JUNO detector design and status

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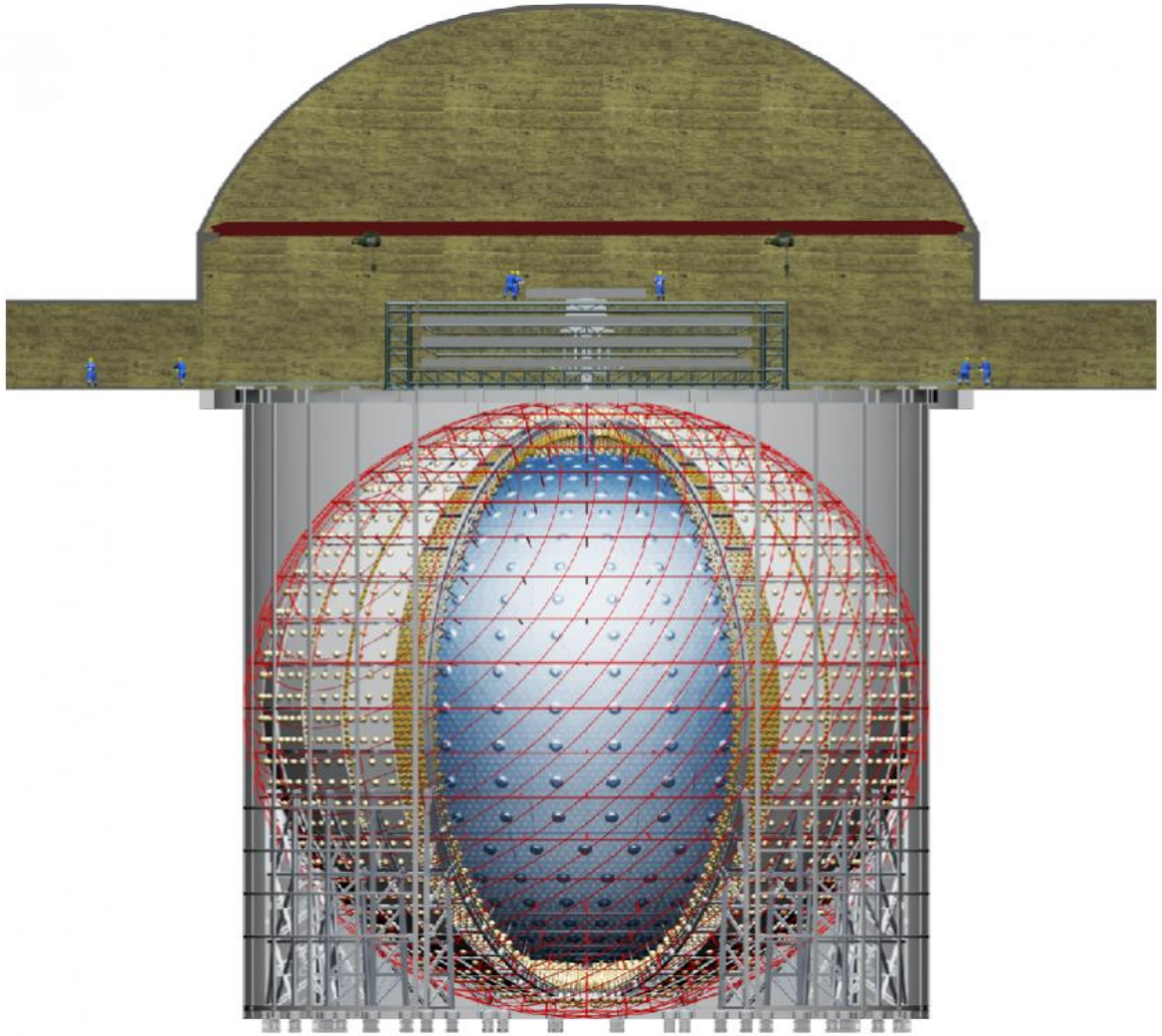
On behalf of the JUNO Collaboration

28/08/2023

Outline

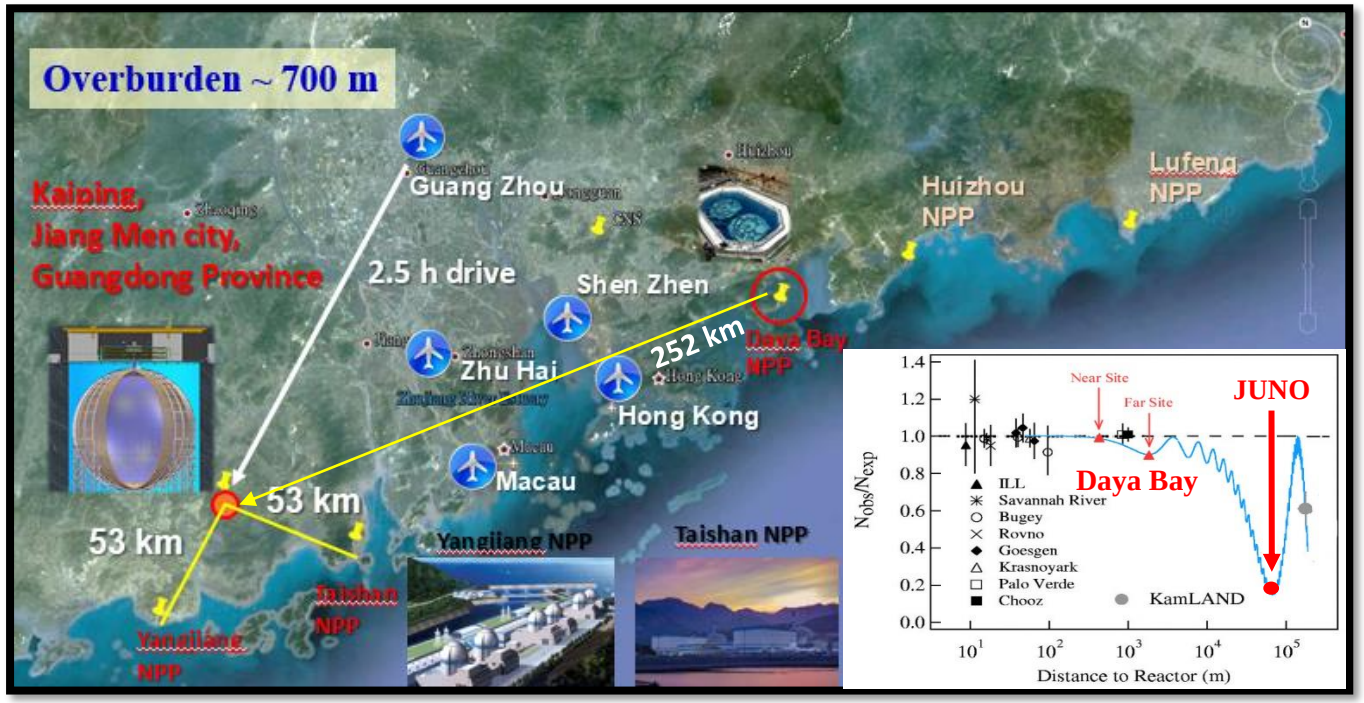
- *An overview of JUNO*
- *The project status of JUNO*
  - *Liquid scintillator*
  - *Central detector*
  - *PMT*
  - *Water Cherenkov Detector*
  - *Top Tracker*
  - *Calibration system*
  - *JUNO-TAO*
- *Summary*



Jiangmen Underground Neutrino Observatory

Project:

- *Major goal： NMO determination；*
- *Project approved in 2013, Underground Laboratory construction started in 2015, Detector construction started in 2022, Data-taking expected in 2024；*
- *Main Source: Reactor neutrinos;*
- *Target: 20 kton liquid scintillator ;*



NPP	Daya Bay	Huizhou	Lufeng	Yangjiang	Taishan
Status	Operation	Planned	Planned	Operation	Operation
Power	17.4 GW_{th}	17.4 GW_{th}	17.4 GW_{th}	17.4 GW_{th}	9.2 GW_{th}

JUNO Onsite

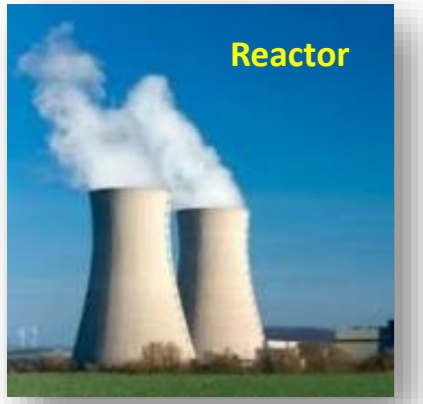

Overburden： 700m
Vertical tunnel: 563 m
Slope tunnel： 1265 m @ slope of 42%

JUNO Collaboration

17 countries， 74 institutions， ~670 members

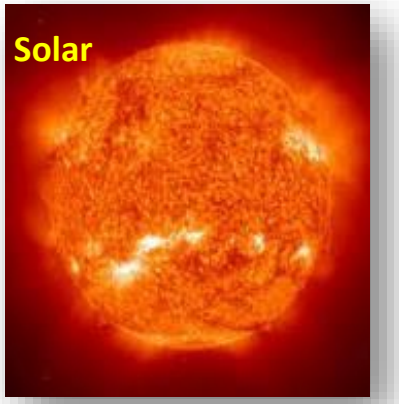
Country	Institute	Country	Institute	Country	Institute
Armenia	Yerevan Physics Institute	China	SYSU	Germany	U. Mainz
Belgium	Universite libre de Bruxelles	China	Tsinghua U.	Germany	U. Tuebingen
Brazil	PUC	China	UCAS	Italy	INFN Catania
Brazil	UEL	China	USTC	Italy	INFN di Frascati
Chile	PCUC	China	U. of South China	Italy	INFN-Ferrara
Chile	SAPHIR	China	Wu Yi U.	Italy	INFN-Milano
Chile	UNAB	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	Pakistan	PINSTECH (PAEC)
China	CIAE	China	CUG-Beijing	Russia	INR Moscow
China	DGUT	China	ECUT-Nanchang City	Russia	JINR
China	Guangxi U.	China	CDUT-Chengdu	Russia	MSU
China	Harbin Institute of Technology	Czech	Charles U.	Slovakia	FMPICU
China	IHEP	Finland	University of Jyvaskyla	Taiwan-China	National Chiao-Tung U.
China	Jilin U.	France	IJCLab Orsay	Taiwan-China	National Taiwan U.
China	Jinan U.	France	LP2i Bordeaux	Taiwan-China	National United U.
China	Nanjing U.	France	CPPM Marseille	Thailand	NARIT
China	Nankai U.	France	IPHC Strasbourg	Thailand	PPRLCU
China	NCEPU	France	Subatech Nantes	Thailand	SUT
China	Pekin U.	Germany	RWTH Aachen U.	U.K.	U. Warwick
China	Shandong U.	Germany	TUM	USA	UMD-G
China	Shanghai JT U.	Germany	U. Hamburg	USA	UC Irvine
China	IGG-Beijing	Germany	FZJ-IKP		

A multi-purpose observatory



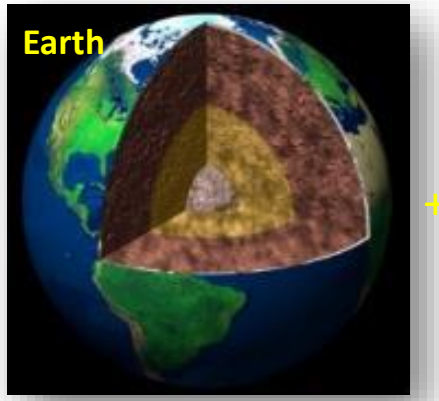
~60 IBDs per day

Several per day



Hundreds per day

~5000 IBDs for CCSN @10 kpc



Several IBDs per day

\+ New physics

Neutrino oscillation & properties

Neutrinos as a probe

Talks:

“Neutrino oscillation physics at JUNO” by Rebin Karaparambil;

“Non-oscillation physics at JUNO” by Gaosong Li;

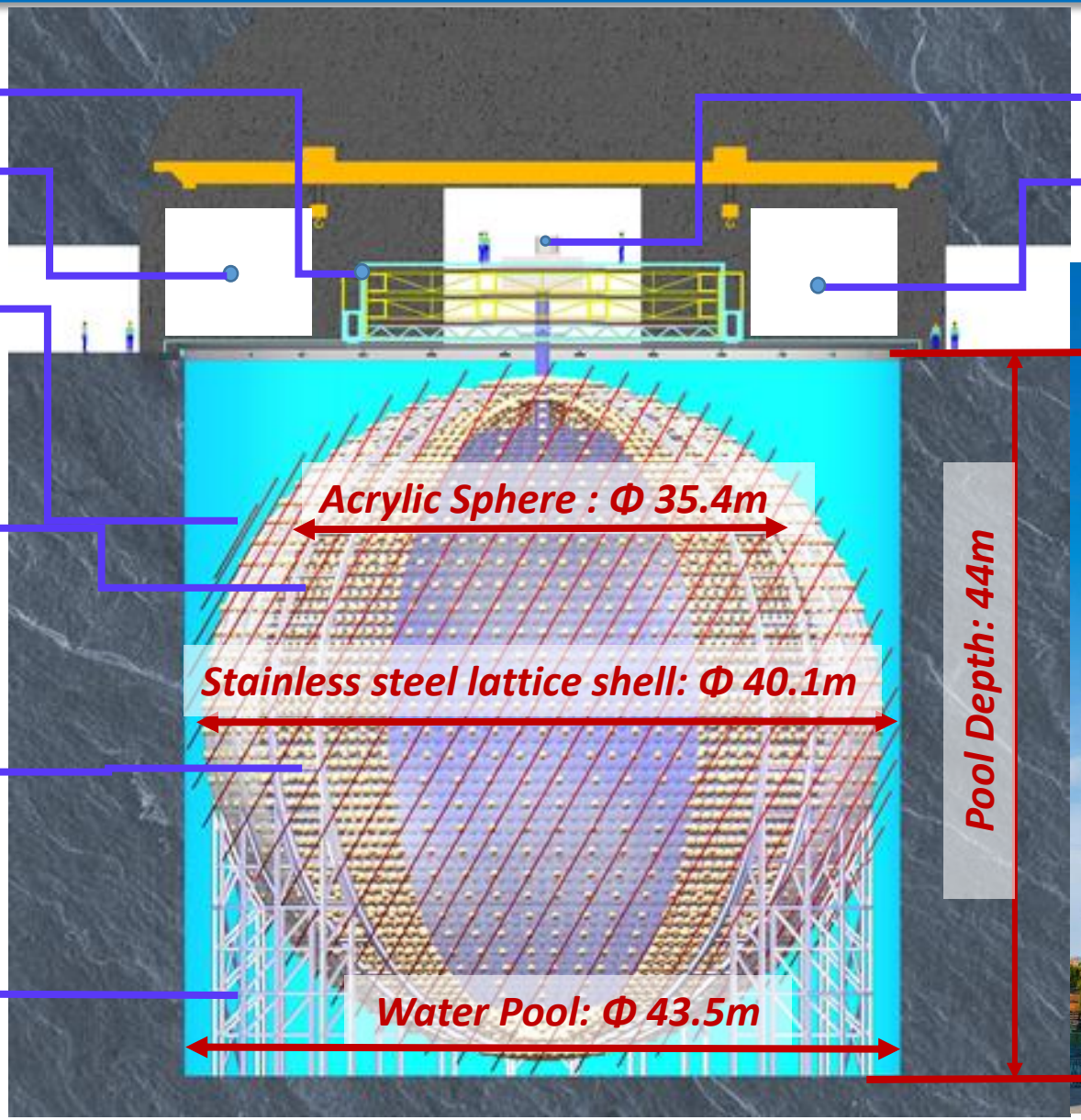
Poster:

“JUNO's Sensitivity on Determining the Neutrino Mass Ordering” by Tobias Heinz;

“Atmospheric neutrino event selection and classification for oscillation analysis at JUNO” by Xinhai He;

JUNO Detector

- Top Tracker
- Pure water Room
- Earth Magnetic Field shielding coils
- Central detector:
  - 20kton LS
  - Acrylic Sphere
  - Steel structure
- PMT:
  - 17612 20'' PMTs
  - 25600 3'' PMTs
  - 78% Coverage
- WCD:
  - 35 kton Pure water
  - 2400 20'' PMTs



Liquid scintillator

- *Using a recipe optimized from Daya Bay's experience, tested and changed to be more suitable for JUNO;*
- *Four purification plants to achieve target radio-purity 10^{-17} g/g U/Th and 20 m attenuation length at 430 nm.*

5000 m^3 LAB tank

Al_2O_3 to remove particles

Distillation to remove radioactive impurities

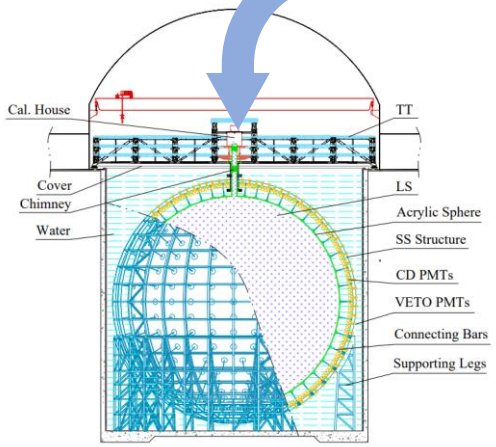
Add 2.5 g/L PPO and 3 mg/L bis-MSB

Water extraction to remove radioactive impurities

Gas stripping to remove Rn and O_2

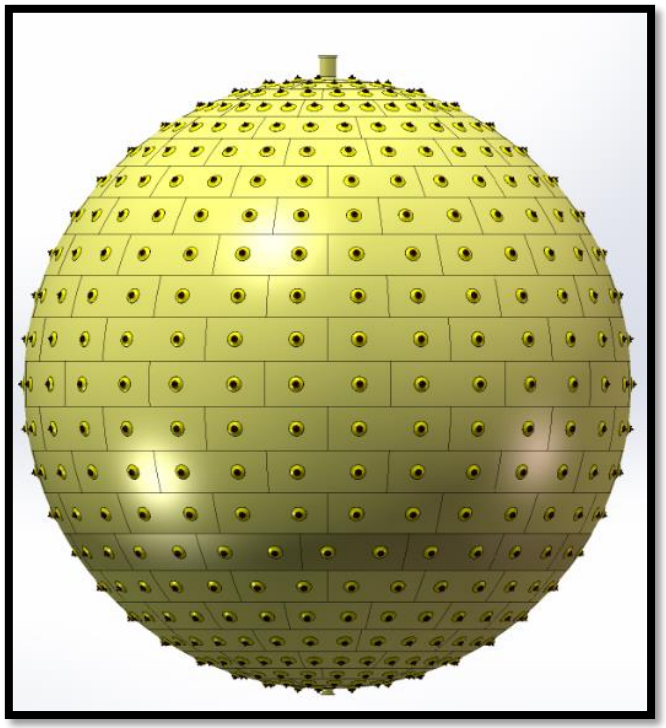
OSIRIS for LS qualification

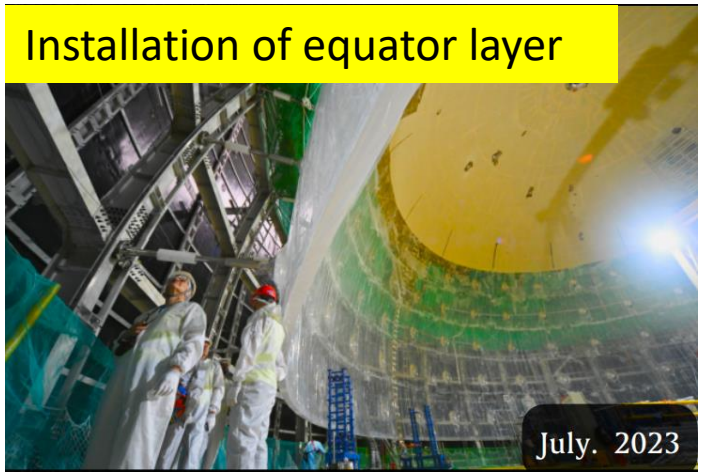
Talk: "The JUNO pre-detector OSIRIS" by Tobia Sterr
Poster: "Upgrade of OSIRIS" by Kai Krister Loo

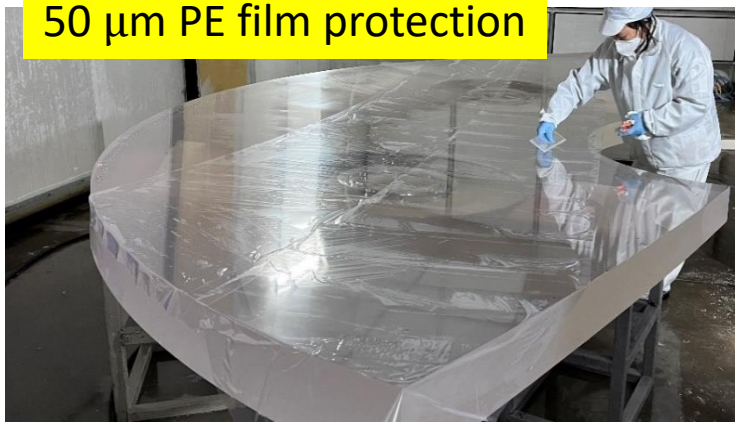


Central Detector

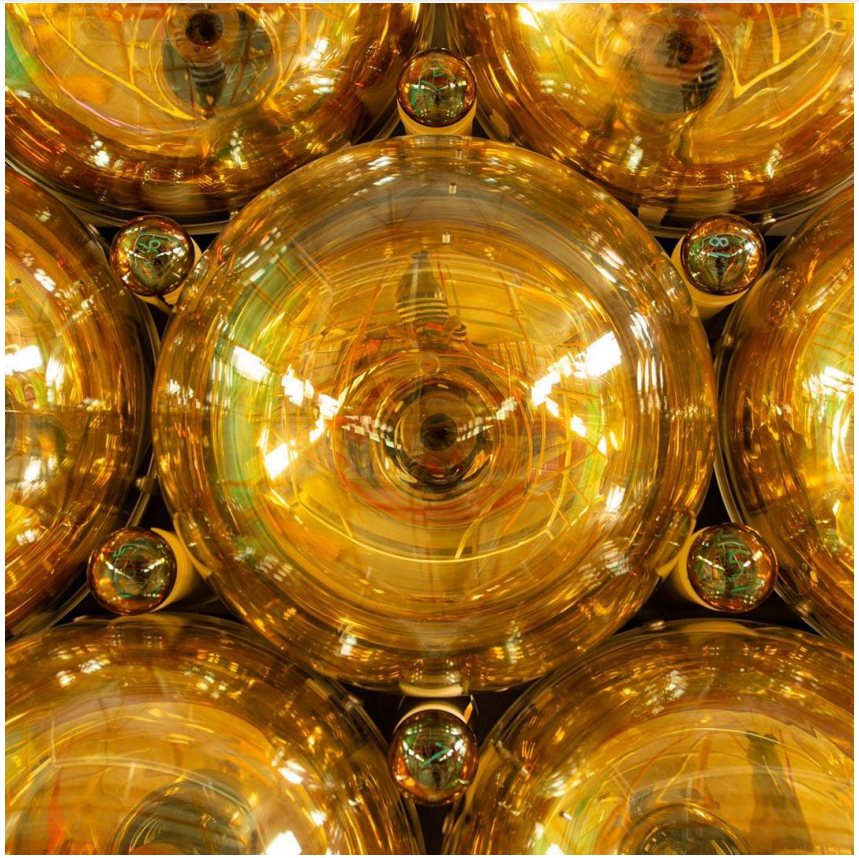
- *The acrylic sphere is composed of 265 pieces of spherical panels;*
- *Thickness:120mm, Net weight: ~600 tons;*
- *Transparency > 96% in pure water;*
- *Radiopurity: U/Th/K < 1 ppt*

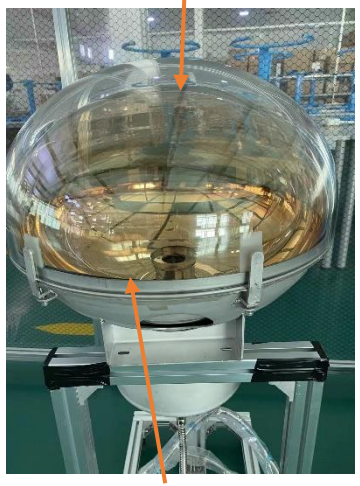


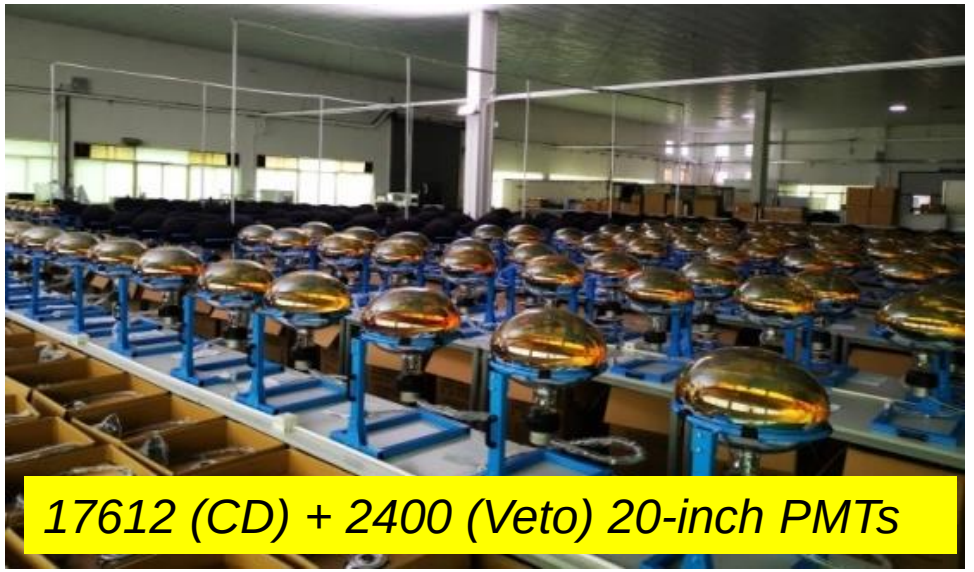




PMT

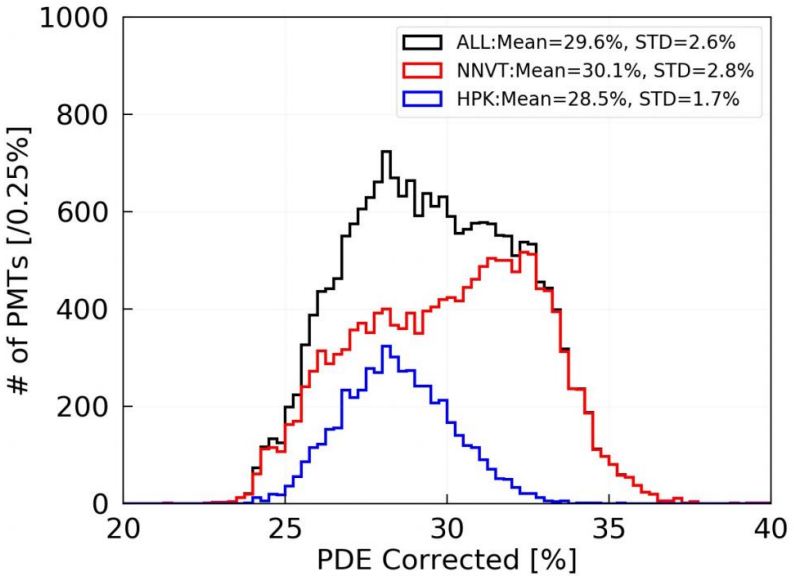


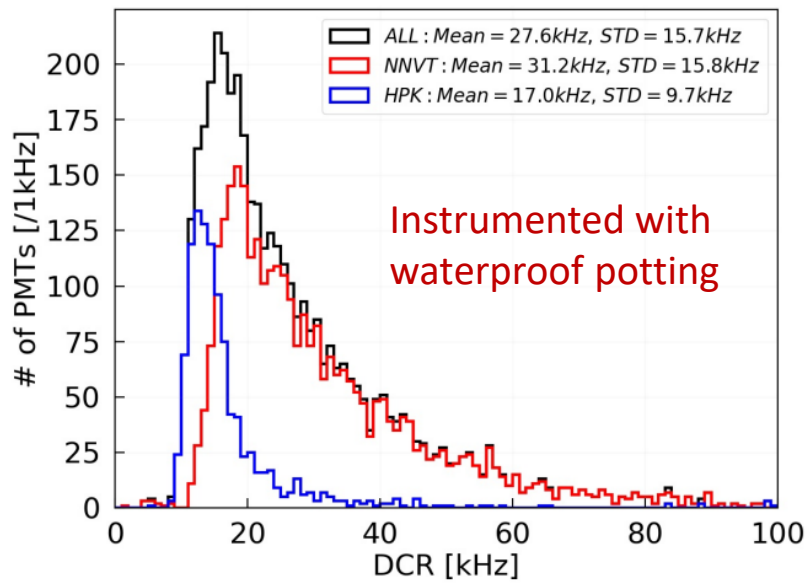




- Synergetic 20-inch and 3-inch PMT systems to ensure energy resolution and charge linearity;
- Clearance between PMTs: 3mm;
- **Assembly precision: < 1mm;**

PMT performance





		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		Eur.Phys.J.C 82 (2022) 12, 1168		NIM.A 1005 (2021) 165347

- *All PMTs produced, tested, and instrumented with waterproof potting;*
- *12.6k NNVT PMTs with higher PDE are selected for CD and the rest are used in the Water Cherenkov detector;*

Poster: "Performance of 20-inch Potted PMTs for JUNO" by Caimei Liu


4600 20’’ PMTs and 3600 3’’ PMTs are installed (June, 2023)

Water Cherenkov Detector

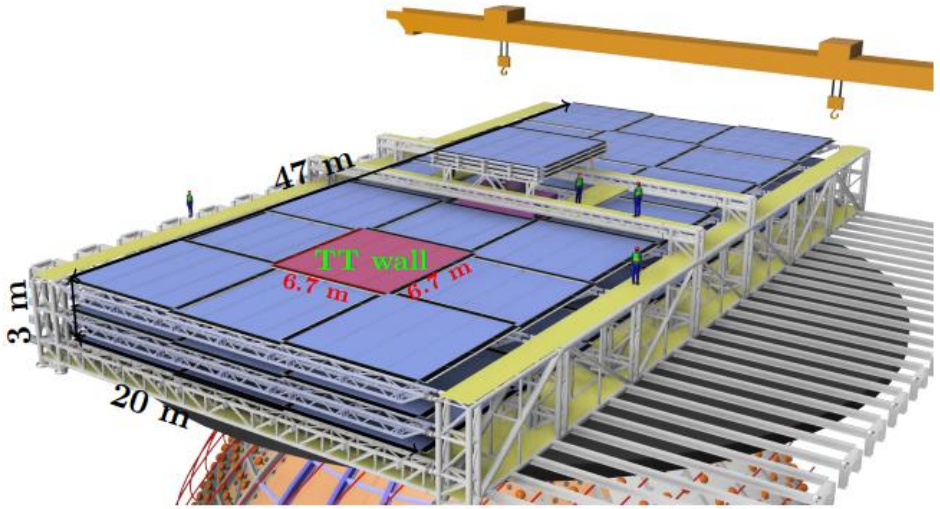
Water room on the ground

Water room underground

- *35 kton of ultrapure water and 2400 MCP-PMTs are used to form the Water Cherenkov Detector;*
- *~6000m^2 HDPE served as Rn barrier;*
- *100t/h ultrapure water system is equipped to*
  - *Keep the temperature at 21 $\pm$ 1℃;*
  - *Reduce the radon concentration inside the water to less than 10mBq/m^3;*

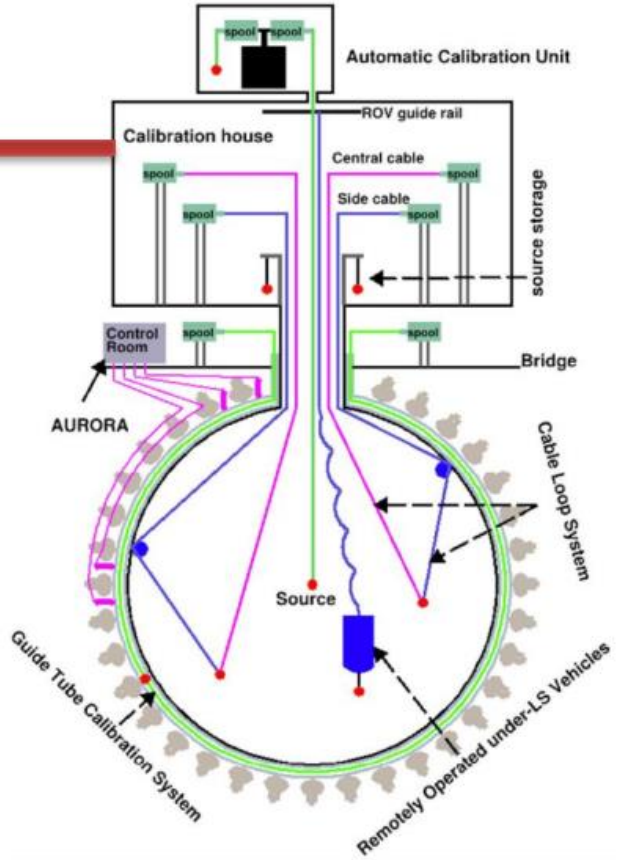
Poster: "The radon and radium concentrations in water measurement systems for JUNO's WCD" by Cong Guo

Top Tracker



- *Reusing the plastic scintillators from OPERA Target Tracker ;*
- *About 50% coverage on the top, three layers to reduce accidental coincidence;*
- *Provide control muon samples to validate the track reconstruction and study cosmogenic backgrounds ;*
- *All scintillator panels arrived on site in 2019;*
- *The TT support bridge is ready for production;*

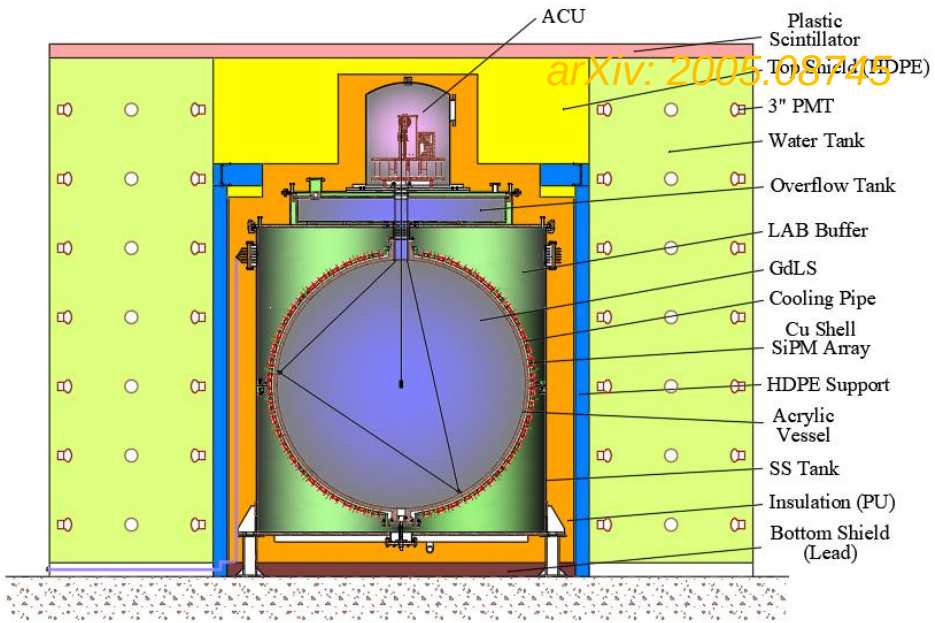
Calibration systems

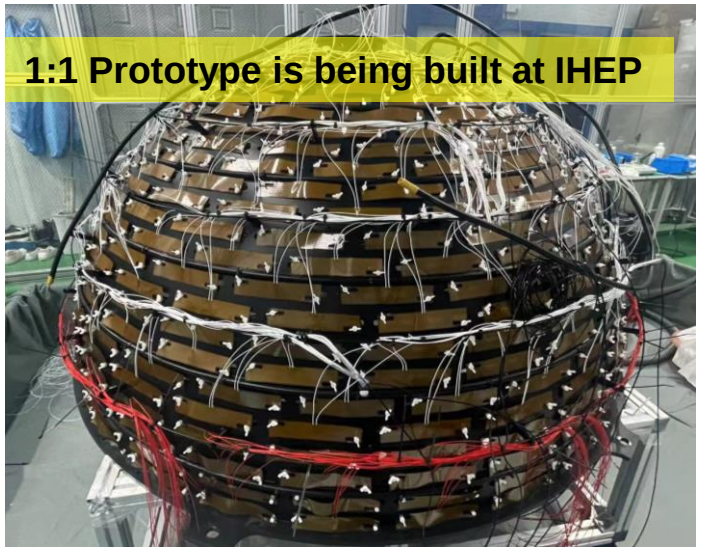


- *Four complementary subsystems will reduce the energy scale uncertainty < 1%;*
  - ✓ *1-D: Automated Calibration Unit(ACU);*
    - *Scan the central axis;*
  - ✓ *2-D: Cable Loop System(CLS);*
    - *Scan vertical plane;*
  - ✓ *2-D: Guide Tube Calibration System(GTCS);*
    - *Scan CD outer surface;*
  - ✓ *3-D: Remotely Operated Vehicle(ROV);*
    - *Full detector scan;*

Poster: "Detector calibration in the sub-MeV range in JUNO" by Akira Takenaka

JUNO-TAO



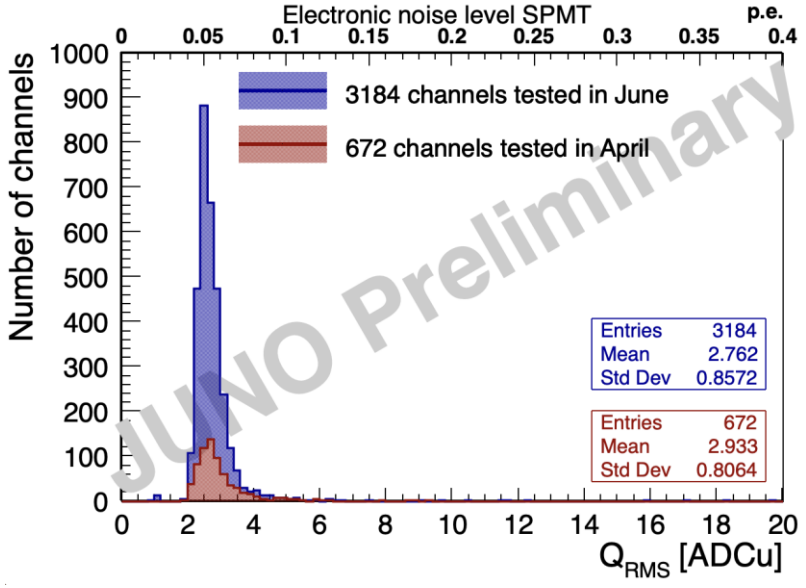


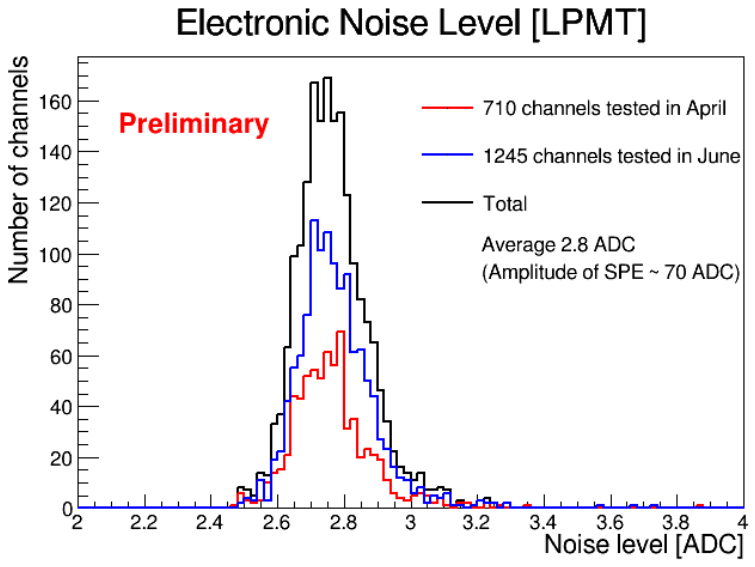
2.8 ton GdLS detector	
Baseline	~30 m
Reactor Thermal Power	4.6 GW_{th}
Light Collection	SiPM
Photon Detection Efficiency	>50%
Working Temperature	-50 ℃
Dark Count Rate [Hz/mm^2]	~100
Coverage	~94%
Detected Light Level [PE/MeV]	4500
Energy resolution	< 2% @ 1 MeV

- *Taishan Antineutrino Observatory (TAO) is a high energy resolution LS detector at 30m from the core;*
- *To measure the fine structure of the reactor neutrino spectrum, and eliminate the model dependence of JUNO NMO determination;*

Commissioning

- *Regular light-off tests and lunch tests during detector assembly started;*
  - *Light off tests: full data taking and processing chain with PMT HV on;*
  - *Light on tests: joint elec./trigger/DAQ/DCS test with PMT HV off during lunch time;*
- *Very good electronics, shielding, and grounding;*
  - *Electronics noise of LPMT is 2.8 ADC counts, 4% of SPE ➔ Much better than the design of 10%;*
  - *Electronics noise of SPMT is 2.8 ADC counts, ~5% of SPE ➔ Much lower than the trigger threshold of 1/3 p.e. ;*
- *All tested PMTs (710 LPMTs and 3,184 SPMTs) were working well;*





Summary

- *JUNO is a multi-purpose neutrino observatory and will determine NMO at 3σ with 6 years data;*
- *JUNO will use 20 kton highly transparent LS and 20012 20'' PMTs and 25600 3'' PMT to realize 3%@1MeV energy resolution;*
- *A satellite experiment (JUNO-TAO) will be built to precisely measure the reactor neutrino energy spectrum;*
- *The detector construction is well in progress;*
- *JUNO is expected to start data-taking in 2024;*

Many thanks for your attention!