IL NUOVO CIMENTO **43 C** (2020) 66
DOI 10.1393/ncc/i2020-20066-7

Colloquia: IFAE 2019

# Features and perspectives of the JUNO experiment

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received 8 June 2020

**Summary.** — We discuss the characteristics and perspectives of JUNO, a huge reactor antineutrino experiment, with a very high energy resolution, designed to perform measurements relevant for particle physics and astrophysics. Its main goal is the determination (at 3–4 $\sigma$ of confidence level) of neutrino mass ordering. JUNO should also significantly reduce the uncertainty on different mass and mixing parameters; it will have an high sensitivity to supernova neutrinos and it will study geoneutrinos and probably atmospheric neutrinos. The JUNO detection of $^{8}$B and $^{7}$Be solar neutrinos will contribute to the solar metallicity study and to test the LMA oscillation pattern, looking for signals of potential Non-Standard Interactions.

## 1. – Neutrino mass ordering

The differences between the 3 neutrino ($\nu$) mass eigenvalues squared can be recovered from the combined analysis of the experimental data cumulated over more than forty years: $\Delta m^2_{21} = (7.37 \pm 0.17) \times 10^{-5}\,\mathrm{eV}^2$ (by KamLAND and solar $\nu$ experiments) and $\Delta m^2_{32(31)} = (2.52 \pm 0.04) \times 10^{-3}\,\mathrm{eV}^2$ (mainly by atmospheric and LBL accelerators). However, 2 possible solutions are still compatible with data, the normal and inverted mass ordering, represented in fig. 1. The ordering determination would be essential to discriminate between possible Standard Model extensions and estimate the potentialities of future experiments. Thanks to the significantly different from zero $\theta_{13}$ mixing angle, it is possible to investigate the mass ordering by analyzing the corrections (proportional to $\sin^2\theta_{13}$) to the antineutrino oscillation probabilities in medium baseline reactor experiments. These studies are complementary to the ones at LBL accelerator experiments (T2K, NO$\nu$A and DUNE) and at neutrino telescopes (IceCube, ORCA and PINGU), but they have the advantages of being independent on the Earth matter density profile and on the CP violation phase. JUNO (Jiangmen Underground Neutrino Observatory) [1], a multipurpose reactor experiment almost ready to operate in the south of China, is designed with a baseline $L = 53\,\mathrm{km}$ (to maximize mass ordering corrections), very high energy resolution and fiducial mass. Its main goal is the mass ordering investigation,

 

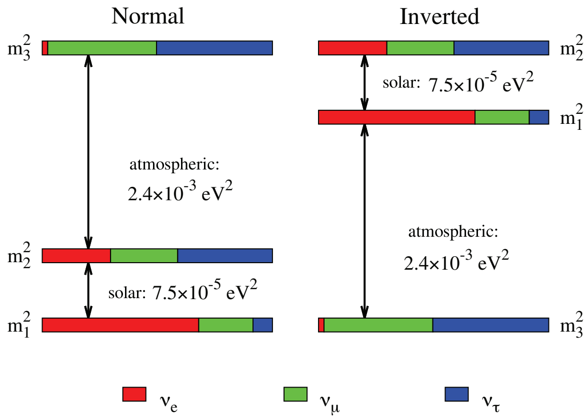


Fig. 1. – The 2 possible mass ordering: normal and inverted.

through inverse $\beta$ decay study, regulated by $\bar{\nu}_e$ survival probability, $P_{ee} = 1 - P_{21} - P_{3x}$, with: $P_{21} = \cos^4\theta_{13}\sin^2 2\theta_{12}\sin^2(\frac{\Delta m^2_{21}L}{4E})$,

$$P_{3x} = \frac{1}{2}\sin^2(2\theta_{13})\left[1 - \left[1 - \sin^2(2\theta_{12})\sin^2\left(\frac{\Delta m^2_{21}L}{4E}\right)\right]^{1/2}\cos\left(2\left|\frac{\Delta m^2_{ee}L}{4E}\right| \pm\phi\right)\right]$$

and $\Delta m^2_{ee} = \cos^2\theta_{12}\Delta m^2_{31} + \sin^2\theta_{12}\Delta m^2_{32}$. The sine and cosine of the "phase factor" $\phi$ are combinations of 1–2 mass and mixing parameters and it regulates the mass ordering dependent fast oscillating corrections superimposed to the general oscillation pattern. The sign in front of it is $+1$ for normal ordering (NO) and $-1$ for inverted ordering (IO). The JUNO detector, located at about 700 m depth, is a 20 kton liquid scintillator contained in an acrylic sphere of 35.4 m in diameter, enclosed in a water pool used as Cherenkov veto and shield for the external environment radiation. On top of the water pool there is a plastic scintillator muon tracker. An excellent energy resolution (3% at 1 MeV) is made possible by a double system of photomultipliers, large (20 inches in diameter) and small (3 inches), that guarantees very high coverage and light yield. A near detector, named TAO (Taishan Antineutrino Observatory), a 1 ton gadolinium doped liquid scintillator, is settled at 30 m from the reactor core, with a full coverage of silicon photomultipliers operating at $-50\,^\circ$C. It will ensure a detailed knowledge of the reactor antineutrino beam spectrum and of its time stability. The $\nu$ mass ordering will be tested at JUNO, with a $\chi^2$ statistical analysis based on inverse $\beta$ decay spectrum and including also the data from all previous neutrino experiments. After six years of data taking, the difference between the best fit $\chi^2$ values corresponding to the two possible mass orderings, $\Delta\chi^2_{MO} = |\chi^2_{MIN,NO} - \chi^2_{MIN,IO}|$, should reach a value of $\simeq$9, that could be further increased, up to $\Delta\chi^2_{MO} \simeq 16$, by using the information on the squared mass difference from future LBL accelerator data. Another important JUNO issue is the subpercent level measurement, with an improvement of almost one order of magnitude, of $\theta_{12}$, $\Delta m^2_{21}$ and the combination $(\cos^2\theta_{12}\Delta m^2_{31} + \sin^2\theta_{12}\Delta m^2_{32})$. JUNO should give important contributions also on other relevant topics [1]. The study of the diffuse Supernova (SN) $\nu$ background and of a potential SN $\nu$ burst could improve the knowledge of stars formation and evolution. The $^8$B and $^7$Be solar $\nu$ detection will be complementary to the data by Borexino and other future experiments for the solar metallicity study (helping in the discrimination between high- and low-$Z$ Solar Standard Models) and for consistency tests of the LMA oscillation pattern (by looking for potentials "anomalies" in the vacuum to matter transition region, indications of Non-Standard Neutrino Interactions). Despite the relevant reactor $\bar{\nu}$ signal background, one expects the detection of about 3–5 hundreds of geoneutrino events in one year of JUNO data taking, thank to its radiopurity and huge size. For more details on all these topics and on JUNO atmospheric $\nu$ and more exotic analyses (like proton decay search and Lorentz invariance and CPT tests) we refer the interested reader to [1, 2].

## REFERENCES

[1] JUNO Collaboration (An F. *et al.*), *J. Phys. G*, **43** (2016) 030401.

[2] JUNO Collaboration (Miramonti L.), *Status and the perspectives of the Jiangmen Underground Neutrino Observatory (JUNO)*, *Mod. Phys. Lett. A*, **35** (2020) 2030004 (Proceedings of NNN19); Antonelli V., Miramonti L. and Ranucci G., *Present and Future Contributions of Reactor Experiments to Mass Ordering and Neutrino Oscillation Studies*, *Universe*, **6** (2020) 52 (Collection on "Neutrino Oscillations", available online `https://www.mdpi.com/2218-1997/6/4/52`).