PROSPECT-II: Extending Scientific Reach through Upgraded Performance

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On Behalf of the PROSPECT Collaboration
Experimental Anomalies

1.4. Global Fits

Attempts have been made to fully incorporate the observed anomalies into frameworks with 3 active neutrinos and 1 sterile state. Combining the short-baseline reactor anomaly with appearance data in models involving 3 active neutrinos and 1 sterile state allows one to determine the allowed regions for neutrino oscillations partially overlap with the allowed regions obtained from different combinations of anomalous experimental results. Because of the tensions between some appearance and disappearance results, different allowed regions are obtained from LSND.

Anomalous results have also been obtained in other neutrino experiments. Both the SAGE reactor uncertainty and GALLEX radiochemical gallium experiments have observed neutrino appearance excess of events. There is some disagreement regarding the compatibility of MiniBooNE disappearance measurements further constrains the parameter space in developing a consistent picture of oscillations in the 3 neutrino framework for several combinations of spectral information included in the analyses. Inclusion of all neutrino experiments.

Additional anomalies have become apparent in accelerator-based neutrino experiments. Because of the tensions between some appearance and disappearance results, different allowed regions are obtained from LSND.

PROSPECT-I GOALS:

1. Search for short-baseline sterile-neutrino oscillations independent of reactor models

2. Measure antineutrino spectrum due to $^{235}\text{U}$

3. Demonstrate near-field surface operation

Daya Bay

PRL 116, 061801(2018)
Experimental Strategy: PROSPECT

-Compact HEU research reactor (all 235U)
-Segmented detector localizes events and supports background rejection
-Measure high-resolution spectrum at a range of baselines (7-9m in current position)
-Search for characteristic relative spectral distortions within detector volume
-46% reactor up time, allows equal stats for detailed study of cosmogenic backgrounds
• Single 4,000 L $^6$Li-loaded liquid scintillator.

• divided into 11 x 14 (154) array of optically separated segments

• 2D segmentation supports:
  - full X,Y,Z event reconstruction
  - fiducialization
  - event topology for signal selection

• Double ended PMT readout, with light concentrators
  - good light collection and energy response ~5%/$\sqrt{E}$ energy resolution

• Optimized shielding to reduce cosmogenic and local backgrounds

PROSPECT, NIM A 922 (2018)
PROSPECT, JINST 14 P04014 (2019)
PROSPECT-I Results

- 50,560 ± 406 IBD signal events
- 28,357 ± 18 accidental bkg events
- 36,934 ± 221 cosmic bkg events
- 530 IBD signal per calendar day

Excellent signal-to-background for a surface detector (<1mwe overburden)
PROSPECT-I Results

- RAA best-fit excluded: 98.5% CL
- Data is compatible with null oscillation hypothesis (p=0.57)
- $\chi^2/NDF = 30.79/31$ for shape-only comparison with model
- PROSPECT feature size with respect to Daya Bay: 84% ± 39%. (No $^{235}$U bump disfavored at 2.2σ CL, all $^{235}$U is disfavored at 2.4σ CL)
Ambiguities in Long Baseline Experiments:

- Can mimic CP violation in DUNE

Yeon-jae Jwa, ICHEP 2018
2018 allowed 3+1 space compared to constraint from a null SBN result

- Ambiguities in mass ordering
- Simple 3+1 models suffer strong tensions, more complex models add rich theoretical texture that short baseline expts. can help disentangle
Spectrum/flux Still Not Understood.

- Spectral shape anomalies still unexplained, both in 4-6 MeV region and an very high and very low energies
- Reference spectrum needed for reactor-based hierarchy measurements, reactor CEvNS, and nuclear safeguards
- Systemically distinct input for joint spectrum analysis

PROSPECT-II absolute flux measurement can:
- Improve understanding of fission isotope yield
- Independent check of 5% deficit observed by STEREO (short-baseline experiment)
PROSPECT -II Detector Upgrade: Evolutionary Design Strategy

Present Design Path
- PTFE lined Al tank
- Rubber gasket
- ¼" Acrylic Window
- Foam
- Al compress flange
- Al PMT mount/Window grid

PMTs and Mounts

PTFE lined chamber
PTFE coating demo

Match initial performance while improving stability (maintain similar segment pitch, same scintillator formulation, etc…) and facilitating redeployment

- Separate PMTs from LiLS volume, reduce exposure to materials, and improve cover gas
- Design approach facilitates operation at multiple sites
- Planned redeployment at HIFR ~ late 2021
• Removing penetrations into central volume requires modification of calibration strategy

• Calibration source tubes will now feed around the outside of the detector

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DNP Meeting, 10/30/2020
Validating Calibration Scheme

Using PROSPECT-I data simulate edge deployed source.

Energy and multiplicity data used to reconstruct detector (non-linear) response.

As before, features, e.g. capture on $^6$Li and cosmogenic $^{12}$B beta decays, constrain model and help determine energy scale.
Cross-talk and signal to background

- Windows allow for communication between segments (Monte Carlo estimates ~ < 5%)
- Data-driven simulations suggest minimal impact of aground rejection
- Increased spatial efficiency allows larger fiducial volume (40% more signal)
- Projected signal to background ~ 3:1
Spectral Shape and Flux

Assume similar performance with increased S:B ~ 3:1 and nominal 2 year and 4 year run times:

- Measurement uncertainties become comparable to model uncertainties
- Significant reduction in uncertainties in 4-6 ‘bump’ region
- Significant increased precision in measuring the amplitude (n) of a bump-like feature in the 4-6 MeV prompt energy; PROSPECT will address hypothesis for the origin of this feature (n=0, no bump from $^{235}\text{U}$; n=1.78, bump entirely from $^{235}\text{UU}$) at high confidence level.
Oscillation Sensitivity

Global context:

- Significant gains over current sensitivity, covers below 5 deg over mid-$\Delta m^2$ phase space
- Addresses high-$\Delta m^2$ region with conflicting experimental results
- PROSPECT-II would continue to provide unique access to high $m^2$ region below Katrin
- Global effort is complementary, particularly if care is taken to support global analysis efforts
Conclusions and Outlook

• PROSPECT has produced both impactful sterile oscillation and spectrum results (highest sensitivity at high-$\Delta m^2$) despite unplanned limitations to data collection (both due to PMT divider failure and a HFIR outage); yet the global picture remains unclear.

• PMT failure is understood. Will be eliminated through a robust design upgrade that is in progress; allows for extended running at HIFR with the option of additional deployments at other reactors, further improving sensitivity.

• Upgrade detector and continued data collection will enable:
  • Definitively addressing the Reactor Anomaly and Neutrino-4
  • Eliminating possible ambiguities in long baseline experiments
  • High significance test of isotopic contributions to the shape anomaly
  • Absolute flux measurement

SN.00002 Machine learning application to event reconstruction from single-ended PMT readout (Xiaobin Lu)

LK.00006 : Machine learning applications for Ortho-Positronium tagging in liquid scintillator for the PROSPECT experiment (Diego Venegas, Blane Heffron)