Sensitivity and Discovery Potential of the PROSPECT Experiment
Karin Gilje
PROSPECT Collaboration
DPF 2015

*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.

Reference Model: Huber (3 isotopes) + Mueller (\(^{238}\text{U}\))

Data / Prediction

- Previous average
  \[ R = 0.943 \pm 0.008 \text{ (exp.)} \]

C. Zhang (Daya Bay)
Neutrino 2014

\[ \chi^2 = 40.8/22 \]
\[ p\text{-value} = 0.009 \]

1.25 MeV - 7 MeV

Statistical uncertainties only

Karin Gilje
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.

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!

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

**Graph:**
- **(c)**: Ratios $\sigma_{\nu_e} / \sigma_{\beta_{\text{conv}}}$ per fission.
- **(d)**: Ratios $S(E_{\nu_e}) / S(E_{\beta_{\text{conv}}})$.

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**Graph Notes:**
- Nuclear Calculation vs. Other Approaches.
- Data from experiments such as Daya Bay, RENO, Double CHOOZ.
- Comparison with theoretical predictions.
Possible Solution #2

- The existence of sterile neutrinos ($\nu_s$)
  - LSND, MiniBooNE and Gallium anomalies would agree.
  - Tension with $\nu_\mu$ disappearance measurements.

![Graphs showing neutrino oscillation parameters](image-url)
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.
- **Goal 1:** A precise measurement of the U-235 spectrum.

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

Goal 2: Perform a sterile neutrino search with interest in $\Delta m^2$ around 1.0 eV$^2$.

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

$\Delta m^2 = 1.78$ sin$^22\theta = 0.5$
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.
**PROSPECT- Precision Reactor Oscillation Spectrum Experiment**

**Physics Objectives**

1. Precision measurement of $^{235}\text{U}$ reactor $\nu_e$ spectrum
2. Search for short-baseline oscillation at distances <10m near detector ~ 7m reactor core
   far detector ~ 18m

**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

Sensitivity: 1 Detector, 1 year of data taking, 3 σ CL
- 12 months front
- 6 months front, 6 month back
- 12 month back
- Reactor Anomaly, 95% CL
- θee, Disappearance Exps, 95% CL
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

![Graph showing mass splitting and sensitivity](image-url)
Comparing Global Fits

Kopp 2013
- arXiv: 1303.3011v3
- Uses Daya Bay 2012 $\sin^2\theta_{13}$
- 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 $\sin^2\theta_{13}=0$
- Includes SBL measurements through 2011.
- Includes Gallium measurements from SAGE and GALLEX.
PROSPECT and Current Fits

Kopp 2013

RAA 2012

Sensitivity: 3σ CL

8/5/15
Karin Gilje
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 ($\nu_\mu$ to $\nu_e$ appearance and $\nu_\mu$ 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
*Deployment complete!!!

Current Prototype Status

PROSPECT Prototype Demonstrations

Run DAQ, remote data-taking
See n-Li + PSD
Demonstrate shielded background rates
Demonstrate full timing and PE response
Deploy final design concepts
Observe relative segment responses
See antineutrinos
Meet physics goals

PROSPECT 0.1*
Dec 2014 - Mar 2015

PROSPECT 2*
Mar 2015

PROSPECT 20*
Aug 2014

PROSPECT 200*

Approximate mass kg

PROSPECT Phase II (10k)?

3x3x1 meter mockup at IIT

1 meter

2 inches

5 inches

1 meter

3x3x1 meter mockup at IIT

Current Prototype Status

See D. Norcini's Talk!
BACKUPS
Comparison to Other Experiments

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B. Littlejohn Fermilab Intesity Frontier Seminar 2015
Current Prototype Status

- **PROSPECT 0.1***
  - Aug 2014
  - Run DAQ, Remote data-taking
  - See n-Li + PSD

- **PROSPECT 2***
  - Dec 2014 - Mar 2015
  - Demonstrate shielded background rates
  - Demonstrate full timing and PE response

- **PROSPECT 20***
  - Mar 2015
  - Deploy final design concepts
  - Observe relative segment responses

- **PROSPECT 200**
  - 2015^*
  - See antineutrinos
  - Meet physics goals

- **PROSPECT 2k**
  - Phase I
  - 2016^*
  - Approximate mass kg

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

*Deployment complete!!!
^Technically driven schedule
PROSPECT Design

- Phased approach
- Optically Separated Segmented Volume
- Double-ended PMT readout
- Li6-Loaded Liquid Scintillator
- Moveable near detector
We calculate the $\chi^2$ for each pair of $\Delta m^2$ and $\sin^22\theta$ that we are interested in.
Goal 1: A precise measurement of the HFIR (High Flux Isotope Reactor) spectrum.

Goal 2: Perform a sterile neutrino search with interest in $\Delta m^2$ around 1.0 eV$^2$.
Absolute Spectrum

- HEU Fuel
- Energy Resolution 4-5%/\sqrt{E}
- Constraints on Nuclear Models
- Inputs for future reactor experiments.
\[ \sin^2 2\theta_{13} \] and allowed regions (Kopp 2013)

Figure 3. Constraints on \( \nu_e \) and \( \bar{\nu}_e \) disappearance in a 3 + 1 model at two different fixed values of \( \Delta m_{41}^2 \). Regions are shown at 95\% CL (2 dof) with respect to the minimum \( \chi^2 \) at the fixed \( \Delta m_{41}^2 \). 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 \( \nu_e^{-12}\text{C} \) 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 combination of all aforementioned experiments (red shaded region).
The PROSPECT Collaboration

Reactor Sites

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/