Searching for Neutrino-Induced Neutron Production at the Spallation Neutron Source (SNS) on Lead

Brandon Becker
On the behalf of the COHERENT Collaboration

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THE UNIVERSITY OF TENNESSEE KNOXVILLE

OAK RIDGE National Laboratory

Outline

- SNS as a Neutrino Source
- COHERENT Experiment Collaboration
- Neutrino-Induced Neutron (NIN) Production
- Lead Based NIN Detector
- Geant4 Simulations

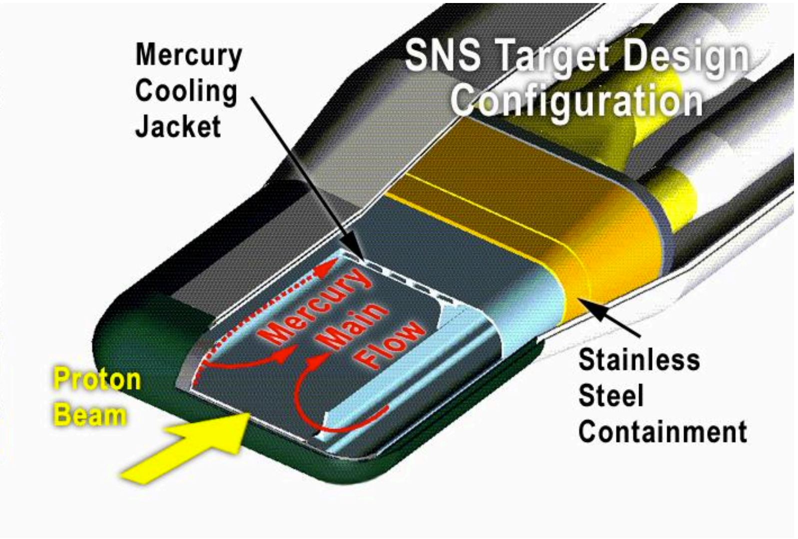
Spallation Neutron Source

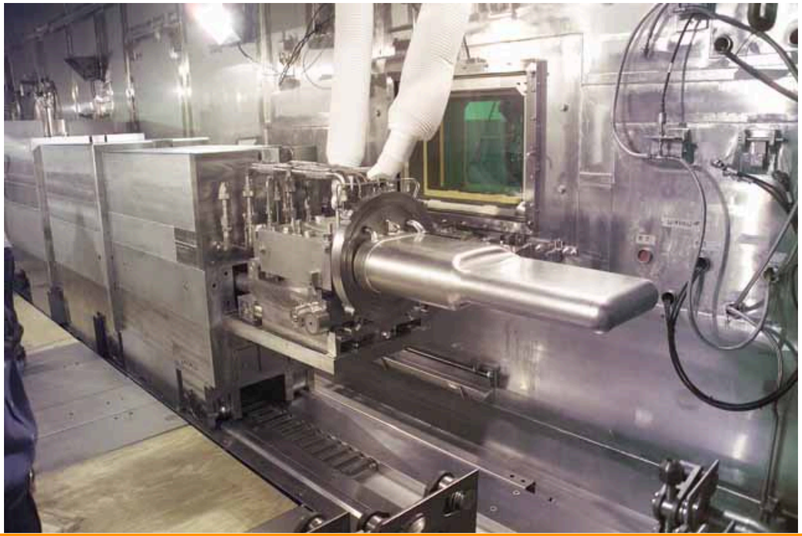
SNS Layout

Front-End Building
Klystron Building
Central Helium Liquefaction Building
Linac Tunnel
Ring
Radio-Frequency Facility
Target
Future Target Building
Support Buildings
Central Laboratory and Office Complex

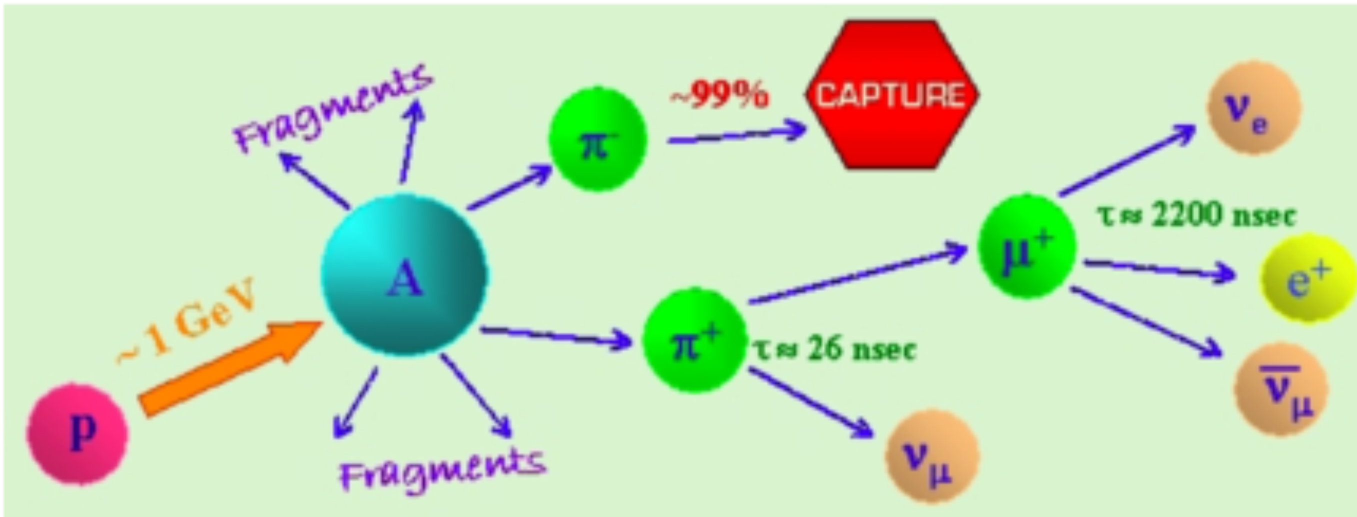
SNS Operation Overview

- Linear Accelerator produces ~1.1 GeV protons.
- Accumulator Ring creates bunches of 10^{14} protons.
- Bunches are timed at 60 Hz.
- → ~1 MW Beam Energy Delivered to Target



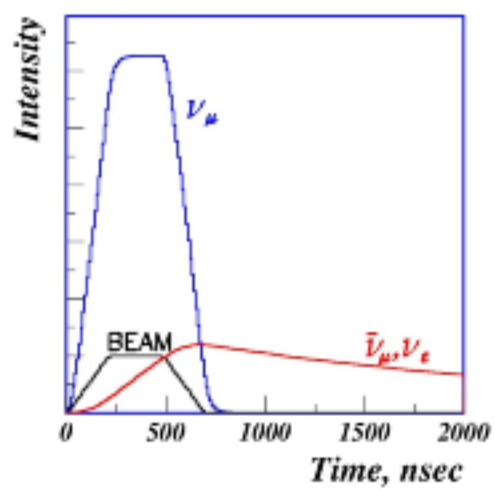


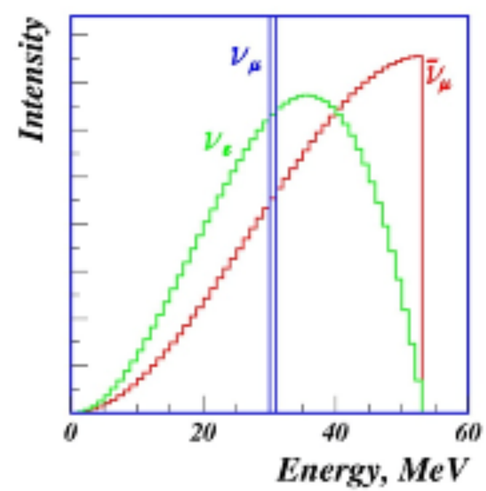
Neutrino Production at SNS



- About 0.08 π^+ are produced per proton

- π^+ have a mean free path of 5 cm in Hg, so most will come to rest before decaying

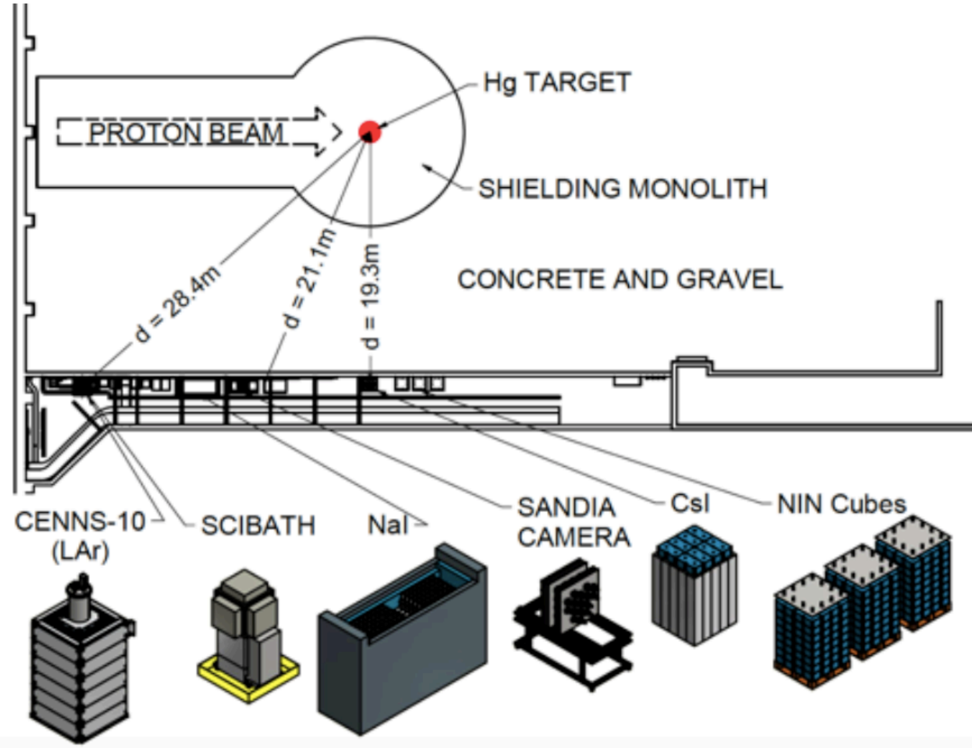




The COHERENT Experiment

The COHERENT collaboration aims to make the **first successful measurement of Coherent Elastic Neutrino-Nucleus Scattering (CEvNS)**, a process predicted in the Standard Model. Furthermore, it is to be done with multiple detector technologies to test the predicted N^2 dependence of the cross-section.

Multiple auxiliary detectors have been deployed for an extensive background measurement campaign including environmental gammas, neutrons, beam-related backgrounds, and neutrino-induced neutrons (NINs).



Neutrino-Induced Neutrons (NINs)

- Neutrino interacts with nucleus, raising the nucleus to an excited state.
- Excited nucleus decays via particle emission (p, n, α, γ)

- Charged-Current

  $\nu_e + {}_{Z}X_{N} \rightarrow e^- + {}_{Z+1}X^*_{N-1}$
- Neutral Current

  $\nu_x + {}_{Z}X_{N} \rightarrow \nu_x + {}_{Z}X^*_{N}$

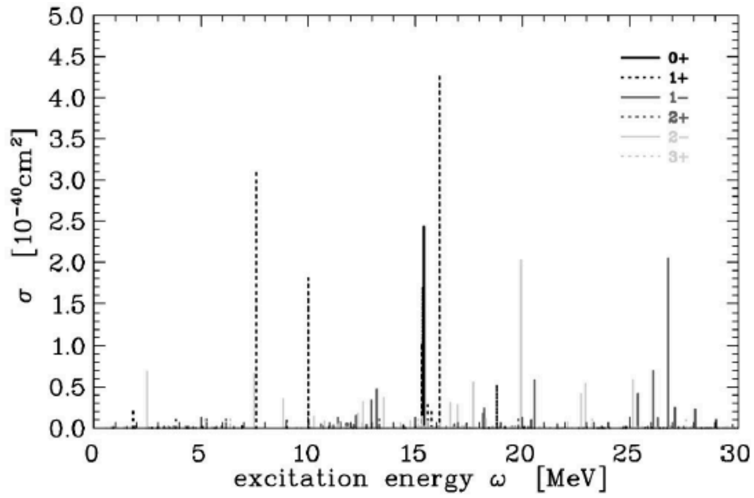
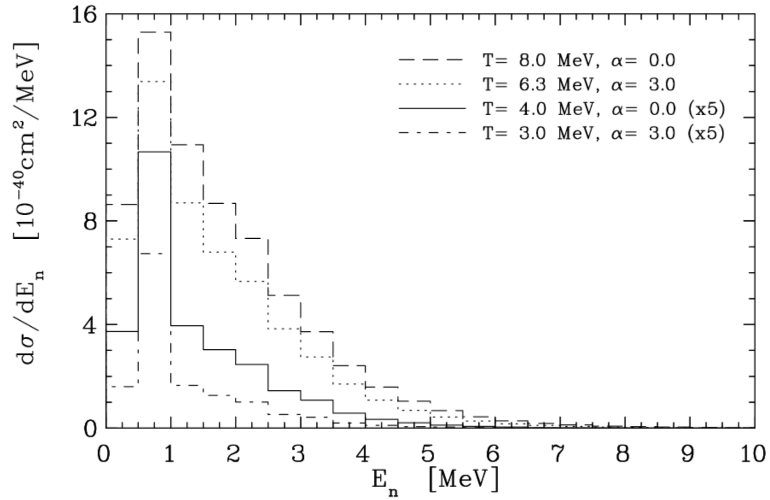


FIG. 1. Multipole decomposition of the RPA response for the charged-current (ν_e, e^-) reaction on ^{208}Pb induced by DAR ν_e neutrinos.



Kolbe, Langanke PHYSICAL REVIEW C, VOLUME 63, 025802

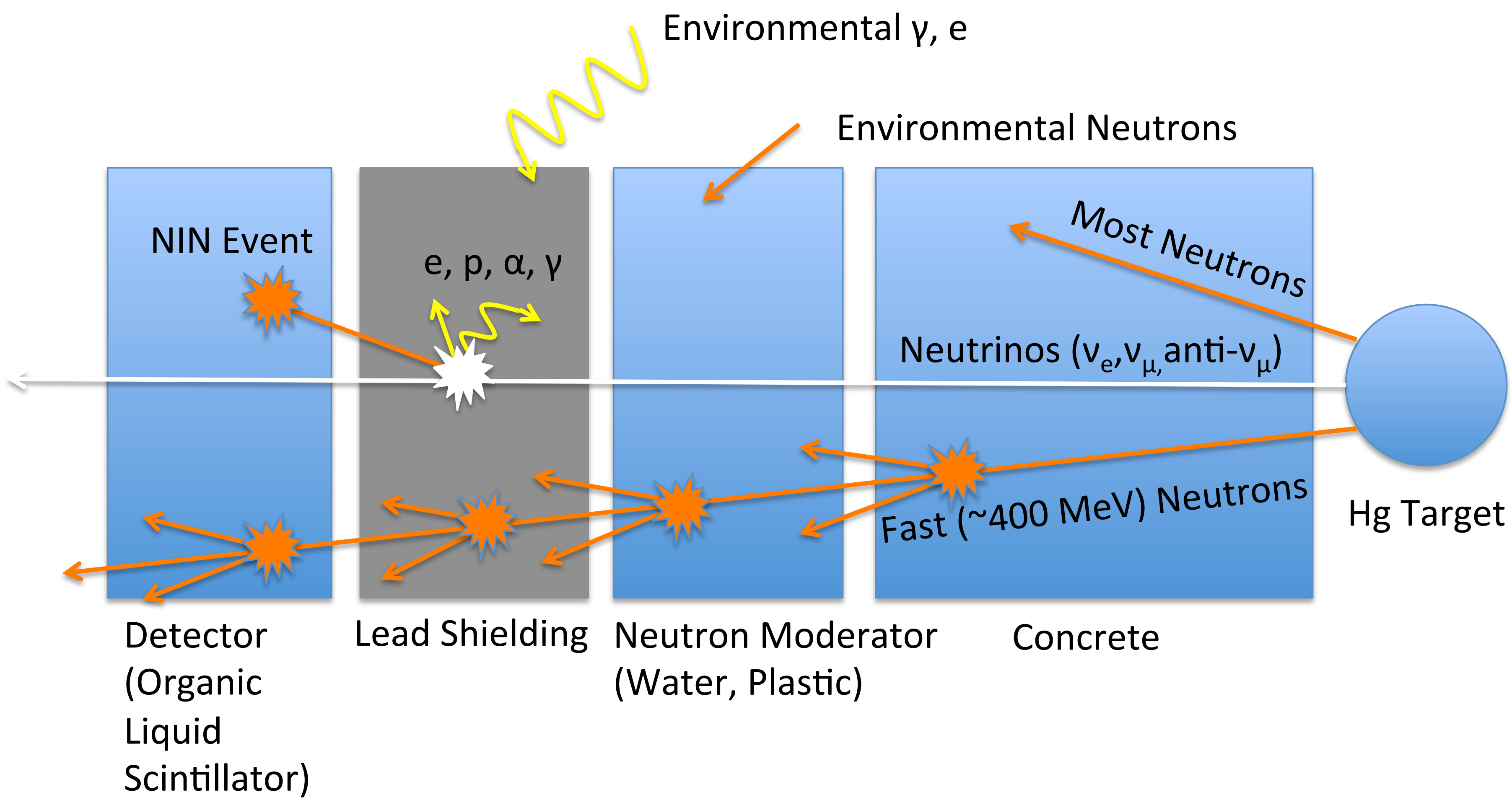
Neutron Production Cross-Section

Volpe, Engel, McLaughlin (Phys. Rev. D 67 013005 2002)	1 Neutron Production	2 Neutron Production
Charged Current (v_e)	$2.35*10^{-39}$ cm^2	$1.38*10^{-39}$ cm^2
Neutral Current (v_e)	$1.37*10^{-40}$ cm^2	$6.15*10^{-41}$ cm^2
Neutral Current (v_u)	$8.7*10^{-41}$ cm^2	$1.5*10^{-41}$ cm^2
Neutral Current (anti-v_u)	$2.85*10^{-40}$ cm^2	$2.98*10^{-40}$ cm^2
Total	$2.86*10^{-39}$ cm^2	$1.75*10^{-39}$ cm^2

The ratio of 1n to 2n production is 1.64:1 total and 1.6:1 in the delayed window (excluding v_u).

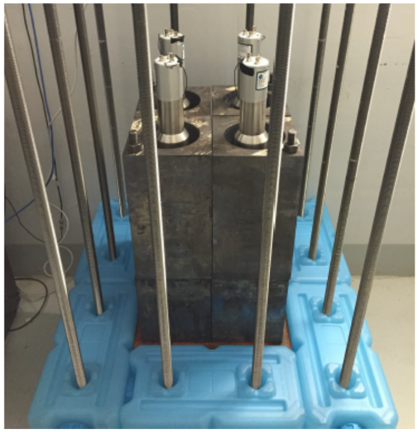
Kolbe (2001) Charged Current: $\sigma = 3.29*10^{-39}$ cm^2
Jacowitz (2002) Neutral Current: $E_v = 50$ MeV $\sigma = 4.8 * 10^{-40}$ cm^2

Neutrino-Induced Neutrons (NINs)



Connection to Supernova Physics

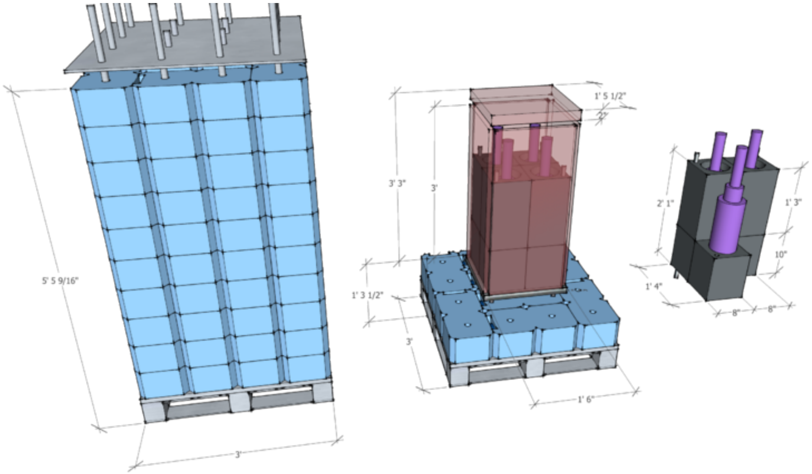
- HALO Supernova Neutrino Observatory relies on inelastic CC cross-section for overall SNν flux.
- "Light" Heavy element production in Supernovae via νp-process.
  - Strong neutrino flux post-bounce produces proton-rich matter. Anti-neutrino capture on free-protons produces neutrons which capture on neutron-deficient, proton-rich nuclei.
- Inelastic neutrino-nucleus interactions influence the spectrum of the ν_e produced during SN



Neutrino-Induced Neutron Detectors: Neutrino Cubes

- The cross-section for Neutrino-Induced Neutron Production is predicted to be quite large for large nuclei such as Pb, an element commonly used in shielding.
- These events share the same time distribution and produce nuclear recoils of similar energy as a CEvNS event.
- Current predictions for this cross-section differ by as much as 30%

- 3 dedicated detector modules.
  - Pb deployed since 2015
  - Fe deployed since late 2016
  - Cu TBD



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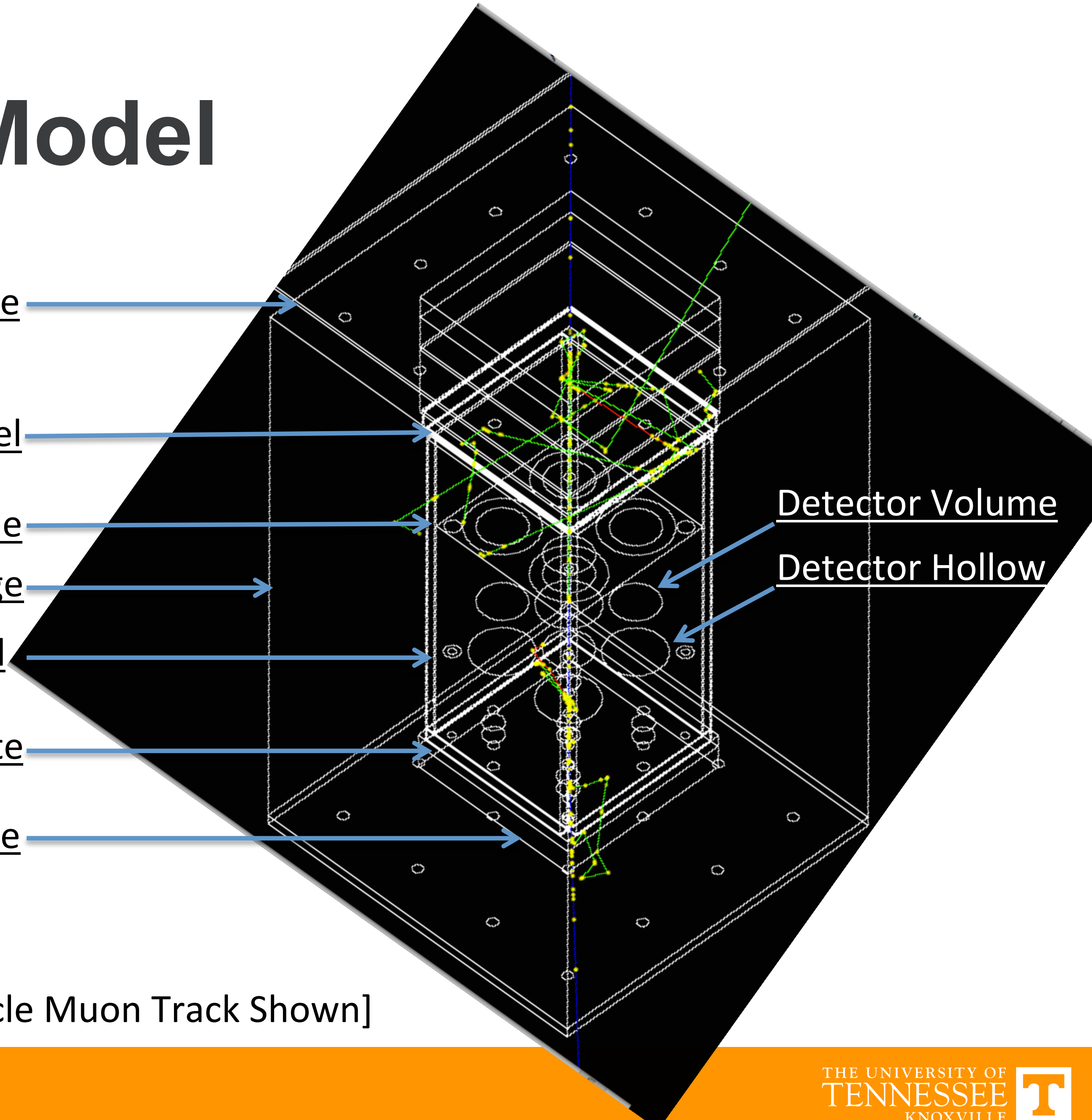
Geant4 Detector Model



Aluminum Roof Plate

Top Muon Panel

Top of Lead Volume

Water Shield Exterior Edge

Side Muon Panel

Aluminum Base Plate

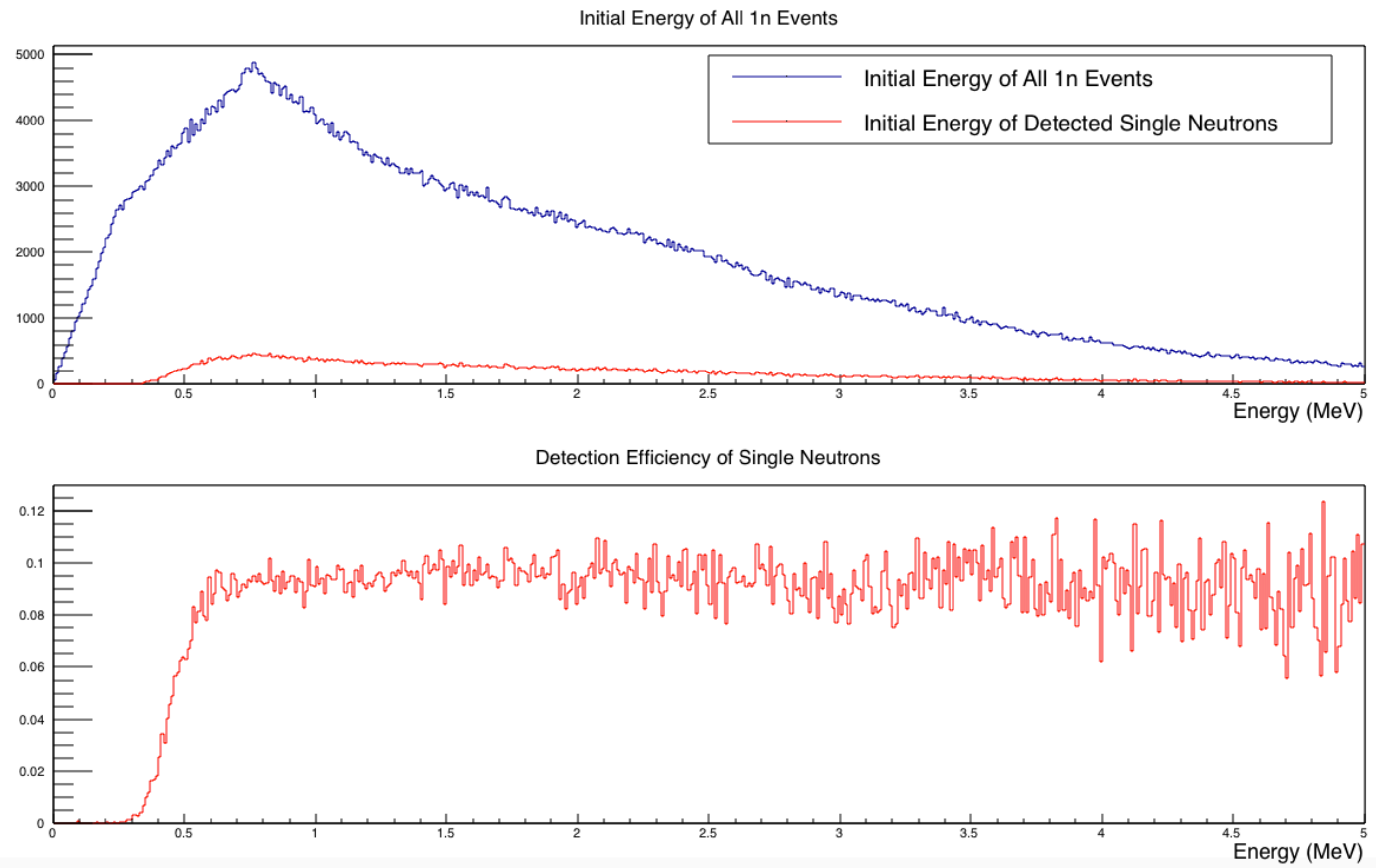
Steel Base Plate

Detector Volume

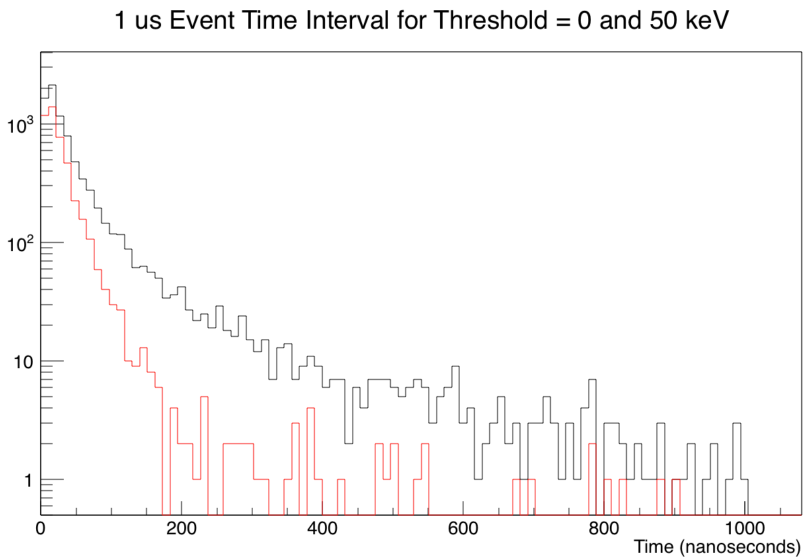
Detector Hollow

[Verticle Muon Track Shown]

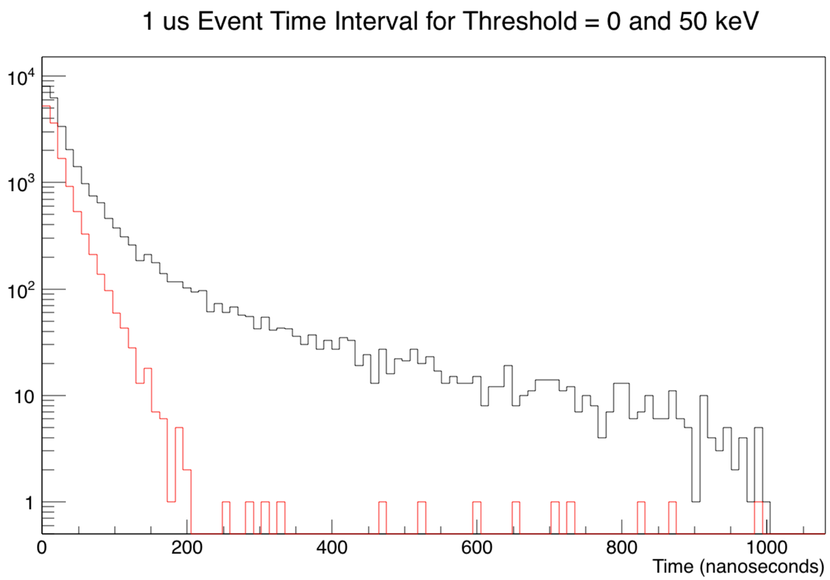
Detection Efficiency



Timing Profile



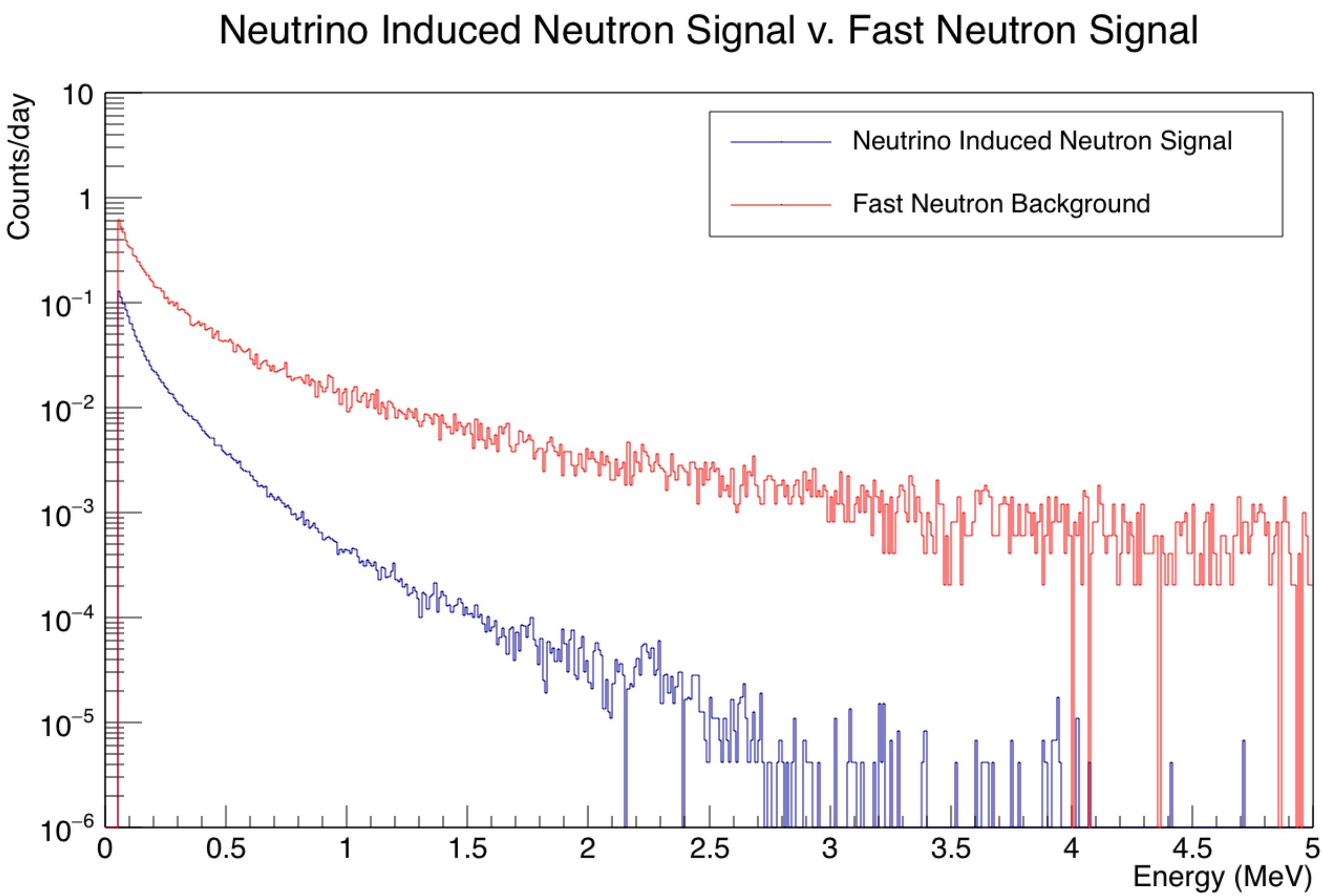
Background Neutrons



Neutrino-Induced Neutrons

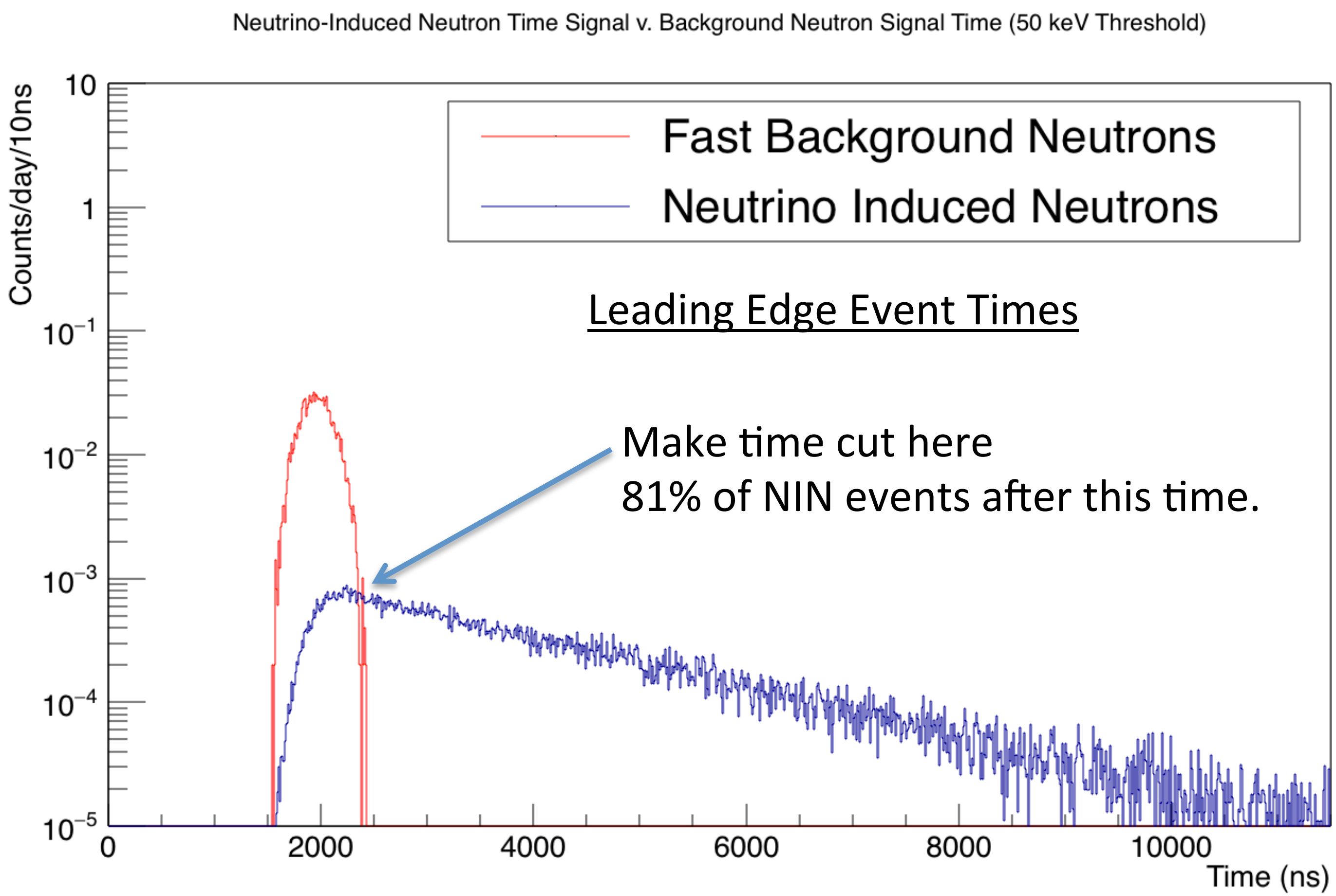
Neutrons which deposit detectable energy do so quickly.

With no time cut, our neutron signal will be mostly background neutrons…

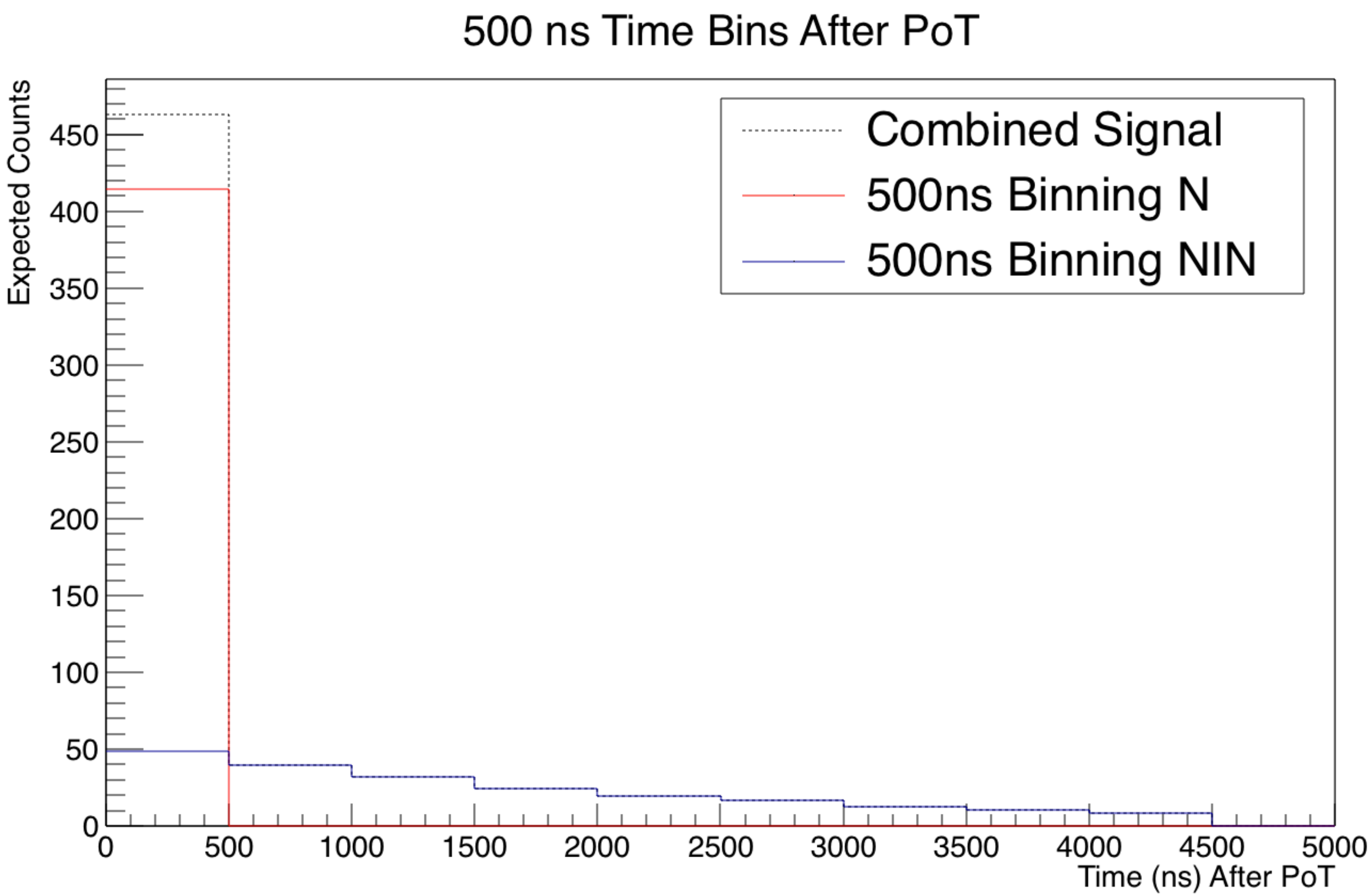


Fast Neutrons normalized to the observed SciBath flux

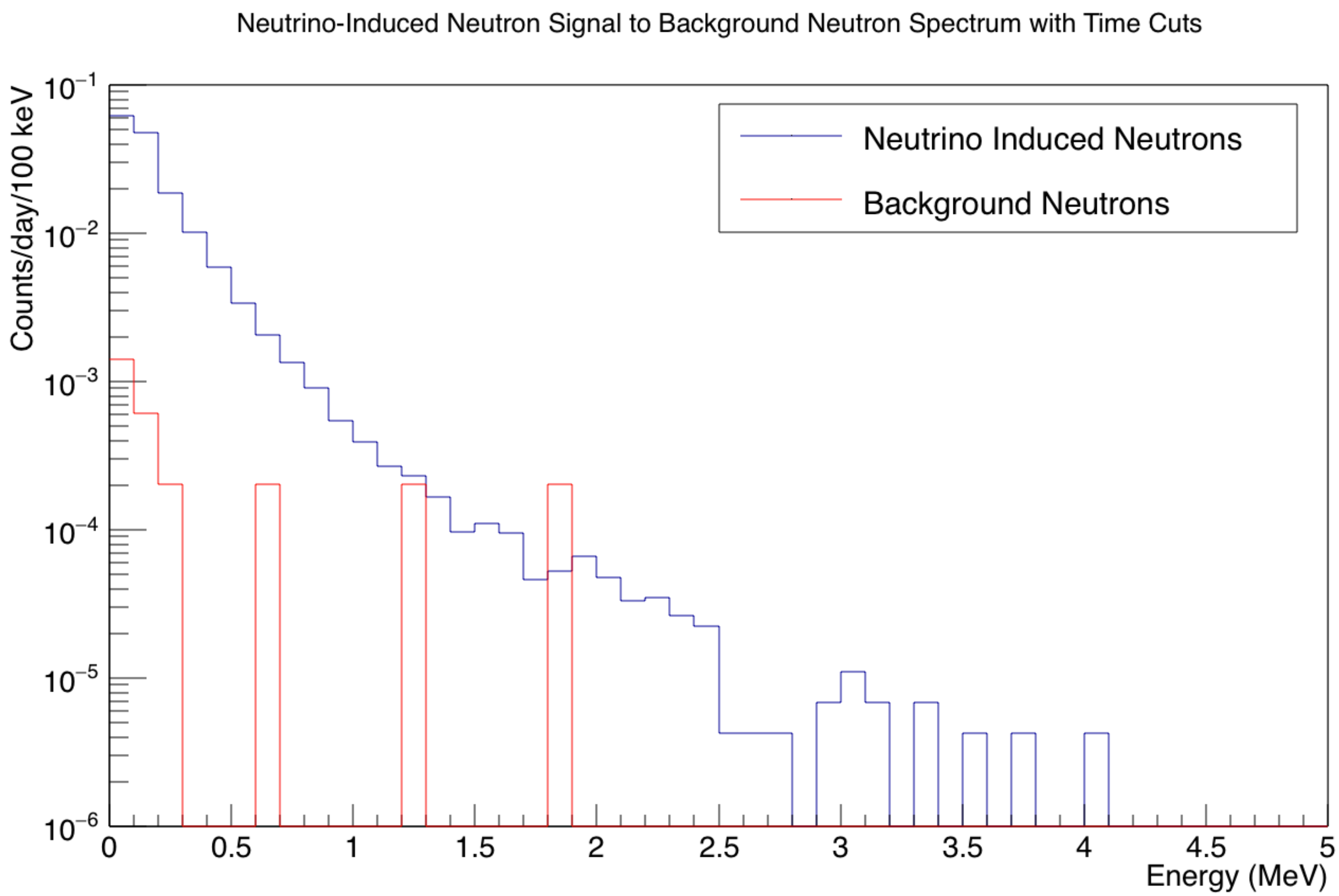
Time Profile



Expected Neutron Signal



NIN and Fast Neutron Energy Spectra with Time Cut



Current Status

- Still accruing statistics for Lead
- Iron has been taking data since late 2016
- Analysis is nearly mature
- Results coming soon!