江门中微子实验首个物理成果简介

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构成物质世界的最基本的粒子有 12 种，包括 6 种夸克，3 种带电轻子和 3 种中微子。它们的基本性质和相互作用由粒子物理的"标准模型"所描述。自上世纪 50 年代起，与标准模型相关的工作获得了 17 次诺贝尔奖。但标准模型仍存在一个突出问题，与中微子直接相关。此外中微子质量起源跟宇宙物质 - 反物质不对称问题、暗物质、天体演化等宇宙起源和演化问题密切相关。在众多可能的新物理图景中，中微子被普遍视为通向标准模型之外新物理的关键"门户"：弄清中微子质量和味混合的起源机制，是理解整个宇宙为何呈现今日面貌的核心问题之一。

中微子振荡间接证明中微子具有非零质量，是目前最清晰、最被普遍接受的标准模型之外新物理的实验证据。描述中微子振荡的规律可以用六个参数来表示，即中微子之间的两个质量平方差Δm_{21}^2和Δm_{32}^2，三个混合角θ_{12}，θ_{13}，θ_{23}，以及一个 CP 相位角δ_{CP}。目前未知的还有Δm_{32}^2的正负符号（又称质量顺序）和δ_{CP}。

目前，θ_{12} 和Δm_{21}^2的测量精度主要由包括加拿大 SNO、日本 KamLAND 在内的太阳与反应堆中微子实验几十年来的测量所决定；$|\Delta m_{32}^2|$和θ_{23} 则主要来自日本超级神冈和 T2K、美国 NOvA 等加速器及大气中微子实验的测量结果。θ_{13} 的世界最高精度由我国的大亚湾中微子实验保持。

江门中微子实验（JUNO）利用 8 月 26 日到 11 月 2 日采集的科学数据，于 11 月 19 日发布第一个物理成果：两个中微子振荡参数的最精确测量。对混合角 $\sin^2\theta_{12}$ 和质量平方差Δm_{21}^2的测量精度比此前实验的最好精度提高了 1.5 到 1.8 倍，即 $\sin^2\theta_{12}$ 的精度从 5.1%提高到 2.8%，Δm^2_{21} 从 2.5%提高到 1.6%。

中微子振荡参数的精确测量将打开检验三代中微子振荡的完整性之门。JUNO 利用 2 个月的实验数据达到的测量精度即超过国际其他实验十到二十年的积累，充分体现了实验装置的先进性。该测量结果将对中微子质量起源、轻子味混合矩阵、无中微子双贝塔衰变等研究领域产生重要影响。特别是，当这些高精度振荡参数与宇宙学观测和 β 衰变实验结果结合时，JUNO 将对多种中微子质量与混合的起源机制、新物理模型给出前所未有的严格约束，使其成为未来数十年中微子物理与宇宙学交叉研究的基准实验之一。

Brief Introduction to the First Physics Results from JUNO

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The fundamental constituents of the material world are twelve elementary fermions, including six quarks, three charged leptons, and three neutrinos. Their basic properties and interactions are described by the Standard Model of particle physics. Since the 1950s, research related to the Standard Model has been recognized with 17 Nobel Prizes. However, a prominent open question within the Standard Model is directly connected to neutrinos. Moreover, the origin of neutrino mass is closely tied to fundamental issues in cosmology and astrophysics, such as the matter–antimatter asymmetry of the Universe, dark matter, and the evolution of astrophysical objects.

In many scenarios beyond the Standard Model, neutrinos are widely regarded as a key "portal" to new physics. Unraveling the origin of neutrino masses and flavor mixing is therefore one of the central questions for understanding the lepton sector and, ultimately, why our Universe appears the way it does today.

Neutrino oscillations, which indirectly demonstrate that neutrinos have non-zero masses, represent the most compelling and widely accepted experimental evidence so far for physics beyond the Standard Model. The pattern of neutrino oscillations can be described by six parameters: two mass-squared differences, Δm^2_{21} and Δm^2_{32}, three mixing angles, θ_{12}, θ_{13}, θ_{23}, and one CP-violating phase, δ_{CP}. At present, the sign of Δm^2_{32} (the neutrino mass ordering) and the value of δ_{CP} remain unknown.

Currently, the precision of θ_{12} and Δm^2_{21} is mainly determined by decades of data from solar and reactor neutrino experiments such as SNO in Canada and KamLAND in Japan. The precision of $|\Delta m^2_{32}|$ and θ_{23} is primarily constrained by accelerator and atmospheric neutrino experiments such as NOvA in the United States and T2K in Japan. The world's most precise measurement of θ_{13} is still provided by China's Daya Bay Reactor Neutrino Experiment.

Using scientific data collected from August 26 to November 2, the Jiangmen Underground Neutrino Observatory (JUNO) will release its first physics results: the world's most precise measurement of two neutrino oscillation parameters. The measurement precision of the mixing parameter $\sin^2\theta_{12}$ and the mass-squared difference Δm^2_{21} is improved by a factor of about 1.5 to 1.8 compared with the previous best results—specifically, the precision of $\sin^2\theta_{12}$ is improved from 5.1% to 2.8%, and that of Δm^2_{21} from 2.5% to about 1.6%.

Such precise measurements of neutrino oscillation parameters will open the door to stringent tests of the completeness of the three-flavor neutrino oscillation framework. With only two months of data, JUNO is already able to reach a precision surpassing that achieved by other international experiments with ten to twenty years of data, fully demonstrating the advanced performance of the detector. These results will have important implications for research on the origin of neutrino mass, the lepton flavor mixing matrix, and neutrinoless double-beta decay.

In particular, when combined with cosmological observations and beta-decay experiments, JUNO's high-precision oscillation parameters will place unprecedented constraints on a wide range of models for the origin of neutrino masses and mixing and for new physics beyond the Standard Model, establishing JUNO as a benchmark experiment for neutrino physics and neutrino–cosmology studies in the coming decades.