Yale
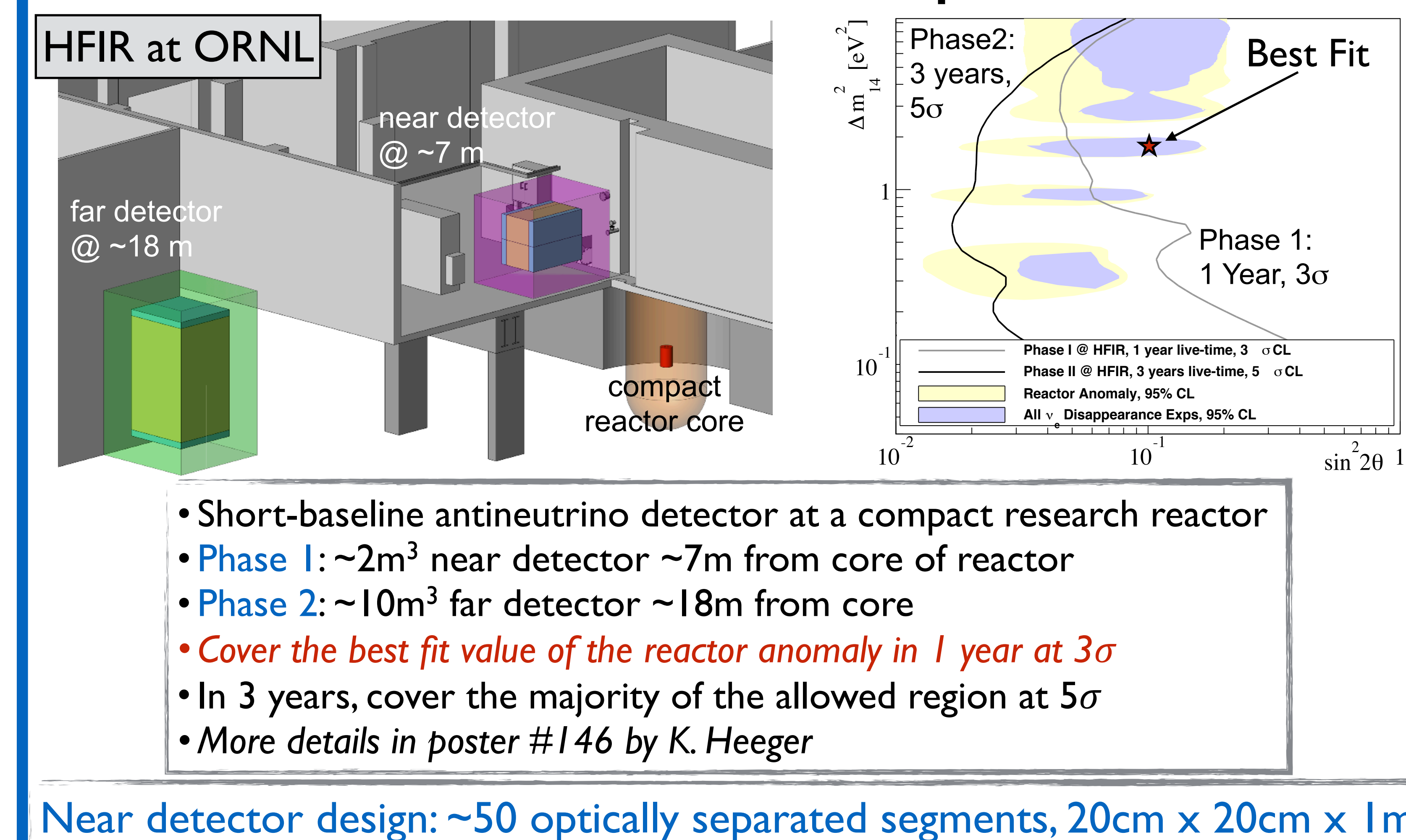
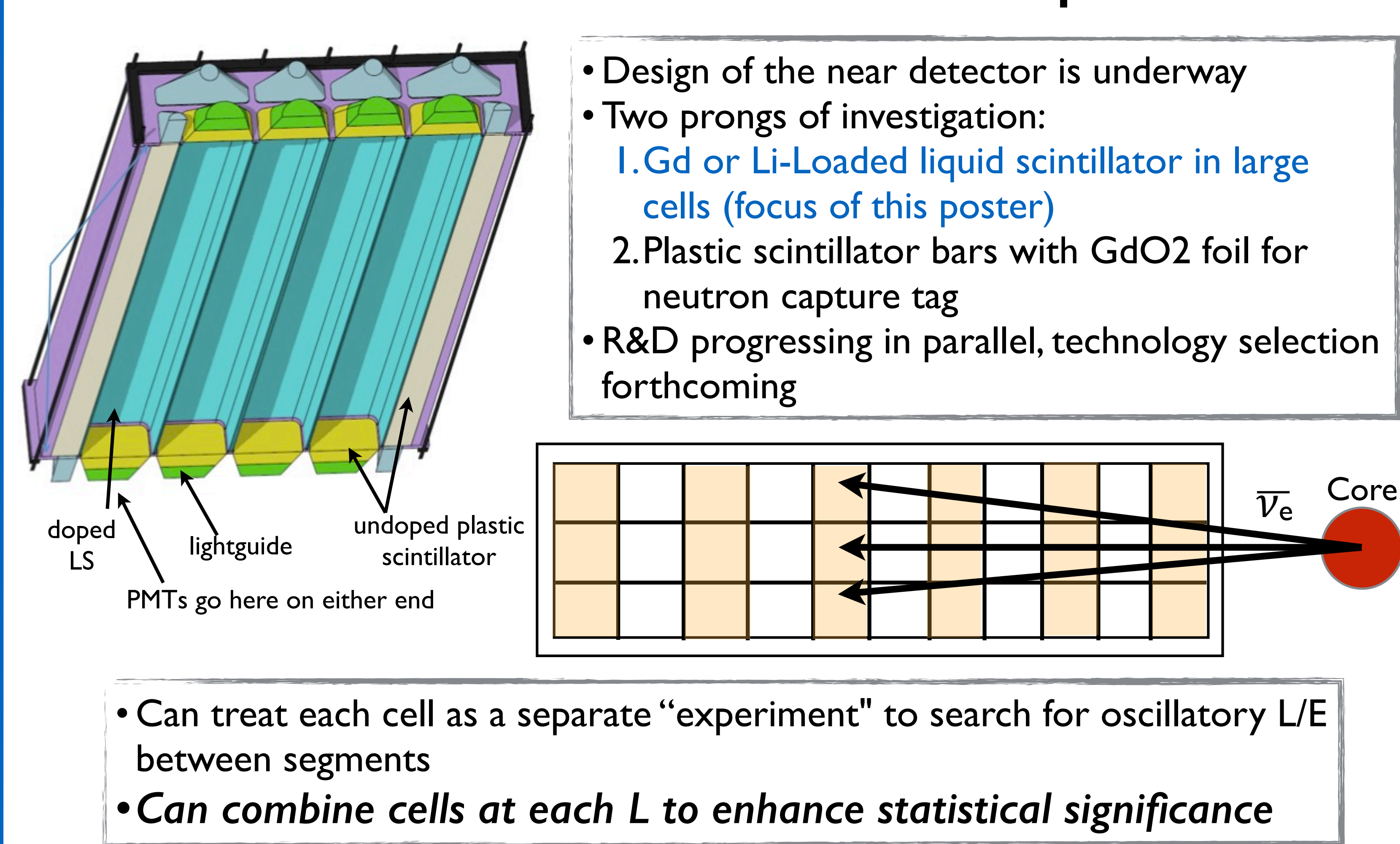# Scintillator Development and Characterization for PROSPECT

Thomas J Langford (Yale University), on behalf of the PROSPECT Collaboration

Abstract: Segmented antineutrino detectors placed near a compact research reactor provide an excellent opportunity to probe short-baseline neutrino oscillations and precisely measure the reactor antineutrino spectrum. Close proximity to a reactor combined with minimal overburden yield a high background environment that must be managed through shielding and detector technology. This poster will focus on the development and characterization of novel loaded scintillator for PROSPECT capable of neutron/gamma pulse shape discrimination and neutron capture tagging. These enhancements improve the ability to identify neutrino inverse-beta decays (IBDs) and reject background events in analysis. Results from these efforts will be covered along with their implications for an oscillation search and a precision spectrum measurement.

PROSPECT
A Precision Reactor Neutrino Oscillation and Spectrum Experiment

The PROSPECT Experiment

HFIR at ORNL
near detector @ ~7 m
far detector @ ~18 m
compact reactor core

- Short-baseline antineutrino detector at a compact research reactor
- Phase 1: ~2m³ near detector ~7m from core of reactor
- Phase 2: ~10m³ far detector ~18m from core
- *Cover the best fit value of the reactor anomaly in 1 year at 3σ*
- In 3 years, cover the majority of the allowed region at 5σ
- *More details in poster #146 by K. Heeger*

Near detector design: ~50 optically separated segments, 20cm x 20cm x 1m

Near Detector Concept

- Design of the near detector is underway
- Two prongs of investigation:
  1. Gd or Li-Loaded liquid scintillator in large cells (focus of this poster)
  2. Plastic scintillator bars with GdO2 foil for neutron capture tag
- R&D progressing in parallel, technology selection forthcoming

doped LS   lightguide   undoped plastic scintillator
PMTs go here on either end
$\overline{\nu}_e$ Core

- Can treat each cell as a separate "experiment" to search for oscillatory L/E between segments
- *Can combine cells at each L to enhance statistical significance*

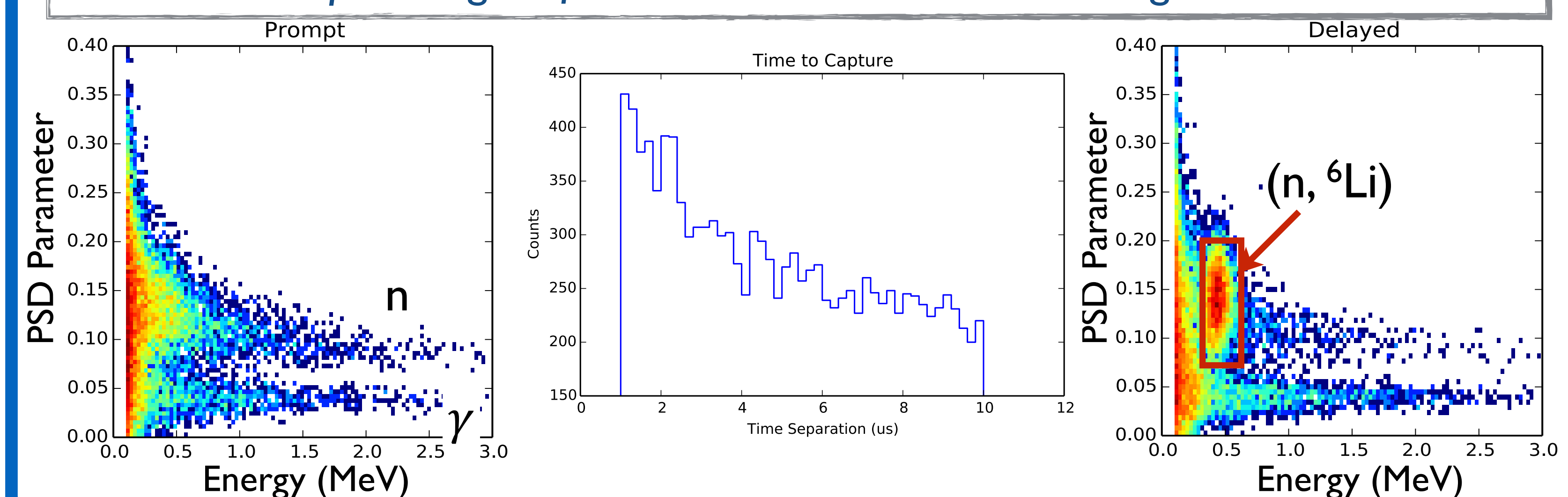## Pulse Shape Discrimination in Liquid Scintillator

- Neutron/Gamma PSD common in liquid scintillators, ex: NE-213, BC-501A
- Typically, these scintillators have low flash points and high toxicity
  - → *Not ideal for operating at a reactor*
- New LAB and DIPN based scintillators with good PSD and light yield are being developed
- Can be used to identify neutrino inverse beta decays through their PSD signatures (e-like prompt, n-like delay signal)
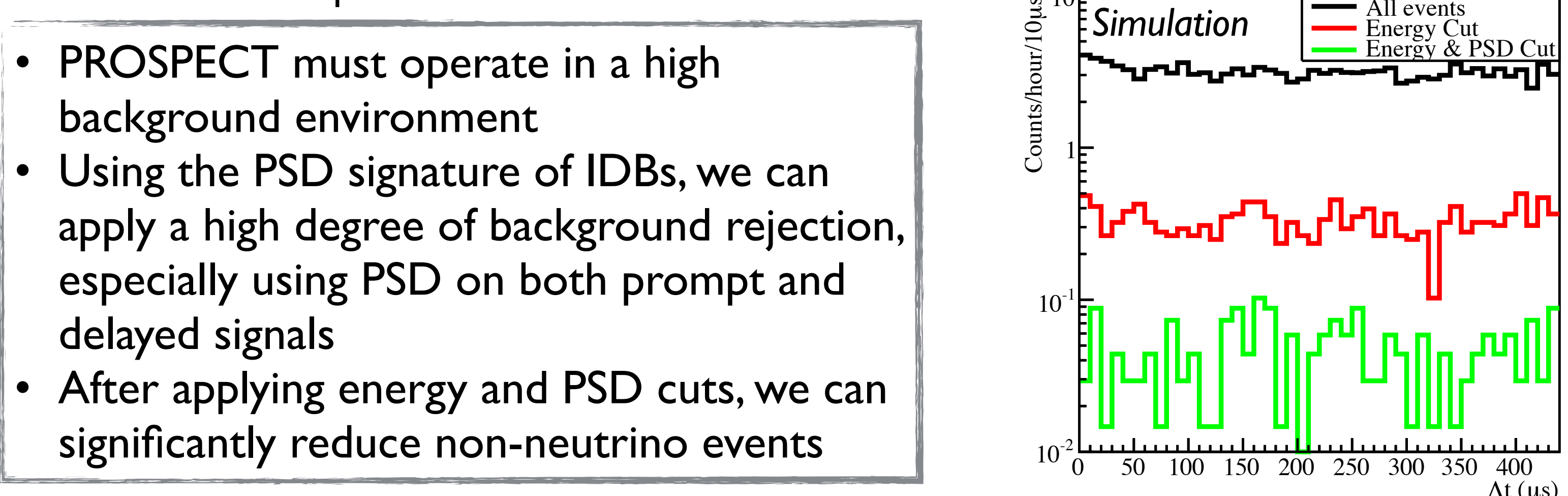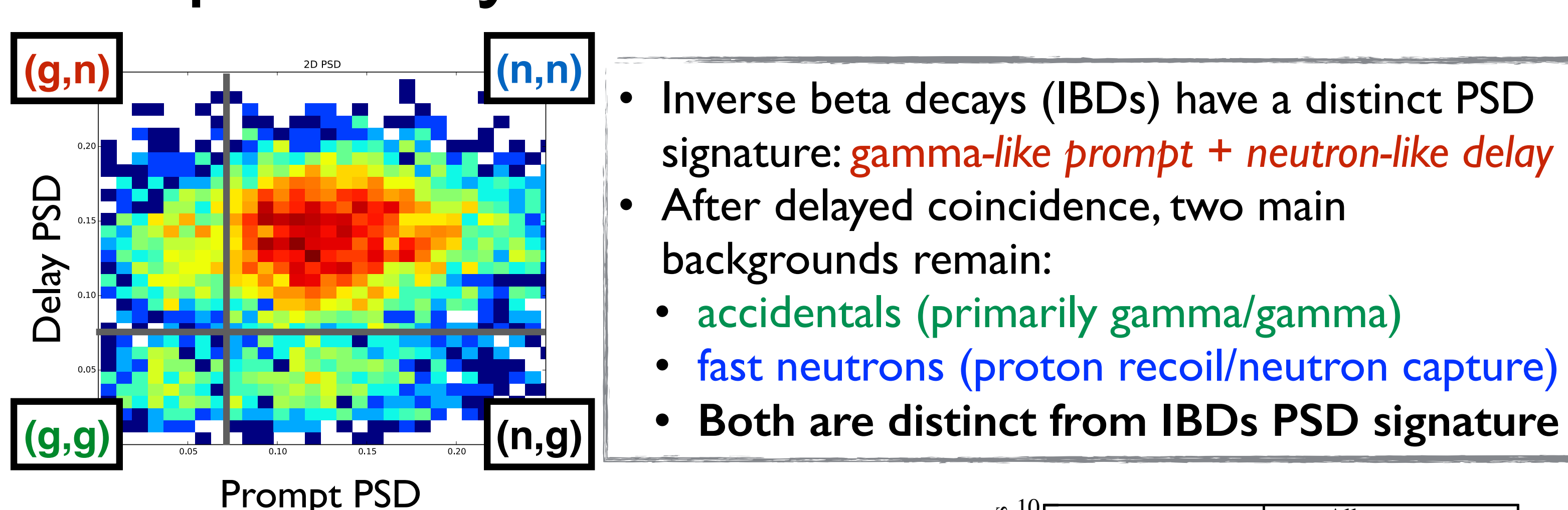

$PSD = Q_{tail}/Q_{full}$

EJ-309
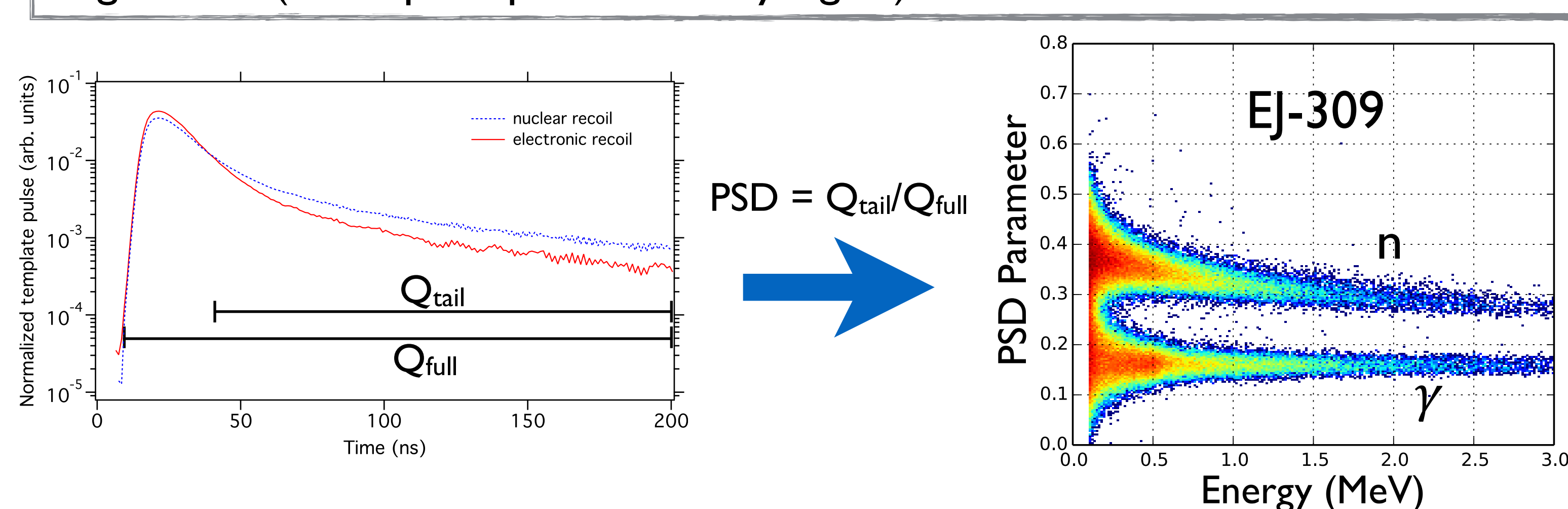
Li-Loaded DIPN Liquid Scintillator Neutron Capture Tagging

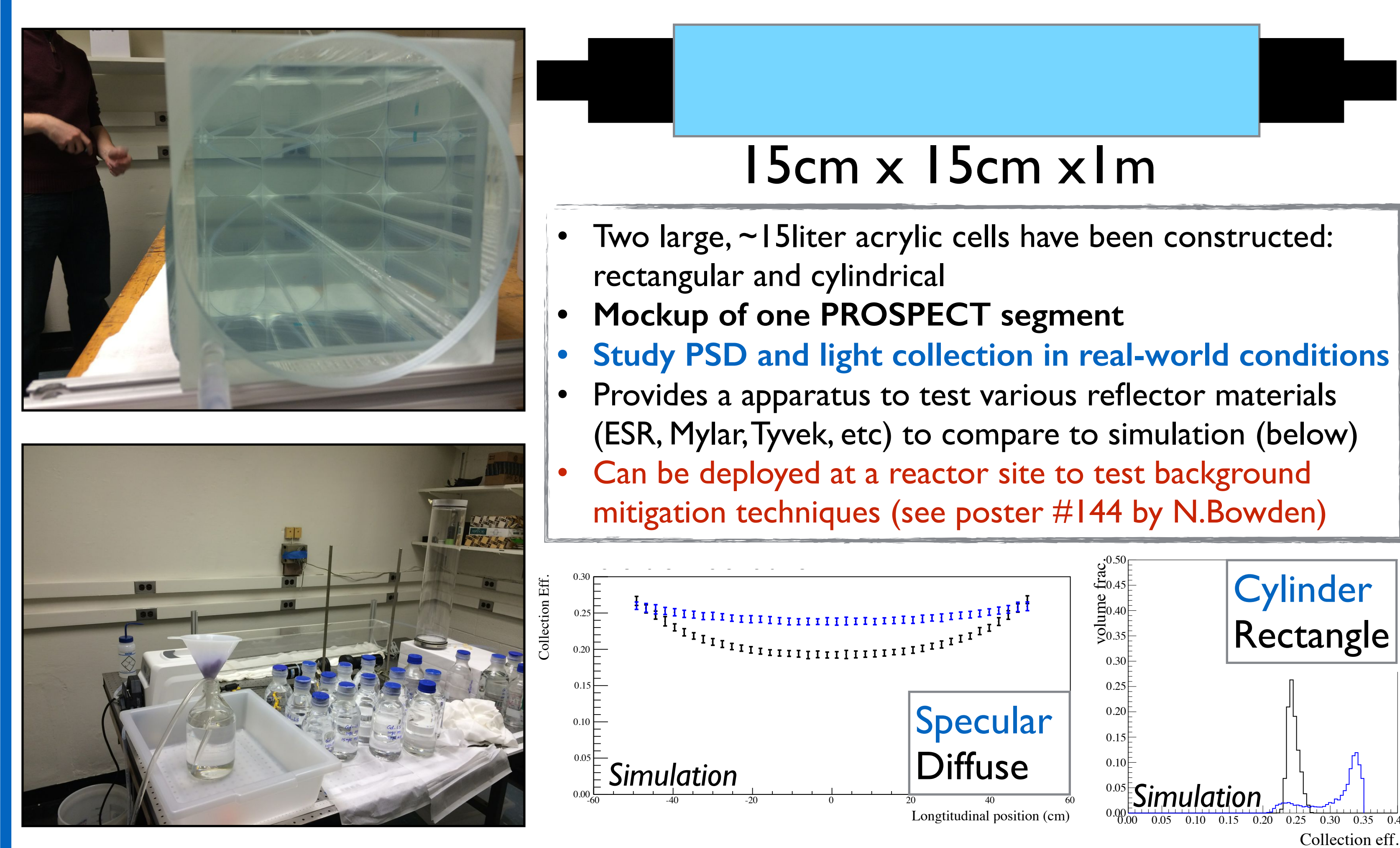$$n + {}^6\text{Li} \rightarrow \alpha + t + 0.5 \text{ MeV}_{vis}$$
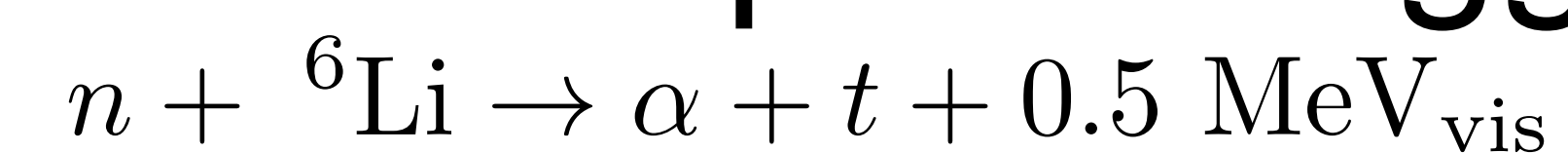
- Capture neutrons from IBDs with high-cross section dopant (Gd, B, Li)
- Time-correlated events → background rejection and subtraction
- *^{6}Li ideal for smaller detectors (charged particle final state vs γ's)*
  - *PSD on capture signal further reduces accidental backgrounds*

Prompt/Delay PSD Identification of IBDs

(g,n)   (n,n)
(g,g)   (n,g)
Delay PSD
Prompt PSD

- Inverse beta decays (IBDs) have a distinct PSD signature: gamma-like prompt + neutron-like delay
- After delayed coincidence, two main backgrounds remain:
  - accidentals (primarily gamma/gamma)
  - fast neutrons (proton recoil/neutron capture)
  - **Both are distinct from IBDs PSD signature**

- PROSPECT must operate in a high background environment
- Using the PSD signature of IDBs, we can apply a high degree of background rejection, especially using PSD on both prompt and delayed signals
- After applying energy and PSD cuts, we can significantly reduce non-neutrino events

Simulation
All events
Energy Cut
Energy & PSD Cut

Full-Scale Scintillator Cell Tests

15cm x 15cm x1m

- Two large, ~15liter acrylic cells have been constructed: rectangular and cylindrical
- Mockup of one PROSPECT segment
- *Study PSD and light collection in real-world conditions*
- Provides a apparatus to test various reflector materials (ESR, Mylar, Tyvek, etc) to compare to simulation (below)
- *Can be deployed at a reactor site to test background mitigation techniques (see poster #144 by N.Bowden)*

Specular   Diffuse
Simulation
Cylinder   Rectangle
Simulation

Wright Laboratory

Neutrinos
Dark Matter
Nuclear Structure
Relativistic Heavy Ions