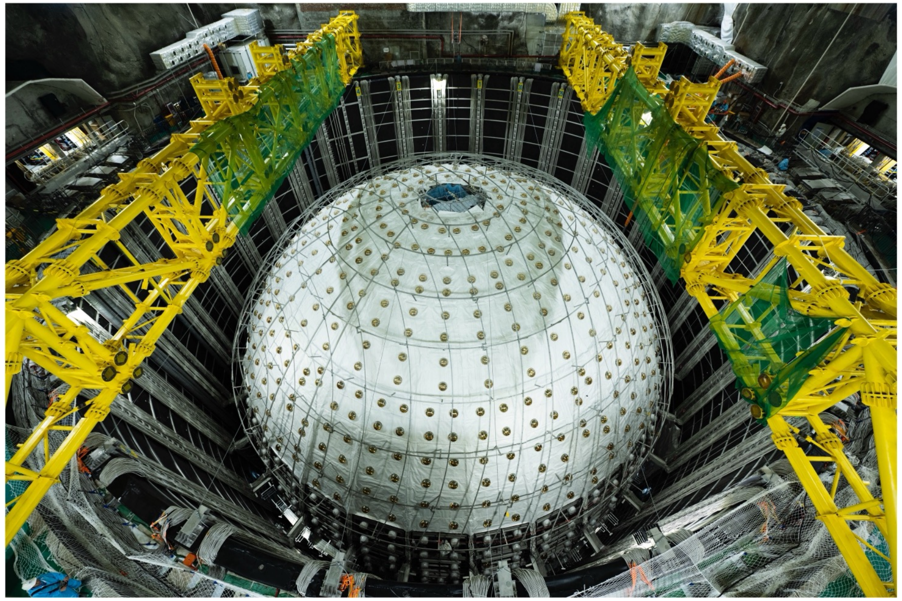
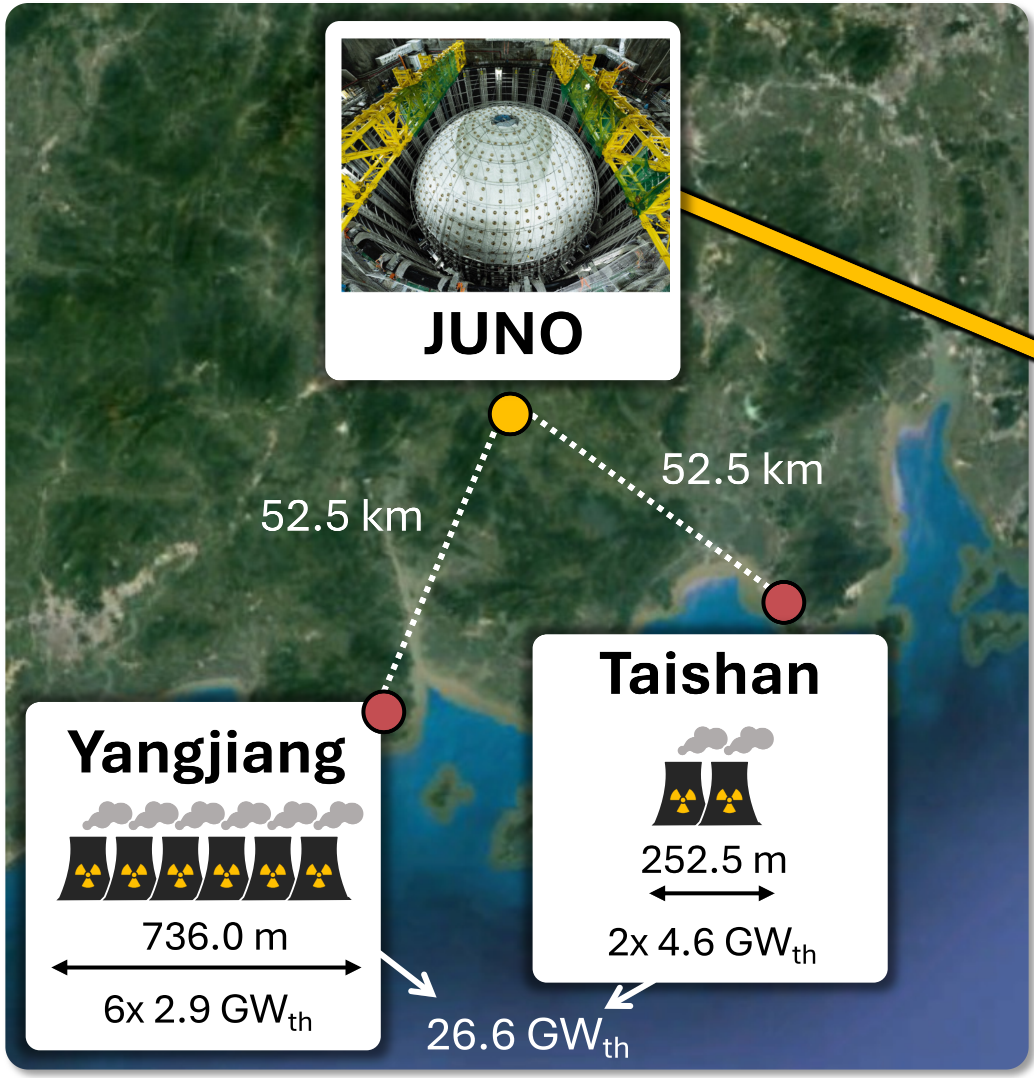


JUNO commissioning phase and first performance results

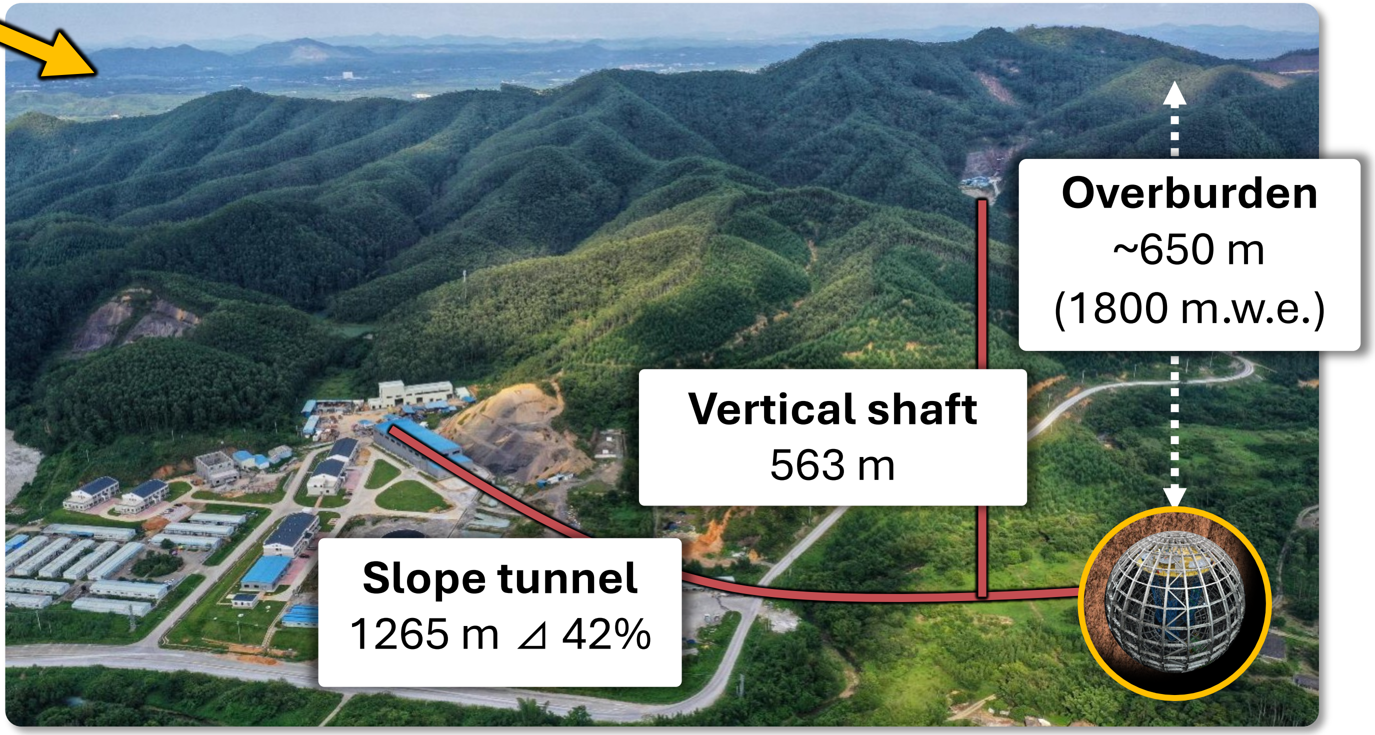
Alberto Garfagnini
Padova University and INFN-Padova
on behalf of the JUNO Collaboration

The Jiangmen Underground Neutrino Observatory



JUNO is a **20 kton** multi-purpose underground **liquid scintillator** detector:

It sits at a baseline of about **52.5 km** from eight **nuclear reactors** in the Guangdong Province of South China.

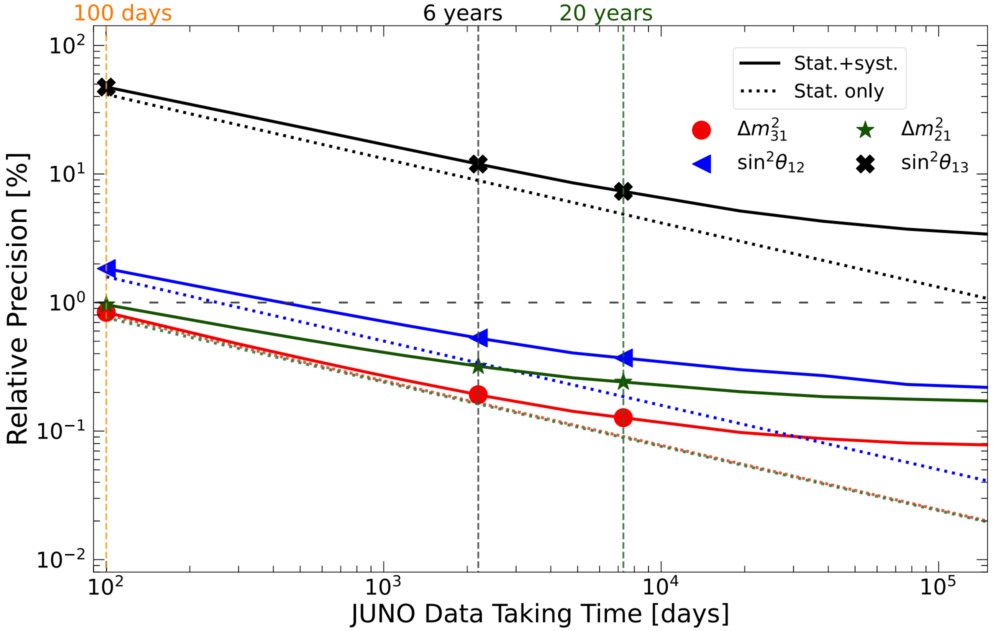


JUNO oscillation physics in a nutshell

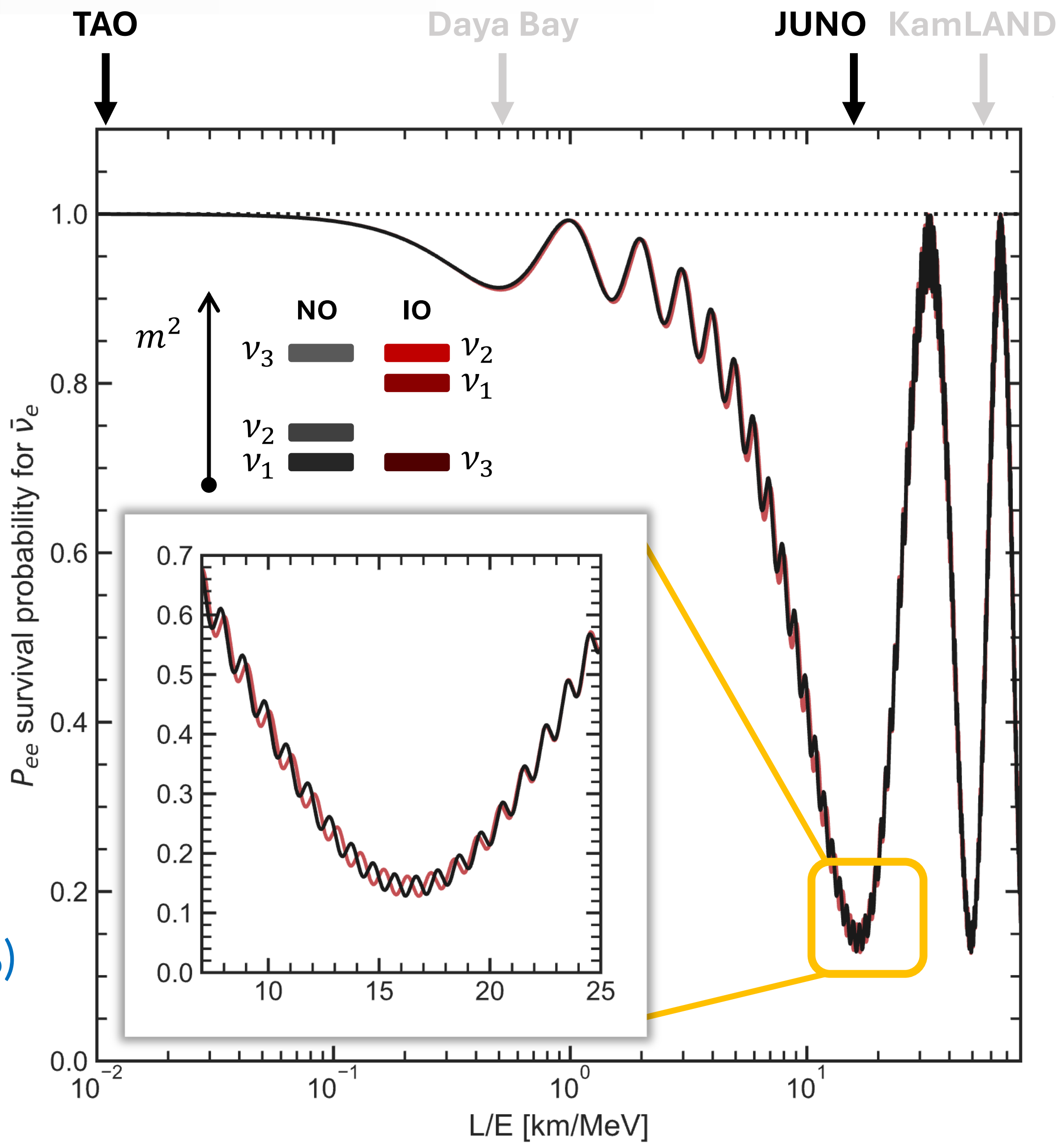
JUNO recipe: $\bar{\nu}_e$ from reactors **as source**, oscillated $\bar{\nu}_e$ **detected** via Inverse Beta Decay (IBD) → sensitive to $\mathbf{P_{ee}}$

Neutrino Mass Ordering (NMO)

NMO sensitivity: 3σ median sensitivity to reject the wrong mass ordering hypothesis in 6.5 years × 26.6 GW thermal power

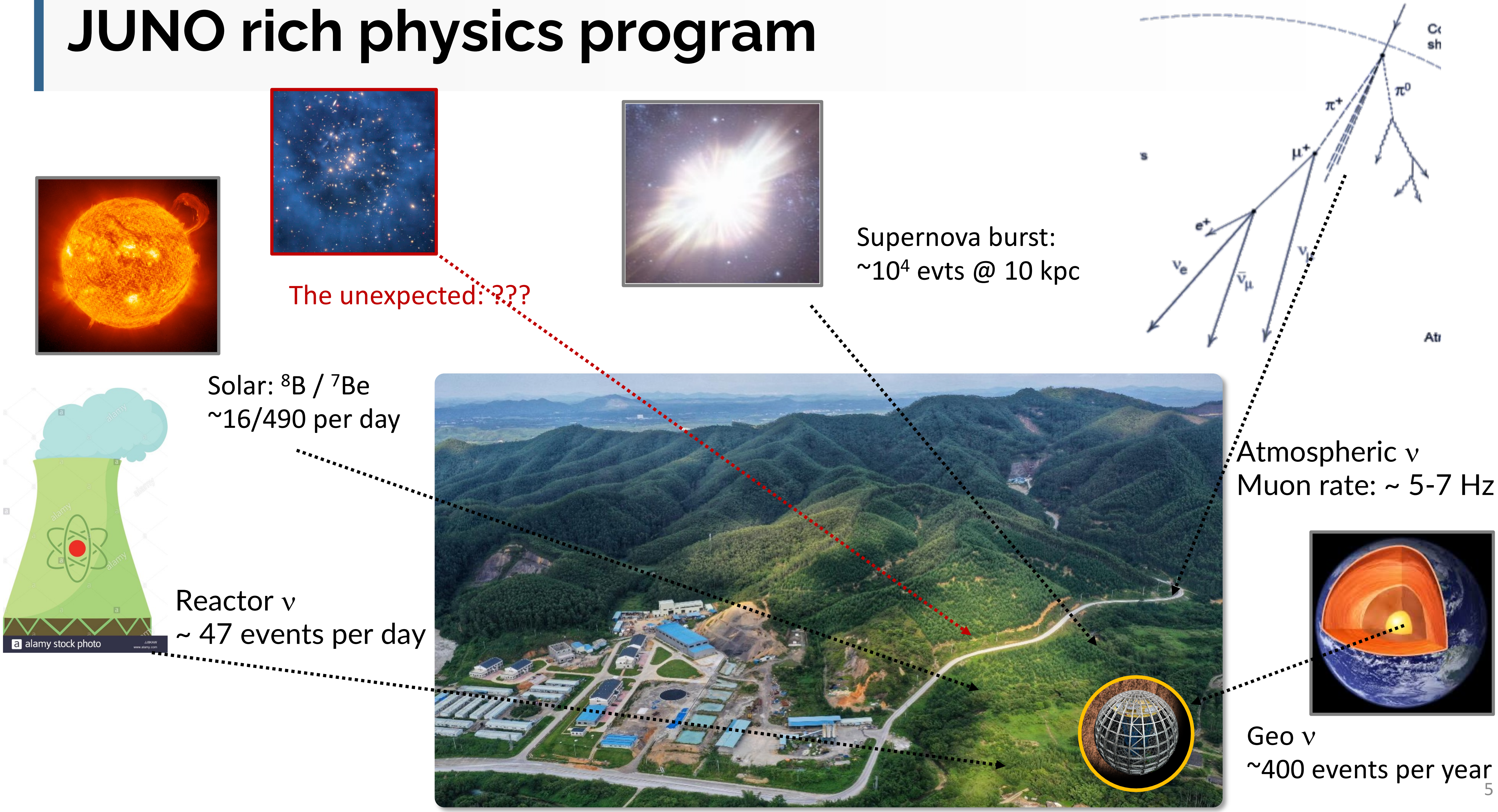


Sensitivity on oscillation parameters O(1%) in 100 days



A. Abusleme *et al* 2022 *Chinese Phys. C* **46** 123001

JUNO rich physics program



The JUNO detector

Central detector (CD)

arXiv: 2311.17314 (2023)

- **20 kton** of **LAB** scintillator
- **17612** 20” **large-PMTs** and **25600** 3” **small-PMTs:**
  → **78%** photocoverage, ~1600 PE/MeV → high resolution
  → dual calorimetry L-PMTs / S-PMTs → self calibration
- Earth’s magnetic field **compensation coils**

→ **Predicted 2.95% resolution @ 1 MeV** arXiv 2405.17860

Water Cherenkov Detector (WCD)

- **35 kton** of high pure **water as shield**
- **2400** 20” **L-PMTs** for **active veto**

Top Tracker (TT)

NIMA 1057 168680 (2023)

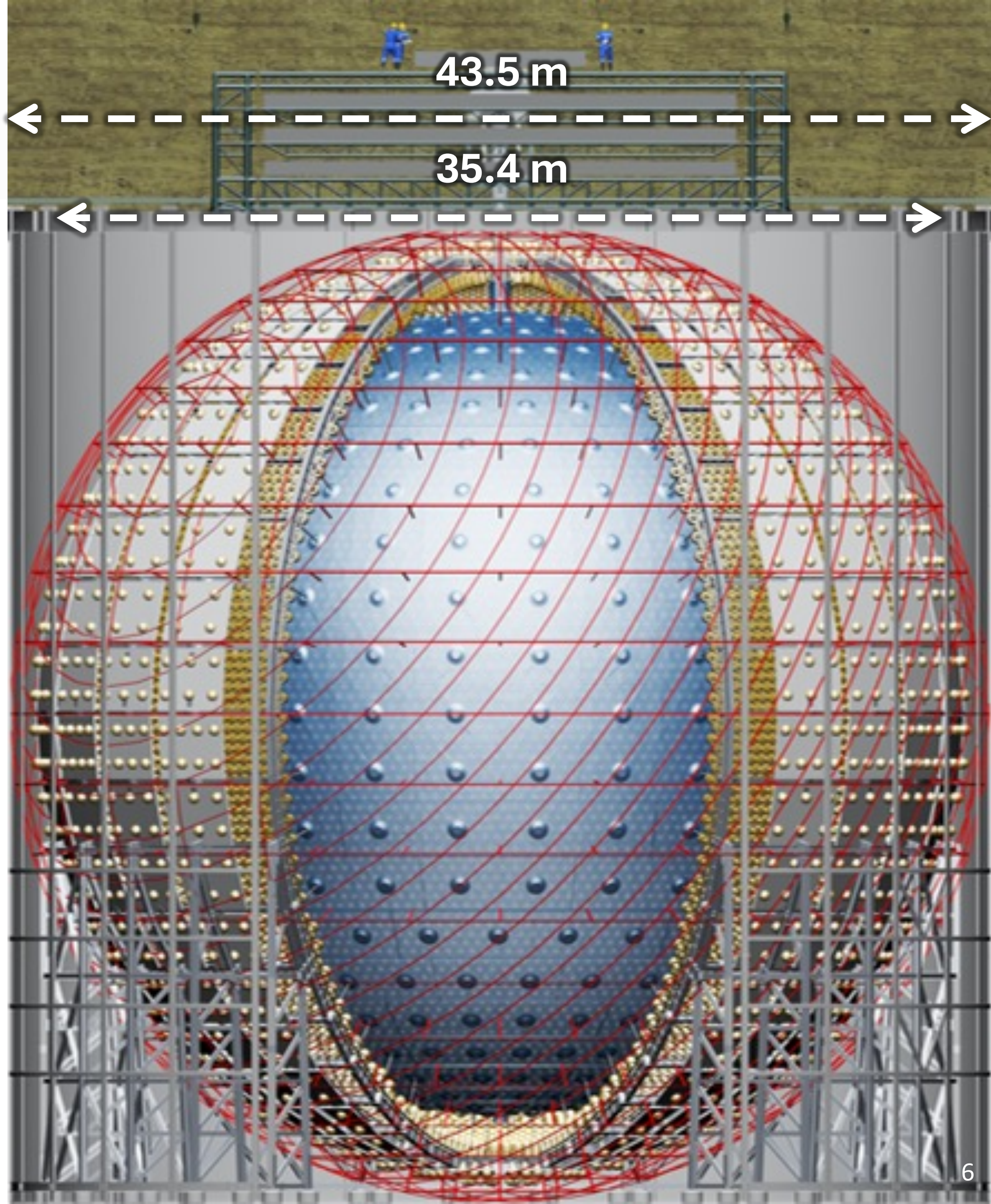
- **3× plastic** scintillator **layers** (coverage ~30% of muons)

→ CD+WP+TT **muon veto strategy** → **92% efficiency**

Calibration system

JHEP 03 (2021) 004

- >6 sources + laser + **calibration system**
  → energy-scale **systematics below 1%**



The JUNO Collaboration

Country	Institute	Country	Institute	Country	Institute
Armenia	Yerevan Physics Institute	China	Wu Yi U.	Italy	INFN di Frascati
Belgium	Universite Libre de Bruxelles	China	Wuhan U.	Italy	INFN-Ferrara
Brazil	PUC	China	Xi'an JT U.	Italy	INFN-Milano
Brazil	UEL	China	Xiamen University	Italy	INFN-Milano Bicocca
Chile	SAPHIR	China	Zhengzhou U.	Italy	INFN-Padova
Chile	UNAB	China	NUDT	Italy	INFN-Perugia
China	BISEE	China	CUG-Beijing	Italy	INFN-Roma 3
China	CAGS	China	ECUT-Nanchang City	Pakistan	PINSTECH (PAEC)
China	ChongQing University	China	CDUT-Chengdu	Russia	INR Moscow
China	DGUT	China	SUSTech-Shenzhen	Russia	JINR
China	Guangxi U.	China	KNRC	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	Jinan U.	France	IJCLab Orsay	Taiwan-China	National Taiwan U.
China	Nanjing U.	France	LP2i Bordeaux	Taiwan-China	National United U.
China	Nankai U.	France	CPPM Marseille	Taiwan-China	NKNU
China	NCEPU	France	IPHC Strasbourg	Taiwan-China	NTUT
China	Shandong U.	France	Subatech Nantes	Thailand	NARIT
China	Shanghai JT U.	Germany	RWTH Aachen U.	Thailand	PPRLCU
China	IGG-Beijing	Germany	TUM	Thailand	SUT
China	SYSU	Germany	U. Hamburg	U.K.	U. Liverpool
China	Tsinghua U.	Germany	GSI	U.K.	U. Warwick
China	UCAS	Germany	U. Mainz	USA	UMD-G
China	U. of South China	Germany	U. Tuebingen	USA	UC Irvine
China	IMP	Italy	INFN Catania		

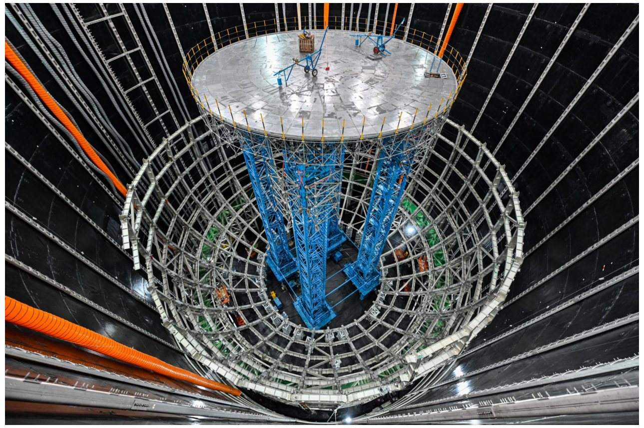
More than 700 collaborators from 74 institutions in 17 countries/regions

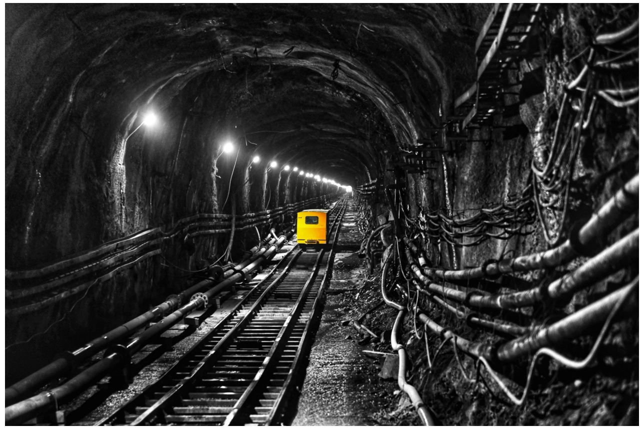
JUNO timeline

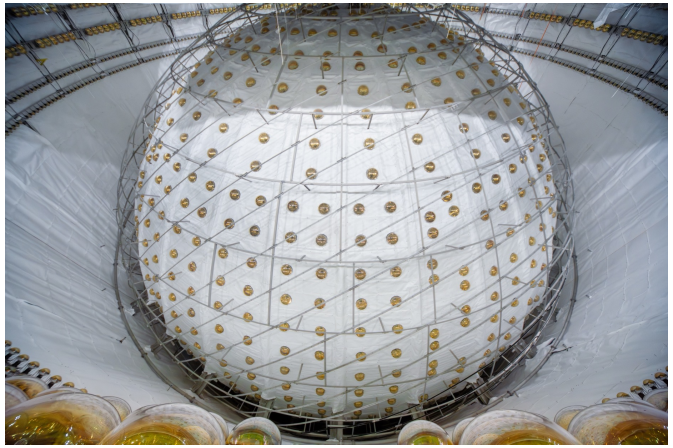
- 2013 — Project started
- 2014 — Collaboration officially formed
- 2015 — Start of Civil Construction
- 2022 — Beginning of detector installation
- 2024 Dec 1 — End detector installation

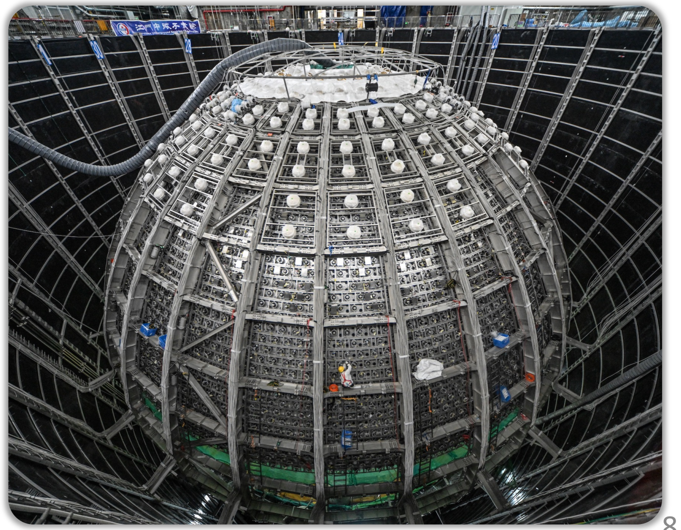
Final cleaning
Extra WCD PMTs installation

- 2024Dec 17 — WCD bottom door sealed

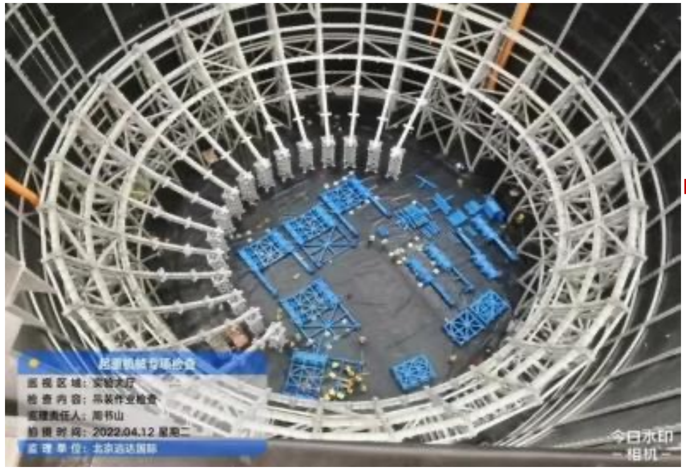






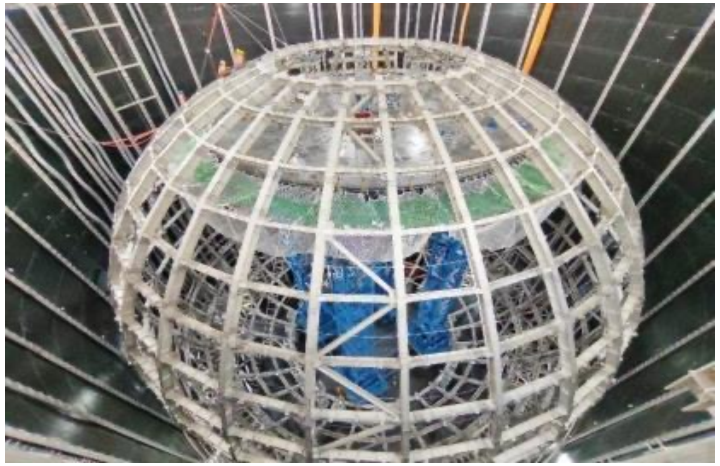


JUNO: Central Detector Construction



Bottom structure

Platform for Acrylic assembly



Top structure

5 layers of Acrylic

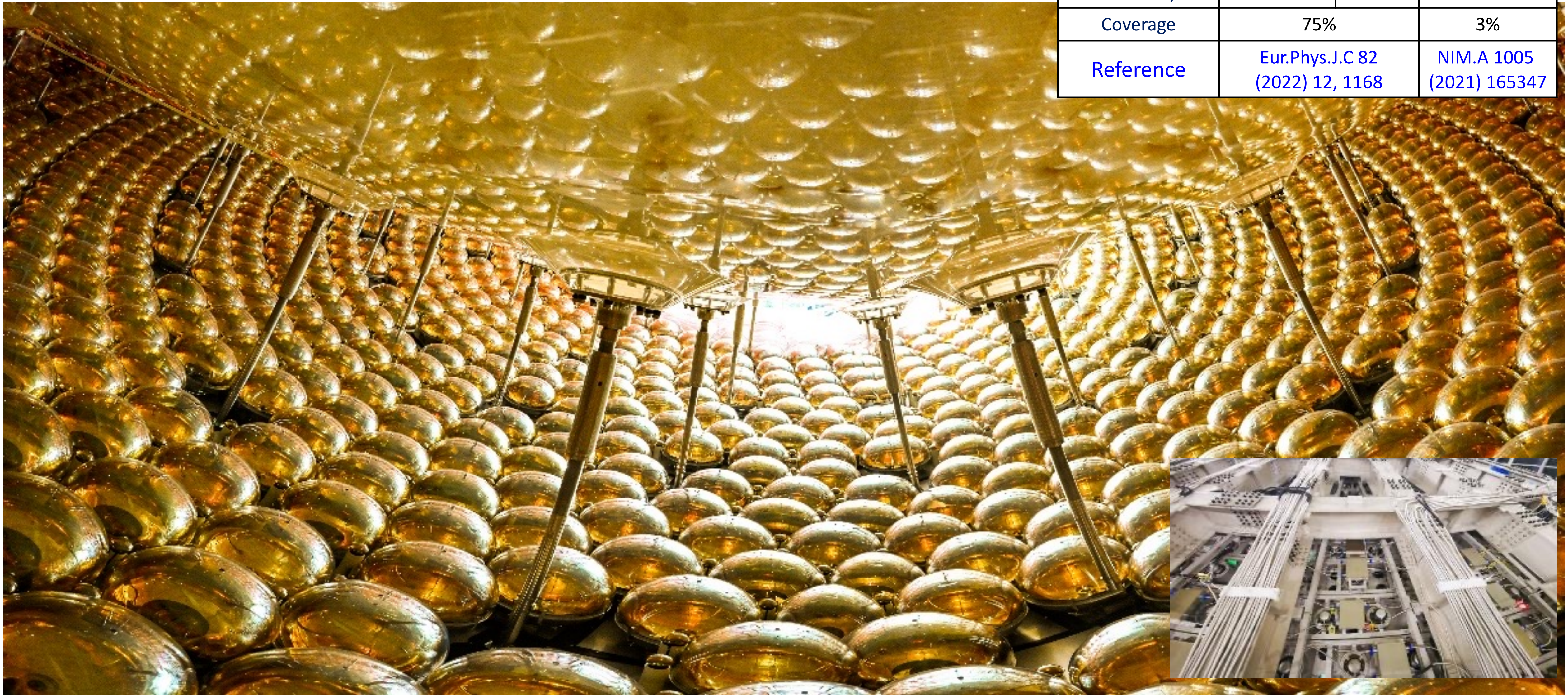
20 layers of Acrylic

23 layers of acrylic

The JUNO detector from the inside

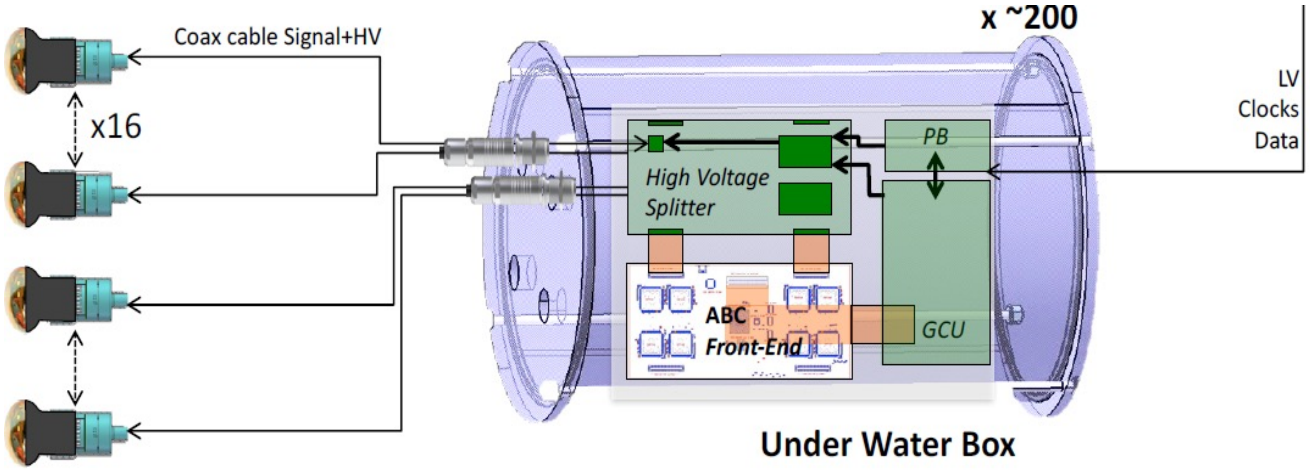
JUNO photomultipliers

	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%
Coverage	75%		3%
Reference	Eur.Phys.J.C 82 (2022) 12, 1168		NIM.A 1005 (2021) 165347



Small PMT system

- 3% more light, higher dynamic range for muons, uniformity and linearity calibration for large PMTs, …
- 25,600 3.1” PMTs (XP72B22) from HZC Photonics
- 200 underwater electronics boxes, each servicing 128 PMTs readout by ASIC Battery Cards (ABC), each with 8 CatiROC chips



200 boxes × 128 PMTs

JINST 16 (2021), P05010

JUNO timeline

- 2024, Dec 18 — **Start of Water Filling**
- 2025, Jan — TT installation started
- 2025, Feb 1 — **End of Water Filling**

Water Phase

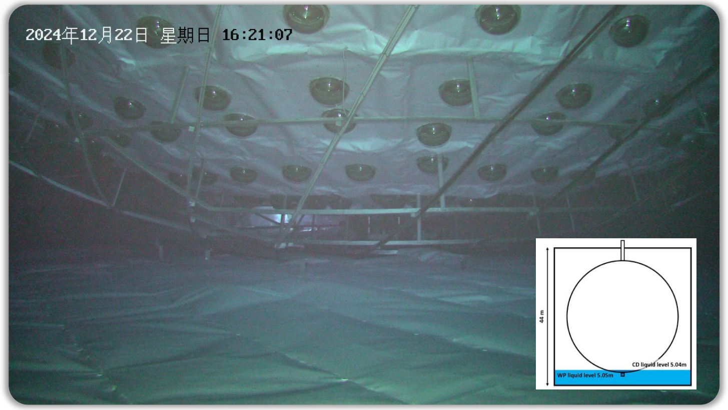
- 2025, Feb 8 — **Start of LS Filling**

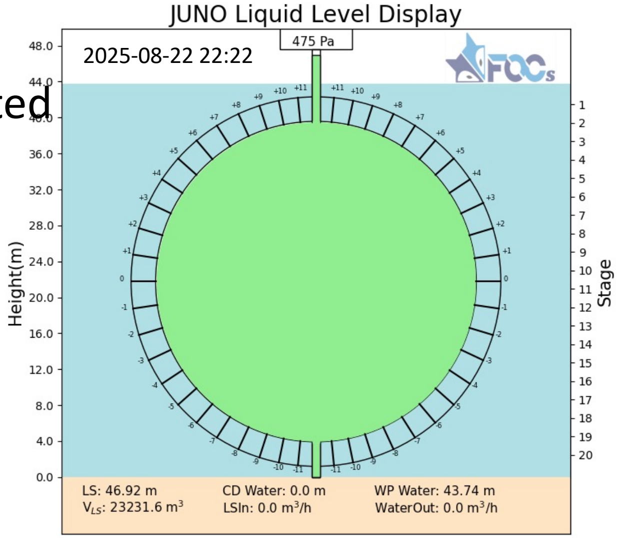
Mixed Phase

- 2025, Jun — TT installation completed
- 2025, Aug 22 — **End of LS Filling**

Full detector calibration

- 2025, Aug 26 08:00 am — Start of Data Taking





JUNO Liquid Scintillator (LS) purification plants

Four purification plants + LS Mixing + QA/QC + high purity N_2 and water production plant to guarantee radio-purity and transparency

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

5000 m^3 LAB tank

Al_2O_3 to remove particles

Distillation to remove radioactive impurities

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Four purification plants + LS Mixing + QA/QC + high purity N_2 and water production plant to guarantee radio-purity and transparency

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

5000 m^3 LAB tank

Al_2O_3 to remove particles

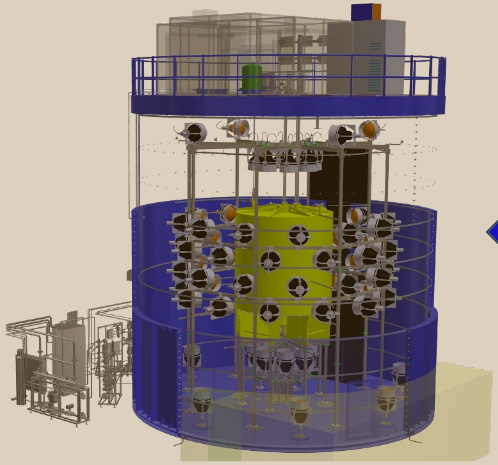
Distillation to remove radioactive impurities

1800 m SS pipes to underground

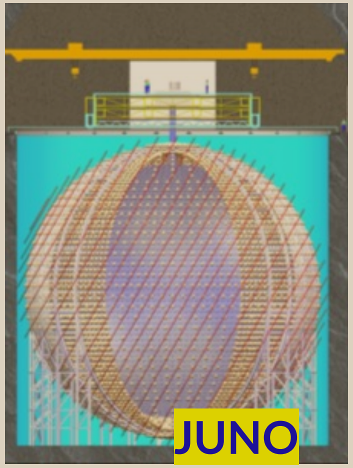
UNDERGROUND LAB

Water extraction to remove radioactive impurities

Gas stripping to remove Rn and O_2

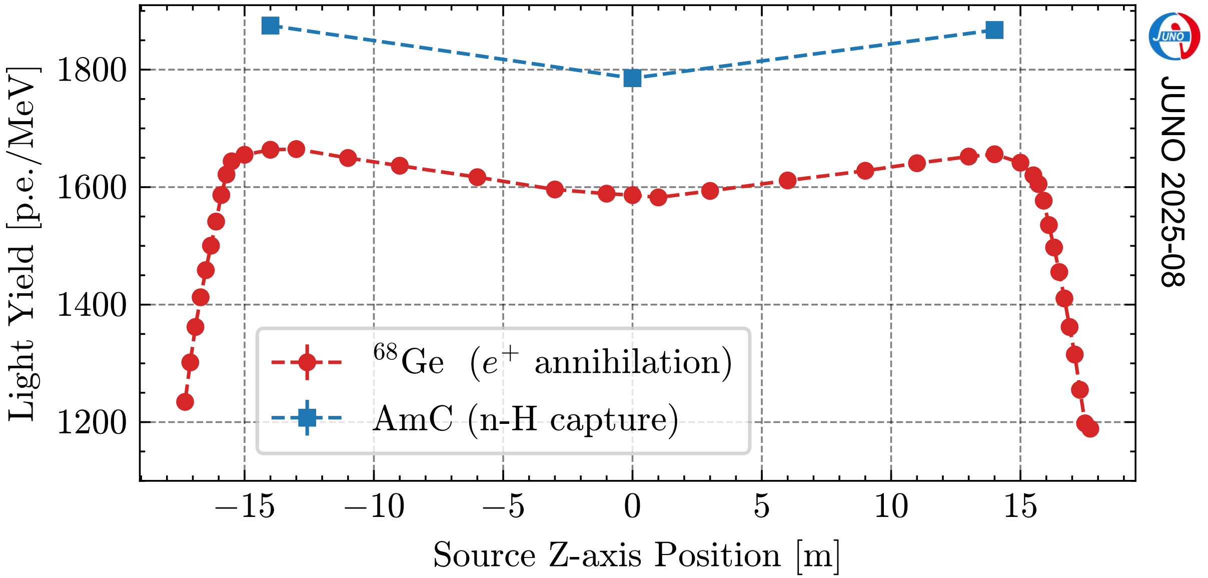


OSIRIS for LS qualification



Commissioning : preliminary detector performances

- Light yield in good agreement with expectations:
  - At the CD center: 1786 p.e./MeV (10% higher than expected)
- Small ΔLY between the upper/lower hemisphere < 17 p.e./MeV



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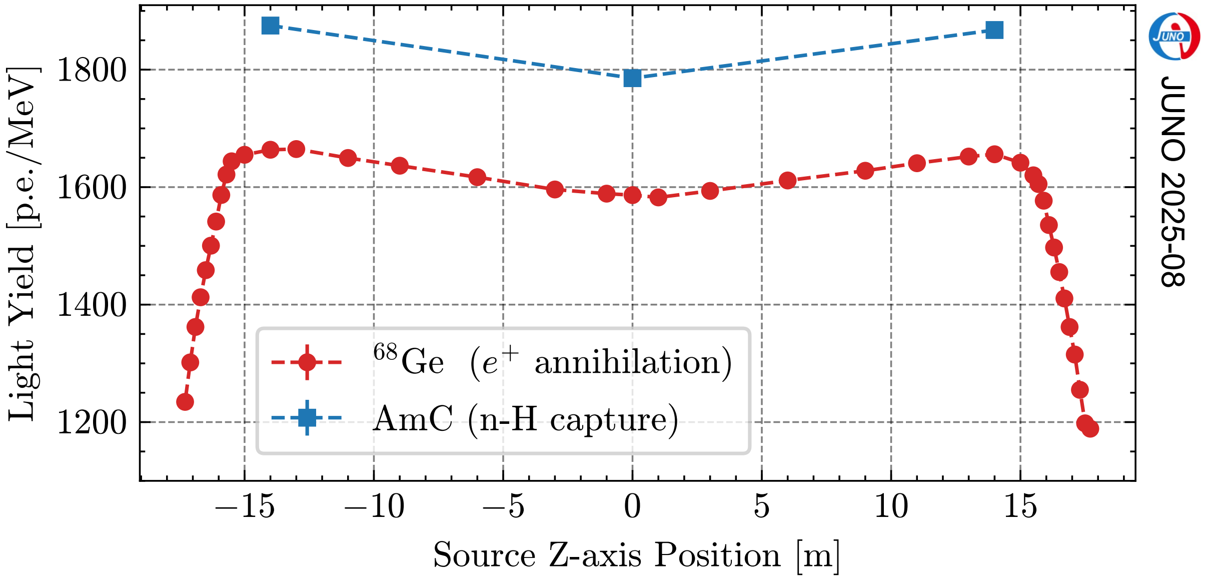
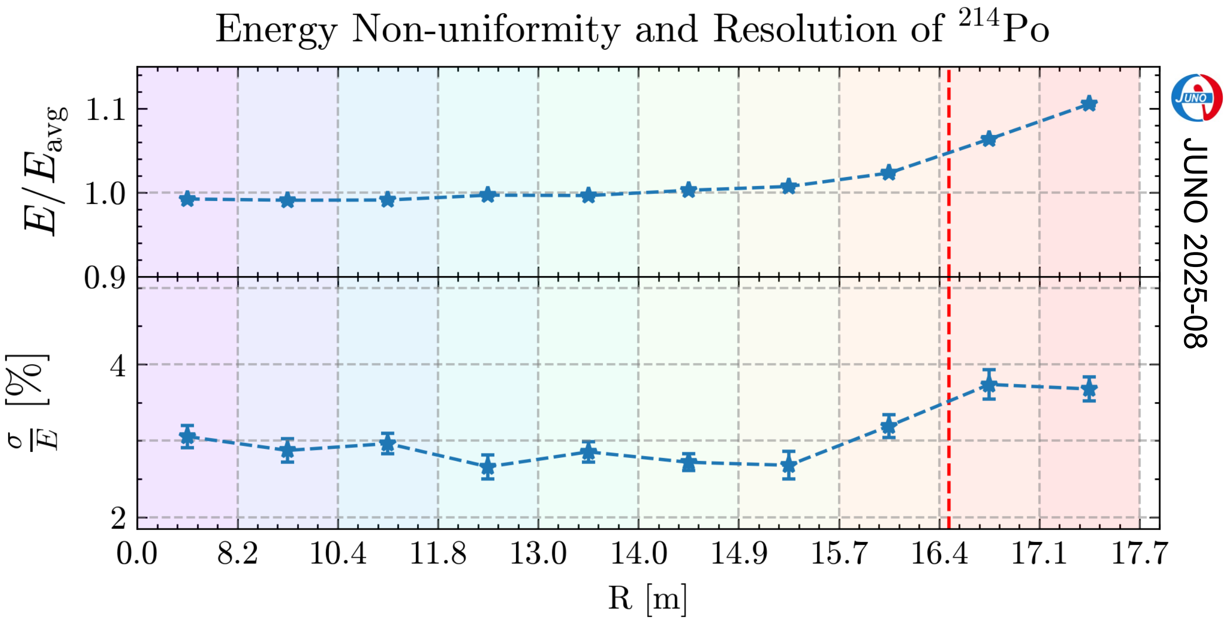
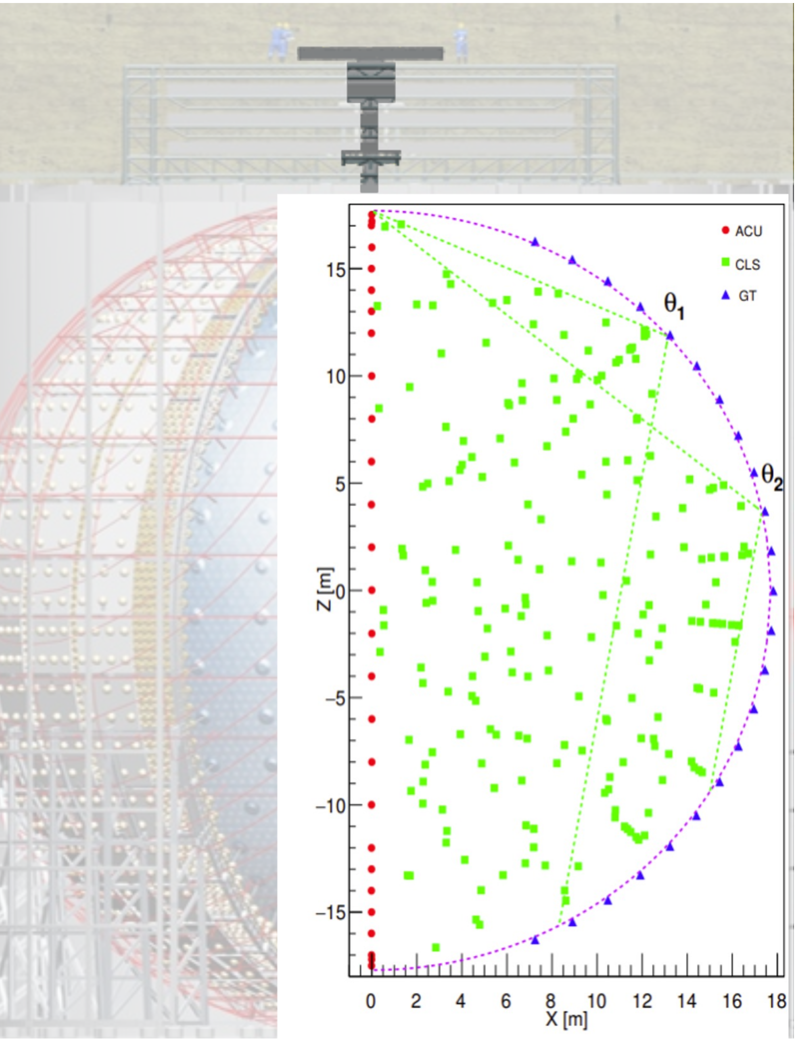


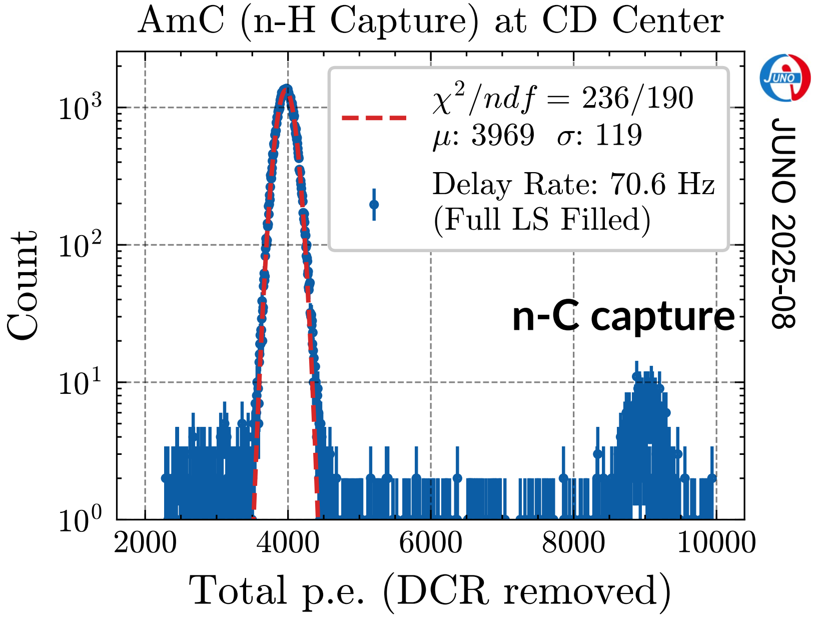
- Energy resolution for alpha from ^{214}Po gives ~3% @0.92MeV
- Residual energy non-uniformity inside Fiducial Volume (FV) < 2.3%

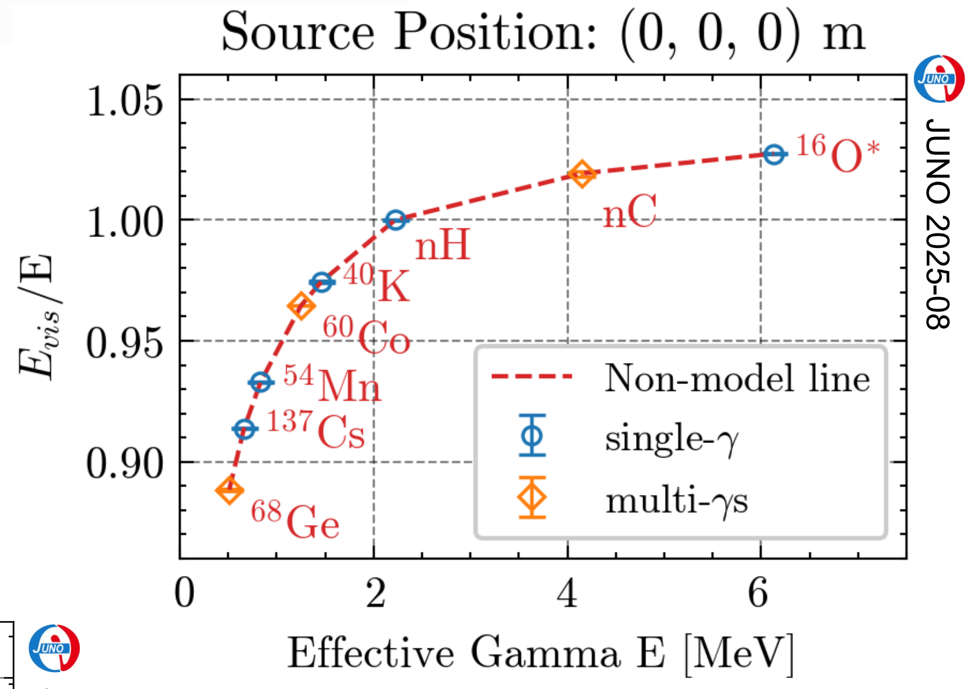


Commissioning : detector energy calibration



- **Automatic Calibration System** (ACU, 1D along central z-axis)
- **Cable Loop System** (CLS, 2D, along a plane)
- **Guided Tube** (GT, 2D along the acrylic sphere)





- **Remotely Operated Vehicle (3D)** can access any position inside the LS volume

Multiple calibration systems have been developed
Results shown here only for ACU

Commissioning : Water/LS radio-purity

Radiopurity control of raw material:

- ✓ Meticulous Monte Carlo Simulation for proper distribution of radioactivity budget
- ✓ Careful material screening
- ✓ Accurate detector production handling

Better than spec. by 15% ! *JHEP* **11 (2021) 102**

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Better than spec. by 15% ! *JHEP* 11 (2021) 102

Radiopurity control:

- ➢ Leak check of all joints (each < 10^{-8} mbar·L/s) for ^{222}Rn and ^{85}Kr √
- ➢ Cleaning and washing of all pipes & vessels to remove dust (by check water/LAB cleanness) √
- ➢ Clean room environment during installation √
- ➢ Acrylic Surface treatment and protection(Rn daughters) √
- ➢ LS filling scheme: water replacement and water washing √

Commissioning : Water/LS radio-purity

VETO Water:

- U/Th < 0.4×10^{-15} g/g, ^{222}Rn < 10 mBq/m^3, ^{226}Ra < 1 mBq/m^3

Acrylic, water, PMTs, steel and LS are clean and water shielding works

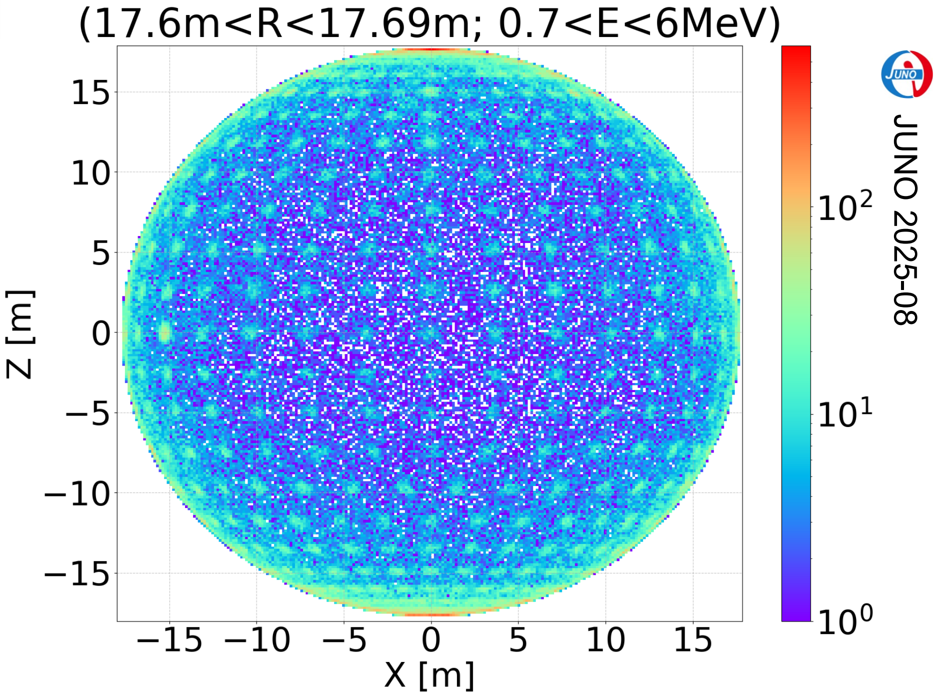
- Single rates < 7 Hz for R < 17.2 m & E > 0.7 MeV (design 7.2 Hz)

→ **Good enough for reactor neutrinos**

LS cleanliness is very close to other solar neutrino experiments:

- ^{238}U < 3×10^{-17} g/g (low radon area in a small fiducial volume)

  < 10×10^{-17} g/g (fitted plateau from full detector radon decay)
- ^{232}Th < 10×10^{-17} g/g (R<13m)
- ^{210}Po < 10×10^{4} cpd/kt



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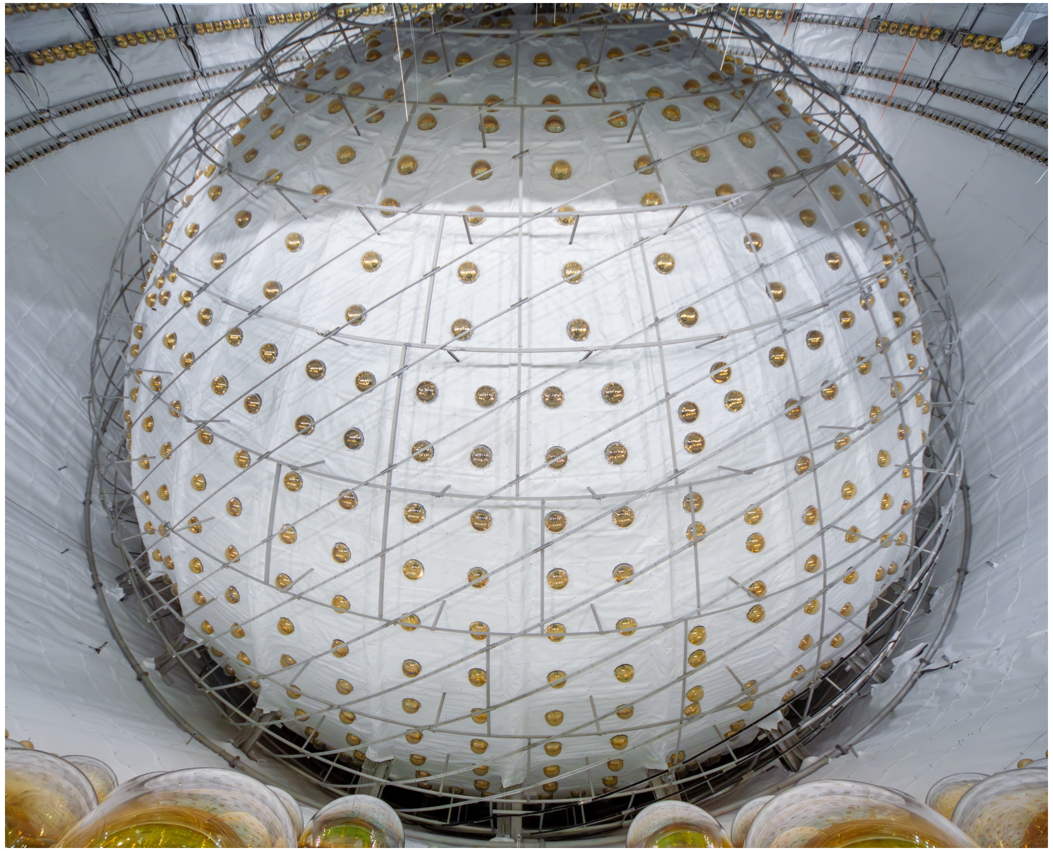
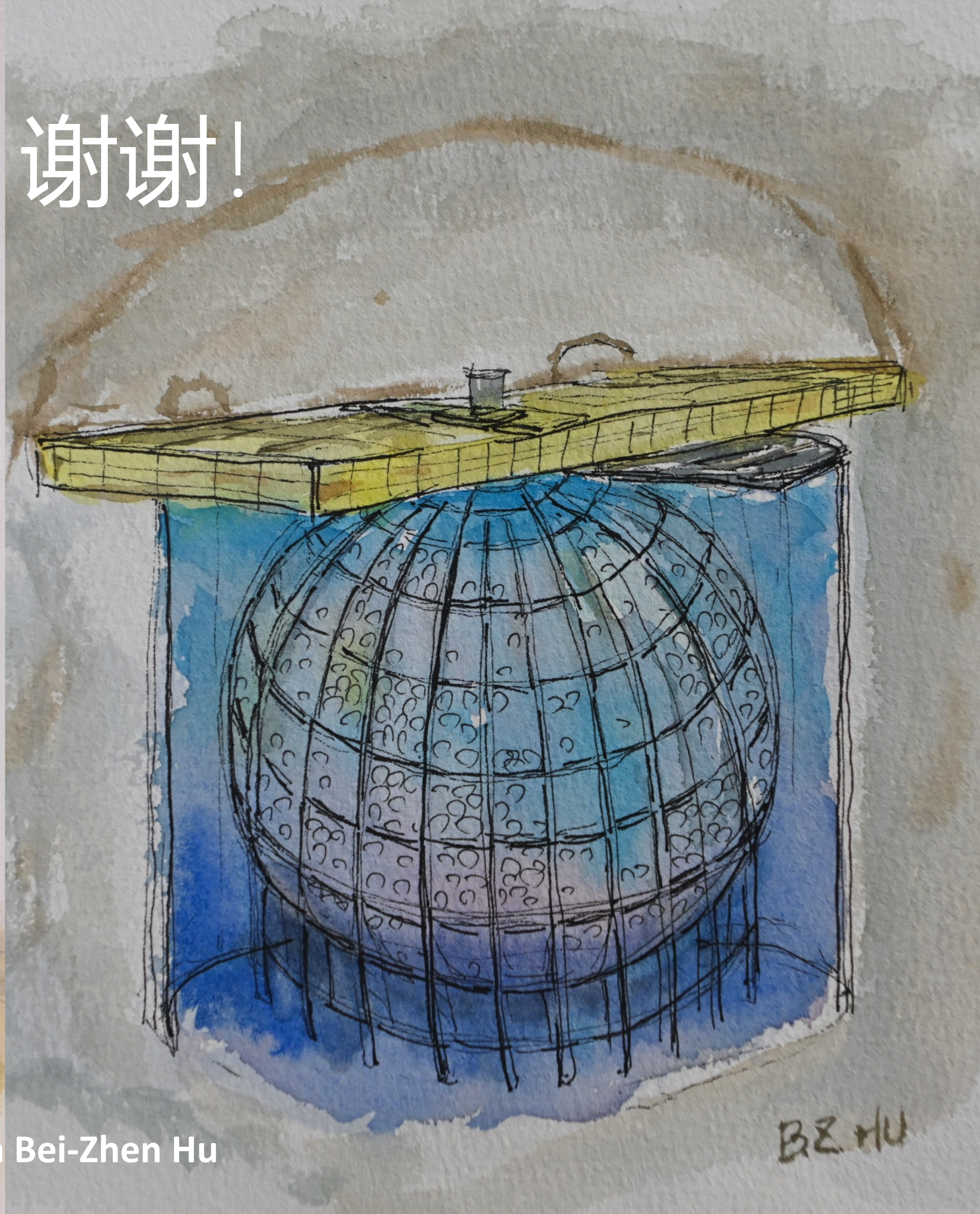
Summary and Outlook

- After 17 years efforts, construction of the JUNO detector is fully completed, despite numerous challenges
- Initial testing and performance studies show that key specifications have been mostly met, such as LS transparency, radiopurity, light yield, linearity and energy resolution
- We are excited to have started the physics data-taking: results shown are fresh obtained after few days of calibration and data taking
- Results from reactor neutrinos will come soon
- Other results on astrophysics will come later



Thanks for your attention! 谢谢！



Drawings from Bei-Zhen Hu