The Daya Bay Calibration System — Key to $\theta_{13}$

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APS/DNP 08 Meeting, Oakland
Oct 26, 2008
Requirement on Systematic Uncertainty

\[ \frac{N_f}{N_n} = \left( \frac{N_{p,f}}{N_{p,n}} \right) \left( \frac{L_n}{L_f} \right)^2 \left( \frac{\epsilon_f}{\epsilon_n} \right) \left[ \frac{P_{sur}(E, L_f)}{P_{sur}(E, L_n)} \right] \]

- **Goal:** <1% to \( \sin^2 2\theta_{13} \)
- **Measured Ratio of Rates:**
- **Number of Proton Ratio:**
- **Detector Efficiency Ratio:**

\[ \sin^2 2\theta_{13} \]

0.3%

0.2%

Key requirement of the calibration program
Calibration of Detector Efficiency

- **Geometry** (edge effects, spill in/out)
  cancel in ratio for identical detectors

- **Positron detection**
  energy cuts at 1, 8 MeV

- **Neutron detection**
  energy threshold at 6 MeV
  delayed timing cuts \([0.3, 200]\) \(\mu s\)
  Gd/H cancels in near/far ratio when filling in pair

Calibration Program
- Routine (weekly) deployment of sources
- Radioactive sources = fixed energy, LED light source = fixed time
- Tagged cosmogenic background (free) = fixed energy & time
Energy Cuts

Prompt Energy Signal (Simulation)

1 MeV  8 MeV

Reconstructed Positron Energy Spectrum

Energy
Entries  68465
Mean  3.576
RMS  1.462
Underflow  0
Overflow  0

Delayed Energy Signal (Simulation)

6 MeV  10 MeV

reconstructed neutron (delayed) capture energy spectrum

Energy
Entries  79999
Mean  7
RMS  2.22
Underflow  0
Overflow  3

• Stopped positron signal using $^{68}\text{Ge}$ source (2 x 0.511 MeV) $\Rightarrow e^+$ threshold
• Neutron (n source, spallation) capture signal
  • 2.2 MeV $\Rightarrow e^+$ energy scale
  • 8 MeV $\Rightarrow$ neutron threshold at 6 MeV
Major Issue: Neutron Threshold

Simulation: 0.2% on detector efficiency ⇔ knowing positron threshold to 2% (easy), relative neutron threshold to 1% (more difficult)

Strategy: use position reconstructed spallation n-Gd capture signals (full fiducial volume) + weekly deployment of neutron sources (3 vertical axes)

<table>
<thead>
<tr>
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<th>Near /day/module</th>
<th>Far /day/module</th>
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<tbody>
<tr>
<td>Spallation Neutrons</td>
<td>13500</td>
<td>1100</td>
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<tr>
<td>σ/E=0.5% per pixel</td>
<td>1 day</td>
<td>10 days</td>
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100 pixel/detector
68Ge Source: Stopped $\text{e}^+$

68Ge → 68Ga → 68Zn

Rate: 100 Bq ($T_{1/2} = 270$ days)

Simulation:
- 3% of positrons hitting the stainless steel capsule. Others annihilated in plastic
- Net energy escaped via Bremsstrahlung $\sim 0.17\%$
Neutron Source

Source “parked” above detector during normal running with borated polyethylene shielding

Neutron “leakage”:

- $^{252}$Cf (3-4 neutrons/fission) or Am-Be (4.4 MeV gammas): coincidence (dangerous) background level too high

Solution:
- Limit neutron rate to 0.5 Hz
- Use $^{241}$Am (alpha) + $^{13}$C $\Rightarrow$ n + $^{16}$O
- Attenuate alpha energy with Au foil to <4.5 MeV to suppress $^{16}$O in excited state (6.15 MeV gamma)

Captures on steel “Neutron-like”!

$^{252}$Cf (3-4 neutrons/fission) or Am-Be (4.4 MeV gammas): coincidence (dangerous) background level too high
Design of Calibration Unit

- Three units per detector (3 z axes)

- Each unit contains three stepper motor systems on a turntable, capable of deploying three sources: $^{68}$Ge, neutron, and LED along a given vertical axis

- 100% automated remote control/monitoring software

- Position encoder, limit switch, load cell to ensure a fail safe system

- Selection of materials: Stainless steel, Teflon, Viton and Acrylic
Full Size Prototype

- Cable restrainer
- Acrylic wheel
- 30:1 Gear box
- Stepper motor
- Turntable motor/gearbox
- Teflon pulley
- Load cell
- Limit switch

Tested in lab >20-year worth of deployment!
Dragging Along Teflon Bellows
Status

• Mechanical/electronics design finished. Performed many prototype tests
• Fabrication in progress. On schedule to ship 3 units to Daya Bay Dec. 08

Turn-table plate out-of the shop

Assembly area at Caltech
Backups
Experimental Principle of Daya Bay

\[ \nu_e \text{ Near} \]

\[ \text{Far} \]

Unoscillated flux

Flux

\[ \sin^2 2\theta_{13} \]

\[ \sim 2 \text{ km} \]