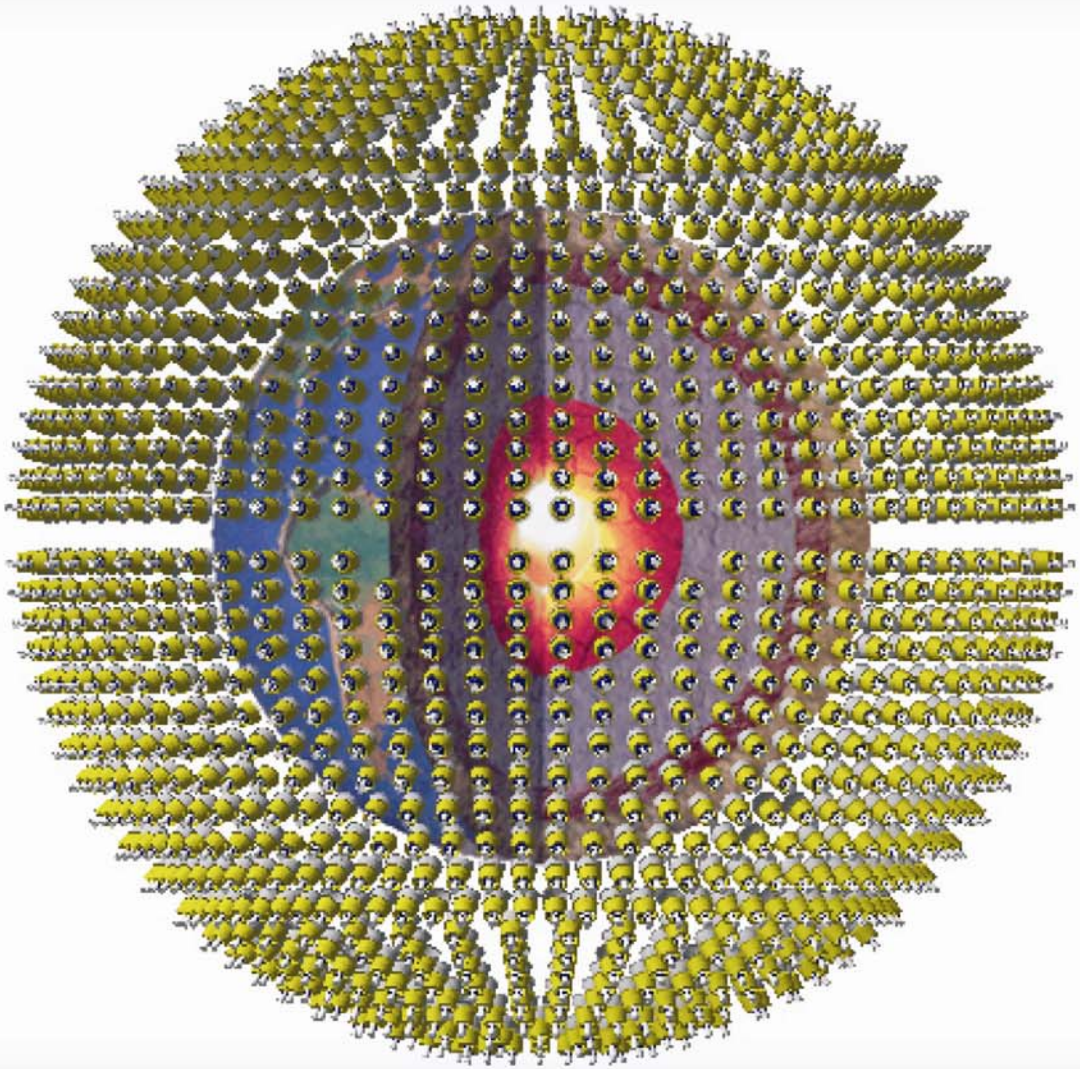
Geo-neutrinos

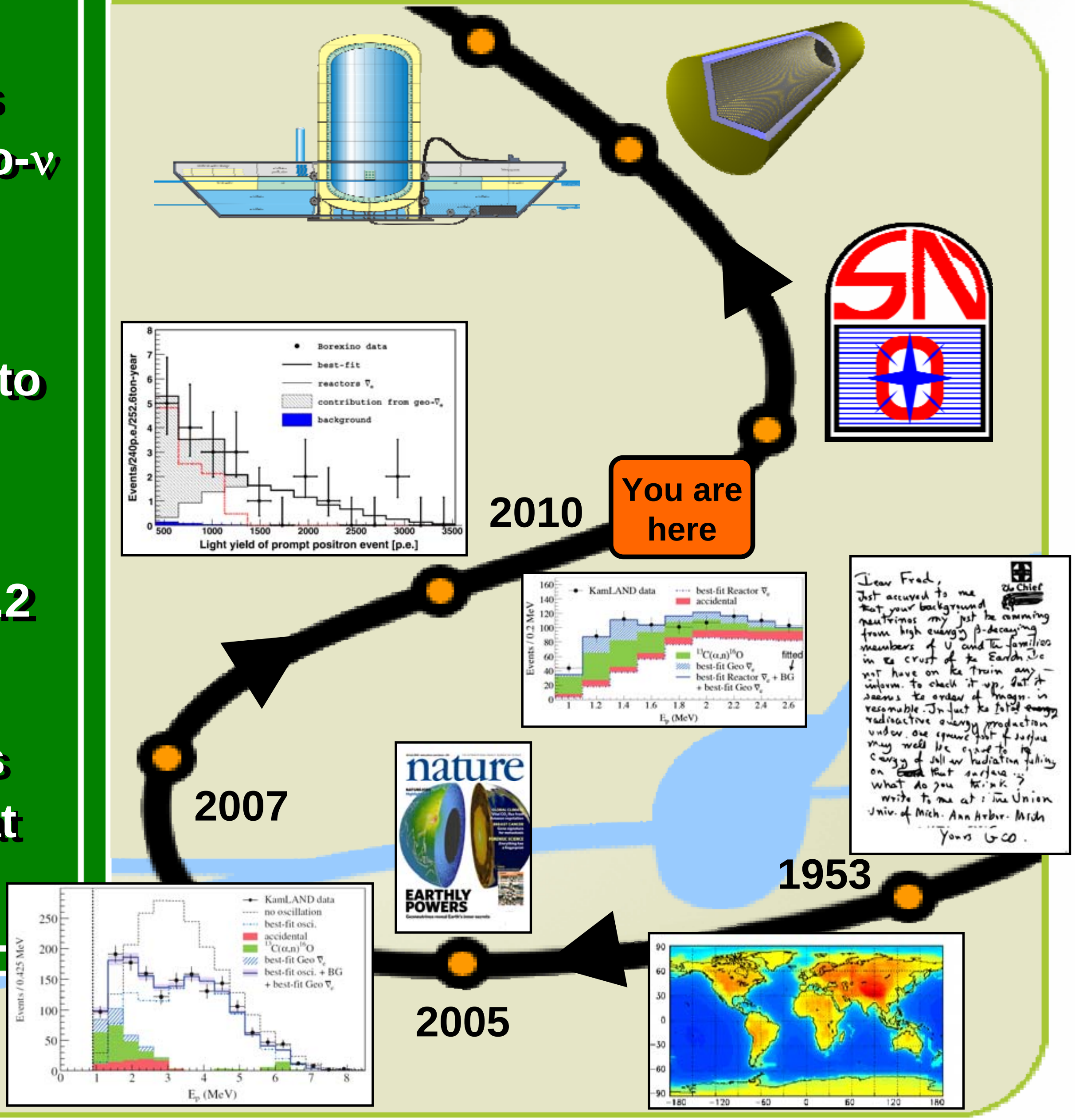


Università di Ferrara – INFN Ferrara – INFN Cagliari

Giovanni Fiorentini – Marcello Lissia – Fabio Mantovani – Barbara Ricci – Chubakov Viacheslav

Geo-ν story

- 1953: geo-ν were born thanks to Gamow
- 2005: KamLAND shows that the technique for geo-ν detection is available
- 2007: KamLAND's evidence for geo-ν close to 2.5 σ C.L.
- 2010: Borexino claims observation of geo-ν at 4.2 σ C.L.
- 2010: KamLAND rejects fully radiogenic models at 2.7 σ (preliminary)



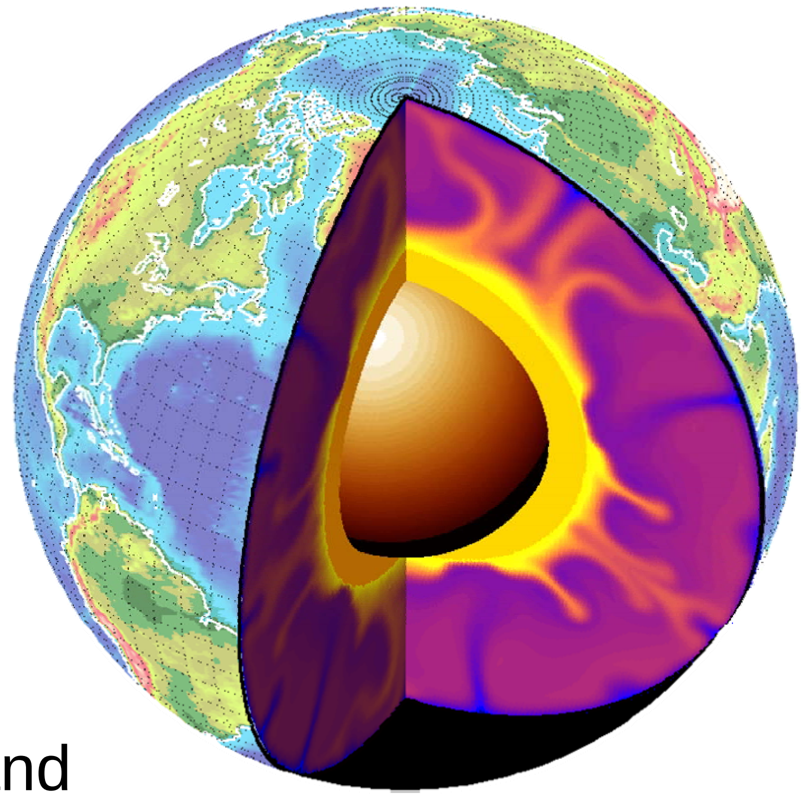
Geo-neutrinos: a new probe of Earth's interior.

Open questions about natural radioactivity in the Earth

1 - What is the radiogenic contribution to terrestrial heat production?

2 - How much U and Th in the crust?

3 - How much U and Th in the mantle?



4 - What is hidden in the Earth's core? (geo-reactor, ^{40}K, …)

5 - Is the standard geochemical model (BSE) consistent with geo-neutrino data?

Borexino: expectations and results

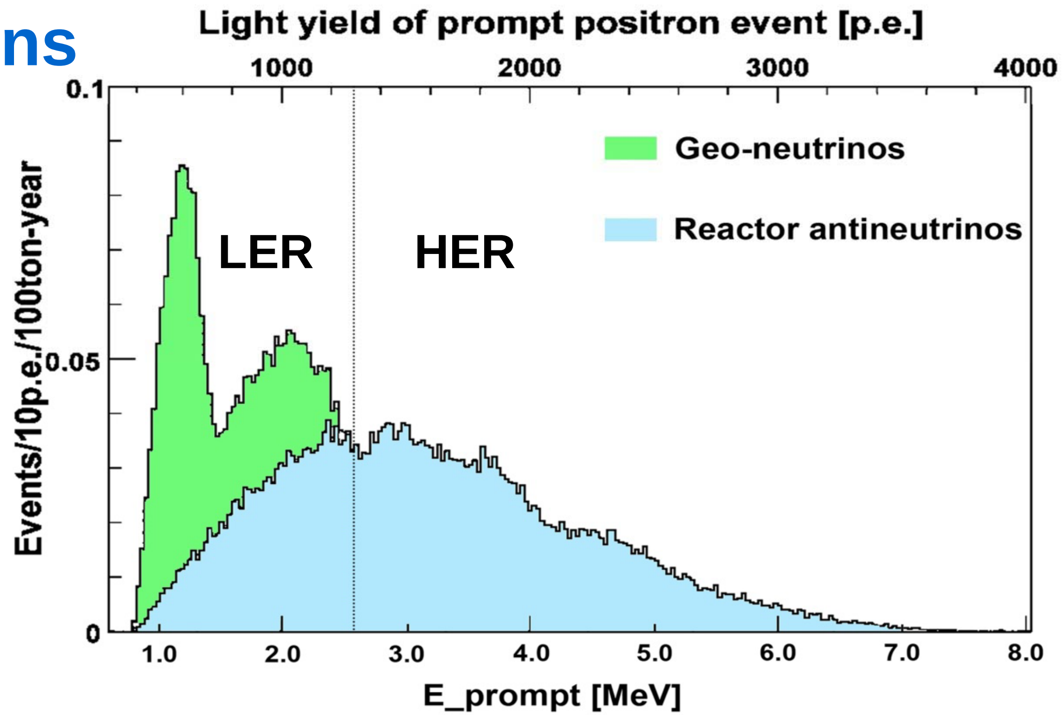
- Predict a total of **20.7** events in 24 months

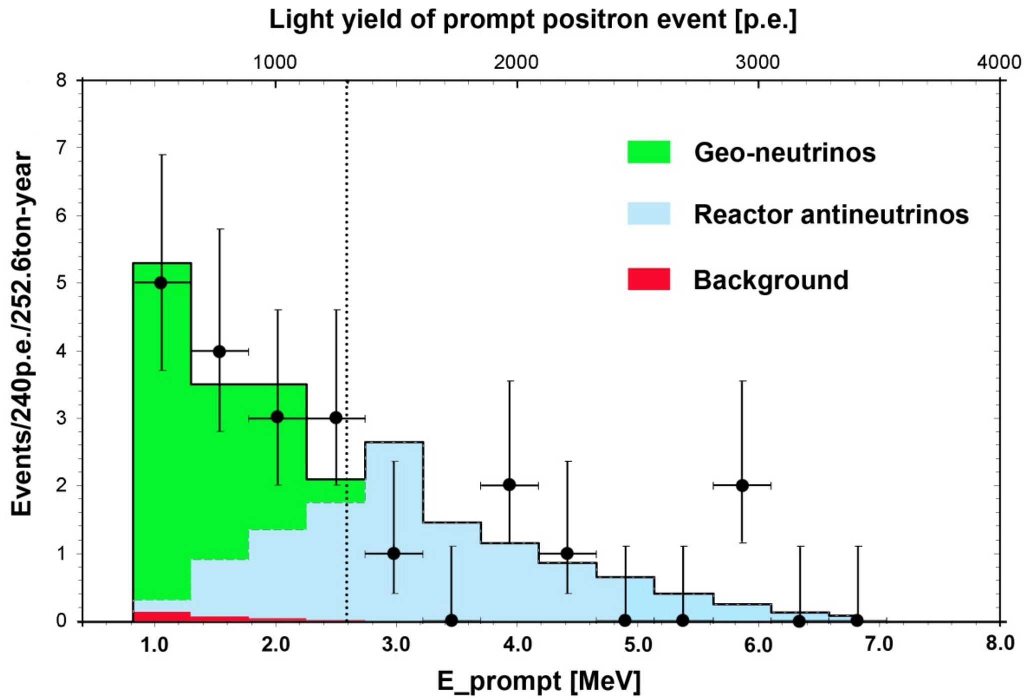
(R=14.0 ; G=6.3 ; Bk=0.4)

- The HER can be used to test the experiment sensitivity to reactors
- In the LER one expects comparable number of geo-ν and reactor-ν
- Observe **21** events in 24 months, attributed to

R=10.7 $_{-3.4}^{+4.3}$
G= 9.9 $_{-3.4}^{+4.1}$
BK=0.4

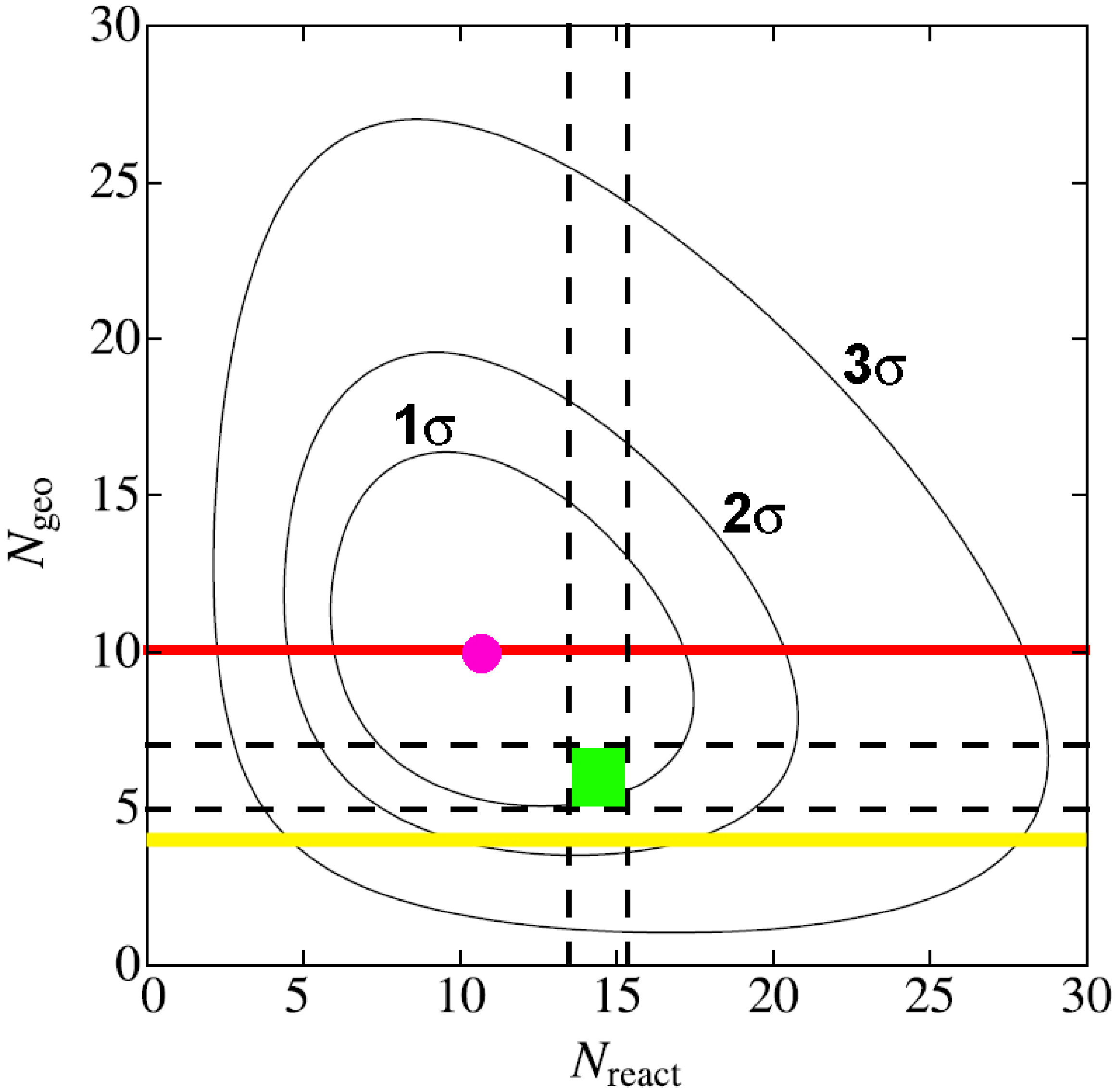
- One event per month experiment!





The significance of the observation

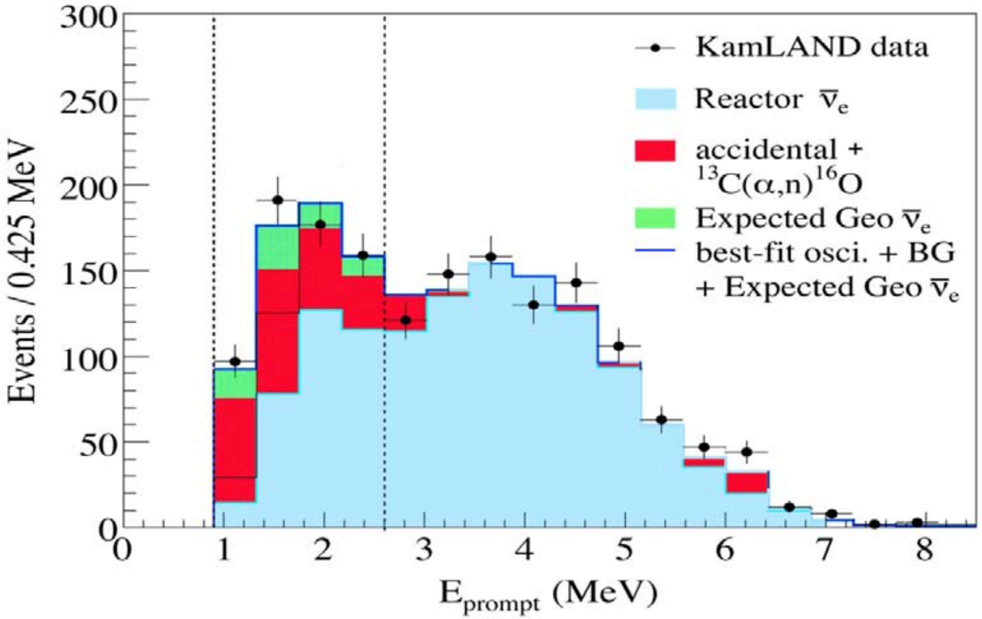
- Geo-ν = 0 is excluded with CL of 99.997 C.L. (corresponding to 4σ)
- The **Best Fit** is:
  - within 1σ from the **BSE** prediction;
  - close to the **fully** radiogenic model;
  - some 2σ from the **minimal** radiogenic model

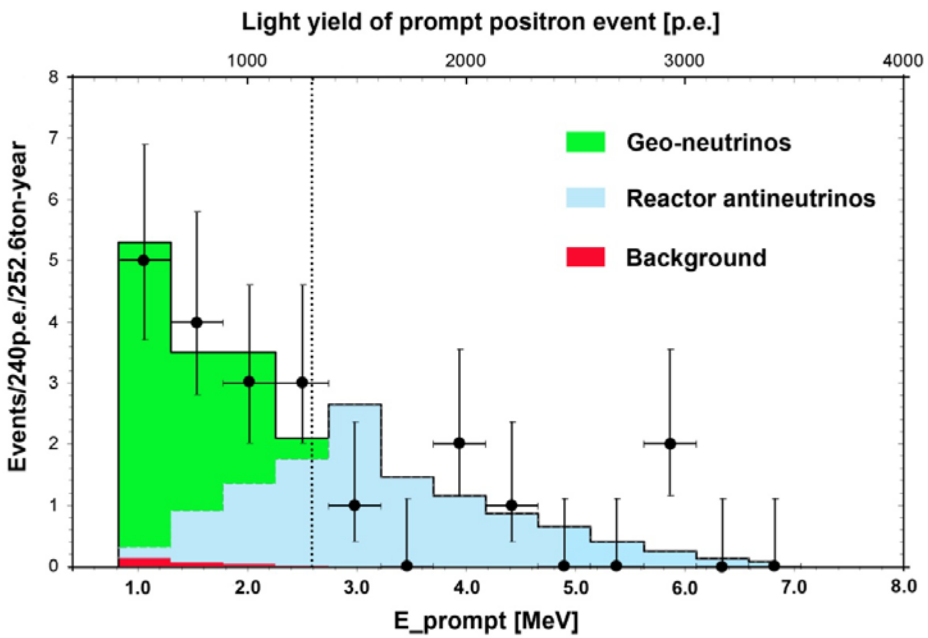


KamLAND vs Borexino

- KamLAND from 2002 to 2007 collected 630 events in the LER.
- Most due to Reactors (340) and Background (220)
- After subtraction one remains with some 70 geo-ν events, a 2.5σ evidence of geo-ν.
- Borexino has a smaller mass and exposure time
- It benefits from:
  - much higher purity
  - absence of nearby reactors

This is why Borexino can give better results even with smaller statistics





KamLAND 2010: preliminary results

KamLAND from March 2002 to November 2009 collected **841** events in the LER:

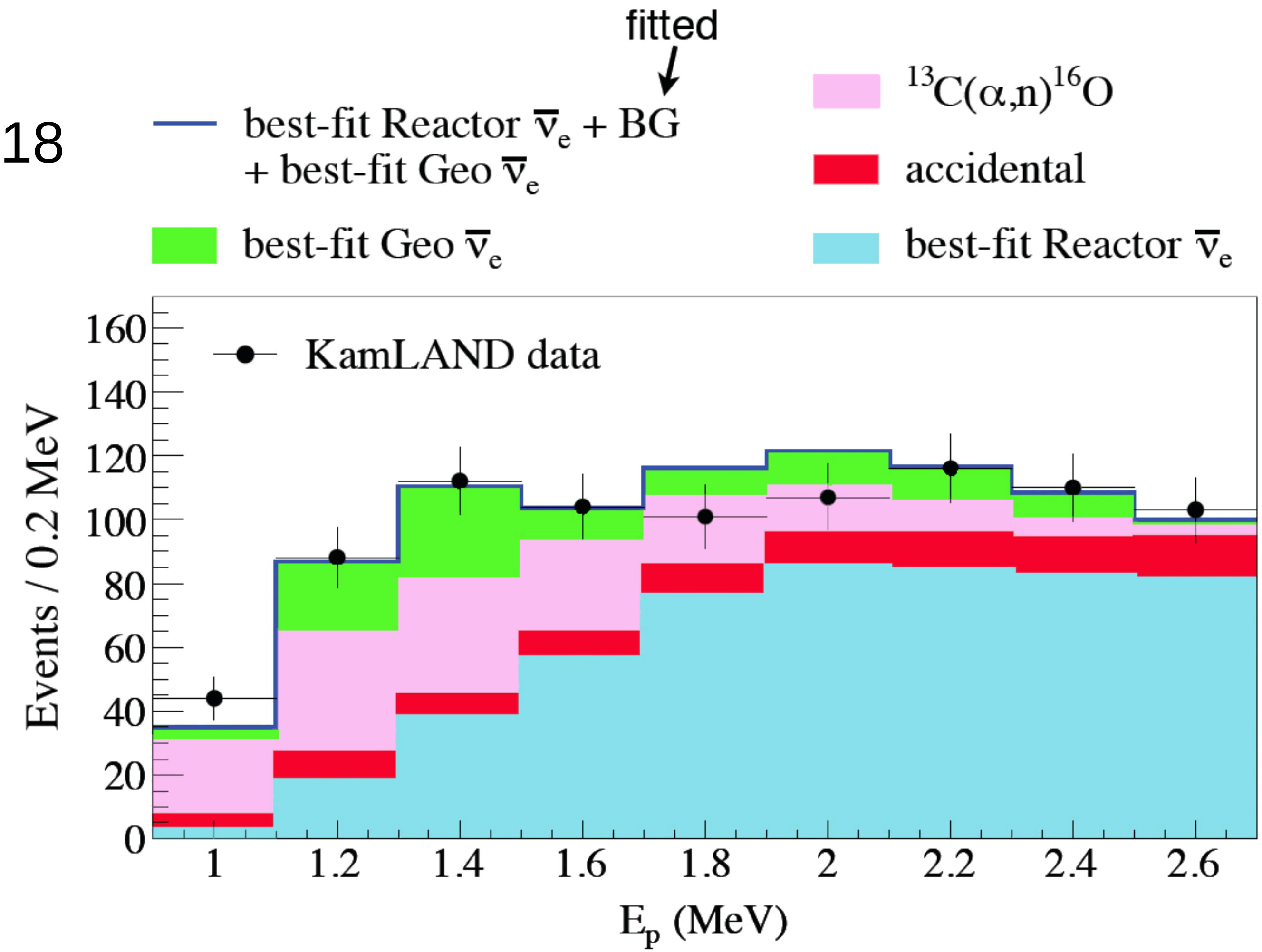
R = 485 ± 27

$^{13}C(\alpha,n)^{16}O$ = 165 ± 18

BK = 80 ± 0.1

With rate-only analysis:

Geo ν = 111^{+45}_{-43}



KamLAND 2010: implications

By using rate-shape-time analysis, the signal is:

$S(U+Th) = 38.3_{-9.9}^{+10.3}$ TNU

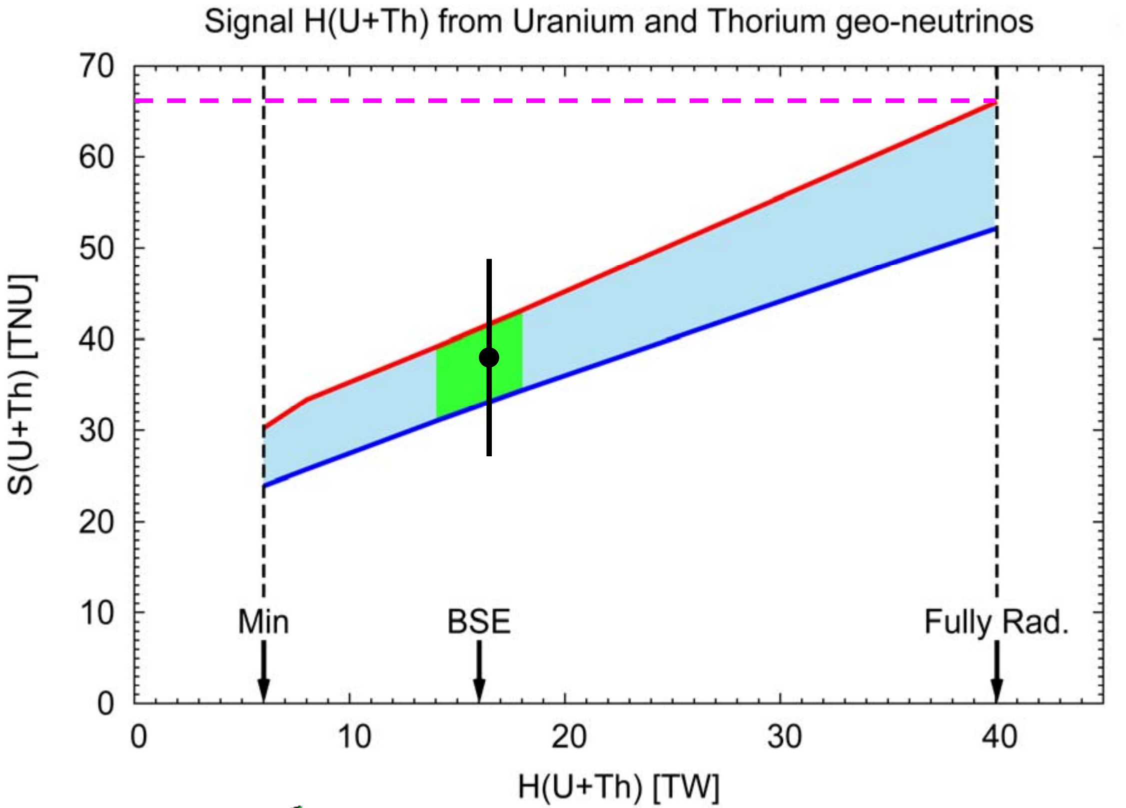
• to compare with the expected signal (Fiorentini et al. 2005):

$S(U+Th) = 36.9 \pm 4.3$ TNU

• fully radiogenic model is excluded with 2.7 σ

The era of the combination of data from multiple sites is open (see Rotunno's talk)

Fiorentini et al. (2005)



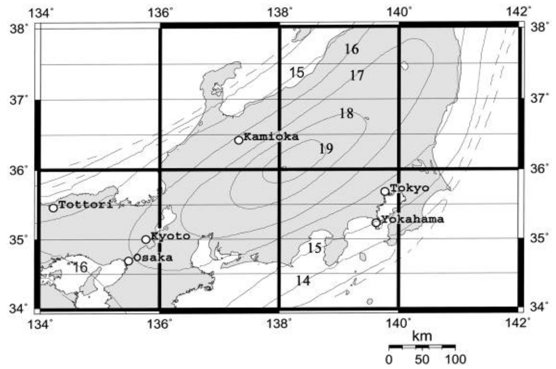
region allowed by BSE: signal between 31 and 43 TNU

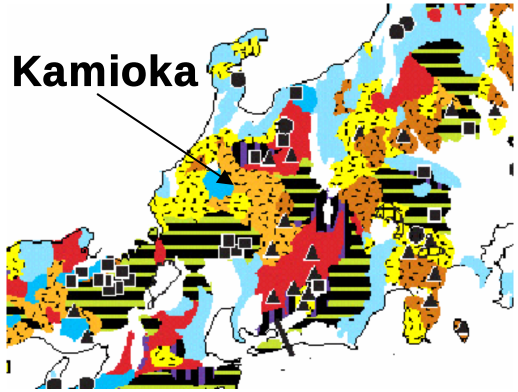
region containing all models consistent with geochemical and geophysical data

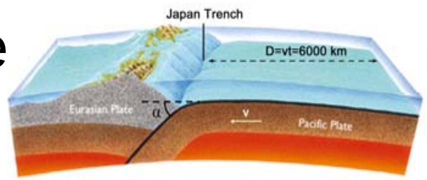

Where we are?

Refining the Reference Model for KamLAND*

- Use a geochemical study of the Japan Arc exposed upper crust (166 samples distinguishing 10 geological classes)
- Use detailed (± 1 km) measurements of Conrad and Moho depth
- Use selected values for abundances LC
- Build a new crustal map of the Japan Arc (scale ¼° x ¼°)
- Consider possible effect of the subducting plate below Japan







- Take into account several sources of uncertainties:
  - ✓ (3σ) errors on sample activity measurements
  - ✓ Finite resolution of geochemical study
  - ✓ Uncertainty from the Japan sea crust characterization
  - ✓ Uncertainty from subducting plates below Japan
  - ✓ Uncertainty of seismic measurements

** G. Fiorentini et al. – Physical Review D72 – 2005 – arXiv:hep-ph/0501111*

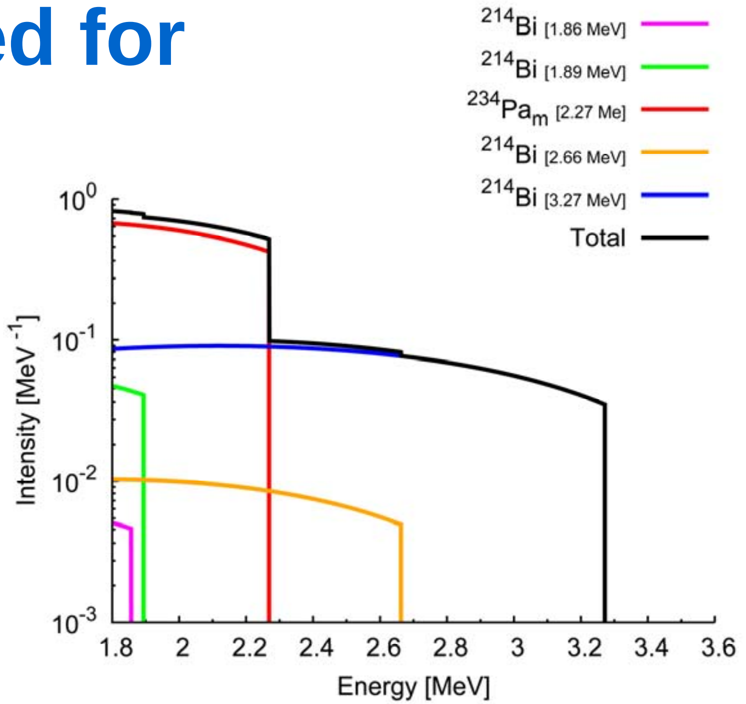
Nuclear physics inputs needed for geo-neutrino studies*

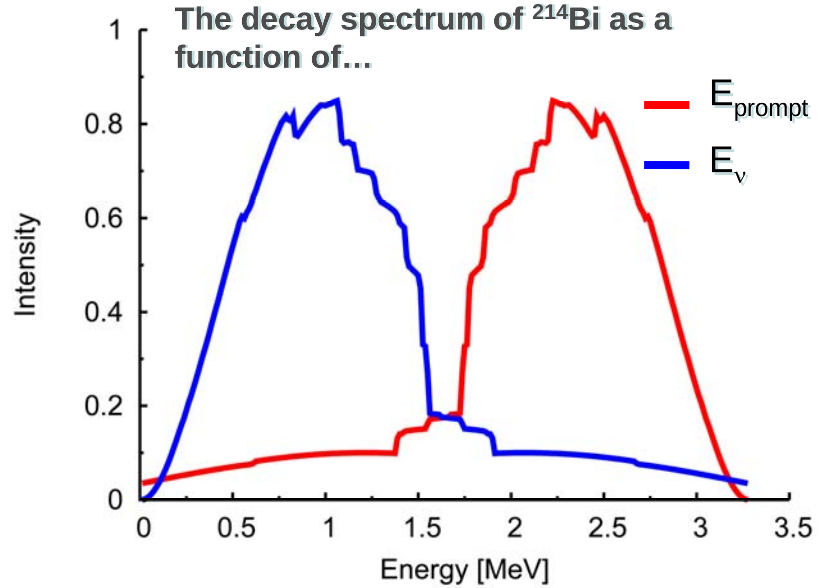
✓ Neutrino spectra are necessary for calculating the geo-neutrino signal. So far, they are derived from theoretical calculations. We propose to measure them directly.

✓ For each nuclear decay, the neutrino energy E_ν and the "prompt energy" $E_{prompt} = T_e + E_\gamma$ are fixed by energy conservation: $Q = E_\nu + E_{prompt}$

✓ Measure E_{prompt} and will get E_ν

✓ With CTF @ LNGS a method for experimental determination of geo-neutrino spectra has been developed measuring the "prompt energy" of ^{214}Bi decay





* *G. Fiorentini et al. – Phys. Rev. C 81 – 2010 arXiv:0908.3433*

Study of ^{214}Bi decay with CTF @ LNGS

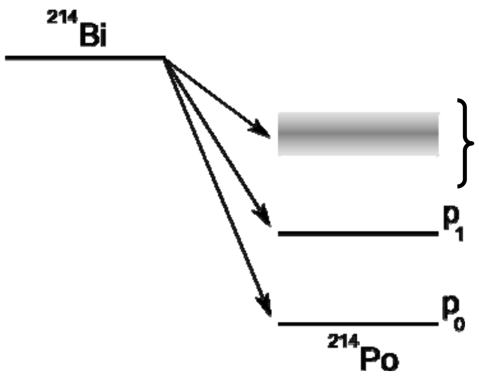
✓ Geo-neutrinos are produced through β and β-γ transitions:

$$X \rightarrow X' + e + \bar{\nu}_e \qquad X \rightarrow X'^{*} + e + \bar{\nu}_e$$
$$\hookrightarrow X' + n\gamma$$

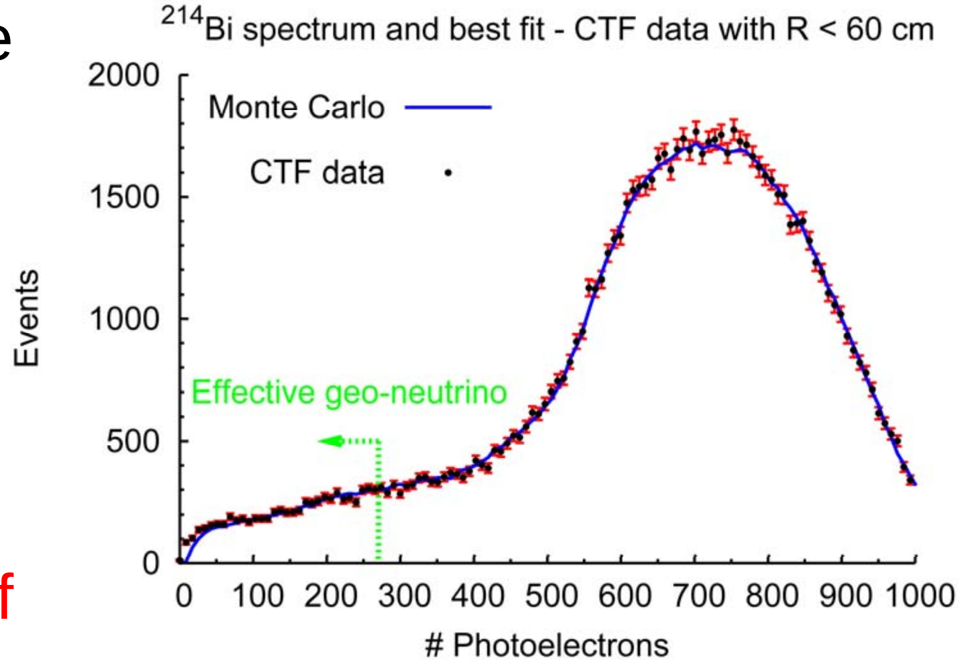
✓ For geo-neutrino studies only the ground and first excited state are relevant.

✓ By using data from a ^{222}Rn contamination of CTF, we measured the feeding probabilities p_0 and p_1 of these states.

✓ The result is consistent and of comparable accuracy with that found in Table of Isotopes (derived from indirect measurements of γ line intensities and theoretical assumptions)



E_γ(max) [keV]	S_{U+Th}(%)
… 1894	0
2663	1.6
3272	46



	CTF	TOI
p_0	0.177 ± 0.004	0.182 ± 0.006
p_1	0.008 ± 0.005	0.017 ± 0.006


Where are we going?

Refining the Reference Model for Gran Sasso

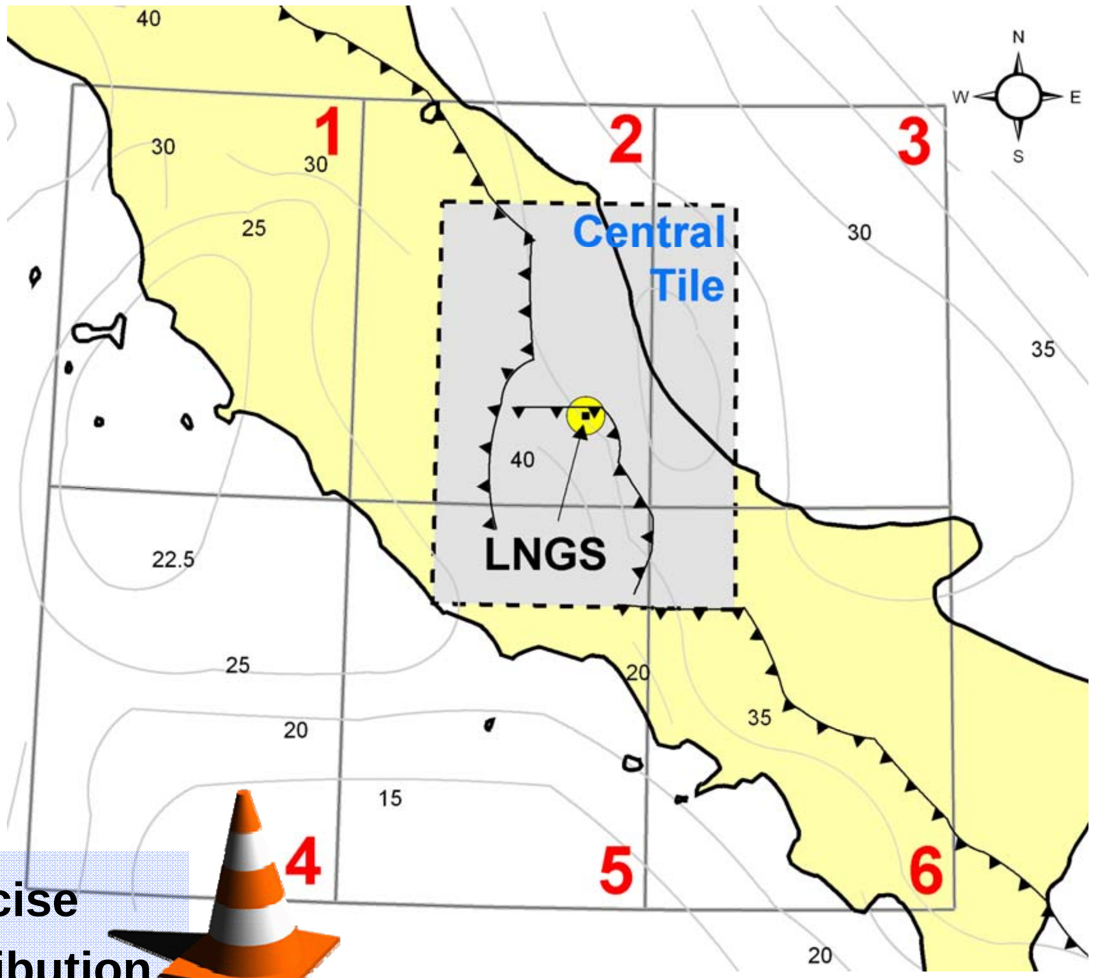
- Our 2004 world wide reference model (16200 2°x2° tiles) predicts for Borexino: $\boxed{S = 40.5 \pm 6.5 \text{ TNU}}$

- The contribution of the 6 tiles near Borexino was found by us (Ref. Mod.) as:

$$\boxed{S_{reg} = 15.5 \text{ TNU}}$$

- A 2°x2° tile centered at Gran Sasso gives:

$$\boxed{S_{CT} = 12.2 \text{ TNU}}$$

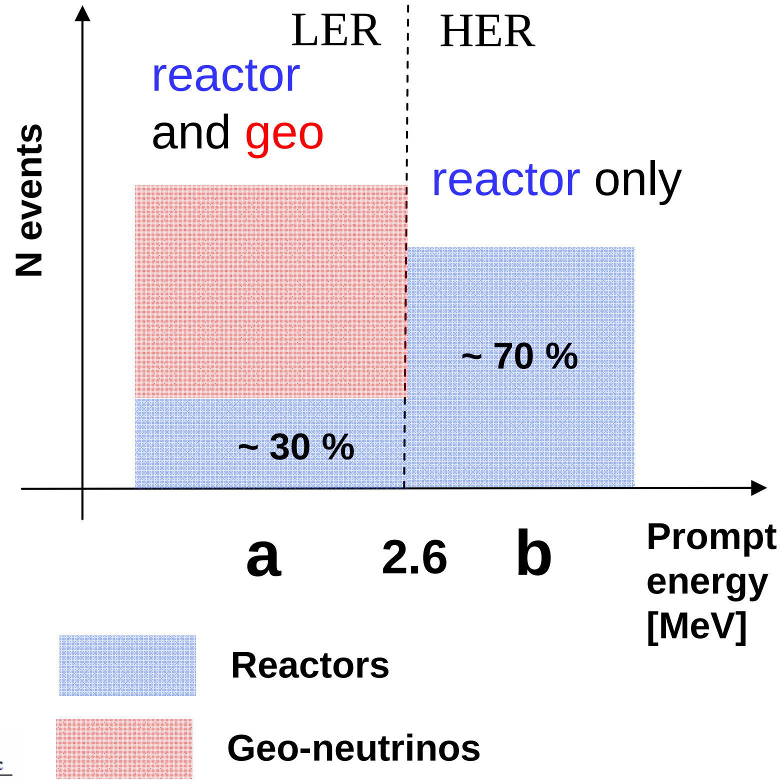


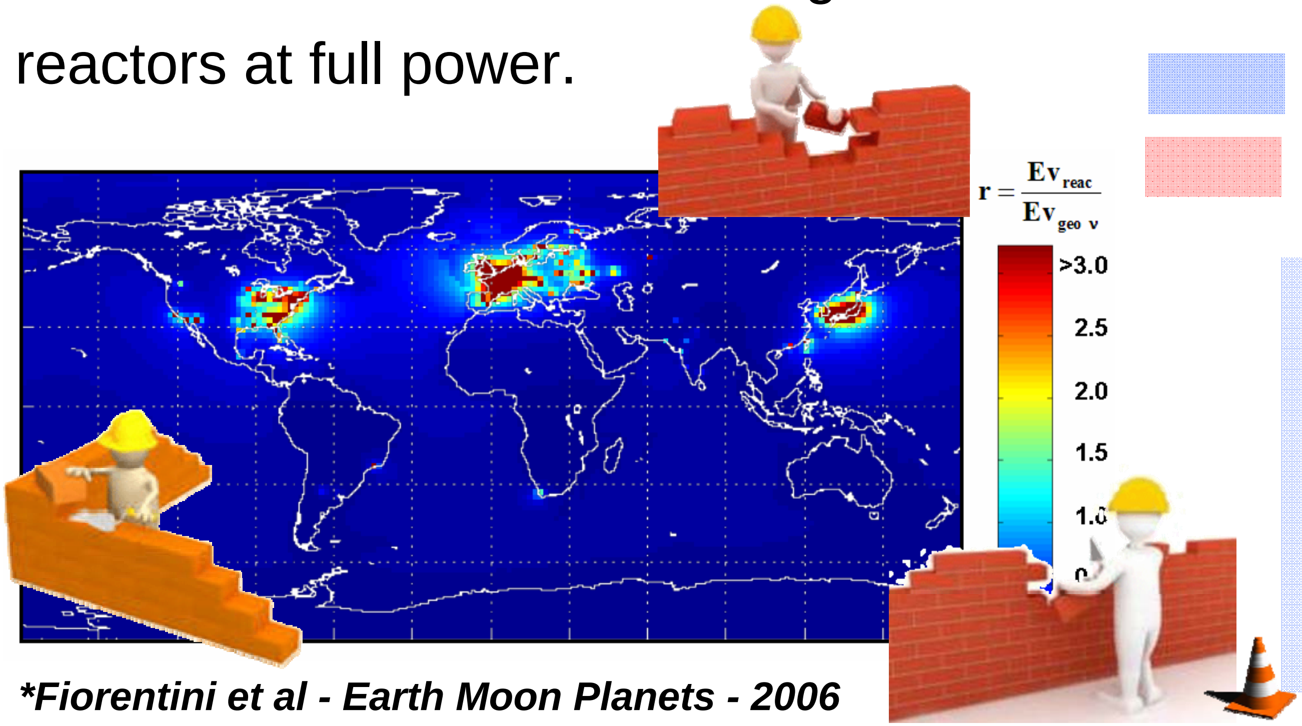
We are completing a more precise assessment of this regional contribution

Antineutrinos from reactors and geo-neutrinos

• The **HER** has to be controlled by studying the different contributions from the nuclear reactors, if one wants to compare $Ev_{geo\text{-}\nu}$ and Ev_{react} in the **LER**.

• The 2006* map is based on 2000 IAEA database and considering all reactors at full power.





Fiorentini et al - Earth Moon Planets - 2006

We are updating the $Ev_{geo\text{-}\nu}$ / Ev_{react} considering more recent data and the uncertainties about the anti-ν flux from reactors

Geological implications

Prof. Roberta Rudnick and Prof. Bill McDonough (University of Maryland) are Copernicus Visiting Scientists at Ferrara University in October 2010: one month partially funded by FA51

A collaboration between physicists and geologists to develop specific topics:

- project of a world wide refined reference model

- the implications of KamLAND and Borexino data on specific sylicate Earth models

Neutrino Geoscience at LNGS – 6-8 October 2010

http://geoscience.lngs.infn.it/

Scientific Committee

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