JUNO Central Detector and its prototyping

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Abstract. JUNO is a multi-purpose underground liquid scintillator experiment; its R&D and civil construction all are in progress. During this July, 2015, JUNO collaboration selects the acrylic option as central detector (CD) scheme. The R&D progress of support point structure and acrylic panel of CD acrylic option all are in good shape. At the same time, a prototype detector of JUNO is designed and under construction, the goal is mainly to study different PMTs, background, electronics etc.

1. Introduction
The Jiangmen Underground Neutrino Observatory (JUNO), a 20 kton multi-purpose underground liquid scintillator detector, located at Guangdong Province, south of China near to Hong Kong and Dayabay experiment, was proposed with the determination of the neutrino mass hierarchy as a primary physics goal. The excellent energy resolution and the large fiducial volume anticipated for the JUNO detector offer exciting opportunities for addressing many important topics in neutrino and astroparticle physics. The JUNO detector is capable of observing not only antineutrinos from the power plants, but also neutrinos/antineutrinos from terrestrial and extra-terrestrial sources, including supernova burst neutrinos, and diffuse supernova neutrino background, geo-neutrinos, atmospheric neutrinos, solar neutrinos. As a result of JUNO’s large size, excellent energy resolution, and vertex reconstruction capability, interesting new data on these topics can be collected. The JUNO detector is also sensitive to several other beyond-the-standard-model physics. The proposed construction of the JUNO detector will provide a nique facility to address many outstanding crucial questions in particle and astrophysics in a timely and cost-effective fashion. It holds the great potential for further advancing our quest to understanding the fundamental properties of neutrinos, one of the building blocks of our Universe.

2. JUNO central detector (CD)
The JUNO is designed to have energy resolution better than ~3%/sqrt(E) with ~20kton liquid scintillator, which means >1000p.e.@1MeV, and plans to use 1GHz PMT waveform sampling electronics, <1kHz trigger rates.
The baseline between JUNO detector and nearby nuclear power plant is ~53km with total thermal power 35.8GW finally. The experiment hall is designed with ~720m rock overburden (underground ~500m) reaching by a vertical and a slope tunnel.

1 On behalf of JUNO collaboration
The detector system of JUNO (as shown in Fig.1) mainly contains the central detector, water Cherenkov veto system, top scintillator track system and more other sub systems not shown. The final design scheme of central detector is the Acrylic sphere+ stainless steel struts option (right figure of Fig.1) which won the competition with the option of a stainless steel sphere+ balloon option in last JUNO collaboration meeting on July 2015 according to physics performance, engineering feasibility/reliability, cost, risk and schedule issues: the inner diameter of acrylic sphere is ~35.4m with ~12cm thickness to contain the ~20kton LAB based liquid scintillator, and with ~18000 high quantum efficiency 20” PMTs covered ~78% surface of the sphere. The arrangement of so many 20” tubes on a sphere surface is proposed and compared for more than 6 possible algorithms, and finally favoured to a single PMT module option (Fig.2) to get higher photocathode coverage to ~78%. Another mixed PMT option with 3” tubes among the gaps of 20” PMTs also is proposed to the collaboration internally for better energy measurement, muon, supernova, higher PMT coverage etc. More optimization and finalization of the detector are still going on.

Most of primary performances of JUNO detector are checked and under developing in more detail with Geant4 simulation, including background contribution, event vertex/track reconstruction (shown in Fig.3) of point like, short track, single long track, multi tracks. At the same time, the vertex and energy reconstruction of point like event be studied in more detail as show in fig.4: with time + charge reconstruction, the vertex reconstruction can be better than 10cm@ 1MeV, and with optical+ vertex correction, we can get further uniformly detector response and better than 3%/sqrt(E) energy resolution.
3. Progress of CD R&D

The whole project of JUNO is going on schedule which aims to fill detector and take data at 2020. Fig.5 shows the main milestones from the project beginning at the end of 2012. The central detector R&D is going well in acrylic material (Fig.6), support point structure (Fig.7) and thick acrylic sphere plates (Fig.8). Till now, acrylic samples from 3 Chinese companies are under test including optical, mechanical, long term stability etc.; 1:4 and 1:1 support point structure already be tested for making up and strength; 2 companies already made up a 17.7m radius sphere plate and 1 company finished sphere plate annealing successfully.

While the onsite civil construction also on going (Fig.9): civil engineering design finalized this year; both vertical shaft and slope tunnel going well. This year, we expect to finish the vertical shaft (totally ~611 meters), and finish the slope tunnel ~ 900 meters (totally ~1340m).

Roughly, JUNO will have the detector component production in 2016-2017; PMT production in 2016-2019; Detector assembly & installation in 2018-2019.
4. JUNO prototype

Following the design of the JUNO experiment and considering R&D requirements of each sub-system, a prototype detector was proposed to test some key technical issues, including test/study of the PMT candidates (Hamamatsu, Hainan Zhan Chuang (HZC), and a newly developed MCP-PMT); Test and study of the liquid scintillator; Test and study of electronics; Waveform algorithms and detector performance study.

The prototype detector is shown in Fig. 10, which re-uses the Daya Bay prototype steel tank [1] as the main container. An acrylic sphere locates at the stainless-steel tank (SST) centre as the LS vessel, and is viewed by 51 PMTs dipped in pure water. The designed photo-cathode coverage is ~55%. A ~1m.w.e shielding system consisted by water tank and PP/Lead is set to reduce the out coming radioactivity of the outside of SST. The diameter of the acrylic sphere is 50cm with ~1cm thickness; it has a $\Phi$ 5cm and ~70cm long tube located at top for filling/calibration. The expected trigger rate is <100Hz@$>0.7$MeV, energy resolution is $\sim4%@1$MeV for electron.

The 51 high quantum efficiency PMTs in diameter 8", 9", 20" (Fig.11) are uniformly arrayed in 4 layers facing to the acrylic sphere centre: Top layer: 4 20” MCP PMTs, 2 20” Hamamatsu PMTs; Each of the two middle layers: 8 8” MCP-PMT, 4 9” HZC-PMT, 4 8” Hamamatsu PMT; Bottom out
group: same as the top layer; Bottom centre group: 3 8” MCP-PMT, 2 9” HZC-PMT, 2 8” Hamamatsu PMT. Now all the PMTs are in hands, and finished the primary test and HV divider design/production, water proof potting and testing after potting are ongoing. At the same time, detector cleaning and installation is doing too (Fig.12). Plan to run the detector in this year.

Fig.10 The scheme of the prototype detector design (left: principle design; middle: engineering design of main detector; right: shielding design)

Fig.11 Prototype related PMTs with potting design and potted samples (left to right: Hamamatsu 20”; MCP 20”; HZC 9”, Hamamatsu 8”; MCP 8”, potted MCP 8”; potted MCP 20”)

Fig.12 The latest status of the prototype installation

5. Summary
JUNO central detector scheme is selected by collaboration: acrylic vessel. Lot of working has been done: principle designed, calculated with simulated for response, background, reconstruction, etc. while more detailed optimization and finalization on going. Onsite civil construction is going well. Prototyping for PMT, potting, LS, electronics, analysis etc. all are going on. JUNO prototype detector will run soon.

References
[1] Wang Z et al 2009 NIMA 602 2 489