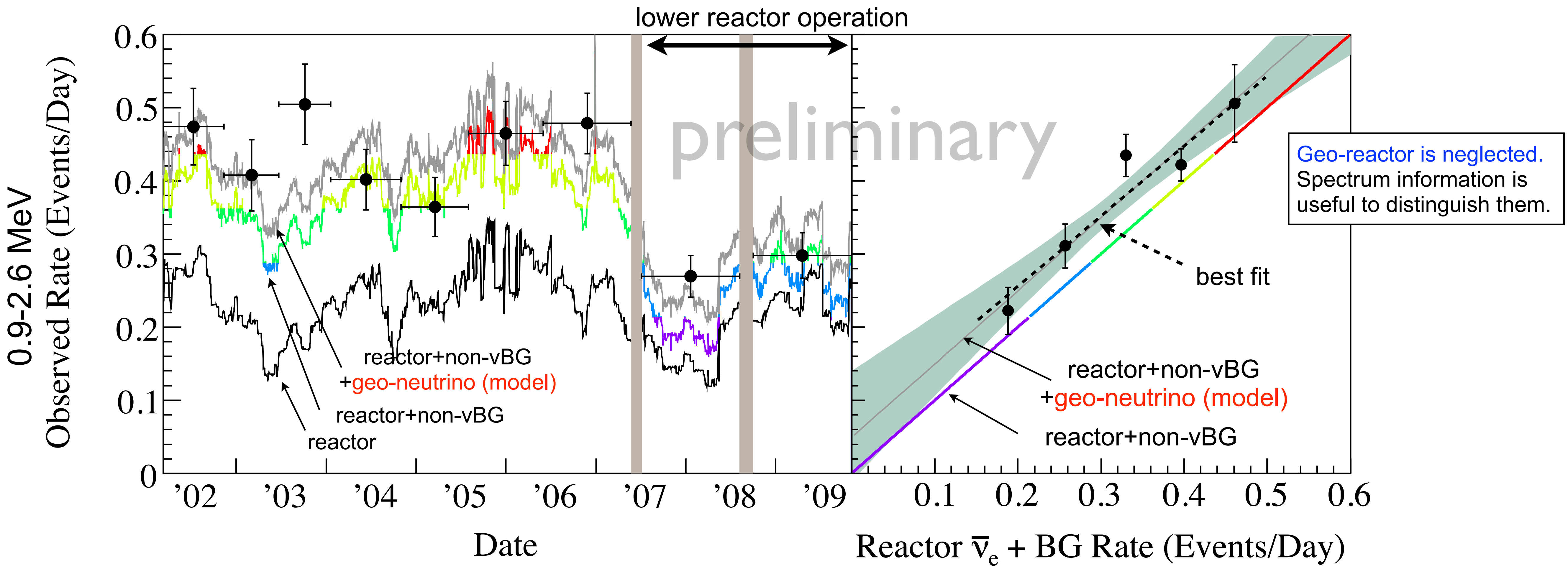


Source calibration Z deviation vs Z



Background-continued

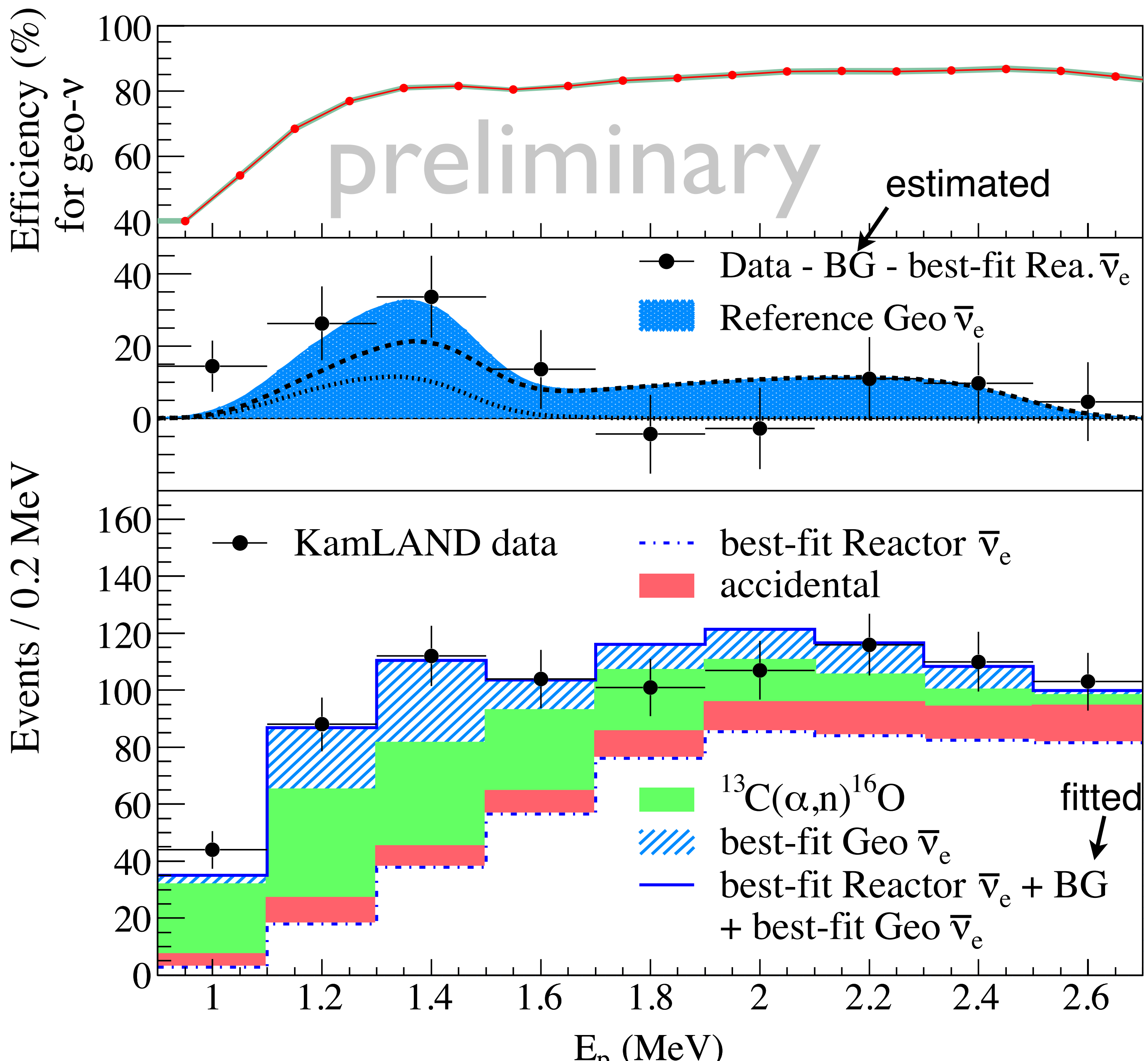
Operational troubles and serious earthquake at the power reactors caused lower reactor neutrino flux. KamLAND has experienced large (and known) time variation of the background. Background rate is about half since 2007.



Constant contribution from geo-neutrinos is seen above the estimated reactor neutrino + non-neutrino background in the energy range, 0.9 - 2.6 MeV.
Time information is effective to improve the quality of the geo-neutrino result.

Observed energy spectrum and estimated backgrounds

Period: March 9, 2002 ~ November 4, 2009
Total exposure: 3.49 x 10^{32} target-proton-years



841 candidates in 0.9-2.6 MeV

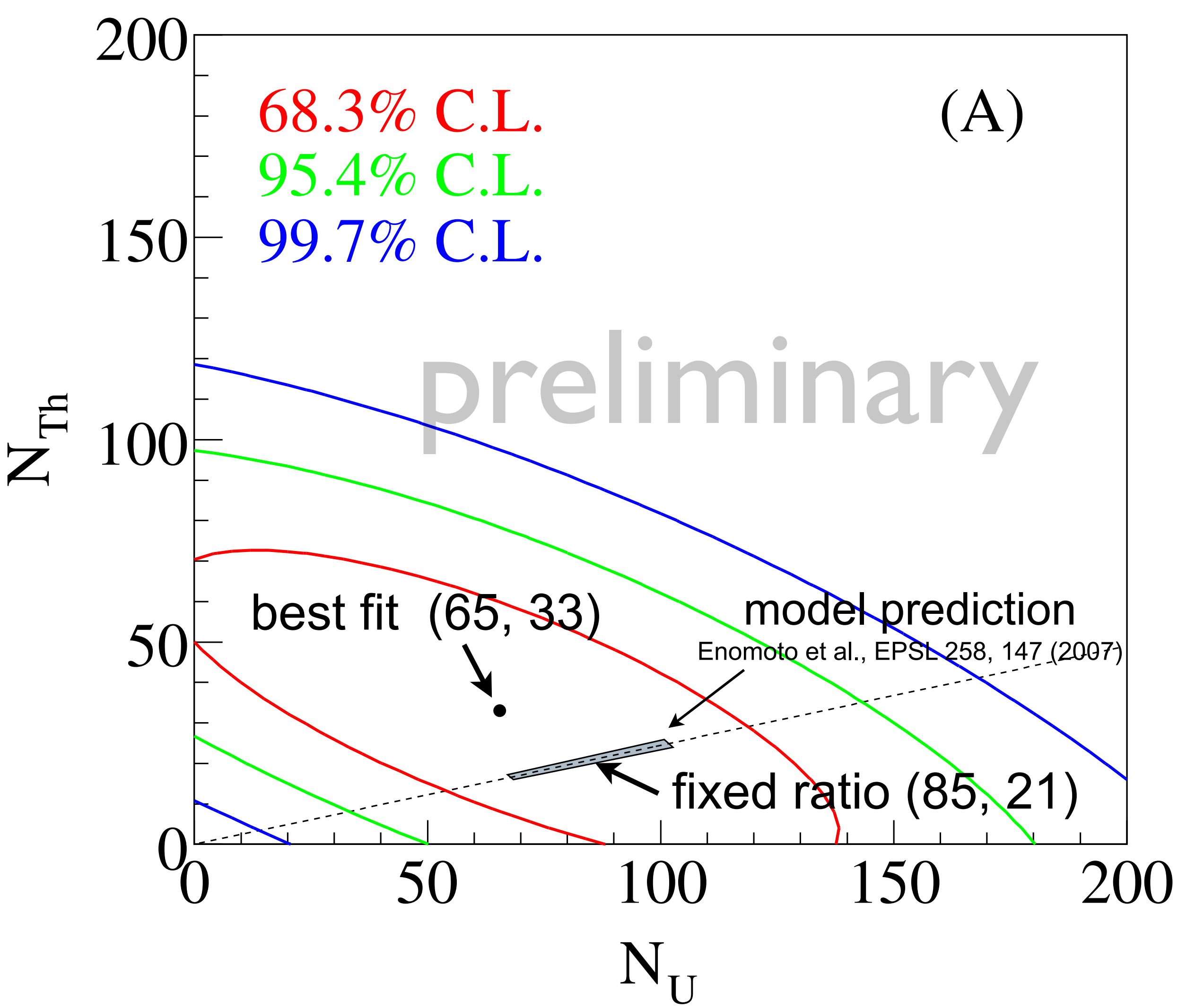
BG summary

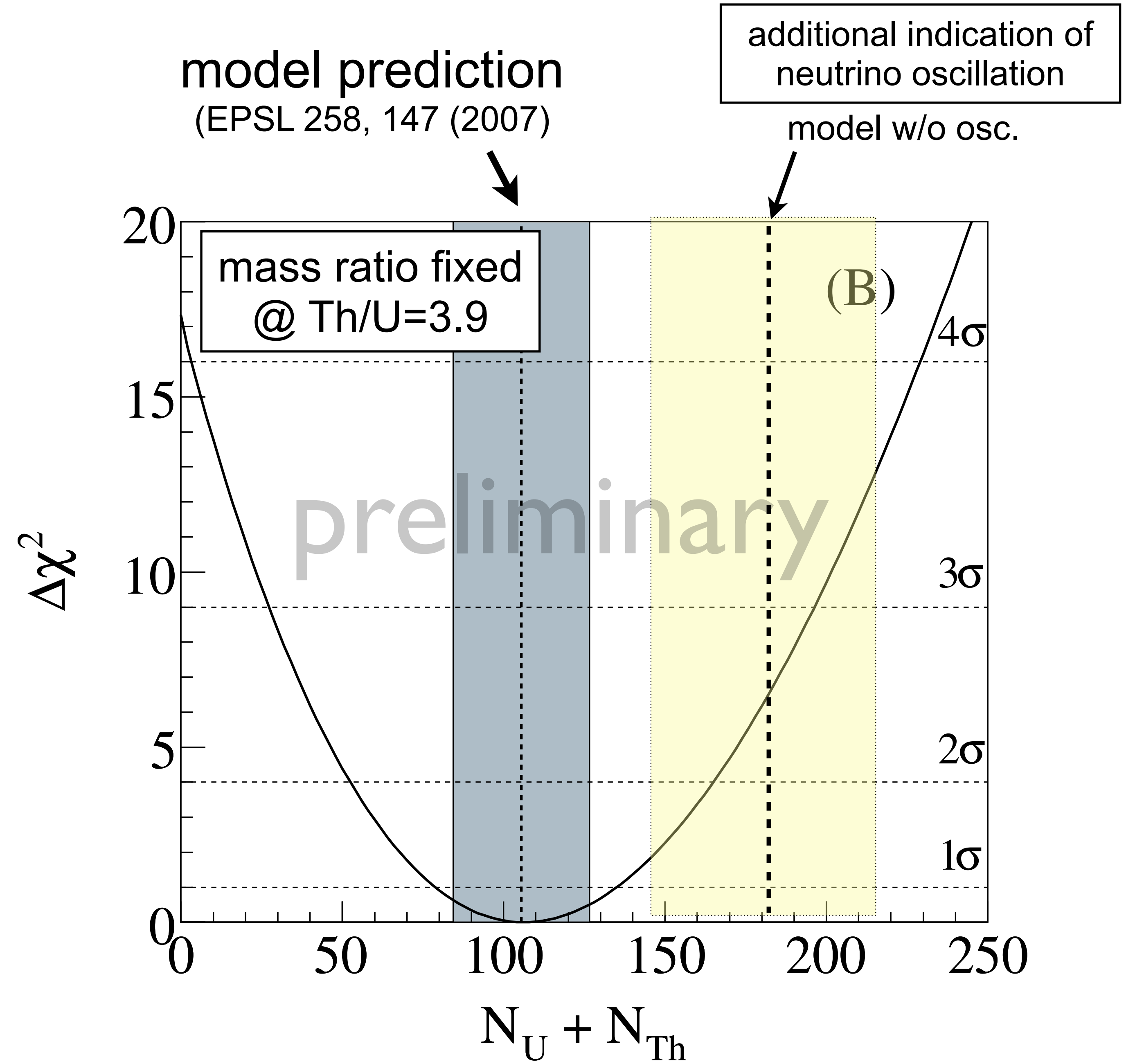
reactor $\bar{\nu}_e$	484.7±26.5
$^{13}C(\alpha,n)^{16}O$	165.3±18.2
accidental	77.4±0.1
^{9}Li	2.0±0.1
atm.ν+fast n	<2.8
Total	729.4±32.3

rate-only analysis 111^{+45}_{-43} events

Null signal exclusion 99.55% CL.
(rate-only hypothesis test)

Rate-shape-time analysis





0 signal is rejected at 99.997% CL. (>4σ)
(rate-shape-time $\Delta\chi^2$)

# of geo-ν events 106^{+29}_{-28}

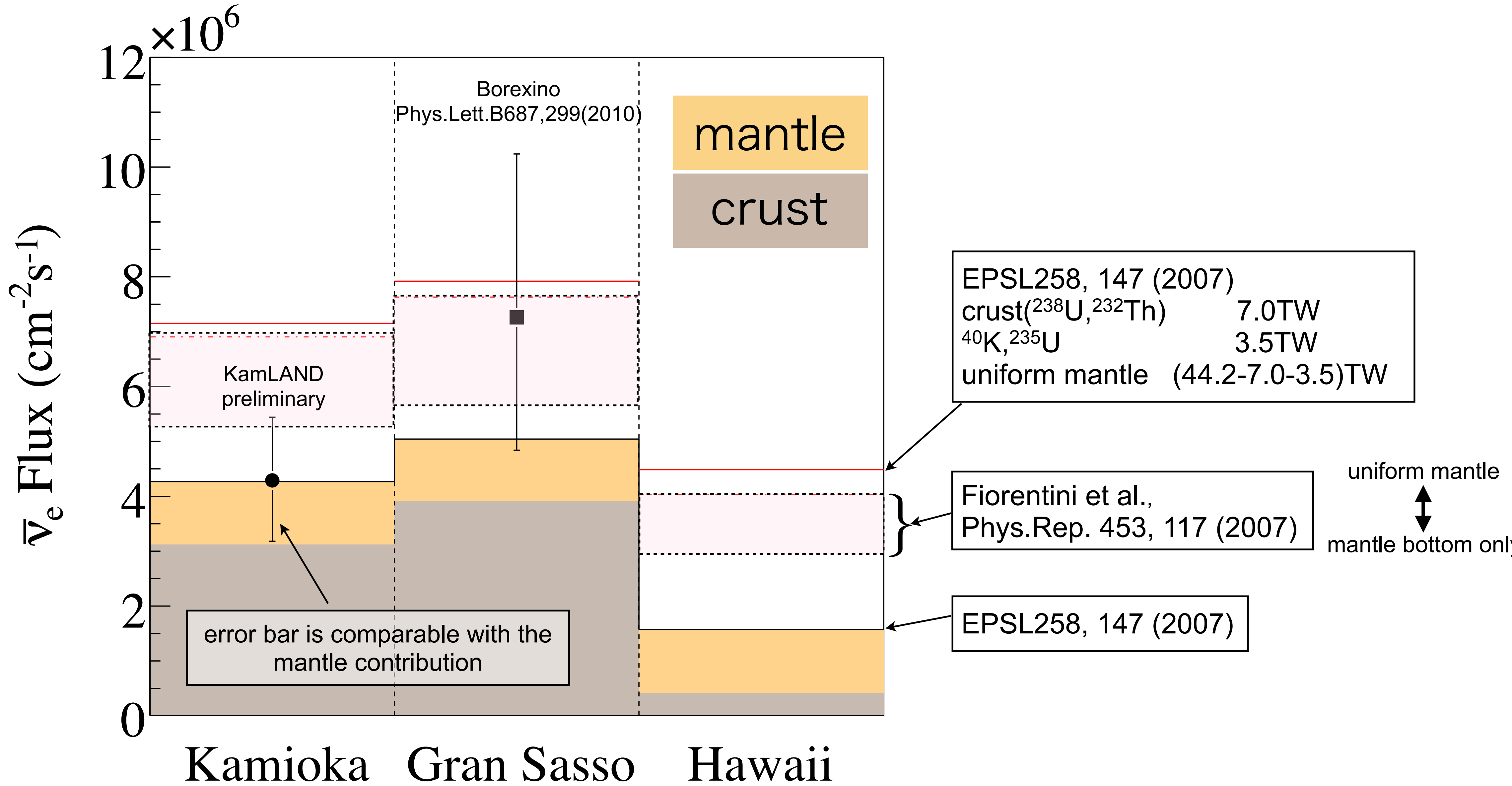
integrated $\bar{\nu}_e$ flux from 0 MeV for ^{238}U, ^{232}Th

$$4.3^{+1.2}_{-1.1} \times 10^6 \ /\mathrm{cm}^2/\mathrm{sec}$$

$(38.3^{+10.3}_{-9.9}\ \mathrm{TNU})$

corresponds to ~16TW (U,Th)

Comparison with models



The observed geo-neutrino flux is quite consistent with the model prediction.
For the first time, fully radiogenic models start to be disfavored. (KL only 2.4σ, KL+Bxino 2.3σ)

From geophysical point of view, extracting mantle contribution is very important.
In the future the combination of data from multiple sites and possible data from an oceanic experiment (where the crust is much thinner and so its contribution much smaller) will provide stronger constraints.

Summary

- KamLAND has improved precision of geo-neutrino measurement thanks to;
  lower non-neutrino background after LS purification,
  lower and varying reactor neutrino flux from surrounding nuclear reactors
  and increased statistics.

- Preliminary results of
  observed number of geo-neutrino events, 106^{+29}_{-28} (mass Th/U=3.9)
  and geo-neutrino flux, $4.3^{+1.2}_{-1.1} \times 10^6$ /cm^2/sec ($\bar{\nu}_e$ from ^{238}U and ^{232}Th)
  have been reported. $(38.3^{+10.3}_{-9.9}\ \mathrm{TNU})$

- Observed flux is just on the model prediction and some extreme models start to be disfavored.

- Multi-site measurements and/or measurement at ocean will propel "neutrino geophysics" more significantly. Multi-site measurements are just started!