ILLINOIS INSTITUTE OF TECHNOLOGY

Sensitivity and Discovery Potential of the PROSPECT Experiment

Karin Gilje

PROSPECT Collaboration

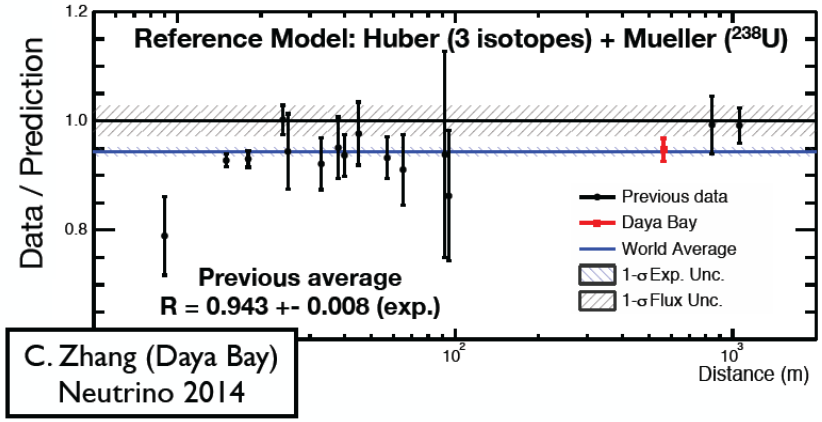
DPF 2015

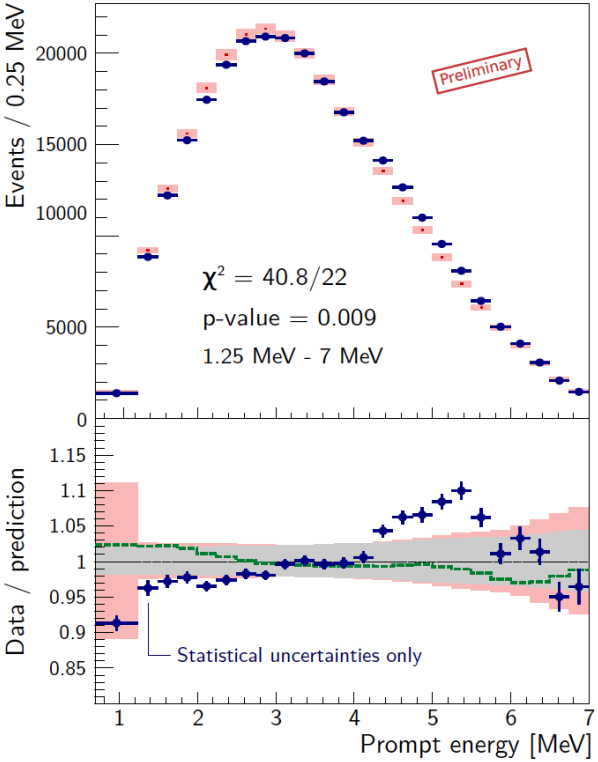
PROSPECT

*Also see D. Norcini's talk following this for PROSPECT Prototypes

Reactor Anomaly

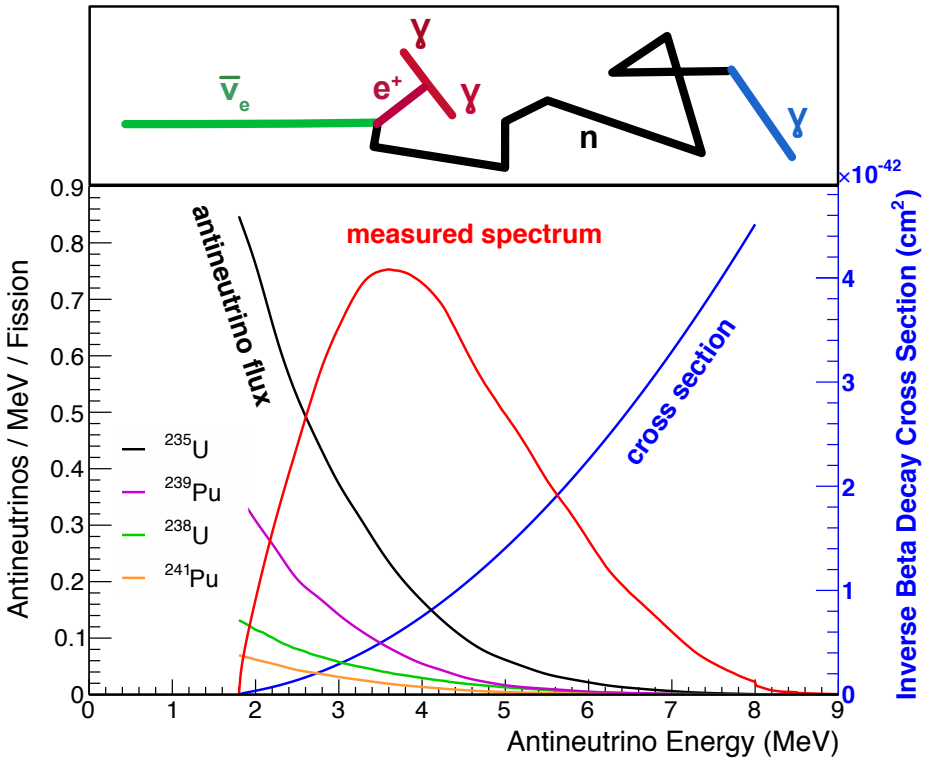
- A deficit of the predicted reactor flux.
- An excess in events around 5 MeV.





Reactor Spectrum Models

- Searches for reactor antineutrinos are typically based on inverse beta decay.
- Reactor Fuels are mixtures of U-235, U-238, Pu-239, and Pu-241.
- The total emitted spectrum is primarily an admixture of these four isotopes.

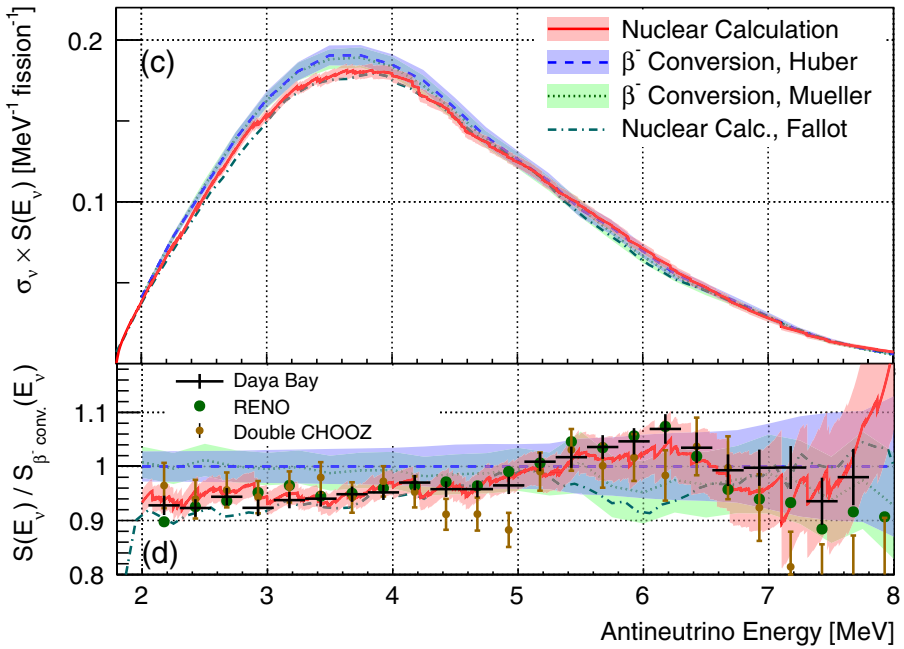


Vogel *et al*, arXiv:1503.01059v2 (2015)

Possible Solution #1

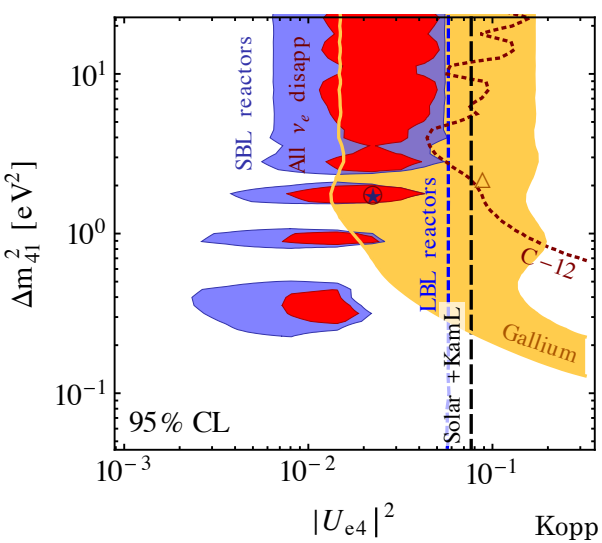
- Deficiency in inputs to Spectral Models.
  - *Ab initio* approach
    - Calculate spectrum branch-by-branch using beta branch databases.
  - Conversion approach
    - Measure beta spectrum
    - Work backwards to $\bar{\nu}_e$ spectrum
  - Both methods have large uncertainties!

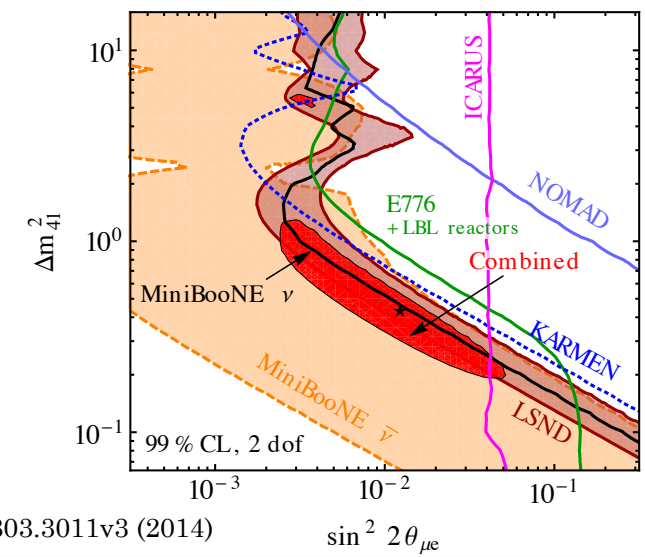
Dwyer and Langford, PRL **114** 012502 (2015)



Possible Solution #2

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





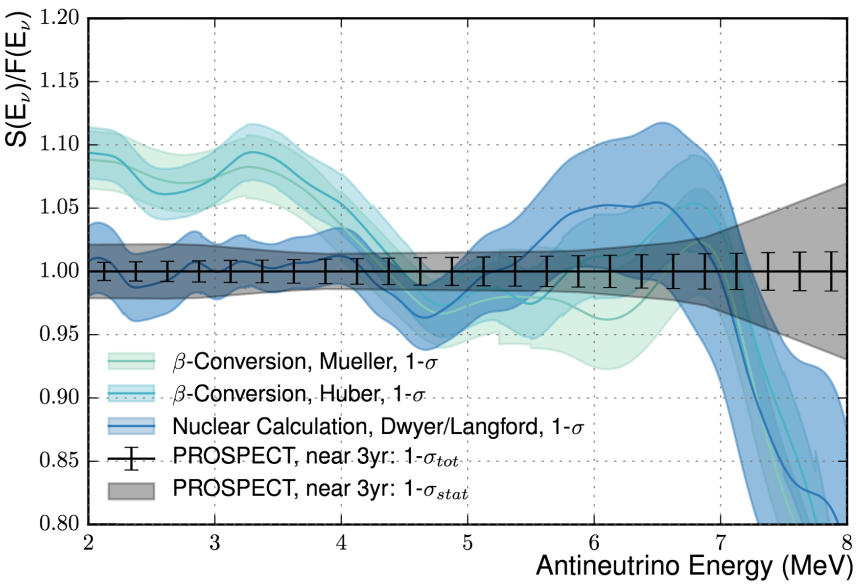
Kopp *et al.* arXiv:1303.3011v3 (2014)

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 physics model of the spectrum (large uncertainties on rare decays in the fission processes).
  - Sterile neutrino or other new physics.
- We need new data to resolve these issues.

PROSPECT- Precision Reactor Oscillation Spectrum Experiment

- Goal 1: A precise measurement of the U-235 spectrum.
- Goal 2: Perform a sterile neutrino search with interest in Δm^2 around 1.0 eV^2.



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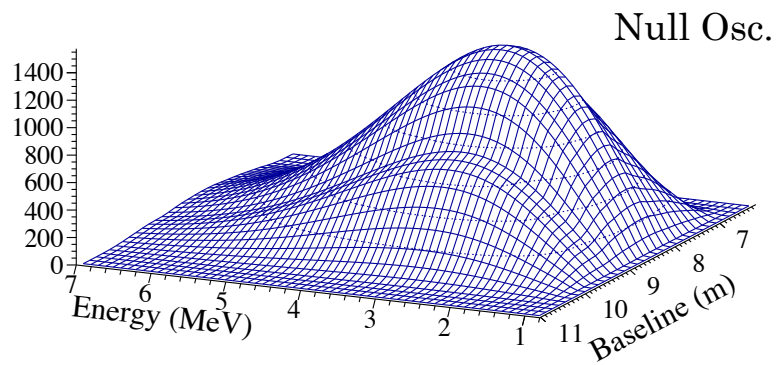
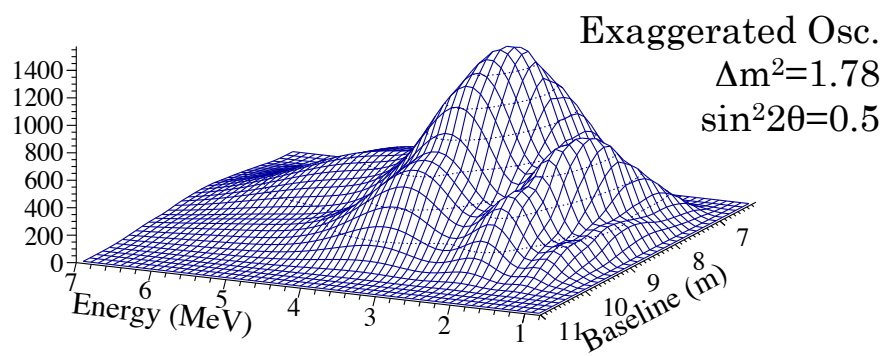


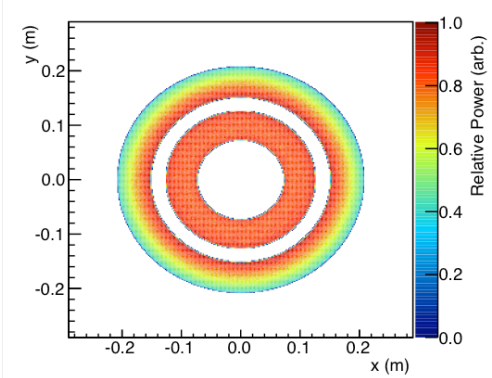
PROSPECT:
E = 1-7 MeV and L = 6-11 m

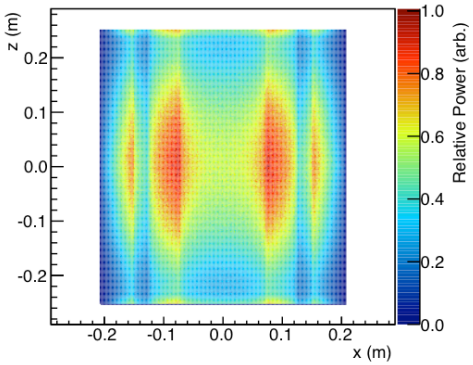


High Flux Isotope Reactor (HFIR) at ORNL

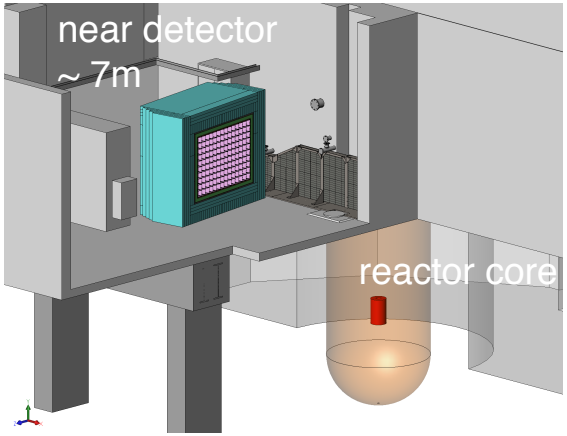
- Compact core research reactor operated at 85 MW
- Highly Enriched Uranium (HEU) Fuel-almost all fissions from U-235
- Scheduled live time: 41%
  - Allows in-depth background study.

ornl.gov

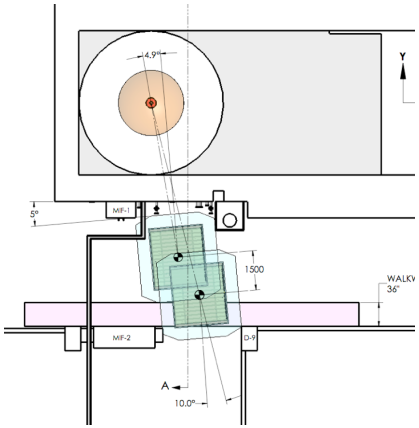




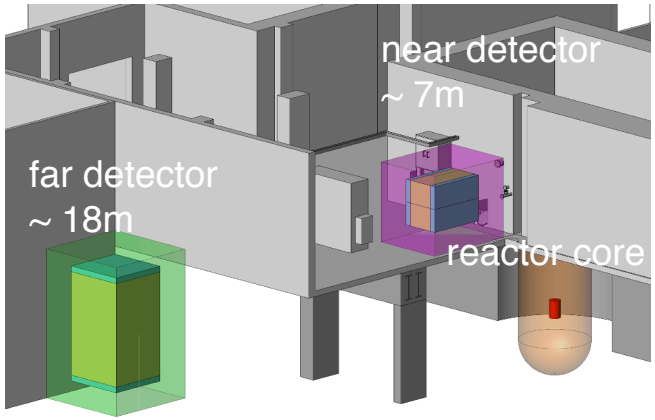
PROSPECT- Precision Reactor Oscillation Spectrum Experiment



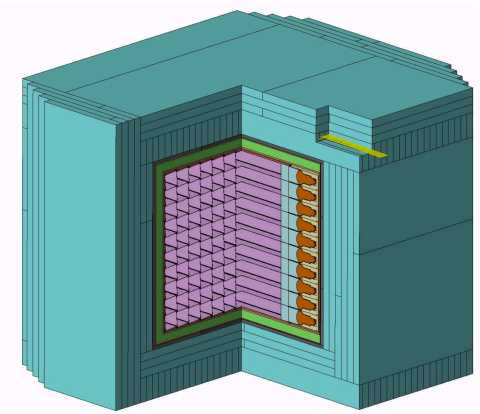
Phase I



Phase I+



Phase II

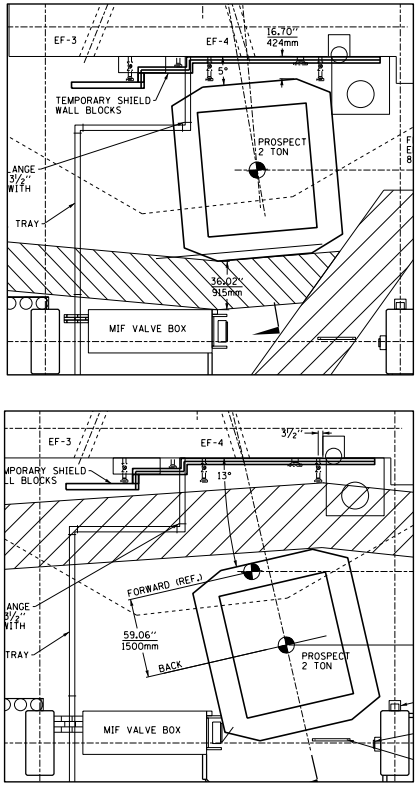


Phased Approach

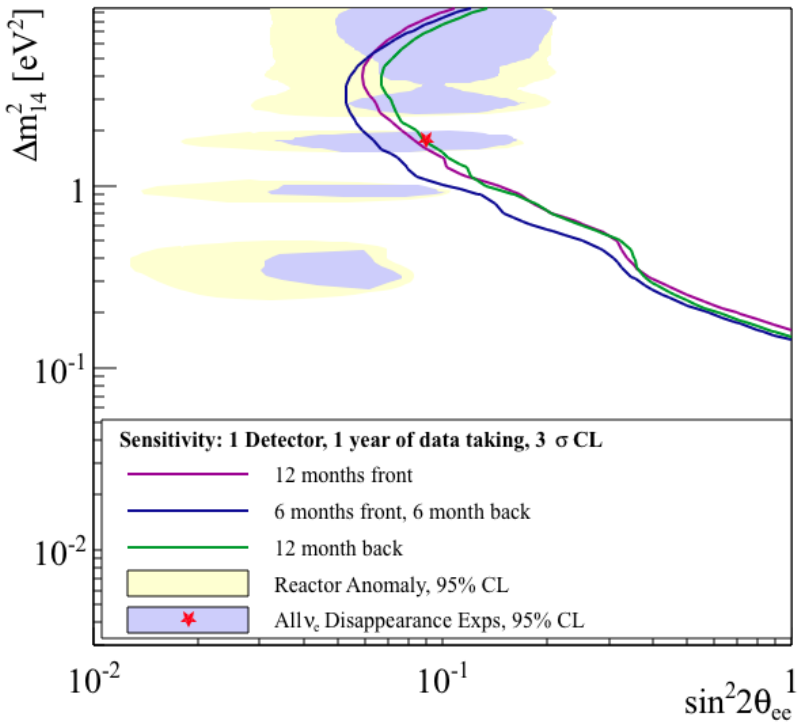
- Addresses experimental situation in a timely manner.
- Mitigates risks.
- Systematic control and increased physics reach.
- Allows flexibility in response to results from Phase I.

Movable Phase I

Logistical and engineering considerations for multiple Phase I detector locations confirmed. Provides greater physics reach through increased L/E range and posibilitiy for systematic cross-checks.

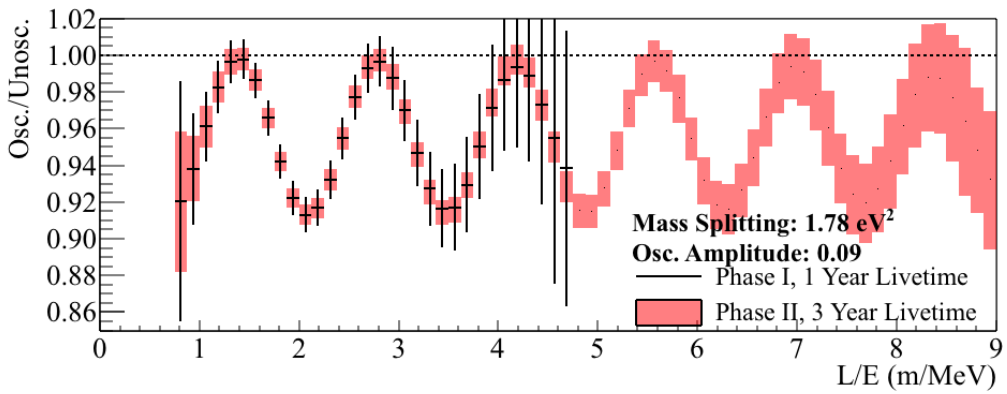


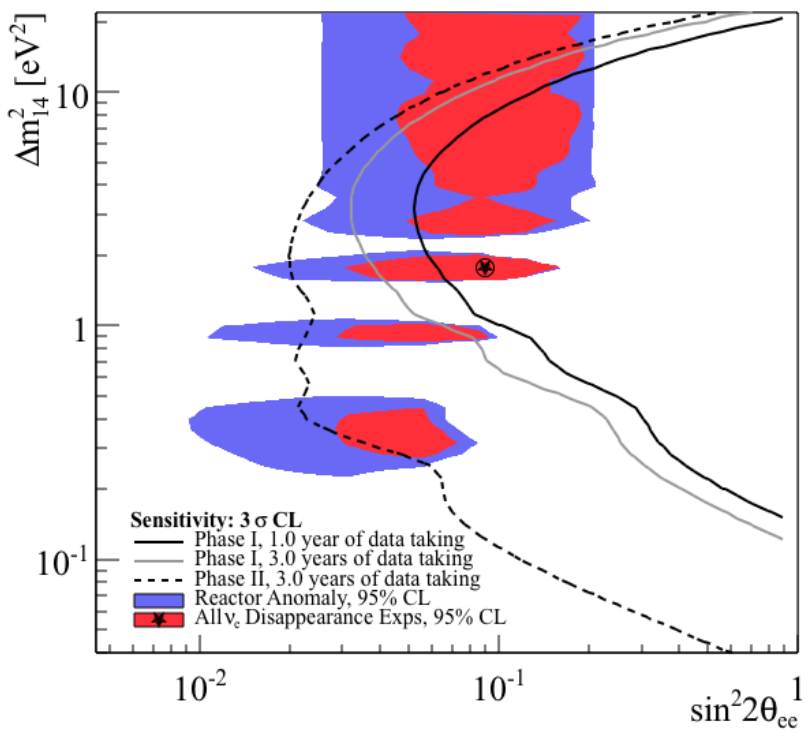
HFIR generated Phase I Front/Back layouts showing mandated egress pathways



Sterile Neutrino Search

- Relative measurement – no absolute spectrum dependence
- Assumptions:
  - 4.5%/√E energy resolution
  - 20cm position resolution
  - 1:1 signal to background
  - 41% reactor uptime





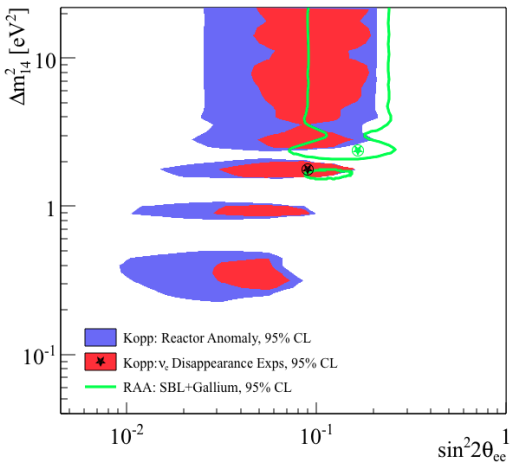
Comparing Global Fits

Kopp 2013

- arXiv: 1303.3011v3
- Uses Daya Bay 2012 $\sin^2 2\theta_{13}$
- Includes SBL measurements through 2011.
- Includes Gallium measurements from SAGE and GALLEX.
- Includes limits from LBL measurements like Double CHOOZ, RENO, and Daya Bay.
- Includes limits from solar experiments and KamLAND.

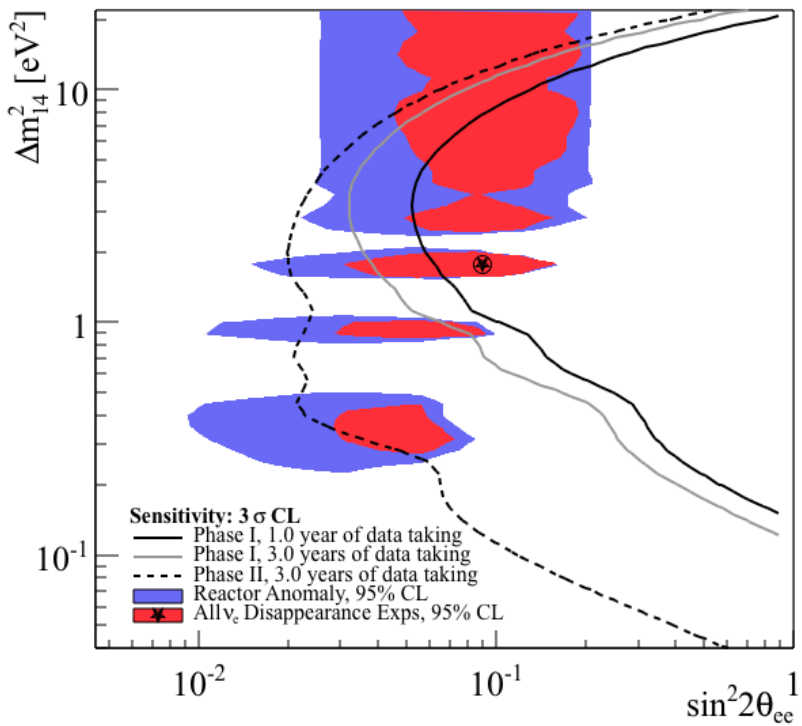
RAA 2012

- arXiv: 1204.5379v1
- Considers $\sin^2 2\theta_{13}=0$
- Includes SBL measurements through 2011.
- Includes Gallium measurements from SAGE and GALLEX.

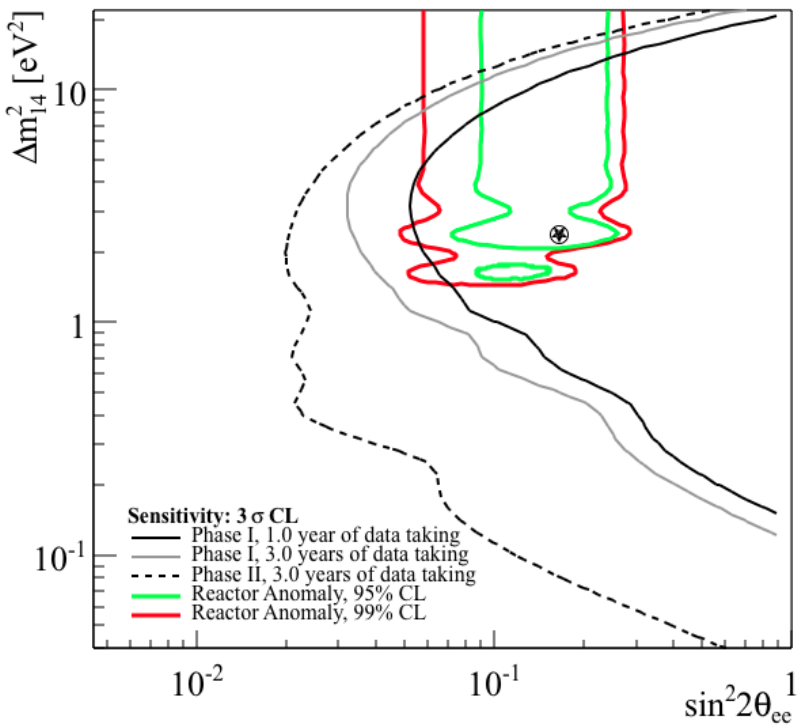


PROSPECT and Current Fits

Kopp 2013



RAA 2012

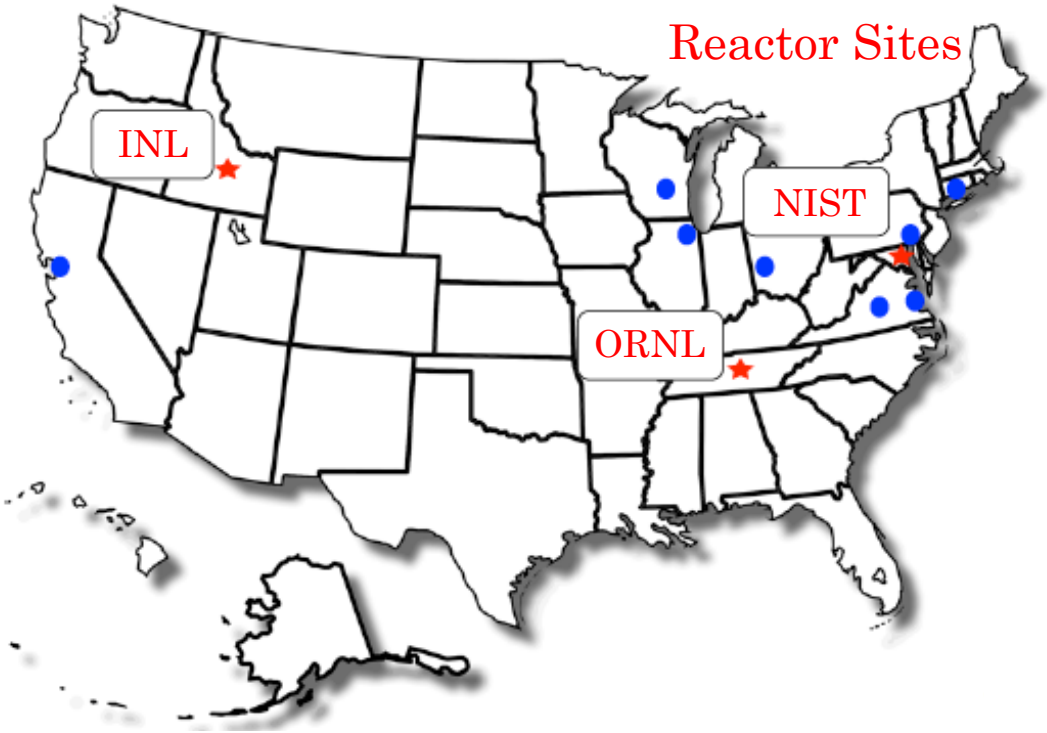


Closing Statements

- PROSPECT will study the reactor antineutrino spectrum and to search for a 1 eV^2 scale sterile neutrino.
  - Measurement of U-235 spectrum will provide new constraints on reactor antineutrino models, complementary to current and future LEU measurements.
  - Within 1 year of Phase I, we will have 3σ coverage over the current global best fit sterile neutrino.
- 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

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



Whitepaper:
arXiv:1309.7647

9 Universities
5 National Labs
63 Members

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

Current Prototype Status

Run DAQ,
Remote data-taking

See n-Li + PSD

Demonstrate shielded background rates

Demonstrate full timing and PE response

physics goals

PROSPECT 0.1*
Aug 2014

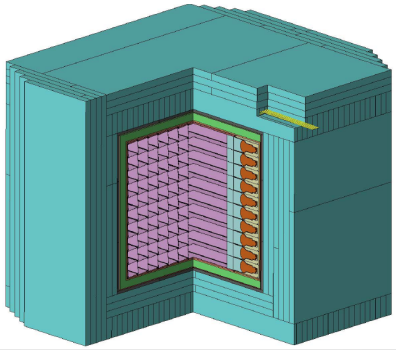
2 inches

PROSPECT 2*
Dec 2014-
Mar 2015

1 meter

3x3x1 meter
mockup at IIT

PROSPECT 2k



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

*Deployment complete!!!

Approximate mass kg

See D. Norcini's Talk!

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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

Current Prototype Status

Run DAQ,
Remote data-taking

See n-Li + PSD

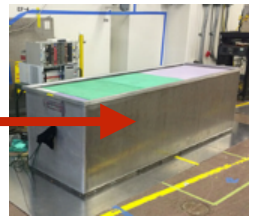
PROSPECT 0.1*
Aug 2014

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

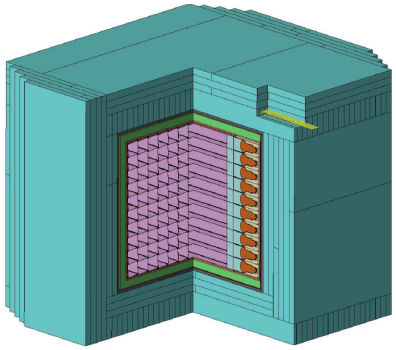
Observe relative segment responses

See antineutrinos

Meet physics goals

PROSPECT 200
2015^

3x3x1 meter
mockup at IIT



PROSPECT 2k
Phase I
2016^

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

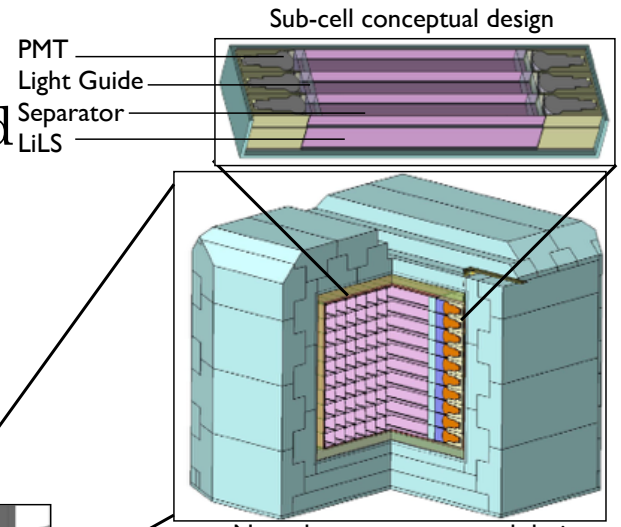
*Deployment complete!!!

^Technically driven schedule

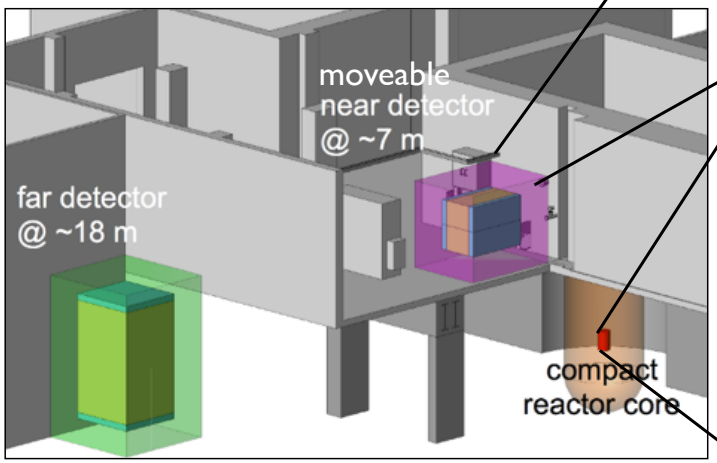
Approximate mass kg

PROSPECT Design

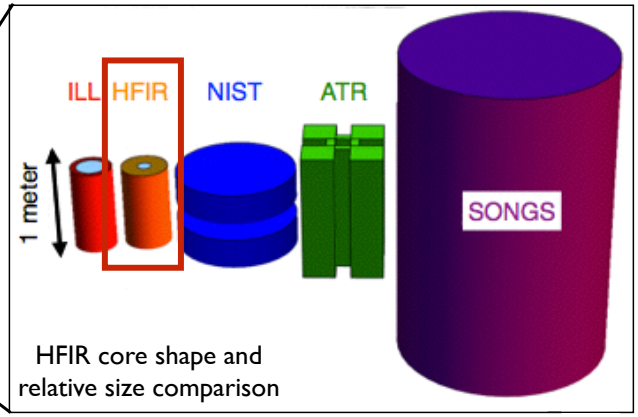
- Phased approach
- Optically Separated Segmented Volume
- Double-ended PMT readout
- Li6-Loaded Liquid Scintillator
- Moveable near detector



Near detector conceptual design



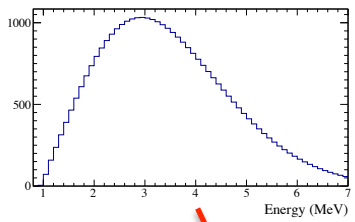
Two-detector PROSPECT deployment at HFIR

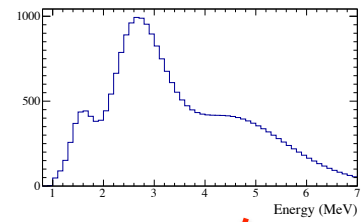


HFIR core shape and relative size comparison

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

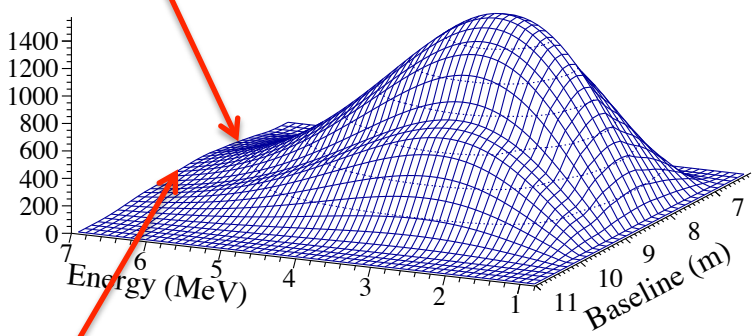
Calculating the Sensitivity

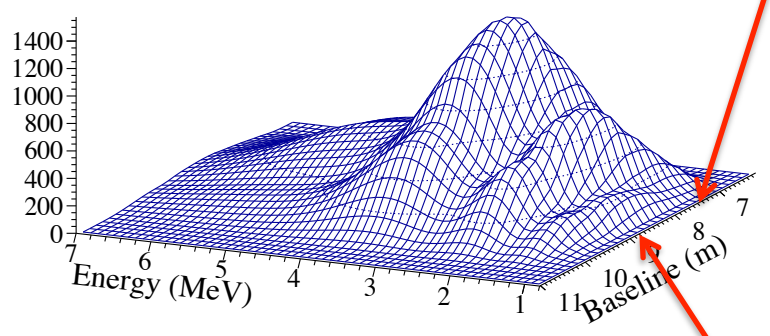


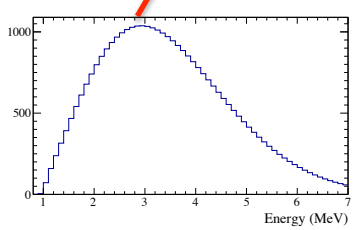


Null Oscillation Spectrum

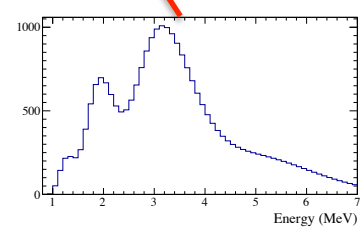
Exaggerated Oscillation Spectrum





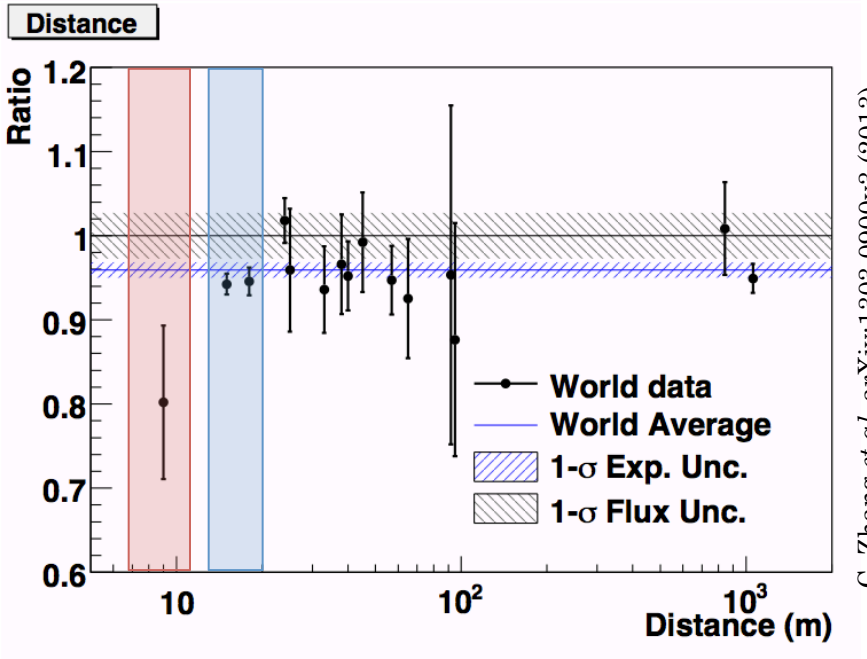


We calculate the χ^2 for each pair of Δm^2 and $\sin^2 2\theta$ that we are interested in.



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.

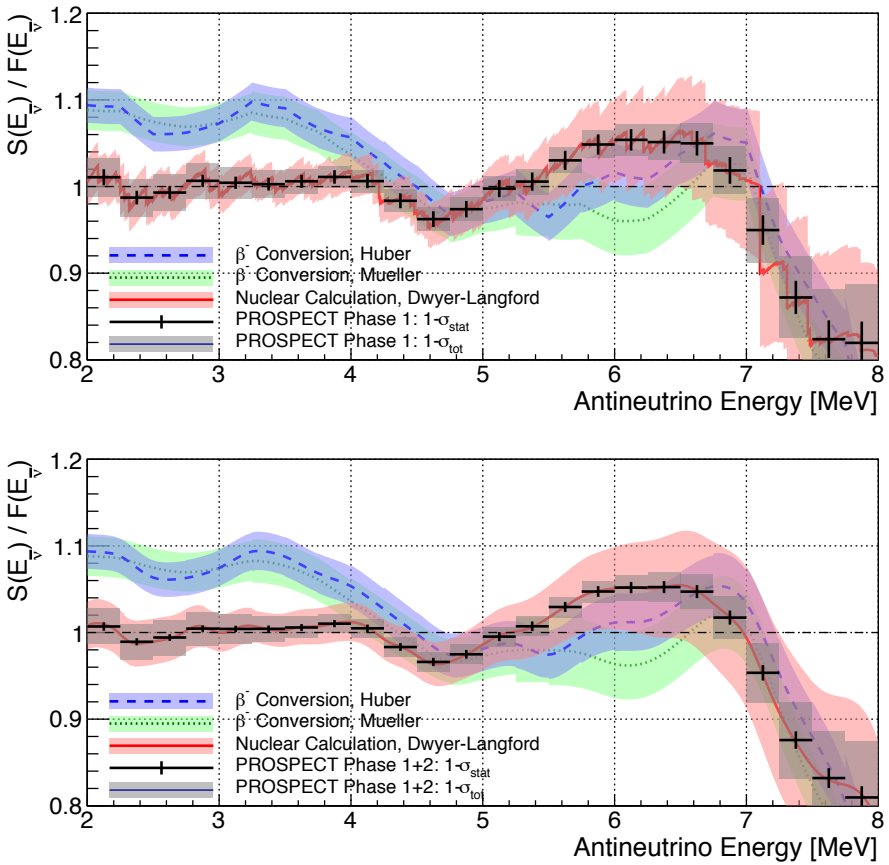


C. Zhang *et al.* arXiv:1303.0900v3 (2013)

PROSPECT Phase I baseline
PROSPECT Phase II baseline

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)

$\sin^2 2\theta_{13}$ and allowed regions (Kopp 2013)

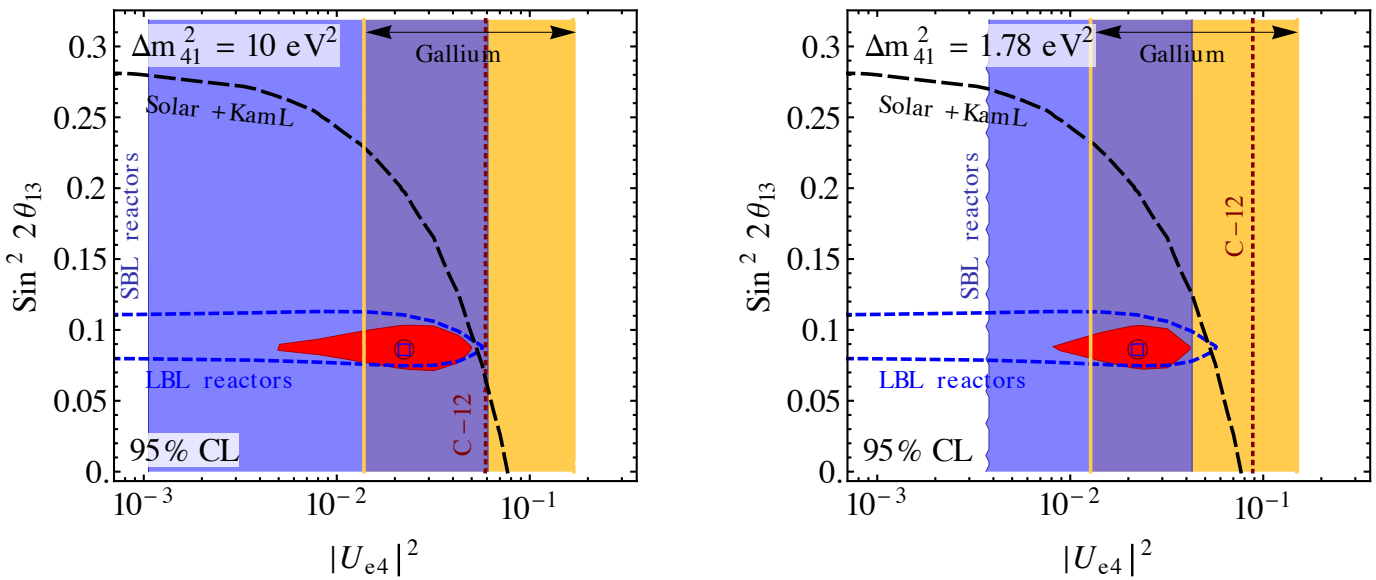
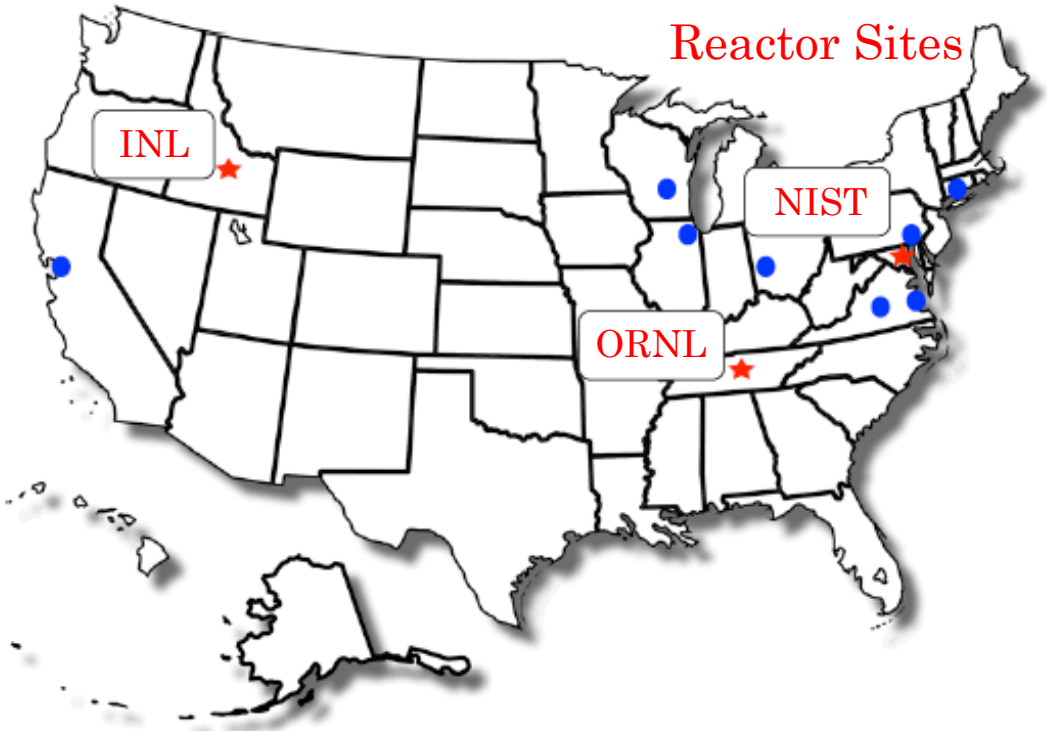
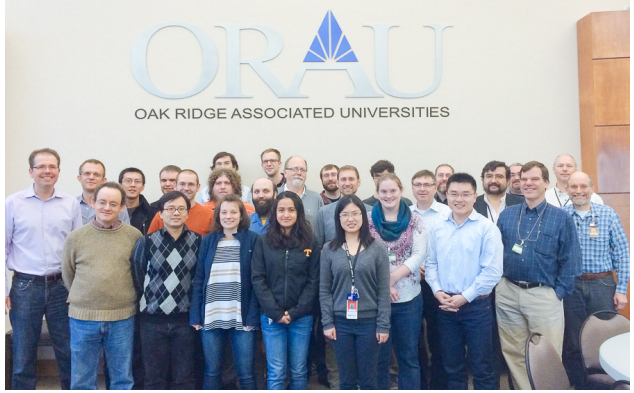


Figure 3. Constraints on ν_e and $\bar{\nu}_e$ disappearance in a $3+1$ model at two different fixed values of Δm^2_{41}. Regions are shown at 95% CL (2 dof) with respect to the minimum χ^2 at the fixed Δm^2_{41}. We show constraints from the radio chemical Gallium experiments using radioactive sources (orange band), from short-baseline reactor experiments (blue band), from the KARMEN and LSND measurements of the ν_e–^{12}C cross section (dark red dotted line), from long-baseline reactor experiments (blue dashed line), from the combined solar+KamLAND data (black dashed line), and from the the combination of all aforementioned experiments (red shaded region).

The PROSPECT Collaboration





Brookhaven National Laboratory
Drexel University
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
University of Waterloo
University of Wisconsin
College of William and Mary
Yale University

9 Universities
5 National Labs

Updated Whitepaper:
arXiv:1309.7647

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