High precision measurement of $\theta_{13}$: Progress of Daya Bay reactor antineutrino experiment

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On behalf of Daya Bay collaboration

NuFact’11, 1st~6th, Aug., Geneva
Daya Bay, China

- Very powerful nuclear power complex:
  - Daya Bay: 2 x 2.9GW
  - Ling Ao I: 2 x 2.9GW
  - Ling Ao II: 2 x 2.9GW (will be online 2011)

~17.4GW
The Daya Bay collaboration

~250 Collaborators
Outline

• Goal
• Daya Bay detectors
• Assembly & Installation & Test
• Current status & Schedule
Goals

- Daya Bay’s goal:
  - Precision measurement of $\theta_{13}$ (if it’s large)
  - Best sensitivity to $\theta_{13}$ (if it’s small)

Reactor neutrinos:
✓ Clean signal
✓ No CP violation
✓ Negligible matter effects
✓ Free neutrinos!

![Image of Daya Bay setup](image_url)
Systematic uncertainties

- Few key factors for systematic uncertainties control:
  - Near-Far measurement
  - Identical Antineutrino detectors
  - Overburden
  - Active/passive multi Muon veto
  - Detector swapping (optional)

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Systematic uncertainties Table

<table>
<thead>
<tr>
<th>Source of uncertainty</th>
<th>Chooz (absolute)</th>
<th>Daya Bay (relative)</th>
</tr>
</thead>
<tbody>
<tr>
<td># protons</td>
<td>0.8</td>
<td>0.3</td>
</tr>
<tr>
<td>Detector Energy cuts</td>
<td>0.8</td>
<td>0.2</td>
</tr>
<tr>
<td>Efficiency Position cuts</td>
<td>0.32</td>
<td>0.0</td>
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<tr>
<td>Time cuts</td>
<td>0.4</td>
<td>0.1</td>
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<tr>
<td>H/Gd ratio</td>
<td>1.0</td>
<td>0.1</td>
</tr>
<tr>
<td>Multiplicity</td>
<td>0.5</td>
<td>0.05</td>
</tr>
<tr>
<td>Trigger</td>
<td>0</td>
<td>0.01</td>
</tr>
<tr>
<td>Live time</td>
<td>0</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Total detector-related uncertainty</td>
<td>1.7%</td>
<td>0.38%</td>
</tr>
</tbody>
</table>

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Numbers from A. Cabrera (DC) and K. K. Joo (RENO)’s talks in NEUTRINO 2010
Antineutrino Detector (AD)

- 8 “identical”, 3-zone detectors in 3 experimental halls
  - 20t GdLS, 20t LS, 40t MO, separated by Acrylic Vessels
  - 192 8” PMTs in 8 rings, top and bottom reflectors
  - Precise target mass control
  - Low background
  - Low charge threshold
  - High precise calibration: auto scan and manual calibration
- No position reconstruction, no fiducial cut needed

![Diagram of AD detector](image)

- Gd-doped liquid scintillator 20ton
- liquid scintillator 20ton, 45cm
- MO 40t, 50cm

![Graphs showing energy spectra](image)

- MC Prompt
- MC Delayed
- Neutron capture time on 0.1% GdLS ~28us
Muon veto detectors

- Multi Muon Veto detectors:
  - Active and passive Muon detectors
  - Two layers water Cherenkov detector
  - RPC detector on top
- Redundant veto system = highly efficient Muon rejection
  - $\epsilon > (99.5 \pm 0.25)\%$

- Water Cherenkov
  - Passive shielding against radioactivity and neutron at least $\sim 2.5m$,
  - Two layers optically separated by Tyvek
- RPC on top
  - 4 layers: X or Y strip direction of each layer
  - Independent Muon tagging
  - Retractable roof above pool
AD assembly

- The assembly of 2 pairs of ADs has been finished at Surface Assembly Building (SAB) of Daya Bay; the 3rd pair is being assembled.
  - Installation in Clean room
  - Leakage check for all the flanges
  - Hardware test after installation: Dry run (results show later)
Move SSV
(Stainless Steel Vessel, Φ 5m)
SSV sits in pit
Clean SSV inside
Insert bottom reflector
Insert outer AV

(Acrylic Vessel, $\Phi 4m$)
Insert inner AV

$(\Phi 3m)$
Close outer AV lid
Lift PMT ladder

(Photo Multiplicity Tube)
Install top reflector
Close SSV lid
Install ACUs

(Auto Calibration Unit)
Daya Bay near Hall
Installation

RPC

Water pool
Daya Bay near hall

- 1\textsuperscript{st} pair of ADs has been put into the pool
  - Doing final installation
  - Water filling
Online / slow control system ready

Daya Bay near hall

• Online system ready
  – GPS clock system: uniform clock and time stamp for all the subsystems
  – Master trigger board for cross trigger (MTB)
  – Local trigger board for event trigger (LTB)
  – Front End Electronics (FEE): precise charge and relative hit time measurements
  – RPC electronics
  – DAQ

• Slow control working

Installed electronics for Daya Bay near hall
AD Prototype (Beijing)

  - Validate detector design principle
  - Geant4 simulation
  - GdLS study: Long term stability
  - Effects of reflectors
  - Reconstruction algorithm
  - Gamma and neutron response: PuC tagged neutron
  - Electronics development / system commissioning

**Data comparison with MC**

**Plutonium-Carbon neutron source**

**Prompt:** 6.13MeV gamma

**Delay:** neutron

**Energy resolution**

**Energy response**
AD Dry run (Daya Bay)

- All the subsystems test for Antineutrino Detector except liquid scintillator
- Goals:
  - Check hardware status for installation
  - System commissioning/debug, software/analysis development
  - Detector/Auto Calibration Units test
  - Detector identical study: differ <1%, and consistent with MC
AD sensors

• To monitor:
  – Detector status, precise target mass
• The sensors:
  – 4 mineral oil temperature sensors at different depth
  – 2 Cameras for vision check after lid final closed
  – Lid sensors for temperature, tilt level, and liquid level of GdLS and LS by ultrasonic, capacitance, CCD etc
Dry water pool test
(Daya Bay near hall)

• Goals:
  – Check the hard ware status
  – LED calibration system
  – Cover light tightness
  – Basic detector performances
GdLS/LS production

- All the Gd-LS and LS for the experiment have been mixed and stored.

- 2 × 1000L 0.5% Gd-LAB
- 500L flour +LAB
- 5000L 0.1% Gd-LS

- 185 tons 0.1% GdLS stored in 5 40-ton tanks
- 180 tons LS stored in 200 ton pool

LS mixing and filling hall
mixing equipment
NuFact'11
GdLS/LS properties

- The liquid properties have been stable so far

Absorption monitoring

UV-vis of 4-ton Dry Run Gd-LS
GdLS/LS filling

- 1st pair of ADs has been filled till now, preparing for 2nd pair
  - Auto liquid level control
  - Precise target mass control
Response of filled AD

- After the installation of filled AD#1 to Daya Bay near hall without water in pool, a short test was taken to check the detector response;
- The plot shows the measured charge spectrum with $^{60}\text{Co}$ located at detector centre;
- All the systems working properly: detector, scintillator, online, slow control, and offline analysis.
Schedule

- Smooth progress: Daya Bay near hall
  - 1\textsuperscript{st} filled pair of ADs fully completed
  - Muon system installation completed.
  - Water pool filling now.
  - Physics data ready this summer;
- Fall 2012:
  - All near/far halls physics ready

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Summary

- Daya Bay experiment can measure the mixing angle $\theta_{13}$ to a great precision: $\sin^2 2\theta_{13} < 0.01 \text{ @ 90\% C.L.}$
- Smooth progresses are going on for civil, detector assembly, filling, detector installation, test/commissioning;

Exciting time as rapidly increasing of test run/commissioning data!
Thanks