Determination of the Neutrino Mass Hierarchy with JUNO Experiment

Qinhua Huang, *qinhua.huang@llr.in2p3.fr*
Laboratoire Leprince-Ringuet, École Polytechnique

Neutrinos in Standard Model and the Mass Hierarchy

- The Neutrinos are three of the elementary particles in the Standard Model (SM). They are only sensitive to the weak interaction and the interaction occurs in their flavour eigenstates, i.e., ν_e, ν_μ and ν_τ (Figure 1). The flavour eigenstates are actually the combination of the mass eigenstates, ν_1, ν_2 and ν_3:
$$|\nu_\alpha\rangle = \sum_j U^*_{\alpha j} |\nu_j\rangle \,,$$
with $\alpha = (e, \mu, \tau)$, $j = (1, 2, 3)$, $U_{\alpha j}$ represents the Pontecorvo–Maki–Nakagawa–Sakata matrix.
- When neutrinos propagate in space-time, their flavours can change according to the oscillation probability, which can be expressed as:
$$P_{\alpha\beta} = \sum_{j,k,j\neq k} U^*_{\alpha j} U_{\beta j} U_{\alpha k} U^*_{\beta k} \exp\left[-i\frac{\Delta m^2_{jk} L}{2E}\right],$$
with $m^2_{jk} = m^2_j - m^2_k$ are the mass differences, L is oscillation distance and E is the neutrino energy.
- In many experiments, for example, Super-Kamiokande Observatory and the Sudbury Neutrino Observatory, the neutrino oscillation has been observed, therefore, the neutrinos should be massive. Since the oscillation can only characterise the mass differences between the neutrino mass eigenstates, two possible mass hierarchies (MH) are suggested : Normal Hierarchy (NH) and Inverted Hierarchy (IH).

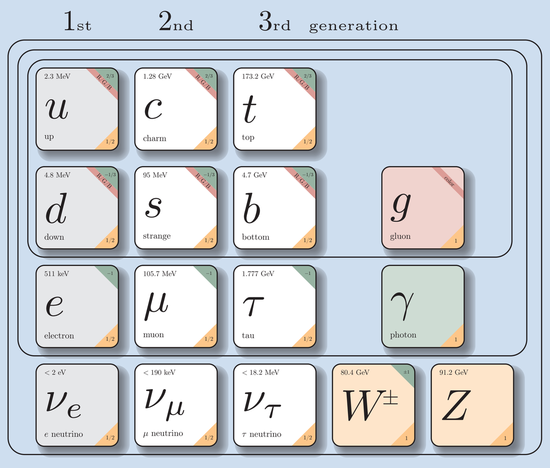


Figure 1: Elementary particles in SM

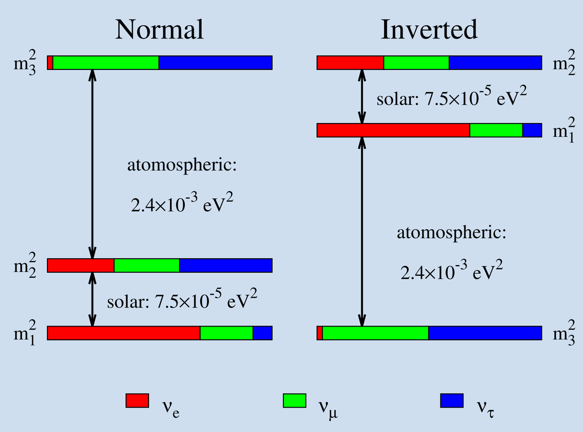


Figure 2: The two possible orderings of the neutrino mass eigenstates.

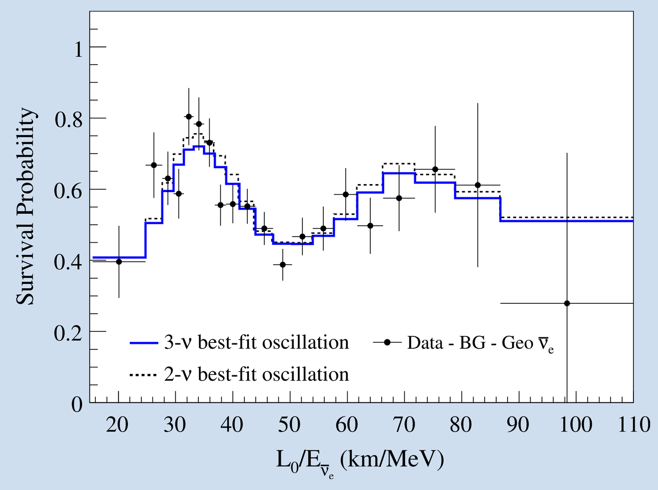


Figure 3: Oscillation in the KamLAND reactor neutrino experiment. From A. Gando et al., Phys. Rev. D83 (2011) 052002.

Double Calorimetry & Physics optimisation

A double calorimetry PMT system is used in JUNO to achieve 3% of energy resolution. The system consists of 18000 20”-PMT (LPMT) and 25000 3”-PMT (SPMT). In JUNO the LPMTs are usually hit by several photons at the same time, this may cause non-linear energy measurement. The SPMTs, however, measure energy via “photon counting”, as they almost detect either one single photon or zero. So the SPMTs will serve to disentangle the non-linear effects in the calibration of the non-uniform response of the detector.

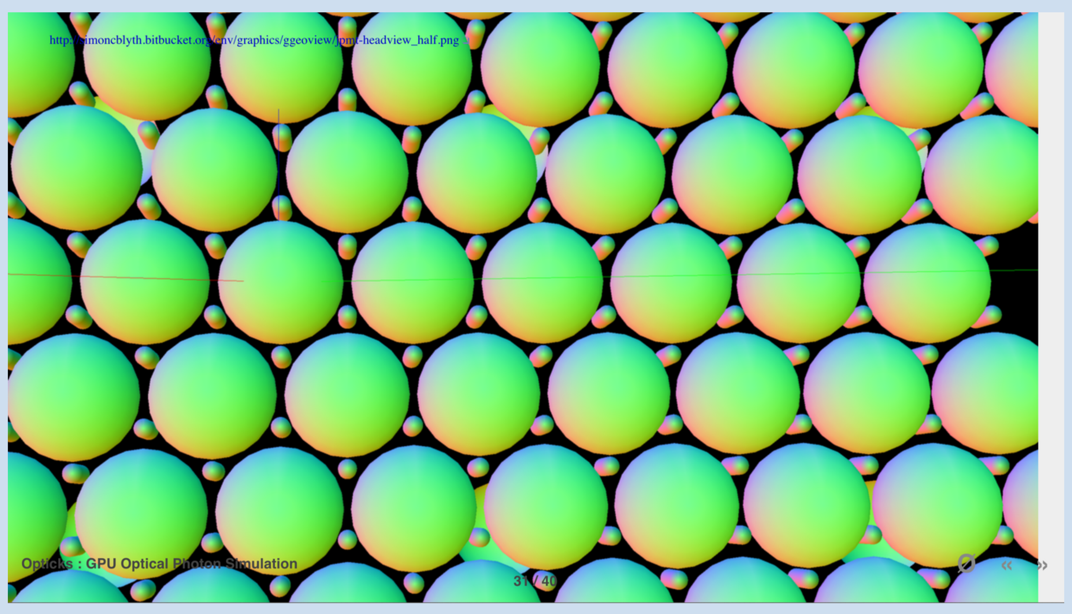


Figure 4: The SPMTs surround the LPMT.

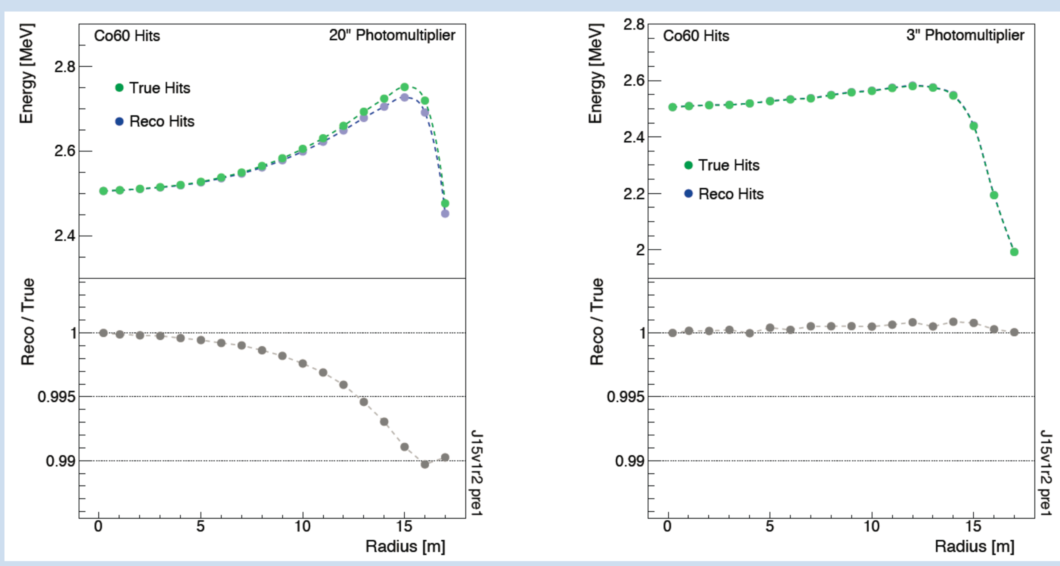


Figure 5: The reconstructed energy is biased for LPMTs compared to Monte-Carlo (MC).

The JUNO collaboration has recently signed the bidding with two Chinese companies for both LPMT and SPMT system. Based on the SPMT characteristics, we are currently focusing on the optimisation of the SPMT system and the test of its reliability. We use the MC to estimate the potential degradation on light collection (energy resolution) caused by the support structure, since the structure forces to reduce the number of SPMTs installed.

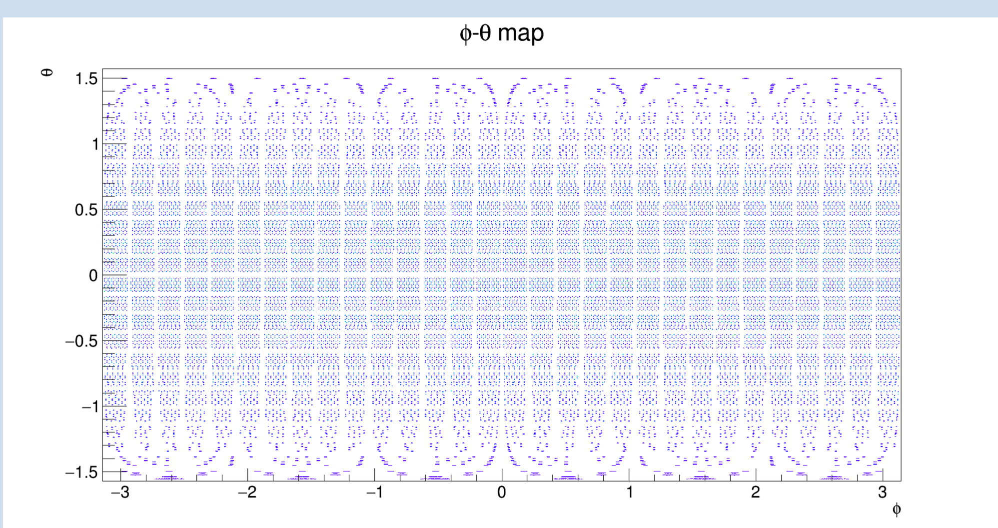


Figure 6: The hit map of the detector MC on ϕ-θ plan.

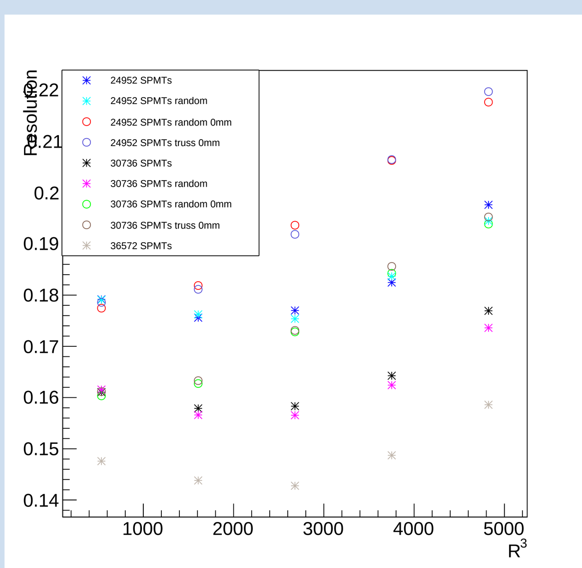
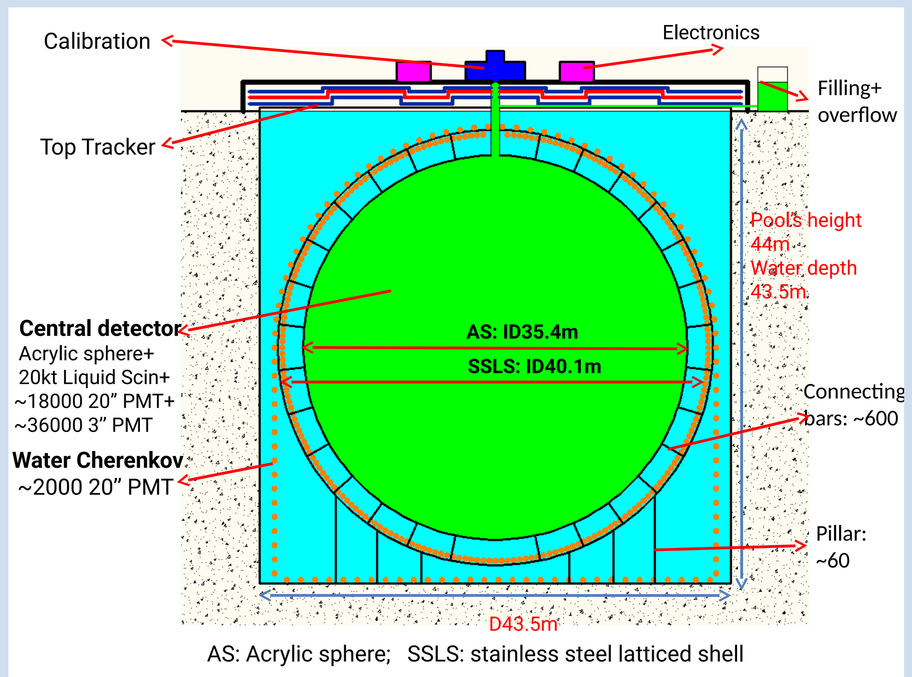


Figure 7: The energy resolution as a function of R^3 for different SPMT setups.

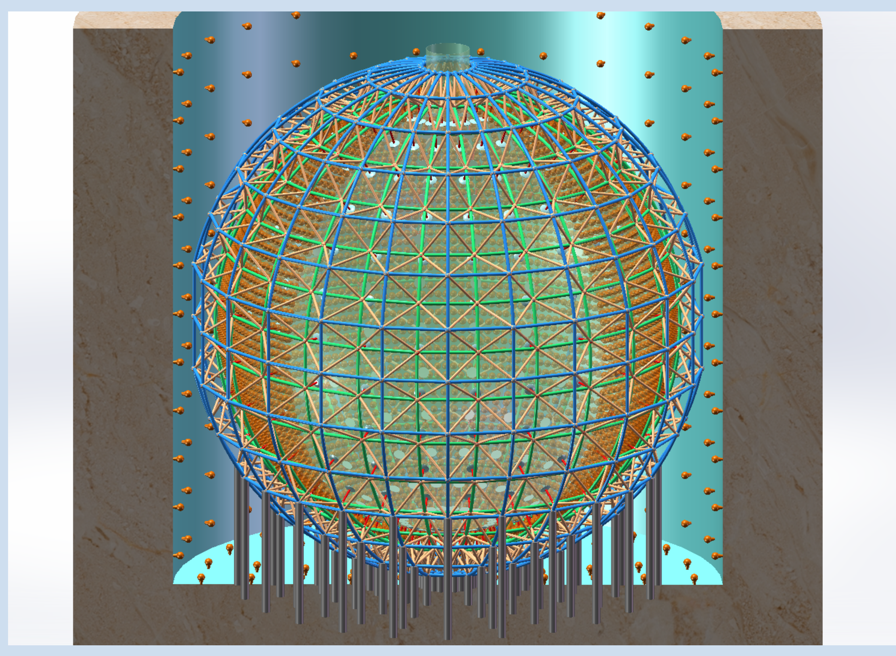
JUNO & Detector

The Jiangmen Underground Neutrino Observatory(JUNO) is a multipurpose underground Neutrino experiment. It will be located in Jinji town, Kaiping, Jiangmen, Guangdong province, China. The underground laboratory will be constructed 700m underground to reduce the background of cosmic particles.

The main scientific goal is the determination of the neutrino MH by detecting reactor antineutrinos from the Yangjiang and Taishan (see the map) nuclear power plants (NPPs). JUNO consists of a central detector, a water Cherenkov detector and a muon tracker.



The central detector is made of an acrylic sphere containing 20kt of liquid scintillator (LS). The optical coverage will attain 75% with a double calorimetry Photomultiplier Tube (PMT) system. This setup will achieve $\mathbf{3\%/\sqrt{E}(MeV)}$ energy resolution. The central detector is submerged in a water pool, to be shielded from natural radio-activity from the surrounding rock. The water pool is equipped with PMTs to serve as a veto water Cherenkov detector. The muon tracker, a.k.a top tracker, will be built to cover the water pool and serve to further suppress the background caused by cosmic muons. A structure is needed to support the center detector and to install the PMT instrument system.



Apart from the determination of MH, JUNO detector will also be capable to investigate other physics, for example,

- Precision measurement of oscillation parameters θ_{12}, Δm^2_{21} and $|\Delta m^2_{ee}|$,
- Supernova and diffuse supernova neutrinos,
- Solar neutrinos, Geoneutrinos, Sterile neutrinos...