Geo-neutrinos at the ANDES Laboratory

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What are Geo-neutrinos ?

Natural Radioactivity of the Present Earth

from isotopes with half-life comparable to Earth's age

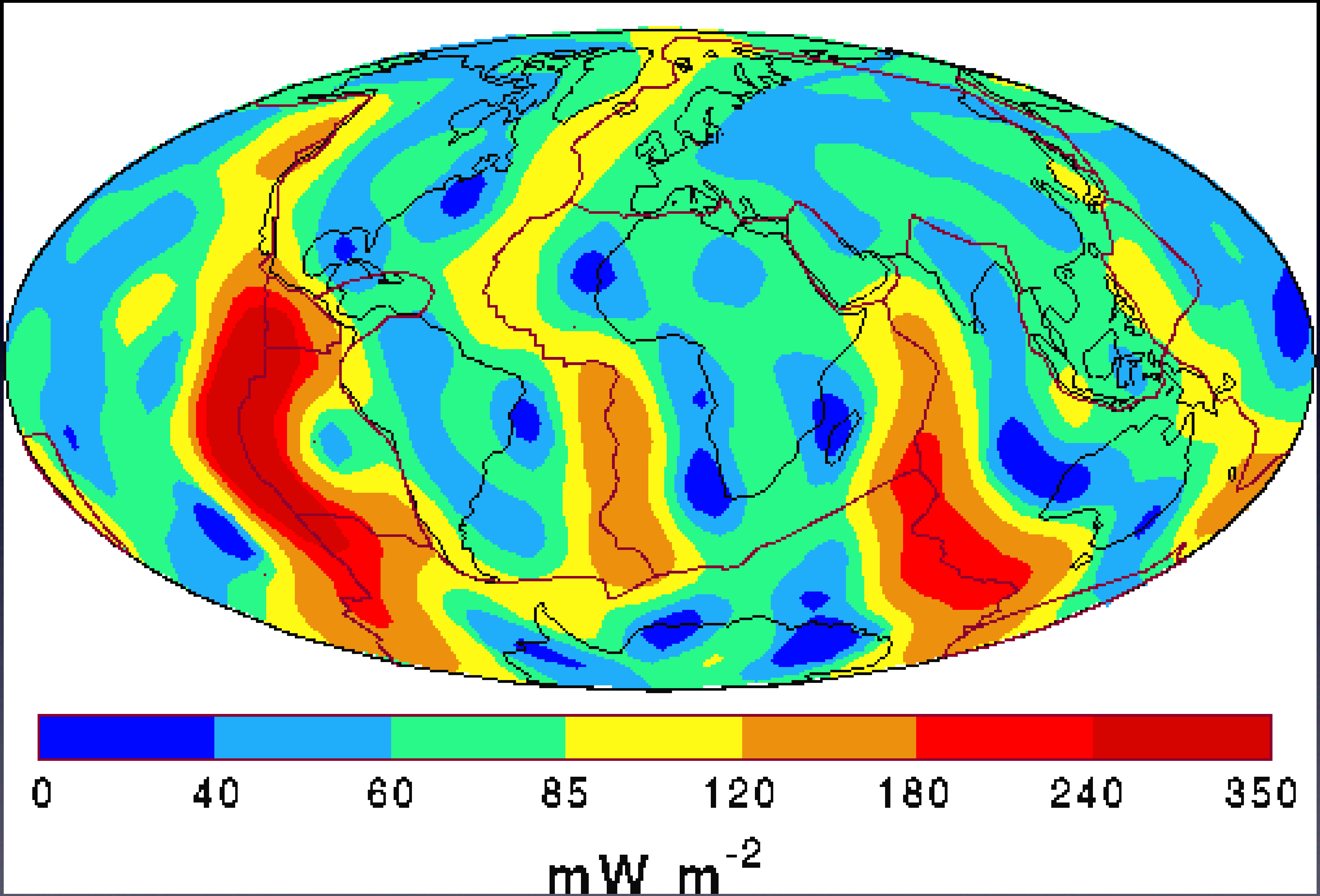
- ^{238}U, ^{232}Th, ^{40}K, ^{235}U and ^{87}Rb
- Radiogenic Heat is produced in the decay chains of these isotopes accompanied by the emission of $\bar{\nu}_e (\nu_e)$

→ **geo-neutrinos**

- Escape freely from Earth's interior bringing to the surface information from the whole planet content

What can be studied with Geo-neutrinos ?

Observed Heat Flow in the Earth Surface



Uncertainties on Total Heat Flow (~40 TW)

What is the Radiogenic Contribution ? 20 TW ?

Earth Science

seismology : can reconstruct density profile but not composition

geochemistry : analyze samples from crust and top mantle (deepest borehole ~12 km, deepest rock sample from ~200 km)

geo-neutrinos : new probe of the global composition of the Earth

Earth Science

geo-neutrinos : new probe of the global composition of the Earth

- Address the Radiogenic Contribution to Earth's Heat Production
- Test the Bulk Silicate Earth (BSE) Model
- Measure abundances in the crust (detectors in the continent)
- Measure abundances in the mantle (detectors far from the continent)

Why can we do this now ?

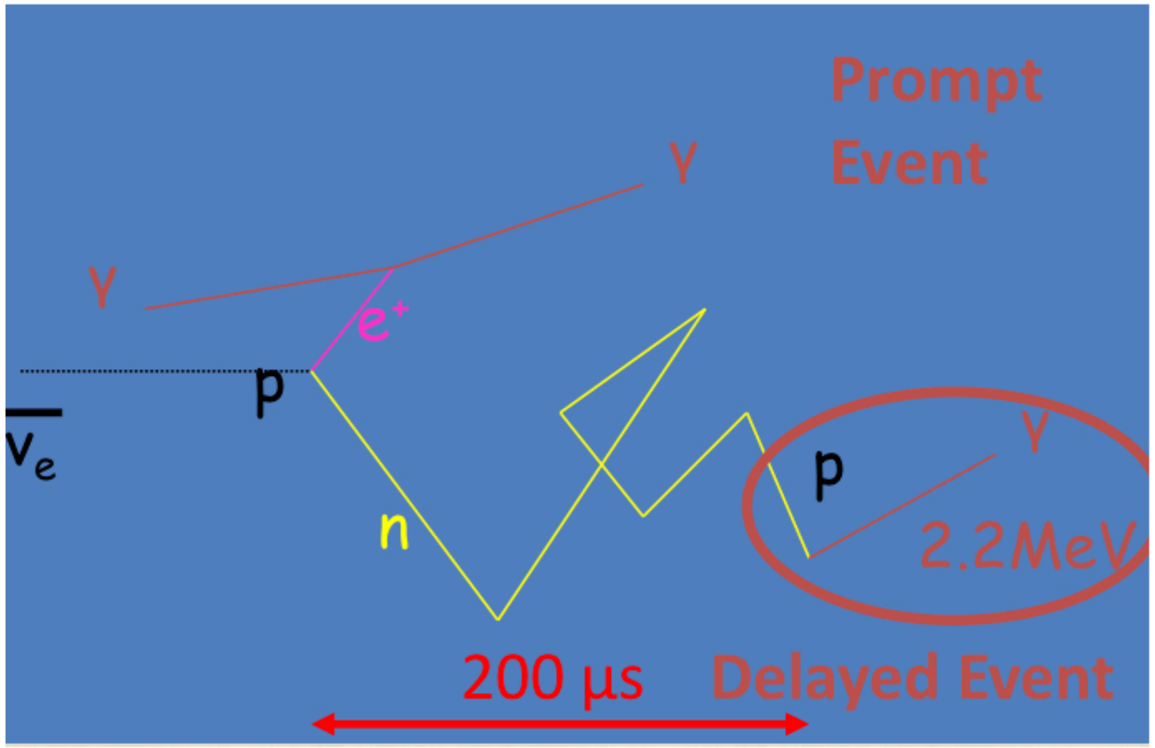
Great Developments in Neutrino Physics

- **Experimentally** : we know how to build extremely low background neutrino detectors

- **Theoretically** : we understand neutrino properties and propagation in matter rather well

How do we observe them ?

Detection

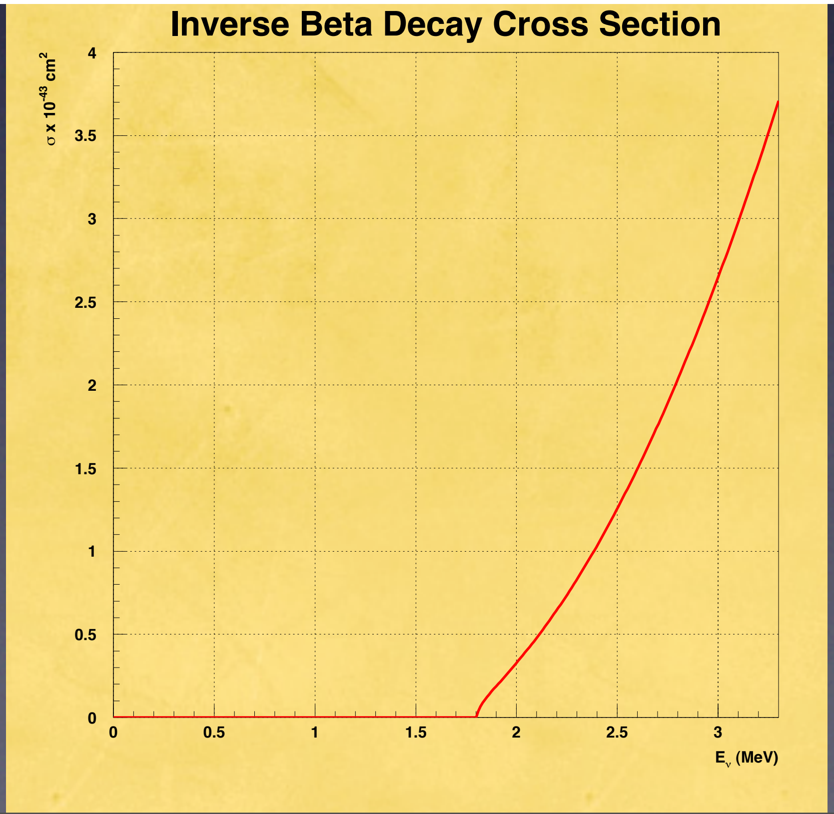


$$\bar{\nu}_e + p \rightarrow e^+ + n$$

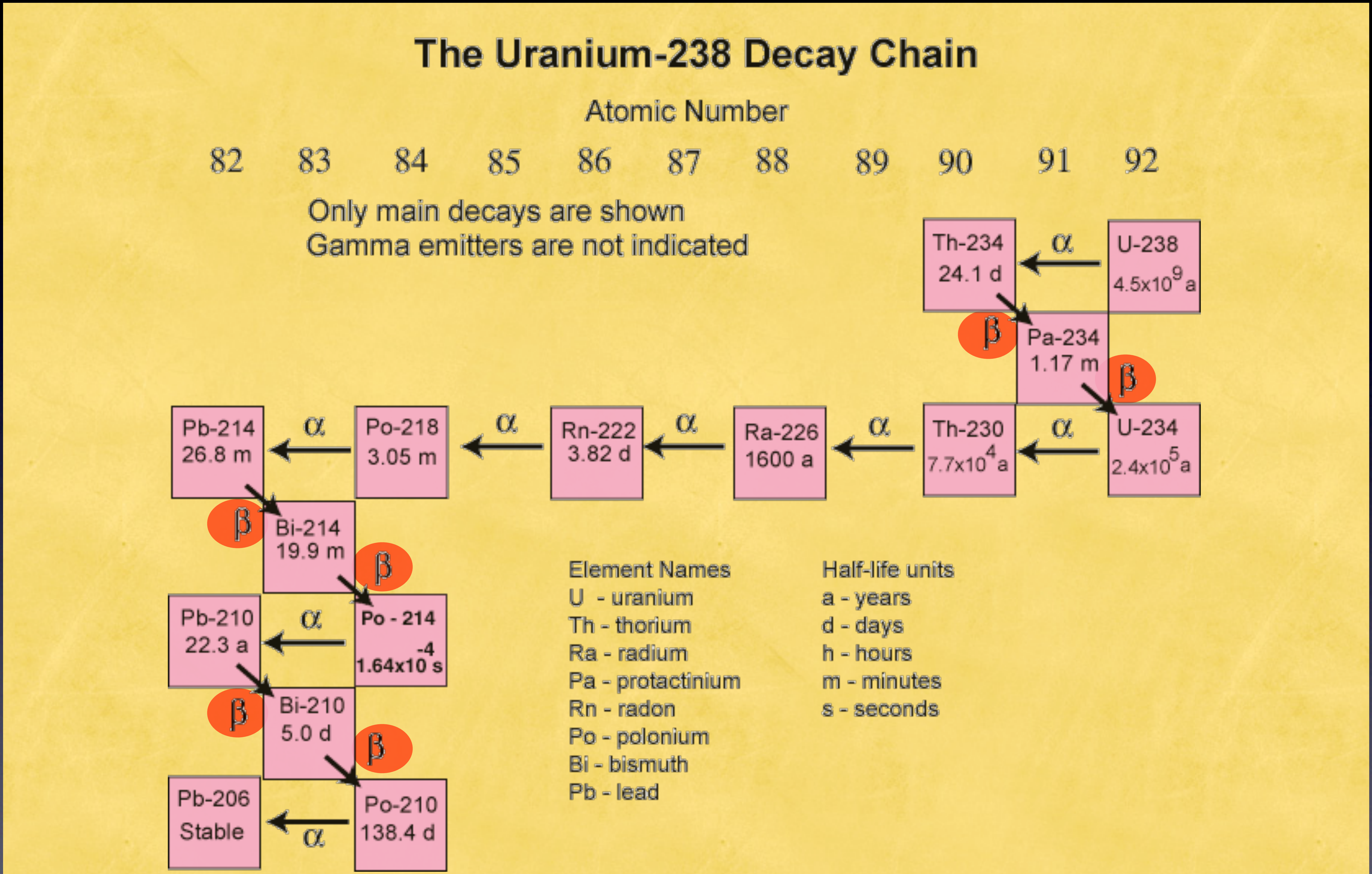
$$E_{\text{prompt}} = E_{\nu_e} - 0.8 \text{ MeV}$$

$$E_{\text{threshold}} = 1.8 \text{ MeV}$$

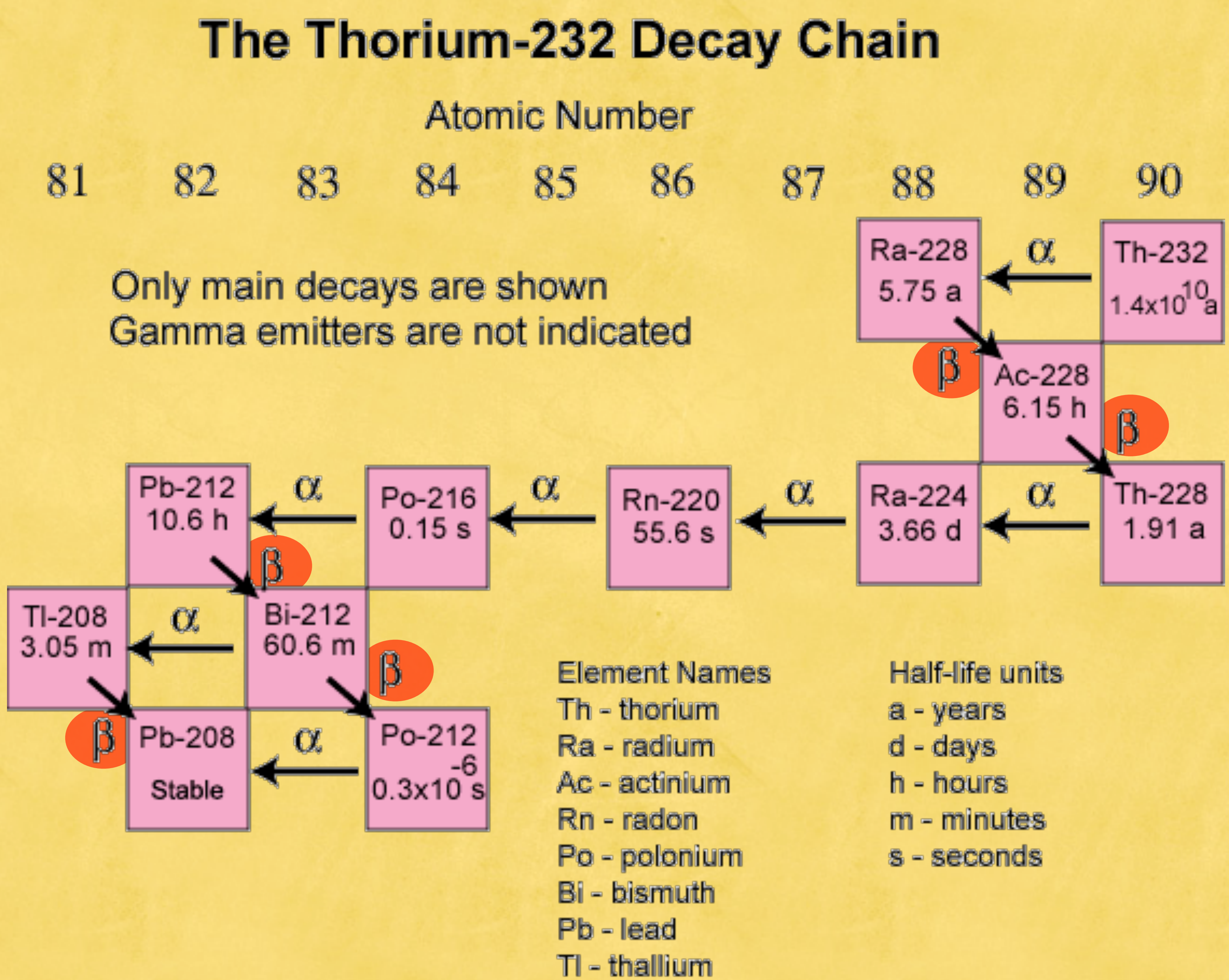
$$1.8 < E_{\text{geo}-\nu_e}/\text{MeV} < 3.3$$



$$\sigma \approx 10^{-43} \text{ cm}^2$$



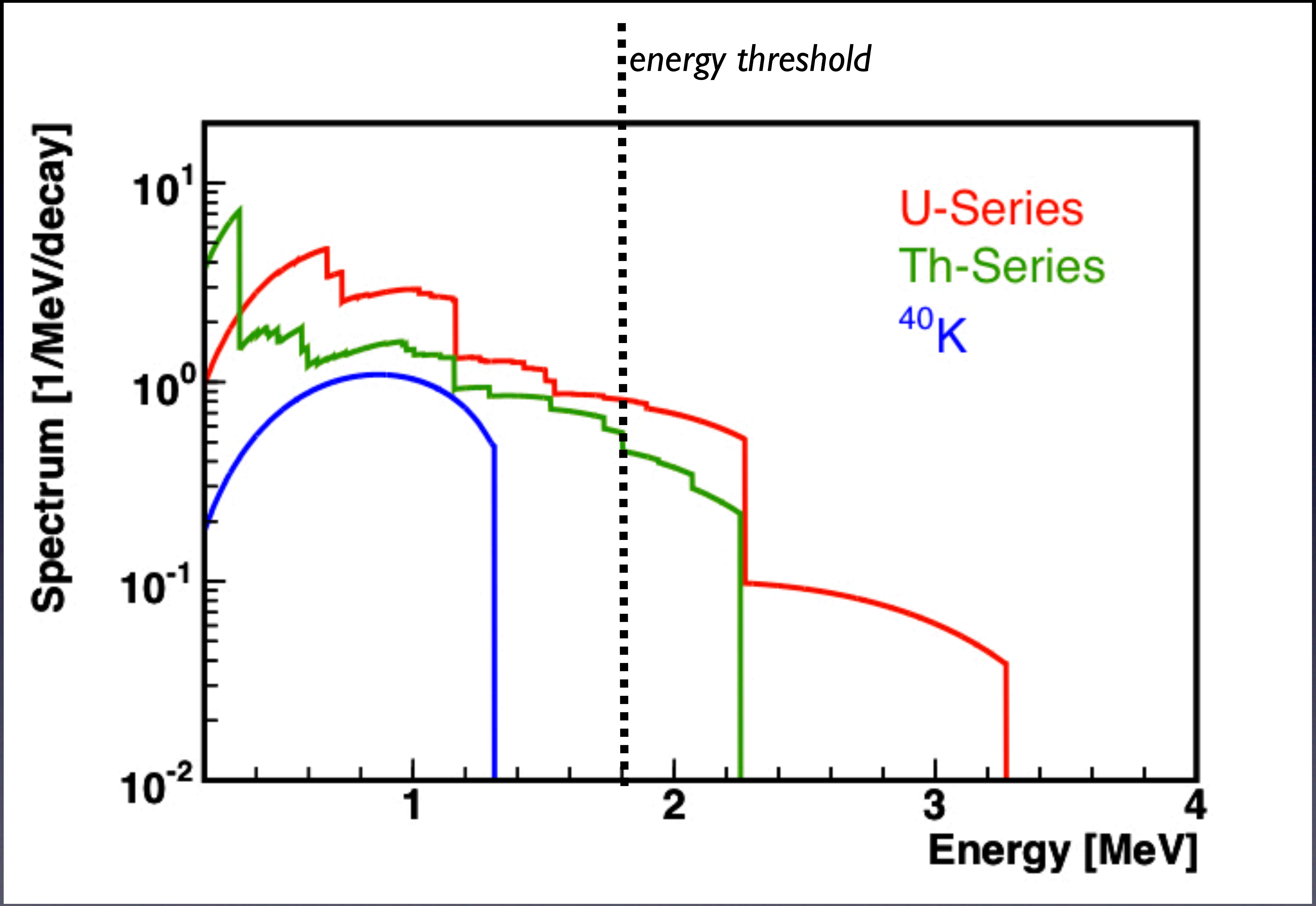
$$^{238}\mathrm{U} \rightarrow \, ^{206}\mathrm{Pb} + 8\, ^{4}\mathrm{He} + 6\,\mathrm{e}^{-} + 6\,\bar{\nu}_{\mathrm{e}} + 51.7\ [\mathrm{MeV}]$$



$$^{232}\mathrm{Th} \rightarrow {}^{206}\mathrm{Pb} + 6\,{}^{4}\mathrm{He} + 4\,\mathrm{e}^{-} + 4\,\bar{\nu}_{\mathrm{e}} + 42.7\ [\mathrm{MeV}]$$

Energy Spectra for U-, Th-Series

Taken from Enomoto's Thesis



fraction of $\bar{\nu}_e$ above threshold 0.15/4 = 3.7% (Th)

fraction of $\bar{\nu}_e$ above threshold 0.38/6 = 6.3% (U)

How do we calculate the expected flux ?

Expected Flux

matter density

$$n_X = \int dE_{\bar{\nu}}\; f_X(E_{\bar{\nu}})$$

$$\Phi_X(\vec{R}, E_{\bar{\nu}}) = \int_V d\vec{r} \frac{\rho(\vec{r})}{4\pi|\vec{R}-\vec{r}|^2} \frac{a_X(r) C_X}{\tau_X m_X} f_X(E_{\bar{\nu}}) P(\bar{\nu}_e \to \bar{\nu}_e; E_{\bar{\nu}}, |\vec{R}-\vec{r}|)$$

$$X = {}^{238}\mathrm{U}, {}^{232}\mathrm{Th}$$

detector position

$$\vec{R} = (R_T \cos\phi \sin\theta, R_T \sin\phi \sin\theta, R_T \cos\theta)$$

$$\langle P(\bar{\nu}_e \to \bar{\nu}_e) \rangle = 1 - \frac{1}{2}\sin^2 2\theta_{12} \approx 0.6$$

survival probability

a_X = mass abundance

C_X = isotopic concentration

τ_X = lifetime

m_X = mass of X

Bulk Silicate Earth (BSE) Model

BSE is a geochemical paradigm

the chemical compositon of the Earth is estimated from that of CI chondritic meteorites

$$m_{\rm BSE}({\rm U}) = m_{\rm M}({\rm U}) + m_{\rm c}({\rm U}) \qquad m_{\rm BSE}({\rm Th}) = 4\, m_{\rm BSE}({\rm U})$$

[McDonough et al, Chem. Geo. 120, 223 (1995)]

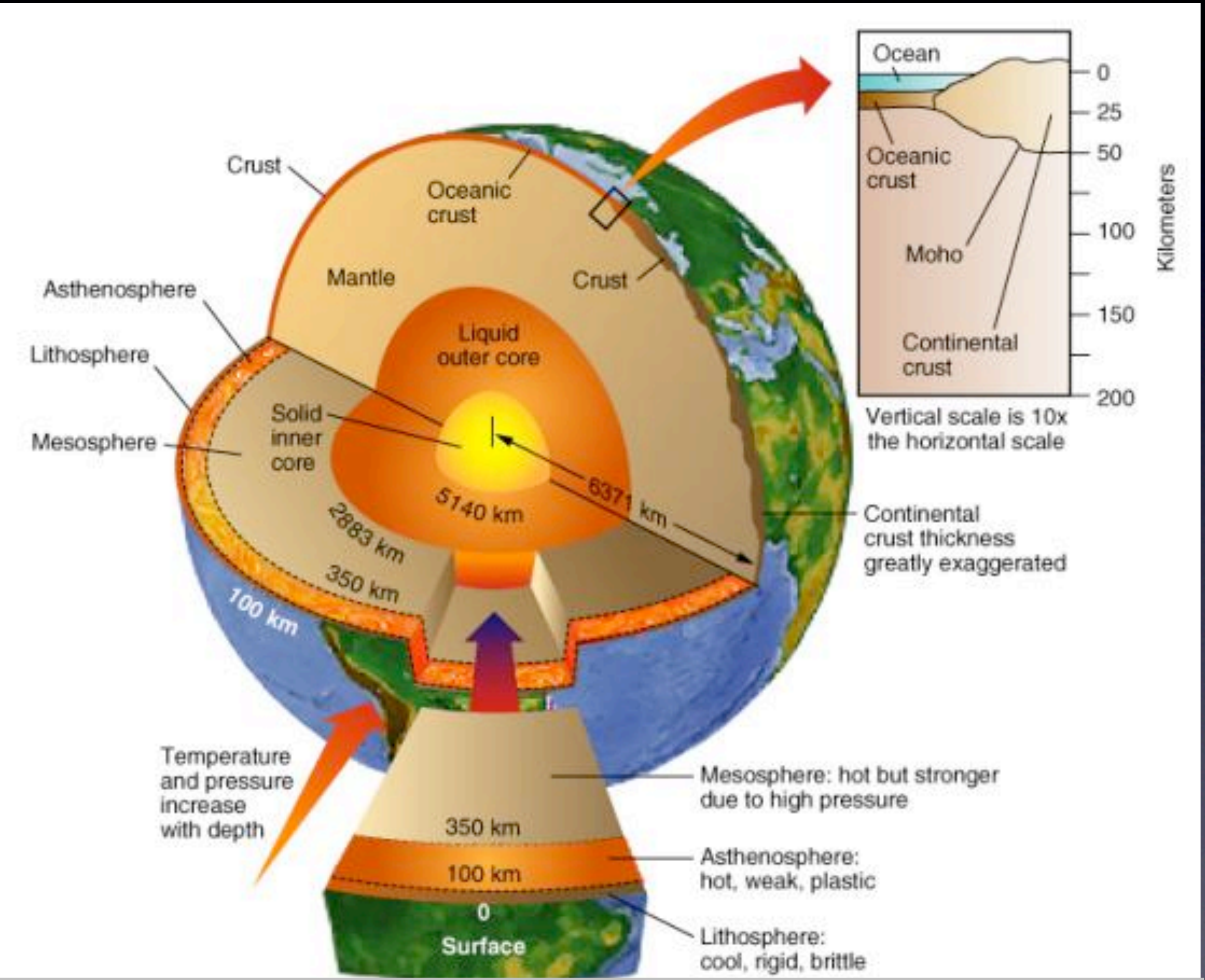
$m_{BSE}(U) = 0.8 \times 10^{17}$ kg

$m_c(U) = (0.3\text{-}0.4) \times 10^{17}$ kg (observational data)

Mass Abundances of U

(Mantovani et al. 2004)

$m_c(U) \sim 0.4 \times 10^{17}$ kg



0.47 % Earth's mass in the crust

Crust:

OC ~ 7 km

a(U) = 0.1 ppm

CC ~ 30 km

UC

a(U) = 2.5 ppm

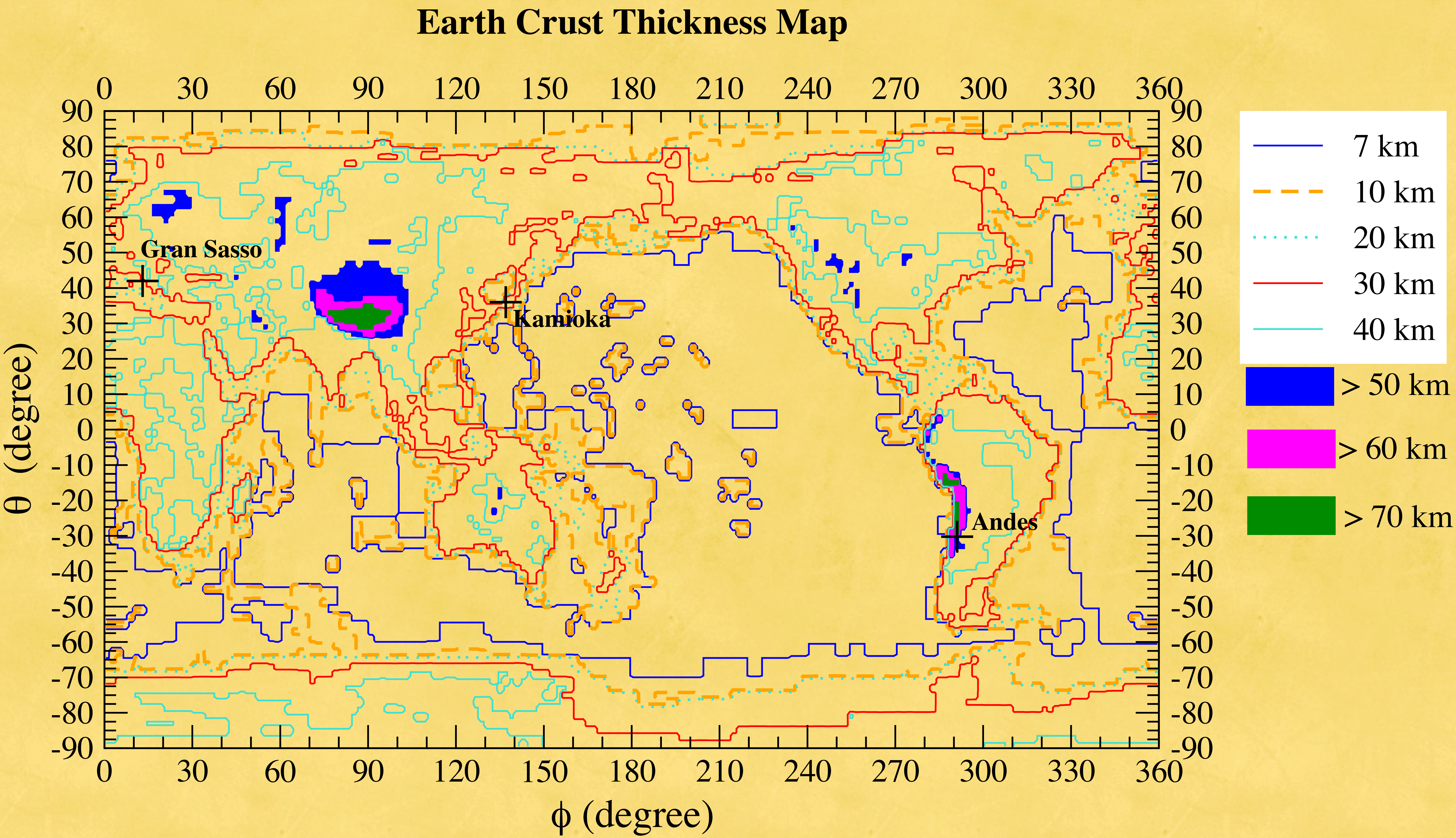
MC

a(U) = 1.6 ppm

LC

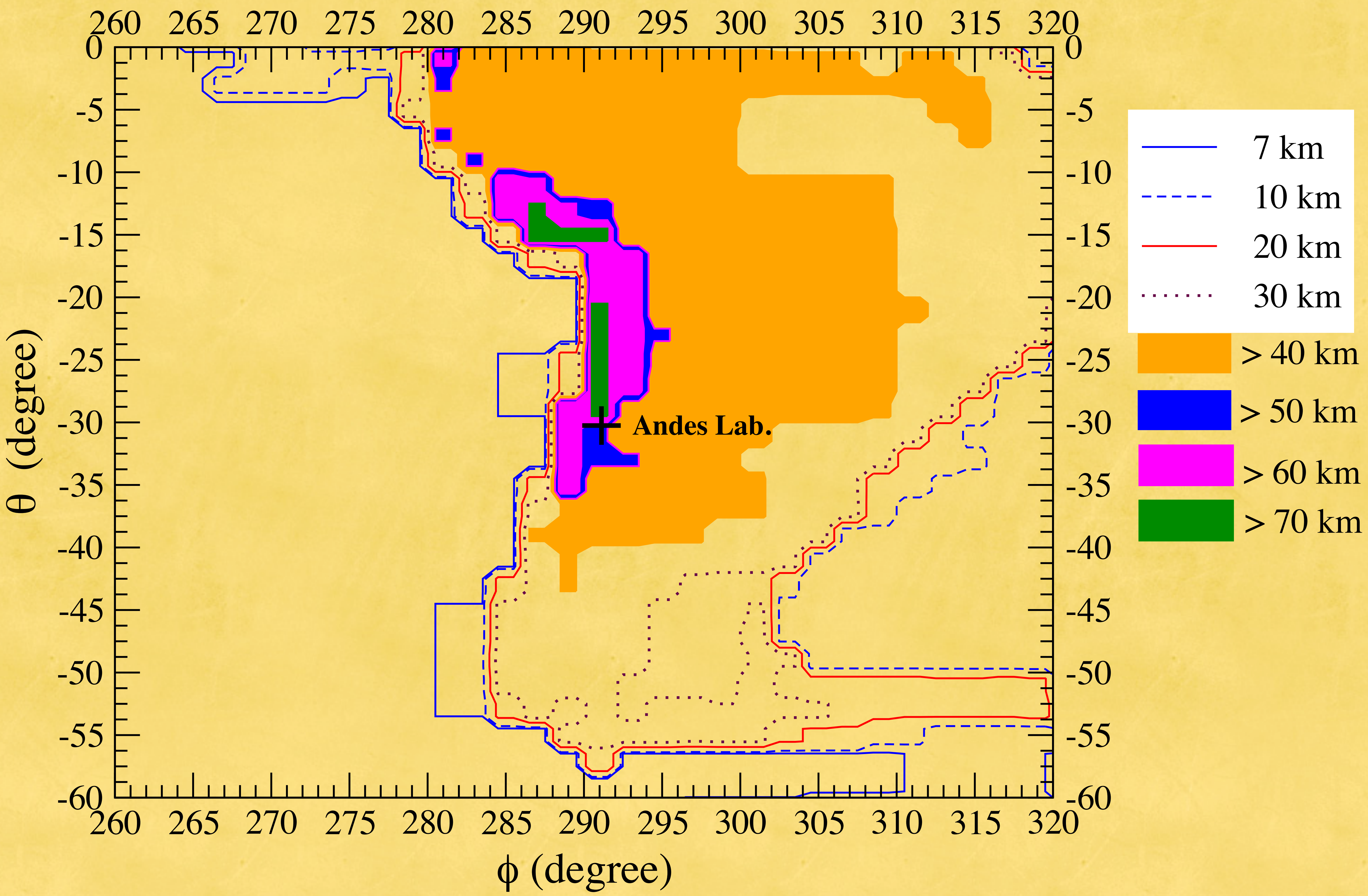
a(U) = 0.63 ppm

Local Geo-Neutrino Flux Depends on the Crust Thickness



Reference: http://igppweb.ucsd.edu/~gabi/crust2.html

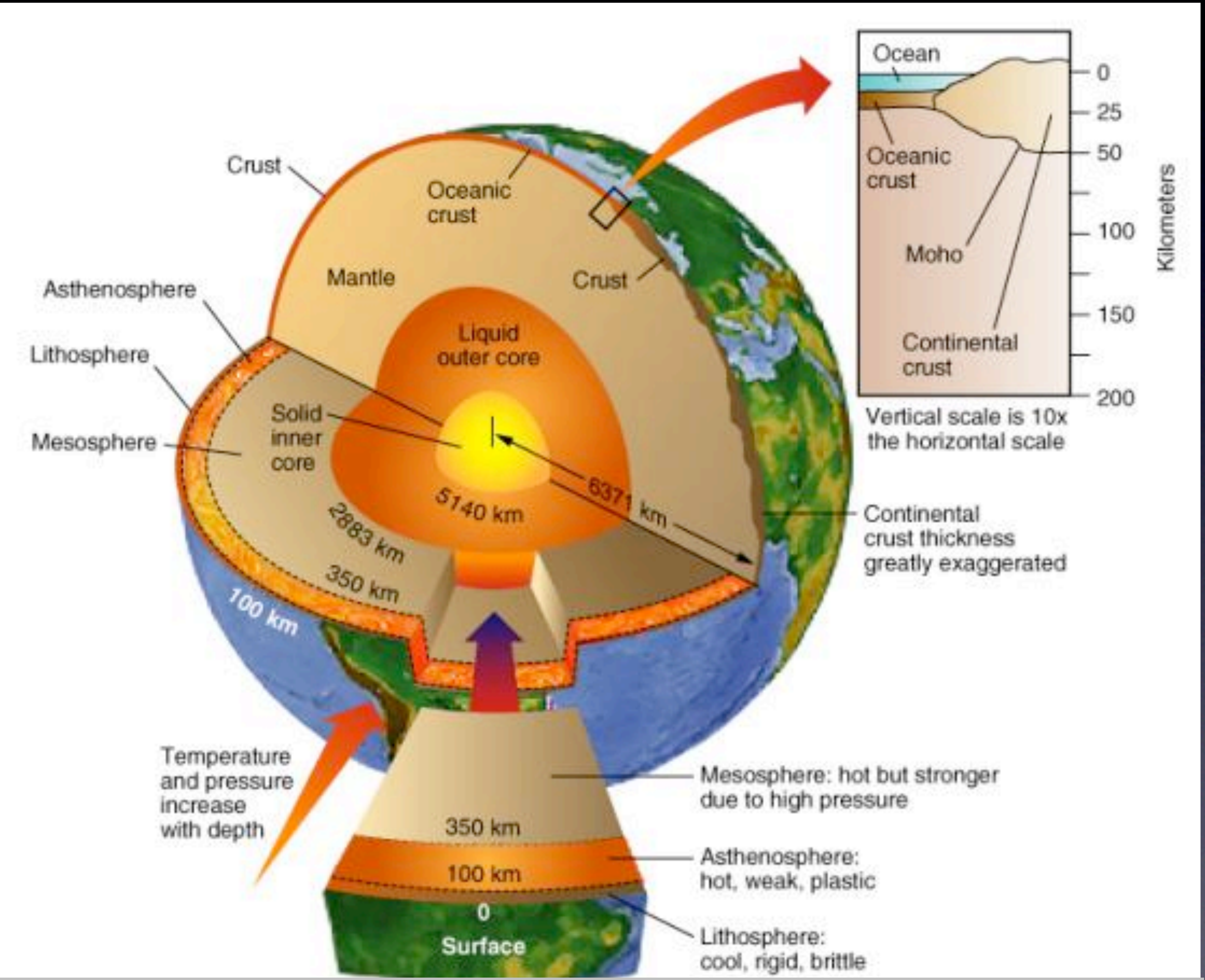
Earth Crust Thickness Map Around Andes Lab.



Mass Abundances of U

(Mantovani et al. 2004)

$m_M(U) \sim 0.4 \times 10^{17}$ kg



68 % Earth's mass in the mantle

Mantle:

UM

~33-670 km

a(U) = 6.5 ppb

LM (BSE)

~670-2900 km

a(U) = 20 ppb

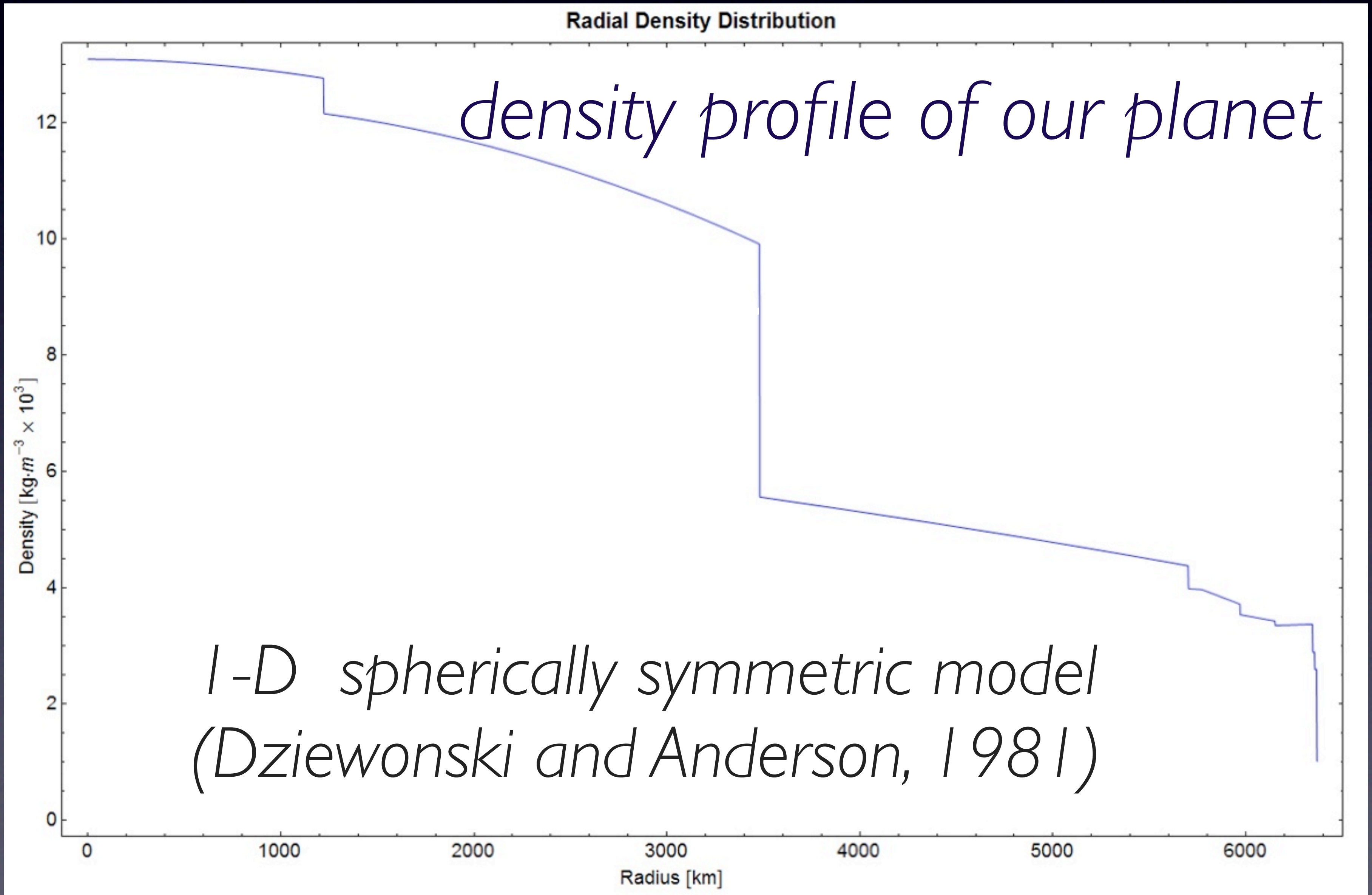
Core:

~3470 km

a(U) = 0

PREM

Preliminary Reference Earth Model

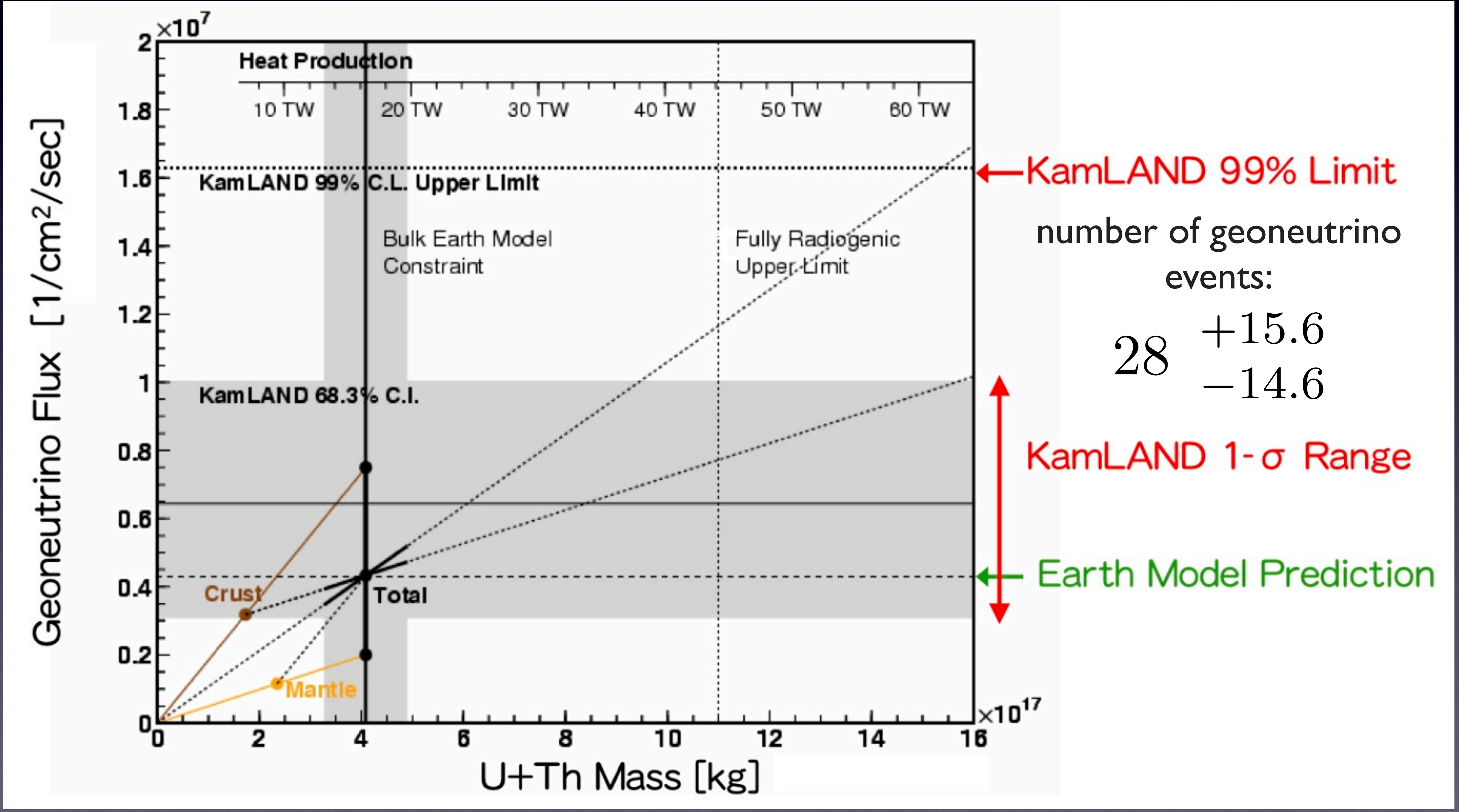


What do we know ?

KamLAND

[Nature 436, 499 (2005)]

Enomoto, Venice 2009

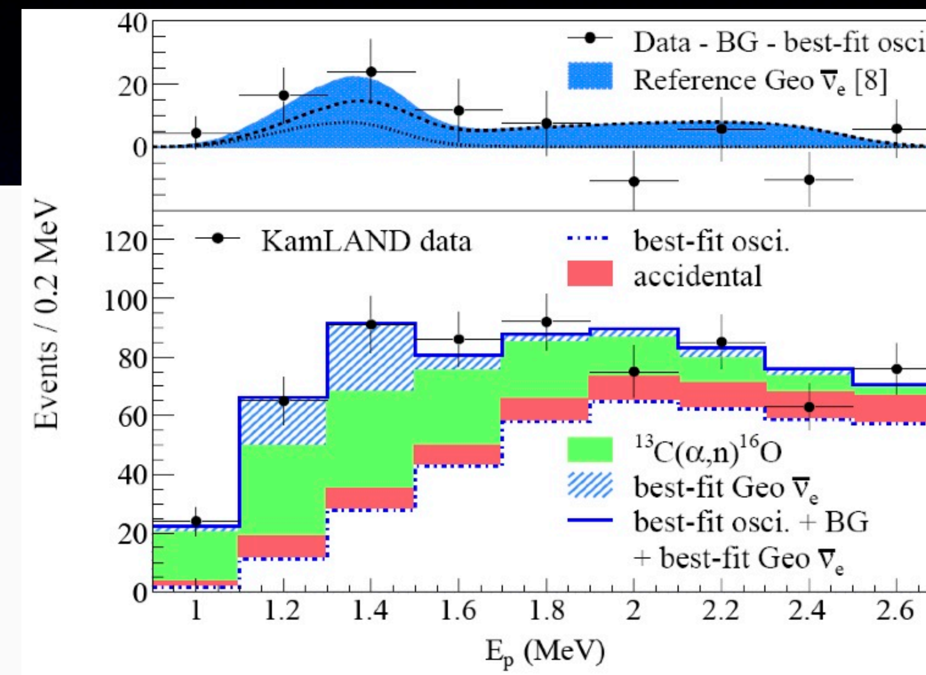


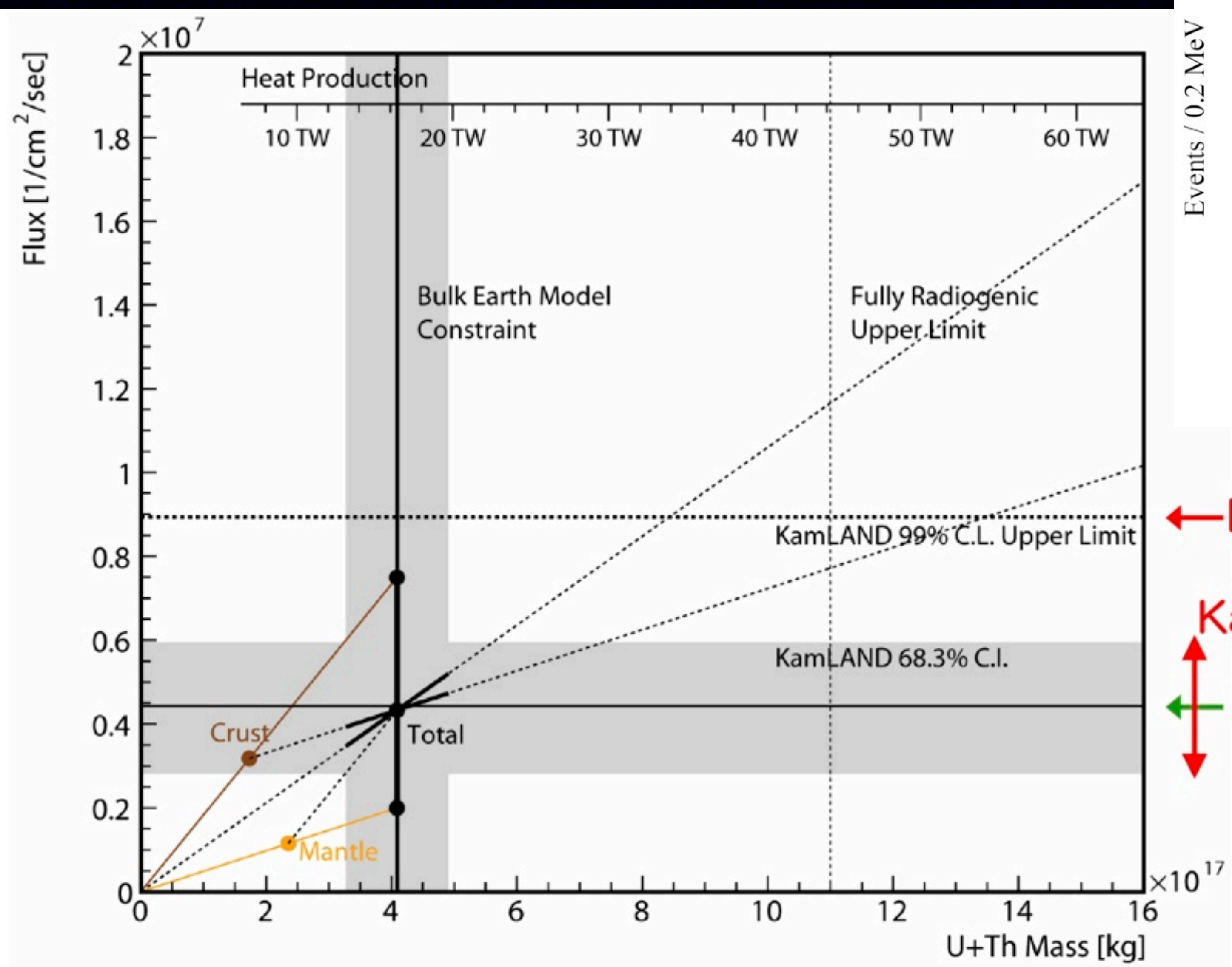
number of geoneutrino events:

$$28 \begin{array}{l} +15.6 \\ -14.6 \end{array}$$

KamLAND

[PRL 100, 221803 (2008)]





←KamLAND 99% Limit

KamLAND 1-σ Range

Earth Model Prediction

Enomoto, Venice 2009

- Error is reduced from 56% to 36%
- Consistent with BSE model predictions
- 99%C.L. upper limit is approaching to the total terrestrial heat

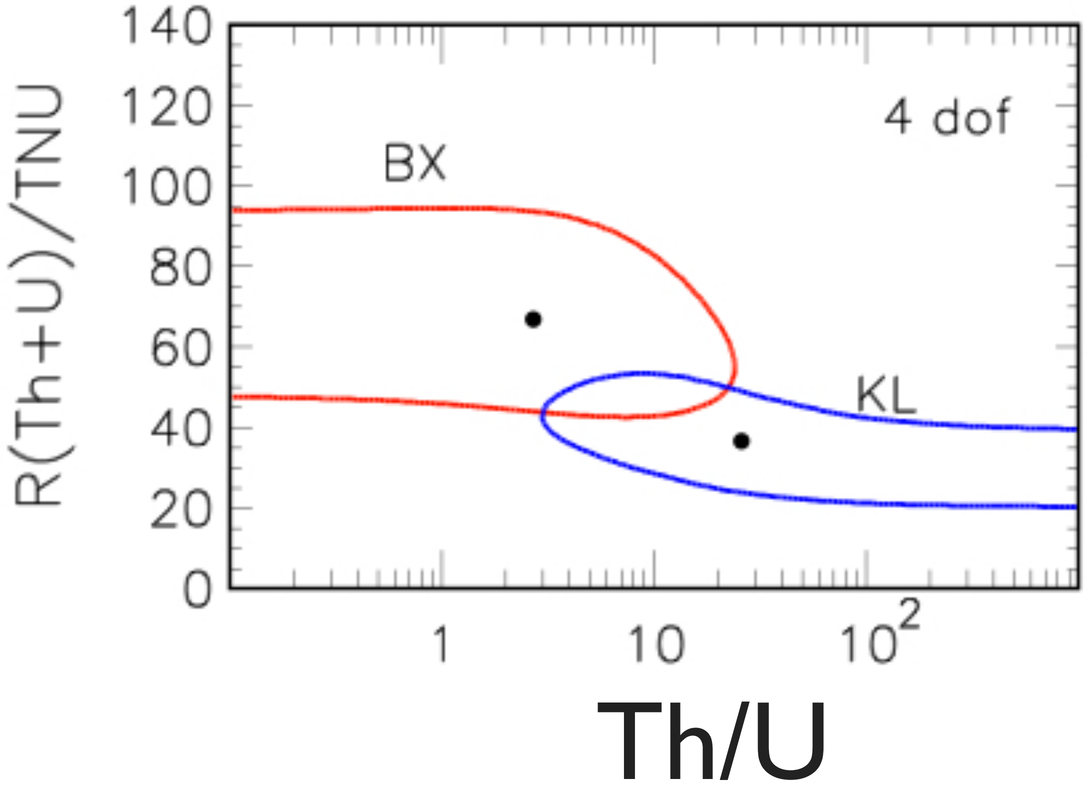
Borexino

Phys. Lett. B687, 299 (2010)

Source	Geo–$\bar{\nu}_e$ Rate [events/(100 ton·yr)]
Borexino	$3.9^{+1.6}_{-1.3}$
BSE [16]	$2.5^{+0.3}_{-0.5}$
BSE [31]	2.5 ± 0.2
BSE [5]	3.6
Max. Radiogenic Earth	3.9
Min. Radiogenic Earth	1.6

KamLAND & Borexino

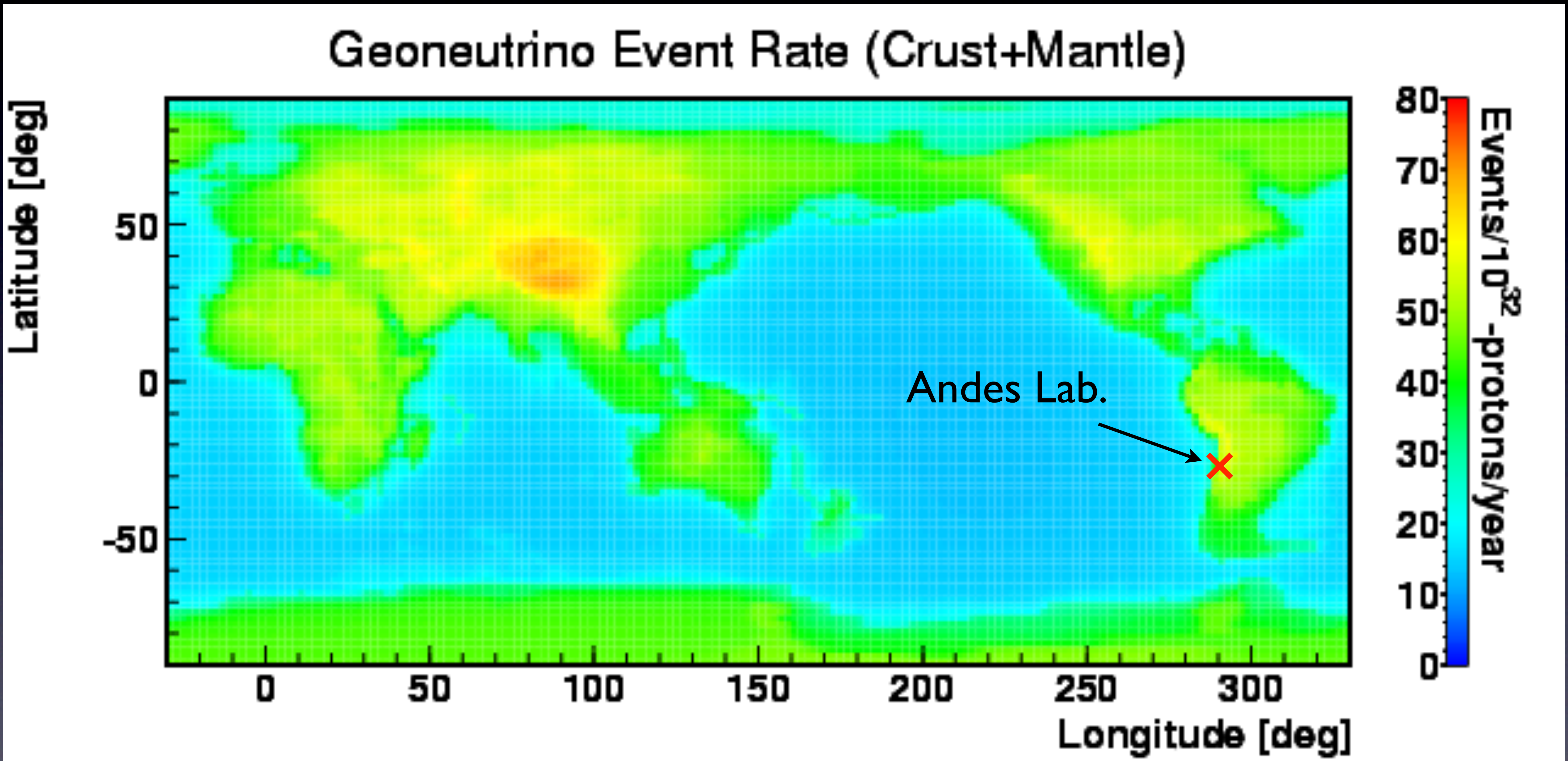
complementarity



G.L. Fogli et al.
Phys.Rev.D82:093006,2010

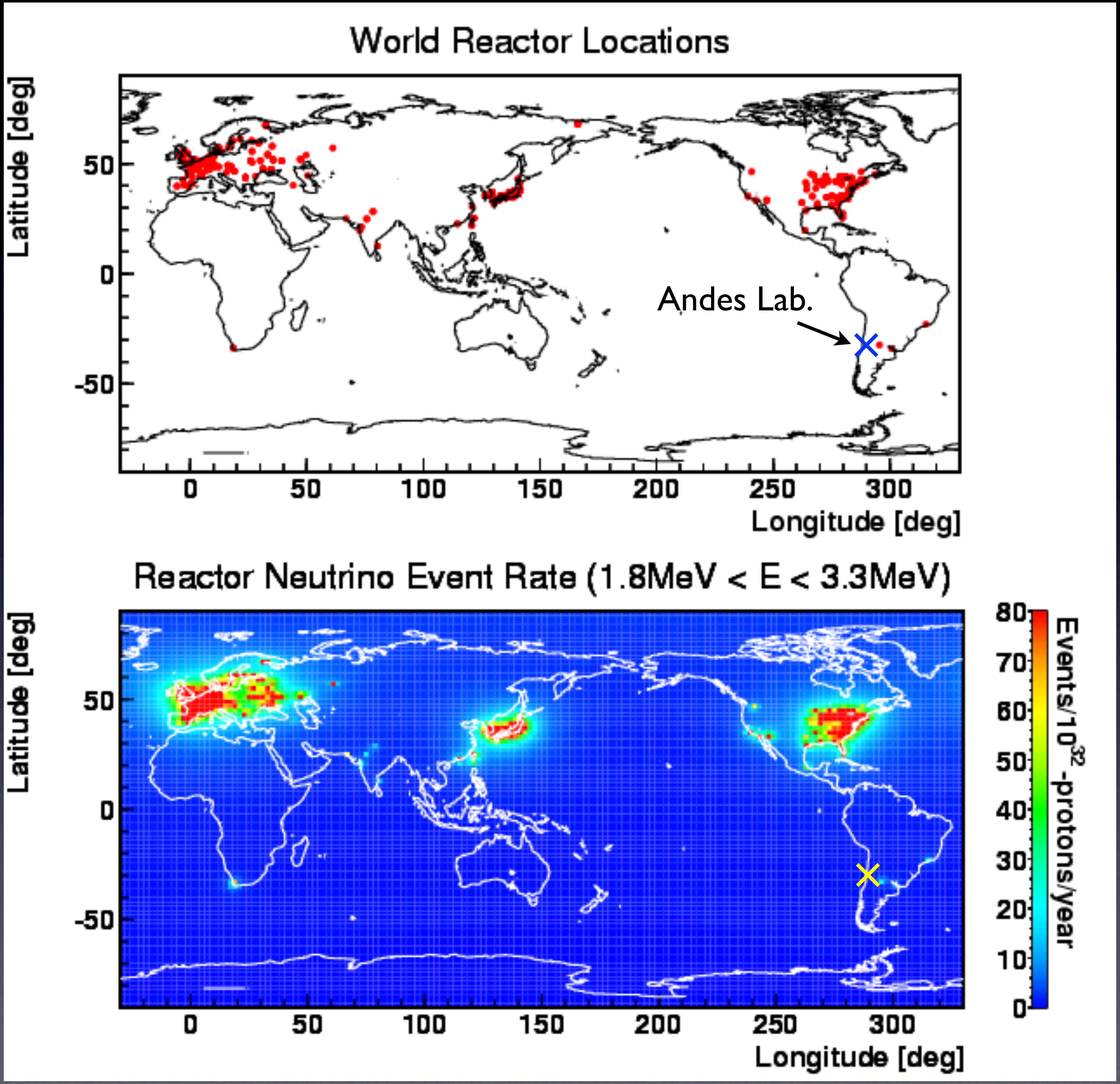
Why do it at the ANDES Laboratory?

Good location due to higher Geo-neutrino flux



Enomoto, Neutrino Sciences 2007

Another Advantage: Very Few Reactors Nearby

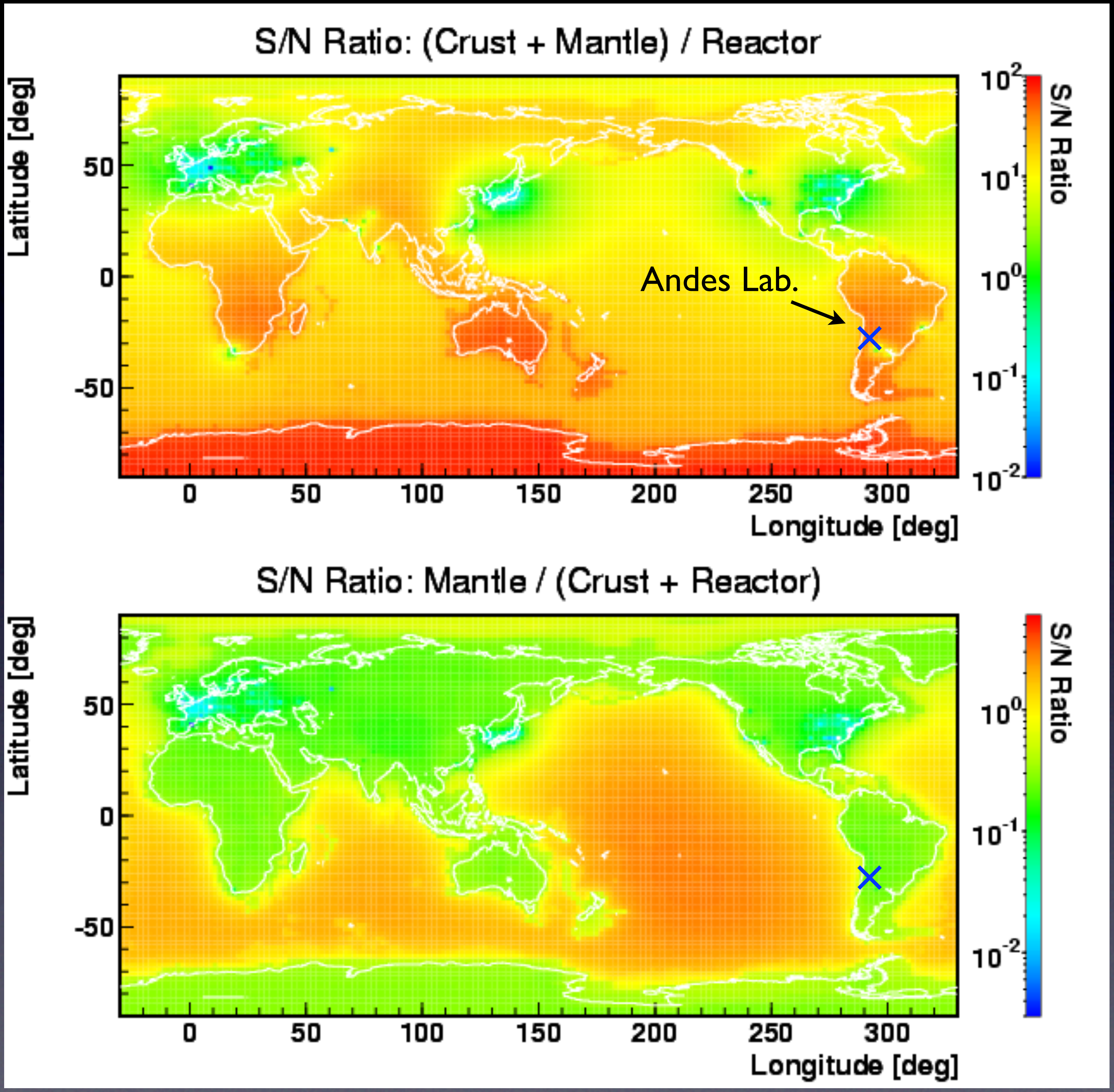


distance to nearest reactor ~ 600 km

N_{reac} < 1 event for 1 kt·yr·GW_{th} at Andes Laboratory

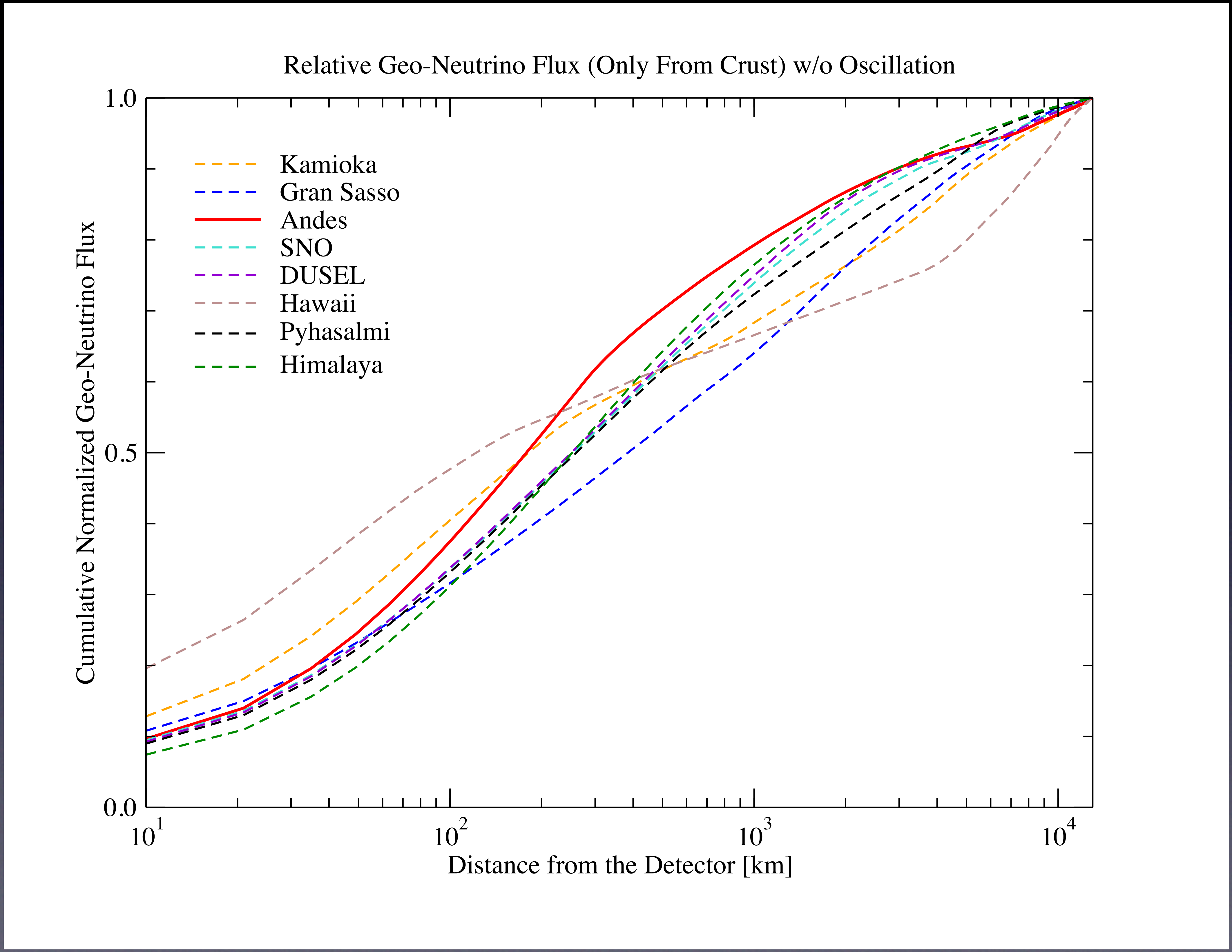
Enomoto, Neutrino Sciences 2007

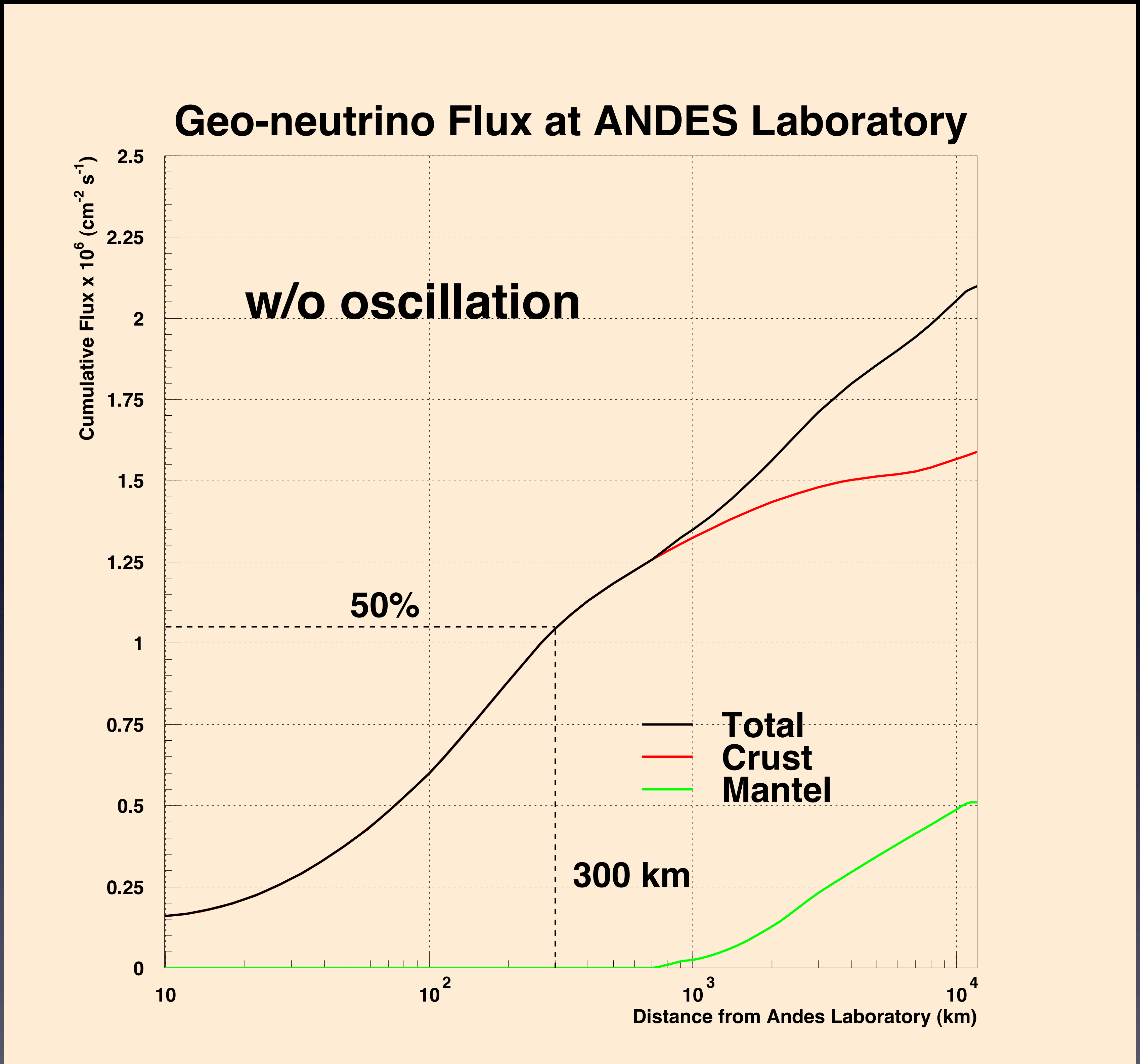
High S/N (Geo-ν/Reactor) Ratio



Enomoto, Neutrino Sciences 2007

Location Dependence of Geo-Neutrino Flux as a function of distance from the sources (only from Crust origin) I

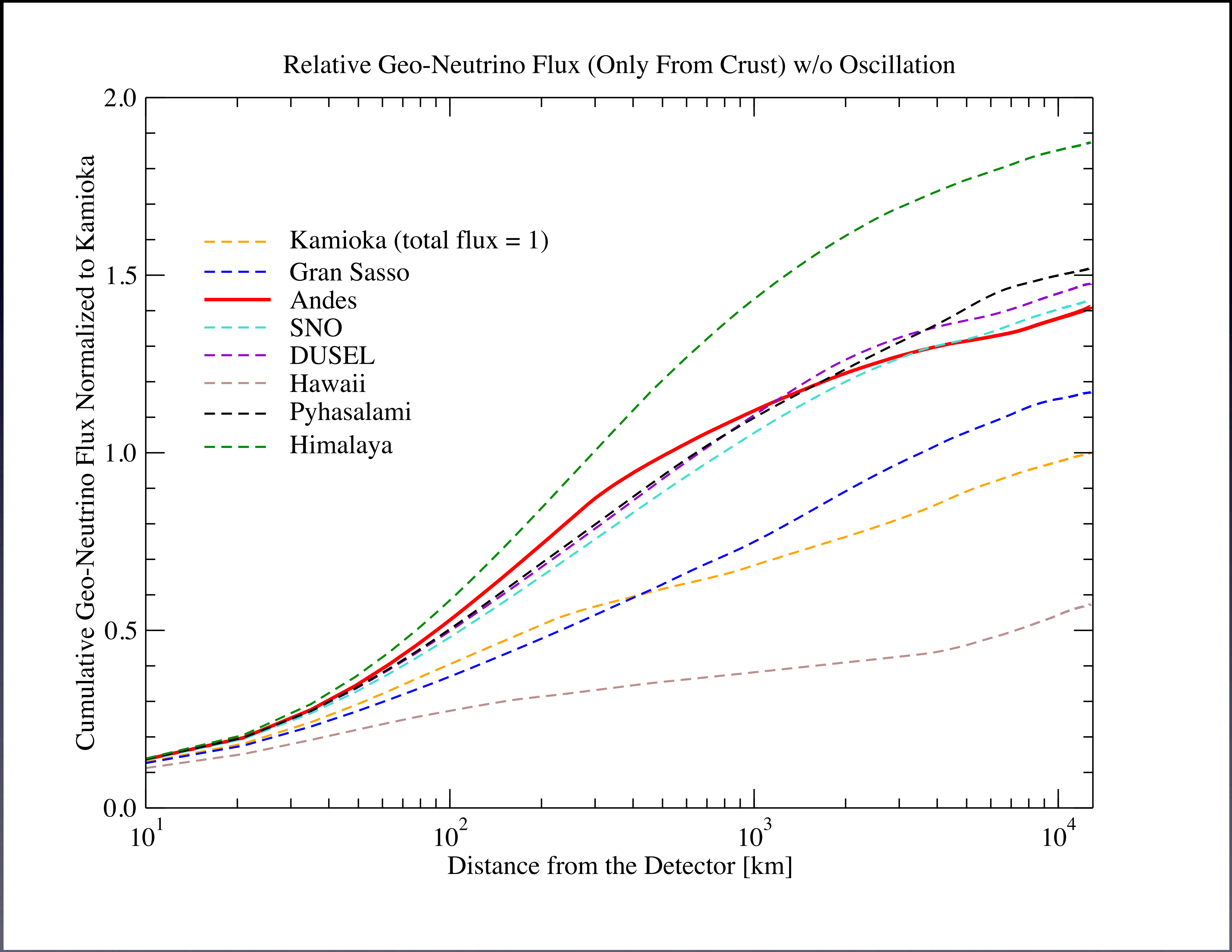




Geo-neutrino Flux at ANDES Laboratory
w/o oscillation
50%
300 km
Total
Crust
Mantel
Cumulative Flux x 10^6 (cm^-2 s^-1)
Distance from Andes Laboratory (km)
2.5
2.25
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
10
10^2
10^3
10^4

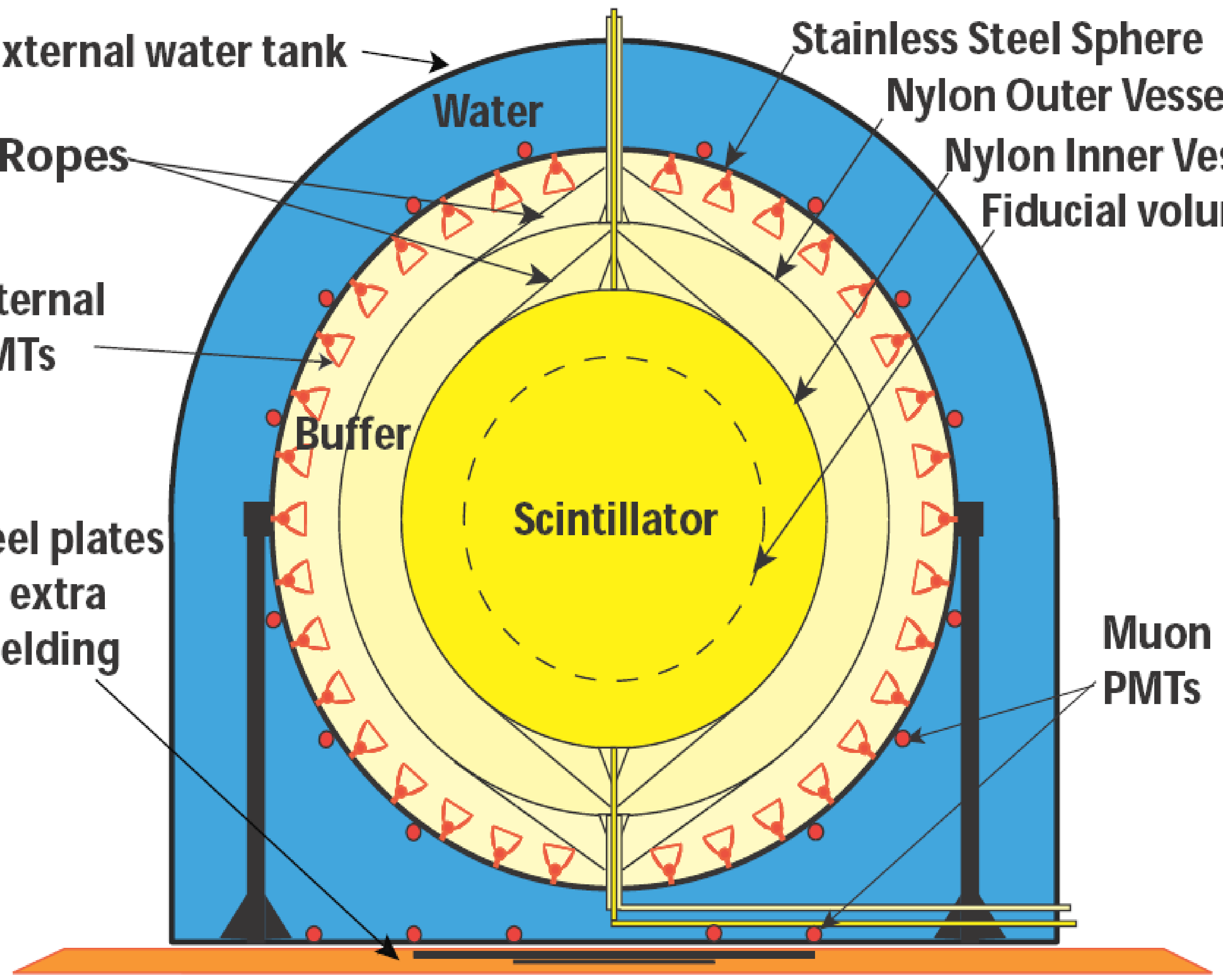
Half of Geo-Neutrinos come from distance within ~ 300 km

Location Dependence of Geo-Neutrino Flux as a function of distance from the sources (only from Crust origin) II



Detector Assumption for Andes Lab.

As a reference detector let us consider BOREXINO-like detector



Active Target: 278 Tons of Liquid Scintillator in Nylon Vessel of 4.25 m radius

number of free protons = 1.7×10^{31}

Expected number of events:

Location comparison assuming the same detector size, exposure and efficiency

For 1.7 x 10^{31} free protons, 1 year, 80% eficiency

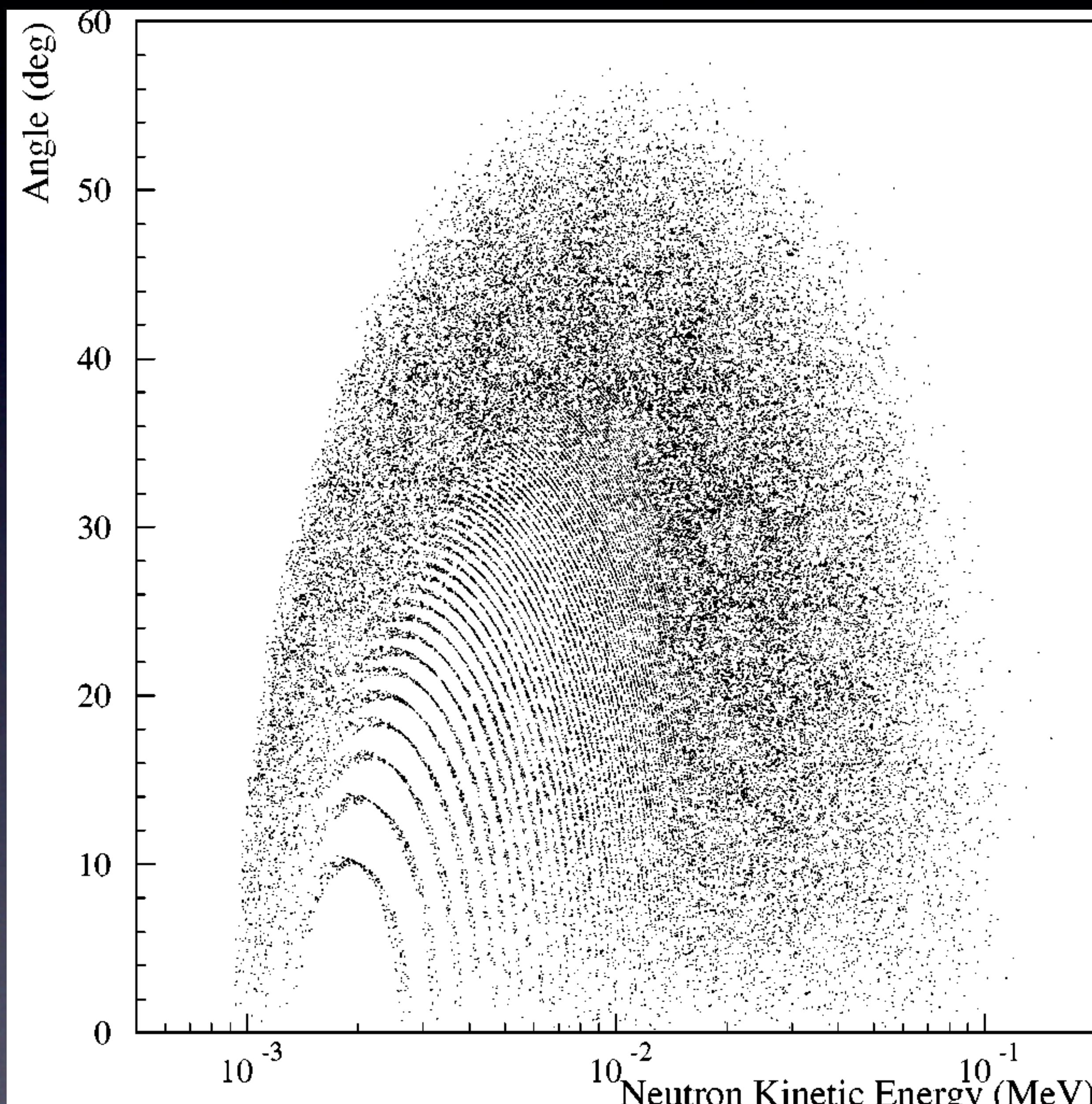
- Kamioka : $N_u + N_{th} = 7.5$
- Gran Sasso: $N_u + N_{th} = 8.4$
- SNO : $N_u + N_{th} = 9.8$
- Pyhasalmi : $N_u + N_{th} = 10.2$
- Hawaii : $N_u + N_{th} = 5.2$
- Andes : $N_u + N_{th} = 9.8$

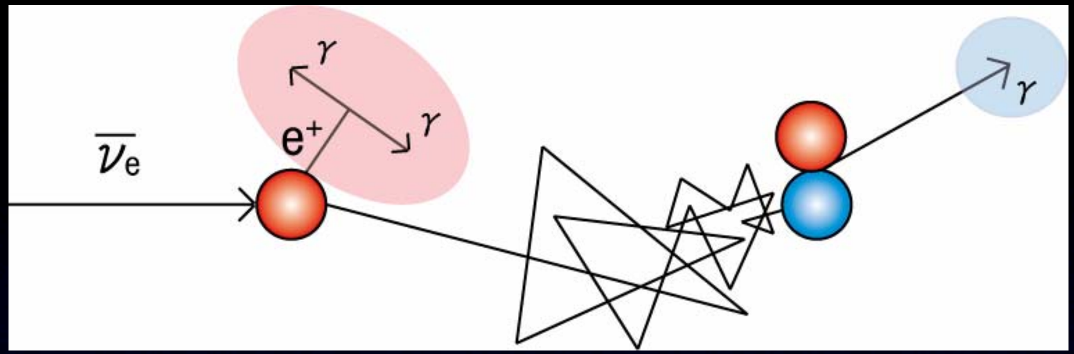
Preliminary

based on H. Nunokawa, W.J.C. Teves and RZF, JHEP 11, 020 (2003)

Future Dream: Directional Sensitivity?

Neutron Emission Angle vs Kinetic Energy





Recoiled neutron remembers direction

but currently, seems very difficult due to

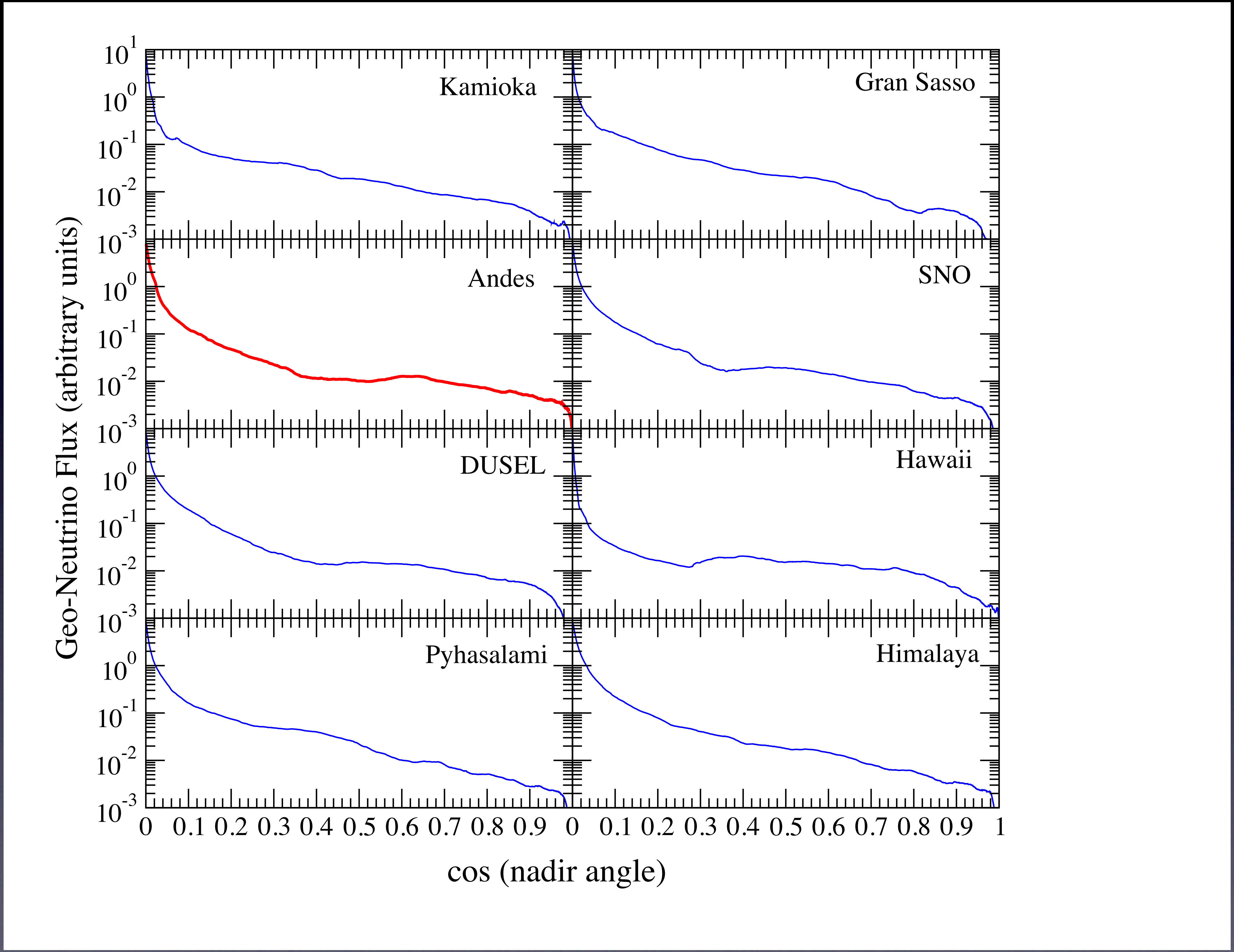
thermalization of neutron

gamma diffusions

very poor resolution of vertex reconstruction

MC simulation by CHOOZ collab. (Apollonio et al, PRD61, 012001, 1999)

Nadir Angle dependence of Geo-Neutrino Flux



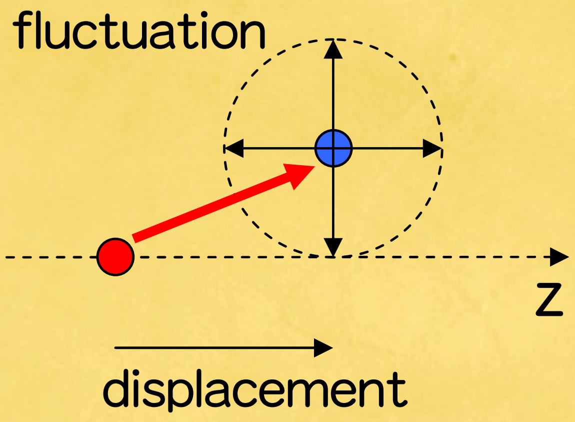
cos(nadir angle) = 0 (horizontal dir.), 1 (from Earth Center)

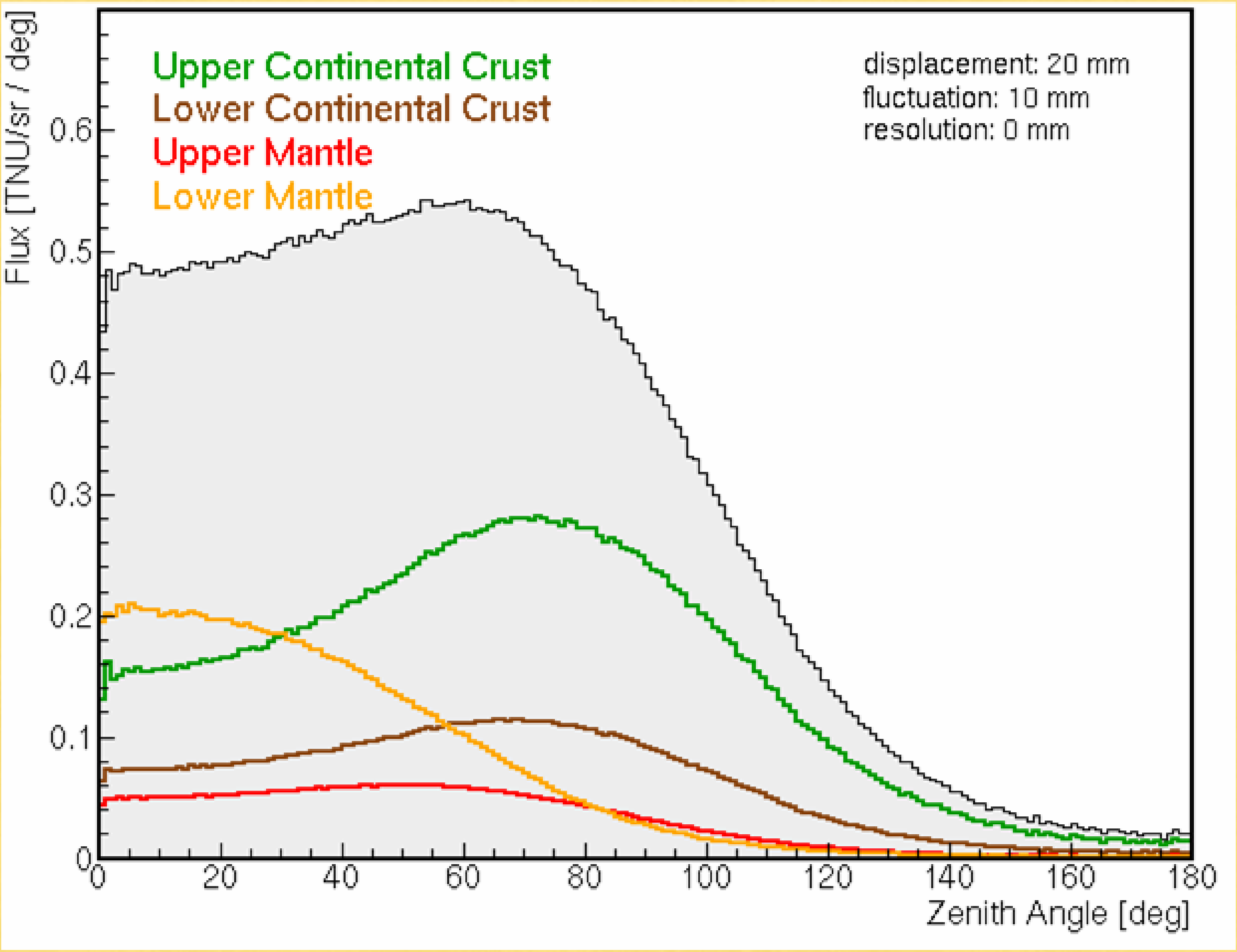
Some Estimations by KamLAND Collab.

LS Directionality and Geoneutrinos

If we achieve

- 20 mm vertex displacement
- 10 mm vertex fluctuation
- Perfect resolution (<~10mm)





Enomoto, Neutrino Telescope 2009

Summary

The Andes Laboratory is in a Good Location to study Geo-Neutrinos due to

- Larger Geo-Neutrino Flux (than Kamioka, Gran Sasso)
- Very Few Reactors Nearby
- Expetected number of Geo-ν events
  $N_u + N_{th} \sim 10$ for $300 \text{ ton} \cdot \text{yr}$
- The same detector can be used to study Neutrinos from a Nearby (Galactic) Supernova


Thank you