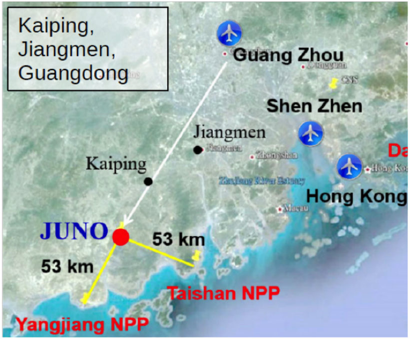
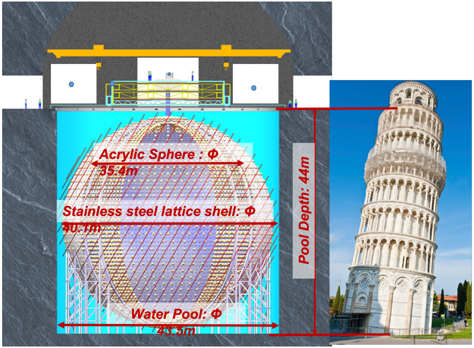
Status and Prospects of the Jiangmen Underground Neutrino Observatory (JUNO)

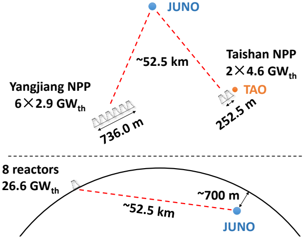
Alberto Garfagnini - Università di Padova
on behalf of the JUNO Collaboration

JUNO in a nutshell

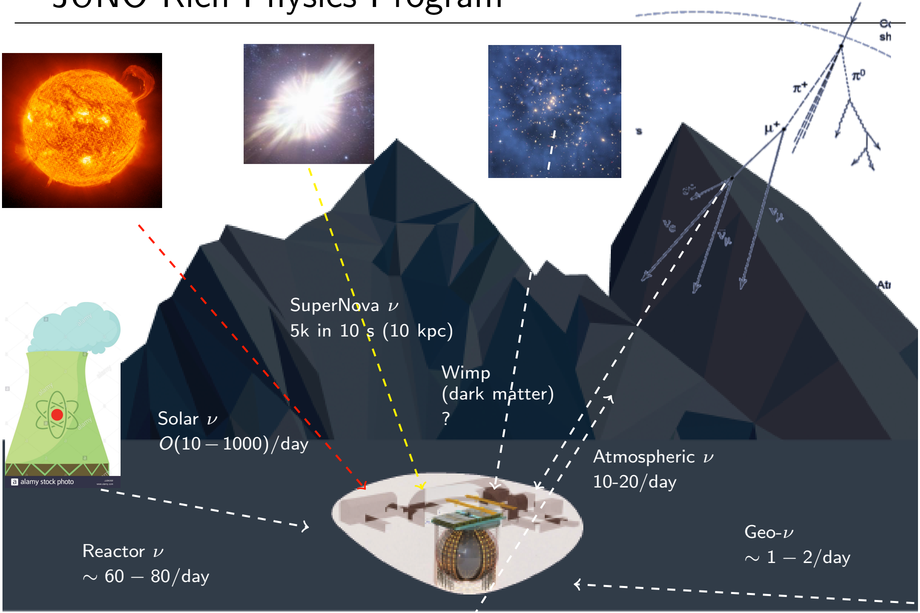
- it's going to be the largest ever built liquid scintillator (LS) detector for neutrino and rare events physics (including dark matter)
- the main target is the determination of the neutrino mass hierarchy, one of the still unanswered questions in neutrino physics
- thanks to the large mass (20 kt) and overburden (1800 m.w.e.), JUNO will be able to exploit several neutrino physics channels







JUNO Rich Physics Program



F. An et al., *Neutrino Physics with JUNO*, J. Phys. **G 43** (2016) 030401, arXiv:1507.05613

A. Abusleme at al., *JUNO Physics and Detector*, accepted by Prog. Part. Nucl. Phys., arXiv:2104.02565

Reactor neutrino disappearance

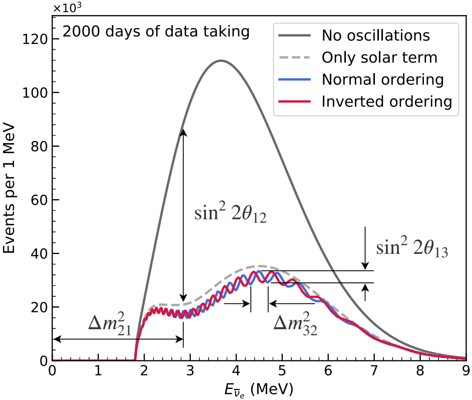
- detector reactor $\overline{\nu}_e$ JUNO will

➜ determine neutrino mass ordering, at $\sim 3-4\sigma$ with 6 years of reactor data

- the measurement is independent of δ_{CP} and $\sin^2\theta_{23}$
- better sensitivities can be obtained with constraints from long baseline experiment measurements

➜ measure at sub-percent level the neutrino oscillation parameters

- $\sin^2 2\theta_{12}$, Δm^2_{21} and $|\Delta m^2_{32}|$



The measurement is challenging

- JUNO needs an unprecedented 3% energy resolution at 1 MeV

➜ large PMT coverage (75%), high photoelectron statistics and detection efficiency

- and energy scale uncertainties controlled at sub-percent level

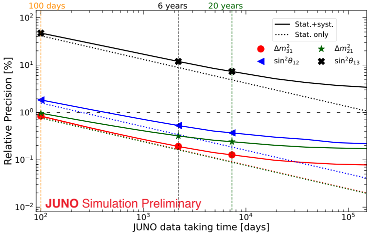
➜ redundant calibration strategies with light and racioactive sources using large (20") and small (3") PMTs

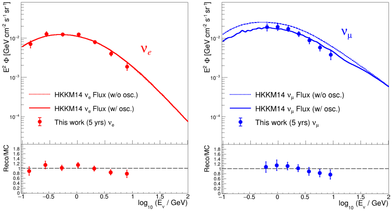
A. Abusleme et al., *Calibration Strategy of the JUNO experiment*, JHEP **03** (2021) 04, arXiv:2011.06405

JUNO has a rich physics potential

Expected sensitivity on neutrino oscillation parameters

A. Abusleme et al., accepted by Eur. Phys. J. C; **arXiv:2103.09908**

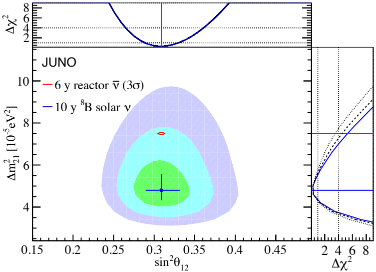




atmospheric neutrinos

A. Abusleme et al., Chin. Phys. **C 45** (2021) 023004; **arXiv:2006.11760**

solar neutrinos



And several other physics channels:
- geo-neutrinos
- supernovae neutrinos
- diffuse supernova ν background
- proton decay

A. Abusleme at al., *JUNO Physics and Detector*, accepted by Prog. Part. Nucl. Phys., **arXiv:2104.02565**

The JUNO detector

Top Tracker

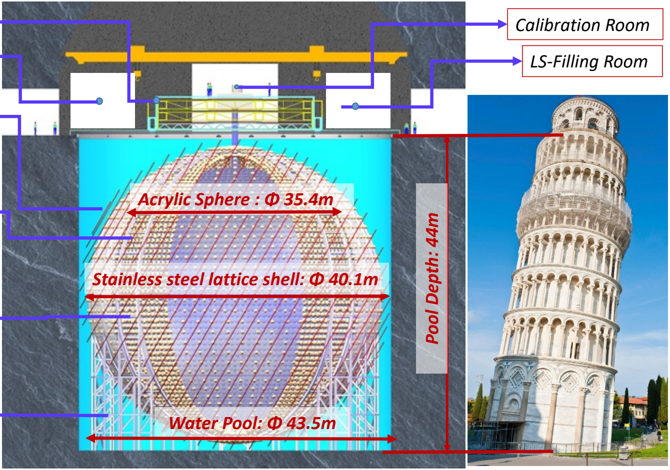
Pure water Room

Earth Magnetic Field shielding coils

Central detector:
- *Steel structure*
- *Acrylic Sphere*
- *20kton LS*

PMT:
- *17612 20'' PMTs*
- *25600 3'' PMTs*
- *77.5% Coverage*

VETO:
- *40 kton Pure water*
- *2400 20'' PMTs*



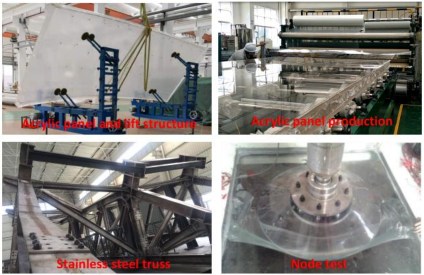
Calibration Room

LS-Filling Room

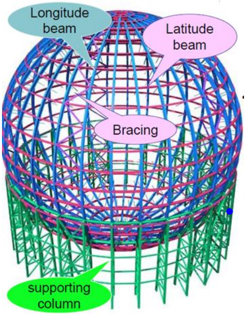
The JUNO Central Detector (CD)

Acrylic spherical vessel

- 35.4 diameter acrylic sphere, made of 8 m × 3 m × 12 cm
- 265 total panels
- 590 connecting nodes
- total weight: 600 t acrylic, 600 t steel structure



Acrylic sphere + SS truss



The Liquid Scintillator

- solvent: Linear Alkyl Benzene
- LS doping: 2.5 g/l PPO + 3 mg/l bis-MSB
- long attenuation length measured: > 20 m at 430 nm

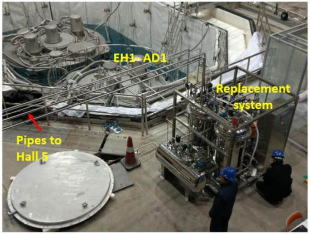
- a LS purification pilot plant built and commissioned at Daya Bay
  (A. Abusleme *et al.*, JUNO + Daya Bay Collaborations, Nucl. Instr. Meth. **A 988** (2021) 164823; arXiv: 2007.00314)

- highly radio-pure LS required:
- 10^{-15} g/g U/Th for reactor antineutrinos
- 10^{-17} g/g U/Th for solar neutrinos

- an online radio-purity measurement system, OSIRIS (Online Scintillator Internal Radioactivity Investigation System), will be built

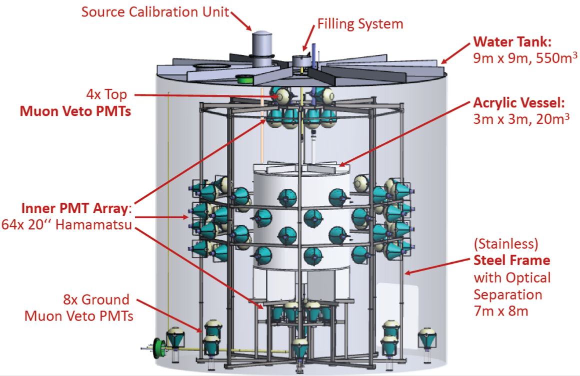
LS pilot plant at Hall 5

Experimental Hall 1



OSIRIS

- solvent: Linear Alkyl Benzene
- Online Scintillator Internal Radioactivity Investigation System (OSIRIS): monitor the radio-purity during LS filling, to monitor the quality of LS entering the JUNO CD
- Sensitivity: 10^{-16} g/g for U/Th within 24 h measurement. Measure $\sim$ 19 t LS per day
- Detector: 81 20" PMTs for photon detection;
- 2.5 m water shielding + 12 20" PMTs;
- to be installed by the end of 2021

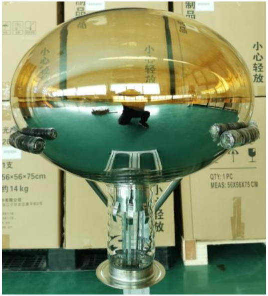


The OSIRIS Detector

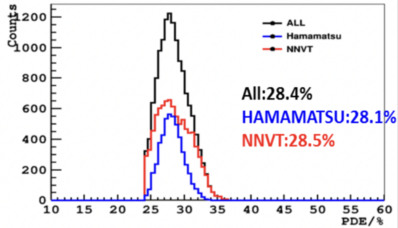
A. Abusleme et al., *The design and sensitivity of JUNO's scintillator radiopurity pre-detector OSIRIS*, accepted by Eur. Jour. Phys. C; arXiv:2103.16900

The 20" Large PMTs

- two types of 20" PMTs will be deployed in JUNO:
  - 15 k NNVT MCP-PMT, (central detector and veto)
  - 5 k Hamamatsu R12860 (central detector only)



- all PMTs have been delivered and tested (22416 PMTs tested)
- mass potting completed
- implosion protection cover mass production completed
- a high Photon Detection Efficiency has been achieved : 29.6% for all PMTs (MCP-PMTs 30%, dynode PMTs: 28.4%)



JUNO 20" PMT Electronics Specifications

Desiderata

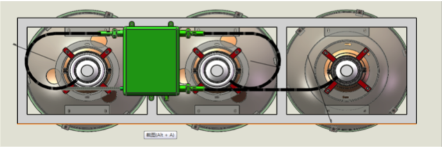
- provide the best possible energy measurement, especially at low energy ➜ essential for mass hierarchy discrimination
- measure with high precision the photons arrival time ➜ crucial for vertex reconstruction and μ track reconstruction/isolation in the central detector
- provide a large dynamic range, allowing not only to record the $\overline{\nu}_e$ coming from the reactors, but also atmospheric and geo-neutrinos, and neutrinos from a possible Supernova burst
- allow for a negligible dead-time, which is mandatory for the recording of Supernova events (lasting up to few seconds)
- install high reliability electronics (no access for repair after installation)

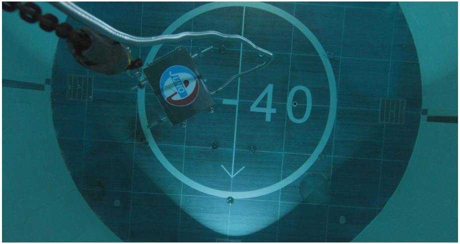
Specifications

- provide full waveform digitization with high speed (1 Gsample/s), high resolution (12-14 bits) ADC
- measure photon pulses with high resolution : $N_{pe} = 1 - 100$ pe with $\sigma = 0.1\sqrt{N_{pe}}$, and $\sigma = 1\%$ for $N_{pe} > 100$ Full dynamic range (charge): 1-1000 pe
- operate single PMT trigger at 50 kHz - 100 kHz single trigger rate, and allow to stand high rates for very short times (up to 1 MHz for 1 s)

JUNO large PMT Electronics Readout Scheme

LPMT installation module





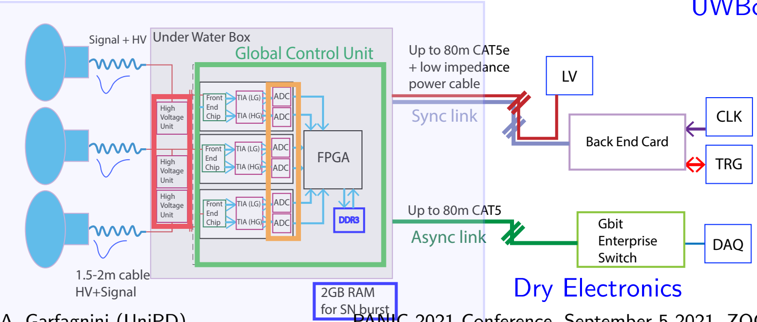
UWBox under water (-40 m)

Under Water Electronics

Custom HV (JINR) (0-3kV)/300uA

Custom ADC (Tsinghua) 12bit, 1Gsps

FPGA for Trigger and Signal Processing



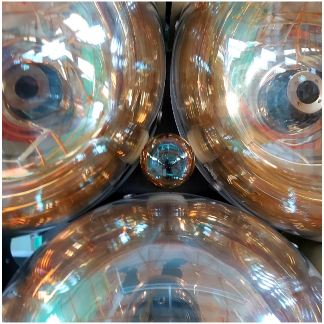
UWBox with electronics

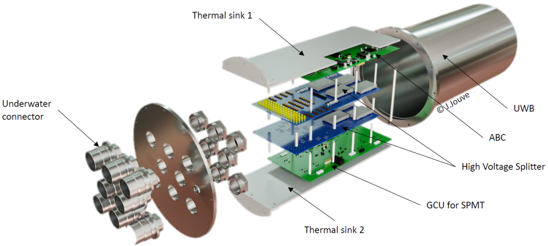
Dry Electronics

The 3" PMTs

- 25,600 3" PMTs will be deployed in JUNO
- XP72B22, custom made by HZC Photonics for JUNO

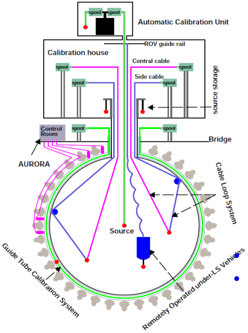
- it's a complementary system to crosscheck the 20" PMTs calibration
- operating in photon-couting mode for MeV energy deposits
- it's a complementary system also for supernova and solar neutrino oscillation parameter measurement
- all 26,500 3" PMTs produced, tested and accepted

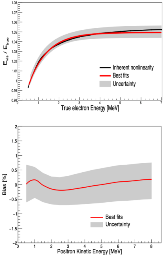


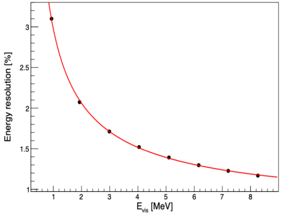


The JUNO calibration systems

- requirements: 3% energy resolution at 1 MeV and 1% energy scale uncertainty
- 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 systems: Calibration house, Ultrasonic Sensor System (USS), CCD and A Unit for Researching Online the LSc tRAnsparency (AURORA)







A. Abusleme et al., *Calibration Strategy of the JUNO experiment*, JHEP **03** (2021) 04, arXiv:2011.06405

The Taishan Antineutrino Observatory

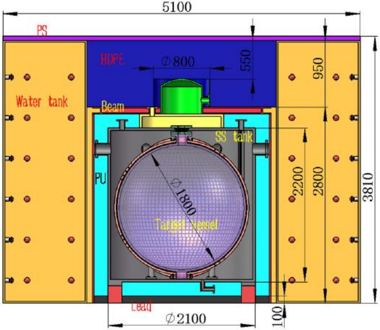
- it's a ton-level high resolution LS based neutrino detector
- located at about 30 m from one of the Taishan reactor cores

- it will allow to measure the reactor antineutrino spectrum:
- a model-independent reference spectrum for JUNO
- and will provide a benchmark measurement for the nuclear database

Detector design

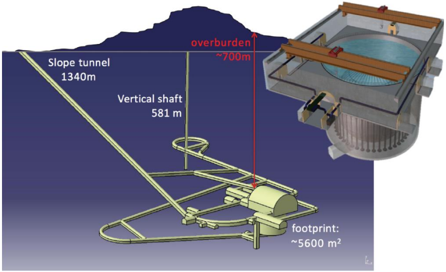
- 2.8 ton gadolinium-doped liquid scintillator
- 10 m^2 95% coverage with SiPM
- operate at -50°C (to reduce SiPM dark noise)
- photon detection efficiency $> 50\%$
- 4500 p.e./MeV
- 2000 reactor antineutrinos / day
- excellent energy resolution: 1.5% at 1 MeV and 1.7% below 2 MeV
- start operation in 2022

Conceptual Design Report: arXiv:2005.08745



JUNO laboratory civil construction

- slope tunnel and vertical shafts completed
- blasting completed in December 2020
- digging in the experimental hall cavern is completed



Conclusions

- JUNO will be the largest reactor neutrinos detector ever built (20 kton of LS) with unprecedent energy resolution (3% at 1 MeV)
- JUNO will measure mass hierarchy (3-4σ with 6 years data taking) and 3 neutrino oscillation parameters to sub-percent level
- JUNO also has a rich physics potential with supernova neutrinos, geo-neutrinos, solar and atmospheric neutrinos, proton decay and other exotic searches such as searches for sterile neutrinos

- the production of the different parts and the civil engineering are well underway
- production and assembly of electronics components is going on
- installation will start soon
- detector completion expected by the end of 2022