Geo-neutrino Measurement with KamLAND

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for the KamLAND Collaboration

Contents

Contents

KamLAND Collaboration

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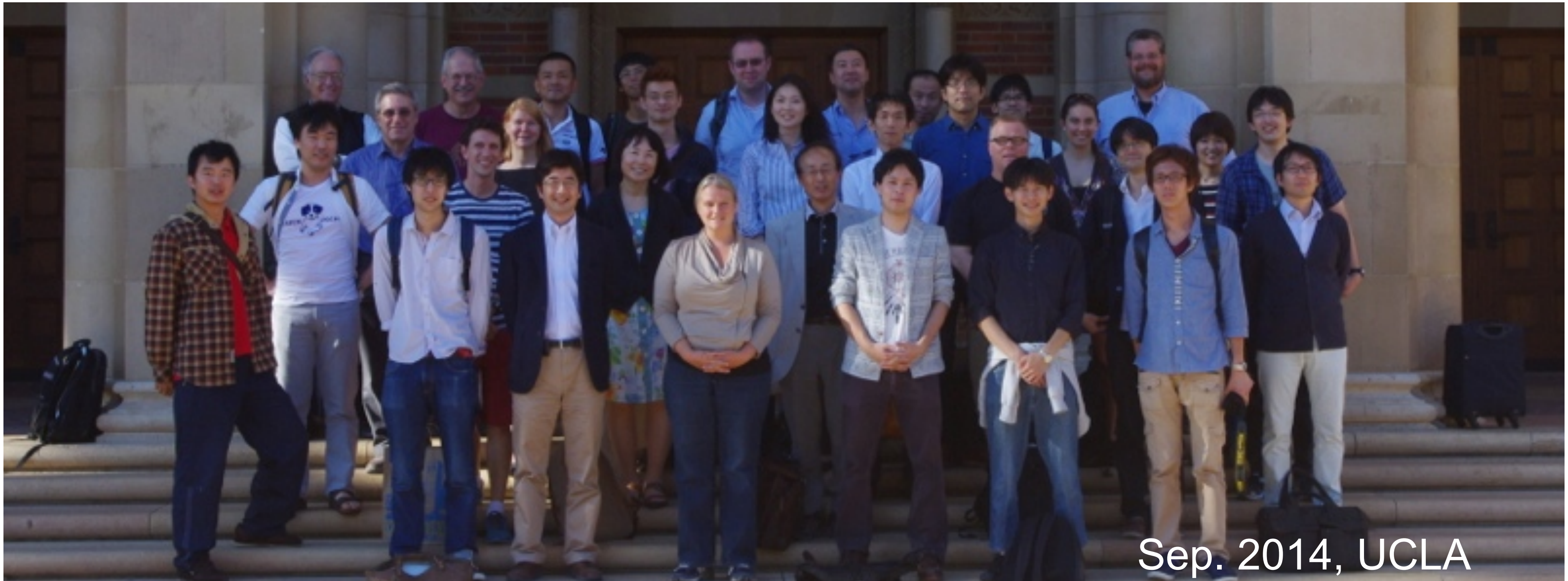
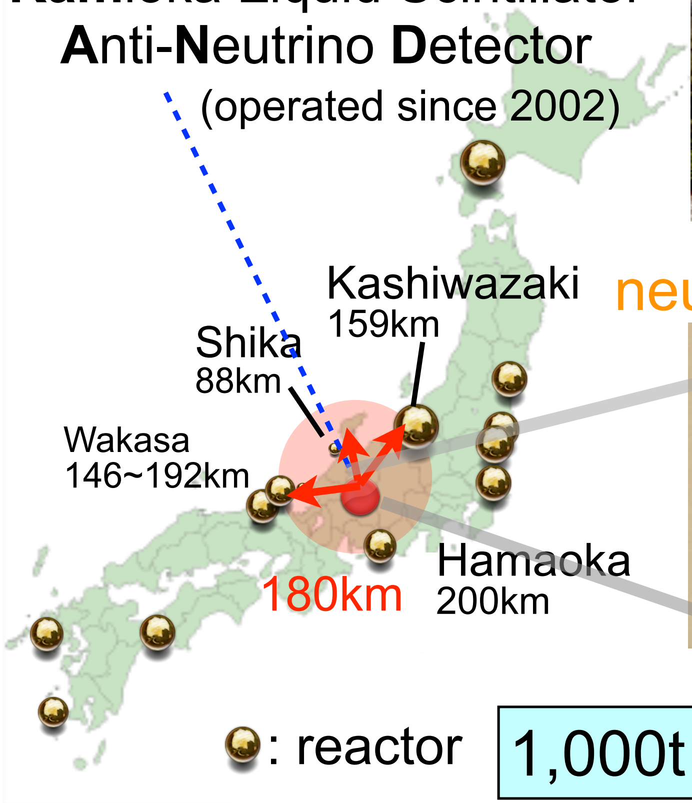


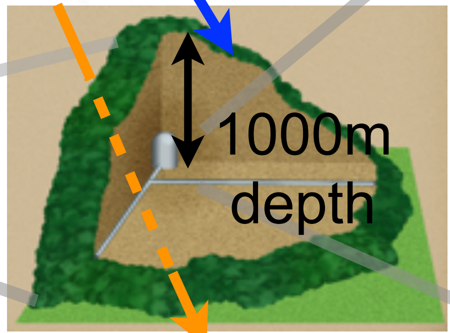
KamLAND Site & Detector

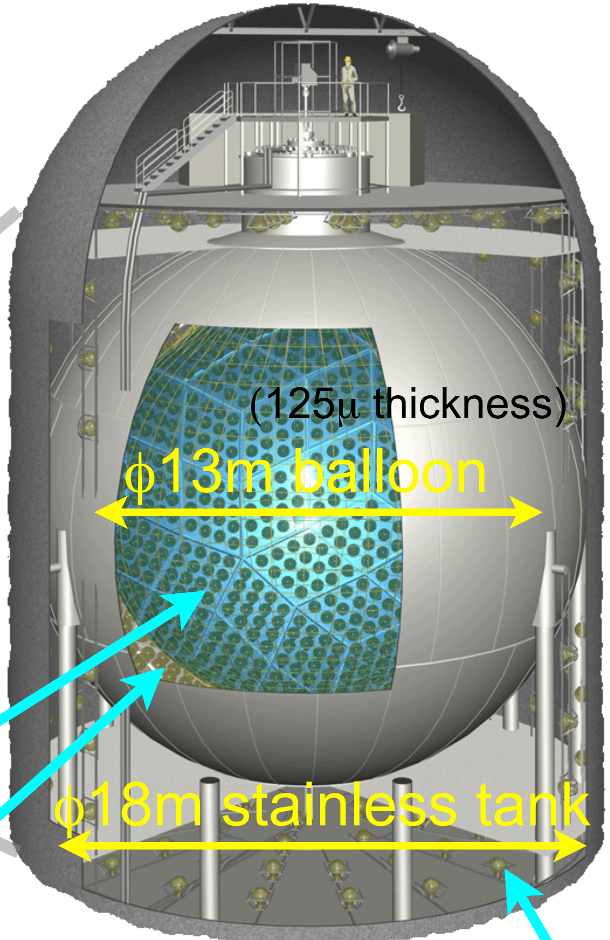
KamLAND

Kamioka **L**iquid Scintillator **A**nti-**N**eutrino **D**etector

(operated since 2002)







1,000t Liquid Scintillator

* Dodecane (80%) Pseudocumene (20%) PPO (1.36 g/l)
* extremely low impurily (^{238}U:3.5×10^{-18}g/g, ^{232}Th:5.2×10^{-17}g/g)

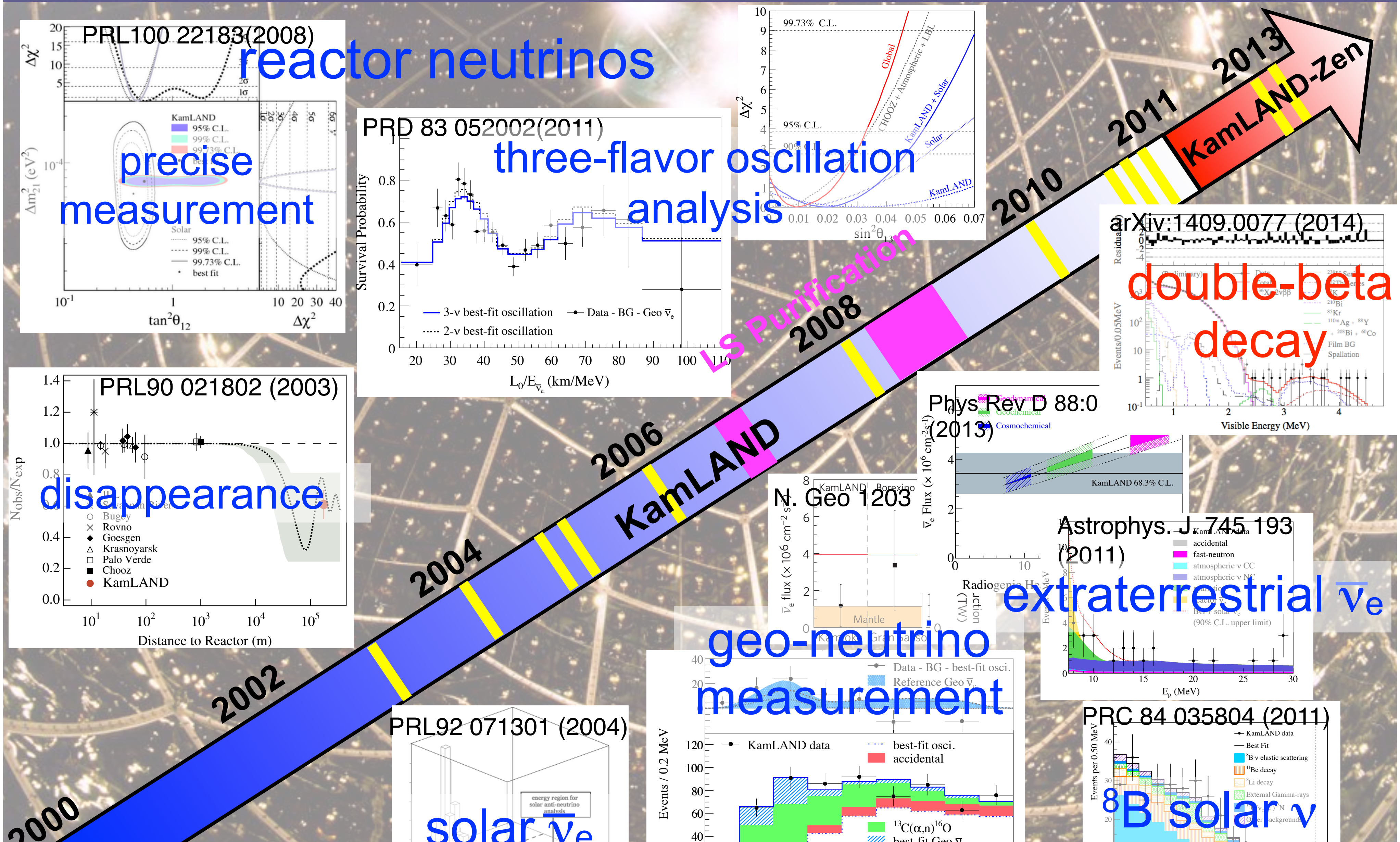
1,325 17inch + 554 20inch PMTs

* Photo coverage 34%

Water Cherenkov Outer Detector

* Muon veto

Overview of KamLAND Neutrino Physics

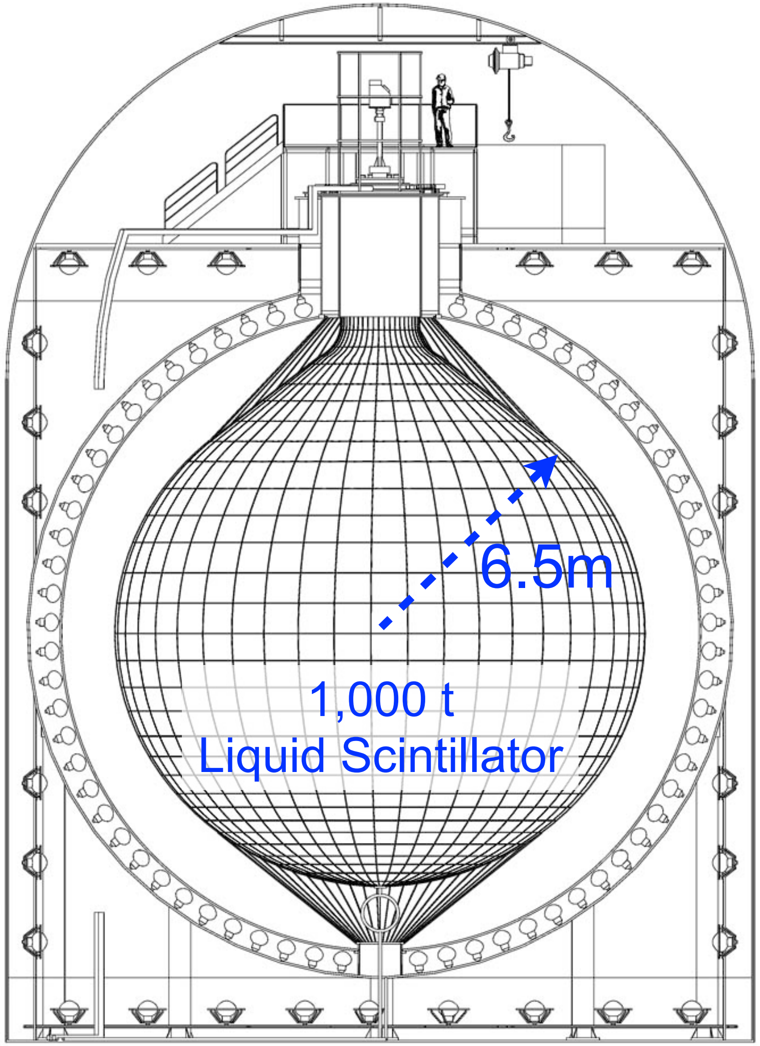


We continue to study neutrino physics with KamLAND

KamLAND

KamLAND

2000~



Detector Features

1,000t ultra-pure liquid scintillator

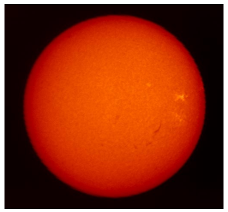
^{232}U: 3.5x10^{-18} g/g, ^{238}Th: 5.2x10^{-17} g/g

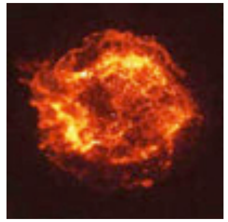
Physics

observed energy [MeV]: 0.4, 1.0, 2.6, 8.5

electron scattering $\nu + e^- \rightarrow \nu + e^-$

inverse beta-decay $\bar{\nu}_e + p \rightarrow e^+ + n$





solar neutrinos
PRC 84, 035804 (2011)

geo neutrinos
Nature Vol. 436 (2005)
Nature Geoscience 4, 647-651 (2011)

reactor neutrinos
PRL 100, 221803 (2008)
PRD 83, 052002 (2011)

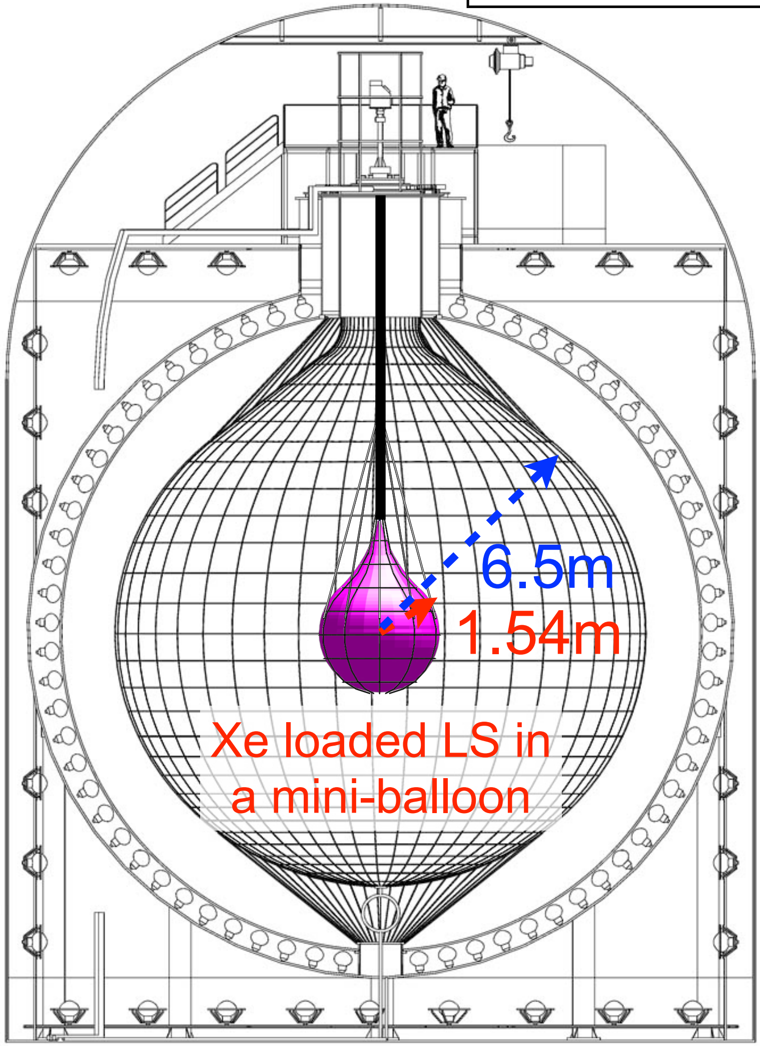
supernova neutrinos, etc.
PRL 92, 071301 (2004)
Astrophys. J. 745, 193 (2011)

Different neutrino physics in a wide energy range

KamLAND-Zen

2011~

Zero Neutrino
double beta decay search

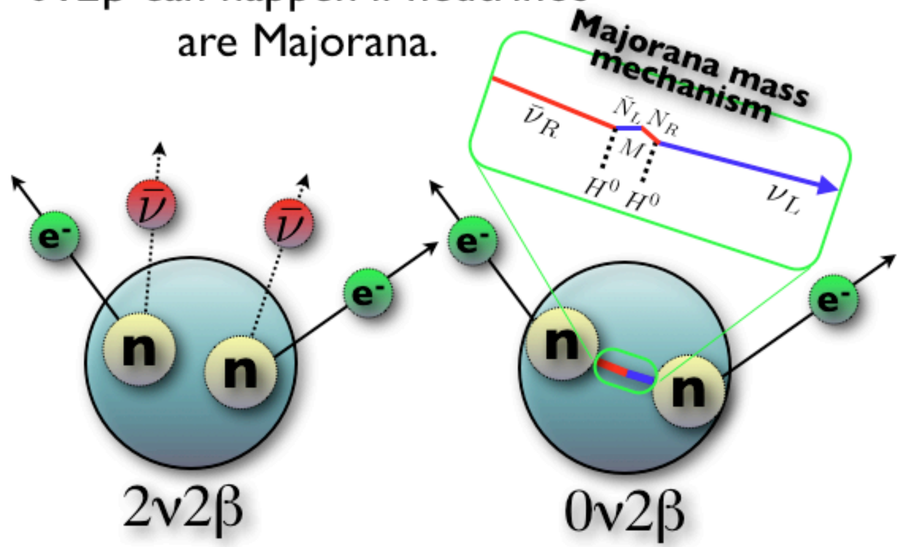


Detector Features

^{136}Xe loaded LS was installed in KamLAND

(383 kg of ^{136}Xe enriched Xe installed)

Physics

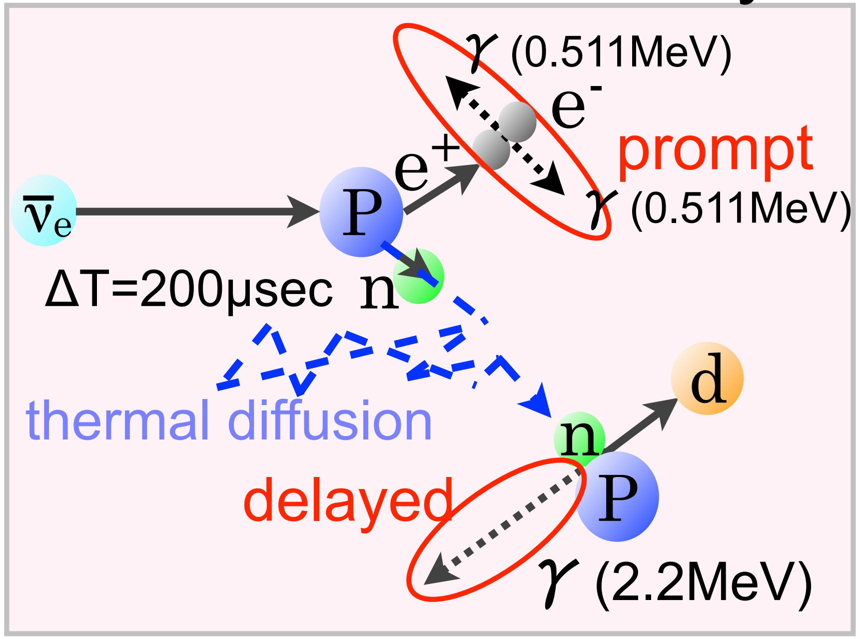


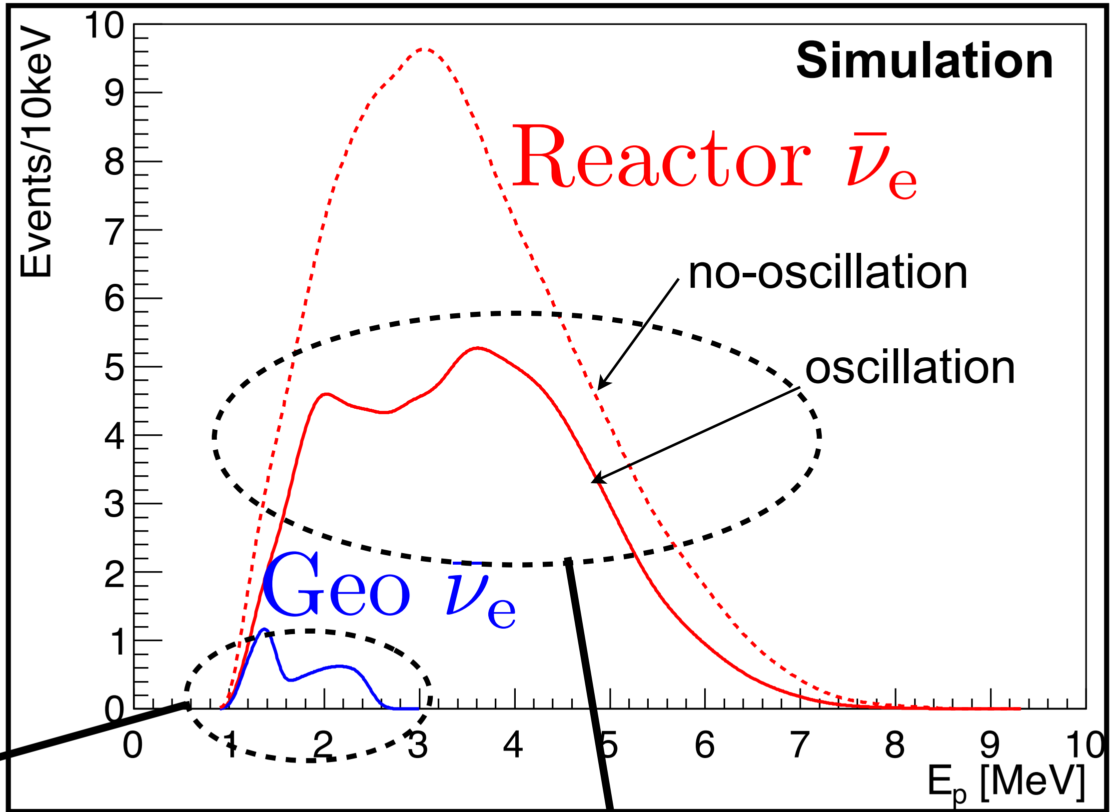
neutrino-less double beta decay

Continue to use LS volume outside of mini-balloon to measure anti-neutrino signals

Anti-neutrino Studies

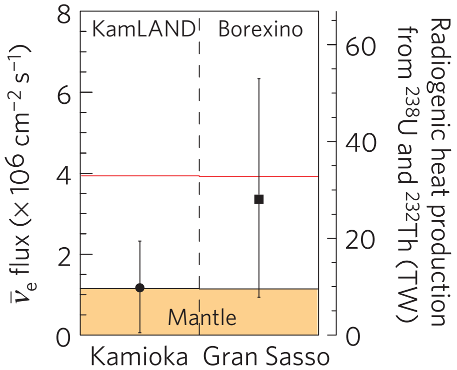
inverse-beta decay





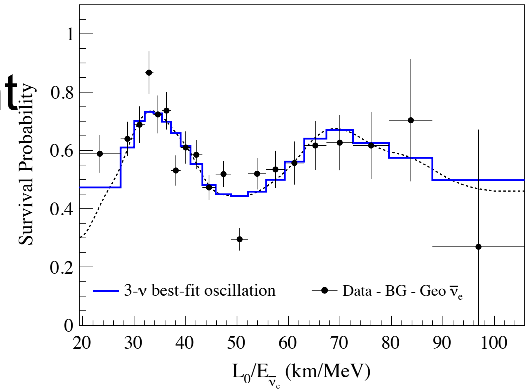
Geoneutrinos

: Neutrino Application



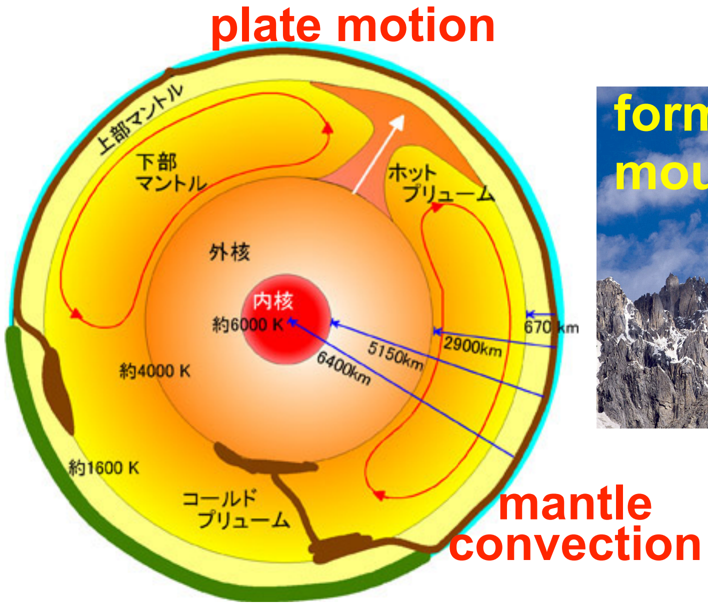
- Direct measurement of radiogenic heat contribution

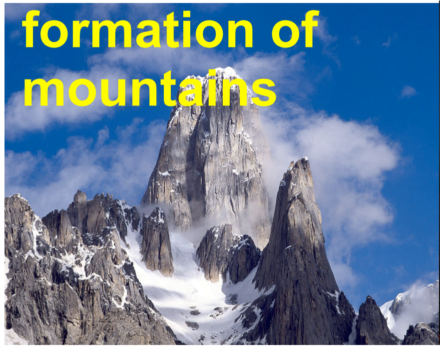
Neutrino Property Study

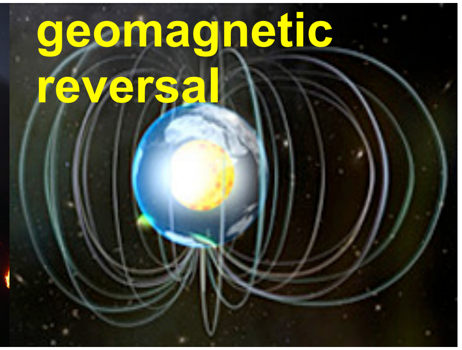


- Signature of neutrino oscillation
- Precise measurement of oscillation parameters

Contents







Question on geophysical activity

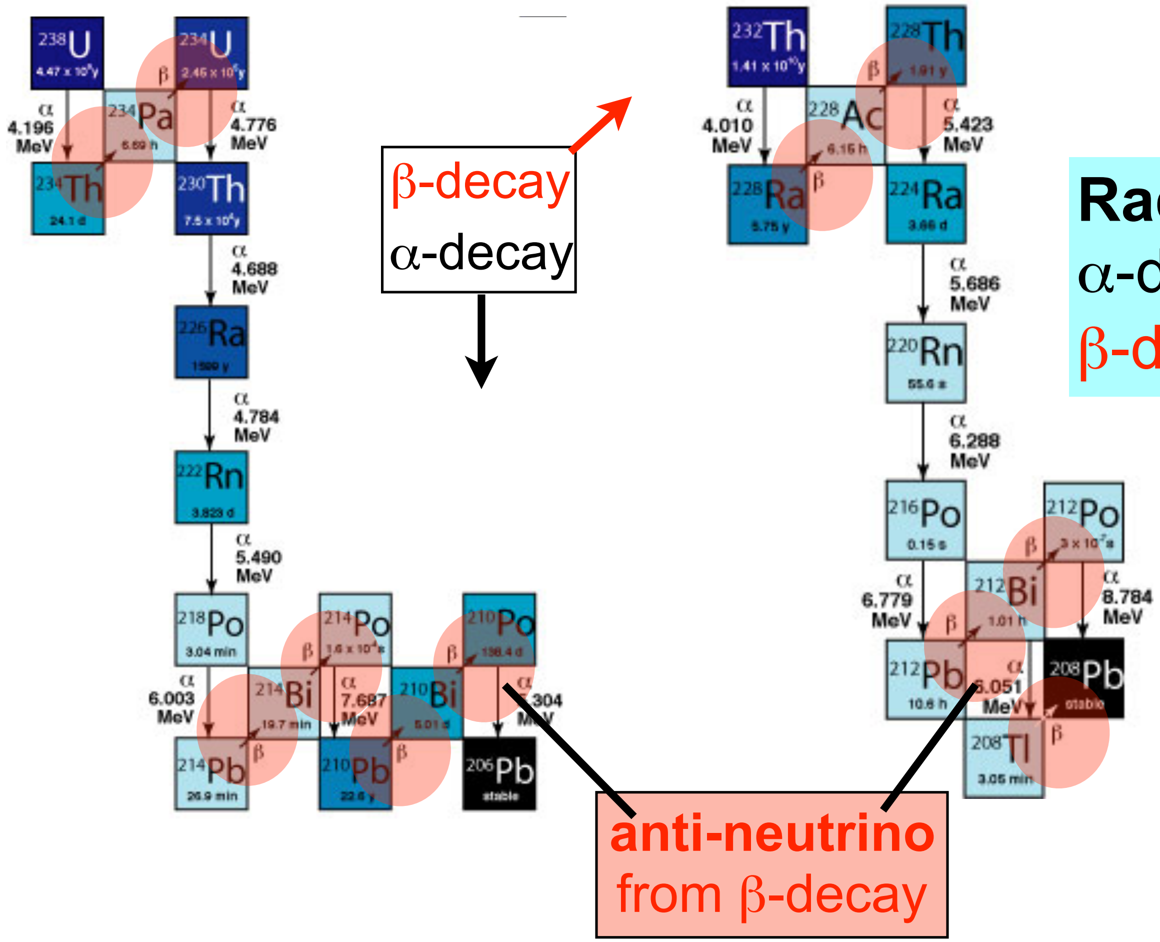
- What are energy sources? How much energy?
- How is the mantle convecting, single or multi-layer convection?
- Why is the frequency of geomagnetic reversals random?

→ It is important to find out the terrestrial heat.

(1) Radiogenic heat from U, Th, K decay
(2) Release of gravitational energy through accretion or metallic core separation
(3) Latent heat from the growth of inner core

U-series

Th-series



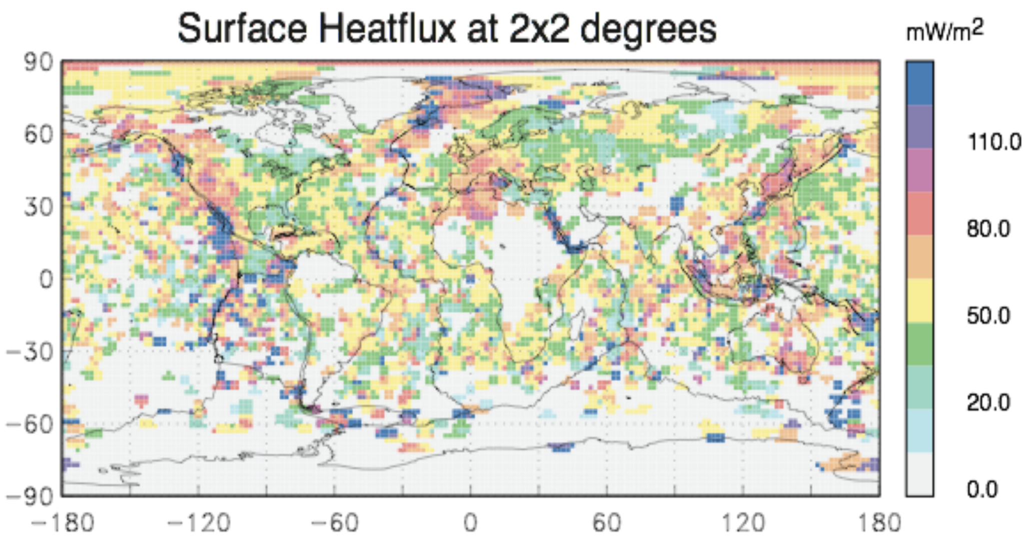
Radiogenic heat :
α-decay or
β-decay emitting “anti-neutrinos”

Terrestrial Heat - Heat Balance

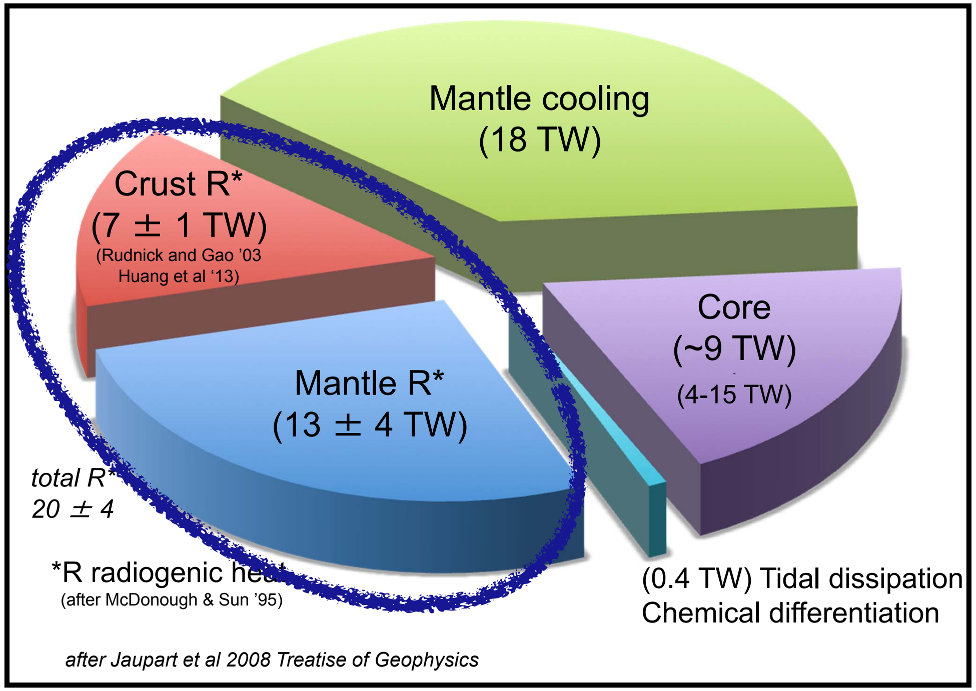
Surface heat flow

46 ± 3 TW

crust heat flux measurement & calculation



Pollack et al. 1933, Rev. of Geophys.



Almost half of radiogenic heat contributes to the surface heat flow.

Radiogenic heat in the Earth

10~30 TW

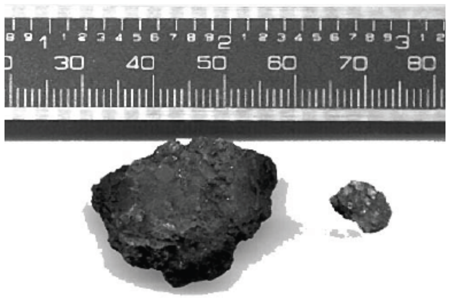
Bulk Silicate Earth (BSE) model

composition of chondrite meteorite

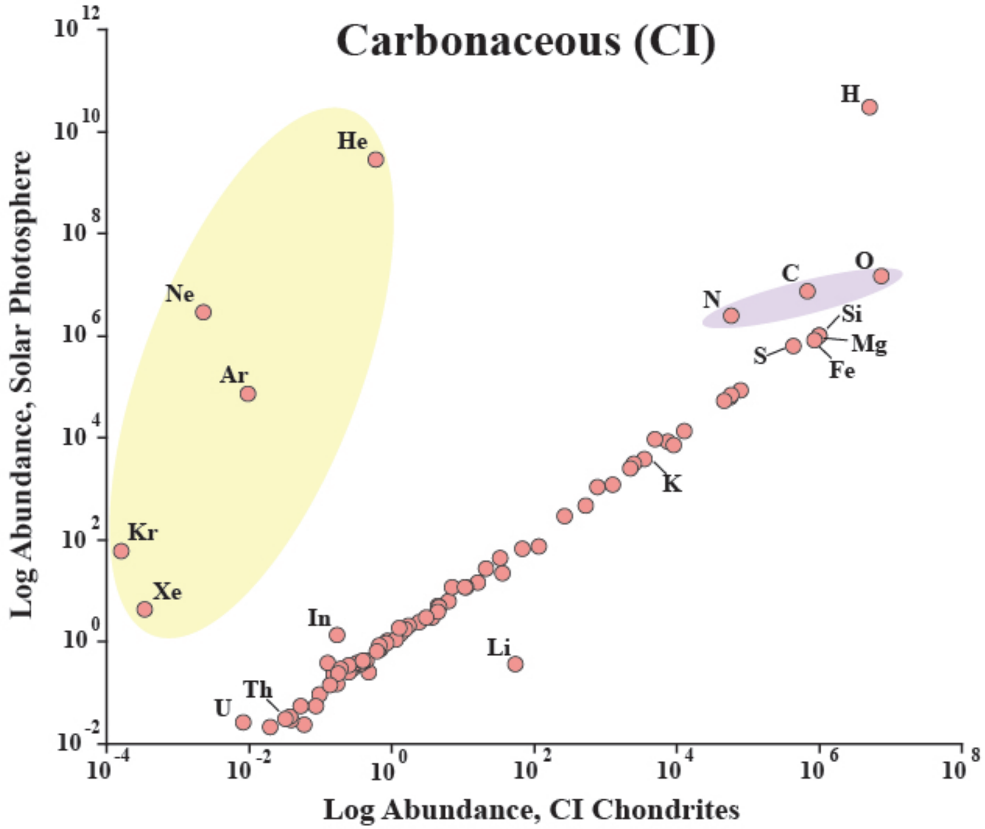
U : 8 TW

Th : 8 TW

K : 3 TW



This is not “direct measurement”.



↓

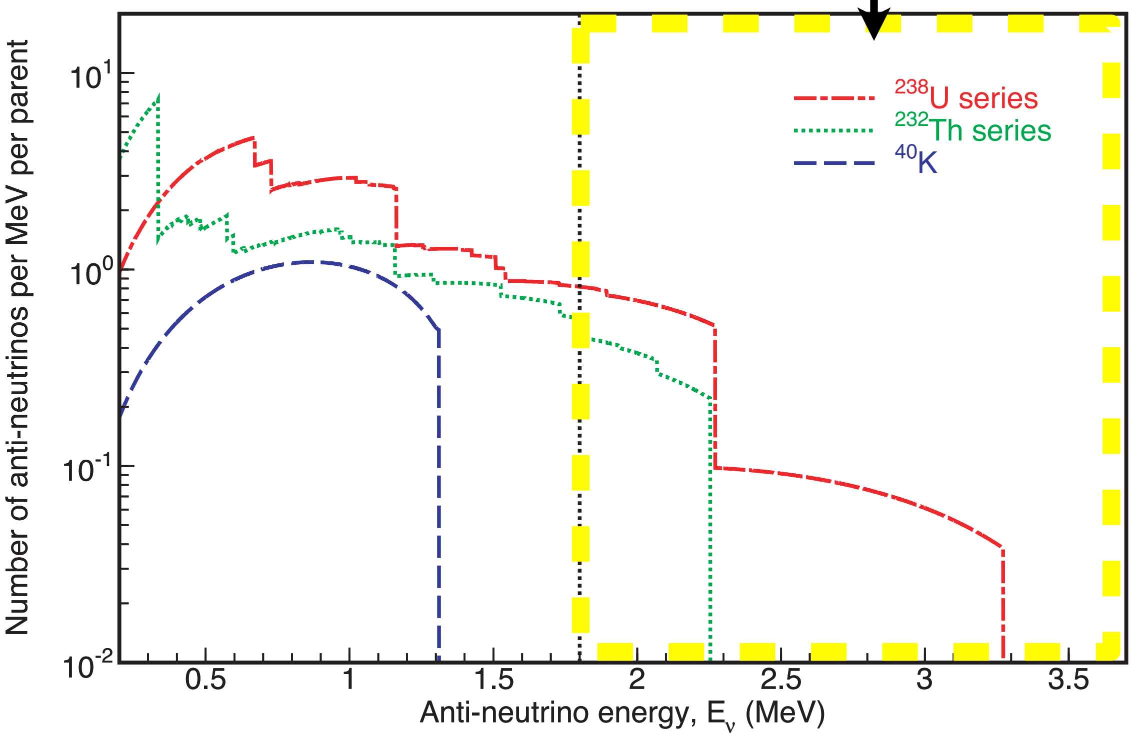
Geo-neutrino can directly test radiogenic heat production.

Geo-neutrino

Geo-neutrinos are a unique, direct window into the interior of the Earth!

Nature 436, 28 July 2005

energy window



beta-decay

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

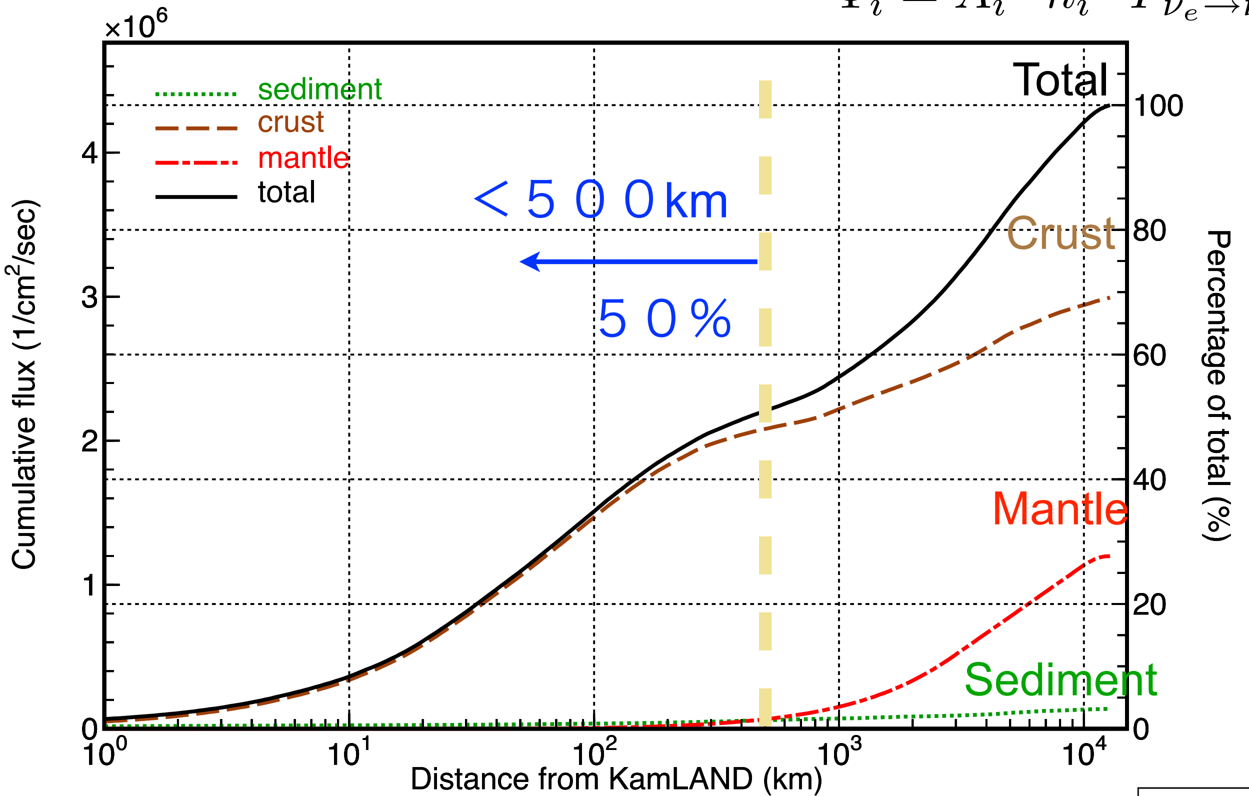
$$^{232}\mathrm{Th} \to ^{208}\mathrm{Pb} + 6\alpha + 4\mathrm{e}^- + 4\bar{\nu}_\mathrm{e} + 42.7\,\mathrm{MeV}$$

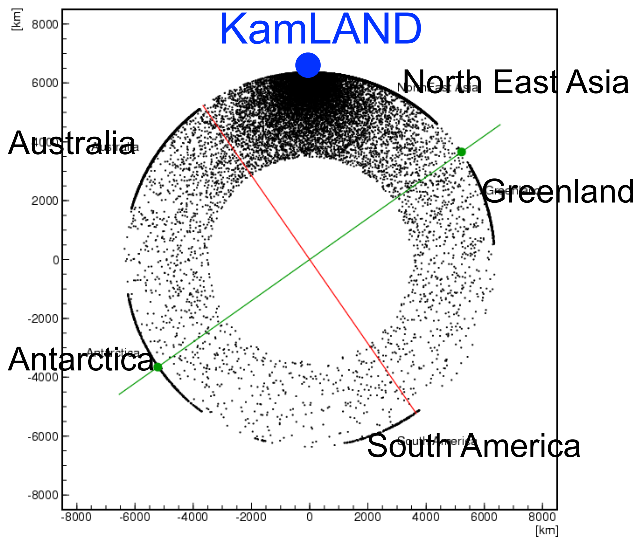
$$^{40}\mathrm{K} \to ^{40}\mathrm{Ca} + \mathrm{e}^- + \bar{\nu}_\mathrm{e} + 1.311\,\mathrm{MeV}\;(89.28\%)$$

detectable

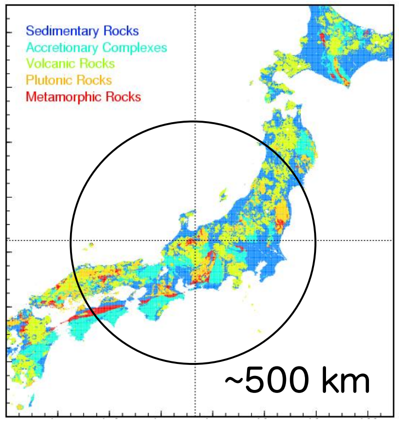
Geo-neutrino Flux at Kamioka

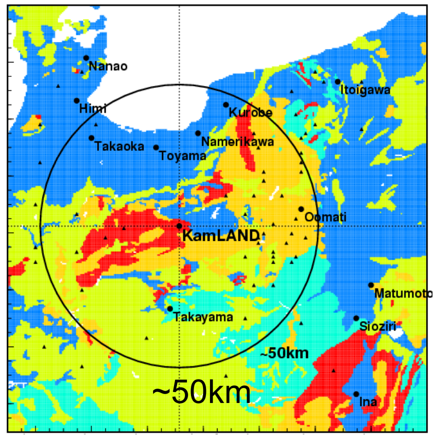
$$\Phi_i = A_i \cdot n_i \cdot P_{\bar{\nu}_e \to \bar{\nu}_e}(E_\nu, |\overrightarrow{L}|) \cdot \int_V \frac{a_i(\overrightarrow{L}) \cdot \rho_i(\overrightarrow{L})}{4\pi|\overrightarrow{L}|^2} \cdot dV$$





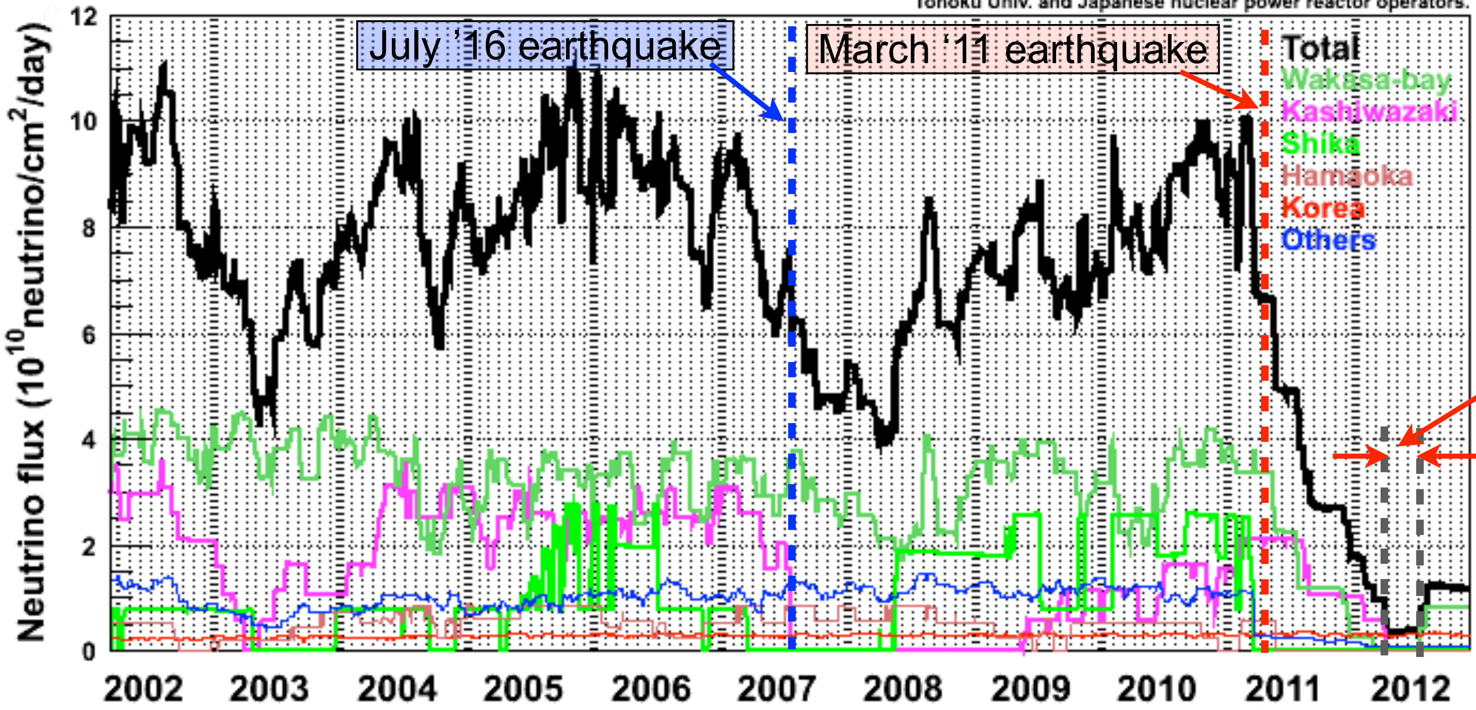
- 50%: distance < 500km
- 25%: distance < 50km
- 1~2%: from Kamioka mine

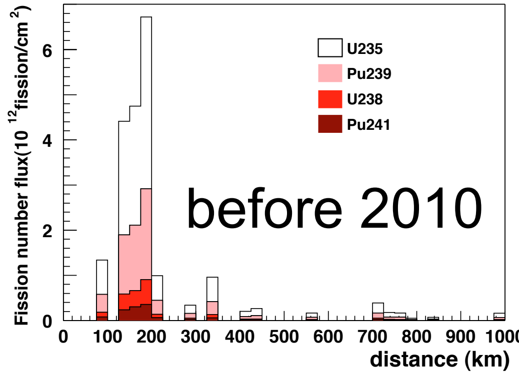




Recent Condition : reactor operation in Japan

time variation of neutrino flux

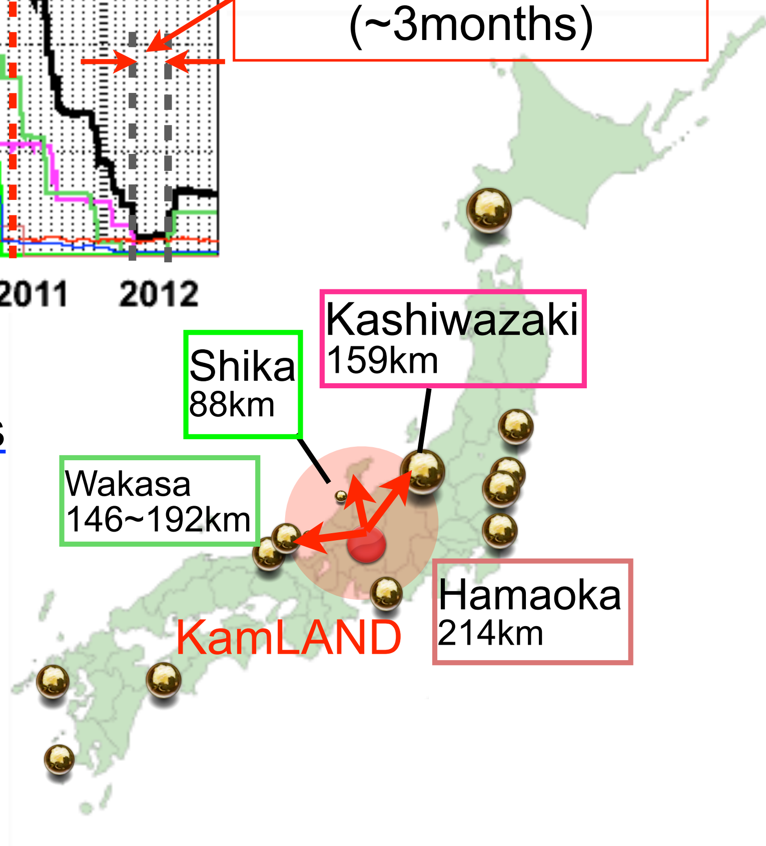




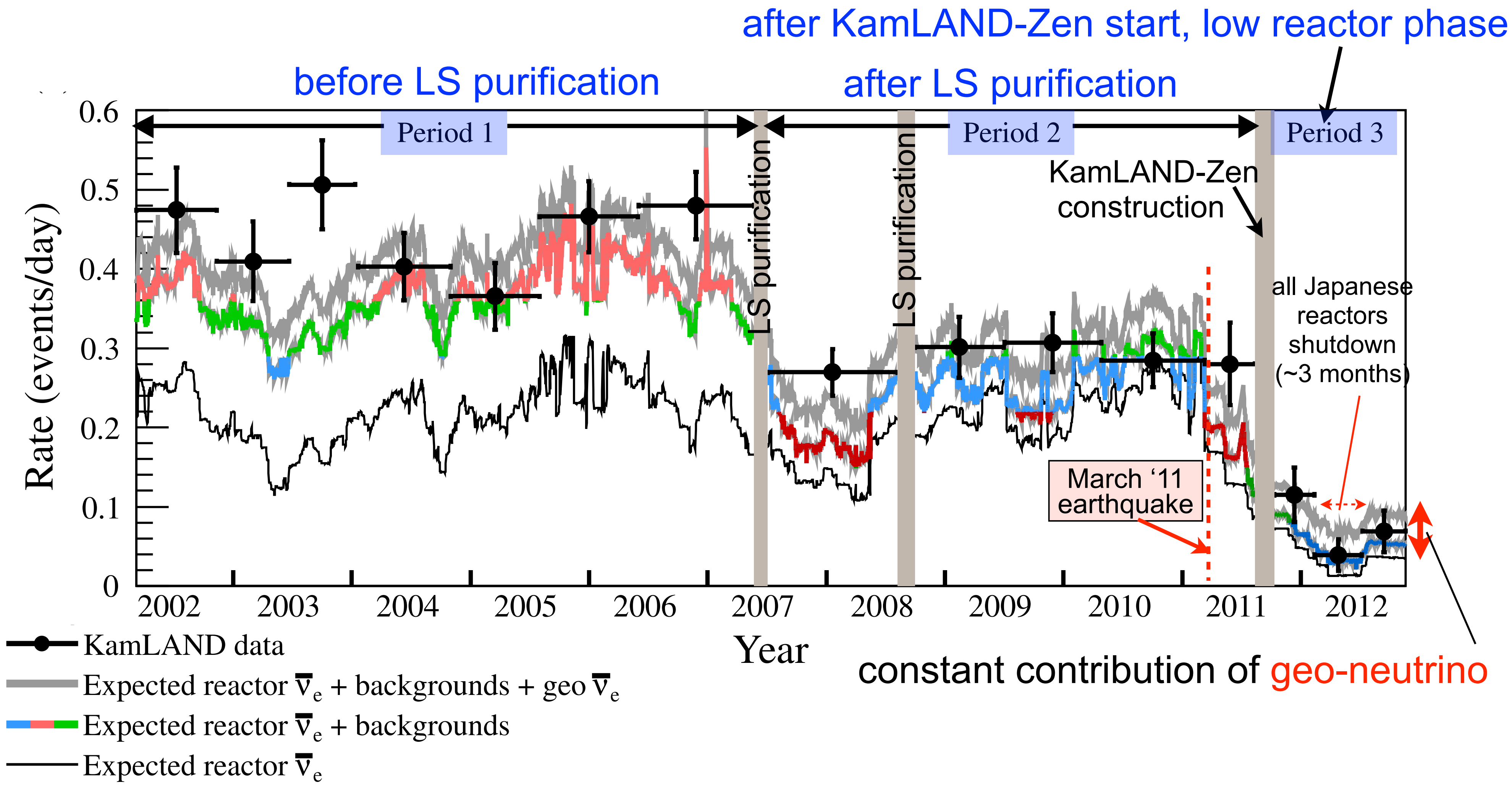
- Following the Fukushima nuclear accident in March 2011, the entire Japanese nuclear reactor industry has been subjected to protected shutdown.

- Reactor neutrino flux, which is outside the control of the experiment, was significantly reduced.

- This situation allows for a "reactor on-off" study of backgrounds for KamLAND neutrino oscillation and geoneutrino analysis.



Analysis - Event rate (0.9-2.6 MeV)

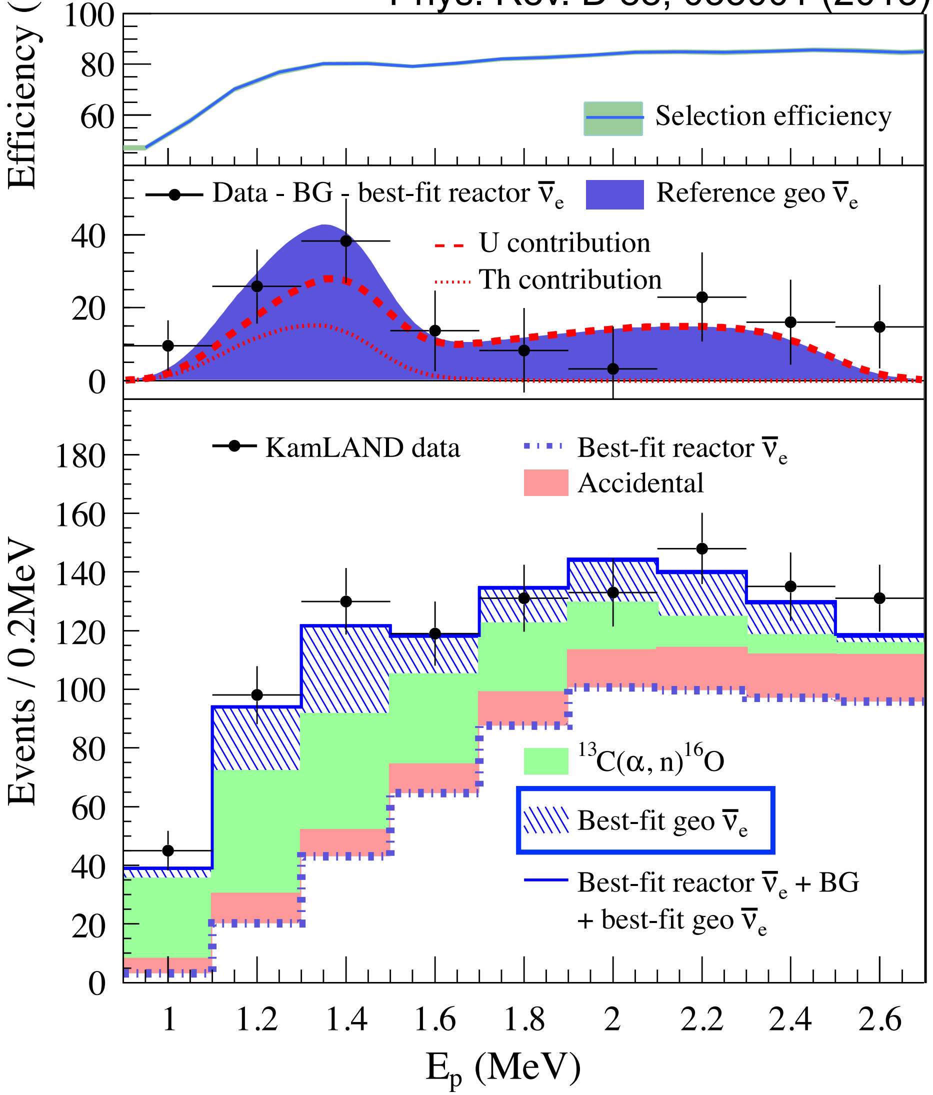


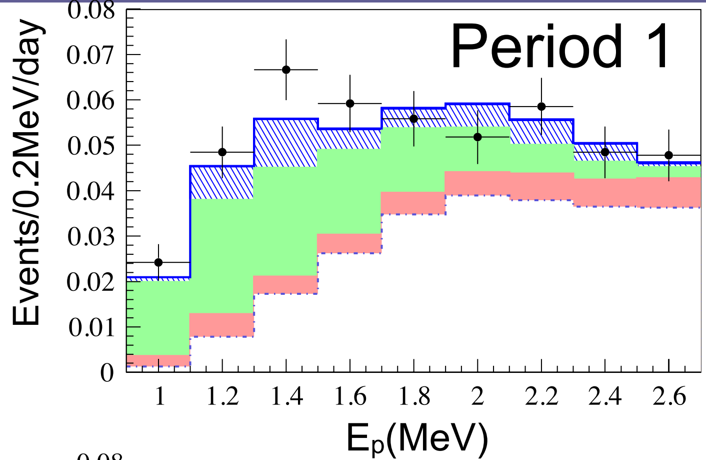
- Backgrounds :
  - LS purification → non-neutrino backgrounds reduction
  - Earthquake → reactor neutrino reduction
- Constant contribution of geo-neutrino
  - Time information is useful to extract the geo-neutrino signal

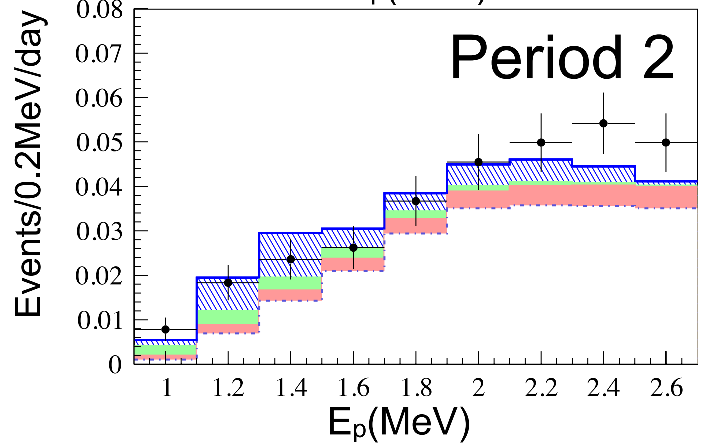
Analysis : Energy Spectrum (0.9-2.6 MeV)

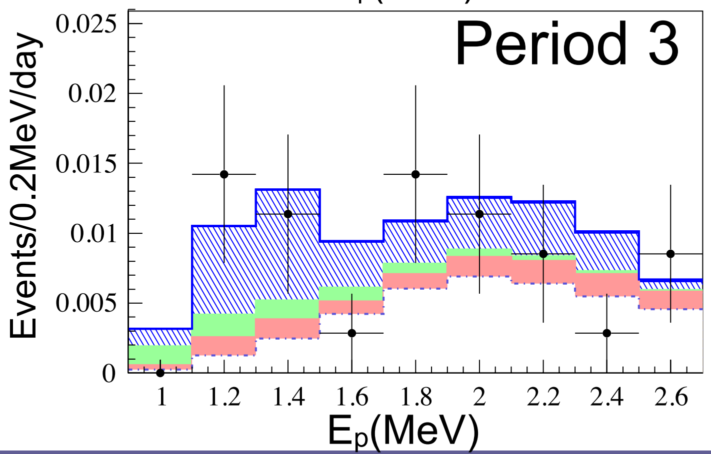
data set : 2991.1 days

Phys. Rev. D 88, 033001 (2013)





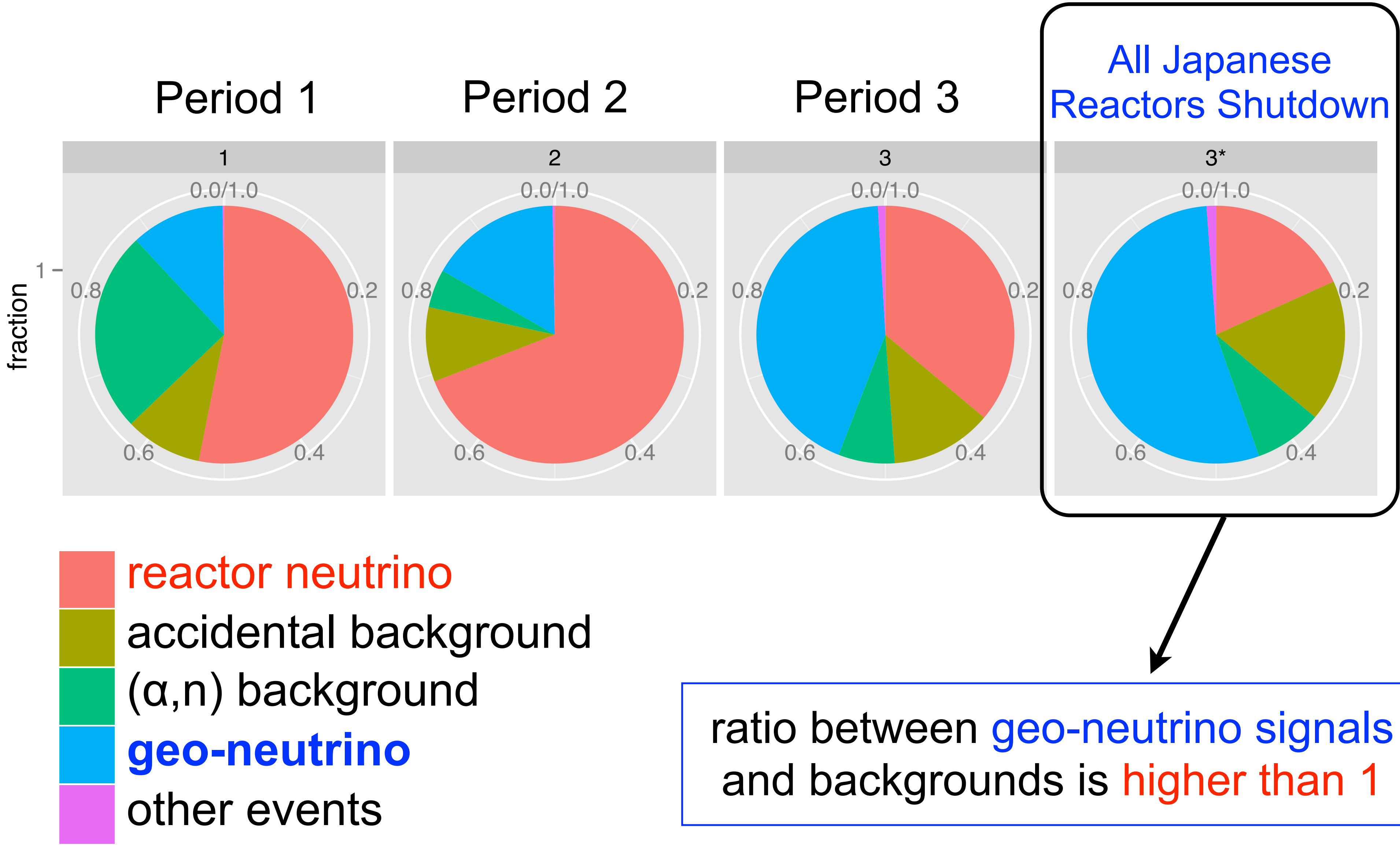




^{13}C $(\alpha, n)^{16}O$ decreased

Reactor-ν decreased

Analysis : Event Profile (0.9-2.6 MeV)



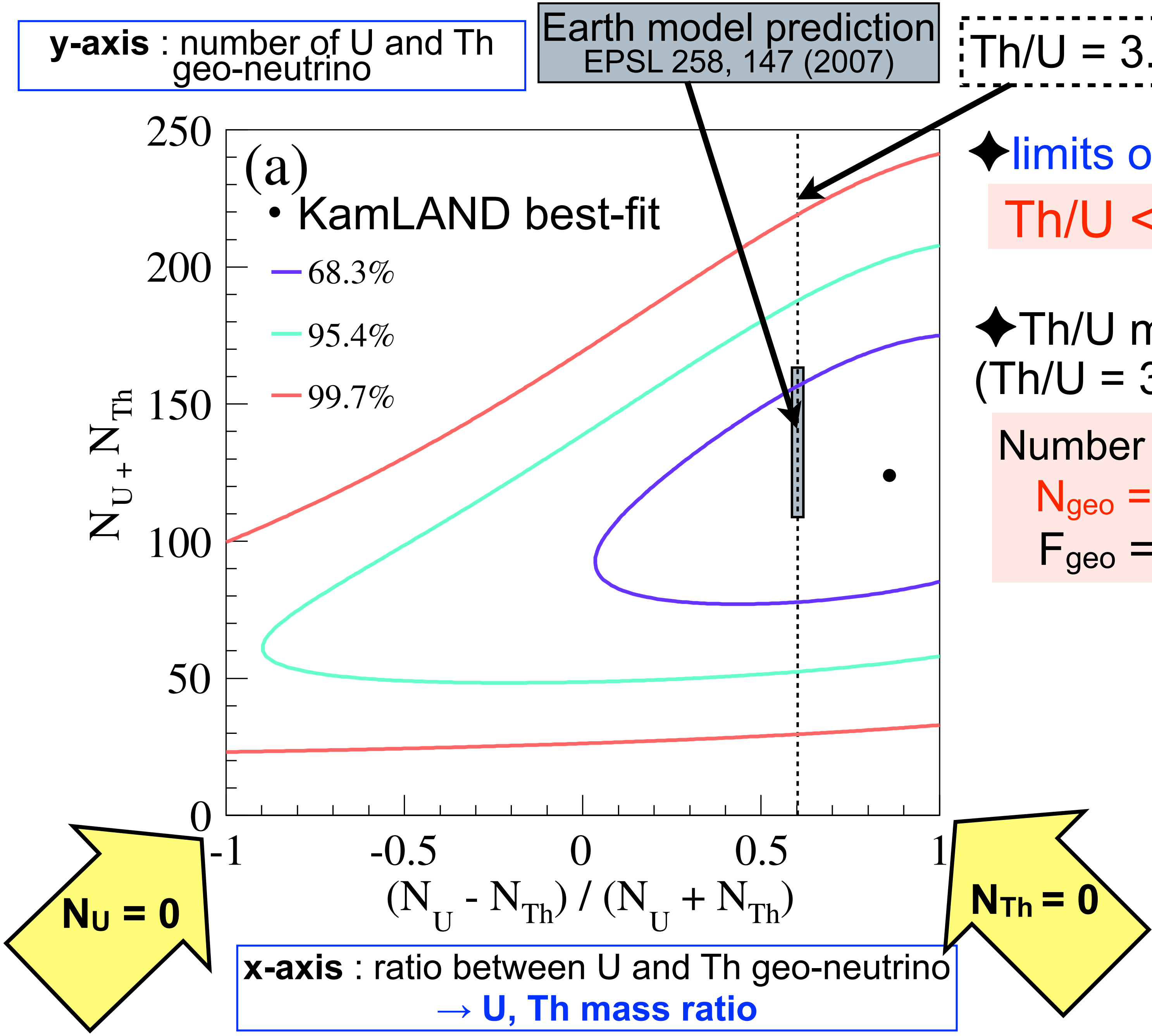
ratio between geo-neutrino signals and backgrounds is higher than 1

Analysis : Rate+Shape+Time Analysis (1)

y-axis : number of U and Th geo-neutrino

Earth model prediction
EPSL 258, 147 (2007)

Th/U = 3.9 fixed



x-axis : ratio between U and Th geo-neutrino
→ **U, Th mass ratio**

✦limits on Th/U ratio

Th/U < 19 (90% C.L.)

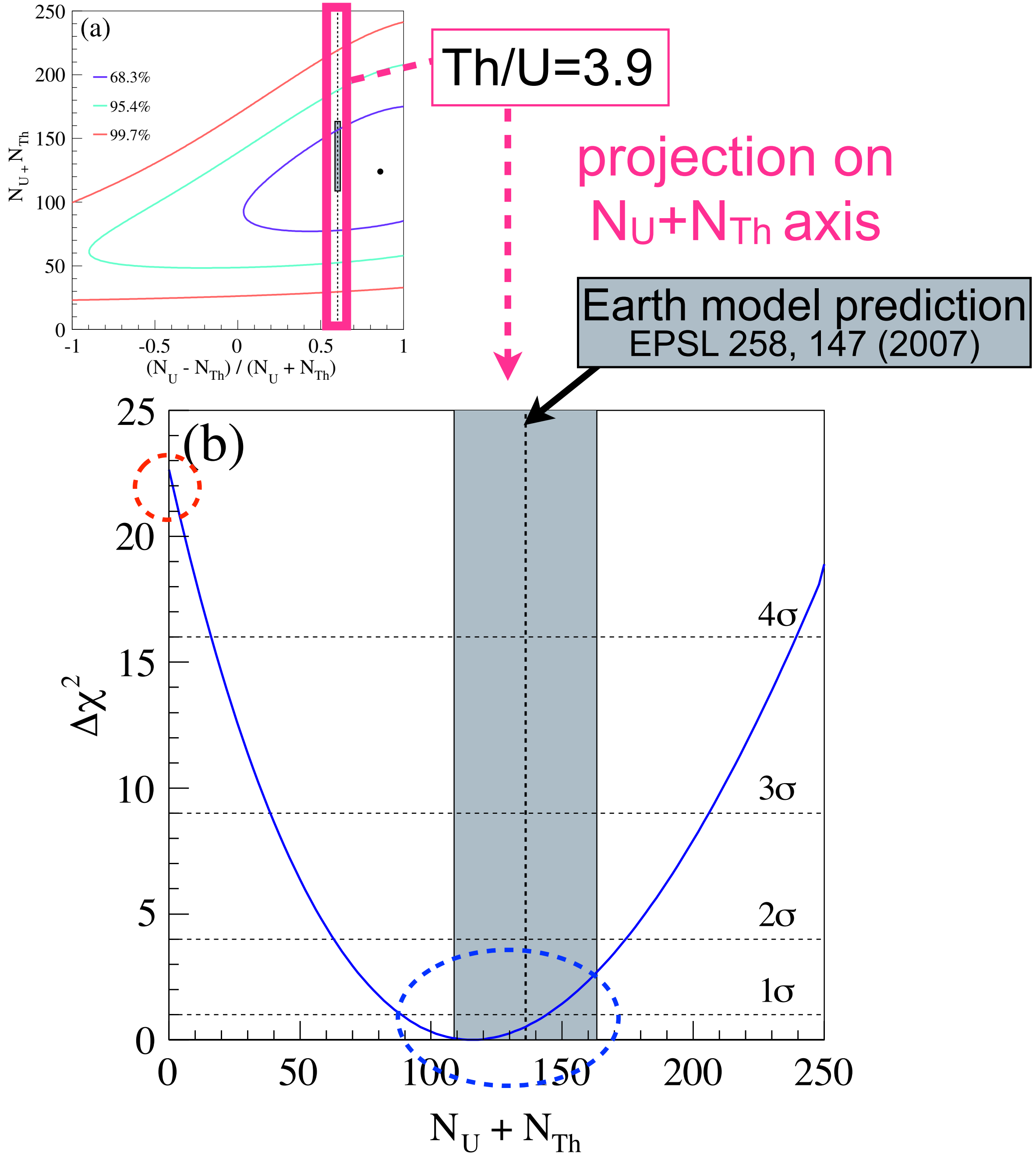
✦Th/U mass ratio
(Th/U = 3.9)

Number of geo-neutrino

$N_{geo} = 116^{+28}_{-27}$ events

$F_{geo} = 3.4^{+0.8}_{-0.8} \times 10^6/cm^2/sec$

Analysis : Rate+Shape+Time Analysis (2)



✦limits on Th/U ratio

Th/U < 19 (90% C.L.)

✦Th/U mass ratio (Th/U = 3.9)

Number of geo-neutrino

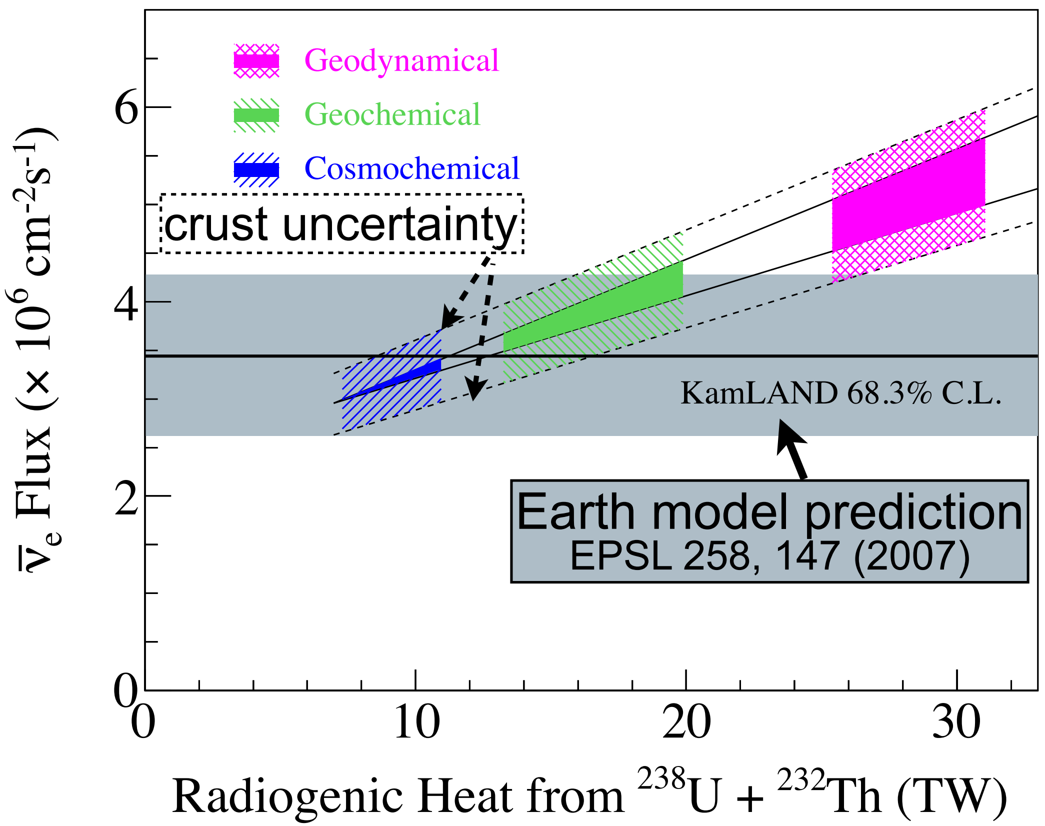
$N_{geo} = 116^{+28}_{-27}$ events

$F_{geo} = 3.4^{+0.8}_{-0.8} \times 10^6/cm^2/sec$

almost same as model prediction

0signal is rejected at 99.9998% C.L.

Analysis : Comparison with Models



[BSE composition models]

Geodynamical 30TW

based on balancing mantle viscosity and heat dissipation

Geochemical 20TW

based on mantle samples compared with chondrites

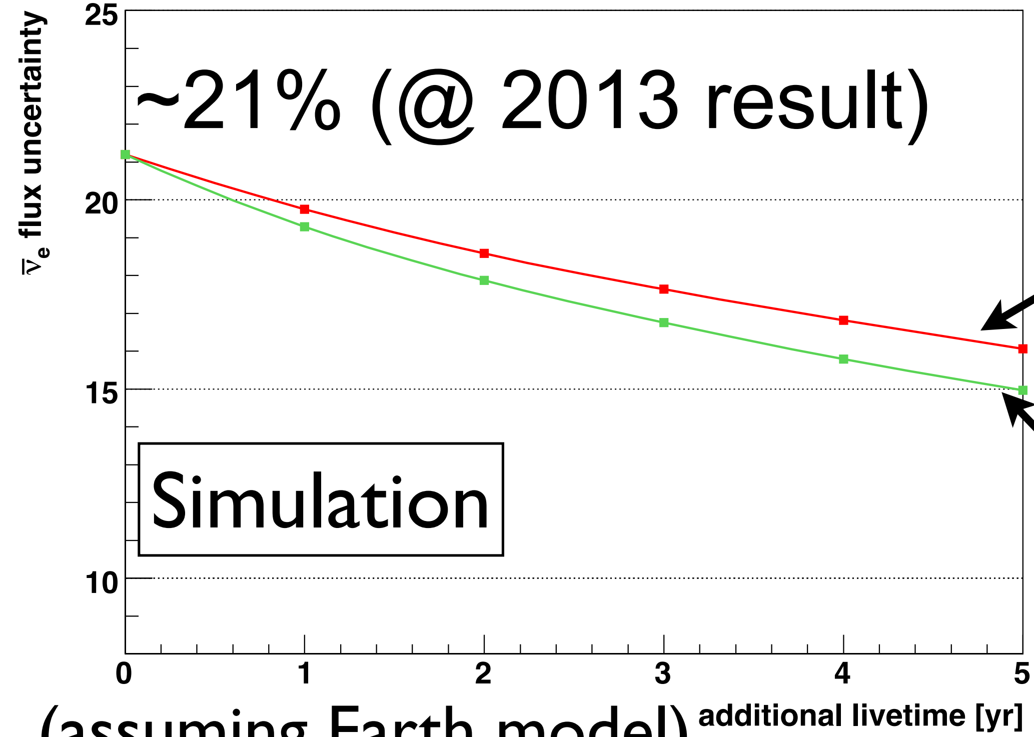
Cosmochemical 10TW

based on isotope constraints and chondritic models

- KamLAND geo-neutrino flux translates to a total radiogenic heat production : $11.2^{+7.9}_{-5.1}$ TW
- The geodynamical prediction with the homogeneous hypothesis is disfavored at 89% C.L.
- All BSE compositional models are still consistent within ~2 σ.

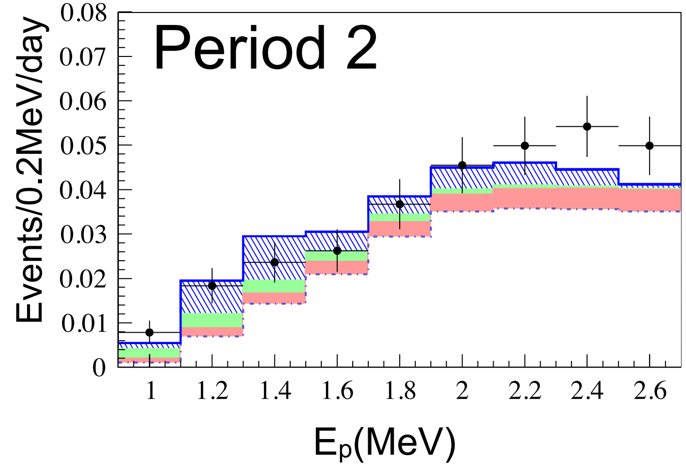
Contents

Geo-neutrino uncertainties

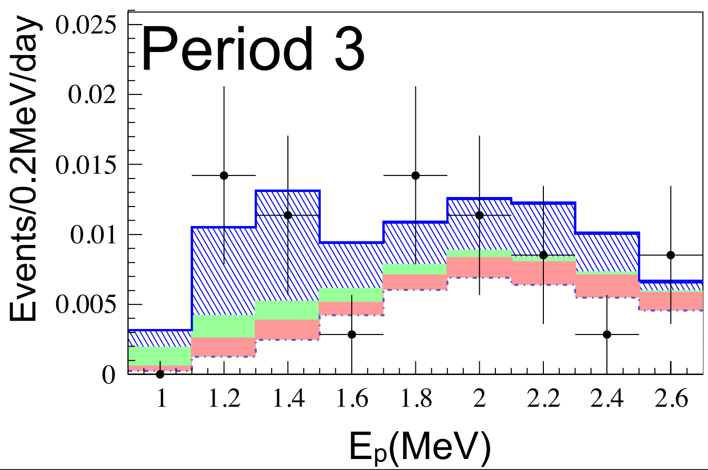


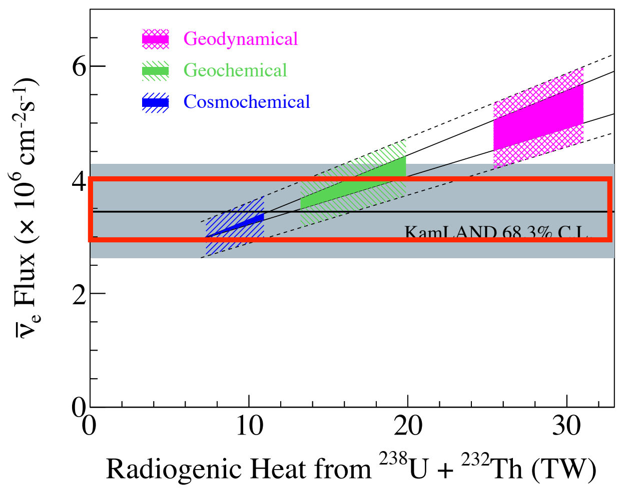
(assuming Earth model)

red line reactor "ON"



green line reactor "OFF"





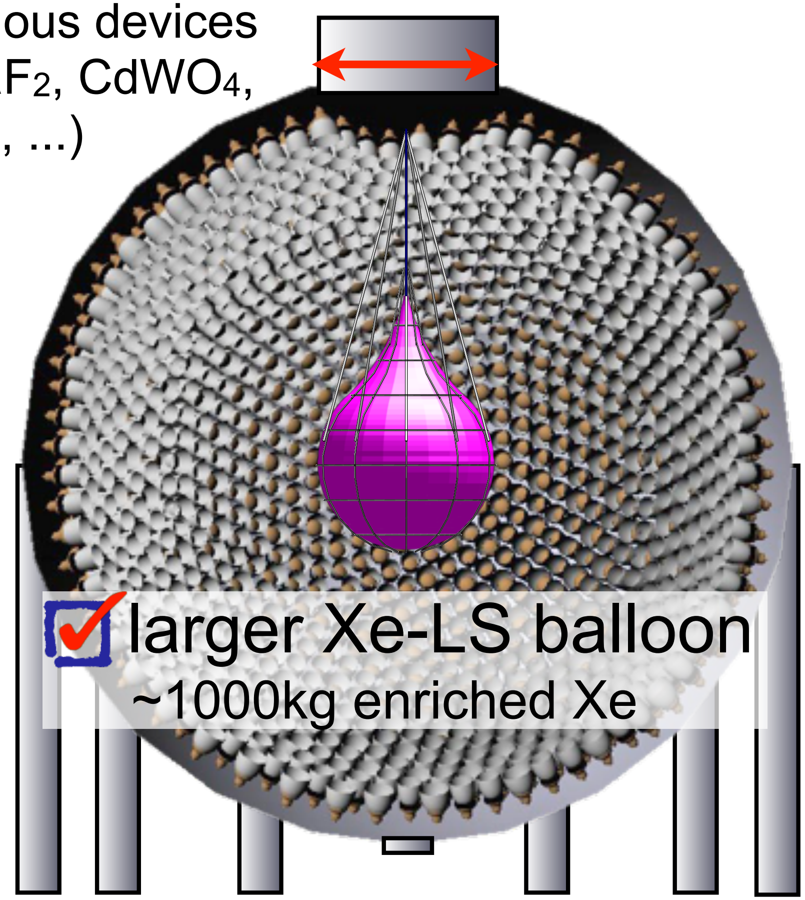
We will achieve 15~16% uncertainty with additional 5 year measurement.
(We already have another 2-year data.)

KamLAND2(-Zen) : better energy resolution

upgrade to KamLAND

☑ enlarge opening

accommodate various devices (CaF_2, $CdWO_4$, NaI, ...)

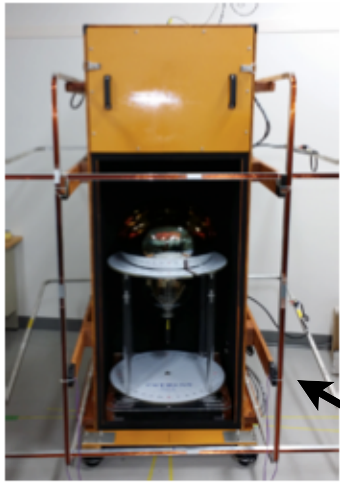


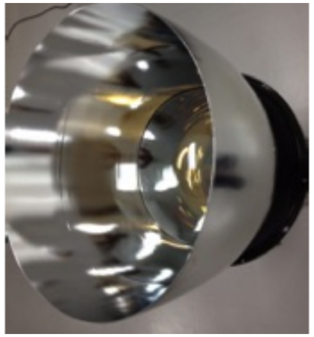
☑ larger Xe-LS balloon

~1000kg enriched Xe

☑ High performance

* High Q.E. PMT   * Winstone Cone





17"Φ→20"Φ,
ε=22% → 30%

Photo-coverage > **×2**
Light Collecting Eff. > **×1.8**

photon yield ×1.9

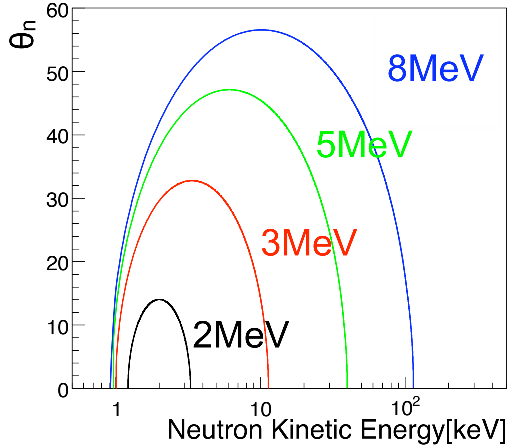
* New Liquid Scintillator **×1.4**

LAB based LS (8,000 → 12,000 photon/MeV)

energy resolution improved
: 6.4%/√E[MeV]→**4.0%/√E[MeV]**

geo-neutrino measurement
* **improvement of U/Th ratio**
* **fiducial volume enlargement**

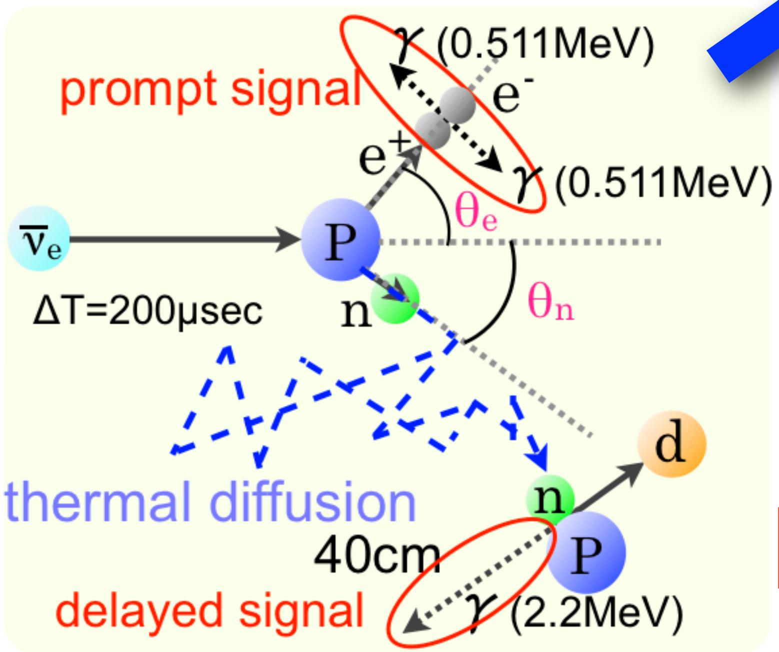
Directional measurement see also “Future Projects” session



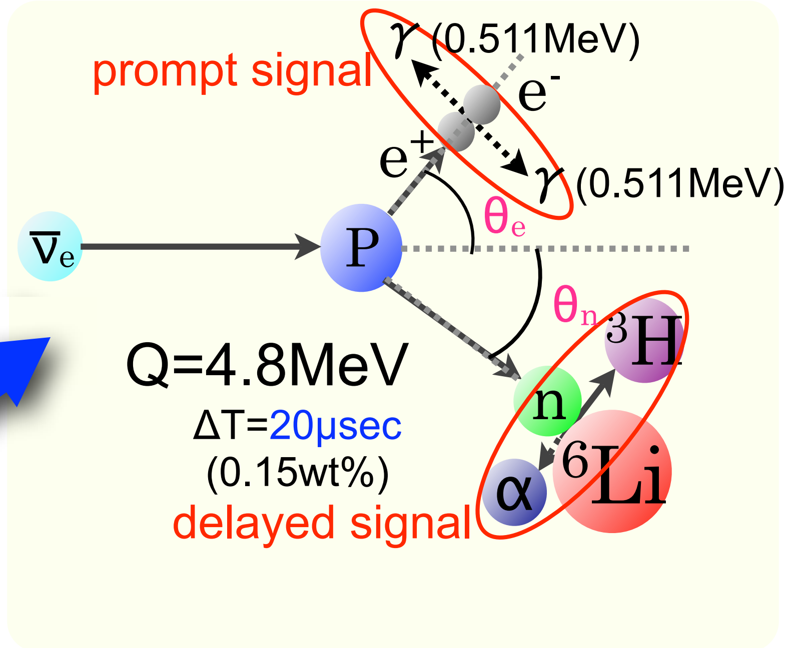
$E_{\bar{\nu}e}$ <3MeV → θ_n<35°

neutron has directional information of anti-neutrino

[current liquid scintillator]



[Li loaded liquid scintillator]



- large neutron capture cross section (^{6}Li 940 barns vs ^{1}H 0.3 barns)
- α does’t travel far

+

high vertex resolution imaging detector

- higher than 2 cm resolution (PMT ~10cm)

Contents

Summary

- The KamLAND experiment measures anti-neutrino from various sources over a wide energy range

- **Geo-neutrino**

  - Observed flux is fully consistent with Earth models

  - Results for low reactor background:
    Geo-neutrino observation is very sensitive

  - Now we enter the era of conducting critical tests of Earth models

- It is important for “Neutrino Geoscience” to further connections between geoscience and neutrino physics.