NalνE: A NaI[Tl] Neutrino Experiment at the SNS

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CEνNS Recoils of Na at the SNS

• Sodium lighter than COHERENT’s other nuclei, test expected $N^2$ scaling
• Lower cross section, but more energetic nuclear recoils
• Collaboration has access to nine tons of NaI[Tl] scintillators from Advanced Spectroscopic Portal program
• Can’t control internal crystal backgrounds
  • Adding crystals can increase backgrounds
• 10-stage PMTs make achieving sufficient energy thresholds difficult
NaI[Tl] Quenching Factor

- Nuclear recoil light output quenched compared to electron recoils of the same energy
- Dedicated beamline at Triangle Universities Nuclear Laboratory (TUNL) for quenching factors measurements
- NaI[Tl] quenching factor run previously measured at TUNL
NalνE-185 Overview

• Array of twenty-four 7.7kg NaI[Tl] scintillators deployed in summer of 2016
• Designed to fit into existing “neutrino cube”
• Two modes of operation:
  • High-voltage mode for backgrounds for CEνNS off Na (<40 keVee)
  • Low-voltage mode for charged-current interaction on $^{127}$I (<52.8 MeV)
• Uses timing, energy, event multiplicity to reduce backgrounds
• Prototype for multi-ton detector capable of simultaneously observing CEνNS and charged-current interactions
Backgrounds for CEνNS Signal

- Neutrinos interacting via in CEνNS in both prompt and delayed beam windows
- CEνNS events will occur in single crystal
  - Reject backgrounds using coincidence window (within 100ns)
- Expect backgrounds to be high in NaIvE-185 lack of high-Z shielding makes it susceptible to environmental gammas
- Steady state beam-off backgrounds 200-500 counts/keV kg day before beam timing suppression
  - In 1µs window: 0.01 to 0.03 counts/keV kg day below 40 keVee
- Environmental steady state backgrounds increase when beam on, but shielding should reduce this
Charged Current Reaction on $^{127}$I at the SNS

- Measure the charged current cross section of $\nu_e$ on $^{127}$I
  
  $\nu_e + ^{127}$I $\rightarrow ^{127}$Xe + $e^-$

- Can measure $g_A$ quenching from $^{127}$I charged current cross section

- Tests nuclear models

- Radiochemical approach at LAMPF measured flux-averaged cross section of 
  
  $\sigma = 2.84 \pm 0.91 \ (stat) \pm 0.25 \ (sys) \times 10^{-40} \ cm^2$

  - Doesn’t include interactions where $^{127}$Xe state unbound (particle emission threshold of 7.23 MeV)

**TABLE III.** Contributions of individual multipoles to the total cross section for neutrinos from muon decay, in units of $10^{-40} \ cm^2$. The two columns correspond to quenched and free values for $g_A$, respectively (see text).

| $|J|$ | $g_A = -1.0$ | $g_A = -1.26$ |
|-----|--------------|--------------|
| 0+  | 0.096        | 0.096        |
| 0−  | 0.00001      | 0.00002      |
| 1+  | 1.017        | 1.528        |
| 1−  | 0.006        | 0.008        |
| 2+  | 0.155        | 0.213        |
| 2−  | 0.693        | 1.055        |
| 3+  | 0.149        | 0.171        |
| 3−  | 0.017        | 0.025        |

**Total**

2.008 3.006


Charged Current Measurement

- Measure energy of lepton produced in charged-current interaction (<52.8 MeV)
- Cosmic rays main background
- Signal in delayed window
  - Prompt neutron flux high in NaIνE location because of void in shielding—larger detector will be different location in hallway
- Expected signal of 0.33 counts/crystal/month

![Energy region of interest](energy_region.png)

![Delayed window](delayed_window.png)
• No muon vetos deployed in initial run
• Charged current event topology expected to be distinguishable from cosmic rays, which can have higher multiplicities
• Focusing on low multiplicity events gives reduction in backgrounds
  • Outer detectors have higher low multiplicity backgrounds because of clipping muons
  • ~45 times higher backgrounds in corners compared to central detectors
• $^{127}$Xe unbound state can emit particles, affect event topology
Background Reduction Through Muon Tracking

- Hough transform parameterizes straight lines in \((\rho, \theta)\) space
- Each detector passing through a straight line increments an accumulator
- After passing through all detectors in event, lines with highest accumulators used to create possible tracks

Duda, Richard O. and Hart, Peter E., Commun. ACM 15(11) 1972
NalνE-185 Upgrade

• Veto panels will reduce muon background
• 1.5” steel shielding between veto and detectors to avoid vetoing signal
• Muon vetos operating in similar triggering configuration, allow for study of muon physics in NaI[Tl] detectors
• Construction complete, testing now, planned deployment in November
Summary and Outlook

- NaIνE-185 collecting data to measure charged current reaction in $^{127}$I
- Planned upgrades will reduce muon backgrounds, help to characterize properties of signal
- NaIνE-185 prototype is one of the ways COHERENT preparing for measuring CEνNS of Na nuclei
- Goal is to deploy a multi-ton detector capable of simultaneously observing CEνNS of Na nuclei and charged current interaction on $^{127}$I
Back up
Previous $^{127}$I Charged Current Measurement

- Radiochemical approach at LAMPF measured flux-averaged cross section of
  \[ \sigma = 2.84 \pm 0.91 \text{ (stat)} \pm 0.25 \text{ (sys)} \times 10^{-40} \text{ cm}^2 \]

- $^{127}$Xe decays exclusively to excited $^{127}$I states:
  \[ ^{127}\text{Xe} \rightarrow ^{127}\text{I}^* + \gamma \text{ (203, 375 keV)} \]
  \[ ^{127}\text{I}^* \rightarrow ^{127}\text{I} + e^- \text{ (~0.9, 4.7 keV)} \]

- Need accurate information on $^{127}$Xe produced through other means (cosmogenic, muons, etc.)

- Doesn’t include interactions where $^{127}$Xe state unbound (particle emission threshold of 7.23 MeV)
Dual Output Bases

• PMTs begin to saturate, see non-linear light output above a certain energy (voltage-dependent)

• Solution is to use a dual-output base designed by Lorenzo Fabris at ORNL
  • With base, have achieved target thresholds for Na CEνNS recoils (3-40 keVee) in low-energy output while avoiding saturation effects up to 60 MeV in high-energy output
Nal\(\nu\)E-185 Data Acquisition

- Use internal digitizers trigger to record signals (regardless of beam presence)
- Separately digitize timing signals from SNS to look for beam-correlated events
- Eight 1250ns accumulator windows used for calculating integral, detecting pile-up of signals
- Peak height, peak high index, pile-up flag also recorded for every signal

![Graph showing baseline, integral, and post-integral components with peak height and peak high index highlighted.](Image)
Prompt Signals in NaIνE
Neutrino Timing Distribution