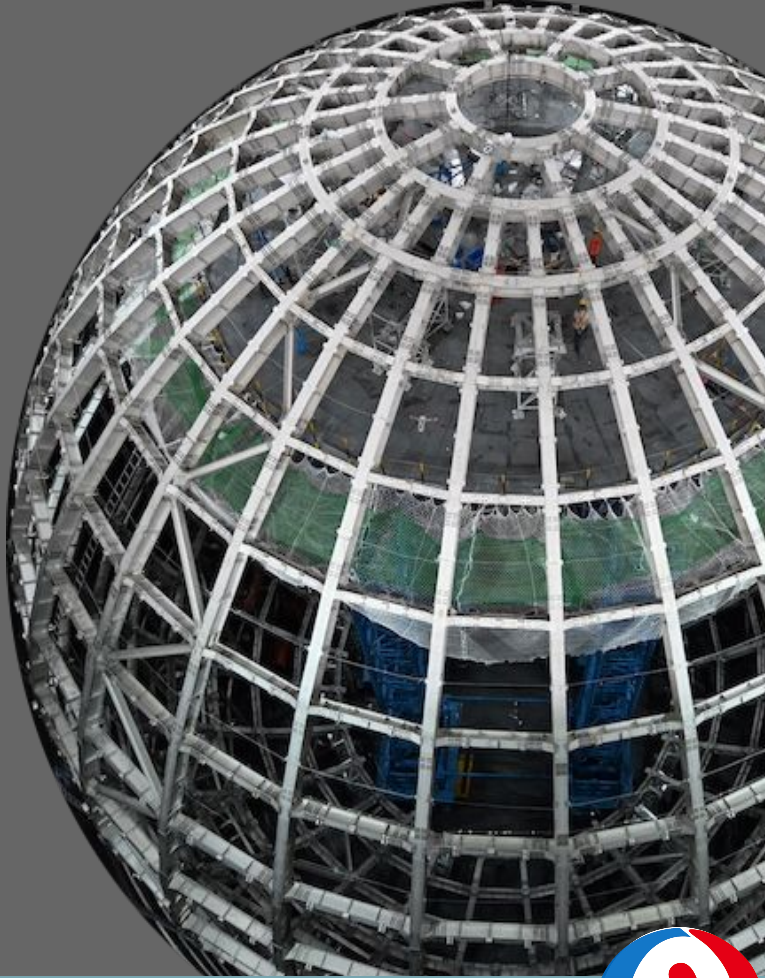
JUNO Sensitivity to Geoneutrinos

MAYORANA School
Modica
7th of July

Cristobal Morales Reveco[1,2,3]

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

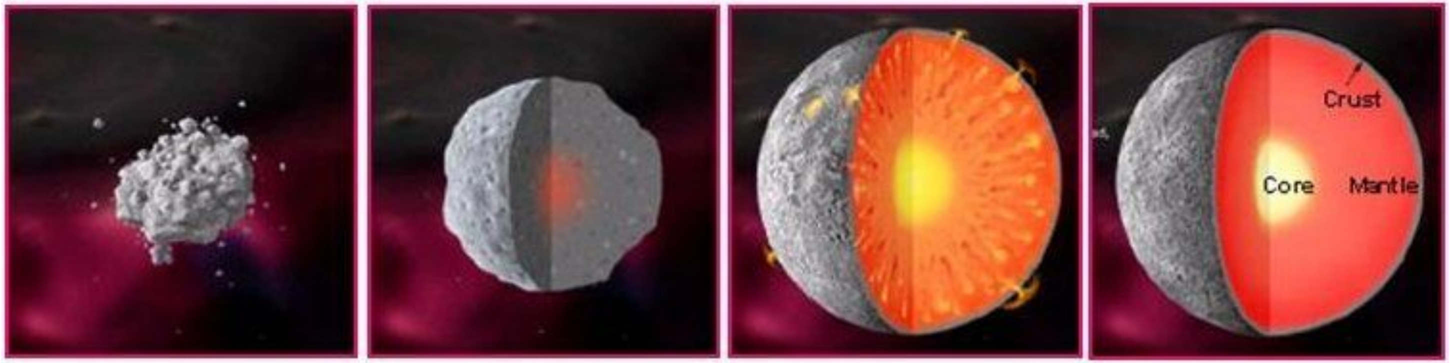


Let's go way back - Earth's formation

Accretion

Enough pressure to melt rocks
Heavy metals sink through the magma

Mantle-Crust differentiation



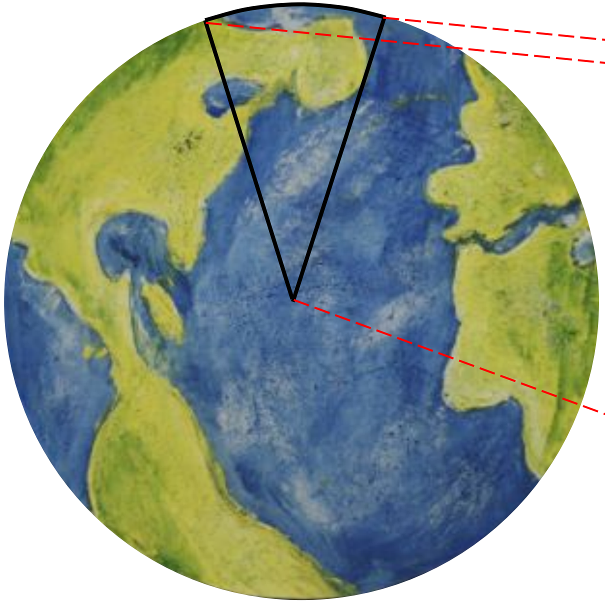
From Smithsonian Museum of Natural History

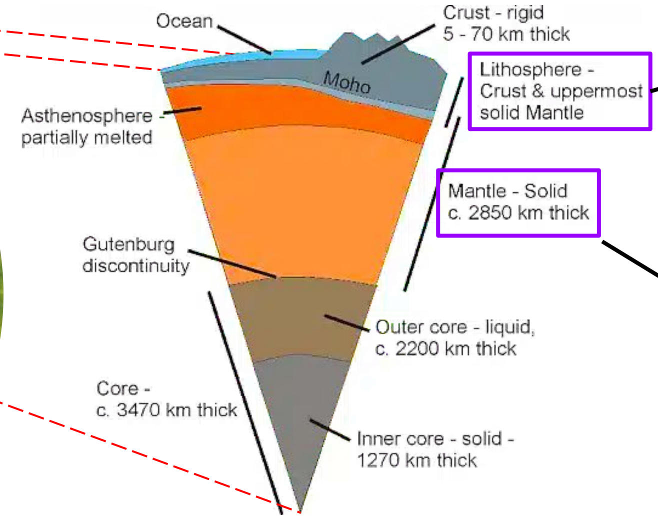
Collection of material on the stellar disc

Core formation

Mantle more homogeneous
Crust depends locally

Now - Earth's Structure





From LotusArise

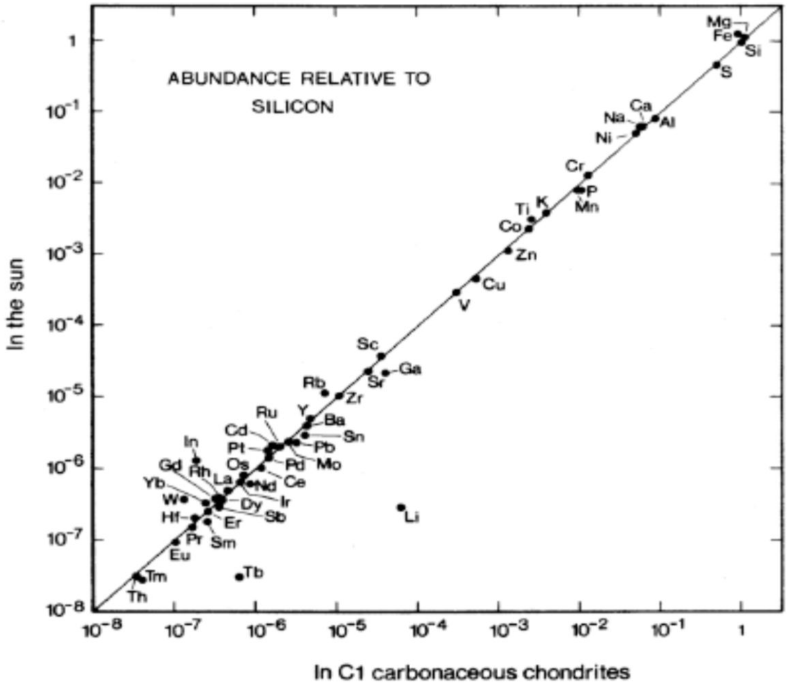
Crust can be accessed directly by collecting rock samples

Mantle hard to access directly:

- Geosismology - No info of chemical composition
- Rocks from tectonic and volcanic activities - Possible alteration of samples during transportation and only for upper mantle

Earth’s Composition

- Close correlation between C1 meteorites chondrites and Sun’s photosphere
- Is the same for primitive Earth? - Bulk Silicate Earth (BSE) Models
  - Several inputs: chondrites, photosphere, rock composition, …
- Predict abundances and radiogenic heat
  - BSE = Lithosphere + Mantle - Lithosphere is very well known (direct measurements)
  - Mantle = BSE - Lithosphere (big uncertainty)



Why to study geoneutrinos?

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

Abundance of the radioactive elements

Radiogenic Heat

Measure the contribution of the radiogenic heat to the total Earth surface heat - input for geophysical and geochemical models

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

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

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

Measuring U/Th ratio:

- Test and discriminate geomodels
- Mantle homogeneity using different experiments

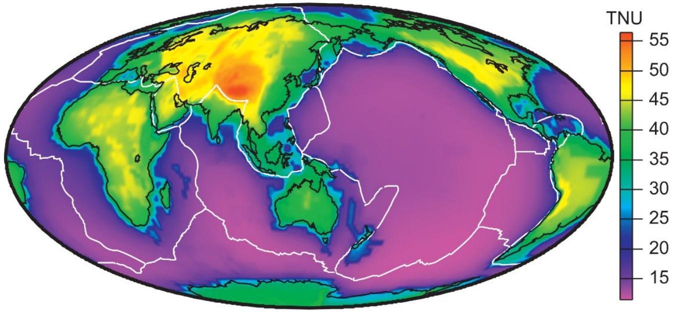
Distribution of the radioactive elements on the Earth

Geoneutrino flux

Particles with half-live time similar to Earths:

- ^{238}U -> 4.4 billion yrs
- ^{232}Th -> 14 billion yrs
- ^{40}K -> 1.25 billion yrs

Predicted Geoneutrino Flux

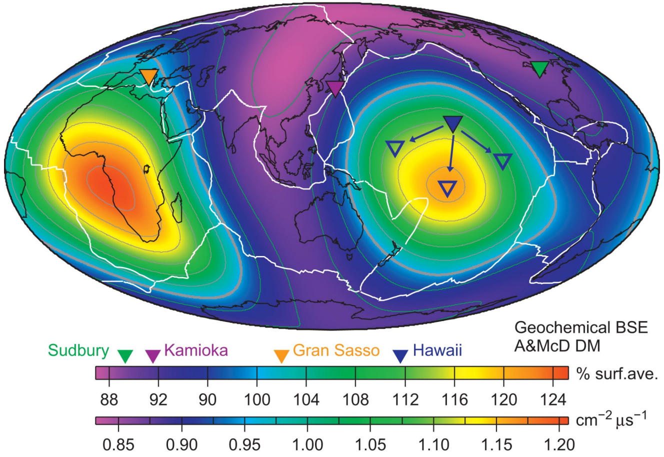


Total signal is small
1 TNU (100% detection efficiency) = 1 event / 10^{32} target protons / year

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

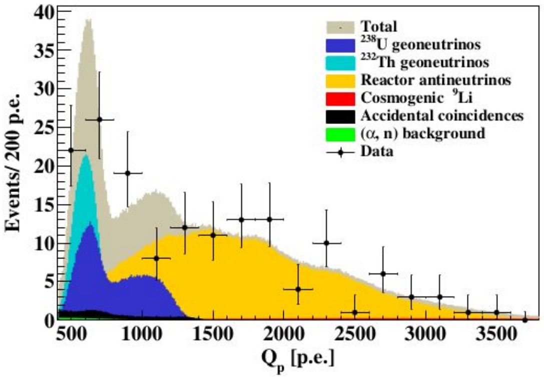


Šrámek, O., McDonough, W. F., Kite, E. S., Lekić, V., Dye, S. T., & Zhong, S. (2013). Geophysical and geochemical constraints on geoneutrino fluxes from Earth's mantle. *Earth and Planetary Science Letters*, *361*, 356–366. https://doi.org/https://doi.org/10.1016/j.epsl.2012.11.001

KamLAND and Borexino Measurements

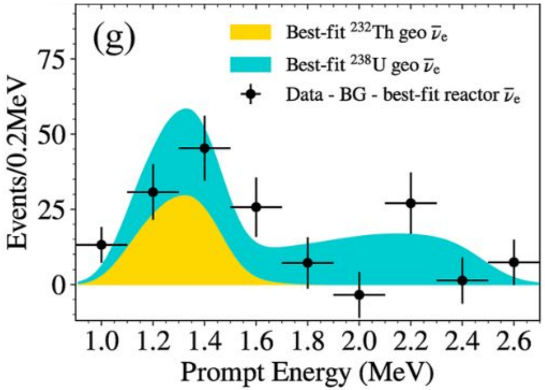
Borexino (2020) [M.Agostini et al., Phys. Rev. D 101, 2020]

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

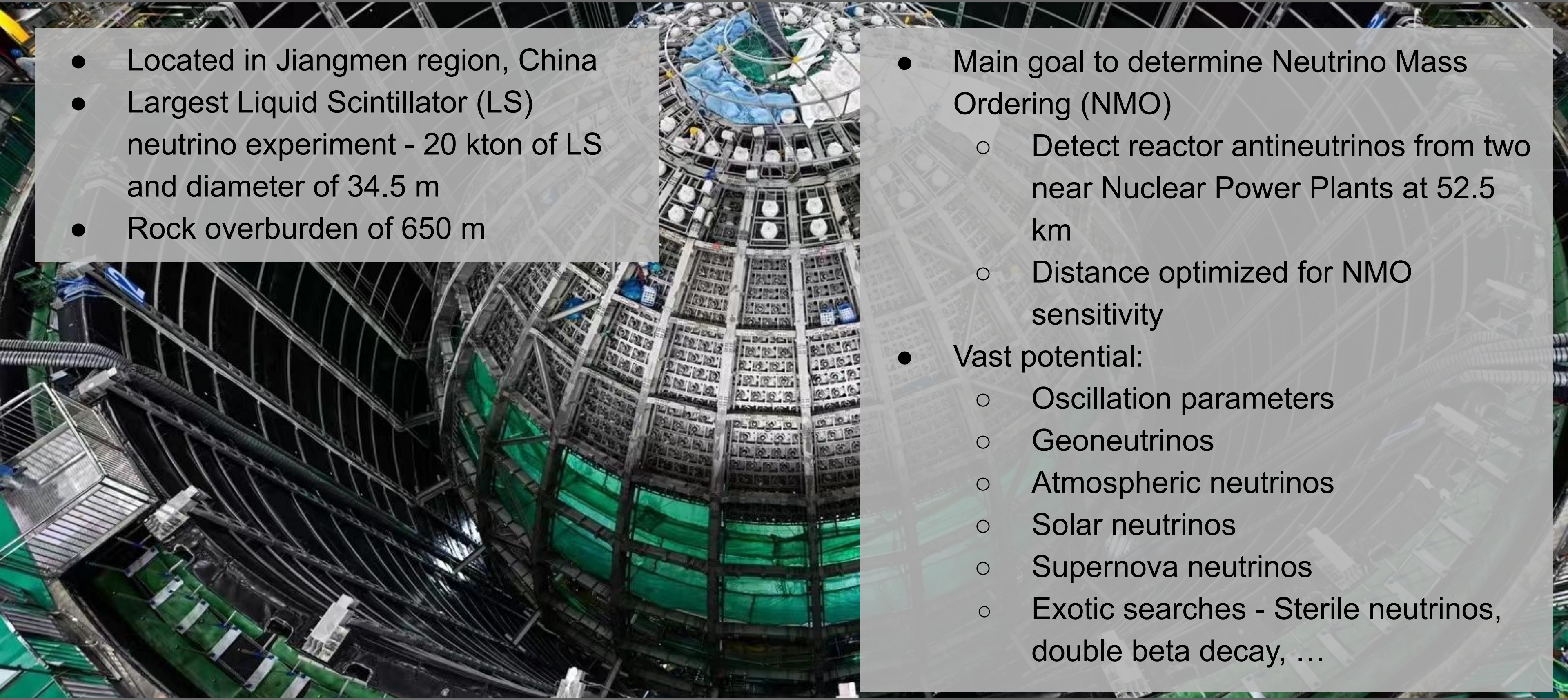


KamLAND (2022) [S.Abe et al., Geophys. Res. Lett. 49 (16), 2022]

- Experiment in Hida, Gifu, Japan
- Liquid Scintillator of 1 kton
- In almost 18 year ~ 170 events
- Precision ~ 15%



Jiangmen Underground Neutrino Observatory



- Located in Jiangmen region, China
- Largest Liquid Scintillator (LS) neutrino experiment - 20 kton of LS and diameter of 34.5 m
- Rock overburden of 650 m

- Main goal to determine Neutrino Mass Ordering (NMO)
  - Detect reactor antineutrinos from two near Nuclear Power Plants at 52.5 km
  - Distance optimized for NMO sensitivity
- Vast potential:
  - Oscillation parameters
  - Geoneutrinos
  - Atmospheric neutrinos
  - Solar neutrinos
  - Supernova neutrinos
  - Exotic searches - Sterile neutrinos, double beta decay, …

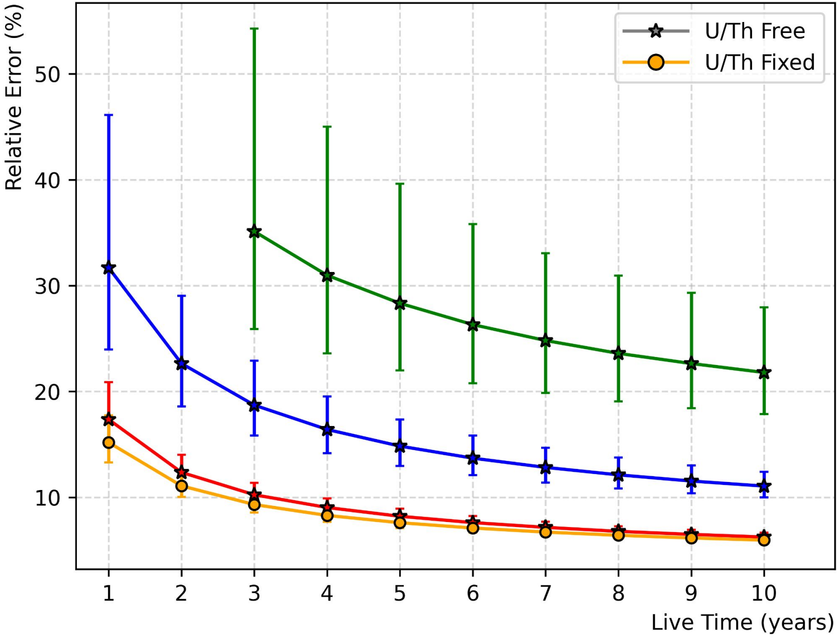
JUNO Sensitivity to Geoneutrinos Studies

Last published results (JUNO Yellow book and Ran Han, et. al.)

- ~6% precision at 10 years
- Exceed statistics of KamLAND and Borexino in 1 year
- Ability to measure Th/U ratio needs large statistics

Current Work - Update:

- Refined local geological model
- Better detector knowledge - New MC simulations
- New Background: atmospheric neutrinos
- Full MC approach including reconstruction



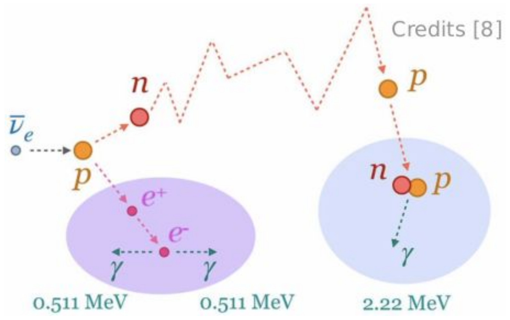
More details in my poster 😉

Thank you!!

Backup Slides

Signals Features

- Detection channel: Inverse Beta Decay (IBD)
    - Prompt signal (e+): Quick annihilation into two 511 gammas
    - Delayed signal (n): thermalized and captured by proton
    - Time between both signals ~ 250 μs
- Energy threshold at 1.8 MeV
    - Only ^{238}U and ^{232}Th are detected
    - ^{40}K decay has low energy
- Processes from main NMO analysis - same signal signature
    - Reactor neutrinos is background
    - Processes rates also inherited



		Energy Range 1.8 ⩽ E ⩽ 12 MeV	Rate [cpd x kton]	Rate unc.	Shape unc.
IBD events	Geoneutrinos	1.2	-	6.7%
	Reactor Neutrinos	43.18	-	Daya Bay
Non-IBD events	Accidentals	0.8	1%	-
	Li/He	0.8	10%	13.4%
	(alpha,n)	0.05	50%	67%
	Fast Neutrons	0.1	100%	27%
	World Reactor	1	5%	6.7%
	Atmospheric	0.16	50%	67%

Analysis Workflow

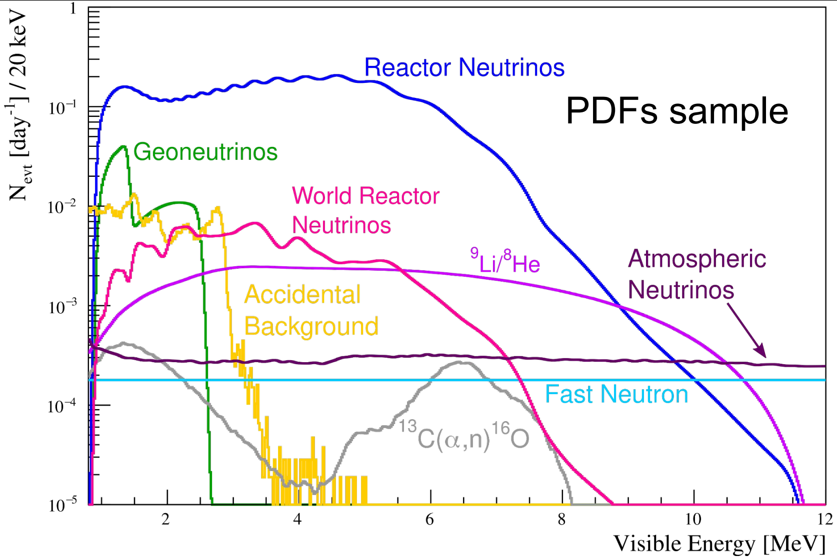
Produce 100k pseudo-datasets

General config:

- Fitting range
- Bin width
- FV Mass
- Exposure
- No. of Fits
- DAQTime

Rates for toyMC production

Fit configuration

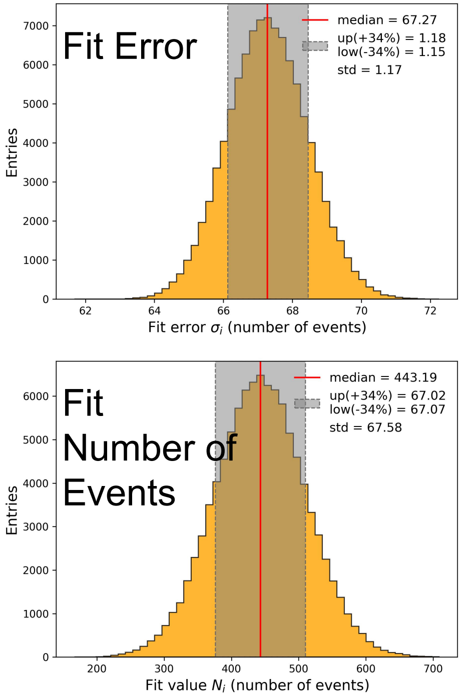


Analysis Workflow

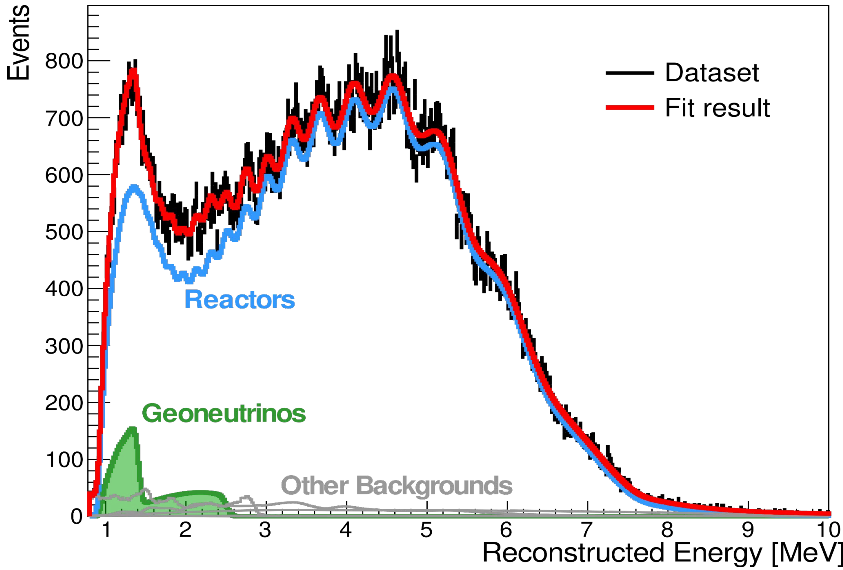
Produce 100k pseudo-datasets

Fit and obtain results for *geo*

Distributions of the results



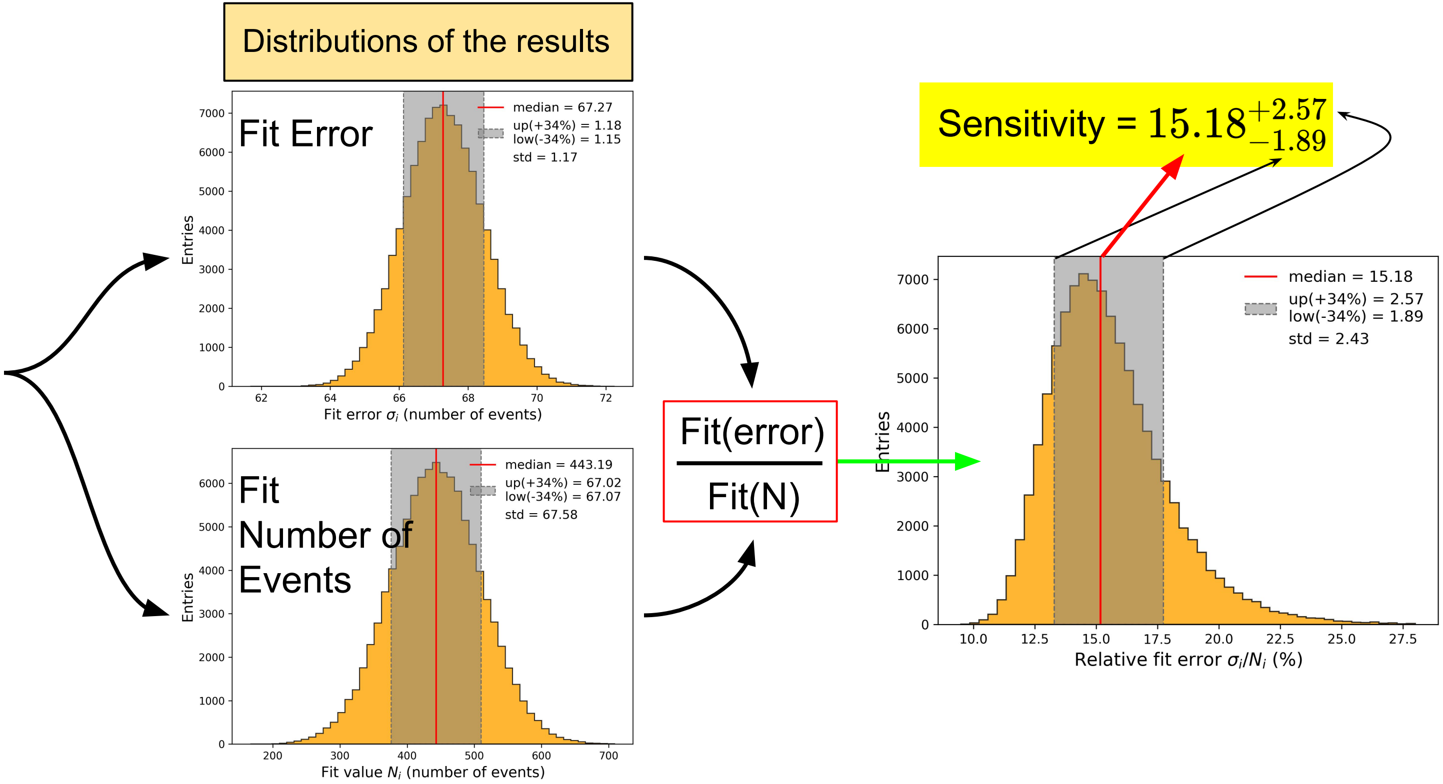
Example of one toy dataset result with 10 years of exposure



Sensitivity Method

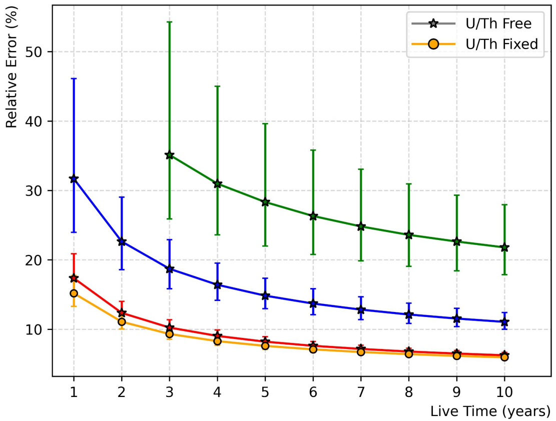
Produce 100k pseudo-datasets

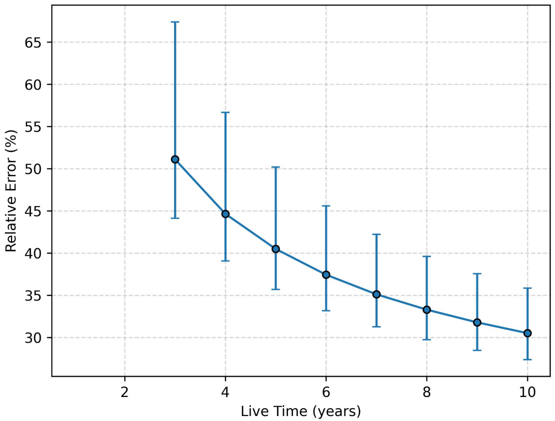
Fit and obtain results for *geo*



Geoneutrinos Precision

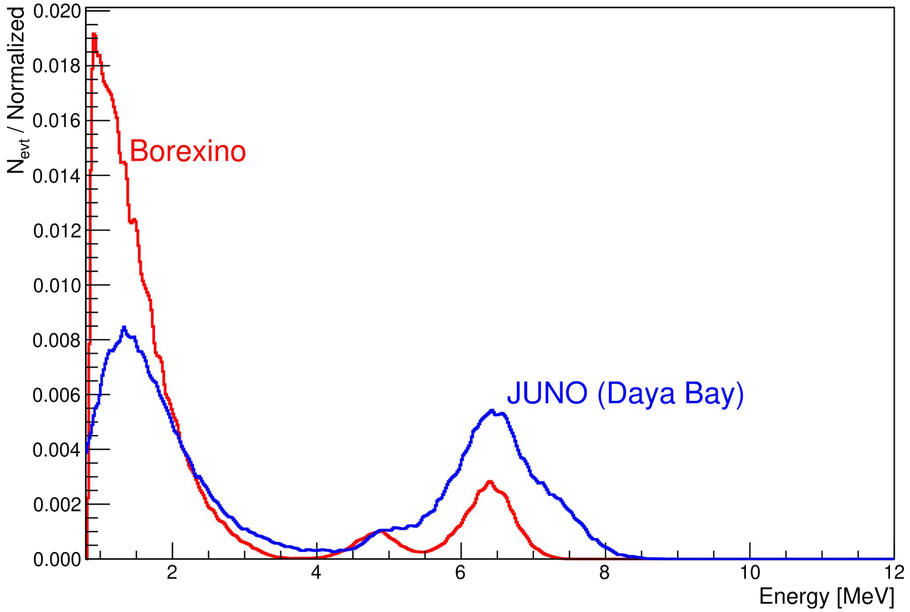
- Two measuring schemes:
  - U/Th Fixed: Signal ratio U/Th is fixed to corresponding CI chondrites abundance ratio - total geoneutrinos rate is fitted
  - U/Th Free: PDFs of U and Th are fitted independently - provides the Th/U ratio measurement
- Combining U+Th gives comparable results to U/Th fixed
- Th/U ratio could be measured in JUNO





(alpha,n) Background

- Use Borexino PDF and different radiopurity scenarios
- Difficult to calculate expected contribution - many variables
  - Cleanness of acrylic vessel and pipes
  - Purity of LS
  - Air leakage
- Significant impact depending on shape and rate
  - Borexino (alpha,n) shape presents a bigger peak in the geoneutrino energy region - harder to fit
  - Current works on updating the expected spectrum
  - Calculation on going for corroboration of the rate



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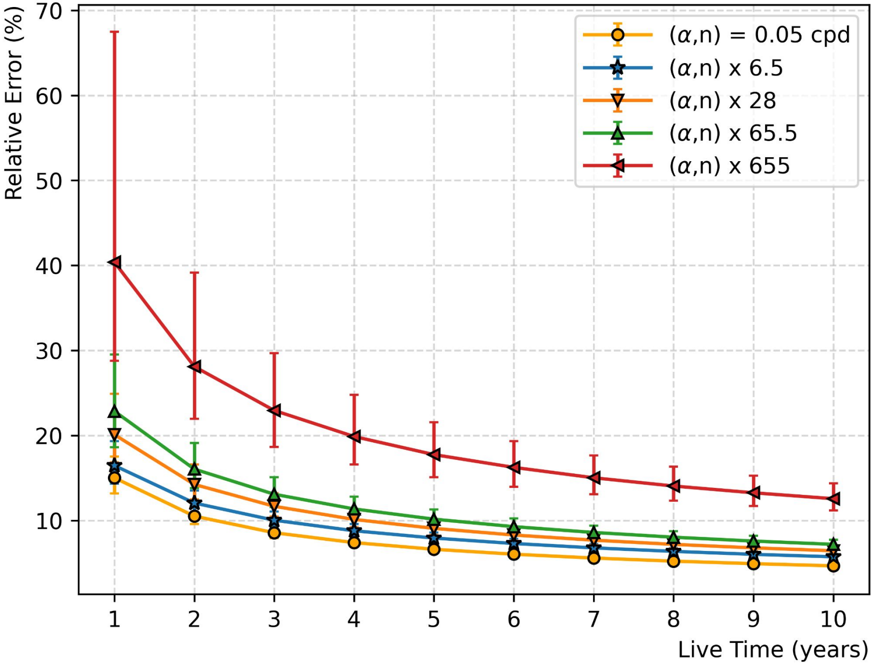
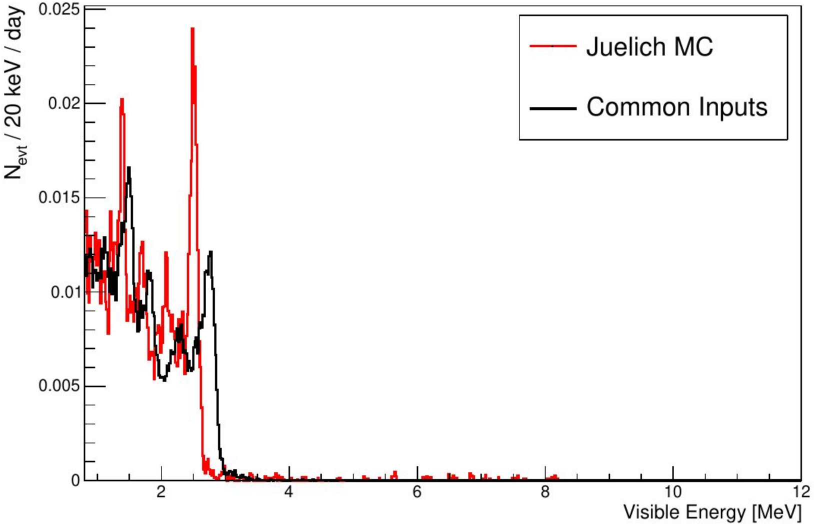


Accidentals Background

- Utilize Accidentals PDF with different reconstruction method
- Rate constraint of 1%
  - It will be possible to measure the Accidentals with real data
- No impact found



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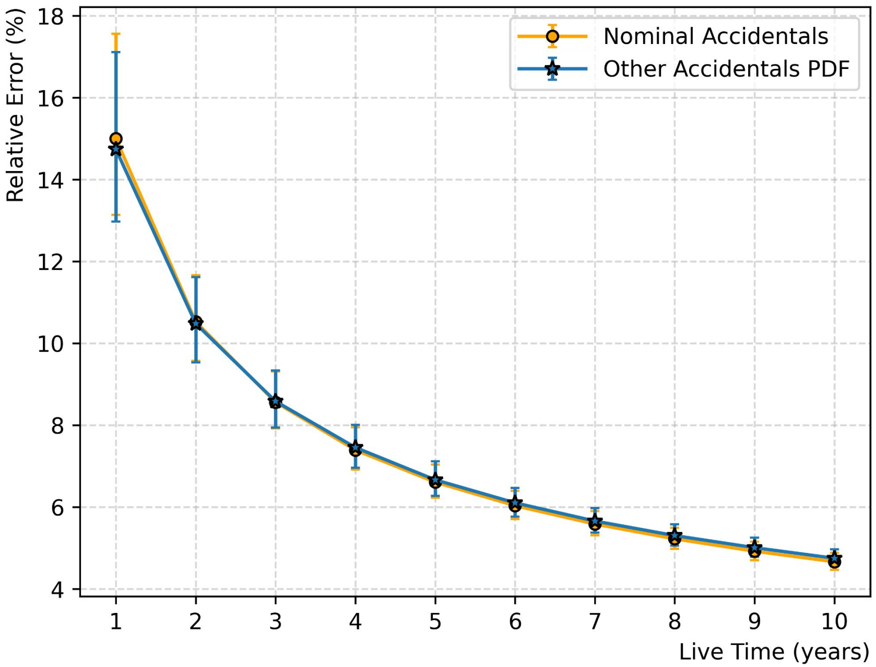
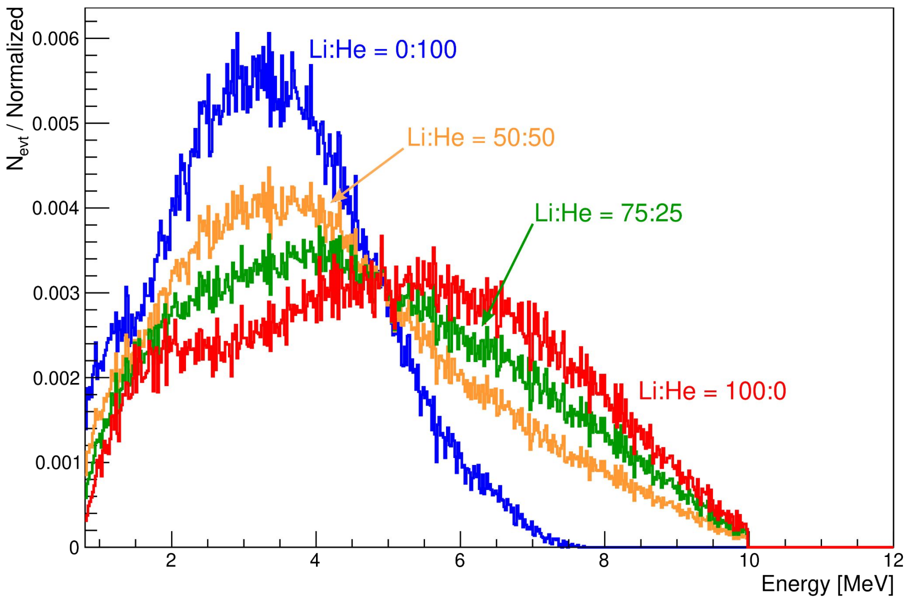


Li/He Background

- Li/He background varies with the experiments
  - overburden dependence
- Test with different PDF and ratios of Li and He
- No impact found



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