Geoneutrino studies with JUNO detector

Oleg Smirnov, JINR, Dubna
on behalf of JUNO collaboration

International Workshop : Neutrino Research and Thermal Evolution of the Earth
October 25 – 27, 2016, Sendai, Japan

JUNO Collaboration

try	Institute
ia	Yerevan Physics Institute
n	Universite libre de Bruxelles
	PUC
	UEL
	PCUC
	BISEE
	Beijing Normal U.
	CAGS
	ChongQing University
	CIAE
	DGUT
	ECUST
	Guangxi U.
	Harbin Institute of Technology
	IHEP
	Jilin U.
	Jinan U.
	Nanjing U.
	Nankai U.
	NCEPU
	Pekin U.
	Shandong U.
	Shanghai JT U.
	IMP-CAS
	SYSU
	Tsinghua U.
	UCAS
	USTC
	U. of South China
	Wu Yi U.
	Wuhan U.
	Xi'an JT U.

Collaboration established in July 2015
Now: 66 institutions
444 collaborators
8 obervers

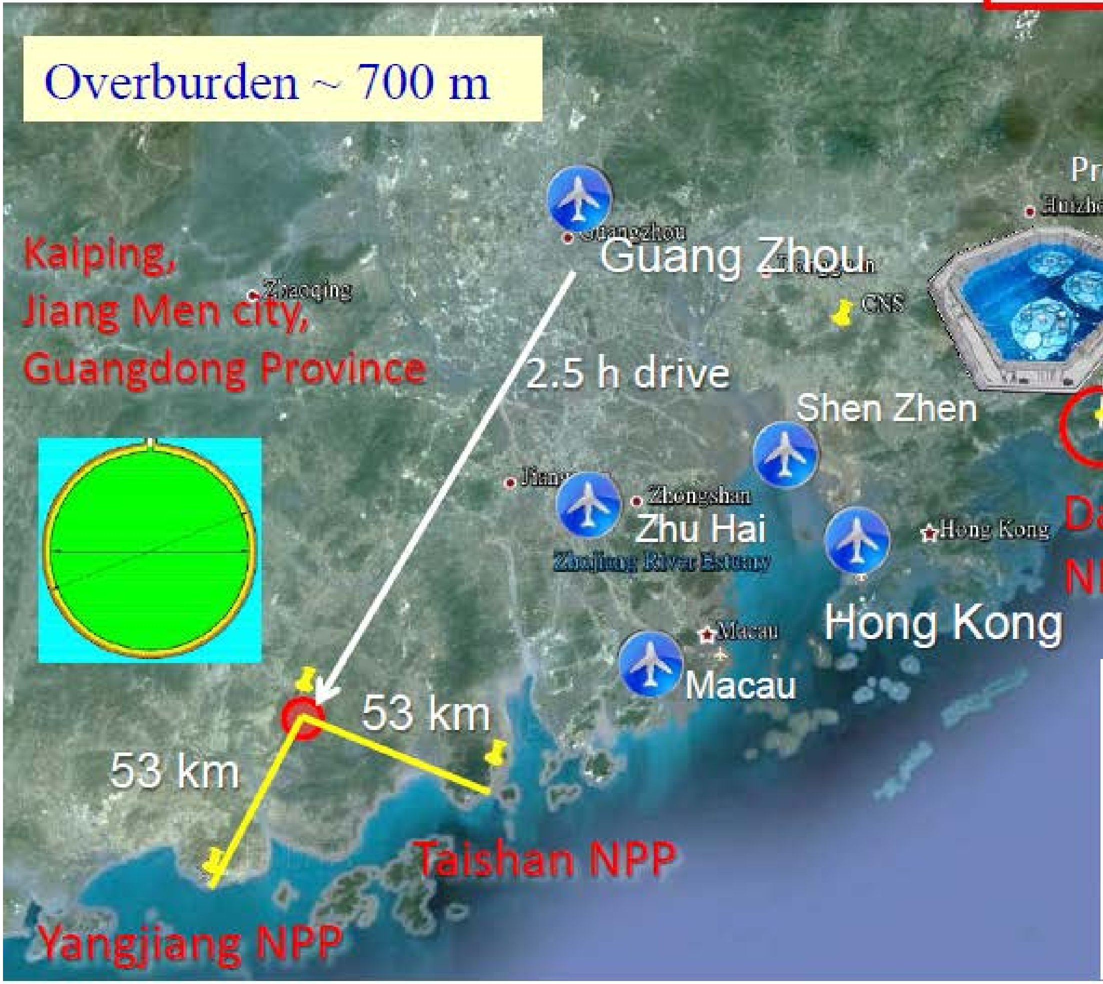
China	Xiamen University
China	NUDT
Czech	Charles U.
Finland	University of Oulu
France	APC Paris
France	CPPM Marseille
France	IPHC Strasbourg
France	LLR Palaiseau
France	Subatech Nantes
Germany	Forschungszentrum Julich
Germany	RWTH Aachen U.
Germany	TUM
Germany	U. Hamburg
Germany	IKP FZI Jülich
Germany	U. Mainz
Germany	U. Tuebingen
Italy	INFN Catania
Italy	INFN di Frascati
Italy	INFN-Ferrara
Italy	INFN-Milano
Italy	INFN-Milano Bicocca
Italy	INFN-Padova
Italy	INFN-Perugia
Italy	INFN-Roma 3
Pakistan	PINSTECH
Russia	INR Moscow
Russia	JINR
Russia	MSU
Taiwan	National Chiao-Tung U.
Taiwan	National Taiwan U.
Taiwan	National United U.
Thailand	SUT
USA	UMD1
USA	UMD2

Location of JUNO

NPP	Daya Bay	Huizhou	Lufeng	Yangjiang	Taishan
Status	Operational	Planned	Planned	Under construction	Under construction
Power	17.4 GW	17.4 GW	17.4 GW	17.4 GW	18.4 GW

by 2020: 26.6 GW

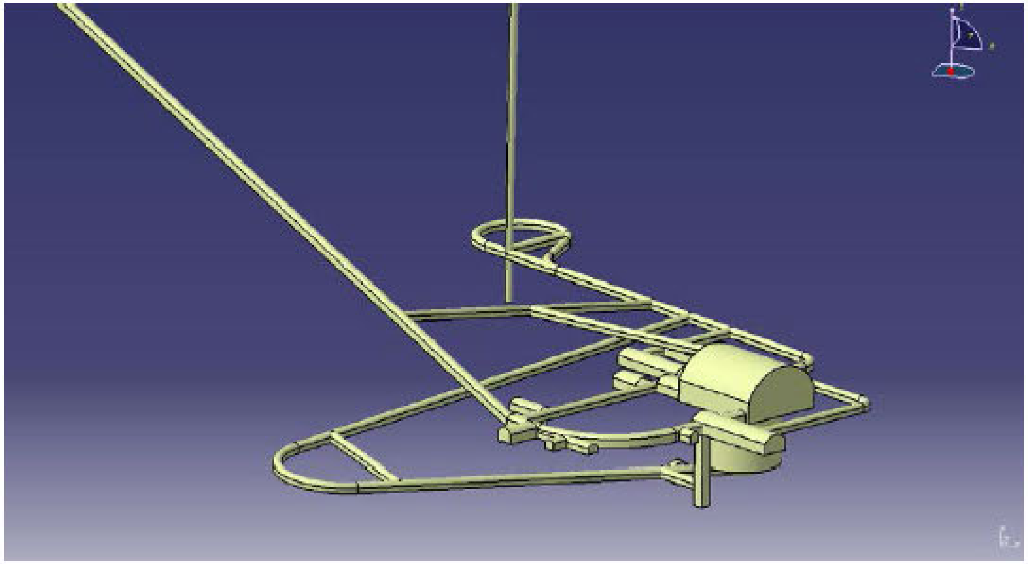
Overburden ~ 700 m



Cores	YJ-C1	YJ-C2	YJ-C3	YJ-C4	YJ-C5	YJ-C6
Power (GW)	2.9	2.9	2.9	2.9	2.9	2.9
Baseline (km)	52.75	52.84	52.42	52.51	52.12	52.21
Cores	TS-C1	TS-C2	TS-C3	TS-C4	DYB	HZ
Power (GW)	4.6	4.6	4.6	4.6	17.4	17.4
Baseline (km)	52.76	52.63	52.32	52.20	215	265

JUNO Progress and Schedule

- **Ground breaking in Jan. 2015**
  - ⇨ **900 m slope tunnel excavated out of 1340 m**
  - ⇨ **330 m vertical shaft excavated out of 611 m**



Schedule:

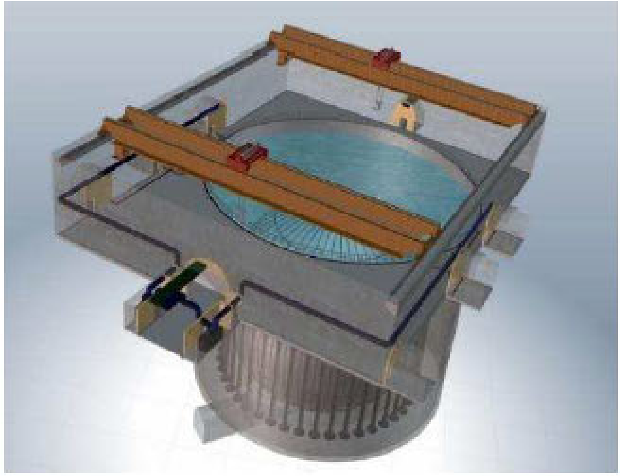
Civil preparation：2013-2014

Civil construction：2014-2017

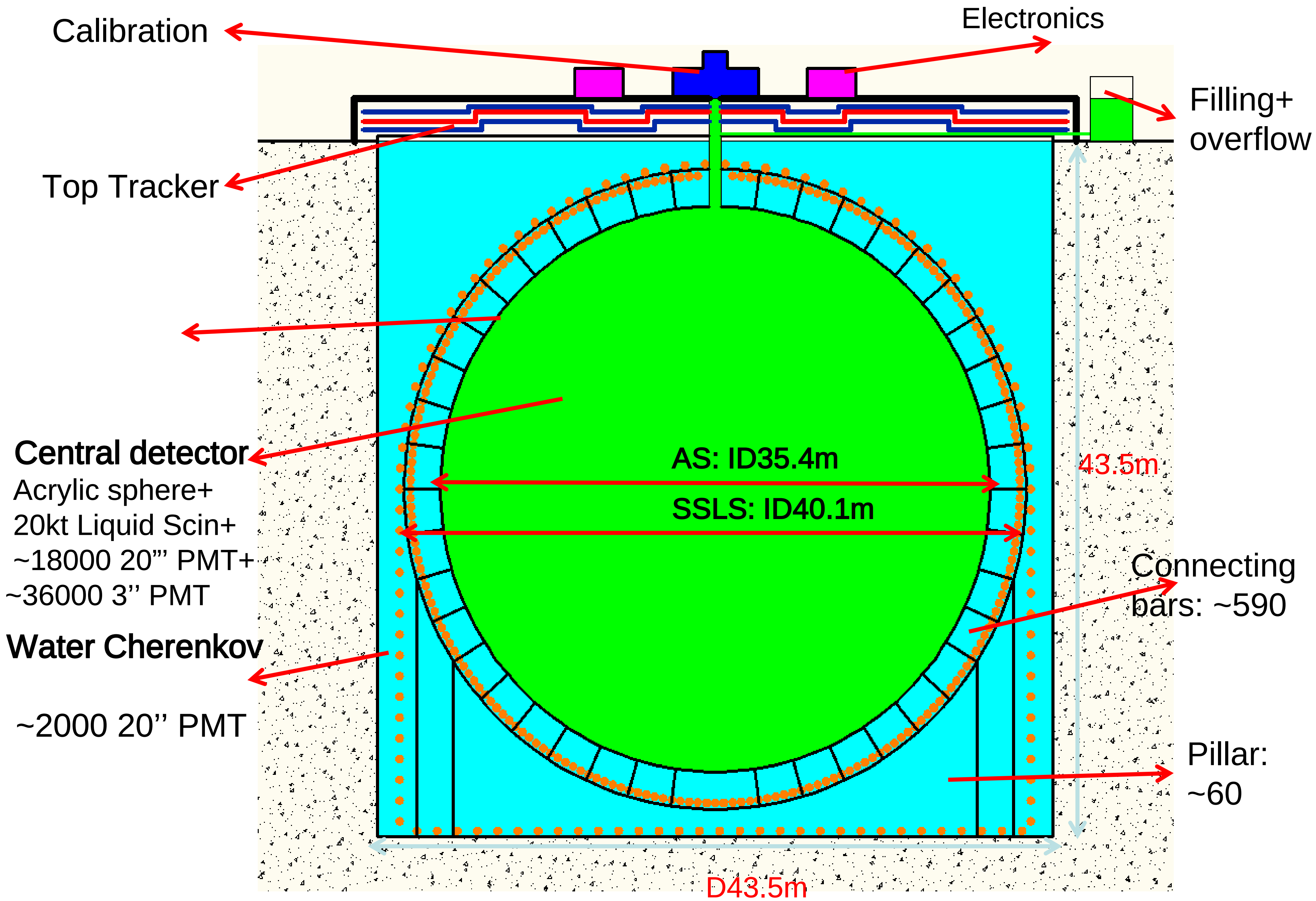
Detector component production：2016-2017

Detector assembly & installation：2018-2019

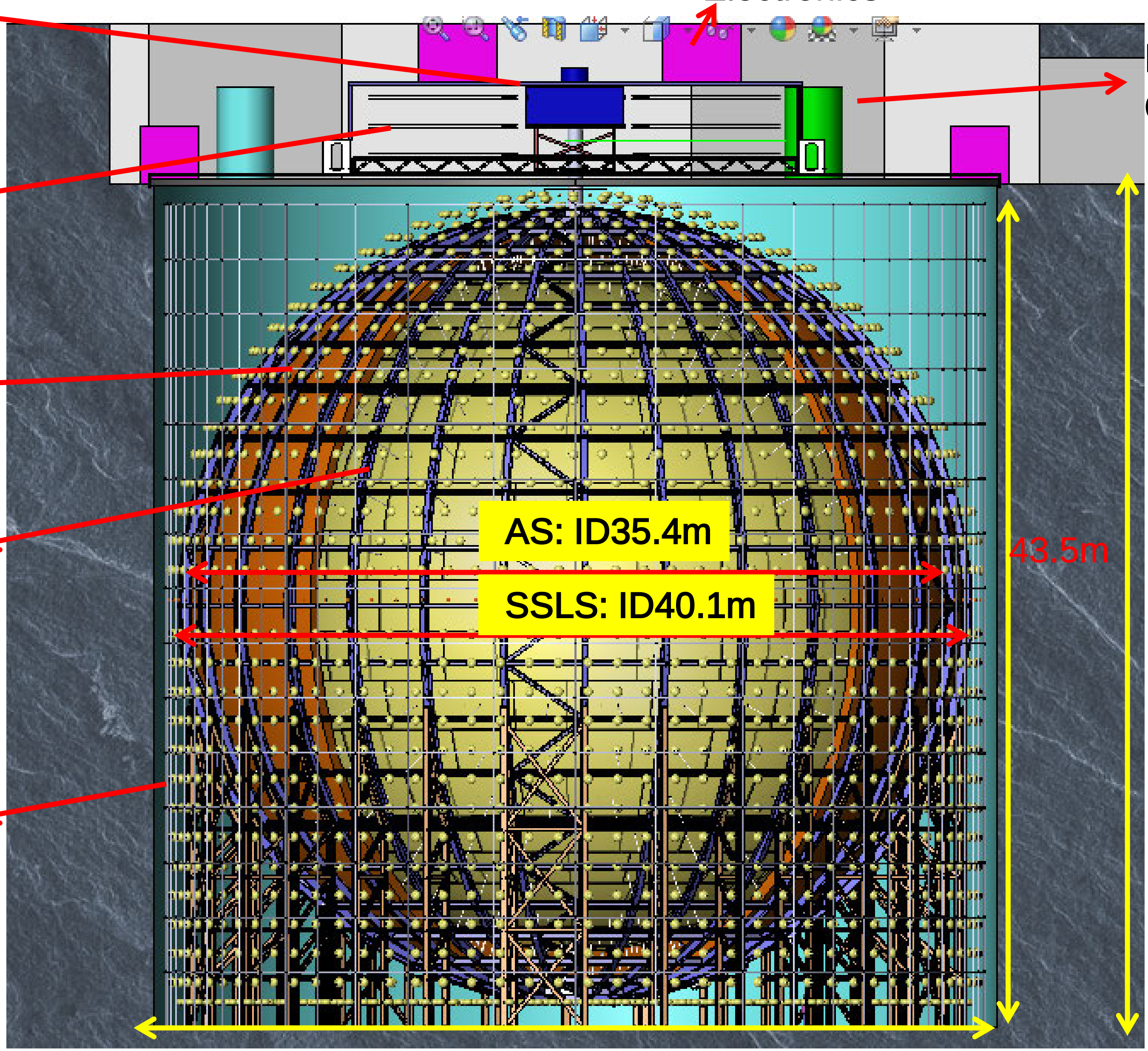
Filling & data taking：2020



Progresses of the excavation



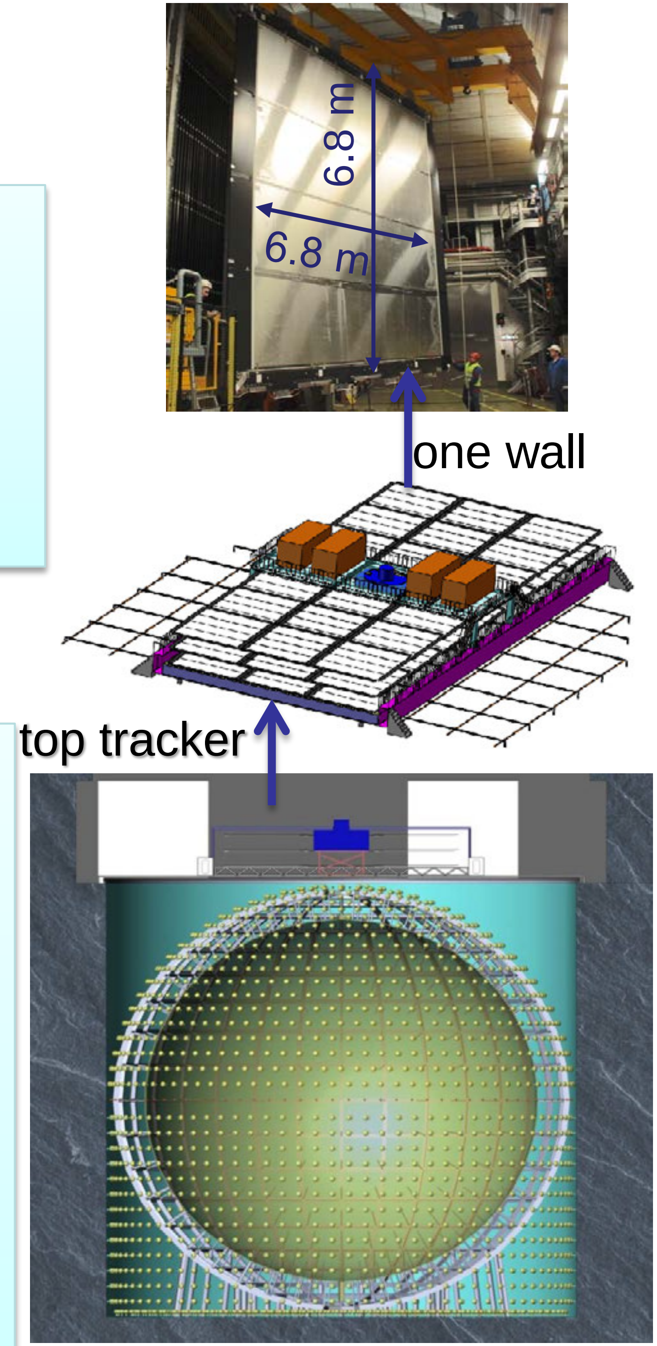
AS: Acrylic sphere; SSLS: stainless steel latticed shell



AS: Acrylic sphere; SSLS: stainless steel latticed shell

Veto system

- **Top tracker (TT):**
  - Re-using the Target Tracker walls of the OPERA experiment;
  - Total number is 62 and cover half of the top area;
  - 3 TT layers spaced by 1 m ,each layer have x,y readout;
  - A solid bridge support the TT and its mechanical structure;
  - Perform a precise muon tracking and provide valuable information for cosmic muon induced Li9/He8 study.



- **Water Cherenkov detector:**
  - 20 inch MCP-PMT used for veto system with number~2000;
  - Detector efficiency requirement is expect to be>95%;
  - Fast neutron background ~0.1/day.
- Compensation coils system used for earth magnet field shielding to keep PMT performance.
- Water system:
  - Employ a circulation/polishing water system;
  - Keep a good water quality -including radon control.

JUNO is mupltipurpose detector

"Neutrino physics with JUNO", J.Phys.G 43 (2016) 030401

- Neutrino mass hierarchy study
- Precision measurement of neutrino oscillation parameters
- Supernova bursts and diffuse supernova neutrinos
- Solar neutrinos
- Atmospheric neutrino
- **Geoneutrino**
- Sterile neutrino
- Nucleon decays
- Neutrinos from DM
- Exotic searches with neutrinos

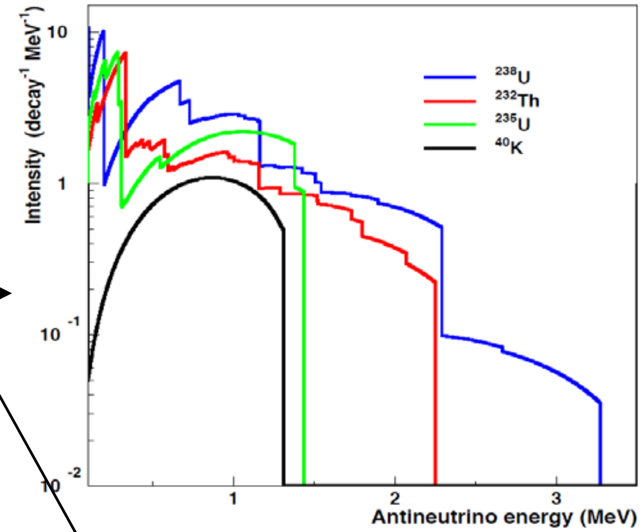
R.Han, Y.-F. Li, L.Zhan, W.F.McDonough, J.Cao, L.Ludhova
"Potential of geoneutrino measurements at JUNO"
Chinese Phys. C, Vol 40, No3 (2016) 033003

V. Strati, M.Baldoncini,I,Callegar, F.Mantovani, W.F.McDonough, B.Ricci,G.Xhixha "Expected geoneutrino signal at JUNO"
Progress in Earth and Planetary Science 2, 1 (2015).

Detection of geo(anti)neutrino

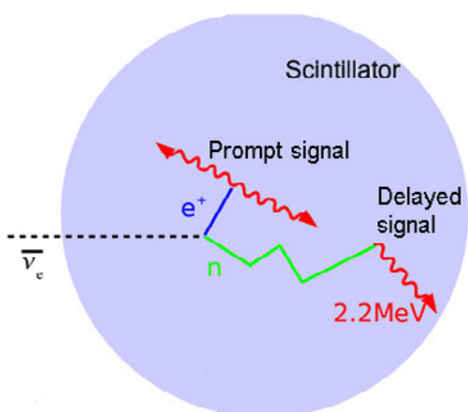
- Earth (in constrast to the Sun) emits antineutrino. $\Phi_{\bar{\nu}} \sim 10^{6}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Part of antineutrino in the U and Th decay chains is emitted with E>1.8 MeV (IBD threshold)
- Contributions from U and Th are distinguishable
- Oscillations are averaged:

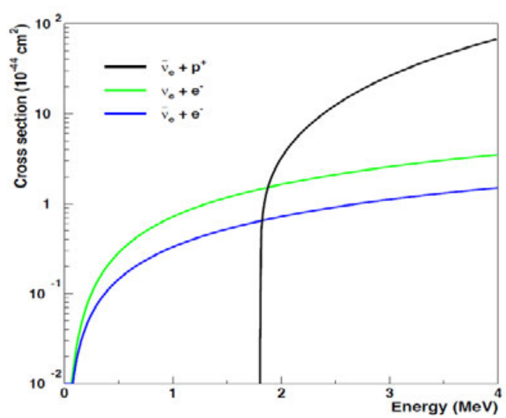
$<Pee>=0.548^{+0.012}_{-0.013}$

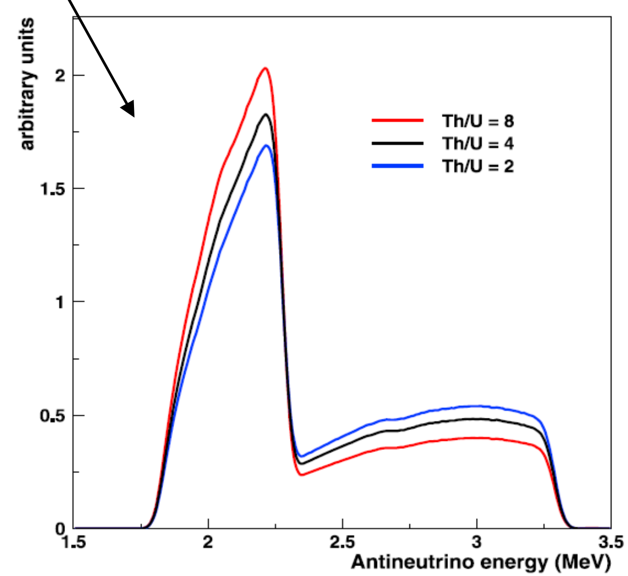


$$\bar{\nu} + p \rightarrow n + e^{+}$$

E_{ν}>1.8 MeV







Expected antineutrino spectrum

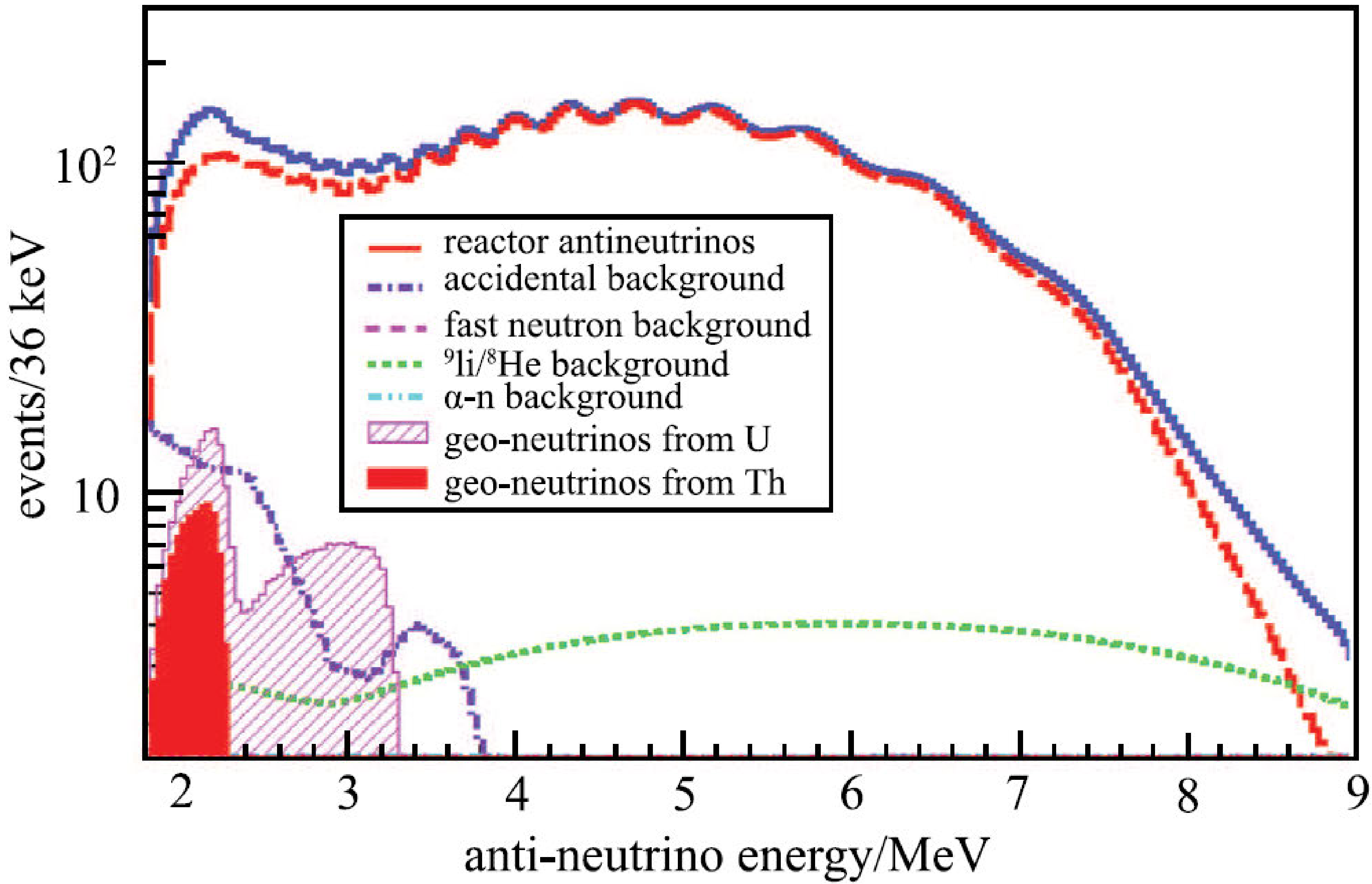


Fig. from R.Han, et al., Chinese Phys. C, Vol 40, No3 (2016) 033003

Expected signals

- **Expected total reactor signal**

1569± 88 TNU*

(~90% contrinution from Taishan and Yangjiang nuclear power stations)

***1 TNU = 1 event on 10^{32} protons an year**

- **Reactor signal in the geoneutrino energy window [1.8-3.27 MeV]:**

351± 21 TNU

- **Expected geoneutrino signal:**

$$S_{tot}=39.7^{+6.5}_{-5.2}\ \text{TNU}$$

$$S_{LOC}=17.4^{+3.3}_{-2.8}\ \text{TNU}$$

(V. Strati, et al.)

Backgrounds for geo-neutrino measurement

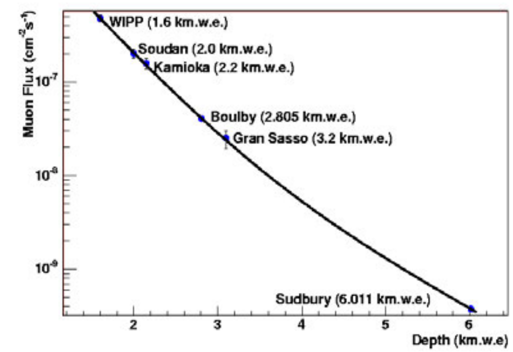
1)Reactor antineutrinos (90% of the total antineutrino signal in geo-nu window):

Geo/Reactor ratio

KamLAND= 0.23 (now much more)

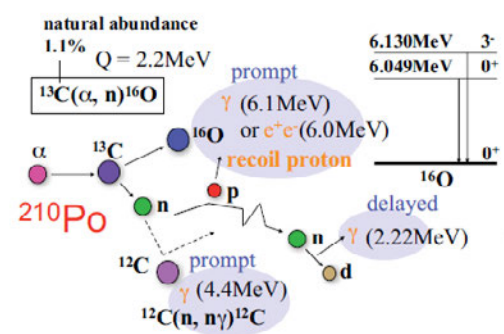
Borexino = 1.8

JUNO = 0.11

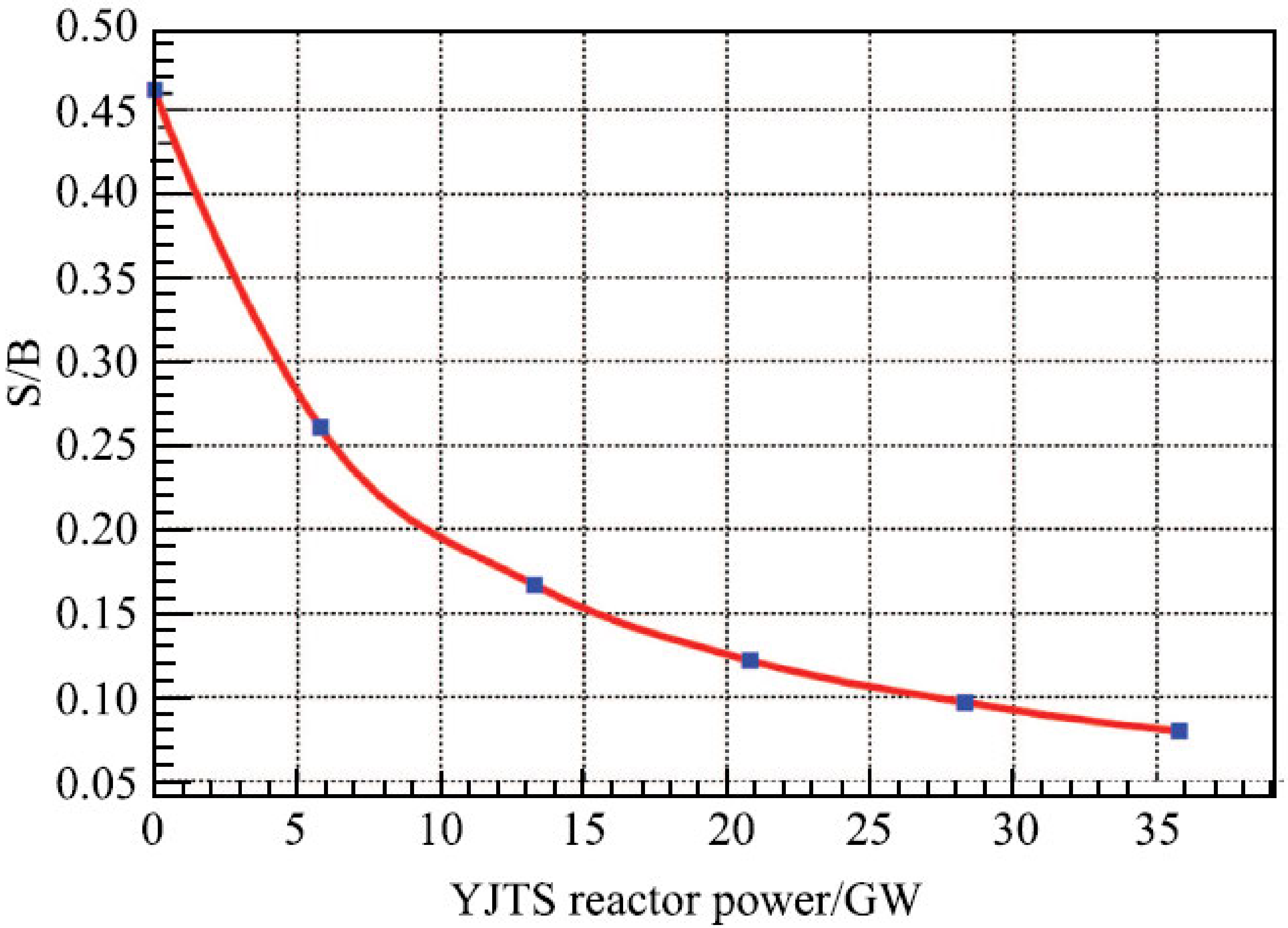


2)Cosmic muons induced backgrounds, including cosmogenic production of (βn)-decaying isotopes (2000 m.w.e.)

3)Internal radioactive contamination: accidental coincidences, (αn) reactions



GeoNu/Backround depends on the thermal power of 2 reactors



Summary of expected rates

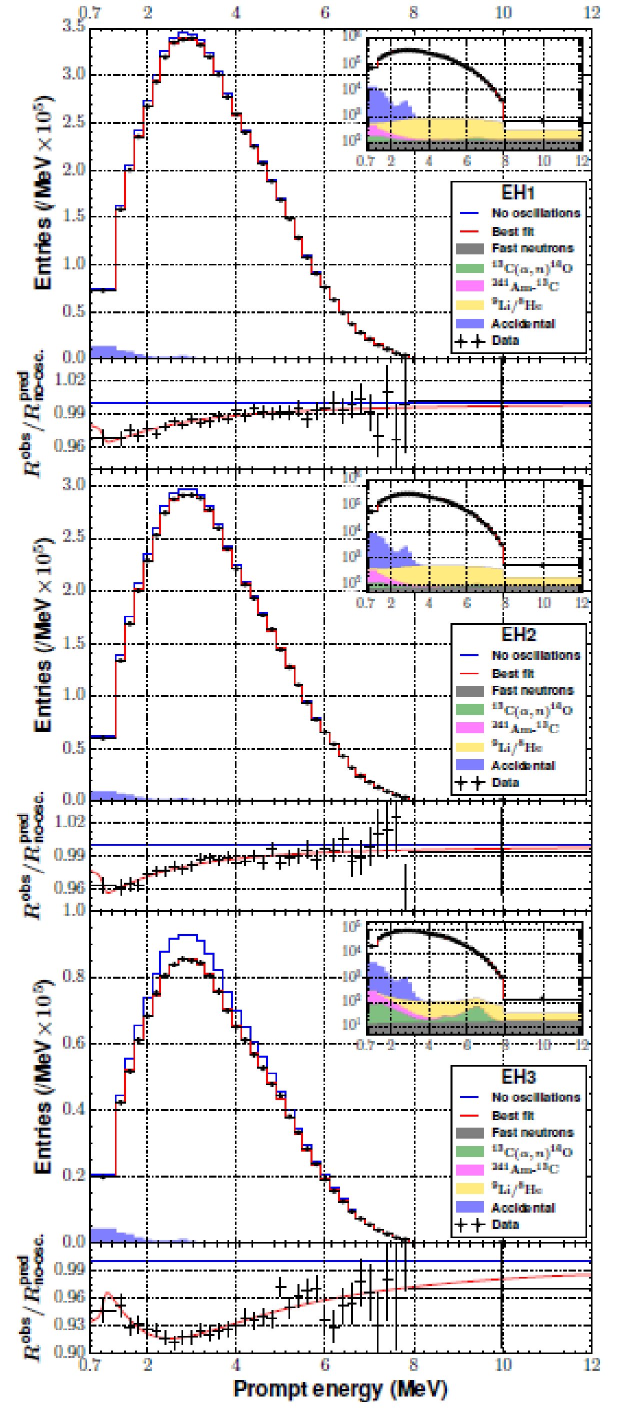
Source	[1.8-9.0] MeV ev/yr	[1.8-3.3] MeV ev/year	Uncertainty
geo	408	406	
reactor	16100	3653	±2.8%(rate)±1%(shape)
^{8}Li/^{8}He	657	105	±20%(rate)±10%(shape)
fast n	36.5	7.7	±100%(rate)±20%(shape)
αn	18.2	12.2	±50%(rate)±50%(shape)
accidental	401	348	±1%(rate)

20t->FV(R<17.2m) 18.35t or $12.85 \cdot 10^{32}$ protons
ε=80% detection efficiency assumed in calculations
acrylic vessel (^{238}U: 10 ppt, ^{232}Th: 10 ppt)
LS: 10^{-15} g/g ^{238}U/^{232}Th

Reactor spectrum : Daya Bay

F. P. An, et al., "Measurement of electron antineutrino oscillation based on 1230 days of operation of the Daya Bay Experiment", arXiv:1610.04802v1 [hep-ex] 16 Oct 2016

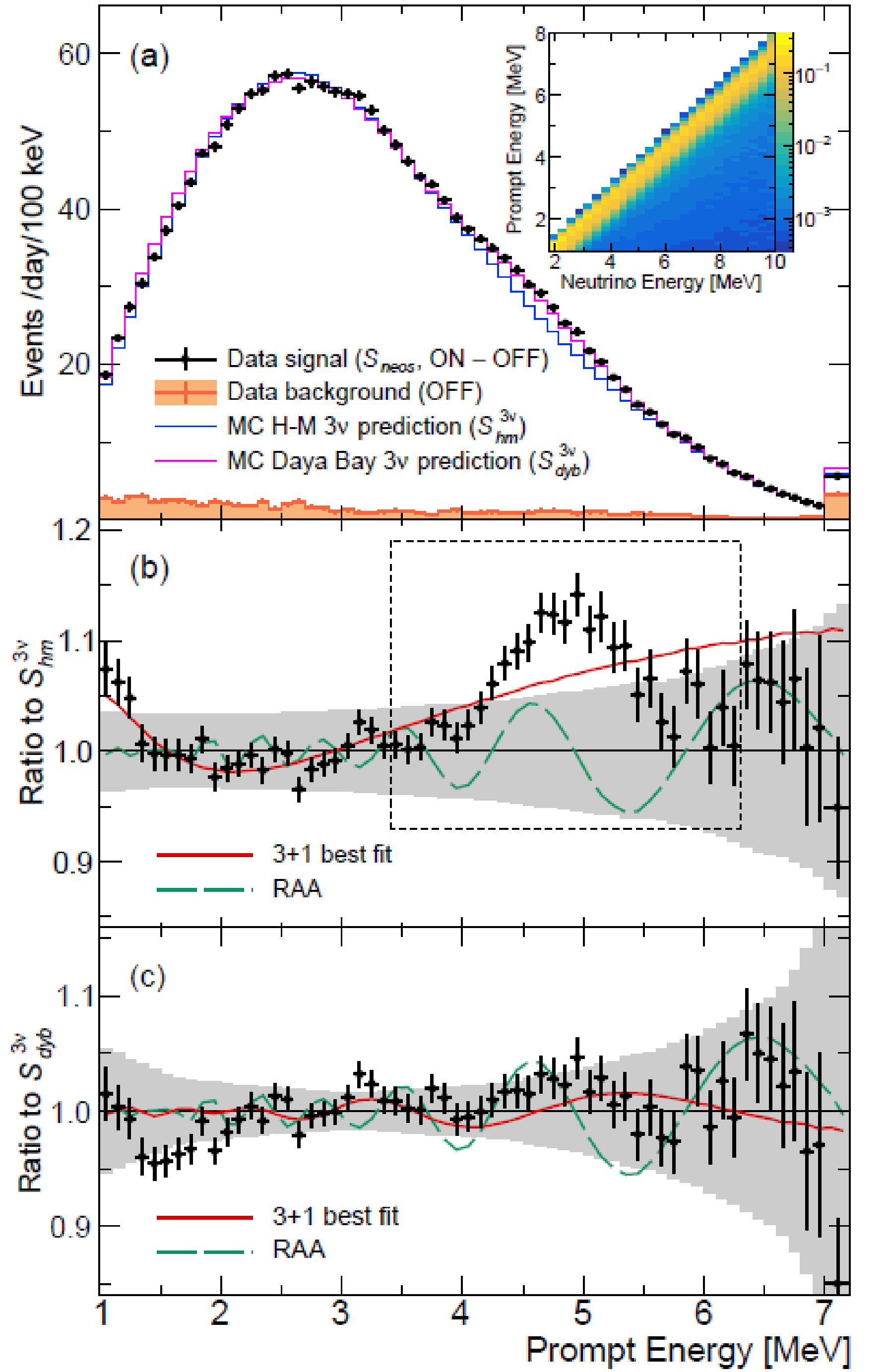
1230 days
>2.5 10^6 antineutrino events
Near detectors 350-600 m



Reactor spectrum

Y.J. Ko, et al., "A sterile neutrino search at NEOS Experiment"

arXiv: 1610.05134v1 [hep-ex] 17 Oct 2016



24 m from reactor
R(E)=5% @ 1 MeV
1965 ev/day
46 days reactor OFF
180 days reactor ON

Refers to F. P. An et al. (Daya Bay), (2016), arXiv:1607.05378 [hep-ex] (621 days of data)

The differences between the fission fractions for the NEOS data and the ones for Daya Bay are taken into account and small corrections are made using the H-M flux model.

Geoneutrino signal extraction precision
fixed M(Th)/M(U)=3.9

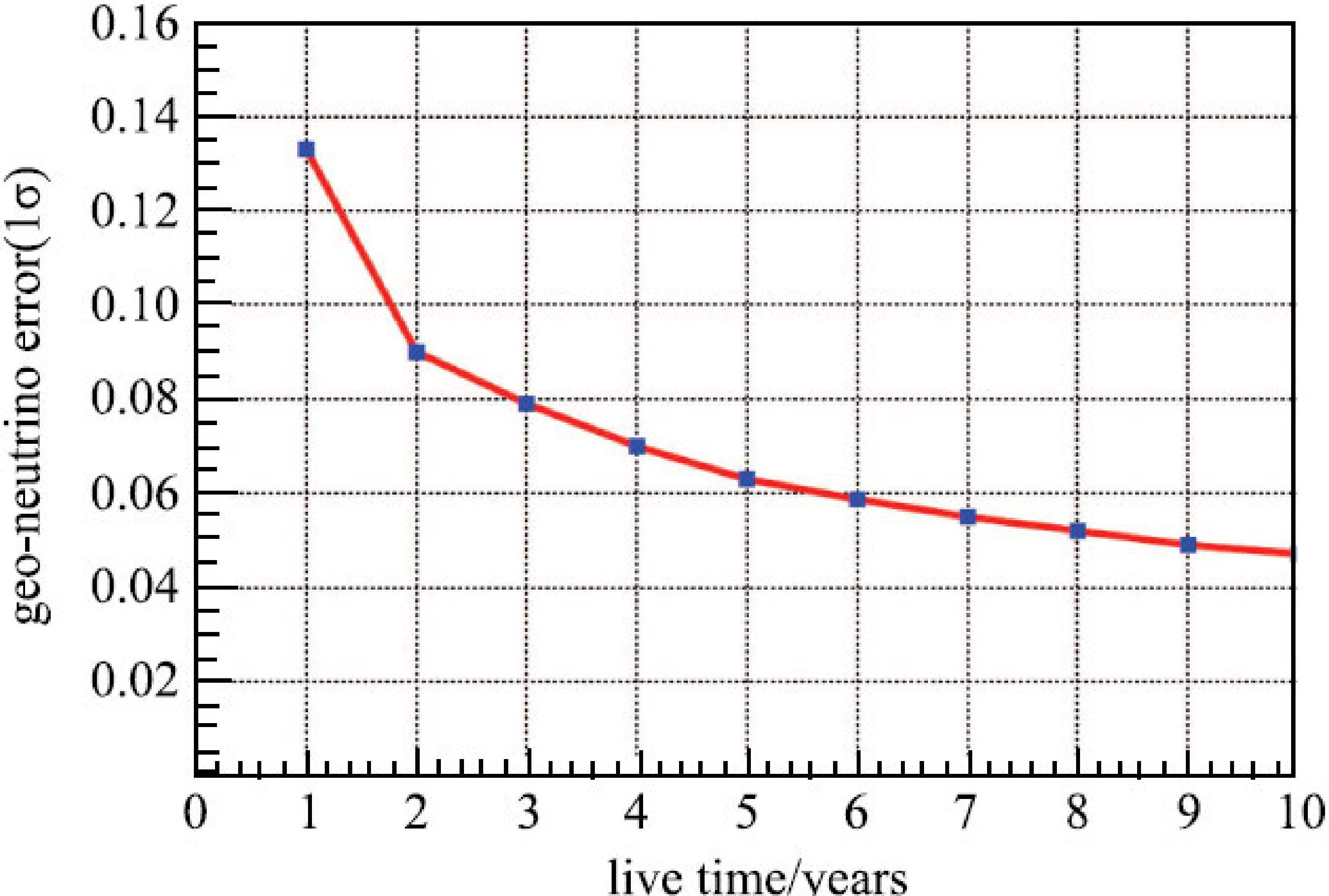


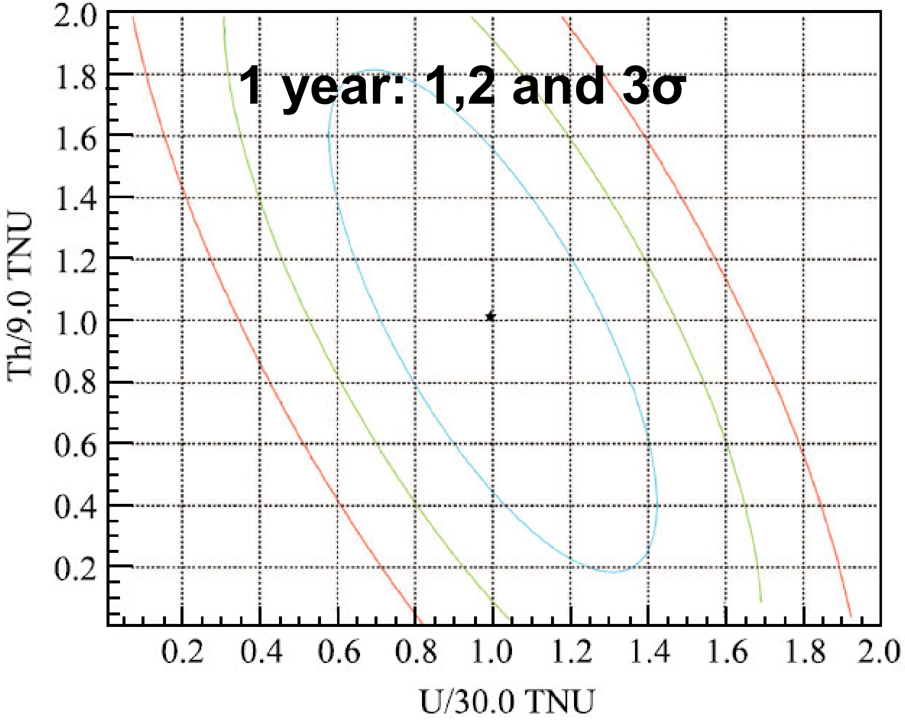
Fig. from R.Han, et al.

In JUNO publication the sensitivity was estimated as 18% for 1 yr with -4% syst.bias

Geoneutrino signal extraction precision

free Th and U components

Figs. from R.Han, et al. : no bias



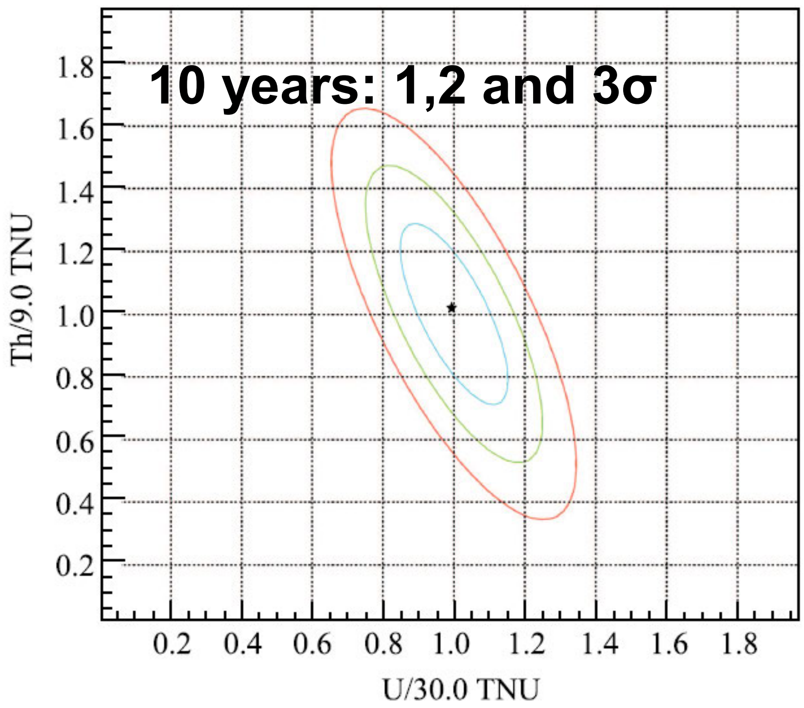
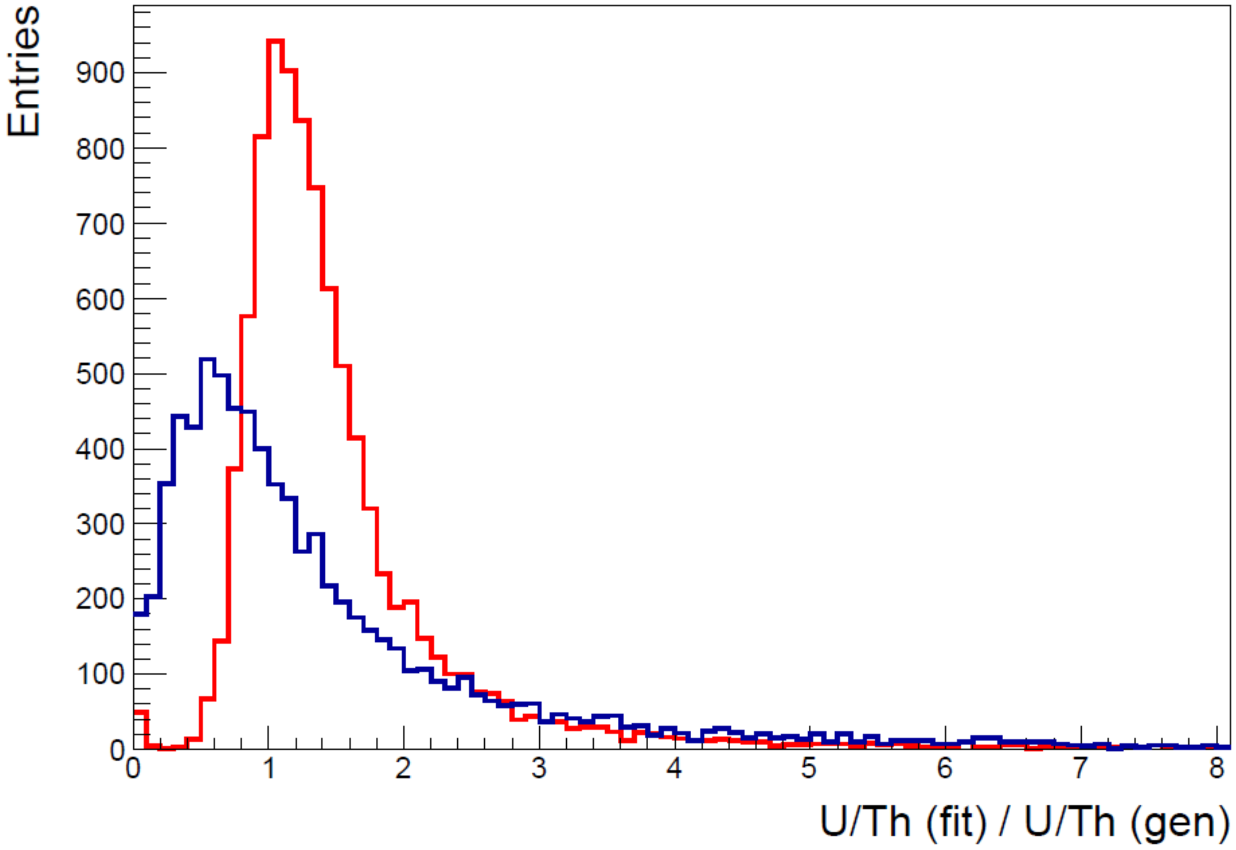


Table from JUNO publication

Number of years	U + Th (fixed chondritic Th/U ratio)	U (free)	Th (free)
1	0.96 ± 0.17	1.02 ± 0.32	0.83 ± 0.60
3	0.96 ± 0.10	1.03 ± 0.20	0.80 ± 0.38
5	0.96 ± 0.08	1.03 ± 0.16	0.80 ± 0.28
10	0.96 ± 0.06	1.03 ± 0.11	0.80 ± 0.19

U/Th ratio reconstruction



Distribution of the ratio reconstructed-to-generated U/Th ratio for 1 (blue line) and 10 (red line) years of lifetime after cuts. The simulations resulting in zero Th contribution are not plot here (fig. from JUNO publication).

Radiogenic heat

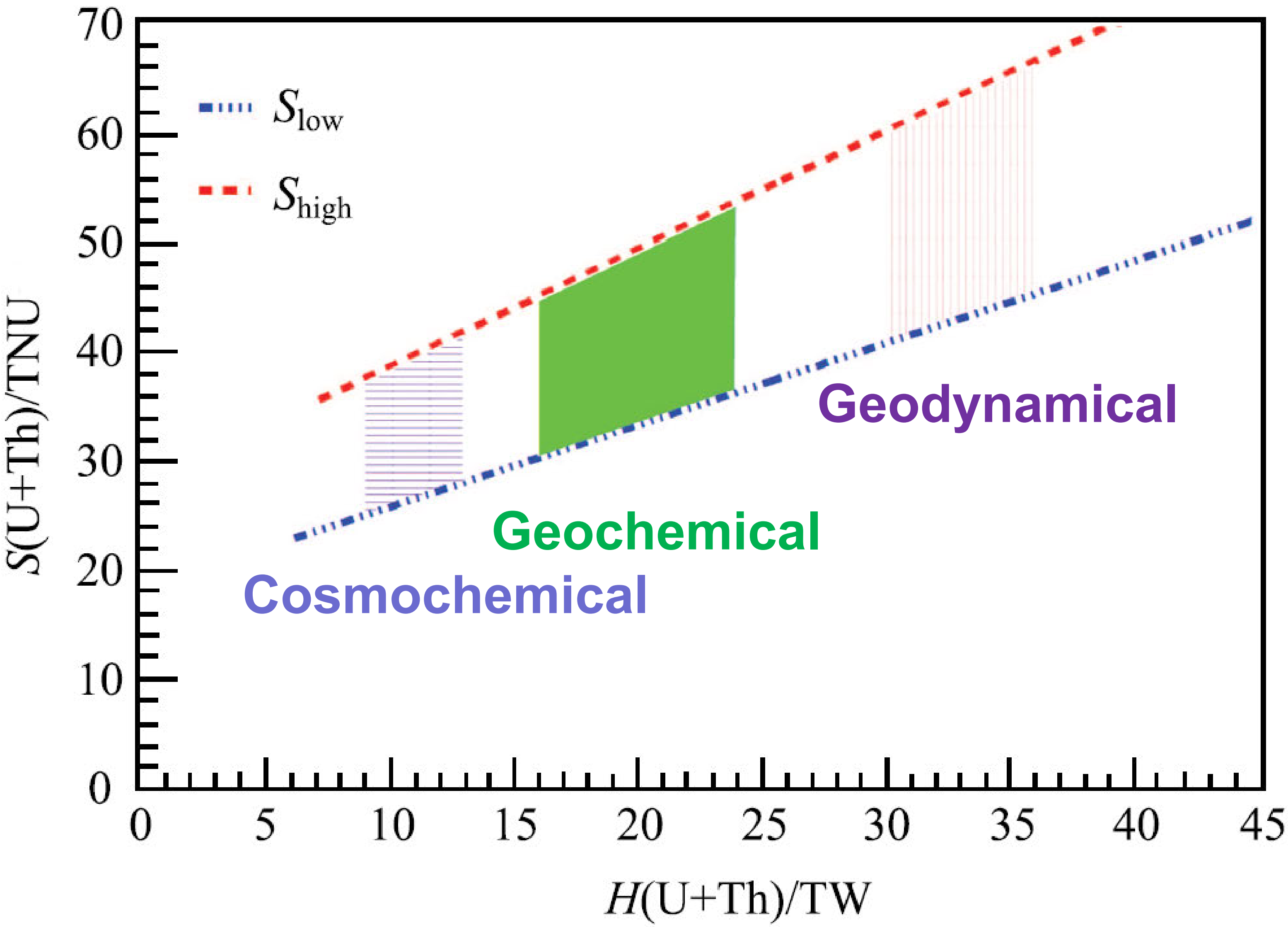


Fig. from R.Han, et al.

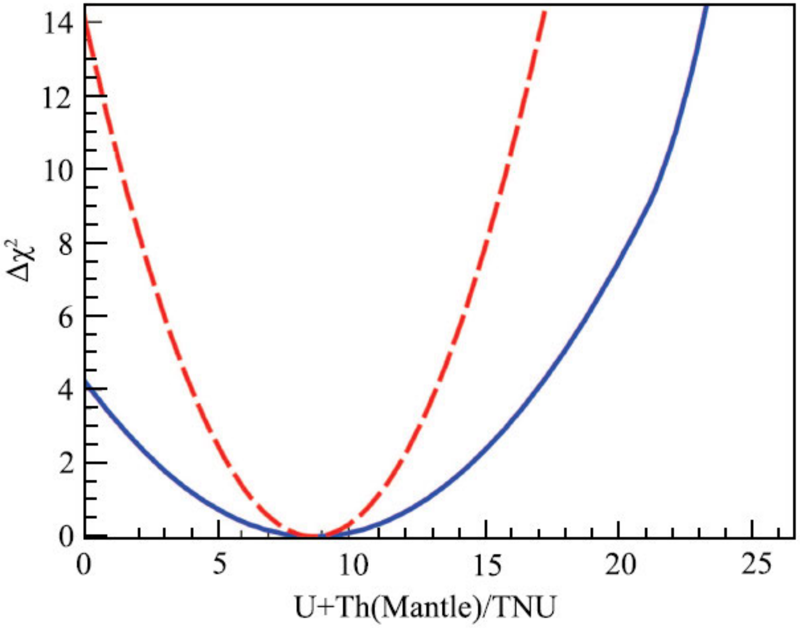
Signal from the mantle

Type equation here.Can be extracted from the measurement if crust contribution is known

R(Mantle)=R(Geo, measured)-R(Crust, predicted)

Current prediction (V. Strati, et al.**) for the R(Crust) has 18% uncertainty – blue line in the plot**

Red line : 8% crust contribution knowledge (KamLAND level)

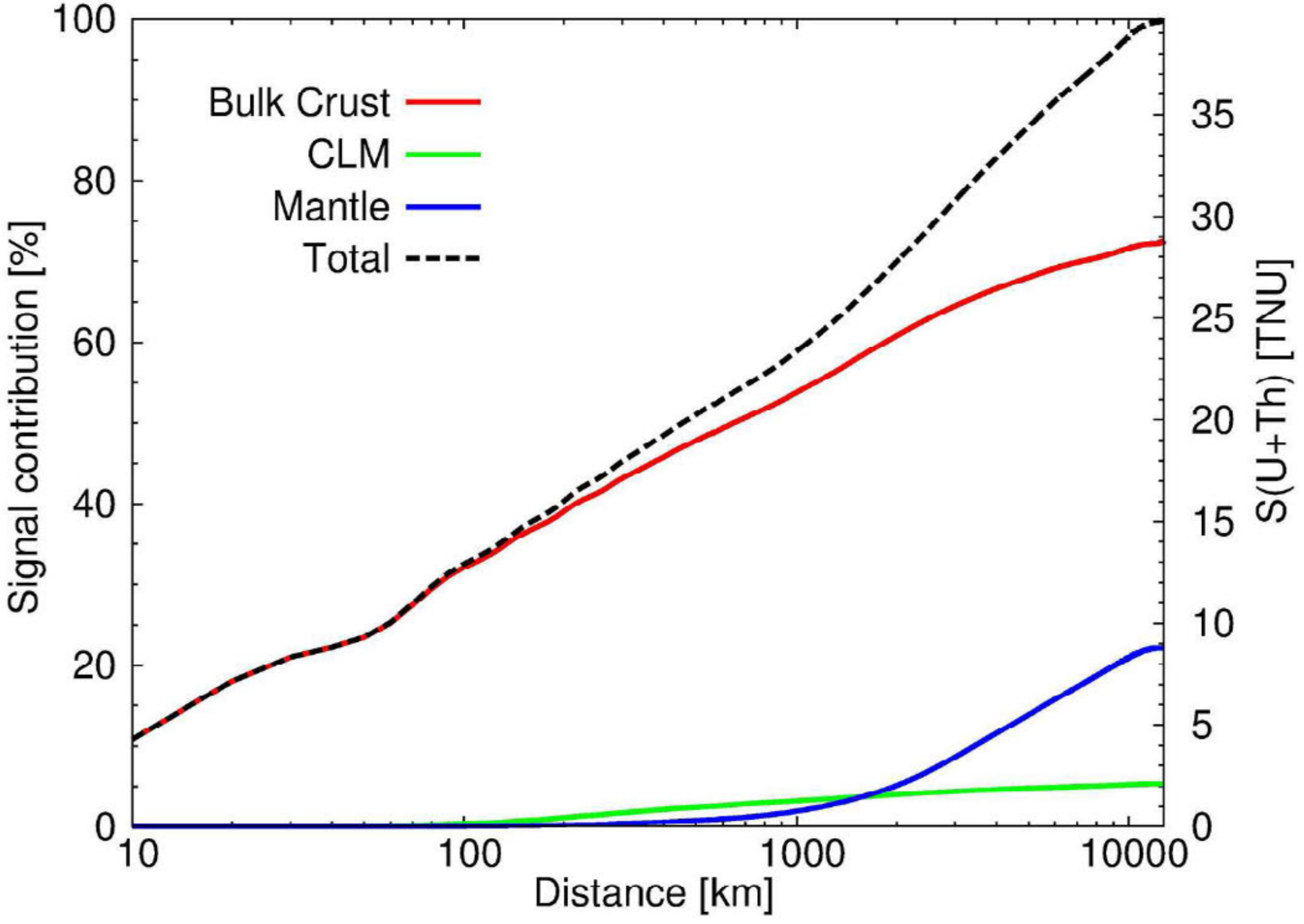


$$\Delta N_M = \sqrt{(\varepsilon_{Geo} N_{Geo})^2 + (\varepsilon_C N_C)^2 + N_C}$$

$$\varepsilon_M = \frac{1}{1-r_C}\sqrt{(\varepsilon_{Geo})^2 + (\varepsilon_C r_C)^2 + \frac{r_C}{N_{Geo}}}$$

$$r_C \equiv \frac{N_C}{N_{Geo}} \qquad \varepsilon \equiv \frac{\Delta N}{N}$$

Importance of local contribution prediction



local (<500 km) crust contributes 50% of geoneutrino signal

Directionality?

- The average forward shift of neutrons in the direction of incoming antineutrinos have been observed by reactor experiments (i.e. by CHOOZ).
- The basic idea is to search for the small statistical displacement of the capture vertex of the neutron with respect to the vertex of the prompt positron event.
- The neutron from the inverse beta decay of geoneutrino carries energy up to tens of keV and is emitted in a relatively narrow range (below ~ 55 degrees) of angles around the incoming antineutrino. The average forward displacement of the neutron capture vertex is about 1.7 cm, as observed by CHOOZ for reactor neutrinos, while the spread due to neutron drifting is about 10 cm.
- Given the small displacement (~1.7 cm) and the large intrinsic smearing (~25 cm), the direction of the reconstructed antineutrino is only meaningful statistically and needs large statistics. Because the direction to the reactors in JUNO is known, it looks promising exploiting the fit of displacement distribution with predicted separate distributions from geo and reactor antineutrinos in conjunction with the spectral fit. An attempt to separate the crust and mantle geoneutrino components could be made. Both tasks need extensive MC studies.

Summary

- **JUNO represents a new opportunity to measure geoneutrinos, recording of 300 to 500 geoneutrino interactions per year. In approximately six months JUNO would match the present world sample of recorded geoneutrino interactions, which is less than 150 events.**
- **Using a well constrained estimate of the reactor signal and reasonable estimates of the non-antineutrino sources, the conclusion is that geoneutrinos are indeed observable at JUNO.**
- **Maximizing the precision of the mantle geoneutrino measurement at JUNO requires detailed knowledge of the uranium and thorium content in the crust within several hundreds of kilometers to JUNO.**
- **The statistical power of the geoneutrino signal at JUNO enables a measurement of the thorium to uranium ratio, which provides valuable insight to the Earth's origin and evolution.**