Performance of the ROADSTR PSD Plastic Prototype Detector

Caiser Bravo *for the Mobile Antineutrino Demonstrator Project*
Georgia Tech
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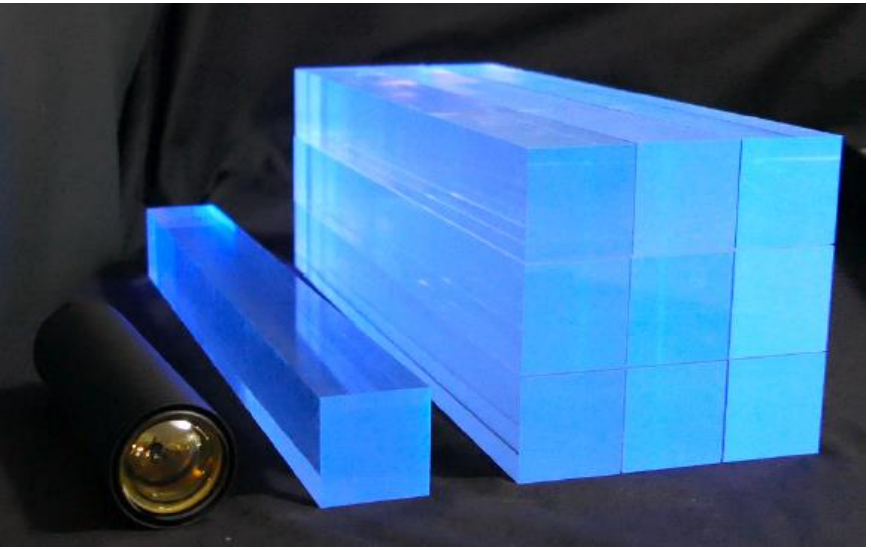

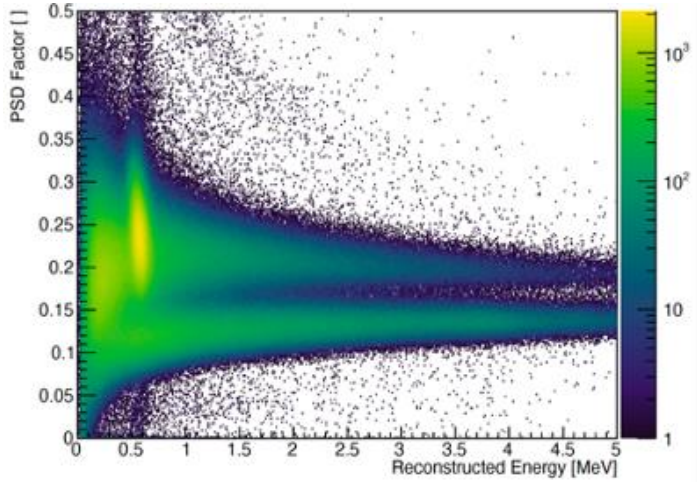

ROADSTR

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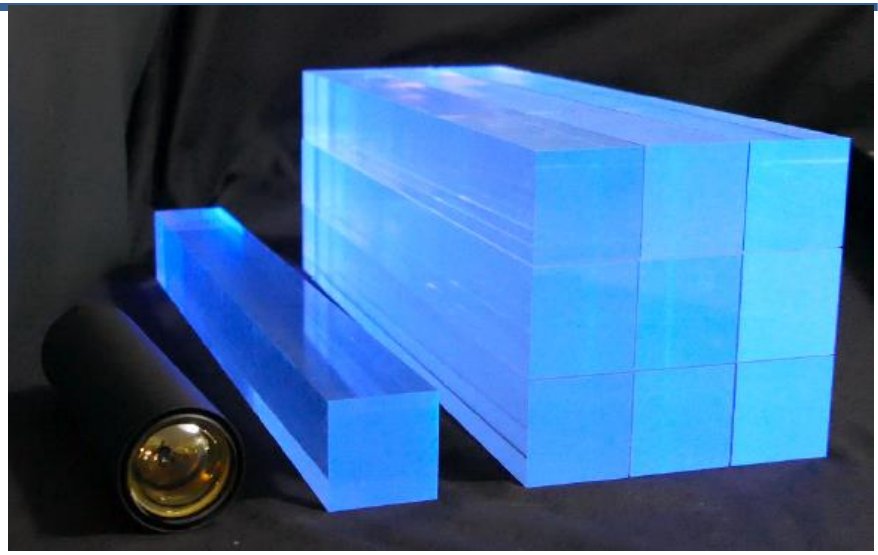
LLNL-PRES-854343
This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

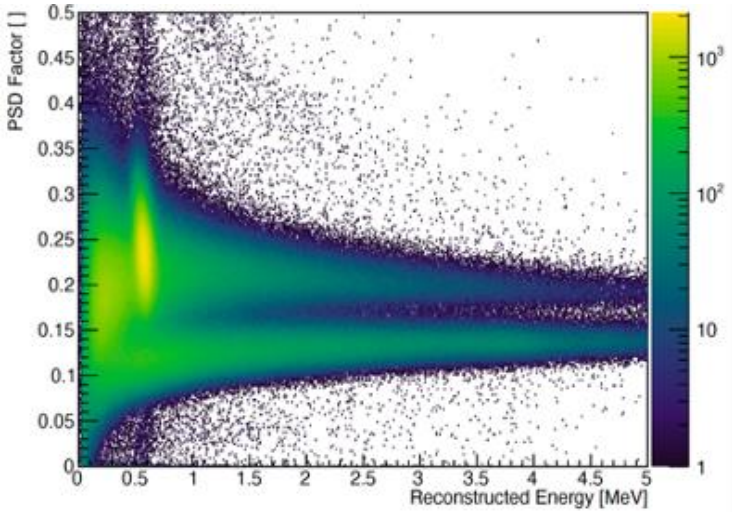
Motivation

Large-scale ^{6}Li-doped PSD plastic scintillators have recently been developed with Eljen Technology (EJ-299-50)

The ROADSTR Prototype is a testbed for:

- Demonstrating these materials for Inverse Beta Decay (IBD) detection
- Understanding and modeling neutron-correlated IBD backgrounds
- Long-term testing and validation of EJ-299-50 material





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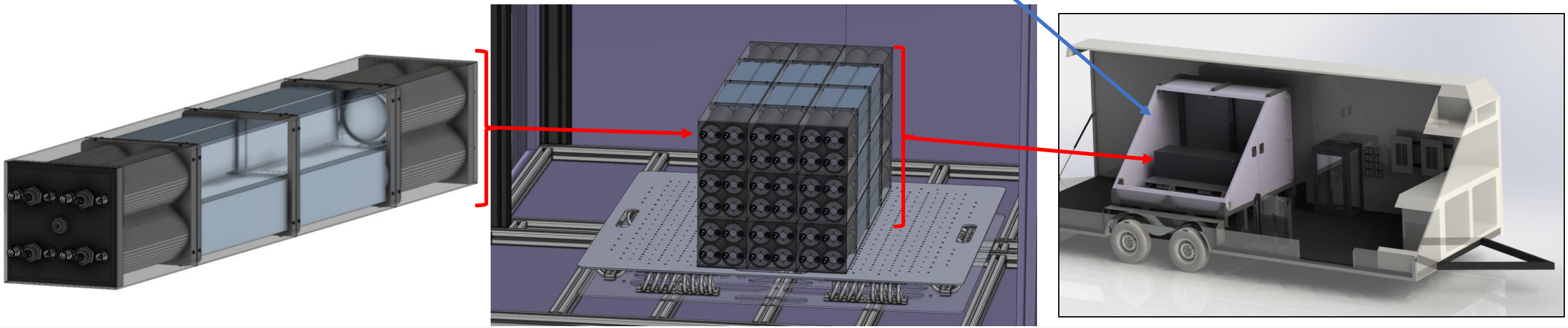
ROADSTR Prototype ^{6}Li PSD Plastic Detector

- 6x6 array of EJ-299-50 ^{6}Li PSD plastic bars with double ended PMT readout
  - Optically coupled to Hamamatsu 2" PMT (R7724-100, H11284-100 Assembly)
  - Wrapped with 'ESR' multi-layer specular reflector
- Bar size: 55 x 55 x 500 mm^3 (1.5 liter)
- Bars packaged in 2x2 modules with 0.8mm Al walls
- 60-kg active mass – largest ^{6}Li PSD plastic scintillator detector operated so far
- Operated in trailer with 2" borated poly thermal neutron shield



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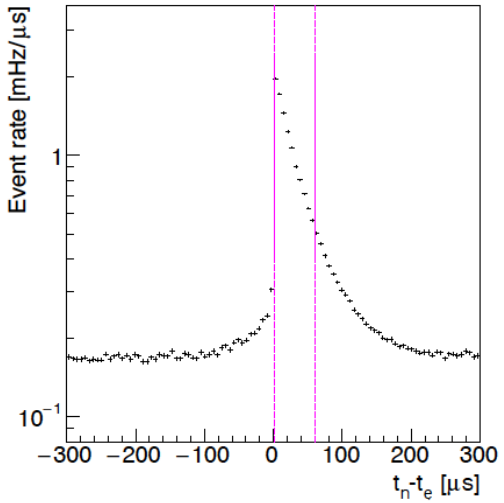
ROADSTR Inverse Beta (Neutron Correlated) Event Selection

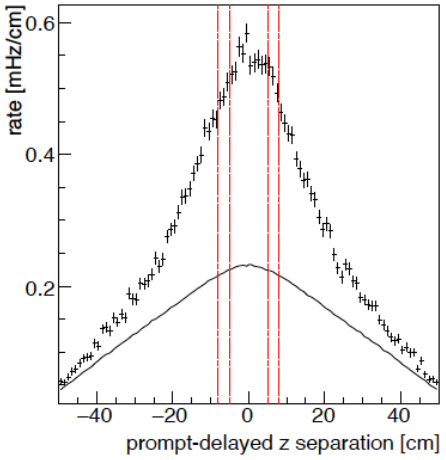
- Apply "PROSPECT-like" correlated selection:
  - *Prompt-Delayed timing separation*
  - *Prompt-Delayed position separation*
  - *Prompt PSD cut to reject fast neutrons*
  - *Delayed PSD cut to select neutron captures*
  - *Vetos on muon, fast neutron, and neutron capture events*

Prompt-Delayed timing

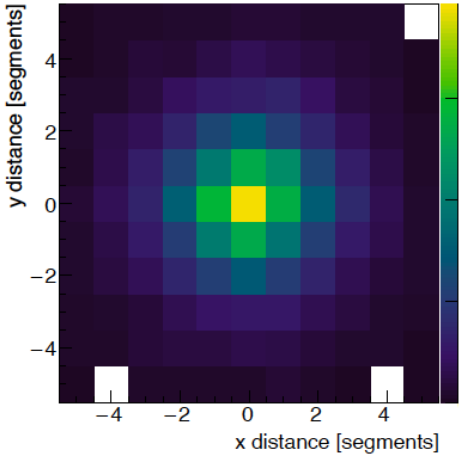


Prompt-Delayed Separation

z-axis (along bar)

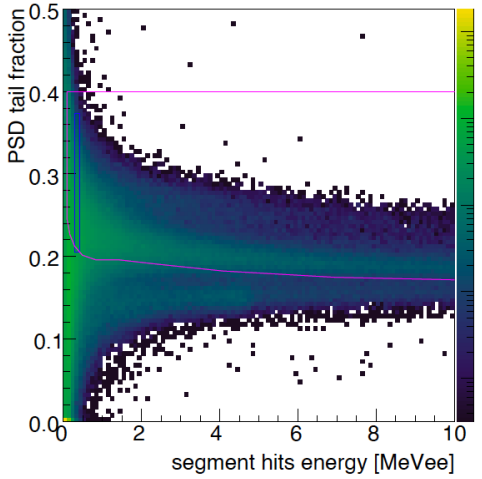


x-y (between bars)



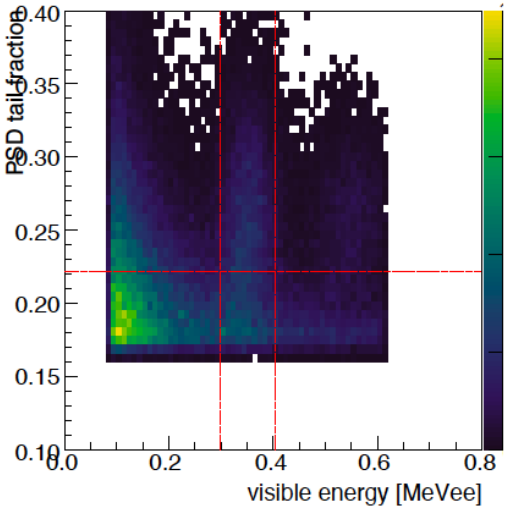
Prompt PSD

- reject fast neutron



Delayed PSD

- select neutron capture



Large scale system has demonstrated excellent selectivity relevant to antineutrino detection, fission correlations, …

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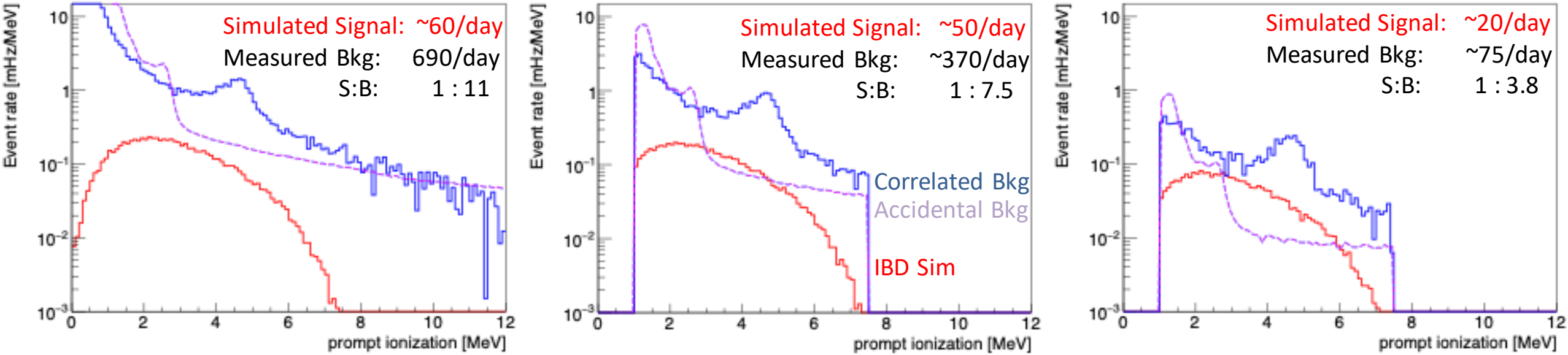
ROADSTR Aboveground IBD Background Measurement

- 44 days of background collected aboveground with 5-cm B-poly shield
- PROSPECT-like IBD selection gives promising background rejection
- Using topological information from finer segmentation provides further rejection
- Compared to simulated IBD rate 25 m from 3-GW_{th} reactor, good S:B for small 60-kg prototype

PROSPECT-like selections: timing, position, PSD, muon & neutron vetos → *+ energy depositions consistent with e^+ annihilation* → *+ spatial arrangement consistent with e^+ annihilation*



^{6}Li-doped PSD plastic supports PROSPECT-like background rejection; finer segmentation & topological selections can push further

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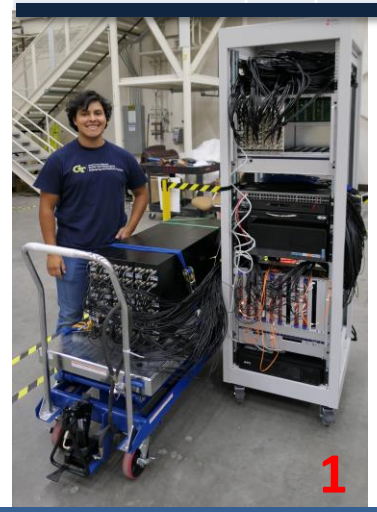
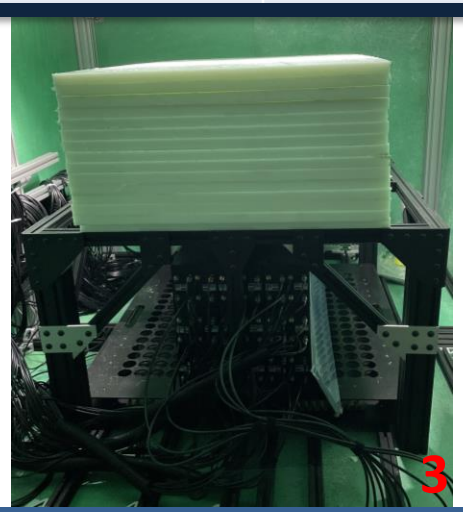
ROADSTR Correlated Neutron Background Measurements

Location	#	Shield	Motivation
Surface Highbay	1	Unshielded	Baseline configuration with minimal overburden and shielding
	2	Trailer and 5cm B-poly shield	Effect of small shielding layer + thermal background neutron suppression
	3	- plus 40.5cm of polyethylene above	Effect of larger shielding layer
	4	- plus high-Z material	Effect of neutron multiplication/spallation source
	5	- plus high-Z material & intervening B-poly	Effect of neutron multiplication/spallation source & thermal neutron suppression
Basement	6	Unshielded	Effect of shallow ~10 m.w.e. overburden





Varied measurements will support background simulation validation & development of background prediction capability

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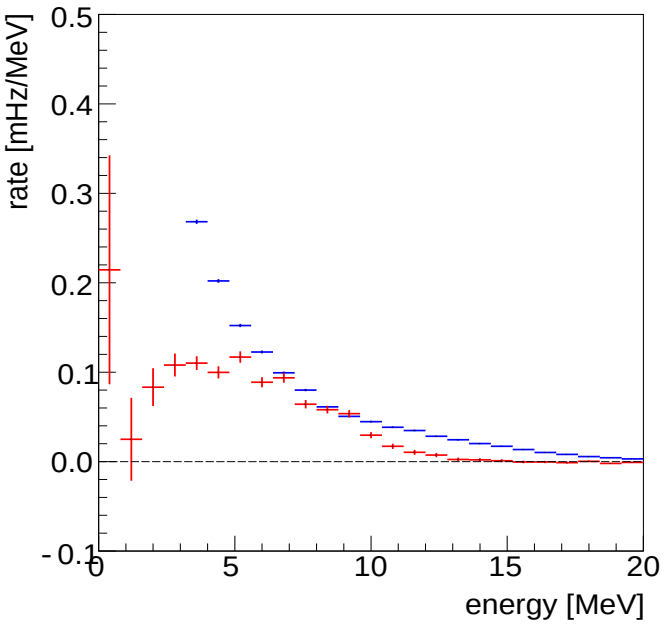
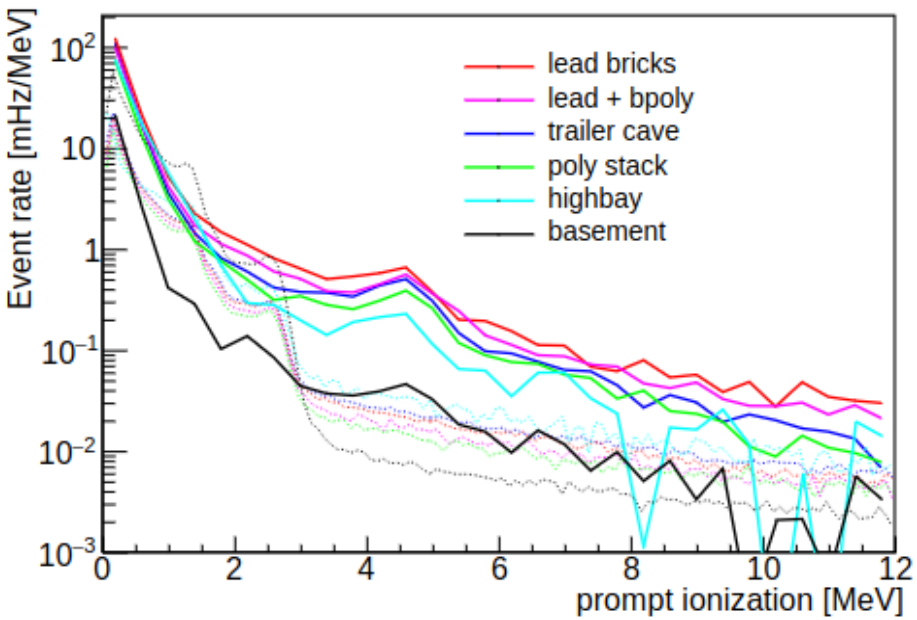
ROADSTR Correlated Neutron Background Measurements

- A variety of measurements have been conducted and processed
- Sensitivity to surrounding material, not only direct shielding, has been observed

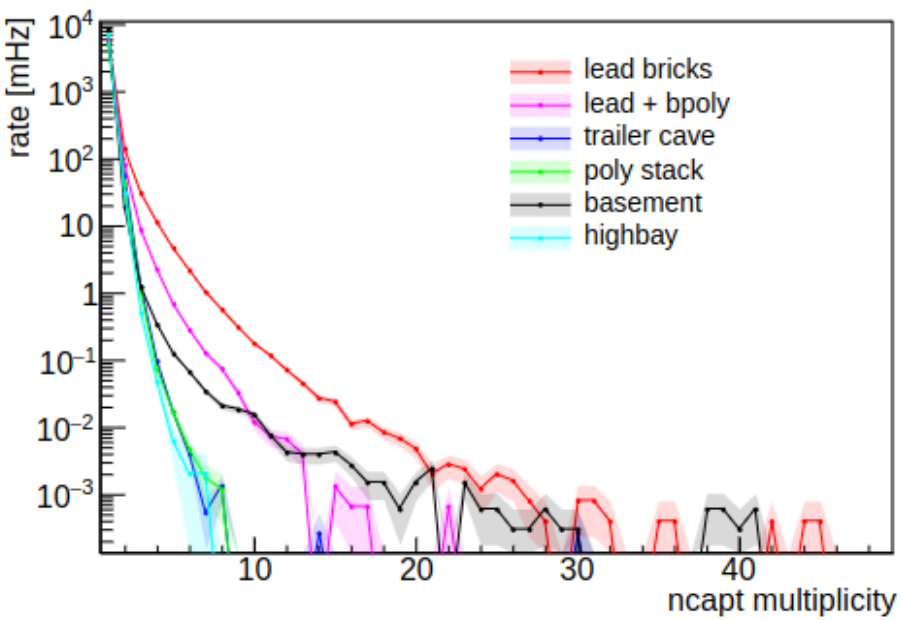
cosmogenic $^{12}C(n,p)^{12}B$



Inverse Beta Decay Background



Neutron Capture Multiplicity



Varied measurements will support background simulation validation & development of background prediction capability

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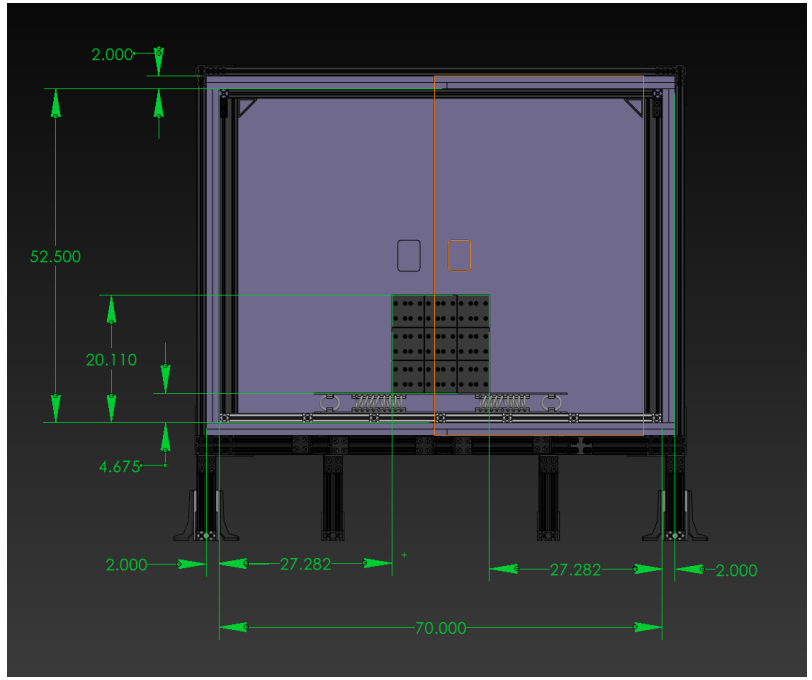
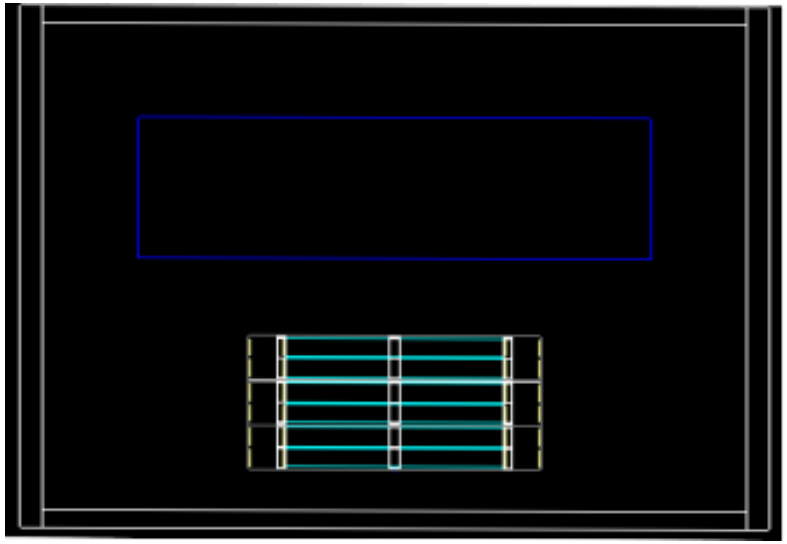
Performance Studies: Simulation Comparison

- Validated background simulation is an investment into more effectively conducting above-ground operations
- Simulated with Cosmic Neutrons and Cosmic Rays as our correlated background in GEANT4
- Characterize neutron mobility using "PROSPECT-like" correlated selection from events that are IBD-like
- Comparison of neutron lifetime to capture
- Shielding Cases
  - Polyethylene
  - Lead and 5% Borated Polyethylene
  - Lead

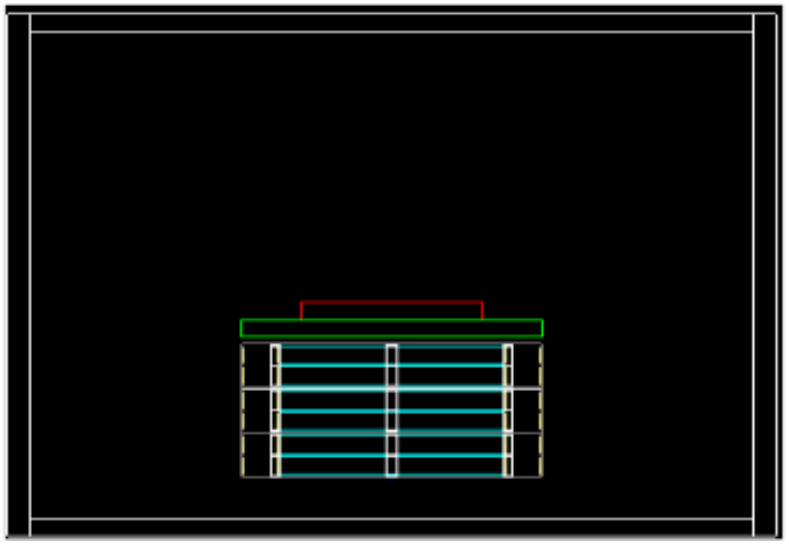


ROADSTR in trailer

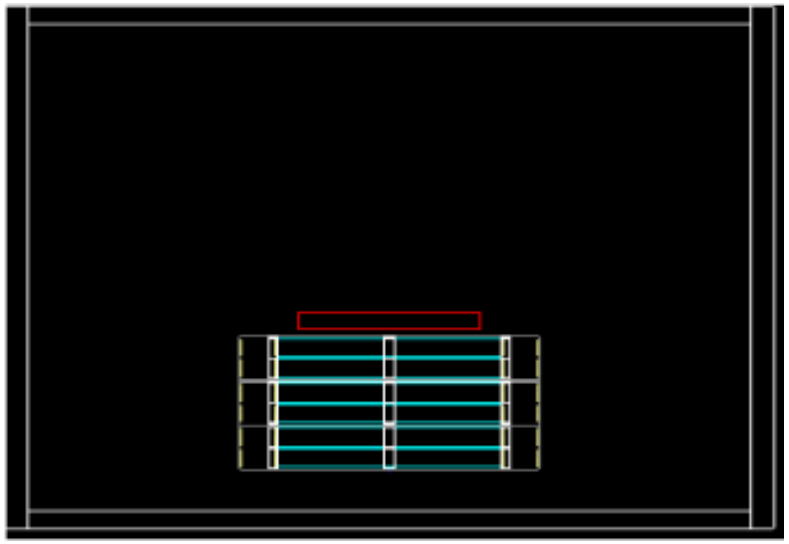
Performance Studies: Simulation



Polyethylene
[36” x 30” x 16”]



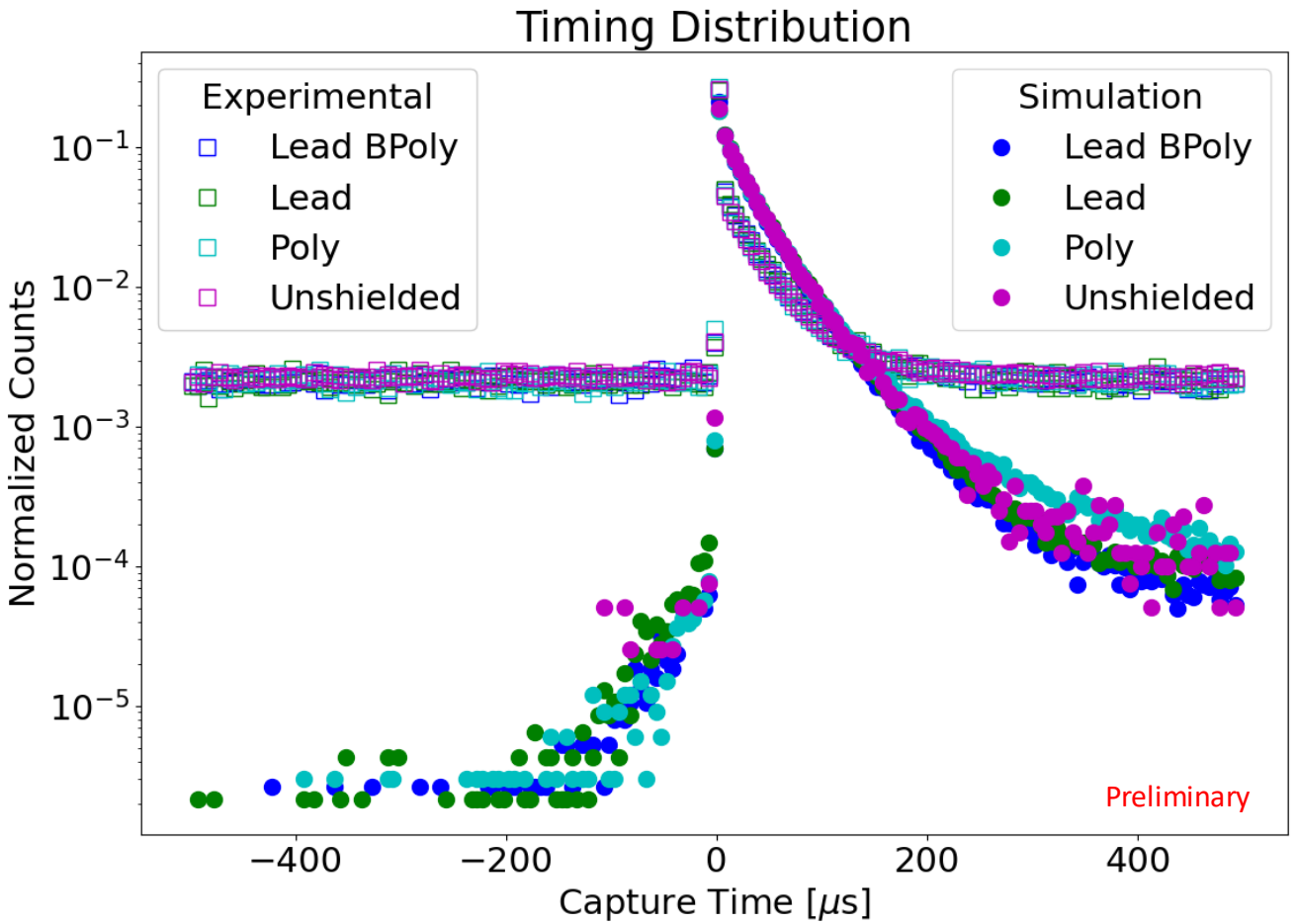
5% Borated Polyethylene
[15.2” x 26.2” x 2”]
Lead
[8” x 16” x 2”]



Lead
[8” x 16” x 2”]

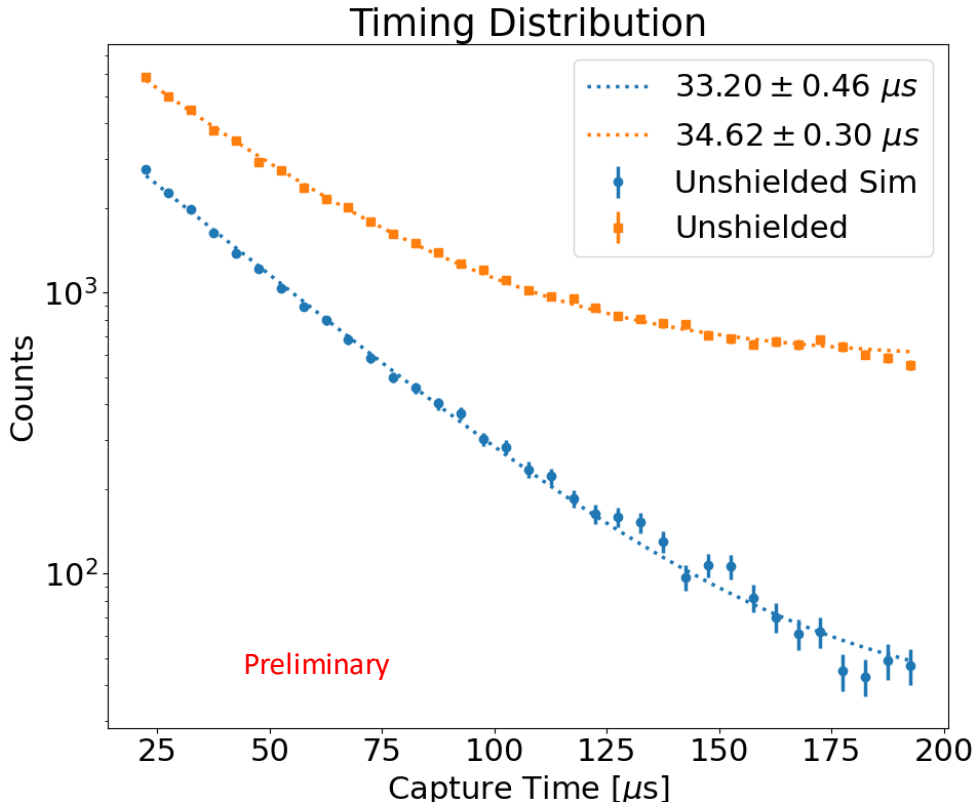
Neutron Lifetime Calculation

- Simulation is not normalized to count rate from acquired data
- Coincidence between prompt neutron and neutron capture in the system
- Single exponential fits applied
  - Investigate effects of neutron scattering
- Energy focused from 0 – 5 MeVee
- Time focused from 20 – 200 µs



Work in progress: simulation and data comparison

- Good agreement between data and simulation for neutron capture time across different configurations for a single-exponential fit



Configuration	Data	Simulation
Trailer and 5-cm B-poly shield	34.6 +/- 0.3 (μs)	33.2 +/- 0.5 (μs)
- plus 40.5cm of polyethylene above	34.0 +/- 0.7 (μs)	33.5 +/- 0.2 (μs)
- plus high-Z material	34.2 +/- 0.5 (μs)	34.6 +/- 0.2 (μs)
- plus high-Z material & intervening B-poly	33.6 +/- 0.4 (μs)	34.6 +/- 0.2 (μs)

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Conclusions

- ROADSTR successfully supports above-ground rejection of IBD-like background using ^{6}Li-doped PSD plastic scintillators.
- Various measurements have been taken to support background simulation validation & development of background prediction capability.
- Developed simulations show good agreement for neutron lifetime calculations.
- Greater characterization of neutron mobility will be performed to further validate background prediction capabilities with simulation.

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Thank you for your attention

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Lawrence Livermore National Laboratory
NIST
OAK RIDGE National Laboratory
VIRGINIA TECH
USNA UNITED STATES NAVAL ACADEMY
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National Nuclear Security Administration

ROADSTR Trailer Details

- Operated in trailer with 2” borated poly thermal neutron shield
- Trailer Dimensions in inches