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

Brandon Becker
On the behalf of the COHERENT Collaboration
April 15th, 2018
Coherent Elastic Neutrino-Nucleus Scattering

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

**Enhanced cross-section for heavy nuclei!**
CEvNS Cross-Section

- 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
- $\rightarrow$ ~1 MW Beam Energy Delivered to Hg Target
Neutrino Production at SNS

- About $0.08 \pi^+$ are produced per proton

- $\pi^+$ have a mean free path of 5 cm in Hg - most will come to rest before decaying
COHERENT Collaboration
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).

![Diagram of the COHERENT experiment setup]

**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 ($p$, $n$, $\alpha$, $\gamma$)
- Charged-Current
  \[ \nu_e + ZX_N \rightarrow e^- + Z+1X_{N-1}^* \]
- Neutral Current
  \[ \nu_x + ZX_N \rightarrow \nu_x + ZX_N^* \]
- Large uncertainty in cross-section
- Interesting physics case on its own!
Neutral-Induced Neutrons (NINs)

NIN Event

Detector (Organic Liquid Scintillator)

Lead Shielding

e, p, α, γ

Neutron Moderator (Water, Plastic)

Concrete

Environmental γ, e

Most Neutrons

Neutrinos (νₑ, νₘ, anti-νₘ)

Environmental Neutrons

Fast (~400 MeV) Neutrons

Hg Target
Connection to Supernova Physics

• HALO Supernova Neutrino Observatory relies on inelastic charged-current cross-section for overall SNv flux

• “Light” Heavy element production in Supernovae via vp-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 $\nu_e$ 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

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.
Example Triggered Event

Detector Channels 0 - 3
Muon Veto (Channel 4)
Event 39 (Channel 8)
Event 61 (Channel 9)

SNS Timing Signals
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

[Vertical Muon Track Shown]
Detection Efficiency

**NINs vs Fast Neutron Background**

Neutrino Induced Neutron Signal v. Fast Neutron Signal

- Neutrino Induced Neutron Signal
- Fast Neutron Background

**NINs vs Fast Neutron Event Times**

Neutrino-Induced Neutron Time Signal v. Background Neutron Signal Time (50 keV Threshold)

- Fast Background Neutrons
- Neutrino Induced Neutrons

**Assuming 50 keVee threshold**

**NINs vs Fast Neutron Background (w/ Time Cut)**

Neutrino-Induced Neutron Signal to Background Neutron Spectrum with Time Cuts

**Detection Efficiency**

Initial Energy of All In Events

- Initial Energy of All In Events
- Initial Energy of Detected Single Neutrons

Detection Efficiency of Single Neutrons

Energy (MeV)

Energy (MeV)
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.