NuPhys2019: Prospects in Neutrino Physics

16-18 December 2019
Cavendish Conference Centre, London, UK
Europe/London timezone

THE JUNO EXPERIMENT: PHYSICS PROSPECTS, DESIGN AND STATUS

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on behalf of the JUNO collaboration

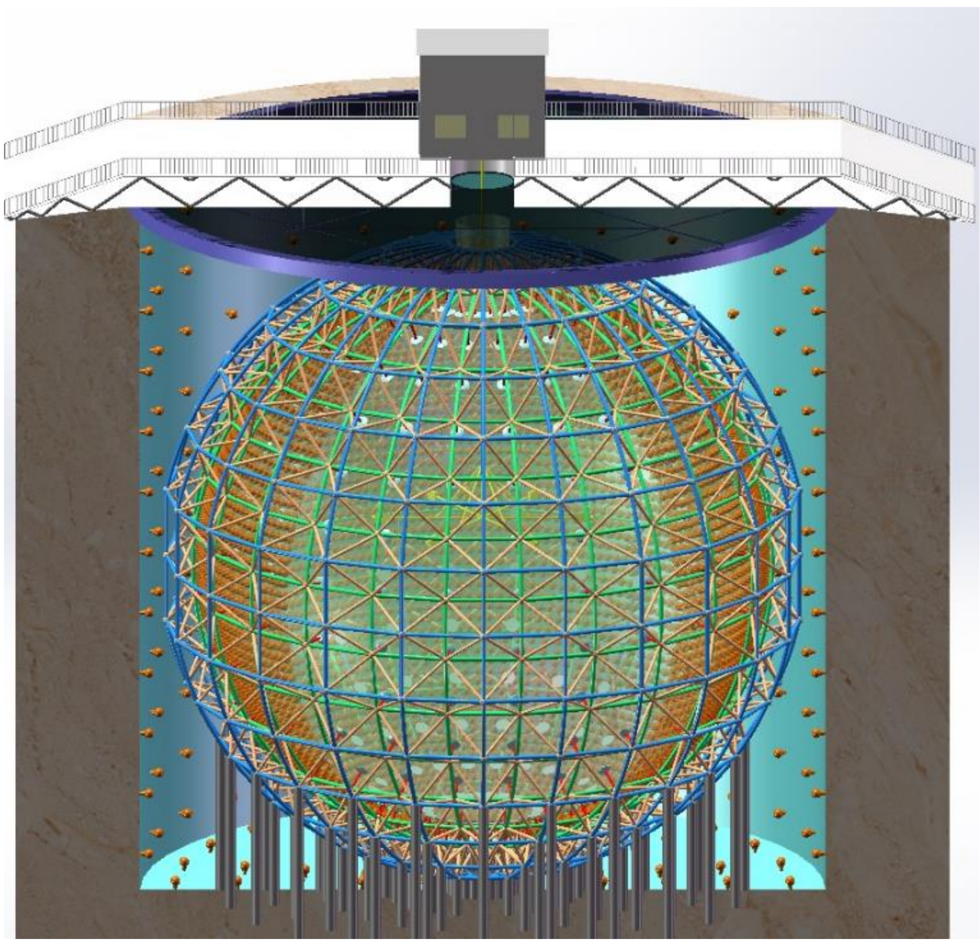
Istituto Nazionale di Fisica Nucleare

UNIVERSITA' DEGLI STUDI DI MILANO BICOCCA

The JUNO experiment

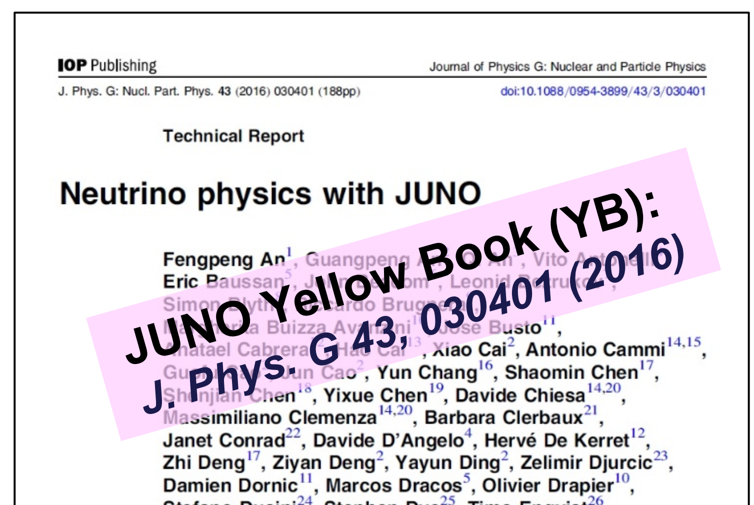
Jiangmen Underground Neutrino Observatory

Massive: ~20 kton Liquid Scintillator (LS)
Underground: ~700 m overburden
High resolution: 3% / √E (MeV)
Energy scale precision: < 1%



Main physics goal:
➔ ν Mass Ordering determination

Rich physics possibilities:
- Precision measurement of oscillation parameters
- Supernovae neutrinos
- Solar neutrinos
- Atmospheric neutrinos
- Geo-neutrinos
- Nucleon decay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J. Phys. G: Nucl. Part. Phys. 43 (2016) 030401 (188pp) — doi:10.1088/0954-3899/43/3/030401

Technical Report

Neutrino physics with JUNO

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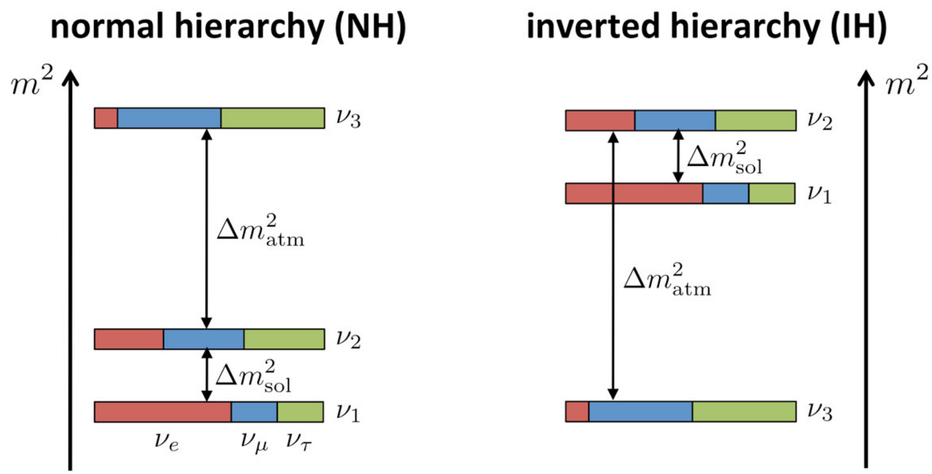
The neutrino mass ordering (νMO) open issue



$\Delta m_{ij}^2 \equiv m_i^2 - m_j^2$

$\Delta m_{21}^2 \approx 7.5 \times 10^{-5}\ eV^2$

$|\Delta m_{32}^2| \approx 2.5 \times 10^{-3}\ eV^2$

$$\text{NH: } |\Delta m^2_{31}| = |\Delta m^2_{32}| + |\Delta m^2_{21}|$$

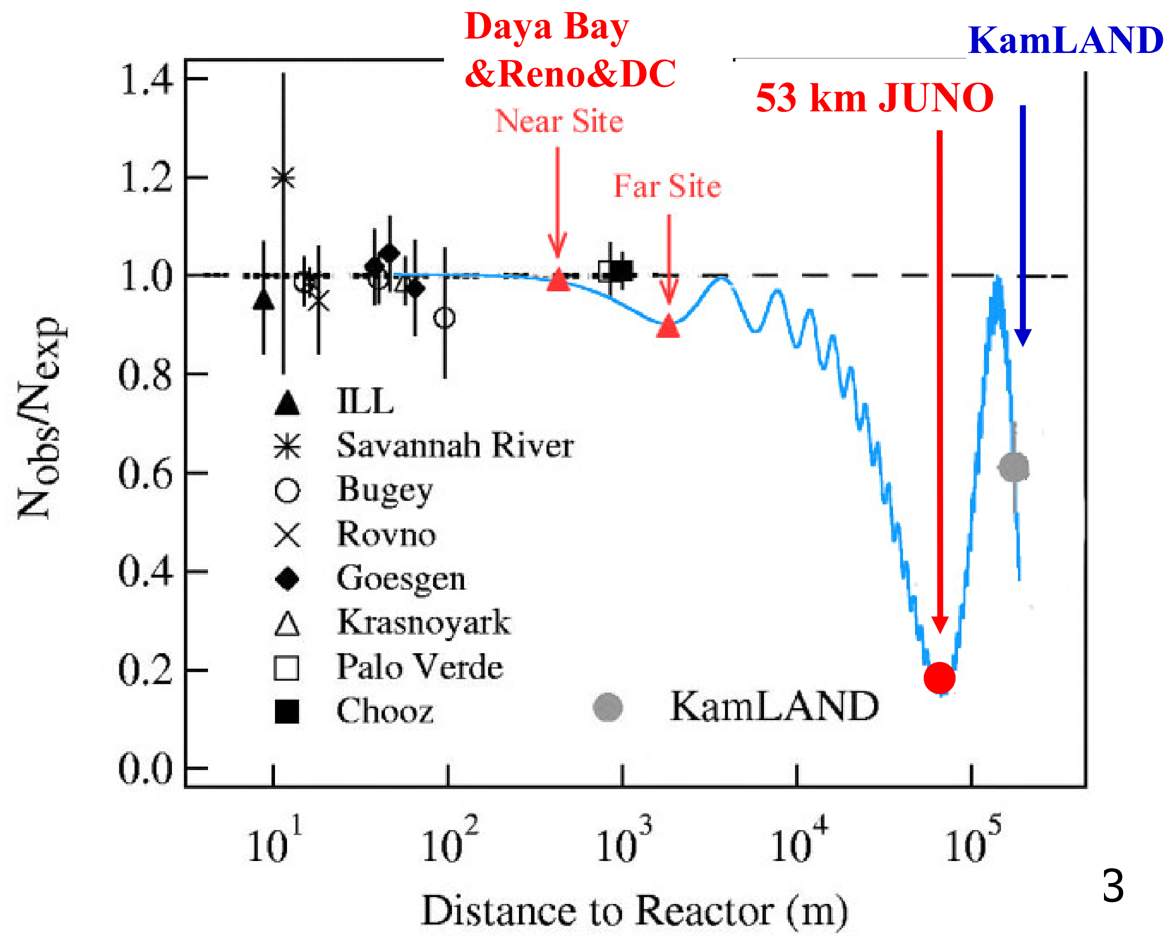
$$\text{IH: } |\Delta m^2_{31}| = |\Delta m^2_{32}| - |\Delta m^2_{21}|$$

In 2002 Petcov and Piai suggested that interference effects between Δm_{sol}^2 and Δm_{atm}^2 driven oscillations can be used by reactor experiments to infer the neutrino mass hierarchy

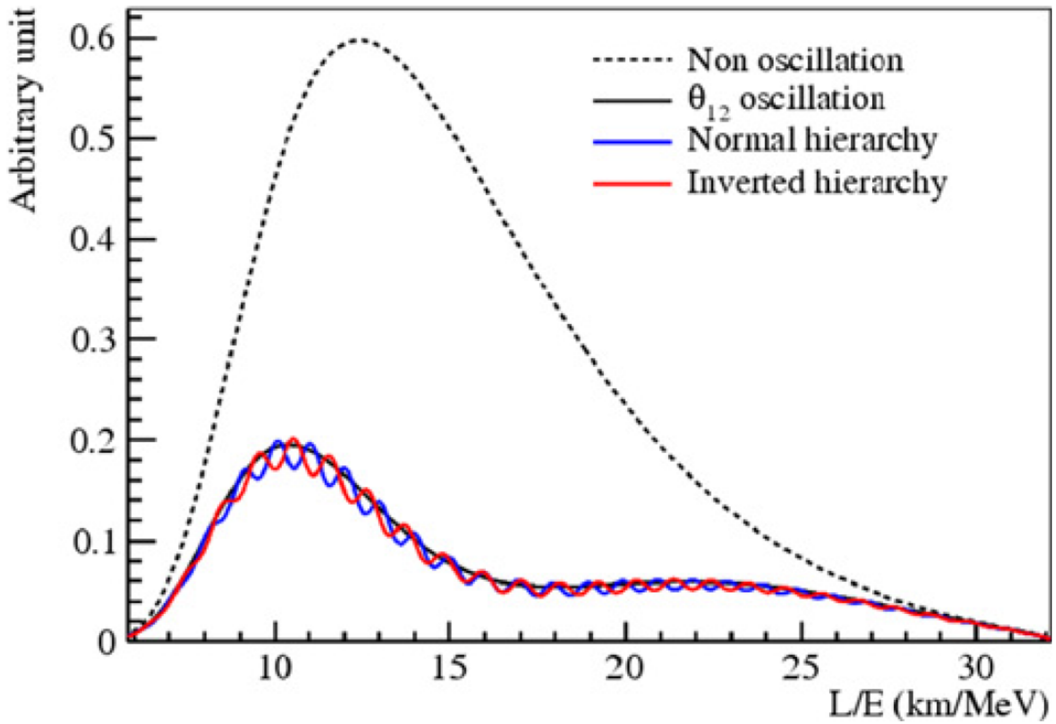
↓

made possible by “large value” of θ_{13}

JUNO is the first experiment to see both Δm^2 at the same time



The neutrino mass ordering (νMO) at reactors



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$\sin^2(\theta_{12}) = 0.307 \pm 0.013$

$\sin^2(\theta_{13}) = (2.18 \pm 0.07) \times 10^{-2}$

S.T. Petcov et al., PLB533(2002)94
S.Choubey et al., PRD68(2003)113006
J. Learned et al., PRD78, 071302 (2008)
L. Zhan, PRD78:111103, 2008, PRD79:073007, 2009
J. Learned et al., arXiv:0810.2580
Y.F Li et al, PRD 88, 013008 (2013)
…

$\bar{\nu}_e$ survival probability:

$$P_{ee}(L/E) = 1 - P_{21} - P_{31} - P_{32}$$

$$P_{21} = \cos^4(\theta_{13})\sin^2(2\theta_{12})\sin^2(\Delta_{21}) \rightarrow \text{SLOW } \Delta m_{sol}^2$$

$$P_{31} = \cos^2(\theta_{12})\sin^2(2\theta_{13})\sin^2(\Delta_{31})$$

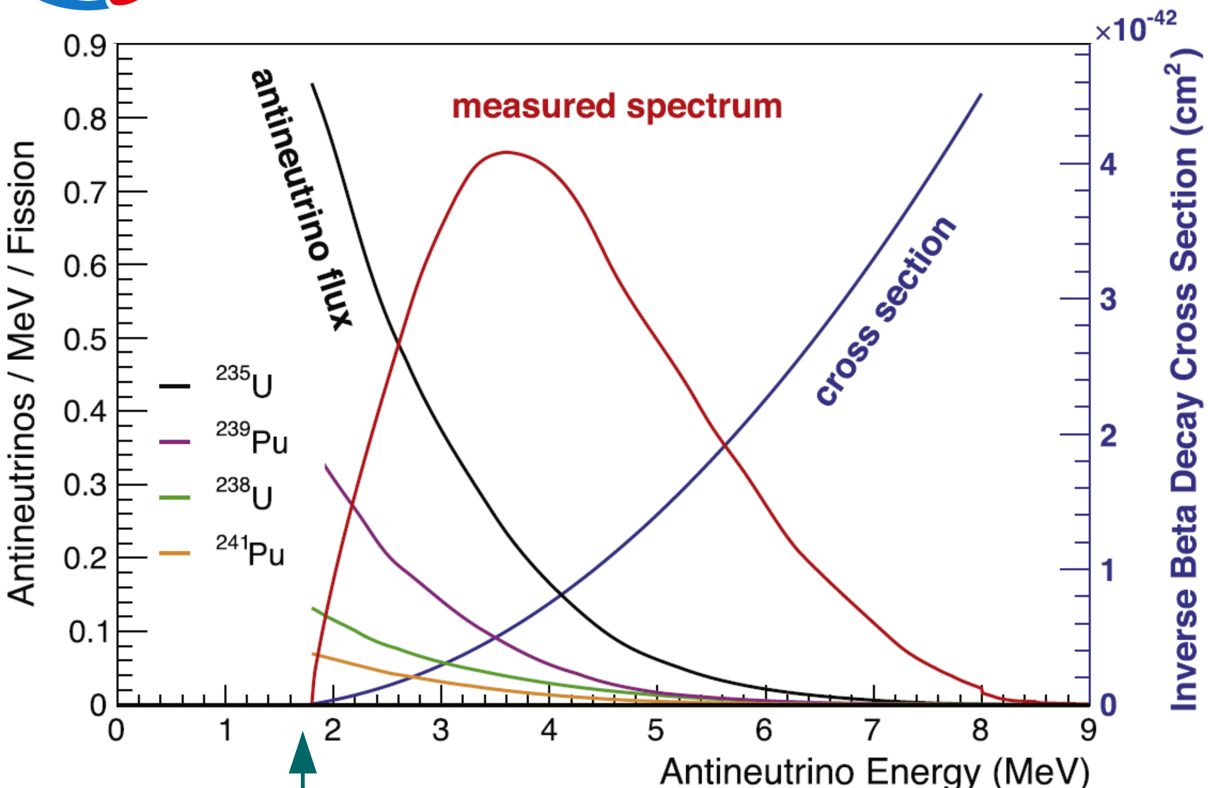
$$P_{32} = \sin^2(\theta_{12})\sin^2(2\theta_{13})\sin^2(\Delta_{32}),$$

$\}\rightarrow$ FAST Δm_{atm}^2

$$\Delta_{ij} \equiv \frac{\Delta m^2_{ij} L}{4E_\nu}$$

Independent of θ_{23} and CP phase

Reactor antineutrino detection

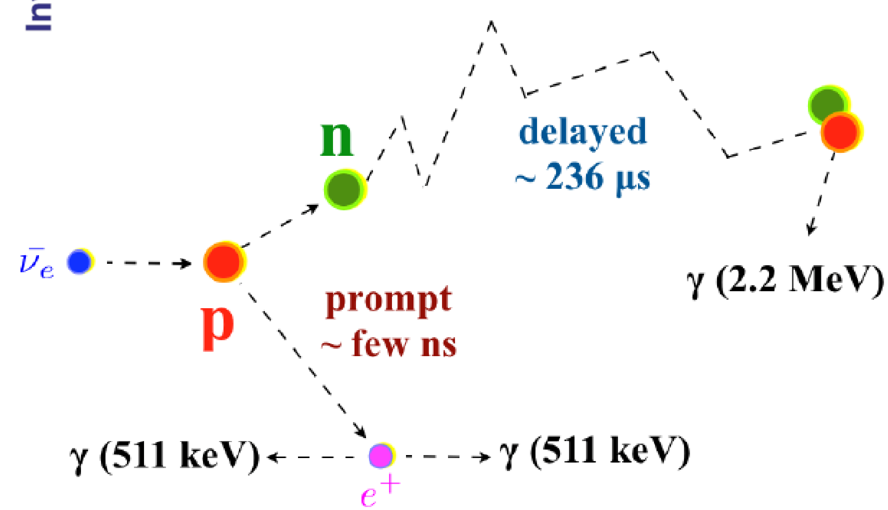


Energy threshold: 1.8 MeV

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

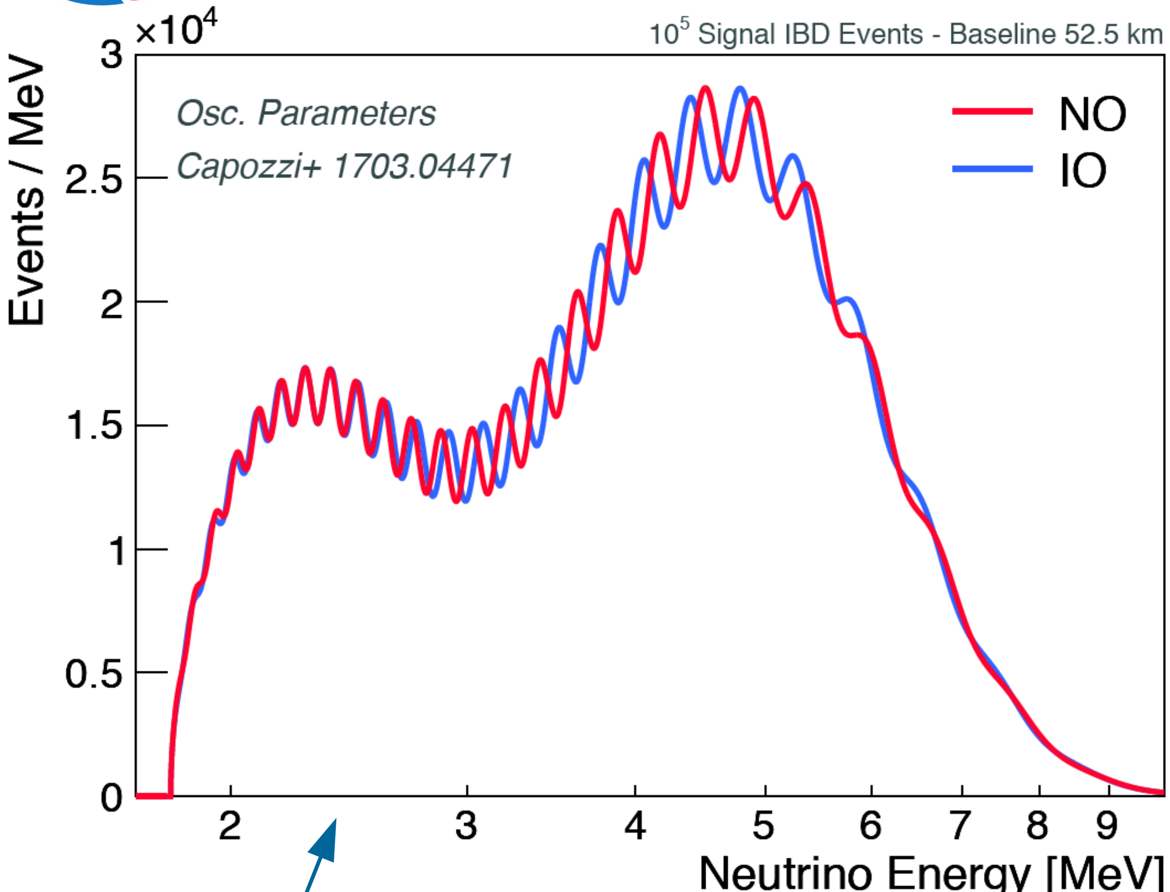
Antineutrinos from reactors

Cascade of beta decays from unstable fission fragments:
3 GW_{th} reactor → ~10^{20} $\bar{\nu}_e$/s



- E_{vis} (e+) ≃ E ($\bar{\nu}_e$) – 0.8 MeV
- Time coincidence between prompt and delayed signals to reject uncorrelated background

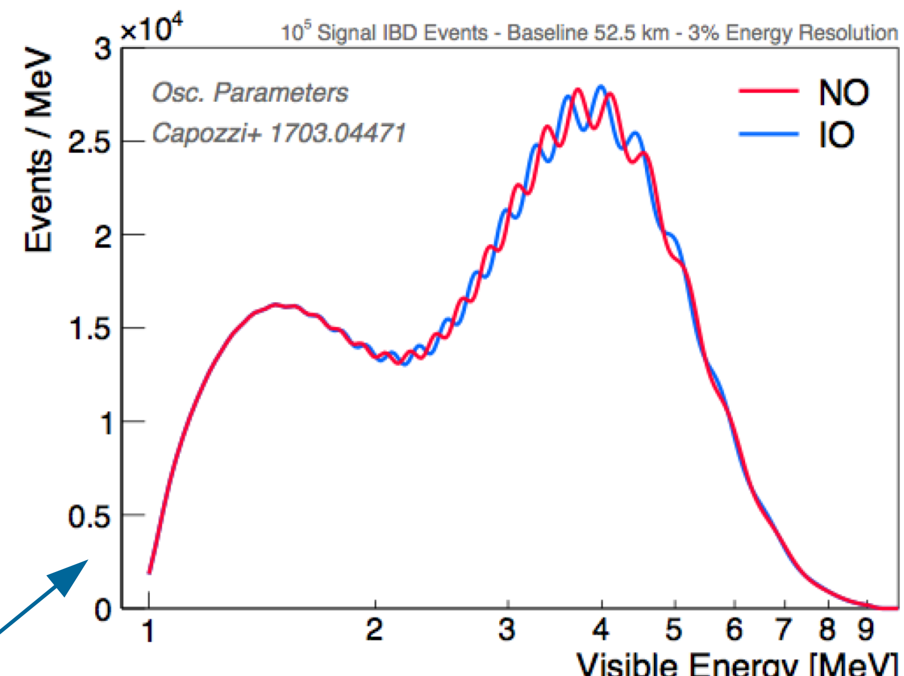
Oscillated antineutrino spectrum



Ideal case for 20 kton × 6 y exposure

DETECTOR CHALLENGES:

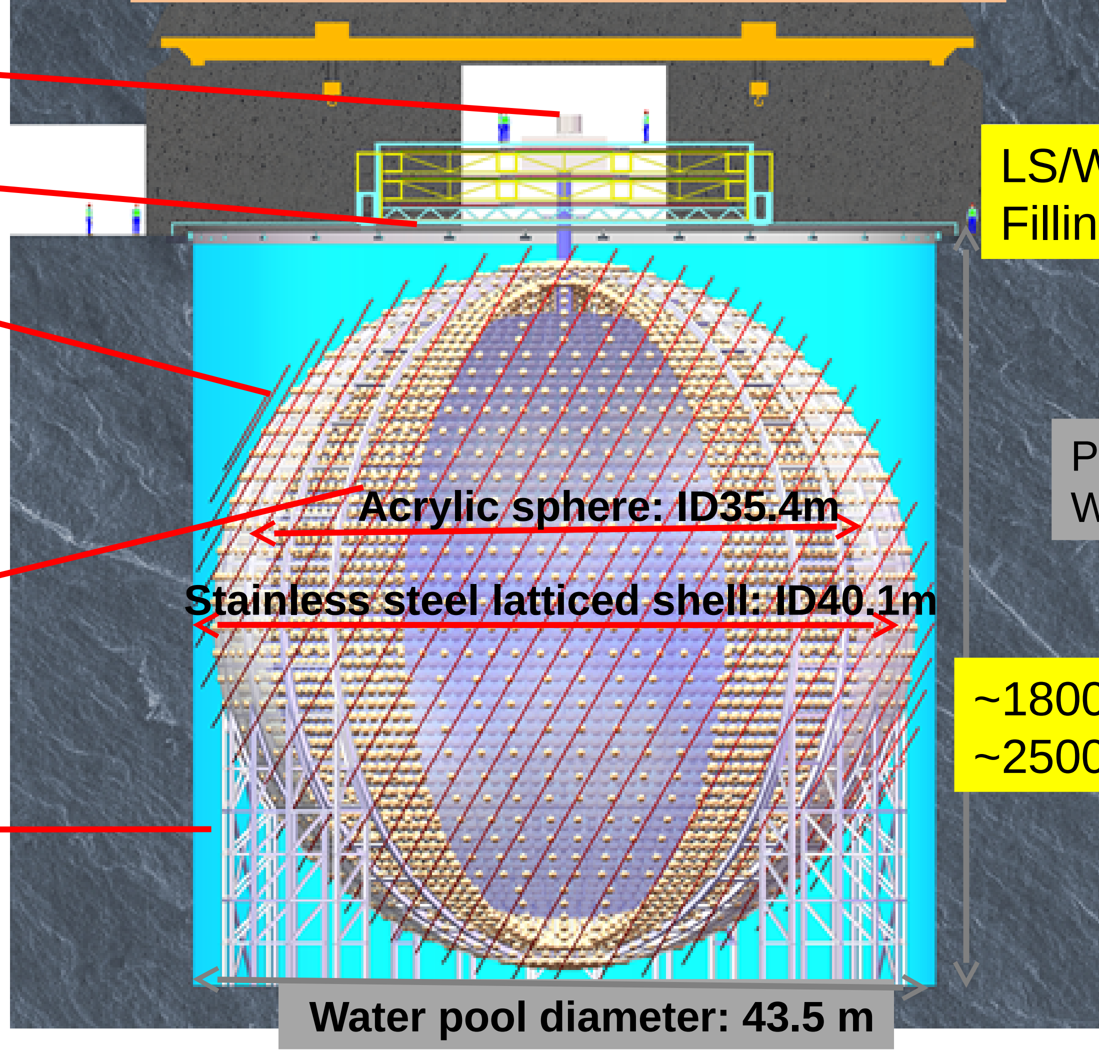
- Energy resolution < 3% / $\sqrt{E[MeV]}$
- Energy scale uncertainty < 1%
- Reactor baseline variation < 0.5 km
- Large statistics: 100k IBD in 6 y



To disentangle the phase difference between NO and IO an energy resolution of at least $\Delta m_{21}^2 / \Delta m_{32}^2$ ~3% at 1 MeV is mandatory

E_{vis} (e+) and 3% energy resolution

JUNO Detector Scheme



Experiment	Daya Bay	BOREXINO	KamLAND	JUNO
LS mass	20 ton	~300 ton	~1 kton	20 kton
Coverage	~12%	~34%	~34%	~80%
Energy resolution	~7.5%/√E	~5%/√E	~6%/√E	~3%/√E
Light yield	~ 160 p.e. / MeV	~ 500 p.e. / MeV	~ 250 p.e. / MeV	~ 1200 p.e. / MeV

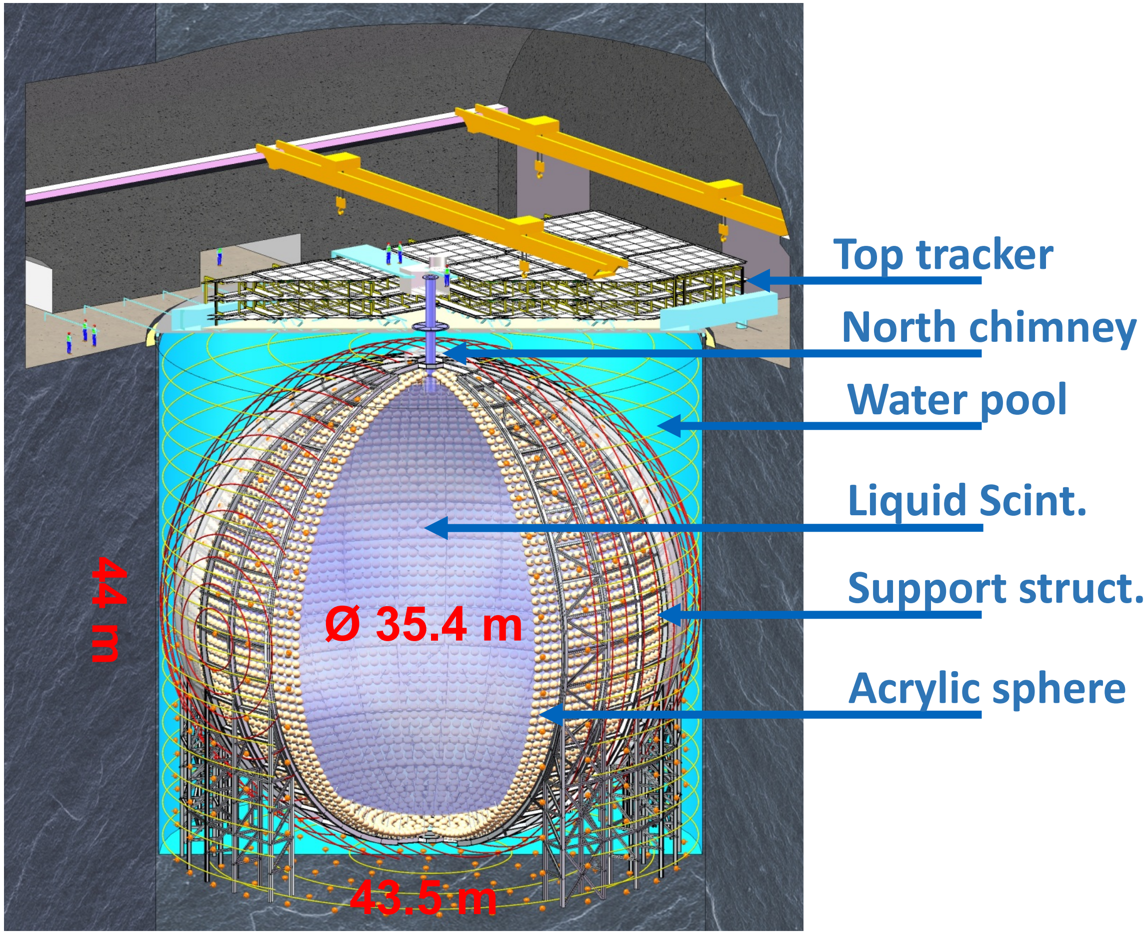
Overall detector design

Central detector:
- Acrylic sphere with liquid scintillator
- 17571 large PMTs (20-inch)
- 25600 small PMTs (3-inch)
- 78% PMT coverage
- PMTs in water buffer

Water Cerenkov muon veto:
- 2400 20” PMTs
- 35 ktons ultra-pure water
- Efficiency > 95%
- Radon control → less than 0.2 Bq/m^3

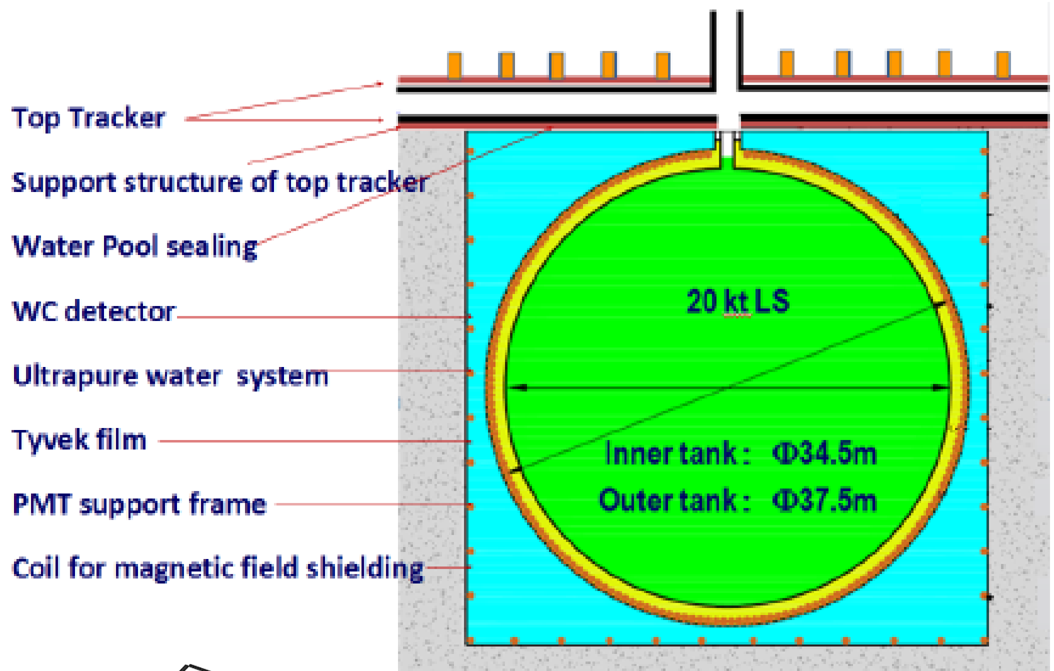
Compensation coils:
- Earth magnetic field <10%
- Necessary for 20” PMTs

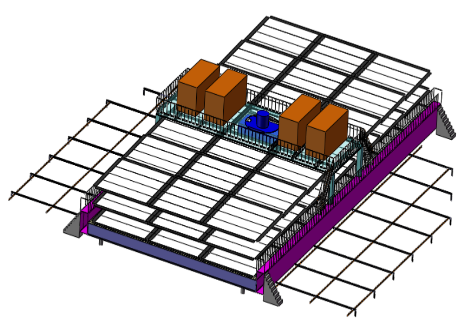
Top tracker:
- Precision muon tracking
- 3 plastic scintillator layers
- Covering half of the top of the water pool

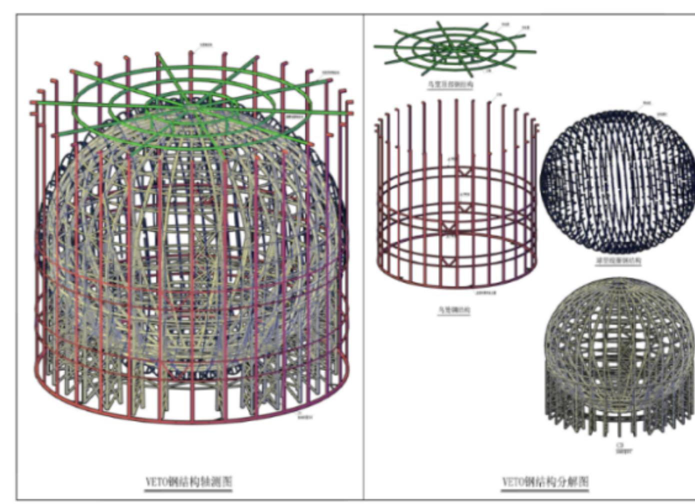


Veto

- **Tasks:**
  - Shield rock-related backgrounds
  - Tag & reconstruct cosmic-rays tracks
- **Detector:**
  - Top tracker: refurbished OPERA scintillators
  - Water Cerenkov detector
- **Pool lining: HDPE**
- **Earth magnetic field compensation coil**

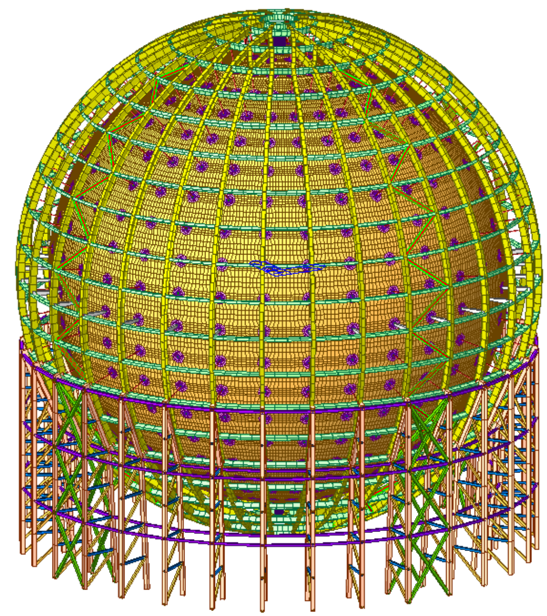






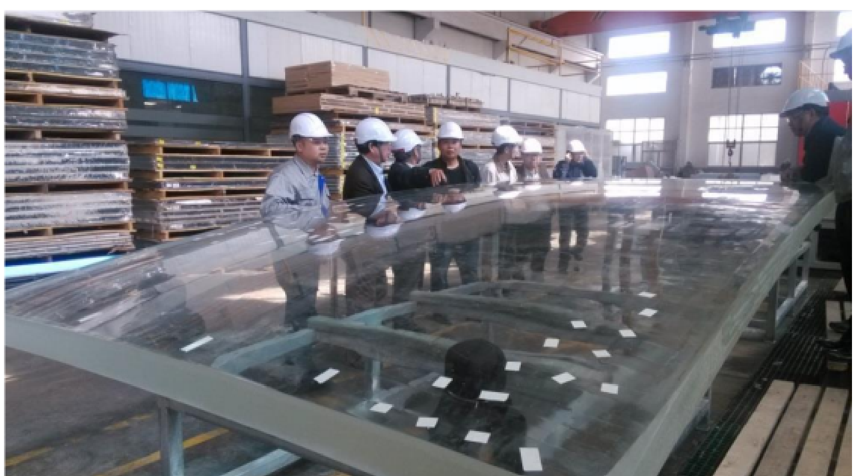
Central Detector: Steel Truss & Acrylic Sphere

- Stainless steel structure to hold the acrylic sphere and to anchor the PMTs
  - ► Supporting bar to hold the acrylic tank
  - ► Stress of the acrylic < 3.5 MPa everywhere

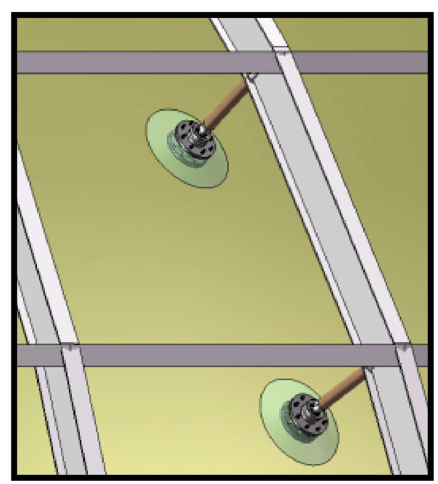


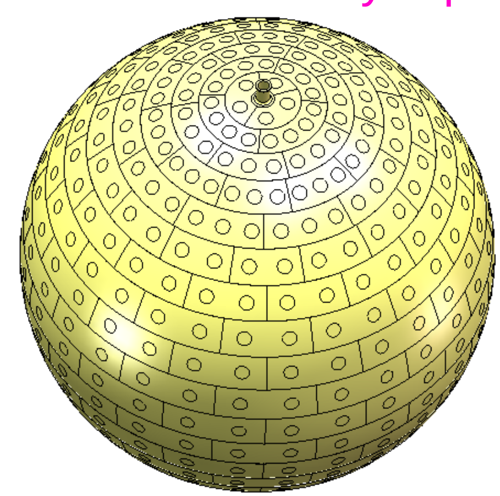
- Main issues:
  - ► Mechanical precision for 3 mm PMT clearance
  - ► Thermal expansion matching: 21°C ± 1°C
  - ► Earthquake and liquid-solid coupling
  - ► Acrylic transparency > 96%
  - ► Radiopurity U/Th/K: Acrylic $\prec$ 1 ppt, Steel $\lesssim$ ppb

More than 200 Acrylic panels



Panel size: 3 m × 8 m × 120 mm





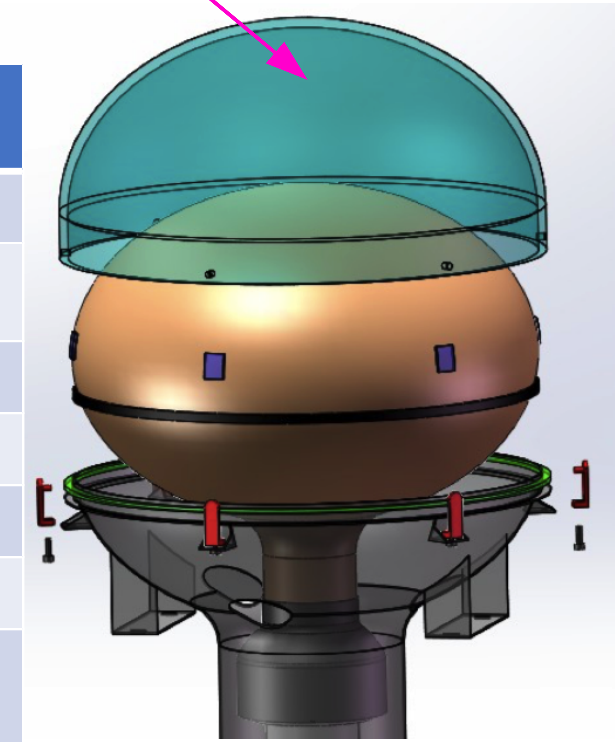
Acrylic panel mass production started

Large PMT array

- 15000 MCP-PMTs from NNVT (Northern Night Vision Technology)
- 5000 dynode PMTs from Hamamatsu (R12860 HQE)
- 17571 PMTs will read out the scintillation light of the Central Detector
- In production since 2016
- PMT testing:
  - Finished for dynode PMTs
  - ~10000 of 15000 MCP-PMTs already tested

Specifications	Unit	MCP-PMT (NNVT)	R12860 Hamamatsu HQE
Det. Efficiency (QE*CE)	%	26.9% (**new Type: 30.1%**)	28.1%
Peak to Valley of SPE		3.5, (>2.8)	3, (>2.5)
TTS on the top point	ns	12, (<15)	**2.7, (<3.5)**
Rise time / Fall Time	ns	RT~2, FT~12	RT~5, FT~9
Anode Dark Count	kHz	20, (<30)	10, (<50)
After Pulse Rate	%	1, (<2)	10, (<15)
Radioactivity (glass)	ppb	**^{238}U: 200** **^{232}Th: 120** **^{40}K: 4**	^{238}U: 400 ^{232}Th: 400 ^{40}K: 40

Acrylic cover to protect from implosion chain reaction

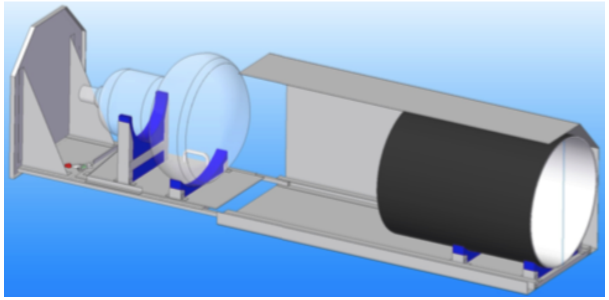


Large PMT testing facility

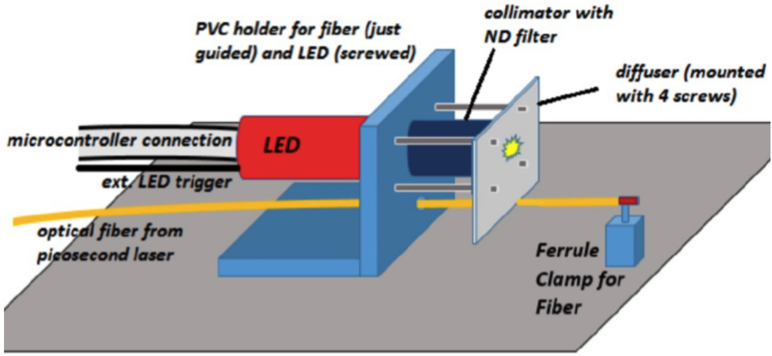
PMT Testing Containers (all PMTs):

- Capacity: 36 (-5) PMTs per Container
- Relative PDE Measurement
  - 1 fixed & 4 rotating reference PMTs
- Four containiers
  - 1 & 2 operational
  - 3 & 4 commissioned
- Magnetic shielding: 10% EMF
- Climate control systems
- Two light sources:
  - stabilized LED
  - Picosecond-Laser

Two testing containers in Zhongshan (Pan-Asia)



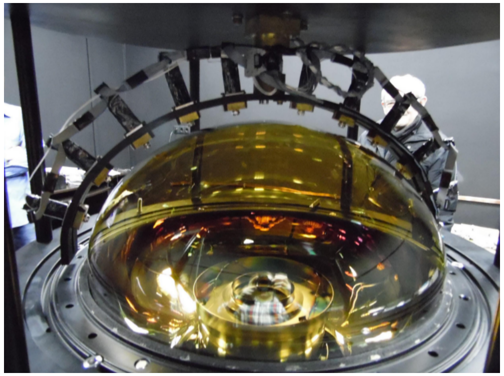
PMT test box with PMT holder



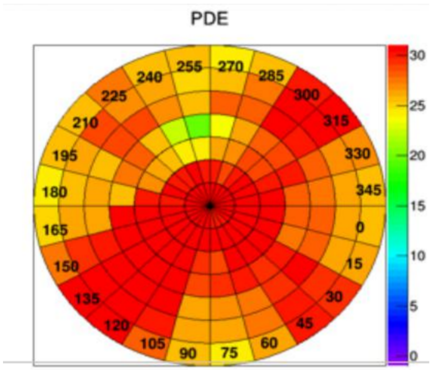
Light sources used in the testing containers

Scanning Station (5-10% of PMTs):

- Provide non-uniformity measurement of PMT parameters
- Study dependence of PMT performance on magnetic field
- Provide a tool for precise PMT studies and cross calibration



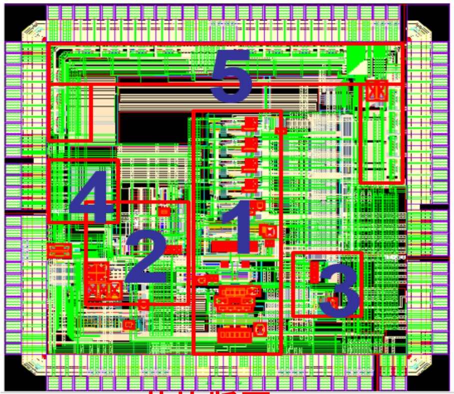
PMT in the scanning station



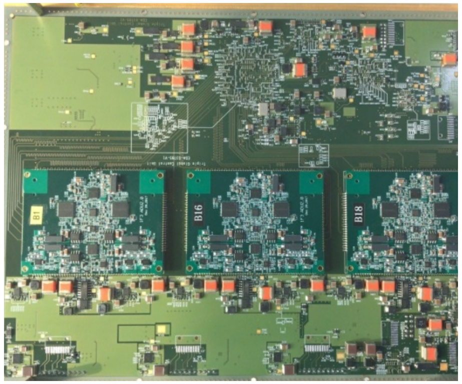
PDE differences (photocathode)

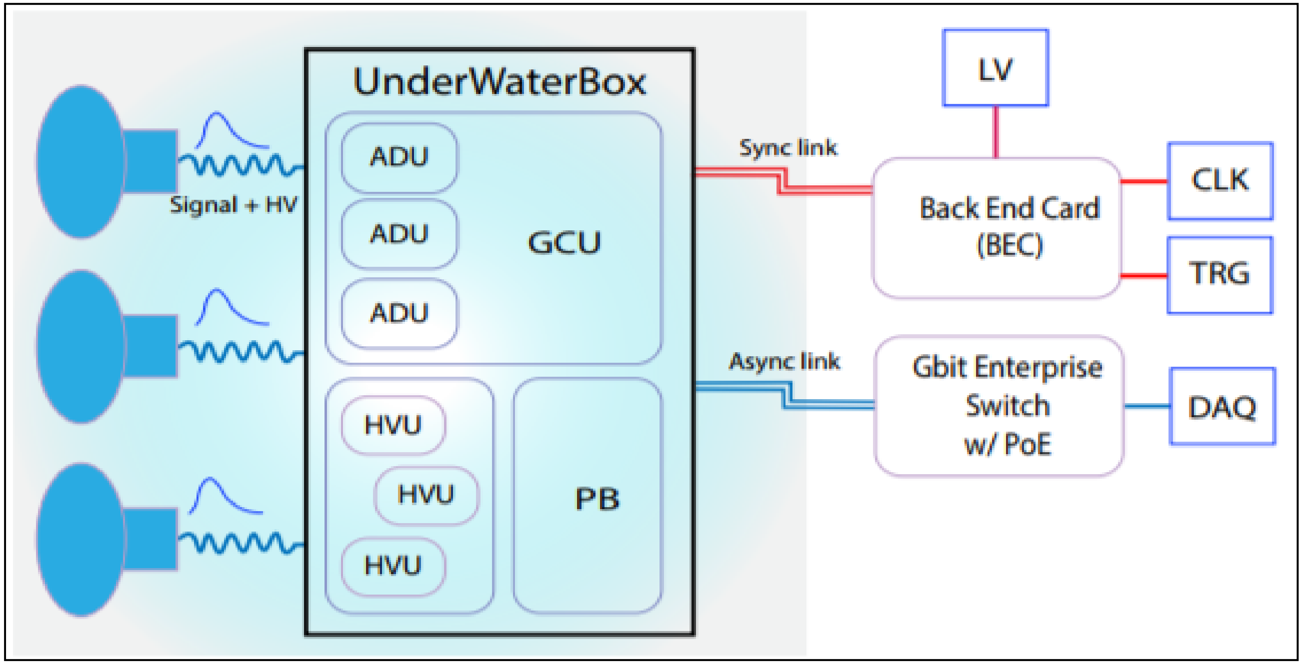
Electronics

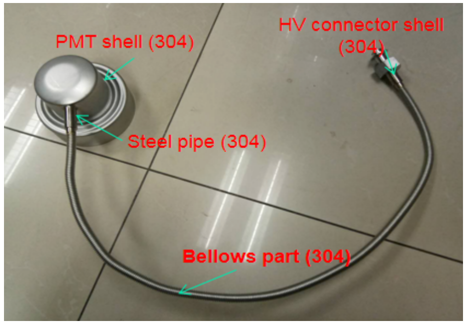
- 20000 ch. for LPMT & 100 m cable needed
- Dynamic range: 1- 4000 PE
- Noise: < 10% @ 1 PE
- Resolution: 10%@1 PE, 1%@100 PE
- Failure rate: < 0.5%/6 years
- Final solution: 1 GHz sampling FADC in a small box (×3 ch.) in water; all cables in corrugated pipes



芯片版图







Small PMT array

Double calorimetry

Always in photon counting mode

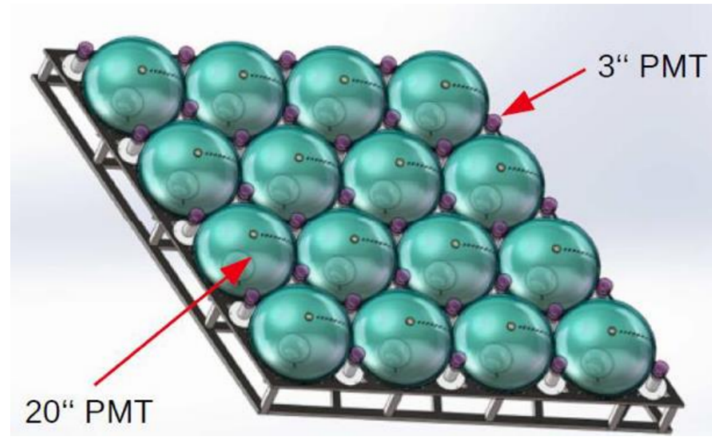
Less non-linearity: calibration of large PMT array

Better dynamic range for high energy signals

Higher granularity of the CD

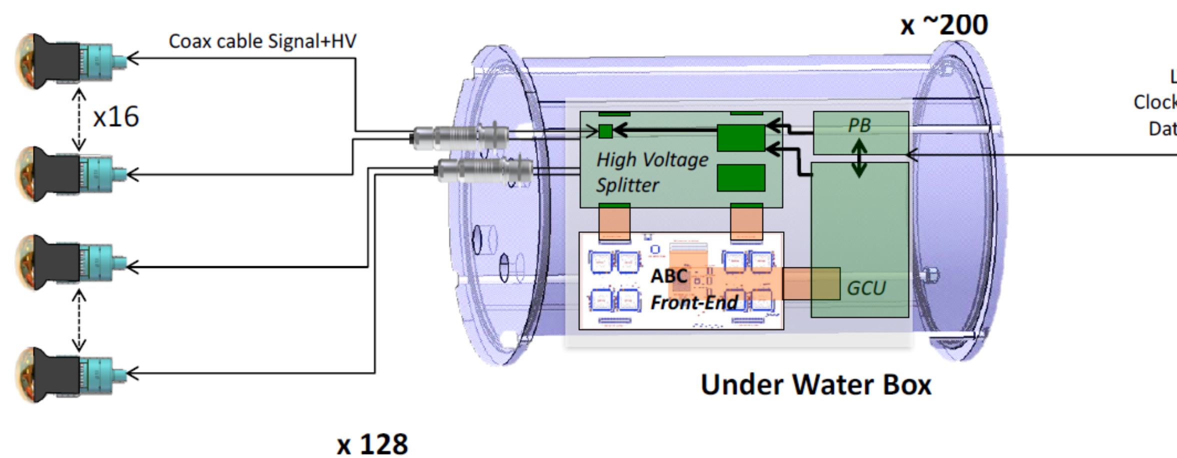
25600 PMTs in the Central Detector
- **2.5% coverage**
- Provided by HZC Photonics (Hainan, PR China)

Can effectively help in:
- Muon tracking (+ shower muon calorimetry)
- **Supernova readout**
- Solar oscillation parameter measurement



Arrangement of large and small PMTs

~ 200 boxes × 128 PMTs



Under water box provides supply for 128 PMTs
(Prototype already built and successfully tested!)

Liquid Scintillator

Purification of LAB in 4 Steps:

- **Al_2O_3 filtration column:** improvement of **optical properties**
- **Distillation:** removal of **heavy metals**, improvement of transparency
- **Water Extraction (underground):** removal of **radio isotopes** from uranium and thorium chains and furthermore of ^{40}**K**
- **Steam / Nitrogen Stripping (underground):** removal of **gaseous impurities** like Ar, Kr and Rn

Optical Requirements:

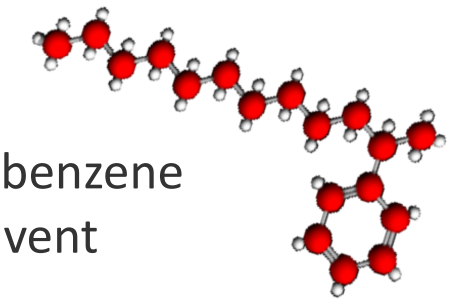
Light output: **~10.000 Photons / MeV**
→ **~1200 p.e. / MeV**
Attenuation length: **> 20 m @ 430 nm**

Required Radiopurity:

Reactor neutrinos:
^{238}U / ^{232}Th < 10^{-15} g/g, ^{40}K < 10^{-16} g/g, ^{210}Pb < 10^{-22} g/g, ^{14}C < 10^{-17} g/g

Solar neutrinos:
^{238}U / ^{232}Th < 10^{-17} g/g, ^{40}K < 10^{-18} g/g, ^{210}Pb < 10^{-24} g/g, ^{14}C < 10^{-18} g/g

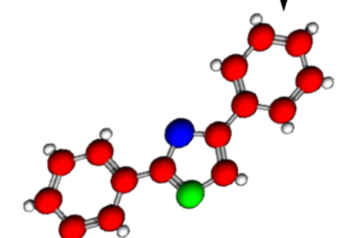
Solvent:
Linear alkylbenzene (LAB) as solvent



+

non-radiative → 280nm

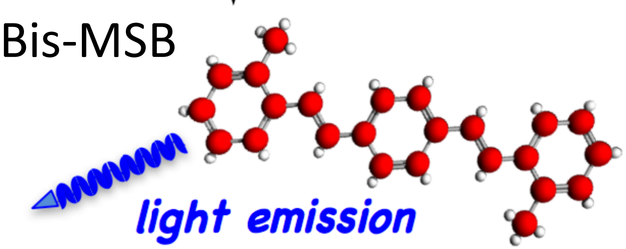
Scintillation Fluor:
2.5 g/l PPO



+

non-radiative → 390nm

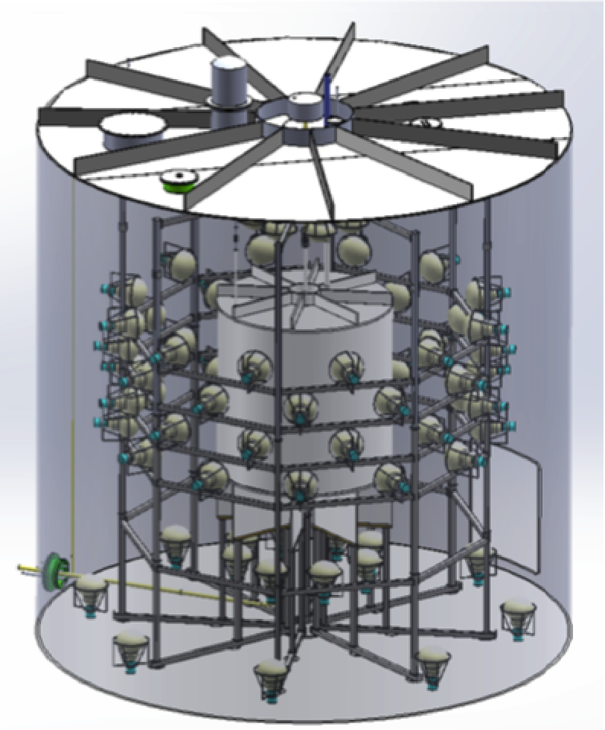
Wavelength Shifter:
3 mg/l Bis-MSB



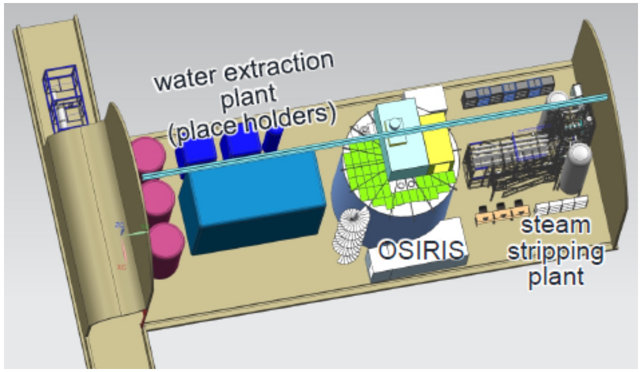
Online Scintillator Internal Radioactivity Investigation System

Liquid Scintillator purity monitor:

Detect radioactive contaminated scintillator **after purification** but **before putting** it into the acrylic vessel!



Exploit fast coincidences in the ^{238}U and ^{232}Th chains



18 ton LS volume (Ø=3 m, H=3 m)

Instrumentation:

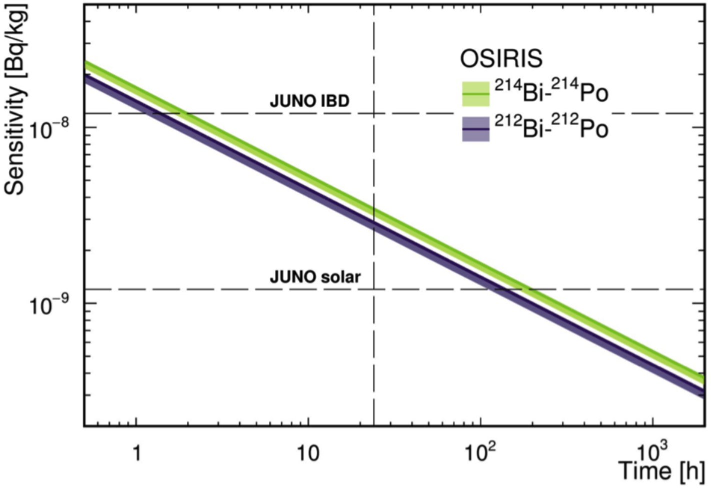
68x 20” PMTs for the scintillator

12x 20” PMTs for the myon veto

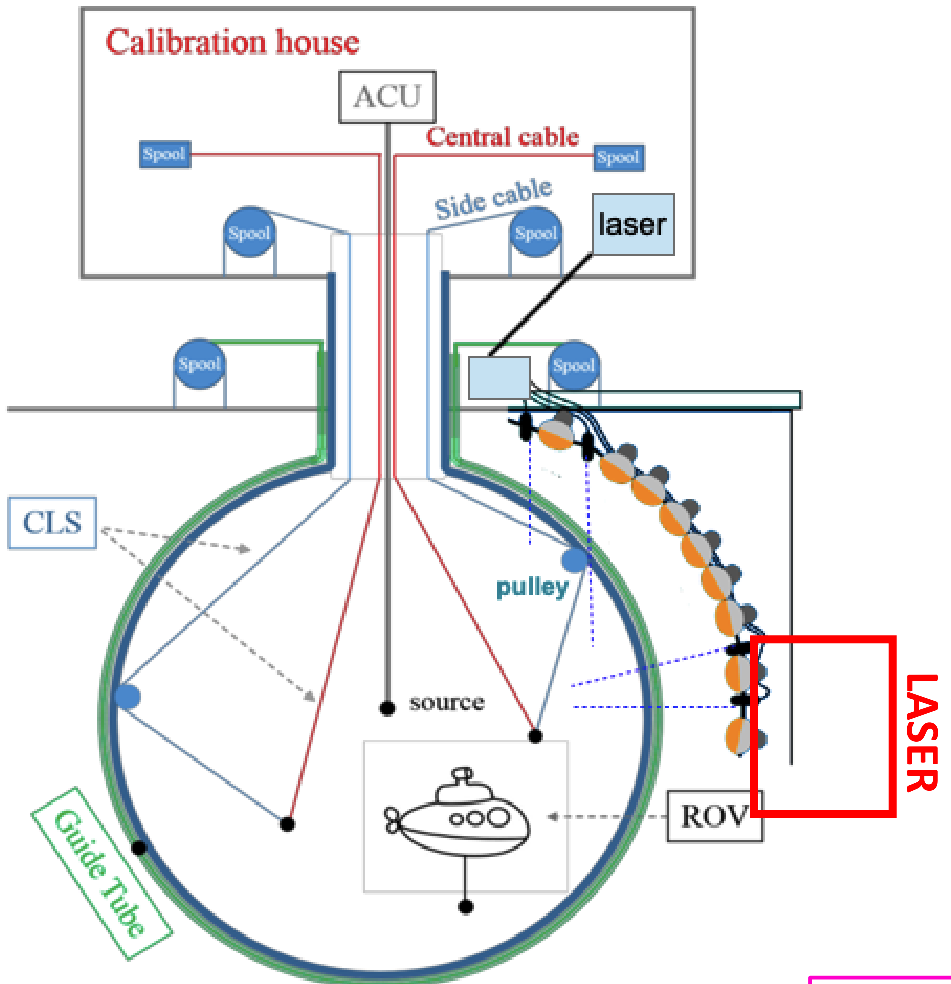
Expected radiopurity level sensitivity (Simulation):

JUNO IBD limit within a few hours

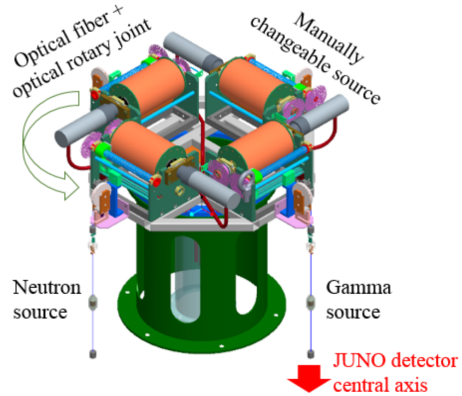
JUNO solar limit possible



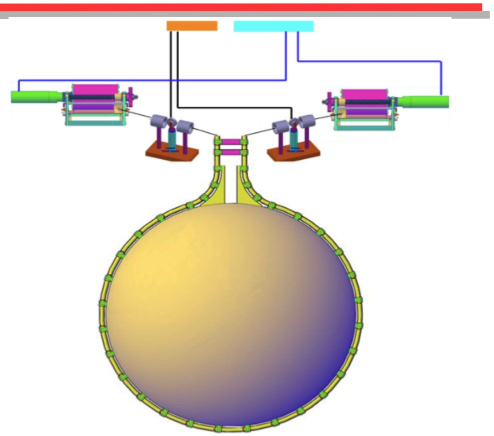
Calibration system



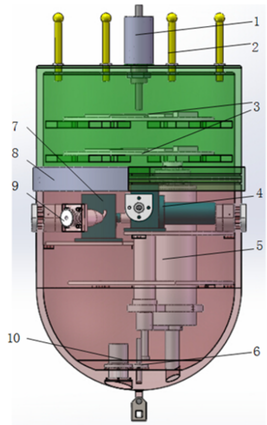
Overview of JUNO's Calibration Systems
(including laser calibration system)



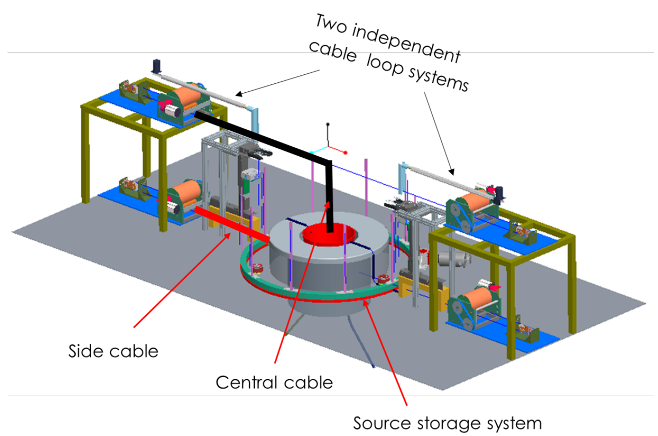
ACU (Automatic Calibration Unit)



Guide Tube System



ROV
(Remotely Operated Vehicle)

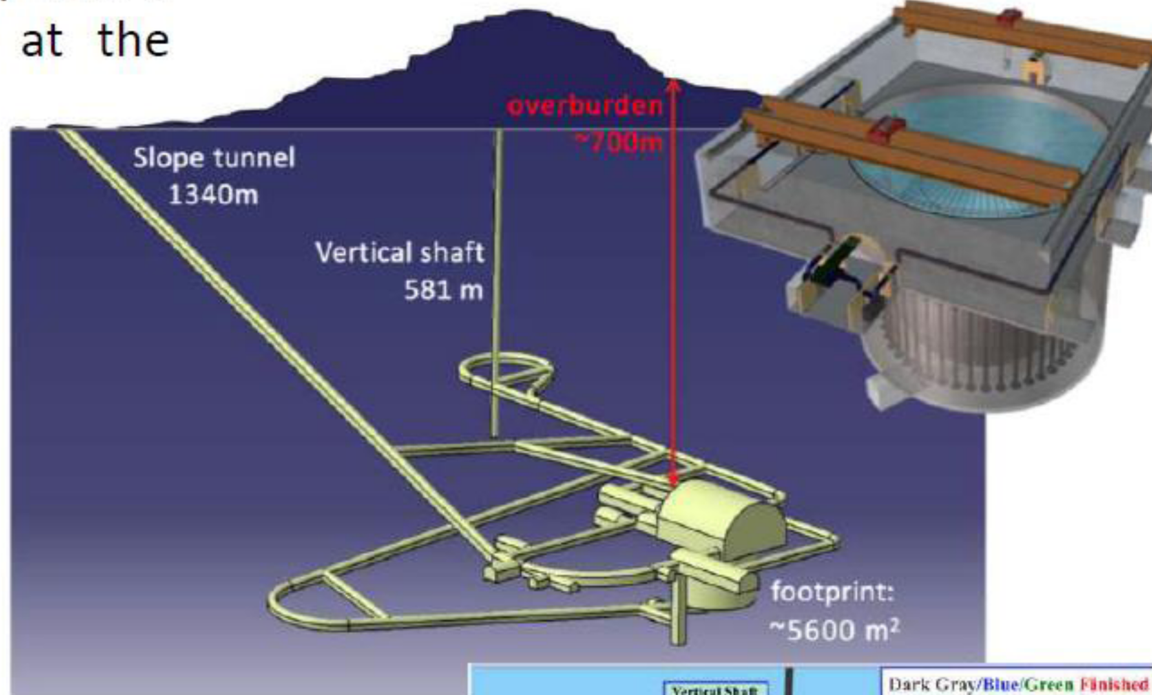


Cable Loop System

Strategy:
- Many sources (LS non-linearity)
- Tunable photon source (electronics non-linearity)
- Many locations (detector non-uniformity)

Civil construction

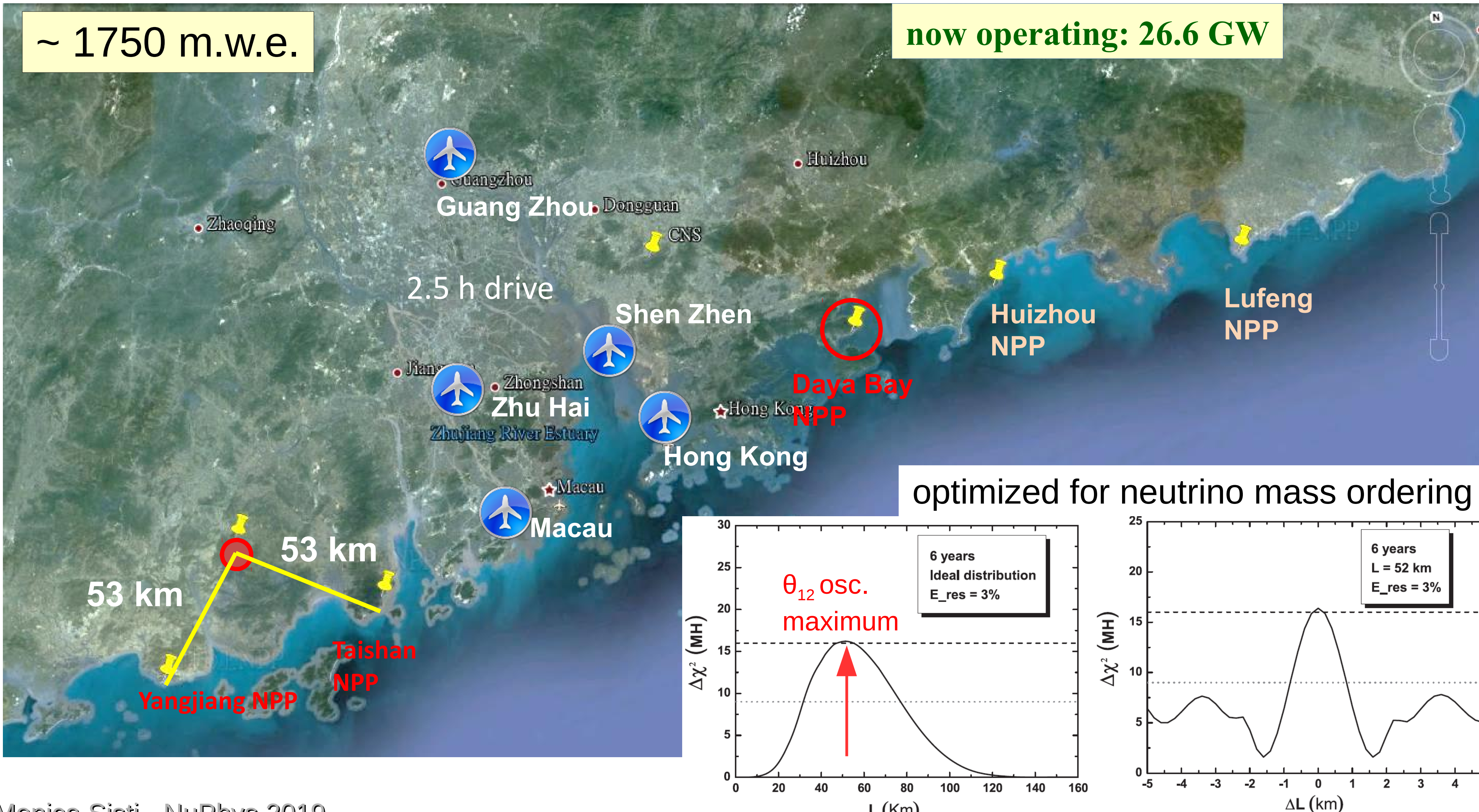
Since 2015 a new underground laboratory with a 700 m overburden and infrastructure at the surface is under construction



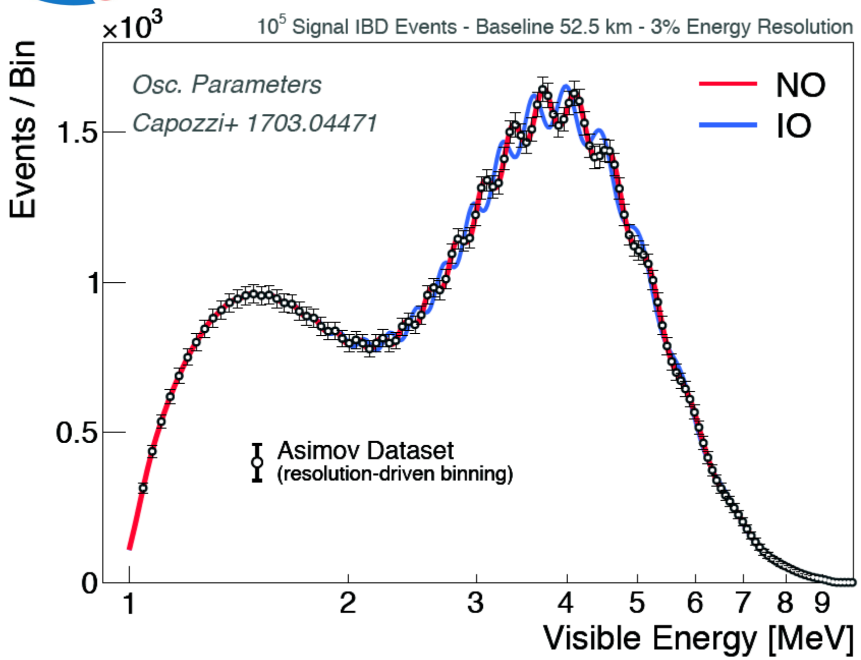
Vertical shaft and slope tunnel completed

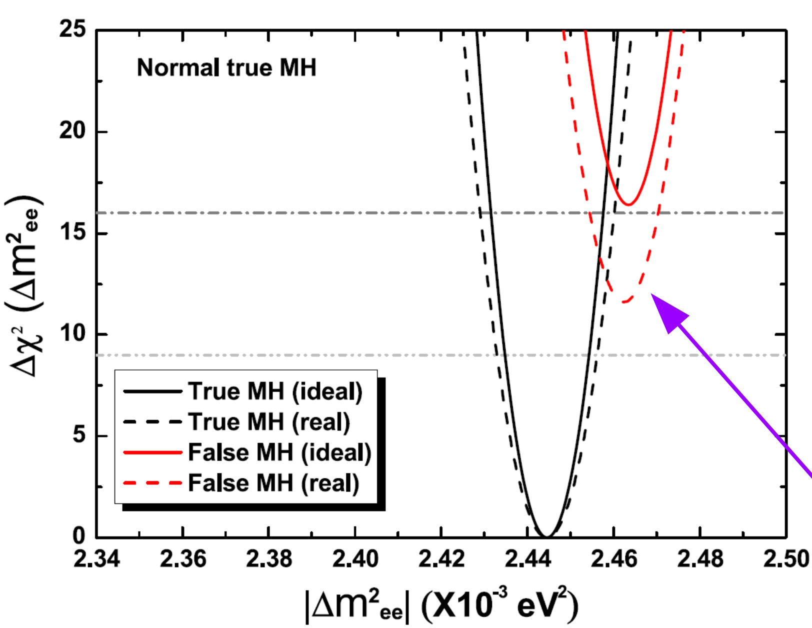
JUNO location

NPP	Daya Bay	Huizhou	Lufeng	Yangjiang	Taishan
Status	Operational	Planned	Planned	Operational	Operational / Planned
Power	17.4 GW	17.4 GW	17.4 GW	17.4 GW	9.2 GW / 18.4 GW



Sensitivity of νMO determination





Fit data against both models

Systematics induced by:

- Energy resolution
- Energy non-linearity
- Distribution of reactor cores
- ...

Sensitivity estimation

Assume NH as true MH, and fit the spectrum with false and true MH cases respectively, to get:

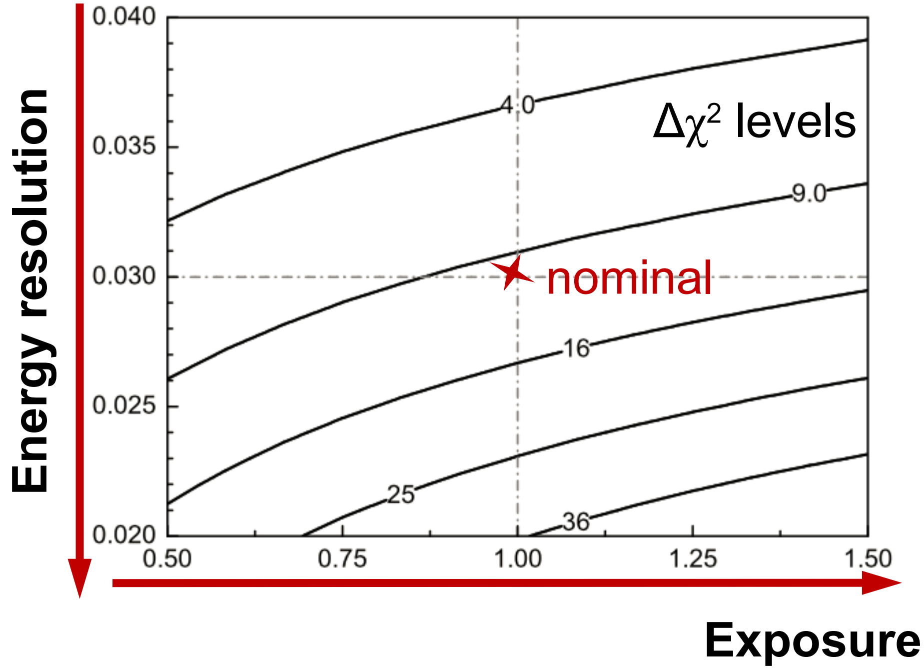
$\Delta\chi^2 = \chi^2(\text{false}) - \chi^2(\text{true})$

$$\chi^2_{\text{REA}} = \sum_{i=1}^{N_{\text{bin}}} \frac{[M_i - T_i(1 + \sum_k \alpha_{ik}\epsilon_k)]^2}{M_i} + \sum_k \frac{\epsilon_k^2}{\sigma_k^2}$$

$$\Delta\chi^2_{\text{MH}} = |\chi^2_{\min}(\text{N}) - \chi^2_{\min}(\text{I})|$$

degradation due to real reactor core distribution

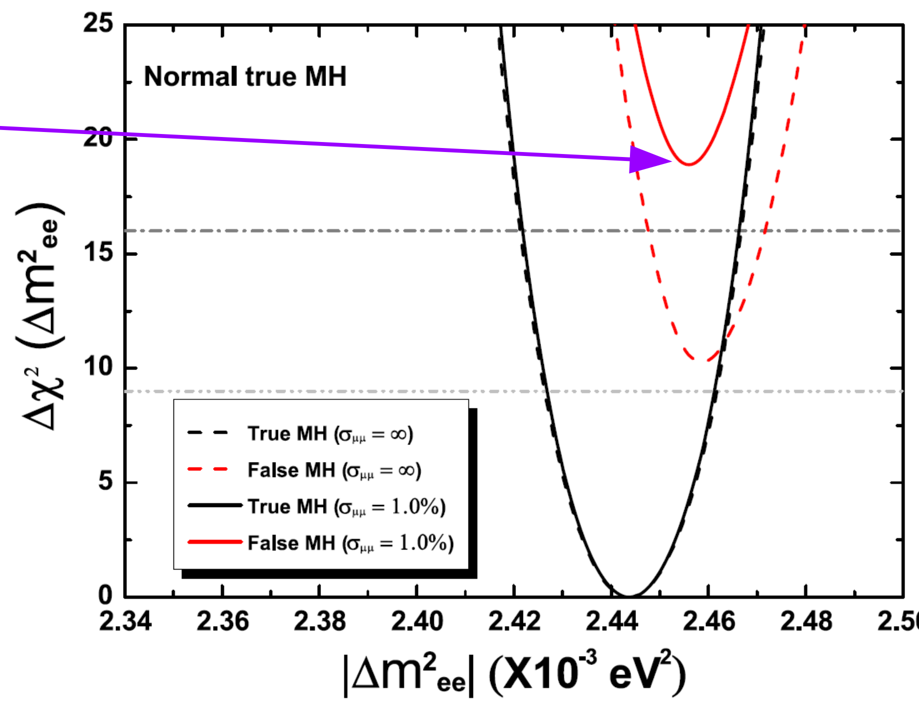
JUNO sensitivity (6 years of data)



	Size	$\Delta\chi^2_{MH}$
Ideal	52.5 km	+16
Core distr.	Real	-3
DYB & HZ [1]	Real	-1.7
Spectral Shape	1%	-1
B/S [2] (rate)	6.3%	-0.6
B/S (shape)	0.4%	**-0.1**

1) Daya Bay & Huizhou reactors
2) Background to Signal

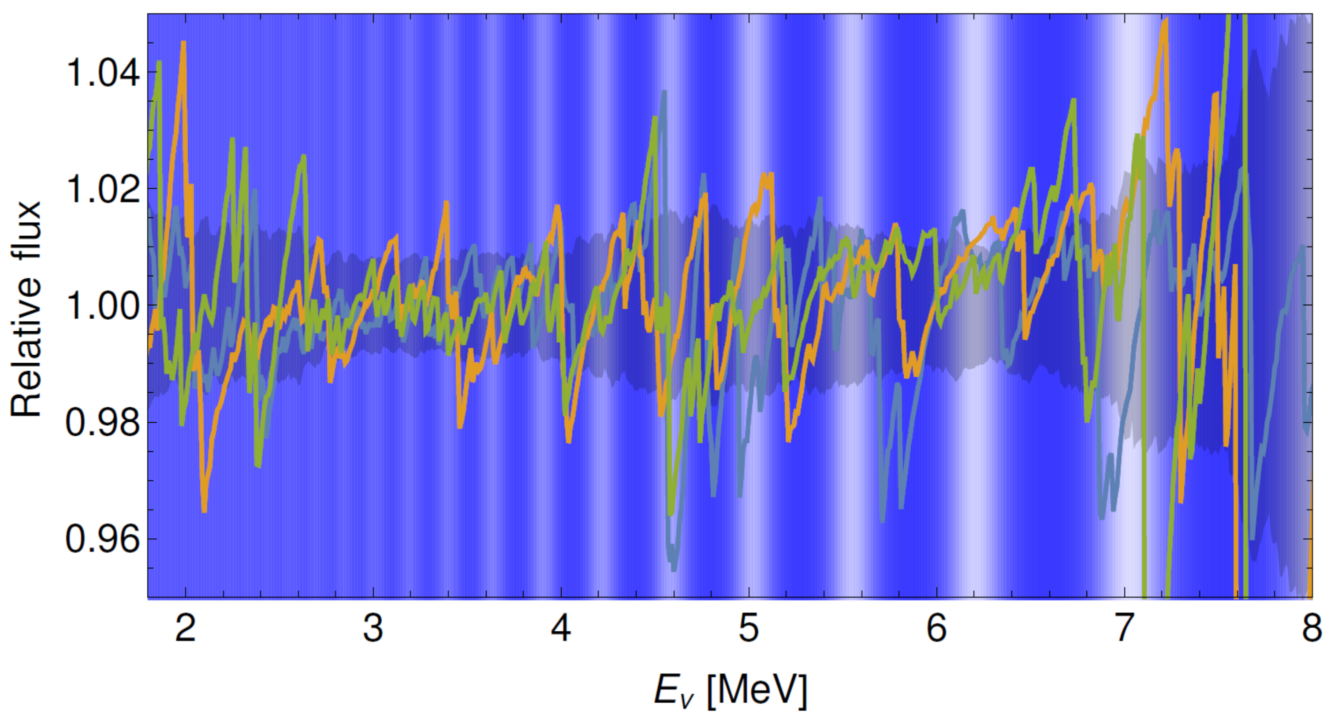
Sensitivity improvement from $\Delta m^2_{\mu\mu}$



- $\nu_\mu \rightarrow \nu_e$ (appearance) channel can also determine the NMO
- T2K+NOvA precision assumed ~ 1%
- Combining T2K+NOvA (both disappearance and appearance) with JUNO: sensitivity improves to 4σ to 5σ or better

Substructures in the reactor spectrum

- Large scale fine structures constrained by Daya Bay experiment
- **A known fine structure does not hurt JUNO MH determination**
  ⇒ Tested with multiple spectra with fine local structure from ab initio calculation (PRL 114:012502, 2015) → no major effect on JUNO sensitivity
- **Unknown fine structure might have a larger impact**



Relative difference of 3 synthetic spectra to ILL data (Huber-Muller model)

arXiv:1710.07378

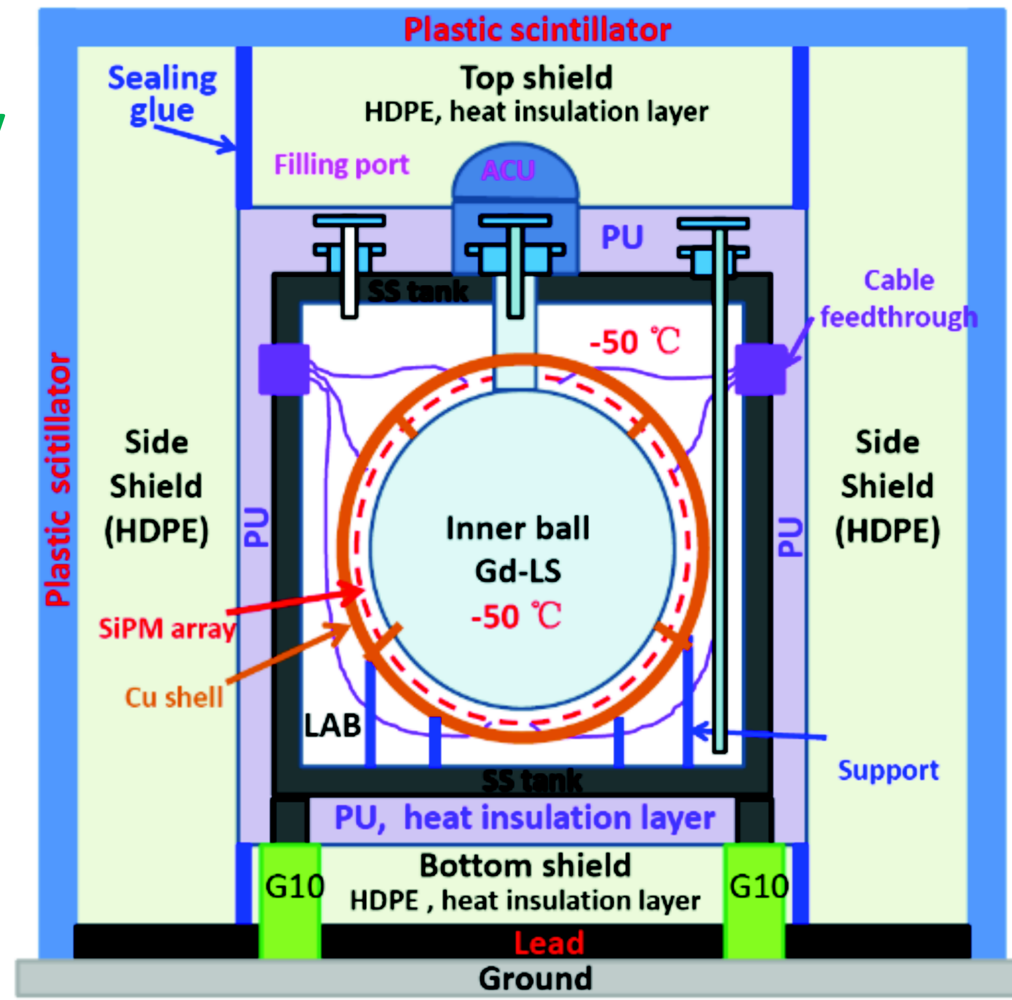
Fine structure depends on the ab-initio calculation using nuclear database and can not be precisely determined.

JUNO-TAO

Taishan Antineutrino Observatory (TAO), a satellite exp. of JUNO.

Measure reactor neutrino spectrum with unprecedented E resolution: ~1.5% / √*E* [MeV]
Provide model-independent reference spectrum for JUNO

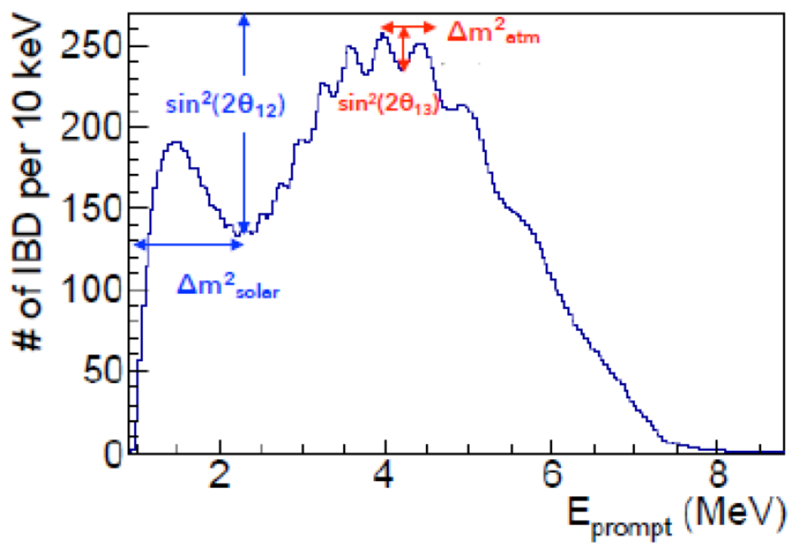
- **2.6 ton Gd-LS in a spherical vessel**
  - **1-ton Fiducial Volume, 4000 ν's/day**
  - **10 m² SiPM of 50% PDE**
- **Operate at -50°C**
- **From Inner to Outside**
  - **Gd-LS working at -50°C**
  - **SiPM and support**
  - **Cryogenic vessel**
  - **1~1.5 m water or HDPE shielding**
  - **Muon veto**
  - **Laboratory in a basement at -10 m,**
- **30-35 m from Taishan core (4.6 GW_{th})**
- **Plan to be online in 2021**



Precision measurement of oscillation parameters

Current precision

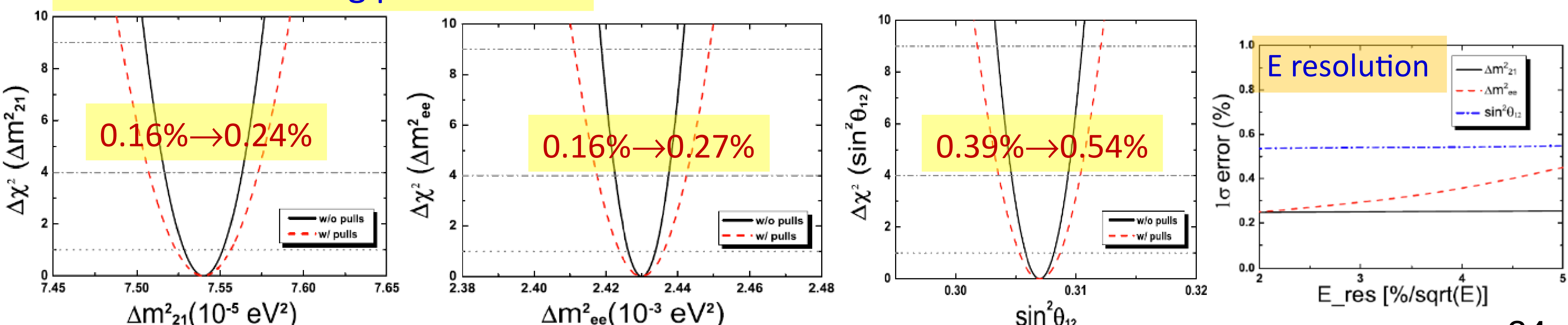
	Δm^2_{21}	$\lvert\Delta m^2_{31}\rvert$	$\sin^2\theta_{12}$	$\sin^2\theta_{13}$	$\sin^2\theta_{23}$	δ
Dominant Exps.	KamLAND	T2K	SNO+SK	Daya Bay	NOνA	T2K
Individual 1σ	2.4%	2.6%	4.5%	3.4%	5.2%	70%
Nu-FIT 4.0	2.4%	1.3%	4.0%	2.9%	3.8%	16%



	Statistics	+BG, +1% bin-to-bin +1% EScale , +1% EnonL
$\sin^2\theta_{12}$	0.54%	**0.67%**
Δm^2_{21}	0.24%	**0.59%**
Δm^2_{ee}	0.27%	**0.44%**

Probing the unitarity of U_{PMNS} to ~1%

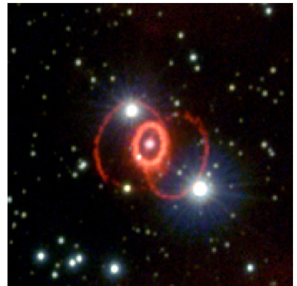
Correlation among parameters:



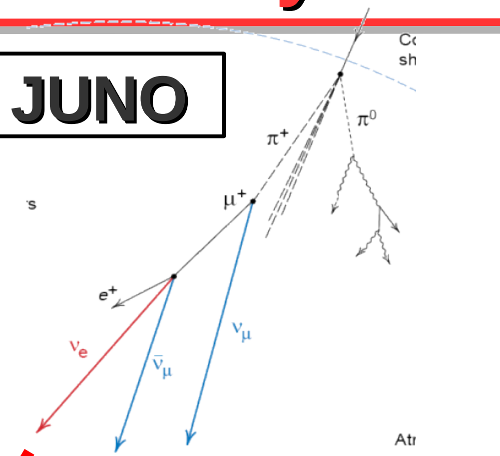
JUNO: a neutrino underground observatory

Neutrino Rates at JUNO

Supernova ν
~ 5k in 10s for 10kpc



Atmospheric ν
several/day

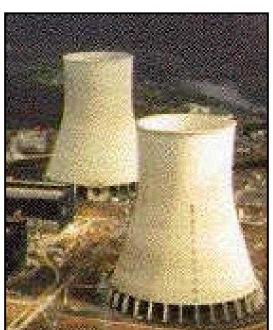


Solar ν
(10s-1000s)/day

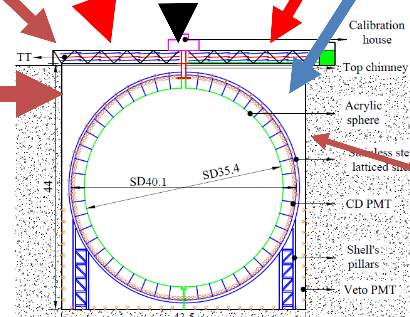
700 m

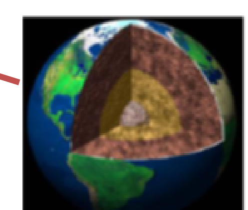
Cosmic muons
~ 250k/day

0.003 Hz/m², 215 GeV
10% multiple-muon



36 GW, 53 km



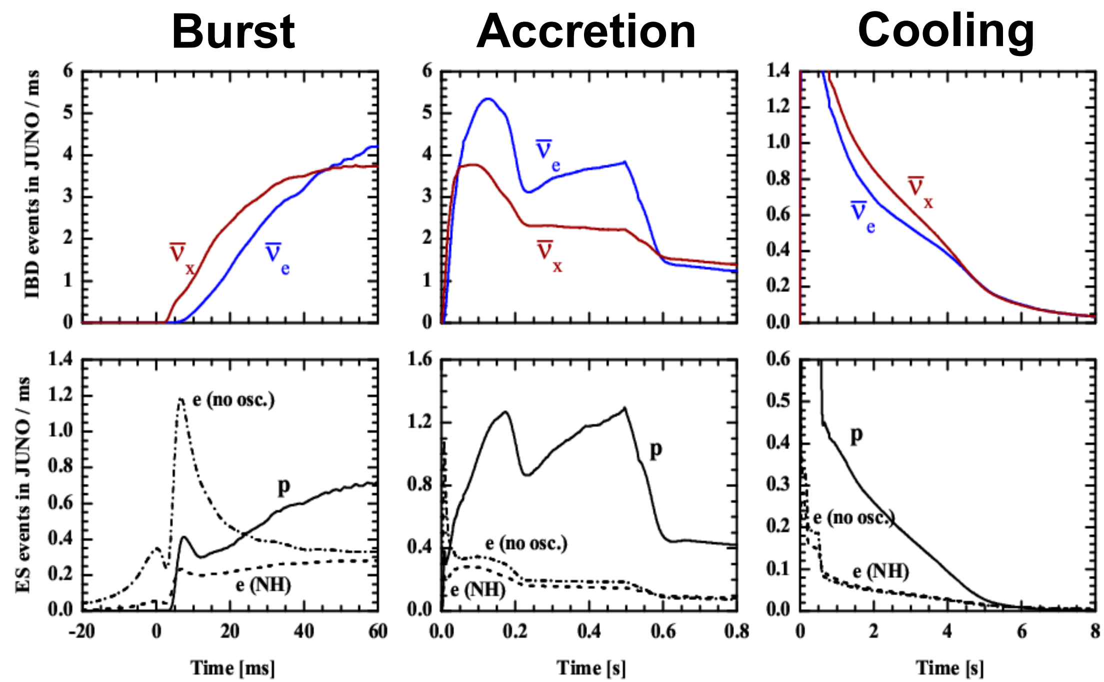


Reactor ν
~ 80/day

Geo-ν
1-2/day

Supernova (SN) burst neutrinos

- Core collapse SN emits 99% of energy in form of ν
- Galactic core-collapse SN rate:
  ~ 3 per century
- JUNO will be able to observe the 3 SN phases from core-collapses happening in our own Galaxy and its satellites
- JUNO will be able to make a real time detection of SN bursts and take part in international SN alert, e.g. SNEWS



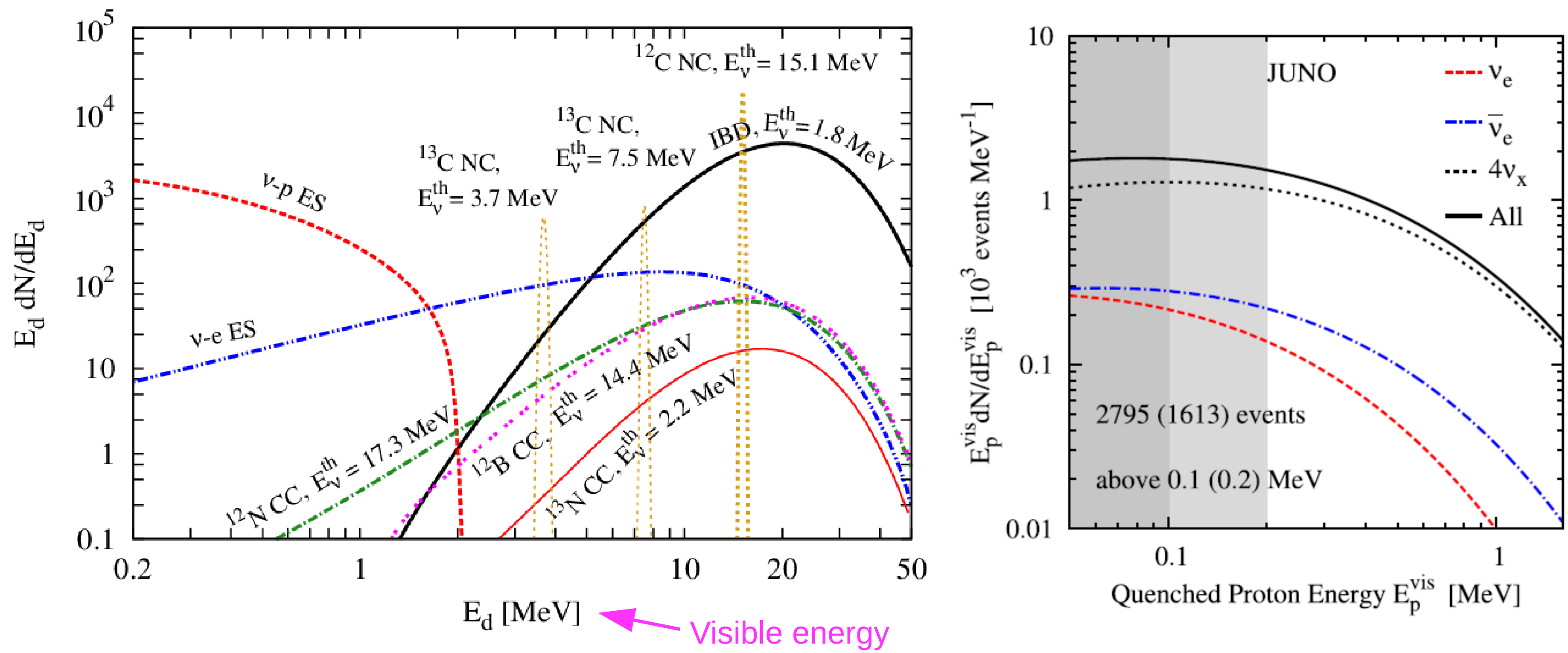
Detection channels in JUNO

Channel	Type	Events for different $\langle E_\nu \rangle$ values		
		12 MeV	14 MeV	16 MeV
$\overline{\nu}_e + p \to e^+ + n$	CC	4.3×10^3	5.0×10^3	5.7×10^3
$\nu + p \to \nu + p$	NC	0.6×10^3	1.2×10^3	2.0×10^3
$\nu + e \to \nu + e$	ES	3.6×10^2	3.6×10^2	3.6×10^2
$\nu + {}^{12}C \to \nu + {}^{12}C^*$	NC	1.7×10^2	3.2×10^2	5.2×10^2
$\nu_e + {}^{12}C \to e^- + {}^{12}N$	CC	0.5×10^2	0.9×10^2	1.6×10^2
$\overline{\nu}_e + {}^{12}C \to e^+ + {}^{12}B$	CC	0.6×10^2	1.1×10^2	1.6×10^2

IBD main detection channel: ~5000 events from a SN at a distance of 10 kpc

Supernova (SN) burst neutrinos

The measurement is almost background free, since SN burst ν lasts for ~10 s

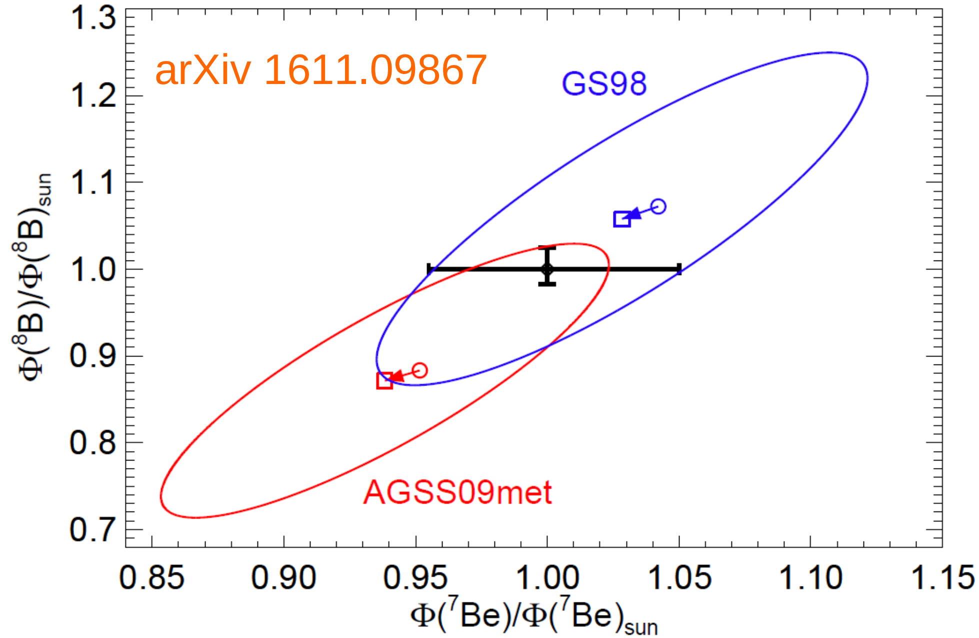


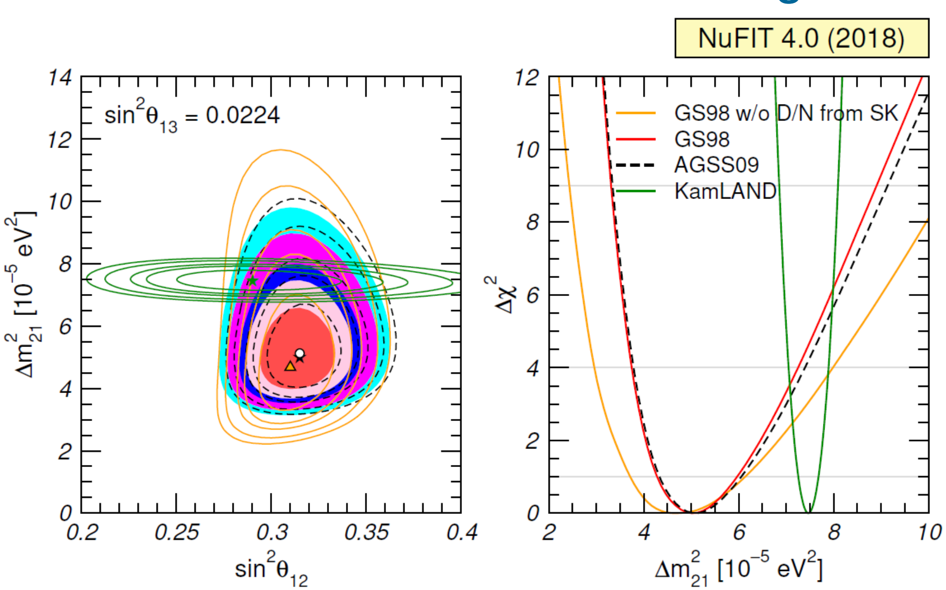
- Full flavor detection and low energy threshold, ~0.2 MeV in LS
- pES is a promising channel, which can provide more informations with respect to other type of detectors (e.g. WC, Lar-TPC)
- Pulse Shape Discrimination (PSD) to distinguish between eES and pES

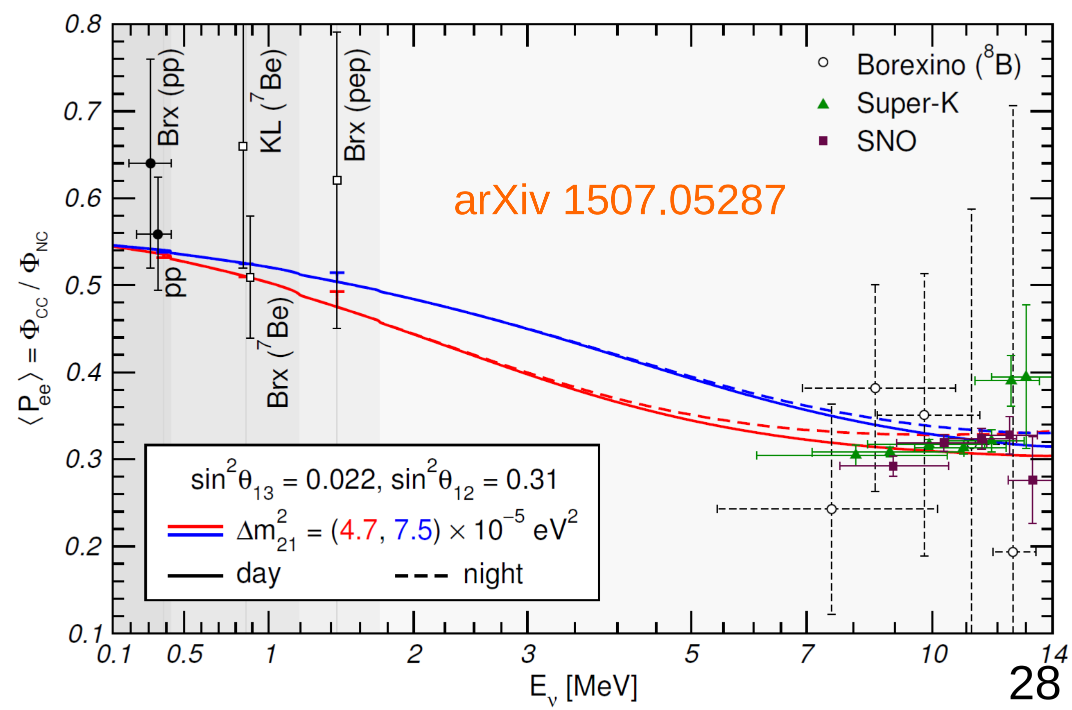
Solar neutrinos

Open issues to be investigated by JUNO:

- Better determination of the oscillation parameters, to test the mild tension between solar and reactor data
- Solution to the solar metallicity problem by improving the accuracy on ^{7}Be and ^{8}B fluxes
- Analysis of the energy dependence of the ν_e survival probability (up-turn in ^{8}B spectrum) to study the transition from vacuum to matter dominated regions







Solar neutrinos

Main detection channel: elastic scattering

$$\nu_{e,\mu,\tau} + e^- \rightarrow \nu_{e,\mu,\tau} + e^-$$

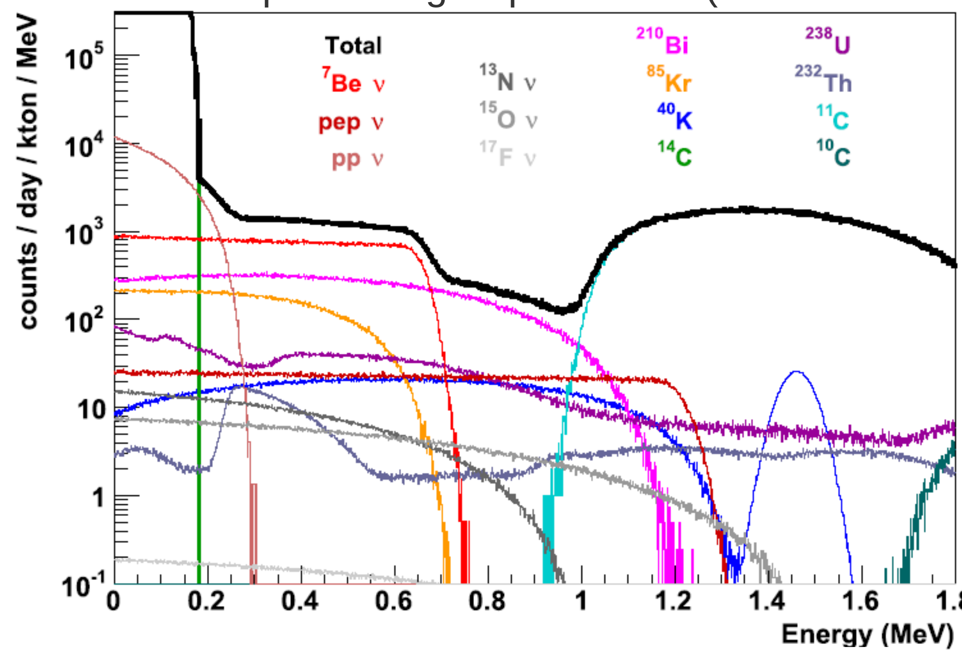
Radioactive background is a severe challenge

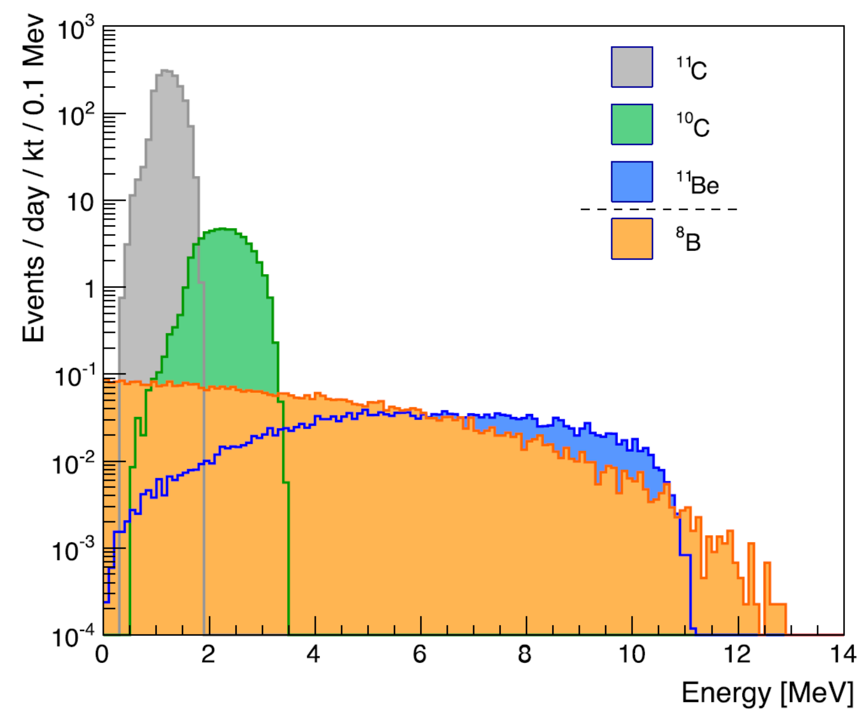
→ required internal radiopurity of LS:
 10^{-15} g/g U/Th, 10^{-16} g/g K baseline
 10^{-17} g/g U/Th, 10^{-18} g/g K solar phase
→ better muon veto approach

Three main observables:

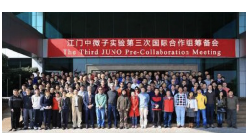
- Electron kinetic energy spectrum
- Day-night asymmetry
- ν_e - ^{13}C charged-current channel (E_{th}~2.2 MeV) [for the first time]

with solar phase bkg requirements (see JUNO-YB)



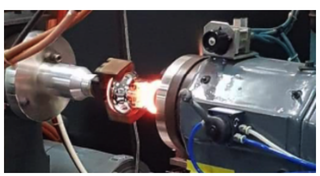


Schedule and milestones



2014

- Int. Collaboration established!



2015

- PMT production line setup
- Start civil construction
- CD parts R&D

2016

- Start PMT production
- Start CD parts production

2017

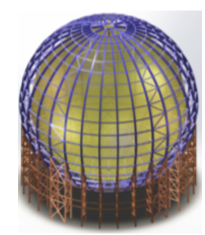
- Start PMT testing
- Top Tracker arrived!
- Daya Bay LS tests

2018

- PMT potting start
- Delivery of surface buildings
- Start production of acrylic sphere
- OSIRIS was funded
- TAO working group formed

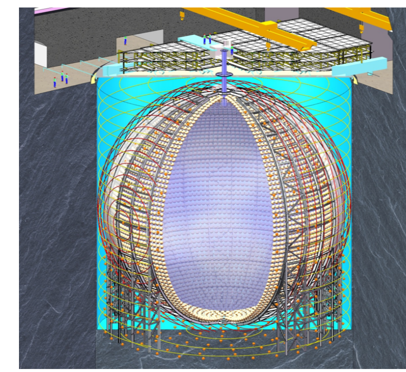
2019-20

- Electronics production starts
- Civil work and lab preparation completed
- Detector construction

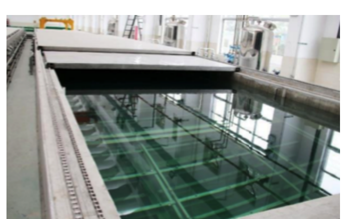


2021

- Detector filled & comissioned
- TAO ready
- Detector ready



Data Taking



Conclusions

- **JUNO will be the largest neutrino observatory ever built with unprecedented energy resolution for detectors of this type**
- **Main goal: determine the neutrino mass ordering with a sensitivity of 3 − 4 σ (with $|\Delta m_{\mu\mu}^2|$ ~ 1%)**
- **First detector to see many oscillation cycles in the same experiment**
- **Sub-percent measurement of neutrino mixing parameters**
- **Very rich parallel physics program, including Supernova neutrinos, atmospheric neutrinos, solar neutrinos, geo-neutrino, nucleon decays, and exotic searches**

- **JUNO was approved in 2013 and the international collaboration was established in 2014**

  ↳ Very strong and tight R&D program and construction schedule

- **Detector construction will be completed by 2021**

The JUNO collaboration

Country	Institute	Country	Institute	Country	Institute
Armenia	Yerevan Physics Institute	China	IMP-CAS	Germany	U. Mainz
Belgium	Universite libre de Bruxelles	China	SYSU	Germany	U. Tuebingen
Brazil	PUC	China	Tsinghua U.	Italy	INFN Catania
Brazil	UEL	China	UCAS	Italy	INFN di Frascati
Chile	PCUC	China	USTC	Italy	INFN-Ferrara
Chile	UTFSM	China	U. of South China	Italy	INFN-Milano
China	BISEE	China	Wu Yi U.	Italy	INFN-Milano Bicocca
China	Beijing Normal U.	China	Wuhan U.	Italy	INFN-Padova
China	CAGS	China	Xi'an JT U.	Italy	INFN-Perugia
China	ChongQing University	China	Xiamen University	Italy	INFN-Roma 3
China	CIAE	China	Zhengzhou U.	Latvia	IECS
China	DGUT	China	NUDT	Pakistan	PINSTECH (PAEC)
China	ECUST	China	CUG-Beijing	Russia	INR Moscow
China	Guangxi U.	China	ECUT-Nanchang City	Russia	JINR
China	Harbin Institute of Technology	Czech R.	Charles University	Russia	MSU
China	IHEP	Finland	University of Jyvaskyla	Slovakia	FMPICU
China	Jilin U.	France	LAL Orsay	Taiwan-China	National Chiao-Tung U.
China	Jinan U.	France	CENBG Bordeaux	Taiwan-China	National Taiwan U.
China	Nanjing U.	France	CPPM Marseille	Taiwan-China	National United U.
China	Nankai U.	France	IPHC Strasbourg	Thailand	NARIT
China	NCEPU	France	Subatech Nantes	Thailand	PPRLCU
China	Pekin U.	Germany	FZJ-ZEA	Thailand	SUT
China	Shandong U.	Germany	RWTH Aachen U.	USA	UMD1
China	Shanghai JT U.	Germany	TUM	USA	UMD2
China	IGG-Beijing	Germany	U. Hamburg	USA	UC Irvine
China	IGG-Wuhan	Germany	FZJ-IKP		

77 members
from
17 countries
for a total of
632 collaborators

Three observers:

- Department of Physics, University of Malaya (Kuala Lumpur)
- University of Zagreb (Croatia)
- Yale University (USA)

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Chile	UTFSM	China	U. of South China	Italy	INFN-Milano
China	BISEE	China	Wu Yi U.	Italy	INFN-Milano Bicocca
China	Beijing Normal U.	China	Wuhan U.	Italy	INFN-Padov[illegible]
China	CAGS	China	Xi'an JT U.	Italy	[illegible]
China	ChongQing University	China	Xiamen University	Italy	[illegible]
China	CIAE	China	Zhengzhou U.	[illegible]	[illegible]
China	DGUT	China	NUDT	[illegible]	[illegible]
China	ECUST	China	CUG-[illegible]	[illegible]	[illegible]
China	Guangxi U.	China	[illegible]	[illegible]	[illegible]
China	Harbin Institute of Technology	[illegible]	[illegible]	[illegible]	MSU
China	IHEP	[illegible]	[illegible]	[illegible]akia	FMPICU
China	Jilin U.	[illegible]	[illegible]	Taiwan-China	National Chiao-Tung U.
China	[illegible]	[illegible]	[illegible] Bordeaux	Taiwan-China	National Taiwan U.
Chi[illegible]	[illegible]	[illegible]	CPPM Marseille	Taiwan-China	National United U.
[illegible]	[illegible]	[illegible]ance	IPHC Strasbourg	Thailand	NARIT
[illegible]	[illegible]	France	Subatech Nantes	Thailand	PPRLCU
[illegible]	[illegible]	Germany	FZJ-ZEA	Thailand	SUT
[illegible]	[illegible]ndong U.	Germany	RWTH Aachen U.	USA	UMD1
[illegible]	Shanghai JT U.	Germany	TUM	USA	UMD2
China	IGG-Beijing	Germany	U. Hamburg	USA	UC Irvine
China	IGG-Wuhan	Germany	FZJ-IKP		

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THANK YOU VERY MUCH!

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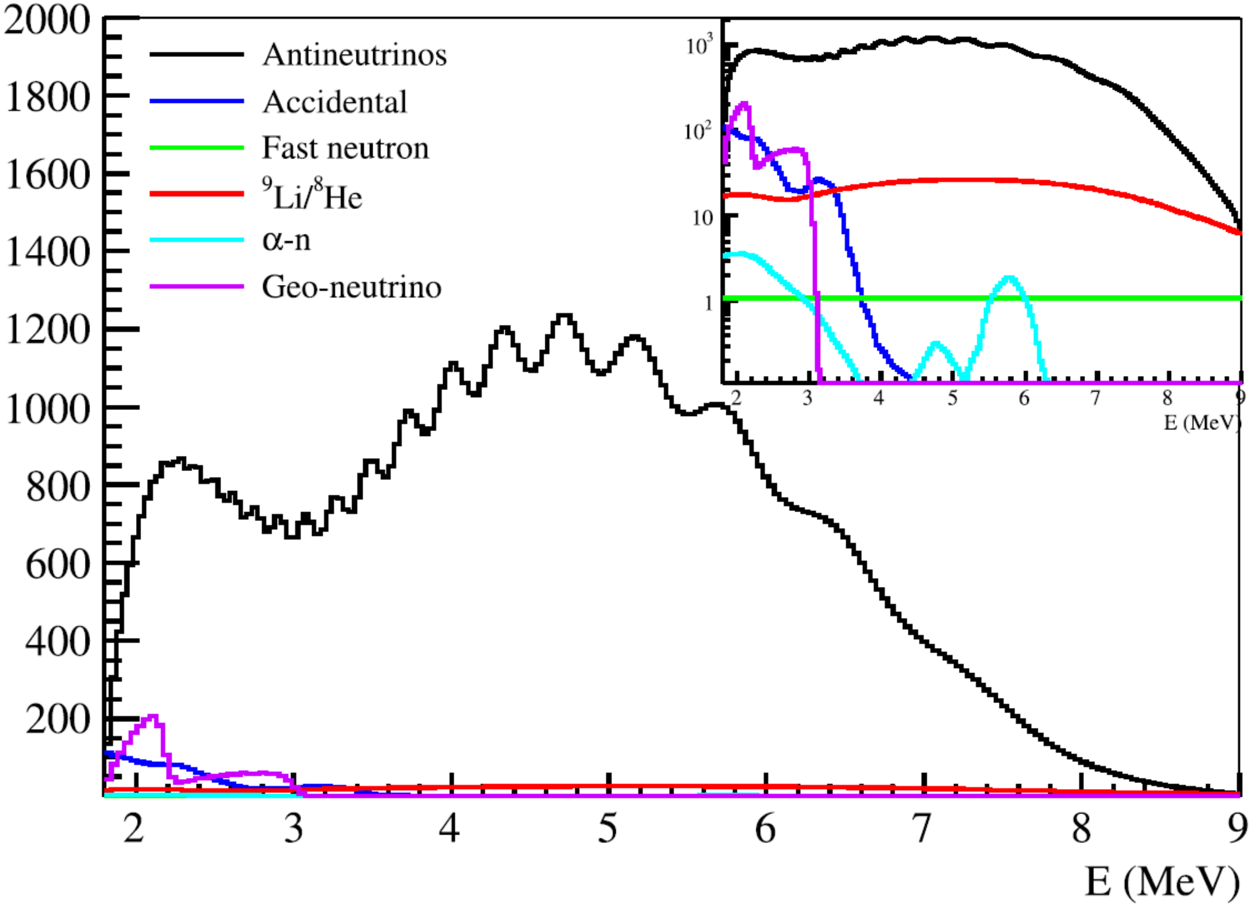
BACK UP SLIDES

Expected background



Main background sources:

- **Natural radioactivity**
- **Cosmogenic isotopes in LS**
- **Fast neutrons**
- **Muons**

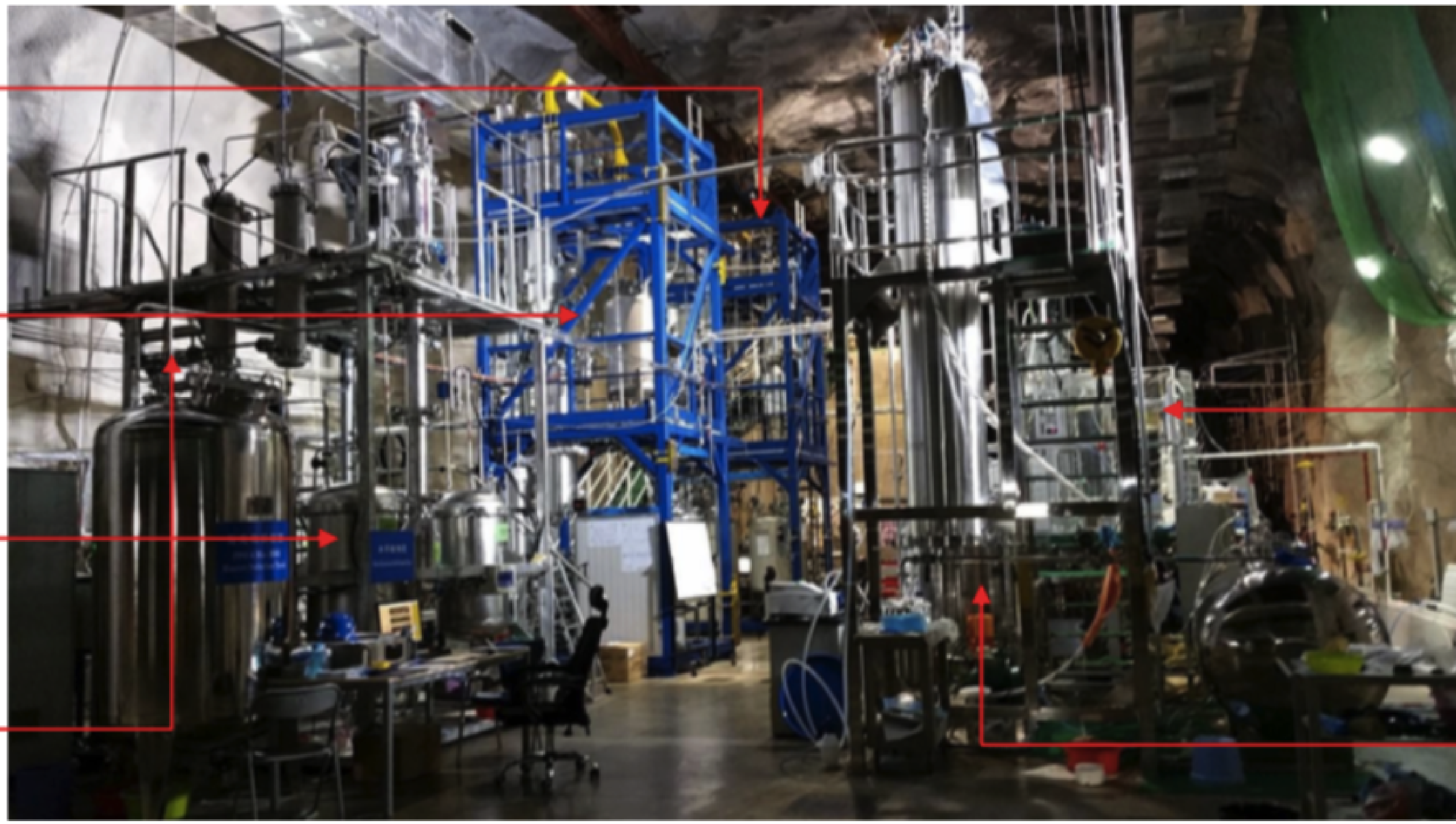
Total Background to Signal (B/S) ratio: ~6.3%

after cuts

Event type	Rate (per day)	Rate uncertainty (relative)	Shape uncertainty
IBD candidates	60	—	—
Geo-νs	1.1	30%	5%
Accidental signals	0.9	1%	negligible
Fast-n	0.1	100%	20%
^{9}Li–^{8}He	1.6	20%	10%
^{13}C $(\alpha, n)^{16}$O	0.05	50%	50%

Liquid Scintillator purification plants

Liquid scintillator purification pilot plants (in Daya Bay)

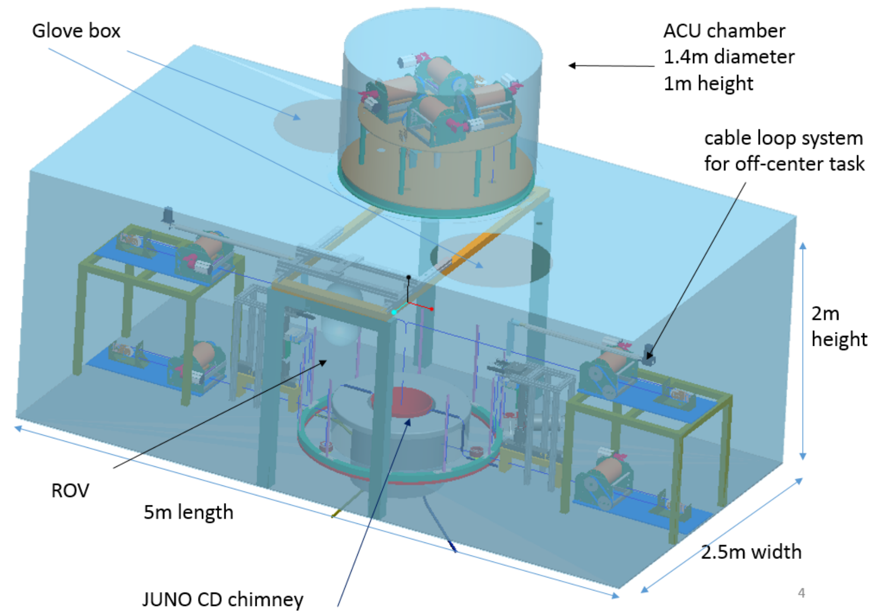


Paper Stripping & Distillation pilot plants:

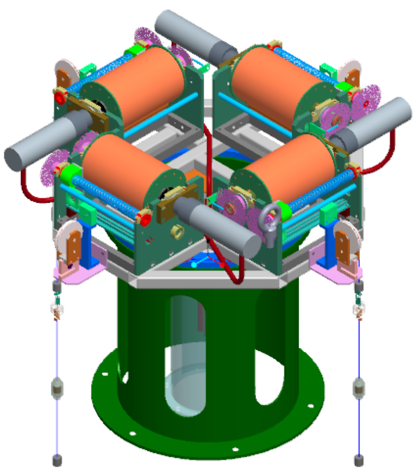
NIM A 925 (2019) 6, arXiv: 1902.05288

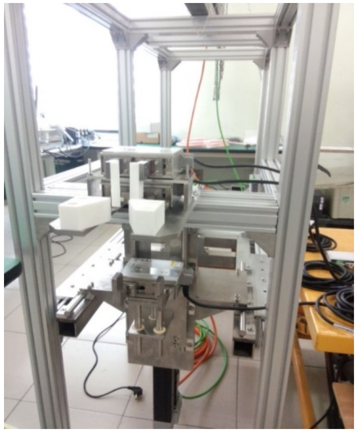
Calibration system

- **Main method**
  - Routinely Source into LS by
    - ✓ ACU: at central axis
    - ✓ rope loop: a plane
  - Source into Guided tube
  - "sub-marine": anywhere in the LS



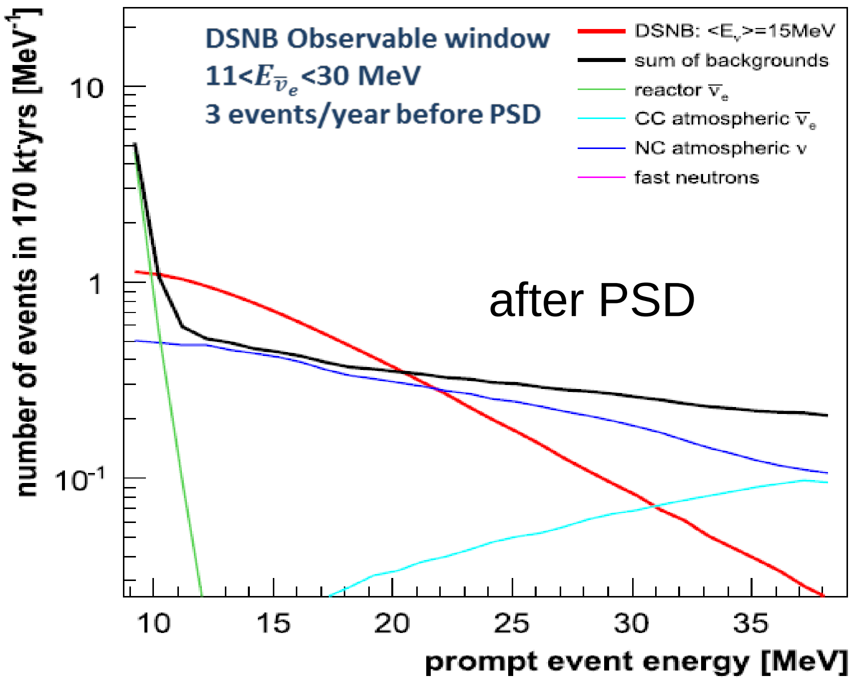
- **Choice of sources & location scan**
  - Simulation shows that the response map of the detector can be obtained

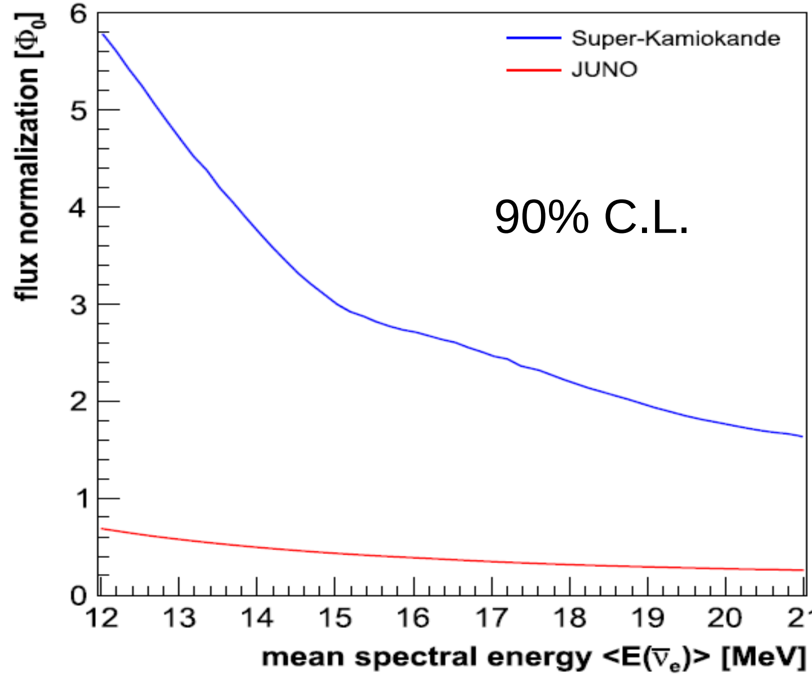




- **R&D on key technical issues**
  - Source deployment
  - Source locating system

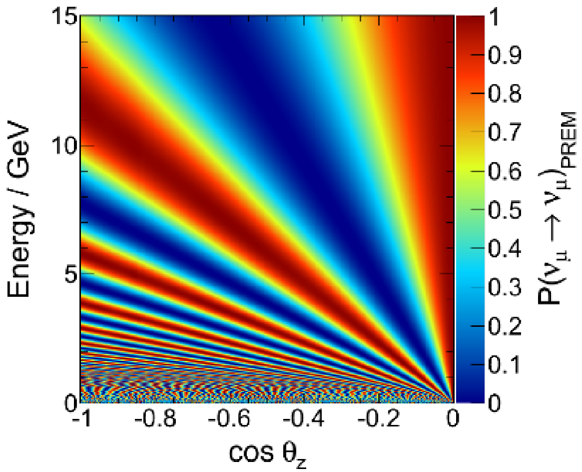
Diffused Supernova ν background (DSNB)



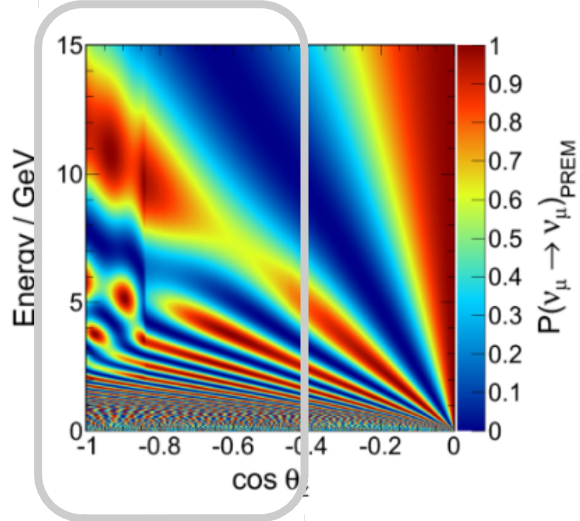


- DSNB rate: approx. **10 core collapse/sec** in the visible universe
- Provide information of star formation rate, emission from average CCSNe and BHs.
- **Pulse Shape Discrimination** to suppress background, mainly **atmospheric neutrinos**
- The expected **detection significance is ~3σ** after 10 years of data taking in JUNO, with ~15 MeV, background systematic uncertainty ~20%

Atmospheric neutrinos

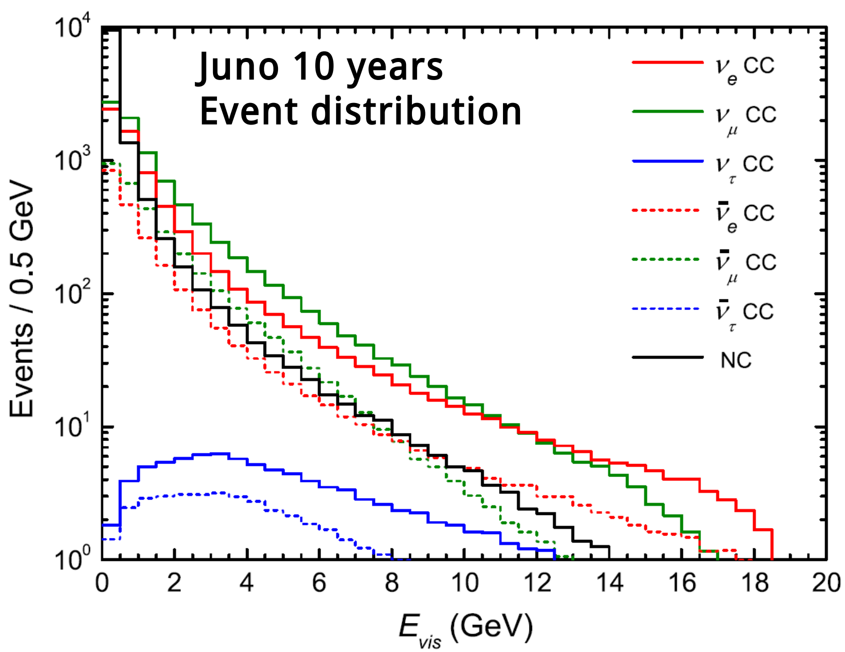


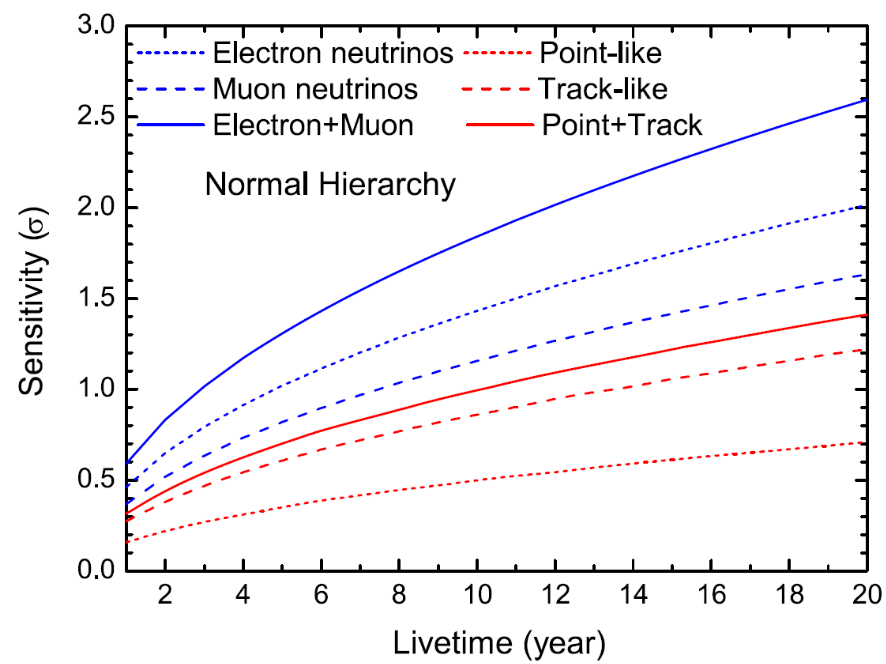
IH



NH

- **Sensitive to MH and θ_{23}**
- MH determination via matter effect
- Complementary to MH with reactor neutrinos
- 1-2 σ for 10 years data taking
- θ_{23} accuracy of 6 deg

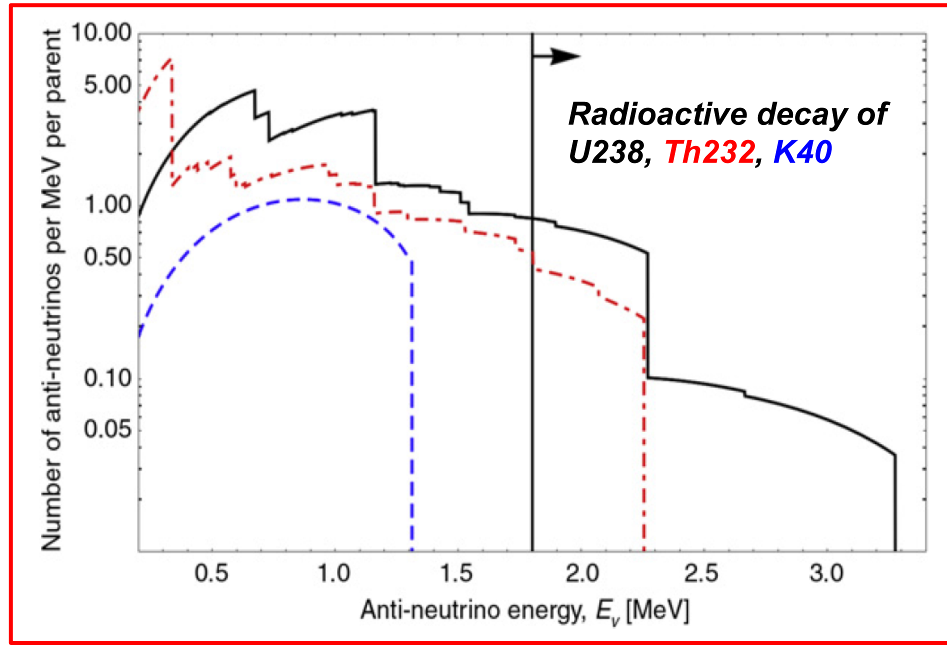




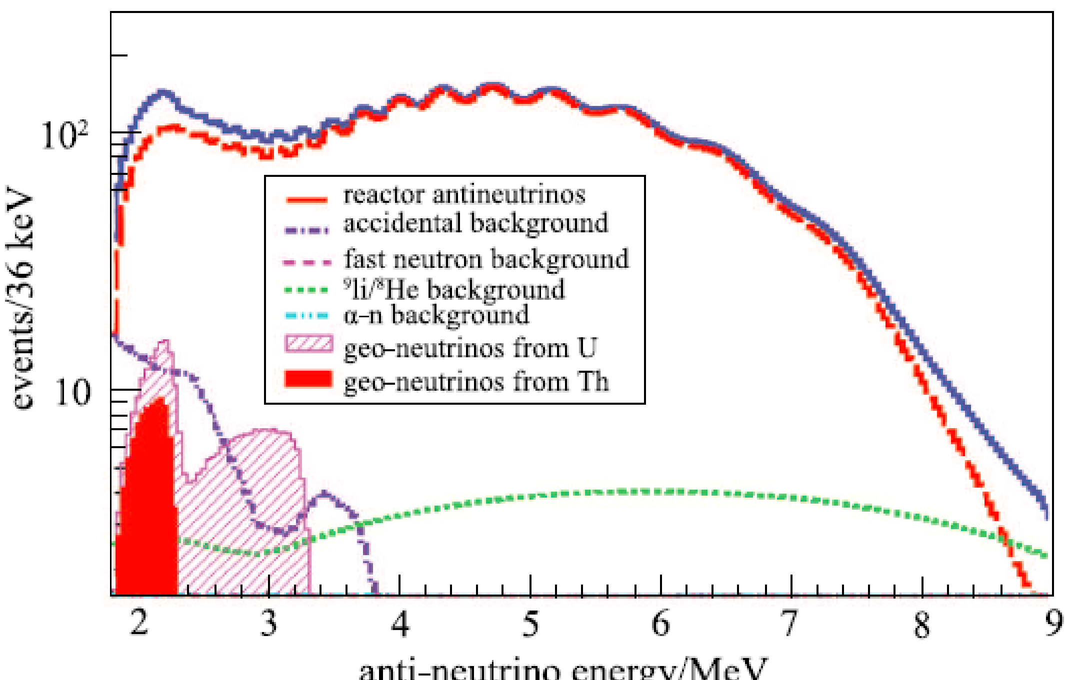
Geo-neutrinos

Geo-ν as a tool to explore the composition of the Earth and to estimate the amount of radiogenic power driving the Earth's engine

$$^{238}\mathrm{U} \rightarrow {}^{206}\mathrm{Pb} + 8\alpha + 6\beta^- + 6\bar{\nu}_e$$
$$^{232}\mathrm{Th} \rightarrow {}^{208}\mathrm{Pb} + 6\alpha + 4\beta^- + 4\bar{\nu}_e$$
$$^{40}\mathrm{K} \rightarrow {}^{40}\mathrm{Ca} + \beta^- + \bar{\nu}_e$$



Detection channel: IBD



- Expected 400-500 IBD/y, larger than all accumulated geo-ν events before
- Challenge: reactor-ν background, ~40 times larger
- Precision will go from 13% (1 year) to 5% (10 years)
- Measure U/Th ratio at percent level
- Interdisciplinary team of physicists and geologists at work to develop a local refined crust model (required to get information on the mantle)

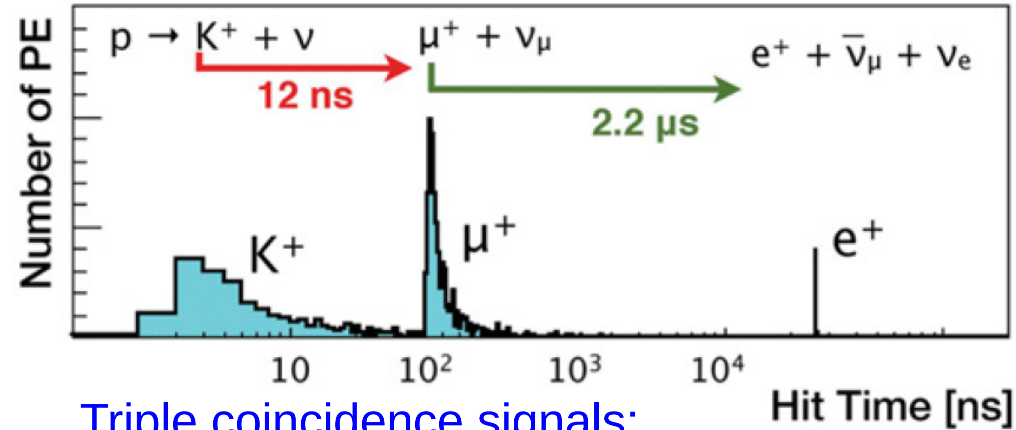
Proton decay

- Two possible decay channels:

$p \rightarrow \pi^0 + e^+$ (favored by GUT)

$\boldsymbol{p \rightarrow K^+ + \upsilon}$ (favored by SUSY)

- Current best limits set by the Super-Kamiokande experiment
- Kaon is invisible in a water Cherenkov detector
- JUNO will focus on the K decay mode to take advantage of the LS technique



Triple coincidence signals:

1st: $\boldsymbol{T_{K^+} = 105}$ **MeV** $\rightarrow \boldsymbol{\tau_{K^+} = 12.38}$ **ns**

2nd: $\boldsymbol{T_{\mu^+} = 152}$ MeV/$\boldsymbol{E_{\pi^+\pi^0} = 494}$ **MeV**

3rd: $\boldsymbol{2.2\mu s}$ $\rightarrow$ **Michel electron**