Status and perspectives of JUNO experiment

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On the behalf of JUNO collaboration

Outline

- ✓ Introduction on neutrino oscillation parameters and neutrino mass hierarchy
- ✓ The Jiangmen Underground Neutrino Observatory (JUNO) experiment: requirements
  - The JUNO detector
  - The JUNO PMT systems
  - The JUNO electronics
- ✓ Physics with JUNO
- ✓ The project schedule
- ✓ Summary

Neutrino oscillations

3 flavor eigenstates:
$|\nu_e\rangle, |\nu_\mu\rangle, |\nu_\tau\rangle$

3 mass eigenstates:
$|\nu_1\rangle, |\nu_2\rangle, |\nu_3\rangle$

They are mixed:

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

Pontecorvo – Maki – Nakagawa – Sakata (PMNS) matrix

The mixing matrix can be expressed as follow:

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{-i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} P_\nu,$$

$c_{ij} \equiv cos\theta_{ij},\ s_{ij} \equiv sin\theta_{ij}$

$P_\nu = Diag\left\{e^{i\rho}\ \ e^{i\sigma}, 1\right\}$ Majorana phase matrix, δ → CP violation phase

We don’t know:

- ✓ the value of δ;
- ✓ the **neutrino mass ordering;**
- ✓ if there are sterile neutrinos (physics beyond the SM).

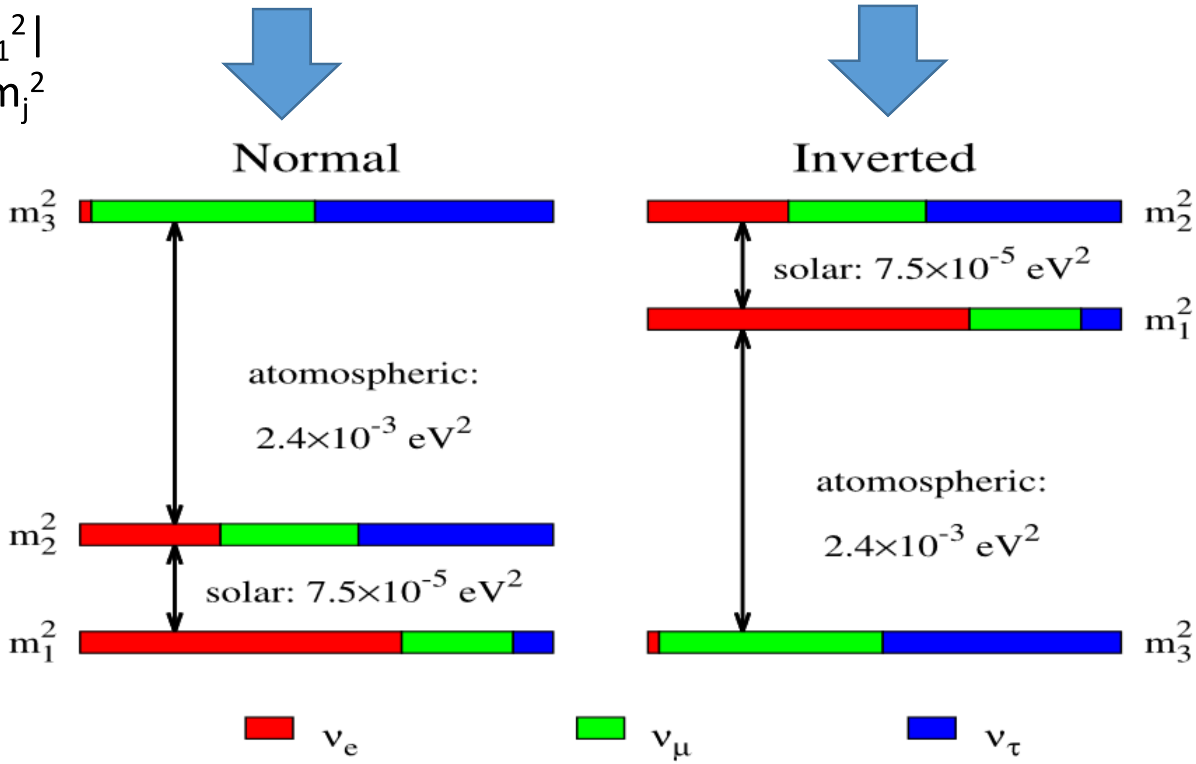
Neutrino mass hierarchy

ν_3 neutrino mass eigenstate is heavier or lighter than the ν_1 and ν_1 (fundamental aspect of SM lepton sector)?
Mass hierarchy determination impacts in the quest of the neutrino nature (Dirac or Majorana mass terms - theory of flavor).

We know:
$m_2 > m_1$
and
$|\Delta m_{31}^2| >> |\Delta m_{21}^2|$
where $\Delta m_{ij}^2 = m_i^2 - m_j^2$

We want to know:

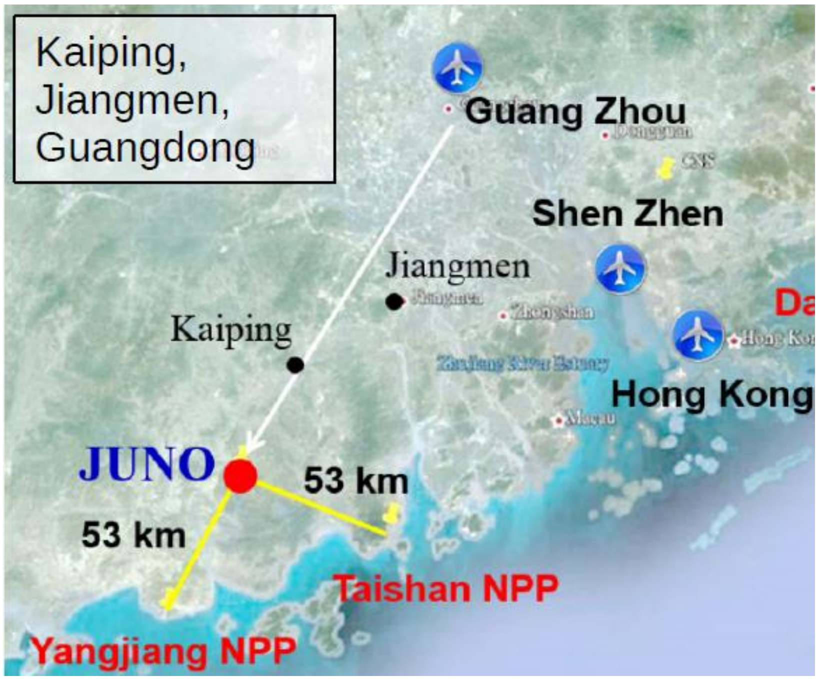
$m_3 > m_{1,2}$ or $m_3 < m_{1,2}$



JUNO Experiment

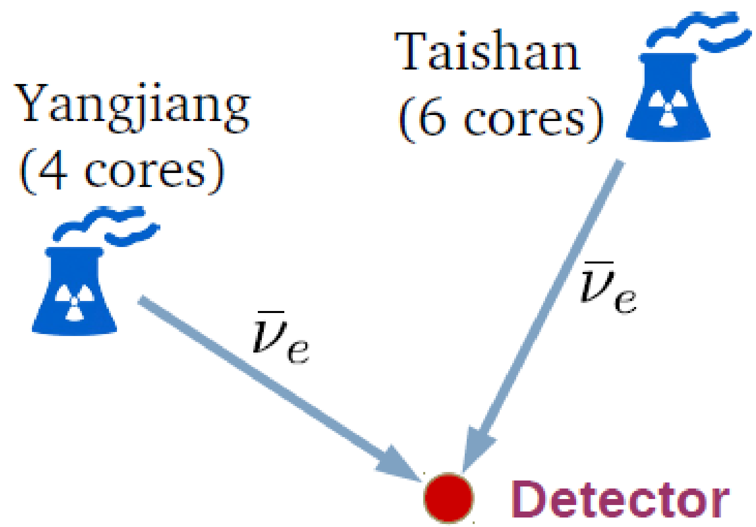
JUNO: Jiangmen Underground Neutrino Observatory

It is a large liquid scintillator neutrino detector under construction in the south of China.



$\bar{\nu}_e$ source: 2 nuclear power plants at ~53 km distance, 10 cores, total of 35.8 GW thermal power (26.6 GW by start of data taking around 2020).

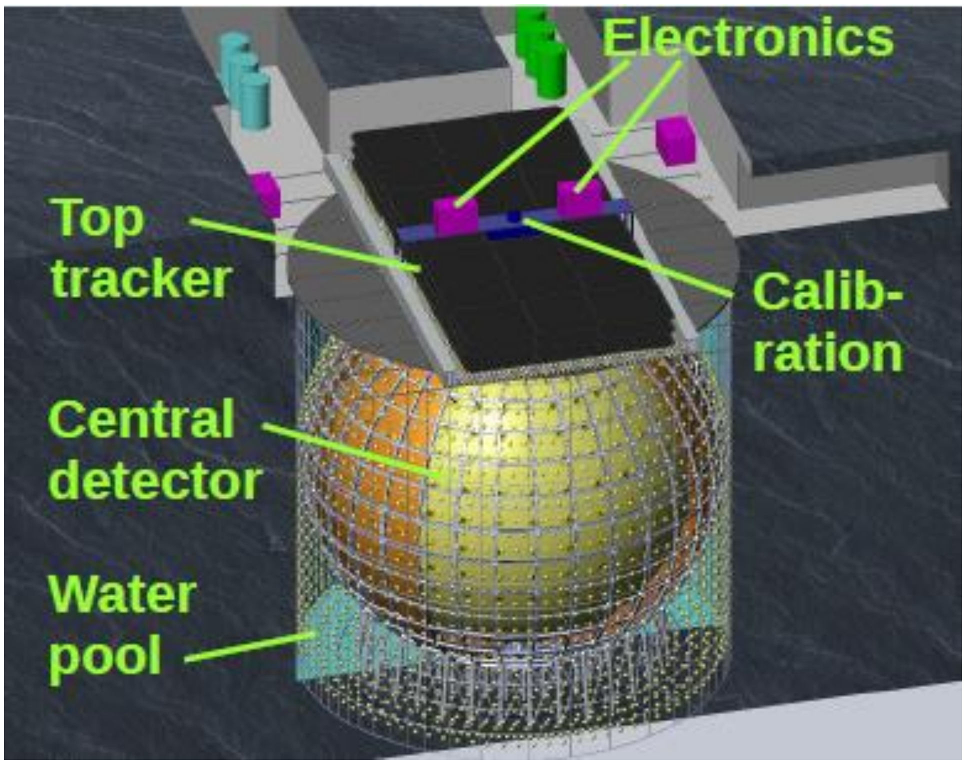
Detector site chosen with respect to optimal mean distance to the cores



- ✓ Detection channel: $\bar{\nu}_e + p \rightarrow e^+ + n$
- ✓ Expected $\bar{\nu}_e$ event rate: 83 per day

JUNO detector

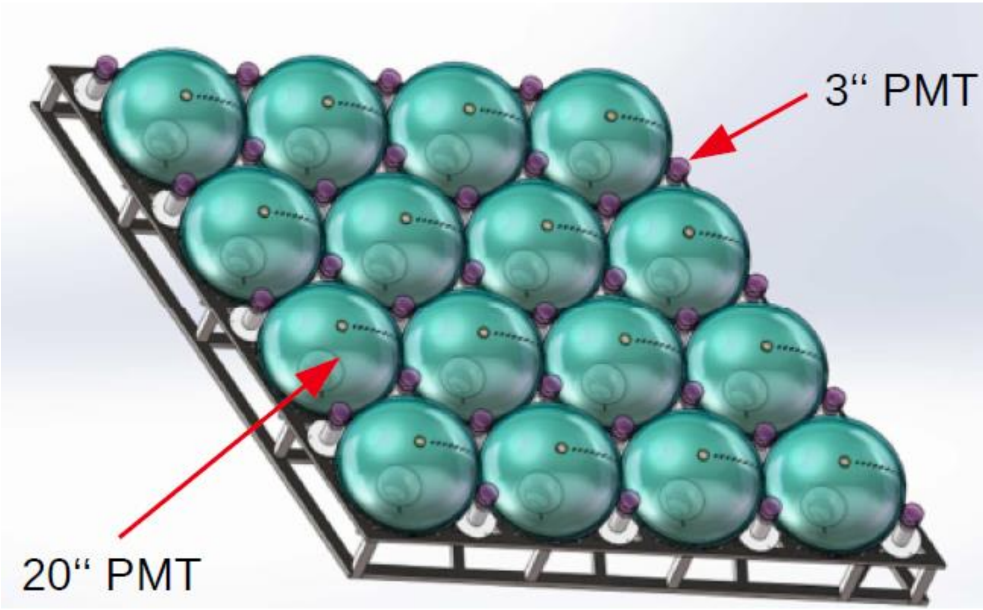
Central detector: ~ 20 kton of active mass of LAB scintillator (sphere of 35.4 m in diameter), it has unprecedented energy resolution (3% at 1 MeV)
Light detection: 18000 20'' PMTs and 25000 3'' PMTs (two independent PMT systems, coverage > 75%)
The detector is overburden of about 700 m.



Top tracker: solid scintillator.
Water pool: Cherenkov veto, 44 m deep and 43.5 m high. The PMTs and the electronics will be under water.

Design goals:
- ✓ Large target mass
- ✓ Excellent energy resolution
- ✓ Low energy scale uncertainty less than 1%.

JUNO PMT systems



Design goal: 1.2k p.e. / MeV
Requirements:
- ✓ High optical coverage
- ✓ High photon detection efficiency
- ✓ Acceptable noise / radio purity levels
- ✓ Acceptable time resolution (event reconstruction)
- ✓ Broad dynamic range

JUNO will have two independent Double calorimetry PMT systems.

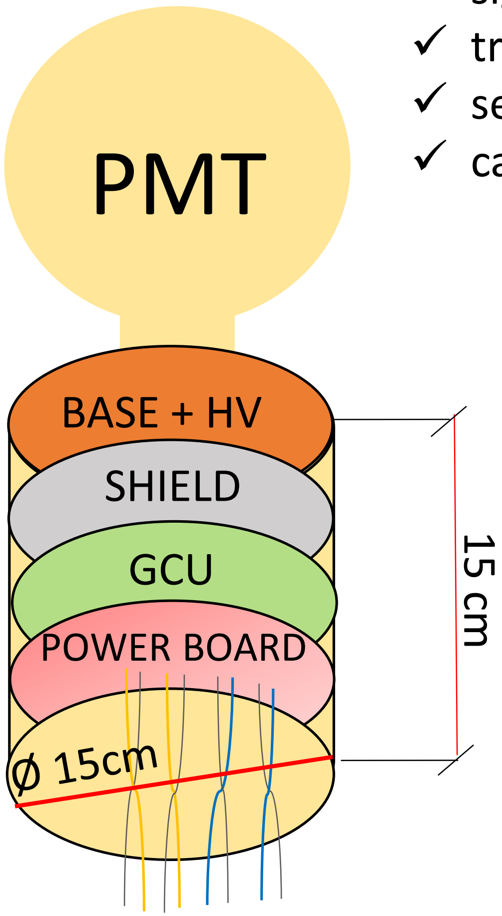
18 k large 20’’ PMTs
- ✓ 75% coverage
- ✓ Stochastic term: 3% / sqrt(E)
- ✓ Slower + worse p.e. resolution
- ✓ High dark noise

25 k large 3’’ PMTs
- ✓ 3% coverage
- ✓ Stochastic term: 14% / sqrt(E)
- ✓ Faster + better p.e. resolution
- ✓ Low dark noise

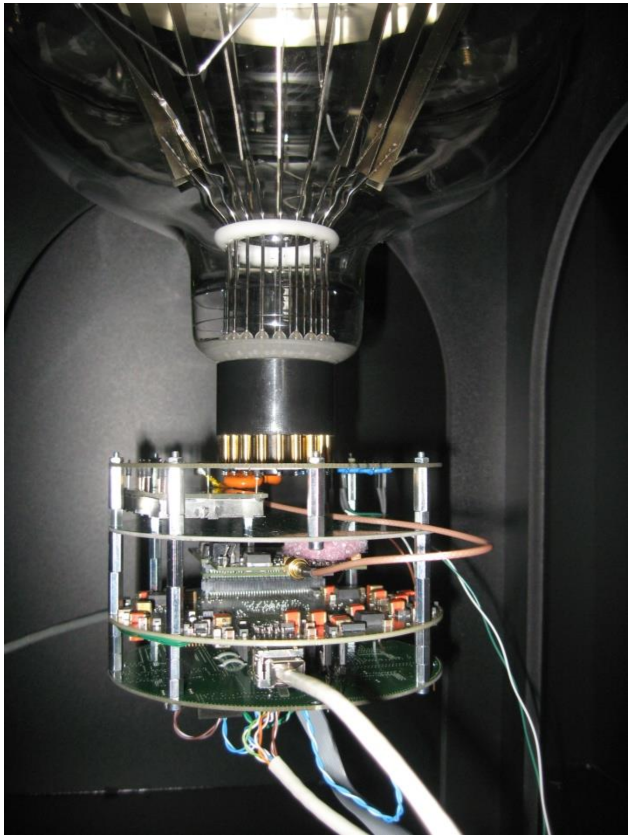
JUNO electronics

The readout architecture of JUNO PMT signal is designed with following functions take place in a watertight box strictly coupled and sealed with the PMT:

- ✓ signal conditioning and digitization,
- ✓ trigger primitive generation,
- ✓ segment buffering,
- ✓ calibration and synchronization tasks,
- ✓ selective data readout,
- ✓ HV control,
- ✓ system monitoring,
- ✓ baseline control.



100 m ethernet cable to BEC and to DAQ.



Constraints:

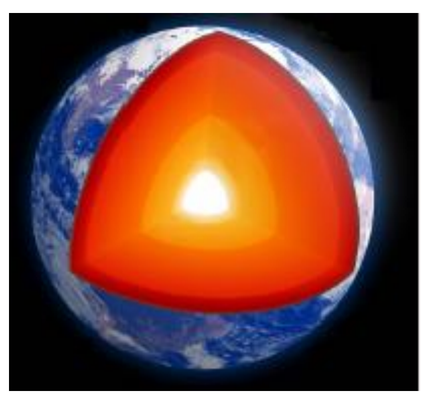
- ➢ Inaccessibility after installation.
- ➢ Minimize the power consumption and cost per channel.
- ➢ Minimize the number of cables and waterproof connectors.

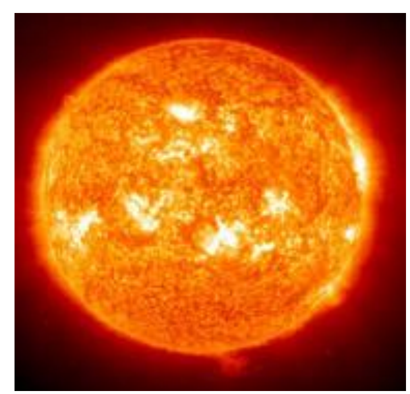
Physics with JUNO

MAIN PHYSICS WITH JUNO: determination of the neutrino mass hierarchy with good sensitivity (3σ after 6 years) and to precisely measure the neutrino mixing parameters:
$\sin^2\theta_{12}$ current precision 4.1 % with **JUNO below 1%**
Δm_{21}^2 current precision 2.3 % with **JUNO below 1%**
Δm_{ee}^2 current precision 1.6 % with **JUNO below 1%**

OTHER PHYSICS WITH JUNO:

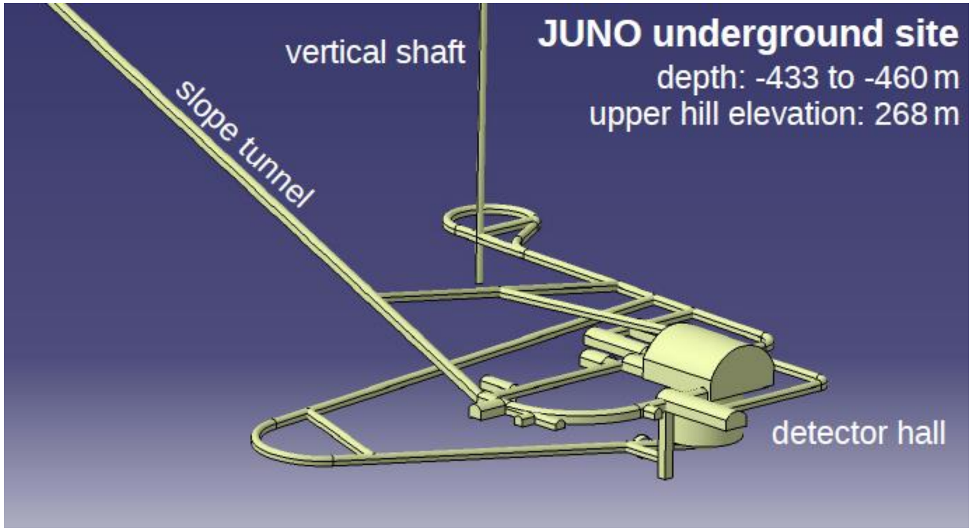
- ✓ like supernova burst and diffuse supernova neutrinos (10^4 events from a burst @ 10 kpc, information on SN model),
- ✓ solar neutrinos (information on ^{7}Be flux and ^{8}B solar neutrinos),
- ✓ atmospheric neutrinos,
- ✓ geo-neutrinos (~400 events/year, information on U/Th ratio),
- ✓ nucleon decay (information on $p \rightarrow K^+ + \bar{\nu}_e$),
- ✓ indirect dark matter searches
- ✓ ...





JUNO schedule

- ✓ **2013** Funding approved
- ✓ **2014** Collaboration officially formed
- ✓ **2014 - 2018** Civil construction
- ✓ **2016 - 2019** Detector component and PMT production
- ✓ **2018 - 2019** Detector assembly & installation
- ✓ **2020** Liquid scintillator filling
- ✓ **2020** Start of data taking



Summary

- ✓ JUNO is a multipurpose reactor neutrino experiment under construction in China
- ✓ The mass hierarchy determination on 3σ after 6 years or even better
- ✓ Significant improvement of the uncertainty of $\sin^2\theta_{12}$, Δm_{21}^2 and Δm_{ee}^2
- ✓ Data for other investigations: supernovae, solar, atmospheric and geoneutrinos, proton decay, ...
- ✓ The detector is under construction and it is expected to start data taking in 2020