Daya Bay Calibration System

- Energy Calibration Basics
- Calibration Subsystems
- Automated Source Calibration System
- Calibration Plans and Simulations

Jianglai Liu
Caltech

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Precise Determination of Energy

Between the near/far detector pair, require a relative

\[ \frac{\delta E}{E} \leq 1\% \]

Visible energy at detector center

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\[ Q(E, \bar{x}) \propto E_{vis} \times R(\bar{x}) \]
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“response function”

- Basic requirement: radioactive sources=fixed energy
- Response function is position-dependent: source at different places to sample the response function in entire fiducial volume
Subsystems

- LED source for gain, threshold, and timing calibration
- Manual source deployment system for full-volume characterization
- Automated source deployment system for routine calibration.
- Use tagged cosmogenics for continuous monitoring of detector performance
Inverse-beta Energy Spectra and Sources

Prompt Energy Signal

Reconstructed Positron Energy Spectrum

Delayed Energy Signal

Reconstructed neutron (delayed) capture energy spectrum

We plan three radioactive sources:

- $^{68}\text{Ge}$, 0 KE $e^+ \rightarrow 1.022$ MeV $\gamma$’s → $e^+$ energy threshold
- $^{60}\text{Co} \rightarrow 2.506$ MeV $\gamma$’s → $e^+$ energy scale
- Cf (or AmBe)$ \rightarrow n \rightarrow $ “delayed” capture on p (2.2 MeV $\gamma$) or Gd (8.0 MeV $\gamma$’s) → neutron threshold and scale
Spallation neutron for Daya Bay

- Muon induced neutrons thermalize and capture on Gd or H.
- Uniformly distributed in detector.
- Tagged by muon detector.
- Signals exactly like the inverse-beta neutron signal: Delayed energy 8 MeV (n-Gd) or 2.2 MeV (n-p). So calibrating $E_{\text{vis}}$.
- Combined with position reconstruction to give the detector position response function $R(x)$. 
Automated System Hardware

- 3 deploy system per module
- Each corresponds to one point in horizontal cross-section with full z axis.
- Each capable of deploying four different sources.
Three Ports/Units

- Central axis
- Outer radius of central region
- Gamma catcher region

Ge, Co, neutron sources

R=1.8 m  R=0  R=1.4m
One step motor unit

- One turn table, 4 step motors.
- Computer automated DAQ using position encoder, load cell readings.
# Detector Parameters and Corresponding Calibration Strategy

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Calibration Method</th>
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</thead>
<tbody>
<tr>
<td>Light yield in central region</td>
<td>Source @ center</td>
</tr>
<tr>
<td>Light yield in gamma catcher</td>
<td>Source in gamma catcher</td>
</tr>
<tr>
<td>Attenuation in central region</td>
<td>Neutron center/uniform ratio or Co center/corner ratio</td>
</tr>
<tr>
<td>Attenuation in gamma catcher</td>
<td>Source in gamma catcher</td>
</tr>
<tr>
<td>Tank reflectivity</td>
<td>Early/later light yield</td>
</tr>
<tr>
<td>Dead PMTs</td>
<td>Source @ center</td>
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<tr>
<td>Crud at the bottom of acrylic</td>
<td>Source along z axis</td>
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Carefully designing calibration to decouple different parameters.
Change of Attenuation Length in Central Region

So the attenuation length affect the detector position uniformity, light yield does NOT.

So “uniform”/”center” ratio ⇒ attenuation length.
- “uniform”: spallation neutrons,
- “center”: calibration.
 10,000 neutrons each.

Similarly, can use “corner”/”center” ratio.

$^{60}$Co source, 1000 events each
Change of Attenuation Length in Gamma Catcher

Q: How to calibrate the attenuation length in the gamma catcher only?

A: put a source in the gamma catcher.
Status Summary

We have a comprehensive plan for detector energy calibration.
Calibration system integrated in detector design. Detail simulations of the calibration performance are ongoing.
We are building prototype for the automated source deploy system.

Goal: to achieve a 1% near/far relative energy Uncertainty.
Backups
LED Calibration of the Antineutrino Detectors

Calibration Goal: PMT gains and timing
Put the source close to the outer layer and look at the tubes close-by. Short distance $\Rightarrow$ attenuation negligible.
Resulting Neutron Efficiency

$\varepsilon = \frac{\text{detected events} > 6 \text{ MeV}}{\text{Total Gd capture events}}$

0.1% variation for reasonable range of parameters.