College of Science and Technology
TEMPLE UNIVERSITY

PROSPECT

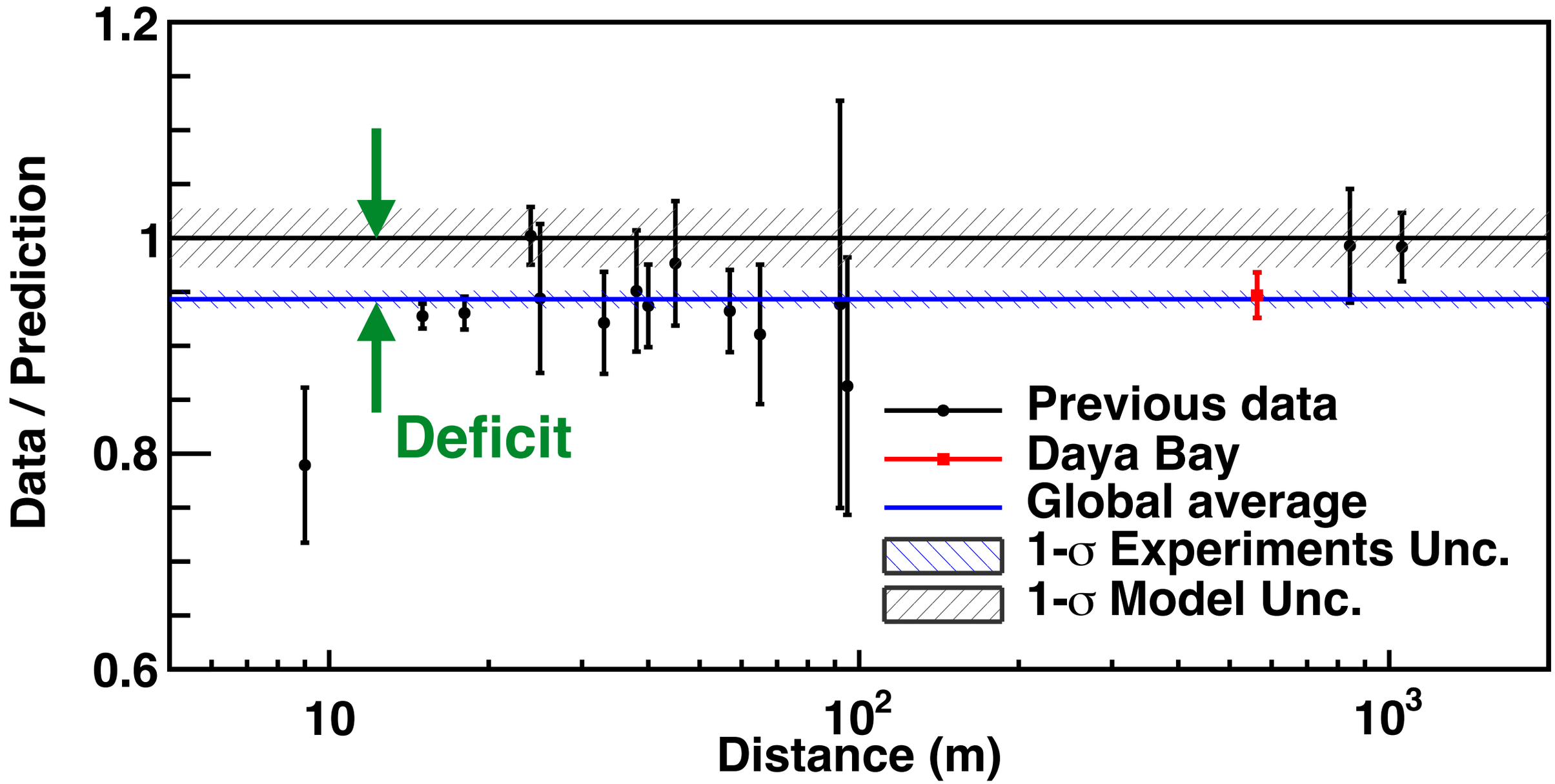
Reactor Neutrinos

Sterile Neutrino Searches with Precision Measurements at Very Short Baselines

Jim Napolitano
Temple University
for the PROSPECT collaboration

Amherst Center for Fundamental Interactions
14-16 December 2015

Reminder: The Reactor Neutrino Anomaly



Is the deficit due to antineutrino disappearance?

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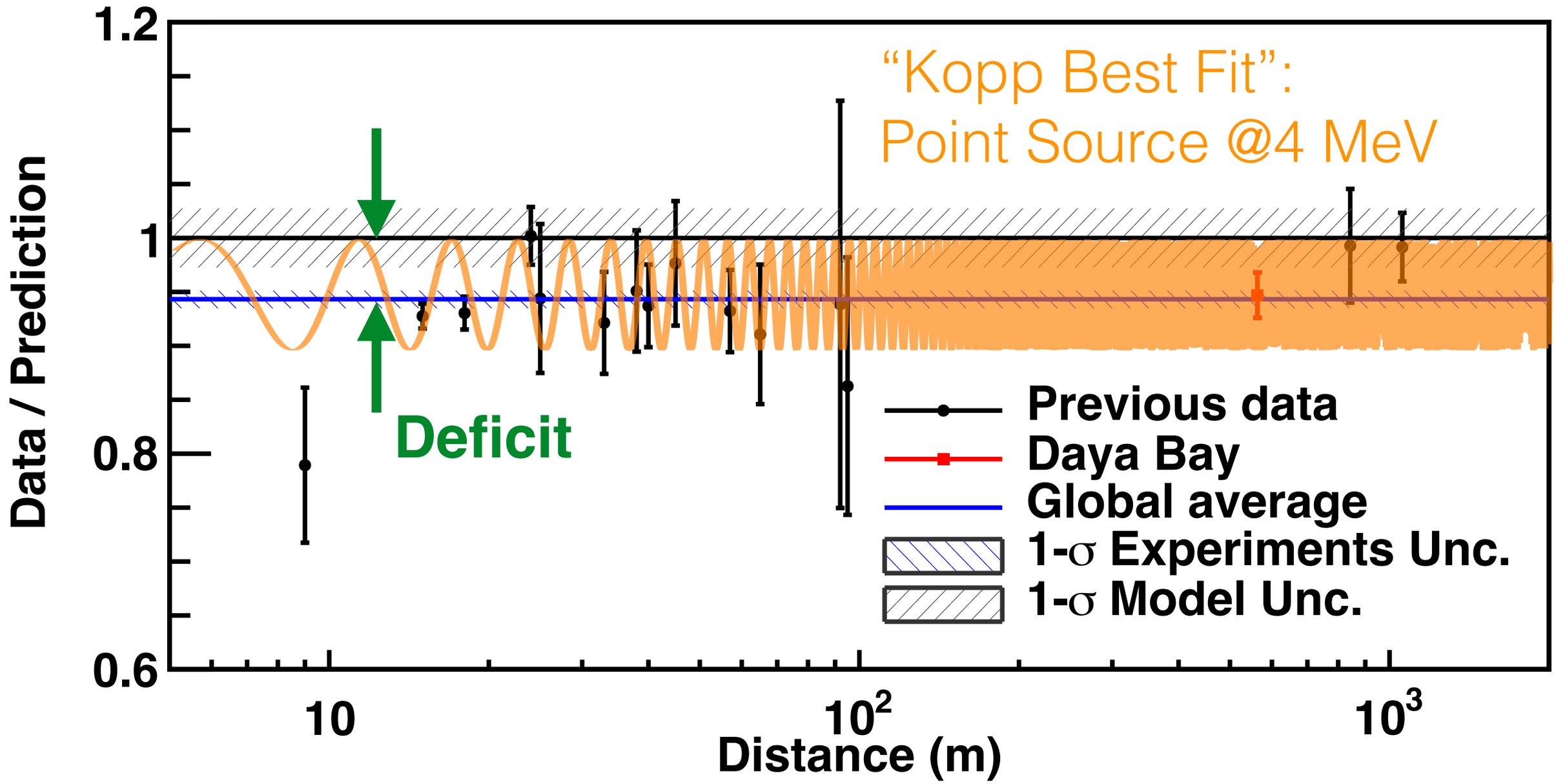
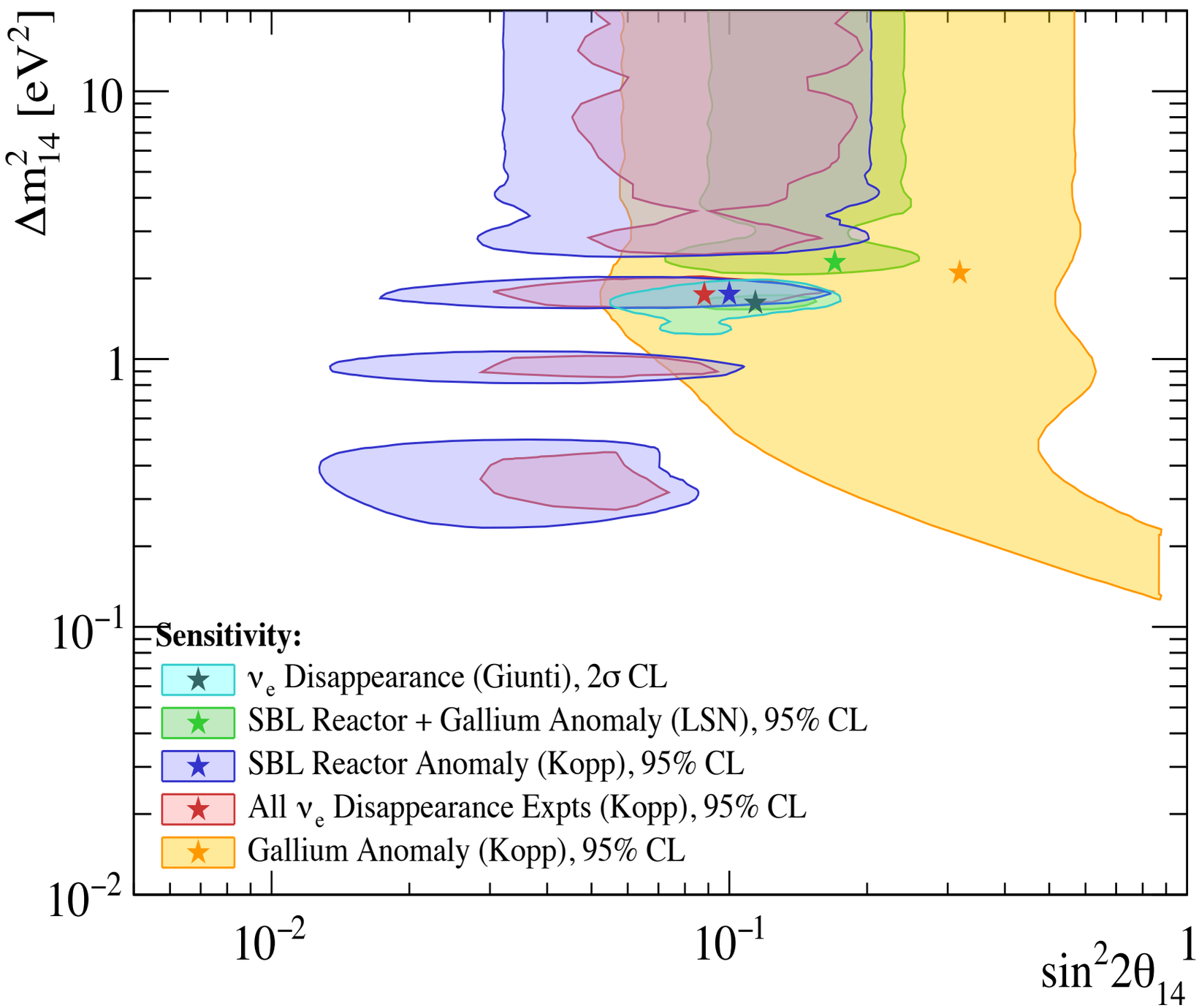


Is the deficit due to antineutrino disappearance?

Reminder: The Status of Sterile Neutrinos

$\Delta m^2 \approx$ few ev^2 and sin^{2}2θ "not so small"



References

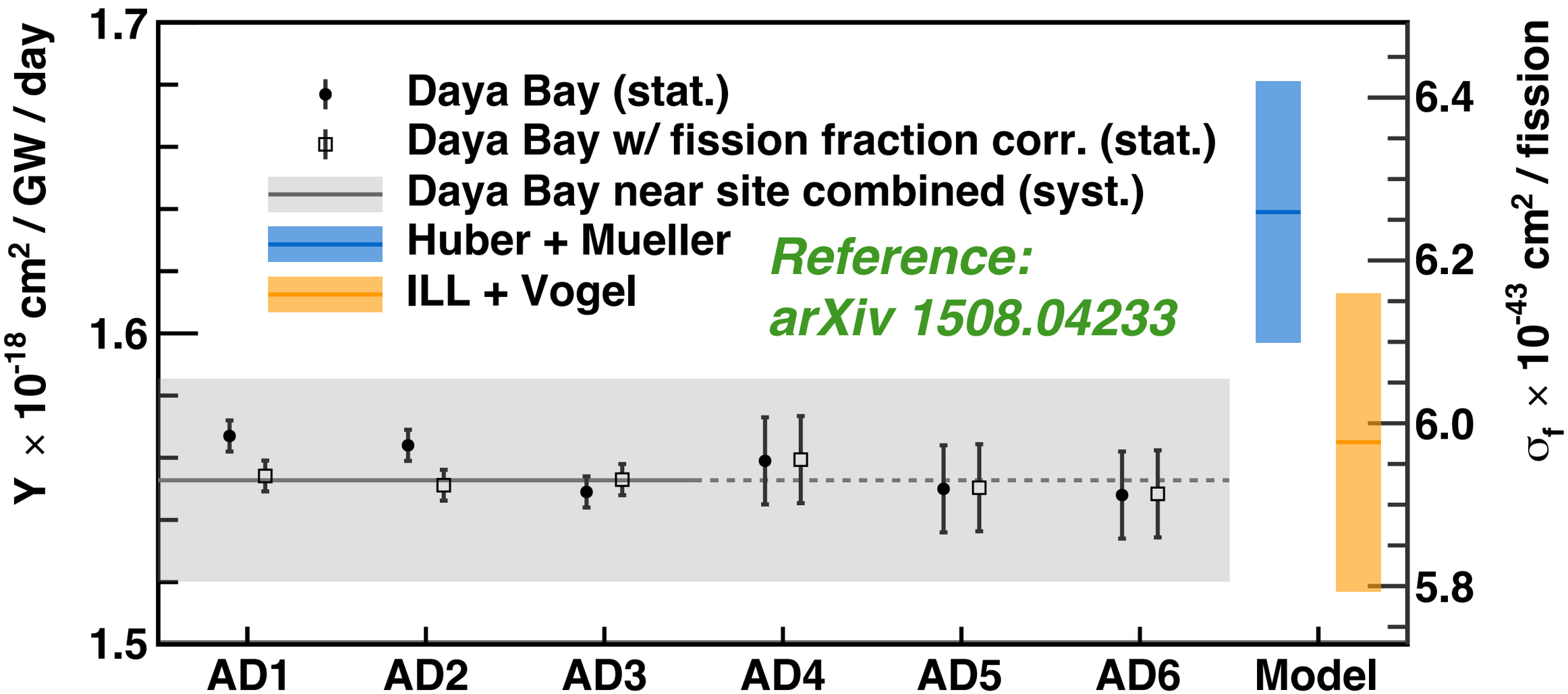
Gallium
PRC 83(2011)065504

BOONE, MiniBOONE
AnnRev 63(2013)45

Global fits
JHEP 1305(2013)050
PRD 88(2013)073008

Reactor Anomaly and Reactor Calculations

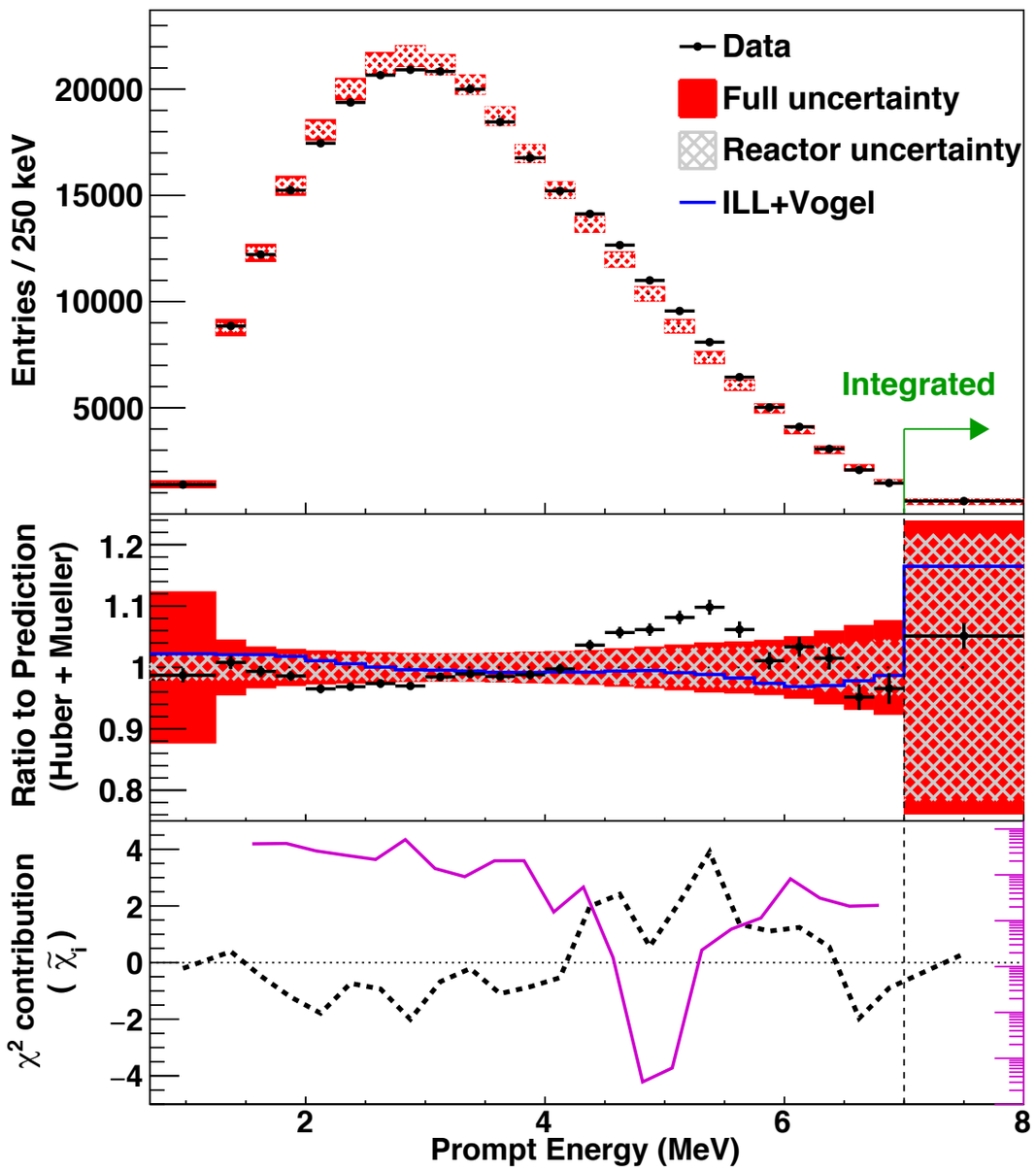
Power Reactors: Mixture of ^{235}U, ^{239}Pu, ^{241}Pu, ^{238}U



ILL+Vogel (1980's): e^- spectra, plus calculation for 238U
Huber + Mueller (2011): Inversion with β-decay corrections

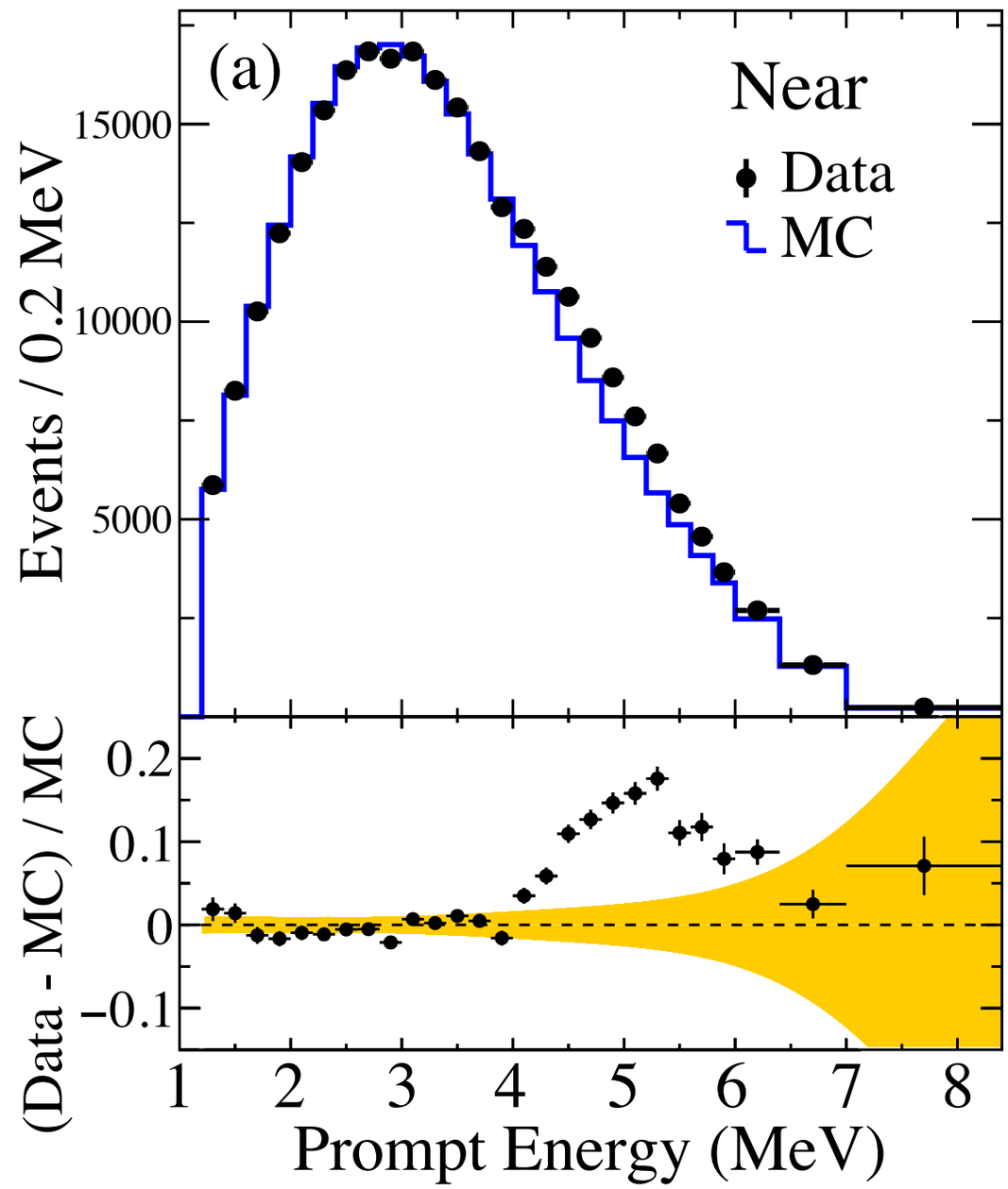
More Reactor Surprises: The “Bump”

Daya Bay



arXiv 1508.04233

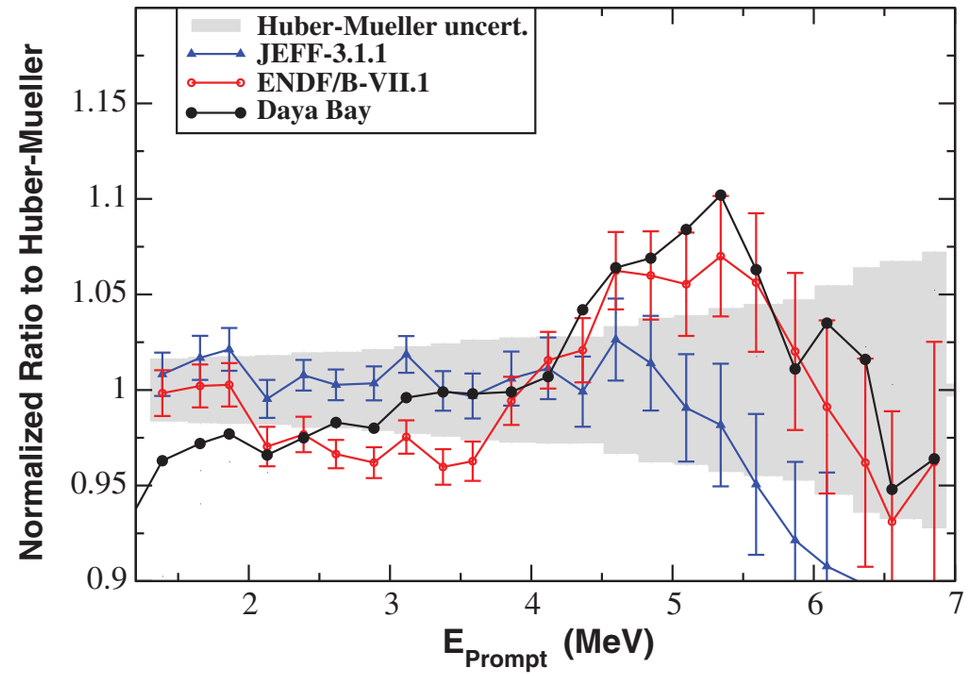
RENO

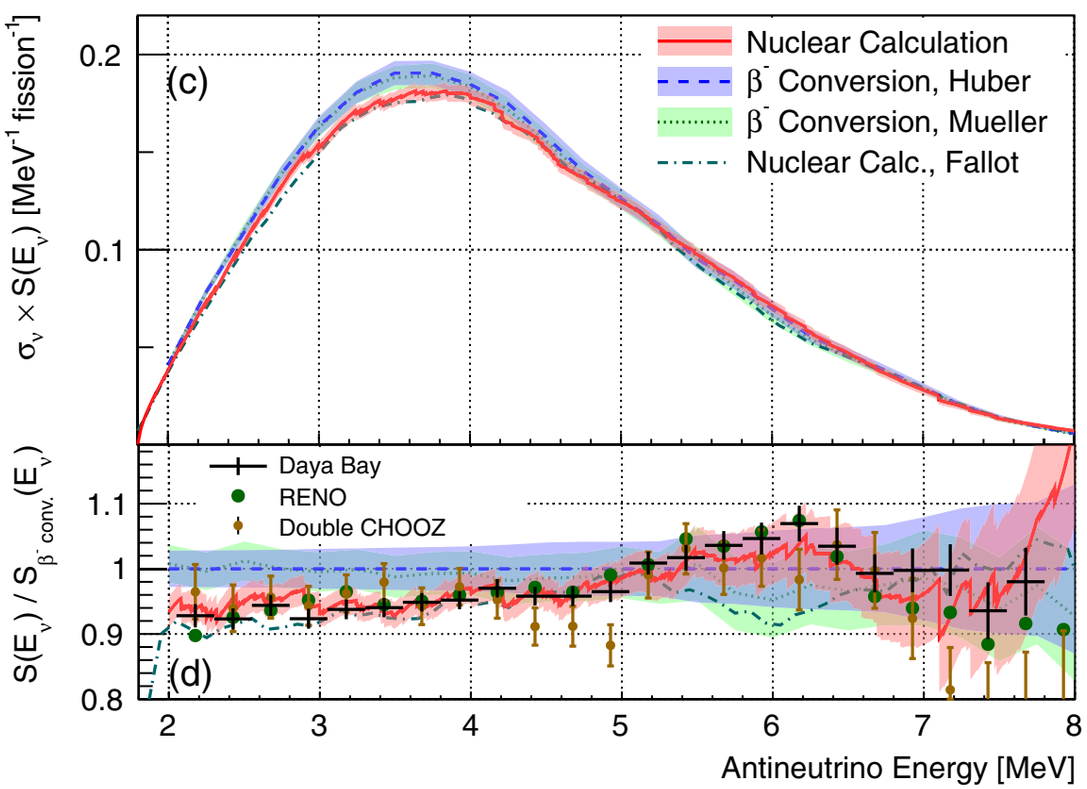


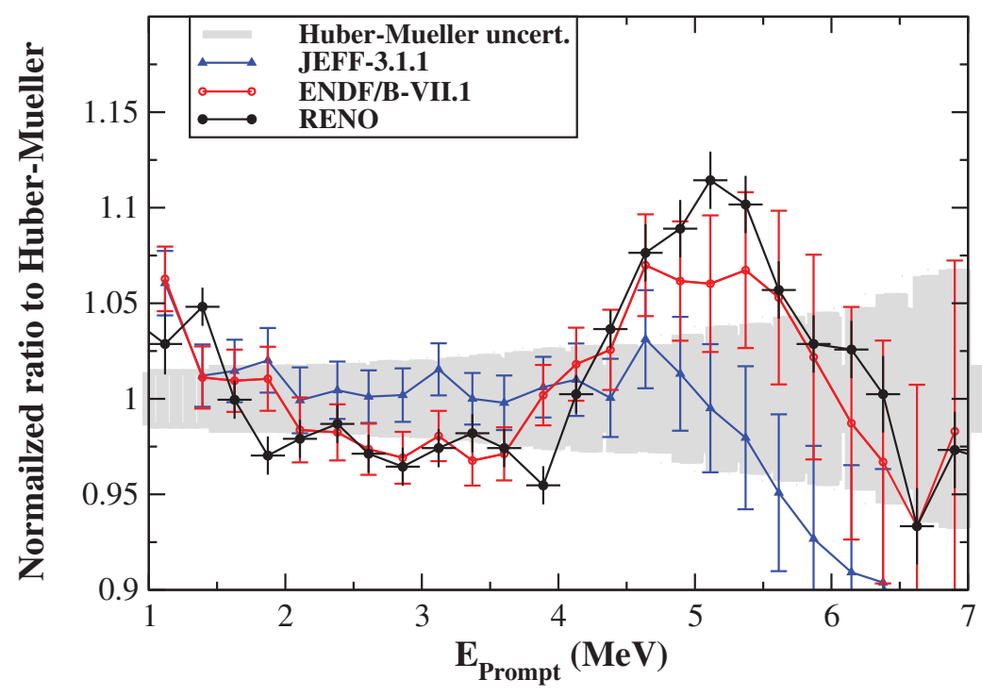
arXiv 1511.05849

➥ New "Direct" Reactor Calculations

Different approaches (and nuclear data bases) give different results, and may point to ^{238}U as the source of "The Bump."







PRL 114(2015)012502

PRD 92(2015)033015

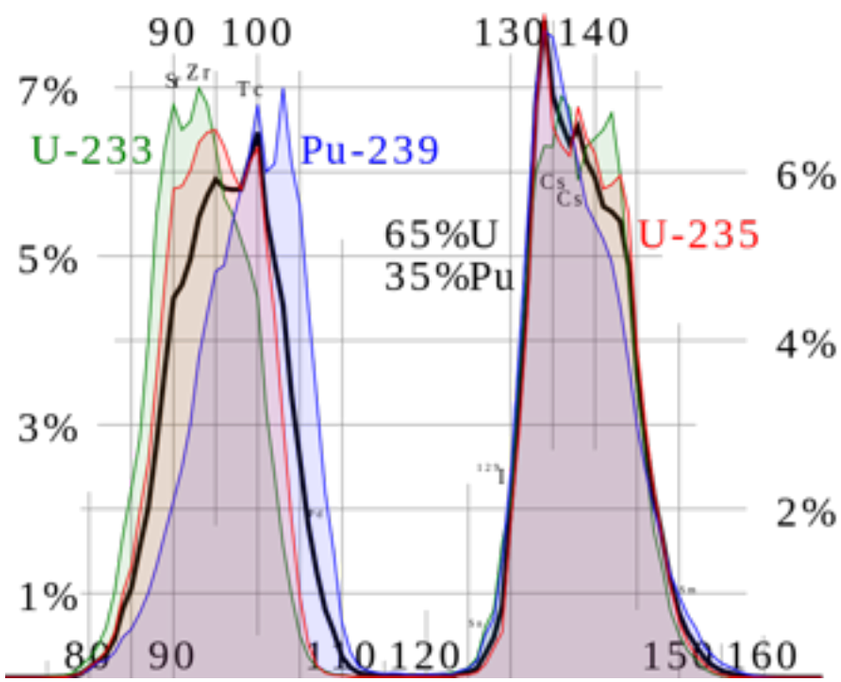
Nuclear Power Plant Reactors

Daya Bay, et.al., use "Near+Far" for oscillations, but…

Nuclear Power Plant Reactors

Daya Bay, et.al., use "Near+Far" for oscillations, but…

- Nuclear fuel evolution uncertainty



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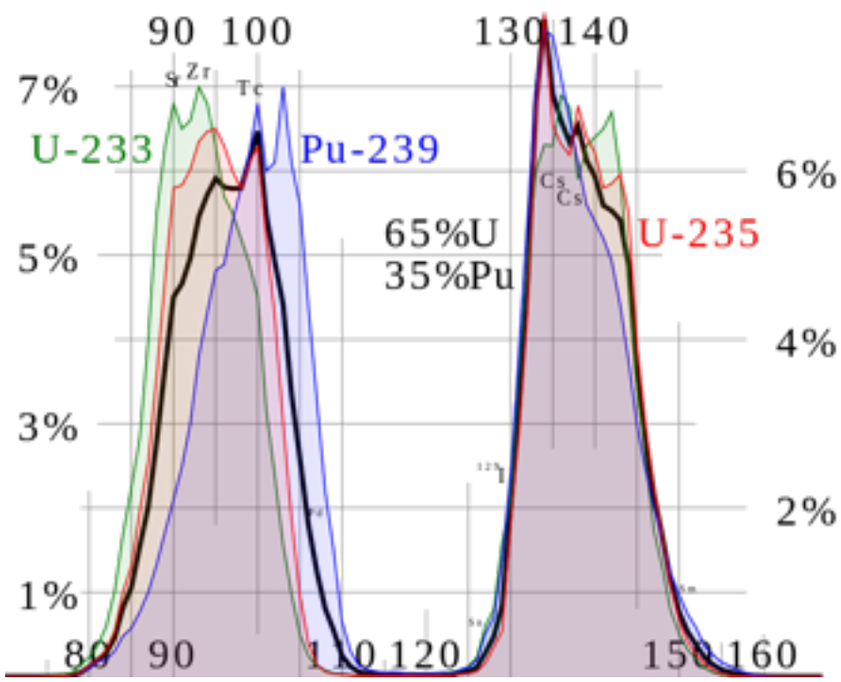

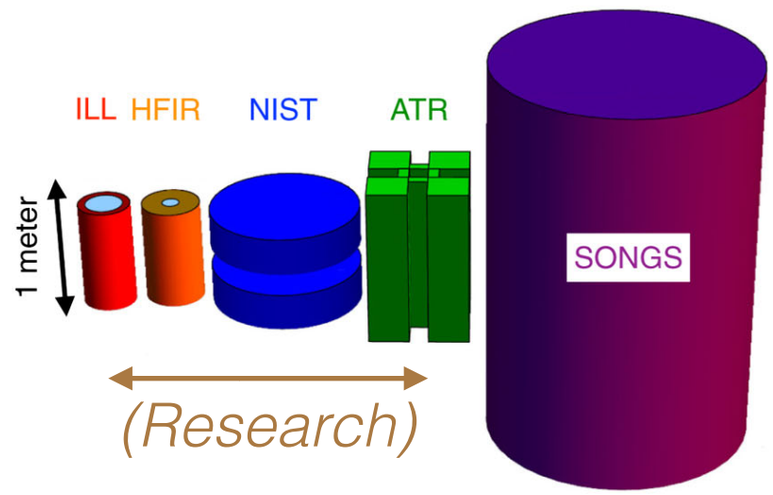

- Relatively large size of reactor core

Nuclear Power Plant Reactors

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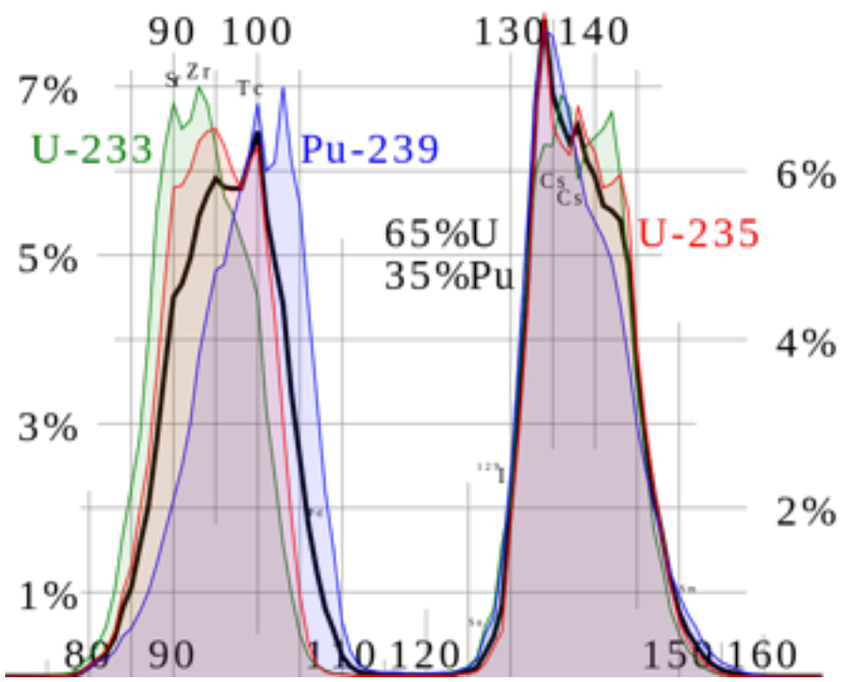

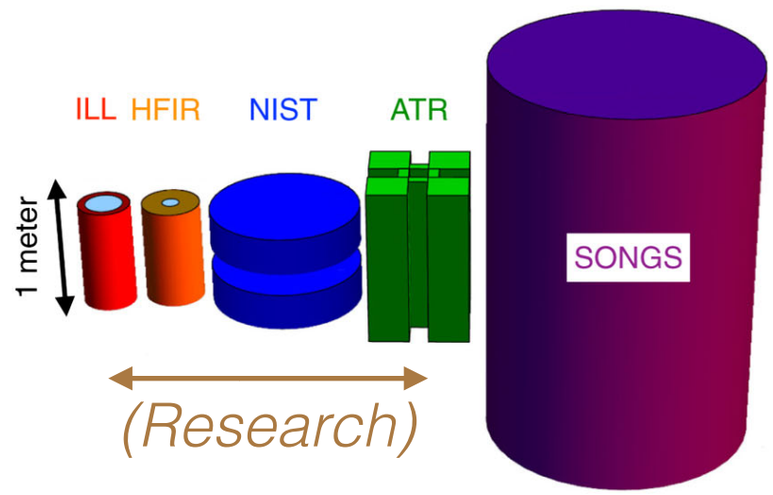

- Relatively large size of reactor core
- Hard to get within meters of the reactor core
- Restricted information and no control over source

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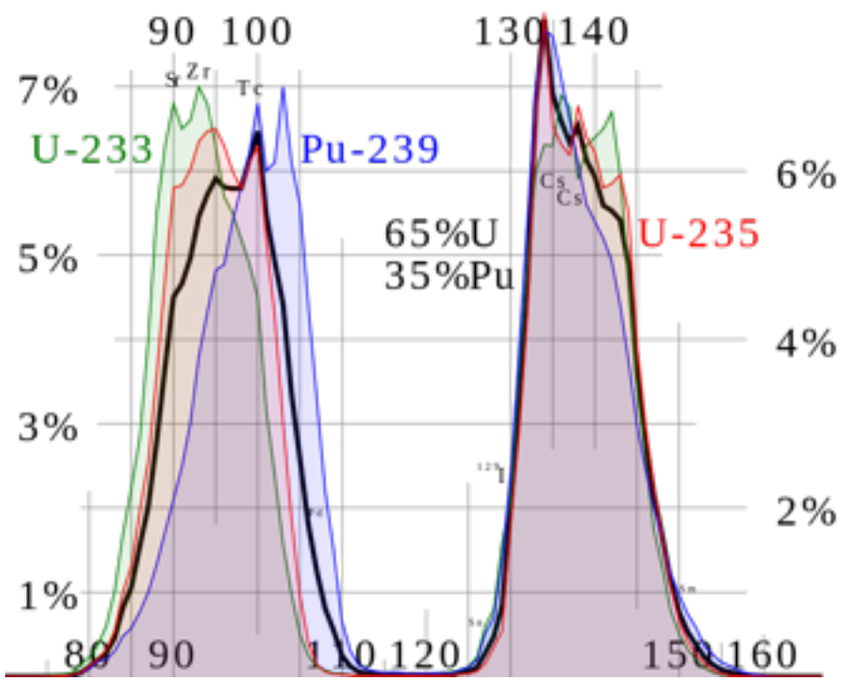

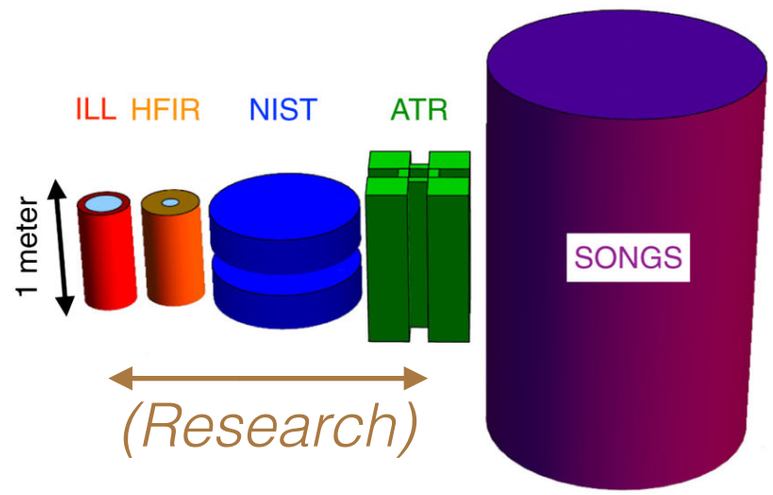

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➥ *Nuclear power plants are not ideal sources for <u>Sterile Neutrino Searches</u>*

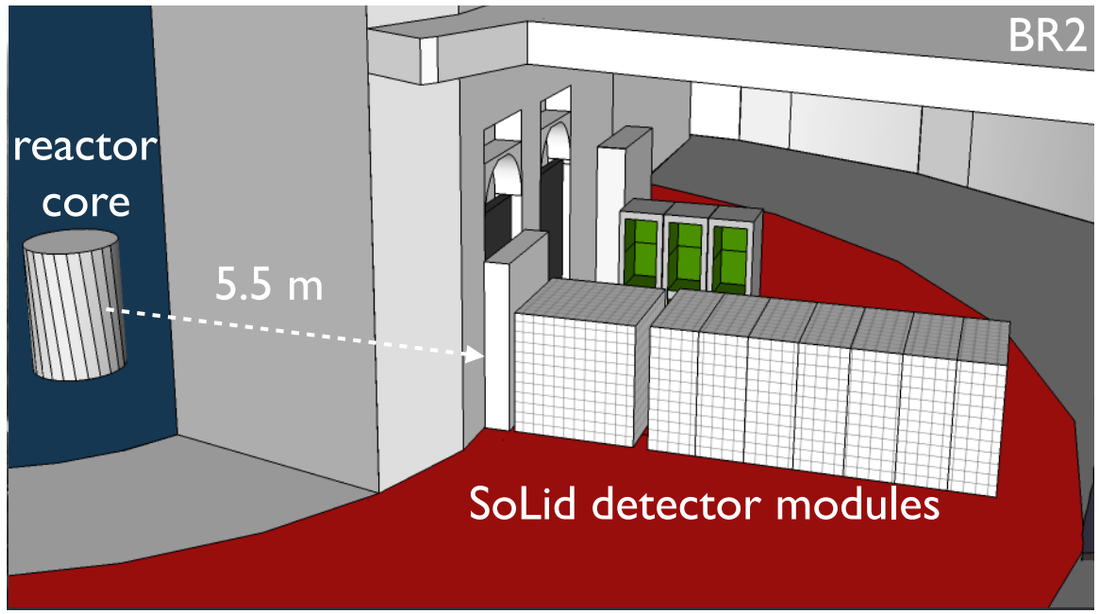
Precision Experiments at Research Reactors

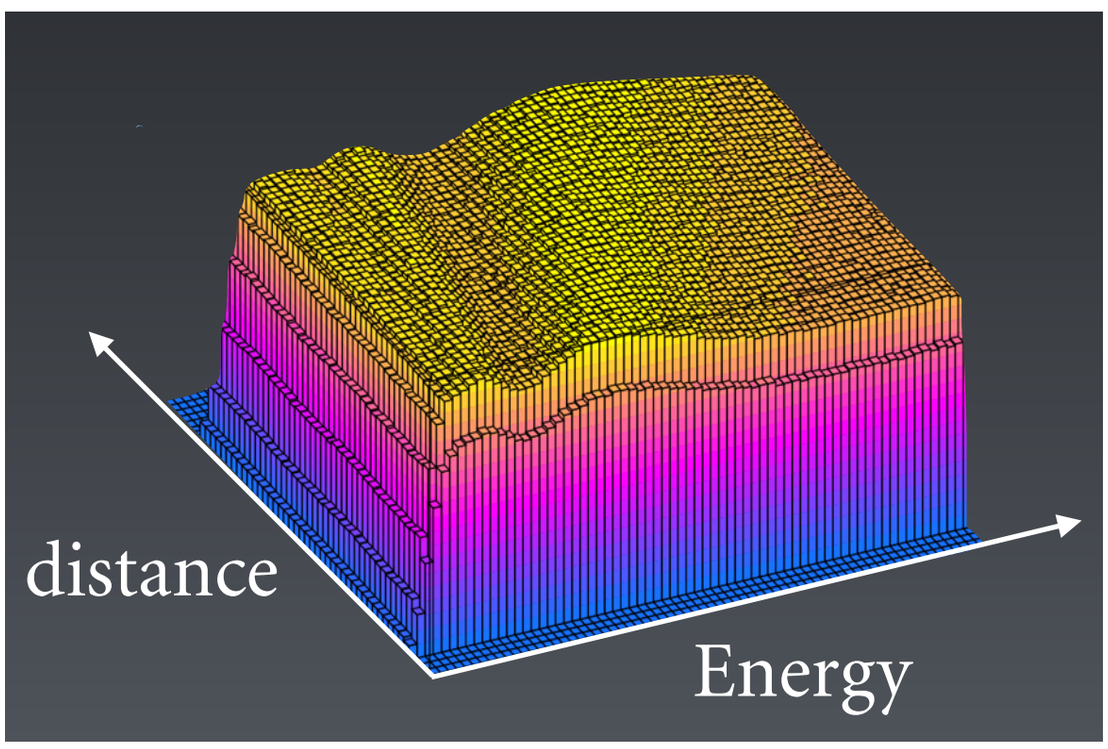
See http://aap2015.phys.vt.edu

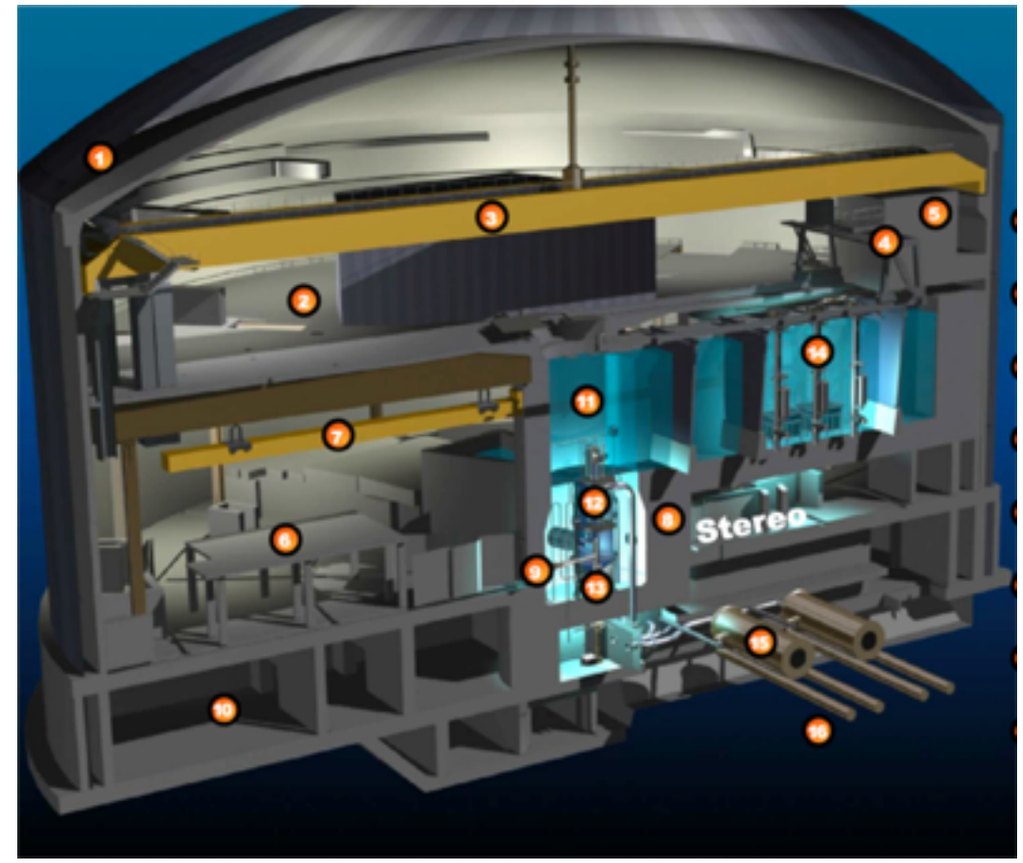
- STEREO @ ILL
  J. Phys. Conference Series 593(2015)012005
- SOLID @ BR2 MTR
  https://www2.physics.ox.ac.uk/research/mars-project/solid
- NEOS @ HANBIT #5 *(Power Reactor!)*
  (See AAP conference presentations)

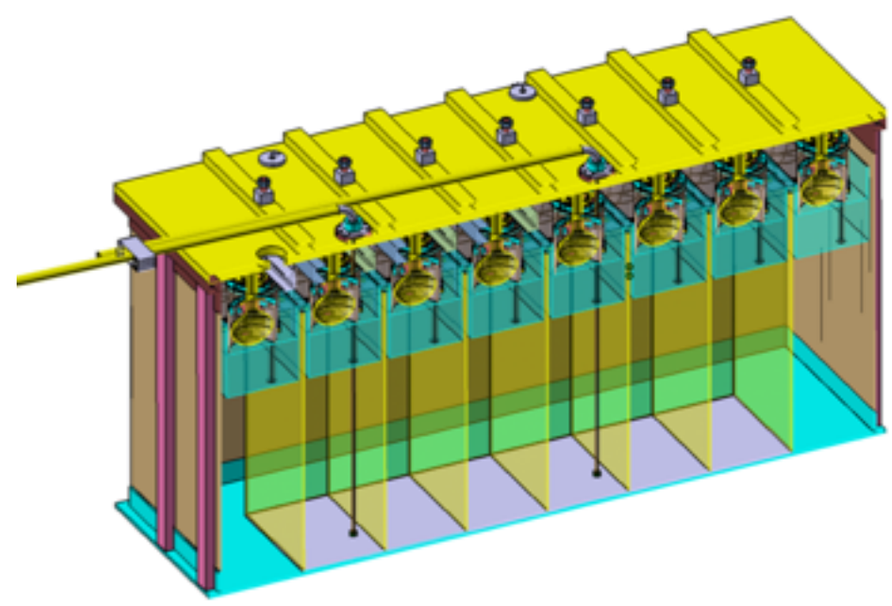
★ PROSPECT @ HFIR
Recent full description at arXiv:1512.02202

SoLiD *and* STEREO









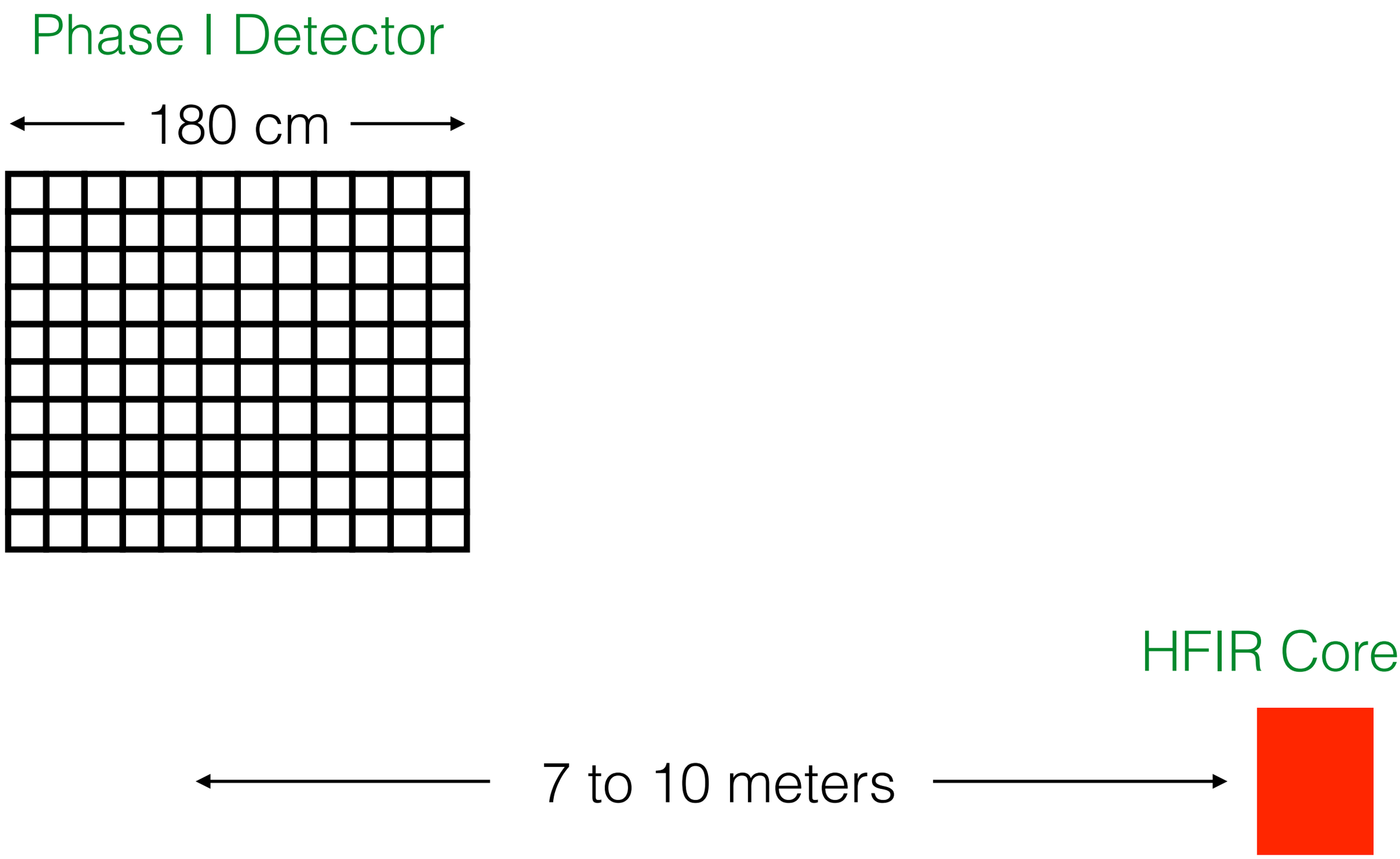
PROSPECT

A PRecision Oscillation and SPECTrum measurement using an array of functionally independent detectors

See arXiv:1512.02202

- Collaboration: BNL, Drexel, IIT, Le Moyne, LLNL, NIST, ORNL, SYSU, Temple, Tennessee, Waterloo, William & Mary, Wisconsin, **Yale**
- High Flux Isotope Reactor (HFIR) at ORNL
- Phase I: Single movable detector ≈7m from core, definitive exclusion of “Kopp Best Fit” region
- Phase II: Second detector at greater distance, for complete exclusion of allowed region

Schematic of the Experiment



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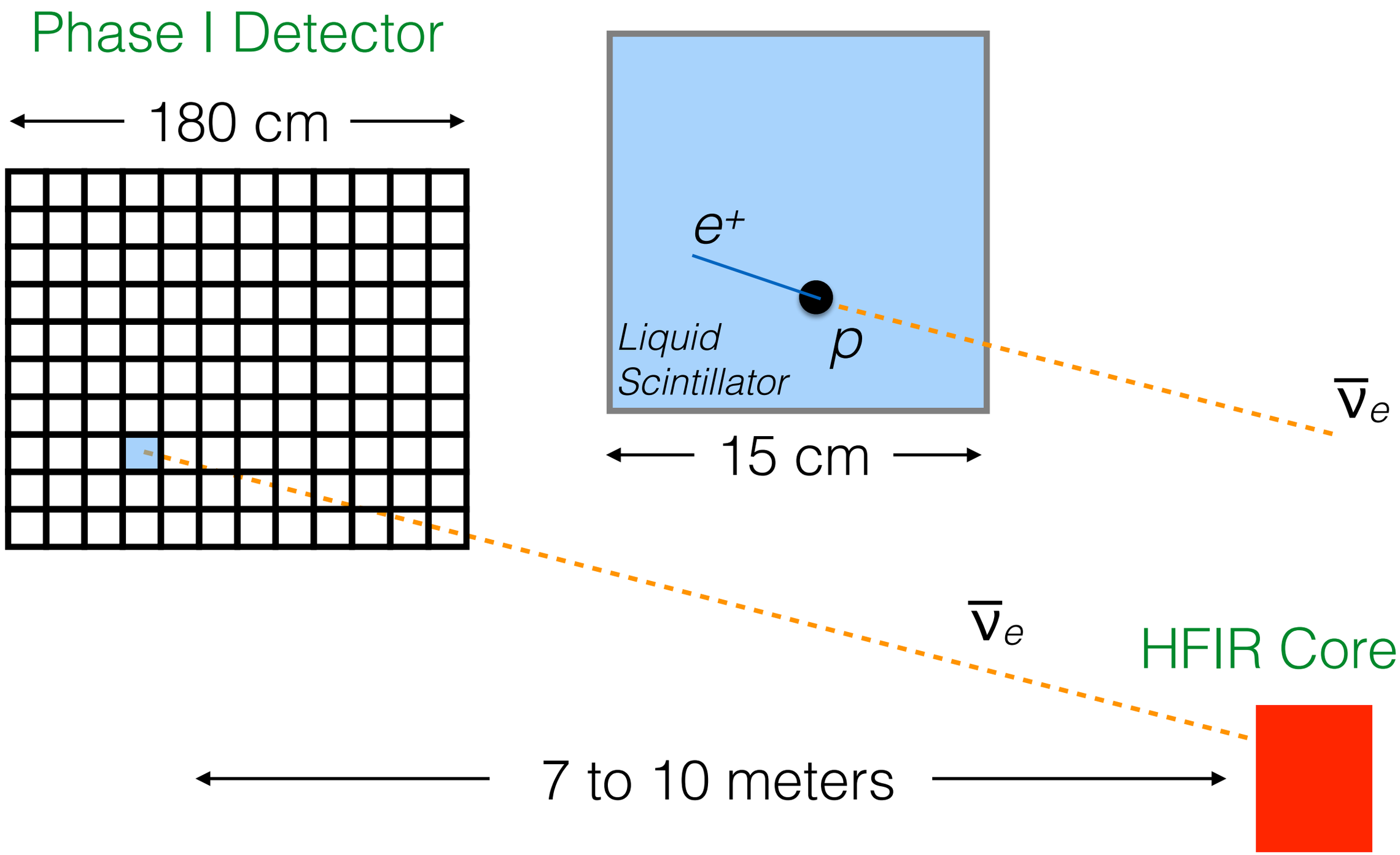

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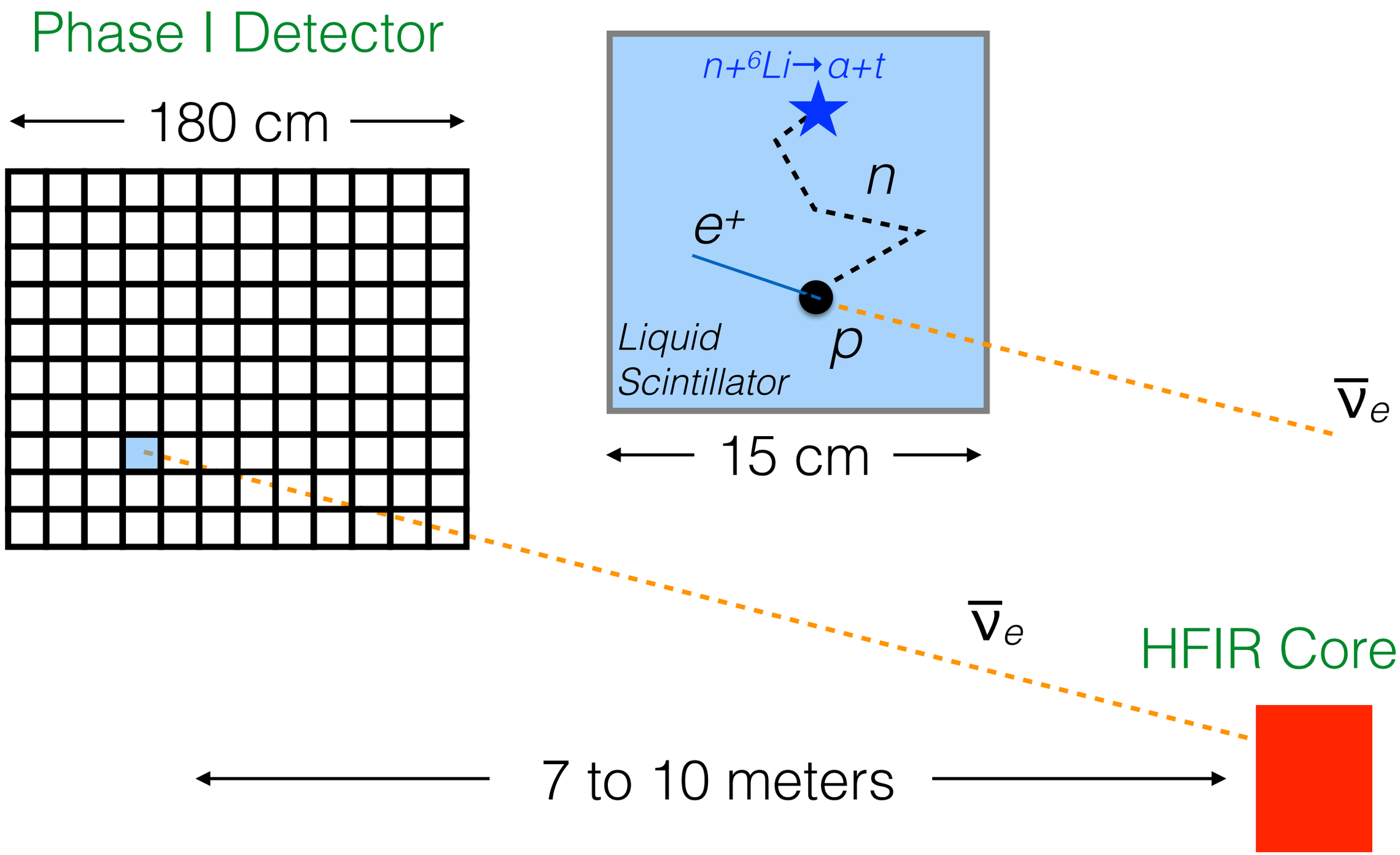
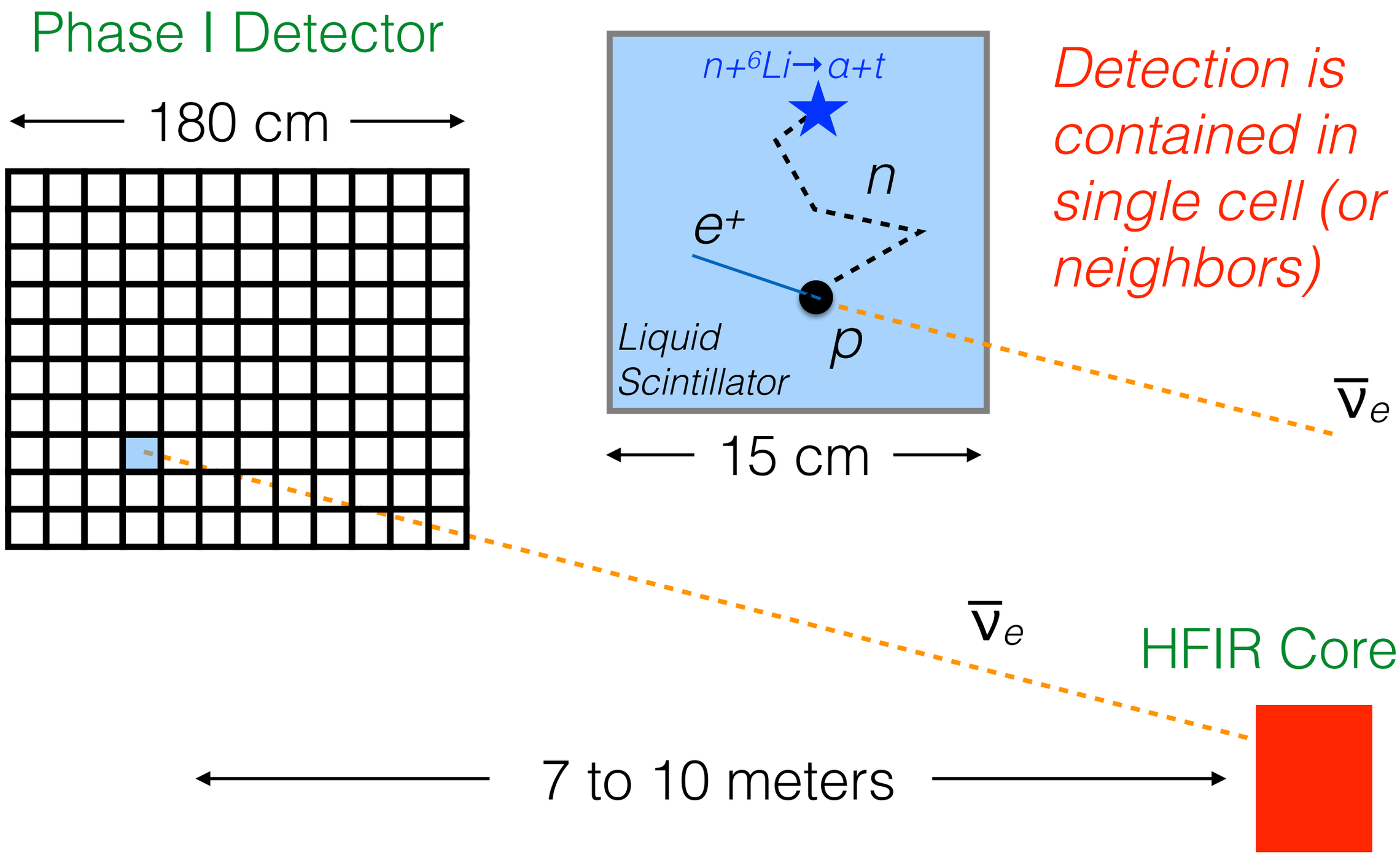
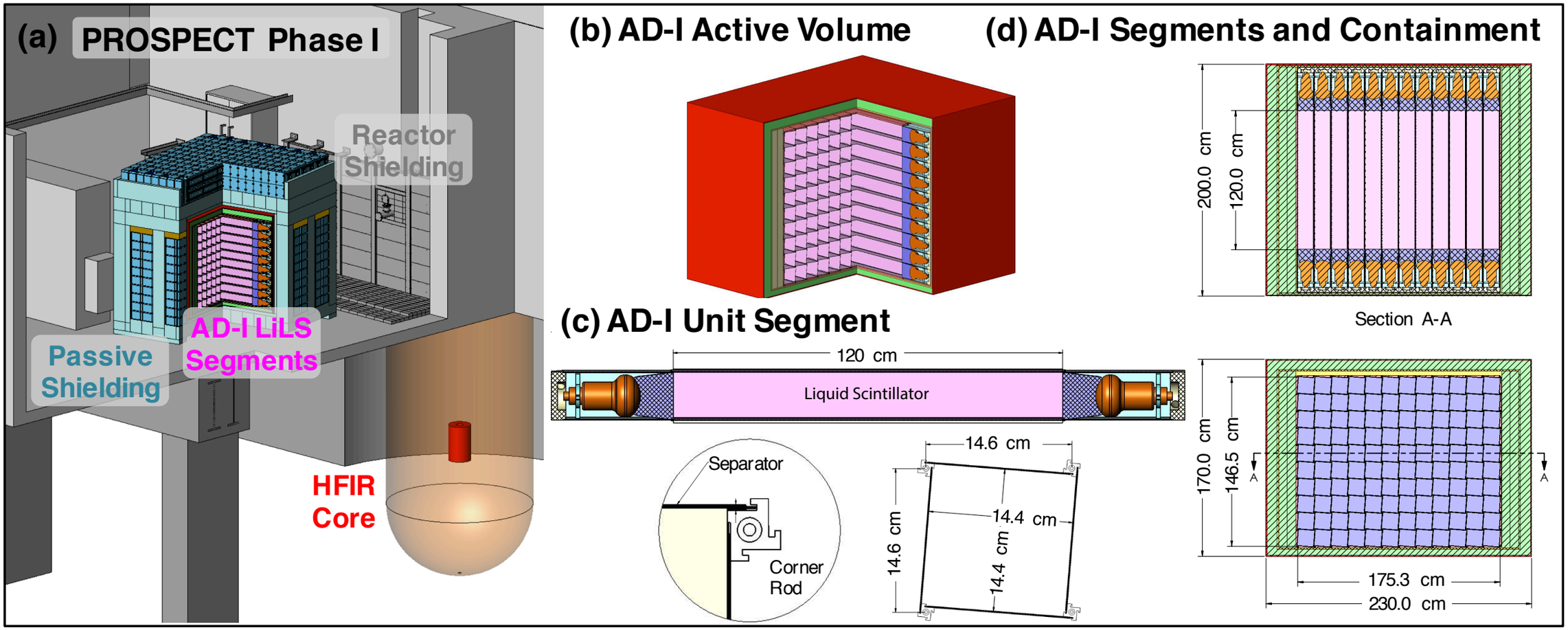


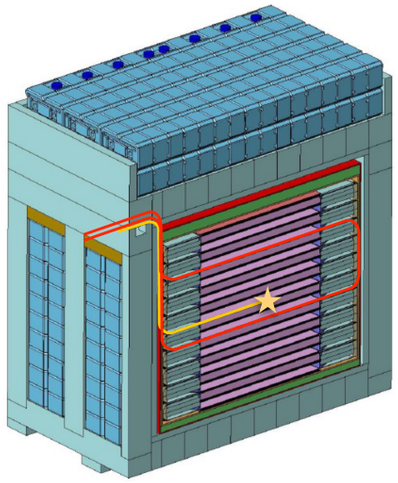
Schematic of the Experiment



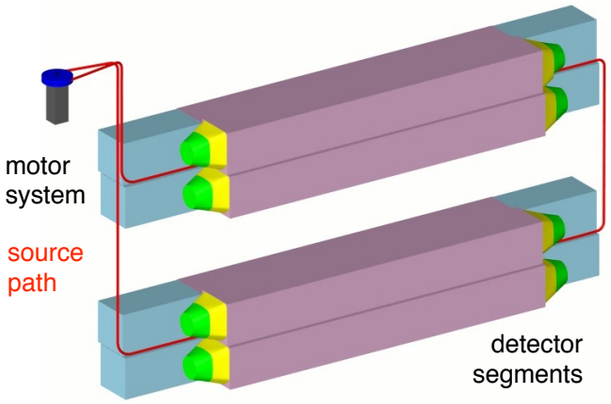
Realization: Phase I



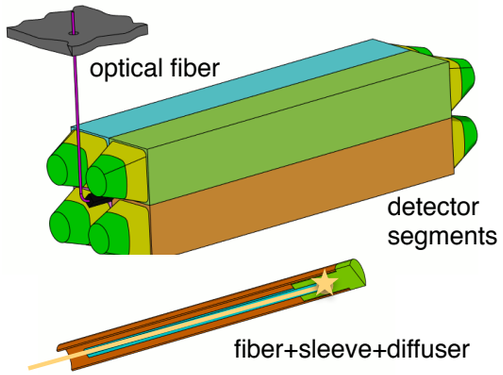
antineutrino detector
with optical and source calibration



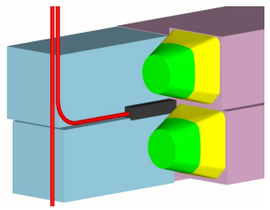
source deployment system
with string and guide tubes



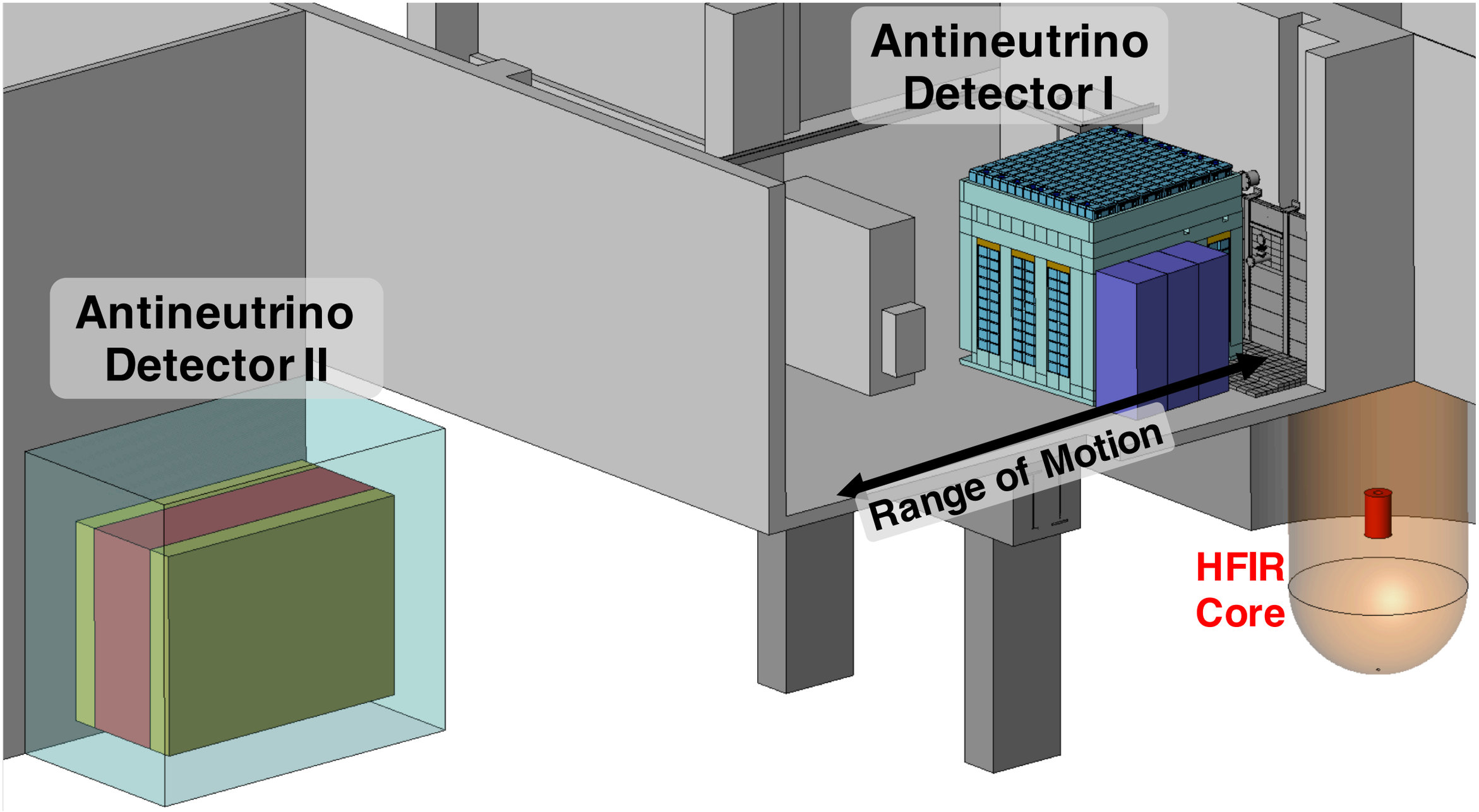
optical calibration system
with string and guide tubes



routing between segments
and PMT modules



Extended Capability: Motion & Phase II



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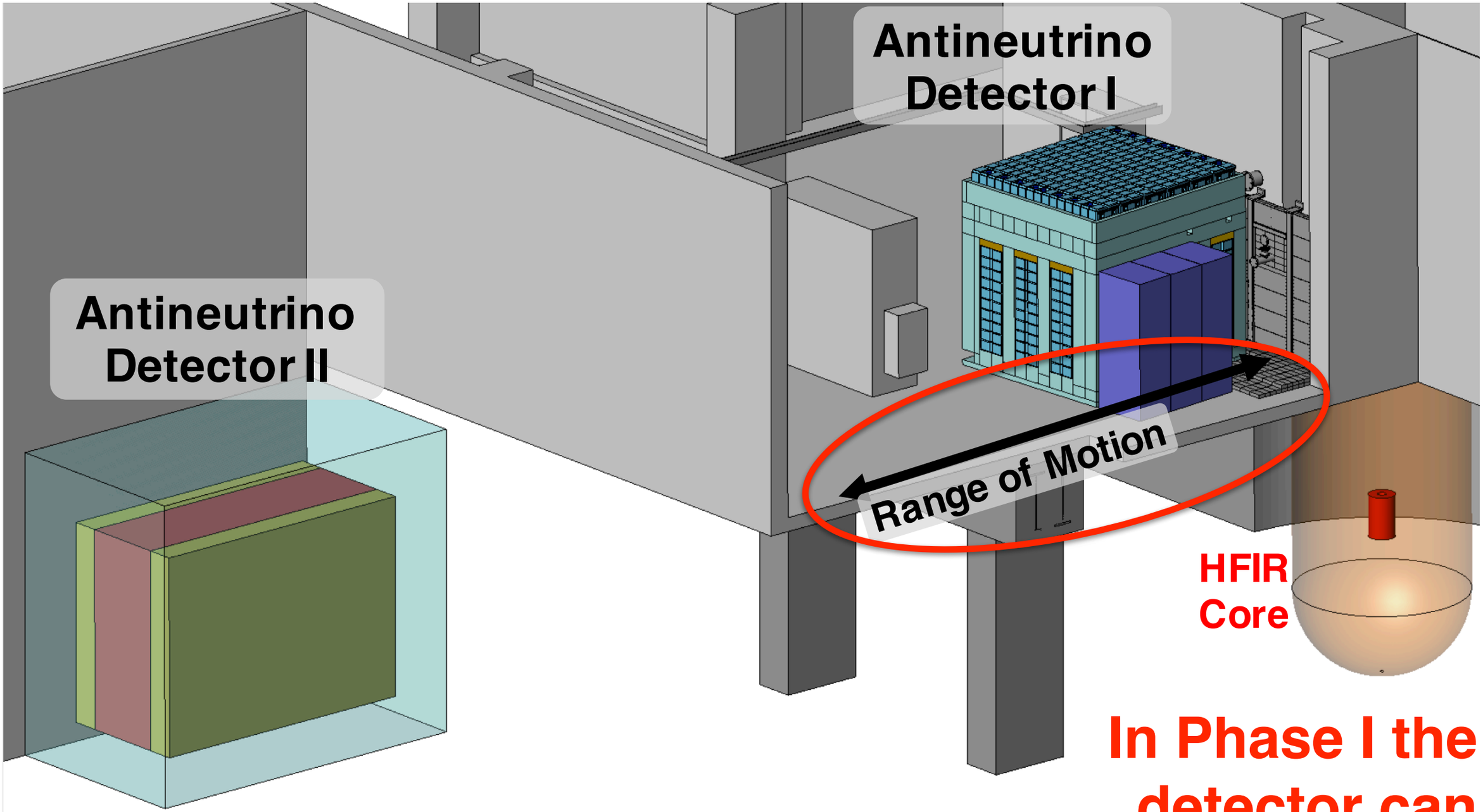

In Phase I the detector can move ≈3m

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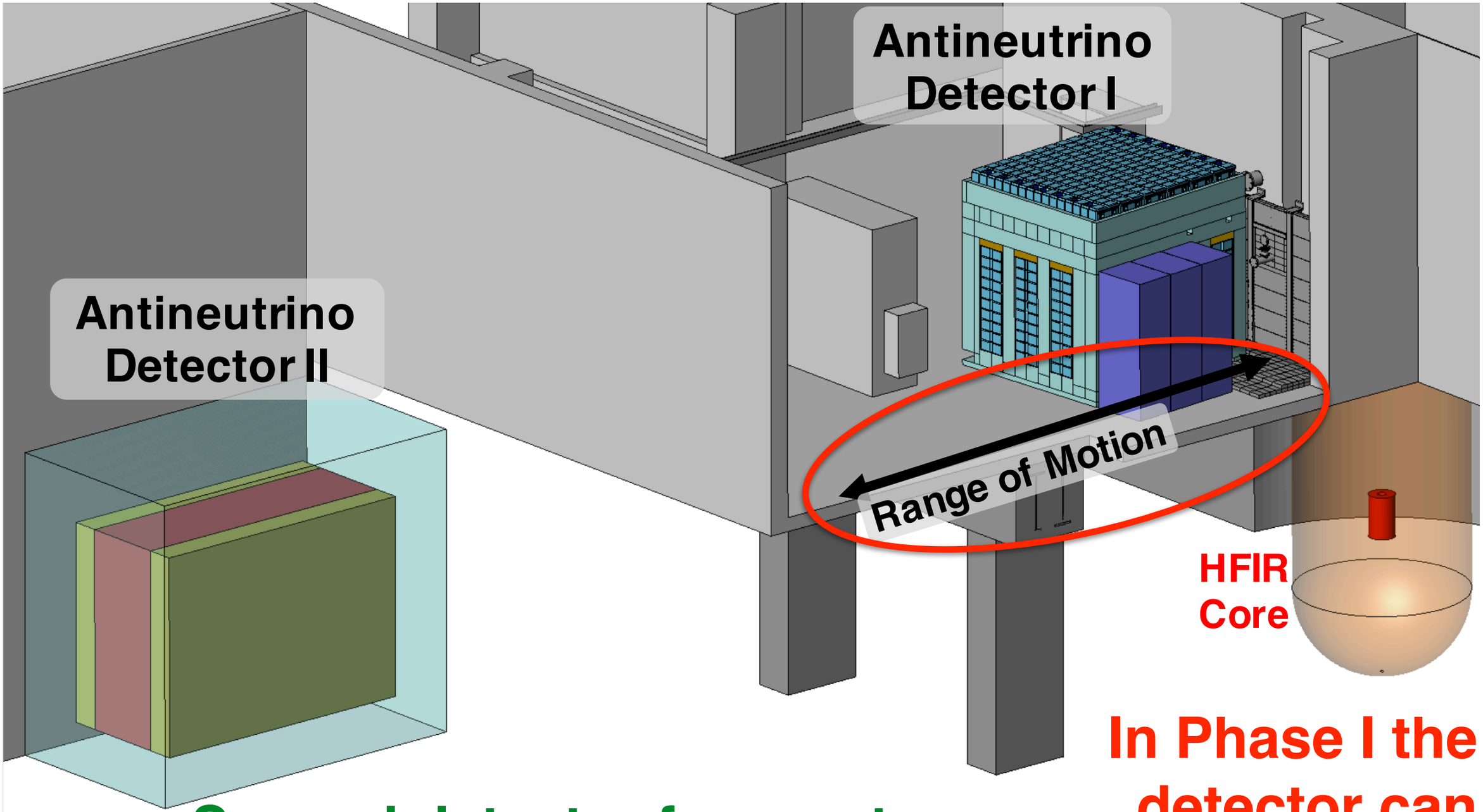


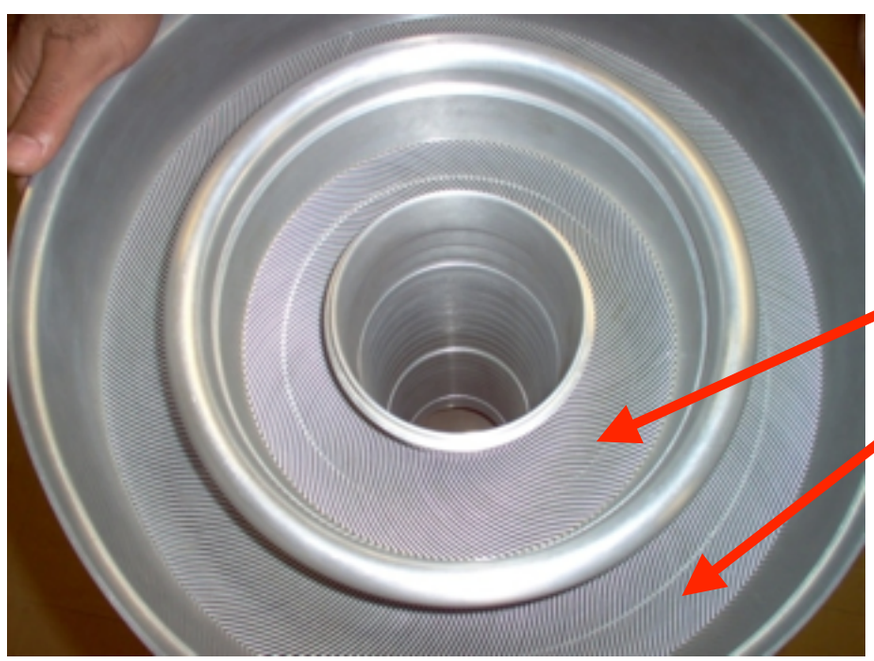
Second detector for greater coverage in Phase II

In Phase I the detector can move ≈3m

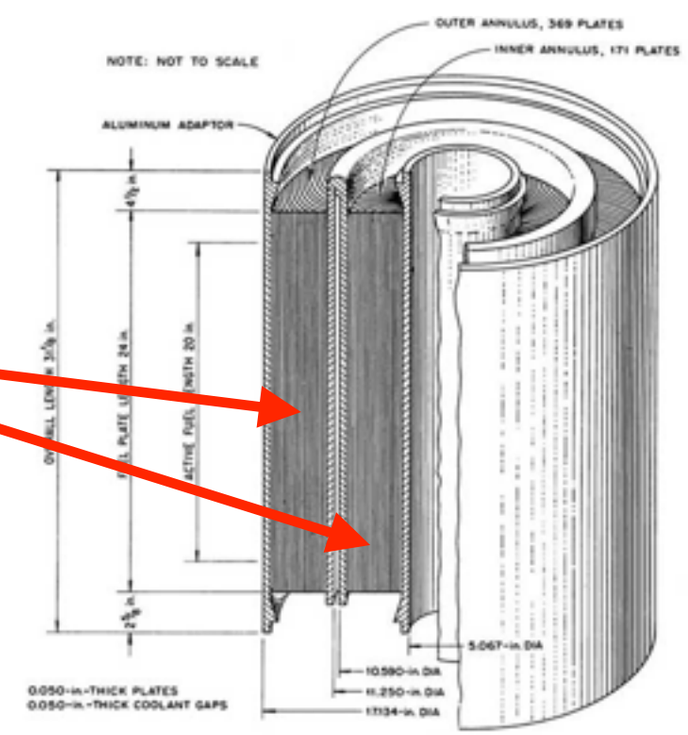
High Flux Isotope Reactor (HFIR)

https://neutrons.ornl.gov/hfir

- 85 MW, highly enriched ^{235}U, light water moderated
- Regular reactor-on periods lasting 25 days, with roughly equal periods of down time in between
- Well understood reactor core, including simulation



Fuel

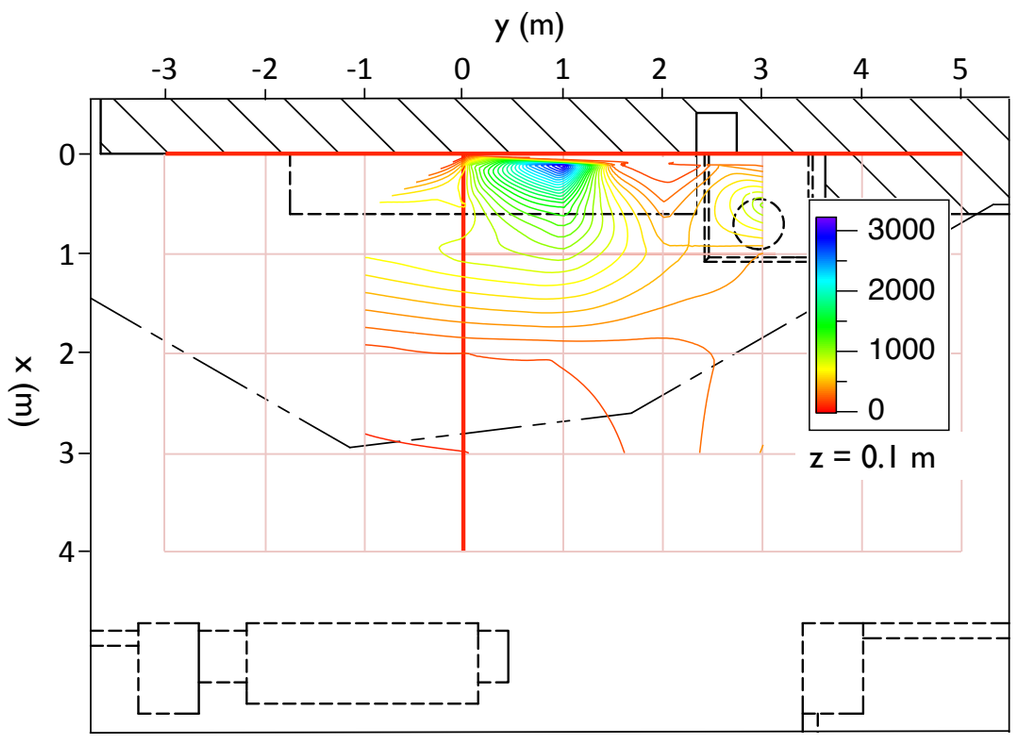


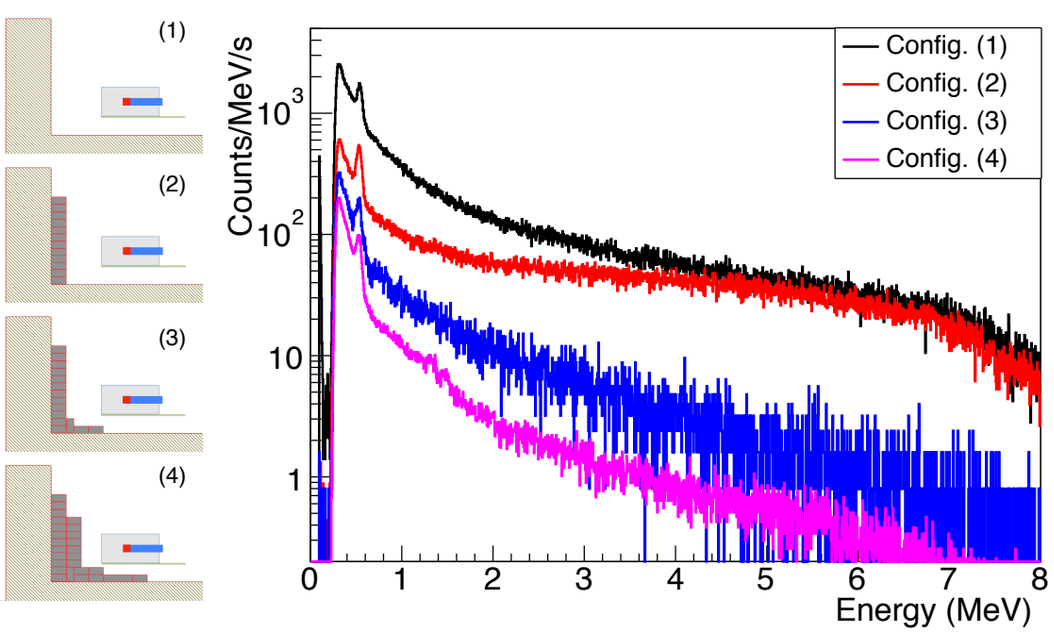
60 cm

37.5 cm

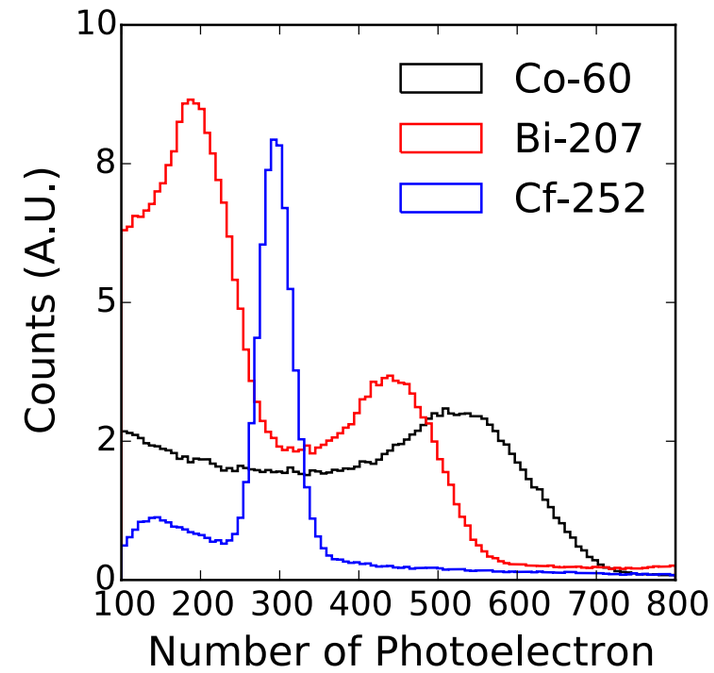
Dealing with Backgrounds

Nucl.Instrum.Meth.
A806 (2016) 401-419

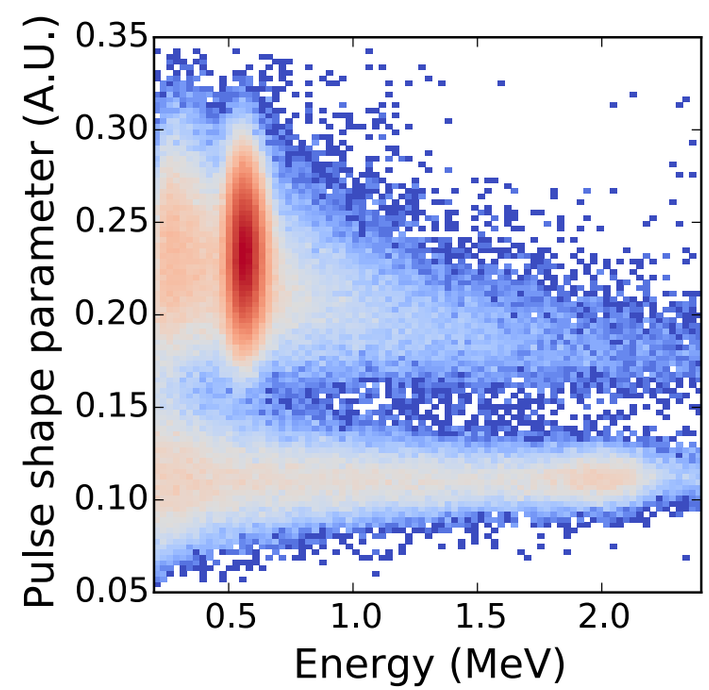




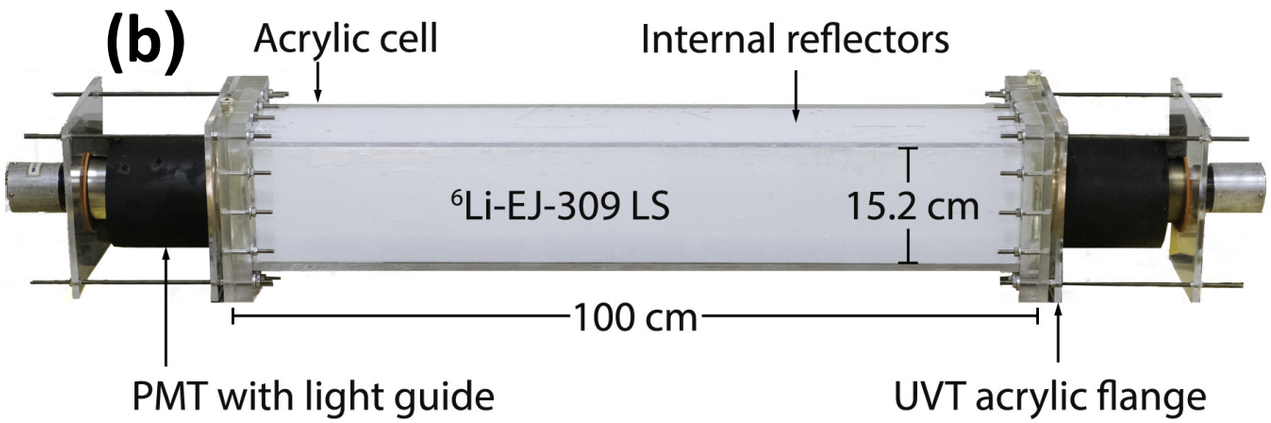
Identifying neutron capture signals via Pulse Shape Discrim.

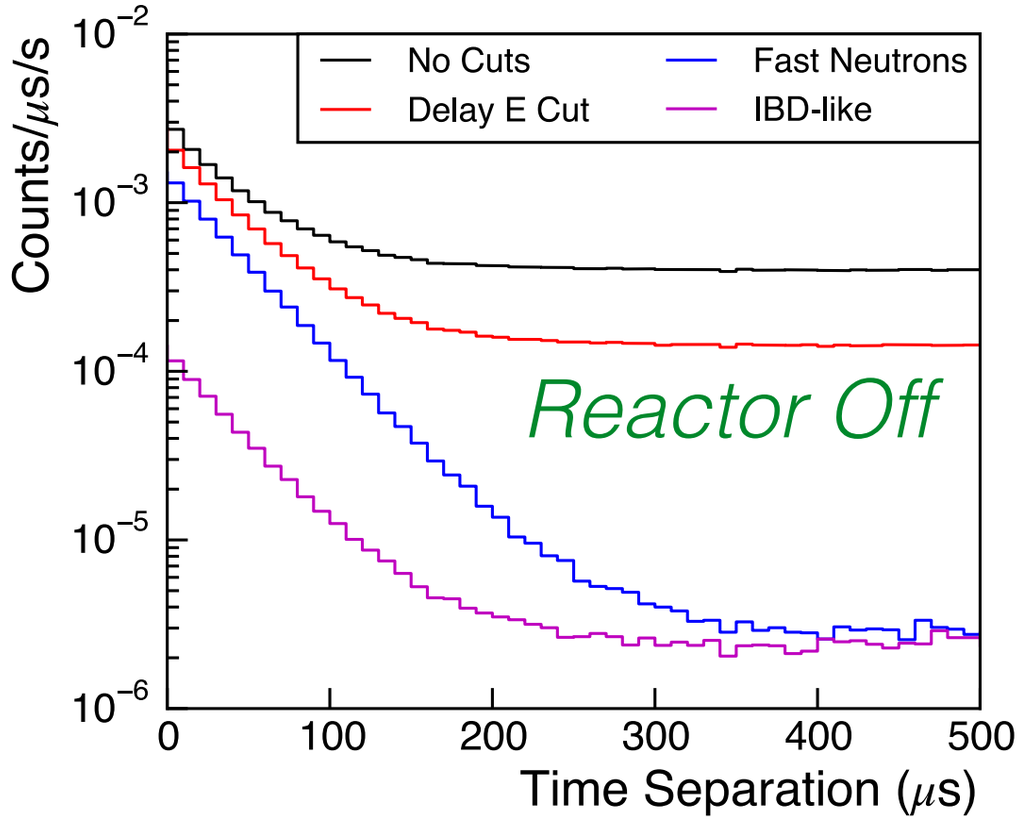


Also helps identify proton recoil from neutron scattering.



Implications from P20 Prototype





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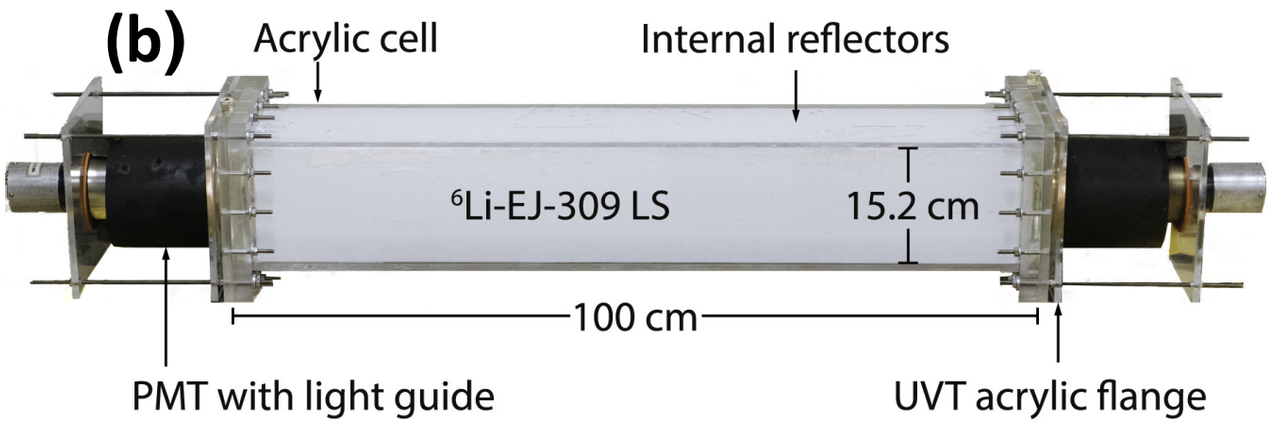

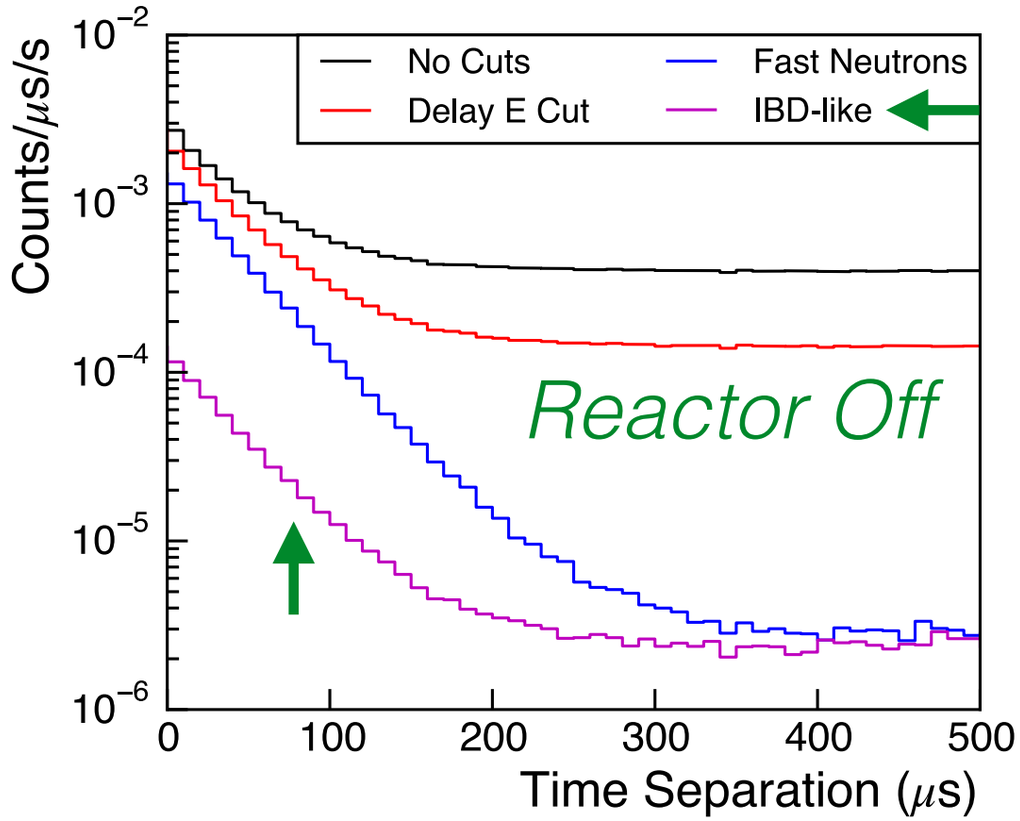

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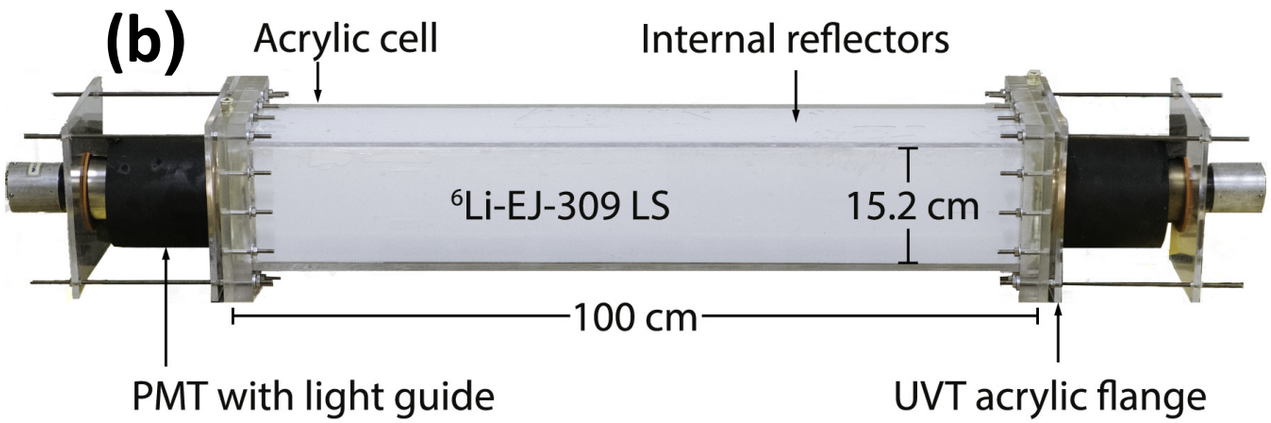
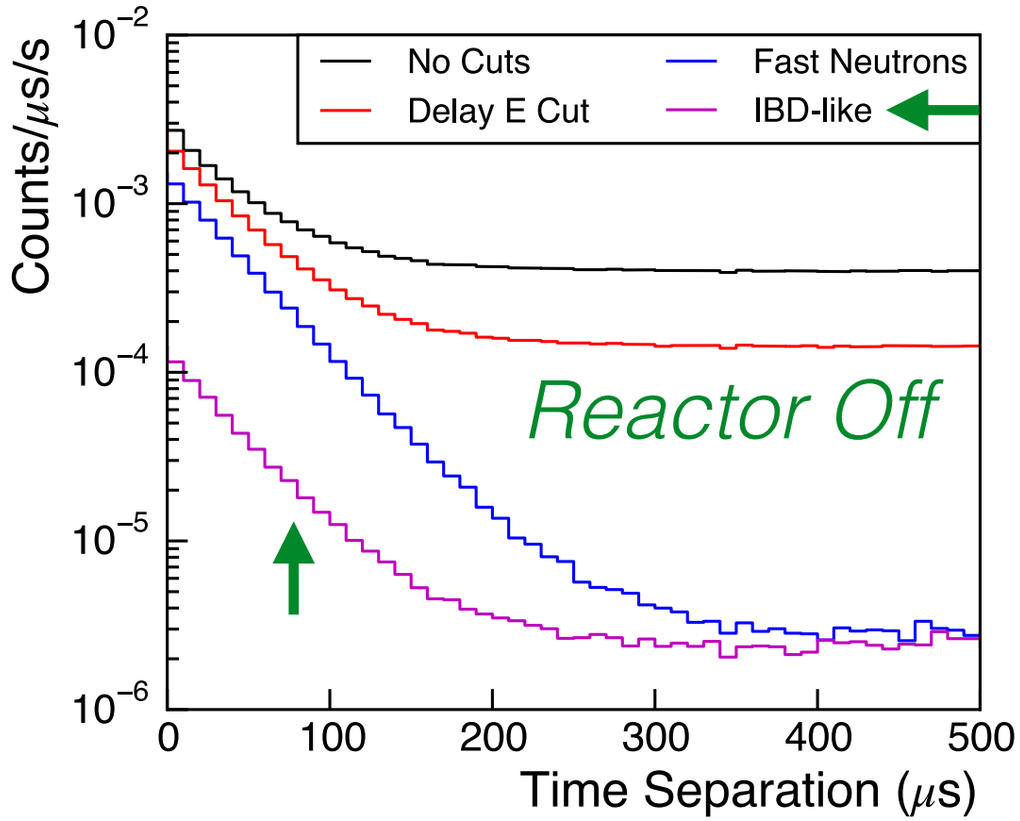
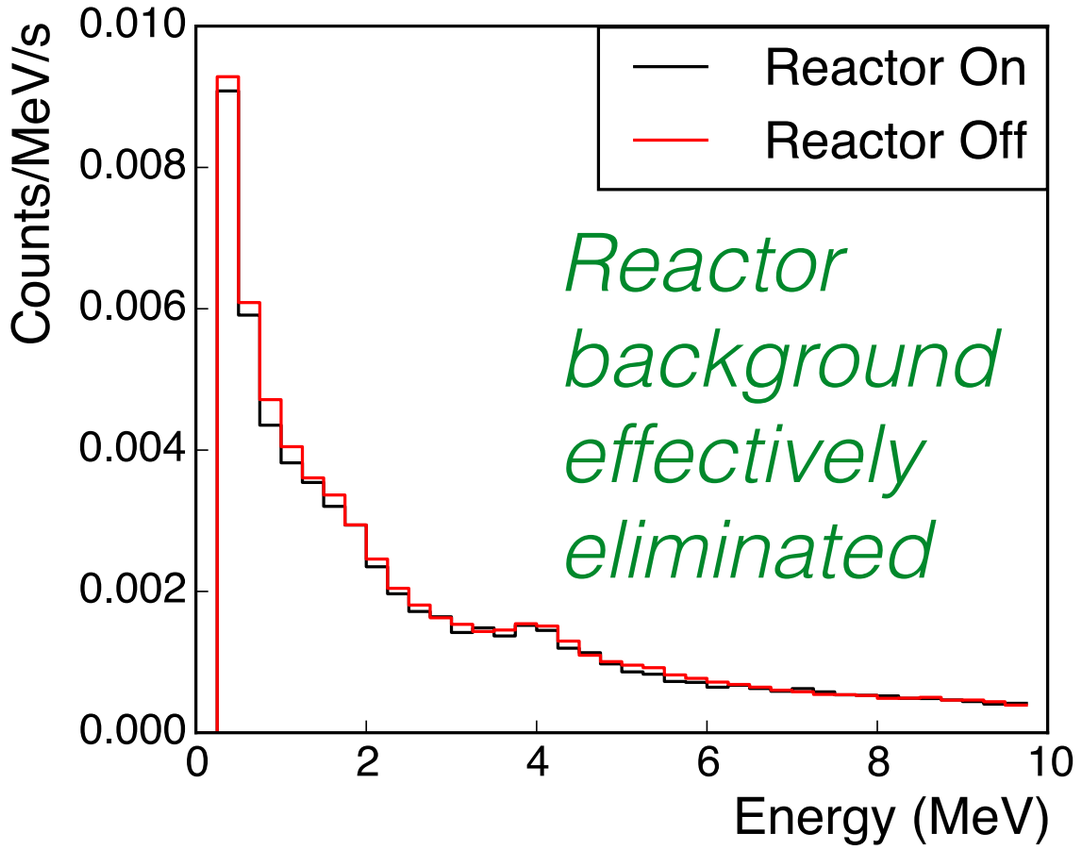






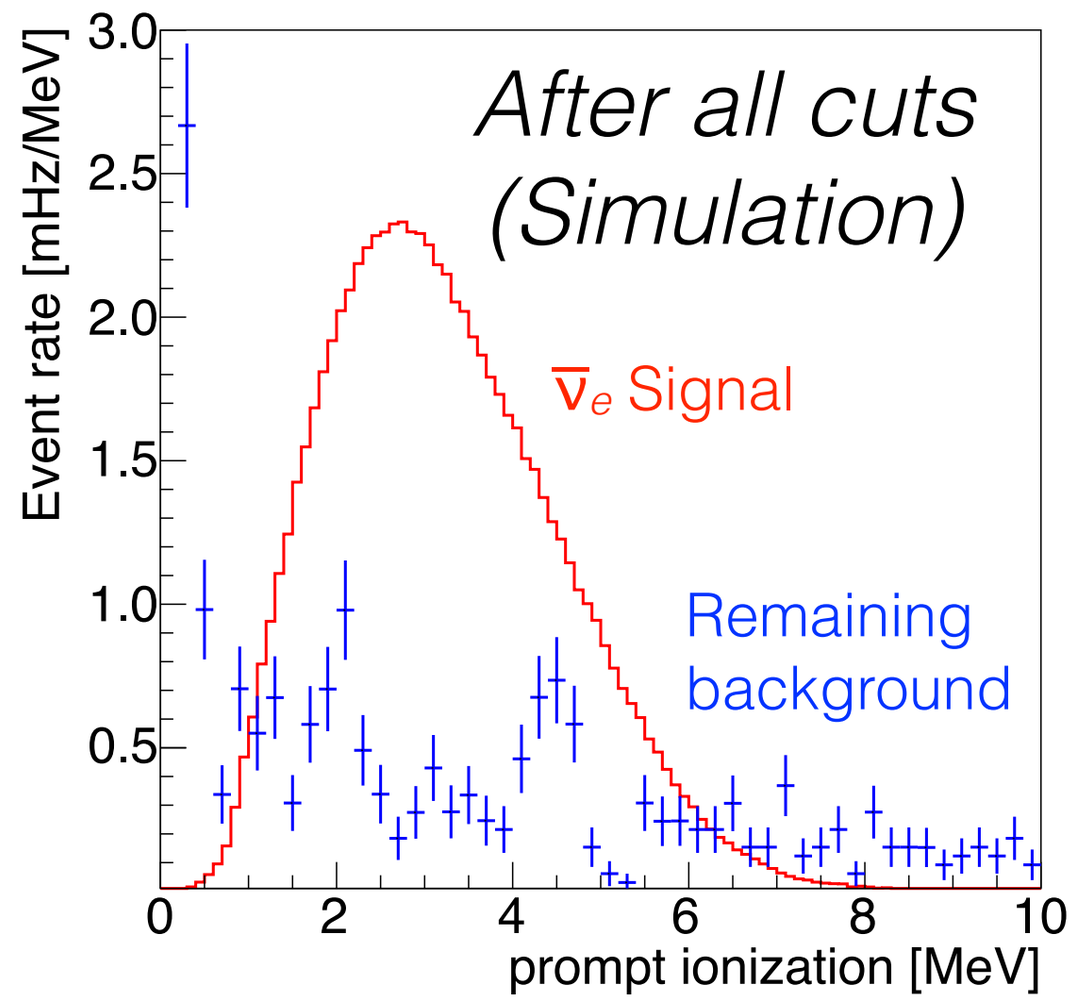
Expected Signal from $\overline{\nu}_e$ Capture

Significant Cosmic Ray Rate in this Configuration

Events Per Day

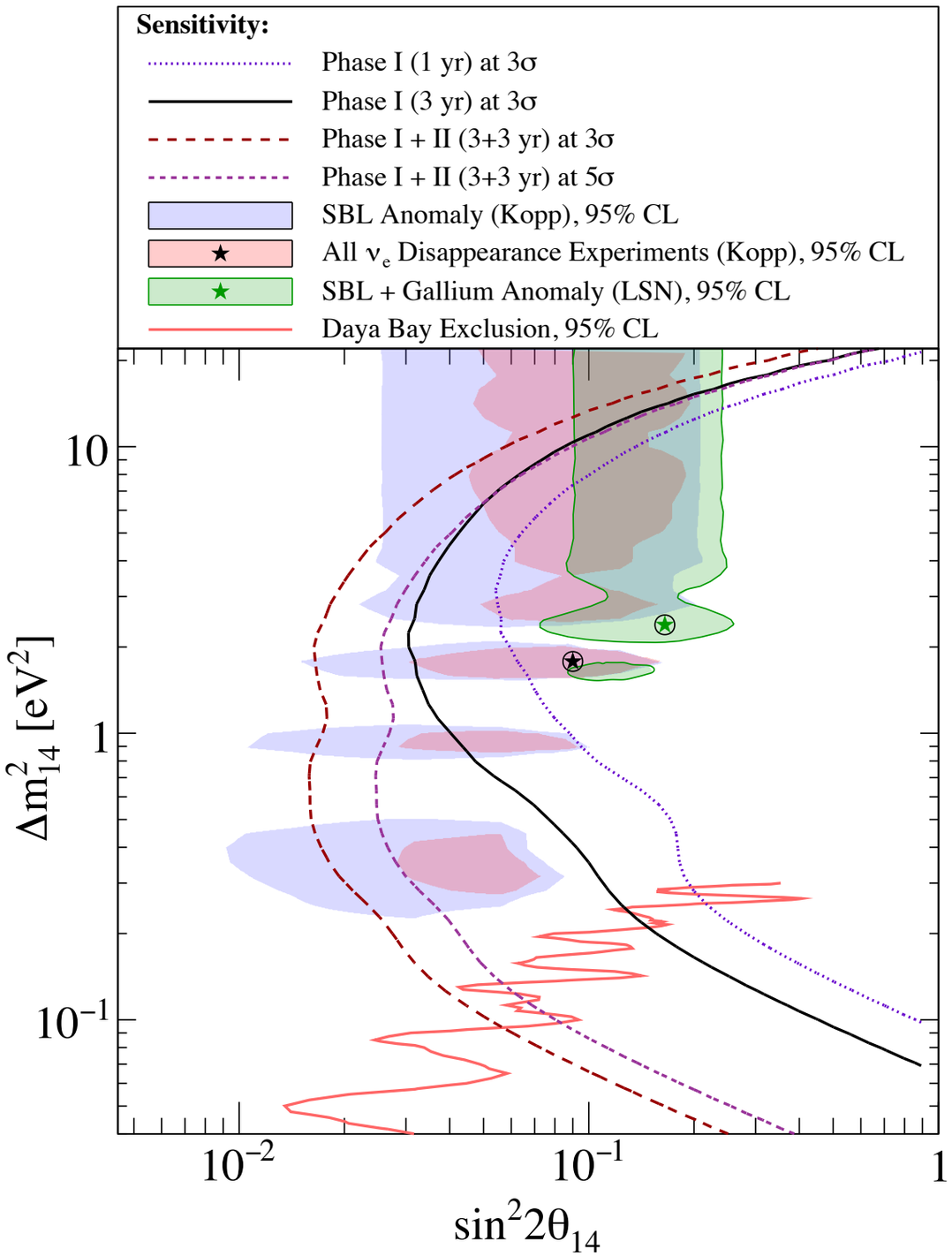
Cuts	IBD signal	Cosmic BG
PSD	1630	2.1e6
Time (1, 2, 3)	1570	3.4e4
Spatial (4, 5)	1440	9900
Fiducial (6)	660	250

Cosmic Ray and Reactor Backgrounds are a challenge, but we are confident that we can achieve S:N=1:1 or better

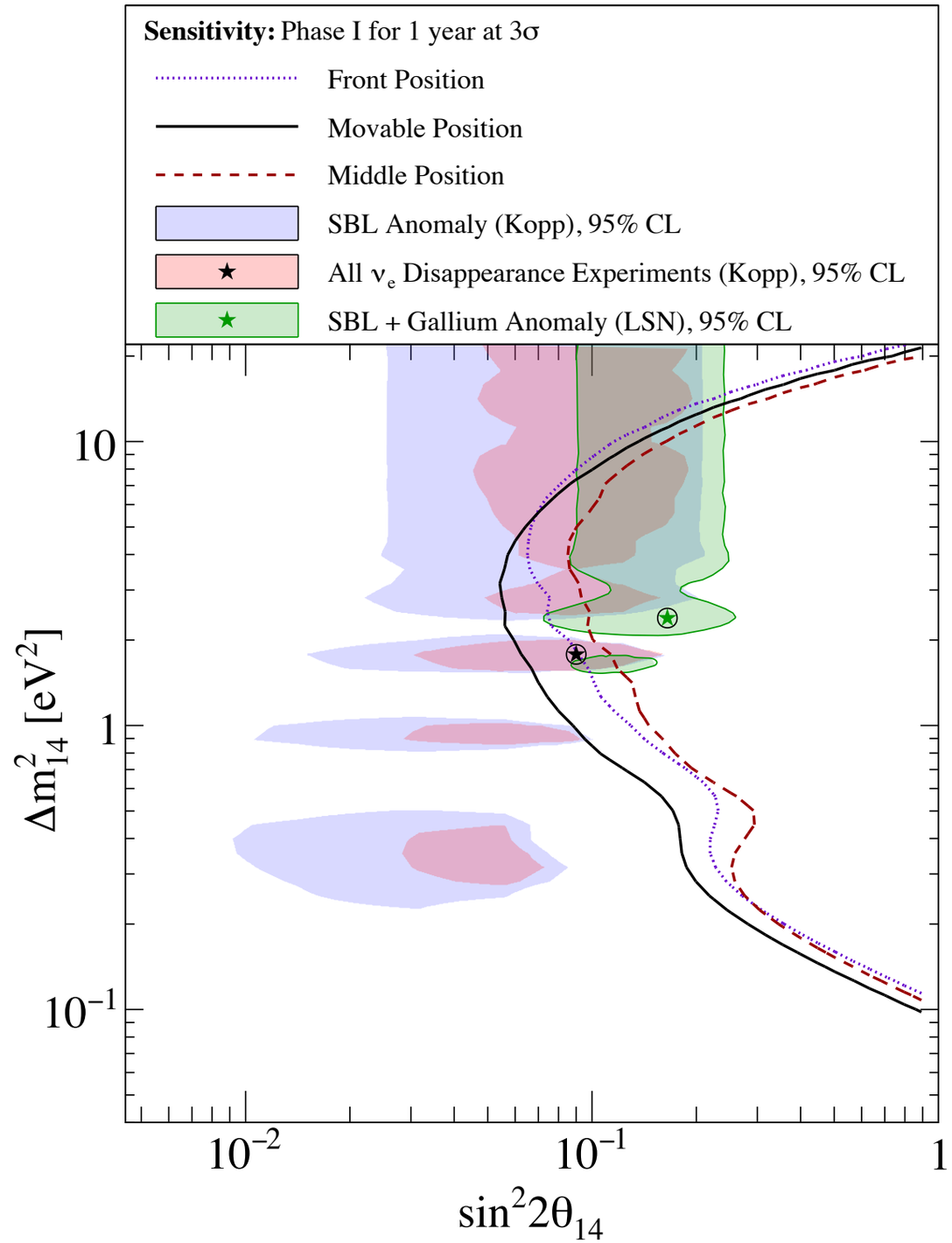


Sensitivity: Sterile Neutrinos

Phase I and Phase II



Phase I with Positioning



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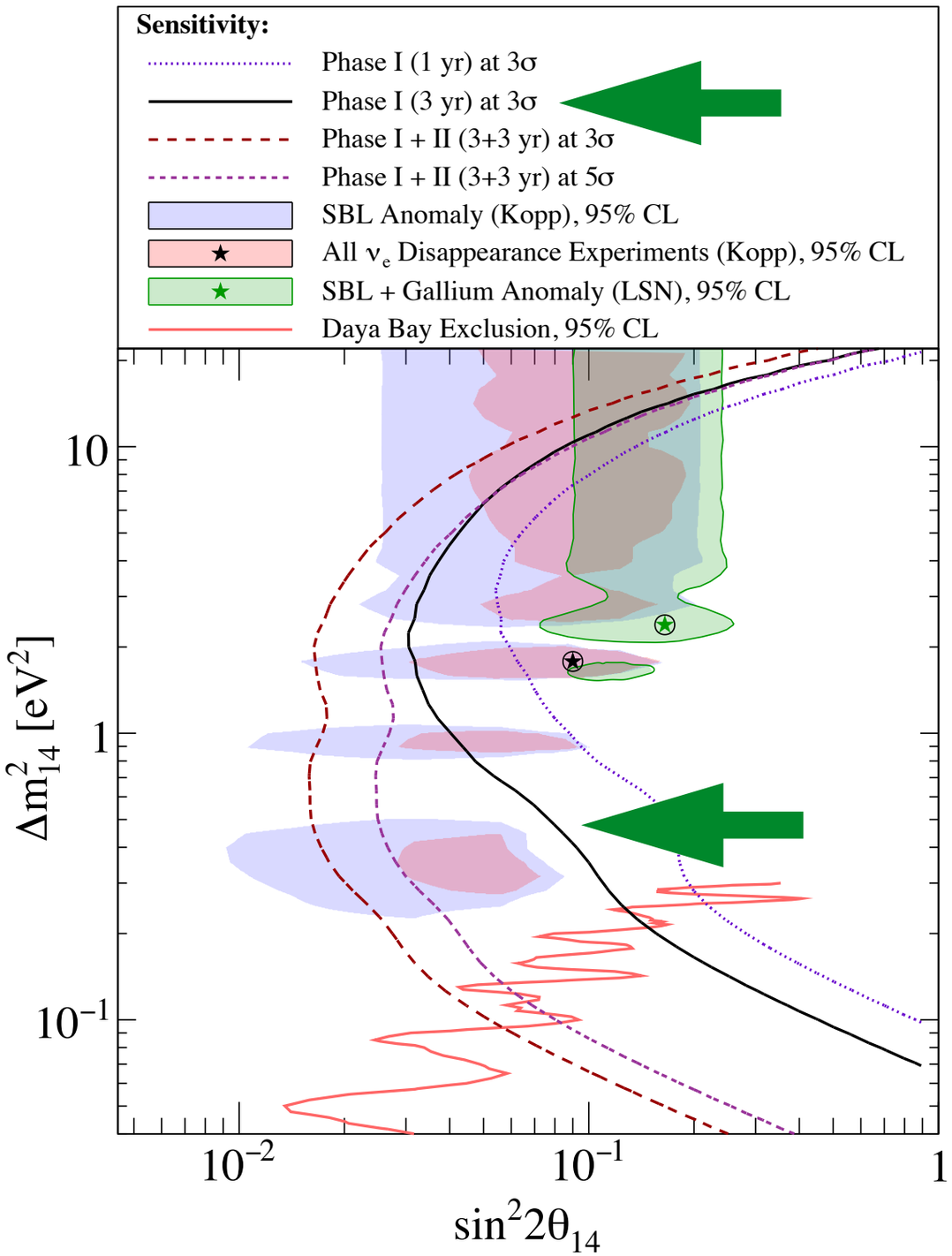

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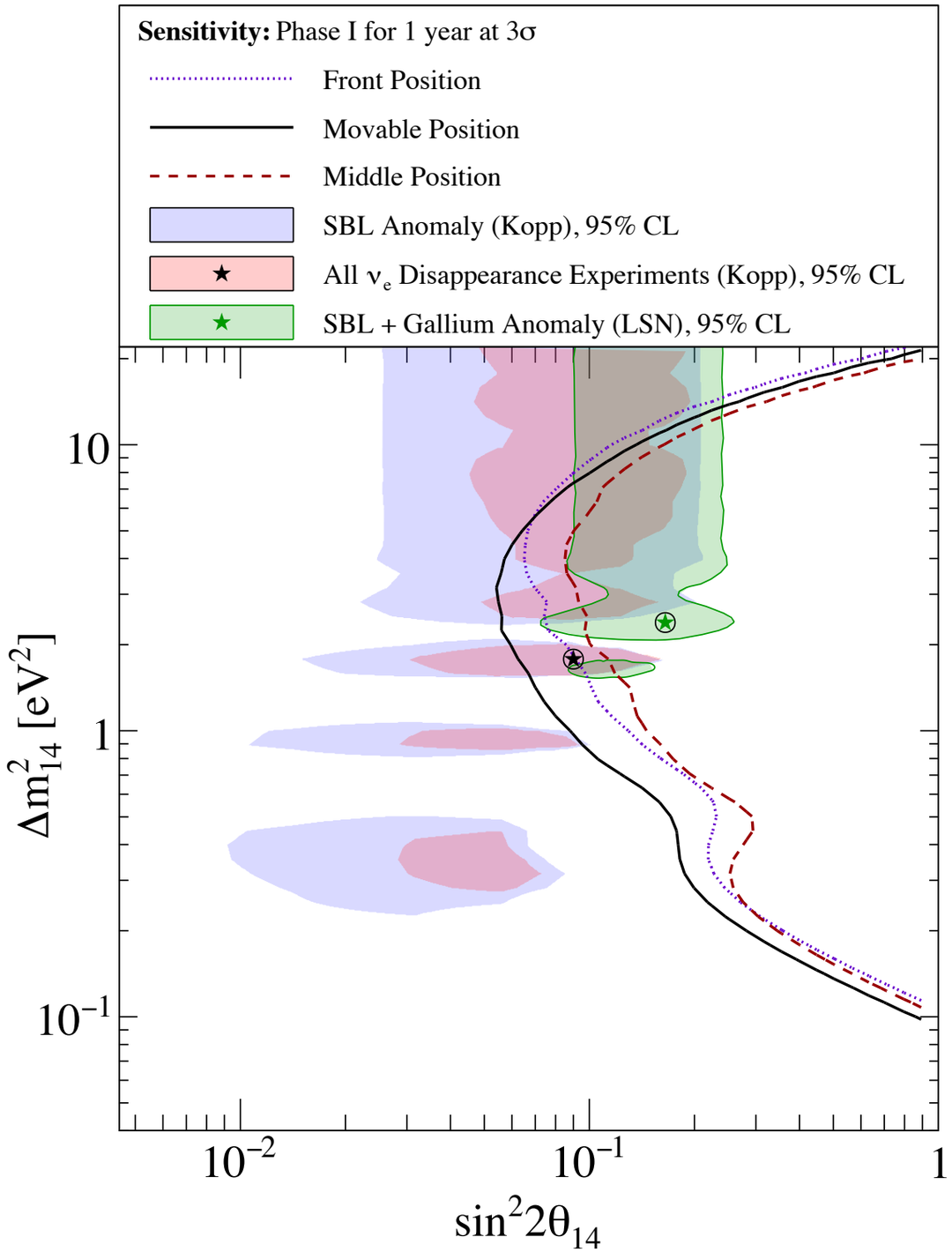
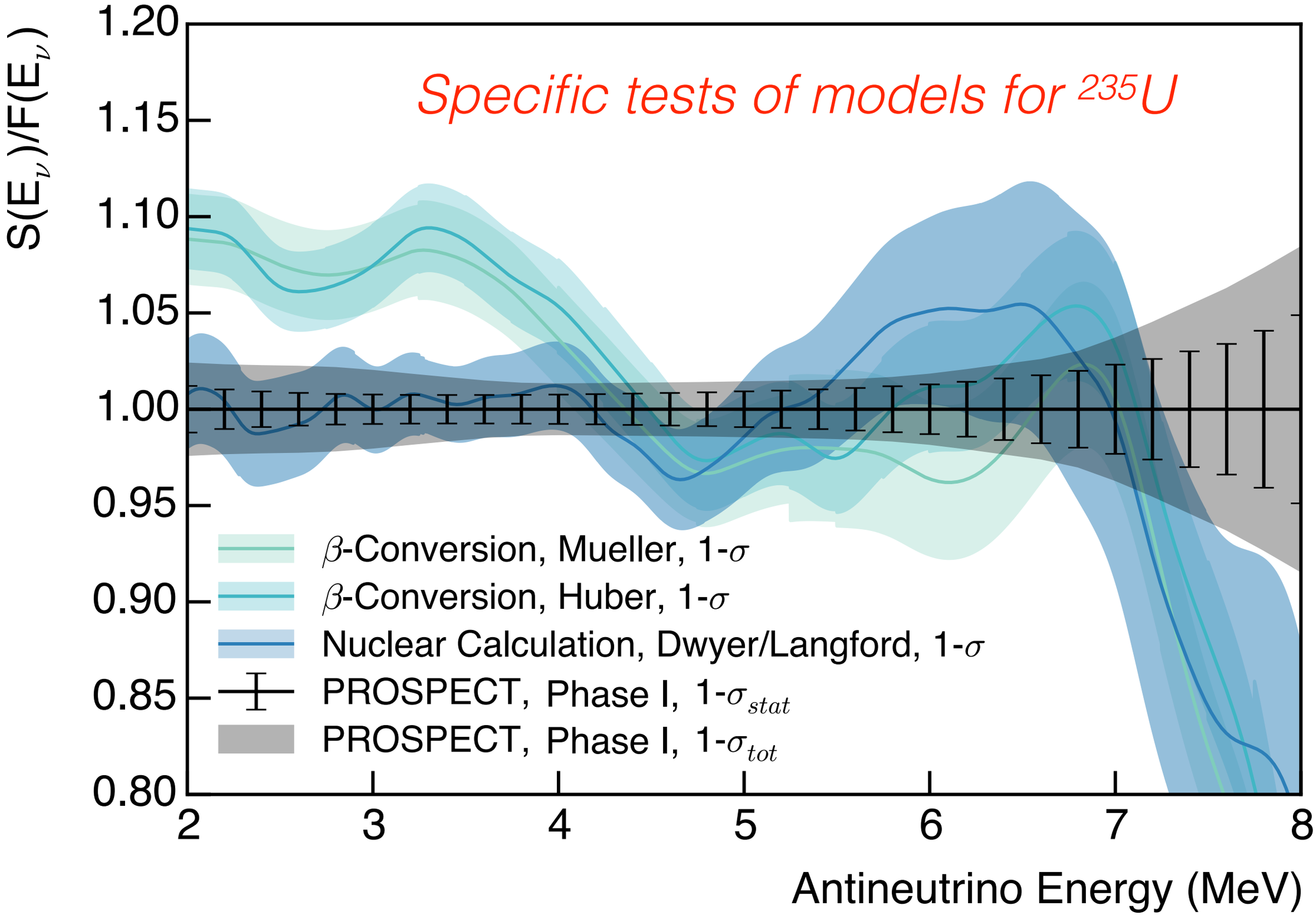


Sensitivity: Reactor Spectrum



Conclusions

- Nuclear reactors are copious sources of $\overline{\nu}_e$, but it is difficult to understand the details at the level of 1%
- The best, most recent calculations indicate the $\overline{\nu}_e$ flux is "anomalously low" ⇒ Sterile neutrinos?

Other experiments support this hypothesis

- Several new experiments are under construction at research reactors to measure the spectrum shape
- PROSPECT @ HFIR will eliminate or verify the "Kopp Best Fit" sterile neutrino solution by 2018

Thank You!