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Cosmogenic Background Characterization with PROSPECT

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for the PROSPECT collaboration

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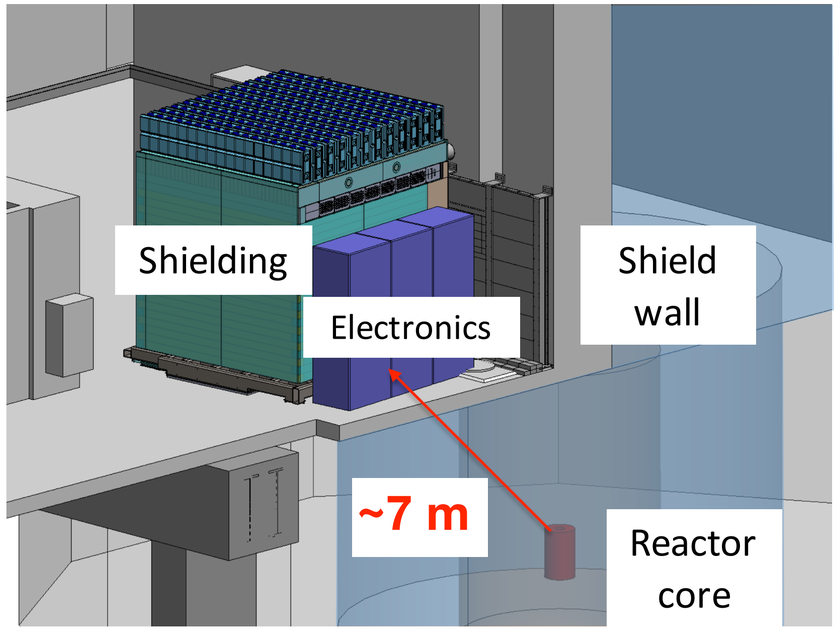
PROSPECT

Introduction

- Cosmogenic neutron background is one of the challenges in rare event detection experiments, especially for on surface experiments.
- Many experiments rely on simulation of cosmogenic or local neutron backgrounds.
- The PROSPECT detector is deployed to measure reactor antineutrino spectrum on-surface.
- The detector design and event selection strategy enables PROSPECT to measure cosmic background *in situ* and achieve our physics goal.

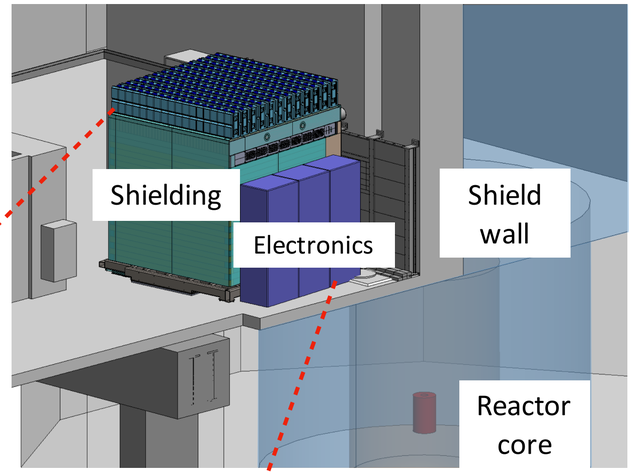
PROSPECT

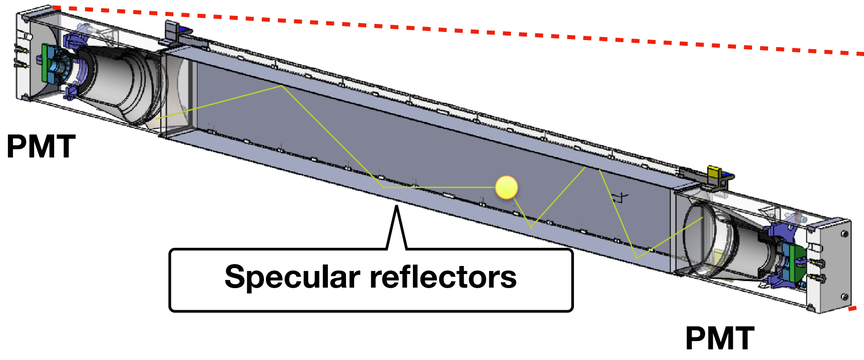
- **Experiment goals:**
  - Probe the ~1 eV sterile neutrino oscillation 7-9 m from the HFIR reactor.
  - Measure ^{235}U antineutrino spectrum.
  - Remote, and non-intrusive evaluation of reactor activity.
- **Reactor**: HFIR @ ORNL, 99% antineutrino from ^{235}U.
- **Detector:**
  - Optically segmented LS detector;
  - Detects IBD, 7-9 meter from the HFIR reactor;
  - 1 m.w.e. overburden.

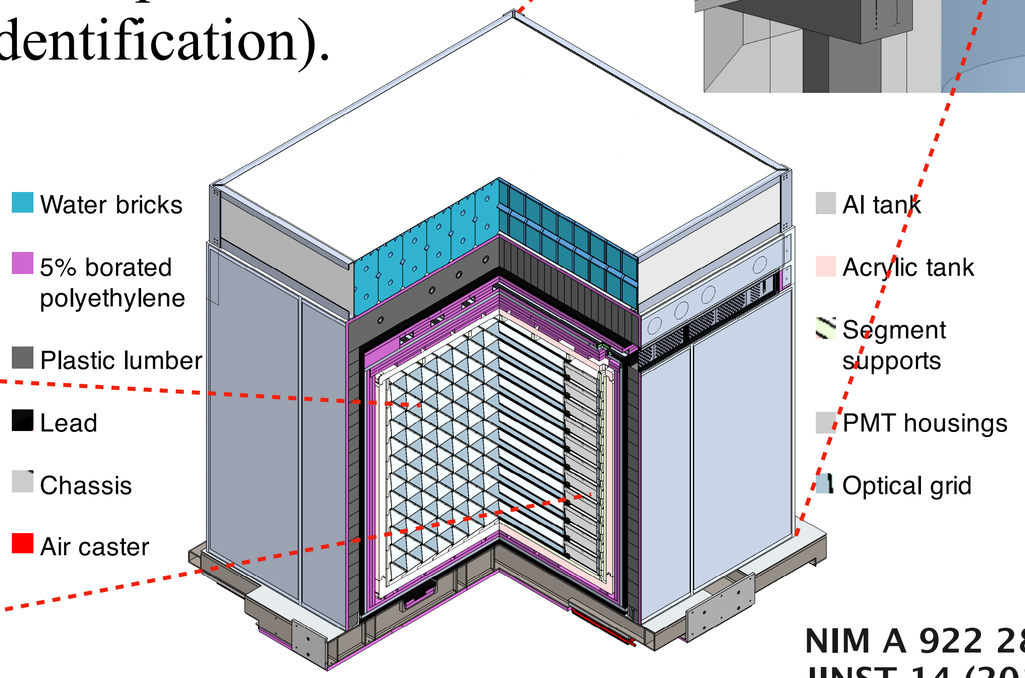


Detector Design

- 14x11 optical segmentation with 3D position reconstruction (Topological event selection).
- ^{6}Li loaded liquid scintillator with Pulse Shape Discrimination (PSD) (for n-capture identification).
- Multi-layer passive background shielding.



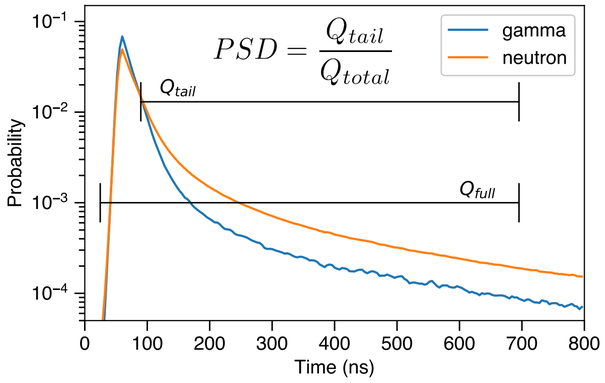


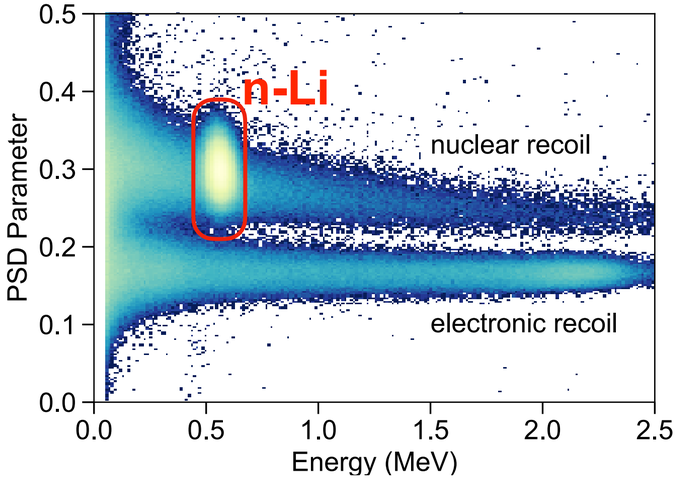


NIM A 922 287–309 (2018).
JINST 14 (2019) no.04, P04014.

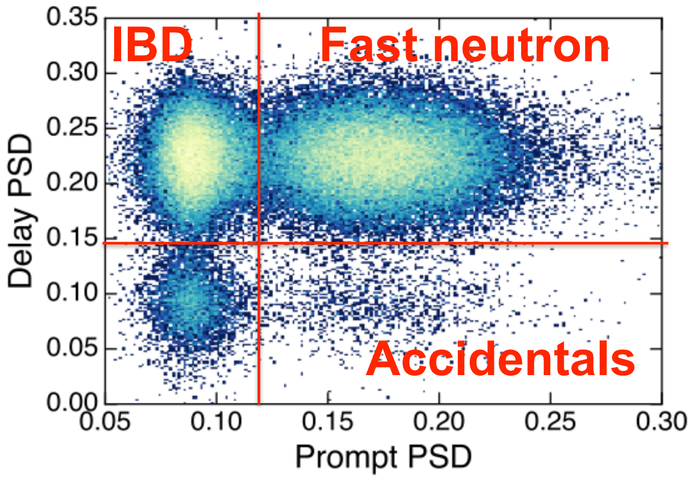
IBD Measurement Strategy

- Neutrino induced IBD event signatures in the PROSPECT detector:
  - Prompt - **β^+**;
  - Delayed - **α and ^{3}H** generated from neutron captured by ^{6}Li (~10s μs delayed).
- PSD of the LS and timing information is used to distinguish **β-like** and **n-like** events.





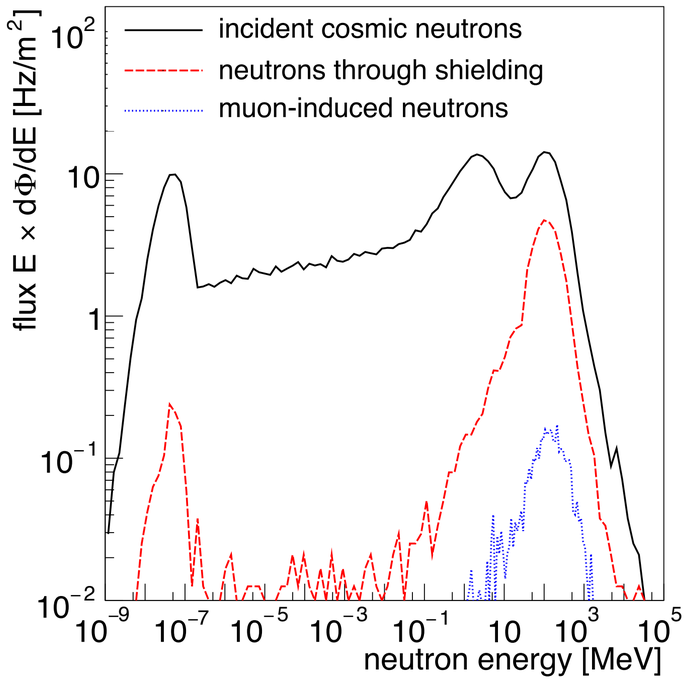
PROSPECT prototype, 2018 JINST 13 P06023



Time-PSD selection demonstrated by prototype

Background Characterization

- Cosmogenic fast neutron within the IBD selection window (10s μs scale) is the primary source of the IBD-mimic events near the earth surface.



Ambient surface neutron spectrum, and toy model processed through 1 m.w.e. shielding.

Cosmic fast neutrons dominate flux in detector at surface.

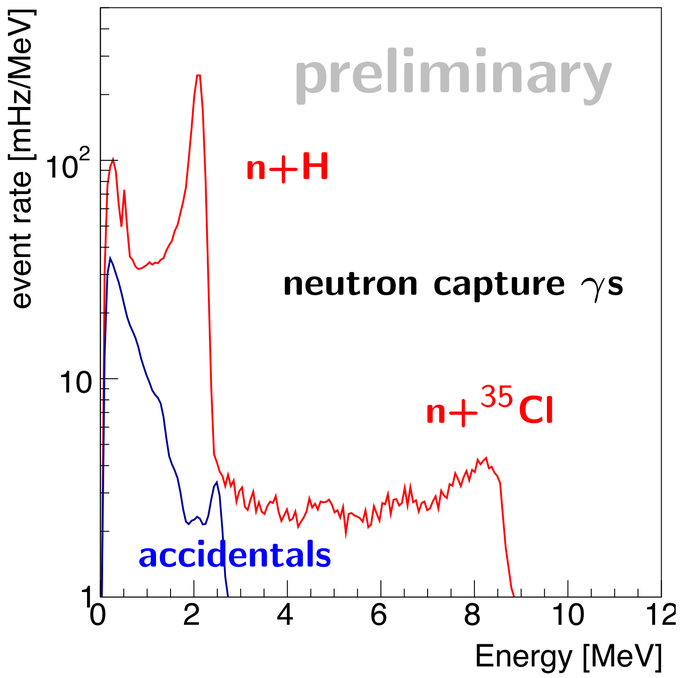
With ~10 m.w.e. overburden, neutrons are sufficiently attenuated that local muon spallation becomes dominant background source.

Cosmogenic Neutron Background in the PROSPECT's IBD Detection

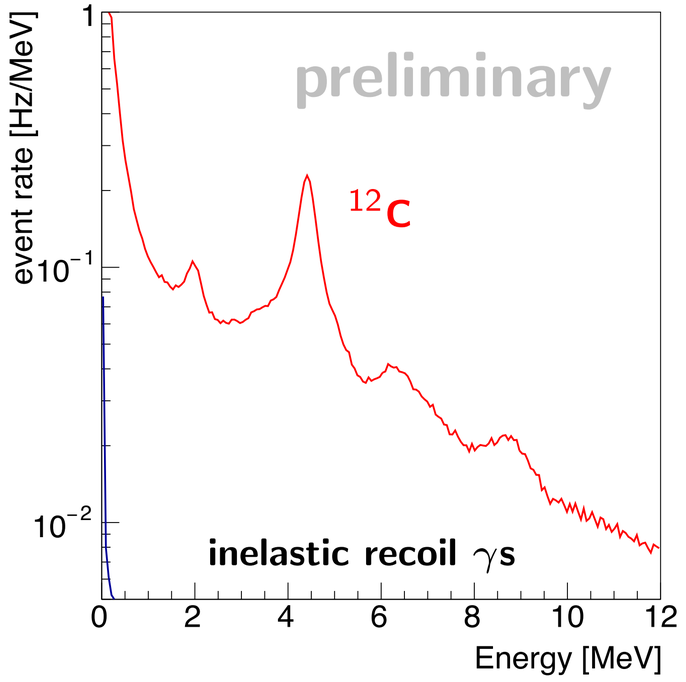
Most false IBD events come from one of the two interaction mechanisms:

- **Capture, capture**: subsequent captures of two thermalized neutrons. The earlier is captured by unintended nucleus and the later captured by ^{6}Li.

- **Recoil, capture**: gamma-like events generated from the recoil of the same or different neutrons prior to a n-Li capture.



Capture, capture



Recoil, capture

Background Rejection Strategy

- **Event selection:**
  - Neutron capture identification (^{6}Li Capture + PSD)
  - Prompt event identification (PSD, segmentation) without PSD, potentially possible with detailed topology information.
  - Shower veto (high energy muon, recoil, or neutron capture)
  - Prompt-delay distance (position reconstruction)
  - Fiducialization (detector as active shielding)
- **Accidental**: prompt and delay off-window event selection.
- **Background**: reactor off measurement

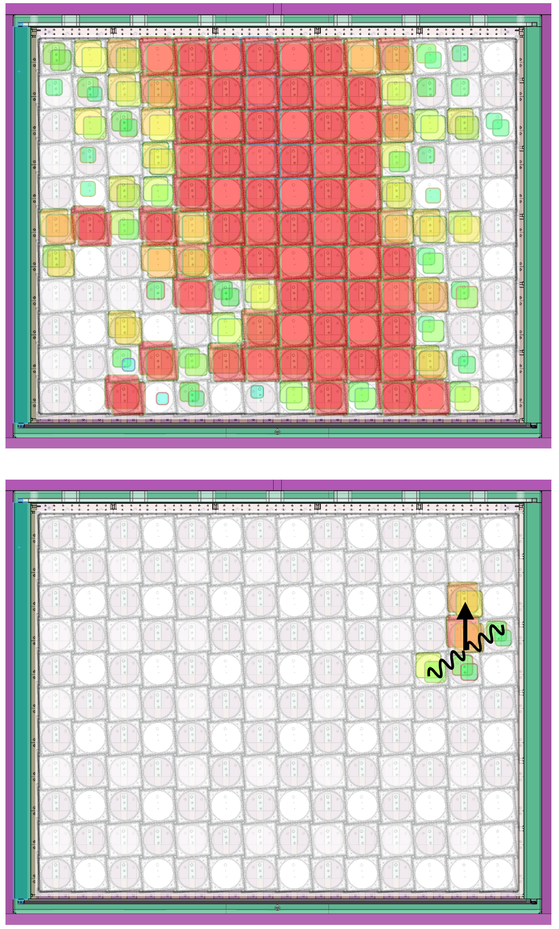


Illustration of track and directional reconstruction

Background Rejection Strategy

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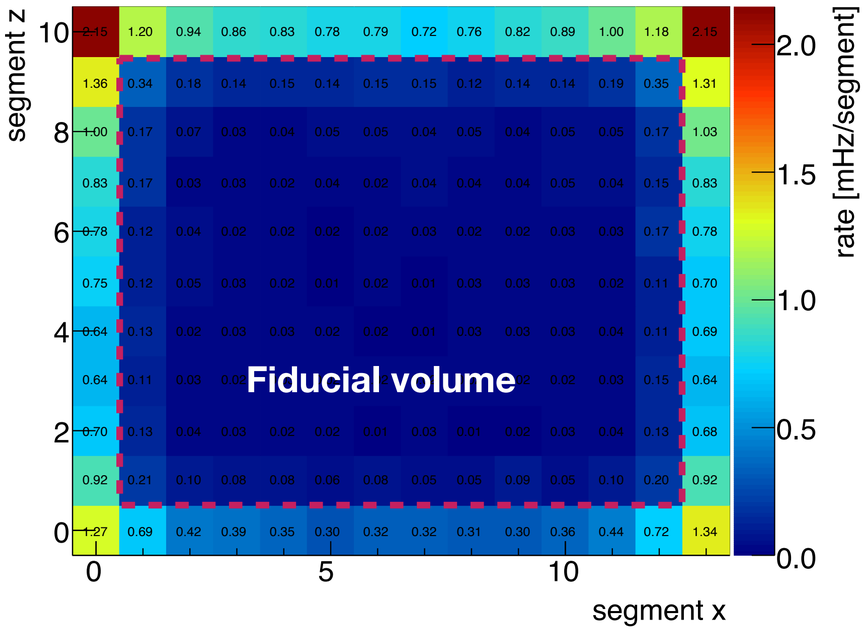


Simulated accidental rate in each cell.

Background Rejection Capability

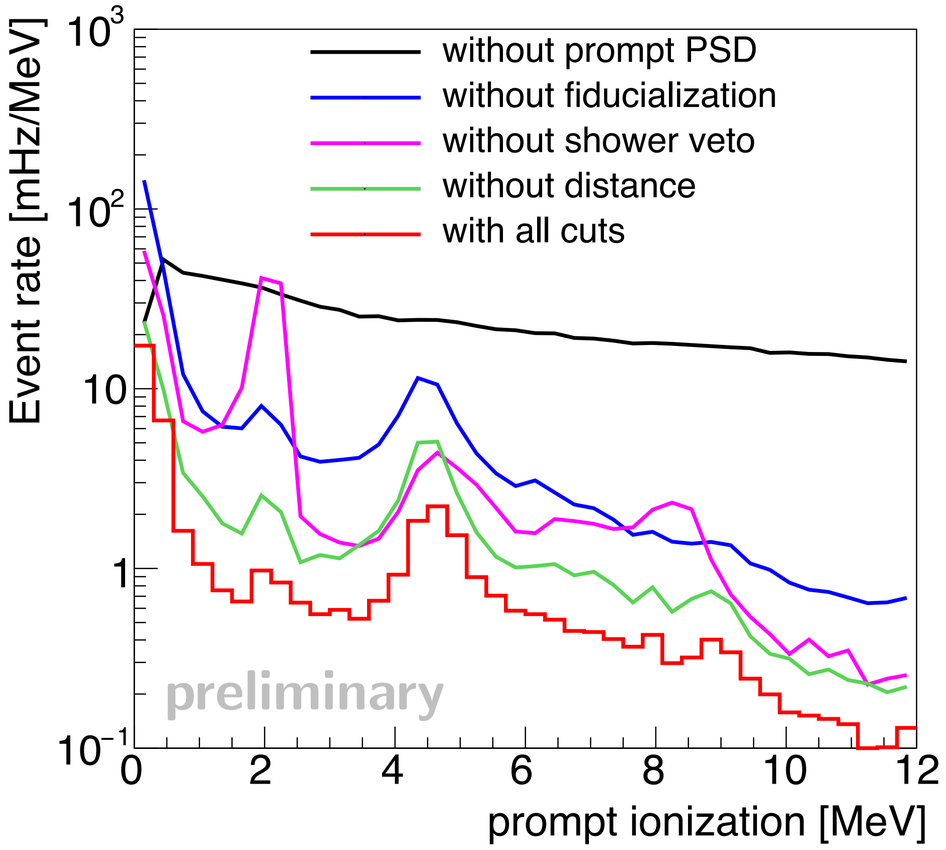


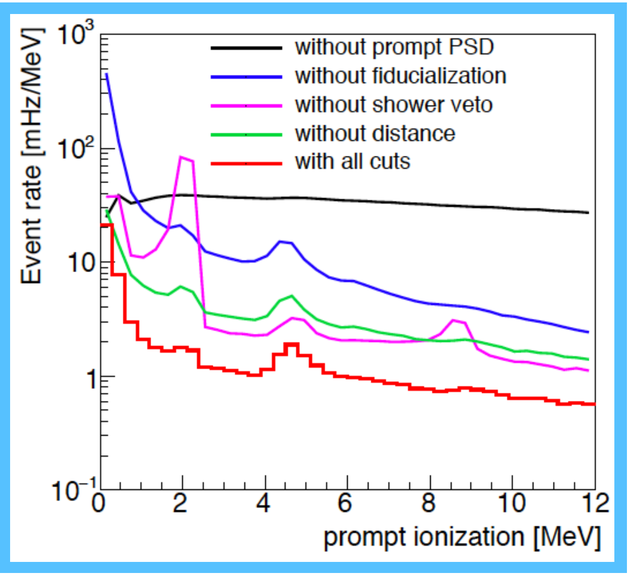
Illustration of the impact of each cuts with PROSPECT reactor off background measurement

- Rejecting prompt event neutron recoils via PSD selection is most critical.
- Sufficient detector size to fiducialize can increase overall sensitivity.
- Shower veto especially effective on capture, capture mechanism.
- Prompt/delay topological cut is straightforward in a detector with few cm position resolution.

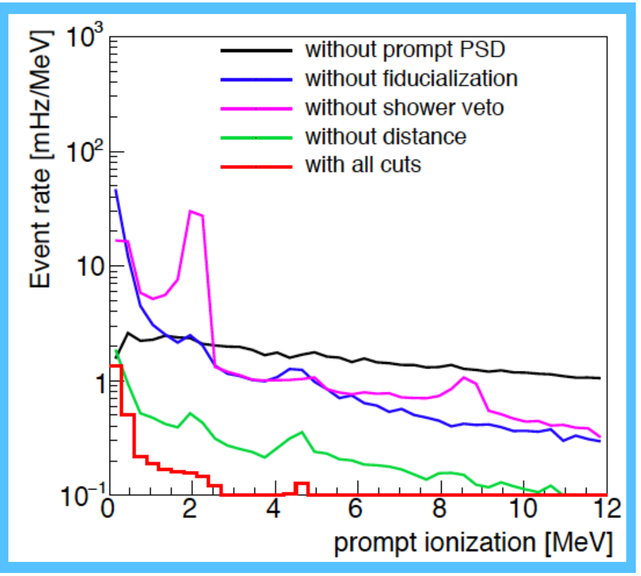
Detector Response to Cosmic Backgrounds

- PROSPECT's Geant4 simulation is able to predict the patterns of background rejection.
- On the earth's surface, muons produce much less correlated background than cosmogenic neutrons.

The cosmogenic neutron simulation with PROSPECT.

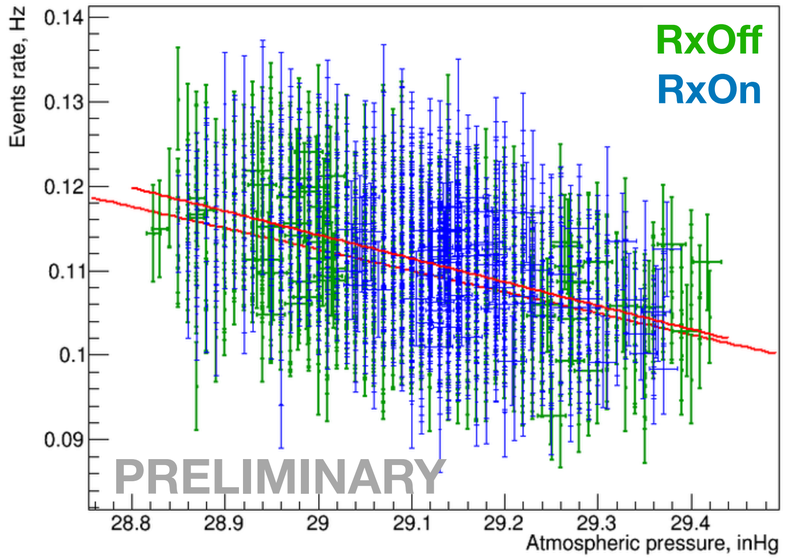


The muon simulation with PROSPECT. In the near surface situation, muons produce less correlated background than cosmogenic neutrons.

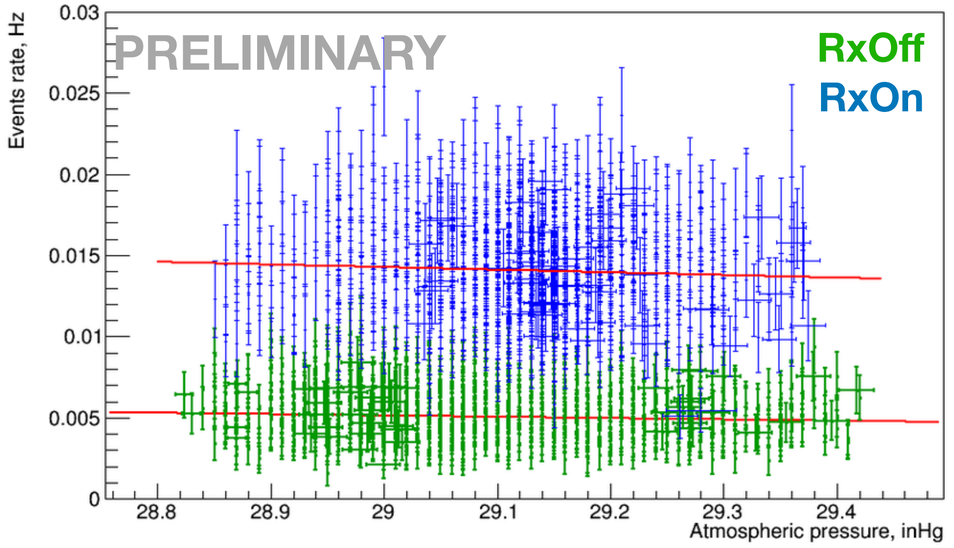


Background Normalization

- Correlations between atmospheric pressure (AP) and background rates were studied among various backgrounds.
- IBD-like background is subtracted upon veto induced dead time and the variation from the atmospheric pressure.



Fast neutron rate vs AP

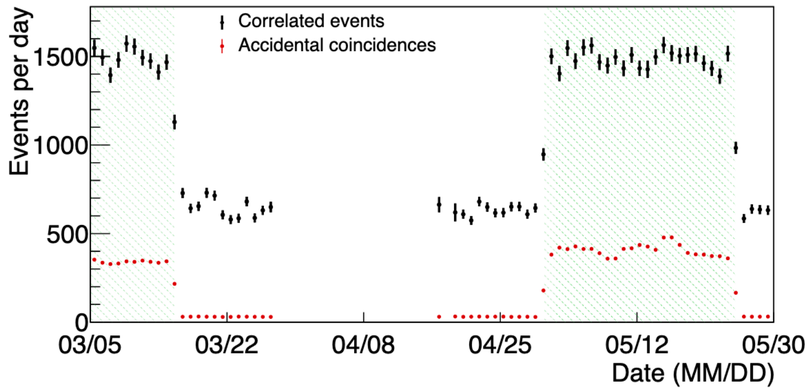


IBD rate vs AP

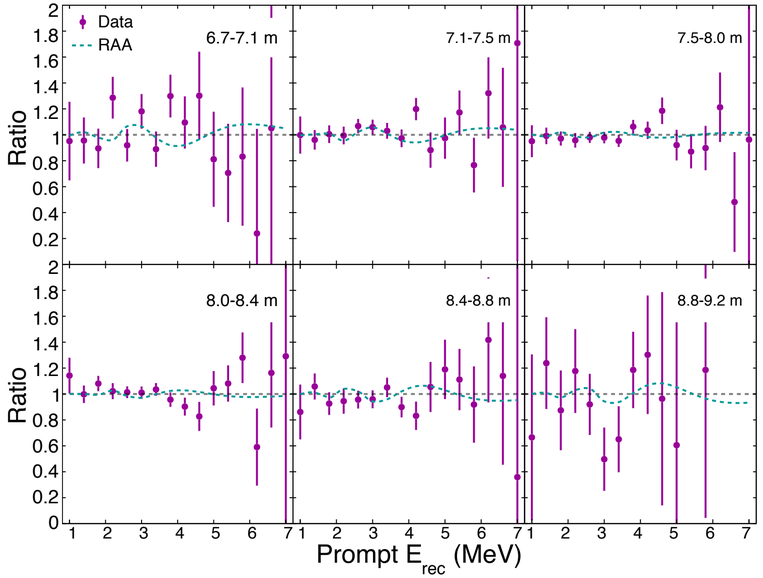
IBD After Background Subtraction

- With proper background measurements and subtraction, PROSPECT achieved precise measurement of spectra along the 7-9 m baseline, on earth surface.

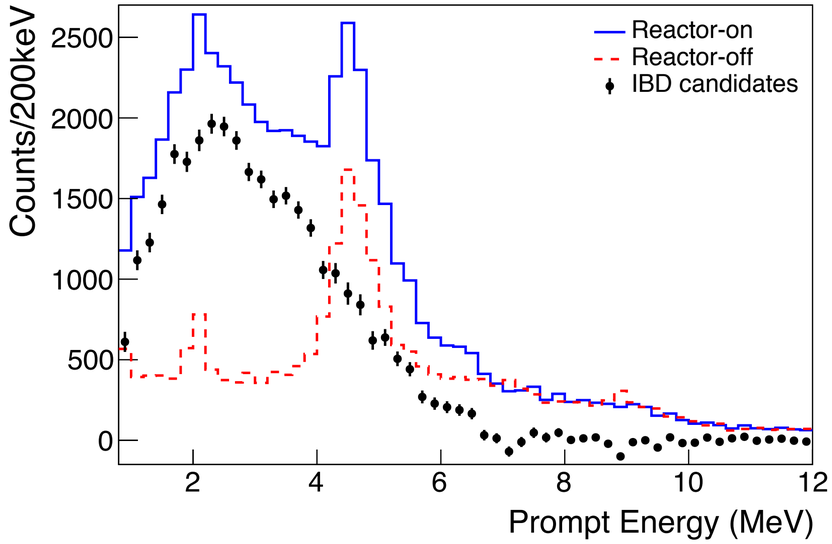
- S:B ~ 1.7:1.



Reactor-on and -off IBD signal rate



Relative IBD spectrum comparison



Absolute IBD spectrum

Phys. Rev. Lett. ***121*** *, 251802*

PRL **122**, 251801 (2019)

Contribution of PROSPECT in Neutron Background Measurement

- PROSPECT can be used to demonstrate the cosmic neutron modeling with its data-MC comparison.

- PROSPECT-style detector (with PSD + ^{6}Li + segmented scintillator) can also be utilized to measure neutrons that hard to be modeled:

  - Making *in situ* measurement of near surface cosmogenic neutron. (i.e. SBN)

  - Measuring beam induced neutron background. (i.e. decay at rest boosted neutrino measurement, coherent neutrino scattering)

  - Underground neutron background measurements. (i.e. DUNE, LZ)

Summary

- Neutron background is one of the outstanding challenges among on-surface and beam induced neutrino experiments.
- PROSPECT is able to measure reactor antineutrino spectrum with background measurement *in situ*.
- PROSPECT's measurement of the near surface cosmogenic neutron can benefit the community by benchmarking cosmic ray models.
- PROSPECT-style detector can also be applied in other P5 experiments to measure cosmogenic and beam generated neutron backgrounds.

PROSPECT

Thank you!