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A side-by-side comparison of Daya Bay antineutrino detectors

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ABSTRACT

The Daya Bay Reactor Neutrino Experiment is designed to determine precisely the neutrino mixing angle θ_{13} with a sensitivity better than 0.01 in the parameter $\sin^2 2\theta_{13}$ at the 90% confidence level. To achieve this goal, the collaboration will build eight functionally identical antineutrino detectors. The first two detectors have been constructed, installed and commissioned in Experimental Hall 1, with steady data-taking beginning September 23, 2011. A comparison of the data collected over the subsequent three months indicates that the detectors are functionally identical, and that detector-related systematic uncertainties are smaller than requirements.

1. Introduction

The precise determination of the neutrino mixing angle θ_{13} by the Daya Bay Reactor Neutrino Experiment (Daya Bay) requires measurement of the antineutrino flux from the six nuclear reactors at different baselines using eight antineutrino detectors [1]. Detection of antineutrinos is via the inverse beta-decay (IBD) reaction

$$\overline{\nu}_e + \mathrm{p} \rightarrow \mathrm{e}^+ + \mathrm{n}. \tag{1}$$

The positron rapidly annihilates with an electron (prompt signal) while the neutron first thermalizes before being captured by a nucleus and releasing energy (delayed signal).

The value of $\sin^2 2\theta_{13}$ can be determined by comparing the observed antineutrino rate and energy spectrum with predictions assuming oscillations. The number of detected antineutrinos N_{det} is given by

$$N_{\mathrm{det}} = \frac{N_p}{4\pi L^2} \int \epsilon \sigma P_{\mathrm{sur}}(E,L,\theta_{13}) S \, dE \tag{2}$$

where N_p is the number of free protons in the target, L is the distance of the detector from the reactor, ϵ is the efficiency of detecting an antineutrino, σ is the total cross-section of the IBD process, P_{sur} is the $\overline{\nu}_e \rightarrow \overline{\nu}_e$ survival probability that depends on the value of $\sin^2 2\theta_{13}$, and S is the differential energy distribution of the antineutrino.

With only one detector at a fixed baseline from a reactor, according to Eq. (2), we must determine the absolute antineutrino flux from the reactor, the absolute cross-section of the IBD reaction, and the efficiencies of the detector and event-selection requirements in order to measure $\sin^2 2\theta_{13}$. It is a challenge to reduce the systematic uncertainties of such an absolute measurement to sub-percent level, especially for reactor-related uncertainties.

Mikaelyan and Sinev pointed out that the systematic uncertainties can be greatly suppressed or totally eliminated when two detectors positioned at two different baselines are utilized [2]. The detector closer to the reactor core is primarily used to establish the flux and energy spectrum of the antineutrinos. This relaxes the requirement of knowing the details of the fission process and operational conditions of the reactor. In this approach, the value of $\sin^2 2\theta_{13}$ can be measured by comparing the antineutrino flux and energy distribution observed with the far detector to those of the near detector.

According to Eq. (2) for a single reactor core and single near and far detectors, the ratio of the number of antineutrino events with energy between E and $E+dE$ detected at distance L_{f} (far detector) from the reactor core to that at a distance L_{n} (near detector) is given by

$$\frac{N_{\mathrm{f}}}{N_{\mathrm{n}}} = \left(\frac{N_{\mathrm{p,f}}}{N_{\mathrm{p,n}}}\right)\left(\frac{L_{\mathrm{n}}}{L_{\mathrm{f}}}\right)^2\left(\frac{\epsilon_{\mathrm{f}}}{\epsilon_{\mathrm{n}}}\right)\left[\frac{P_{\mathrm{sur}}(E,L_{\mathrm{f}},\theta_{13})}{P_{\mathrm{sur}}(E,L_{\mathrm{n}},\theta_{13})}\right] \tag{3}$$

where $N_{\mathrm{p,f}}$ and $N_{\mathrm{p,n}}$ refer to the number of target protons at the far and near sites, respectively. The relative detector efficiency $(\epsilon_{\mathrm{f}}/\epsilon_{\mathrm{n}})$ can be determined more precisely than the absolute efficiency. Hence, the detector-related systematic uncertainty in this approach is greatly reduced. Furthermore, the use of multiple modules at each site enables internal consistency checks. Daya Bay will implement this strategy by deploying two functionally identical modules at each of two sites near the reactor cores, and four detectors at a site further away.

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