The design and expanded physics reach of the PROSPECT-II detector update

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On behalf of the PROSPECT collaboration
The High Flux Isotope Reactor - Oak Ridge

- Compact HEU core
- Pure U-235 fuel
- Research reactor ~ 85MW - 46% reactor up time
Reactor Antineutrino Anomalies

Short baseline flux deficit

6% flux deficit from beta conversion models

Sterile neutrinos?
Incorrect prediction for different fuels?

Experimental bump-like feature at 4-6 MeV region observed by Double Chooz, Daya Bay, RENO...

Spectral shape deviation

PRL 116, 061801 (2016)
PROSPECT-I design

Segmented detector tailored for $\bar{\nu}_e$ detection

- Liquid Scintillator loaded to a mf of 0.08% $^6$Li
- High-resolution spectrum at a range of baselines (7-9 m)
- 14x11 Segmented detector allows topology selection and background rejection
- Double PMT readout with light concentrators $\sim 5\% \sqrt{E}$ energy resolution

- Prompt Signal: $\beta^+$, 1-8 MeV
- Delayed Signal: $\alpha$, $E_{vis} = 0.526$ MeV
- Selection cuts on $\Delta r, \Delta t$
- Search for relative spectral distortions within the detector volume

$E_{vis} = 0.526$ MeV
Status of PROSPECT-I 
& the Reactor Anomalies

Start: Mar 2018  
End: Oct 2018  
5 reactor cycles  
HFIR outage!

95.65 ON days  
73.09 OFF days  
530 IBDs/ON day

- $S:B = 1.4:1$ and $1.8:1$ for correlated and accidental respectively
- RAA best-fit disfavored at the $2.5\sigma$ C.L
- Compatible with non-oscillation hypothesis ($p = 0.57$)

• Shape analysis agreement with Huber model ($\chi^2/\text{ndf} = 30.79/31$)
• Both no-U235-bump / all-U235-bump disfavored at the $2.4 / 2.2\sigma$ C.L .
From PROSPECT-I to PROSPECT-II

SB Spectrum and flux anomalies are still such a hot topic!

- Reference anti neutrino spectrum needed.
- Shape anomaly 4-6 MeV not explained.
- Absolute flux isotopic dependence continually under discussion.

<table>
<thead>
<tr>
<th>Case</th>
<th>Description</th>
<th>Precision on $\sigma_1$ (%)</th>
<th>$^{238}$U</th>
<th>$^{239}$Pu</th>
<th>$^{239}$U</th>
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<td>Daya Bay LEU</td>
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<td>Daya Bay LEU + P-II HEU</td>
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<td>P-II LEU + P-II improved HEU</td>
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<tr>
<td>4</td>
<td>P-II LEU + P-II improved HEU, Correlated</td>
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<td>3.0</td>
<td>8.7</td>
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</table>
Ambiguities in Long Baseline Experiments

- LBL experiments will shed light into lepton CPV and neutrino mass hierarchy
- Existence of sterile neutrino induced oscillations would create ambiguity.
- SBL experiments like Prospect II could help disentangle the sterile from CPV

3+1 scenarios lead to substantial degeneracy with 3+0 CP violation.
Inside PROSPECT-II

Applying lessons learned

- Match initial performance
- Improved stability
- Facilitating redeployment

5” PMTs removed from LS target region

- PMT bases and HV components covered by epoxy potting

50% reduced material surface in contact with LiLS

- LiLS formulation retested in lab: results show stable solution

No planned HFIR outages until 2023: lots of data!
Inside PROSPECT-II

Calibration system: External deployment

- Internal penetrations removed in favor of external system
- A setup with simplified design!

Prioritizing intrinsic sources like $n$-capt in H and $^6Li$, cosmogenic $^{12}B$ beta decays...

For more info, Xiaobin Lu's talk: E18.0005: Calibration system for PROSPECT-II

Simulated outside calibration vs P-I data shows excellent agreement
As much as 7x improvement in oscillation sensitivity will result in world-leading limits from ~2-20 eV$^2$

Higher sensitivity at high $\Delta m^2$ below KATRIN, region with conflicting experimental claims (Neutrino-4)

Covering region below 5deg - mid $\Delta m^2$ region, could be key to disambiguate CPV observations from LBL
PROSPECT-II: spectral analysis

Improved physics: looking into the bump

- 10x increase in effective statistics with 2 years PROSPECT-2 running at HFIR.
- Improved S:B ratio to ~ 3:1
- Expected uncertainties < 5% per 200 keV bin

Reduced uncertainties in 4-6 MeV region, comparable to model. Very sensitive to bump - P-II will address hypothesis of origin.

Intended redeployment at an LEU reactor after the 2y HFIR initial deployment!
Conclusions and Outlook

**PROSPECT-I**

+50000 IBD signals and S:B = 1.4:1, rejecting RAA best fit at $2.5\sigma$

Antineutrino spectrum measured that favors bump caused by several isotopes.

Malfunction of some PMT dividers and degradation of LY and AL.

HFIR outage reduced to 12% of intended data taking.

**PROSPECT-II**

Upgrades prepared to improve PROSPECT-I while keeping the core concept intact

Expected uncertainties below 5% per 200 keV bin, permitting to address bump hypotheses

Expected $x10$ more statistics with S:B = 3:1, allowing $7x$ oscillation sensitivity

Possibility to expand the scope of the analysis towards LEU reactors

Chance at disambiguation LBL CPV and mass hierarchy