

論文 / 著書情報  
Article / Book Information

題目(和文)	Precise measurement of neutrino mixing angle 13 using the Double Chooz detector
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種別(和文)	論文要旨
Type(English)	Summary

## 論文要旨

THE S I S S U M M A R Y

専攻： Department of	基礎物理学	専攻	申請学位（専攻分野）： Academic Degree Requested	博士（理学） Doctor of
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要旨（英文800語程度）  
Thesis Summary (approx.800 English Words)

A measurement of neutrino mixing angle  $\theta_{13}$  using the Double Chooz detector is presented in this thesis. Double Chooz observes neutrinos from nuclear reactors located at Chooz nuclear power plant in France. Double Chooz has been taking data since April 2011 with a detector located at 1 km from the reactors, which is called as far detector. Result of the measurement with 460 days of live-time is shown in this thesis. Currently, construction of near detector is completed, and data taking with the far and near detectors is expected to begin in 2015.

From solar, atmospheric, accelerator, and reactor neutrino experiments, existence of neutrino flavor and mass eigenstates mixing in a three flavor framework was revealed. The mixing is characterized as three mixing angles, and one phase  $\delta_{CP}$ , and mass differences between their mass eigenstates.  $\theta_{13}$  is one of the three mixing angles.  $\theta_{13}$  had not been measured for about a decade after the measurement of other mixing angles, because of its small value. Double Chooz is the first reactor experiment to indicate the non-zero value of  $\theta_{13}$ . From these measurements of neutrino oscillation, neutrinos are found to have finite mass, otherwise, the neutrino oscillation cannot happen. Still, there are problems in neutrino physics. For example, 1) Neutrino mass hierarchy problem: ordering of neutrino masses is not determined. Namely, it is not known that if  $m_1 < m_3$  (normal hierarchy) or  $m_1 > m_3$  (inverted mass hierarchy). 2) Octant of  $\theta_{23}$  determination: It is a question whether the  $\theta_{23}$  is larger or smaller than  $\pi/4$ . 3) Measurement of CP violation phase  $\delta_{CP}$ . 4) Whether neutrinos are Dirac or Majorana particle. Sensitivities to the mass hierarchy determination, and other parameters such as CP violating phase depend on the mixing angles including  $\theta_{13}$ . Therefore, precise measurement of  $\theta_{13}$  is essential for further understanding of the neutrino nature by future experiments.

There are several experiments to measure  $\theta_{13}$  using reactor neutrinos and accelerator neutrinos. There are three reactor experiments to measure  $\theta_{13}$  in the world: Double Chooz, Daya Bay, and RENO. Benefit of the reactor neutrino experiments is that precise measurement of  $\theta_{13}$  is possible, since the sensitivity of  $\theta_{13}$  is not affected by the uncertainties from other neutrino oscillation parameters. On the other hand, accelerator based experiments such as the NOvA and Hyper-Kamiokande are sensitive not only to  $\theta_{13}$ , but also the other parameters such as  $\delta_{CP}$ ,  $\theta_{23}$  octant, and mass hierarchy. Therefore, accelerator based experiments and reactor neutrino experiments are complementary to each other. Among the reactor experiments, Double Chooz is unique to low accidental background rate. Furthermore, low flux uncertainty is expected with near and far detectors run due to its layout of reactors and detectors.

Currently in Double Chooz,  $\theta_{13}$  is measured by a deficit of electron antineutrino at the far detector place which is 1 km from the reactor cores, compared with Monte-Carlo simulation. Neutrinos are emitted by beta decay in the reactor cores, and the neutrinos are detected by inverse beta decay (IBD) reaction in the detector. The detection is carried out by observing the two signals of the positron and neutron by the detector filled with gadolinium doped liquid scintillator. The positron signal and the neutron signal are called prompt signal, and delayed signal respectively. The delayed signal happens about 30  $\mu$ s after the prompt signal due to neutron capture on gadolinium nuclei. Since most of the neutrino energy is transferred into the prompt event, the neutrino energy can be measured by energy of the prompt signal. In this thesis, not only neutrino rate but also neutrino energy spectrum is used for the measurement of  $\theta_{13}$ , so the precision of the energy measurement is one of the most important factor. Precise measurement of the neutrino energy is enabled by energy calibration which is described in detail in this thesis. Most of the background is suppressed by requiring both of the prompt and delayed signals. Remaining backgrounds are cosmogenic background, correlated background, and accidental background. These backgrounds are further reduced by techniques described in this thesis, and their rates and energy spectra are estimated. The measurement of neutrino mixing angle  $\theta_{13}$  is carried out by comparing the observed energy spectrum with the Monte-Carlo simulation. Systematic uncertainties due to the detector response, flux prediction, background estimation, and efficiency is included in the analysis. From the 460 days of data since April 2011, the neutrino mixing angle is measured to be:  $\sin^2 2\theta_{13} = 0.105 \pm 0.030$ . Thus, evidence of non-zero value  $\theta_{13}$  is found. Moreover, impact of the energy calibration to the sensitivity of  $\sin^2 2\theta_{13}$  is evaluated.

備考：論文要旨は、和文2000字と英文300語を1部ずつ提出するか、もしくは英文800語を1部提出してください。  
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