Status and Prospects of JUNO

Yee Bob Hsiung

National Taiwan University, Taipei

on behalf of JUNO collaboration

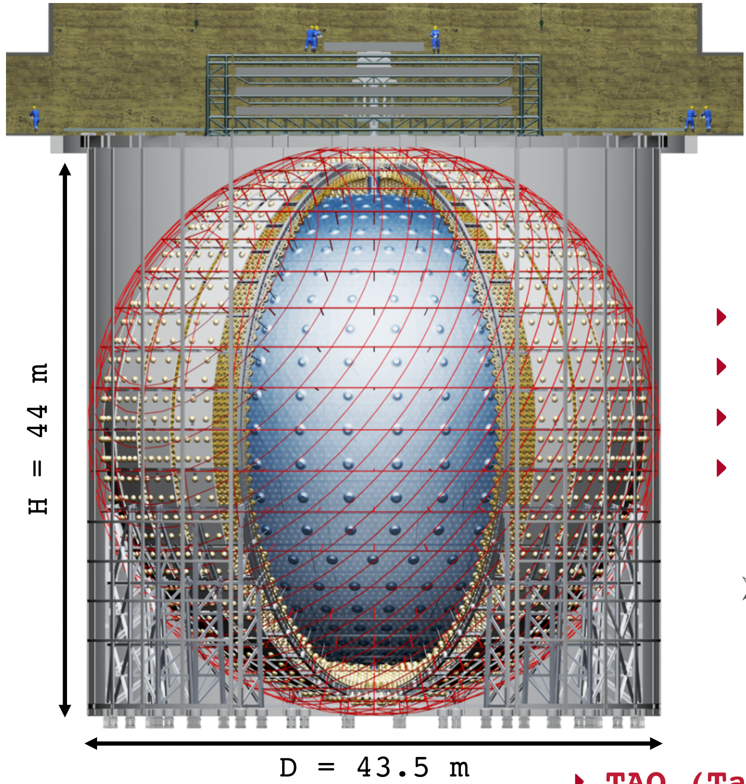
WIN2023 — Zhuhai, China — July 3-8, 2023

Outline

- *Introduction to JUNO experiment*
- *JUNO Detector Progress and Status*
- *Highlight of JUNO Physics Reach*
- *Outlook and stay tuned*

Jiangmen Underground Neutrino Observatory

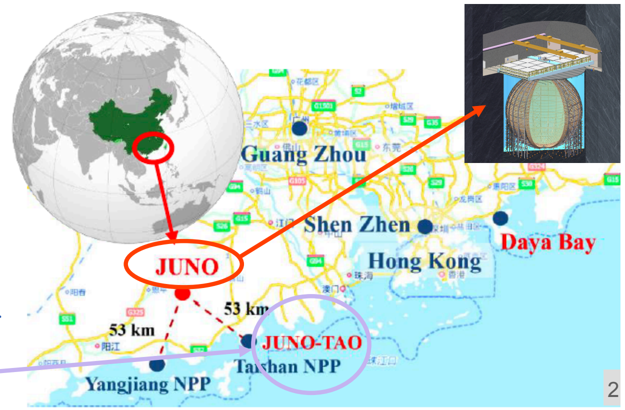
PPNP 123 (2022) 103927
JPG 43 (2016) 030401
arXiv: 1508.07166



Primary physics goals:
ν Mass Ordering determination
and precision measurement of ν oscillation parameters

- **Huge mass:** 20 kton Liquid Scintillator (LS)
- **Underground:** ~650 m overburden (1800 m.w.e.)
- **Unprecedented energy resolution:** ~3% / √E (MeV)
- **Energy scale precision:** < 1%

➢ Currently under construction in Jiangmen at ~53 km from two reactor power plants (Total 26.6 GW thermal power)



- **TAO (Taishan Antineutrino Observatory):** 1 ton satellite LS detector at ~30 m from one reactor core to precisely measure the antineutrino energy spectrum

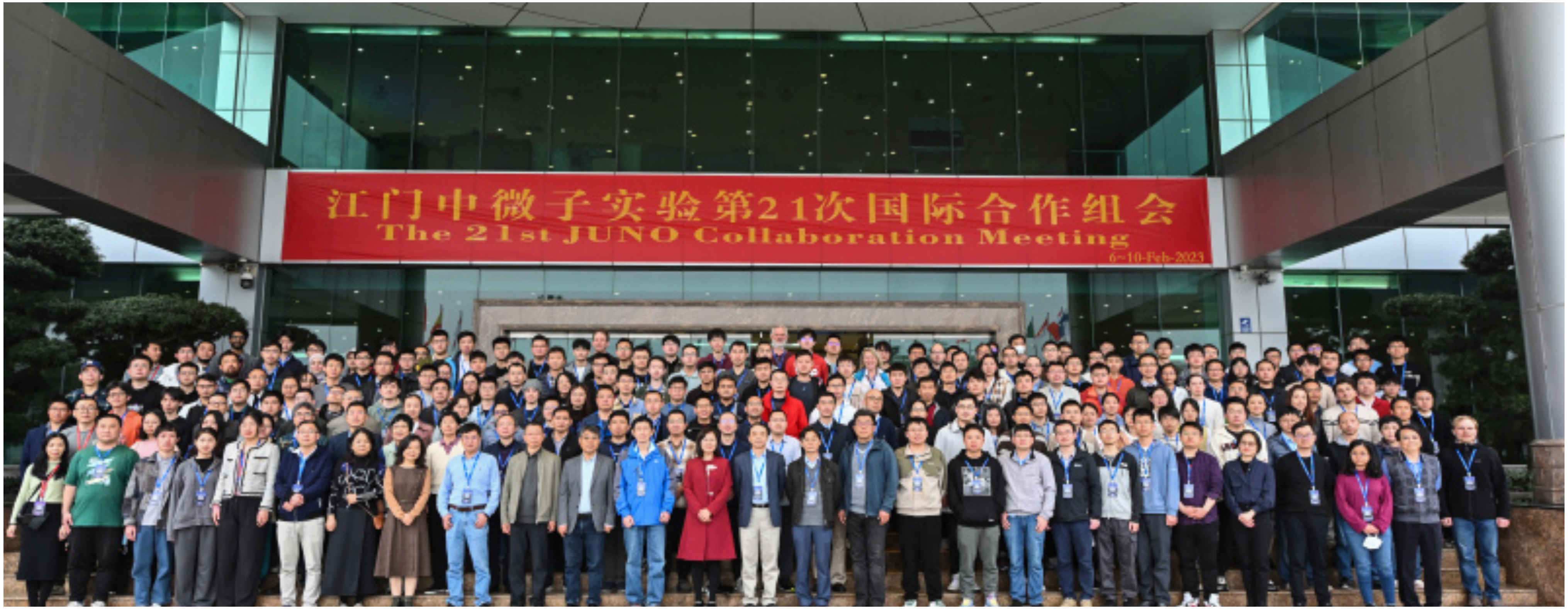
The JUNO Collaboration

74 institutions, ~650 members (As end of 2022)

Country	Institute	Country	Institute	Country	Institute
Armenia	Yerevan Physics Institute	China	Tsinghua U.	Germany	U. Tuebingen
Belgium	Universite libre de Bruxelles	China	UCAS	Italy	INFN Catania
Brazil	PUC	China	USTC	Italy	INFN di Frascati
Brazil	UEL	China	U. of South China	Italy	INFN-Ferrara
Chile	PCUC	China	Wu Yi U.	Italy	INFN-Milano
Chile	SAPHIR	China	Wuhan U.	Italy	INFN-Milano Bicocca
China	BISEE	China	Xi'an JT U.	Italy	INFN-Padova
China	Beijing Normal U.	China	Xiamen University	Italy	INFN-Perugia
China	CAGS	China	Zhengzhou U.	Italy	INFN-Roma 3
China	ChongQing University	China	NUDT	Latvia	IECS
China	CIAE	China	CUG-Beijing	Pakistan	PINSTECH (PAEC)
China	DGUT	China	ECUT-Nanchang City	Russia	INR Moscow
China	Guangxi U.	Croatia	PDZ/RBI	Russia	JINR
China	Harbin Institute of Technology	Czech	Charles U.	Russia	MSU
China	IHEP	Finland	University of Jyvaskyla	Slovakia	FMPICU
China	Jilin U.	France	IJCLab Orsay	Taiwan-China	National Chiao-Tung U.
China	Jinan U.	France	LP2i 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	RWTH Aachen U.	Thailand	SUT
China	Shandong U.	Germany	TUM	U.K.	U. Warwick
China	Shanghai JT U.	Germany	U. Hamburg	USA	UMD-G
China	IGG-Beijing	Germany	FZJ-IKP	USA	UC Irvine
China	SYSU	Germany	U. Mainz		

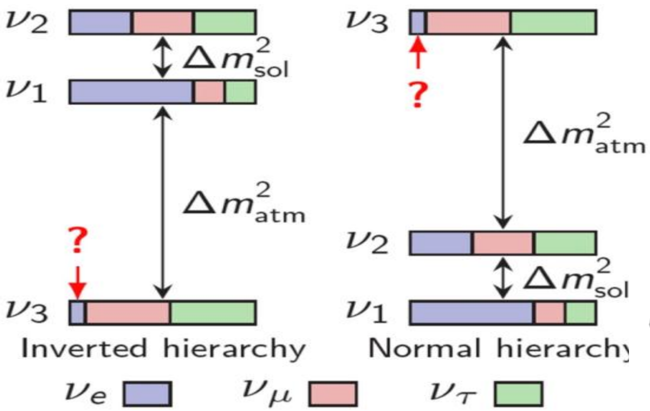
The JUNO Collaboration

The 21th JUNO meeting in Kaiping, China — Feb. 2023



Neutrino Mixing

In a 3-ν framework



$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -\sin\theta_{13}e^{i\delta} & 0 & \cos\theta_{13} \end{pmatrix} \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$\Delta m^2_{sol} : \Delta m^2{}_{21}$ $\quad$ $\Delta m^2_{atm} : \Delta m^2{}_{31}, \Delta m^2{}_{32}$

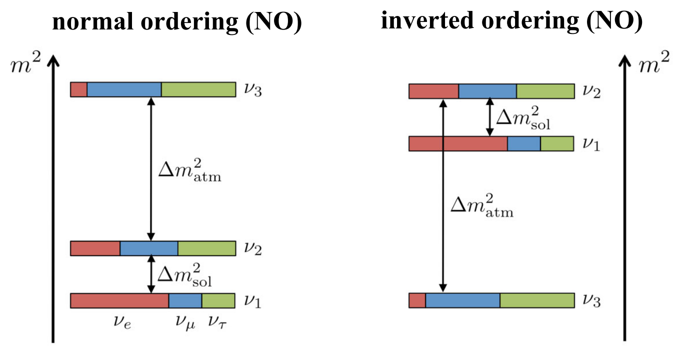
Values of θ_{12}, θ_{23} and θ_{13} have been determined by different methods of neutrino experiments.

$$\mathrm{NH} : |\Delta m^2_{31}| = |\Delta m^2_{32}| + |\Delta m^2_{21}|, \quad |\Delta m^2_{31}| > |\Delta m^2_{32}| \qquad \Delta m^2{}_{31} > 0$$

$$\mathrm{IH} : |\Delta m^2_{31}| = |\Delta m^2_{32}| - |\Delta m^2_{21}|, \quad |\Delta m^2_{31}| < |\Delta m^2_{32}| \qquad \Delta m^2{}_{31} < 0$$

Next generation neutrino experiments mainly focus on the determination of *mass hierarchy (MH)* and measurement *of CP Phase*.

Neutrino Mass Ordering at Reactors

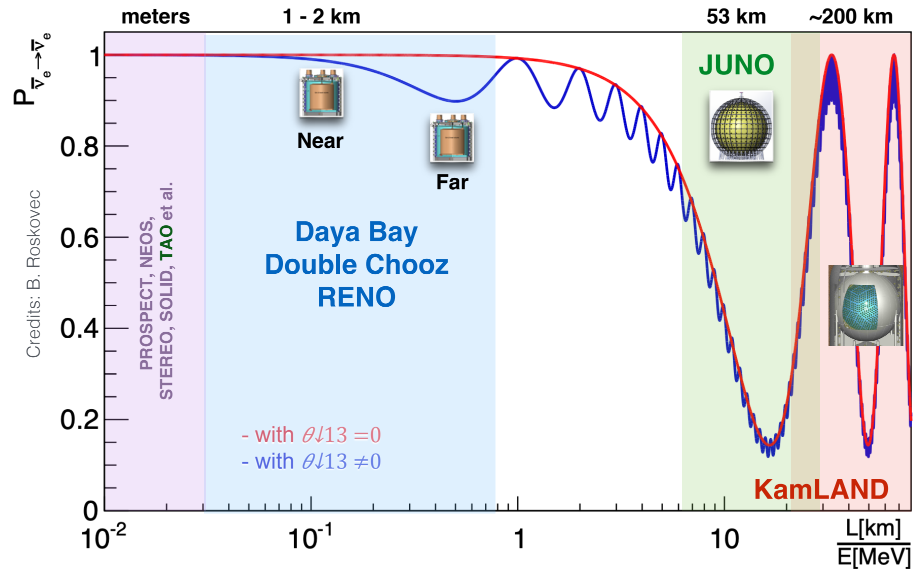


NO: $|\Delta m^2_{31}| = |\Delta m^2_{32}| + |\Delta m^2_{21}|$

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

Suggested by Petcov and Piai, PLB 533(2002)94

Learned et al, PRD 78(2008)071302



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

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

$$P_{21} = \cos^4(\theta_{13})\sin^2(2\theta_{12})\sin^2(\Delta_{21})$$ → SLOW Δm_{sol}^2

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

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

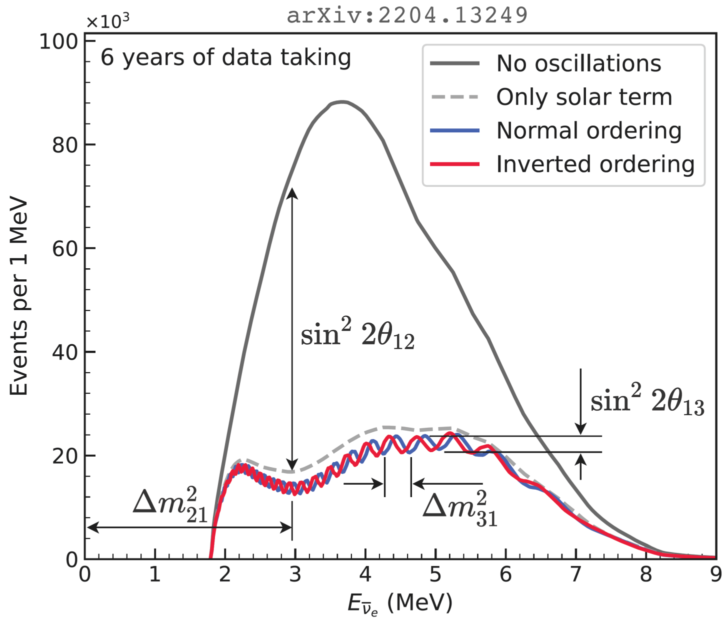
$$P_{32} = \sin^2(\theta_{12})\sin^2(2\theta_{13})\sin^2(\Delta_{32}),$$

} → FAST Δm_{atm}^2

→ *Independent of θ_{23} and CP phase*

Reactor Antineutrino Spectra at JUNO

Detector challenges



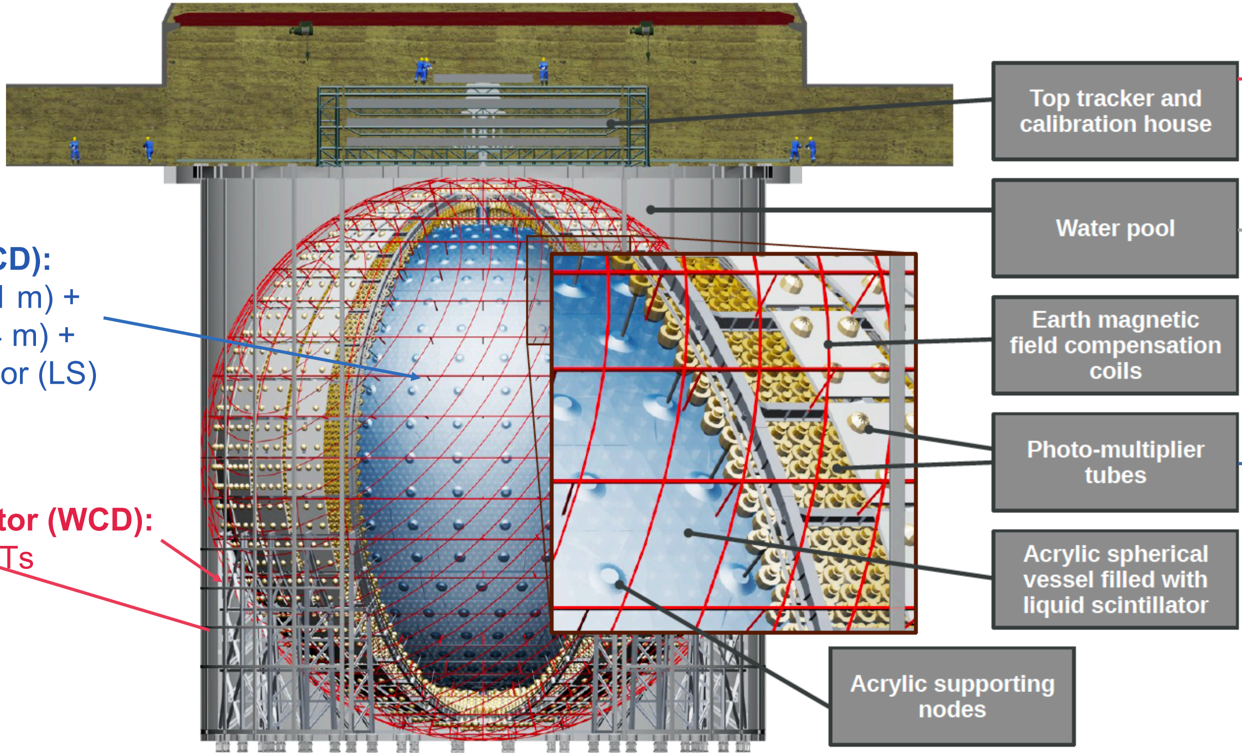
(matter effect contributes maximal ~4% correction at around 3 MeV, *arXiv:1605.00900, arXiv:1910.12900*)

- **Large statistics**
  - ✓ Large target mass (20 kton LS)
  - ✓ Powerful reactor source (26.6 GW_{th})
- **Good energy resolution**
  - ✓ Large PMT coverage (78%)
  - ✓ High photon yield, higly transparent LS
  - ✓ Highly efficient PMTs (PDE ~30%)
- **Small shape/scale uncertainties**
  - ✓ TAO satellite detector
  - ✓ Redundant calibration system
- **Low background**
  - ✓ Good overburden (~650 m)
  - ✓ Highly efficient veto system (>99.5%)
  - ✓ High sensitivity material screening
  - ✓ Careful control of installation cleanliness

The JUNO Detector

Central Detector (CD):
Steel structure (⌀ 40.1 m) +
Acrylic vessel (⌀ 35.4 m) +
20 kton Liquid Scintillator (LS)

Water Cherenkov Detector (WCD):
2400 20-inch PMTs



Top Tracker (TT):
3 plastic scintillator layers

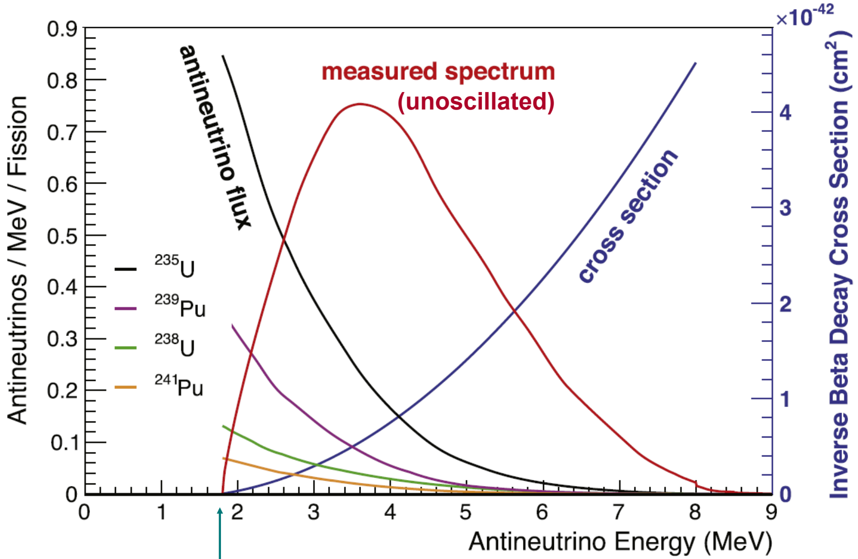
Pool's dimensions
- height: 44 m
- diameter: 43.5 m
- water depth: 43.5 m

Light read-out:
17612 20-inch PMTs
25600 3-inch PMTs

The largest LS detector ever built!

Experiment	Daya Bay	BOREXINO	KamLAND	JUNO
LS mass	20 ton	~ 300 ton	~ 1 kton	20 kton
Coverage	~ 12%	~ 34%	~ 34%	~ 78%
Energy resolution	~ 8% /√E	~ 5% /√E	~ 6% /√E	~ 3% /√E
Light yield	~ 160 p.e. /MeV	~ 500 p.e. /MeV	~ 250 p.e. /MeV	> 1345 p.e. /MeV

Reactor Antineutrino Detection

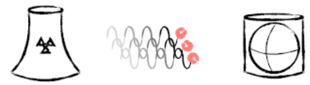


Energy threshold: 1.8 MeV

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

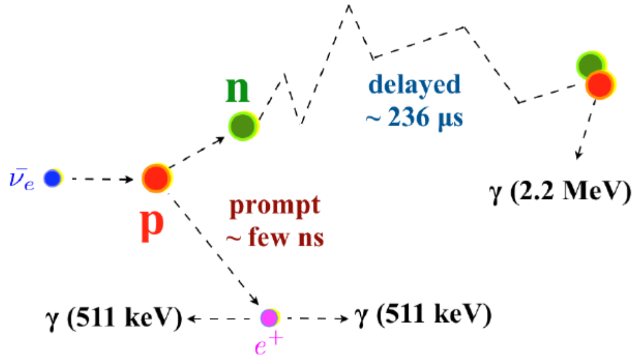
- E_{vis} (e+) ≃ E (ν_e) – 0.78 MeV

Antineutrinos from reactors



3 GW_{th} reactor → ~10^{21} $\bar{\nu}_e$/s

Inverse Beta Decay (IBD) reaction



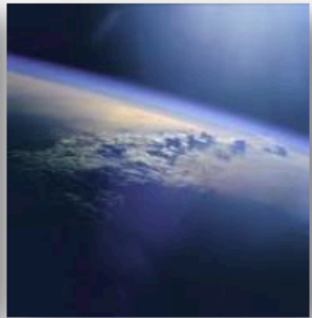
- Space-Time coincidences between prompt and delayed signals to reject uncorrelated background

JUNO: A Neutrino Observatory

Reactor anti-ν

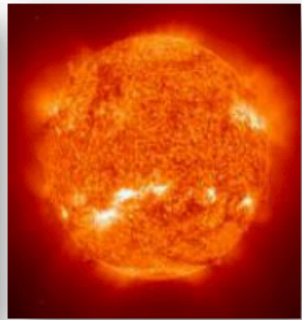
~60 / day

Atmospheric ν



Several / day

Solar ν



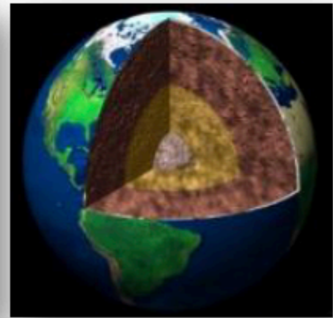
^{8}B: ~50/day
CNO: ~1000/day
^{7}Be: ~10000/day

Supernovae (SN) ν

Core Collapse SN
@ 10 kpc:
thousands in few sec.

Diffuse SN signal:
few / year

Geoneutrinos



~400 / year

+

New physics

Proton decay

Neutrino magnetic moment

Sterile neutrinos

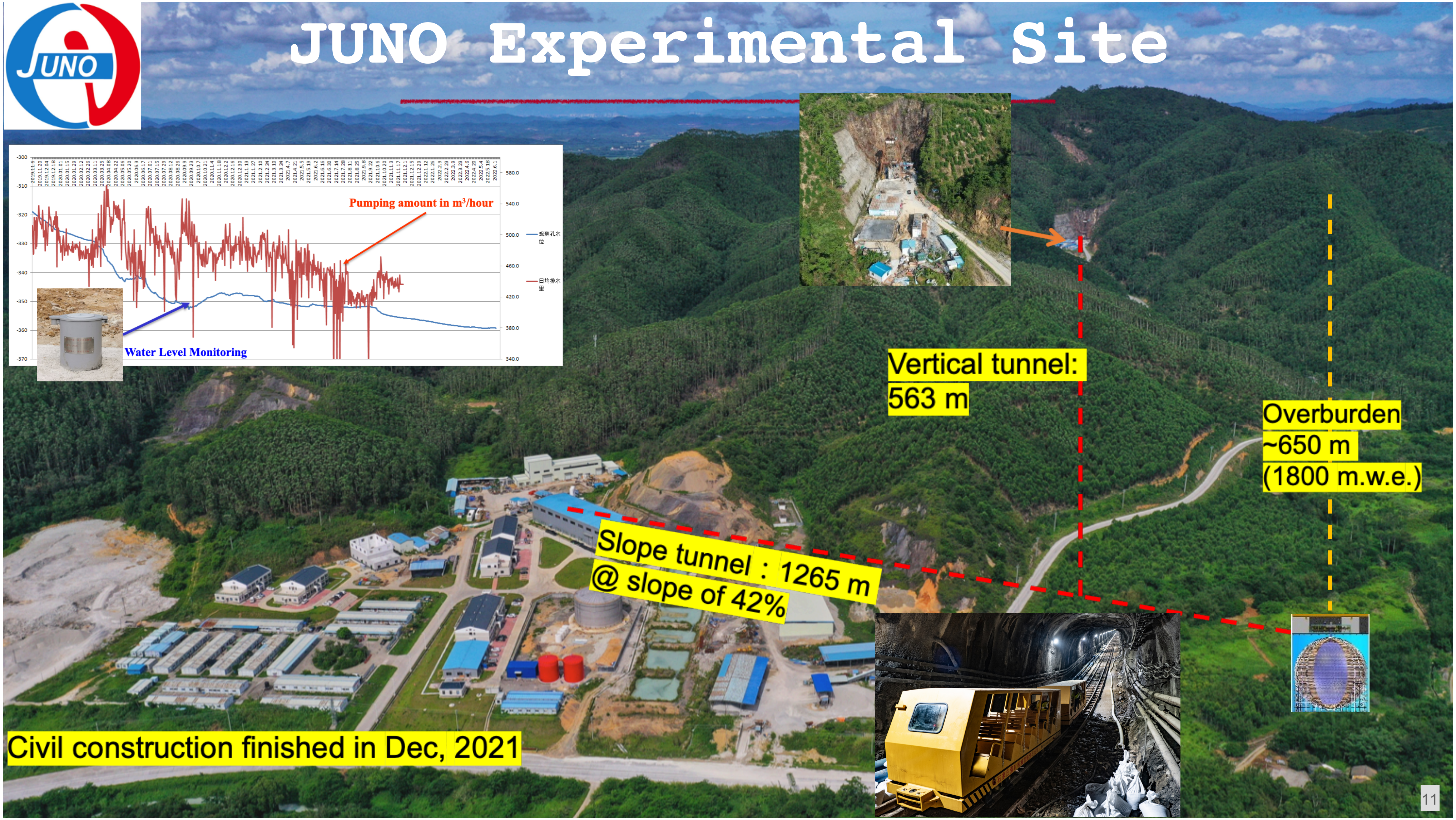
Non standard interactions

Lorentz invariance

Others

Neutrino oscillation & properties

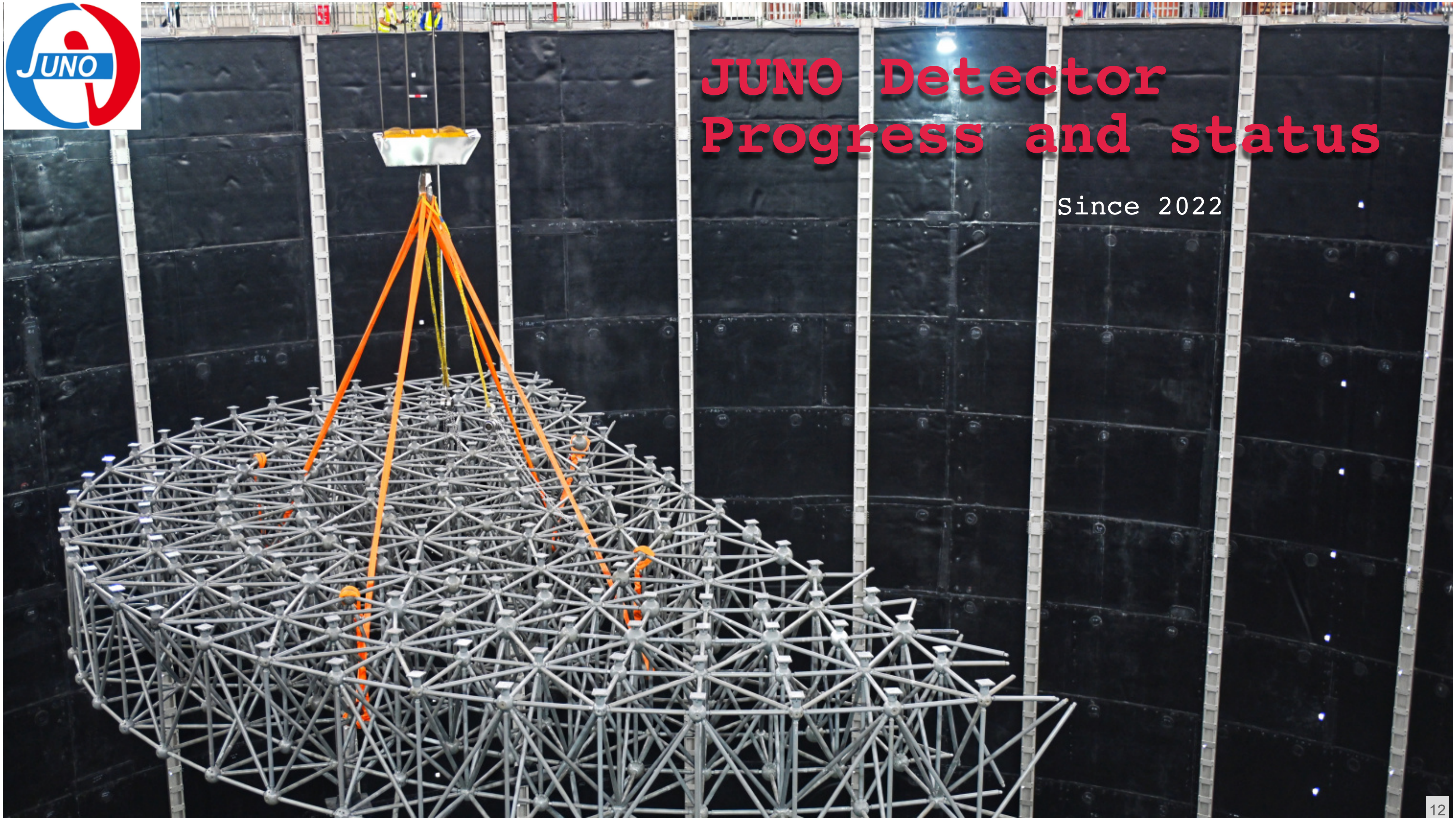
Neutrinos as a probe



JUNO
JUNO Experimental Site
Pumping amount in m³/hour
Water Level Monitoring
Vertical tunnel:
563 m
Overburden
~650 m
(1800 m.w.e.)
Slope tunnel : 1265 m
@ slope of 42%
Civil construction finished in Dec, 2021
11

JUNO Detector Progress and status

Since 2022




JUNO
June 2023

Central Detector status

- **Stainless Steel (SS) structure**

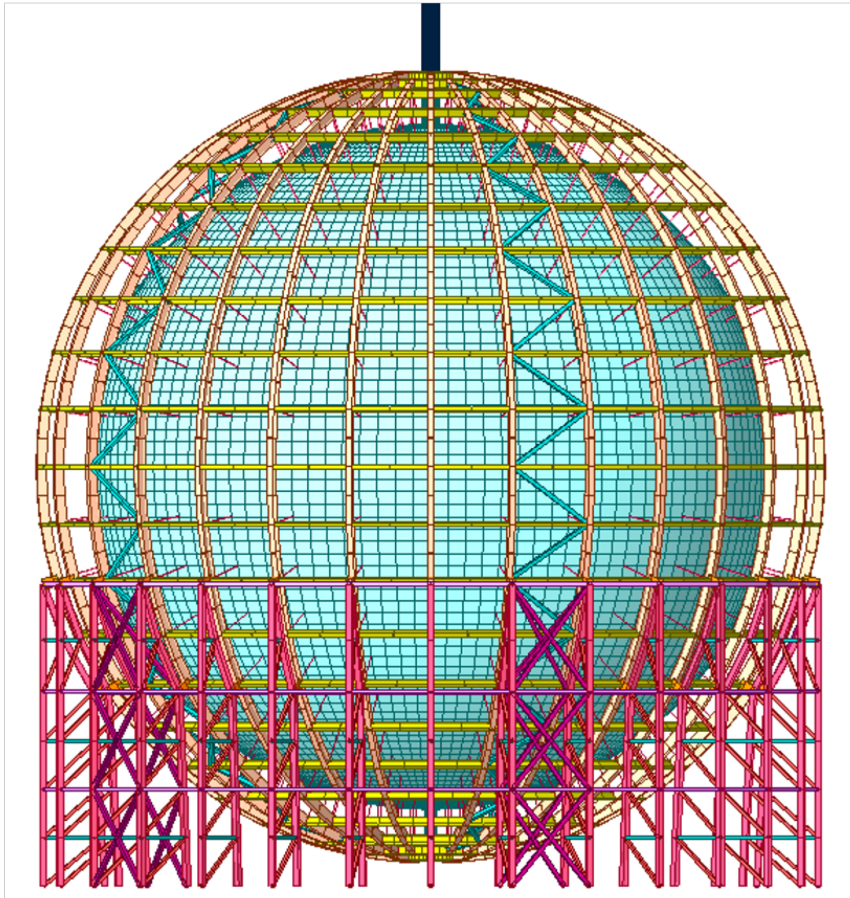
Completely assembled (except bottom layers to grant access)

- **Acrylic Vessel (AV)**

Construction on-site started at the end of June 2022 → chimney and upper 11 layers already in place (reach equator)

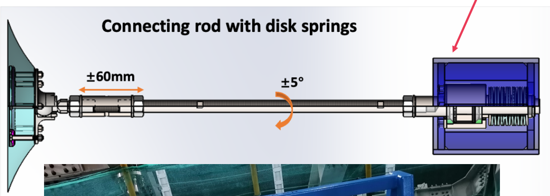
- **Liquid Scintillator (LS)**

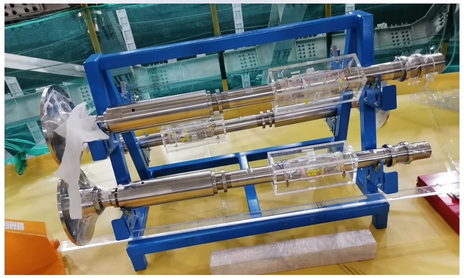
Purification plants are constructed onsite under initial flushing/testing

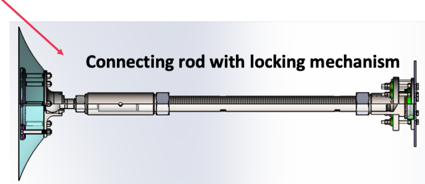


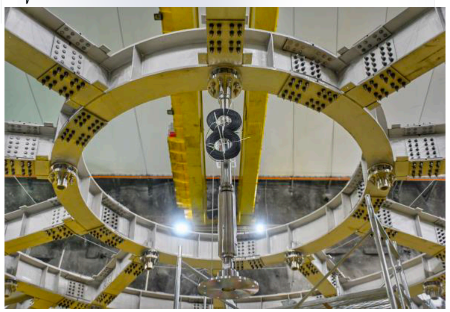
CD - Stainless Steel structure

- Supports the load of AV, LS, PMTs, front-end electronics, light separation plate, EM coils, etc.
- Sustains the upward buoyancy
- Divided into 30 longitudinal and 23 latitudinal layers
- Made of low background SS304
- 590 connecting rods to uphold the AV



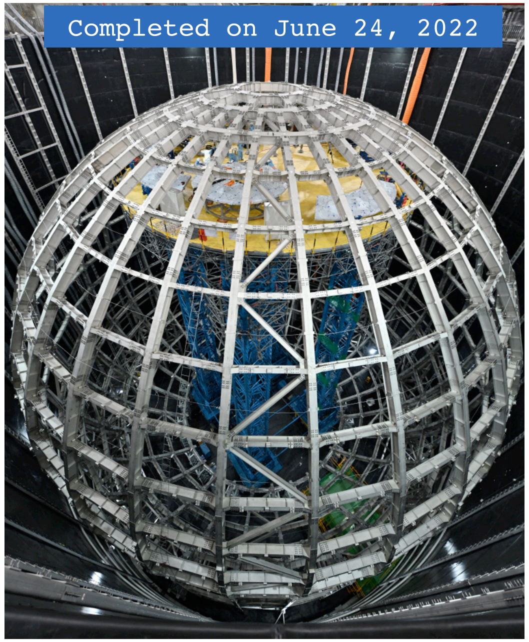


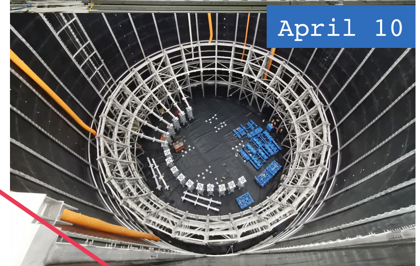


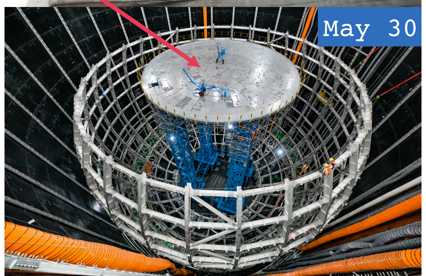


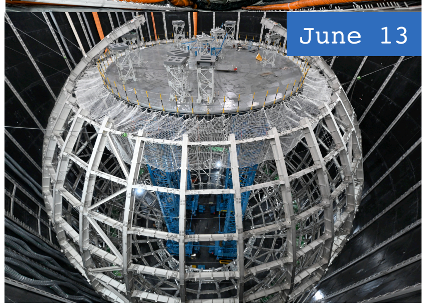
Assembly precision must be < 3 mm to maximize PMT number

Lift platform for acrylic vessel installation





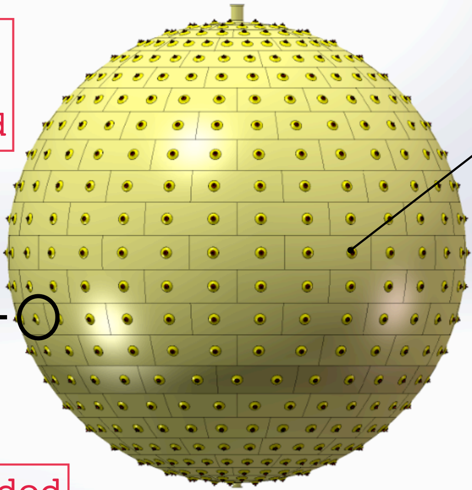




CD – Acrylic vessel

- Contains 20 kton of LS
- Inner diameter: (35.40±0.04) m
Thickness: (124±4) mm
- Light transparency: > 96% @LS
- Radiopurity: U/Th/K < 1 ppt

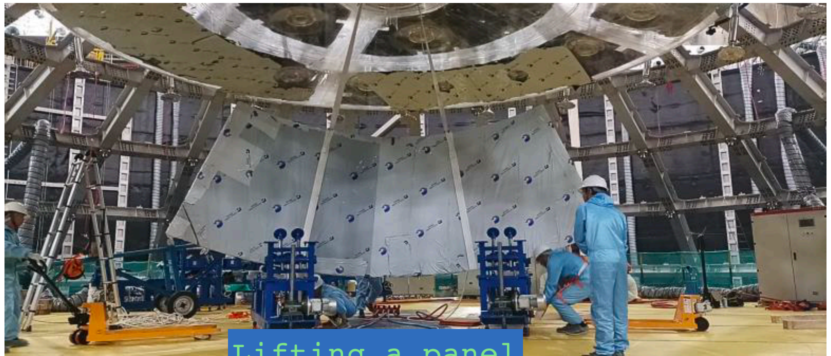
265 panels +
2 chimneys →
100% produced



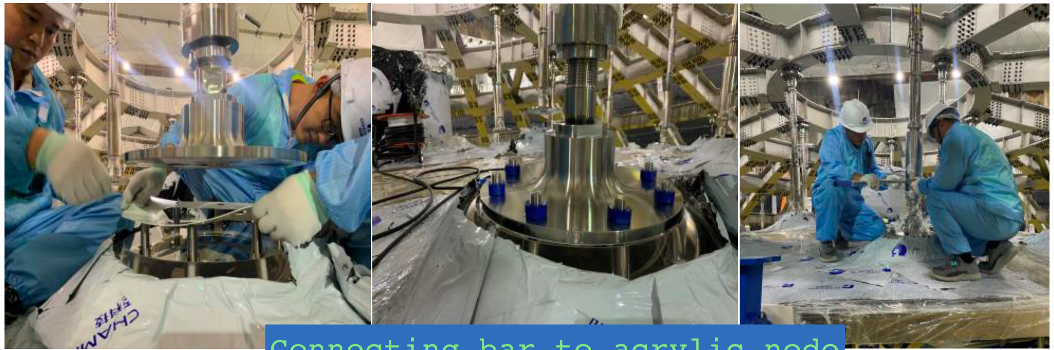
nodes bonded

CD - Acrylic vessel

On-site construction, July-August 2022



Lifting a panel



Connecting bar to acrylic node

Chimney + Layers #9, #10, #11


June 2023

CD - Liquid Scintillator

Linear Alkyl Benzene (LAB) + 2.5 g/L PPO + 3 mg/L bis-MSB

JUNO LS: JHEP 03(2021)004

- High light yield: >1345* p.e./MeV
- Long attenuation length: > 20 m
- Extremely high radiopurity →

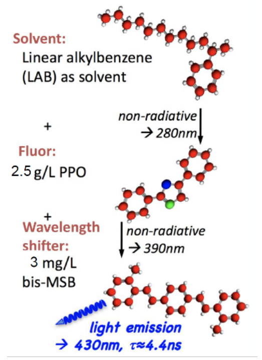
*Recent studies suggest up to 20% increase in the light level

Required radiopurity:

➔ IBD (reactor ν):
^{238}U / ^{232}Th < 10^{-15} g/g
^{40}K < 10^{-16} g/g
^{210}Pb < 10^{-22} g/g

➔ Ideal (solar ν):
^{238}U / ^{232}Th < 10^{-17} g/g
^{40}K < 10^{-18} g/g
^{210}Pb < 10^{-24} g/g

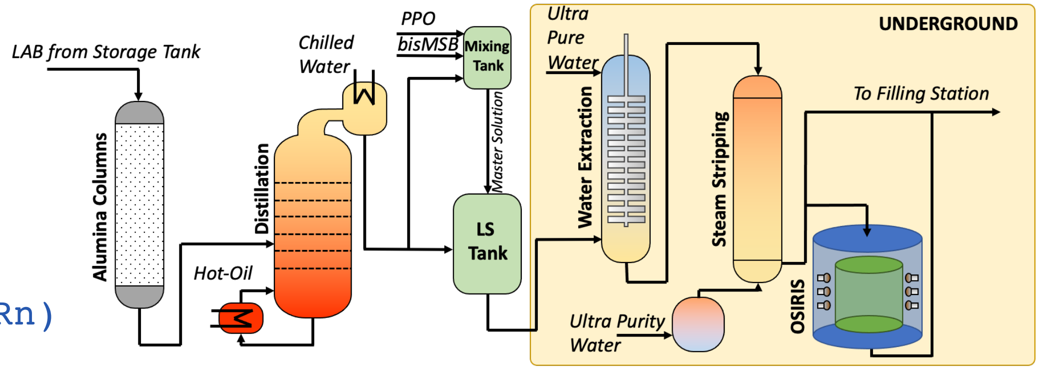
NIM A 988(2021)164823



Purification of LAB in 4 steps:

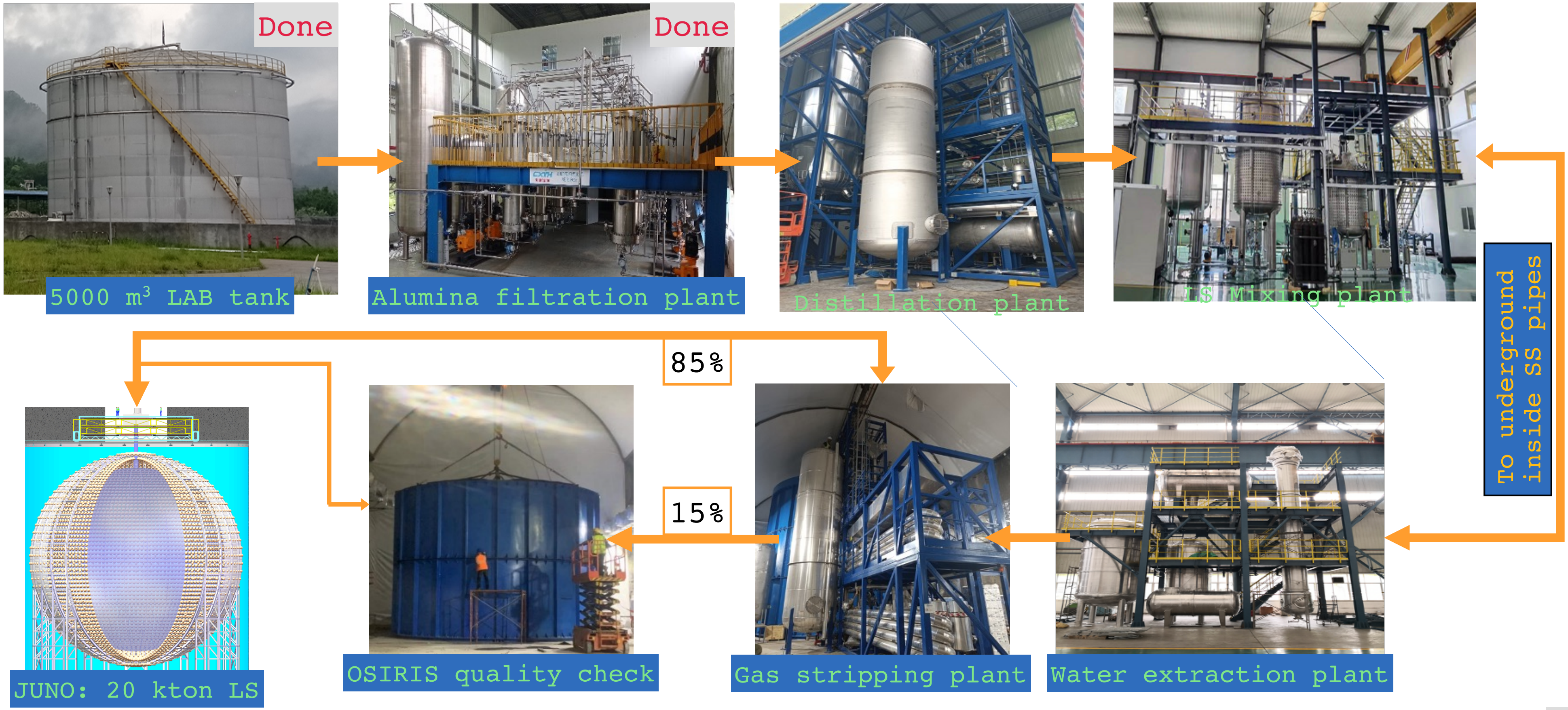
- Al_2O_3 filtration column
  ➡ improvement of optical properties
- Distillation
  ➡ removal of heavy metals
  ➡ improvement of transparency
- Water Extraction (underground)
  ➡ removal of heavy elements U/Th/K
- Steam / Nitrogen Stripping (underground)
  ➡ removal of volatile impurities (Ar/Kr/Rn)

➡ an industrial scale purification process



Radiopurity control strategy

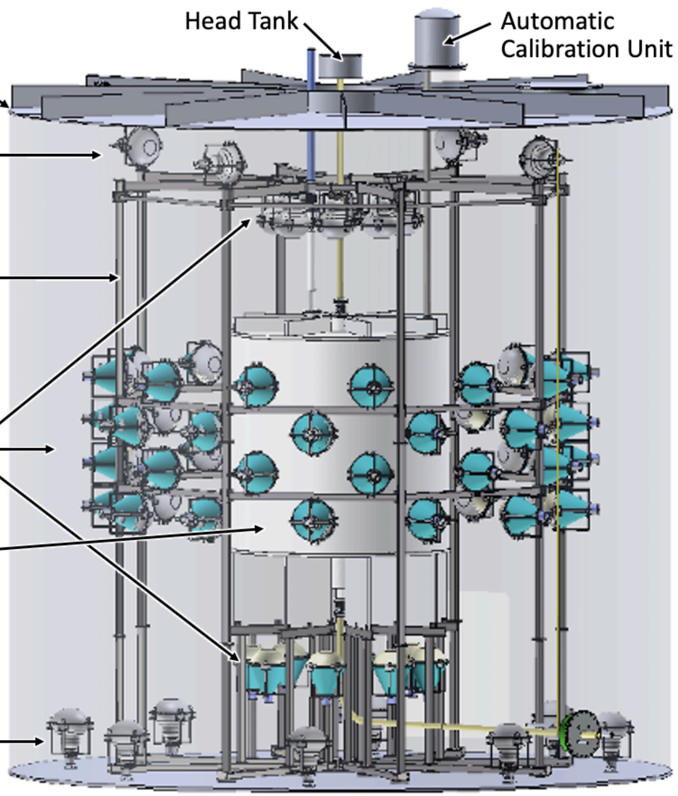
LS: ongoing installation of different purification systems



OSIRIS Detector

Online Scintillator Internal Radioactivity Investigation System

EPJC 81 (2021) 973



A 20 ton detector to monitor LS radiopurity during purification plants commissioning and JUNO detector filling

- Exploit fast coincidences in ^{238}U and ^{232}Th chains
- 17 ton LS volume (Ø=3 m, H=3 m)
- 280 p.e./MeV; energy resolution: σ ~6% at 1 MeV
- Instrumentation:

  64x 20" PMTs for scintillator (9% coverage)
  12x 20" PMTs for muon veto

- Few days for a sensitivity ~10^{-15} g/g (U/Th)
- 2-3 weeks for a sensitivity ~10^{-17} g/g (U/Th)
- Other measurable isotopes: ^{14}C, ^{210}Po, ^{85}Kr

arXiv: 2109.10782

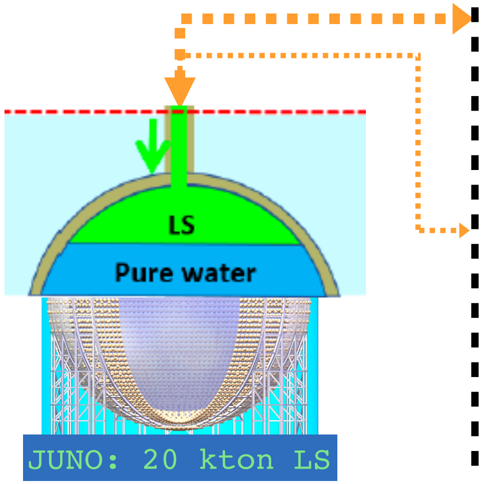
✦ Possible upgrade to Serappis (SEarch for RAre PP-neutrinos In Scintillator)
➡ A precision measurement of solar pp neutrinos on the few percent level

Radiopurity Control Strategy

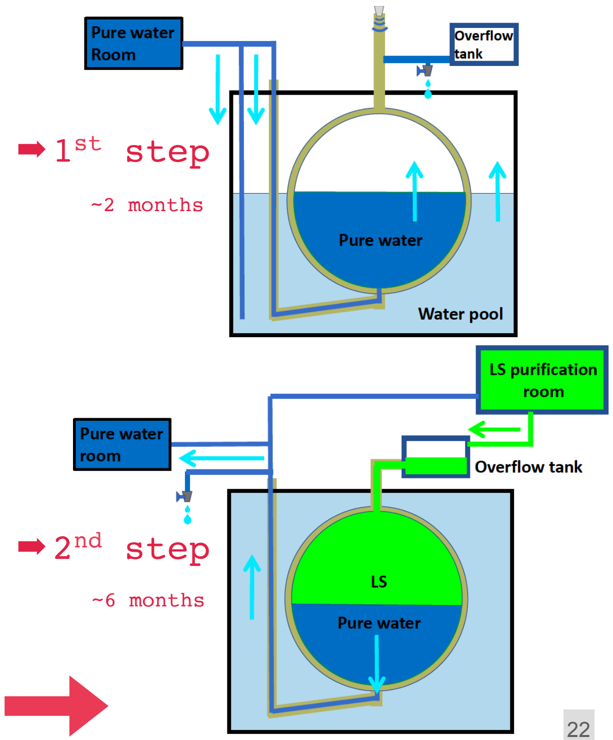
JUNO detector filling

✦**LS recirculation is not feasible at JUNO (20 kton!)**
➡ **Target radiopurity must be met since the beginning**

✦Planned strategy:
- Leakage control (single component < 10^{-6} mbar·L/s)
- Acrylic vessel cleaning before filling
- Clean environment
- **Water-exchange filling scheme**



Best compromise between engineering risks and background contamination risks



Schematic of the filling sequence ➡

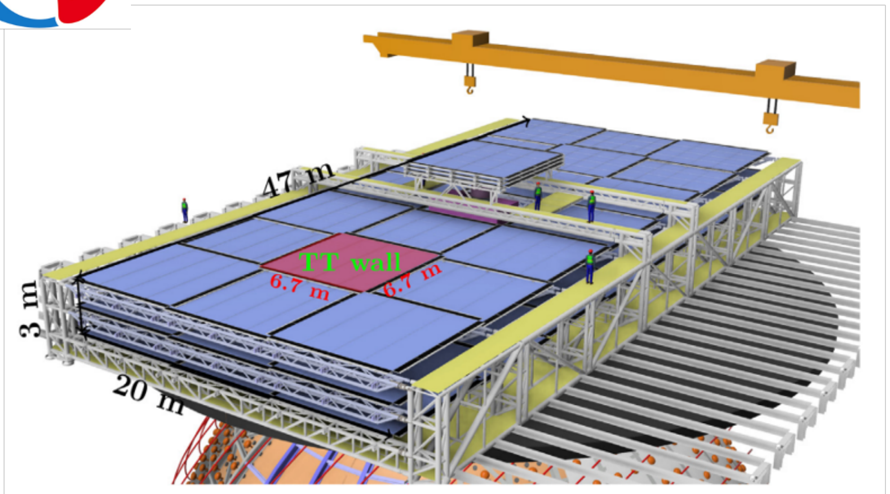
Veto Water Cherenkov Detector

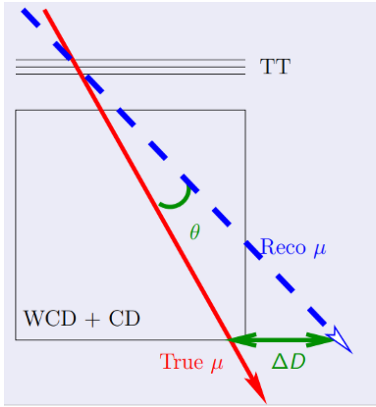
~650 m rock overburden (1800 m.w.e.) → residual μ rate 4 Hz (mean μ energy: 207 GeV)

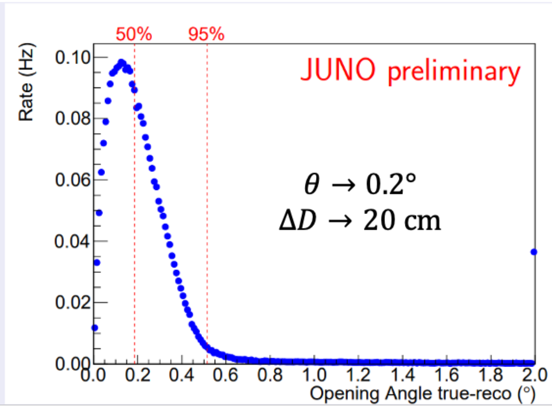
35 kton of ultrapure water serving as passive shield and Water Cherenkov detector

- 2400 20-inch MCP PMTs, detection efficiency of cosmic muons larger than 99.5%
- Keep the temperature uniform and stable at (21±1) °C
- Quality: ^{222}Rn < 10 mBq/m^3, attenuation length 30~40 m
- 5 mm liner covering the pool wall as Rn barrier

Veto – Top tracker







Plastic scintillators refurbished from the OPERA experiment:

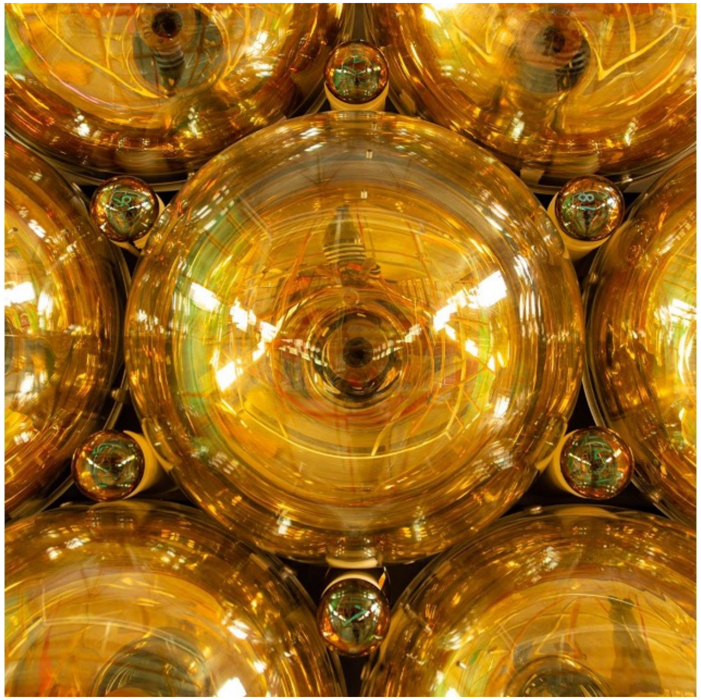
- Covering about 50% of the top of the water pool
- Three scintillator layers to reduce accidental coincidences
- All scintillator panels arrived on-site in 2019
- Precision muon tracking
- Study of cosmogenic background

Photomultiplier Tubes

20012 20-inch PMTs
(17612 CD + 2400 veto)

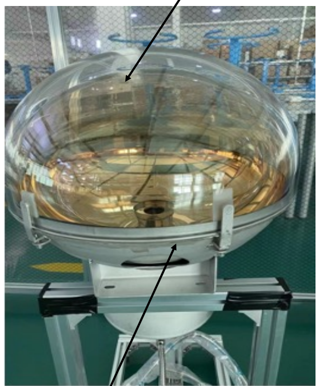
25600 3-inch PMTs

Synergetic 20-inch and 3-inch PMT systems to ensure energy resolution and charge linearity



Clearance between PMTs: 3 mm
➡ assembly precision: < 1 mm

Acrylic cover



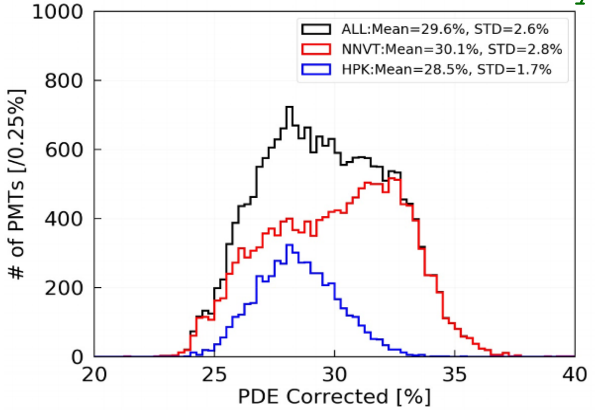
SS cover

- ✦ 17612 large PMTs (20-inch)
  - ✦15012 MCP-PMTs from NNVT*
  - ✦5000 dynode PMTs from Hamamatsu
- ✦ 25600 small PMTs (3-inch) from HZC

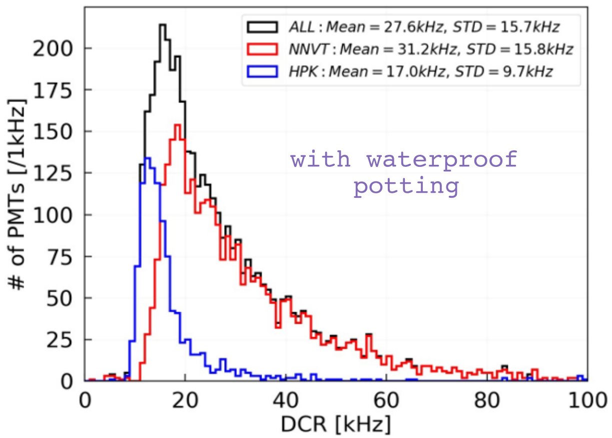
*Northern Night Vision Technology

Photomultiplier Tubes

Photon Detection Efficiency



Dark count rate

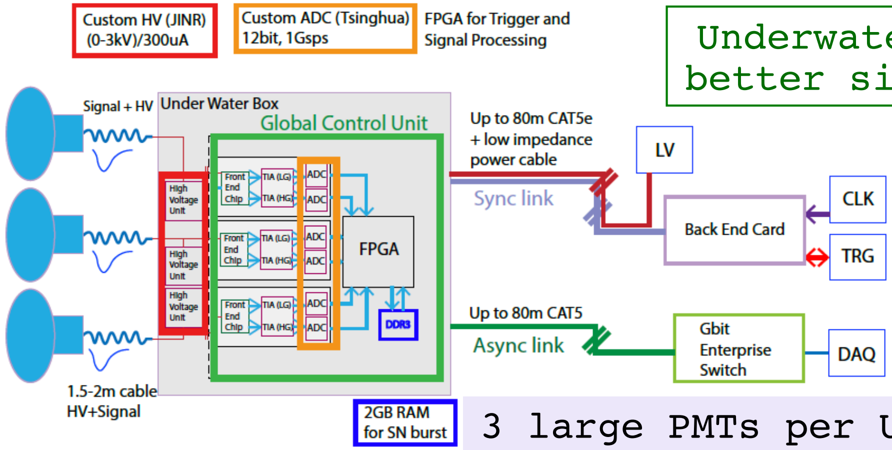


All PMTs produced, tested, and instrumented with waterproof potting

Parameter		LPMT (20-inch)		SPMT (3-inch)
		Hamamatsu	NNVT	HZC
Quantity		5000	15012	25600
Charge Collection		Dynode	MCP	Dynode
Photon Detection Efficiency		28.5%	30.1%	25%
Mean Dark Count Rate [kHz]	Bare	15.3	49.3	0.5
	Potted	17.0	31.2	
Transit Time Spread (σ) [ns]		1.3	7.0	1.6
Dynamic range for [0-10] MeV		[0, 100] PEs		[0, 2] PEs
Coverage		75%		3%
Reference		arXiv: 2205.08629		NIM.A 1005 (2021) 165347

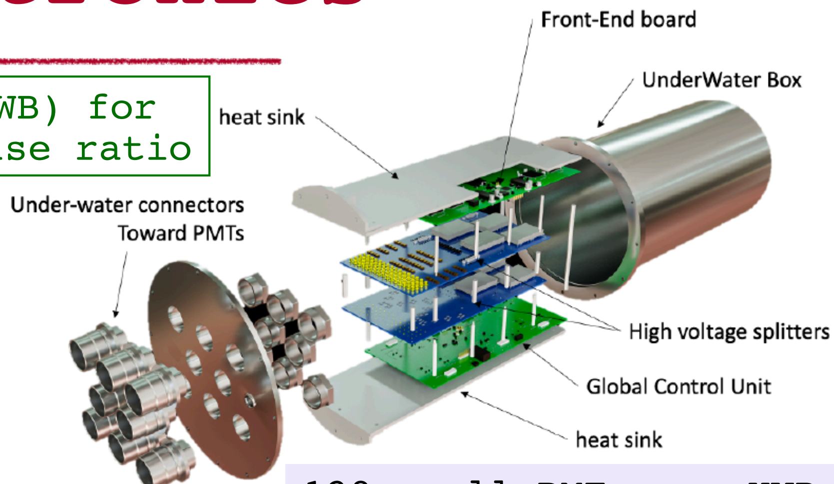
12612 NNVT PMTs with the highest PDE are selected for the CD; the remaining ones are used in the WCD

JUNO PMT Electronics

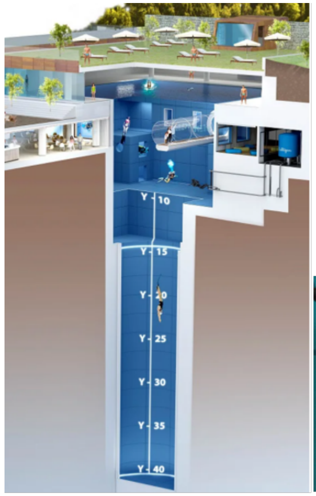


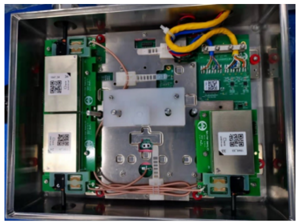
Underwater boxes (UWB) for better signal-to-noise ratio

3 large PMTs per UWB

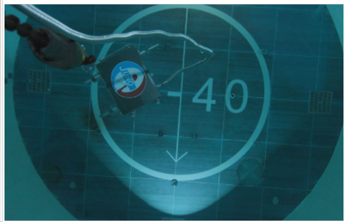


128 small PMTs per UWB





Underwater test



Large PMTs:

- 1 GHz sampling
- Dynamic range: 1 – 4000 PE
- Noise: < 10% @ 1 PE
- Resolution: 10% at 1 PE, 1% at 100 PE
- Failure rate: < 0.5% over 6 years

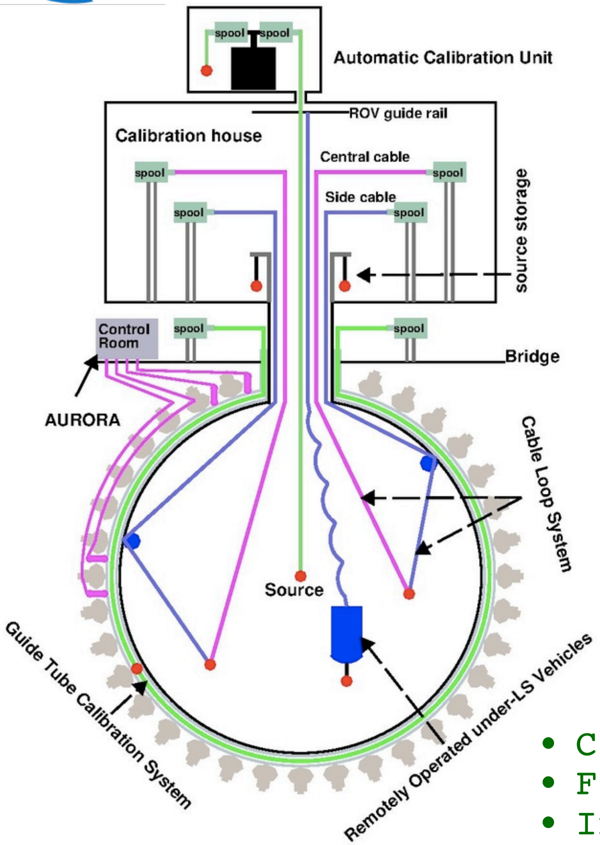
Small PMTs:

- Always in **photon counting mode** in 1~10 MeV range

Electronics assembly ongoing

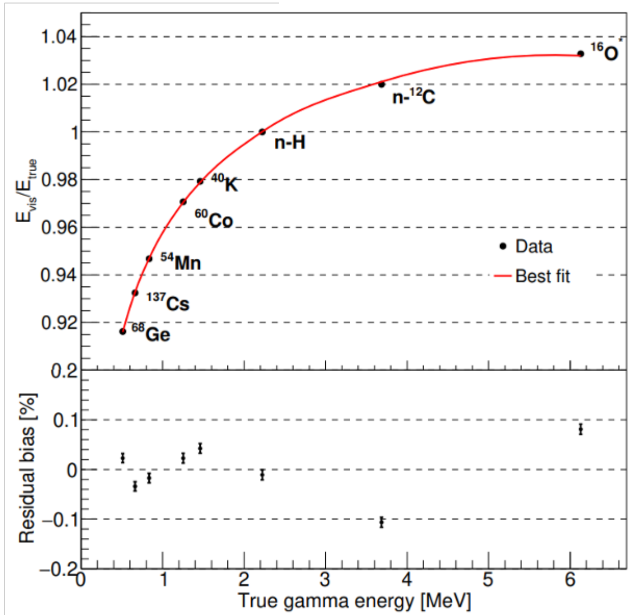
Calibration system

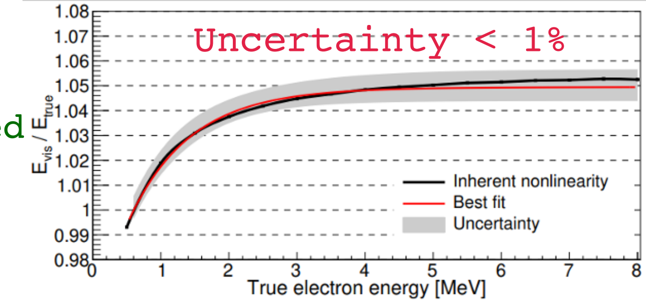
JHEP 03(2021)004



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

- Different **tools** deployed for detector calibration:
  - 1D: Automatic Calibration Unit (ACU)
  - 2D: Cable Loop System (CLS) and Guide Tube Calibration System (GTCS)
  - 3D: Remotely Operated Vehicle (ROV)
  - Auxiliary system: Calibration House, Ultrasonic Sensor System (USS) CCD and A unit for Researching Online LSc tRAnsparency (AURORA)

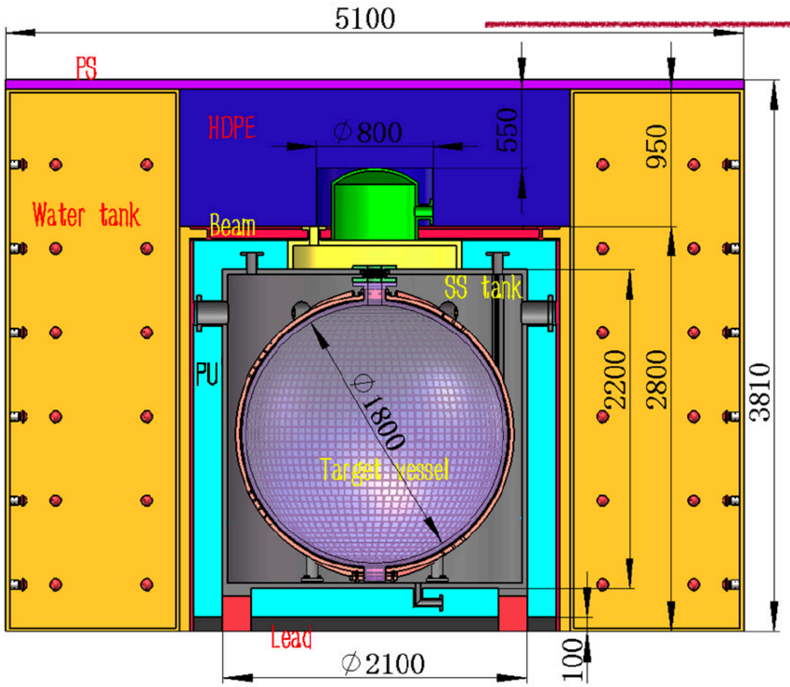




- Calibration house and ACU produced
- Final reliability tests ongoing
- Installation of different systems is being prepared on-site

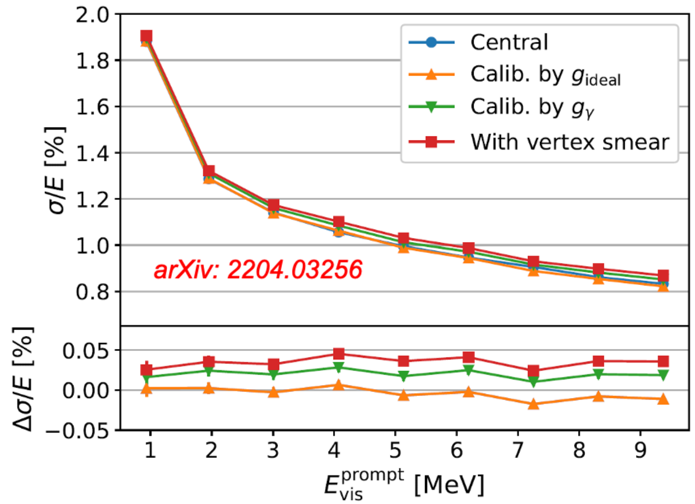
JUNO-TAO detector

arXiv: 2005.08745



Surface not treated yet

- 2.8 ton Gd-LS (**1 ton fiducial volume**) in acrylic vessel
- 10 m^2 SiPM with **50% PDE** for light detection on a spherical copper shell (~**94% coverage**)
- Operated at -50 °C
- **4500 p.e./MeV**
- **30 m** from Taishan core (**4.6 GW$_{th}$**)
- 30x JUNO event rate
- High energy resolution:

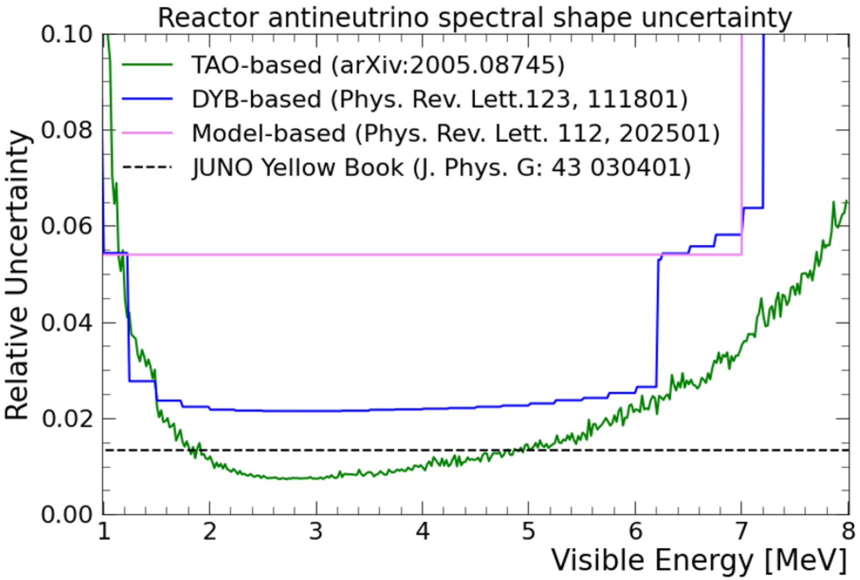


1:1 prototype @IHEP

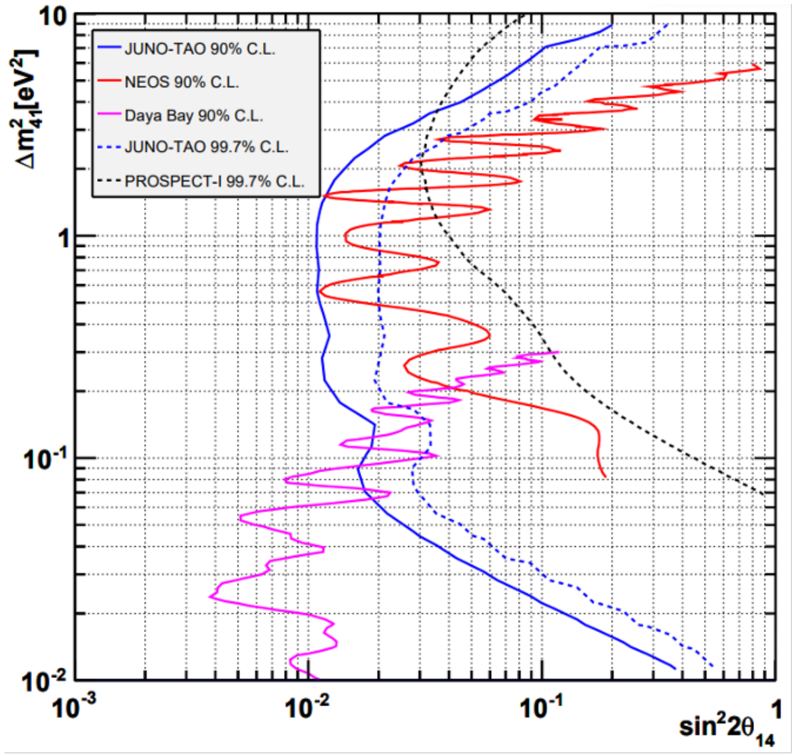
JUNO-TAO detector

Physics potential

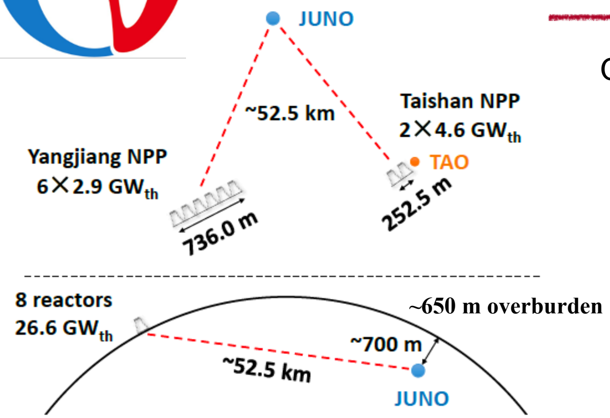
✦ Precise measurement of antineutrino spectra



✦ Sterile neutrino searches




Updates on JUNO
physics sensitivities
For topics not covered here, please refer to PPNP 123 (2022) 10392
32



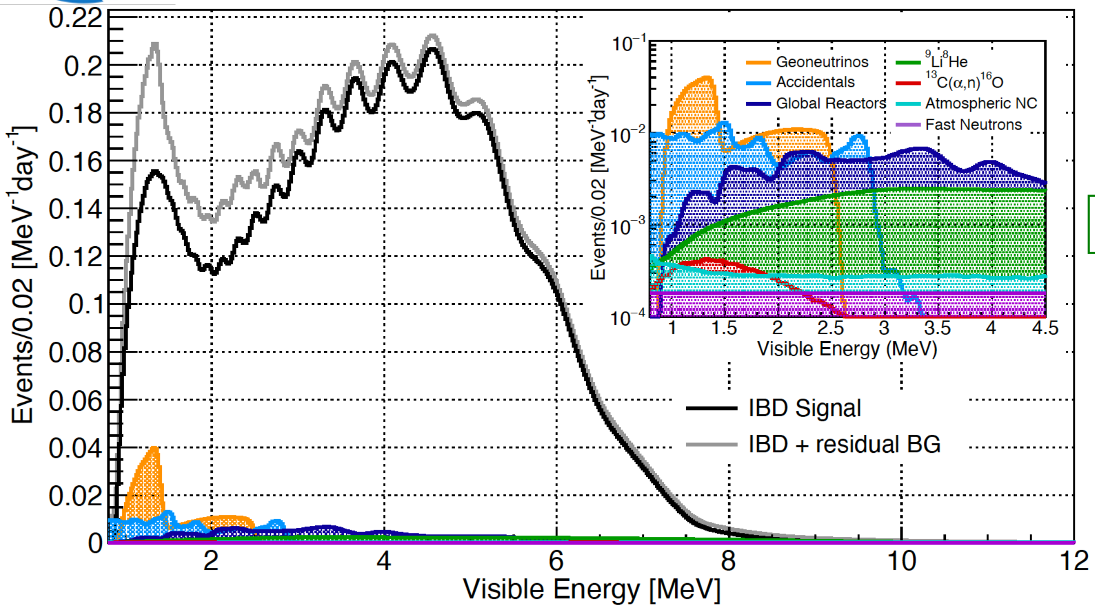
Oscillation Analysis

Original JUNO estimates: JPG 43 (2016) 030401 (*"Physics Book"*)

1. Only 2 reactor cores at Taishan → **26%↓** less power (from 35.8 to 26.6 GWth)
2. JUNO experimental hall ~30 m shallower → **33%↑** higher cosmic muon flux (from 3 to 4 Hz)

1. Improved energy resolution, from 3% to 2.9% at 1 MeV (**3%↑**)
   - Increased PMT photon detection efficiency (after mass testing)
   - Improved understanding of the PMT optical model
   - More accurate simulation of the detector geometry
2. Improved muon veto efficiency, from 83% to 91.6% (**10%↑**)
3. Improved reactor spectral shape uncertainty from combined analysis with TAO
4. Updated values on the expected backgrounds and radiopurity of the construction materials

Signal and background



	Efficiency (%)	IBD Rate (day^{-1})
All IBDs	100	57.4
After Selection	82.2	47.1

Total background rate: 4.11 /day (~9%)

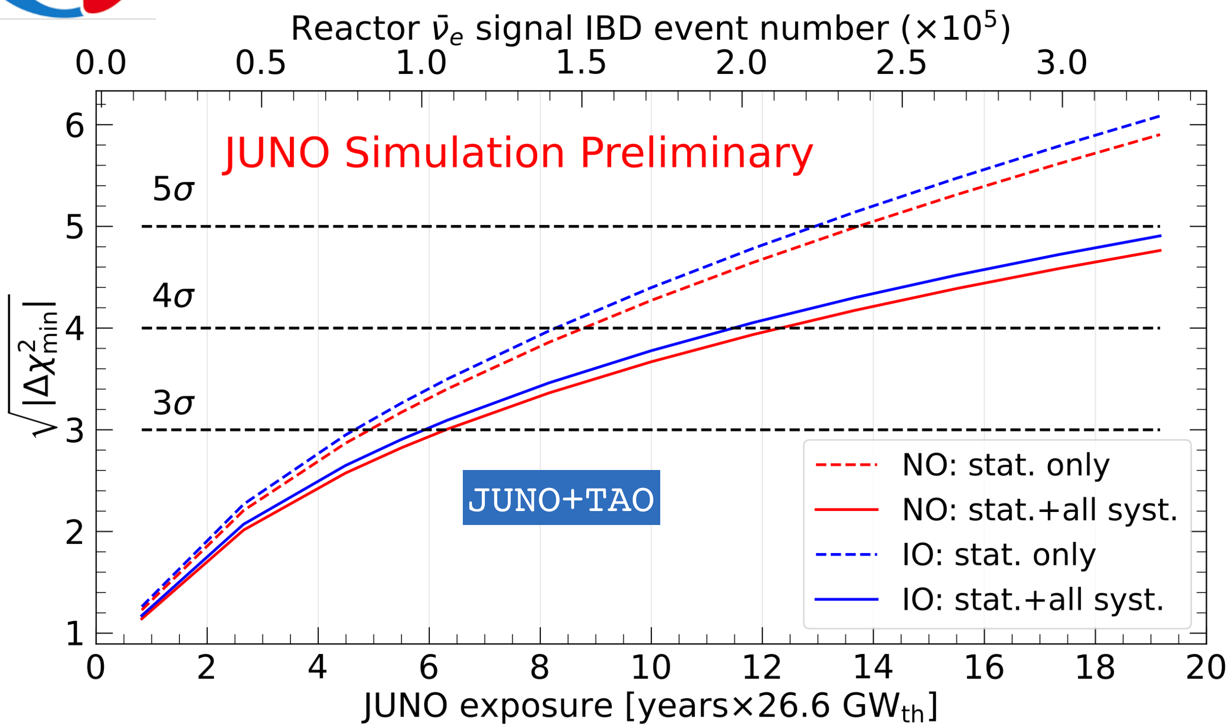
Main selection cuts:
- Fiducial volume: R_{LS} < 17.2 m
- Energy threshold: E_{vis} > 0.7 MeV
- Time correlation: $\Delta T_{p\text{-}d}$ < 1 ms
- Spatial correlation: $\Delta R_{p\text{-}d}$ < 1.5 m
- Muon veto (Temporal⊕Spatial)

Accidental background mainly due to natural radioactivity in detector components.

Background reduction strategy:
- careful material screening and selection
- meticulous Monte Carlo simulations
- accurate detector production handling

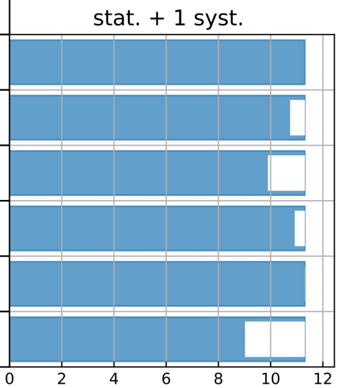
JHEP 11(2021)102

Neutrino Mass Ordering



Impact of systematics

	$\Delta\chi^2_{min}$
Statistics	11.3
Stat.+Flux error	-0.6
Stat.+Backgrounds	-1.4
Stat.+Nonlinearity	-0.4
Stat.+Others	< -0.05
Total	9.0



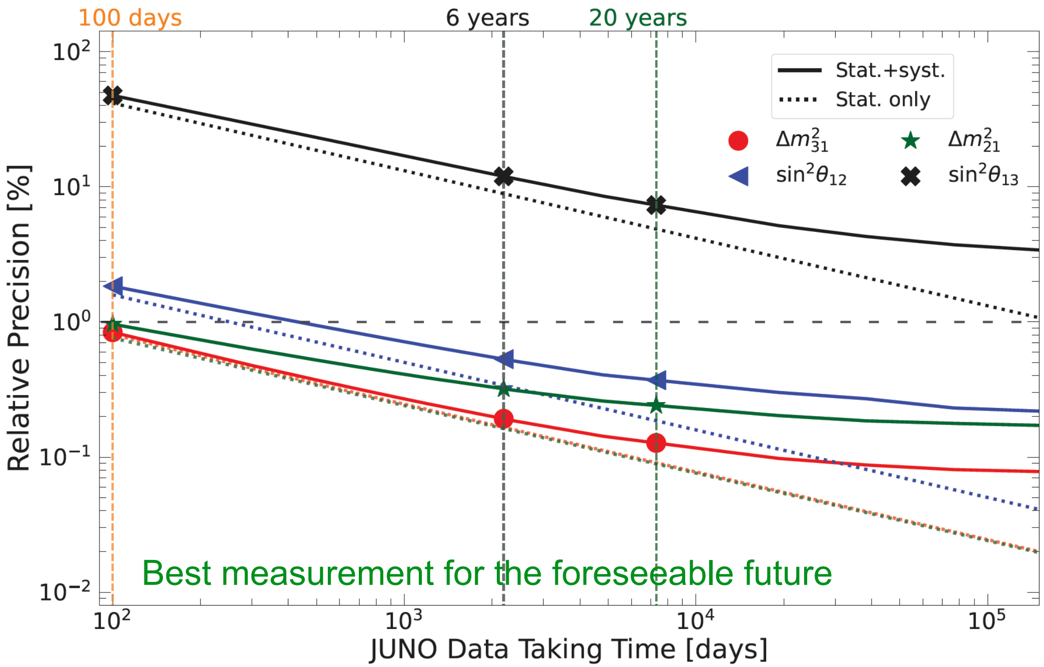
JUNO Simulation Preliminary

Paper in preparation

JUNO sensitivity on neutrino mass ordering: 3σ (reactor only) in ~6y with 26.6 GW_{th}

Estimation with combined sensitivity reactor + atmospheric neutrino analysis is under preparation

Neutrino Oscillation parameters



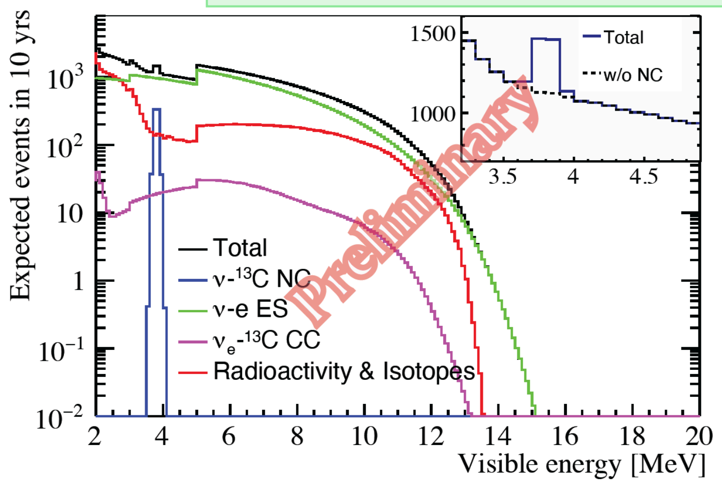
- Percent precision on $\Delta m^2{}_{31}/\Delta m^2{}_{21}$ in ~100d
- Precision on $\sin^2\vartheta_{12}$, $\Delta m^2{}_{31}$, $\Delta m^2{}_{21}$ < 0.5% in 6y using reactor neutrinos
- Measurement of $\sin^2\vartheta_{12}$, $\Delta m^2{}_{21}$ also with ^{8}B solar neutrino (next slide)
- Solar neutrino oscillation parameters with neutrinos and antineutrinos in only one detector!

arXiv 2204.13249
→ accepted for publication by Chinese Physics C

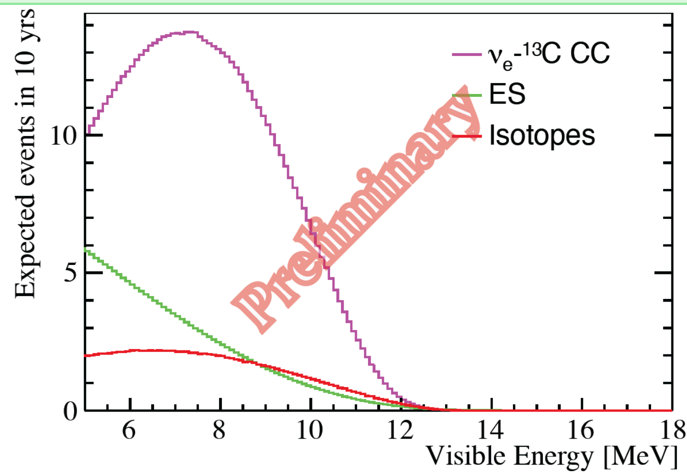
Solar neutrinos (E_{vis} >2 MeV)

Model independent measurement of ^{8}B solar neutrinos at JUNO

~200 tons ^{13}C in JUNO: observation of ^{8}B solar ν via NC and CC on ^{13}C



Single visible signal channel



Prompt signal of the prompt-delayed pair signal channel

ES: Chin.Phys.C 45(2021)023004
ES+NC+CC: in preparation

Expected precision in 10 years:

- ^{8}B flux: 5% JUNO 3% JUNO+SNO
- $\sin^2\vartheta_{12}$: $^{+9\%}/_{-8\%}$
- Δm^2_{21}: $^{+27\%}/_{-17\%}$

Unprecedented threshold of 2 MeV for ES

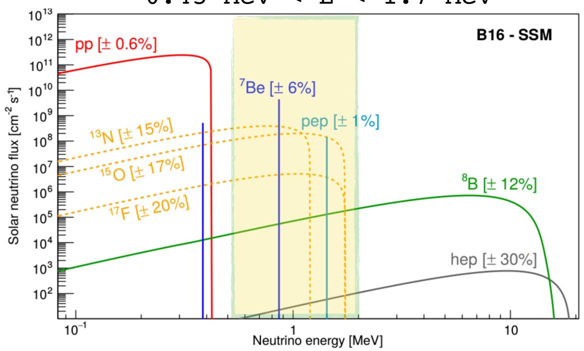
Channels		Threshold [MeV]	Signal	Event numbers [200 kt×yrs]	Event numbers after cuts
CC	$\nu_e + ^{13}\mathrm{C} \rightarrow e^- + ^{13}\mathrm{N}\,(\frac{1}{2}^-;\mathrm{gnd})$	2.2 MeV	$e^- + ^{13}$N decay	3929	647
NC	$\nu_x + ^{13}\mathrm{C} \rightarrow \nu_x + ^{13}\mathrm{C}\,(\frac{3}{2}^-;3.685\,\mathrm{MeV})$	3.685 MeV	γ	3032	738
ES	$\nu_x + e \rightarrow \nu_x + e$	0	e^-	3.0×10^5	6.0×10^4

Correlated events (CC)
Singles events (NC, ES)

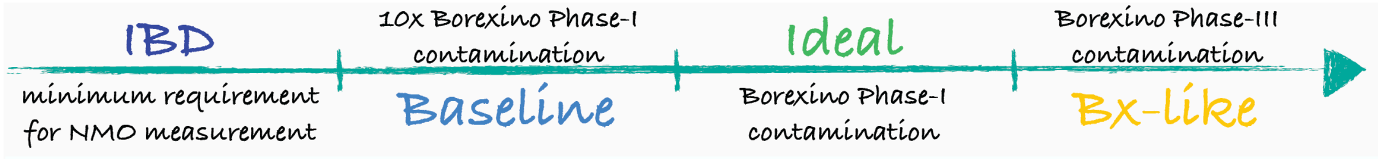
Solar neutrinos (E_{vis} <2 MeV)

Intermediate energy solar neutrinos: ^{7}Be, pep, CNO

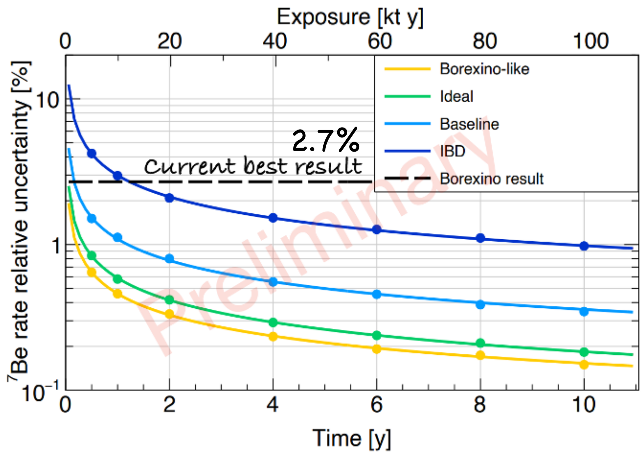
0.45 MeV < E < 1.7 MeV

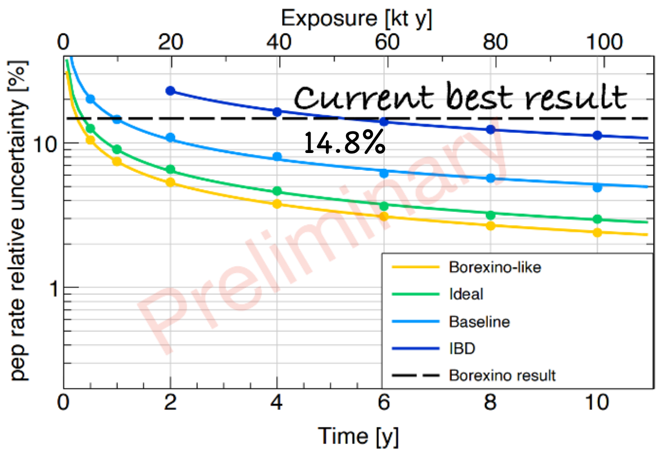


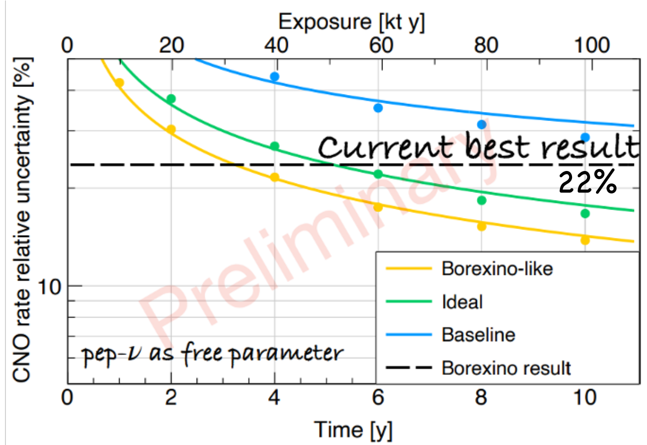
Different radiopurity scenarios considered:



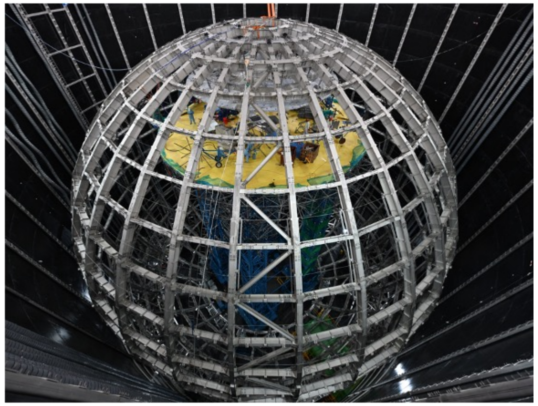
Paper in preparation

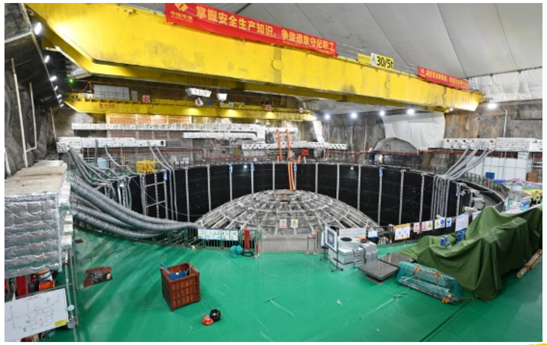


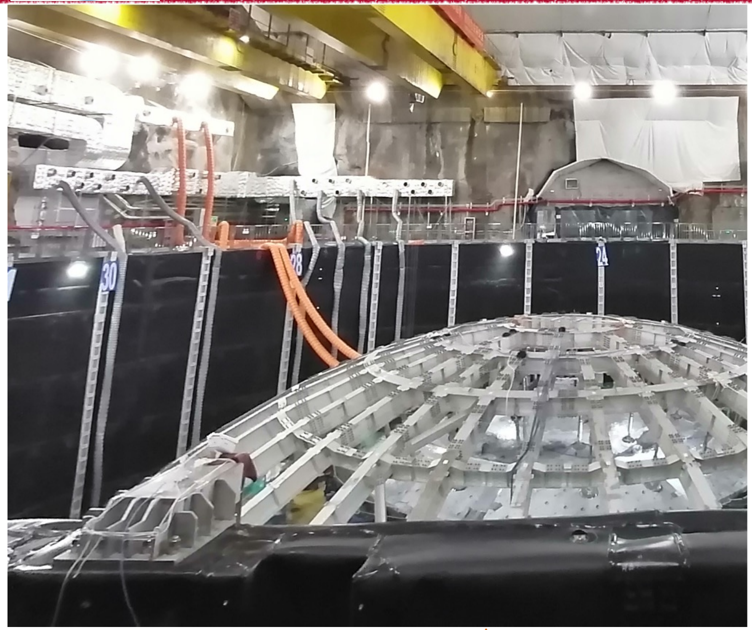


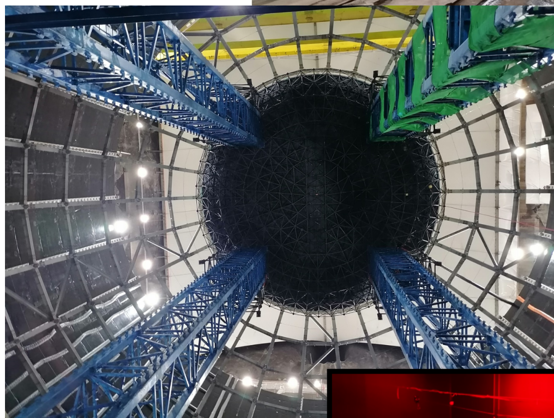


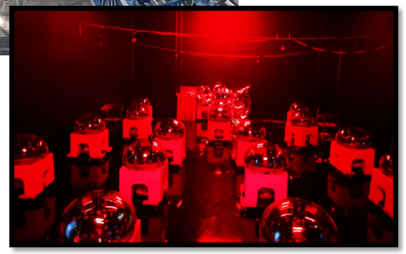
Outlook…

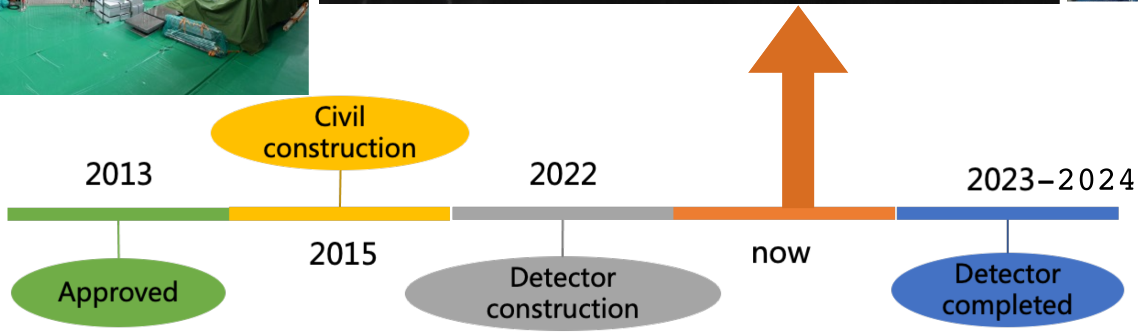






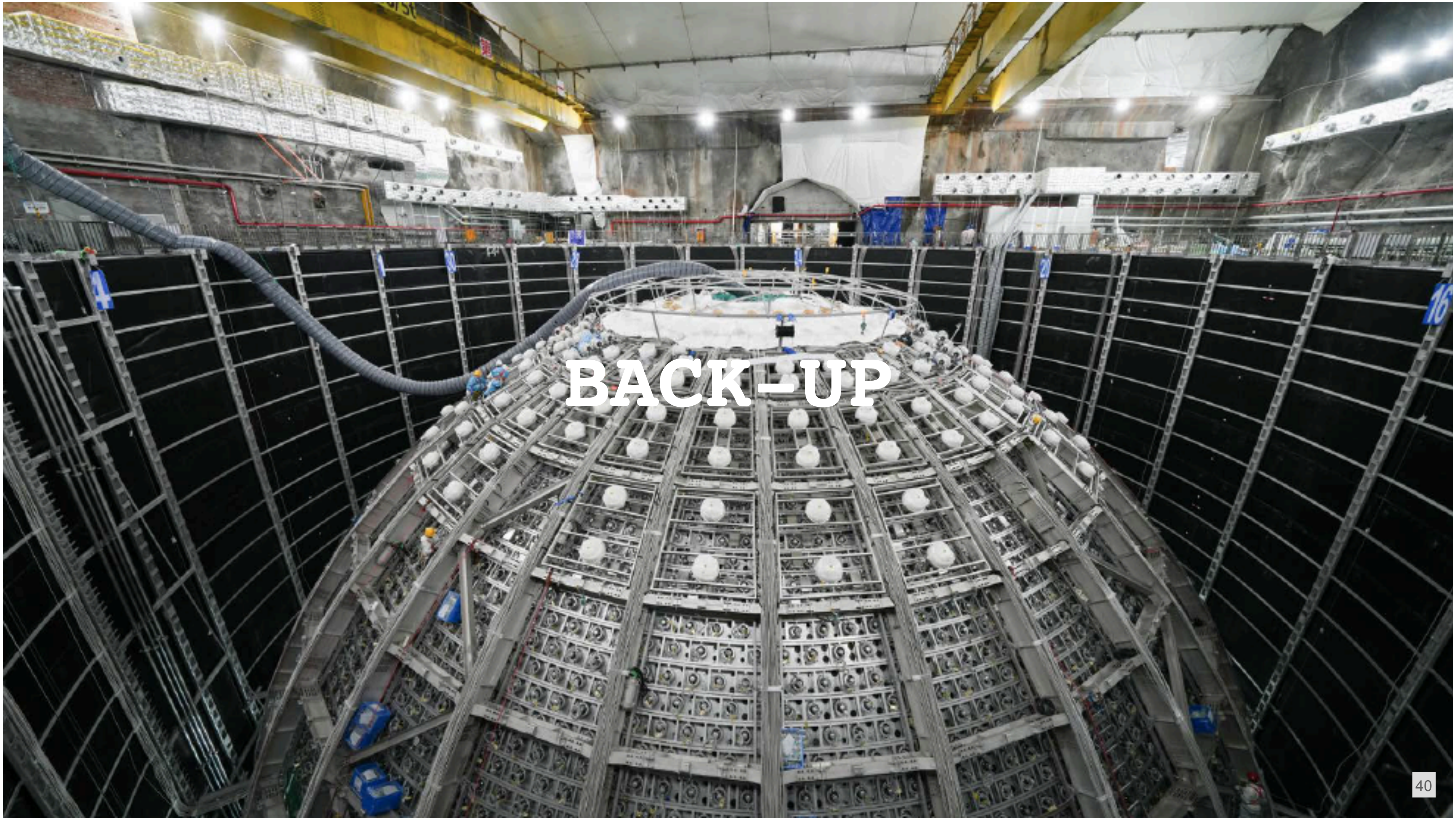






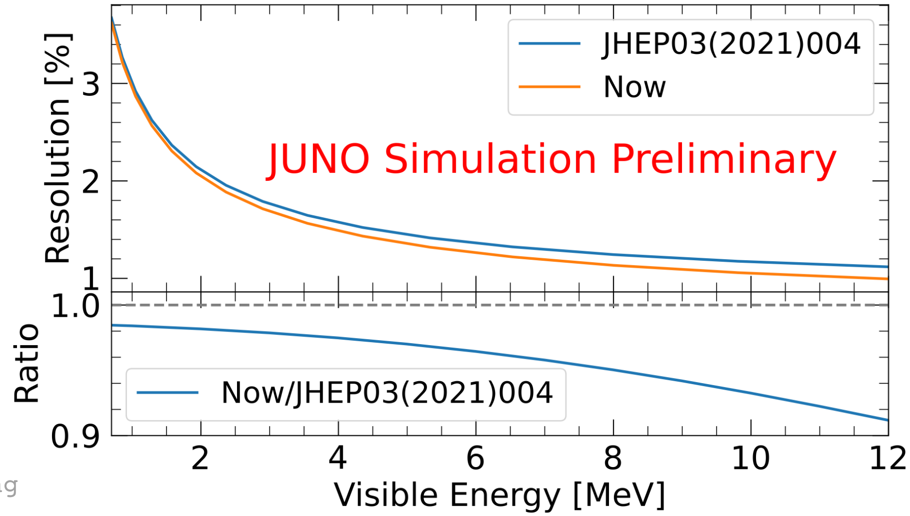
… and stay tuned!

BACK-UP



Energy resolution

Change	Light yield in detector center [PEs/MeV]	Energy resolution
Previous estimation JHEP03(2021)004	1345	3.0% @1MeV
Photon Detection Efficiency (27%→30%) arXiv: 2205.08629	+11% ↑	**2.9% @ 1MeV**
New PMT Optical Model EPJC 82 329 (2022)	+8% ↑	
New Central Detector Geometries	+3% ↑	

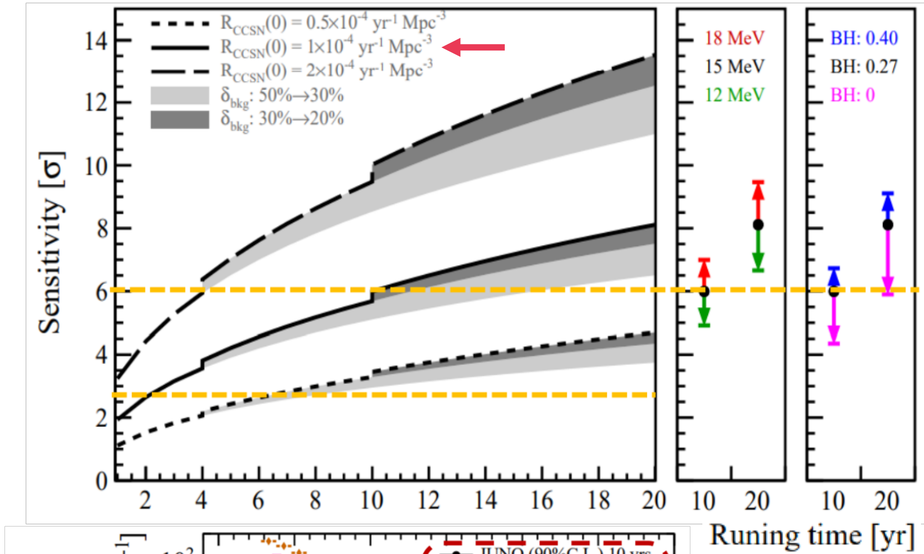


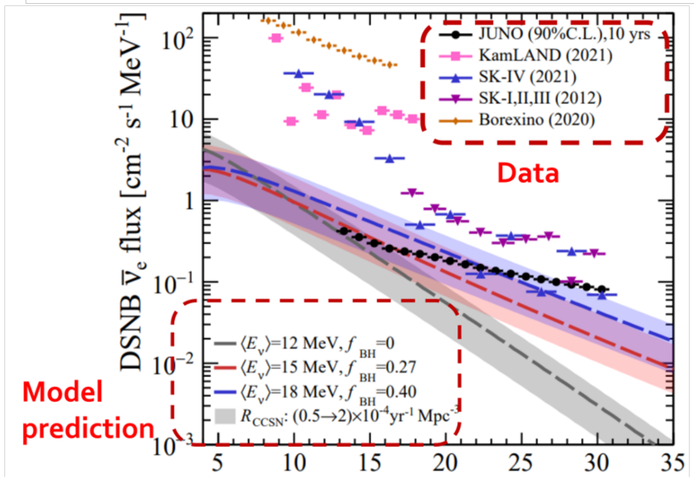
Diffused Supernova Neutrinos(DSNB)

- Integrated flux of all Supernova (SN) explosions in the visible Universe
- Not yet observed
- Expected few $\bar{\nu}_e$/y
- Main backgrounds:
  - ✦IBD from reactor ν (E > 10 MeV)
  - ✦NC interactions from atmospheric ν

Sensitivity improvement by:

- Accurate background evaluation (reduction from 0.7/y to 0.54/y)
- Increased signal efficiency from 50% to 80% thanks to pulse shape discrimination
- Better DSNB signal model



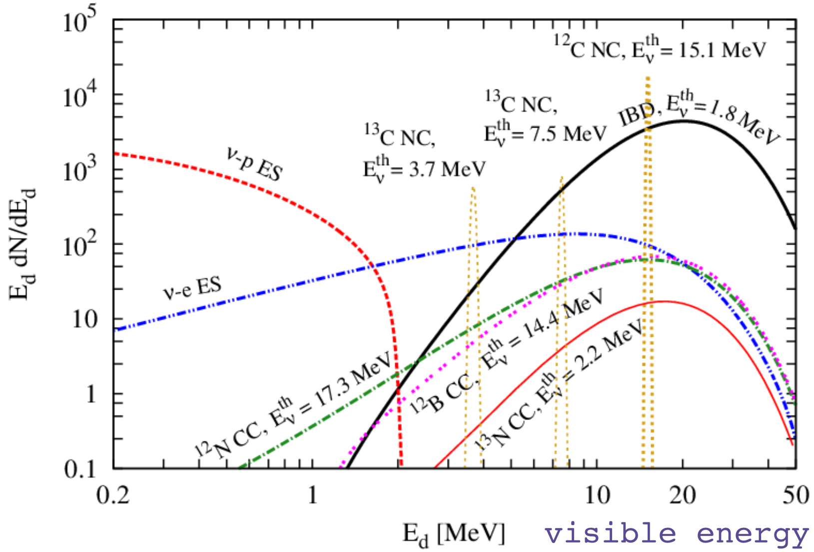


arXiv 2205.08830

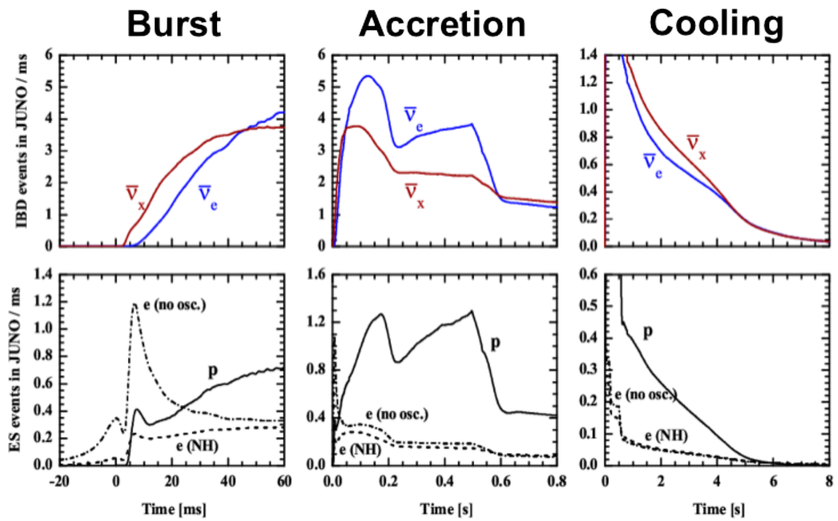
DSNB discovery potential: 3σ in 3 yrs with reference model

Supernova (SN) neutrinos

- Core collapse SN emits 99% of energy in form of ν
- Galactic core-collapse SN rate: ~ 3 per century
- JUNO will observe the 3 SN phases: determination of flavour content, energy spectrum, signal time evolution
- 200 keV energy threshold



visible energy



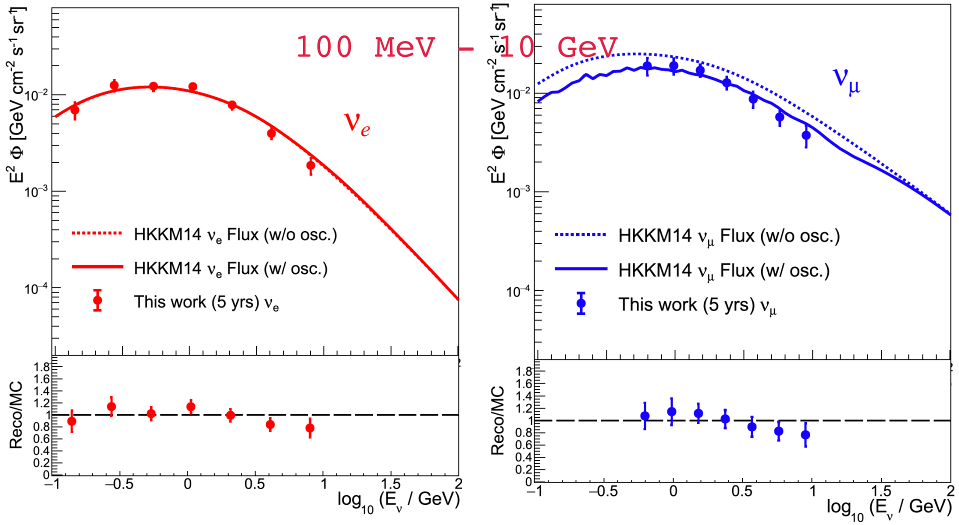
Detection channels in JUNO

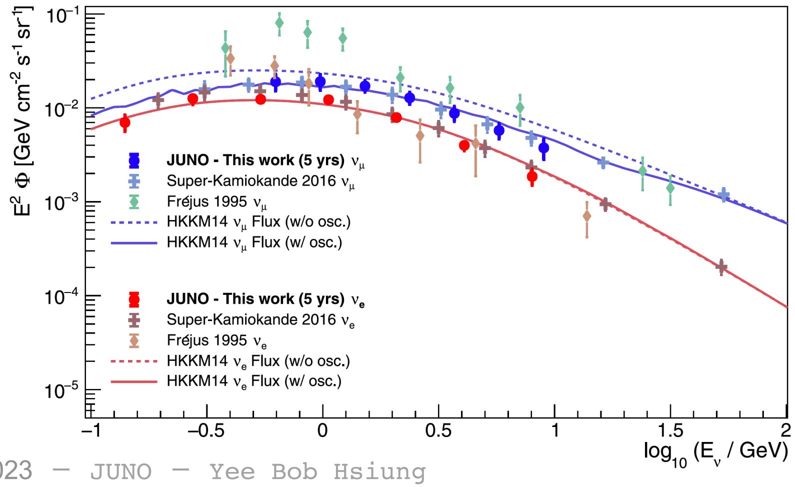
Channel	Type	Events for different $\langle E_\nu \rangle$ values		
		12 MeV	14 MeV	16 MeV
$\overline{\nu}_e + p \rightarrow e^+ + n$	CC	4.3×10^3	5.0×10^3	5.7×10^3
$\nu + p \rightarrow \nu + p$	NC	0.6×10^3	1.2×10^3	2.0×10^3
$\nu + e \rightarrow \nu + e$	ES	3.6×10^2	3.6×10^2	3.6×10^2
$\nu + {}^{12}C \rightarrow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

Atmospheric neutrinos

EPJC (2021) 81:887

- First measurement with LS: can give important inputs in the 100 MeV - 10 GeV energy range, where current measurements show discrepancies
- Analysis focus on fully contained CC events
  - ➡ Muon/electron flavour distinction based on hit time (by 3-inch PMTs)
  - ➡ ν_e and ν_μ spectra reconstructed with precision of 10% to 25% in 5 years





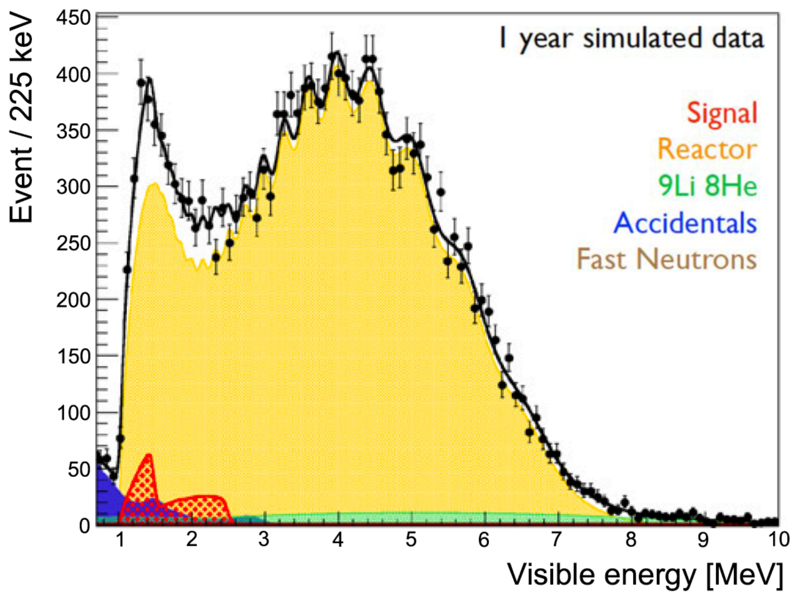
- Sensitive to NMO and ϑ_{23}
- NMO determination through matter effects
- Sensitivity to NMO complementary to that of reactor neutrinos ⇒ possible improvement of the sensitivity by a combined analysis is under study

Geoneutrinos

PPNP 123 (2022) 103927
JPG 43 (2016) 030401

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

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



- Expected ~400 IBD/y, larger than all accumulated geo-ν events until now: (KamLAND+Borexino) ~230 events
- Challenge: reactor-ν background, ~40 times larger
- Precision on the measured flux will go from 13% in 1 year to 5% in 10 years (current precision ~16-18%)
- Sensitive to Th/U 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)

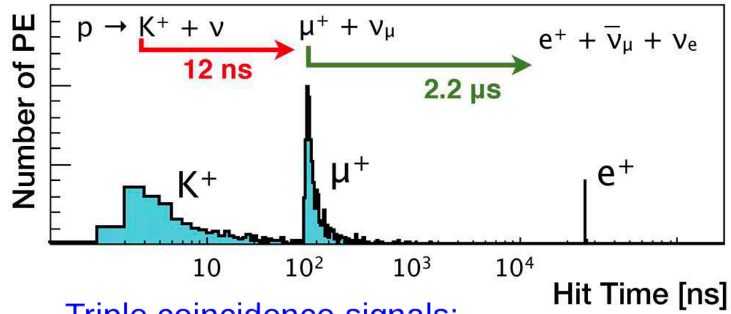
Proton decay

- Two possible decay channels:

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

  $\boldsymbol{p \rightarrow K^+ + \nu}$ (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

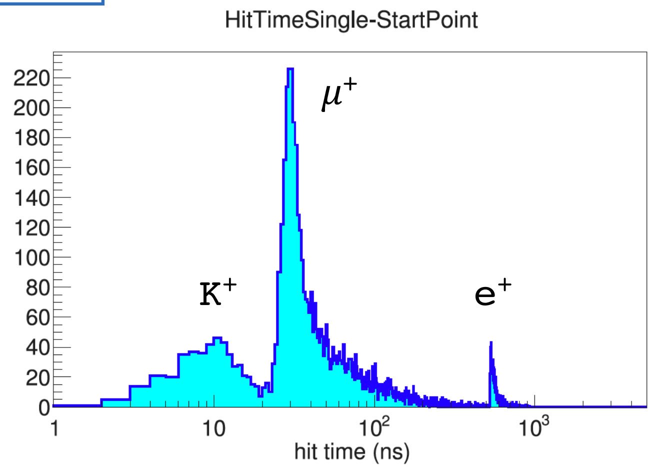


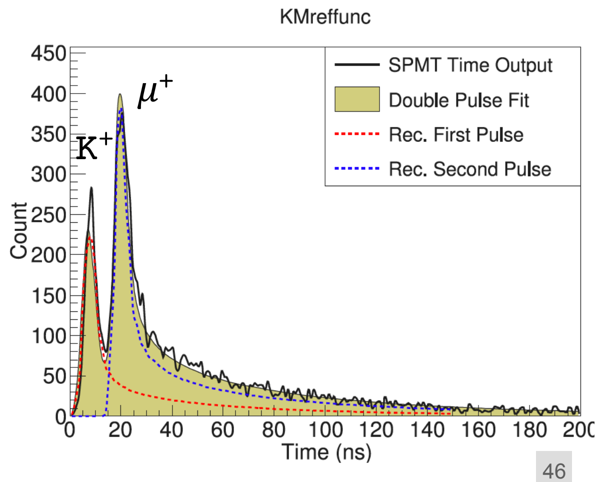
Triple coincidence signals:

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

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

3rd: $2.2\mu s \rightarrow$ Michel electron



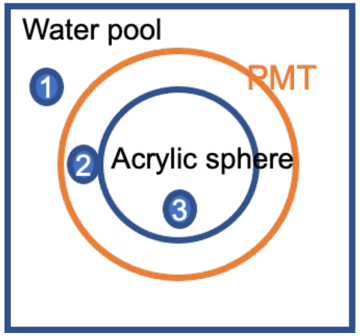


Expected sensitivity:
8.34×10^{33} y (90% CL) in 10 y
on the proton half-life

PPNP 123 (2022) 103927
JPG 43 (2016) 030401

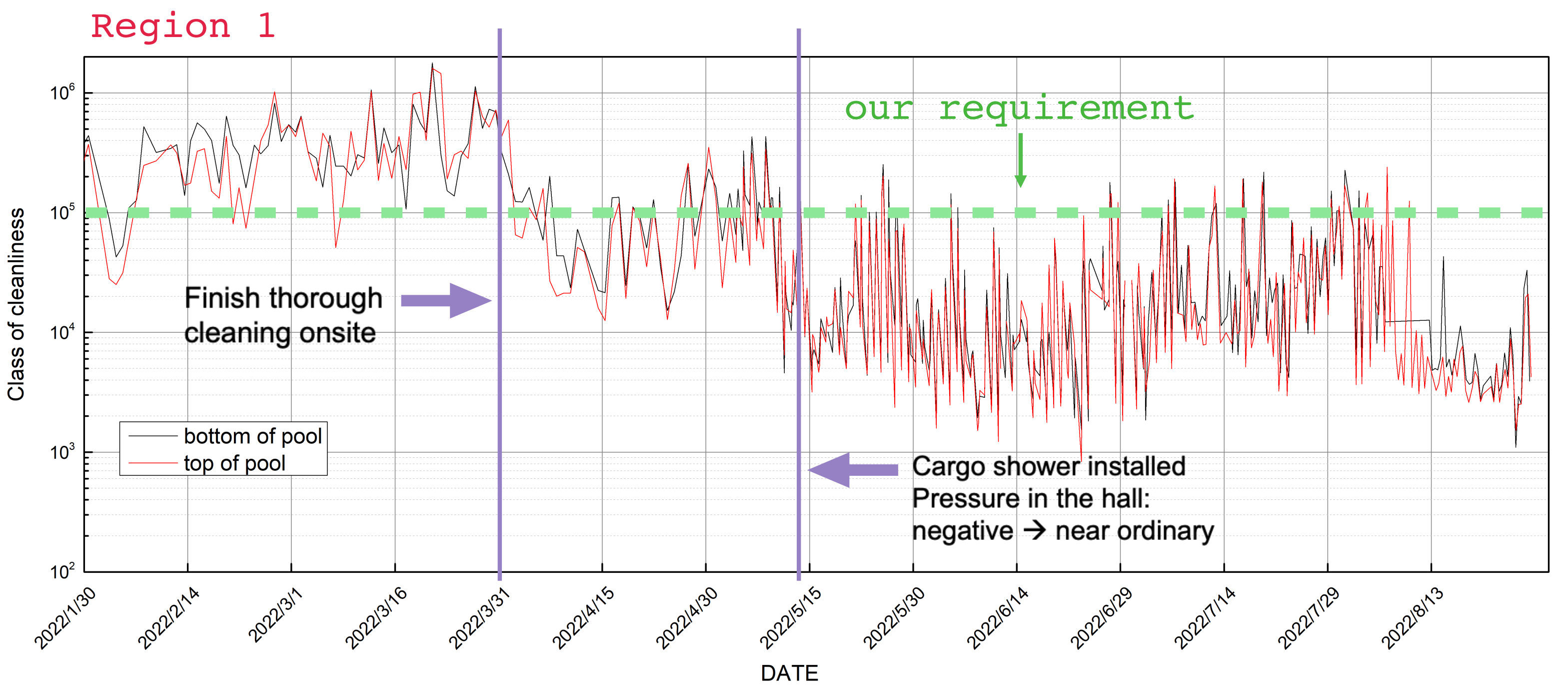
Radiopurity control strategy

Environmental control



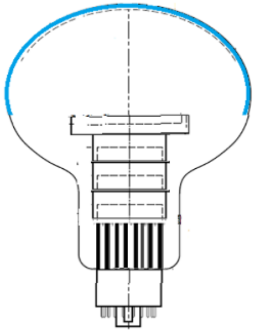
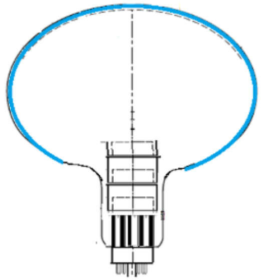
Region	Level
1	Class 100,000
2	Class 10,000
3	Class 1000

Temperature: 21℃±1℃

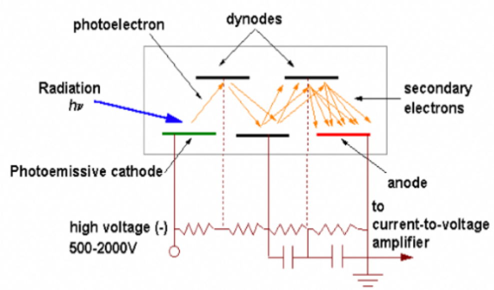


Large PMTs

Two types of 20-inch PMTs

Dynode Hamamatsu 5000 in CD	MCP (multichannel-plate) NNVT 12612 in CD and 2400 in veto
 	 

TRANSMISSION ONLY



TRANSMISSION + REFLECTION