

New results from T2K conclusively show muon neutrinos transform to electron neutrinos

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T2K Collaboration

High Energy Accelerator Research Organization (KEK)

Institute for Cosmic Ray Research, The University of Tokyo

J-PARC Center

Today at the European Physical Society meeting in Stockholm, the international T2K collaboration announced definitive observation of muon neutrino to electron neutrino transformation. In 2011, the collaboration announced the first indication of this process, a new type of neutrino oscillation, then; now with 3.5 times more data this transformation is firmly established. The probability that random statistical fluctuations alone would produce the observed excess of electron neutrinos is less than one in a trillion. Equivalently the new results exclude such possibility at a 7.5 sigma level of significance. This T2K observation is the first of its kind in that an explicit appearance of a unique flavor of neutrino at a detection point is unequivocally observed from a different flavor of neutrino at its production point.

In the T2K experiment in Japan, a muon neutrino beam is produced at the Japan Proton Accelerator Research Complex, called J-PARC, located in Tokai village, Ibaraki prefecture, on the east coast of Japan. The neutrino beam is monitored by a detector complex in Tokai and aimed at the gigantic Super-Kamiokande underground detector in Kamioka, near the west coast of Japan, 295 km (185 miles) away from Tokai. An analysis of the data from the Super-Kamiokande detector associated with the neutrino beam time from J-PARC reveals that there are more electron neutrinos (a total of 28 events) than would be expected (4.6 events) without this new process.

Neutrino oscillation is a manifestation of a long range quantum mechanical interference. Observation of this new type of neutrino oscillation leads the way to new studies of charge-parity (CP) violation, which provides a distinction in physical processes involving matter and antimatter. This phenomenon has only been observed in quarks (for which Nobel prizes were awarded in 1980 and 2008). CP violation in neutrinos in the very early universe may be the reason that the observable universe today is dominated by matter and no significant antimatter, which is one of the most profound mysteries in science. Now with T2K firmly establishing this form of neutrino oscillation that is sensitive to CP violation, a search for CP violation in neutrinos becomes a major scientific quest in the coming years, and T2K will continue to play a leading role. The T2K experiment expects to collect 10 times more data in the near future, including data with antineutrino beam for studies of CP violation in neutrinos.

The T2K experiment was constructed and is operated by an international collaboration. The current T2K collaboration consists of over 400 physicists from 59 institutions in 11 countries [Canada, France, Germany, Italy, Japan, Poland, Russia, Switzerland, Spain, UK and US]. The experiment is primarily supported by the Japanese Ministry of Education, Culture, Sports, Science and Technology (MEXT). Additional support is provided by the following funding agencies from participating countries: NSERC, NRC and CFI, Canada; CEA and CNRS/IN2P3, France; DFG, Germany; INFN, Italy; Ministry of Science and Higher Education, Poland; RAS, RFBR and the Ministry of Education and Science of the Russian Federation; MICINN and CPAN, Spain; SNSF and SER, Switzerland; STFC, U.K.; DOE, U.S.A.

This discovery was made possible with the unyielding and tireless effort by the J-PARC staff members and the management to deliver high quality beam to T2K after the devastating March 2011 earthquake in eastern Japan, which caused severe damage to the accelerator complex at J-PARC, and abruptly discontinued the data-taking run of the T2K experiment.

[Media Contact]

About T2K Experiment

Takashi Kobayashi

The Institute of Particle and Nuclear Studies, KEK

TEL : +81-29-864-5414

About J-PARC and KEK in general

Masanori Yamauchi

Director, The Institute of Particle and Nuclear Studies, KEK

TEL : +81-29-864-5352

Scientific inquiry about Super-Kamiokande, the far detector

Yoichiro Suzuki,

Director, Kamioka Observatory, The Institute for Cosmic Ray Research, The University of Tokyo

TEL : +81-578-85-9601

About J-PARC Center (Public Relations)

Shinichi Sakamoto

Public Relations Section leader, J-PARC Center

TEL : +81-29-284-3587

E-Mail: shinichi.sakamoto@j-parc.jp

About KEK (Public Relations)

Saeko Okada

Senior Press Officer, Public Relations Office, KEK

TEL : +81-29-879-6047/+81-080-1359-2730

E-Mail: sokada@post.kek.jp

*Related links:

<http://t2k-experiment.org>

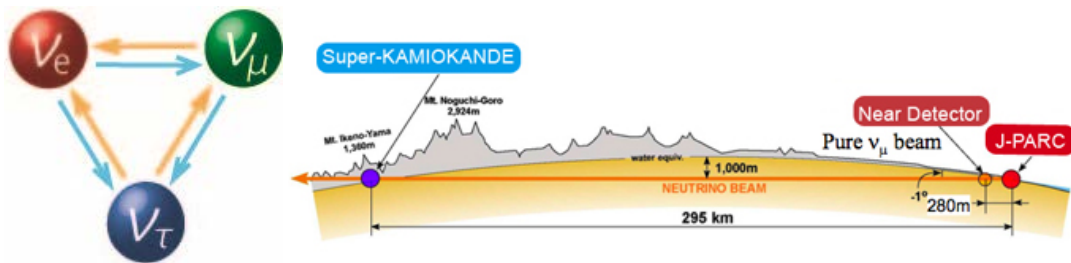


Fig.1 Overview of the T2K experiment



Fig.2 : J-PARC Neutrino Experimental Facility

The proton beam extracted from the J-PARC Main Ring synchrotron are directed westward through the T2K **primary beam line**. At the **target station** the protons strike a ① **target** composed of graphite rods and produce numerous positively charged π -mesons which are in turn focused towards the forward direction under the effect magnetic horns. The π -mesons then decay into muon and muon neutrino pairs during flight in a 100-m-long tunnel, called ② **the decay volume**. ③ **Neutrino detectors** located 280 m downstream of the target can monitor these muon neutrinos. A comparison of the measurements with those observed at Super-Kamiokande facilitates detailed studies of neutrino oscillation.

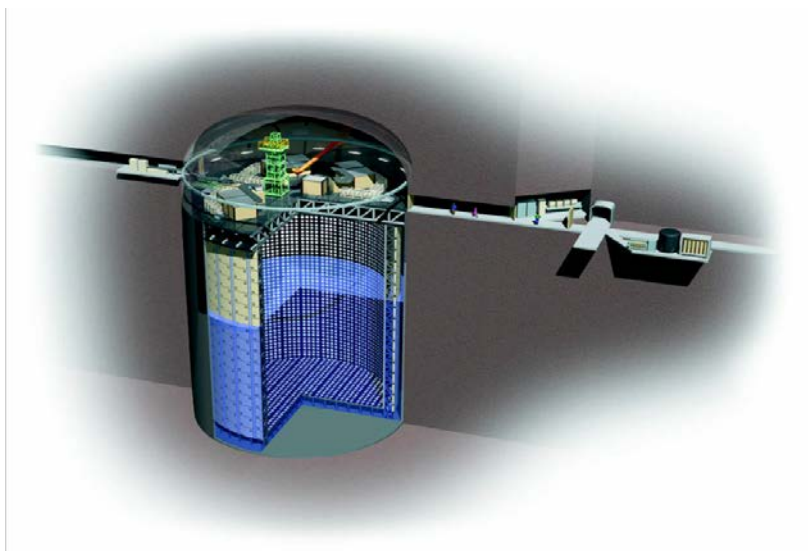


Fig. 3 : Super-Kamiokande Detector

The world's largest underground neutrino detector affiliated with the Kamioka Observatory of the Institute for Cosmic Ray Research, the University of Tokyo. It is situated 1,000 m underground in the Kamioka Mine in Hida, Gifu Prefecture. Super-Kamiokande is observing neutrinos from outer space and conducting experiments and detects yet-to-be-discovered proton decays in addition to detecting neutrinos from J-PARC. This detector contains about 11,200 photomultiplier tubes, which are installed on the inside wall of a cylindrical water tank (39.3 m in diameter and 41.4 m in height) filled with 50,000 tons of water, to detect faint Cherenkov light emanating from charged particles traveling faster than the speed of light in water.

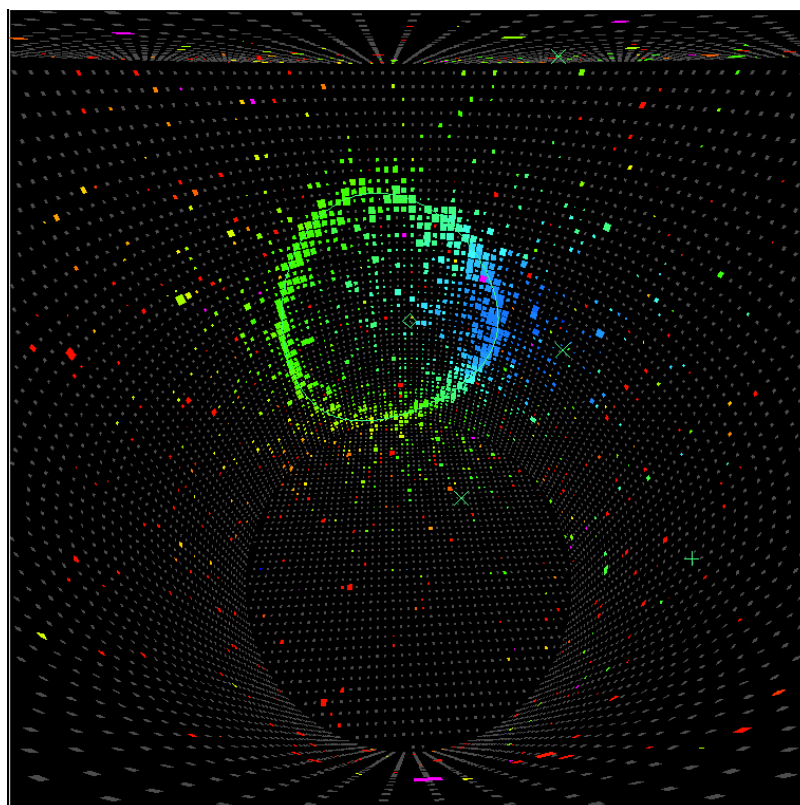


Fig. 4 : An Electron neutrino candidate event

In this 3D-image of cylinder-shaped Super-Kamiokande, each colored dot shows a photomultiplier tube that detected light. Electron neutrinos interact with water in the detector to produce electrons, which subsequently induce electromagnetic showers and eventually emit Cherenkov light, detected as

a ring-shaped structure. This is the first candidate obtained after recovery from the 2011 great earthquake in the east coast of Japan.

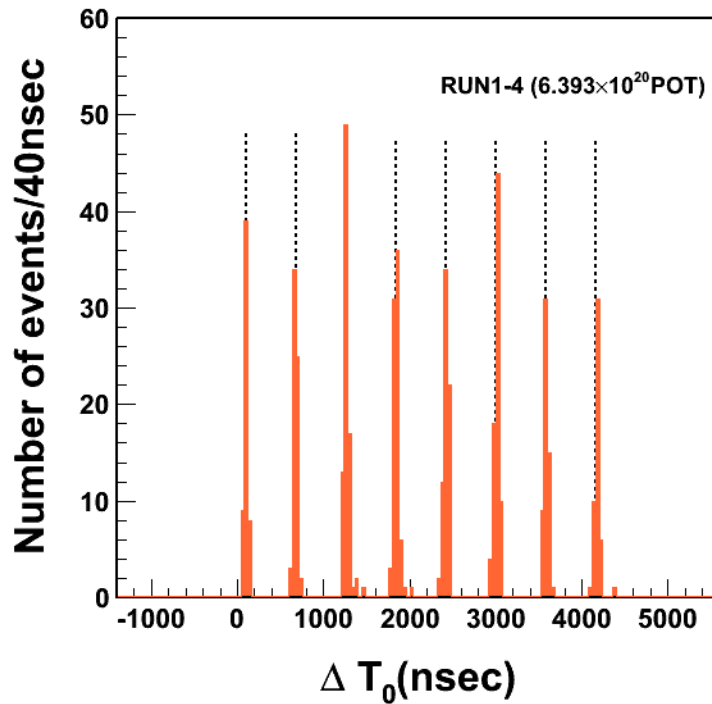


Fig. 5 : Distribution of the T2K event timing observed at Super-Kamiokande

At J-PARC, neutrino beams are produced as pulses once in every 2.5 seconds. Each pulse has a fine-structure, with 8 “bunches”, originating from the scheme of acceleration of the proton beam. This figure shows the timing distribution of the events observed at Super-Kamiokande, where zero in the horizontal axis stands for the time when the forefront of each beam-shot arrives at Super-Kamiokande. We can clearly observe the beam-bunch structure.

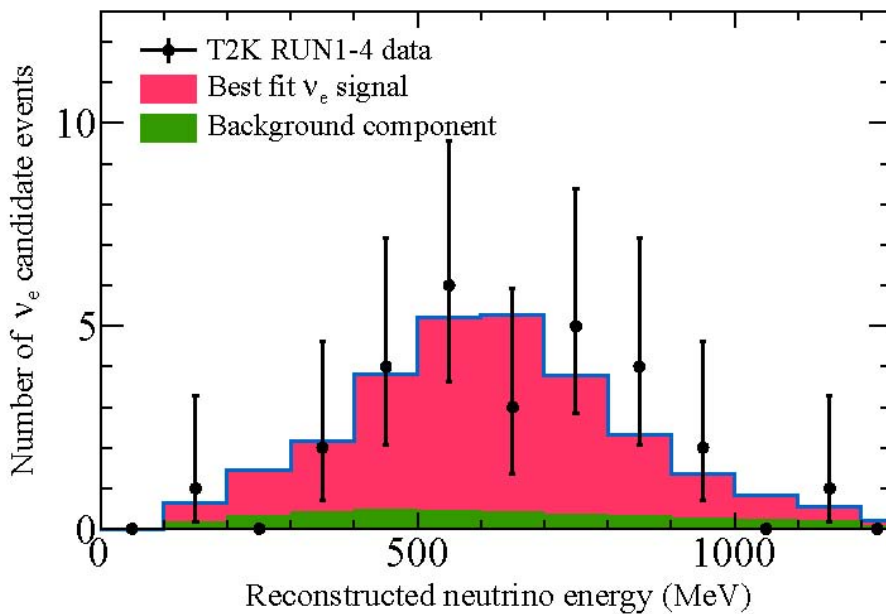


Fig. 6 : Energy distribution of the electron neutrino appearance candidates

The data distribution (black dots with error bars) agrees well with the expectation, which consists of background events (green histogram) and electron neutrino appearance candidate events (red histogram).

■Glossary

※1 T2K experiment

A long baseline neutrino oscillation experiment, where a neutrino beam produced at J-PARC is detected with Super-Kamiokande, a neutrino detector, located in Kamioka in Gifu Prefecture, 295 km away from J-PARC. T2K (Tokai to Kamioka) was named from the first letters of Tokai where J-PARC is located, and Kamioka where Super-Kamiokande is located. One of the primary purposes of the T2K experiment is to detect electron neutrino appearance, which has now, with this announcement, been realized. The T2K experiment, which has the world-leading sensitivity for neutrinos, has attracted many researchers from around the world, and in fact about 500 researchers from 11 countries: Japan, US, UK, Italy, Canada, Switzerland, Spain, Germany, France, Poland, and Russia have joined this international experiment. In Japan, 85 researchers and students from Osaka City University, Okayama University, Kyoto University, KEK, Kobe University, Tokyo Metropolitan University, University of Tokyo, Institute for Cosmic Ray Research of the University of Tokyo, Kavli IPMU of the University of Tokyo, and Miyagi University of Education participate in this experiment as core members.

※2 Neutrinos

One of the elementary particles. They are electrically neutral, and their masses are postulated to be about one millionth of quark or electron masses. Neutrinos come in three types: electron neutrinos, muon neutrinos, and tau neutrinos.

※3 Electron neutrino appearance

If two different types of neutrinos have different masses, they can transform into each other while traveling. This phenomenon is called neutrino oscillation, which was predicted by Pontecorvo and Maki, Nakagawa, and Sakata in 1962. Neutrinos come in three types: electron neutrinos, muon neutrinos, and tau neutrinos, and thus three patterns of oscillations may occur between them. If appearance from muon neutrinos to electron neutrinos is detected, the ratio of the three types of neutrino oscillations can be determined; therefore many studies have been conducted around the world to detect such events, but nothing had been successful so far. T2K is a special type of neutrino oscillation study, in which different types of neutrinos are identified before and after the oscillation, and thus can be the best candidate to search for CP violation in leptons.

※4 CP violation

Due to CP violation, the characteristics of matter and antimatter differ. CP violation is thought to be a possible explanation for why the universe mostly consists of matter and not antimatter (a matter dominated universe). Lepton CP violation is thought to be a key component of this explanation.

※5 leptons

A group of elementary particles including the electron and its family particles, and neutrinos that have no electric charge. As with quarks, there are six types of leptons: e (electron)- ν_e (electron neutrino), μ (muon)- ν_μ (muon neutrino), and τ (tau)- ν_τ (tau neutrino). These leptons are thought to correspond one-to-one with six quarks: u (up)- d (down), c (charm)- s (strange), and t (top)- b (bottom). However, detailed nature of this correspondence has yet to be elucidated. Note that leptons have their antiparticles, as quarks have antiquarks. The anti-electron is especially called a positron.