NOW 2024
Neutrino Oscillation Workshop

Geoneutrino physics at JUNO

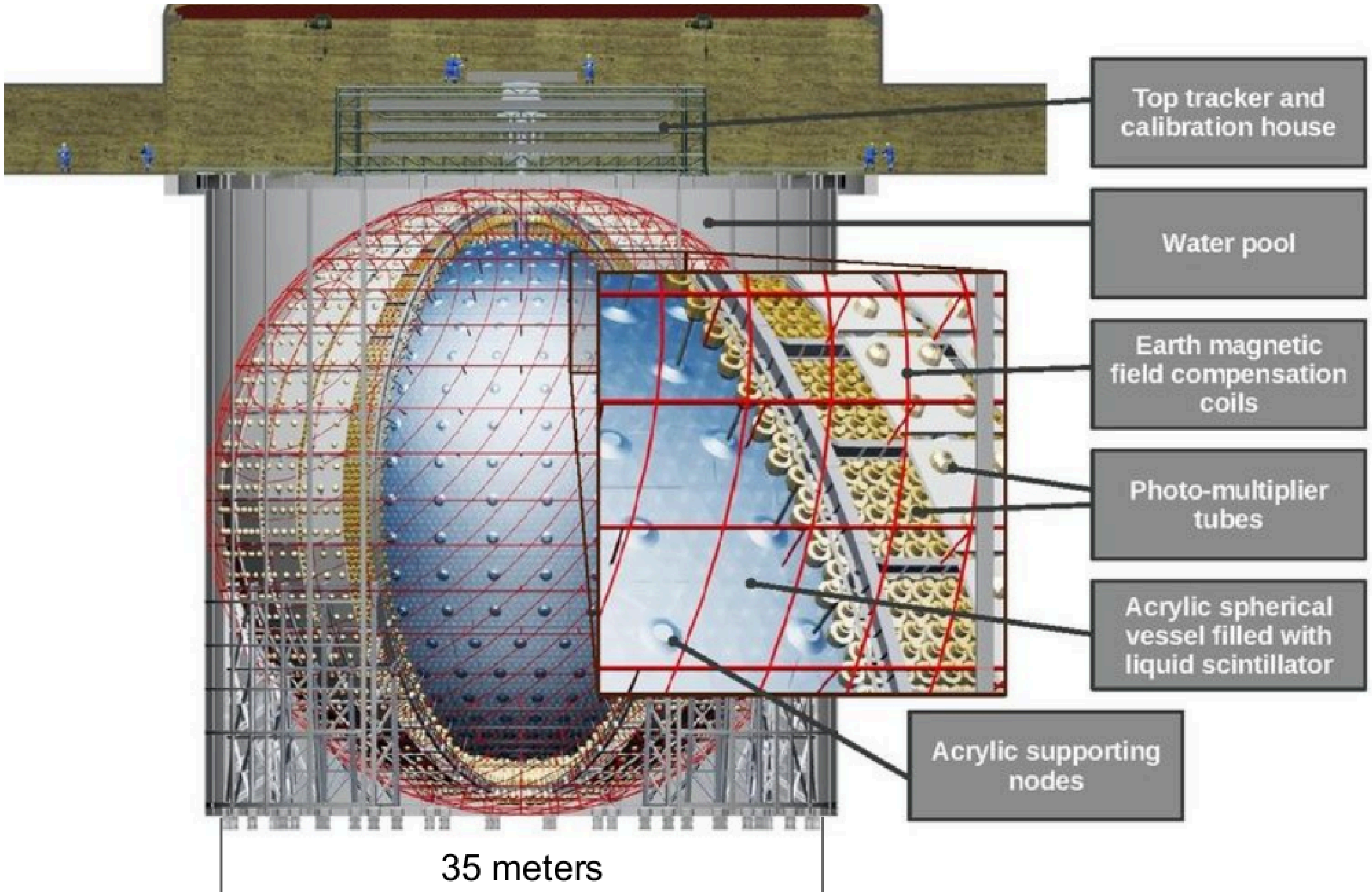
Fernanda Rodrigues
On behalf of the JUNO Collaboration

Institute of High Energy Physics - Beijing

Jiangmen **U**nderground **N**eutrino **O**bservatory (**JUNO**)

- Located in Jiangmen, Guangdong province in Southern China;
- Placed at 52.5 km from two Nuclear Power Plants;
- Overburden ~ 700 m;
- **20 ktons of Liquid Scintillator (LS);**
- **17612 20" Large Photomultiplier Tubes (LPMT) and 25600 3" Small Photomultiplier Tubes (SPMT).**

Jiangmen Underground Neutrino Observatory

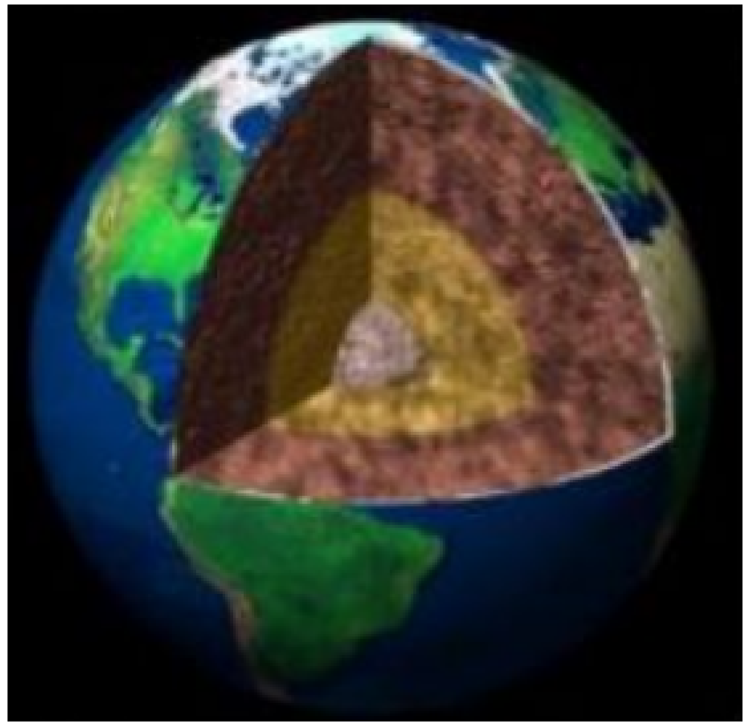


Designed for unprecedented energy resolution, 3% at 1 MeV !

Neutrino oscillation: mass ordering, 3 sigmas in 6 years

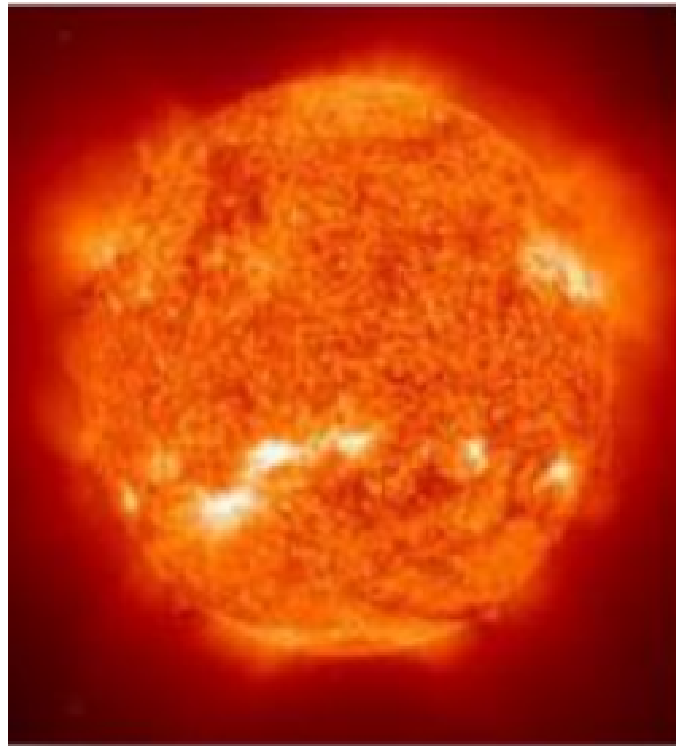
JUNO: Multi-purpose detector

Reactor anti-neutrino



Geoneutrino

Atmospheric neutrino



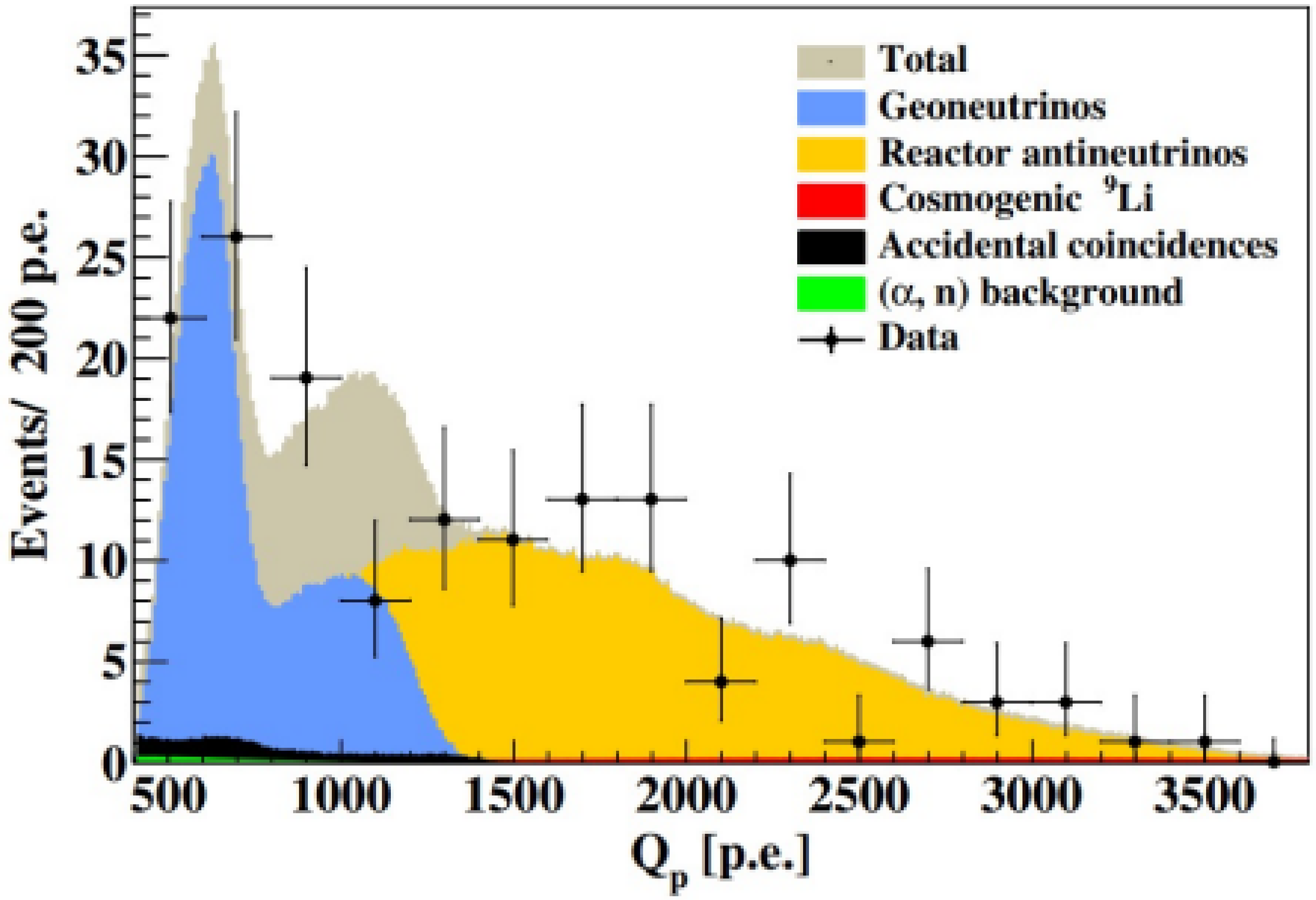
Solar neutrino

Supernova neutrino

Current Measurements

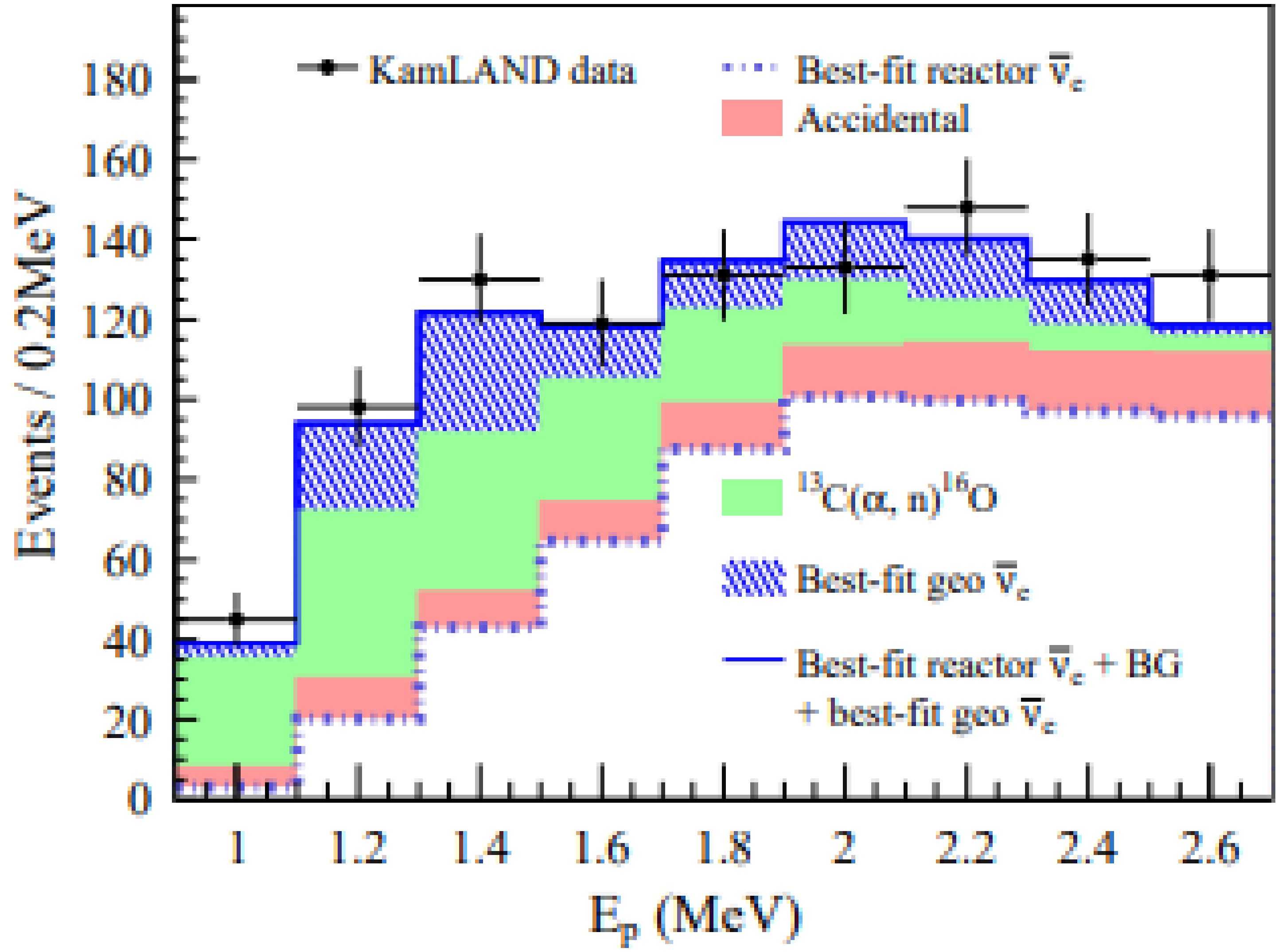
Borexino 2020 Phys. Rev D 101, 2020

- Experiment in Gran Sasso, Italy
- Liquid Scintillator ~ 0.3 kton
- In 10 years ~ 50 geoneutrinos
- Precision ~ 17%

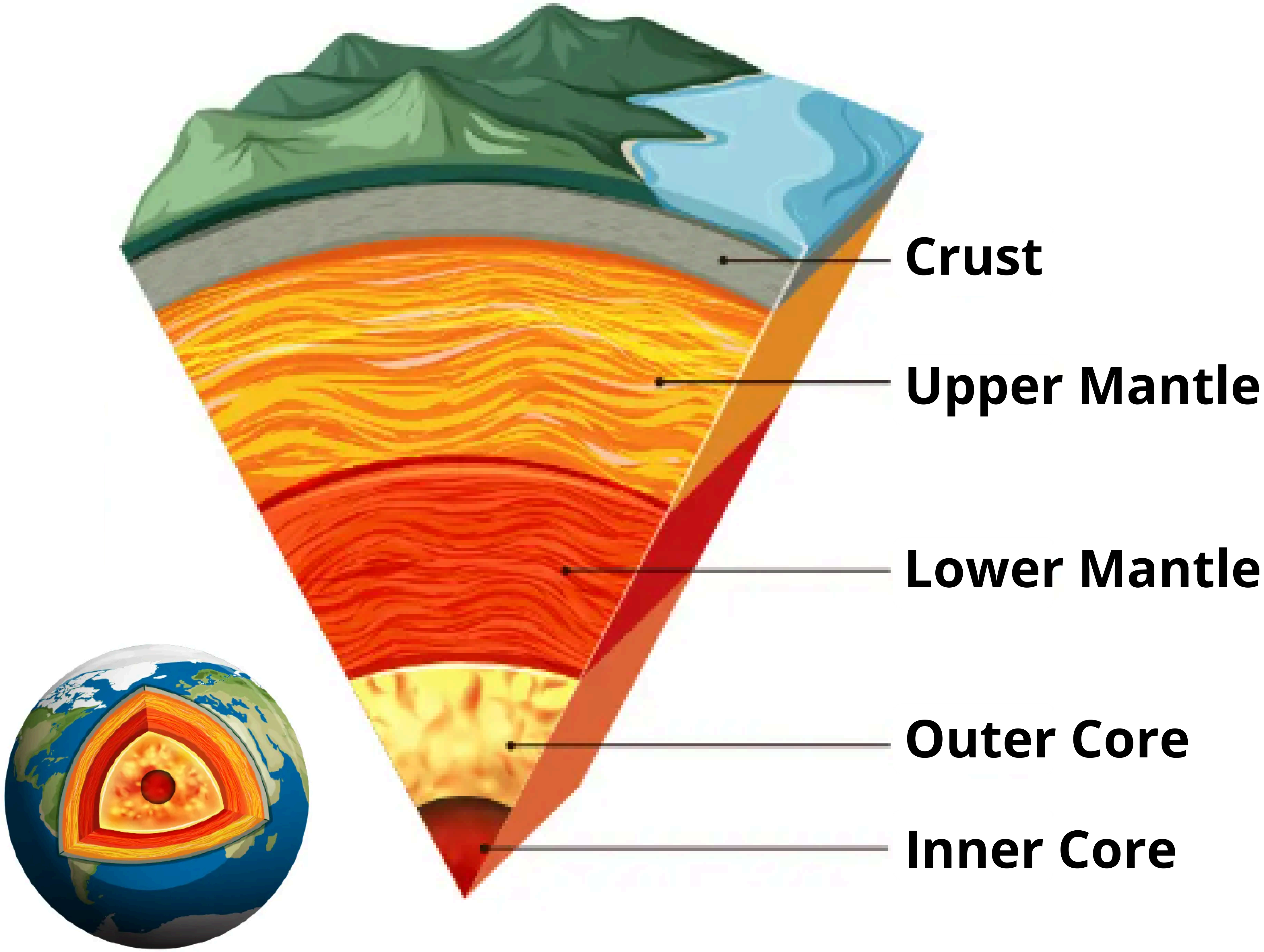


KamLAND 2022 Geophys. Res. Lett. 49 (16), 2022

- Experiment in Hida, Gifu, Japan
- Liquid Scintillator of 1 kton
- In 18 years ~ 170 geoneutrinos
- Precision ~ 15%



Earth's Structure



Crust can be "accessed" directly by collecting rocks samples

Mantle is hard to access:

- Seismology;
- Rocks from tectonic and volcanic activities.

Geoneutrinos

Geoneutrinos: (anti)neutrinos from the decay of long-lived particles

Abundance of the radioactive elements → **Radiogenic heat**

Accessible via anti-ν_e measurement

$$^{238}_{92}\mathrm{U} \rightarrow ^{206}_{82}\mathrm{Pb} + 8\alpha + 6e^- + 6\bar{\nu}_e + 51.698\ \mathrm{MeV}$$

$$^{235}_{92}\mathrm{U} \rightarrow ^{207}_{82}\mathrm{Pb} + 7\alpha + 4e^- + 4\bar{\nu}_e + 46.402\ \mathrm{MeV}$$

$$^{232}_{90}\mathrm{Th} \rightarrow ^{208}_{82}\mathrm{Pb} + 6\alpha + 4e^- + 4\bar{\nu}_e + 42.652\ \mathrm{MeV}$$

Geoneutrinos

Geoneutrinos: (anti)neutrinos from the decay of long-lived particles

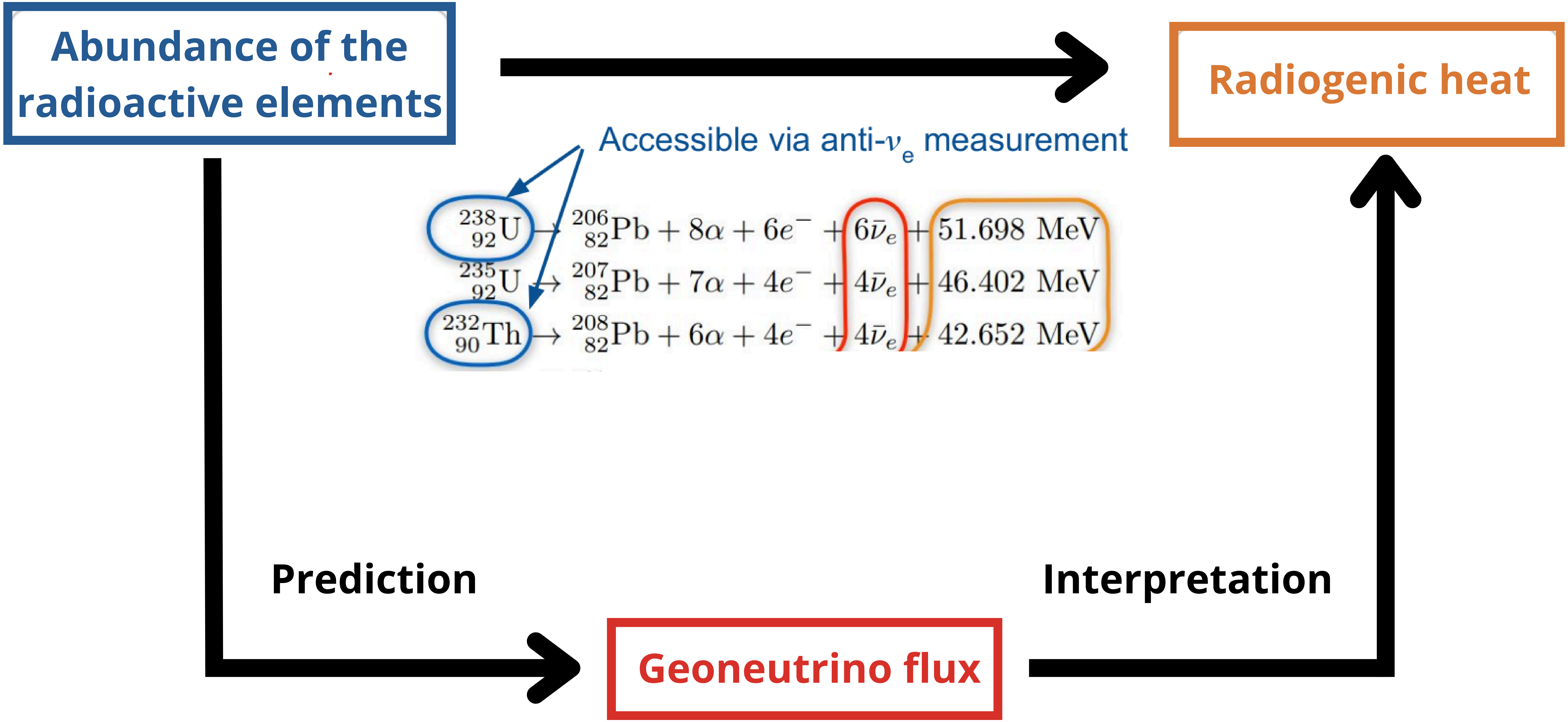
Abundance of the radioactive elements → **Radiogenic heat**

Accessible via anti-ν_e measurement

$$^{238}_{92}\mathrm{U} \rightarrow {}^{206}_{82}\mathrm{Pb} + 8\alpha + 6e^- + 6\bar{\nu}_e + 51.698\ \mathrm{MeV}$$
$$^{235}_{92}\mathrm{U} \rightarrow {}^{207}_{82}\mathrm{Pb} + 7\alpha + 4e^- + 4\bar{\nu}_e + 46.402\ \mathrm{MeV}$$
$$^{232}_{90}\mathrm{Th} \rightarrow {}^{208}_{82}\mathrm{Pb} + 6\alpha + 4e^- + 4\bar{\nu}_e + 42.652\ \mathrm{MeV}$$

Prediction → **Geoneutrino flux**

Geoneutrinos: (anti)neutrinos from the decay of long-lived particles



Signal Prediction at JUNO

Geoneutrino group at JUNO:

- Selects state-of-the-art local and global models, including structure, density and U/Th abundance;
- Calculate **geoneutrino flux** and evaluate the uncertainties.

Geoneutrino flux: **Lithosphere** (Crust + Continental Lithosphere Mantle (CLM)) + **Mantle**

Geoneutrino Prediction

Geoneutrino Rate

based on lithosphere and mantle models

Geo-$\bar{\nu}_e$ = Lithosphere + Mantle

Lithosphere model	Signal [TNU]
Global model Prog. in Earth and Planet. Sci. **2**, 5 (2015)	$30.9^{+6.5}_{-5.2}$
JULOC model Phys.Earth Planet.Interiors 299 (2020) 106409	$40.4^{+5.6}_{-5.0}$

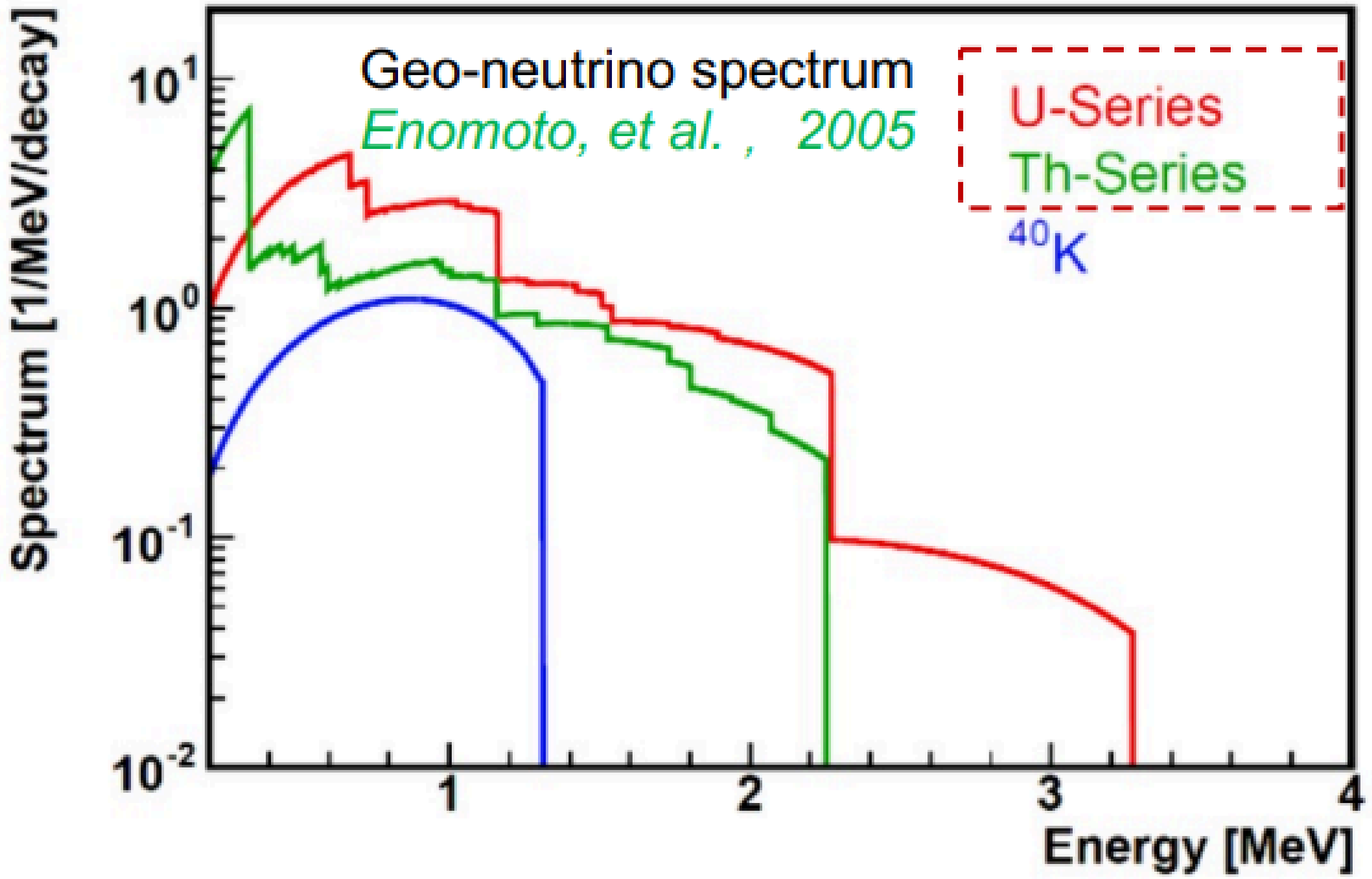
Mantle model	Signal [TNU]
Cosmochemical (CC)	~ 2
Geochemical (GC)	~ 10
Geodynamical (GD)	~ 20

1 TNU (Terrestrial Neutrino Unit): one interaction over a year-long fully efficient exposure of 10^{32} free protons.

Geoneutrino Shape

based on Enomoto flux model

- ^{238}U and ^{232}Th decay chains
- Summation model



https://www.awa.tohoku.ac.jp/~sanshiro/research/geoneutrino/spectrum/

Event Selection (IBD signals)

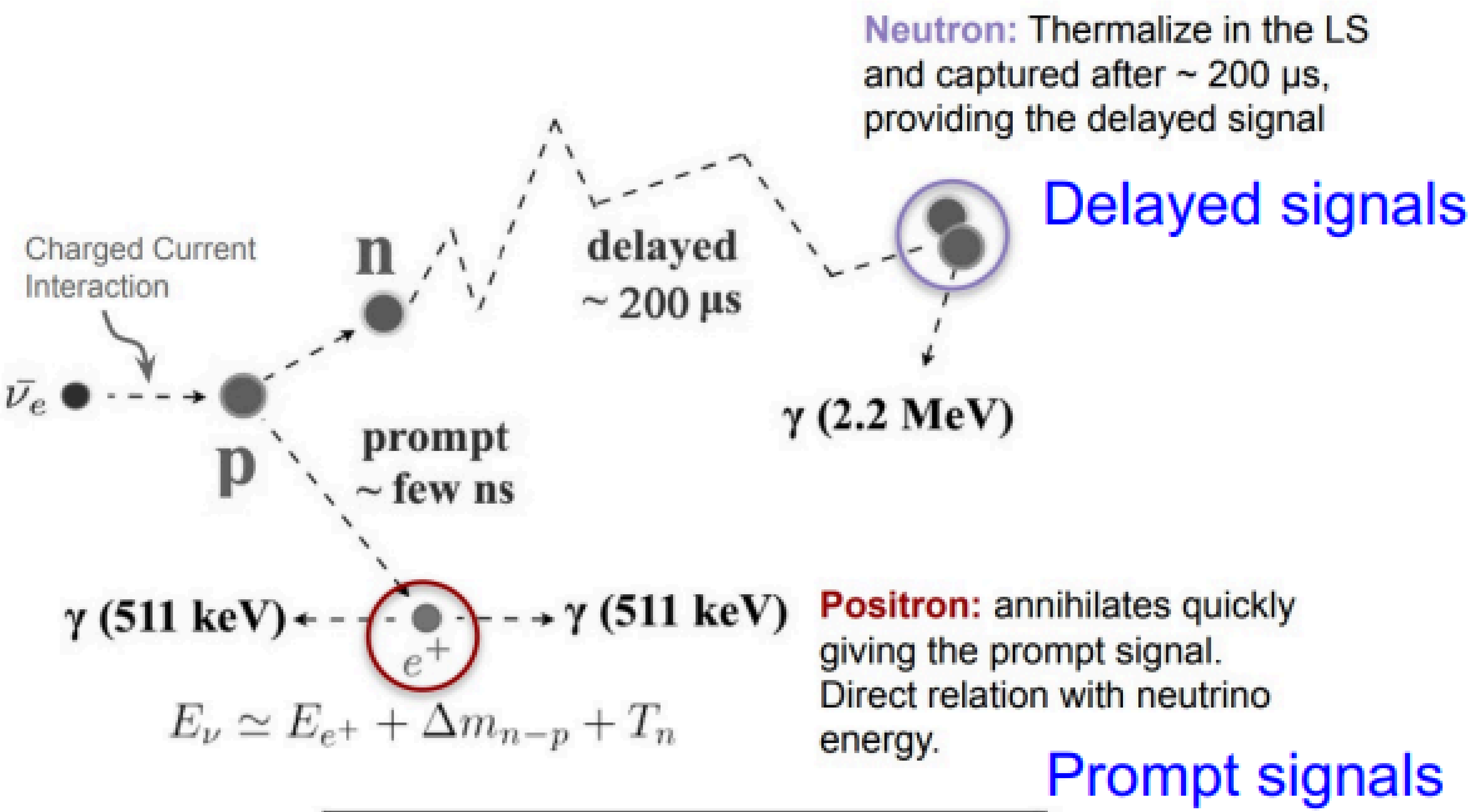
Inverse Beta-Decay (IBD):

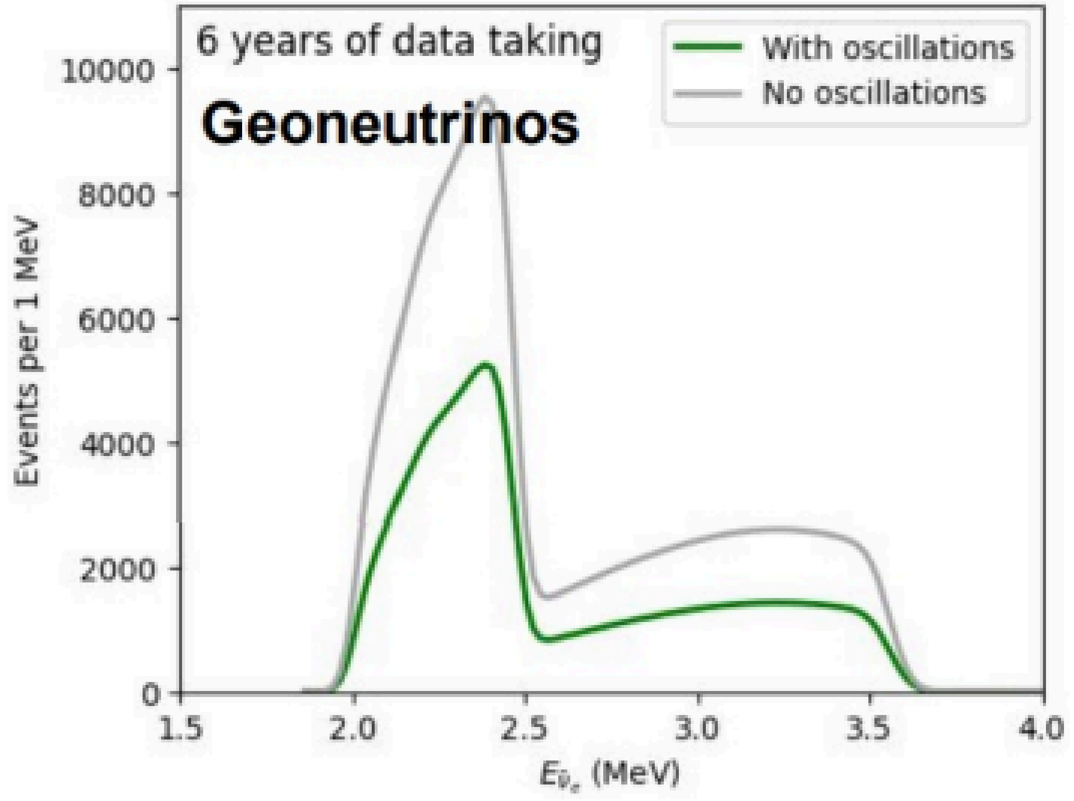
$$\bar{\nu}_e + p \rightarrow e^+ + n$$

Selection of IBD candidates:

- Muon veto
- Selection cuts ($\sim 10^4$ suppression of IBD-like events):
  - Prompt energy: [0.7, 12.0] MeV
  - Delayed energy: [1.9, 2.5] MeV & [4.4, 5.5] MeV
  - Time difference: 1 ms
  - Distance: 1.5 m

Neutrino selection efficiency: $\mathbf{82.2\%}$





Geoneutrino signal and Backgrounds

Geoneutrino signals

- From the decay chains of ^{232}Th and ^{238}U
- About 1 event per day

Reactor neutrinos

- contributed by two near NPPs (52.5 km) and Daya Bay NPP (~200 km)

Neutrino selection efficiency: **82.2%**

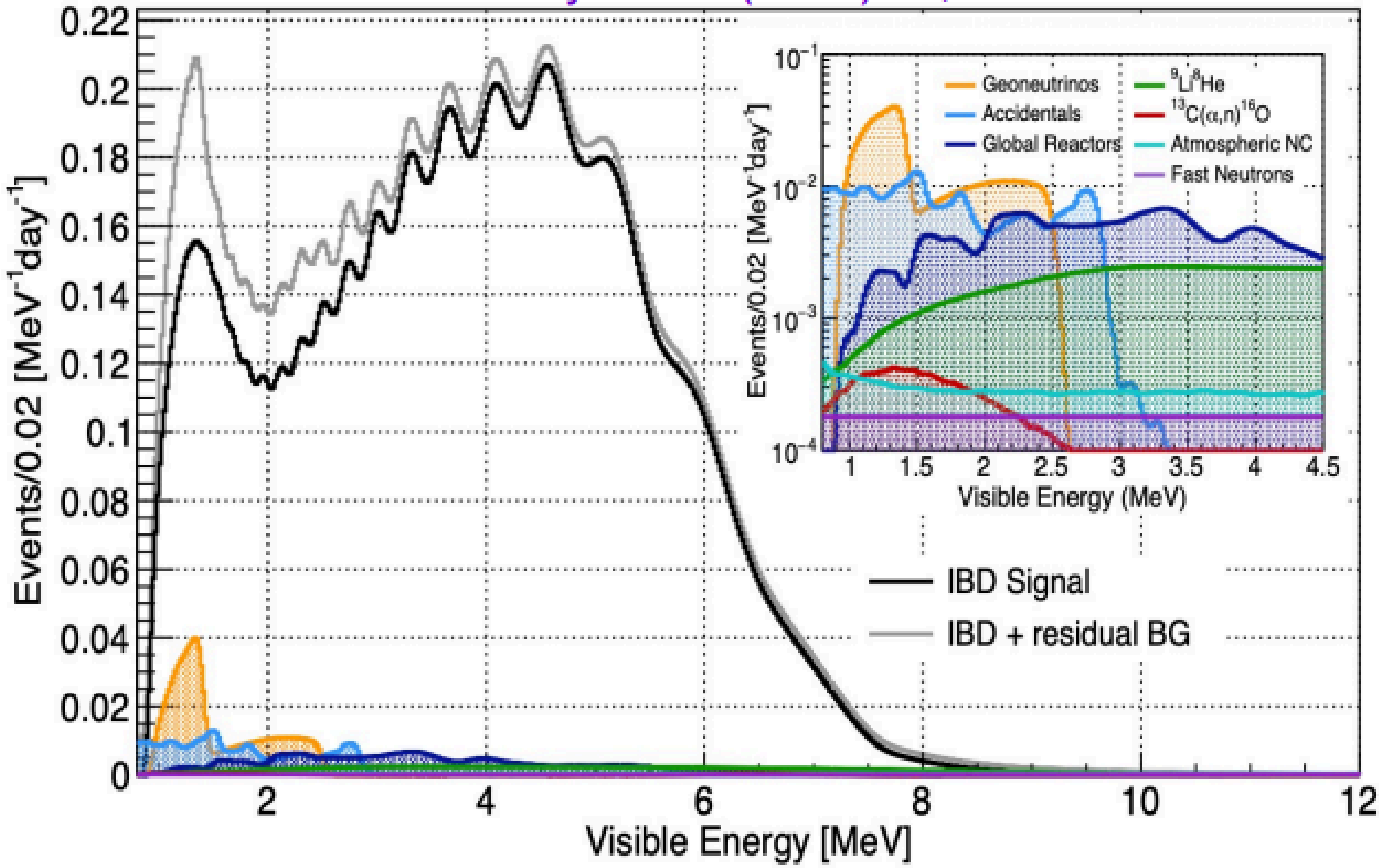
	Rate [cpd]	Rate uncert.	Shape uncert.
Geo-neutrinos	1.2	-	5%
Reactor neutrinos	47.1	-	Daya Bay/ TAO
Accidental	0.8	1%	-
^{9}Li/^{8}He	0.8	20%	10%
^{13}C(α, n)^{16}O	0.05	50%	50%
Fast neutron	0.1	100%	20%
World reactor neutrinos	1	2%	5%
Atmospheric neutrinos	0.16	50%	50%

World reactor neutrinos

- contributed by the NPPs (>300km)

JUNO will measure in 1y ~400 **geoneutrino** events more than Borexino and KamLAND in >10y!

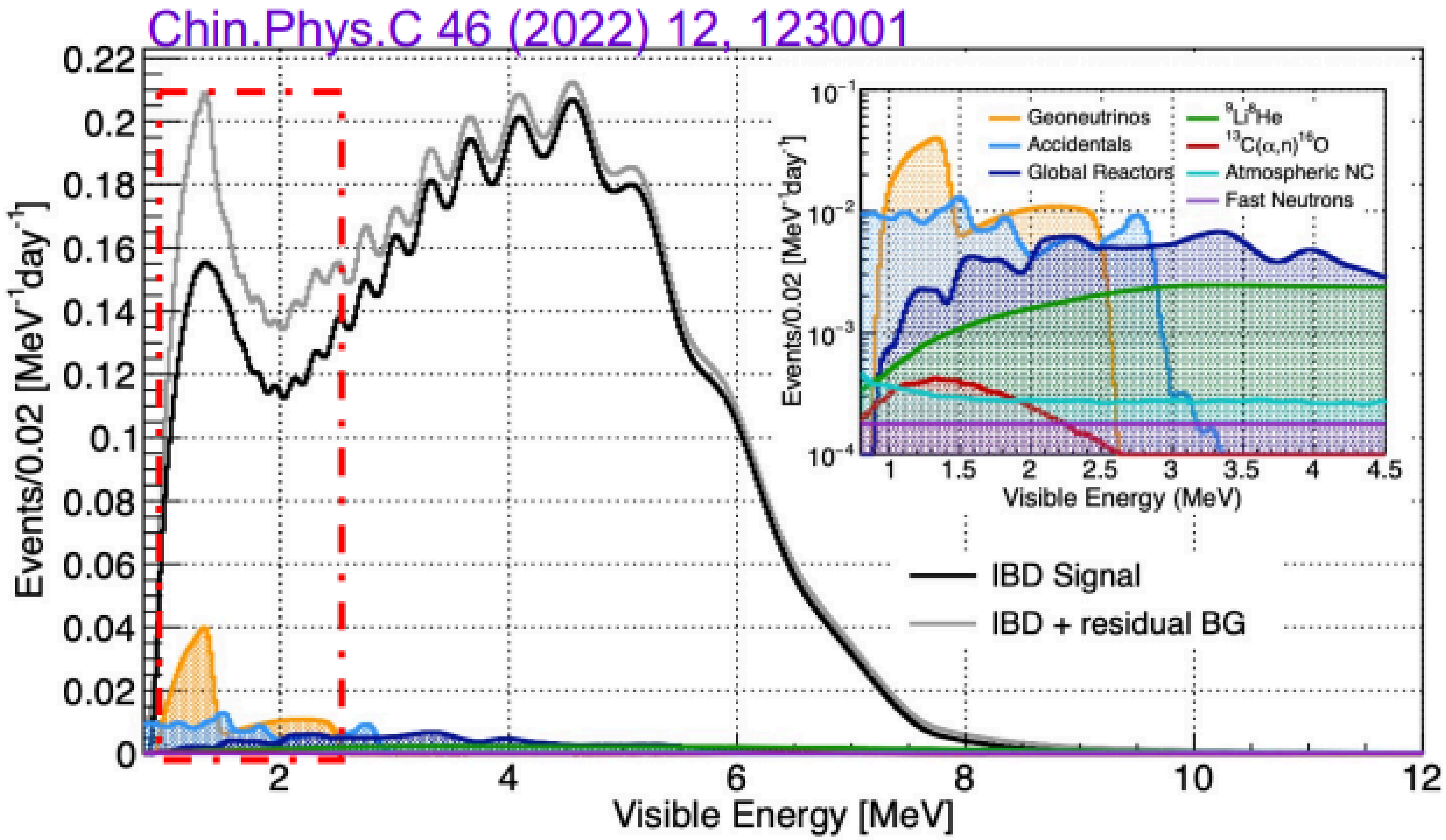
Chin.Phys.C 46 (2022) 12, 123001

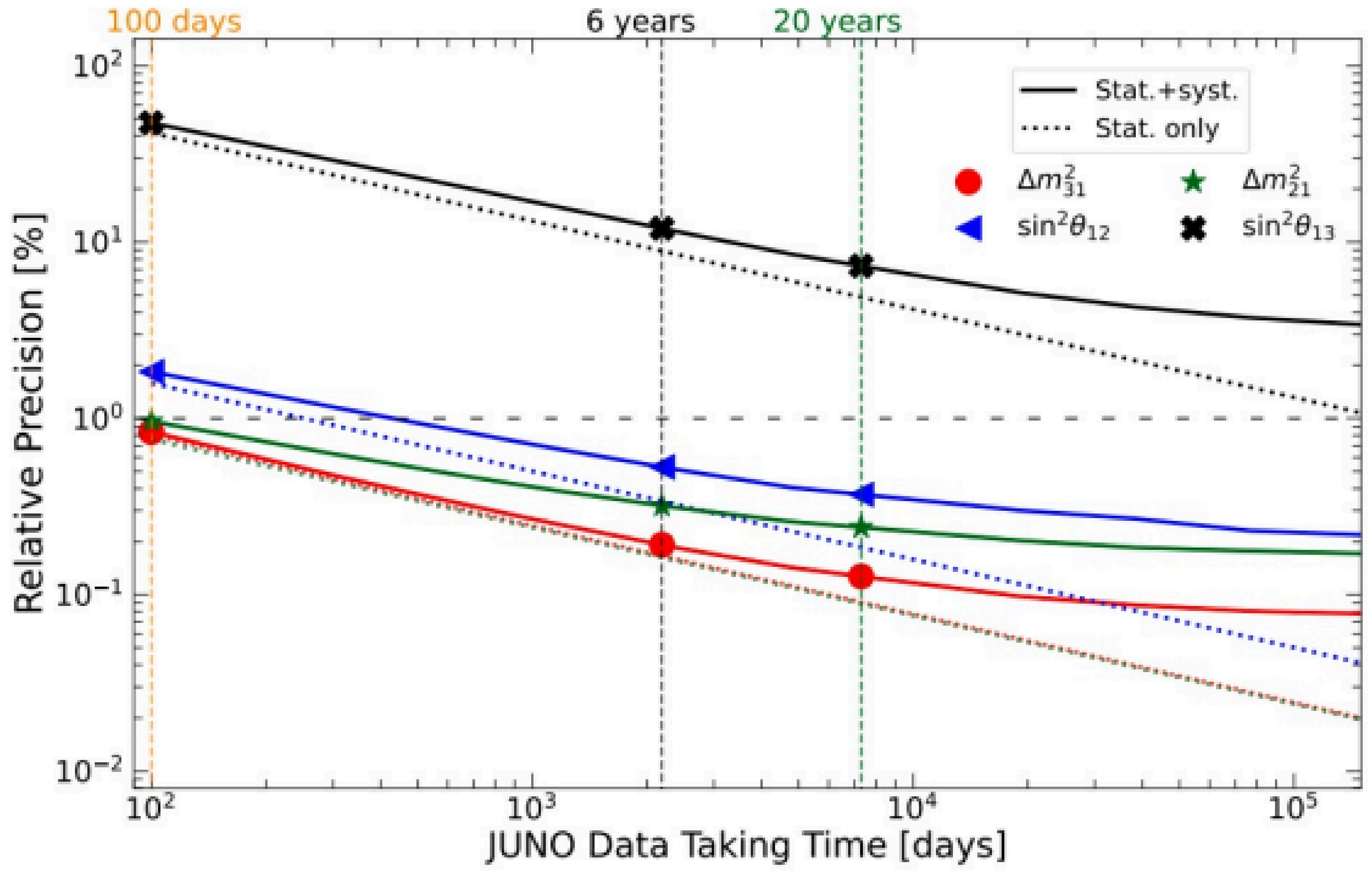


Detecting geoneutrinos at JUNO

Reactor neutrinos Irreducible background

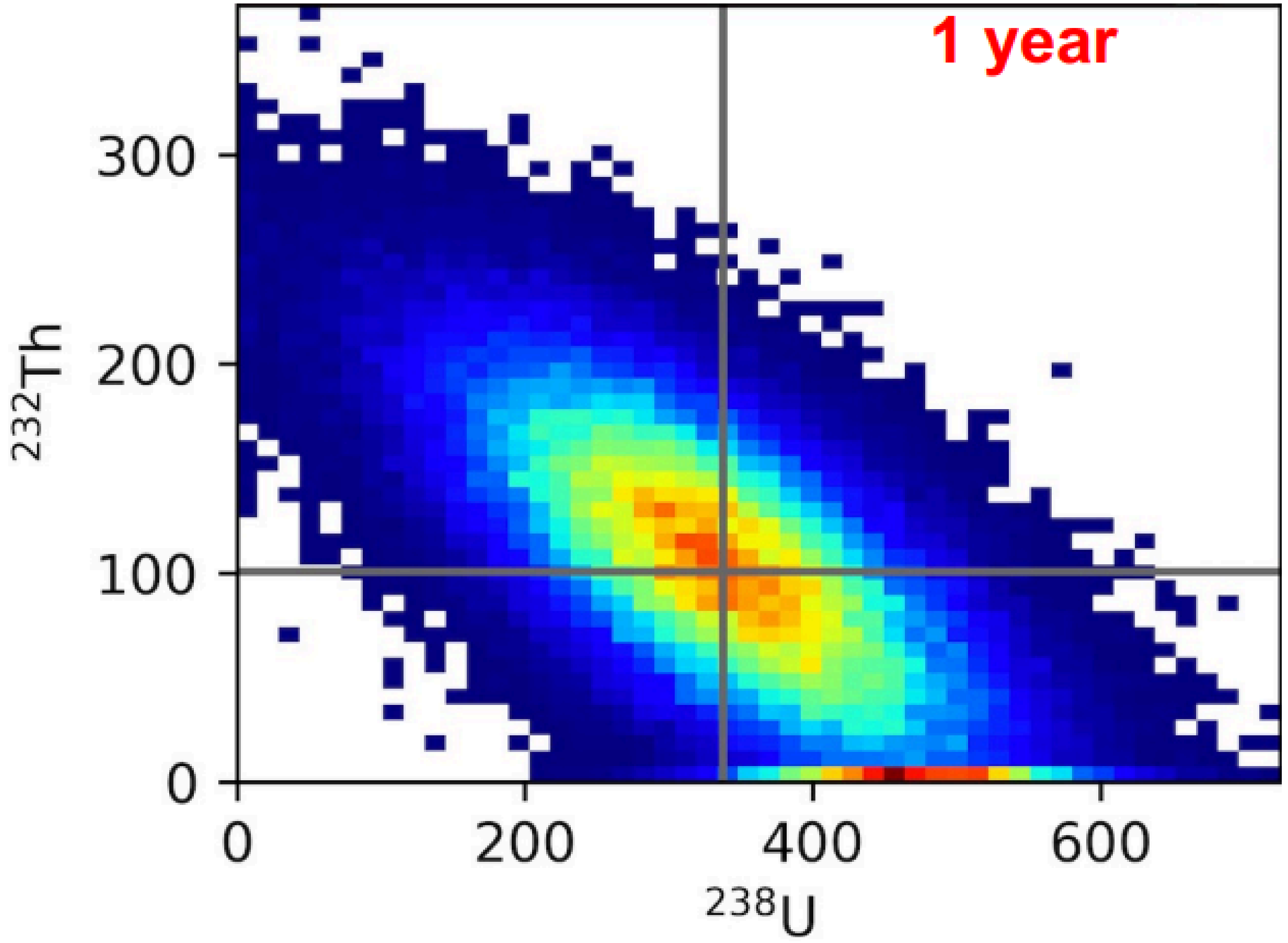
- Much higher rate
- Same signature, no way to distinguish on event by event basis
- Rate and shape uncertainty affects the precision
- Strong impact from neutrino oscillations - the largest systematic





Sensitivity to the Total Geoneutrino Flux

fit results with **fixed oscillation parameters**
Only for illustration



Th and U are strongly anticorrelated

Expected precision
fit results with **free oscillation parameters**

	6 years	10 years
^{232}Th:	~40%	~35%
^{238}U:	~35%	~30%
^{232}Th+^{238}U:	~18%	~15%
^{232}Th/^{238}U ratio:	~70%	~55%

PRELIMINARY

Summary

- Geoneutrinos can provide a unique probe to the Earth's composition and structure
- JUNO will collect the highest geoneutrino statistics

  More geoneutrino events than all the other experiments with 1 year data

- Precise measurement of total geoneutrino flux:
  - Borexino ~17% precision (10 years)
  - KamLAND ~15% precision (18 years)
  - **JUNO ~ 22% precision (1 year) and ~ 8% precision (10 years)**

- JUNO can measure U and Th individual contributions with high statistical significance
- The study of potential to observe **signal from mantle** in JUNO is ongoing

- The data taking is planned to start next year
- The sensitivity paper is planned to be submitted before data taking