Background Mitigation in the PROSPECT Short-Baseline Reactor Experiment and other Surface Detectors

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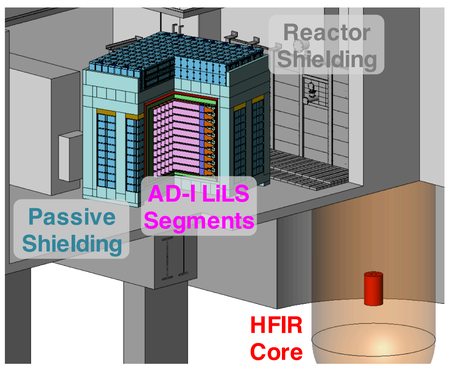
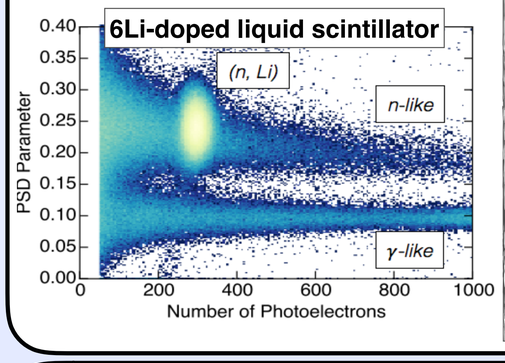
See also: P03.053, P03.055, P03.056

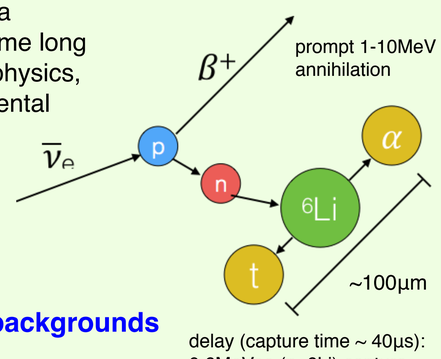
PROSPECT: The Precision Oscillation and Spectrum Experiment





PROSPECT will probe short-baseline oscillations & spectral distortions using a compact, segmented, high-resolution antineutrino detector

- Minimal (~1m) overburden and proximity to a reactor core (~10m) requires excellent control of backgrounds
- **Signal (Inverse Beta Decay) is *neutron-capture* correlated and low rate** (analogues in fast neutron spectroscopy, SNM detection, active/passive interrogation)
- Neutron capture can be a distinctive tag: capture time long compared to scattering physics, short compared to accidental rate.
- PSD allows for the separation of gamma-like and n-like events, as well as capture.

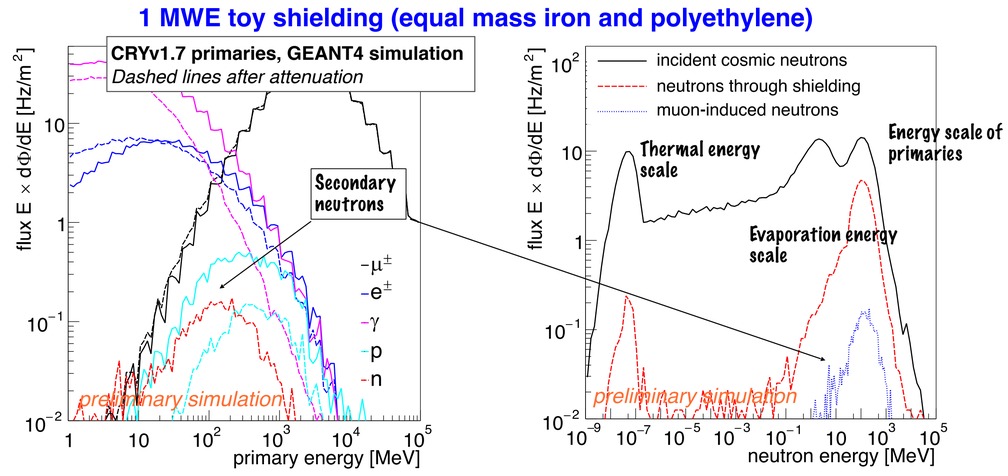


Implication: Relevant backgrounds involve a neutron (s)

Surface backgrounds have a significant (and critical) cosmic neutron component

The usual case with neutrino experiments is kilometer scale overburden. Only easily vetoed muons remain from the surface. Surrounding rock and radio-purity of detector critical.

1 MWE toy shielding (equal mass iron and polyethylene)



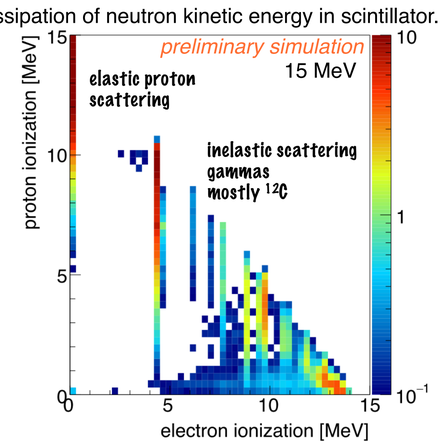
In near-surface experiments (~m scale overburden) primary neutrons are significant and cosmic ray induced neutron showers dominate over neutrons produced in detector shielding.

Neutron backgrounds are largely downward directed at higher energies. Can be very time-dependent, up to 10s percent. Depends on space weather, atmospheric depth, etc…

Fast neutrons penetrate shielding potentially yielding time and space correlated energy deposition

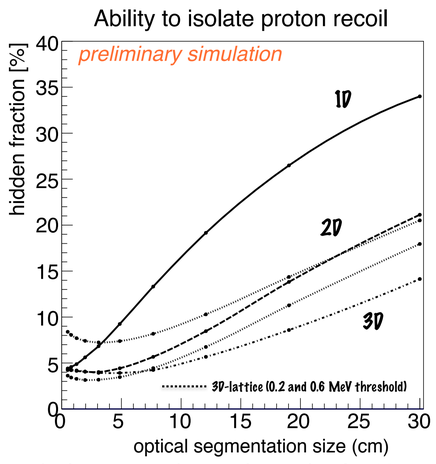
Neutral, shield-penetrating, neutrons above ~5 MeV can produce the prompt electron-like recoil with delayed-neutron-capture signature of an IBD through inelastic scattering. At lower energies, neutrons yield only elastic scatters that can be vetoed with PSD. Neutron spallation can create time correlated multi-neutron events.

Dissipation of neutron kinetic energy in scintillator.



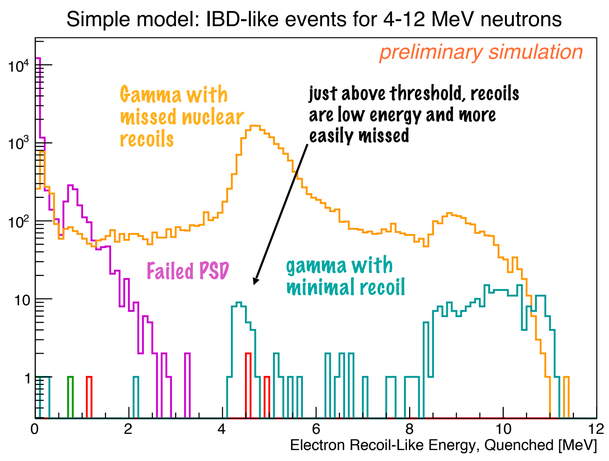
Energy split between between protons and inelastic gammas. Remainder goes to heavier recoils.

Ability to isolate proton recoil



optical segmentation on the scale of 5-10 cm allows physical separation of recoil and inelastic gammas

Simple model: IBD-like events for 4-12 MeV neutrons

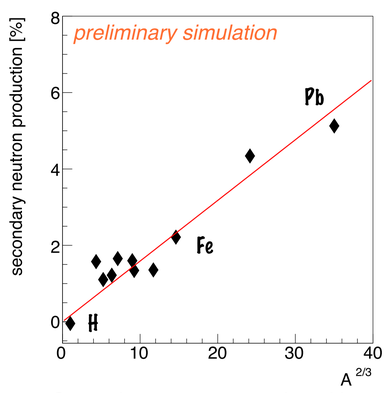


IBD-like events that miss selective cuts with toy model of bulk liquid scintillator detector

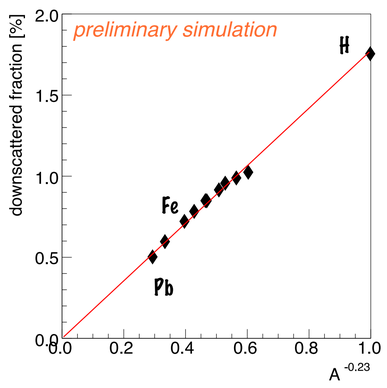
Length scale of IBD-like events is ~10 cm, detector must be capable of 'seeing' recoils (signature of non-IBD) against an electron-like component at this scale. That is, not allowing inelastic gammas 'mask' recoil signature.

Shielding

Strategy for neutron specific shielding: hydrogenous material best by mass, needed near fiducial volume to reduce secondaries.



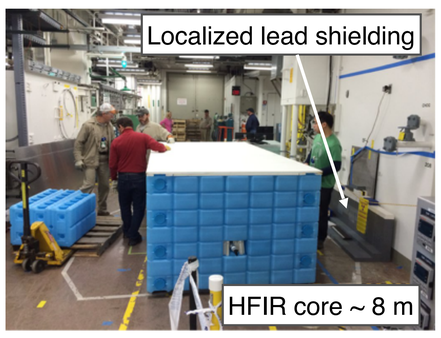
Secondary neutrons produced by 200MeV to 1GeV primaries passing through 1g/cm of material

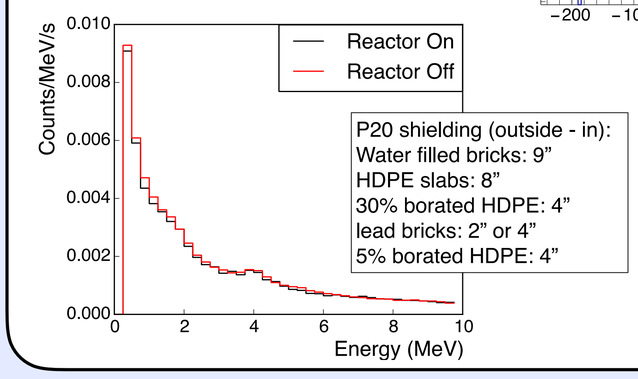


>= 10% energy loss in fastest emerging neutron) through 1g/cm of materials

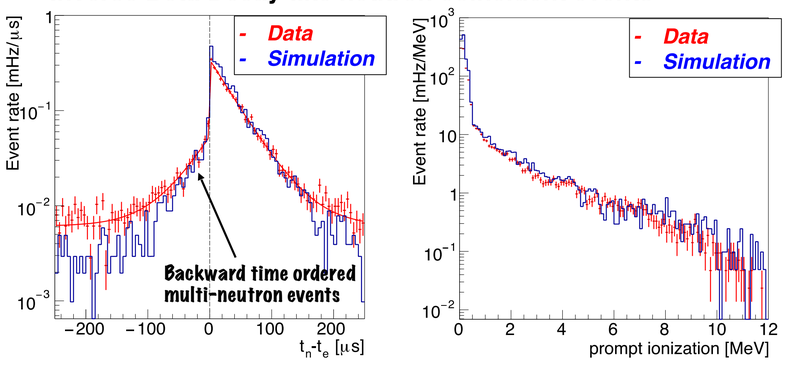
Interactions in high-Z shielding produce high-multiplicity neutron showers. Can be vetoed, or minimized by material choice. With nominal PROSPECT shielding, roughly half of neutrons that pass cuts are produced locally

PROSPECT-20: In situ validation of background models





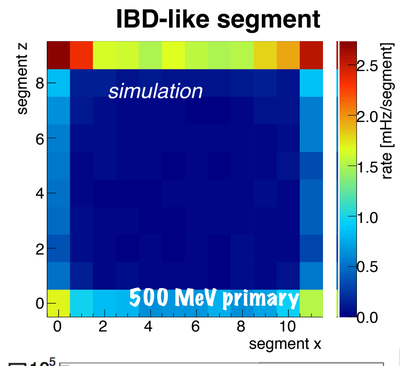
Inverse Beta Decay-like neutron coincident events

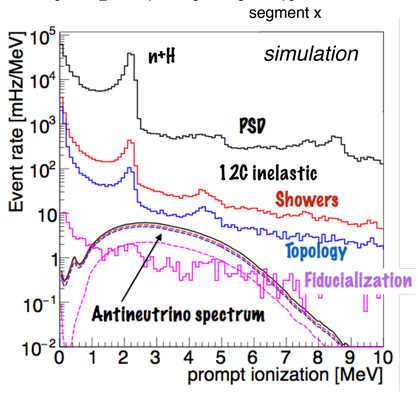


- **Background models validated in situ by a series of prototypes in both laboratory and reactor settings**
- **Monte Carlo matches data well (with minimal adjustments to overburden and capture time)**
- **Reactor-correlated backgrounds have minimal impact on "IBD-like" rate**

Fiducialization, PSD, and topology (Full PROSPECT)

IBD-like segment





Studies of Pulse Shape Discrimination (PSD) and topology suggest excellent signal to background and lessons for other detectors

Spatial topology:

- prompt and delayed signals proximate;
- multiple cell hits in the prompt signal must be compact (e.g. rejecting extended minimum ionizing tracks)
- events occurring outside the inner fiducial volume are vetoed (partial energy deposition reduces BG rejection).

Timing:

- delayed capture must occur within 100 μs of the prompt ionization (set by ~40 μs neutron capture time)
- multiple hits in the prompt cluster must occur within 5 ns (reject slower-moving neutron recoil events)
- events must be isolated from other neutron recoils or captures in a ±250 μs window, (reject multi-neutron spallation showers)

No single cut clearly isolates IBD events, yet a sequence of cuts leveraging the spatial and timing characteristics of an IBD reduces background several orders of magnitude and yields an expected signal to background of > 1:1.

Conclusions:

- **With reasonable detector and shielding choices surface backgrounds are dominated by cosmic fast neutrons.**
- **With PSD, key to background suppression is separating prompt electron-like component from heavier recoils.**
- **Length scales are 10s cm.**
- **A combination of PSD, topology, and fiducialization provides robust background suppression (i.e. PSD, light collection, segmentation, etc... can all be relaxed without significant degradation in performance.**
- **The surface deployed PROSPECT detector is projected to achieve a signal to background of better that 1:1**

PROSPECT Publications
arXiv: 1506.03547, 1508.06575, 1512.02202

http://prospect.yale.edu

P3.054