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The Daya Bay Reactor Neutrino Experiment

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Abstract. Search for the value of θ_{13} mixing angle is of importance in understanding the lepton flavor mixing matrix, and in motivating future experiments to probe CP violation in the lepton sector. Among the present experimental approaches, reactor experiment can provide a clean laboratory for the θ_{13} -measurement. The Daya Bay experiment will start civil construction this year at Daya Bay, Guangdong, China. The goal of this experiment is to reach a sensitivity in $\sin^2 2\theta_{13}$ of < 0.01 at 90% C.L. by precisely measuring the disappearance and spectral distortion of reactor electron anti-neutrinos with multiple identical detectors at different baselines. The talk will present the current status and prospects of the experiment.

1. Introduction

CP violation has been an important issue of study in both theory and experiment for many years. After neutrino oscillations were discovered, whether or not CP violation can also occur in the lepton sector is now drawing more and more attention [1]. Theoretically, analogous to mixing in the quark sector, CP violation in the lepton sector can be incorporated into the PMNS matrix with one Dirac CP phase and two Majorana CP phases. Experimentally, the last two phases are extremely difficult to determine, while the Dirac CP phase may be accessible through neutrino oscillation as long as the value of $\sin^2 2\theta_{13}$ is not so small. Current knowledge on θ_{13} is $\sin^2 2\theta_{13} < 0.17$ at 90% C.L. [2], and is even smaller as obtained from a three-flavor global fit [3]. Many theoretical models attempt to predict this value but cannot yield a consistent picture [4]. Therefore, θ_{13} is not only a gateway of CP violation in the lepton sector but also a guide in understanding the lepton flavor mixing matrix. Among all the efforts of determining $\sin^2 2\theta_{13}$, a reactor experiment can avoid the cross talk between the θ_{13} and the unknown Dirac CP phase, and thus provide a clean measurement.

2. The Daya Bay experiment

The Daya Bay nuclear power plant, which is located in the Guangdong province, China and 55 km away from the Hong Kong Island, currently has two pairs of reactor cores (Daya Bay and Ling Ao) in operation with a total of 11.6 GW_{th}. One more pair (Ling Ao II) will be added after 2011, giving additional 5.8 GW_{th}. These cores can provide about 2.3×10^{21} (3.5×10^{21} after 2011) electron anti-neutrinos ($\bar{\nu}_e$'s) per second with energies up to 8 MeV. The plant is near a mountainous terrain, which can provide sufficient overburden to suppress cosmic muon induced backgrounds to less than 1% of the antineutrino signal. This greatly reduces the systematic uncertainty due to background.

The principle of the Daya Bay experiment is to look for the disappearance and spectral distortion of $\bar{\nu}_e$'s produced by reactors. The concept of using near and far site detectors to

cancel the common systematic uncertainties from both the reactors and the detectors is adopted. Tunnels connecting the near and the far halls will enable the option of interchanging detectors. The target mass for each near site is 40 tons. In addition to the baseline, the far detector is optimized to be 80 tons in weight to achieve the designed sensitivity with minimum cost. The optimization procedure takes into account the $\bar{\nu}_e$ flux, oscillation, energy spectrum, systematic uncertainties from both the reactors and the detectors, overburden, ambient background, spectra of the cosmogenic neutrons and ${}^9\text{Li}$, etc. The first near hall is chosen to be 363 m away from the Daya Bay reactor cores with a 98 m overburden; the second near hall is about 500 m from the Ling Ao reactor cores with a 112 m overburden; the far hall is 1,985 m from Daya Bay and 1,615 m from Ling Ao with 350 m overburden.

Eight identical cylindrical $\bar{\nu}_e$ detector modules (AD's) will be built. Each AD, consists of three nested cylindrical zones contained within a stainless steel tank, will be deployed to detect $\bar{\nu}_e$ via the inverse beta-decay reaction: $\bar{\nu}_e + p \rightarrow n + e^+$. Each AD will have 20 tons of 0.1% Gd-doped liquid scintillator (Gd-LS) in the inner-most $\bar{\nu}_e$ target zone (3.1 m in diameter and 3.1 m in height, a detailed design information is given in Fig. 2.3 and 2.4 in Reference [5]). A 45-cm-thick second zone, separated from the target and outer buffer zones by two transparent acrylic vessels, is filled with undoped liquid scintillator (LS) for capturing γ rays that escape from the target thereby improving the detection efficiency. A total of 192 8-inch photomultiplier tubes (PMT's) are arranged along the circumference of the stainless steel tank in the outer-most zone (45 cm in thickness), which contains mineral oil to attenuate γ rays from trace radioactivity in the PMT glass and nearby materials including the outer tank. With reflective surfaces at the top and bottom of the outer acrylic vessel, the energy resolution and the vertex resolution of the detector are estimated to be about 12% at 1 MeV and 12 cm, respectively. The Gd-LS candidate is Linear Alkyl Benzene doped with 0.1% of Gd by weight. It has excellent long-term stability. The current AD design can achieve a neutron detection efficiency of 78% (combining 85% Gd fraction and 93% energy cut) and a 98% e^+ detection efficiency. It is expected that the signal event rates for each AD are 960/day in the Daya Bay near hall, 760/day in the Ling Ao near hall and 90/day in the far hall, respectively. The rate and energy distribution of the $\bar{\nu}_e$'s from the reactors will be measured with two AD's in each near hall. This configuration will enable a cross calibration to verify that the detectors are identical.

To reduce the γ rays and spallation neutrons produced in the surrounding rock from entering the AD's, in each hall, the AD's are separated by 1 m from each other and immersed in a large pool of highly purified water. The pools are octagonal in cross-section. The far hall pool has a cross-section of 16 m² with corners cut off at 45° such that the shortest distance from the walls to the steel tank of an AD is 2.5 m. The near hall pools have a cross-section of 16 m × 10 m rectangles also with corners cut off at 45°. The minimum distance between the outer surface of the detectors and the walls of the pools is 2.5 m. The water shield of each pool is divided into inner and outer sections and instrumented with PMT's to detect Cherenkov photons from muons transverse through the water. The partition is realized with Tyvek film 1070D reflectors stretched over a stainless steel frame. The frame holds PMT's for both the inner and outer sections of the pool. The water Cherenkov detectors are augmented with a muon tracker consisted of four layers of Resistive Plate Chambers (RPC's) placed above the pool. The tracker extends 1 m beyond the edge of the pool in all directions, to allow studies of background caused by muon interactions in the rocks surrounding the pool. The water Cherenkov counters combined with the RPC's give an overall efficiency of cosmic muon detection of better than 99.5%, with an uncertainty <0.25%.

The response of the detectors will be calibrated and monitored throughout the experiment. Calibration sources with energy range from about 0.5 MeV to 10 MeV are Am-Be, ${}^{252}\text{Cf}$, Pu(C), ${}^{22}\text{Na}$, ${}^{68}\text{Ge}$, ${}^{60}\text{Co}$ and ${}^{238}\text{Pu}$ - ${}^{13}\text{C}$. These sources will be deployed regularly along a few vertical axes of the detectors to calibrate and monitor the detector response to positrons, and neutron

Table 1. Summary of background, statistical and systematic uncertainties.

Source	Uncertainty
$\bar{\nu}_e$ from reactors	0.087% (4 cores), 0.13% (6 cores)
Detector (per AD module)	0.38% (baseline), 0.18% (goal)
Backgrounds	0.32% (Daya Bay), 0.22% (Ling Ao), 0.22% (far)
Statistics	0.2%

capture. LED's with ns widths are used to check the optical properties of LS, the performance of the PMT's and the timing of the data acquisition systems. The radioactive sources and the LED's are deployed with automatic systems attached to the top lid of the AD. Trigger efficiency and PMT dark noise will be measured by using the random trigger events. Cosmogenic radioactive nuclei and neutrons will also be used to provide continuous calibration of the entire fiducial volume of for the detector.

Each AD and each muon system will use separated front-end electronics, trigger and data acquisition system to minimize possible systematic uncertainty. The systems in all the three halls will share a common clock signal. The $\bar{\nu}_e$ signal will be triggered by the multiplicity of PMT hits with a cross-check from the energy sum trigger. The event rate is estimated to be < 1.5 MBytes/s per site. This system is also designed to have capability to readout any detector module based on information from any adjoining module, giving an opportunity to extensively study the cosmogenic neutron background, and independently measure the detection efficiency.

3. Current status and conclusion

The Daya Bay experiment received strong recommendation from the Chinese institutions at the 250th Xiangshan Scientific Meeting held in Beijing in 2005, a standard procedure to initiate a major research project in China. There are currently more than 190 physicists from 34 research institutes in China, the US, Russia and the Czech Republic working on this experiment. The CDR was released in January, 2007 [5]. The TDR is now complete. We have received funding from the Chinese funding agencies. Civil construction began on October 13, 2007. Deployment of the first pair of the AD's to the Daya Bay near hall will take place in 2009. Data taking using the baseline configuration of the two near halls and far hall will begin in 2010. Based on the estimated background, statistical and systematic uncertainties given in Table 1, after three years of running the sensitivity of Daya Bay for $\sin^2 2\theta_{13}$ will reach 0.008, relatively independent of the value of Δm_{31}^2 within its allowed range.

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