**Abstract**

The Daya Bay experiment has made the most precise measurement of neutrino mixing angle $\theta_{13}$ and the first direct measurement of the $\nu_e$ mass-squared difference $\Delta m^2_{\odot}$ through the relative measurements between near and far detectors. In addition, efforts are made toward the absolute reactor flux and spectra measurements, which require a precise understanding of the absolute detection efficiency and detector response. The Monte Carlo simulation plays a crucial role in understanding the detector performance. A Geant4-based full detector simulation software has been built under the Gaudi framework, and is tuned with various data sets. This poster will describe details of the improvements on Monte Carlo simulation and studies of the absolute detection efficiency at Daya Bay.

**Introduction**

Daya Bay simulation software has been developed based on GEANT4 within the offline software framework known as NuWa, in which the detailed detector geometries have been constructed. Kinds of generators have also been custom built, like IBED, cosmic muons and specific decay chains. Optical photons generated in liquid scintillation (LS) will be tracked by Geant4 for precision simulations. The electronics and trigger simulations are implemented to model the response of electronics and trigger systems.

We made many efforts to improve Monte Carlo (MC) simulations to match the observed detector response. The main improvements include:

1. Get MC inputs from real data.
2. Study time components of LS.
3. Improve thermal neutron scattering simulation.
4. Investigate several gamma spectrums from $^{157}$Gd capture.

Finally, based on tuned MC, we will show some studies on absolute detection efficiency, which are essential inputs of absolute reactor flux and spectra measurements.

**MC Inputs from real data**

- **Optical properties**
  - Most of optical properties of materials used in central detector (AD) have been well measured, like attenuation length, emission spectrum, refractive index, reflectivity, etc. These parameters can be used in MC directly. For other optical properties with large uncertainties, we can tune them to find the best values that can match data.

- **Properties of PMTs**
  - The gain, dark rate and quantum efficiency of each PMT are key MC inputs and can be gotten from different datasets.
    - a) Gain: (ADC/single photon-electron) is calibrated by fitting the ADC output to a p.p. peak.
    - b) Dark rate: is measured by random trigger data. Dark rate versus time is shown in left figure below.
    - c) Relative quantum efficiency (RQE) is measured by low energy calibration source ($^{55}$Fe) in ACU-A. RQE is shown in right figure.

- **Time components of LS**
  - Three time components and fractions are summarized.

- **Gamma spectrum from Caltech**
  - The gamma spectrum from Caltech HPGe is used to validate MC, shows MC and data agree within 1% for high energy neutron.

**Gamma spectrum from nGd capture**

- The gammas released from nGd capture provide the delayed signals of IBD reactions.

Using Daya Bay data, we investigated several gamma spectrums of nGd capture from different sources, shown in lower plot.

- Finally, we found the spectrum based on Geant4 provides the best fit to data, and a spectrum from HPGe measurement at Caltech is also acceptable.

- The upper plot shows the old gamma spectrum (used as default before) and the new G4-based gamma spectrum.

**Thermal neutron scattering (TNS)**

Thermal neutron scattering can affect the spill-in ratio, which is a key parameter in absolute efficiency studies.

- *Free gas model* can not well simulate thermal neutron scattering process, we need to consider chemical bond effect.
- *Due to no cross section data of TNS available in Geant4 for scintillator, we use C from graphite and H from water.*
- *After updates, the new MC (red color in right two plots) has better agreements with data.*
- *Based on truth information, we also compared neutron drift distance in GdLS for two models, shown in left figure.*

**Spill-in**

- The new MC can well match with data at the region > 3MeV, shown as blue line in figure.
- Since the NH peak obscure the nGd tail, to be conservative, we assign 100% uncertainty for the region < 3MeV.
- The gamma spectrum from Caltech HPGe measurement is applied to do cross check and consistent within the errors.
- The relative uncertainty is estimated to be 0.97%.

**Absoloute detection efficiency**

- The error on absolute flux measurement is dominated by heat source uncertainty.
- The main sources of efficiency uncertainty are from $^{157}$Gd capture ratio, delayed energy cut and spill-in.

**Gd capture fraction ($F_{Gd}$)**

- Using new MC to estimate the expected Gd capture fraction for IBEDs, which is determined by Gd concentration and leakage of neutrons out of GdLS.
- Gd capture fraction at detector center measured in many datasets and compared to MC, shown in table below.

Full-volume Gd fraction measured by manual calibration system (MCS) using a PuG source.

- The relative uncertainty is estimated to be 0.95%.

**Summary of absolute efficiency**

<table>
<thead>
<tr>
<th>Input</th>
<th>$\epsilon$</th>
<th>$\Delta \epsilon$</th>
<th>$S_{\epsilon}/\epsilon$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target protons</td>
<td>0.477%</td>
<td>0.011%</td>
<td>0.11%</td>
</tr>
<tr>
<td>Flasher cut</td>
<td>99.99%</td>
<td>0.02%</td>
<td>0.02%</td>
</tr>
<tr>
<td>Muon veto cut</td>
<td>99.99%</td>
<td>0.00%</td>
<td>0.00%</td>
</tr>
<tr>
<td>Multiplicity cut</td>
<td>98.70%</td>
<td>0.12%</td>
<td>0.12%</td>
</tr>
<tr>
<td>Capture cut</td>
<td>99.99%</td>
<td>0.01%</td>
<td>0.01%</td>
</tr>
<tr>
<td>Prompt energy cut</td>
<td>99.99%</td>
<td>0.01%</td>
<td>0.01%</td>
</tr>
<tr>
<td>Gd capture ratio</td>
<td>84.2%</td>
<td>0.8%</td>
<td>0.95%</td>
</tr>
<tr>
<td>nGd detection efficiency</td>
<td>92.7%</td>
<td>0.9%</td>
<td>0.97%</td>
</tr>
<tr>
<td>Spill-in correction</td>
<td>104.9%</td>
<td>-</td>
<td>1.50%</td>
</tr>
</tbody>
</table>

- $S_{\epsilon}/\epsilon$ denotes the standard error of the measurement.

**Other contributions**

- The prompt energy, timing and flasher cuts have quite high efficiency, which means small errors.
- Muon veto and multiplicity cut efficiencies can be calculated precisely.
- Target protons uncertainty from target mass, proton density measurements.

**MC Inputs from real data**

- **Optical properties**
  - Most of optical properties of materials used in central detector (AD) have been well measured, like attenuation length, emission spectrum, refractive index, reflectivity, etc. These parameters can be used in MC directly. For other optical properties with large uncertainties, we can tune them to find the best values that can match data.

- **Properties of PMTs**
  - The gain, dark rate and quantum efficiency of each PMT are key MC inputs and can be gotten from different datasets.
    - a) Gain: (ADC/single photon-electron) is calibrated by fitting the ADC output to a p.p. peak.
    - b) Dark rate: is measured by random trigger data. Dark rate versus time is shown in left figure below.
    - c) Relative quantum efficiency (RQE) is measured by low energy calibration source ($^{55}$Fe) in ACU-A. RQE is shown in right figure.

- **Time components of LS**
  - Three time components and fractions are summarized.

- **Gamma spectrum from Caltech**
  - The gamma spectrum from Caltech HPGe is used to validate MC, shows MC and data agree within 1% for high energy neutron.

**Gamma spectrum from nGd capture**

- The gammas released from nGd capture provide the delayed signals of IBD reactions.

Using Daya Bay data, we investigated several gamma spectrums of nGd capture from different sources, shown in lower plot.

- Finally, we found the spectrum based on Geant4 provides the best fit to data, and a spectrum from HPGe measurement at Caltech is also acceptable.

- The upper plot shows the old gamma spectrum (used as default before) and the new G4-based gamma spectrum.

**Thermal neutron scattering (TNS)**

Thermal neutron scattering can affect the spill-in ratio, which is a key parameter in absolute efficiency studies.

- *Free gas model* can not well simulate thermal neutron scattering process, we need to consider chemical bond effect.
- *Due to no cross section data of TNS available in Geant4 for scintillator, we use C from graphite and H from water.*
- *After updates, the new MC (red color in right two plots) has better agreements with data.*
- *Based on truth information, we also compared neutron drift distance in GdLS for two models, shown in left figure.*

**Spill-in**

- The new MC can well match with data at the region > 3MeV, shown as blue line in figure.
- Since the NH peak obscure the nGd tail, to be conservative, we assign 100% uncertainty for the region < 3MeV.
- The gamma spectrum from Caltech HPGe measurement is applied to do cross check and consistent within the errors.
- The relative uncertainty is estimated to be 0.97%.