Oak Ridge National Laboratory

Machine Learning Applications for Reactor Antineutrino Detection at PROSPECT

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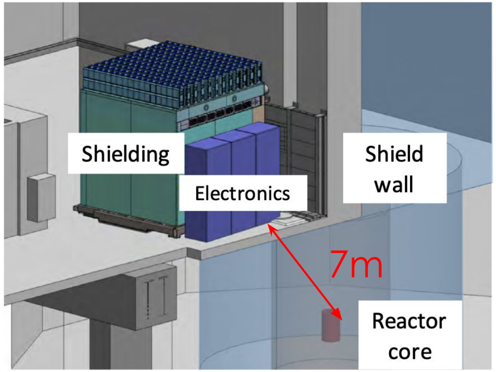
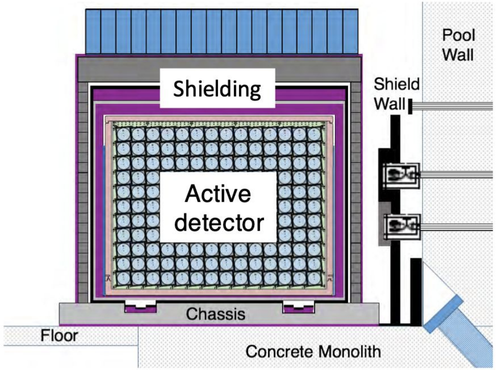
On behalf of ORNL's PROSPECT Team

U.S. DEPARTMENT OF ENERGY

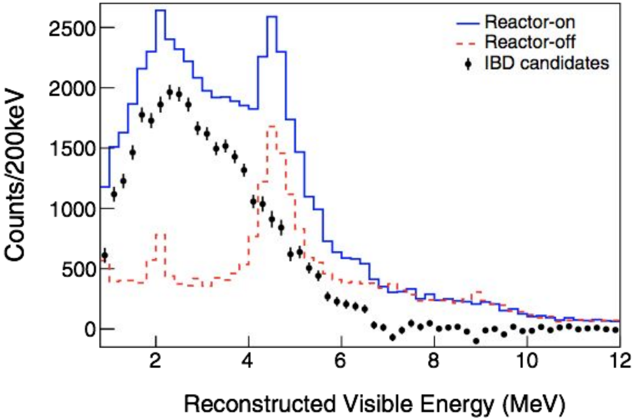
Precision **R**eactor **O**scillation and **SPECT**rum Experiment

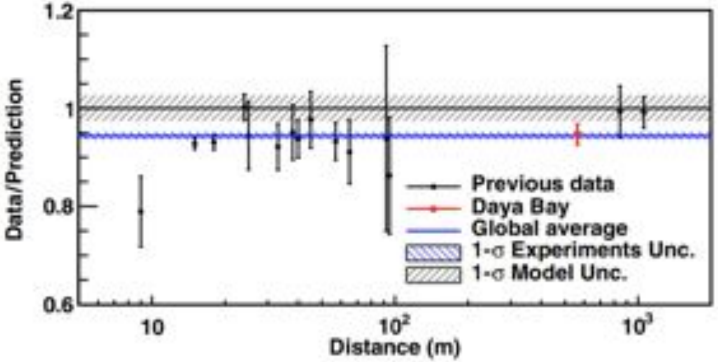
- Short-baseline reactor neutrino experiment. Designed to address:
    - Anomalies in flux and spectrum
    - ~6% deficit in measurement of antineutrino.
    - "Bump" around 5-7 MeV range
- Possible explanations:
    - Sterile neutrino hypothesis
    - Incorrect isotope predictions (235U)
- Challenge: Above-ground deployment - large backgrounds





PROSPECT detector at **High Flux Isotope Reactor (HFIR)** at **ORNL**.





Detector Design + Results

- Full design report:
  - The PROSPECT Reactor Antineutrino Experiment
- Observed anomalies in spectrum. Published results:
  - Measurement of the Antineutrino Spectrum from U 235 Fission at HFIR with PROSPECT
  - First Search for short-baseline neutrino oscillations at HFIR with PROSPECT
- Most recent results soon to be published.

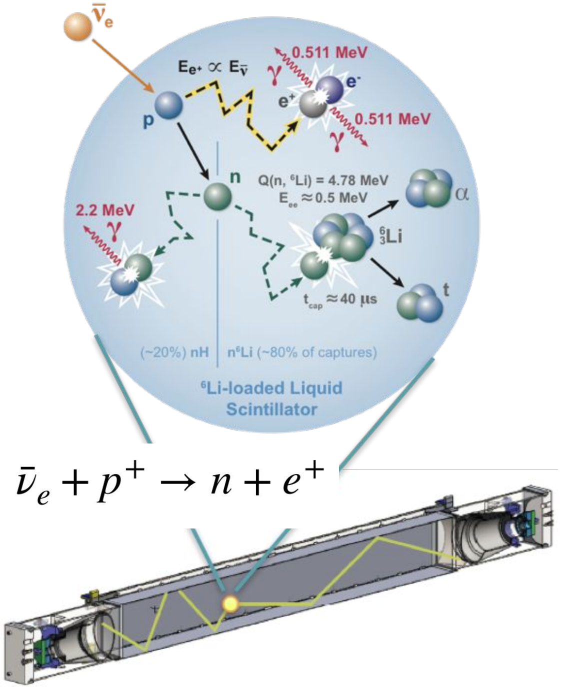
Neutrino 2020 Talks & Posters

- Talk: Recent Results from PROSPECT (B. Littlejohn) - June 25
- Posters: 158, 516, 408, 527, 540, 556

Detector Performance

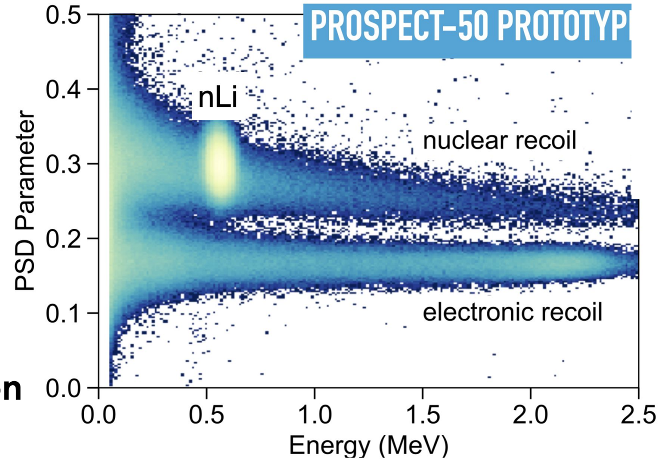
- Detector response has been fully characterized.
- PROSPECT-Geant4 (PG4): Geant4 - based simulation package for full detector response simulation (by Michael Mendenhall)

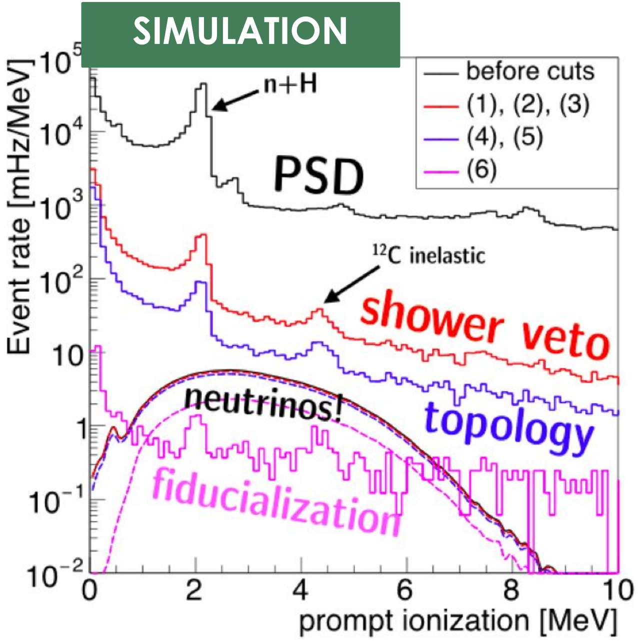
Antineutrino Event Reconstruction



Antineutrinos detected through Inverse Beta Decay (IBD) interaction

Background suppression through set of cuts based on IBD topology, PSD, cosmic shower veto, etc...





Particle ID classification in 6Li-doped liquid scintillator allows to differentiate ionization/nuclear recoil/quenched n-Li

Prompt signal: ~1-10 MeV positron energy

Delayed signal: ~ 0.5 MeV neutron capture

MVA Analysis for Background Suppression

Used in addition to set of rectangular selection cuts to optimize IBD selection efficiency.

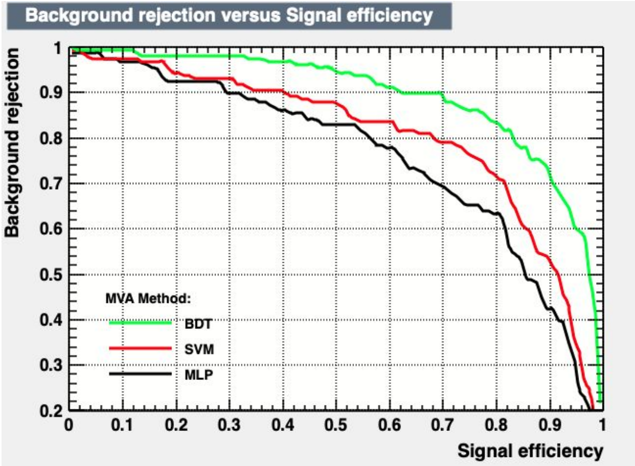
- Keep signal rate, but reduce background contamination.
- Use spatial and temporal correlations of prompt and delayed signals.
- Use ROOT's TMVA package for simplicity + easy to add to existing analysis framework.

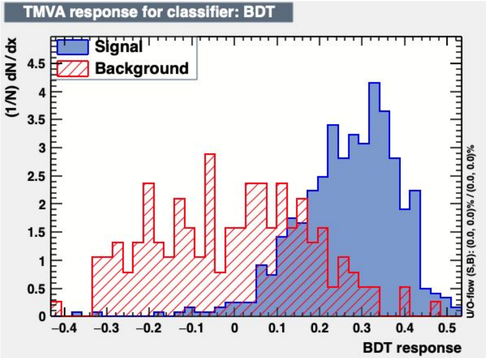
MVA Classifiers

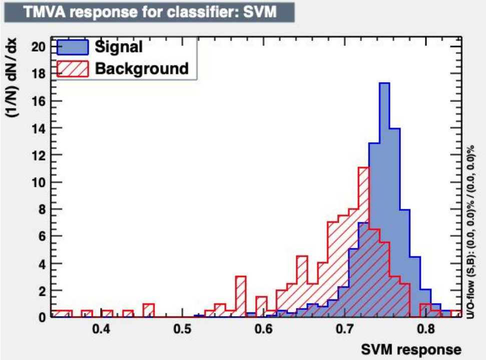
- *Multi-Layer Perceptron (MLP)*
- *Boosted Decision Tree (BDT).*
- *Support Vector Machine (SVM).*

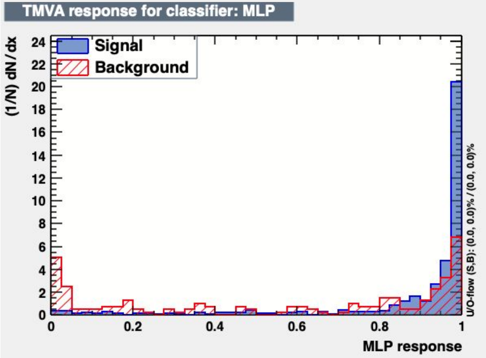
Training/test datasets

- *IBD simulation from PG4 for signal*
- *Reactor-off dataset for background*



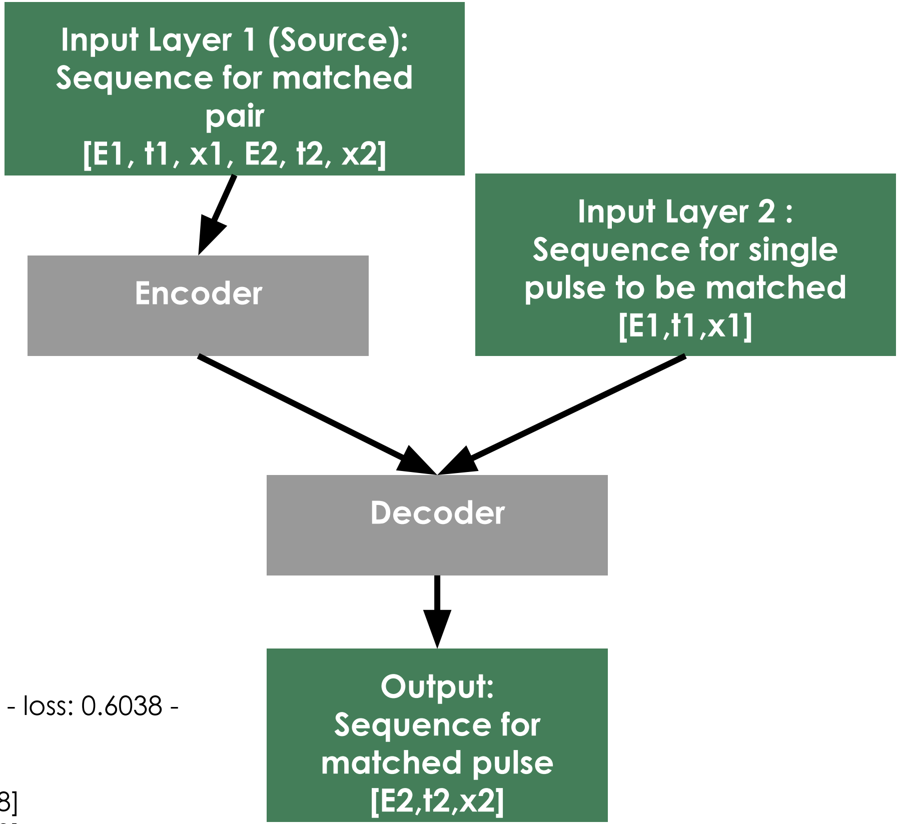






Encoder-decoder Model for Pulse Matching

- Cast pulse matching to a sequence prediction problem.
- Encoder-decoder model to organize two recurrent neural networks (RNNs) for sequence prediction.
  - one to encode the source sequence (encoder),
  - and a second to decode the encoded source sequence into the target (decoder)



Toy dataset:

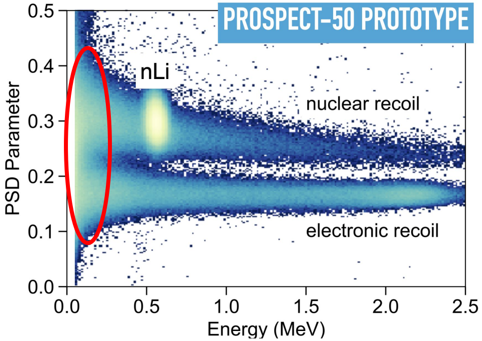
Value of 0 as padding

100000/100000 [==============================] - 30s 297us/step - loss: 0.6038 - accuracy: 0.8045
Accuracy: 99.00%
Source=[26, 17, 48, 43, 35, 18] Input Layer 2=[0, 26, 17] Target=[43, 35, 18]
Source=[17, 24, 6, 37, 25, 33] Input Layer 2=[0, 17, 24] Target=[37, 25, 33]

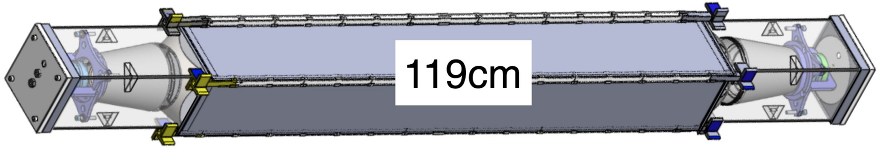
Current/future ML exploration

Particle ID

- Improve particle ID efficiency at low energy where electronic and nuclear recoils have similar PSD value.



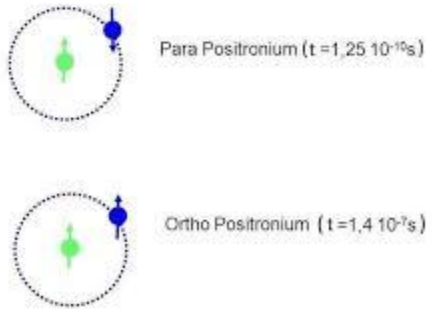
- Currently exploring ML technique to reconstruct events in segments with only one live PMT.

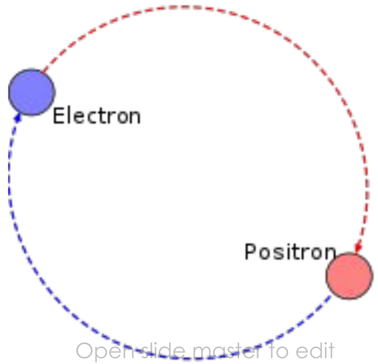


Positron Tagging

- Exploring the possibility of tagging positrons by detecting a potential distortion in the photon emission time distribution induced by ortho-positronium formation.

- o-Ps formation in liquid scintillator, with a lifetime of about 3ns, provides a mean to discriminate positron decay events via photon emission time distribution differences between o-Ps and annihilation events.





Summary

- Presented a few ideas on the directions our team is pursuing on ML applications to antineutrino data from PROSPECT experiment/simulation.
- Why Oak Ridge National Laboratory?
  - Access to CPU/GPU resources through the Oak Ridge Leadership Computing Facility.
    - CADES, "An environment for scientific discovery". Access to dedicated storage capacity, high-speed data transfer nodes, scalable high-performance computing
  - Large community of machine learning experts.
  - Synergy with existing groups working on machine learning + quantum computing (ask me about QC!)

Thank you!

Questions?

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