JUNO's Sensitivity to Geoneutrinos

42nd International Symposium on Physics in Collision

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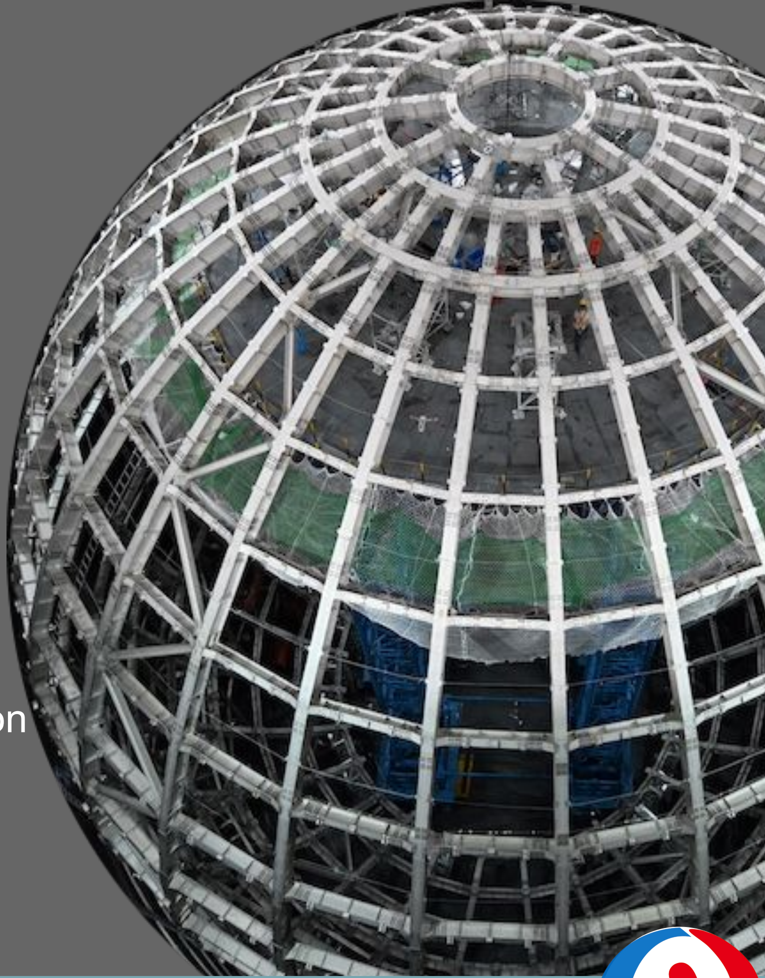
Cristobal Morales Reveco[1,2,3] on behalf of the JUNO Collaboration

1. GSI Helmholtzzentrum für Schwerionenforschung GmbH, Germany
2. Forschungzentrum Julich GmbH, Germany
3. RWTH Aachen University, Germany

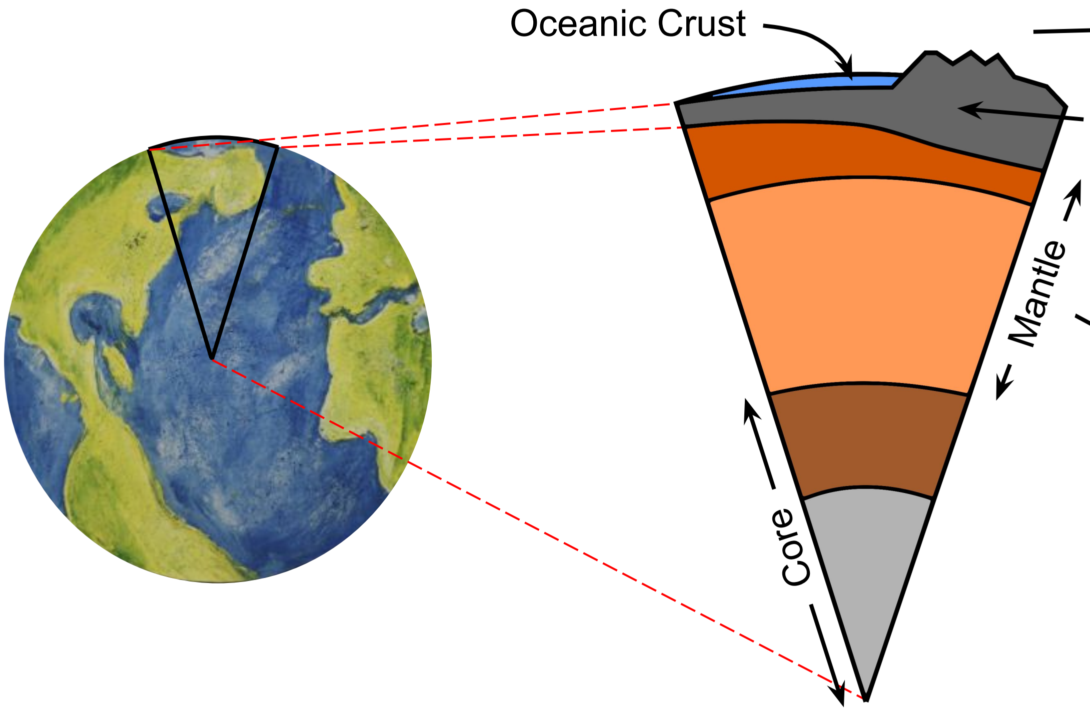


GSI JÜLICH Forschungszentrum RWTH AACHEN UNIVERSITY JUNO

Outline

- Introduction and Motivation
- JUNO Experiment
  - Detector Design
  - Expected antineutrino signal
  - Analysis Inputs
- Total Geoneutrino Signal
- Summary and Outlook

Credit to Borexino Collaboration



Credit to LotusArise

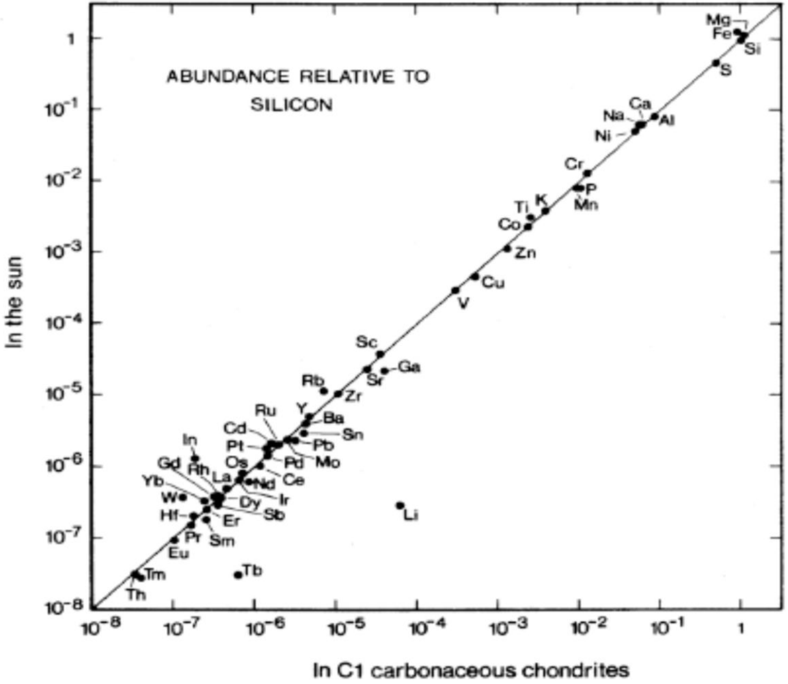
Crust can be “accessed” directly by collecting rock samples

Mantle hard to access directly:

- **Seismology** - No direct info about chemical composition
- **Rocks from tectonic and volcanic activities** - Possible alteration of samples during transportation and only for the upper mantle

Earth's Chemical Composition

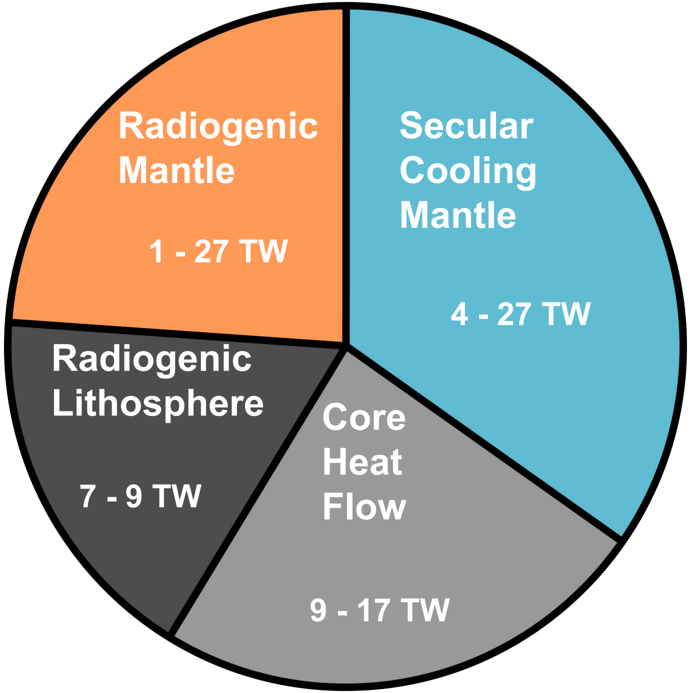
- Close correlation between C1 meteorites chondrites and the Solar photosphere
- Ratio of abundances between the elements is better known than the absolute values
- Is it the same for primitive Earth?
  - **Bulk Silicate Earth (BSE) Models**
- Predict elements abundances and radiogenic heat
  - Lithosphere = crust + continental lithospheric mantle
  - BSE = Lithosphere + Mantle -> Lithosphere is very well known (direct measurements)
  - Mantle (big uncertainty) = BSE - Lithosphere



Hartmut Holweger 1996 Phys. Scr. 1996 151

The Earth’s Heat Budget

- Total heat loss have been measured 41 - 47 TW
- Total amount of the heat loss by the Earth is composed by the Radiogenic Heat and the Secular Cooling
  - **Radiogenic Heat:** produced in the decays of natural radioactive isotopes on the Earth (**H**eat **P**roducing **E**lements)
  - **Secular Cooling:** loss of the primordial heat from the Earth’s formation period
- Dynamical processes of the Earth must correspond to the current energy budget



Credit to O. Smirnov (2019)

Why to study geoneutrinos?

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

Abundance of the radioactive elements → Radiogenic Heat

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

$$^{232}\mathrm{Th} \rightarrow {}^{208}\mathrm{Pb} + 6\alpha + 4e^- + 4\bar{\nu}_e + 42.8\ \mathrm{MeV}$$

$$^{40}\mathrm{K} \rightarrow {}^{40}\mathrm{Ca} + e^- + \bar{\nu}_e + 1.32\ \mathrm{MeV}$$

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Distribution of the radioactive elements on the Earth

Prediction

Geoneutrino flux

Measured/Observed

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- Test and discriminate geomodels
- Mantle homogeneity

Distribution of the radioactive elements on the Earth

Prediction

Interpretation

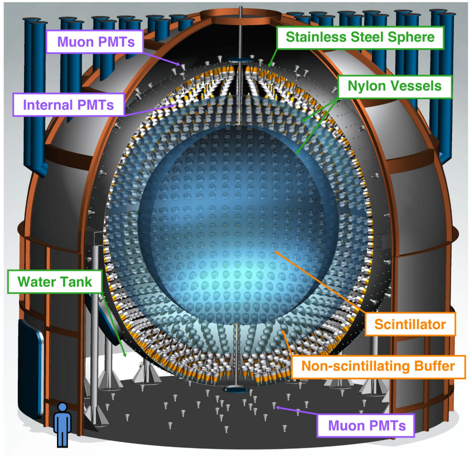
Geoneutrino flux

Measured/Observed

KamLAND and Borexino Measurements

Borexino (2020) [M.Agostini et al., Phys. Rev. D 101, 2020]

- Experiment in Gran Sasso, Italy



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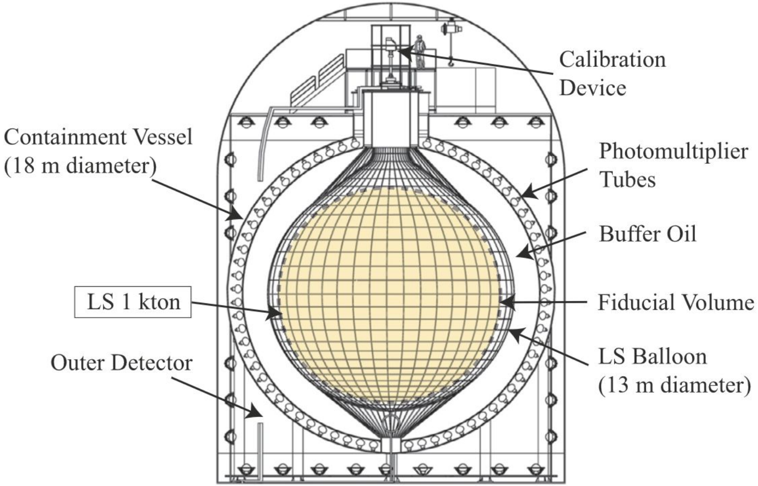

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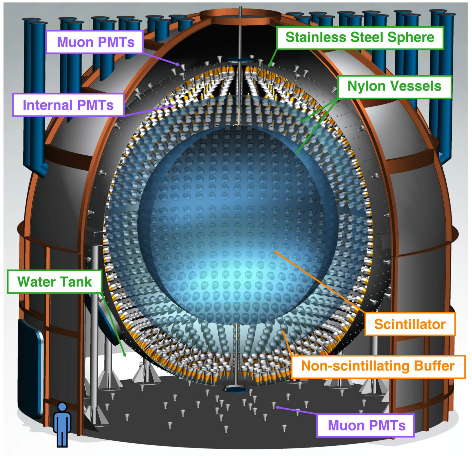

KamLAND (2022) [S.Abe et al., Geophys. Res. Lett. 49 (16), 2022]

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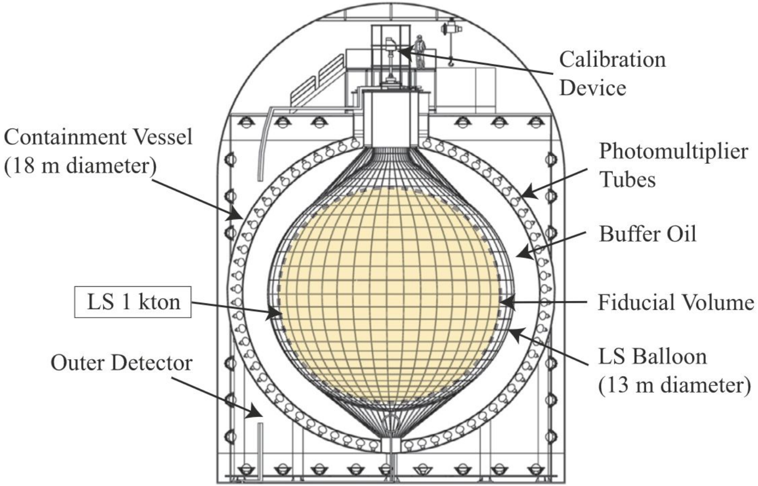

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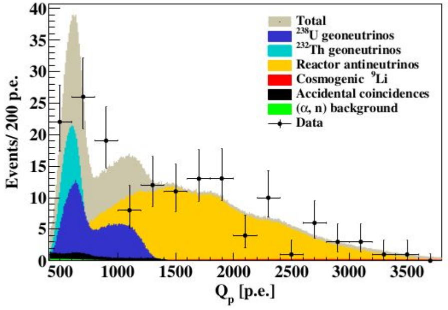

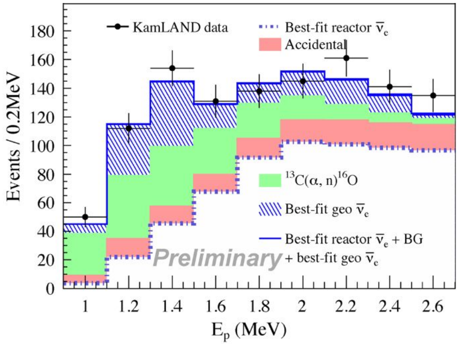

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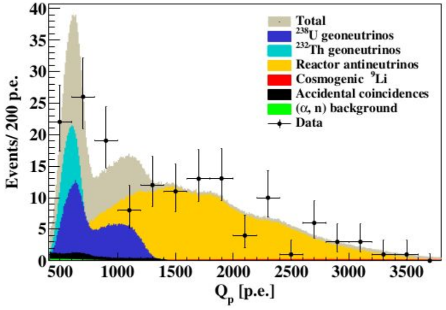

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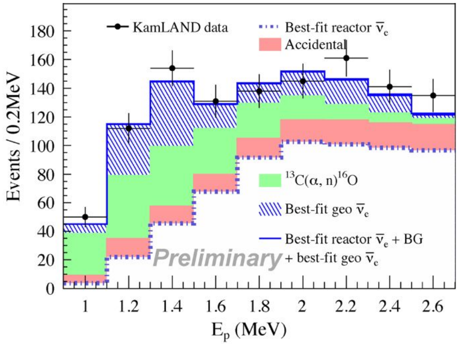

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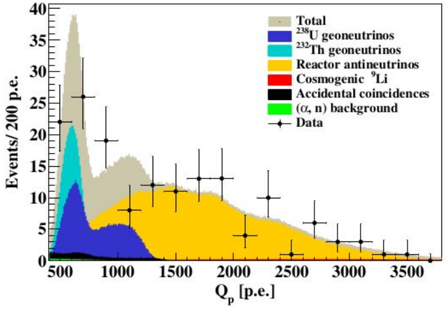

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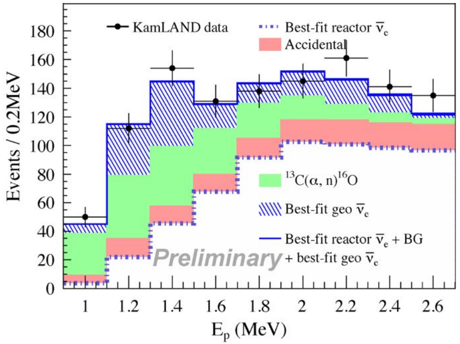

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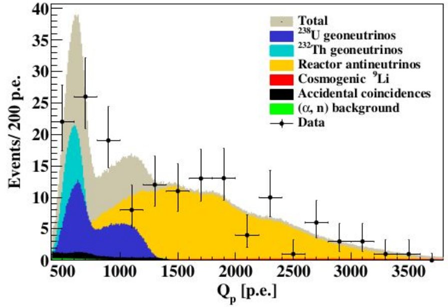
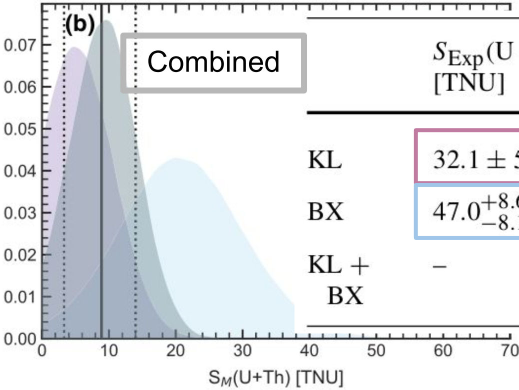
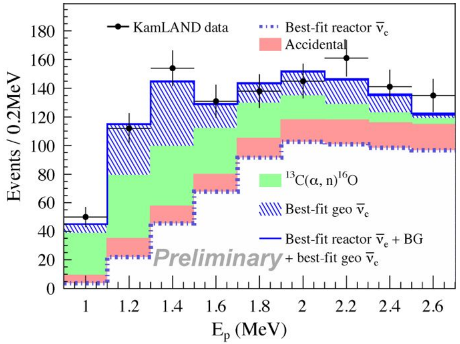
[G. Bellini et al., La Revista del Nuovo Cimento 45, 2022]





	S_{Exp}(U + Th) [TNU]	S_M(U + Th) [TNU]
KL	32.1 ± 5.0	$4.8^{+5.6}_{-5.9}$
BX	$47.0^{+8.6}_{-8.1}$	$20.8^{+9.4}_{-9.2}$
KL + BX	–	$8.9^{+5.1}_{-5.5}$



*Lateral mantle homogeneity is assumed for the combination

Jiangmeng **U**nderground **N**eutrino **O**bservatory

Located in Kaiping, Jiangmen in China

Placed at 52.5 km from two Nuclear Power Plants

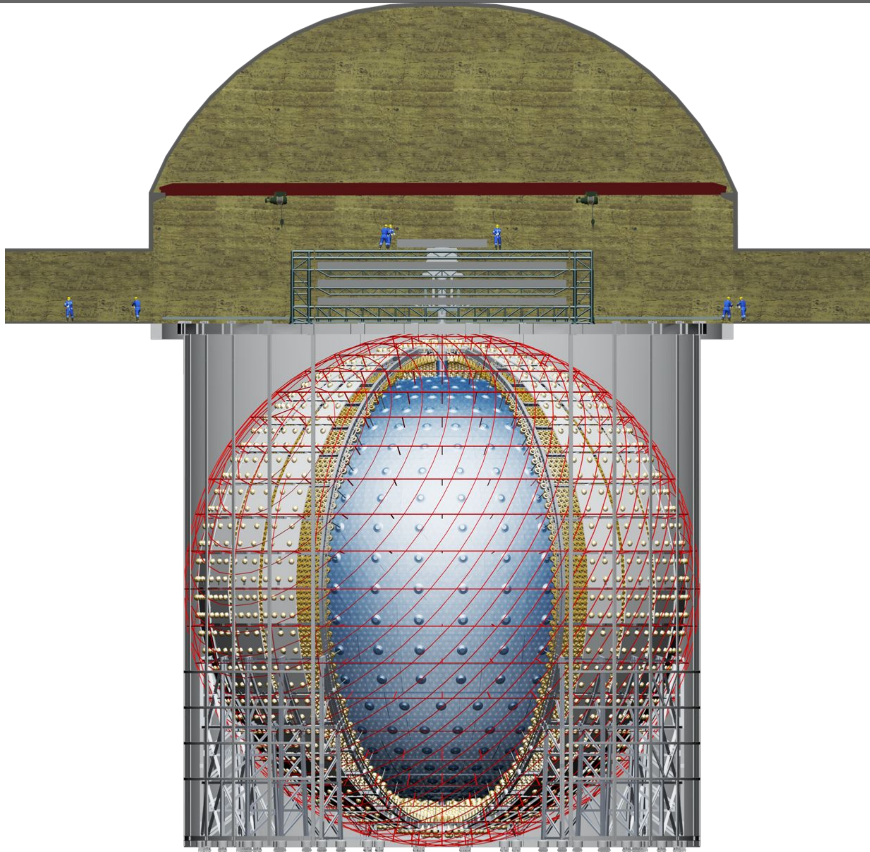
Overburden of 650 m

Designed to reach 3% energy resolution at 1 MeV for the determination of the Neutrino Mass Ordering using reactor anti-ν

JUNO Experiment

Experiment main components

1. Top Tracker and Calibration house
2. Water Pool
3. Central Detector with Liquid Scintillator

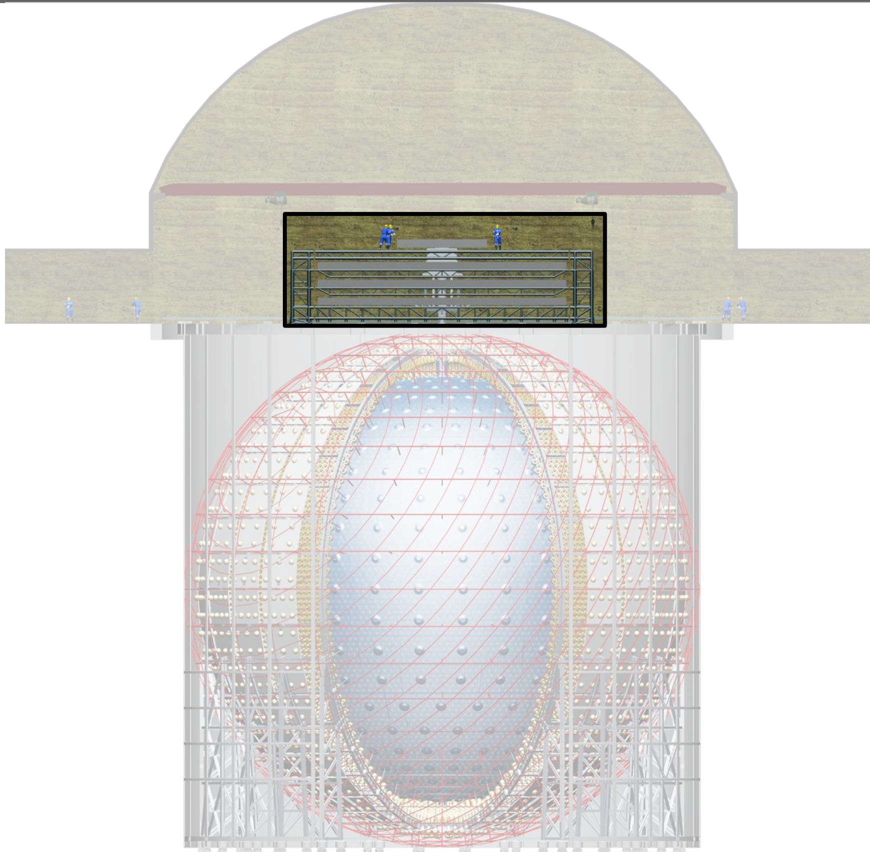


JUNO Experiment

Experiment main components

1. Top Tracker and Calibration house
   - Calibration House contain the calibration sources and deployment mechanism
   - Top tracker consists on a stack of plastic scintillator strip design for extrapolation and veto of muon tracks

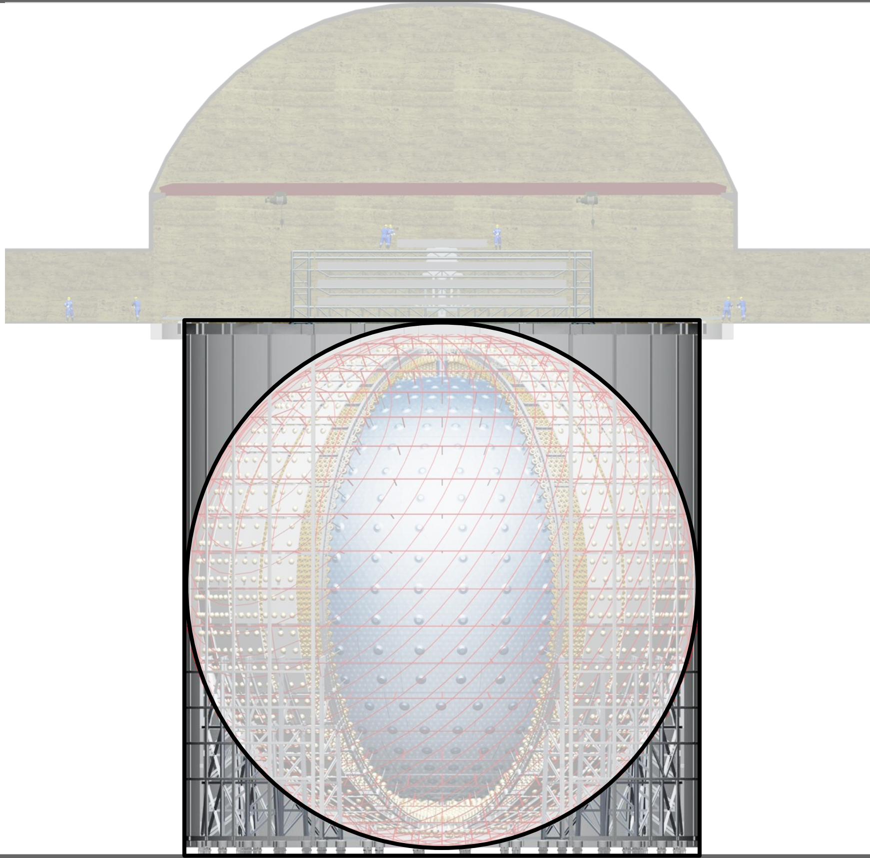
2. Water Pool
3. Central Detector with Liquid Scintillator



JUNO Experiment

Experiment main components

1. Top Tracker and Calibration house
2. Water Pool
    - 35 kton of ultrapure water
    - Shield for natural radioactivity
    - Water cherenkov detector for muon tagging
    - 2400 20” PMTs



3. Central Detector with Liquid Scintillator

JUNO Experiment

Experiment main components

1. Top Tracker and Calibration house
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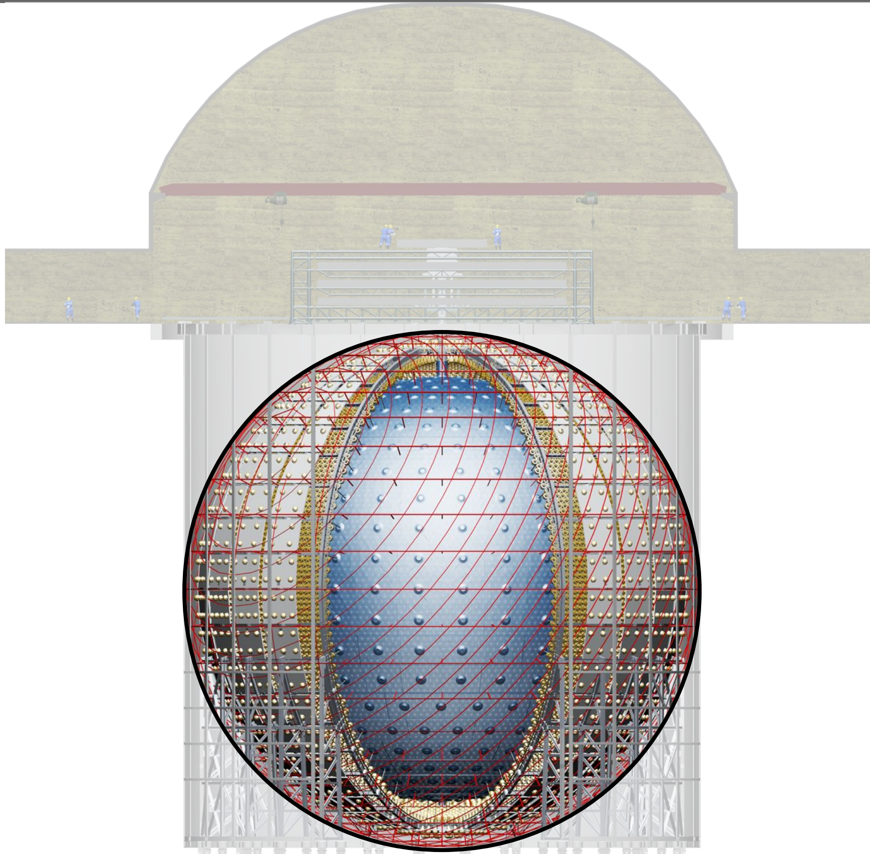
3. Central Detector with Liquid Scintillator
   - Central detector of 20 kton of LS
   - 35.4 m of diameter
   - Integrated with 17612 20” PMTs and 25600 3” PMTs



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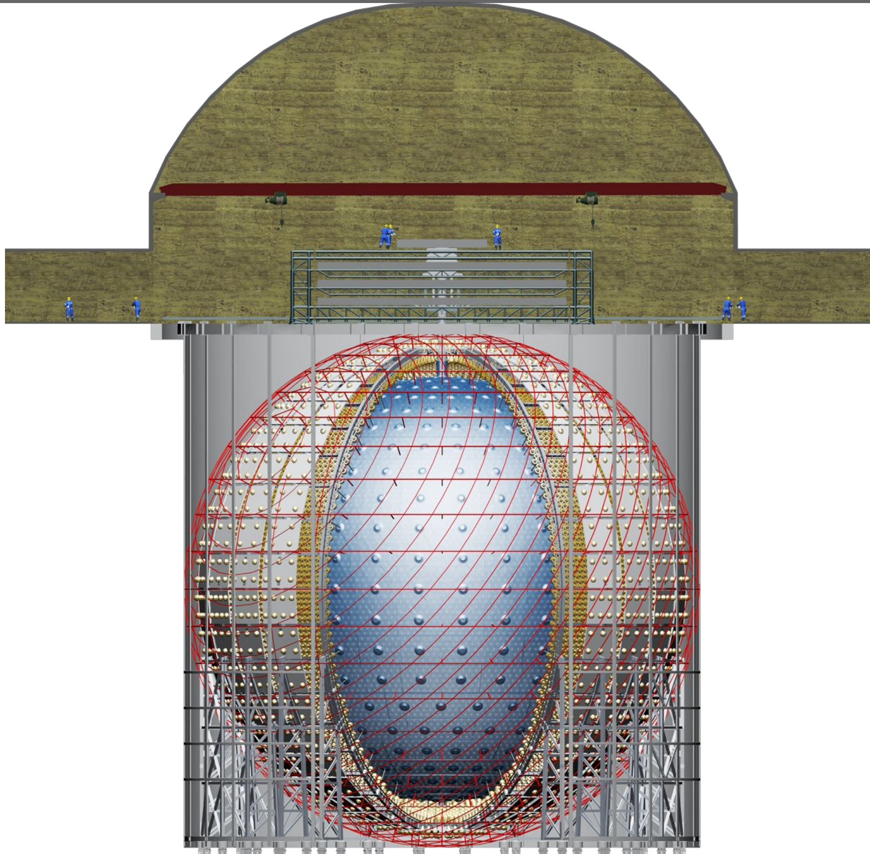
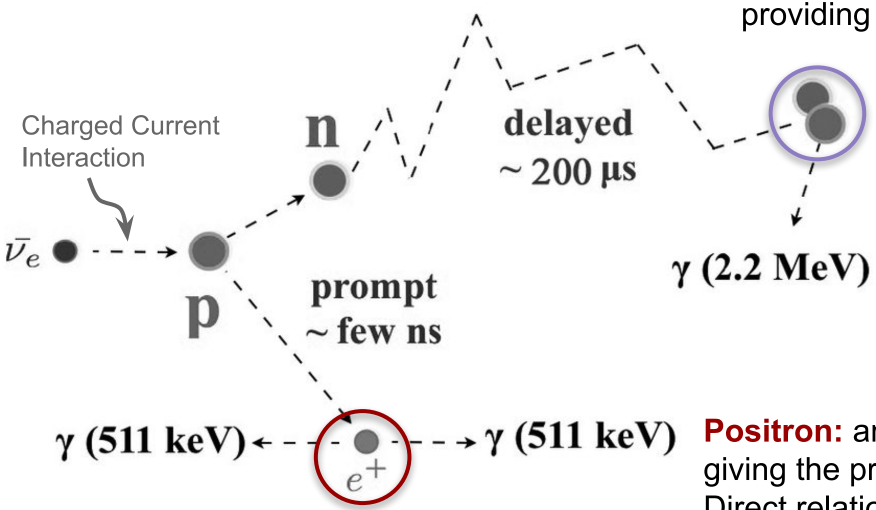


More information in Bei-Zhen Hu’s Talk!

Signal Signature - IBD

Electron antineutrinos detected via the **Inverse Beta Decay (IBD)** $\bar{\nu}_e + p \rightarrow e^+ + n$



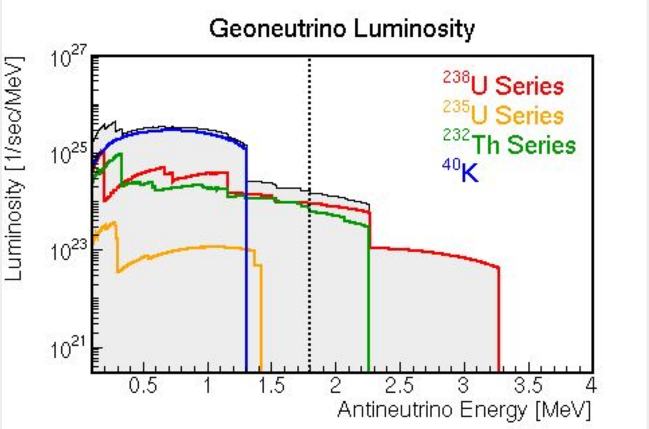
$$E_\nu \simeq E_{e+} + \Delta m_{n-p} + T_n$$

Neutron: Thermalize in the LS and captured after ~ 200 µs, providing the delayed signal

Positron: annihilates quickly giving the prompt signal. Direct relation with neutrino energy.

Energy Threshold at 1.8 MeV

- Only geoneutrinos from ^{238}U and ^{232}Th are detected
- ^{40}K neutrinos do not have enough energy

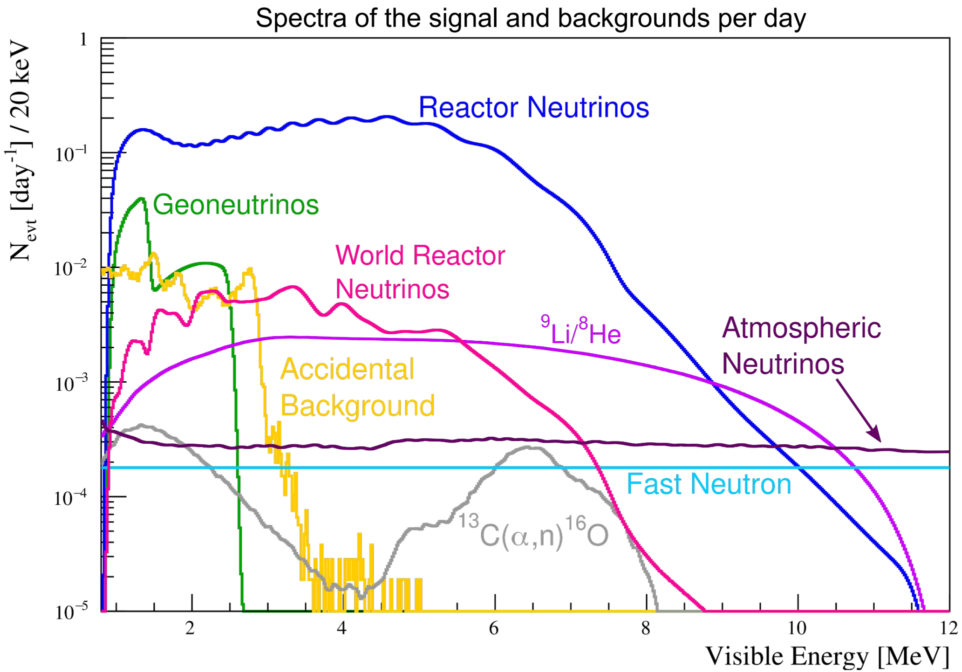


Source Sanshiro

Expected Signal and Backgrounds in JUNO

- Geoneutrinos signal generated by decays of ^{238}U and ^{232}Th
- Reactor neutrinos contributed by two near NPP (52.5 km) and Daya Bay NPP (~200 km)
- Reactor neutrinos from NPP for the rest of the world (> 300 km) considered as a background
- Rates include the selection and veto efficiencies

	Rate [counts per day]	Rate uncertainty	Shape uncertainty
Geoneutrinos	1.2	-	5%
Reactor Neutrinos	43.175	-	Daya Bay
Accidentals	0.8	1%	-
$^{9}Li/^{8}He$	0.8	10%	10%
$^{13}C(\alpha,n)^{16}O$	0.05	50%	50%
Fast Neutron	0.1	100%	20%
World Reactor Neutrinos	1	5%	5%
Atmospheric Neutrinos	0.16	50%	5%



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

Precision to Geoneutrinos with Chondric Ratio

Fit configuration:

- Th/U abundance fixed to the chondritic ratio (3.9)
- Geo- and reactor neutrino rates are free
- Other background rates are constrained based on independent data
- Shape uncertainty included
- Energy scale uncertainty (negligible impact)
- Oscillation parameters free

Expected geoneutrino precision
(assuming Th/U mass ratio fixed to 3.9)

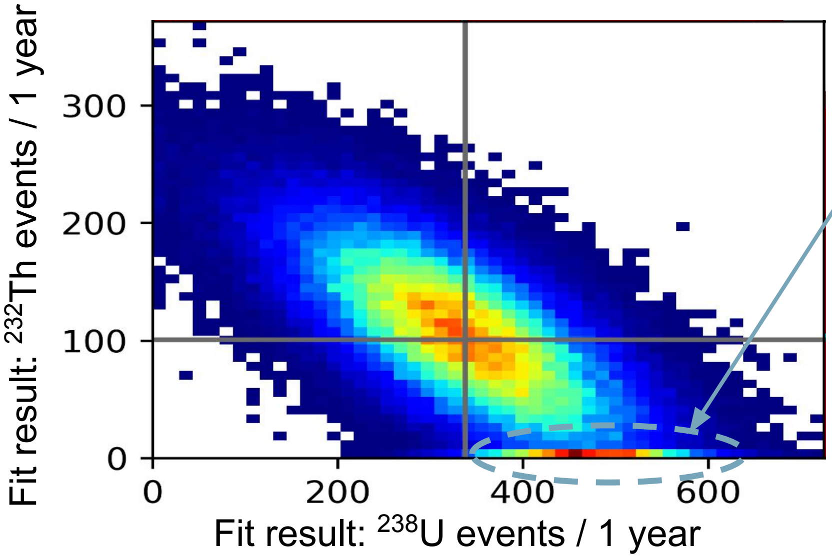
PRELIMINARY

1 year	**~22%**
6 years	**~10%**
10 years	**~8%**

Borexino reached 17% precision and KamLAND 15% in >10 years

Precision to ^{238}U and ^{232}Th Geoneutrinos

Distribution of possible fit results with fixed oscillation parameters



- **High statistics is crucial:**
  after 1 year there is a large chance to get Th railed to 0 even with fixed oscillation parameters

- **Th and U are strongly anticorrelated:**
  JUNO can disentangle the Th and U contributions and make a very good measurement of their sum

Expected precision

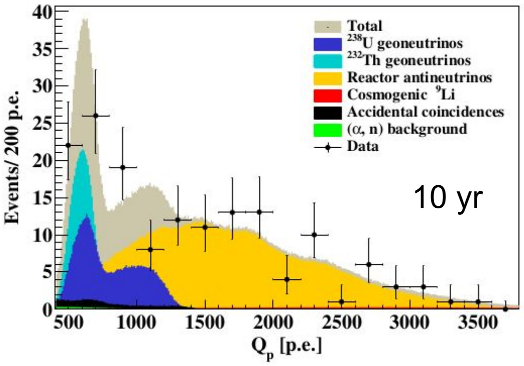
	6 years	10 years
^{232}Th:	**~40%**	**~35%**
^{238}U:	**~35%**	**~30%**
^{232}Th+^{238}U:	**~18%**	**~15%**
^{232}Th/^{238}U ratio:	**~70%**	**~55%**

PRELIMINARY

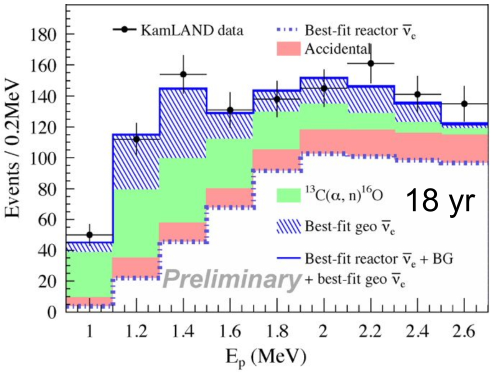
Summary

Total geoneutrino precision with chondric U/Th ratio

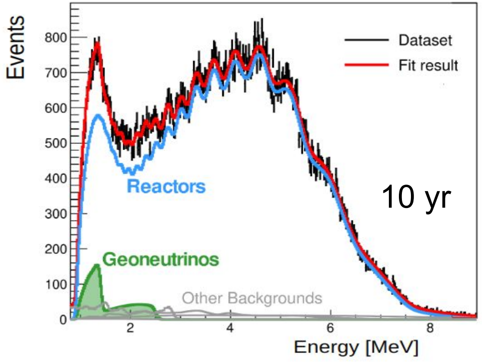
Borexino: ~17% precision



KamLAND: ~15% precision



JUNO: ~8% precision



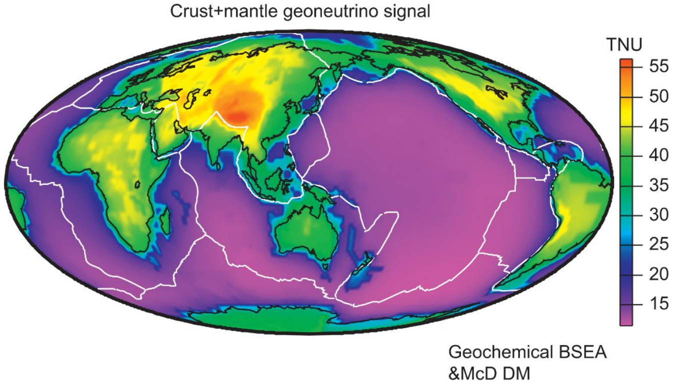
Summary and Outlook

- Geoneutrinos can provide a unique probe to the Earth's composition and structure
  - Joint effort of geoscientists (elements abundances and distribution, and Earth's models) and physicist (neutrino expected flux and detection)
- KamLAND and Borexino measured geoneutrinos with ~15% precision
- JUNO has a potential to measure Geoneutrinos
  - Provide the World's most precise measurements
  - Measure U and Th individual contributions with high statistical significance
- Refined local crustal model is being developed for JUNO
  - Required for the Mantle signal extraction
  - About half of the geoneutrino signal comes from ~500 km
  - Sensitivity to Mantle geoneutrinos is under preparation
- JUNO will provide a measurement at the third complementary geological location

Thank You!

Backup

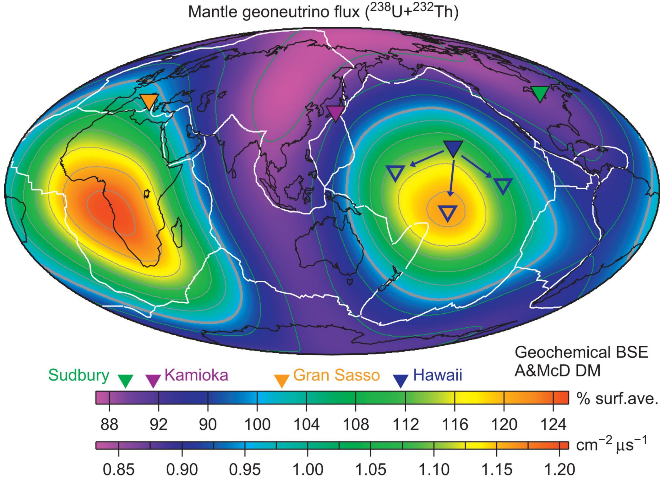
Predicted Geoneutrino Flux



Total signal is small
1 TNU (100% detection efficiency) = 1 event / 10^{32} target protons / year

Solution: Big Detectors!

Mantle signal no more than ~ 10 TNU
Complicated to measure



Homogeneity of the radiogenic heat of the mantle is crucial for understanding the dynamics of the Earth

Šrámek, O., McDonough, W. F., Kite, E. S., Lekić, V., Dye, S. T., & Zhong, S. (2013). Geophysical and geochemical constraints on geoneutrino fluxes from Earth's mantle. *Earth and Planetary Science Letters*, *361*, 356–366. https://doi.org/https://doi.org/10.1016/j.epsl.2012.11.001