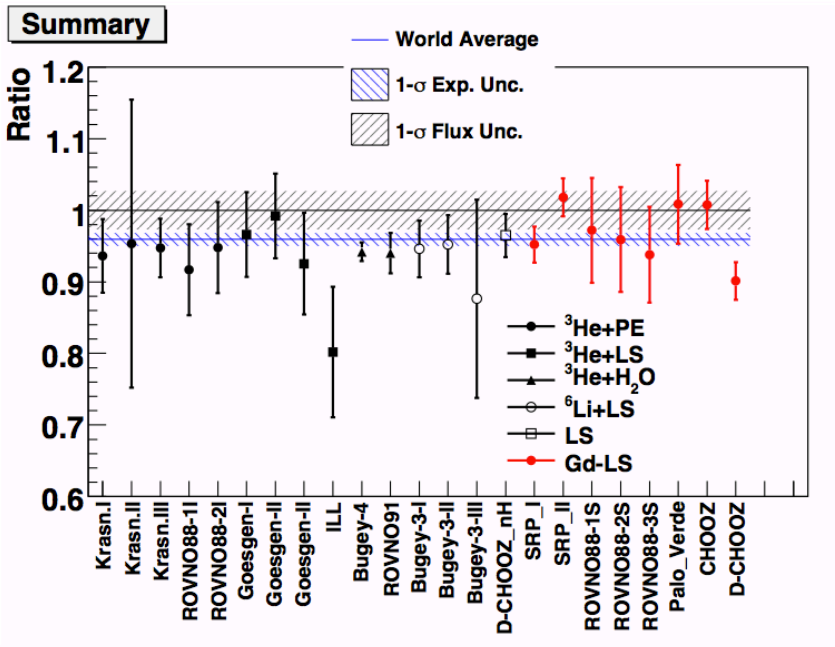
ILLINOIS INSTITUTE OF TECHNOLOGY

A Precision Reactor Oscillation and Spectrum Measurement

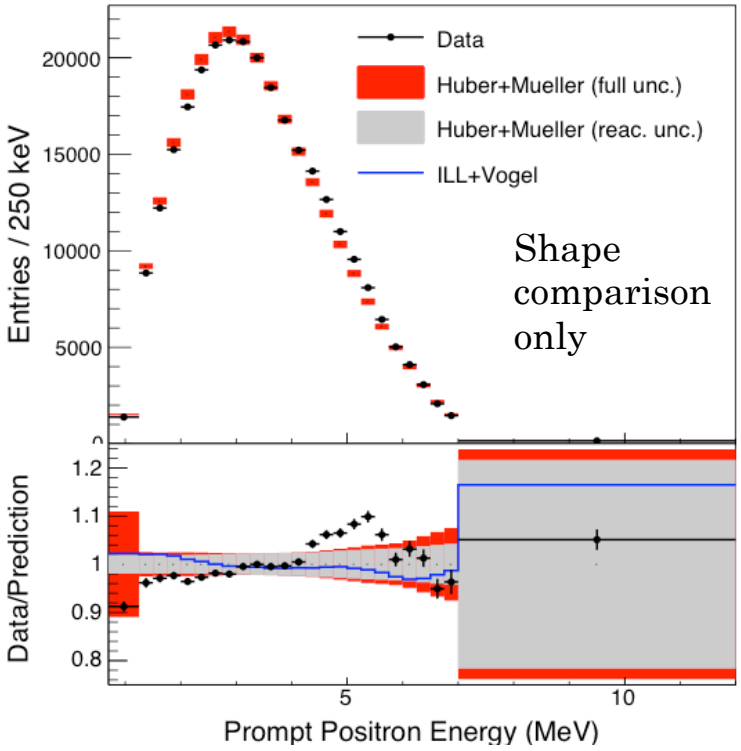
Karin Gilje
PROSPECT Collaboration
IPA 2015

Reactor Anomaly

- A deficit of the predicted reactor flux.
- An excess in events around 5 MeV.



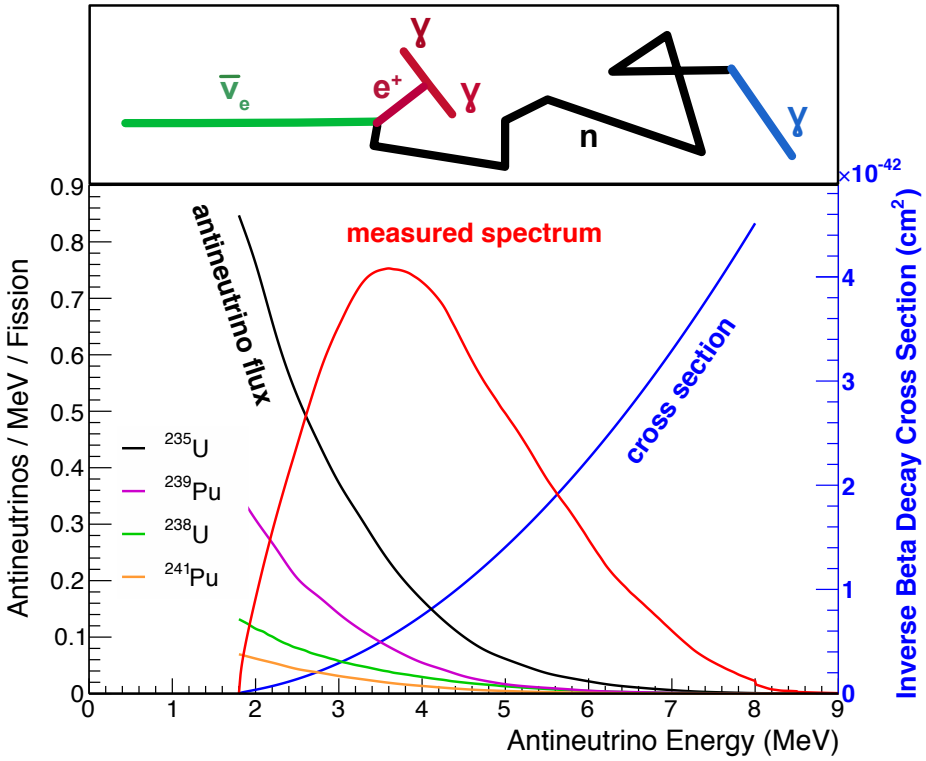
C. Zhang *et al.* arXiv:1303.0900v3 (2013)



D. Naumov (Daya Bay) arXiv:1412.7860 (2015)

Reactor Spectrum Models

- Searches for reactor antineutrinos are typically based on inverse beta decay.
- Reactor Fuels are mixtures of Uranium 235, Uranium 238, Plutonium 239, and Plutonium 241.
- The total emitted spectrum is the fractional sum of the modeled spectra.

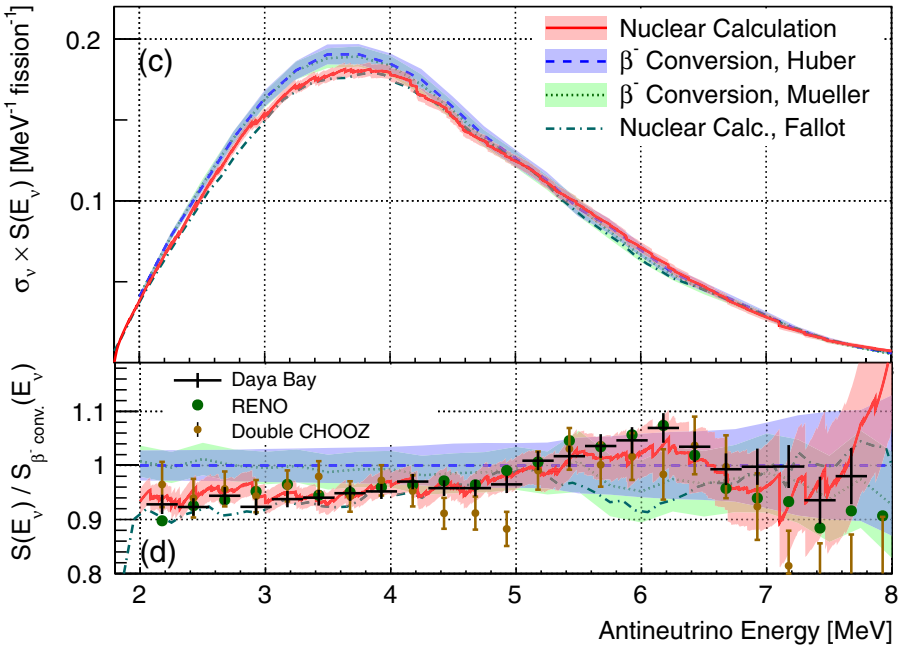


Vogel *et al,* arXiv:1503.01059v2 (2015)

Possible Solution #1

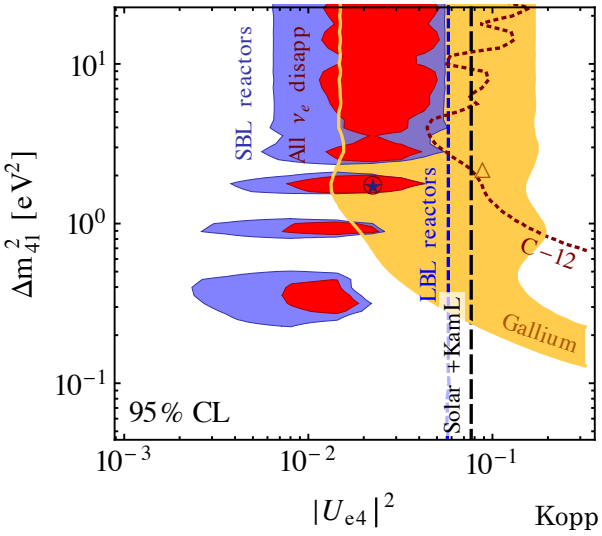
- Inaccurate Spectra Models.
  - *Ab initio* approach
    - Calculate spectrum branch-by-branch using beta branch databases.
  - Conversion approach
    - Measure beta spectrum
    - Work backwards to $\bar{\nu}_e$ spectrum

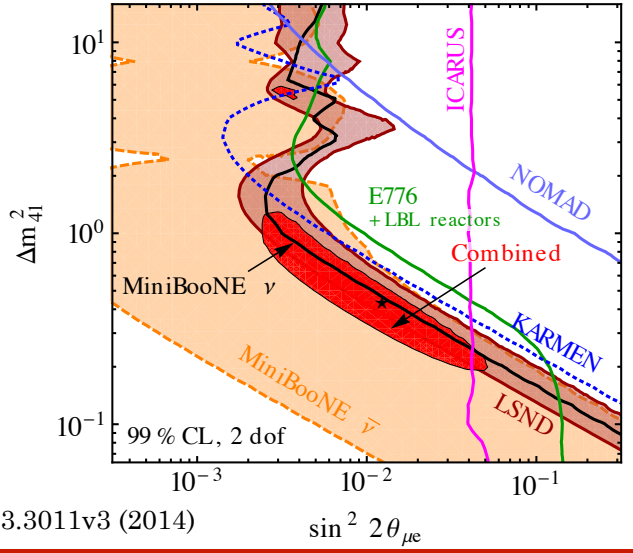
Dwyer and Langford, PRL **114** 012502 (2015)



Possible Solution #2

- The existence of sterile neutrinos (ν_s)
  - LSND, MiniBooNE and Gallium anomalies would agree.
  - Tension with ν_μ disappearance measurements.





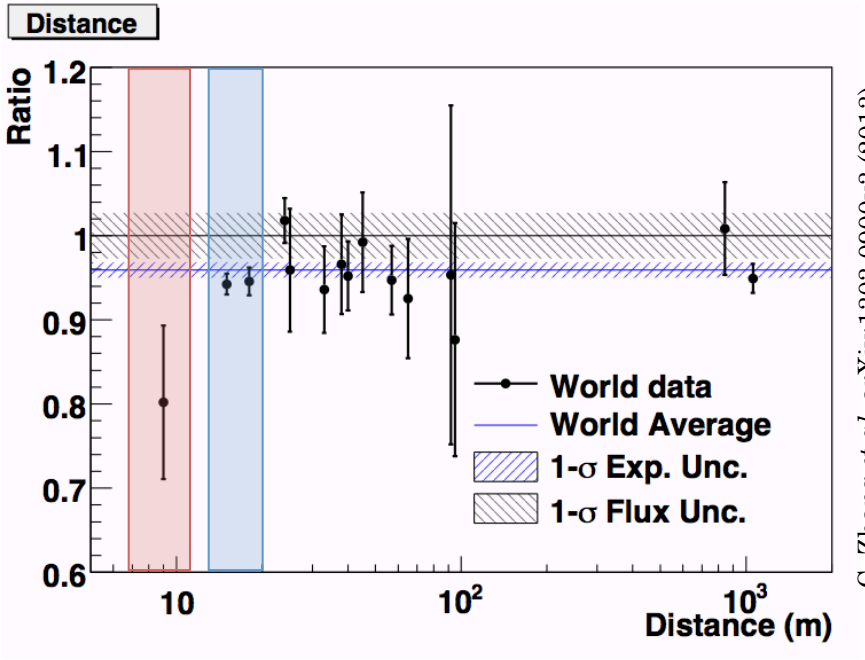
Kopp *et al.* arXiv:1303.3011v3 (2014)

Problem Summary

- We see a deficit in the expected reactor flux
- We see a deviation from the expected reactor spectrum shape.
- Two possible solutions:
  - Incomplete picture of the spectrum.
  - Sterile neutrino exists.

PROSPECT

- Goal 1: A precise measurement of the HFIR (High Flux Isotope Reactor) spectrum.
- Goal 2: Perform a sterile neutrino search with interest in Δm^2 around 1.0 eV^2.



C. Zhang *et al.* arXiv:1303.0900v3 (2013)

PROSPECT Phase I baseline
PROSPECT Phase II baseline

PROSPECT

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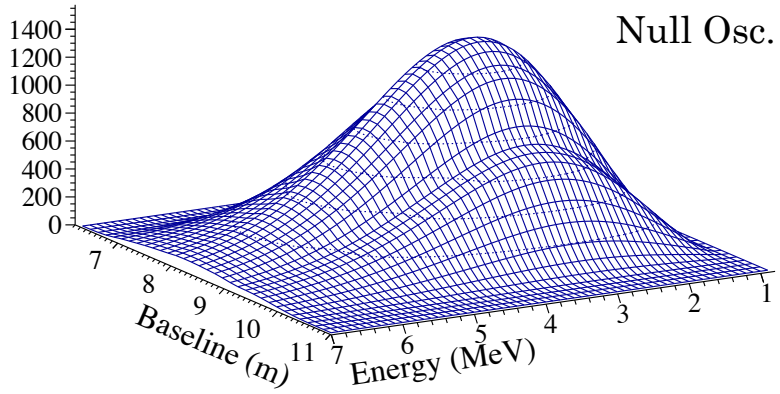
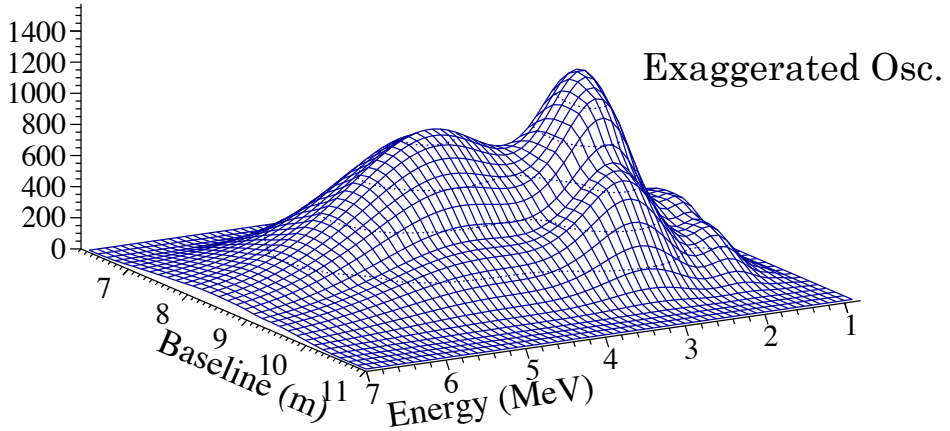
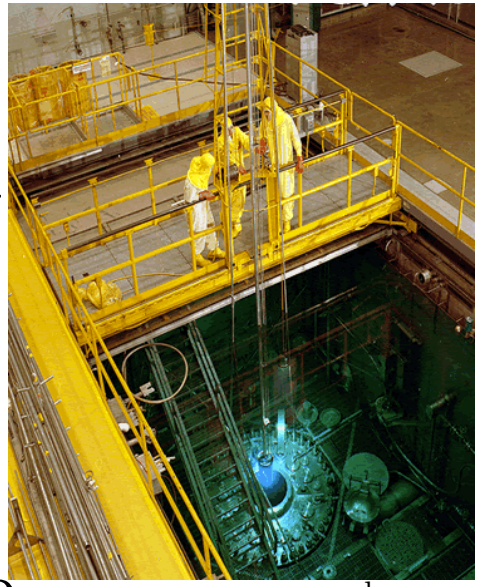


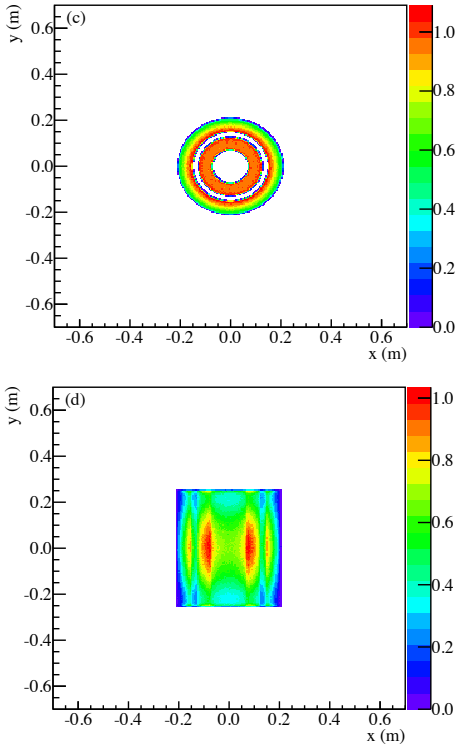


HFIR

- Operates at 85 MW
- Compact Core
- Located at ORNL
- Uses Highly Enriched Uranium (HEU) Fuel
  - The neutrino spectrum is almost entirely from Uranium-235.
- Typically 41% up-time
  - Allows in-depth background study.



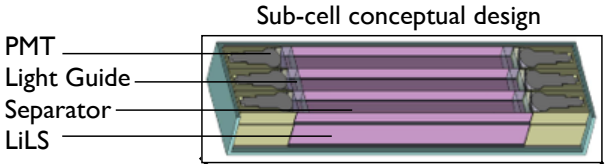
ornl.gov

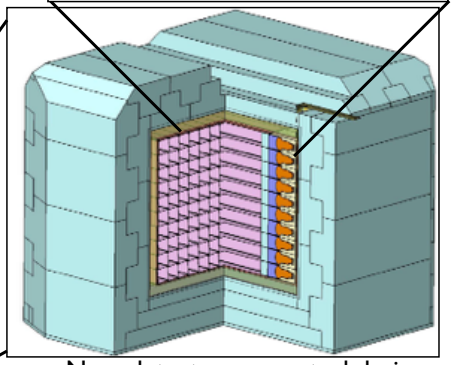


Ashenfelter *et al.* arXiv:1309.7647v3 (2015)

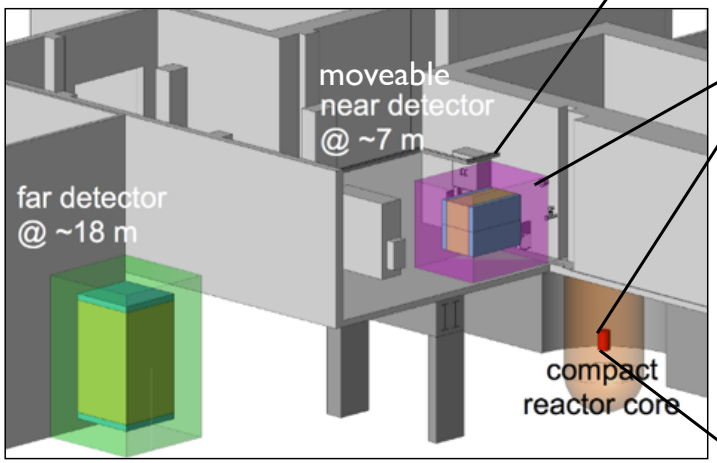
PROSPECT Design

- Phased approach
- Optically Separated Segmented Volume
- Double-ended PMT readout
- Li6-Loaded Liquid Scintillator
- Moveable near detector

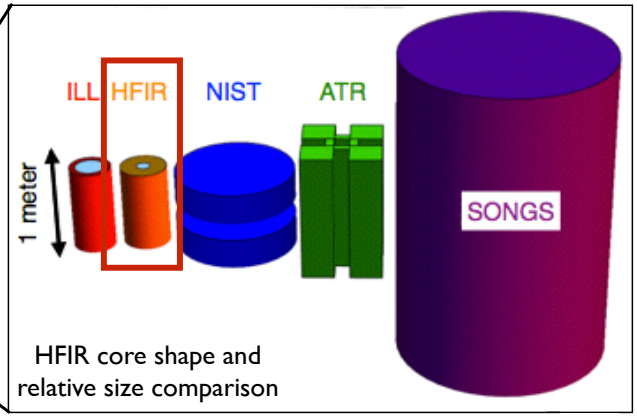




Near detector conceptual design



Two-detector PROSPECT deployment at HFIR



HFIR core shape and relative size comparison

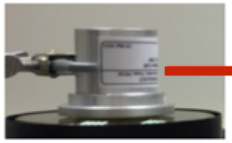
Ashenfelter *et al.* arXiv:1309.7647v3 (2015)

Current Prototype Status

Run DAQ, Remote data-taking

See n-Li + PSD

PROSPECT 0.1*
Aug 2014

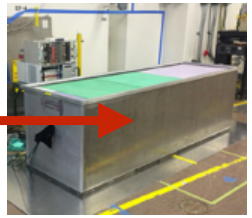


2 inches

Demonstrate shielded background rates

PROSPECT 2*
Dec 2014-
Mar 2015

5 inches



Demonstrate full timing and PE response

PROSPECT 20*
Mar 2015

1 meter

Deploy final design concepts

Observe relative segment responses

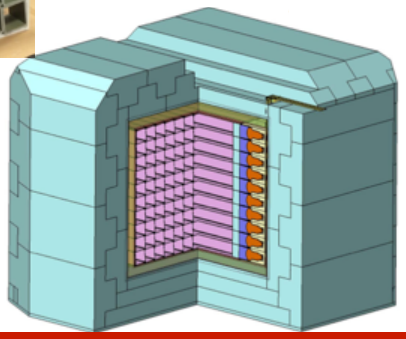
See antineutrinos

Meet physics goals

PROSPECT 200

3x3x1 meter mockup at IIT

PROSPECT 2k



PROSPECT
Phase II **(10k)?**

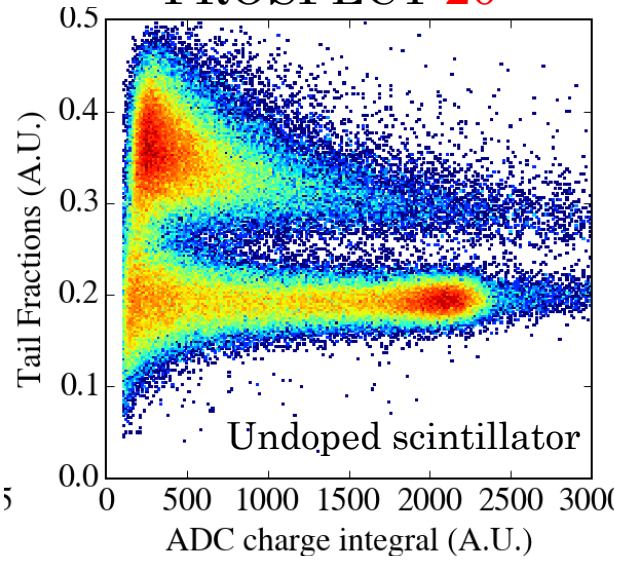
*Deployment complete!!!

Approximate mass kg

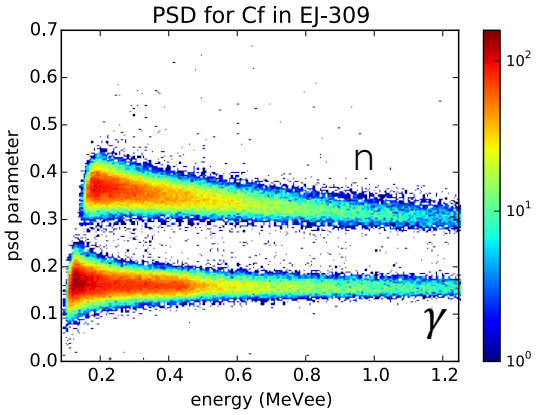
Early Validation

- PSD Discrimination
- Li6 doping
- Double Ended readout
- Reactor On/Off comparisons
- And many others …

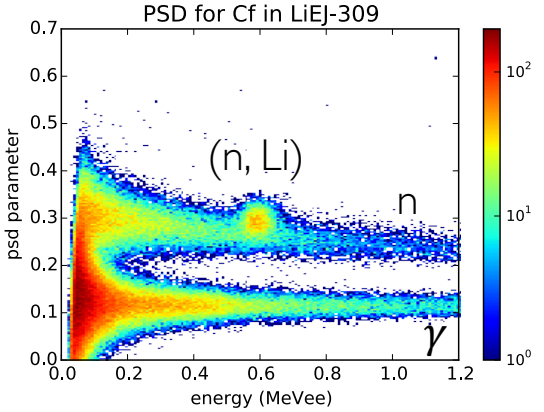
PROSPECT 20



K. Han (PROSPECT Collaboration) APS 2015



PROSPECT 0.1



D. Norcini (PROSPECT Collaboration) APS 2015

Early Validation

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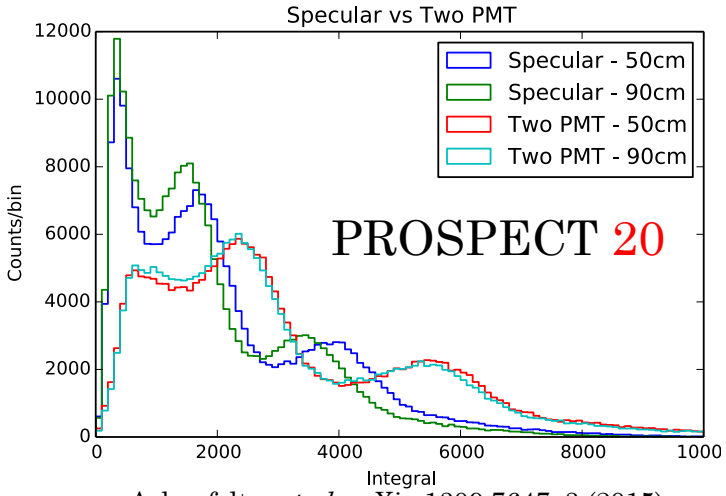
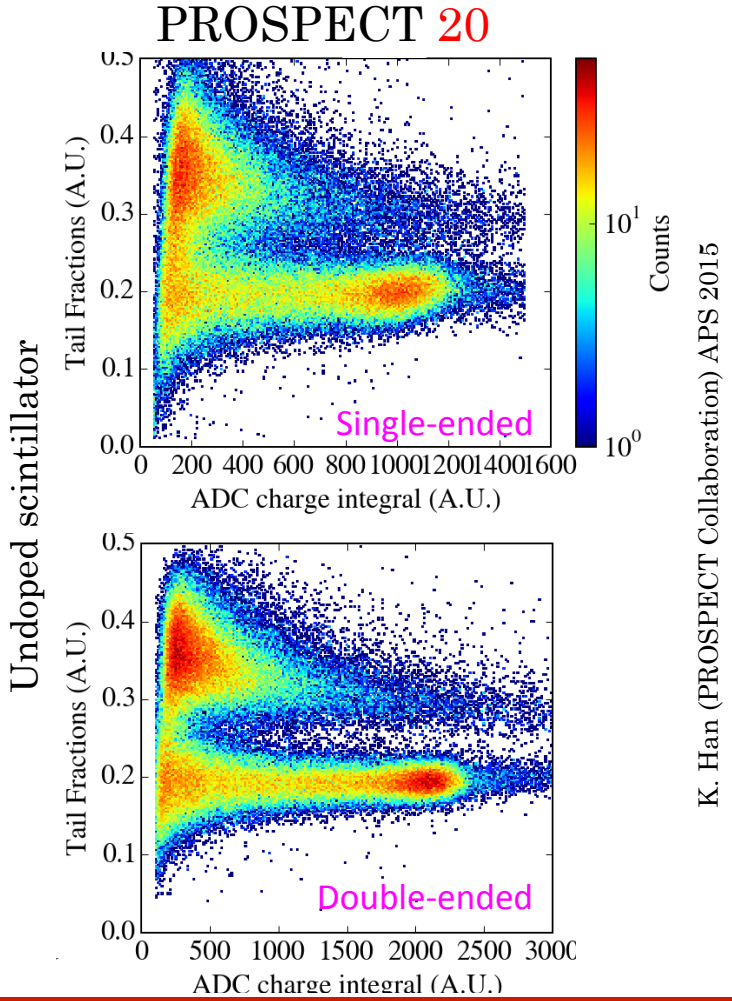


Ashenfelter *et al.* arXiv:1309.7647v3 (2015)



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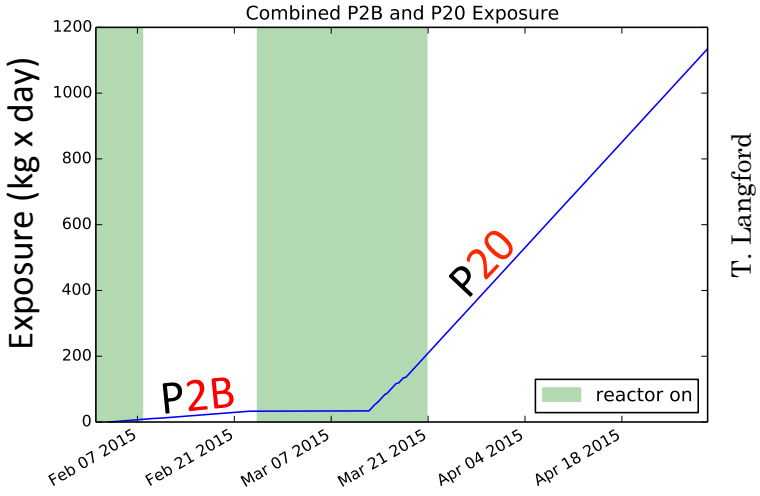
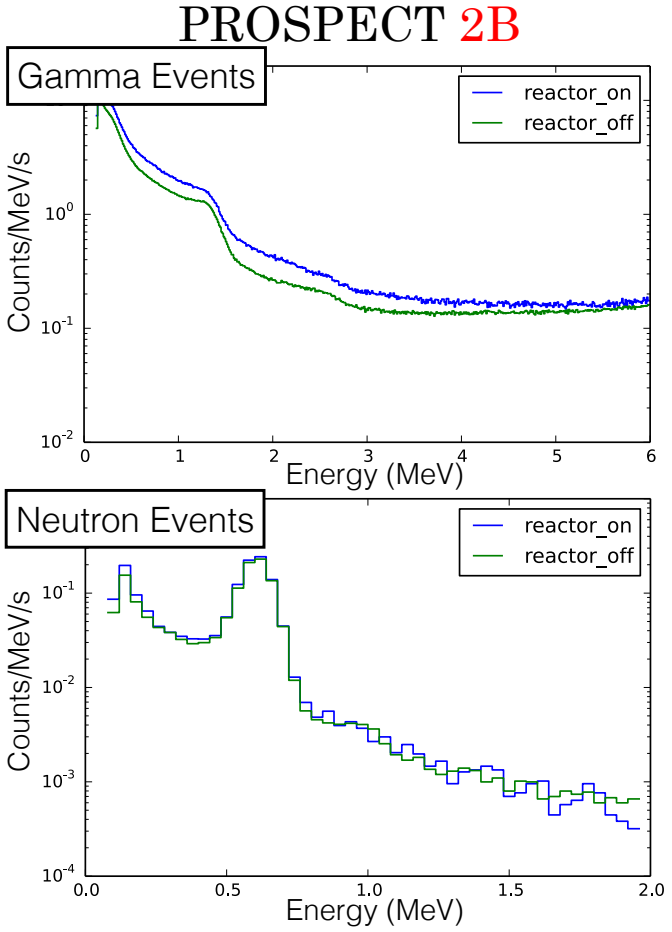
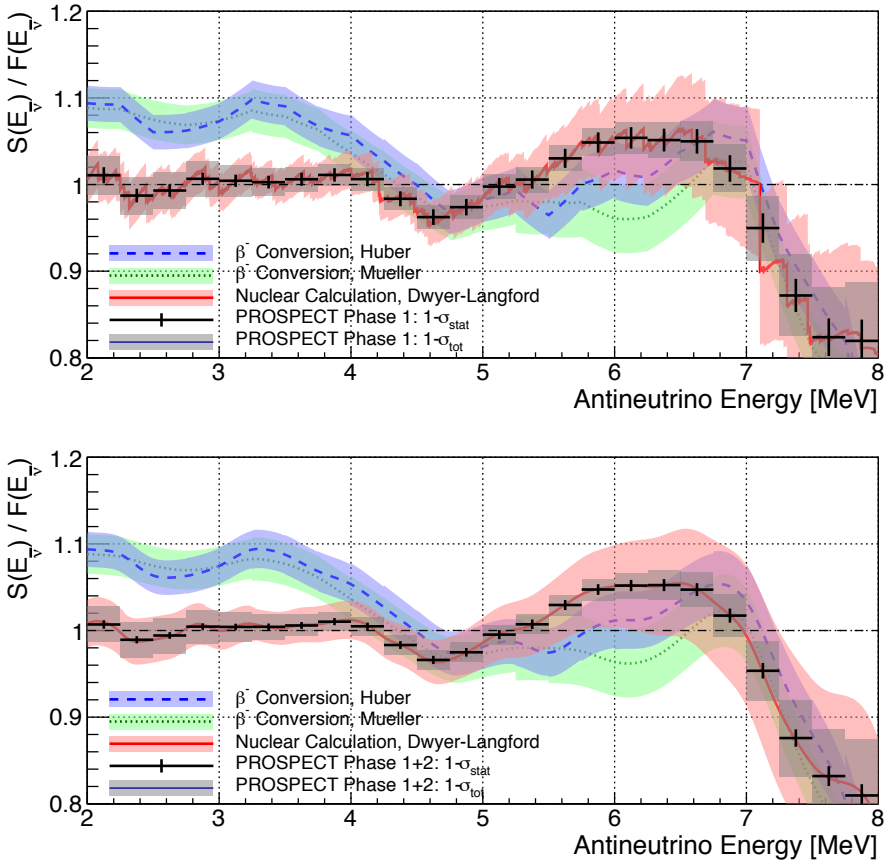




Absolute Spectrum

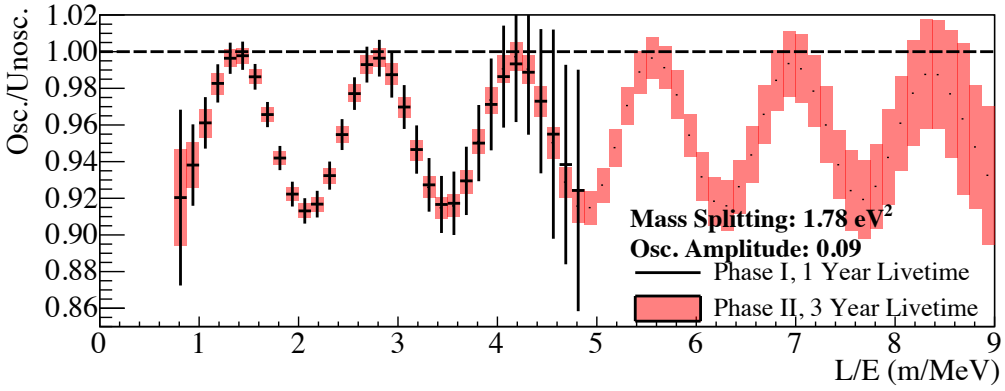
- HEU Fuel
- Energy Resolution 4-5%/√E
- Constraints on Nuclear Models
- Inputs for future reactor experiments.

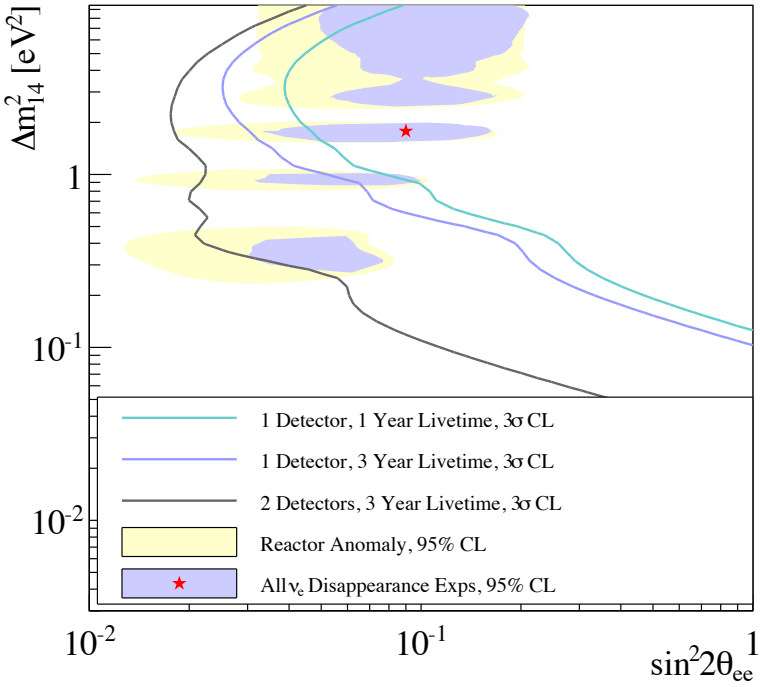


Ashenfelter *et al.* arXiv:1309.7647v3 (2015)

Sterile Neutrino Search

- Relative measurement – no absolute spectrum dependence
- Assumptions:
  - 4.5%/√E energy resolution
  - 20cm position resolution
  - 1:1 signal to background



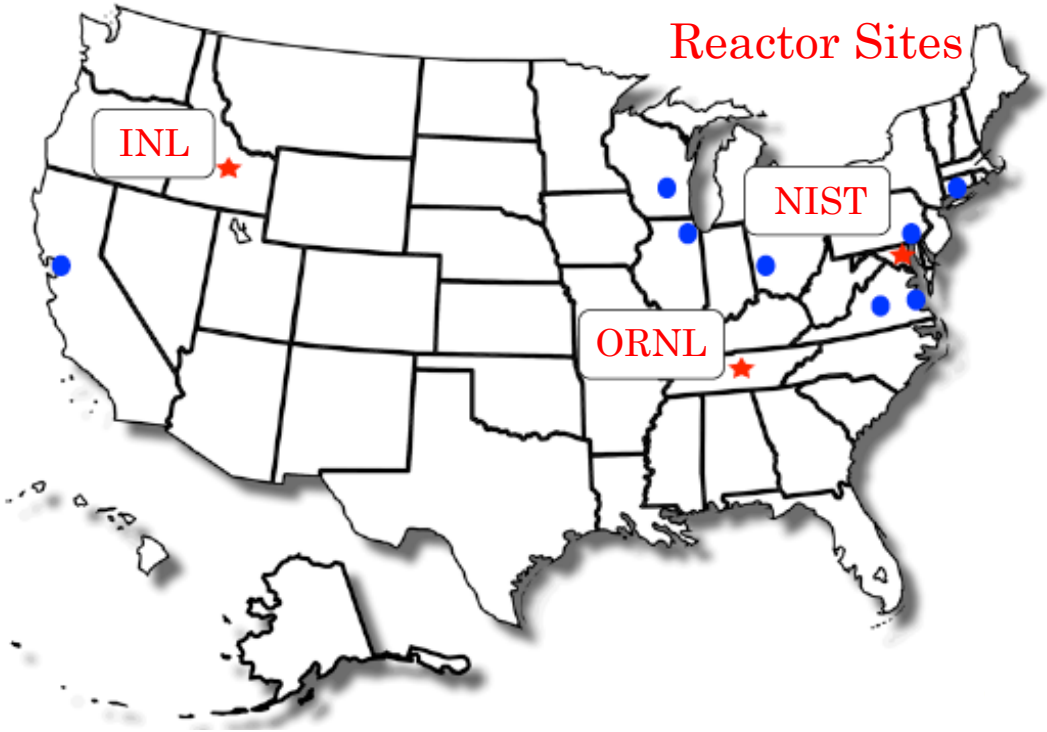


Ashenfelter *et al.* arXiv:1309.7647v3 (2015)

Closing Statements

- PROSPECT is being proposed to study the reactor antineutrino spectrum and to search for a 1 eV^2 scale sterile neutrino.
  - Using HEU fuel, we can greatly decrease the uncertainties on the Uranium 235 spectrum and aid to guide future reactor models.
  - Within 1 year of P2k, we will have 3σ coverage over the current global best fit sterile neutrino.
- Prototypes have been deployed and are aiding in the final detector configuration.
- The studies of $\bar{\nu}_e$ disappearance provide complementary studies to current Fermilab SBL program (ν_μ to ν_e appearance and ν_μ disappearance)

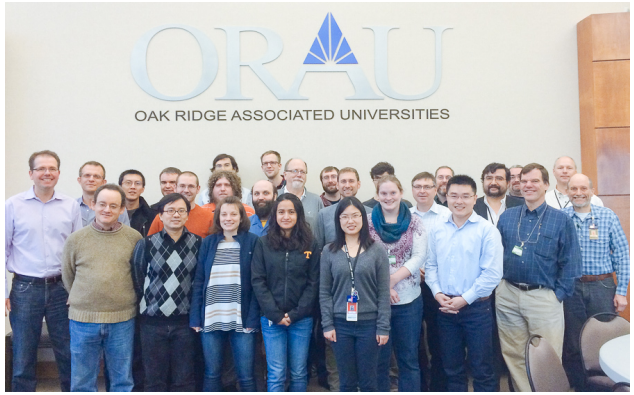
The PROSPECT Collaboration



10 Universities
6 National Labs

Updated Whitepaper:
arXiv:1309.7647

Website:
http://prospect.yale.edu/



Brookhaven National Laboratory
Drexel University
Idaho National Laboratory
Illinois Institute of Technology
Lawrence Berkeley National Laboratory
Lawrence Livermore National Laboratory
National Institute of Standards and Technology
Oak Ridge National Laboratory
Temple University
University of Tennessee
Virginia Tech University
University of Waterloo
University of Wisconsin
College of William and Mary
Yale University

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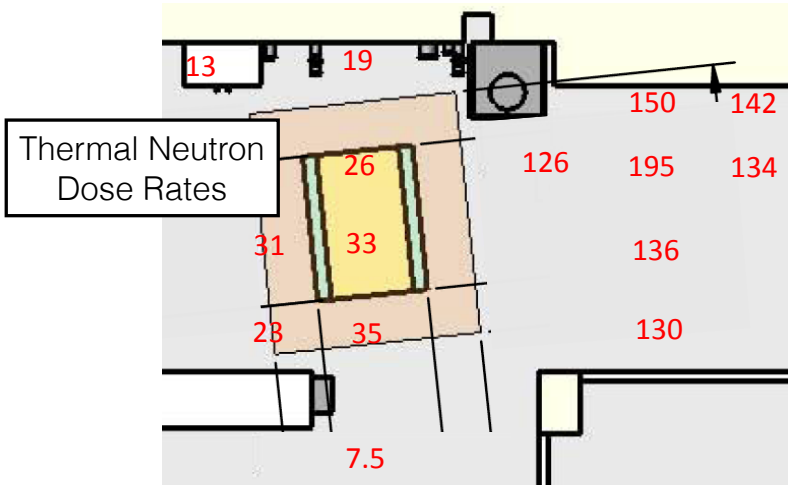
BACKUPS

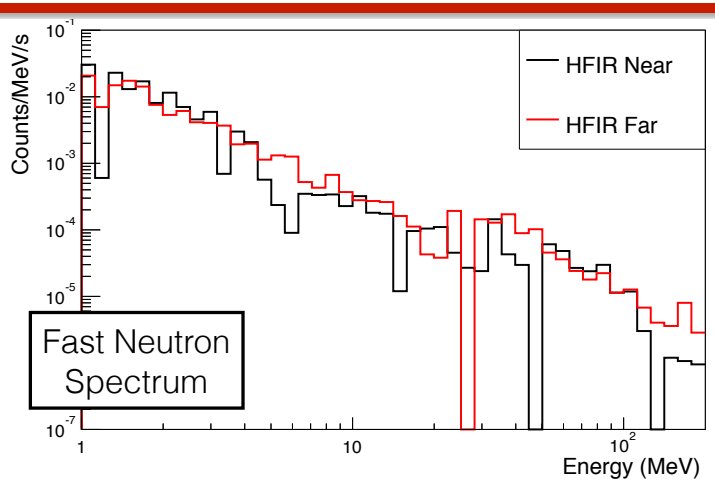
Comparison to Other Experiments

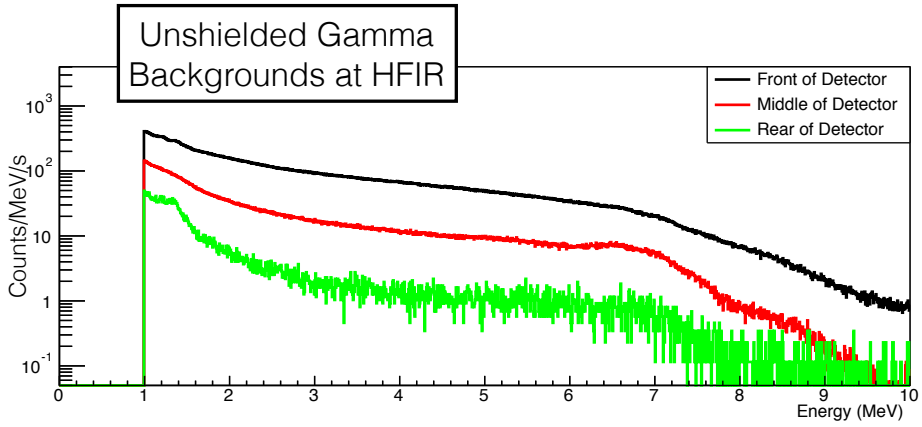
	Effort	Dopant	Good X-Res	Good E-Res	L Range (meters)	Fuel	Exposure, MW*ton	Move-able?	Running at intended reactor?
US	**PROSPECT**	**Li**	**Yes**	**Yes**	**6.5-20**	**HEU**	**185**	**Yes**	**Yes**
	NuLat	Li/B	Yes	Yes	TBD	TBD	TBD	Yes	No
EU	Nucifer	Gd	No	Yes	7	HEU	56	No	Yes
	STEREO	Gd	Yes	Yes	9-11	HEU	100	No	Yes
	SoLid	Li	Yes	No	6-8	HEU	155	No	Yes
Russia	DANSS	Gd	Yes	No	9.7-12	LEU	2700	Yes	Yes
	Neutrino4	Gd	Yes	No	6-12	HEU	150	Yes	Yes
Asia	Hanaro	Li/Gd	No	Yes	20-ish	LEU	30	No	No

B. Littlejohn Fermilab Intesity Frontier Seminar 2015

Backgrounds at HFIR







- **Spacial variation in thermal n and gamma rates**
- *No evidence for reactor-correlated fast neutron backgrounds*
- Backgrounds are well modeled in simulation
- *Paper detailing results will be out soon*

T. Langford (PROSPECT Collaboration) APS 2015