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

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On the behalf of the COHERENT Collaboration

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Coherent Elastic Neutrino-Nucleus Scattering

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Coherent effects of a weak neutral current

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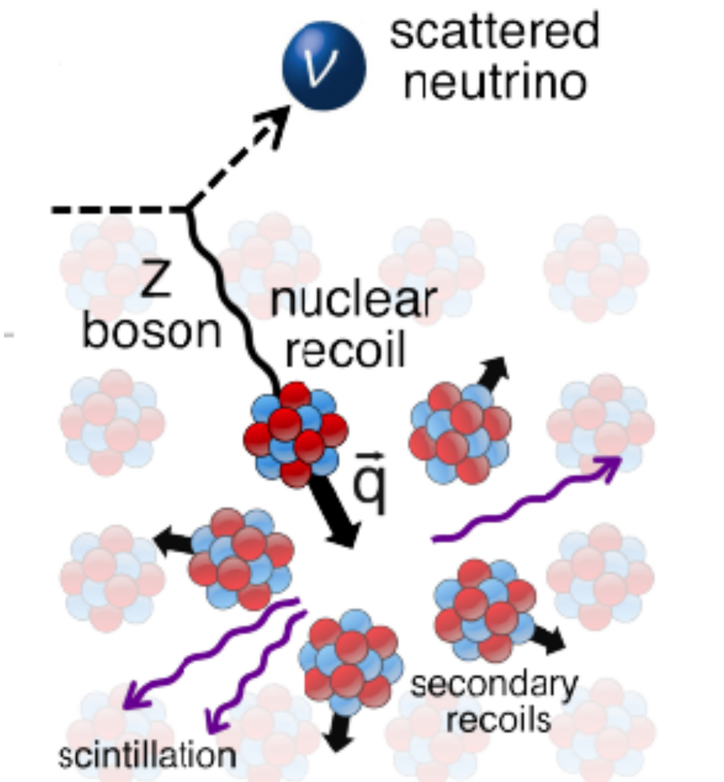
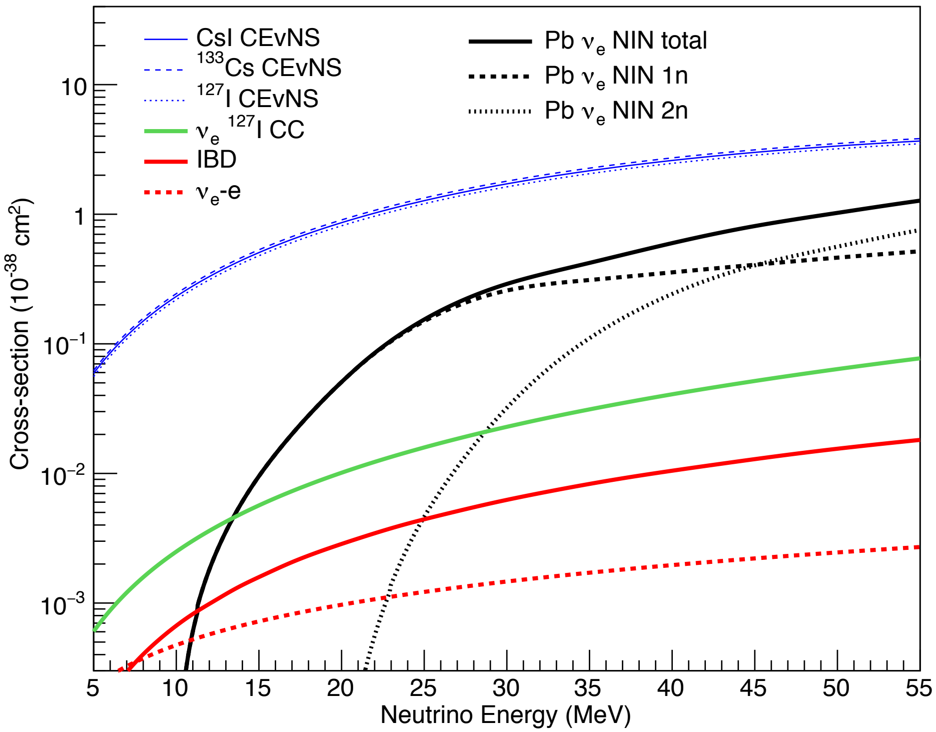


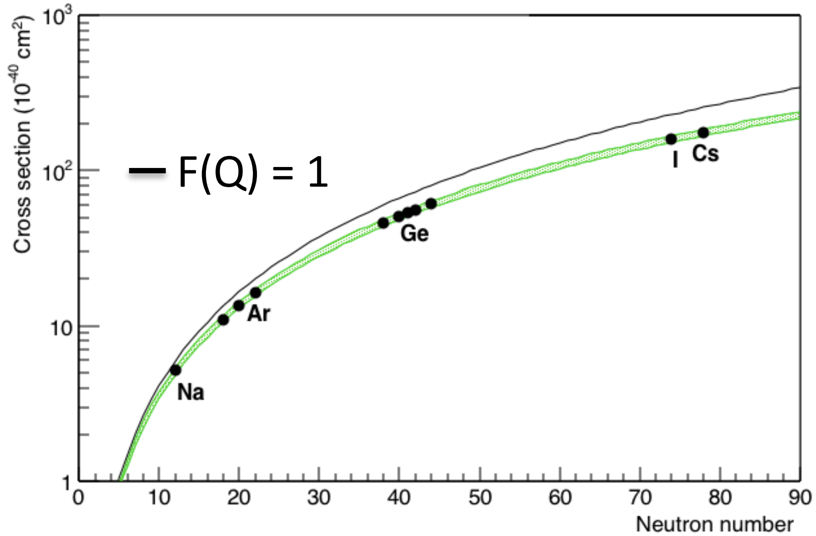
- Weak neutral current process
- Low momentum transfer: $1/q<R_N$
- Identical initial and final states
- Coherence preserved for E_ν < ~50 MeV

<u>Enhanced cross-section for heavy nuclei!</u>

CEvNS Cross-Section



Influence of the Form Factor

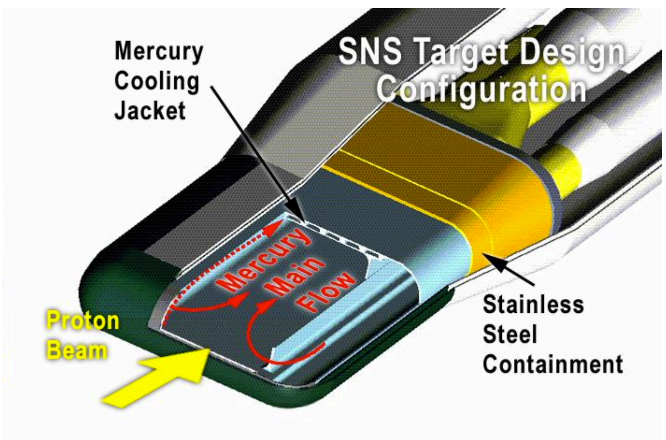


- Cross section proportional to N^2 of the target
- Some correction due to neutron radius is necessary

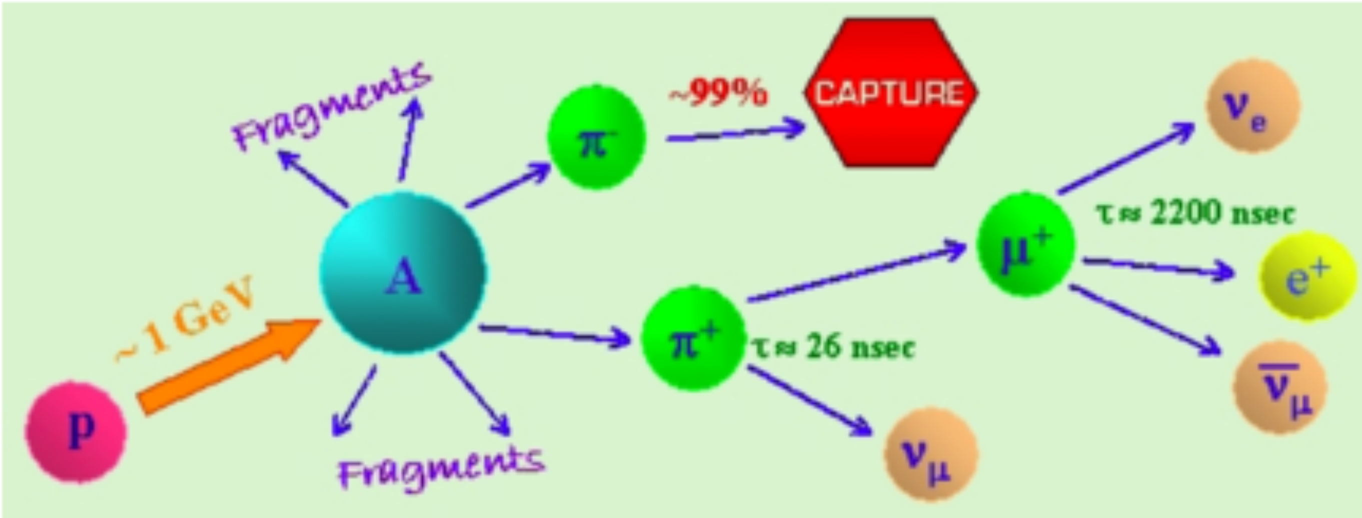
Spallation Neutron Source

SNS Operation Overview

- Linear Accelerator produces ~1.1 GeV protons
- Accumulator Ring creates bunches of 10^{14} protons @ 800 ns FWHM
- Bunches are timed at 60 Hz
- → ~1 MW Beam Energy Delivered to Hg Target

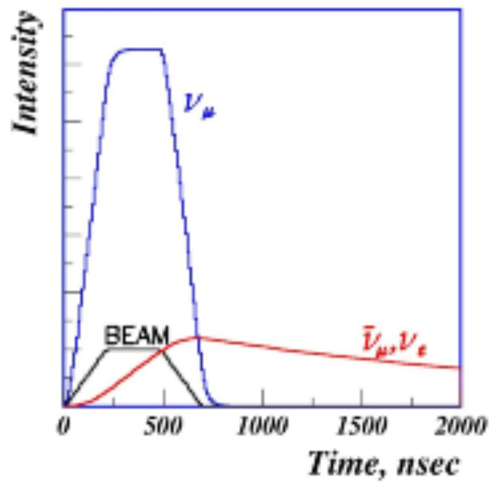


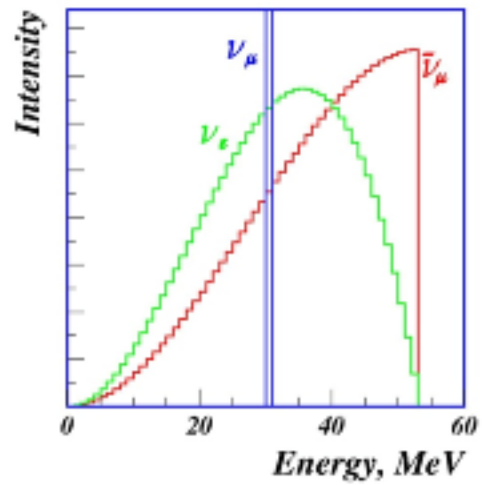
Neutrino Production at SNS



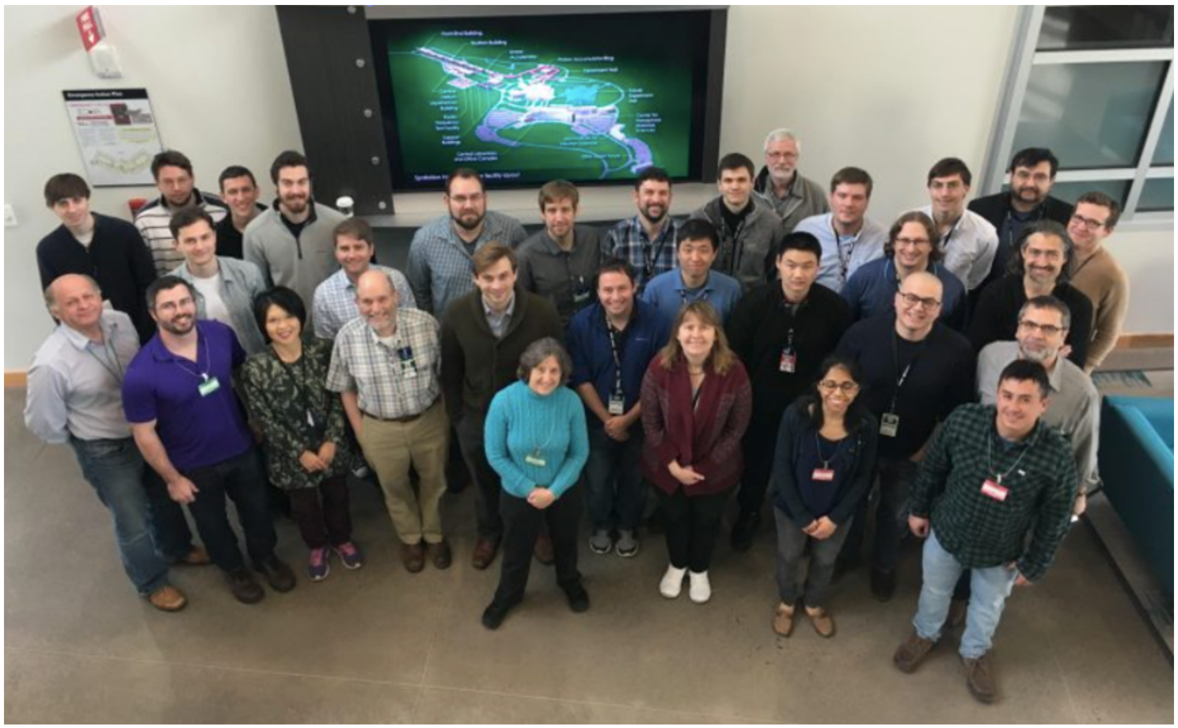
- About 0.08 π^+ are produced per proton

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





COHERENT Collaboration



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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).

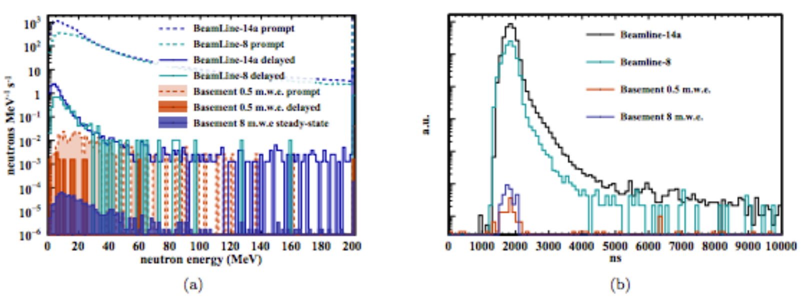
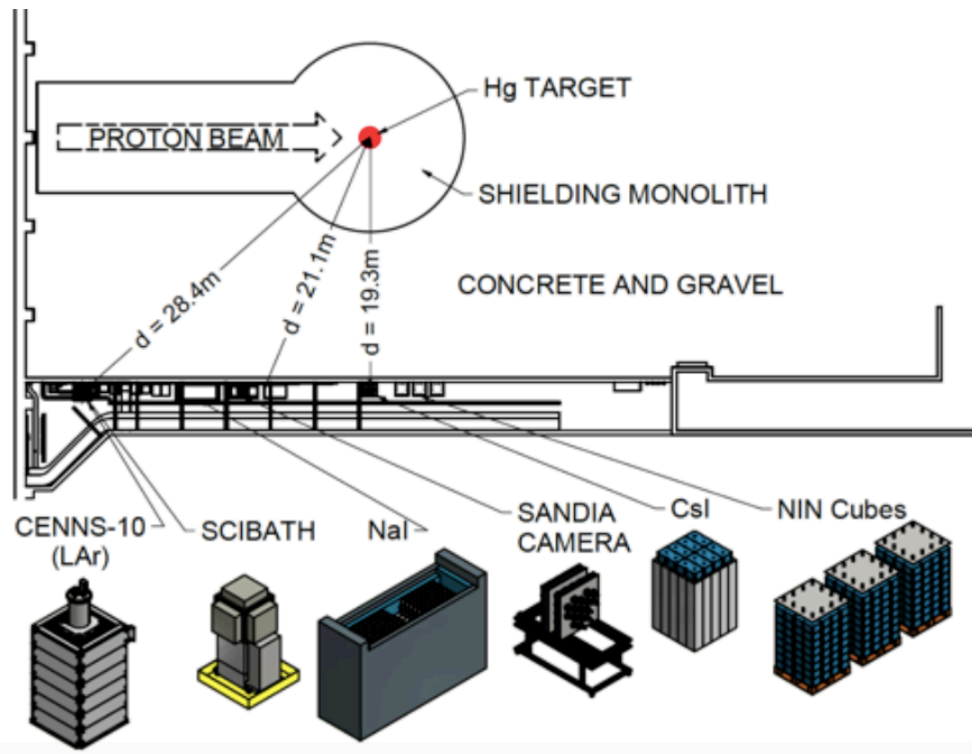


FIG. 4: (a) Fast neutron spectra measured with the neutron scatter camera throughout the SNS facility. A clear reduction by over four orders of magnitude from the experimental hall to the basement locations is seen. No neutron scatters were detected in the delayed window for the basement 8 m.w.e. location. (b) Arrival times of neutrons with respect to SNS beam timing signals.



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

  $\nu_x + {}_{Z}X_N \rightarrow \nu_x + {}_{Z}X^*_N$
- Large uncertainty in cross-section
- Interesting physics case on its own!

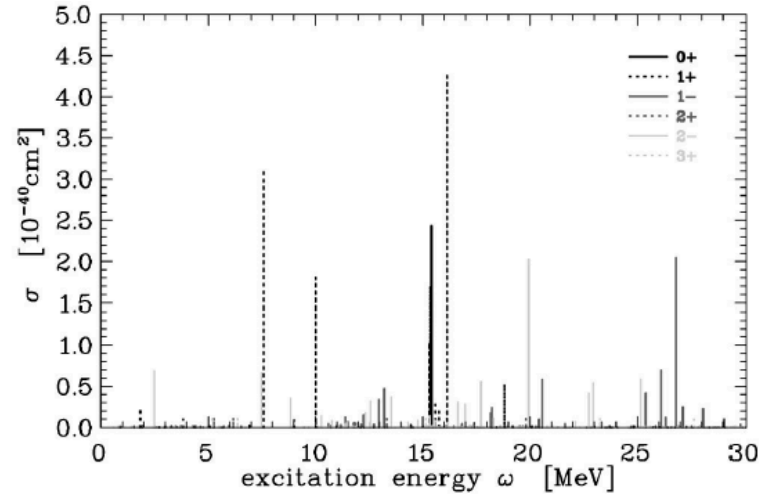
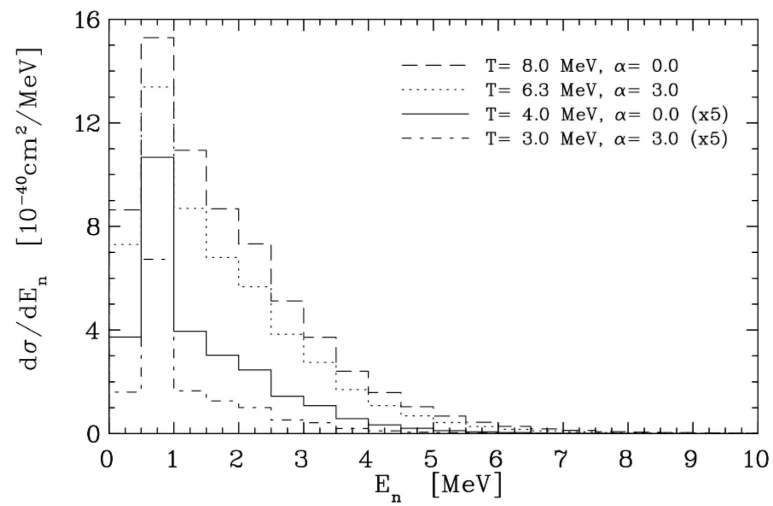


FIG. 1. Multipole decomposition of the RPA response for the charged-current (ν_e, e^-) reaction on ^{208}Pb induced by DAR ν_e neutrinos.



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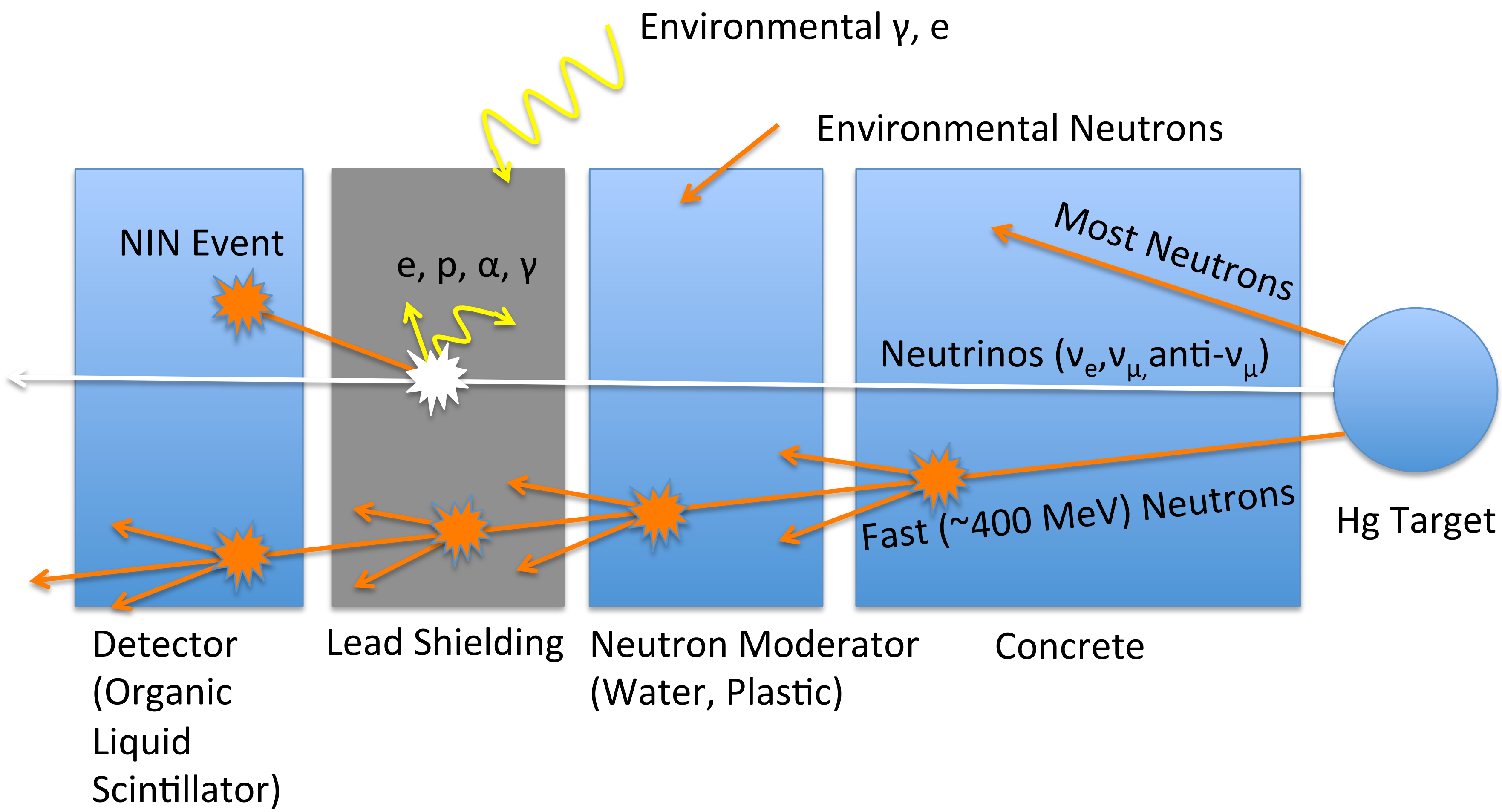
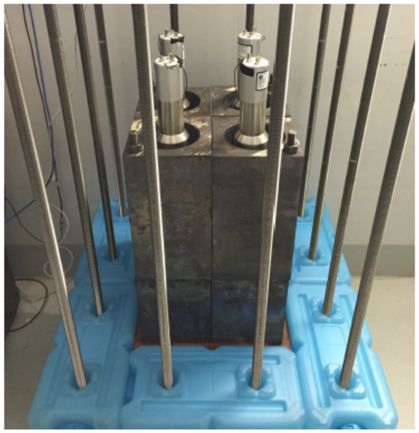
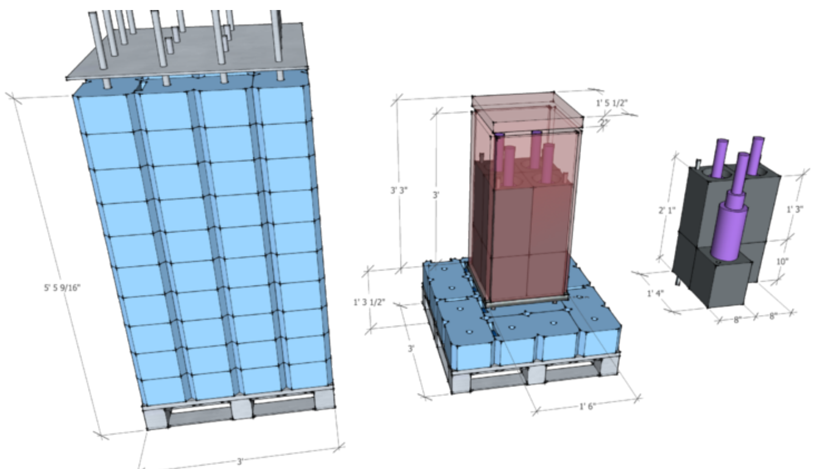
Neutrino-Induced Neutrons (NINs)



Connection to Supernova Physics

- HALO Supernova Neutrino Observatory relies on inelastic charged-current 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

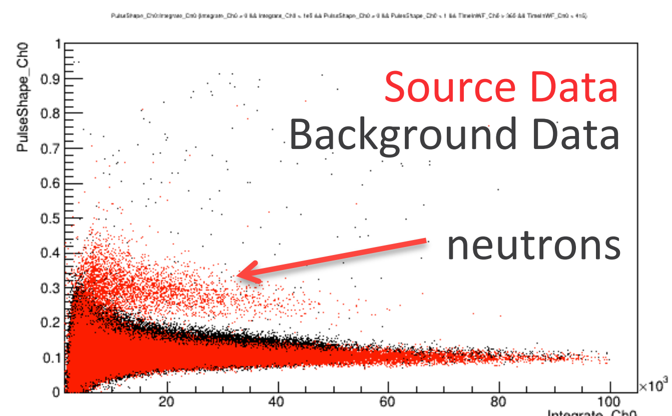




Pb detector assembly includes 980 kg of cast lead with hollow volumes for Liquid Scintillator (EJ-301) detectors chosen for neutron/gamma discrimination. Assembly sits atop a steel palette with 5 muon veto panels on top and sides of lead volume. Exterior water bricks provide shielding against background neutrons.

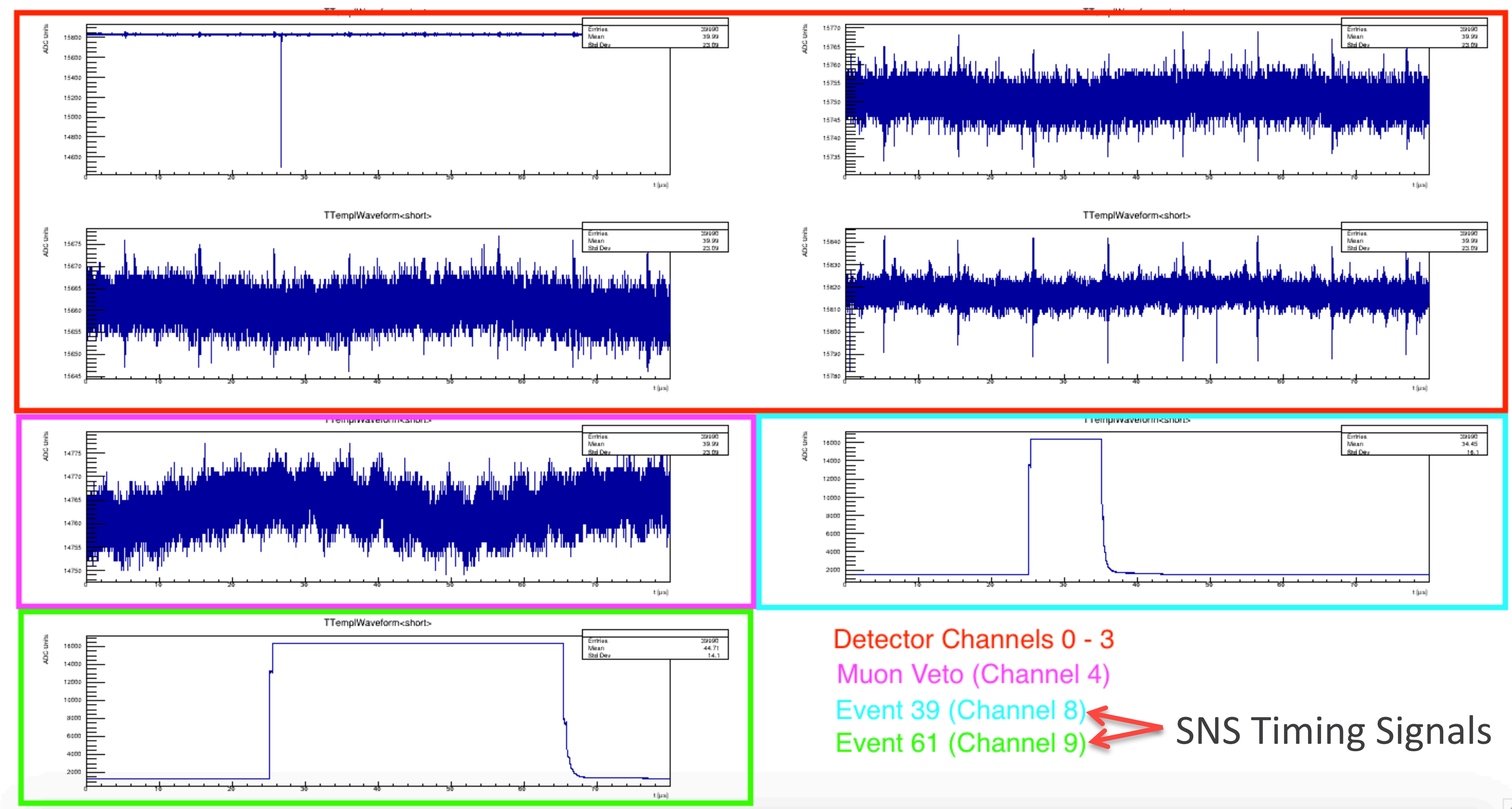
Neutrino-Induced Neutron Detectors: Neutrino Cubes

- 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

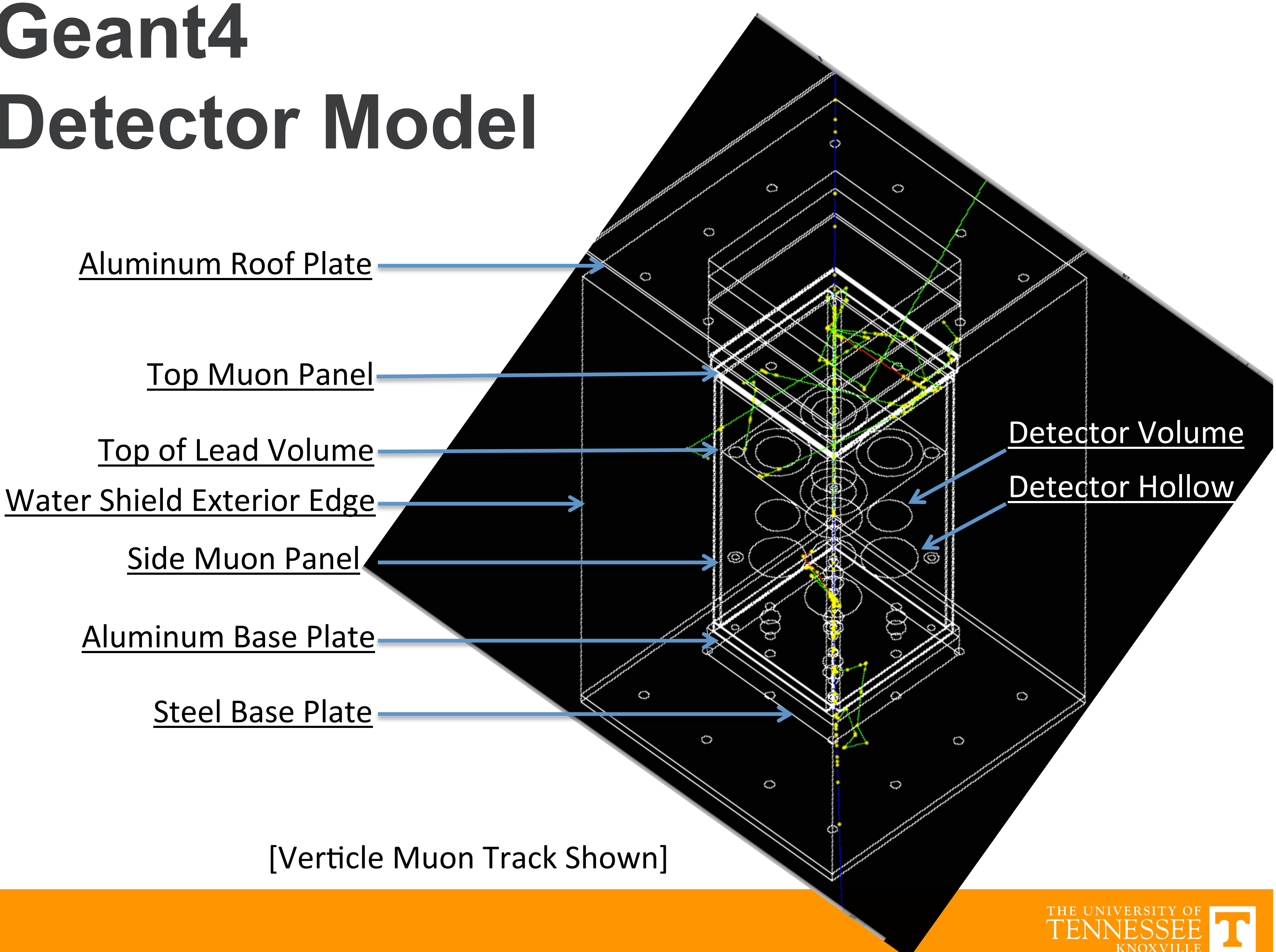


^{252}Cf Calibration Run (Single Channel)

Example Triggered Event

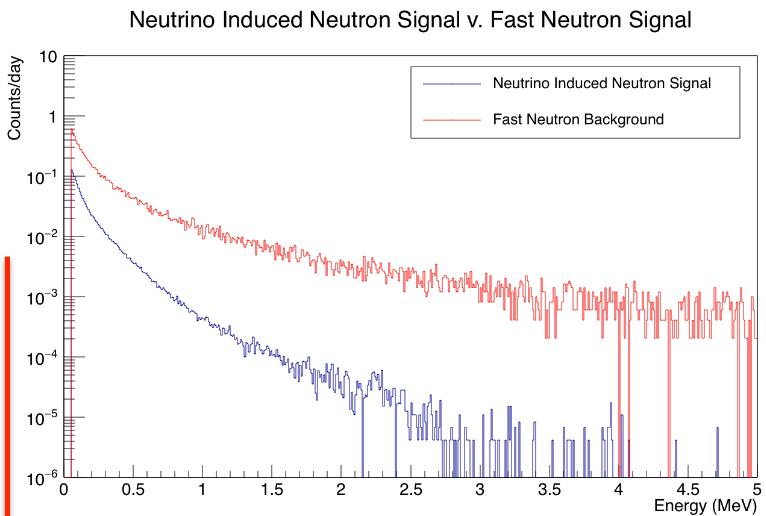


Geant4 Detector Model

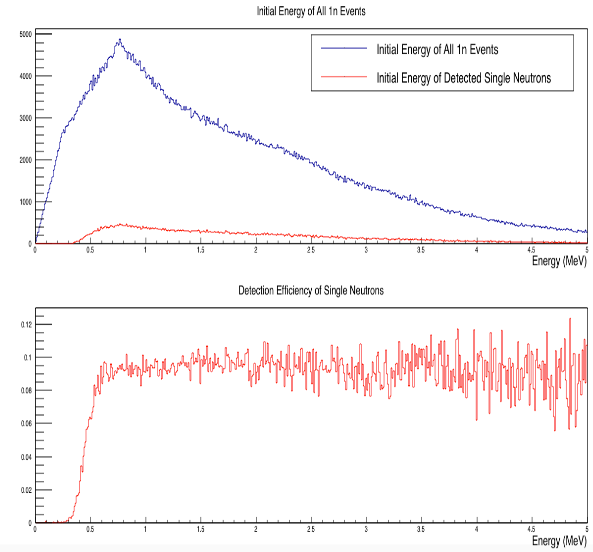


[Verticle Muon Track Shown]

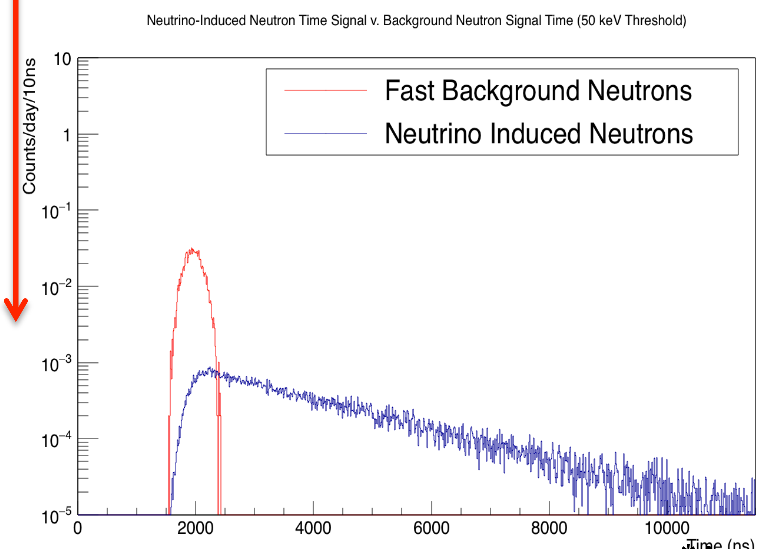
NINs vs Fast Neutron Background



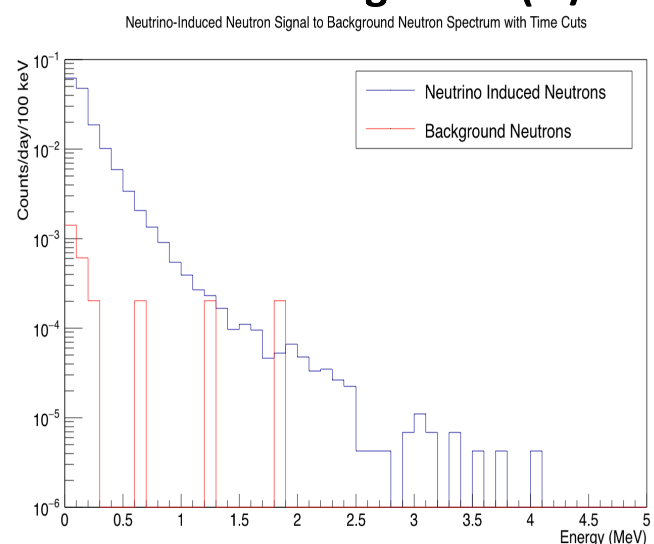
Detection Efficiency



NINs vs Fast Neutron Event Times



NINs vs Fast Neutron Background (w/ Time Cut)



Assuming 50 keVee threshold

Current Status

- Still accruing statistics for Lead and Iron
  - Considering possible upgrades options – Boron Loaded Liquid Scintillator
- Pb analysis is nearly mature
  - Investigating methods to improve particle discrimination

Backup Slides: Electronics/Technical Details

- 4 EJ-301 Organic Liquid Scintillator Cells
  - 4.5” diameter, 9” length
  - Electron Tubes 9821-KEB 3” PMT
- CAEN V1730 digitizer
- CAEN V895 discriminator – Muon Veto System
- CAEN V1495 FPGA/trigger unit
- CAEN V2718 – Optical VME bridge card
- CAEN A3818 – PCIe card
- CAEN 4527 HV Mainframe

Currently operating 2 EJ-301 cells per Nube with Fe detector deployed. Additional replacement liquid scintillators are being installed.