The Daya Bay Reactor Neutrino Experiment

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for the Daya Bay Collaboration

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Measuring $\theta_{13}$ at a Reactor

Neutrino mixing:

$$U_{MNSP} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & C_{23} & S_{23} \\ 0 & -S_{23} & C_{23} \end{pmatrix} \begin{pmatrix} C_{13} & 0 & S_{13} e^{-i\delta} \\ 0 & 1 & 0 \\ -S_{13} e^{i\delta} & 0 & C_{13} \end{pmatrix} \begin{pmatrix} C_{12} & S_{12} & 0 \\ -S_{12} & C_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

known: $\theta_{23}$ & $\theta_{12}$, mass differences $|\Delta m_{32}^2|$ & $\Delta m_{21}^2$; unknown: $\theta_{13}$ and $\delta$ (CP-violating)

Look for disappearance of reactor $\bar{\nu}_e$ over a baseline of $\sim2$ km where the probability is dominated by $\sin^2 2\theta_{13}$

$$P_{\text{dis}} \approx \sin^2 2\theta_{13} \sin^2 (1.27 \Delta m_{32}^2 L/E) + C_{13}^4 \sin^2 2\theta_{12} \sin^2 (1.27 \Delta m_{21}^2 L/E)$$

Reactor-$\nu_e$ disappearance, PDG09 values
Keys to a Precise Measurement

high statistics

identical near and far detectors
(systematic uncertainties from flux and cross sections cancel)

control of detector-related systematic uncertainties

background suppression
The Daya Bay Site

nuclear power complex located in China ~55 km from Hong Kong

Ling Ao
- 2 x 2.9 GW cores
- 2 more 2.9 GW cores by 2011

Daya Bay
2 x 2.9 GW cores

~2e20 $\bar{\nu}_e /s$ per GW
The Daya Bay Site

2 near detector sites

Far site:
- 1985 m from Daya Bay cores
- 1615 m from Ling Ao cores

movable detectors

more than one detector at each site allows side-by-side comparison

shielding provided by mountain
Antineutrino Detectors

Target region: 20 tons Gd-loaded (0.1%) LAB-based liquid scintillator

PMTs: 192 8-inch PMTs around the tank, reflectors on top and bottom

Steel tank

Acrylic vessels

γ-catcher: 20 tons LAB-based liquid scintillator

Oil buffer: 40 tons mineral oil

Signal is coincidence between prompt positron energy and delayed neutron capture

Inverse Beta Decay

\[ \bar{\nu}_e p \rightarrow e^+ n \]
Muon Veto System

- a 2.5 m active water shield around the antineutrino detectors instrumented with 8-inch PMTs
- water shield divided into inner region and outer region separated by Tyvek partitions
- RPCs on top of the water pool
- combined system has muon tagging efficiency of >99.5%
Sensitivity

Region of interest for $\Delta m^2$ from atmospheric $\nu$ experiments

Daya Bay's sensitivity: $\sin^2 2\theta_{13} < 0.01$ in 3 years of running (90% C.L.)

<table>
<thead>
<tr>
<th>Source</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detector</td>
<td>0.38% (baseline)</td>
</tr>
<tr>
<td>Reactor</td>
<td>0.18% (goal)</td>
</tr>
<tr>
<td>Signal Statistics</td>
<td>0.13%</td>
</tr>
<tr>
<td></td>
<td>0.2%</td>
</tr>
</tbody>
</table>
Status

Tunneling progress as of mid-January

Inside the tunnel

Daya Bay Near Hall
Status

Test assembly

Test batch of 0.1% Gd-LS in 5000 L tank

Test batch of Gd-LS has been studied for almost one year now!

Vehicle to transport the detectors

4m acrylic vessel

Assembled PMT ladder

February 14, 2010

L. Whitehead, BNL
Project Schedule

October 2007: Ground breaking
August 2008: CD 3 reviews completed
2010: Daya Bay Near Hall ready for data
2011: Far Hall ready for data
North America (15)(~83)
BNL, Caltech, Cincinnati, George Mason Univ.,
LBNL, Iowa State Univ., Illinois Inst. Tech.,
Princeton, RPI, UC-Berkeley, UCLA,
Univ. of Houston, Univ. of Wisconsin,
Virginia Tech.,
Univ. of Illinois-Urbana-Champaign

Europe (3) (9)
JINR, Dubna, Russia
Kurchatov Institute, Russia
Charles University, Czech Republic

Asia (18) (~126)
IHEP, Beijing Normal Univ., Chengdu Univ.
of Sci. and Tech., CGNPG, CIAE, Dongguan Polytech. Univ., Nanjing Univ., Nankai Univ.,
Shandong Univ., Shenzhen Univ.,
Tsinghua Univ., USTC, Zhongshan Univ.,
Univ. of Hong Kong,
Chinese Univ. of Hong Kong,
National Taiwan Univ., National Chiao Tung Univ., National United Univ.

> 200 collaborators
Backup Slides
### Backgrounds

#### Table

<table>
<thead>
<tr>
<th></th>
<th>DYB site</th>
<th>LA site</th>
<th>far site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antineutrino rate (/day/module)</td>
<td>840</td>
<td>740</td>
<td>90</td>
</tr>
<tr>
<td>Natural radiation (Hz)</td>
<td>&lt;50</td>
<td>&lt;50</td>
<td>&lt;50</td>
</tr>
<tr>
<td>Single neutron (/day/module)</td>
<td>18</td>
<td>12</td>
<td>1.5</td>
</tr>
<tr>
<td>$\beta$-emission isotopes (/day/module)</td>
<td>210</td>
<td>141</td>
<td>14.6</td>
</tr>
<tr>
<td>Accidental/Signal</td>
<td>&lt;0.2%</td>
<td>&lt;0.2%</td>
<td>&lt;0.1%</td>
</tr>
<tr>
<td>Fast neutron/Signal</td>
<td>0.1%</td>
<td>0.1%</td>
<td>0.1%</td>
</tr>
<tr>
<td>$^8\text{He}^9\text{Li}$/Signal</td>
<td>0.3%</td>
<td>0.2%</td>
<td>0.2%</td>
</tr>
</tbody>
</table>

1) **$^9\text{Li}/^8\text{He}$ isotopes** – have significant beta-neutron decay branching fractions

2) **Fast neutrons** – recoil proton gives prompt signal followed by neutron capture

3) **Accidentals** – coincidence of neutron capture with natural radioactivity in the detector
## Systematic Uncertainties

<table>
<thead>
<tr>
<th>Source of uncertainty</th>
<th>Chooz (absolute)</th>
<th>Daya Bay (relative)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Baseline</td>
</tr>
<tr>
<td># protons</td>
<td>0.8</td>
<td>0.3</td>
</tr>
<tr>
<td>Detector Efficiency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy cuts</td>
<td>0.8</td>
<td>0.2</td>
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<tr>
<td>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>n multiplicity</td>
<td>0.5</td>
<td>0.05</td>
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<tr>
<td>Trigger</td>
<td>0</td>
<td>0.01</td>
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<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>

### Detector-related uncertainty

<table>
<thead>
<tr>
<th>assumption</th>
<th>uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>reactor-related correlated</td>
<td>2%</td>
</tr>
<tr>
<td>reactor-related per core</td>
<td>2%</td>
</tr>
<tr>
<td>spectrum shape</td>
<td>2%</td>
</tr>
<tr>
<td>detector-related correlated</td>
<td>2%</td>
</tr>
<tr>
<td>detector-related per module</td>
<td>0.38%</td>
</tr>
<tr>
<td>accidental background</td>
<td>100%</td>
</tr>
<tr>
<td>fast neutron background</td>
<td>100%</td>
</tr>
<tr>
<td>He/Li background</td>
<td>0.3%</td>
</tr>
<tr>
<td>bin to bin</td>
<td>0.3%</td>
</tr>
</tbody>
</table>
Global Sensitivity Comparison

arXiv:0907.1896