



A Short-baseline Reactor Precision Spectrum and Oscillation Experiment

ICHEP 2016 • Chicago, IL

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 Lawrence Livermore
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for the PROSPECT
Collaboration



- 3-ton ${}^6\text{Li}$ -loaded liquid scintillator detector with neutron-interaction-sensitive pulse-shape discrimination (PSD)
- inverse beta decay (IBD) $\bar{\nu}_e$ detection
- movable for extended baseline reach
- 6–12m from HEU research reactor core (HFIR at Oak Ridge National Laboratory)
- precision spectrum and short-baseline oscillation measurement
- low-mass optical segmentation
- high light collection (>500 PE/MeV) PMT readout
- $\Delta E/E < 4.5\%$ at 1 MeV
- complementary larger Phase II longer-baseline detector possible

PROSPECT Collaboration



prospect.yale.edu

Brookhaven National Laboratory
Drexel University
Georgia Tech
Illinois Institute of Technology
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



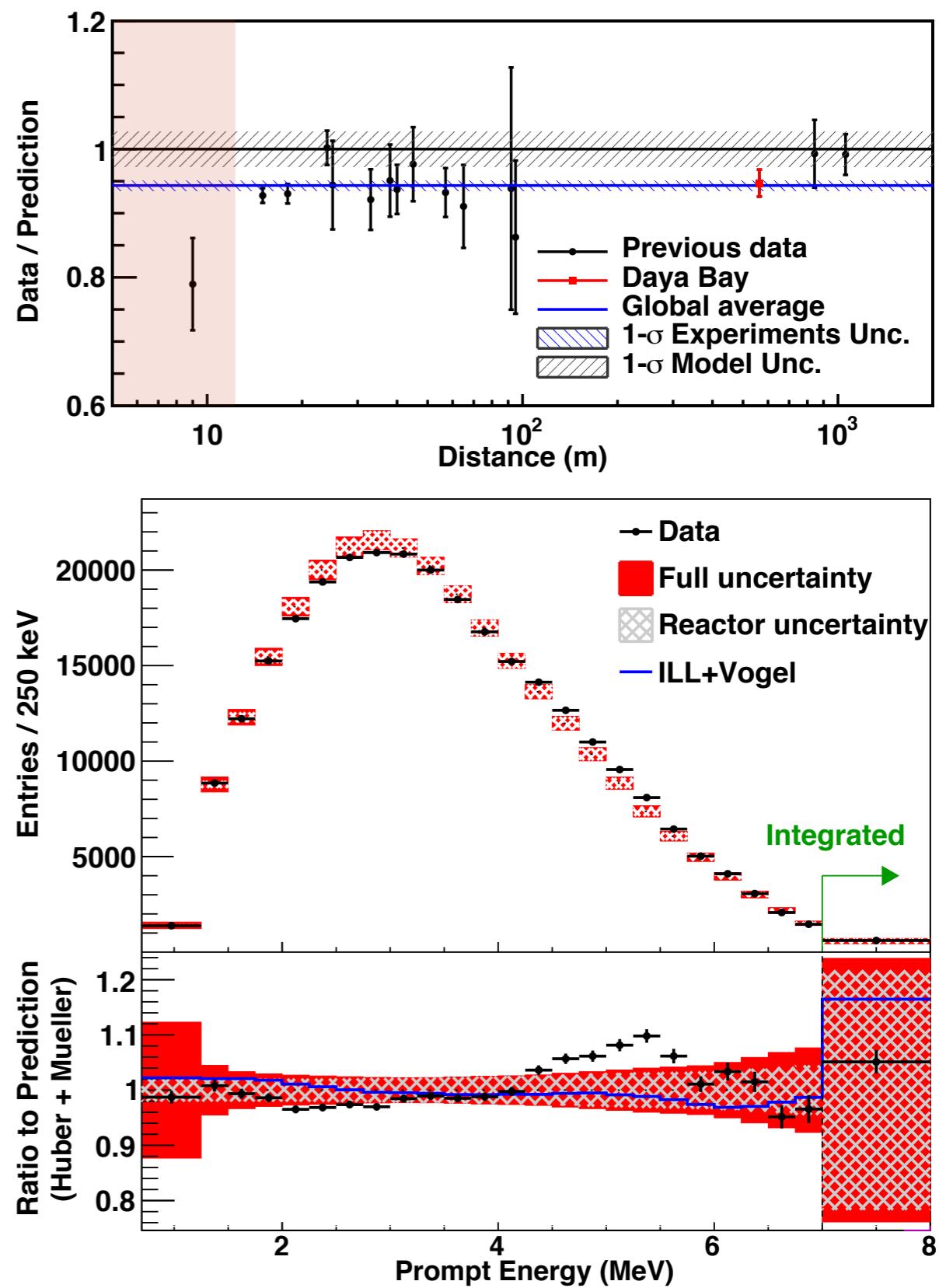
supported by the US DOE Office of Science

why?

overall reactor electron antineutrino flux deficit
(also MiniBoone, LSND,
Ga anomalies, ...)

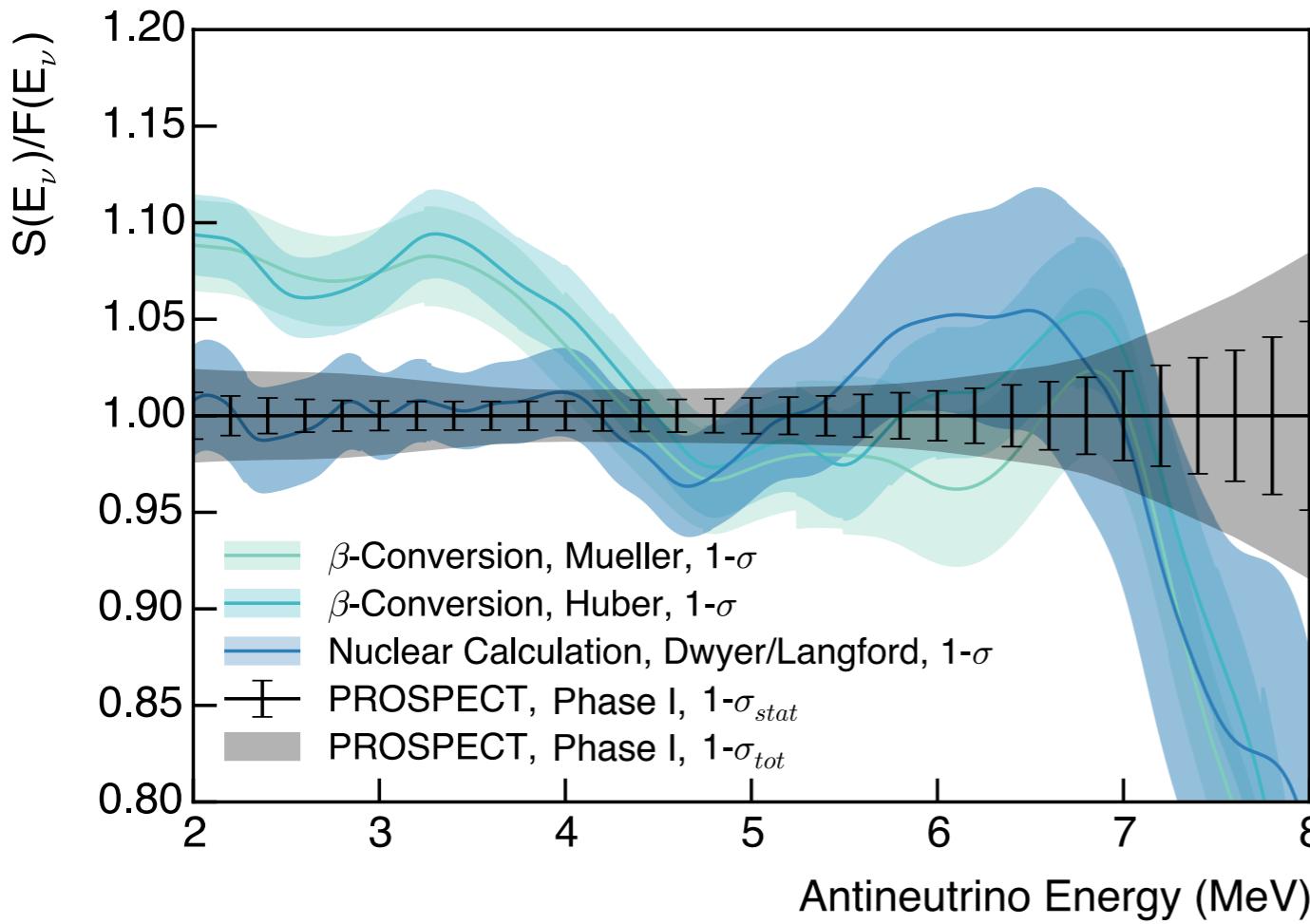
spectral shape disagreement
with models (“the bump”)

need new reactor experiment
to both probe short-range
oscillation possibilities and
provide precision spectrum
shape measurement



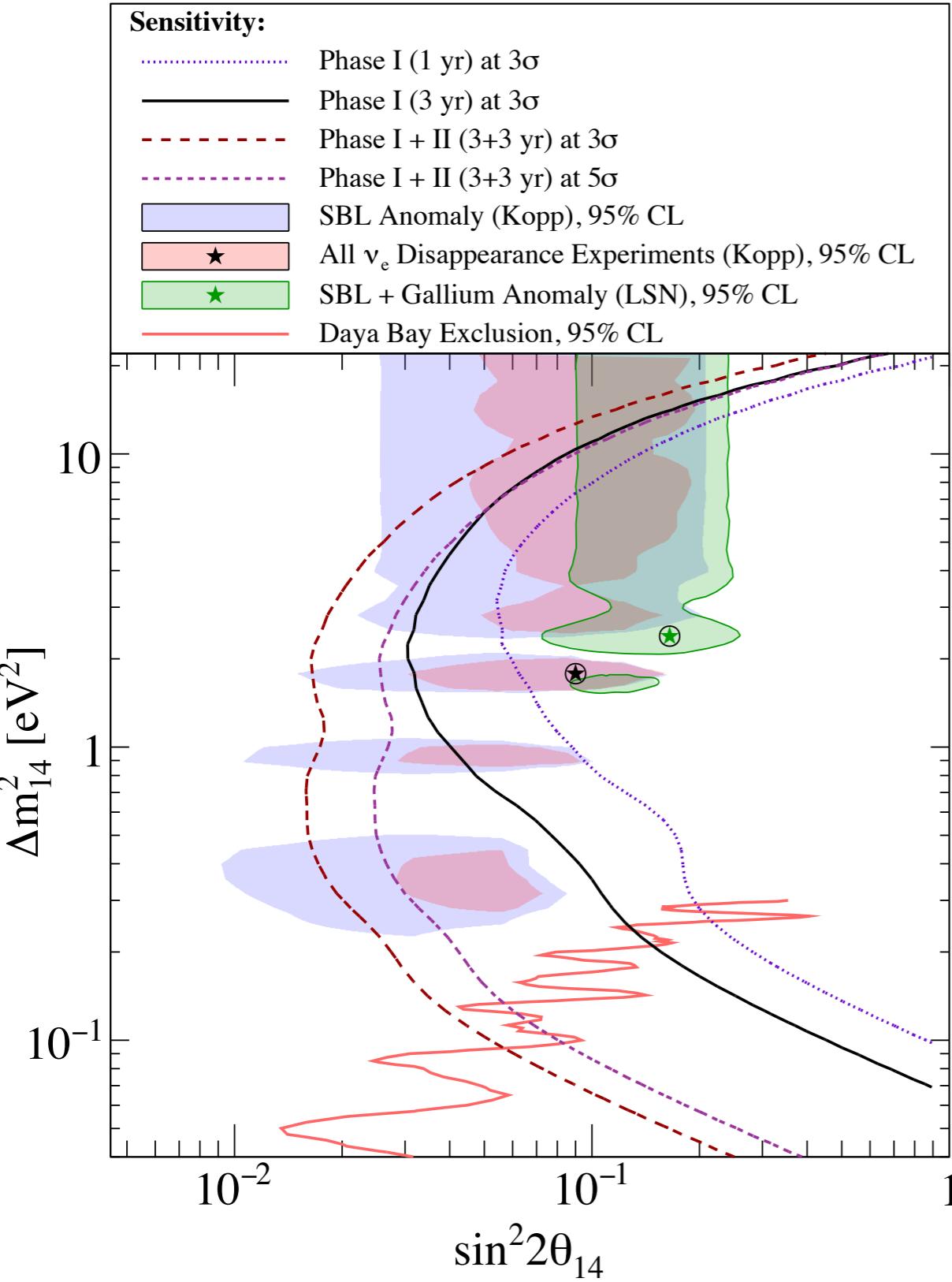
F. P. An et al. (Daya Bay),
2015, arXiv:1508.04233

precision spectrum shape measurement



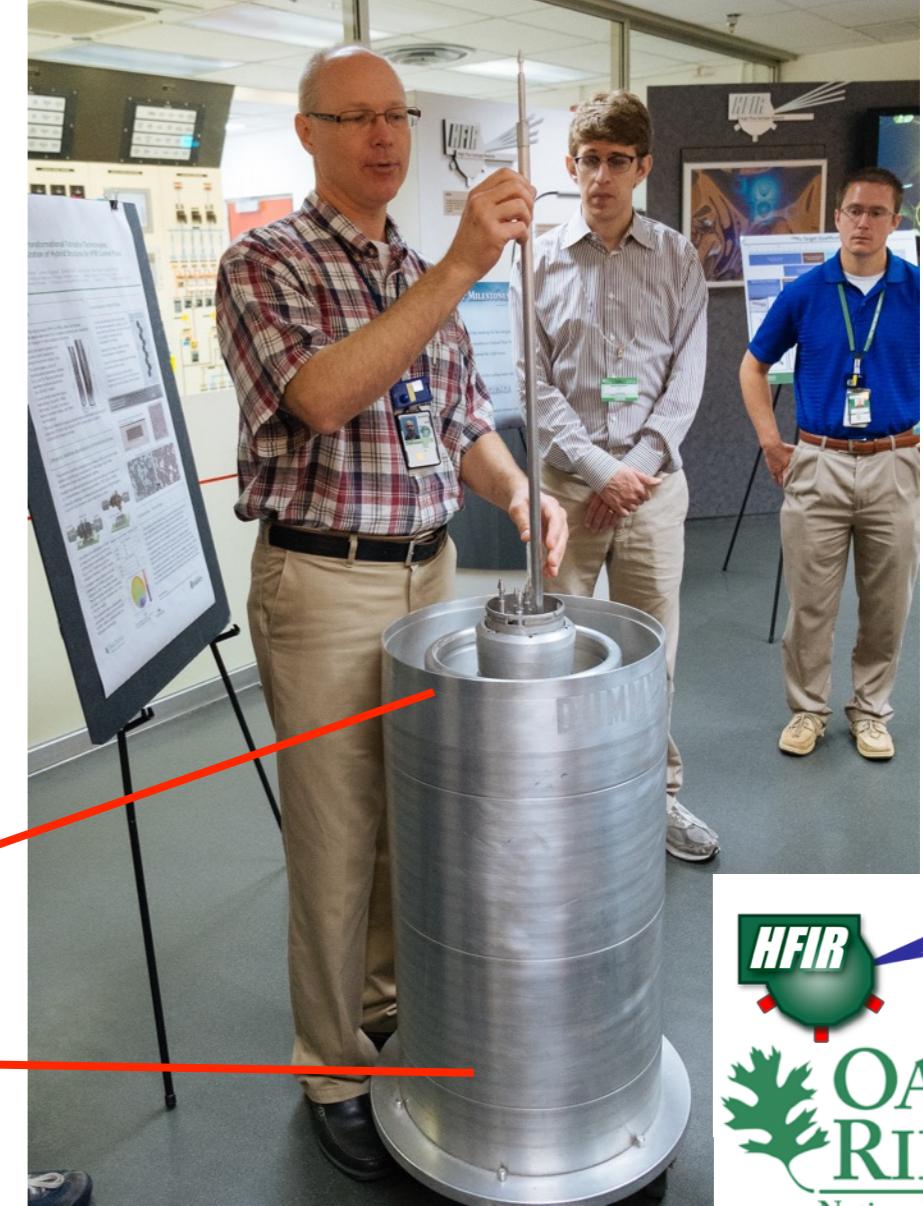
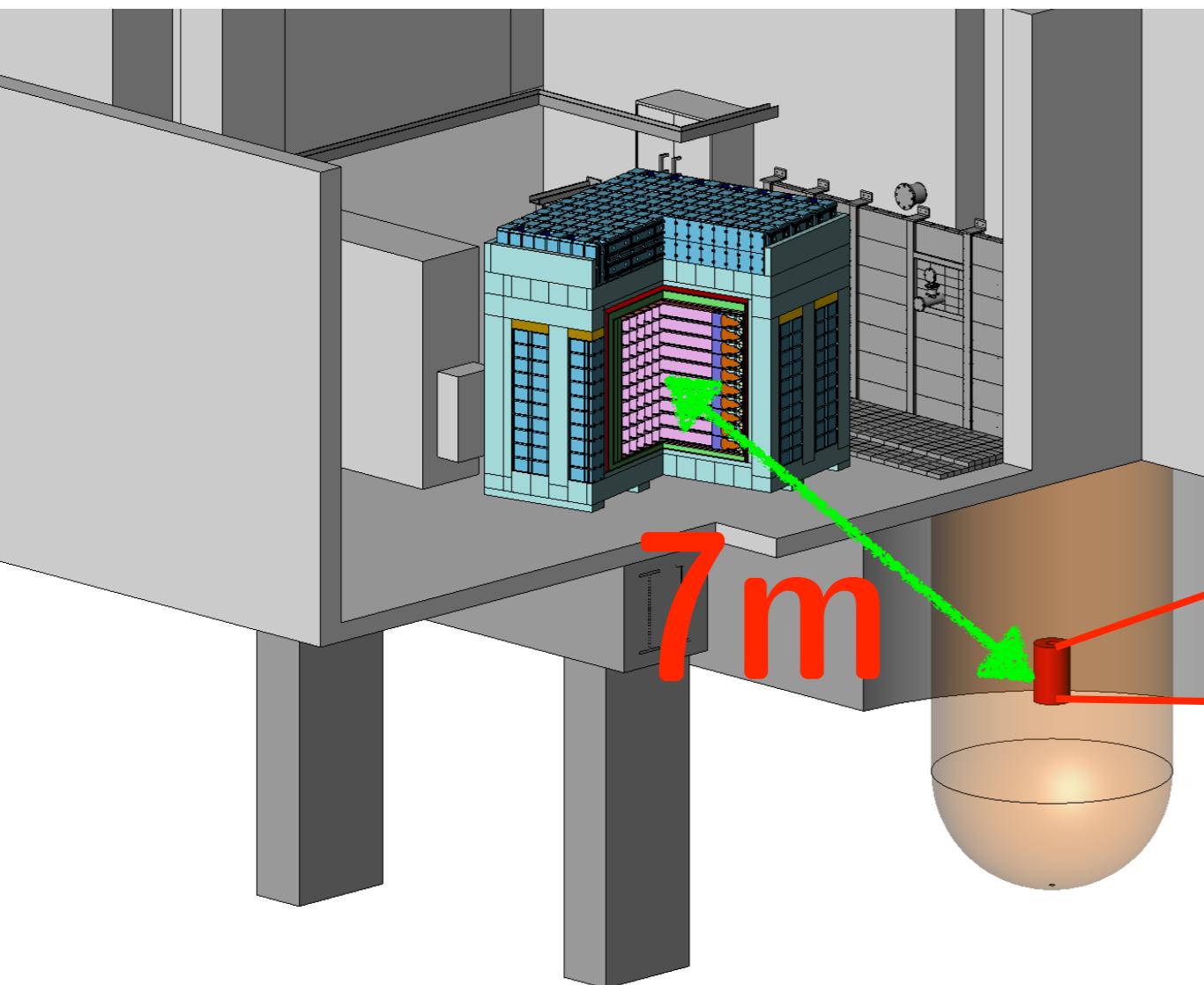
- distinguish between theoretical models (and benchmark for future theory)
- isolate ^{235}U fuel spectrum contribution
- $\Delta E/E < 4.5\% @ 1\text{MeV}$

oscillation search

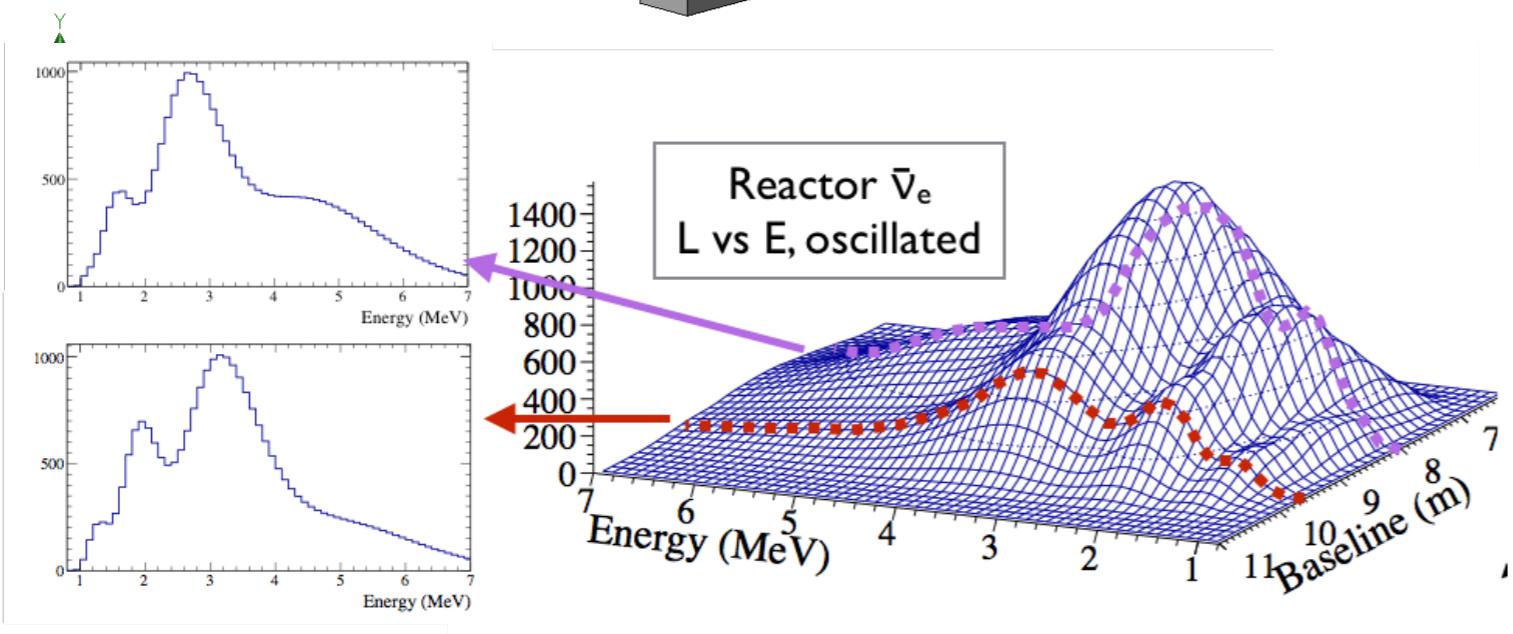


- cover best-fit points for sterile neutrino hypothesis at 3σ in first year
- expanded oscillation phase space coverage in 3 years operation
- possible Phase II longer-baseline detector

method:



HFIR 85MW HEU reactor core
(mock-up)



put a movable position/
energy sensitive neutrino
detector close to a
compact HEU reactor.

getting there: phased R&D approach

PROSPECT-0.1

Characterize LS

Aug 2014-Spring 2015

5cm length

0.1 liters

LS, ${}^6\text{Li}$ LS



PROSPECT-2

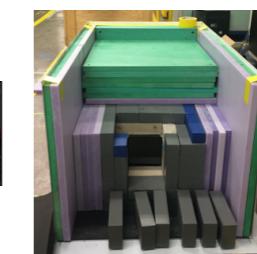
Background studies

Dec 2014 - Aug 2015

12.5 cm length

1.7 liters

${}^6\text{Li}$ LS



PROSPECT-20

Segment characterization

Scintillator studies

Background studies

Spring/Summer 2015

1m length

23 liters

LS, ${}^6\text{Li}$ LS



PROSPECT-50

Baseline design
mechanical prototype

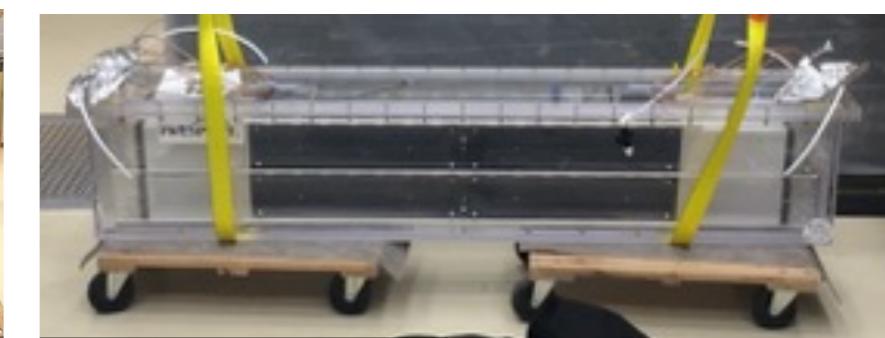
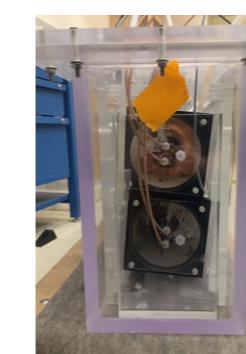
Spring/Summer 2016

1x2 segments

1.2m length

50 liters

${}^6\text{Li}$ LS



PROSPECT AD-I

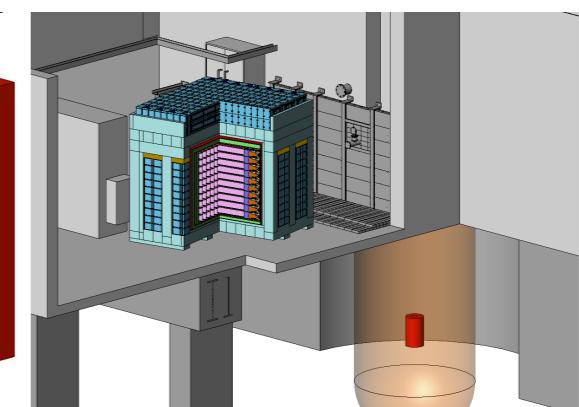
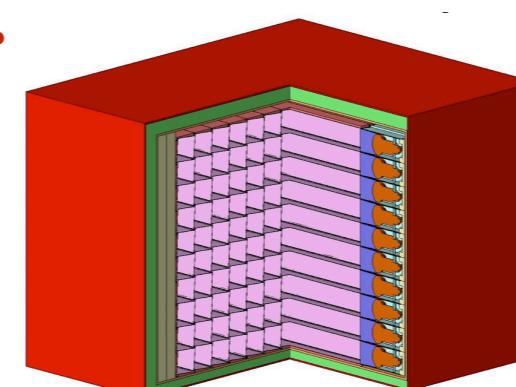
2017

12x10 segments

1.2m length

~3 tons

${}^6\text{Li}$ LS

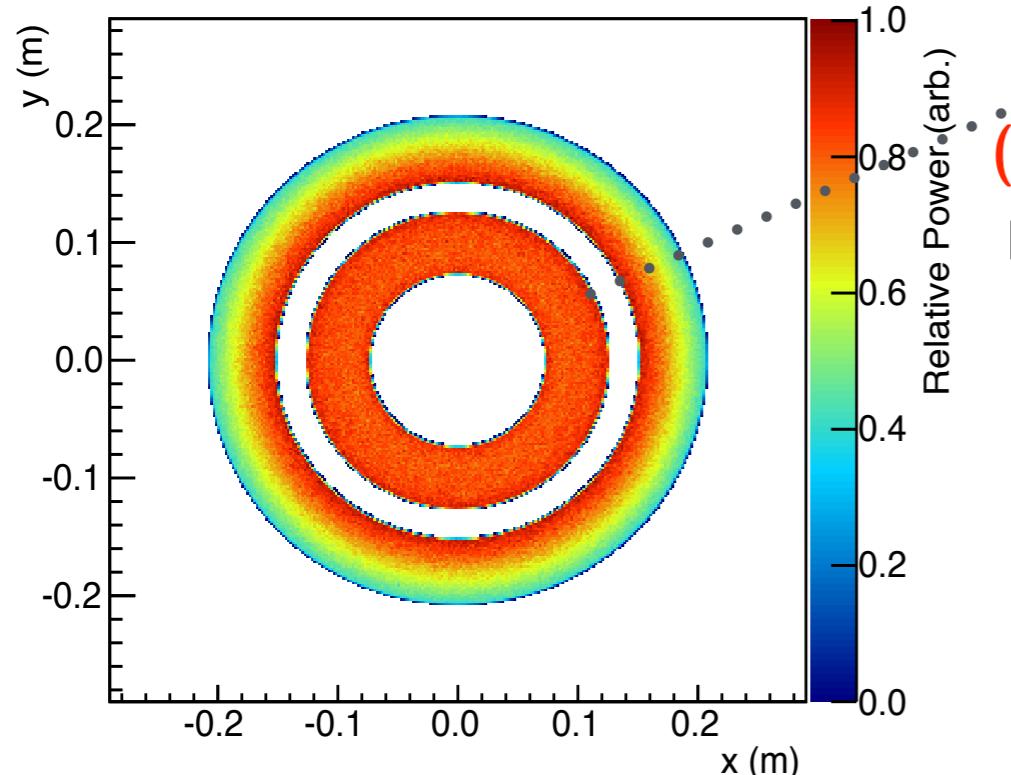


P0.1



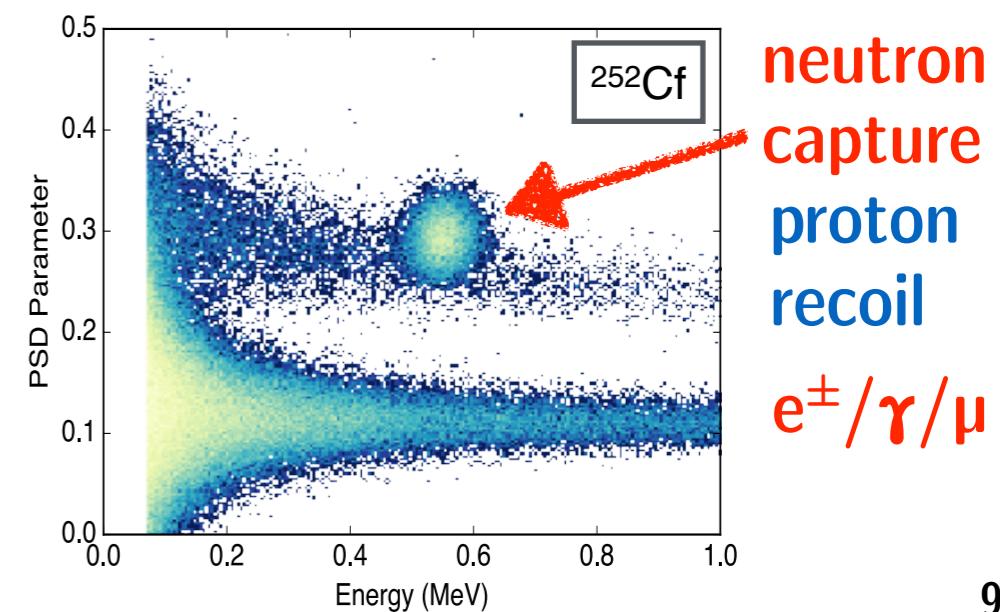
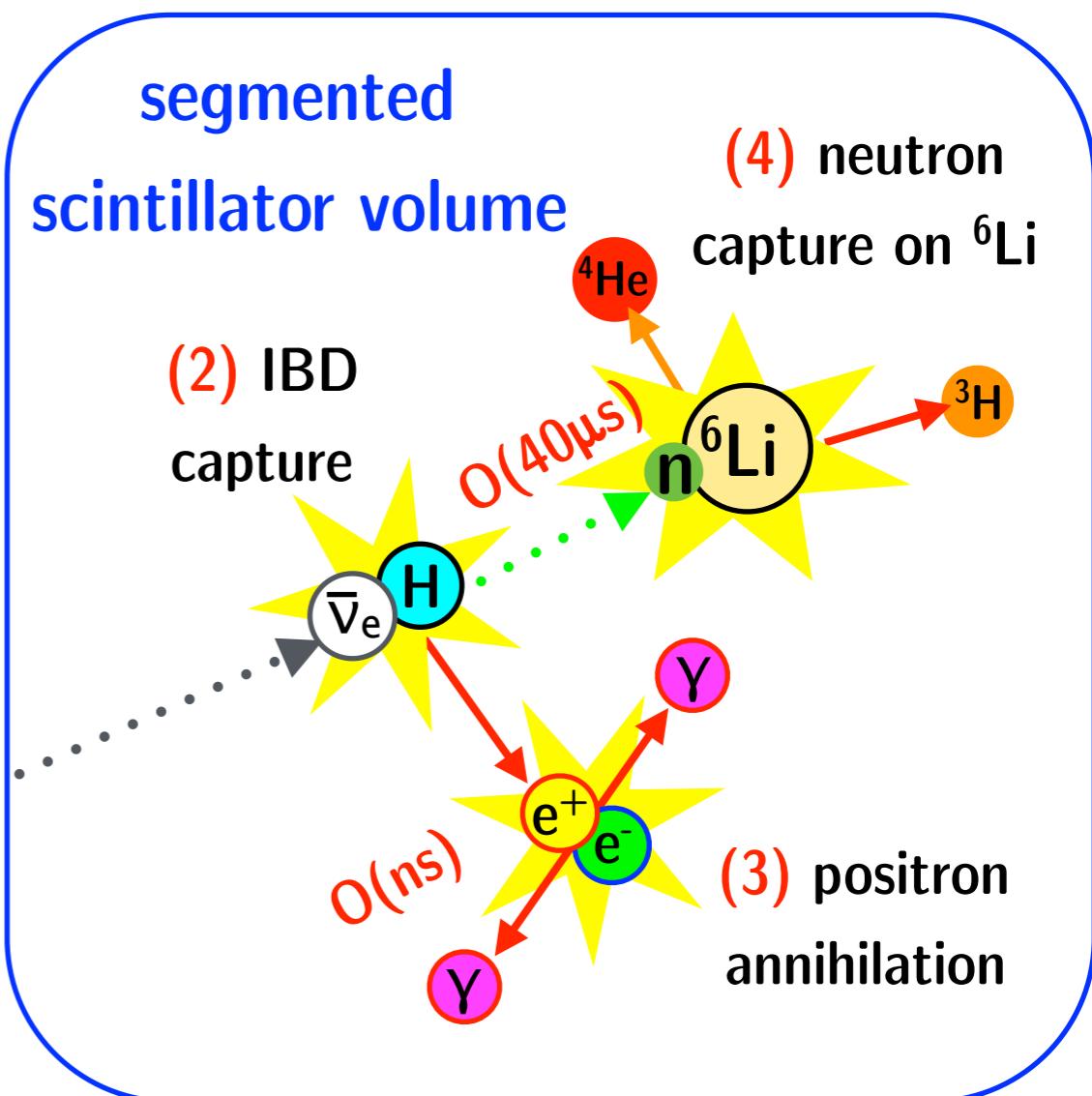
detection medium:

inverse beta decay (IBD) in
neutron-interaction-sensitive
0.1% ${}^6\text{Li}$ -loaded liquid scintillator with
pulse shape discrimination (PSD)

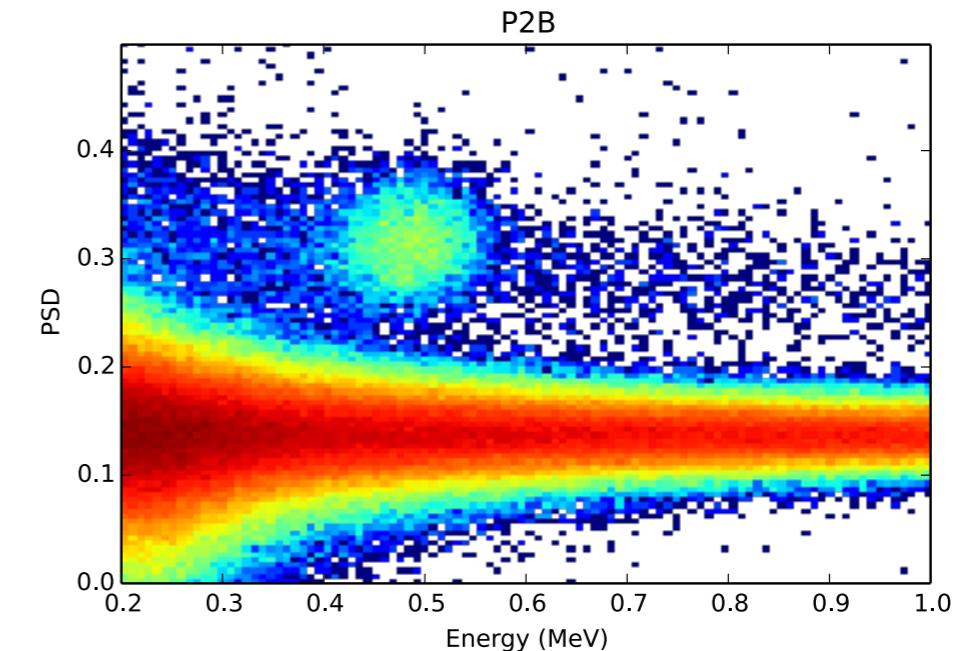
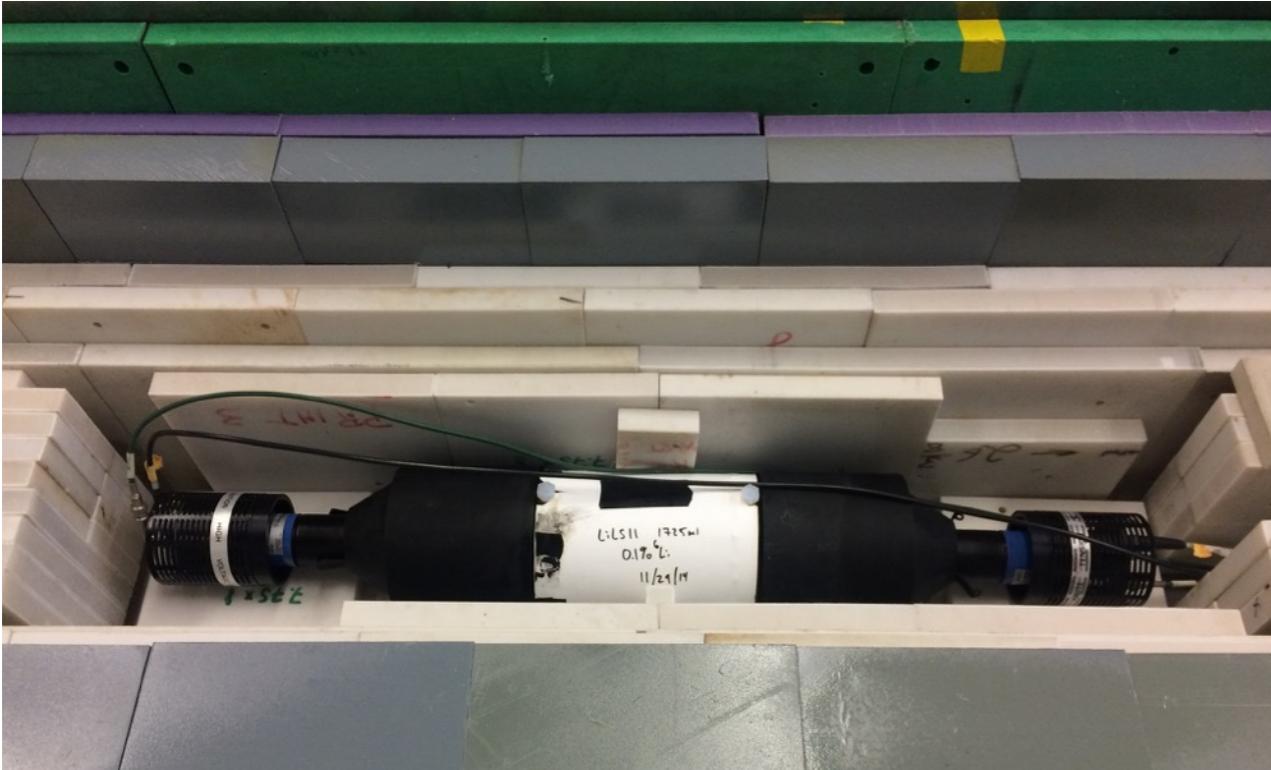


High Flux Isotope Reactor (HFIR) core
highly-enriched ${}^{235}\text{U}$ (HEU)
Oak Ridge National Laboratory

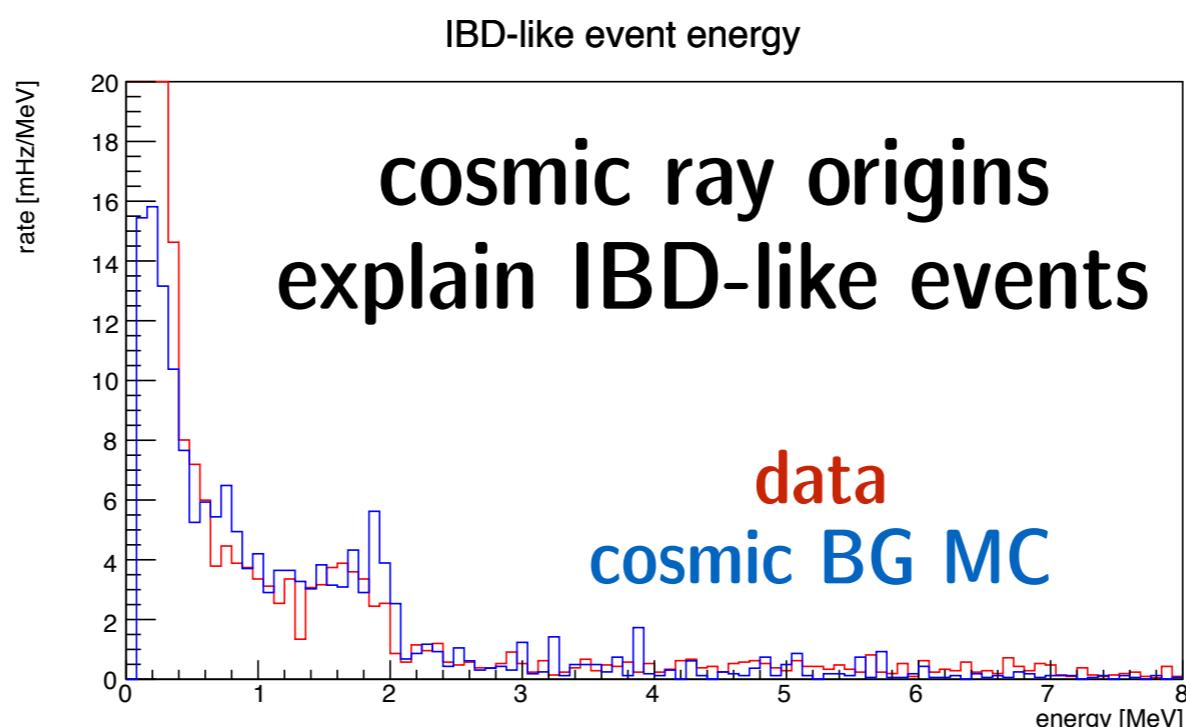
PSD
distinguishes
neutron
interactions.



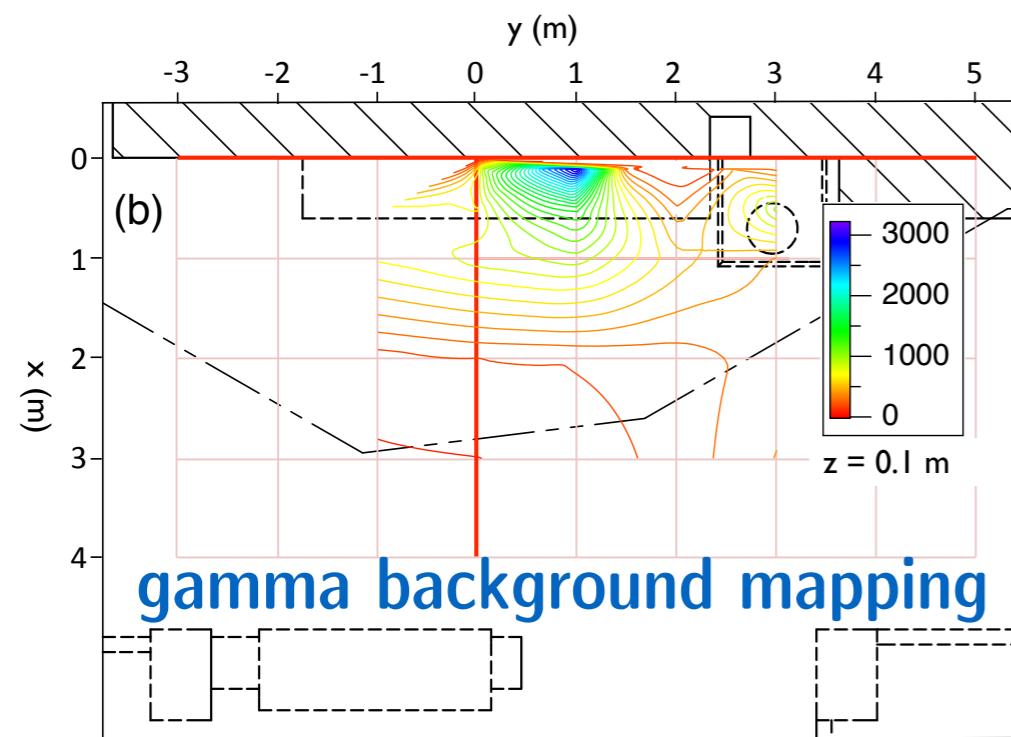
PROSPECT-2 operation in HFIR environment



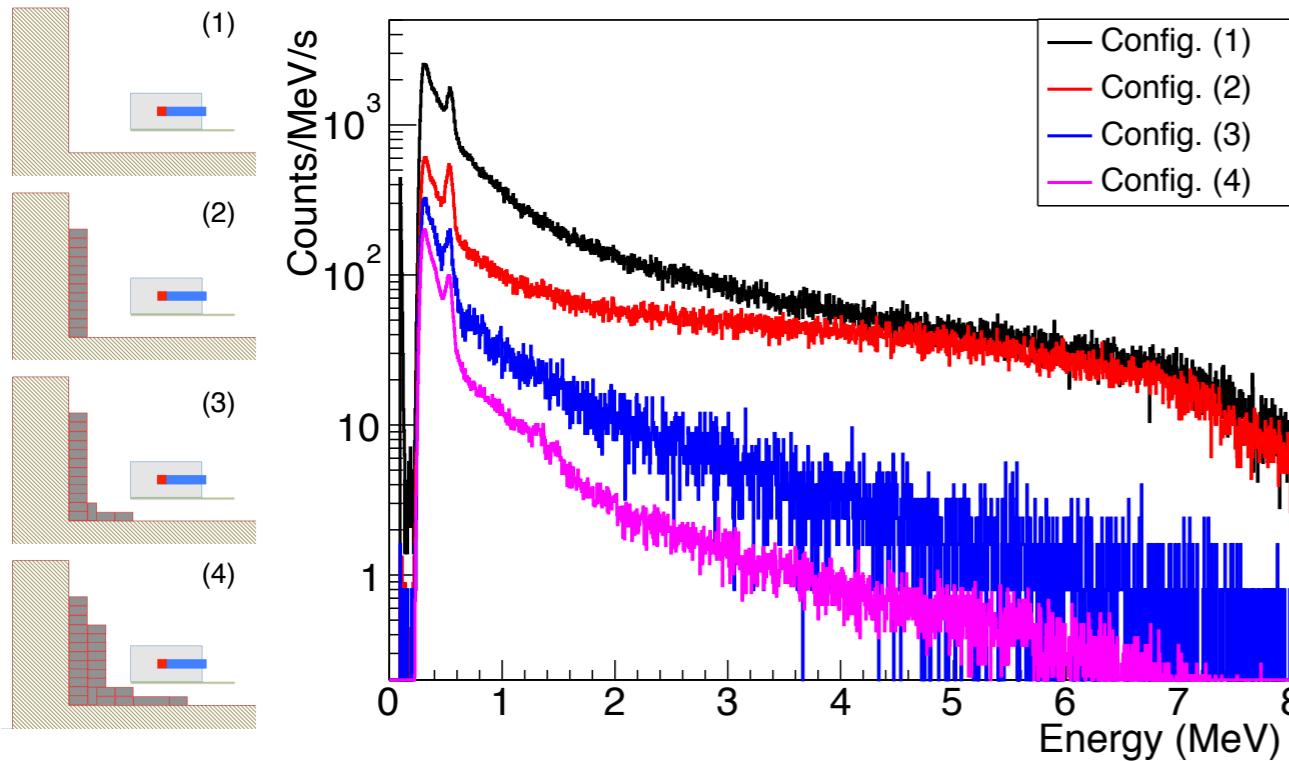
${}^6\text{Li}$ scintillator performance



continuing HFIR background mapping

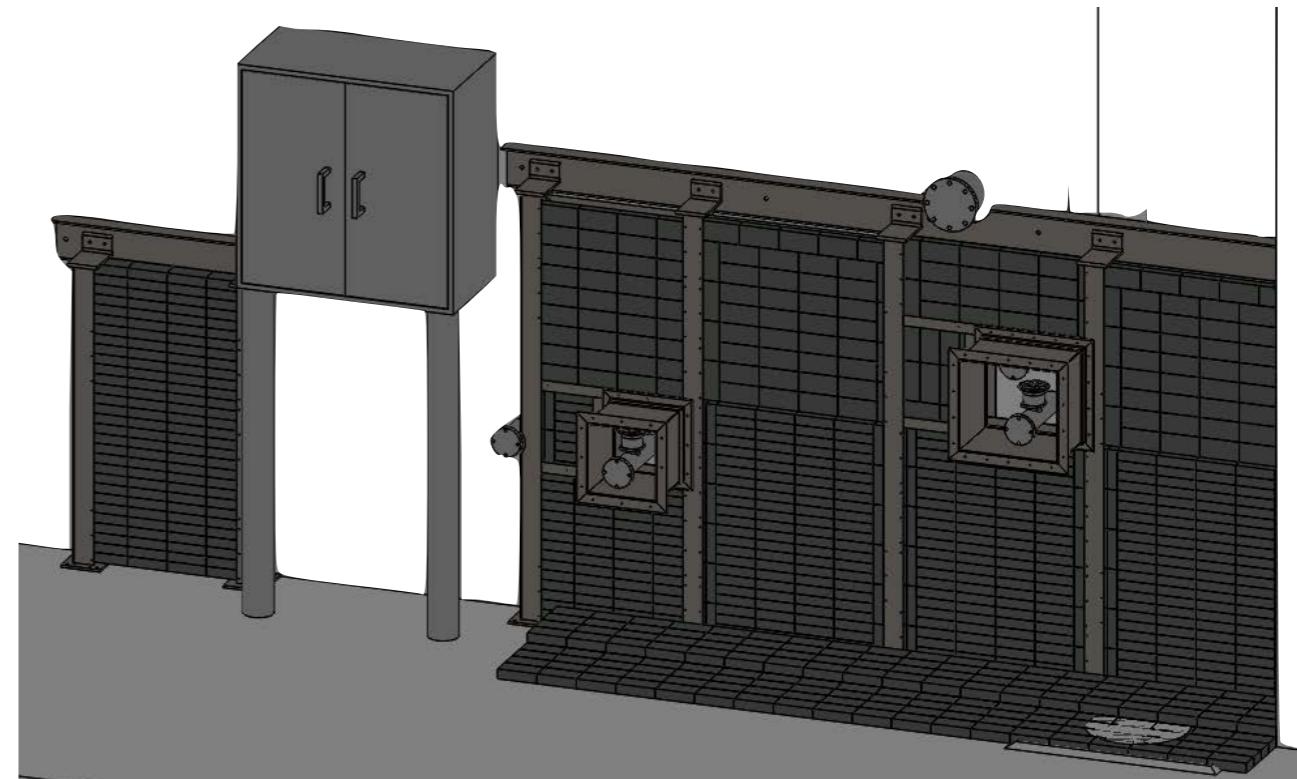


NIM A 806 (2016) p.401
arXiv:1506.03547

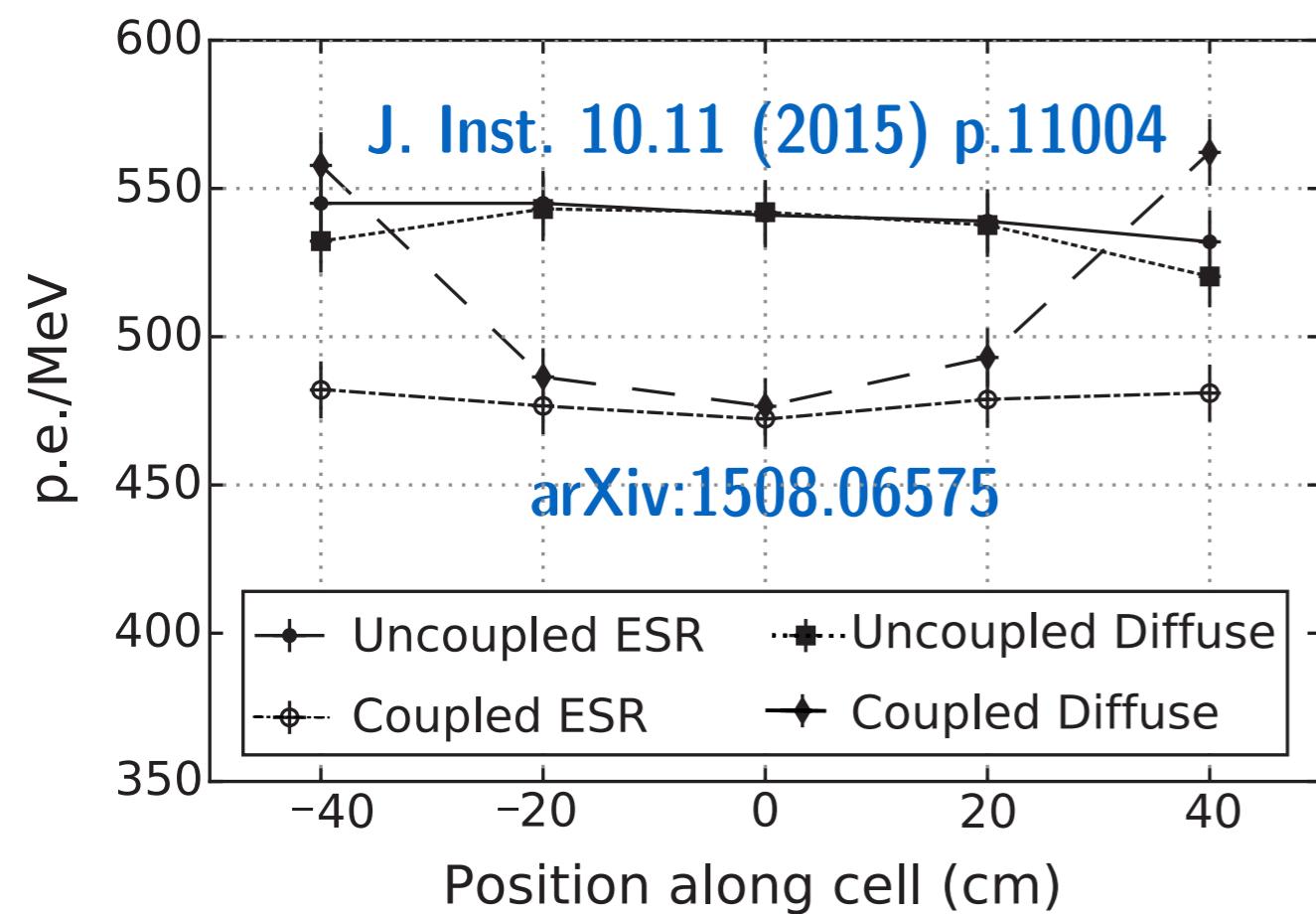
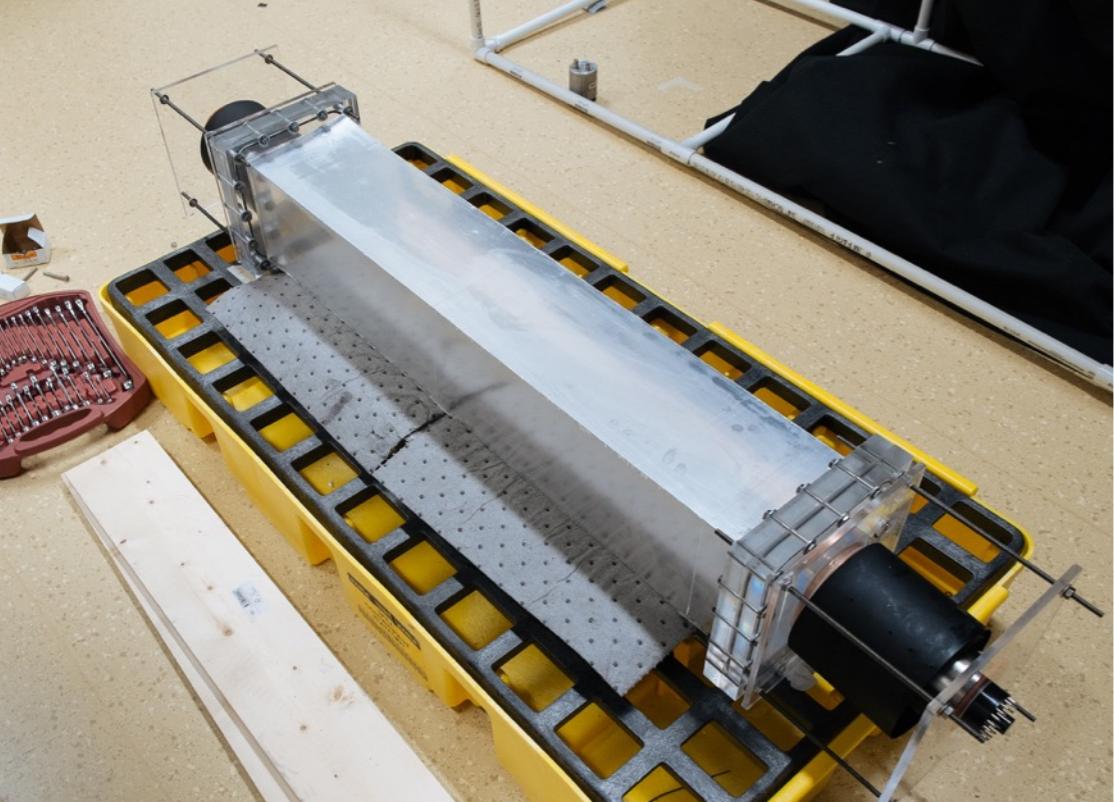


targeted
lead
shielding

local shielding wall design

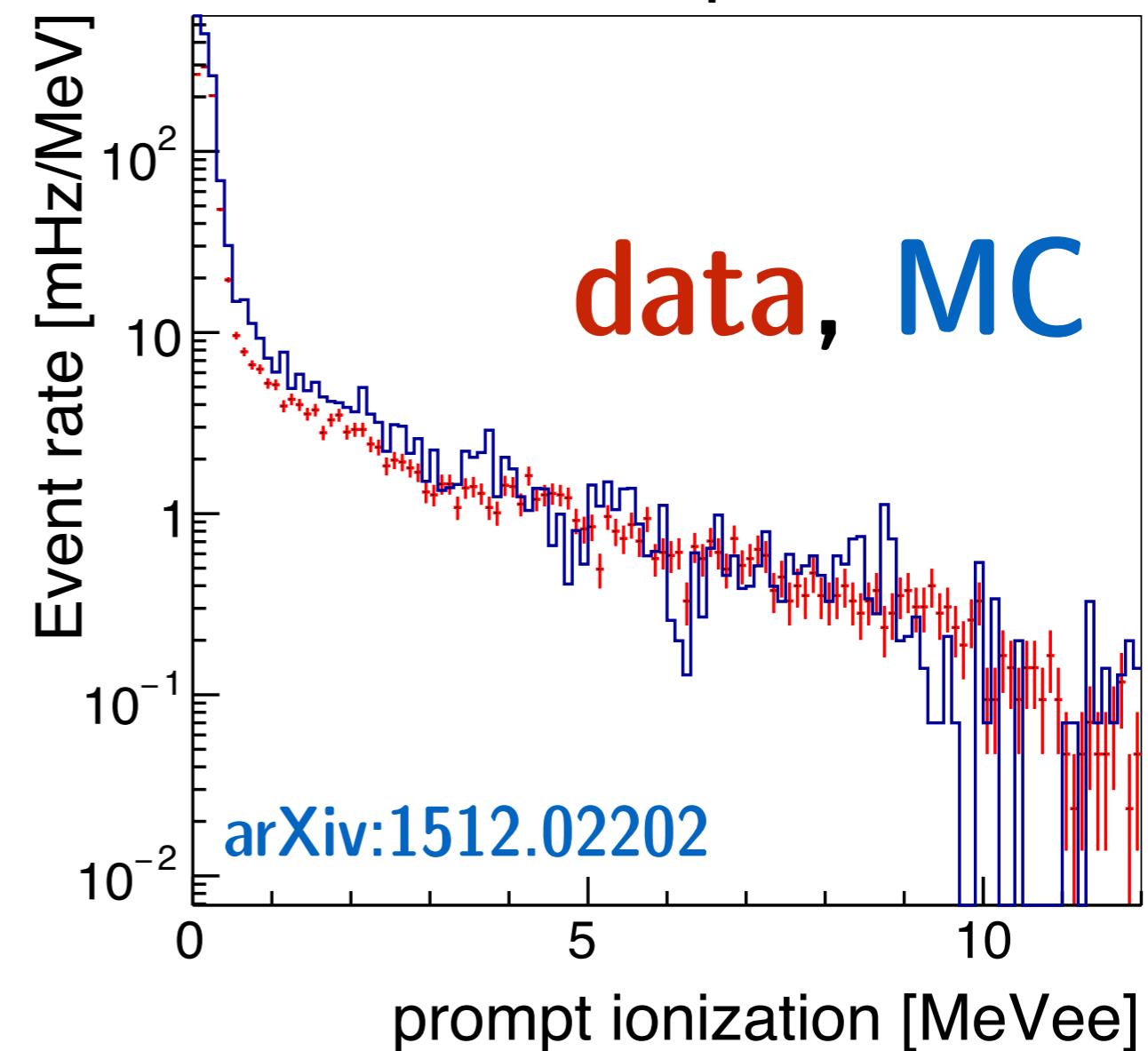


P20: full-sized cell



optical performance
>500 PE/MeV

P20 IBD-like spectrum



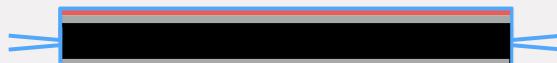
background model
benchmarking

P50: mechanical prototype

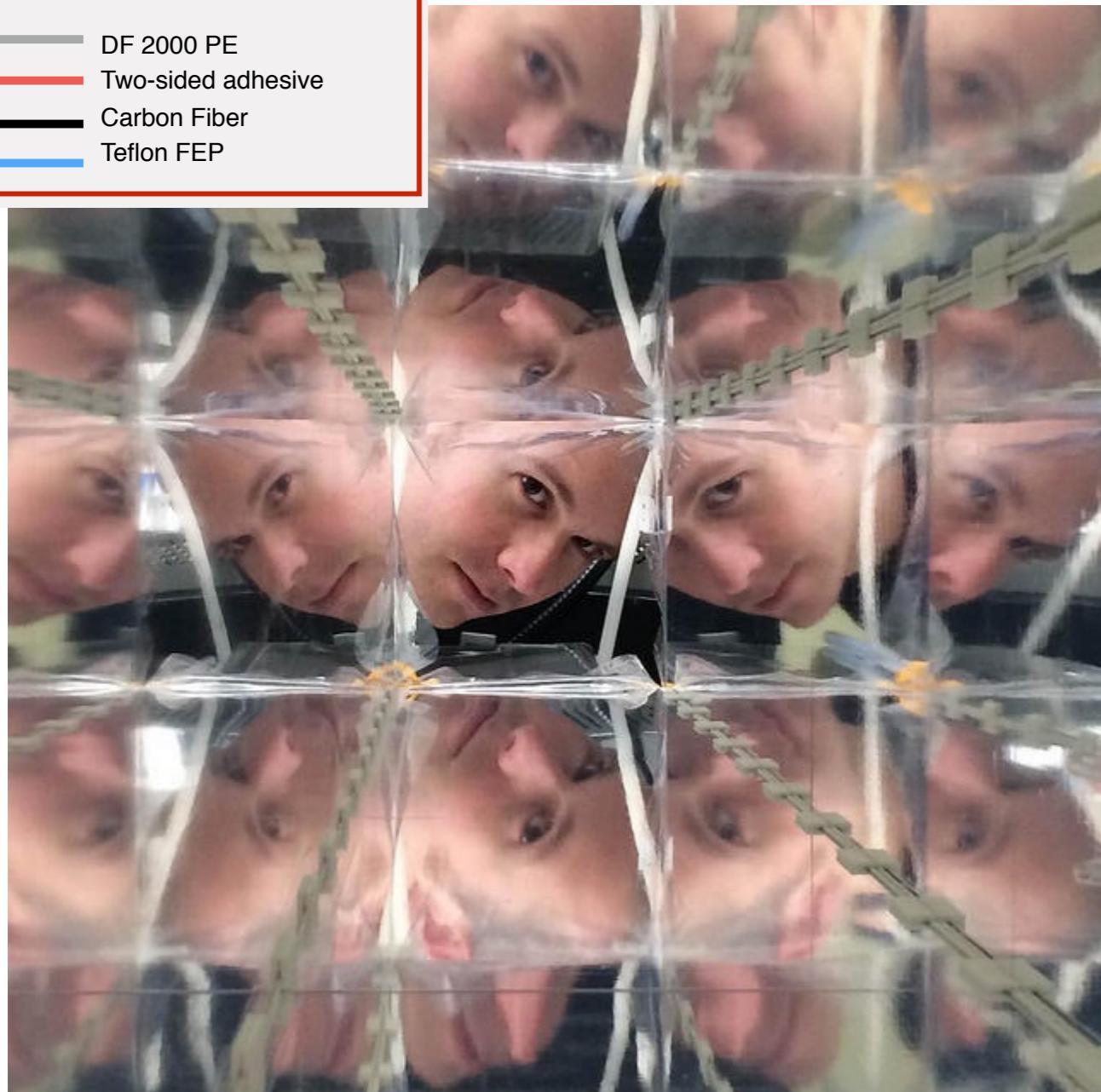


test/refine final
mechanical components
and assembly/operation
procedures





- DF 2000 PE
- Two-sided adhesive
- Carbon Fiber
- Teflon FEP

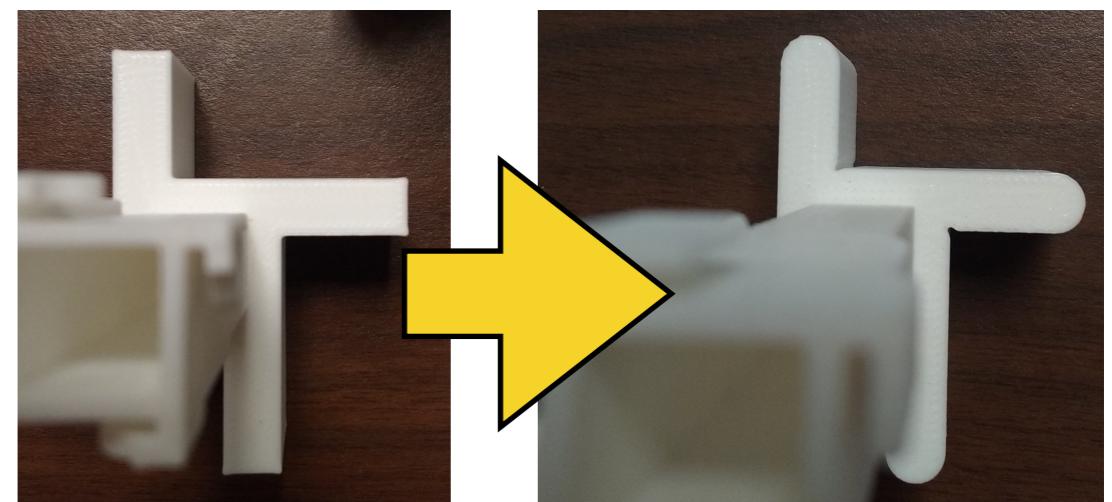


low-mass optical segmentation:
minimize energy losses
improve background rejection
decouple energy/position reconstruction for
L/E oscillation systematics

optical segmentation lattice

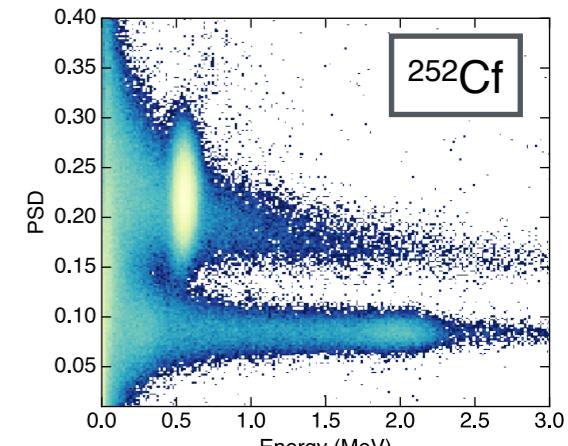
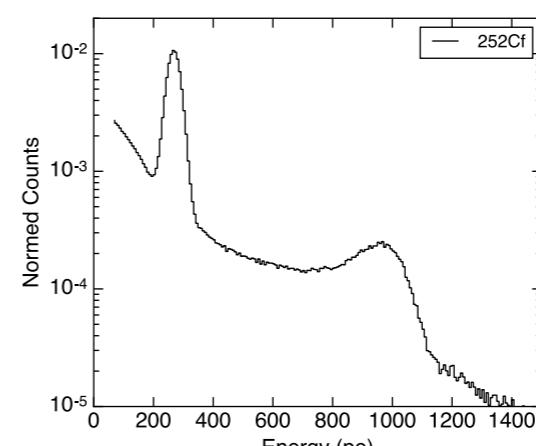
reflector panels joined
by “pinwheel” rods

3D-printed “pinwheel” rods
internal space for calibration sources



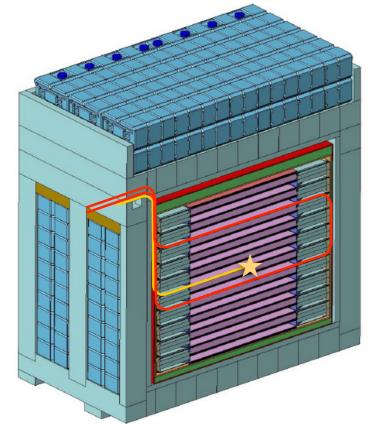
improve mechanical tolerances

good light yield, PSD performance

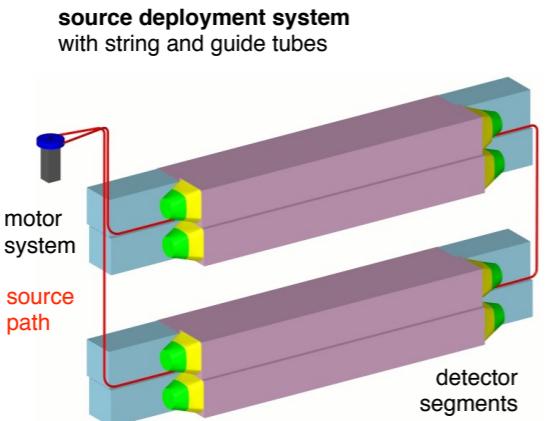


calibration systems

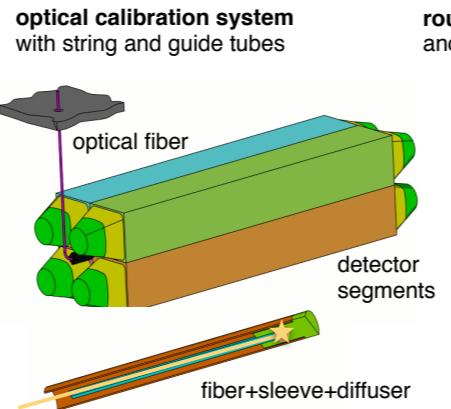
antineutrino detector
with **optical** and **source** calibration



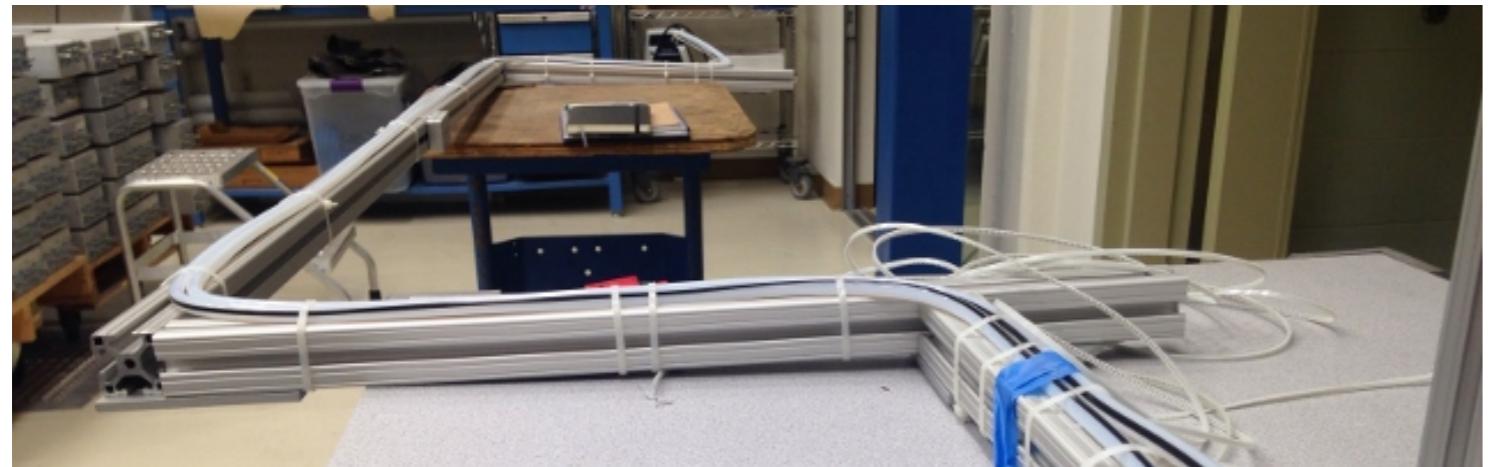
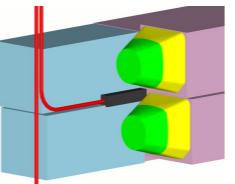
source deployment system
with string and guide tubes



optical calibration system
with string and guide tubes



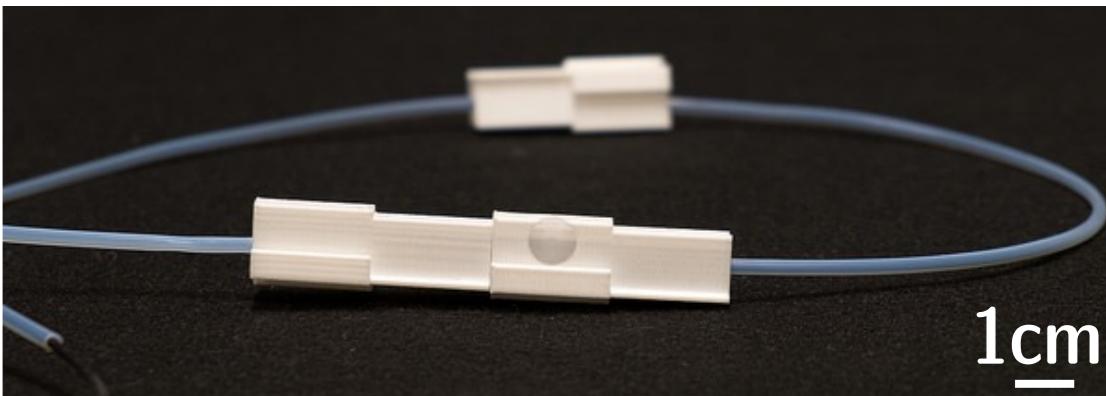
routing between segments
and PMT modules



source capsule tube

^{22}Na , ^{60}Co , ^{137}Cs , ^{207}Bi , ^{252}Cf , ...

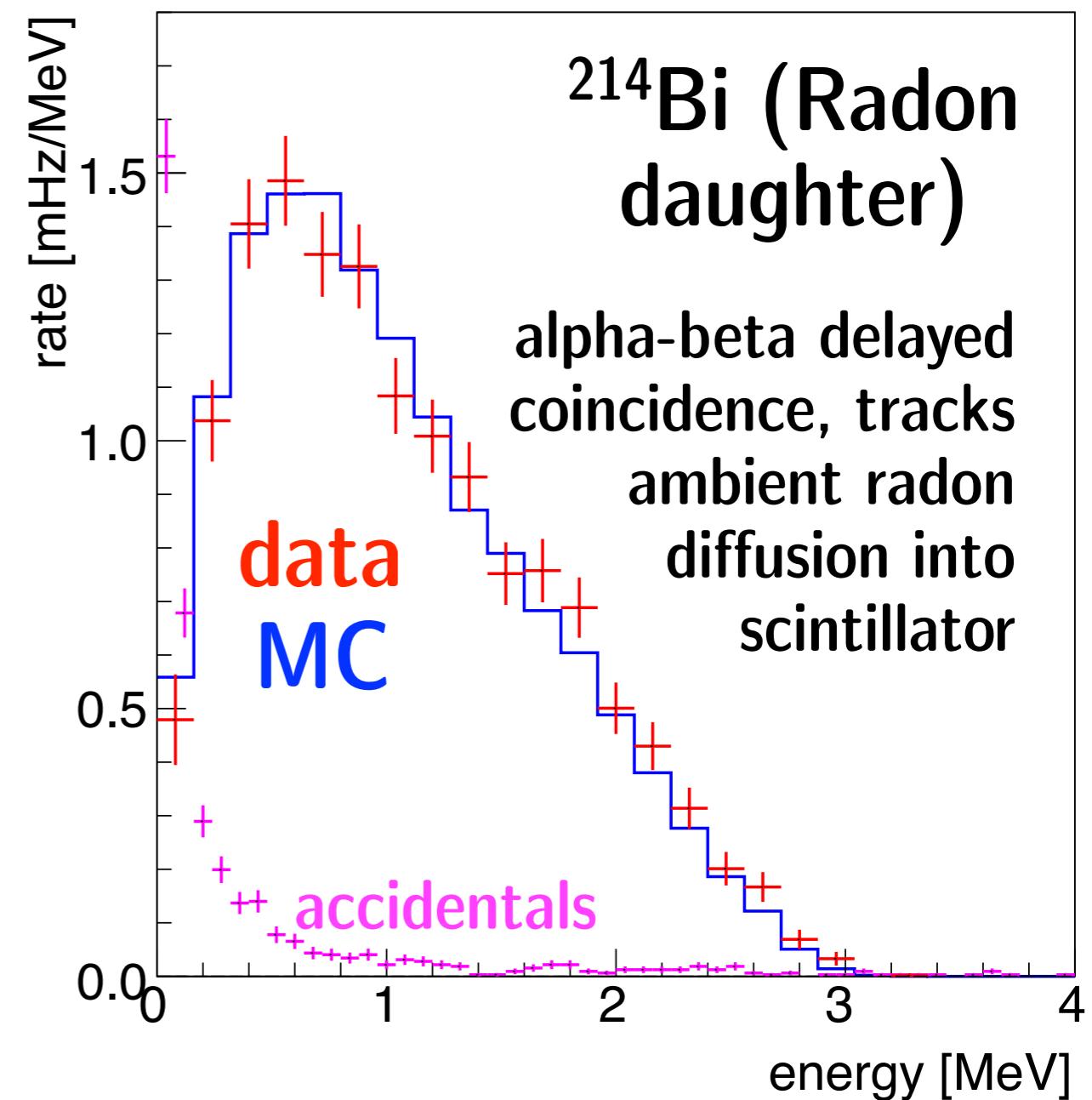
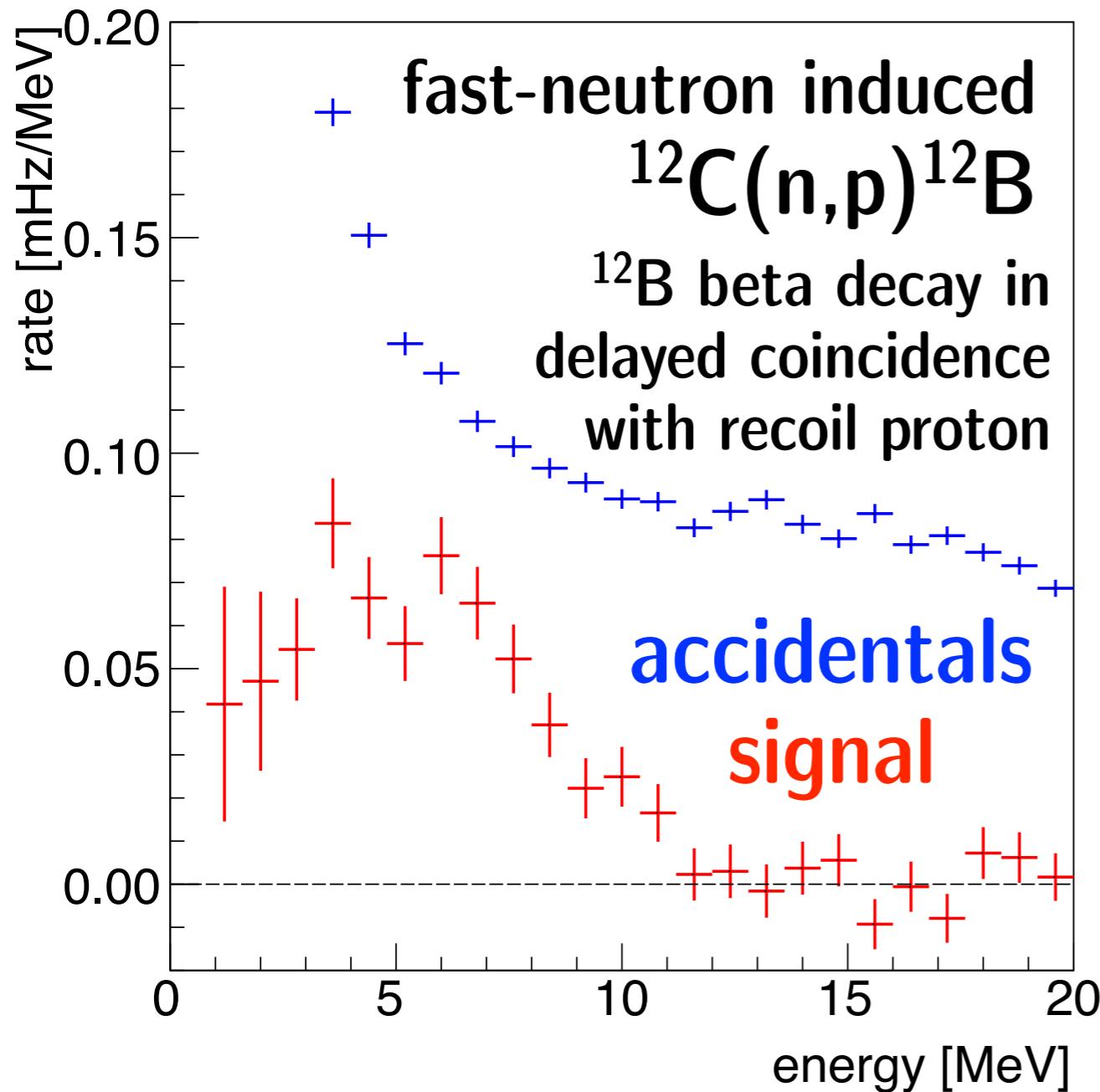
fiber splitter tests
for illuminated pinwheels



1cm

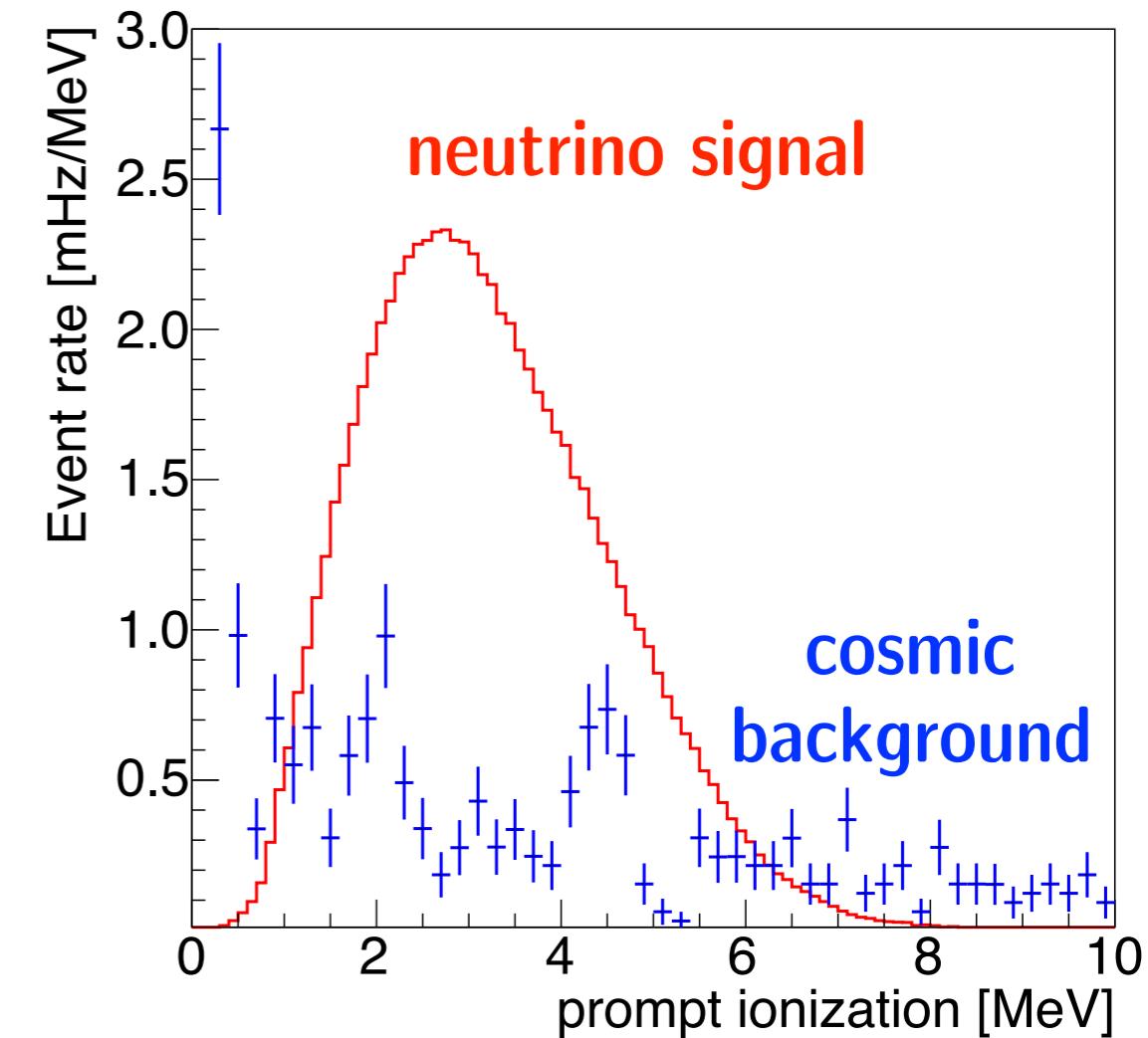
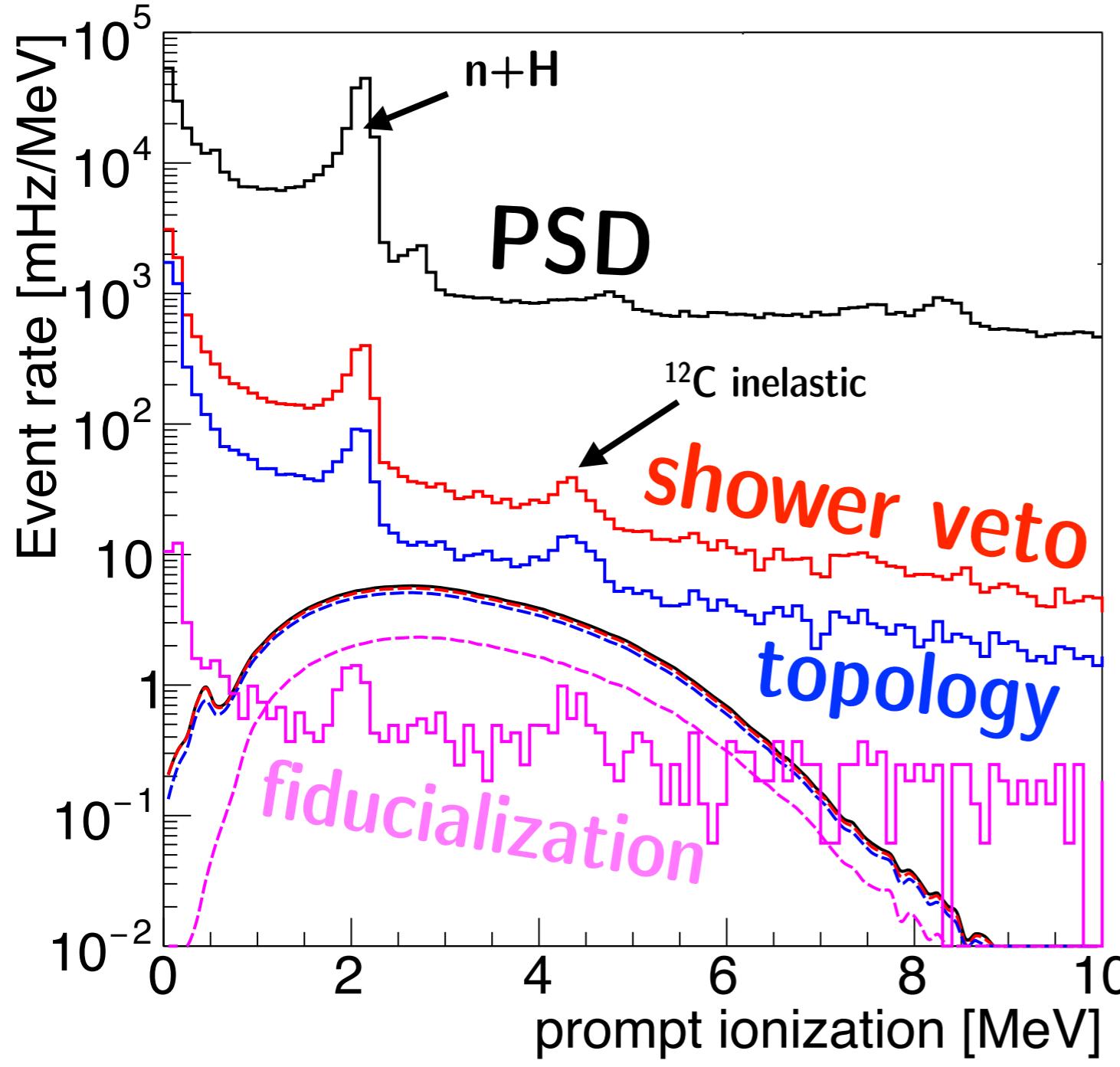
P50: time-correlated events

increased sensitivity to rarer interactions with distinctive delayed coincidences
potential applications for high-energy calibrations



Phase I background projections

arXiv:1512.02202



Expected IBD backgrounds primarily come from cosmic ray fast neutrons.

Segmentation + PSD gives strong fast neutron identification and veto.

Phase I AD shielding package

emphasis on cosmic neutron background reduction

water bricks

polyethylene

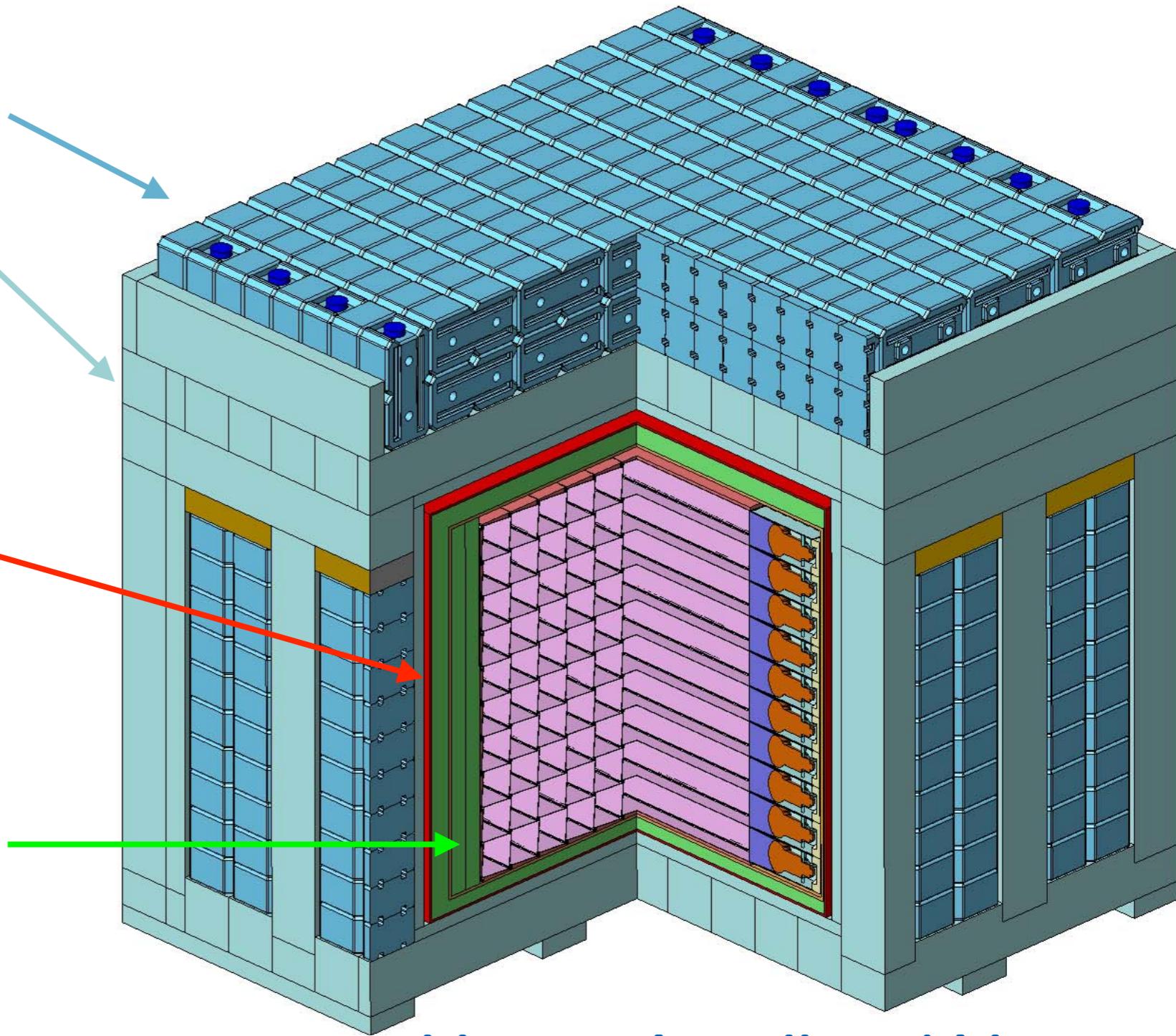
("top-heavy" neutron moderation layers)

lead

(dense all-purpose shielding)

borate poly

(spallation secondary neutron absorber)



movable on air pallet skids

conclusions

- need high-precision short-baseline reactor measurements for pressing questions in neutrino and reactor physics
- phased R&D in lab and deployment has proven technologies ready for AD-1 detector construction
- fast access to best-fit sterile neutrino hypothesis in first year of running
- high energy resolution for benchmark ^{235}U spectrum shape



For more details, see our posters:

Saturday, 6:00 pm

spectrum measurement (Xianyi Zhang)

sterile neutrino sensitivity (Karin Gilje)

experimental design (Pranava Surukuchi)

cosmogenic backgrounds (Bryce Littlejohn)

Monday, 6:30 pm

detector development (Tom Langford)

(Riverwalk A/B)