Jeremy Lu

On behalf of the PROSPECT Collaboration

ORNL is managed by UT-Battelle, LLC for the US Department of Energy

Past(Tue):
FK.00005: Precise Measurement of Reactor Antineutrino Spectra from Joint Analyses of PROSPECT, STEREO, and Daya Bay
Benjamin T Foust
FK.00006: PROSPECT-II: Physics goals with an upgraded precision reactor oscillation and spectrum neutrino experiment
Thomas J Langford
FK.00007: Working Towards an Absolute Reactor Antineutrino Flux Measurement using PROSPECT-I Data
Paige Kunkle
FK.00008: Reactor Background Measurements at HFIR in Support of the PROSPECT-II Experiment
BLAINE HEFFRON
Poster Session:
HA.00031: Directional Neutrino Detection with PROSPECT
Manjinder Oueslati
Outline

• PROSPECT-I introduction
• PROSPECT-I calibration
• Changes in PROSPECT-II upgrades
• Results of R&D study on P-II calibration
• Summary
PROSPECT experiment

PROSPECT detector:

- Short baseline reactor neutrino experiment located at HFIR, ORNL
- \(~4\) ton \(^6\)Li-loaded liquid scintillator detector
- Optically segmented into 14 x 11 identical detectors
- In-situ internal calibration access
- Less than \(~1\)m w.e. overburden

High Flux Isotope Reactor: HFIR

- 85 MW research reactor
- Compact core
- Fresh highly-enriched \(^{235}\)U fuel
Inverse Beta Decay as neutrino signal

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

- Distinctive spatial/temporal correlation
- Particle ID capable LS via PSD
- Segment fiducialization, veto cuts, etc

Sequential application of event selection

PRD103, 032001(2020)

Jeremy Lu
P-I Calibration system

• 14×11 segments and 5×7 source tubes
• ~5° tilted pinwheels house source capsules transported by stepper motor

Table 1
Calibration sources and their uses.

<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 $\mu$Ci</td>
</tr>
<tr>
<td>$^{22}$Na</td>
<td>Gamma</td>
<td>2×0.511, 1.275</td>
<td>Positron, edge effects</td>
<td>0.1 $\mu$Ci</td>
</tr>
<tr>
<td>$^{60}$Co</td>
<td>Gamma</td>
<td>1.173, 1.332</td>
<td>Energy scale</td>
<td>0.1 $\mu$Ci</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 energy non-linearity model is best fitted to data in both spectrum and event multiplicity

- Energy scale calibration ensures the energy reconstruction within +/-1% uncertainty and consistent across the data-taking period
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 robust 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 is level of degradation in calibration parameter precision?

Validation R&D study based P-I simulation/data

Internal calibration used in PROSPECT-I

- Fiducial volume
- Inactive segments

---

Jeremy Lu
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:

\[ E_{MC} = A \sum_i \left( E_{\text{scint},i}(k_B, k_B) + E_{c,i}(k_C) \right). \]

- Birks’ empirical law
- Cherenkov light production

\[ \frac{dE_{\text{scint}}}{dx} = \frac{dE}{dx} \frac{dE}{dx} \]

• Best fit response model is determined by minimizing data-MC chi2 for both spectrums and event multiplicity in parameter space \((kB, kC)\)

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

- Chi2 map in parameter space (kB,kC)

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

- Quantify how well the model parameters are constrained.

<table>
<thead>
<tr>
<th>Configuration</th>
<th>A</th>
<th>kB1</th>
<th>kC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal</td>
<td>1.008 ± 0.002</td>
<td>0.172 ± 0.003</td>
<td>0.377 ± 0.034</td>
</tr>
<tr>
<td>External</td>
<td>1.006 ± 0.003</td>
<td>0.167 ± 0.007</td>
<td>0.361 ± 0.058</td>
</tr>
</tbody>
</table>
Preliminary results

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

• Toy-model generated covariance matrix and compare energy model uncertainty, still dominated P-I statistics.
Summary

• PROSPECT-I collected over ~50k IBD events in less than a year and updated oscillation and spectrum analysis on the way (next speakers).

• 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 and will improve in actual P-II detector.
Thank you!

Funding provided by:

14 Institutions, 70 collaborators
**Past(Tue):**
FK.00005: Precise Measurement of Reactor Antineutrino Spectra from Joint Analyses of PROSPECT, STEREO, and Daya Bay
Benjamin T Foust  
FK.00006: PROSPECT-II: Physics goals with an upgraded precision reactor oscillation and spectrum neutrino experiment
Thomas J Langford  
FK.00007: Working Towards an Absolute Reactor Antineutrino Flux Measurement using PROSPECT-I Data
Paige Kunkle  
FK.00008: Reactor Background Measurements at HFIR in Support of the PROSPECT-II Experiment
BLAINE HEFFRON

**Poster Session:**
HA.00031: Directional Neutrino Detection with PROSPECT
Manjinder Oueslati

**Today(Wed):**
LK.00006: PROSPECT-II calibration strategy
Xiaobin Lu  
LK.00007: Improved Event Reconstruction and Spectrum Analysis using PROSPECT Antineutrino Data
Christian Roca Catala  
LK.00008: Improved Inverse Beta Decay event selection and its impact on the PROSPECT oscillation analysis
Diego C Venegas Vargas