Optimization of Inverse Beta Decay event selection for active background reduction in PROSPECT

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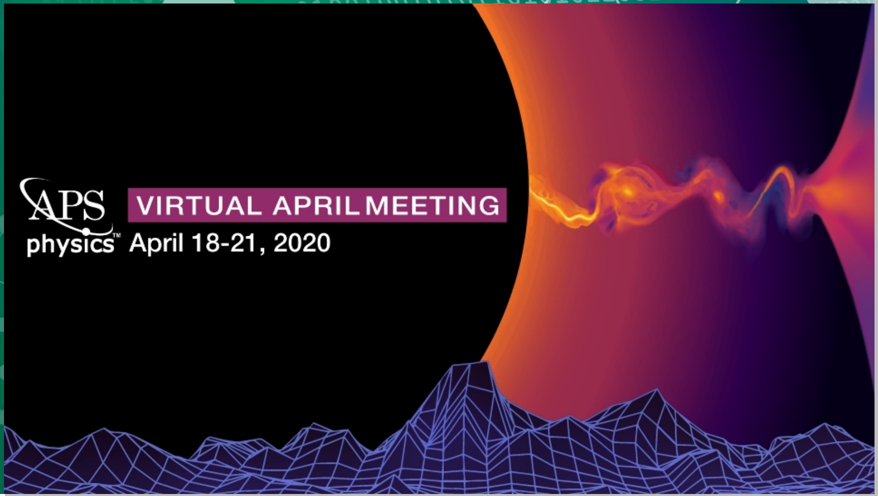
On behalf of the PROSPECT Collaboration



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U.S. DEPARTMENT OF ENERGY

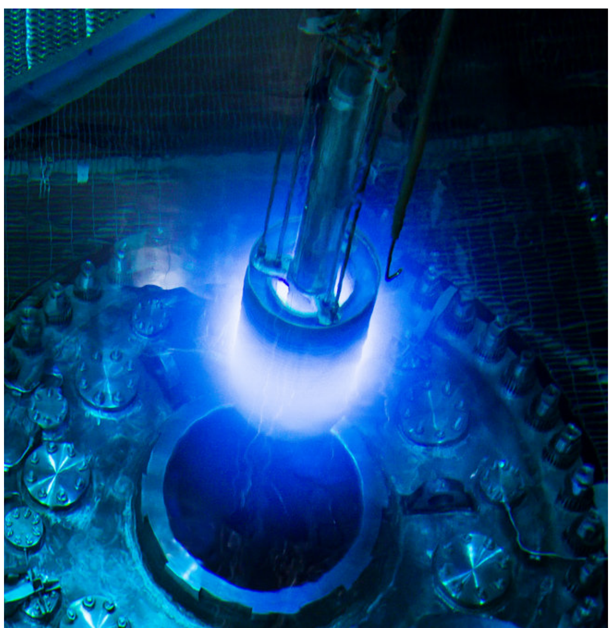
J20: Cosmogenic Fast Neutron Backgrounds in the PROSPECT Reactor Antineutrino Detector
Christian Nave
J20: Cosmic ray muons in the PROSPECT reactor antineutrino detector
James Minock
J20: The PROSPECT Short-Baseline Reactor Experiment
Bryce Littlejohn

ORNL's Opportunities: World Class Neutrino Sources

Spallation Neutron Source: SNS

- Pulsed neutron source
- 1 GeV protons on Hg target
- 1.4 MW beam power
- 2nd target station

arXiv:2003.10630



High Flux Isotope Reactor: HFIR

- 85 MW research reactor
- Compact core
- Fresh highly-enriched ^{235}U fuel

PROSPECT

PhysRevLett 122 (2019) 251801
PhysRevLett 121 (2018) 251802

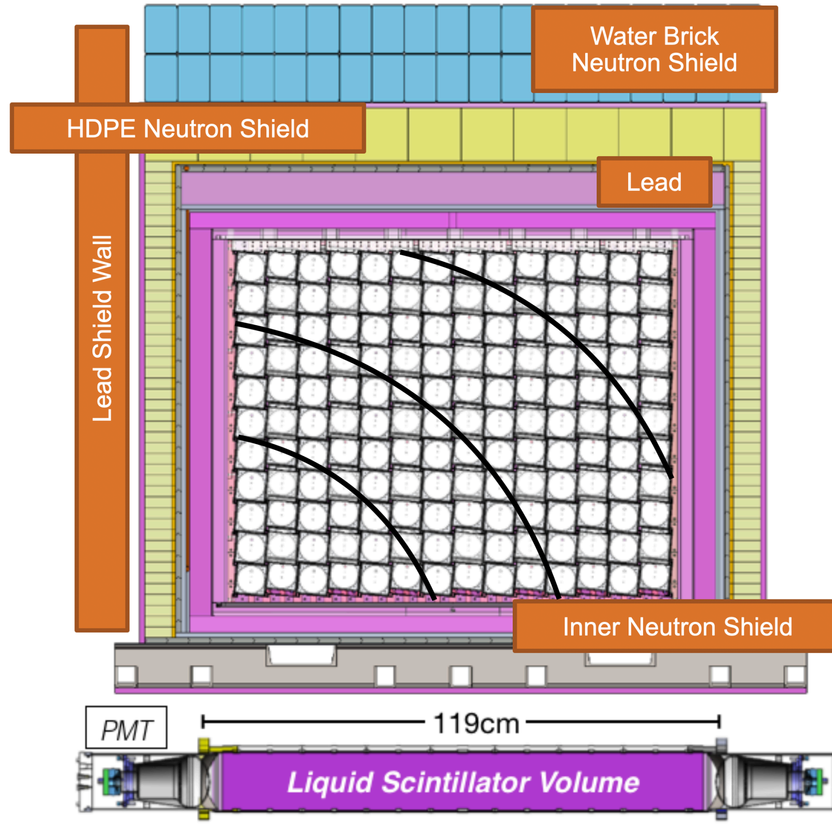
PROSPECT introduction

PROSPECT detector:

- Short baseline reactor neutrino experiment located at HFIR, ORNL
- ~4 ton ^{6}Li-loaded liquid scintillator detector
- Optically segmented into 14 x 11 identical detectors

Physics goals:

- Precise measurement of ^{235}U anti-neutrino spectrum.
- Model-independent search for oscillations into eV-scale sterile neutrino.

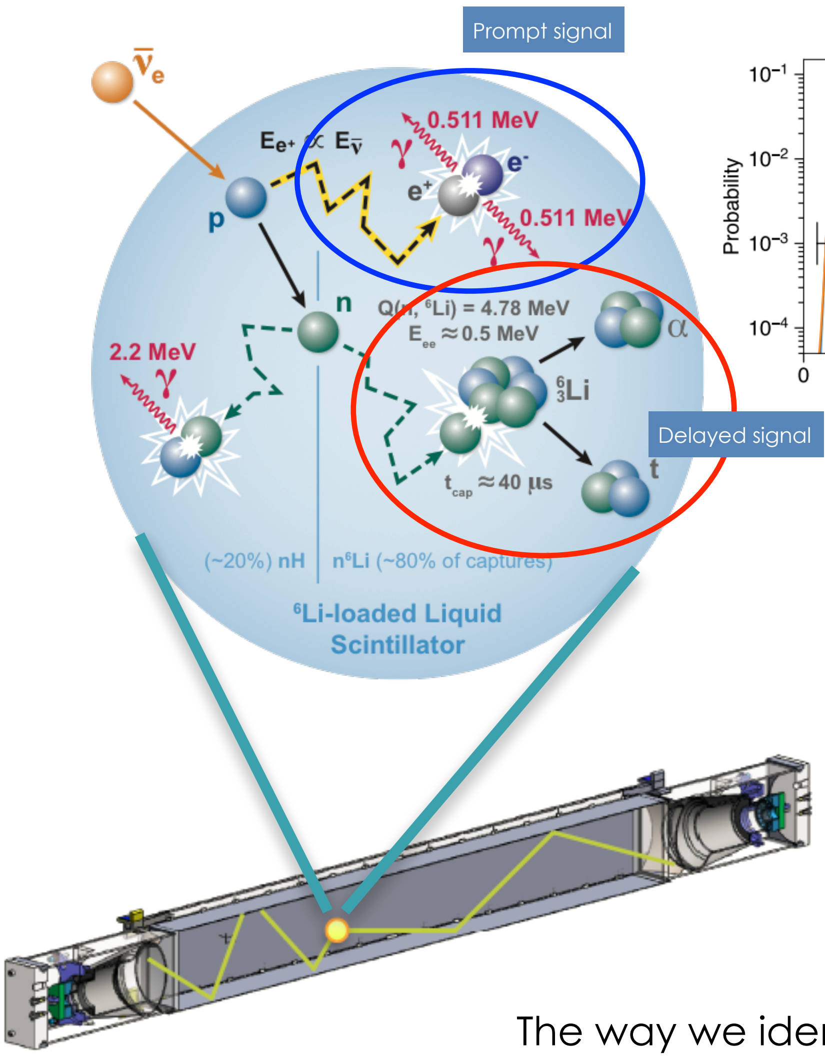


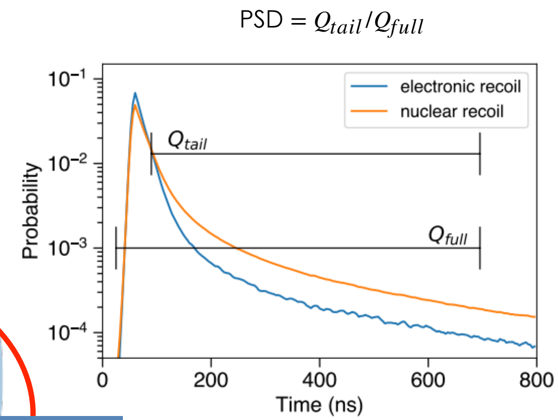
$$P_{dis} \sim \sin^2 2\theta \sin^2\left(1.27 \frac{\Delta m^2 L}{E} \frac{[eV^2][km]}{[GeV]}\right)$$

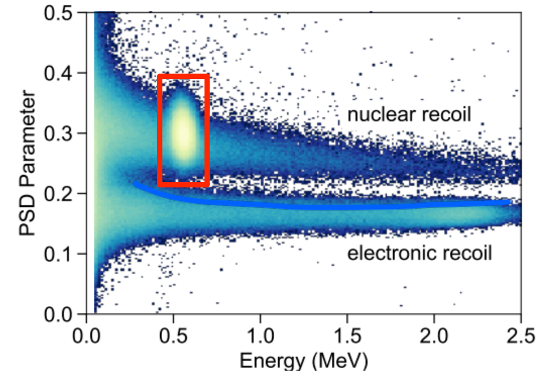
Challenge:

- On-surface experiment with minimal overburden
- Passive neutron and gamma shields mitigate the abundant reactor background but still exposed to immense cosmogenic backgrounds.

Detection Principle - Inverse Beta Decay







$$\bar{\nu}_e + p \rightarrow e^+ + n$$

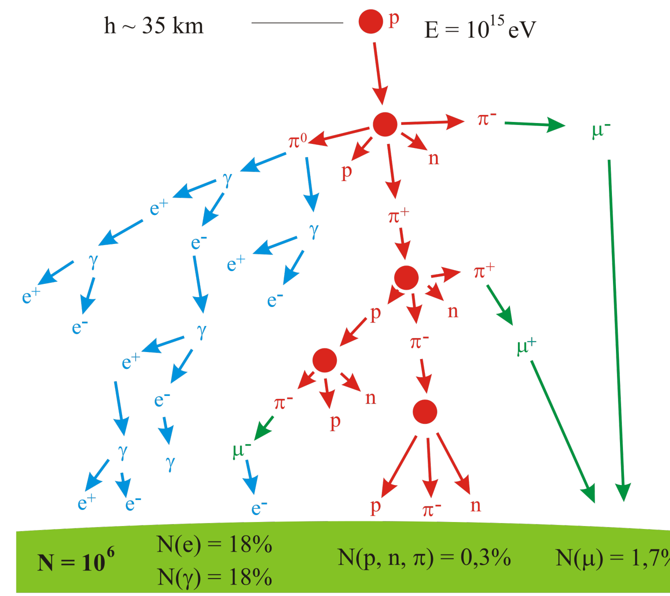
Prompt signal Delayed signal

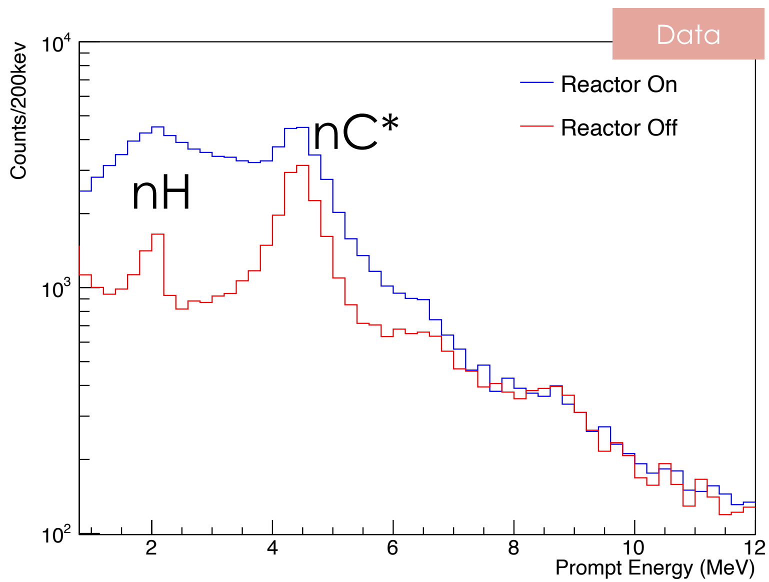
- Background suppression and IBD pair event identification
- Customized EJ-309-based 6LiLS gives excellent PSD(Pulse Shape Discrimination) performance

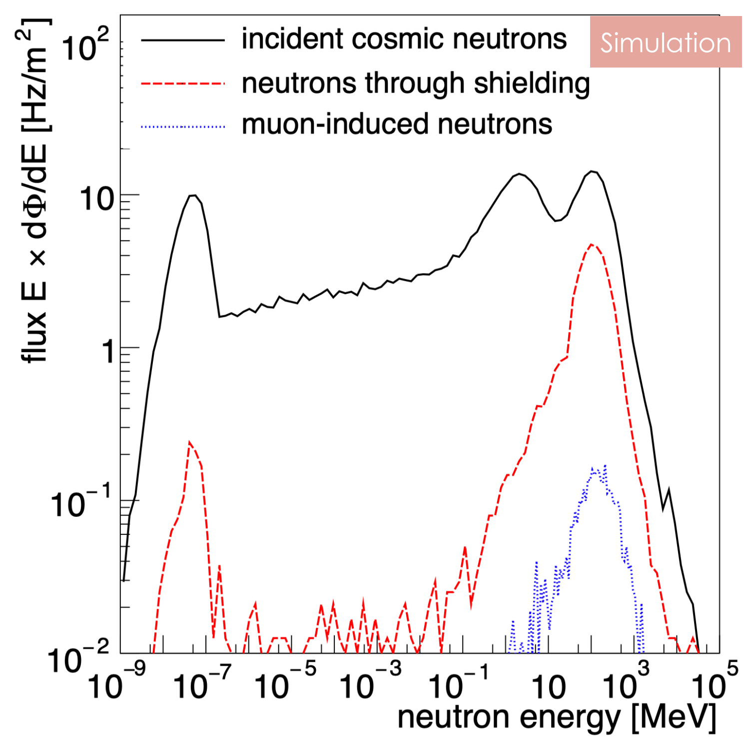
The way we identify IBD signals leaves us intrinsic background, for example, multi-neutron shower where nH + nLi.

Cosmogenic backgrounds

- Primary cosmic rays interaction with atmosphere generating secondary cosmic rays like neutrons/muons;
- Fast neutrons/muon spallation shower inside the detector become dominant background source.





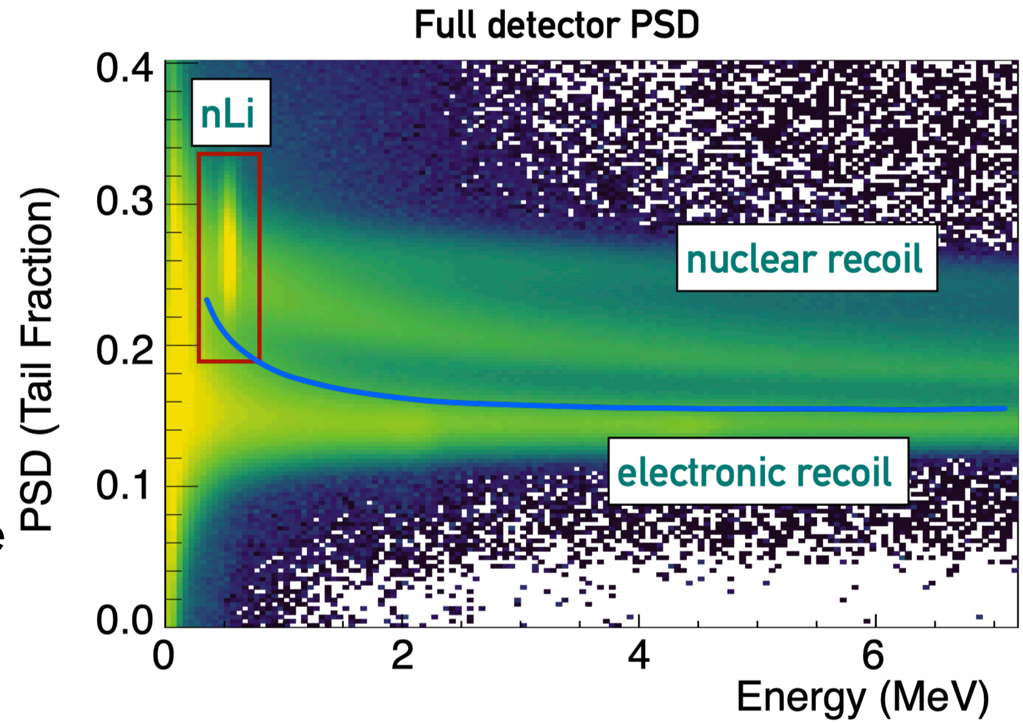


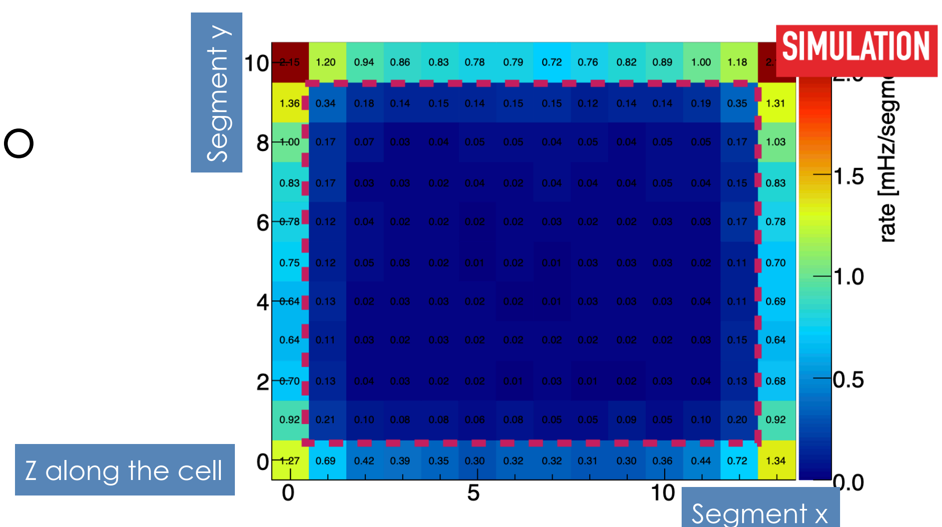
HFIR operates ~7 reactor cycles, each cycle about 24 days

OAK RIDGE National Laboratory

Event selection cuts - IBD cuts

- Neutron capture box
  - PSD 2σ
  - Energy 3σ
- Prompt e/γ
  - PSD 2σ
- Prompt-delay signal distance
  - (same, adjacent) cell
  - Δz = +/- (140, 100) mm
- Prompt-delay timing
  - Δt = [1-120]μs
- Additional fiducial volume to catch escaping e/γ as well as neutron shielding.





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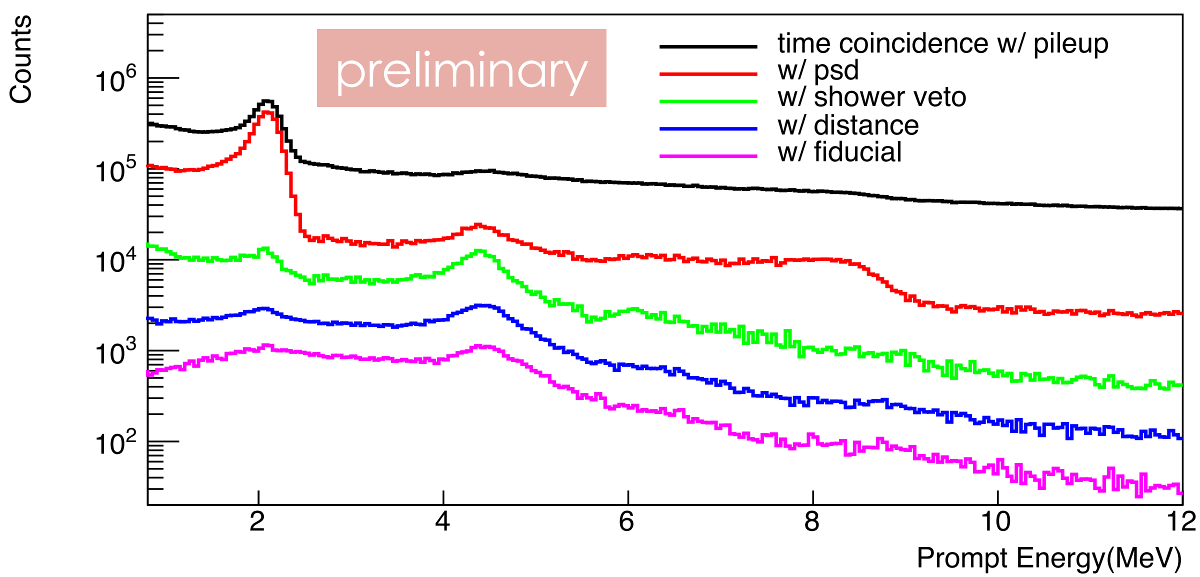
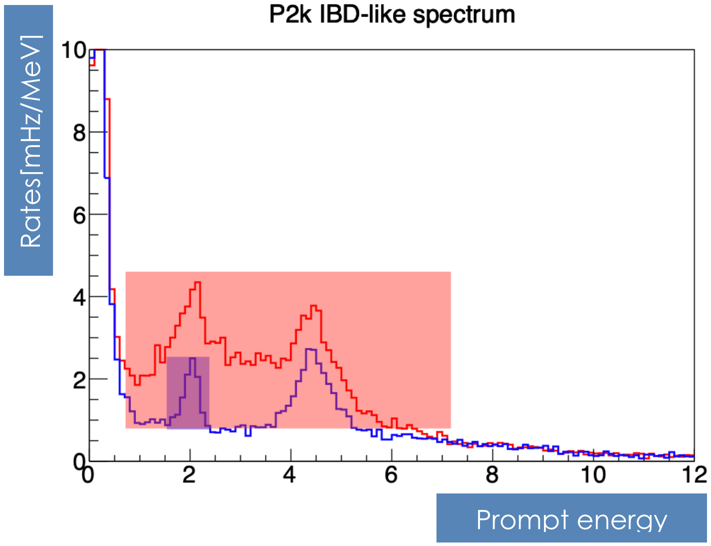
Event selection cuts - Veto cuts

- PileupVeto: 800ns
  - Eliminate overlapping waveform
- Muon veto: 200μs
  - Veto after "muon events" with E > 15 MeV
- NeutronVeto: +/- 400μs
  - Veto delayed candidates around a neutron capture
- RecoilVeto: +200μs
  - Veto delayed candidate after a recoil-containing cluster



Optimization Figure of Merit(FOM)

- FOM = Area of IBD / Area of (nH/nC*) peak
  - Minimize dominant background
- Effective Counts = ∑ 1.0/relative error bar²
  - Range of interest: 0.8 - 7.2 MeV
  - Relative error bar ~ 1/√N
  - Maximize statistical power of the data



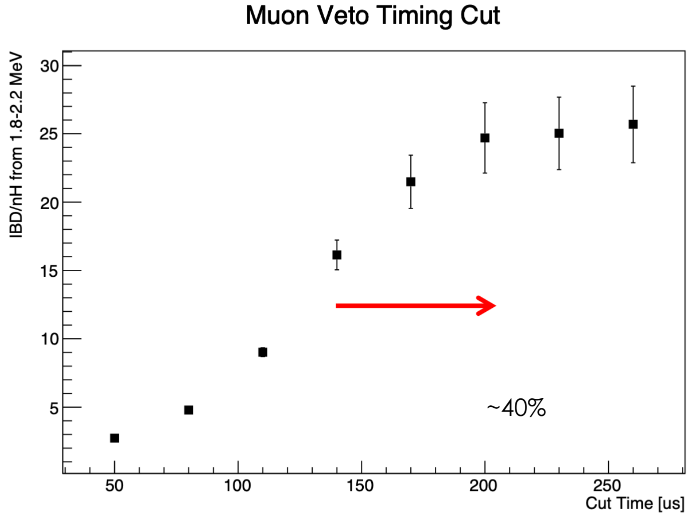
Used ~ 20% of the data evenly distributed over time.

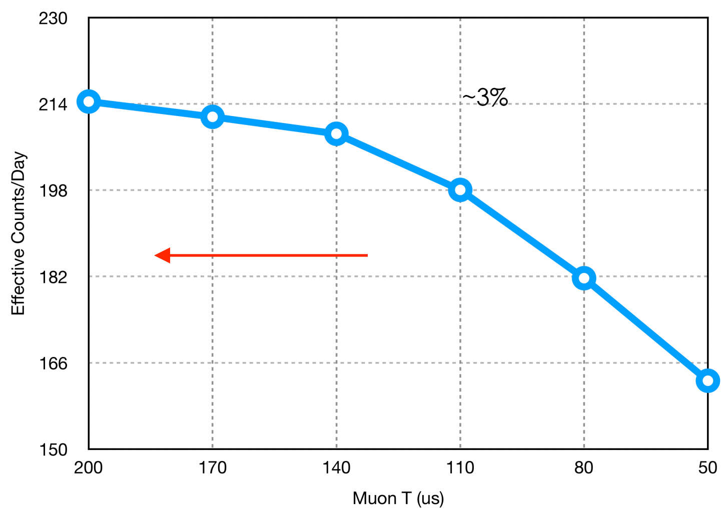
Examples of the optimization

Example: Muon veto time

- Set muon veto to 200μs
- Tighten up prompt/delay event coincident distance to (140,100) mm
- Tighten up PSD requirement of prompt/ delayed events
- Performed detailed fiducialization study

nH FOM

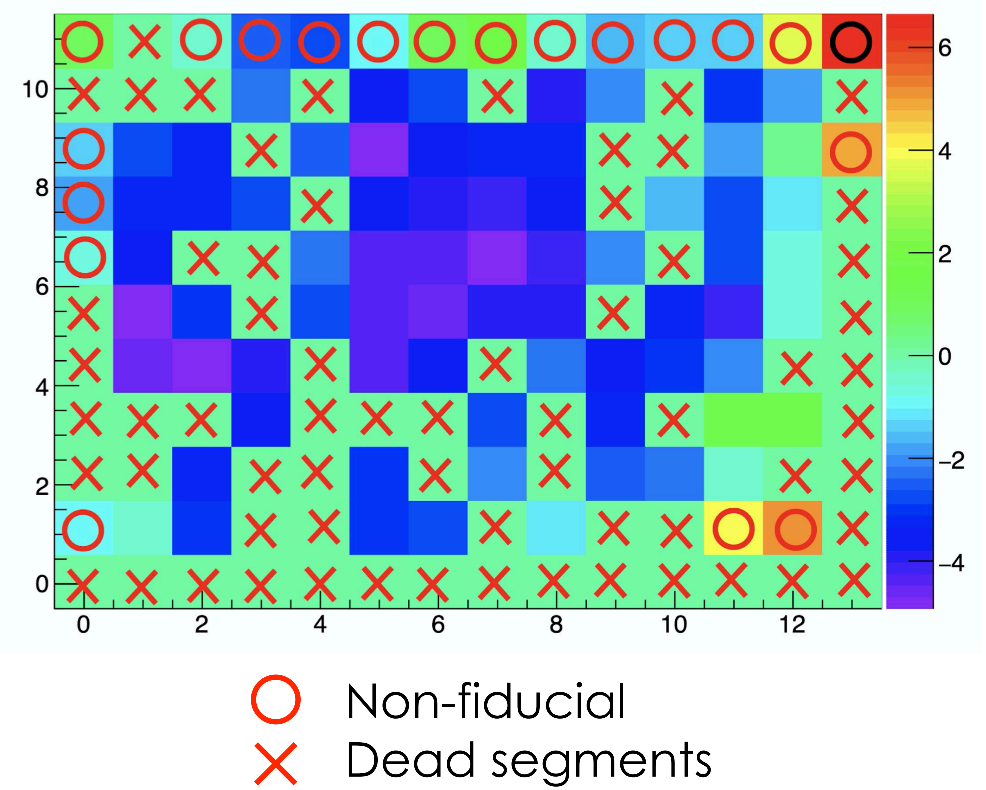




Examples of the optimization

- Performed calculation of effective stats changes for each cell to be fiducialized individually.
- Hot cells "dirty cells"
- Cold cells "clean cells"
- Bottom right hot gamma corner is caused by beam lines.

Effective stats changes if cells were fiducialized



As a result of the optimization of event selection cuts, ~16% improvement in IBD effective statistics, with better signal-to-background ratio ~1.4:1.

Conclusion:

- PROSPECT is currently analyzing a larger data set with optimized event selection cuts
- Multiple FOMs optimization based on ~20% data set produces unbiased high quality signals
- ~17% increased effective statistics with signal to background ratio ~1.4:1
- Spectrum/oscillation results are on the way, stay tuned


Thank you
prospect.yale.edu
15 Institutions, 70 collaborators
HEISING-SIMONS FOUNDATION
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GRFP
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