New Geo-neutrino Measurement with KamLAND

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for the KamLAND collaboration

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Brief history

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

Despite 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.

$$^{238}\mathrm{U} \rightarrow ^{206}\mathrm{Pb} + 8\alpha + 6\mathrm{e}^- + 6\bar{\nu}_\mathrm{e} + 51.7\,\mathrm{MeV}$$
$$^{232}\mathrm{Th} \rightarrow ^{208}\mathrm{Pb} + 6\alpha + 4\mathrm{e}^- + 4\bar{\nu}_\mathrm{e} + 42.7\,\mathrm{MeV}$$
$$^{40}\mathrm{K} \rightarrow ^{40}\mathrm{Ca} + \mathrm{e}^- + \bar{\nu}_\mathrm{e} + 1.311\,\mathrm{MeV}\,(89.28\%)$$
$$^{40}\mathrm{K} + \mathrm{e}^- \rightarrow ^{40}\mathrm{Ar} + \nu_\mathrm{e} + 1.505\,\mathrm{MeV}\,(10.72\%)$$

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, a low background and large liquid scintillator detector, first established the method of detecting geo-neutrinos in 2005 and further improved the measurement in 2008.

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

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

Background

In our 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. The uncertainty of the cross section was improved by the in-situ calibration.

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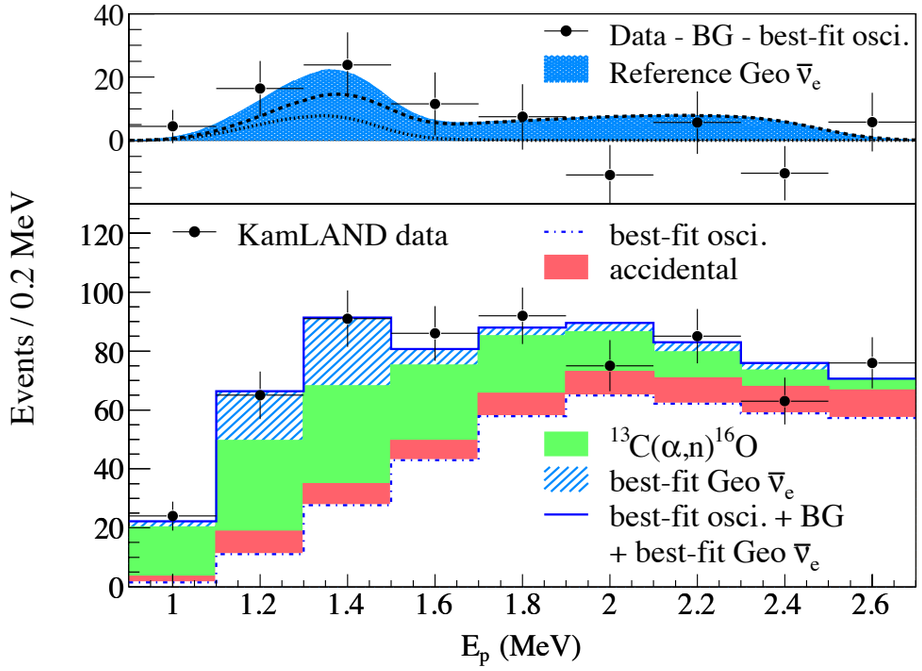
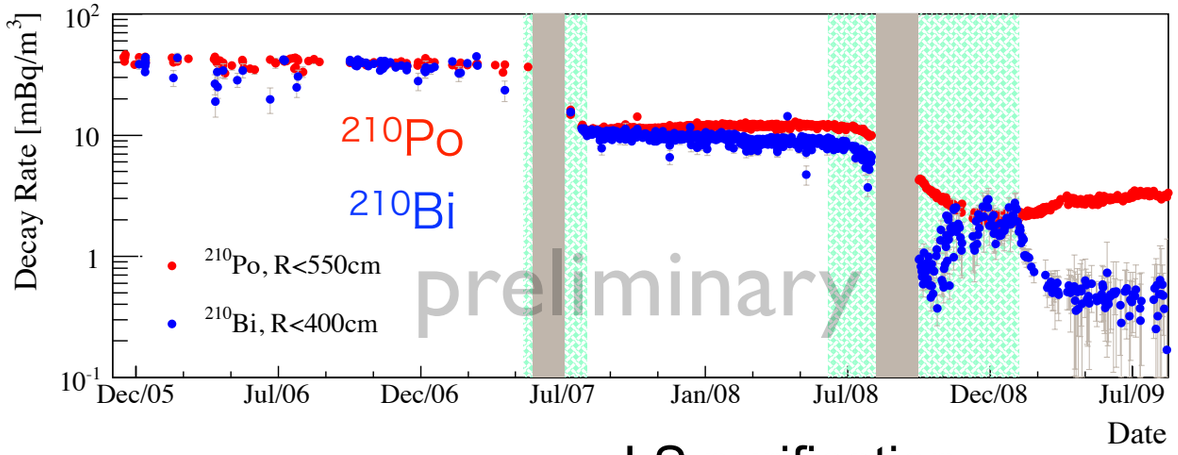
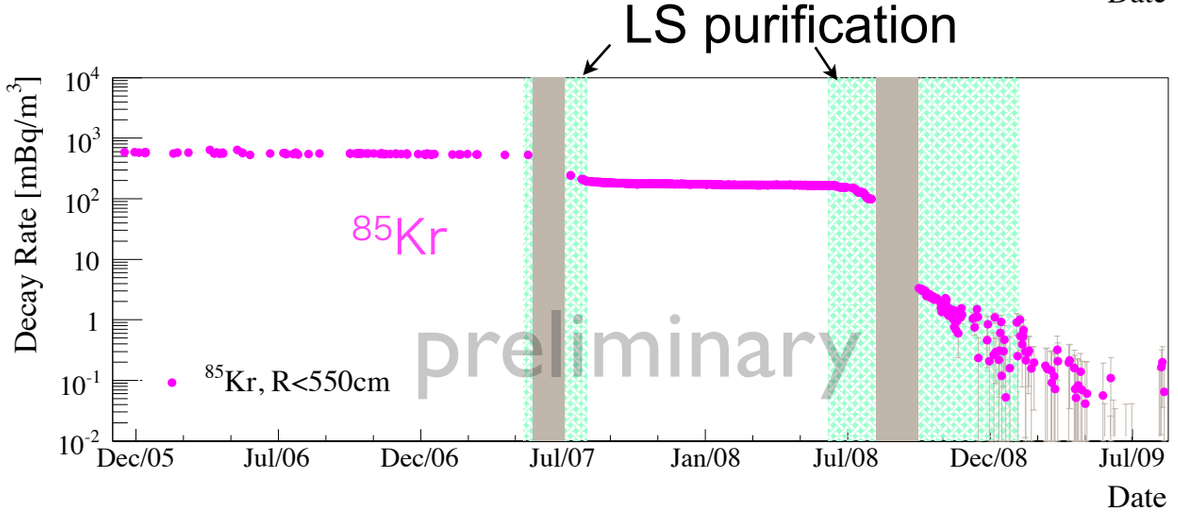
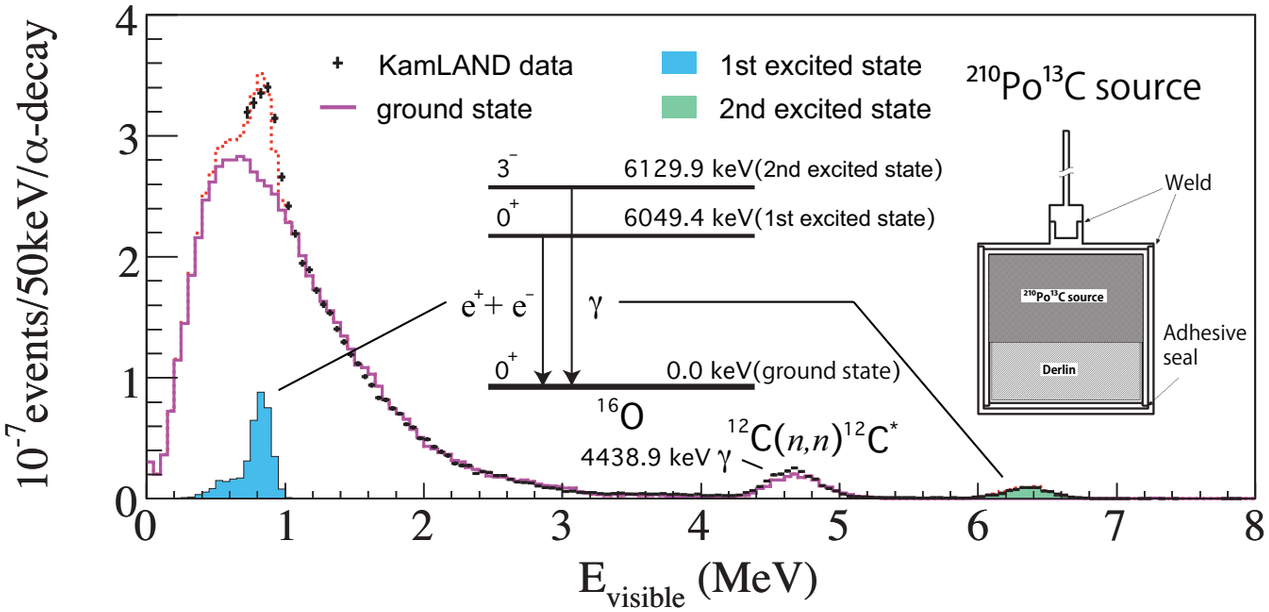






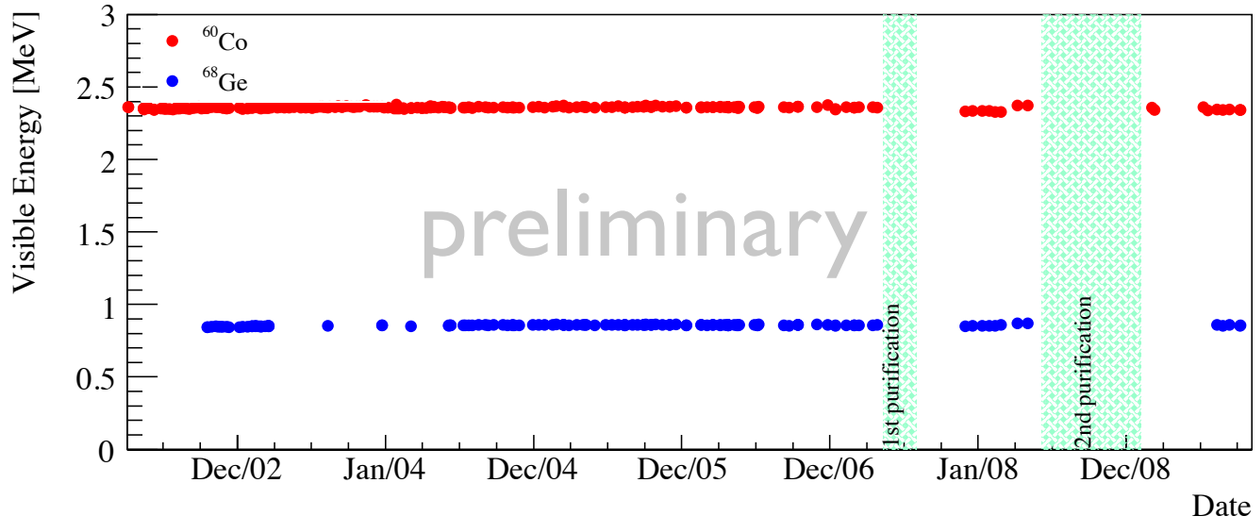
in-situ calibration with $^{210}Po^{13}C$ source



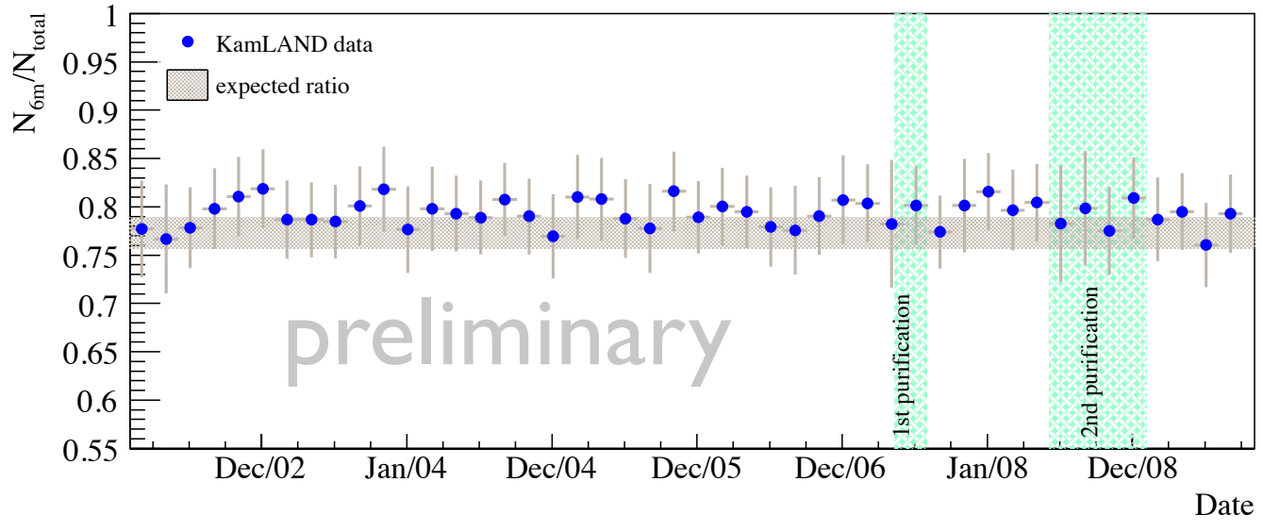
uncertainty of the cross section to the ground state is 11%.

Calibrations

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

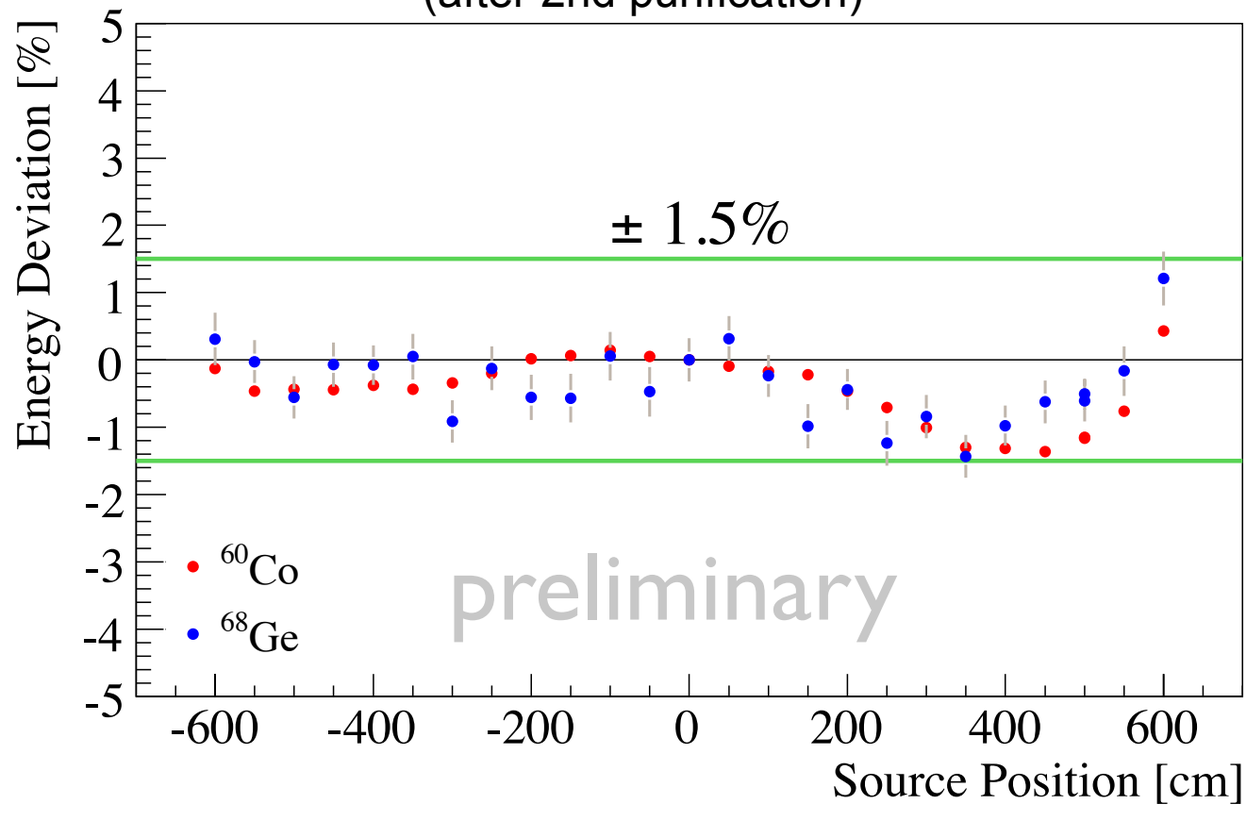


^{12}B N_{6m}/N_{total} vs time

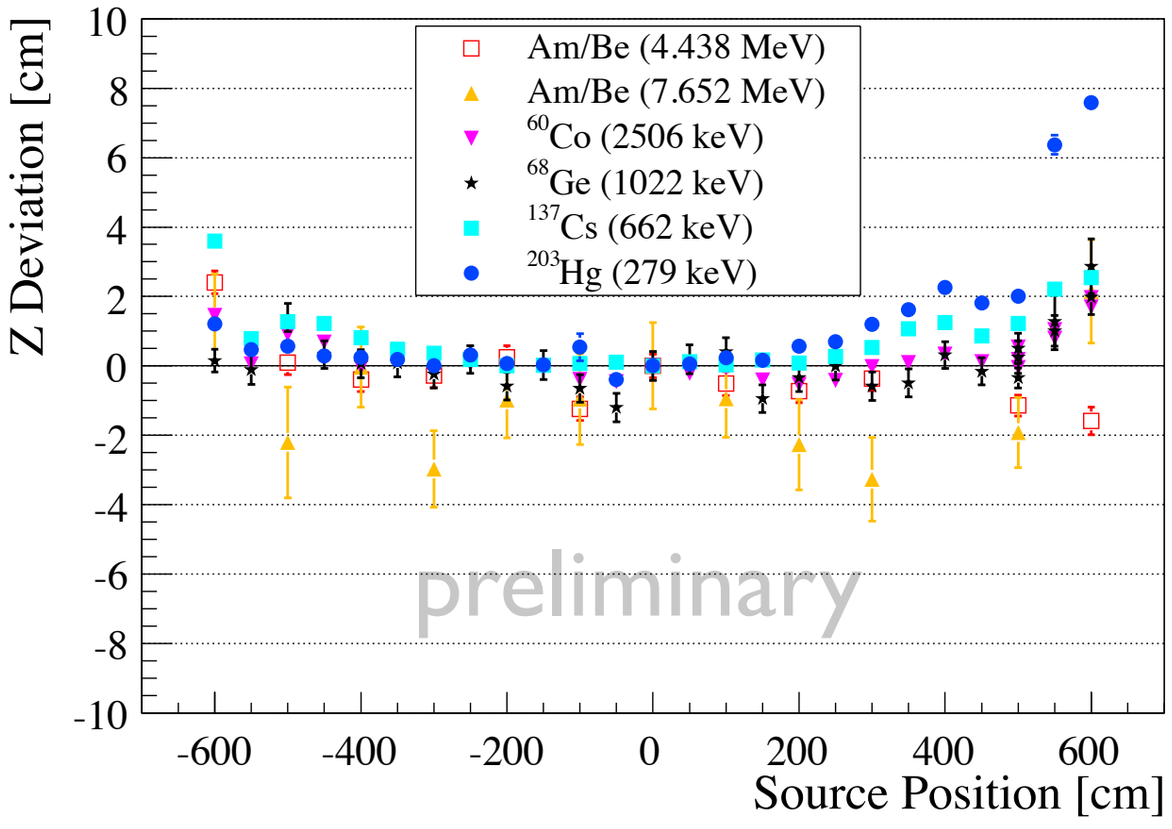


$^{60}Co/^{68}Ge$ energy deviation vs Z

(after 2nd purification)

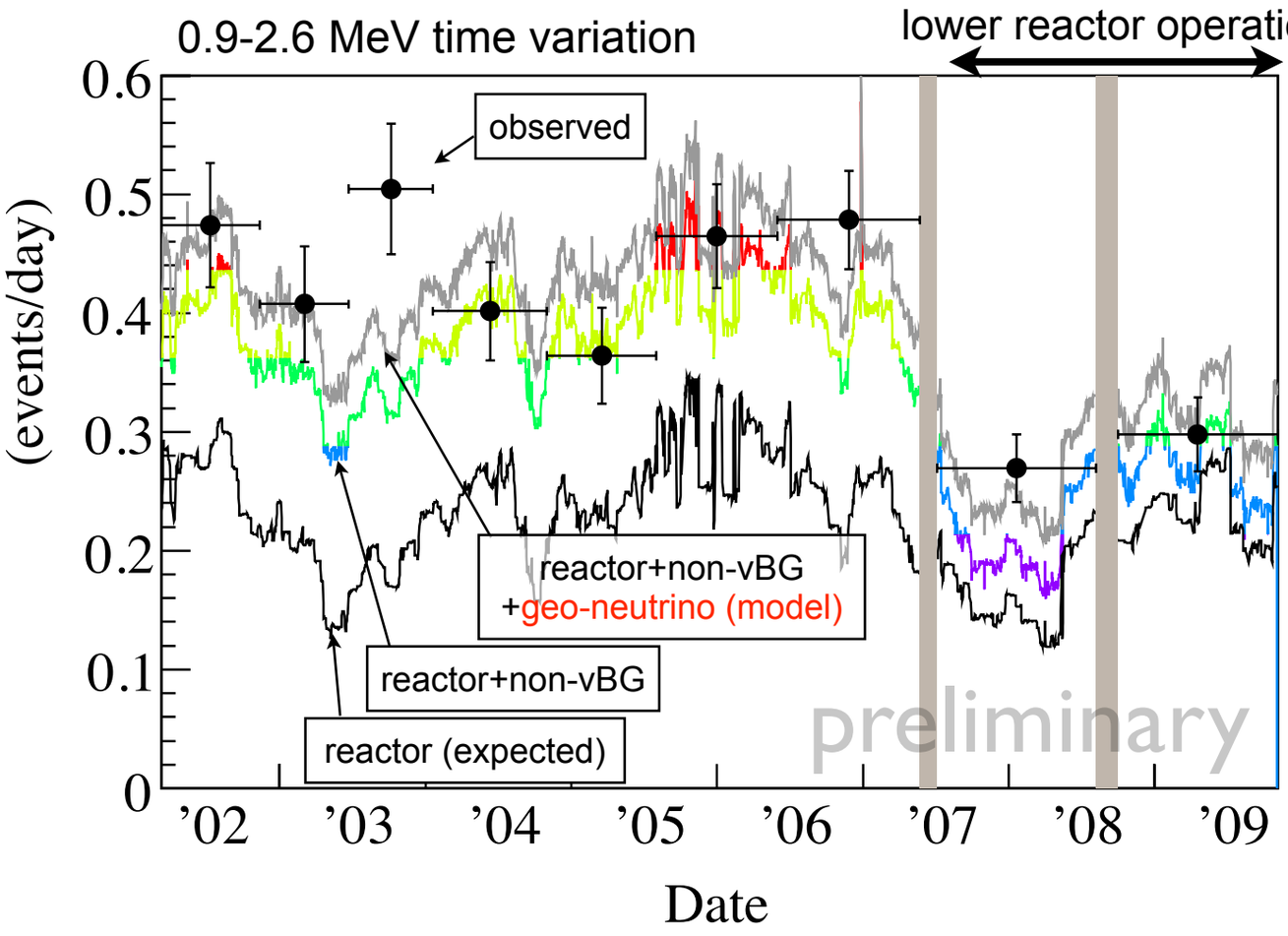


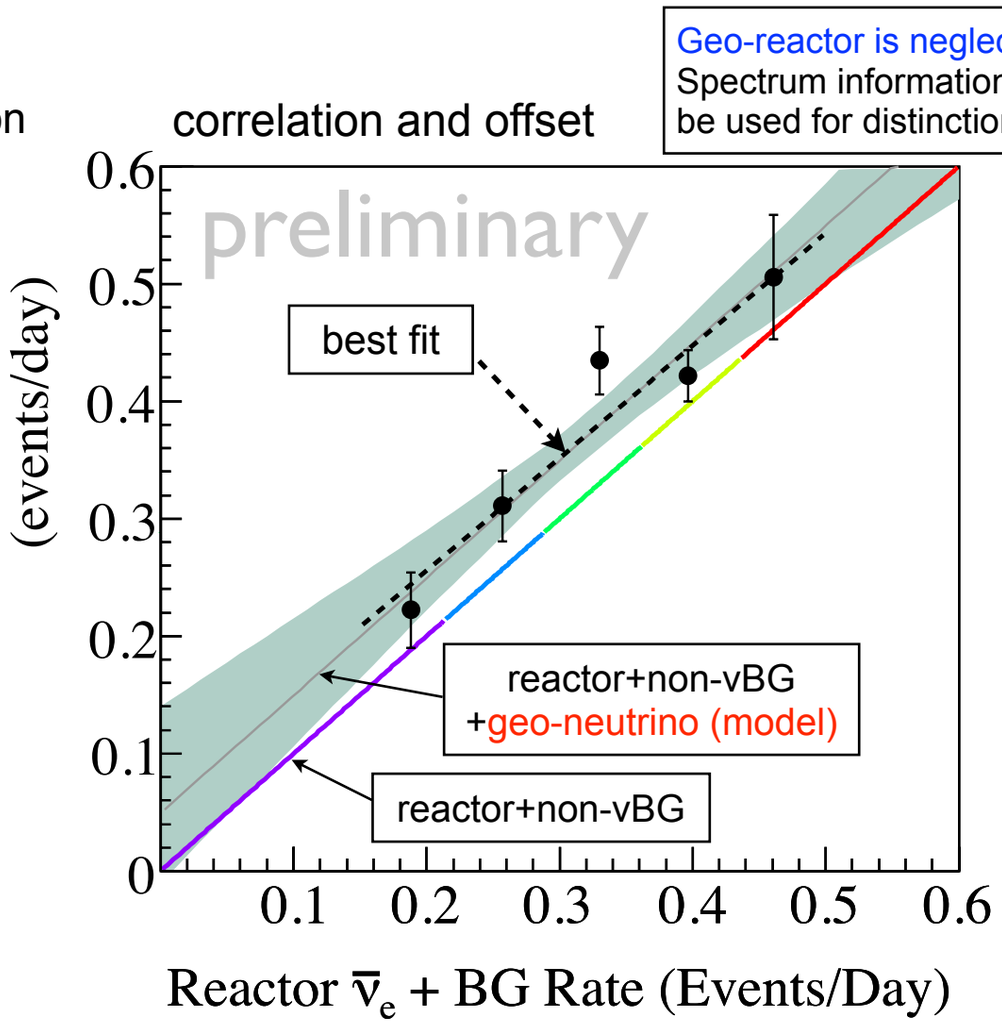
Source calibration Z deviation vs Z



Background-continued

Operational issues at the power reactor and a serious earthquake reduced the reactor neutrino flux. KamLAND has experienced a large (but known) time variation of the background. The geo-neutrino background rate is about half of what it was before 2007.

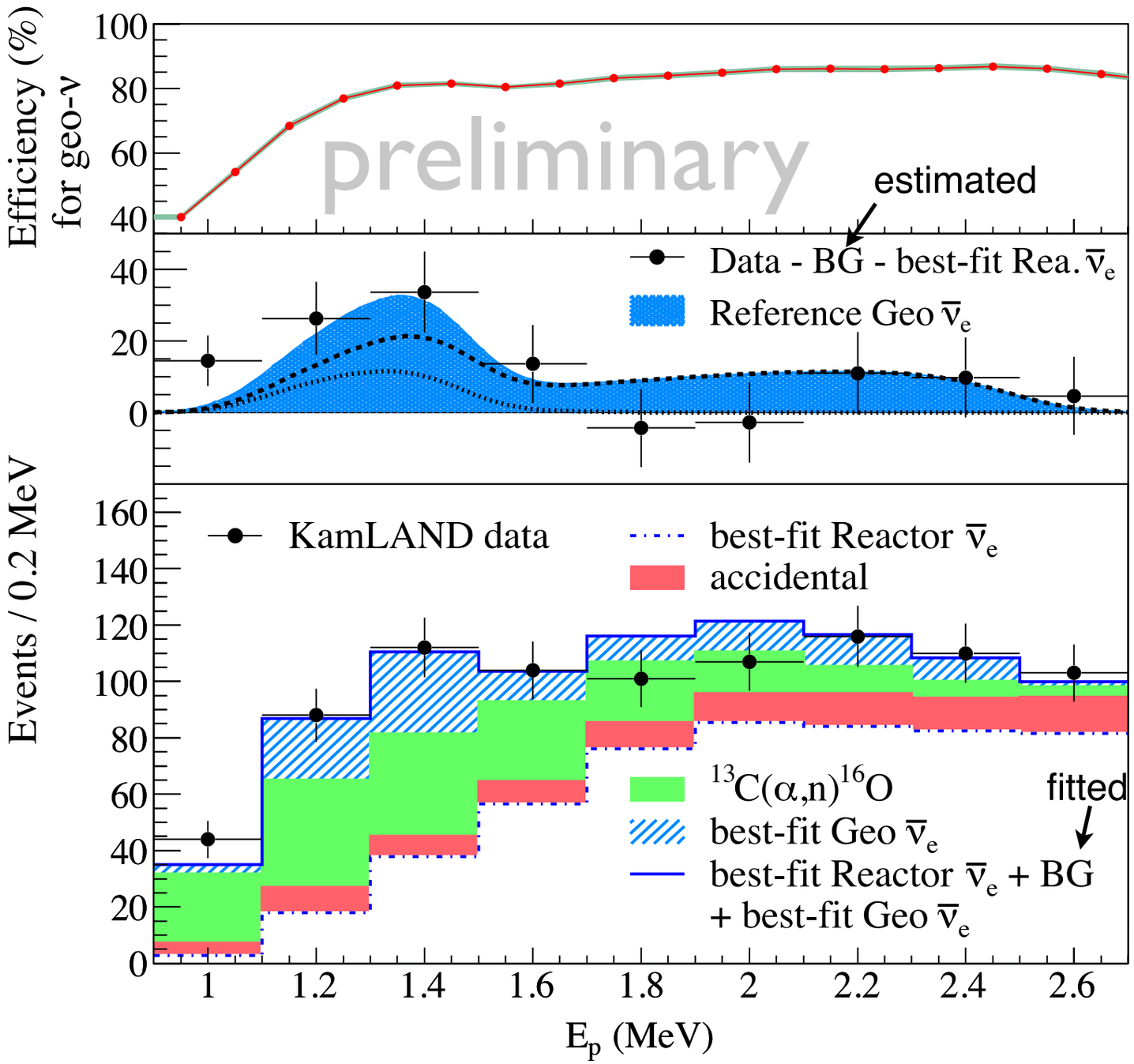




Constant contribution from geo-neutrinos is seen above the estimated reactor neutrino + non-neutrino background in the energy range 0.9 - 2.6 MeV.
Time information is effective to improve geo-neutrino discrimination.

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

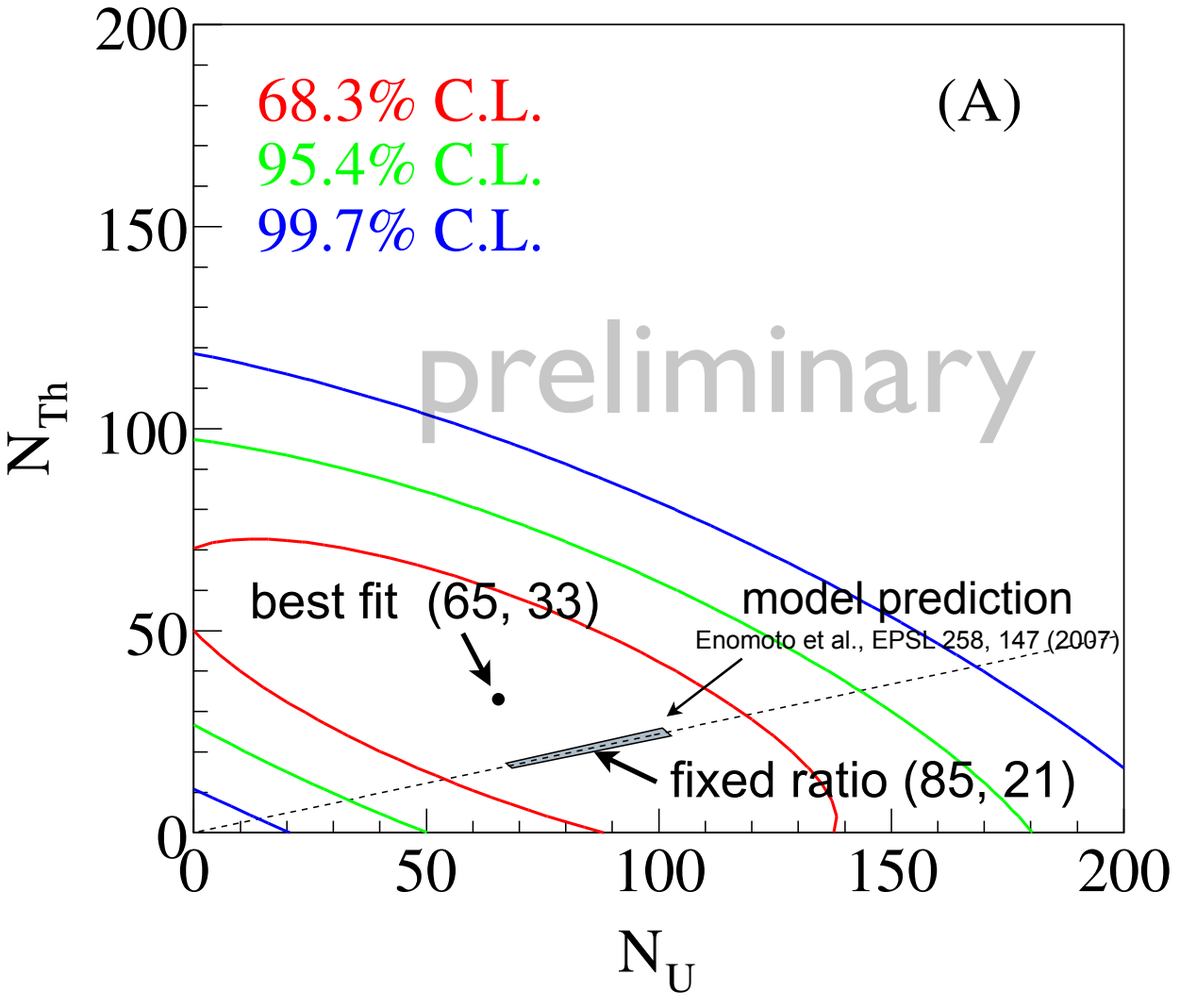
BG summary

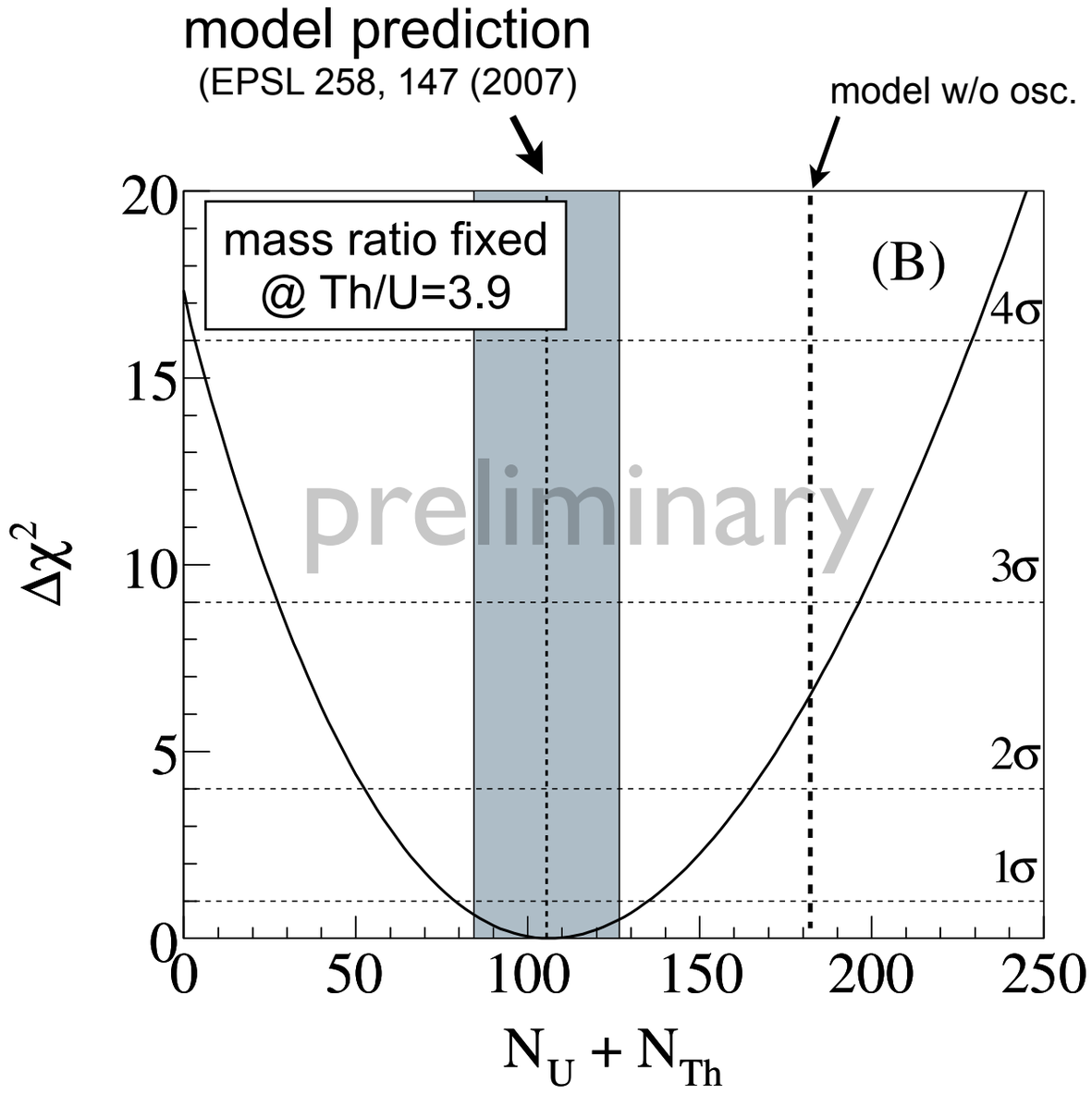
reactor $\bar{\nu}_e$	484.7±26.5
$^{13}C(\alpha,n)^{16}O$	165.3±18.2
accidental	77.4±0.1
^{9}Li	2.0±0.1
atm.ν+fast n	<2.8
Total	729.4±32.3

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}

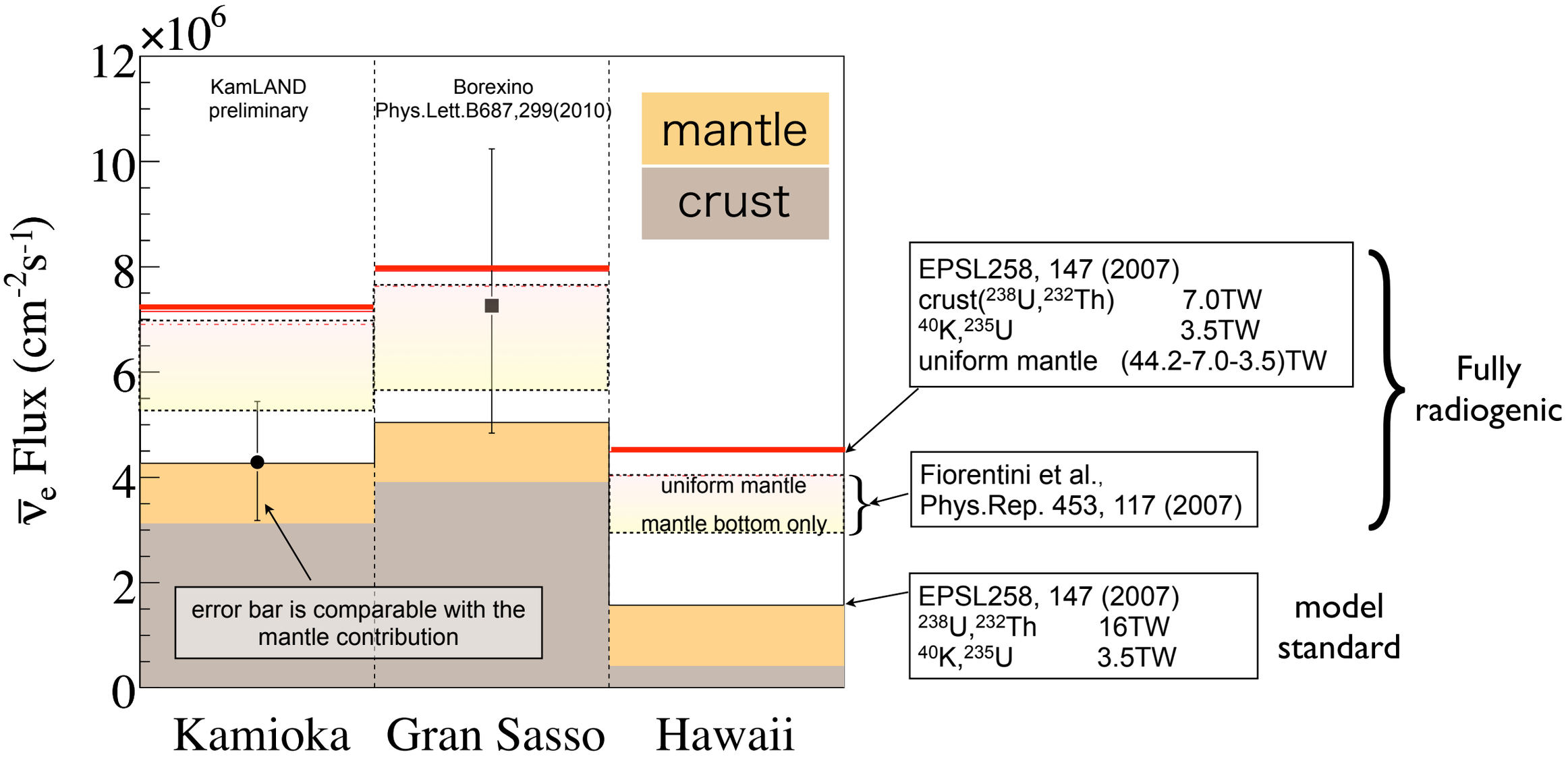
integrated $\bar{\nu}_e$ flux from 0 MeV for ^{238}U, ^{232}Th

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

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

corresponds to ~16TW (U,Th)

Comparison with models



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

From a geophysical point of view, extracting the 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 the precision of the 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, $4.3^{+1.2}_{-1.1} \times 10^6\ /\mathrm{cm}^2/\mathrm{sec}$ ($\bar{\nu}_\mathrm{e}$ from ^{238}U and ^{232}Th)
  have been reported. $(38.3^{+10.3}_{-9.9}\ \mathrm{TNU})$

- Observed flux is fully consistent with the model prediction but some extreme models start to be disfavored.

- Multi-site measurements and/or a measurement on the oceanic crust will significantly advance “neutrino geophysics”. Multi-site measurements have just started!