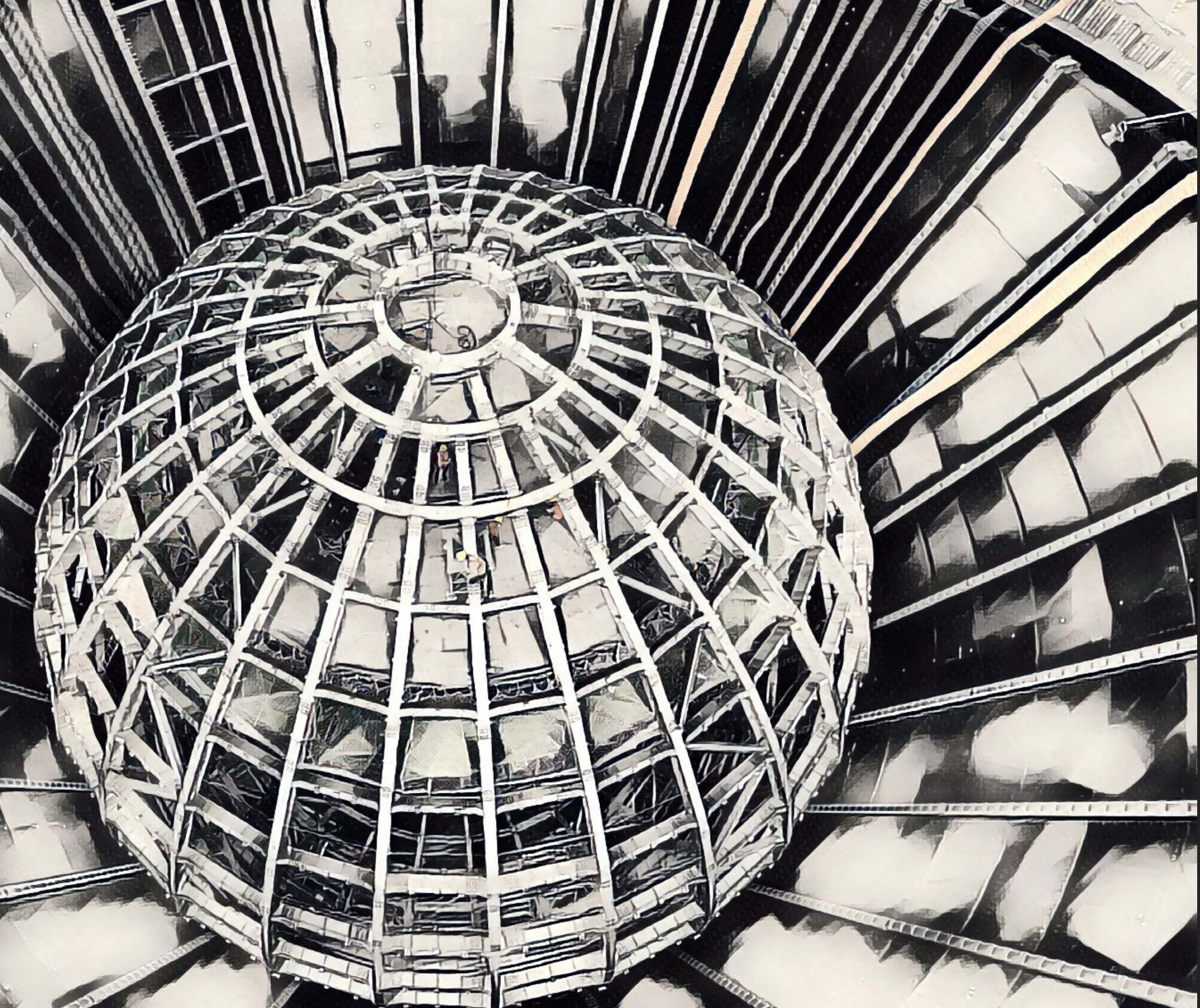

The JUNO detector: design concept and status

Alessandra Carlotta Re

for the JUNO collaboration

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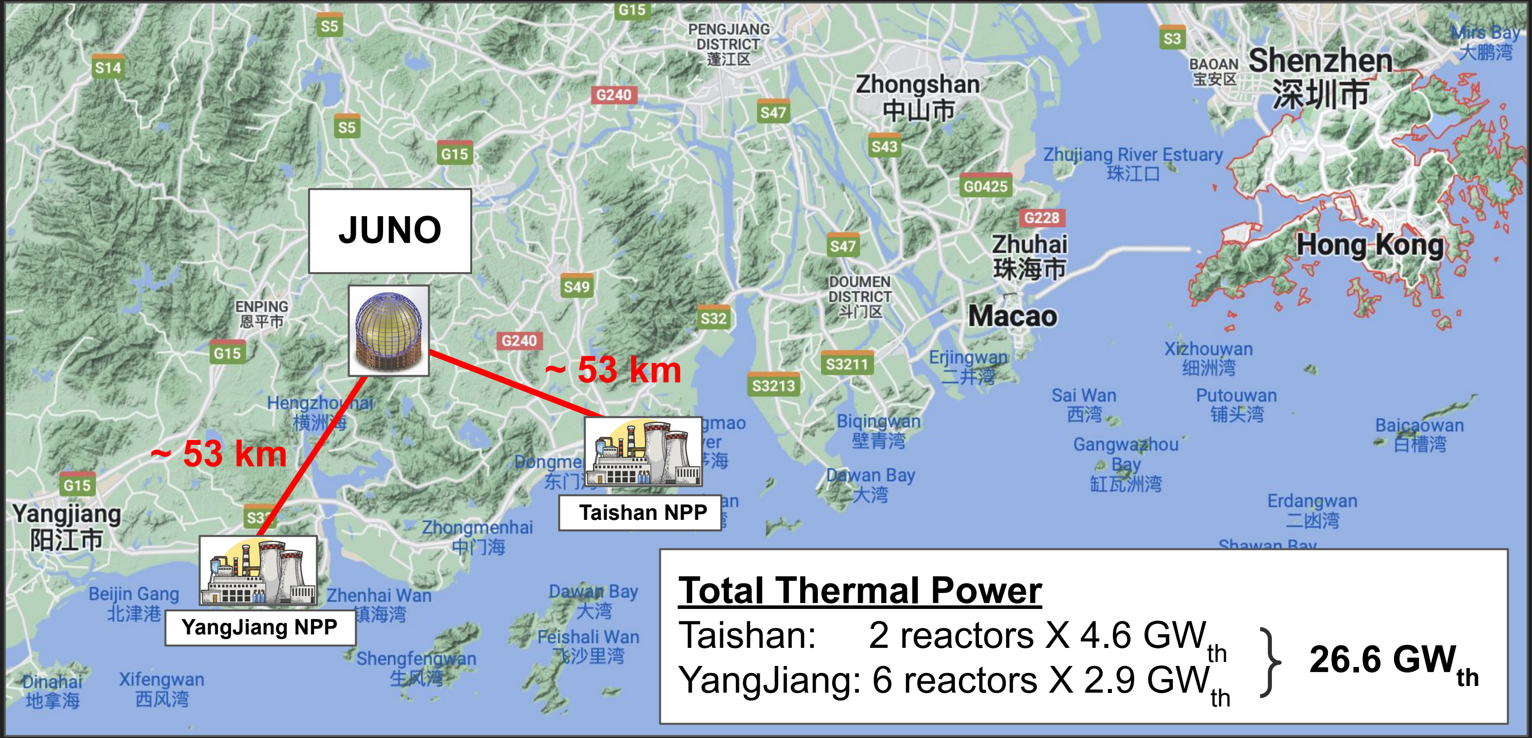
The Jiangmen underground laboratory

The Jiangmen underground laboratory



Total Thermal Power

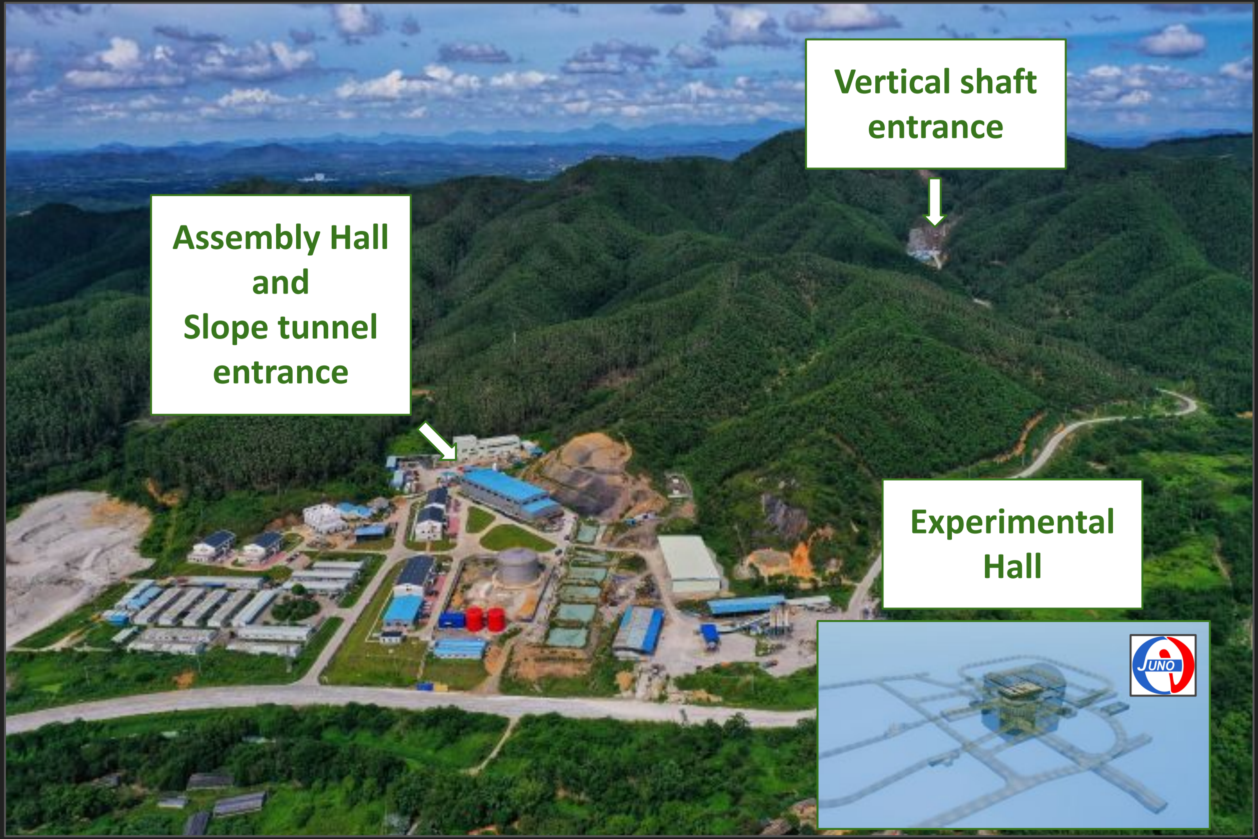
Taishan: 2 reactors X 4.6 GW_{th}

YangJiang: 6 reactors X 2.9 GW_{th}

} **26.6 GW_{th}**

The Jiangmen underground laboratory

The Jiangmen underground laboratory



The Jiangmen underground laboratory

Why to perform neutrino physics underground?

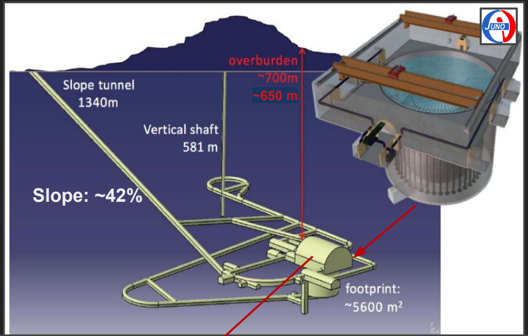
The JUNO experimental hall is located below an average rock cover of about 650 m: the shielding capacity against cosmic rays is about 1800 m.w.e.

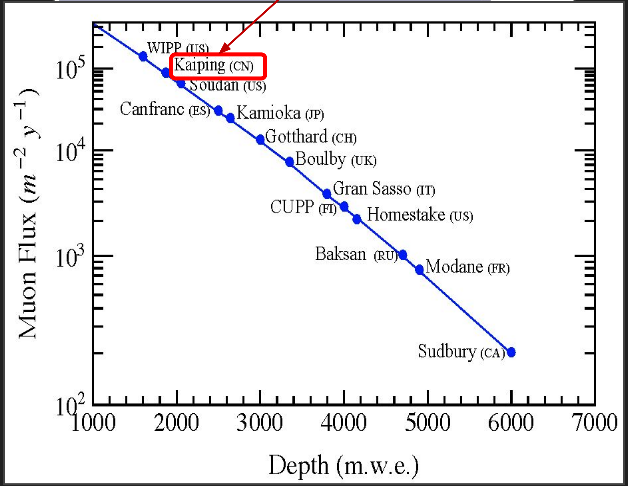
Expected muon flux in JUNO:

$$\Phi(\mu) \sim 0.004\ \mu/\mathrm{m}^2/s \rightarrow 10^5\ \mu/\mathrm{m}^2/y$$

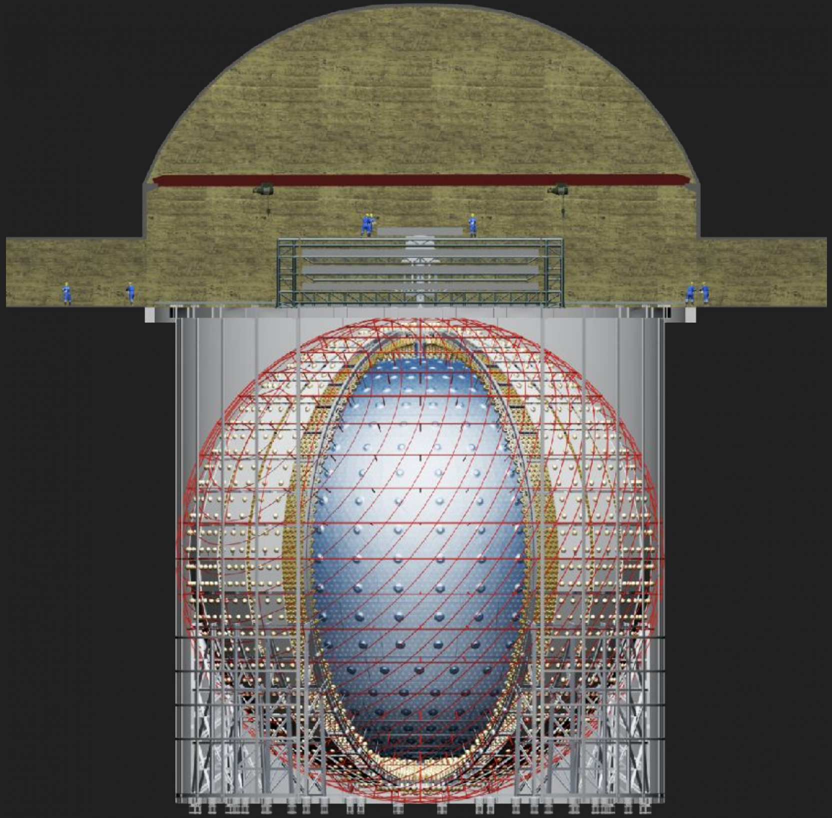
Prog. Part. and Nucl. Phys 123 (2022) 103927

To fulfill its rich physics program (previous talk: "JUNO's physics prospects" by Jie Cheng) JUNO needs to reach the target radiopurity from its very beginning!





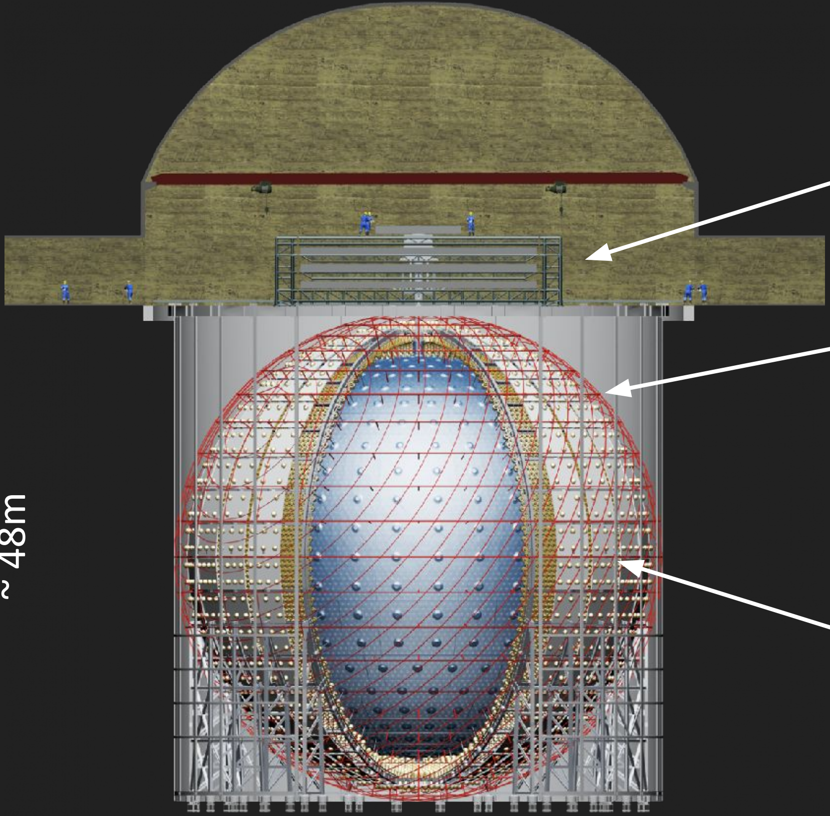
The JUNO detector



The JUNO detector

Torre Garisenda (Bologna)

~ 48m



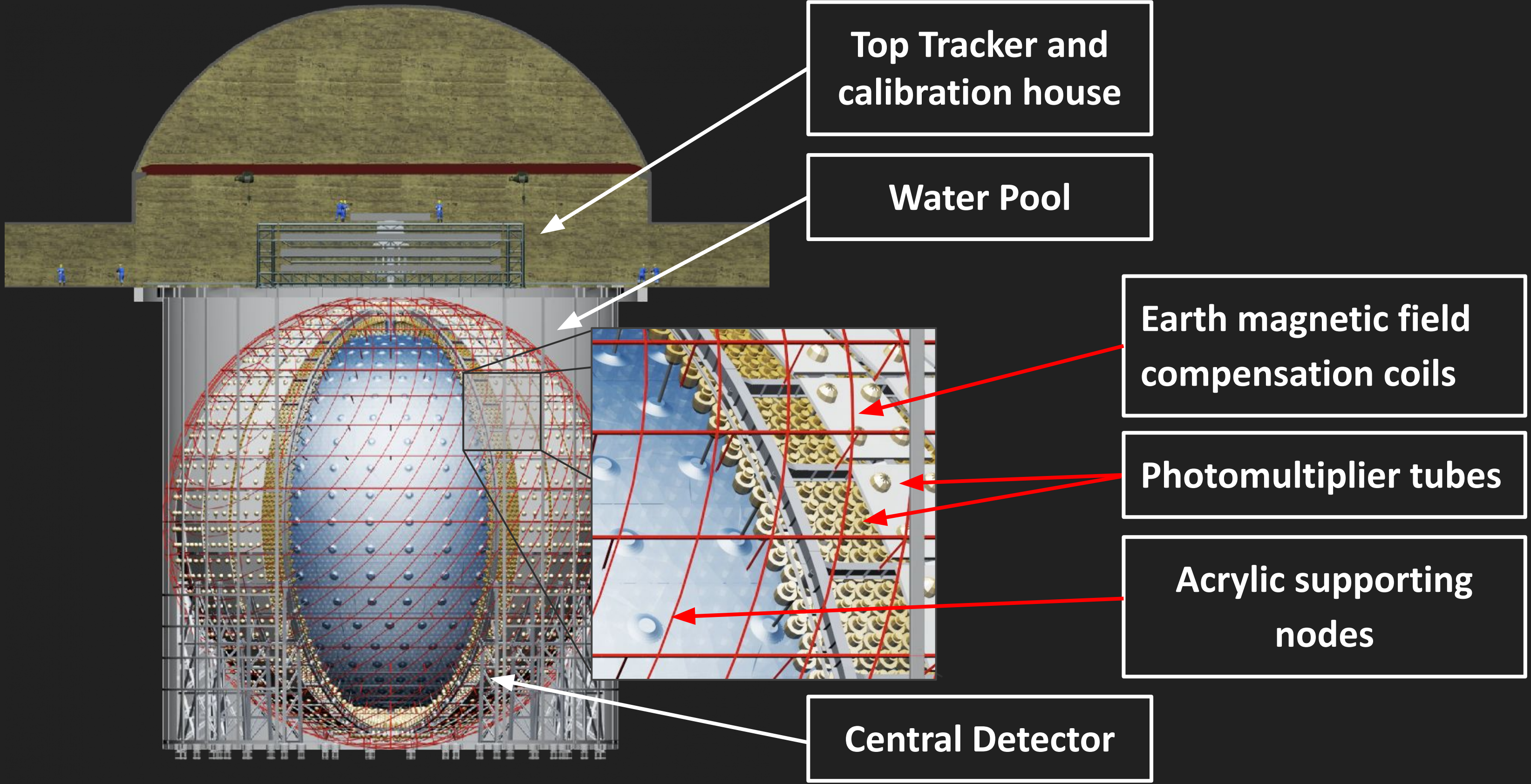
Top Tracker (TT) and calibration house

Water Pool (WP) a.k.a. Water Cherenkov Detector

Central Detector (CD)

Acrylic spherical vessel filled with 20 kton of LAB based liquid scintillator

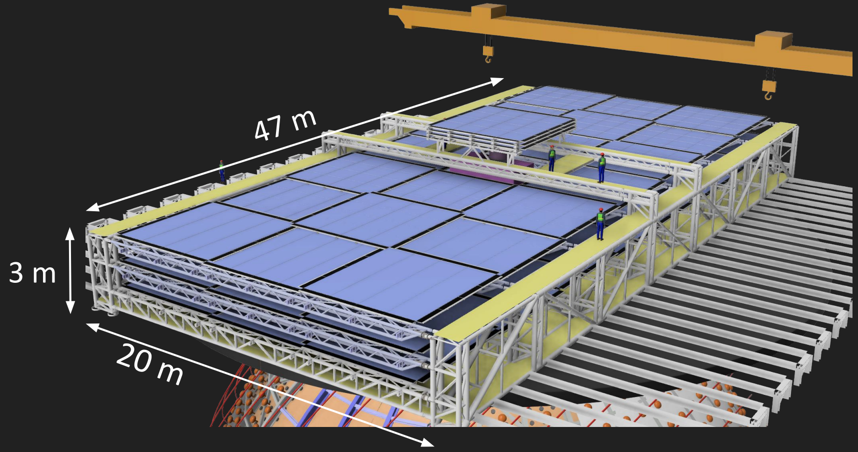
The JUNO detector



The Top Tracker

- **Goals:**
  1. Precise muon tracking
  2. Study of the cosmogenic background.

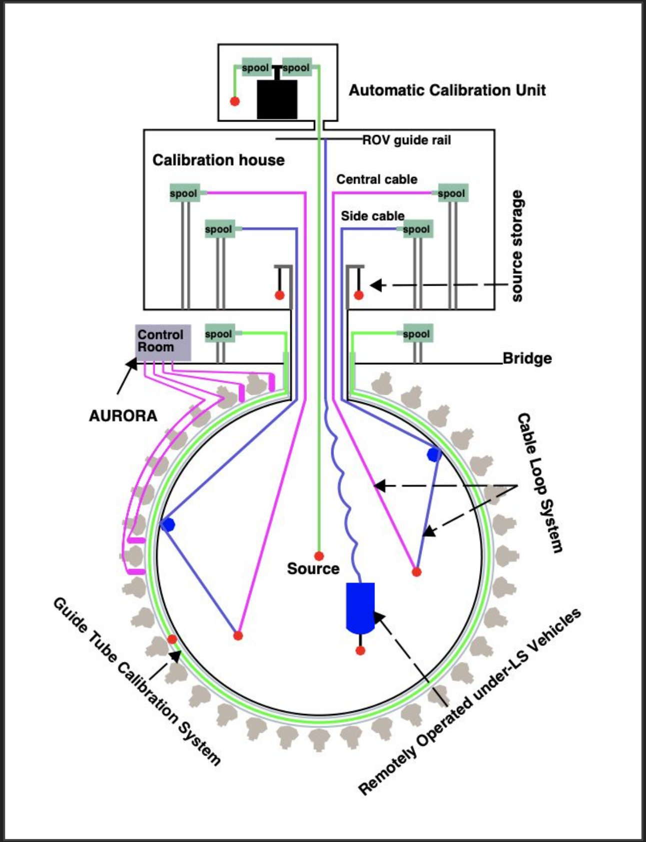
  The TT will cover 1/3 of all atmospheric muons passing through the CD (60% top of the WP) → provide well μ reconstructed samples for other systems.



- **Detection medium:** 3 layers of plastic scintillator.
  Environmentally friendly! We refurbished the plastic scintillators from OPERA Target Tracker.

- **Status:**
  All plastic scintillator modules already in China.
  New supporting structure designed.
  Finishing up electronics development/firmware.

The Calibration house



Motivation: to control energy scale, to study detector response non-uniformity and energy non-linearity

How: different scan systems

1D: Automatic Calibration Unit

2D: Cable Loop System, Guide Tube Calibration System

3D: Remotely Operated Vehicle

With: Several radioactive sources (γ, e^+, n) @ different energies (from ~0.5 MeV to ~8 MeV)

The Water Cherenkov Detector

The VETO System of JUNO consists in the Top Tracker + Water Cherenkov Detector.
See poster by Eric Baussan (P103)

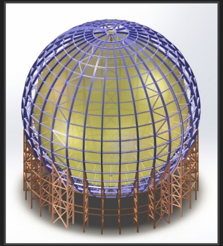
Main features:

- 35 kton ultrapure water
- 2400 20'' PMTs
- μ detection eff. > 99.5%
- Passive shield for natural radioactivity

Requirements:

- $^{222}Rn < 10\ mBq/m^3$
- Stable temperature: (21 ± 1) ^{0}C
- Attenuation length: ~35 m

The Central Detector - Support Structure (SS)



Geometry: 40.1 m diameter

The assembly of the SS is finished and we are now starting to install the acrylic sphere.

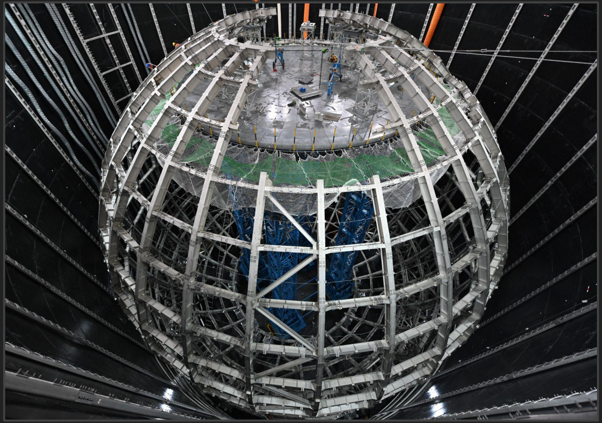
The acrylic sphere will be supported by 590 connecting bars

Assembly precision: < 3 mm for each grid!

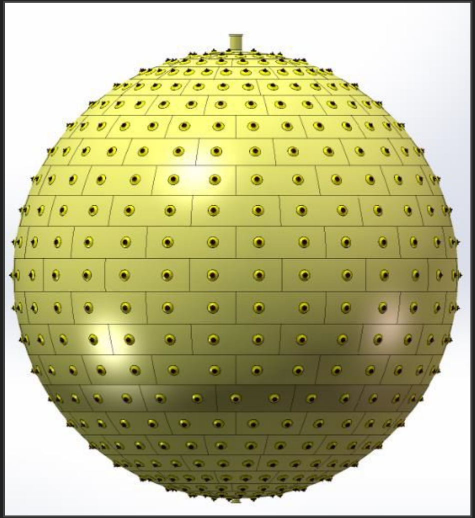
The Support Structure assembly

April 2022

June 2022



The Central Detector - Acrylic Sphere



Main features:

- Geometry: 35.4 m diameter
- Structure: 265 Acrylic plates
- Thickness: (124 ± 4) mm
- Radiopurity: U/Th/K < 1 ppt
- Light transparency > 96%

  (in LS, after installation).

The plates (up to 8m x 3m) are pre-assembled at the production factory (Donchamp).

The Central Detector - Acrylic Sphere

Each acrylic plate has been:

1. polished
2. cleaned
3. PE protective film added.

The film will be removed before the Liquid Scintillator filling.

The Central Detector - PhotoMultipliers

Main features:

- CD: 17612 - 20” PMTs (γ det. efficiency ~ 30%) } ~ 43200 PMTs
  25600 - 3’’ PMTs (γ det. efficiency ~ 25%)
- Assembly precision: < 1 mm
- Clearance between PMTs: 3 mm

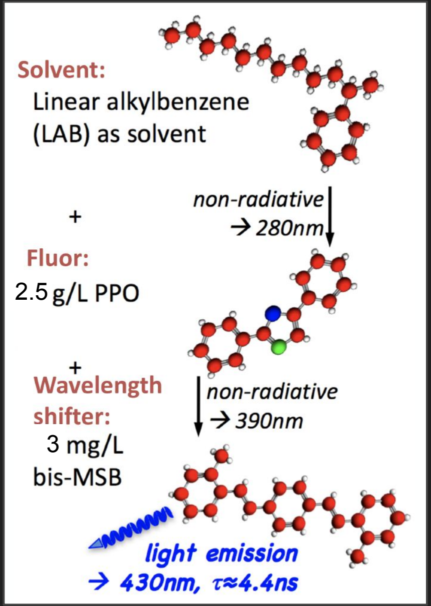
➡ Largest PMT coverage to date: 78% active surface

All PMTs were produced, tested, and instrumented with waterproof potting.

Underwater electronics to improve signal-to-noise ratio: assembly ongoing.
→ JUNO will profit of an unprecedented light level for a PMT-based detector: ~1665 pe/MeV expected.

For more informations about PMTs and electronics, see posters by Vanessa Cerrone (P106), Riccardo Triozzi (P109), and Zhonghua Qin (INDICO ref. #853).

The Central Detector - Scintillator



Main features:

- Solvent: Linear Alkyl Benzene (LAB)
- Doping: 2.5 g/L PPO (fluor)
  + 3 mg/L bis-MSB (wavelength shifter).
- Attenuation length: > 20 m @ 430 nm (measured)
- Radiopurity: highly radiopure LS required
  10^{-15} g/g in U/Th for reactor antineutrinos physics;
  10^{-17} g/g in U/Th for solar neutrinos physics;
- Scintillator light yield: ~10^4 phot/MeV.

Further details on the JUNO scintillator characterization can be found in the poster by Federico Ferraro (P110).

About the scintillator - further details

The JUNO experiment: a recap

JUNO is going to be the largest ever liquid scintillator (20 kton) experiment, equipped with ~43200 PMTs to collect scintillation light. The detector construction will be completed by the end of 2023.

Key features:

1. Large mass of ultrapure liquid scintillator.
2. Low background levels:
   - Cosmic ray natural shielding of ~ 1800 m.w.e.;
   - Material screening;
   - Passive shielding;

   } → Internal radiopurity → background suppression;
   - Careful installation procedure & clean environment.
3. Very high energy resolution:
   - Scintillator light yield (~10^4 phot/MeV);
   - PMTs coverage (78%);
   - High transparency of the liquid scintillator;
   - Comprehensive calibration program.

The JUNO timeline so far…

2014

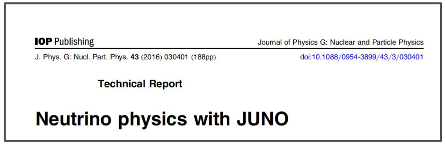
The JUNO Collaboration is established

2015

- PMT production line setup
- CD parts R&D
- Civil construction started

2016

- PMT production start
- CD parts productions start
- Yellow book published



IOP Publishing — Journal of Physics G: Nuclear and Particle Physics

J. Phys. G: Nucl. Part. Phys. 43 (2016) 030401 (188pp) — doi:10.1088/0954-3899/43/3/030401

Technical Report

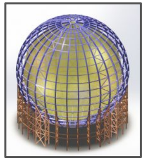
Neutrino physics with JUNO

2017

- PMT testing start
- TT arrived

2018

- PMT potting
- Surface building delivery start
- Acrylic sphere production start



2019-2020

- Electronics production start
- Covid19 Pandemic DELAYS

2021

- Civil construction and Lab preparation completed

2022-2023

- Distillation plants assembly
- Detector completion

Ready to start!

July 2022: we are almost ready!

The JUNO experiment @ ICHEP 2022: detector-related posters

- **[P103] Eric Baussan:** The Veto System of the JUNO Experiment
- **[P106] Vanessa Cerrone:** Characterization of JUNO Large-PMT electronics in a complete small scale test setup
- **[P110] Federico Ferraro:** Improved measurements of timing and optical properties of the JUNO liquid scintillator with SHELDON
- **[P109] Riccardo Triozzi:** Mass testing of Large-PMT electronics at Kunshan for the JUNO experiment
- **[#853] Zhonghua Qin:** Overall status of 20-inch PMT Instrumentation for the JUNO experiment
  online only

About the scintillator - further details

Reduced by 15% compared to the design. Ref: *JHEP* 11 (2021) 102

Singles (R < 17.2 m, E > 0.7 MeV)	Design [Hz]	Change [Hz]	Comment
LS	2.20	0	
Acrylic	3.61	-3.2	10 ppt -> 1 ppt
Metal in node	0.087	+1.0	Copper -> SS
PMT glass	0.33	+2.47	Schott -> NNVT/Ham
Rock	0.98	-0.85	3.2 m -> 4 m
Radon in water	1.31	-1.25	200 mBq/m^3 -> 10 mBq/m^3
Other	0	+0.52	Add PMT readout, calibration sys
Total	8.5	-1.3	

Radiopurity control on raw material:

- ✓ Careful material screening
- ✓ Meticulous Monte Carlo Simulation
- ✓ Accurate detector production handling

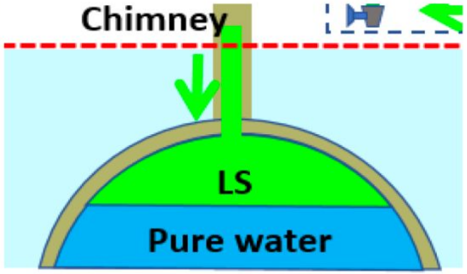
Liquid Scintillator Filling

✓ Recirculation is impossible at JUNO due to its large size

→ Target radiopurity need to be obtained from the beginning

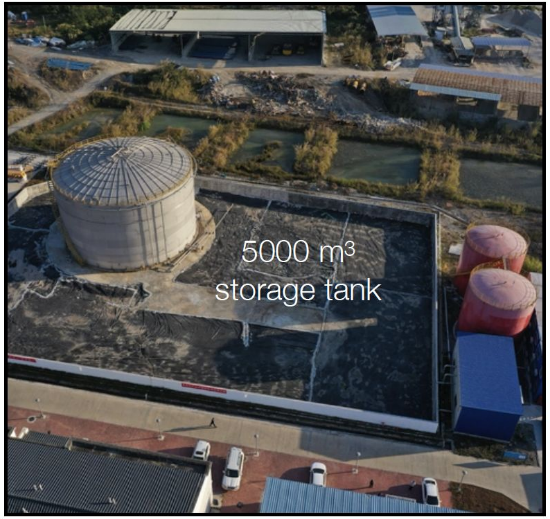
✓ **Strategies:**

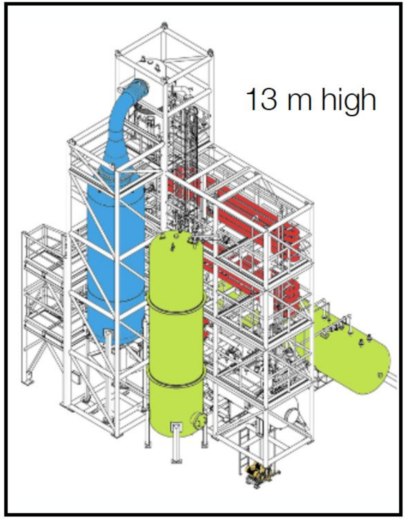
1. **Leakage** (single component < 10^{-6} mbar·L/s)
2. **Cleaning vessel** before filling
3. **Clean environment**
4. **Water/LS filling**



About the scintillator - further details(3)

Marco Grassi
-
Talk @
LaThuile 2022





Radioactive contaminants yield background events → Purification

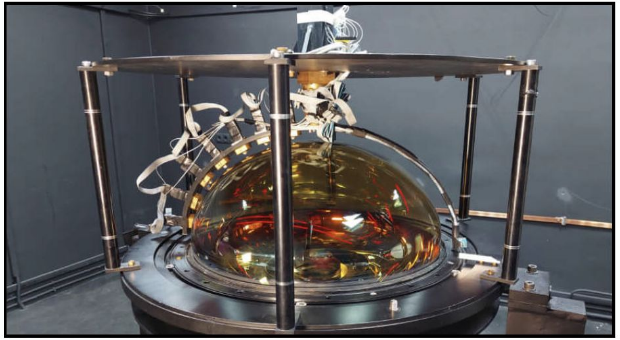
JHEP 11 (2021) 102

Requirements	^{238}U	^{232}Th	^{226}Ra	^{40}K	^{210}Pb(^{222}Rn)	^{85}Kr / ^{39}Ar
Reactor physics	10^{-15} g/g	10^{-15} g/g		10^{-16} g/g	10^{-22} g/g	
Solar physics	10^{-17} g/g	10^{-17} g/g	$5 \cdot 10^{-24}$ g/g	10^{-18} g/g	10^{-24} g/g	1μBq/m³

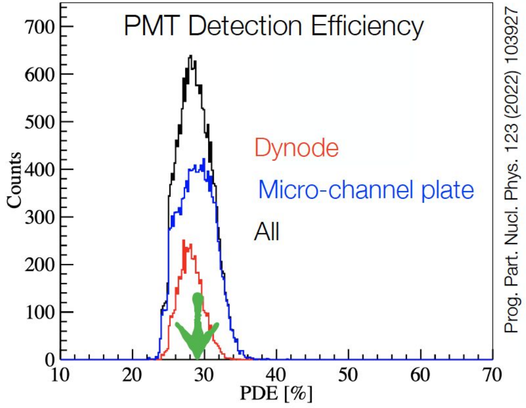
About the PhotoMultipliers - further details

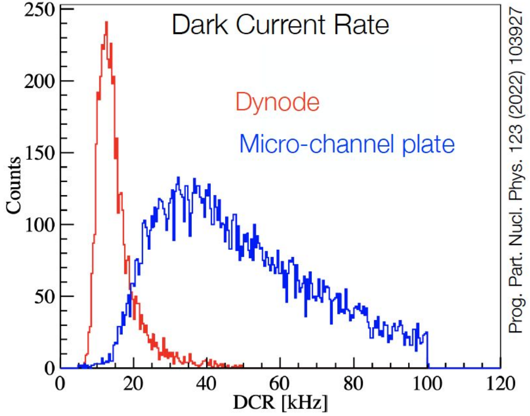
Marco Grassi
-
Talk @
LaThuile 2022

20-inch (large) photomultiplier tubes (PMTs)

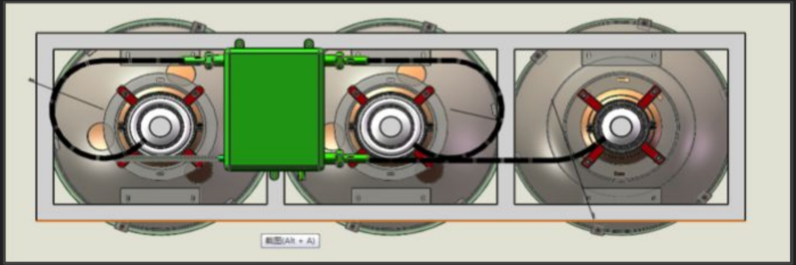


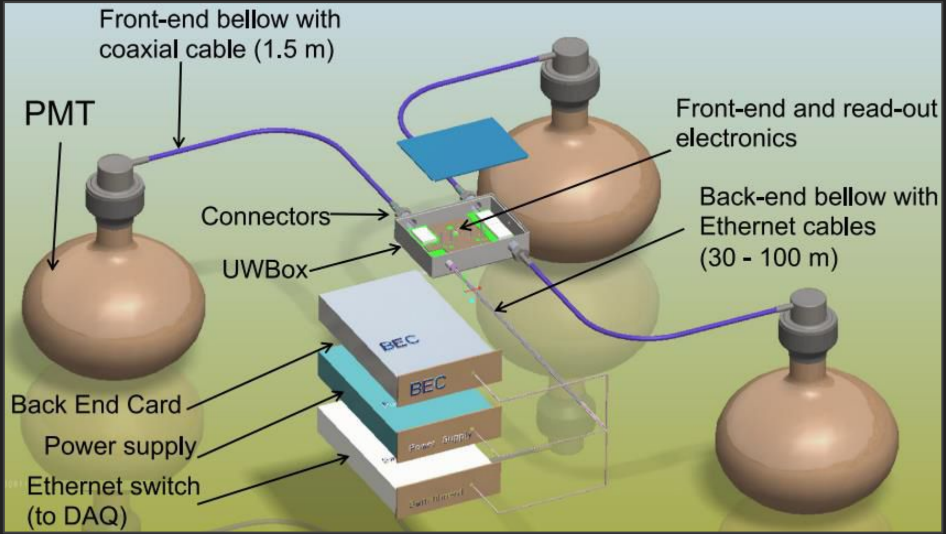
Quantity	~5000	~15000
Manufacturer	Hamamatsu (JP)	NNTV (CN)
Photocatode	Upper hemisphere	Both hemispheres
Charge Collection	Dynode	Micro-channel plate
Transit Time Spread	σ 1.2 ns FWHM 2.8 ns	σ 9.1 ns FWHM 21.5 ns





The JUNO Central Detector electronics





3 20-inch PMTs connected to one underwater box

128 3-inch PMTs connected to one underwater box

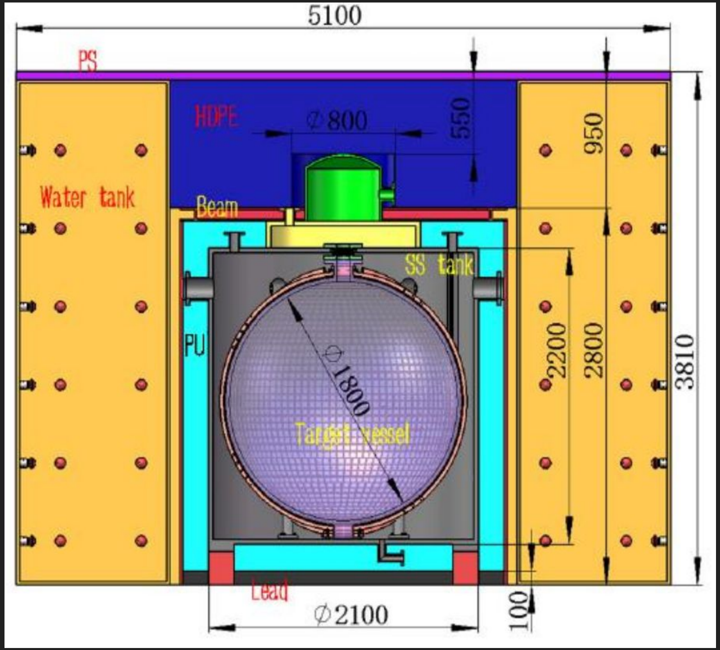
Electronics assembly is currently ongoing

TAO (Taishan Antineutrino Observatory)

High resolution anti-neutrino detector, located at 30 m from one of the Taishan reactor cores

2.6 ton Gd-doped LS detector at 30 m from a Taishan reactor core (4.6 GW)

- >95% photo-coverage
- Measure the reactor antineutrino spectrum at % level → model-independent reference spectrum for JUNO
- Benchmark measurement for the nuclear database
- Effective light yield: 4500 p.e./MeV → energy resolution ~ 1.8%/√E (MeV)



TAO CDR: https://doi.org/10.48550/arXiv.2005.08745

OSIRIS

(Online Scintillator Internal Radioactivity Investigation System)

A 20-t detector to monitor radiopurity of LS before and during filling to the central detector

- ✓ Few days: U/Th (Bi-Po) ~ 1×10^{-15} g/g (reactor baseline case)
- ✓ 2~3 weeks: U/Th (Bi-Po) ~ 1×10^{-17} g/g (solar ideal case)
- ✓ Other radiopurity can also be measured: ^{14}C, ^{210}Po and ^{85}Kr

Expect to start commissioning in July.

Eur.Phys.J.C 81 (2021) 11, 973