Calibration system for PROSPECT-II

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On behalf of the PROSPECT Collaboration
Outline

• PROSPECT-I physics results
• PROSPECT-I calibration
• Changes in PROSPECT-II upgrades
• Results of R&D study on P-II calibration
• Summary
PROSPECT spectrum

• Per-baseline IBD spectra offers model-independent search for sterile neutrino oscillation

• High statistics (~50k) IBD candidates energy spectrum from $^{235}$U core
PROSPECT energy scale calibration

- Energy scale calibration ensures the energy reconstruction within +/-1% uncertainty and consistent across the data-taking period

- PROSPECT IBD candidate spectrum is currently still statistics-dominated
P-I Calibration system

- 14x11 segments and 5x7 source tubes
- ~5° tilted pinwheels house source capsules transported by stepper motor

Table 1

<table>
<thead>
<tr>
<th>Source</th>
<th>Type</th>
<th>$\gamma$ Energy (MeV)</th>
<th>Primary purpose</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{137}$Cs</td>
<td>Gamma</td>
<td>0.662</td>
<td>Segment comparison</td>
<td>0.1 µCi</td>
</tr>
<tr>
<td>$^{22}$Na</td>
<td>Gamma</td>
<td>2x0.511, 1.275</td>
<td>Positron, edge effects</td>
<td>0.1 µCi</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>Gamma</td>
<td>1.173, 1.332</td>
<td>Energy scale</td>
<td>0.1 µCi</td>
</tr>
<tr>
<td>$^{252}$Cf</td>
<td>Neutron</td>
<td>2.223 (n-H capture)</td>
<td>Neutron response</td>
<td>866 n/s</td>
</tr>
<tr>
<td>AmBe</td>
<td>Neutron</td>
<td>–</td>
<td>Neutron response</td>
<td>70 n/s</td>
</tr>
</tbody>
</table>
P-I Calibration result

- Internal radioactive sources + cosmogenic $^12$B events for energy calibration
- Detector non-linearity model is best fitted to data in both spectrum and event multiplicity
- Achieved sub-percent level stability in energy reconstruction for various types of events
Preliminary detector design for PROSPECT-II

• Several PROSPECT PMTs showed current instability
• Separate PMTs from liquid scintillator volume to improve long term stability
• Simple and rigid to be redeployed at other reactor sites
• External calibration source
External calibration performance simulation

- Can external calibration perform as well as we had in PROSPECT?
- What level of degradation should we expect?
- Any extra internal modification in PROSPECT-II needed?

Internal calibration used in PROSPECT

- Fiducial volume
- Dead segments
External calibration performance simulation

- Manually switch off certain segments in the analysis
- Calibration sources are effectively <1cm outside the fiducial volume
Methodology

• The non-linearity detector response model is not directly simulated via the computational-resource-heavy process of optical photon production and propagation.

• Instead, fractional conversion of true deposited energy to scintillation light is calculated step-by-step during GEANT4 propagation of the particle using parametrization of these physics processes:

\[
E_{MC} = A \sum_i \left( E_{\text{scint},i}(k_{B1}, k_{B2}) + E_{c,i}(k_c) \right).
\]

Birks’ empirical law

\[
\frac{dE_{\text{scint}}}{dx} = \frac{dE}{dx} \frac{1}{1 + k_{B1} \frac{dE}{dx} + k_{B2} \left( \frac{dE}{dx} \right)^2},
\]

Cherenkov light production

\[
E_c = k_c \sum \lambda N_\lambda E_\lambda,
\]

• Best fit response model is determined by minimizing data-MC chi2 for both spectrums and event multiplicity in parameter space \((k_{B1}, k_{B2}, k_c)\)

\[
\chi^2_{\text{data-MC}} = \sum \gamma \chi^2 + \sum \chi^2_{\text{multi}} + \chi^2_{12B},
\]
Preliminary results

• Both calibration setups show great agreement in spectrum and event multiplicity.

\[
\text{Chi}^2/\text{ndf} = 521.97/379\text{(internal)} => 575.44/468\text{(external)}
\]

• The best fit response models are compatible with each other.

• Quantify how well the model parameters are constrained.
Summary

• PROSPECT-I deploys internal calibration campaign that allows event reconstruction at sub-percent level precision.

• PROSPECT-II detector aims to improve long term stability with simpler and more rigid design.

• This R&D study evaluate the external-source-only performance for PROSPECT-II calibration

• External calibration demonstrates promising performance with simplified P-II geometry that needs more follow-up work
Thank you!

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Backup slides