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

Christian Roca Catala - 17.04.2021

On behalf of the PROSPECT collaboration

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prospect.yale.edu

PROSPECT

recent new collaborators: MIT, BU

Funding provided by:

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U.S. DEPARTMENT OF ENERGY

GRFP

14 Institutions, 70 collaborators

BROOKHAVEN NATIONAL LABORATORY

NIST

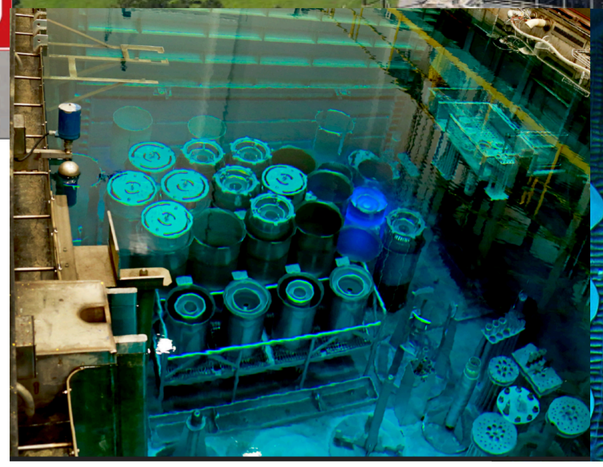
Lawrence Livermore National Laboratory

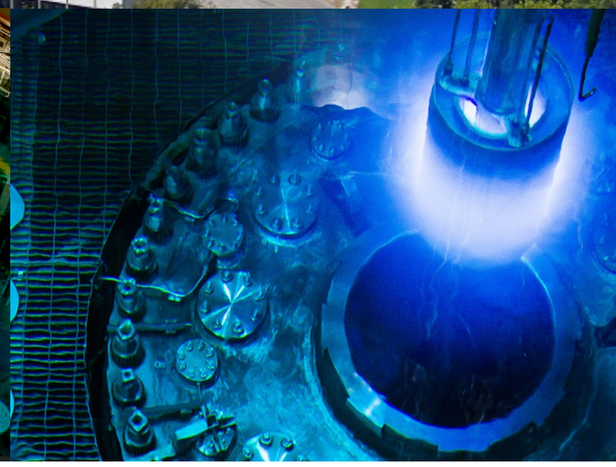
OAK RIDGE National Laboratory

Drexel

BU

Yale



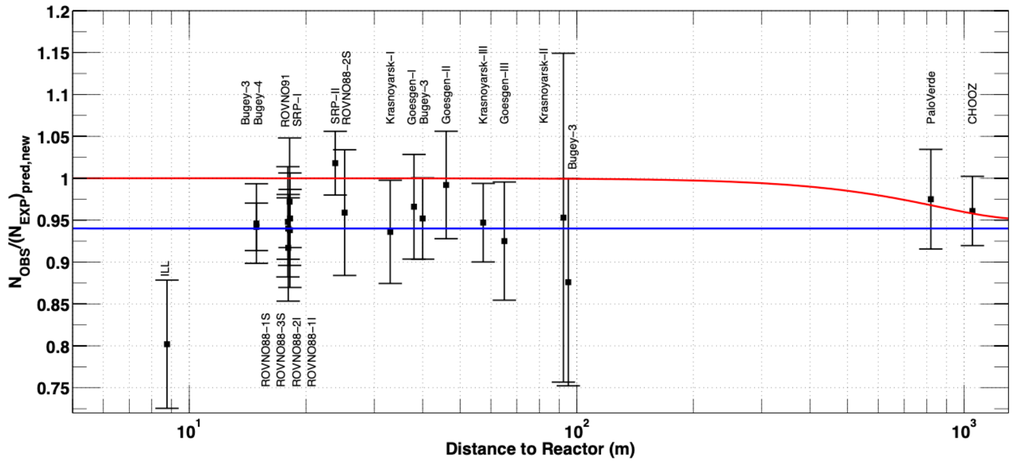


The High Flux Isotope Reactor - Oak Ridge

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

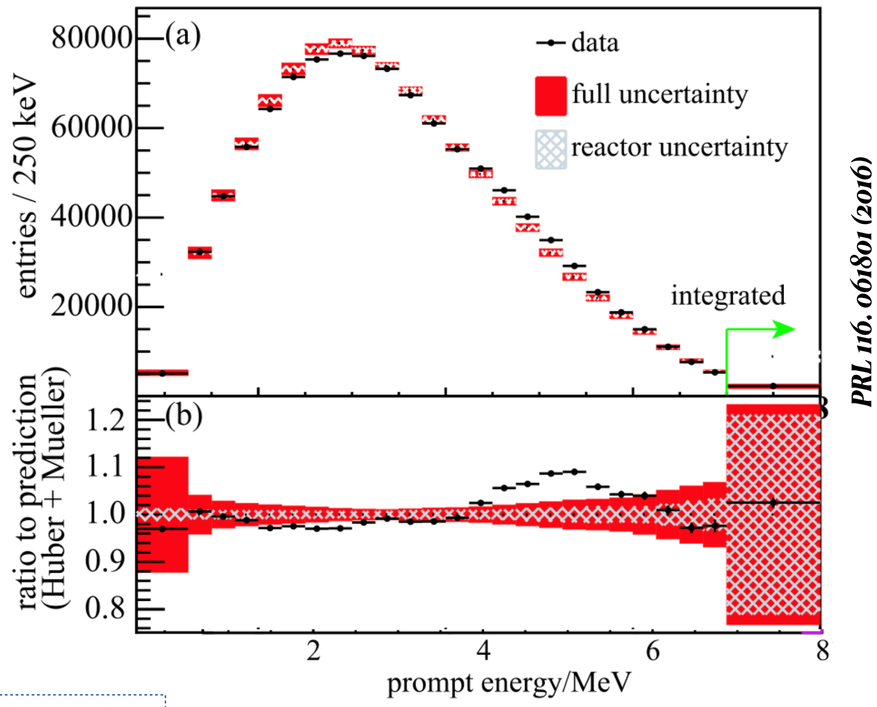
Reactor Antineutrino Anomalies

Short baseline flux deficit



arXiv: 1101.2755 (2011)

Spectral shape deviation



PRL 116, 061801 (2016)

6% flux deficit from beta conversion models

Sterile neutrinos?

Incorrect prediction for different fuels?

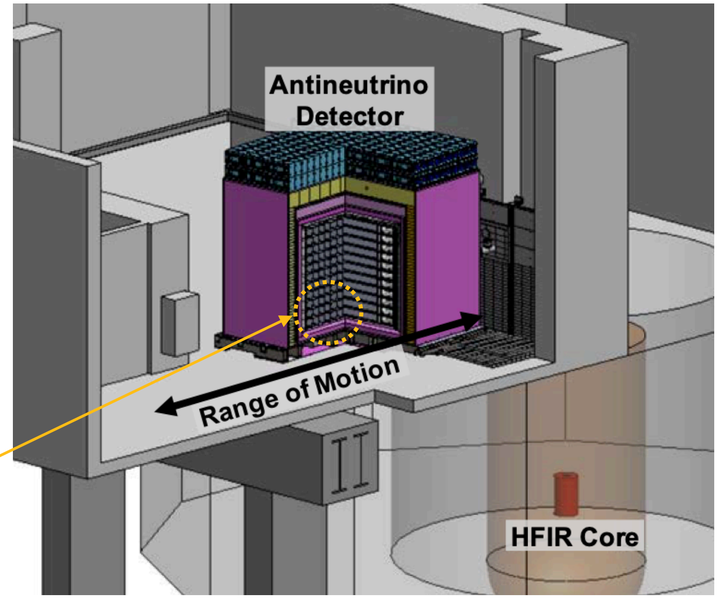
PROSPECT

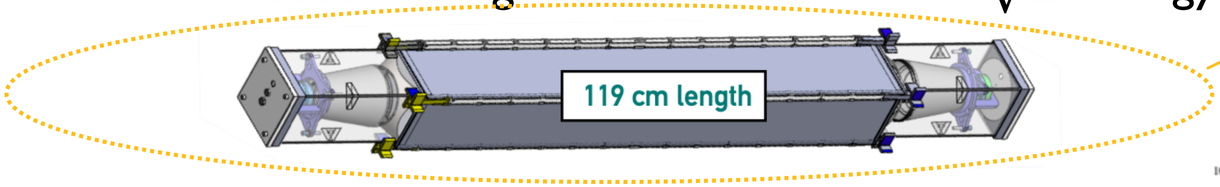
Experimental bump-like feature at 4-6 MeV region observed by Double Chooz, Daya Bay, RENO...

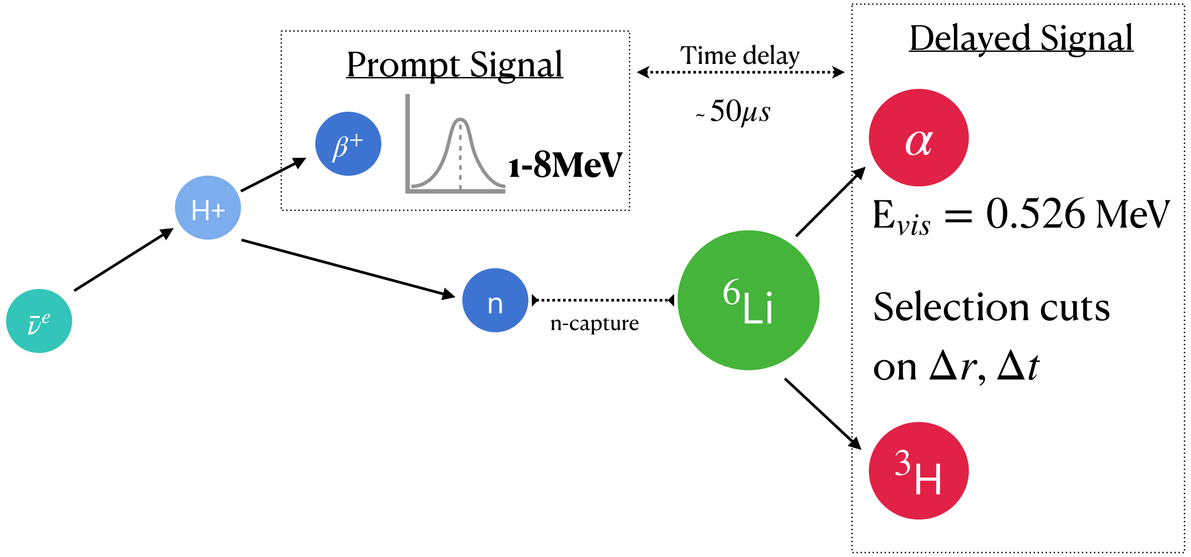
PROSPECT-I design

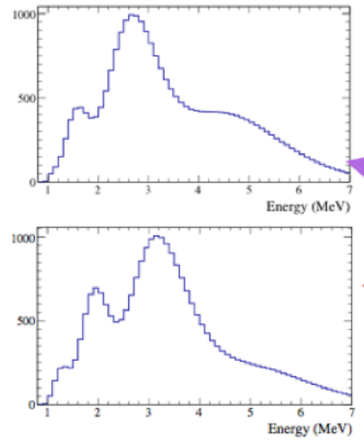
Segmented detector tailored for $\bar{\nu}_e$ detection

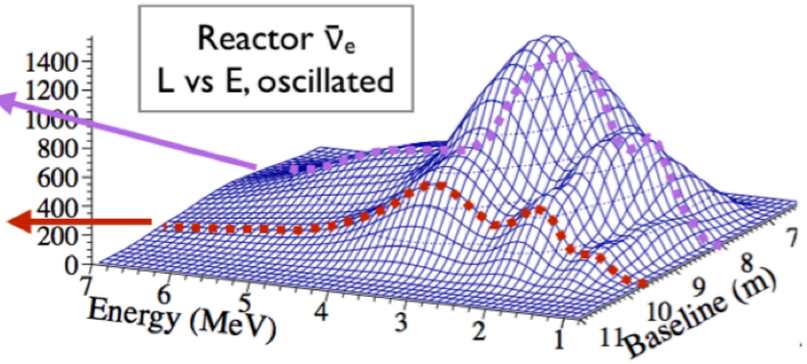
- Liquid Scintillator loaded to a mf of 0.08% ^6Li
- High-resolution spectrum at a range of baselines (7-9 m)
- 14x11 Segmented detector allows topology selection and background rejection
- Double PMT readout with light concentrators ~ 5% $\sqrt{E}$ energy resolution







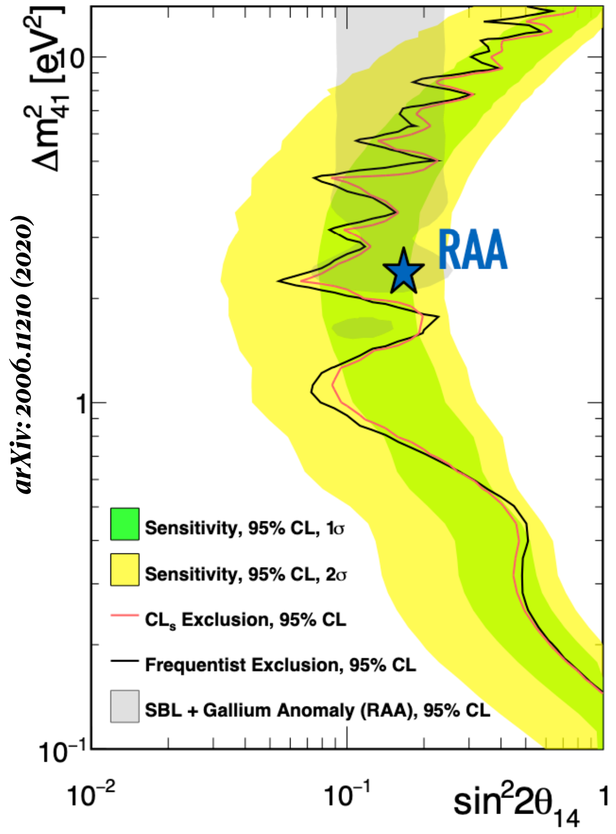




- Search for relative spectral distortions within the detector volume

Status of PROSPECT-I

& the Reactor Anomalies



arXiv: 2006.11210 (2020)

Start: Mar 2018

End: Oct 2018

5 reactor cycles

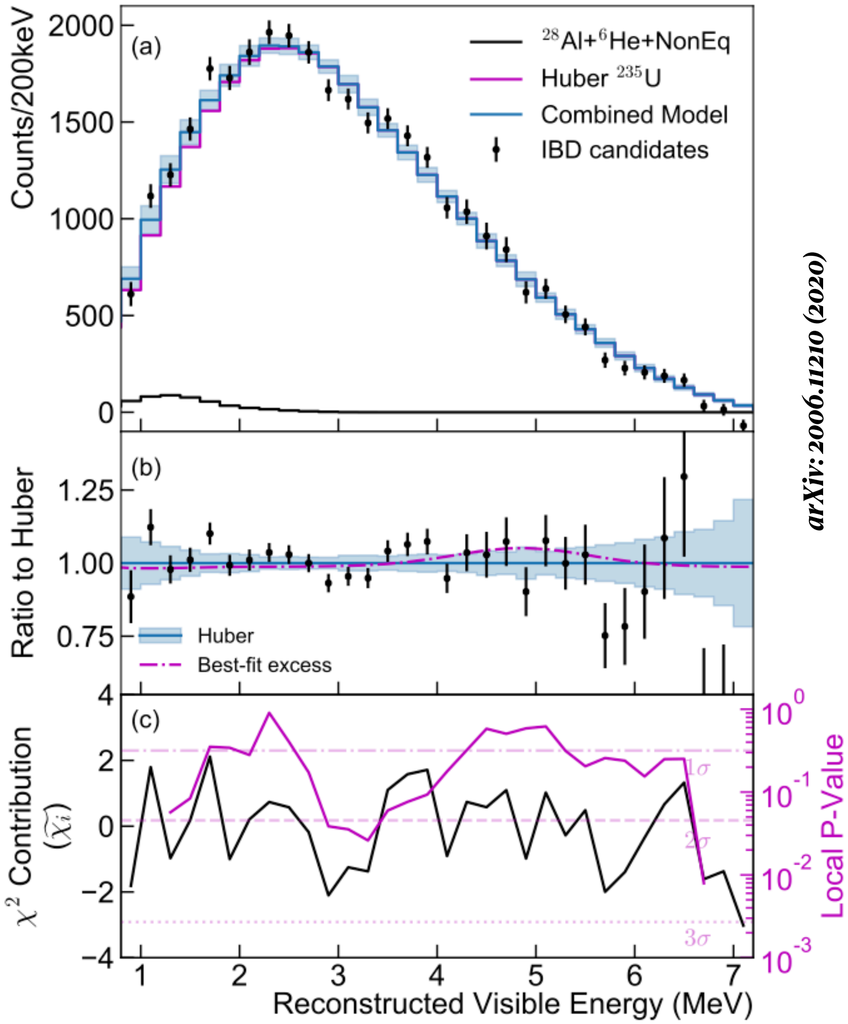
HFIR outage!

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 2.5σ C.L
- Compatible with non-oscillation hypothesis (p = 0.57)



arXiv: 2006.11210 (2020)

- Shape analysis agreement with Huber model (χ^2/ndf = 30.79/31)
- Both no-U235-bump / all-U235-bump disfavored at the 2.4 / 2.2σ C.L .

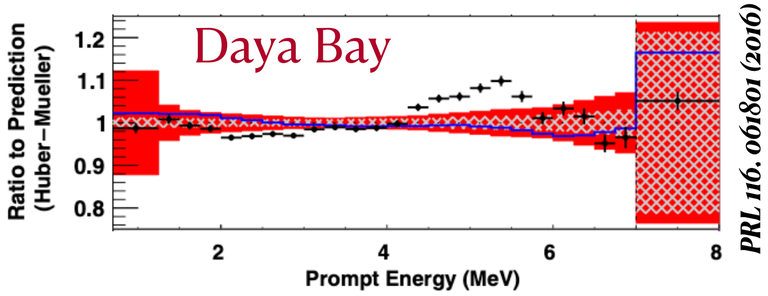
From PROSPECT-I to PROSPECT-II

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

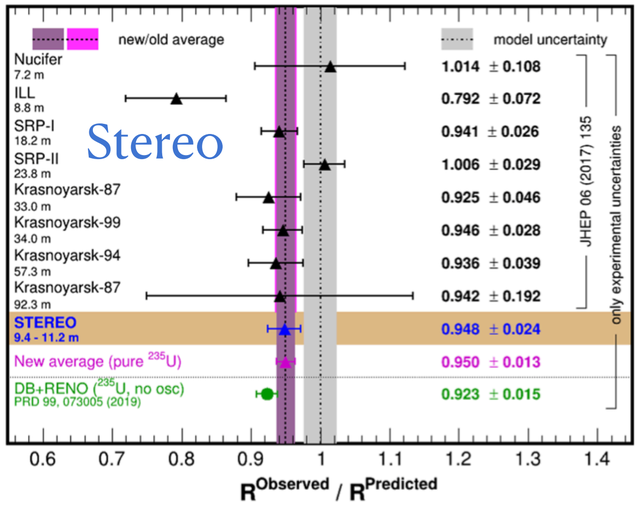
- Reference anti neutrino spectrum needed.
- Shape anomaly 4-6 MeV not explained.
- Absolute flux isotopic dependence continually under discussion.

PROSPECT II

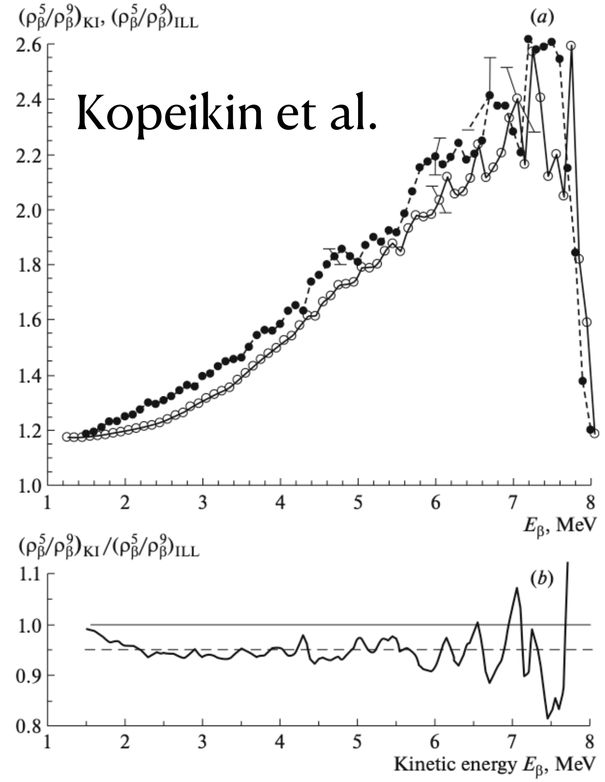
Case	Description	Precision on σ_i (%)		
		^{235}U	^{239}Pu	^{238}U
1	Daya Bay LEU	3.7	8.2	30
2	Daya Bay LEU + P-II HEU	2.4	6.3	21.3
3	P-II LEU + P-II improved HEU	1.4	3.4	15.9
4	P-II LEU + P-II improved HEU, Correlated	1.4	3.0	8.7



PRL 116, 061801 (2016)



PRL 125, 201801 (2020)

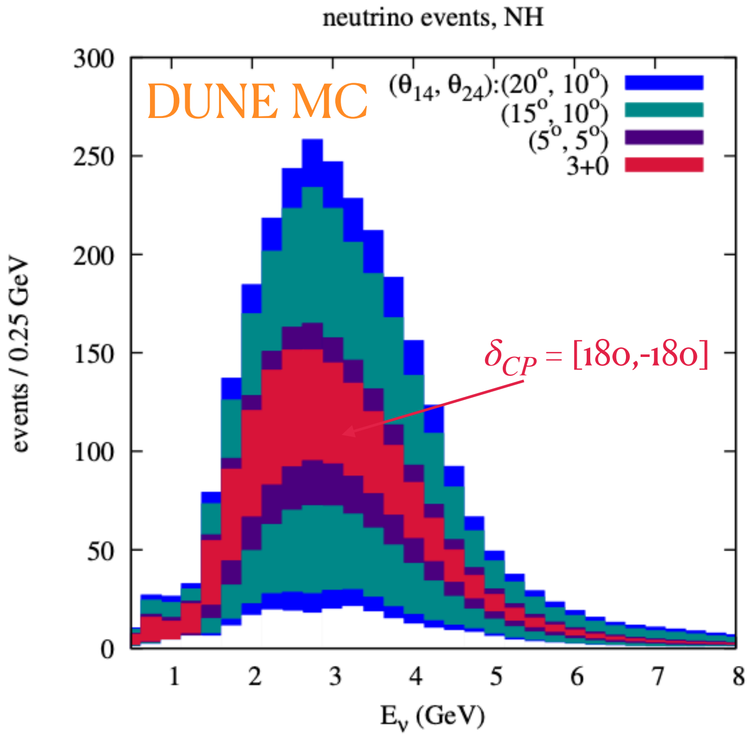


Phys. At. Nucl. Vol. 84, N. 1, 1-10 (2021)

From PROSPECT-I to PROSPECT-II

Ambiguities in Long Baseline Experiments

arXiv:1508.06275 (2015)

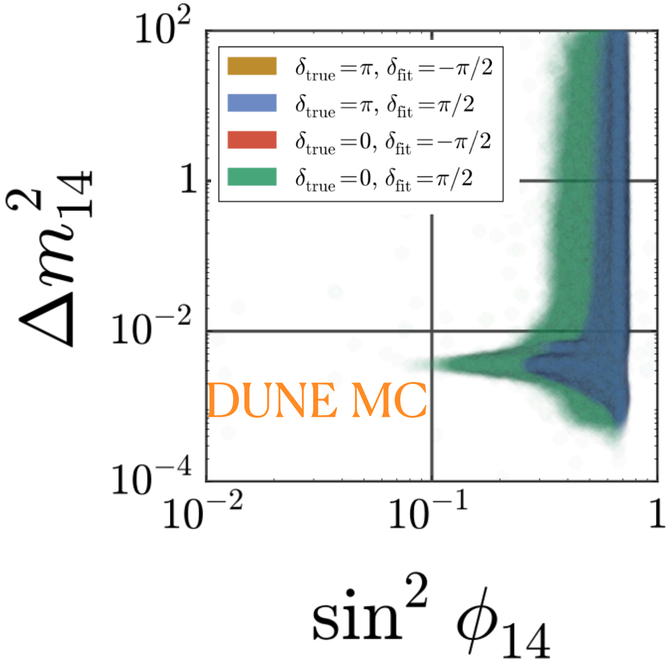


3+1 scenarios lead to substantial degeneracy with 3+0 CP violation.

- 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

PROSPECT II

CP-conserving 4ν scenarios can mimic 3ν large CP-violation.



arXiv:1605.09376 (2016)

Inside PROSPECT-II

Applying lessons learned

No planned HFIR outages until 2023: lots of data!

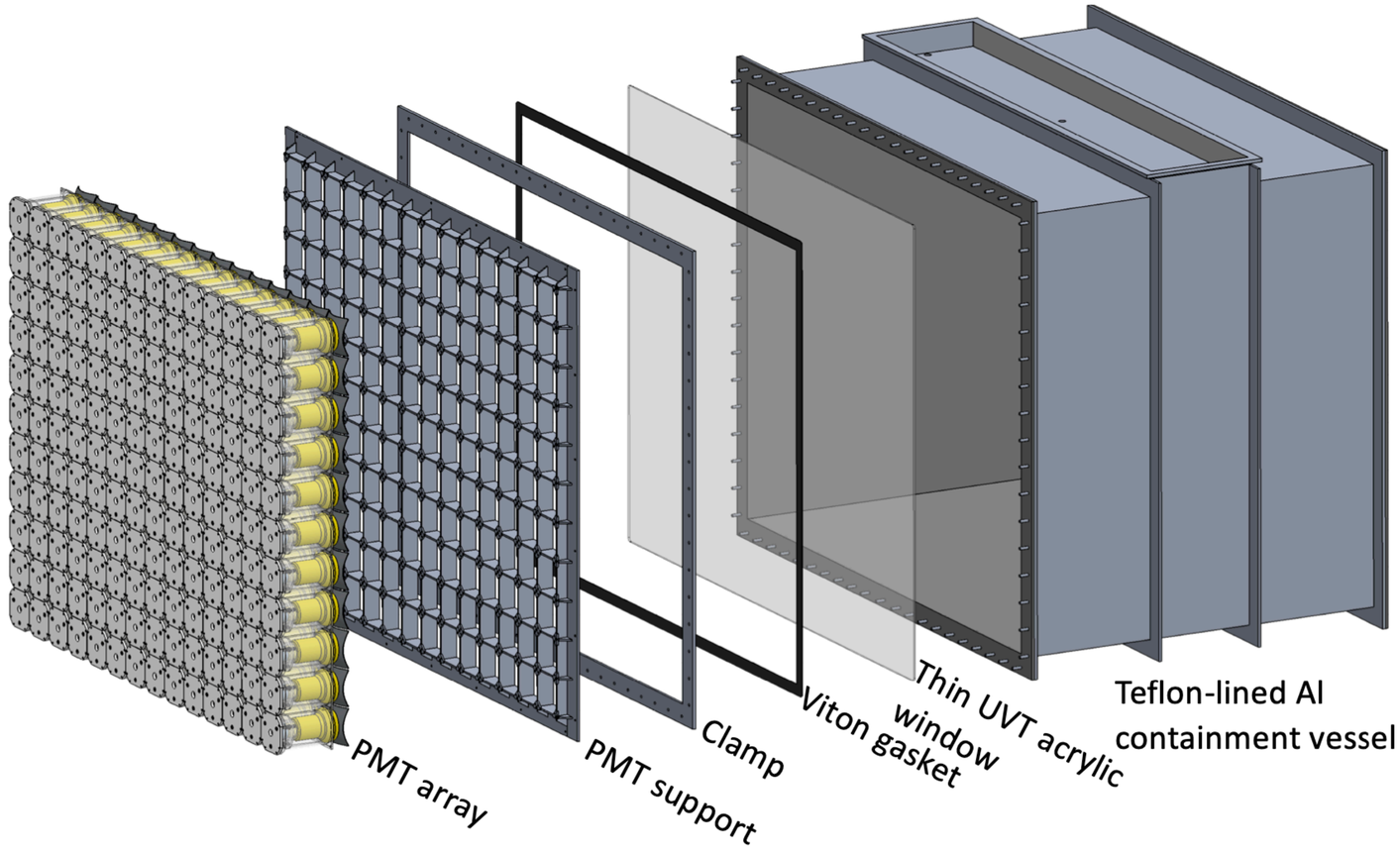
Match initial performance

Improved stability

Facilitating redeployment

5” PMTs removed from LS target region

PMT bases and HV components covered by epoxy potting

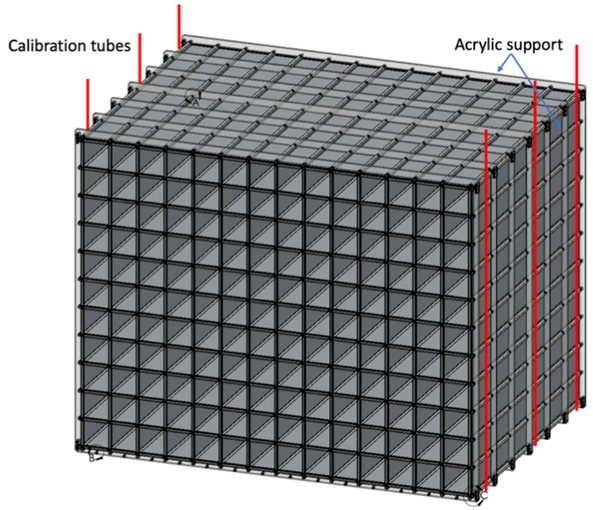


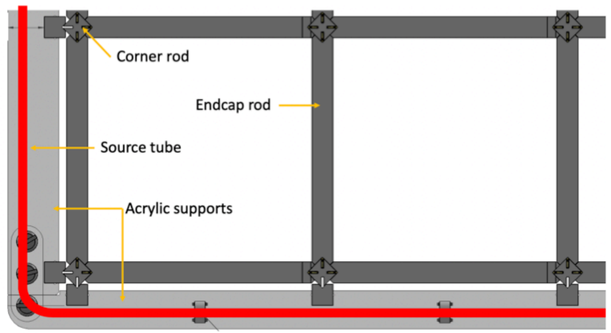
50% reduced material surface in contact with LiLS

LiLS formulation retested in lab: results show stable solution

Inside PROSPECT-II

Calibration system: External deployment





Internal penetrations removed in favor of external system

↓

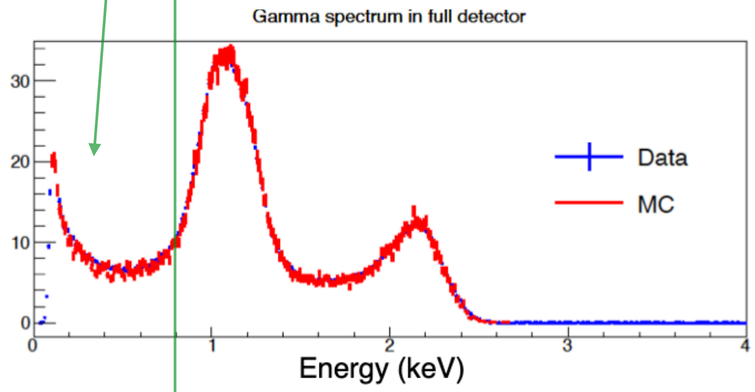
A setup with simplified design!

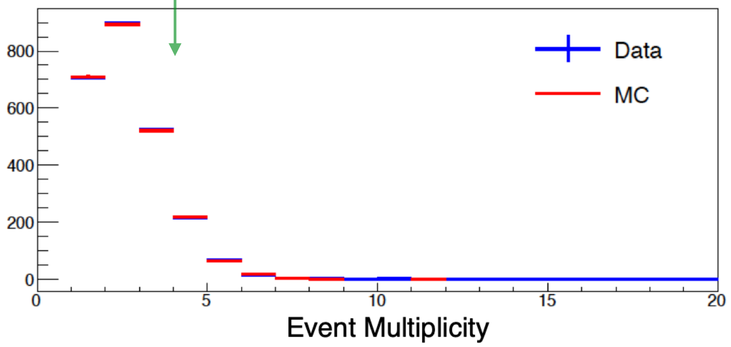
Prioritizing intrinsic sources like n-capt in H and ^{6}Li, cosmogenic ^{12}B beta decays…

For more info, Xiaobin Lu's talk:

E18.0005: Calibration system for PROSPECT-II

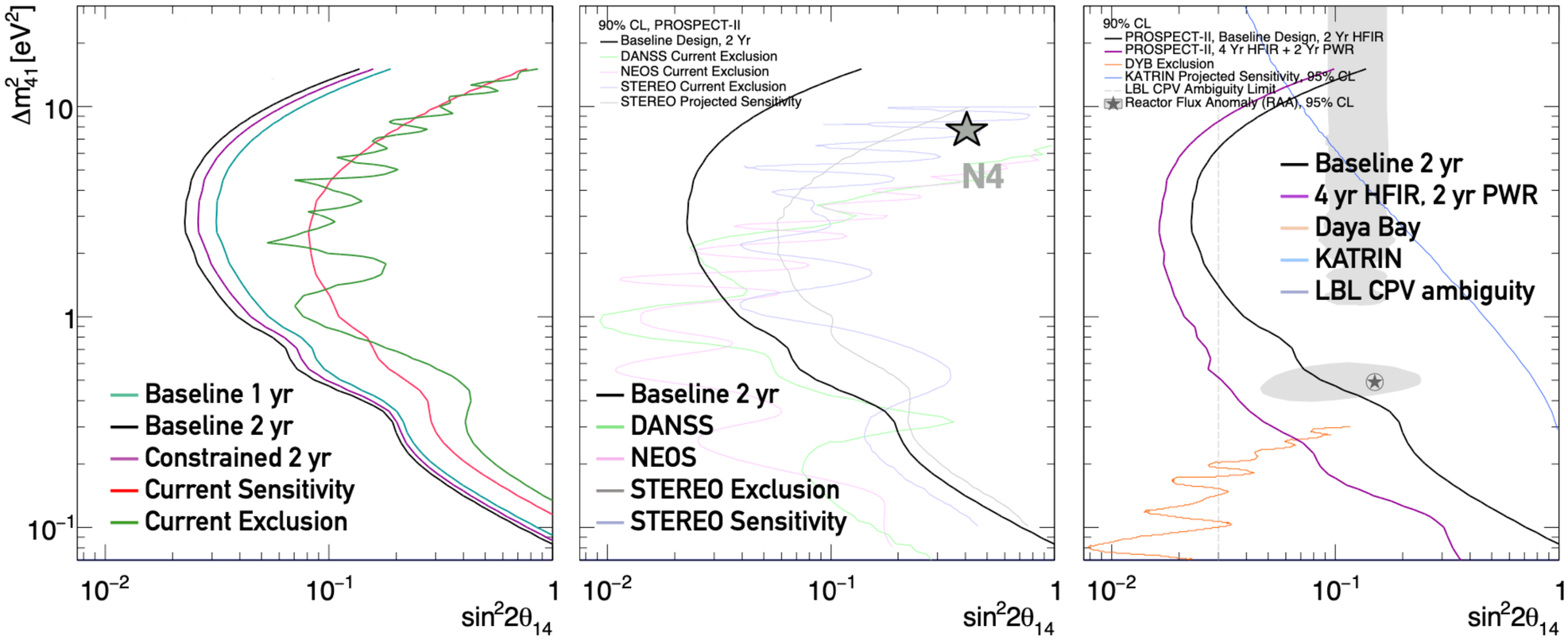
Simulated outside calibration vs P-I data shows excellent agreement





PROSPECT-II: oscillation sensibility

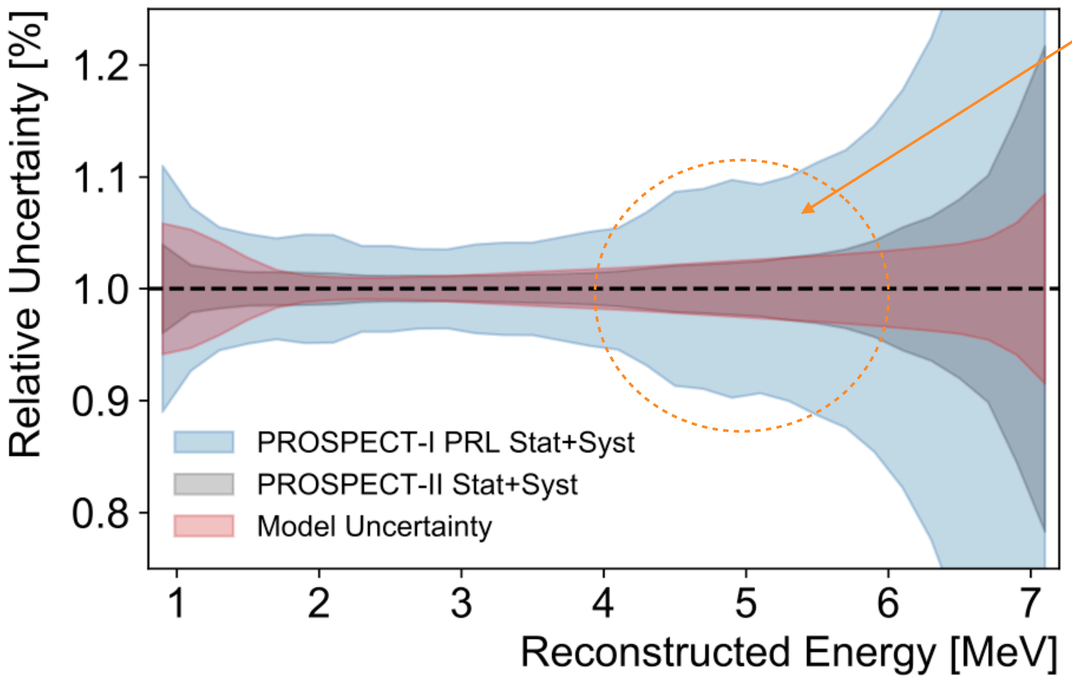
Improved physics: enlarging the available phase space



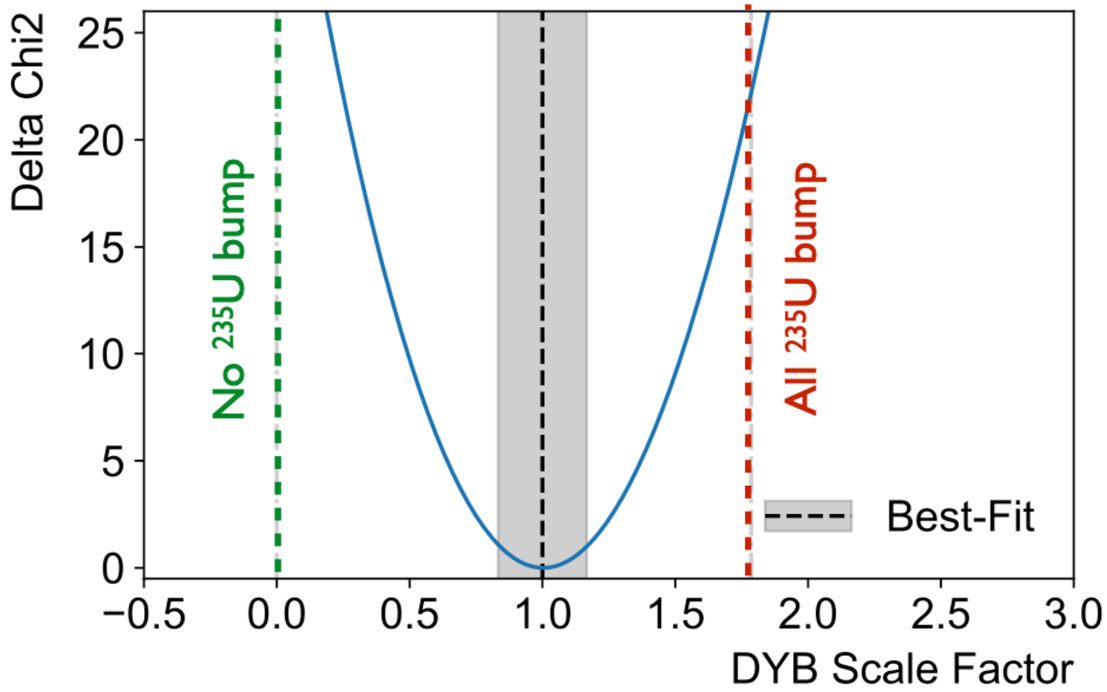
- As much as 7x improvement in oscillation sensitivity will result in world-leading limits from ~2-20 eV^2
- Higher sensitivity at high Δm^2 below KATRIN, region with conflicting experimental claims (Neutrino-4)
- Covering region below 5deg - mid Δm^2 region, could be key to disambiguate CPV observations from LBL

PROSPECT-II: spectral analysis

Improved physics: looking into the bump



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



- 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

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 2.5σ

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

B13.0003: Joint Isotope-Dependent Analysis of the Daya Bat and PROSPECT Reactor Antineutrino spectra Calibration system for PROSPECT-II

B13.0004: A Joint Analysis of the PROSPECT and STEREO ^{235}U Antineutrino Spectra

E18.0004: Optical Photon Tracking in Geant-4 for the PROSPECT-II Detector Upgrade

E18.0005: Calibration system for PROSPECT-II

E18.0006: Machine Learning Analysis of PROSPECT Data

Y18.00006: PROSPECT's latest results

Y18.00007: Improving PROSPECT Neutrino Measurements with Single Ended Event Reconstruction

X10.00007: Cosmic ray boosted dark matter at PROSPECT—theory and propagation

X10.00008: Cosmic ray Boosted Dark Matter at PROSPECT – Experimental Analysis