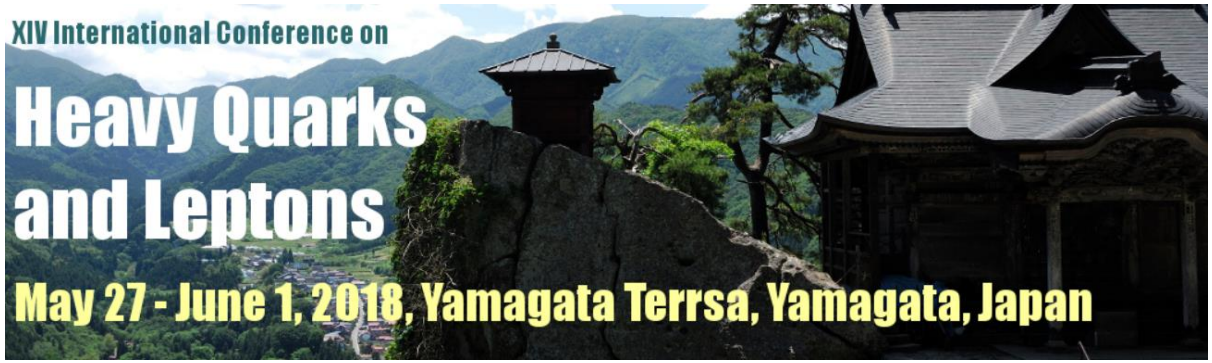
Results on geoneutrinos at Borexino experiment

Heavy Quarks and Leptons 2018 - Yamagata

Davide Basilico



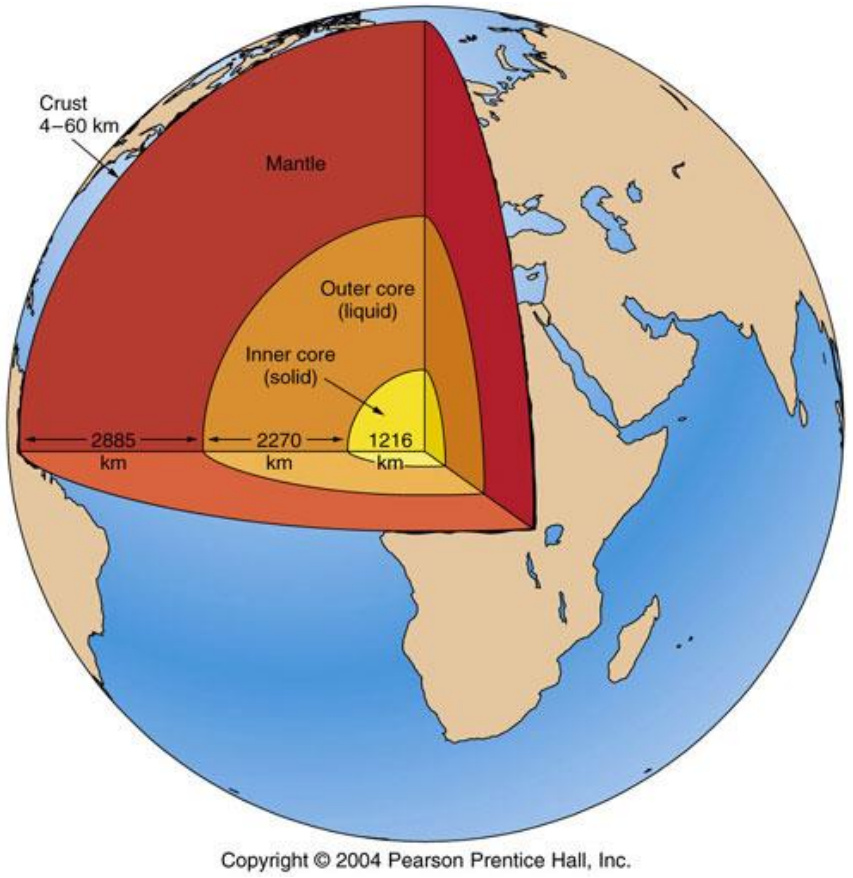
UNIVERSITÀ DEGLI STUDI DI MILANO

INFN

Istituto Nazionale di Fisica Nucleare

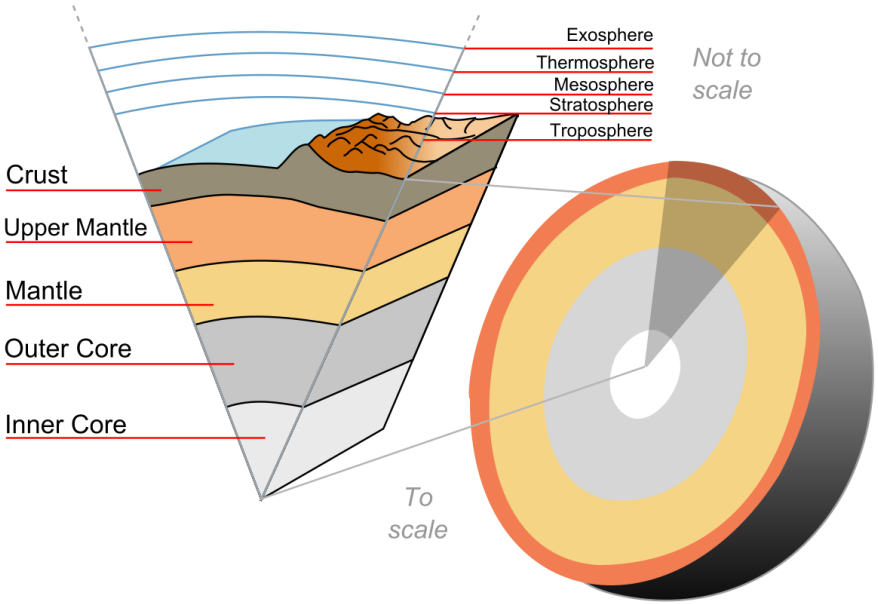
Outline

1. Geoneutrinos
2. Borexino
3. Analysis and results



What are geoneutrinos?

Distribution of long-lived nuclides in the Earth (^{238}U and ^{232}Th chains) → β^- decay



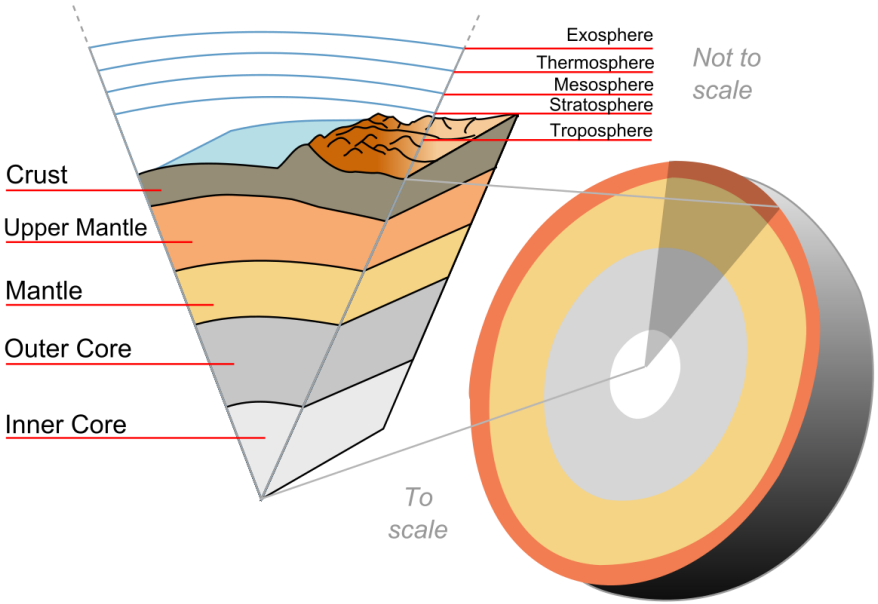
What are geoneutrinos?

Distribution of long-lived nuclides in the Earth (^{238}U and ^{232}Th chains)

→ β^- decay

→ Energy net release: heat

→ Anti-neutrinos: geoneutrinos



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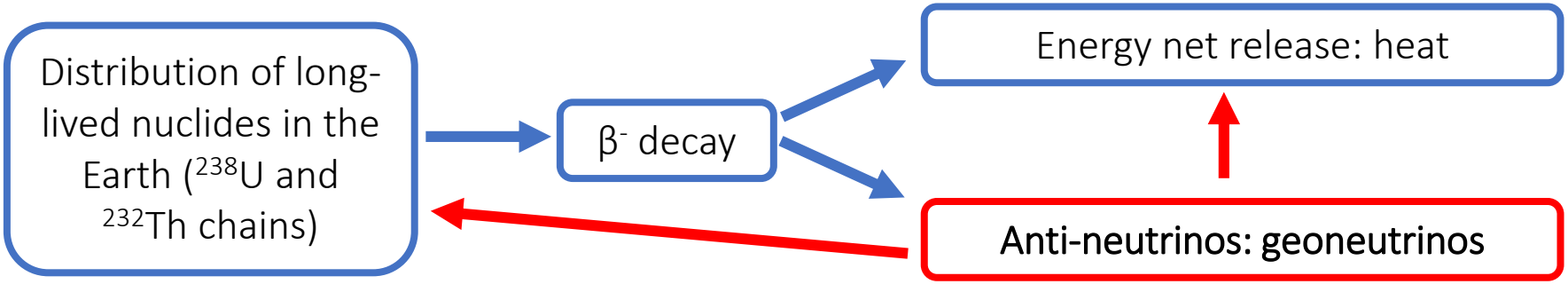

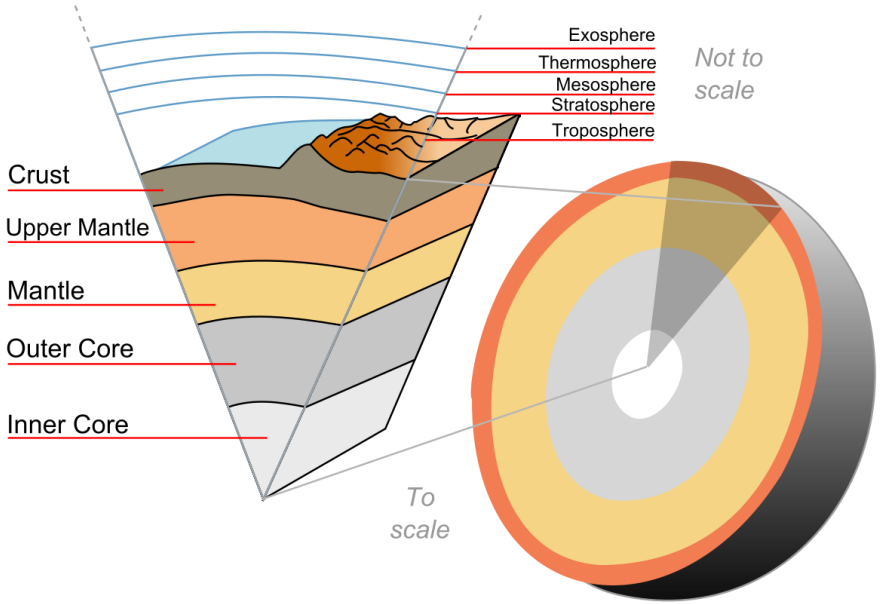

- **Direct messengers** of the abundances of radioactive elements
- Measuring their flux and spectrum → understand the radiogenic contribution to the total heat balance of the Earth.
- **Discriminate Earth models** (cosmochemical, geochemical, geodynamical etc…)

How to measure geoneutrinos?

What do we need to measure geoneutrinos?

Anti-neutrinos have **low interaction rates:** $\sigma \sim 10^{-44}$ cm^2 @ MeV

→ experiments with **extremely low background**

- Large volume detectors
- Construction materials → high radiopurity

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KamLAND in Japan

- Main goal: reactor anti-neutrinos measurements

Borexino experiment in Gran Sasso, Italy

- **Extreme radiopurity** achieved to perform solar neutrinos spectroscopy (main goal)
- But also able to measure anti-neutrinos!
- **No nuclear power plant in Italy** → smaller background wrt Kamland
- **Underground lab** → shielding cosmic rays radiation and related background

Gran Sasso National Laboratory (Italy)

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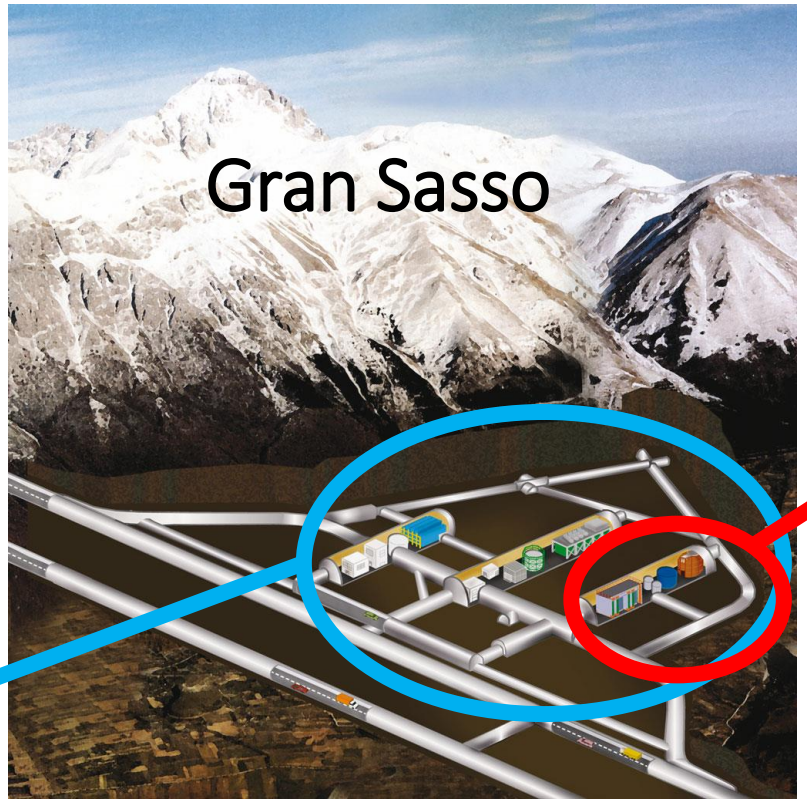
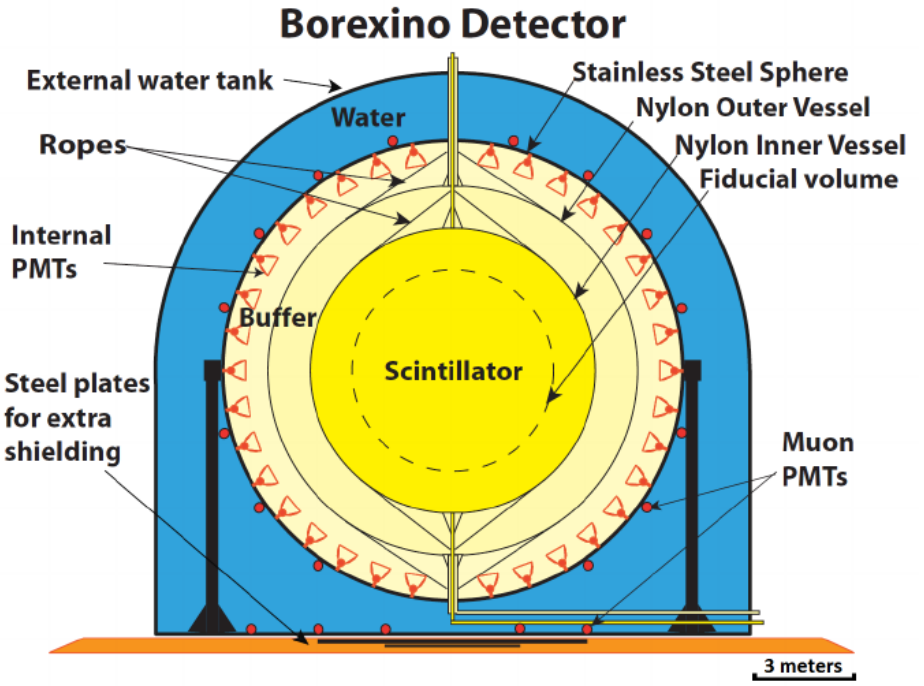
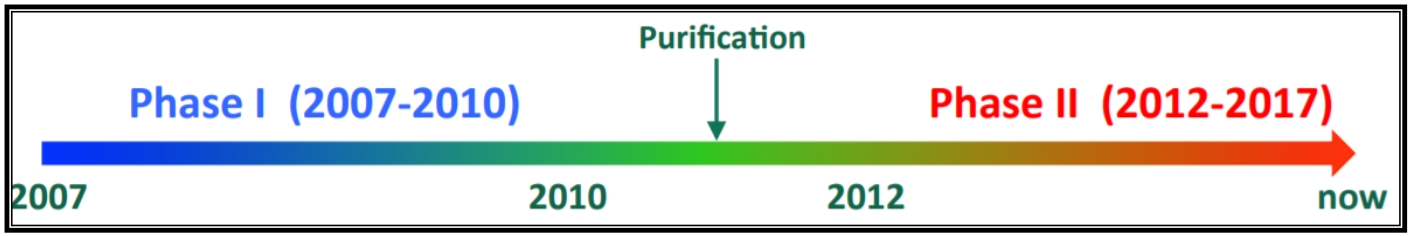


Borexino detector



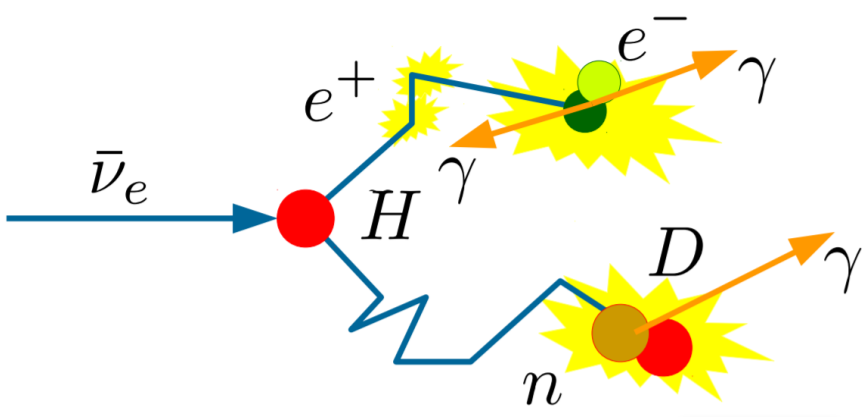
- DAQ started in 2007
- Main analysis: **solar neutrinos spectroscopy** (see David Bravo's talk)
- 300 ton of ultra-pure liquid scintillator
- Extremely low radioactive background
- 2000 PMTs to measure:
  - positions → photons time arrival
  - energy → number of photons detected



How to detect geo-ν in Borexino? ($\rightarrow \bar{\nu}$)

Inverse Beta Decay

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



Energy $\bar{\nu}_e$ threshold: 1.8 MeV

Prompt signal:

- e^+ scintillation + annihilation (2γ)
- $E_{prompt} \approx E_{geoneutrino}$ - 0.782 MeV

Delayed signal (neutron):

- n capture on H
- $E_{delayed} \approx 2.2$ MeV
- $\langle \Delta t \rangle = 254.5 \pm 1.8$ μs

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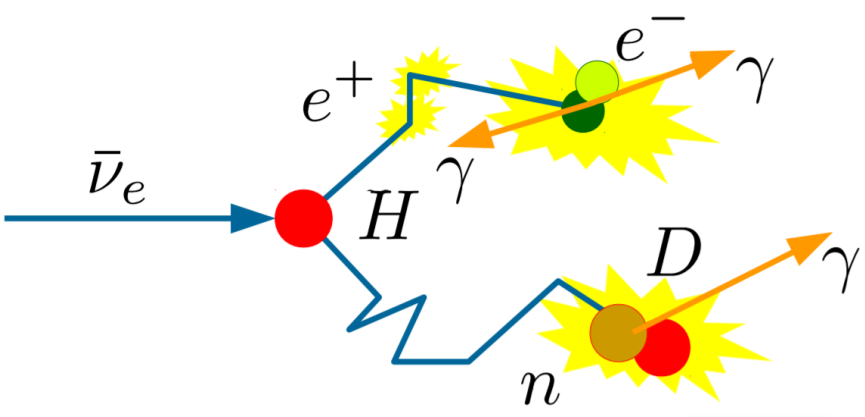

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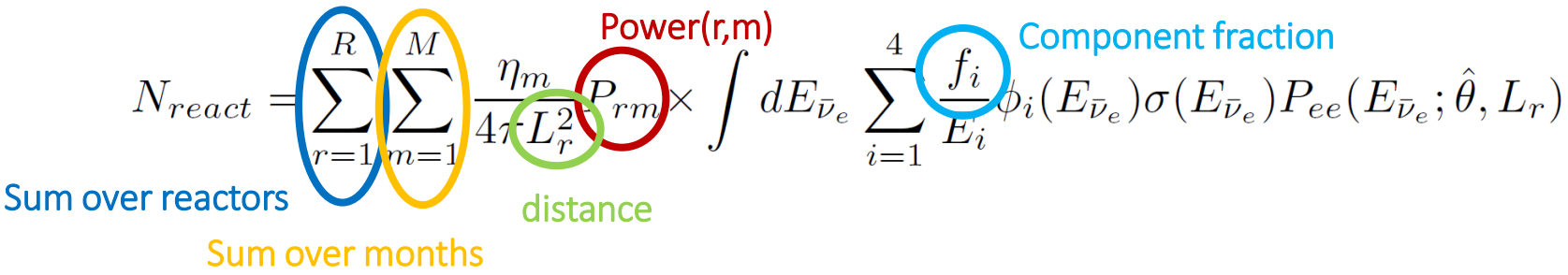
Coincidence in time / space / energy between prompt and delayed guarantees a **very high signal/background ratio** (100:1 in Borexino)

Reactor $\bar{\nu}$ background

- MeV anti-ν background: nuclear power plants (E < 8 MeV)
- 98% European ones
- Estimation of the exp. events from the spectral components of ^{235}U, ^{238}U, ^{239}Pu and ^{241}Pu



$$N_{react} = \sum_{r=1}^{R} \sum_{m=1}^{M} \frac{\eta_m}{4\pi L_r^2} P_{rm} \times \int dE_{\bar{\nu}_e} \sum_{i=1}^{4} \frac{f_i}{E_i} \phi_i(E_{\bar{\nu}_e}) \sigma(E_{\bar{\nu}_e}) P_{ee}(E_{\bar{\nu}_e}; \hat{\theta}, L_r)$$

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Power(r,m)

Component fraction

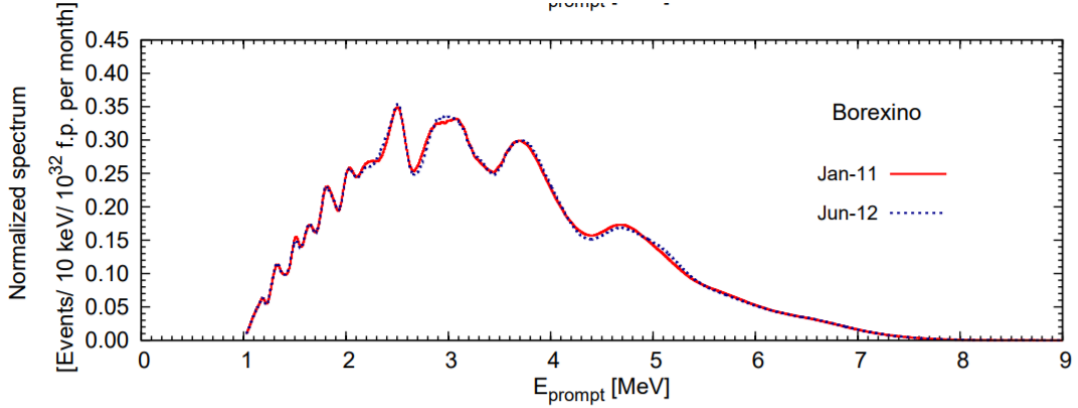
Sum over reactors

distance

Sum over months

Expected:
5.7 ± 0.3 events / (100 ton yr)

→ Information on fuel power composition (in time!) is required



Other background (not $\bar{\nu}$ related)

1) Cosmogenic-muon related:
- ^{9}Li and ^{8}He decaying β^{-} + neutron;
- High-energy neutrons: neutron scattering + neutron capture = prompt + delayed

2) Accidental coincidences

3) Internal radioactivity:
(α,n) and (γ,n) reactions

Source	Rate [events/100ton yr]
^{9}Li-^{8}He	$0.194^{+0.125}_{-0.089}$
Accidental coincidences	0.221 ± 0.004
Time correlated	$0.035^{+0.029}_{-0.028}$
(α,n) in scintillator	0.165 ± 0.010
(α,n) in buffer	<0.51
Fast n's (μ in WT)	<0.01
Fast n's (μ in rock)	< 0.43
untagged muons	0.12 ± 0.01
Fission in PMTs	0.032 ± 0.003
^{214}Bi-^{214}Po	0.009 ± 0.013
Total	$0.78^{+0.13}_{-0.10}$
	< 0.65(combined)

Almost negligible
(if compared to reactors)

Selection cuts

Prompt signal:

- $Q_{prompt} > 408$ p.e.
- Fiducial Volume Cut

1 MeV ≈ 500 p.e.

Delayed signal:

- $860 < Q_{delayed} < 1300$ p.e.

Coincidence:

- Time: $20 < \Delta t < 1280$ μs
- Space: $\Delta R < 100$ cm

Muon correlated cuts

Pulse shape discrimination cuts

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Pulse shape discrimination cuts

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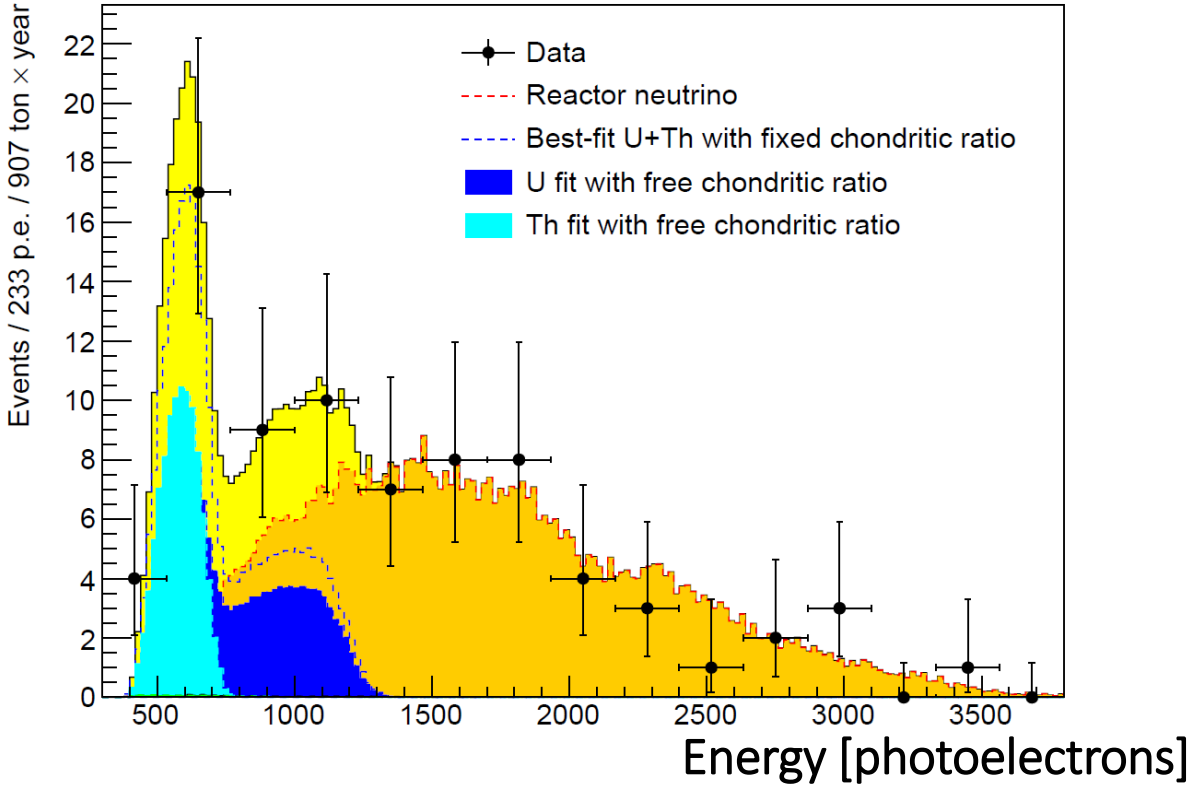
Total efficiency = (84.2 ± 1.5)% (MC). 77 candidates selected

Spectrum from 2056 days data-taking

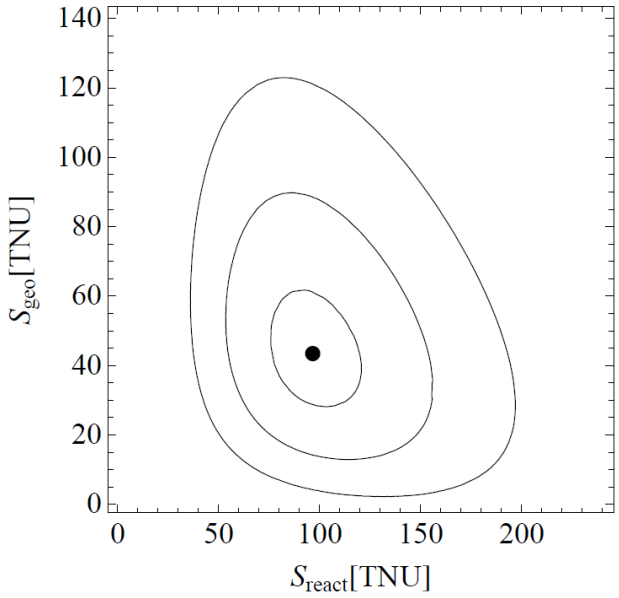


Two fits: U/Th ratio

1. **Fixed** to chondritic value model
2. **Free**

- **Un-binned likelihood fit** of prompt events energy spectrum
- **Reactor spectrum** is obtained by MC simulations and left free in the fit
- **Non-$\overline{\nu}_e$ background** considered in the fit but constrained to independent estimations → completely negligible

Evidence and implications



1 TNU = 1 event detected over 1 year exposure of 10^{32} target protons at 100 % efficiency

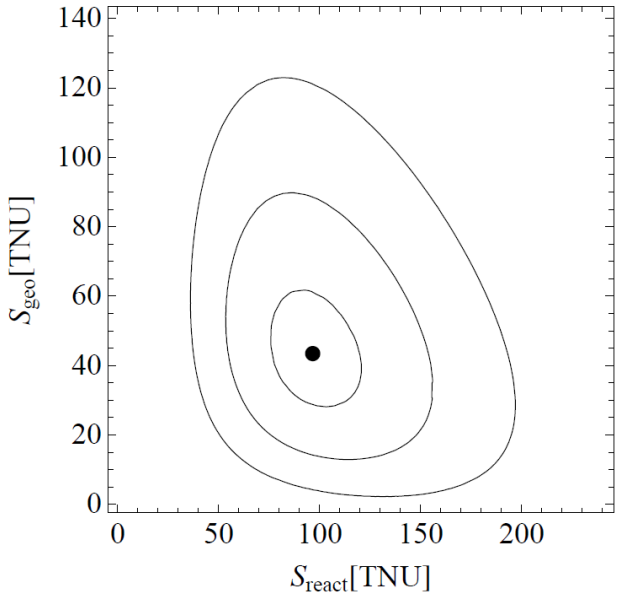
Fixing mass ratio U/Th=3.9

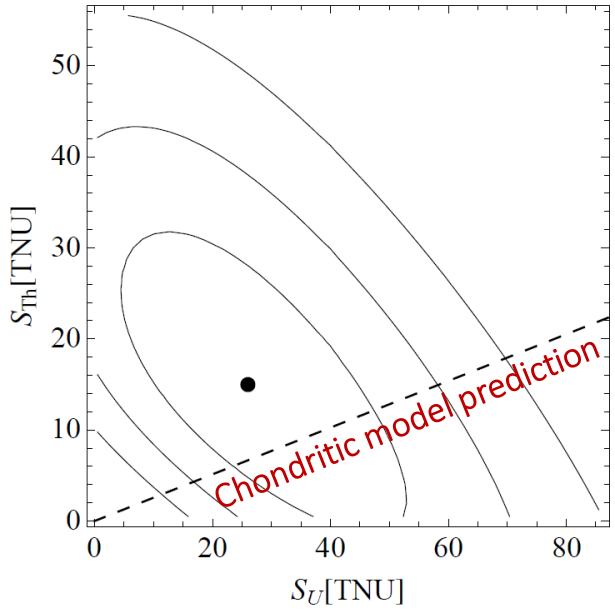
$$N_{geo} = 23.7^{+6.5}_{-5.7}(stat)^{+0.9}_{-0.6}(syst)$$

geoneutrino events: <u>5.9σ evidence</u>

$$S_{geo} = 43.5^{+11.8}_{-10.4}(stat)^{+2.7}_{-2.4}(syst)TNU$$

Evidence and implications





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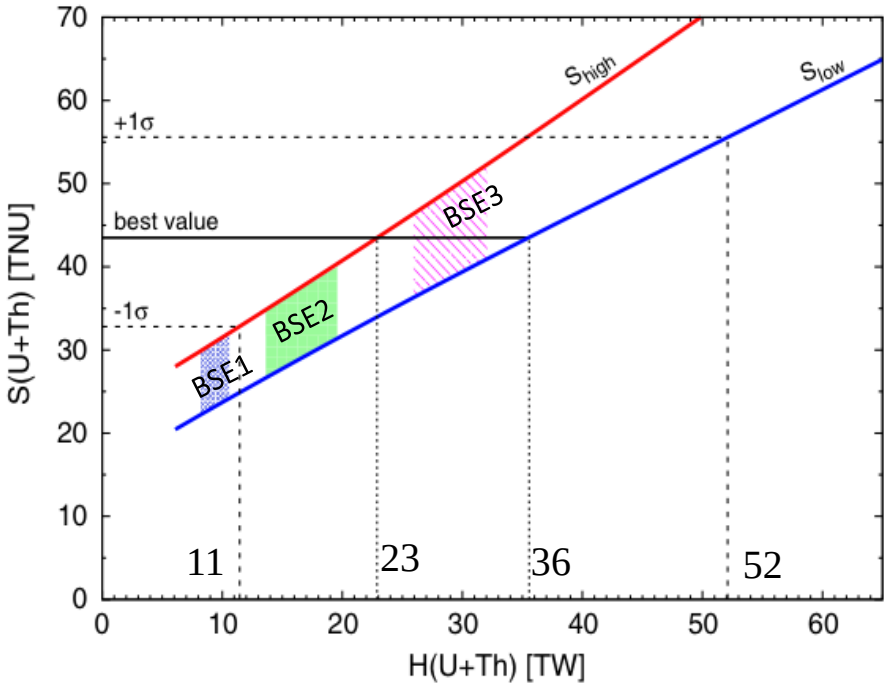
Mass ratio U/Th free parameter

Best fit value compatible with U/Th=3.9

Implications: heat



Vertical band between red and blue line due to U+Th distribution in the mantle

U+Th: radiogenic heat is 23-36 TW (best fit) and 11-52 TW for 1σ interval
Complete – U+Th+K: mass ratio U/Th=3.9 and K/U = 10^4, radiogenic heat 33^{+28}_{-20} TW

Independently measured total Earth surface power: 47 ± 2 TW
→ large contribution from radioactive decays!

Conclusions

1) The background level in Borexino allows to perform a **real-time spectroscopy of geoneutrinos**, limited only by the size of the detector;

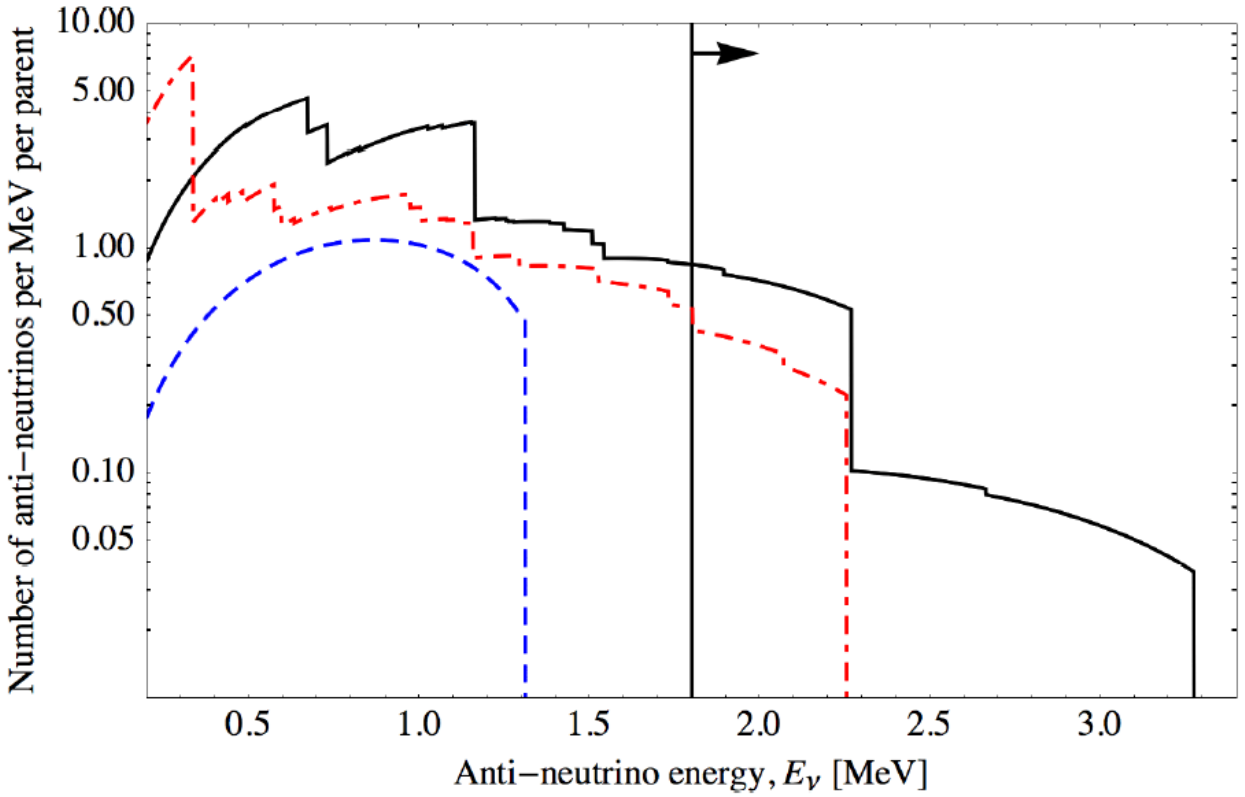
2) Borexino-only data: **geoneutrinos exist, with 5.9 significance;**

3) The **radiogenic heat** gives an important contribution to the Earth power balance;

4) **Interdisciplinary field** between physics and geoscience.

Thank you!

Geoneutrinos energy spectra



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

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

$$^{40}\mathrm{K} \rightarrow ^{40}\mathrm{Ca} + e^- + \bar{\nu}_e + 1.31 \quad \mathrm{MeV}$$

Energy spectra of geo-neutrinos released in the reactions: 238U chain in black, 232Th chain in red, 40K in blue. Vertical line: IBD threshold (1.806 MeV)

Chondrites

- Chondrites are primitive, undifferentiated meteorites, a collection of the earliest formed material in the solar system.
- Studies of meteorites add much to our understanding of the age of the solar system and the nature of the building blocks that makes up the planets.
- Mixture of silicate and metal materials in proportions similar to that found in the terrestrial planet