JUNO Sensitivity to Geoneutrinos

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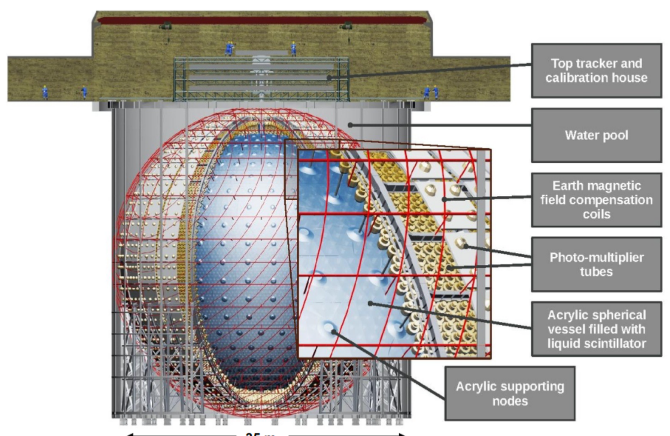
Introduction

Jiangmen Underground Neutrino Observatory

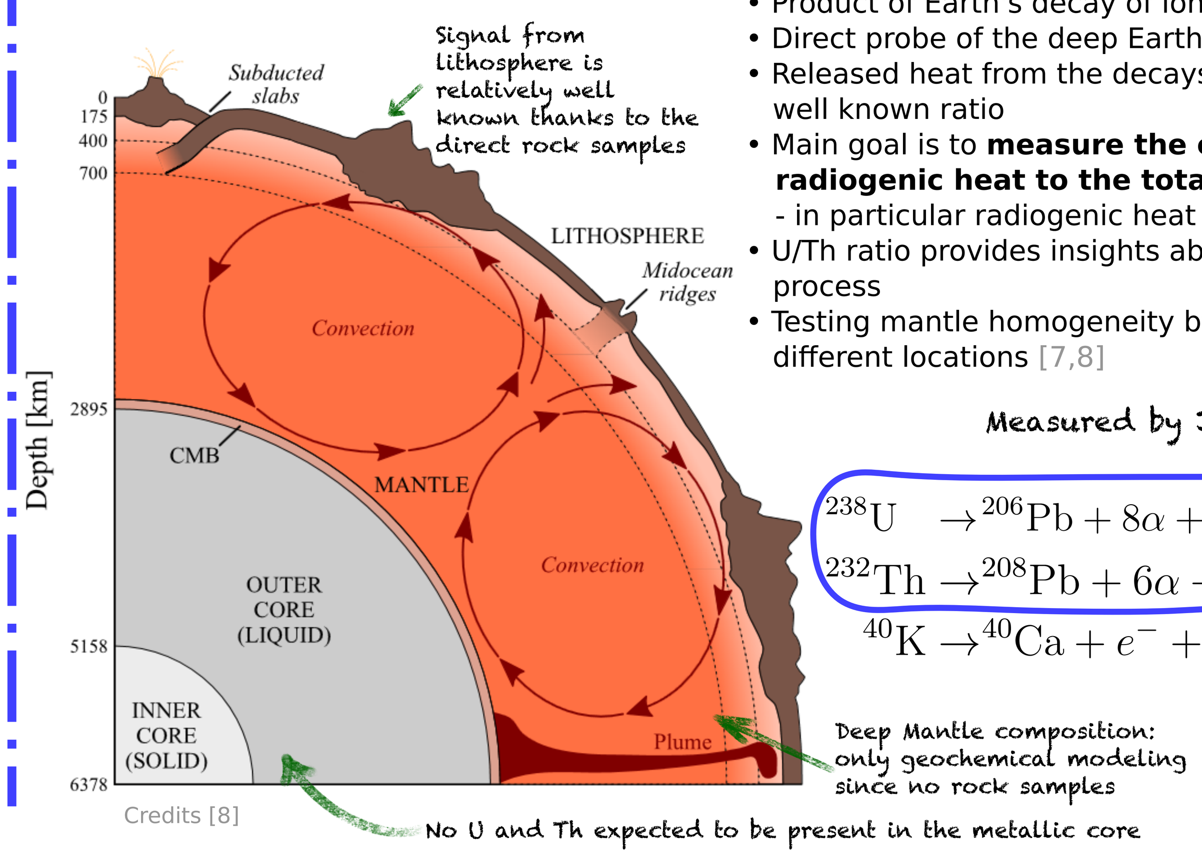


- Largest liquid scintillator neutrino experiment
- Under construction at the Jiangmen region, China
- Near two nuclear power plants at 52.3 km
- Rock overburden of 650 m
- 20 kton Liquid Scintillator target
- Detector with diameter of 34.5 m
- Energy resolution of 3% at 1 MeV

- **Main objective:** determine the Neutrino Mass Ordering [3] with reactor anti-neutrinos. Precise measurement of oscillation parameters with subpercent precision [2]
- Potential in other topics: Atmospheric neutrinos, **Geoneutrinos**, Solar neutrios, Supernova neutrinos, and many others

This work aims to update previous results published [1,4]:
- Refined geological model around JUNO - latest in [5]
- Reactor spectrum and uncertainty
- Updates on detector response and backgrounds
- Impact of oscillation parameters
- Full MC approach including reconstruction

Geoneutrinos



Credits [8]

- Product of Earth's decay of longlived radioactive elements
- Direct probe of the deep Earth
- Released heat from the decays and geoneutrino flux is in a well known ratio
- Main goal is to **measure the contribution of the radiogenic heat to the total Earth's surface heat flux** - in particular radiogenic heat of the mantle
- U/Th ratio provides insights about the the Earth's formation process
- Testing mantle homogeneity by measuring geoneutrino at different locations [7,8]

Measured by JUNO

$$^{238}\mathrm{U} \rightarrow {}^{206}\mathrm{Pb} + 8\alpha + 8e^- + 6\bar{\nu}_e + 51.7\,\mathrm{MeV}$$
$$^{232}\mathrm{Th} \rightarrow {}^{208}\mathrm{Pb} + 6\alpha + 4e^- + 4\bar{\nu}_e + 42.8\,\mathrm{MeV}$$
$$^{40}\mathrm{K} \rightarrow {}^{40}\mathrm{Ca} + e^- + 1\bar{\nu} + 1.32\,\mathrm{MeV}$$

Low energy < 1.8 MeV

Signal Signature

Inverse Beta Decay

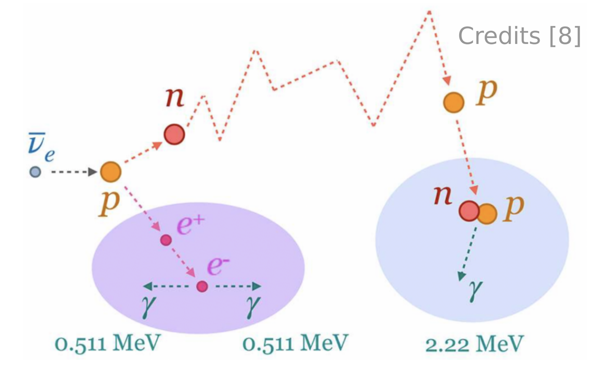
$$\bar{\nu}_e + p \rightarrow e^+ + n$$

Delayed signal: thermalize and captured ~ 200µ

Prompt signal: Quick anihilation into two 511 MeV gammas

$$E_{prompt} \approx E_{\bar{\nu}} - 0.782\,\mathrm{MeV}$$

Credits [8]



IBD candidate: correlated prompt-like with a following delayed-like event

Procedure

Toy MC approach with the software **Julich nUsol Sensitivity Tool (JUST)** [6]

Rates of each process

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

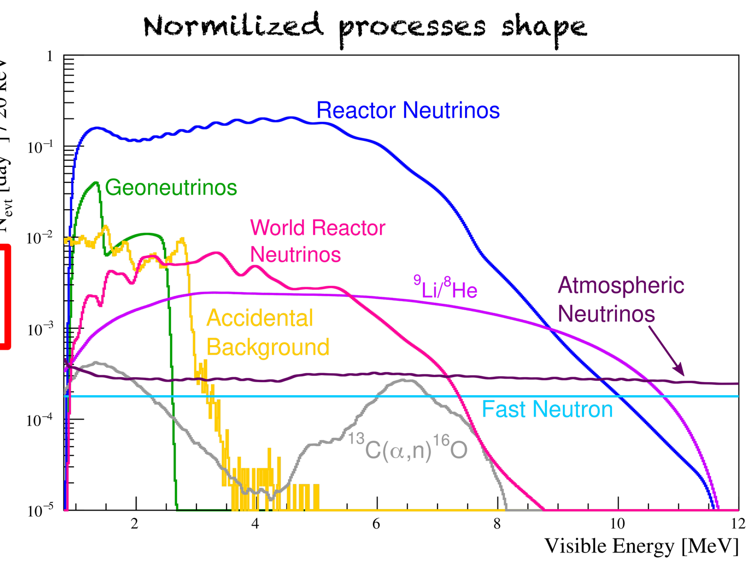
Experiment Exposure

Number of toyMC

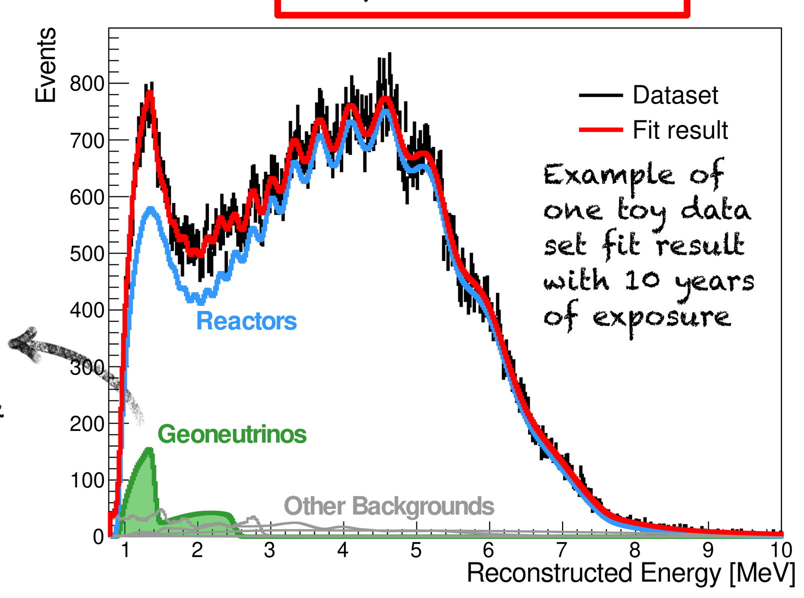
PDFs

JUST: Configuration

Normilized processes shape



JUST: Sampling and Fitting



Example of one toy data set fit result with 10 years of exposure

Toy data sets generated by randomly sampling the PDFs and stastically fluctuate the injected rate

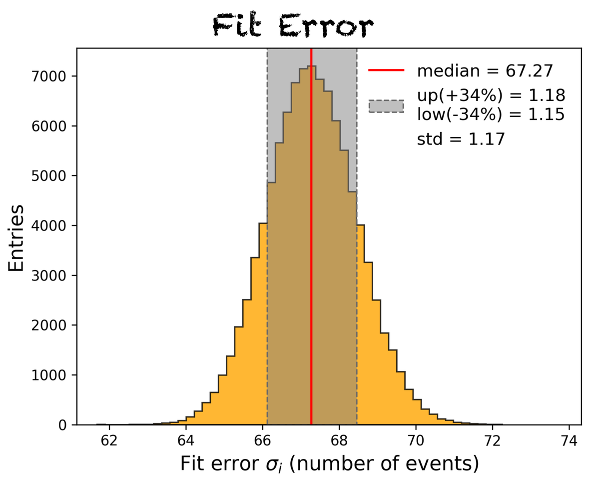
Fitting characteristics:
- Energy rage: 1.8-12 MeV
- Pearson χ^2
- Minimization using Minuit
- Rate uncertainty introduced as constrain and addtional pull term in χ^2 for other backgrounds
- Shape uncertainties modify the χ^2 definition

$$\chi^2 = \frac{(y-n)^2}{y + (\sigma_{shape} \cdot y)^2} + \text{Pull Terms}$$

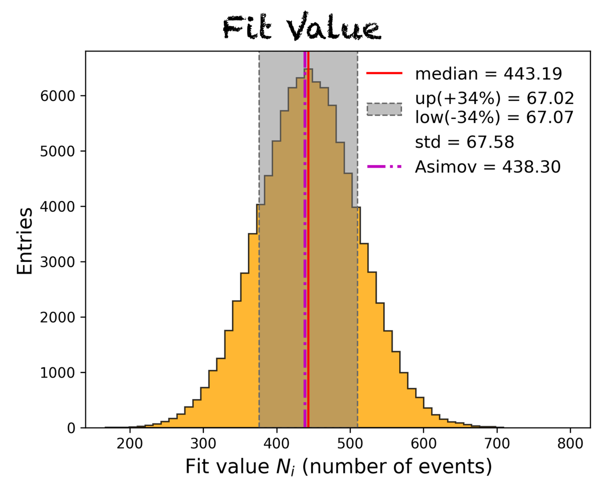
- PDFs are fluctuated given the shape uncertainty on every fit
- Fitting errors provided by minimizer
- Fixed oscillation parameters

Analyze fits: 100k Output results

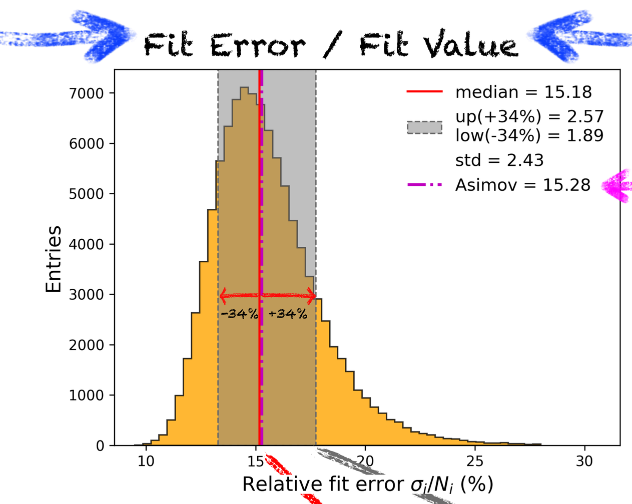
Fit Error



Fit Value



Fit Error / Fit Value



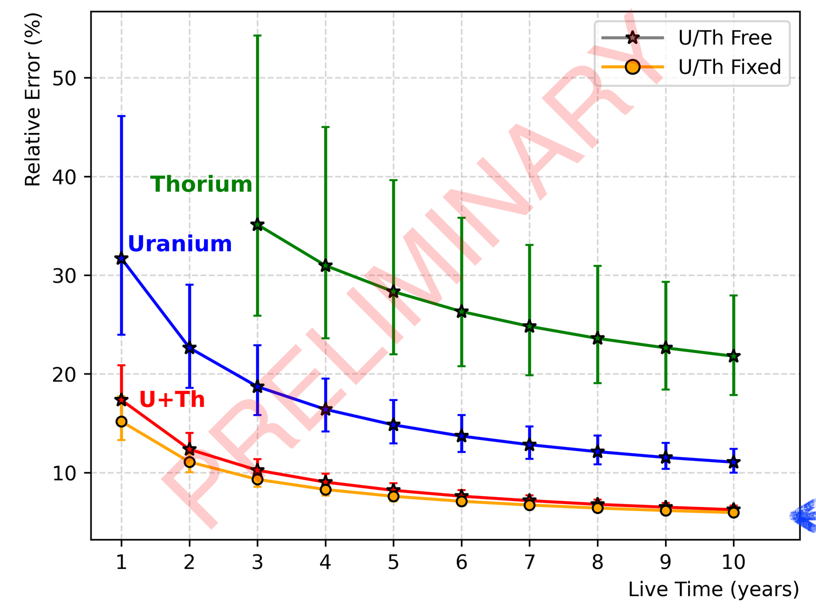
Asimov data set can also be produced and fitted, where a single toy is produced without any statistical fluctuation

- Median from toy approach agrees closely to asimov fit
- Toy approach provides extra information: 68% C.I.

$$\text{Sensitivity} = \text{median}^{+34\%}_{-34\%}$$

Results

Geoneutrinos Precision



Two measuring schemes:

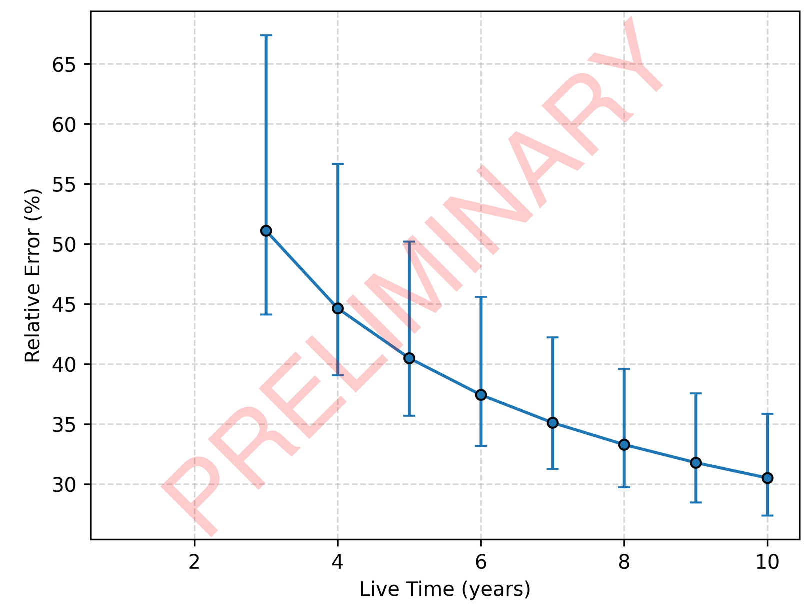
1. U/Th Fixed: Signal ratio U/Th is fixed and the total geoneutrino signal is fitted. The ratio assumed is 0.29 corresponding to abundances from CI chondrites

2. U/Th Free: The PDFs of U and Th are fitted independently. Provides the observed Th/U ratio and their correlation

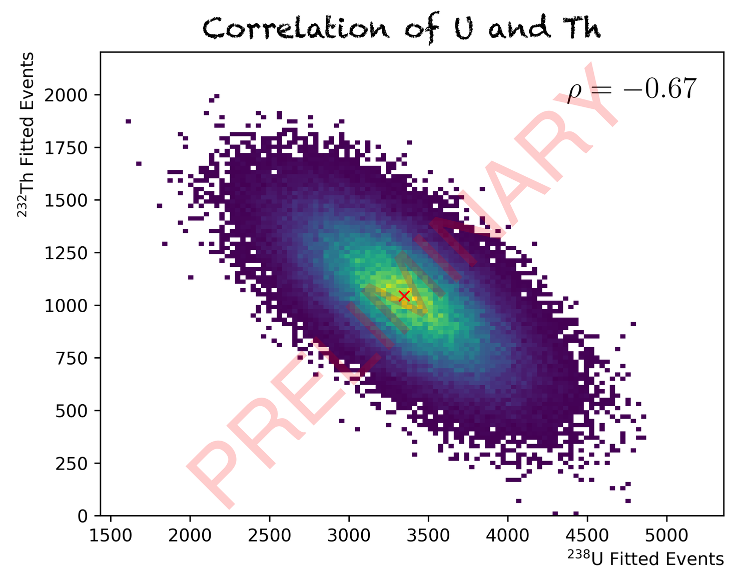
Combined U+Th signals offer a comparable result to U/Th fixed

$$\sigma(U+Th) = \sqrt{\sigma_U^2 + \sigma_{Th}^2 + 2\sigma_U\sigma_{Th}\rho}$$

Th/U Ratio Precision

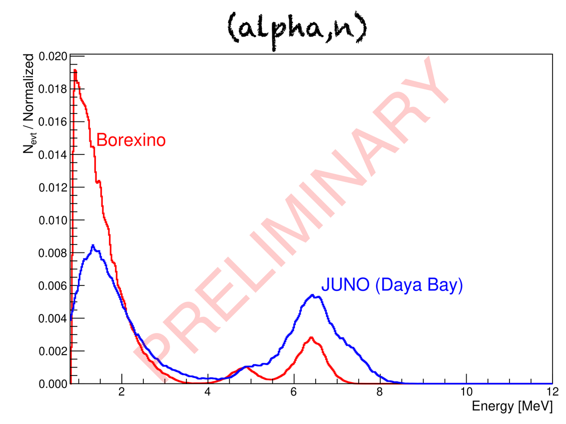


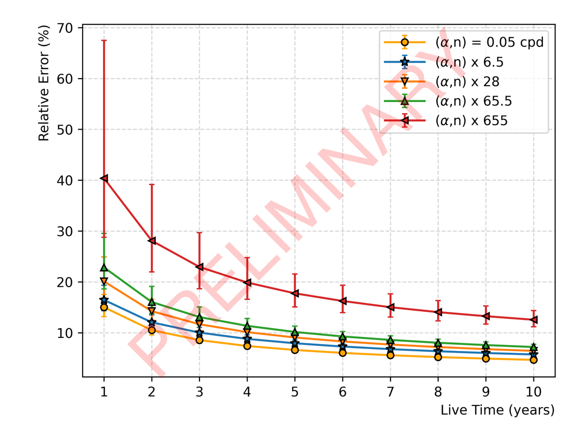
Correlation of U and Th



Background Impact Analysis

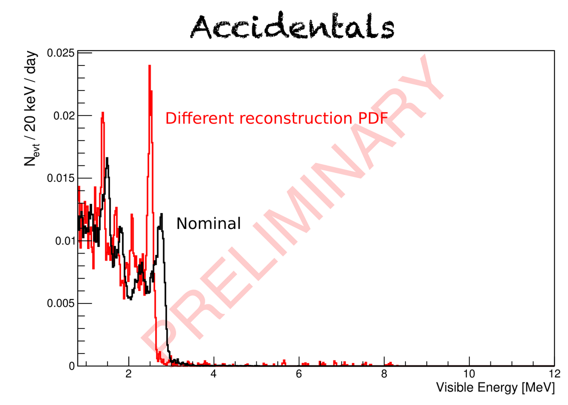
(alpha,n)

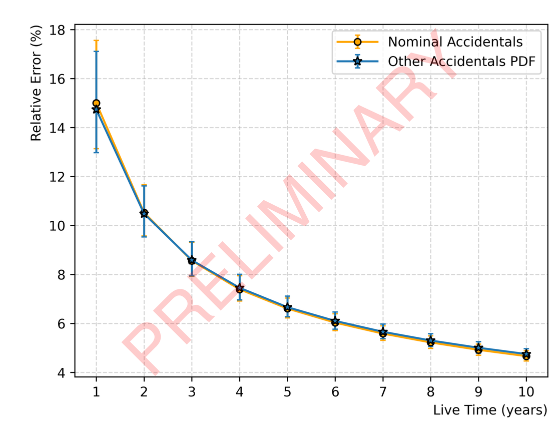




- Different radiopurity scenarios considered
- Borexino (alpha,n) PDF
- **Most critical background**, after reactor neutrinos
- Current works on improved spectrum and rate estimation

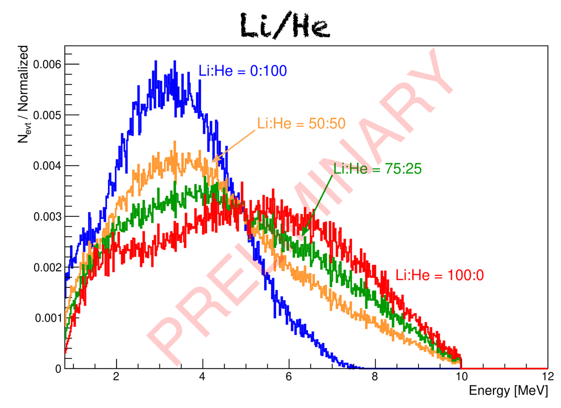
Accidentals

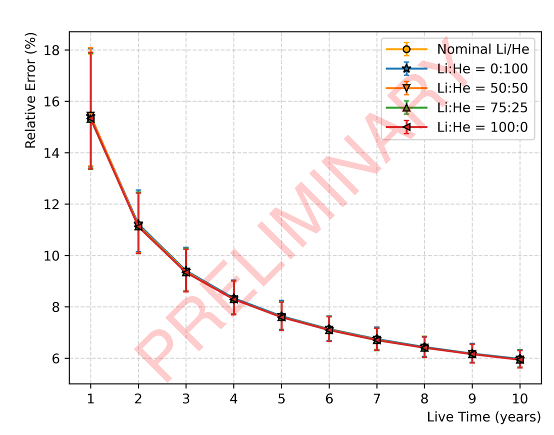




- Test with a PDF with a different reconstruction for accidentals
- Rate constrain of 1%
- Constrain will be from real data
- **No impact**

Li/He





- Generate Li/He PDF using different contribution ratio of Li and He
- Contribution varies with the experiment - dependance with the overburden
- Test Li/He with different PDF
- **No impact**

Conclusions

- **Highest geoneutrino statistics:** JUNO with just 1 year will collect more events (~400) than other experiments, e.g: KamLAND ~ 175 events in 18 years [7] and Borexino ~ 53 events in 11 years [8]
- Biggest challenge is to **disentangle geoneutrinos from reactor neutrinos.** A **understanding of the radiopurity** for the (alpha,n) background contribution is needed
- **Precise measurement of total geoneutrino signal** can be achieved for both U/Th fixed and free JUNO could also be sensitive to measuring Th/U signal ratio

Next Plans

- **Update PDFs** with new MC production - better detector knowledge
- **Geological crust model** - refined rates and spectrum Ongoing work of updated geomodel
- **Mantle signal sensitivity and precision** to different models
- Overhaul of **(alpha,n) background** - new generator and rate estimation
- Inclusion of neutrino **oscillation parameters**

References

[1] Juno Collaboration. (2016). Neutrino physics with JUNO. Journal of Physics G: Nuclear and Particle Physics, 43(3), 030401. https://doi.org/10.1088/0954-3899/43/3/030401

[2] A. Abusleme et. al. (JUNO Collaboration). Sub-percent precision measurement of neutrino oscillation parameters with JUNO. Chinese Physics C, 46(12):123001, dec 2022

[3] JUNO Collaboration. JUNO physics and detector. (2022). Progress in Particle and Nuclear Physics, 123, 103927. https://doi.org/10.1016/j.ppnp.2021.103927

[4] Han, R., Li, Y.-F., Zhan, L., McDonough, W. F., Cao, J., & Ludhova, L. (2016). Potential of geo-neutrino measurements at JUNO*. Chinese Physics C, 40(3), 033003. https://doi.org/10.1088/1674-1137/40/3/033003

[5] Gao, R., Li, Z., Han, R., Wang, A., Li, Y., Xi, Y., Liu, J., Mao, X., Sun, Y., & Xu, Y. (2020). JULOC: A local 3-D high-resolution crustal model in South China for forecasting geoneutrino measurements at JUNO. Physics of the Earth and Planetary Interiors, 299, 106409. https://doi.org/https://doi.org/10.1016/j.pepi.2019.106409

[6] Göttel, A., Ludhova, L., Meraviglia, A., Pelicci, L., & Settanta, G. (2021). JUST: A neutrino fit software for JUNO's solar analysis and sensitivity. Nuovo Cim. C, 45(1), 9. https://doi.org/10.1393/ncc/i2022-22009-8

[7] Abe, S., Asami, S., Eizuka, M., Futagi, S., Gando, A., Gando, Y., et al. (2022). Abundances of uranium and thorium elements in Earth estimated by geoneutrino spectroscopy. Geophysical Research Letters, 49, e2022GL099566. https://doi.org/10.1029/2022GL099566

[8] Agostini, M., & et. al. (2020). Comprehensive geoneutrino analysis with Borexino. Phys. Rev. D, 101(1), 012009. https://doi.org/10.1103/PhysRevD.101.012009

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