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

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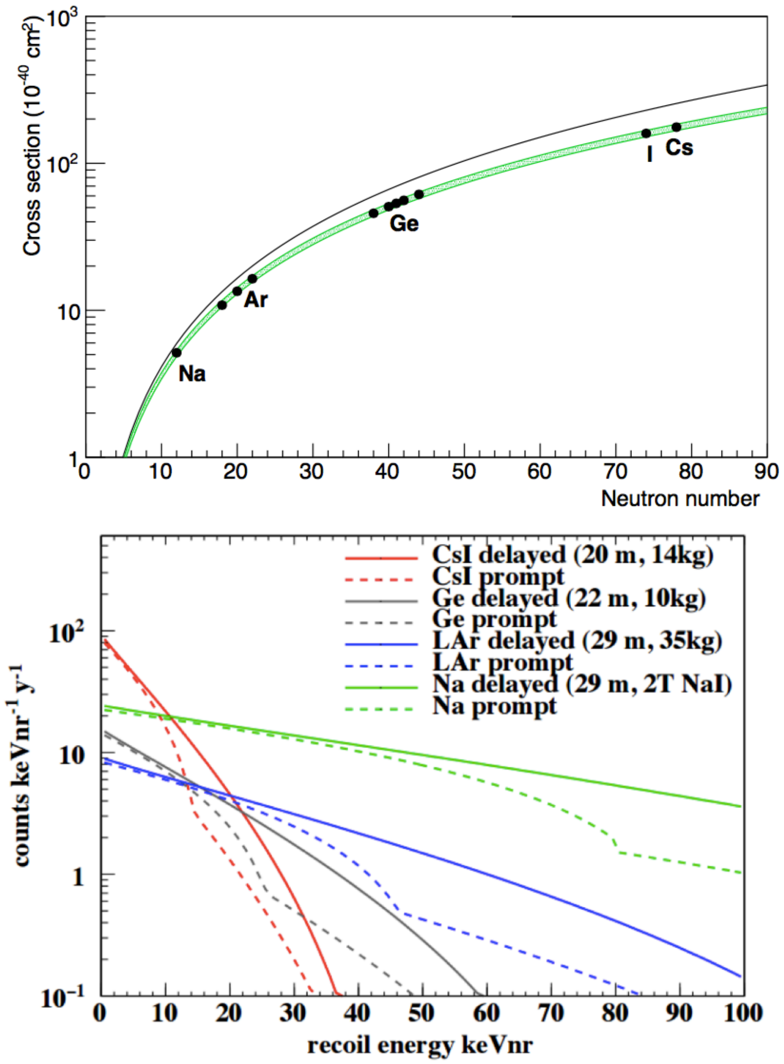
TUNL

COHERENT SNS

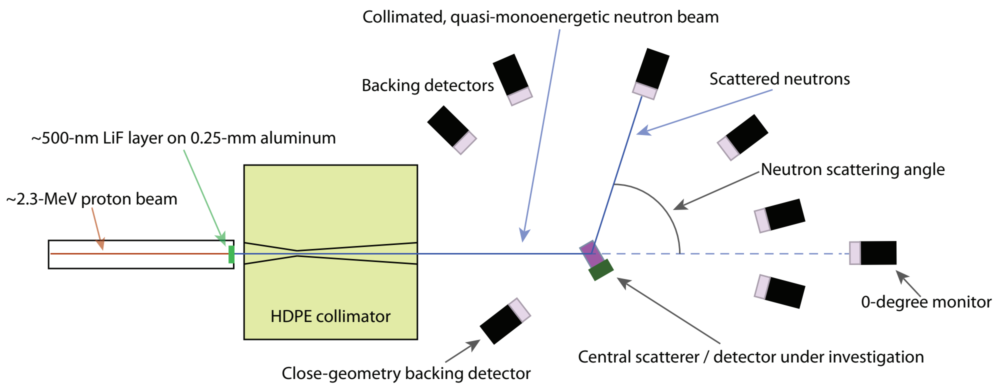
CEνNS Recoils of Na at the SNS

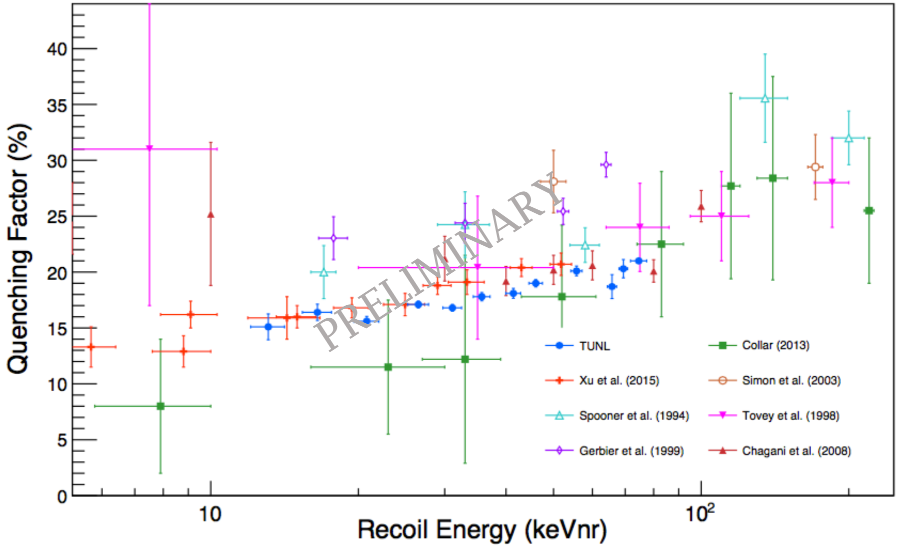
- Sodium lighter than COHERENT's other nuclei, test expected N^2 scaling
- Lower cross section, but more energetic nuclear recoils
- Collaboration has access to nine tons of NaI[Tl] scintillators from Advanced Spectroscopic Portal program
- Can't control internal crystal backgrounds
    - Adding crystals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

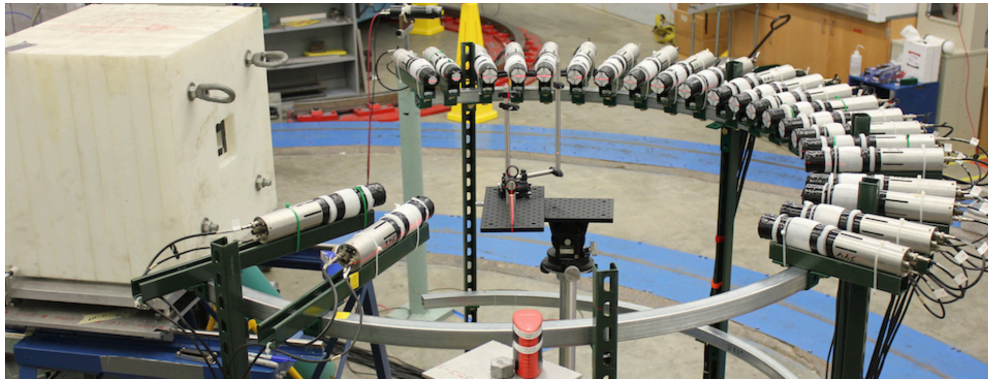


NaI[Tl] Quenching Factor

- 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

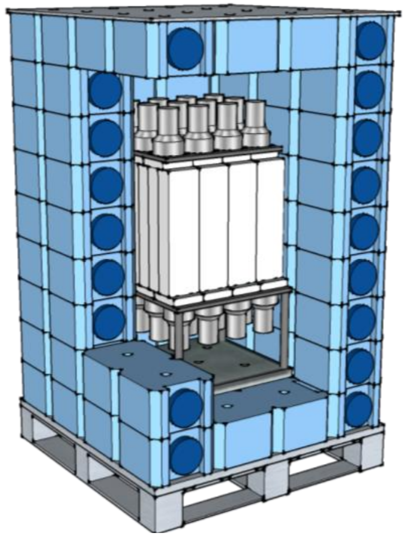


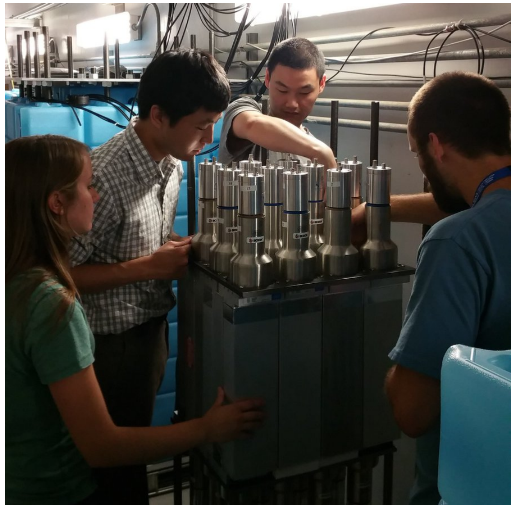




NaIνE-185 Overview

- 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

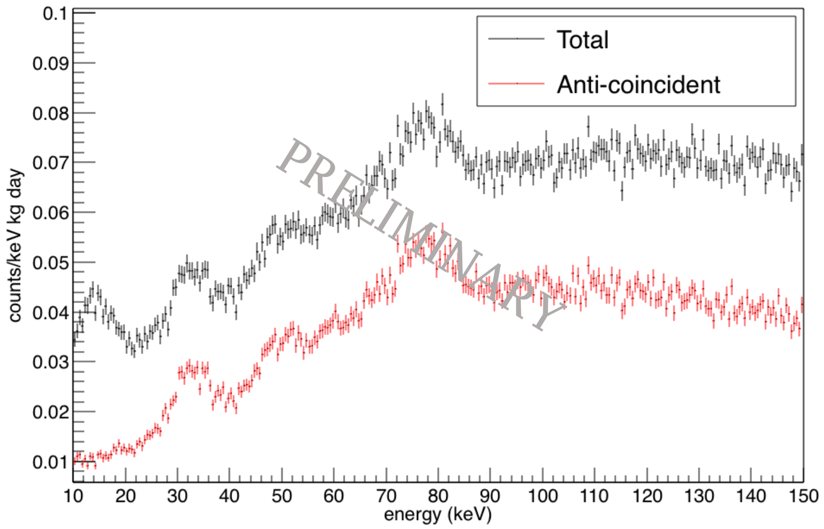




Backgrounds for CEνNS Signal

- 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

Steady State Backgrounds in Central Detector in 1μs Window



Charged Current Reaction on ^{127}I at the SNS

- Measure the charged current cross section of ν_e on ^{127}I

$$\nu_e + {}^{127}\mathrm{I} \rightarrow {}^{127}\mathrm{Xe} + e^-$$

- 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

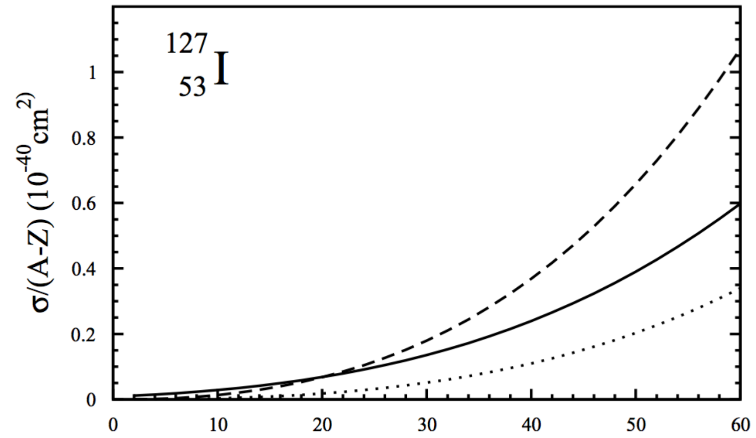
$$\sigma = 2.84 \pm 0.91\ (stat) \pm 0.25\ (sys) \times 10^{-40}\ \mathrm{cm}^2$$

  - 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^π	$g_A = -1.0$	$g_A = -1.26$
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	2.098	3.096

J. Engel, S. Pittel, and P. Vogel, Phys. Rev. C **50**(3), 1994

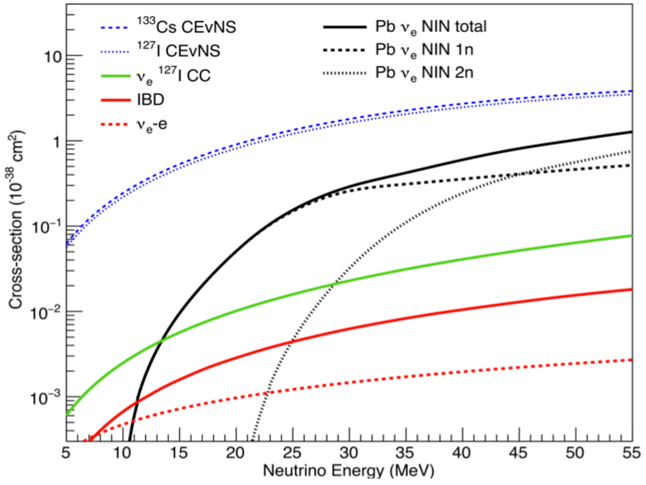


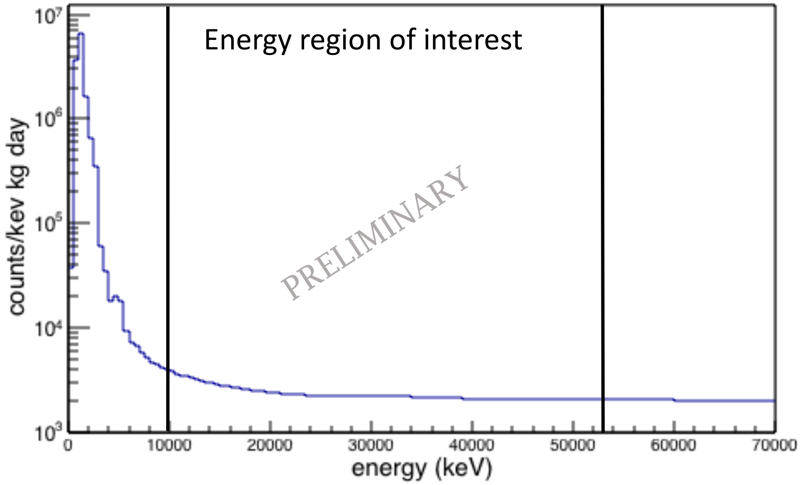
M. Sajjad Athar, Shakeb Ahmad, and S.K. Singh, Nuc. Phys. A 764(9), 2006

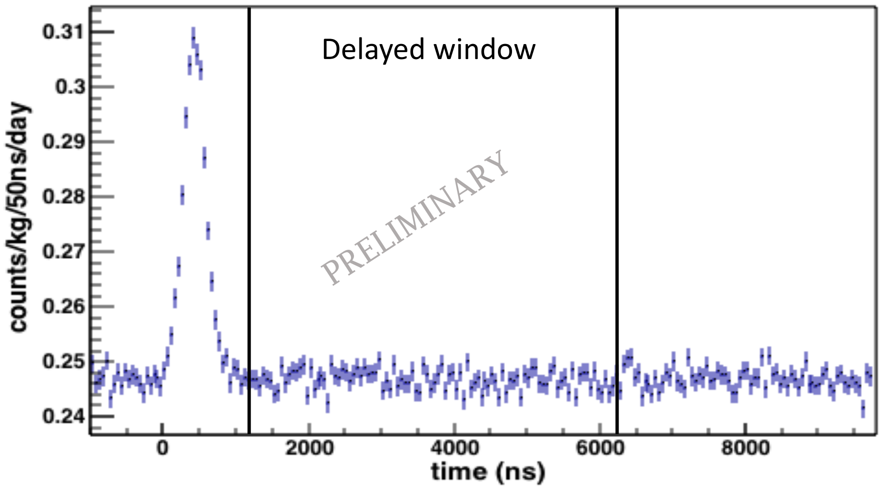
J. R. Distel, B. T. Cleveland, K. Lande, C. K. Lee, P. S. Wildenhain, G. E. Allen, and R. L. Burman Phys. Rev. C 68 054613, 2003

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



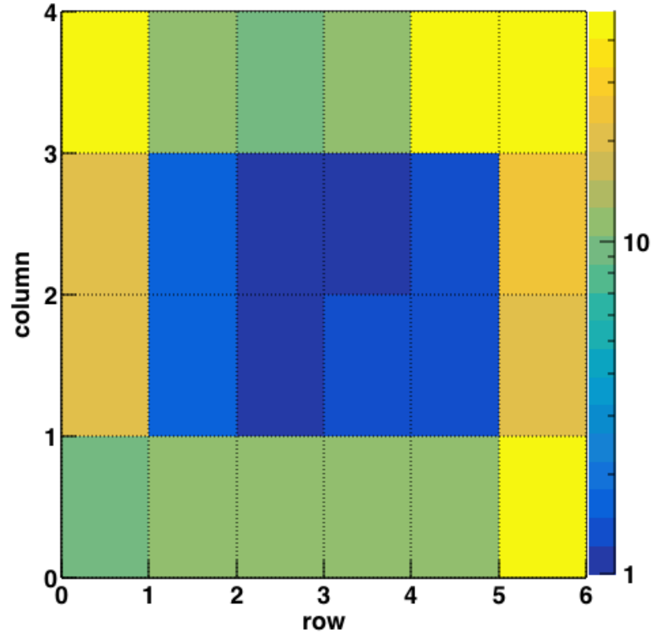




Background Reduction Through Self-Vetoing

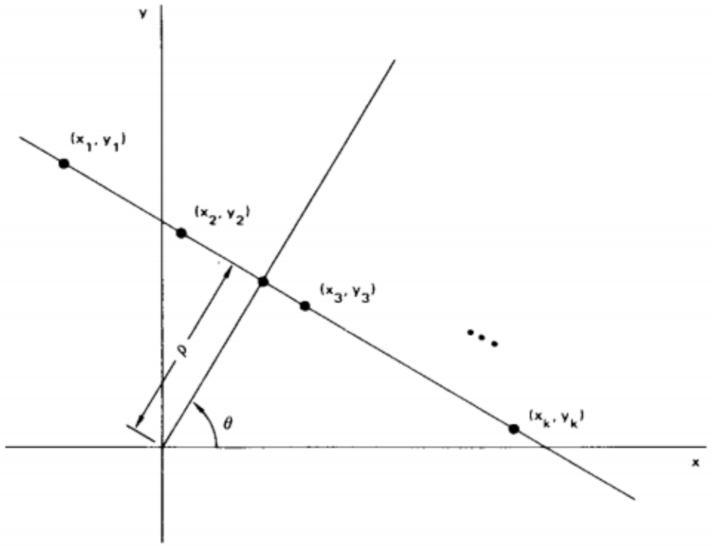
- No muon vetos deployed in initial run
- Charged current event topology expected to be distinguishable from cosmic rays, which can have higher multiplicities
- Focusing on low multiplicity events gives reduction in backgrounds
  - Outer detectors have higher low multiplicity backgrounds because of clipping muons
  - ~45 times higher backgrounds in corners compared to central detectors
- ^{127}Xe unbound state can emit particles, affect event topology

Relative high energy backgrounds for multiplicity=1 events



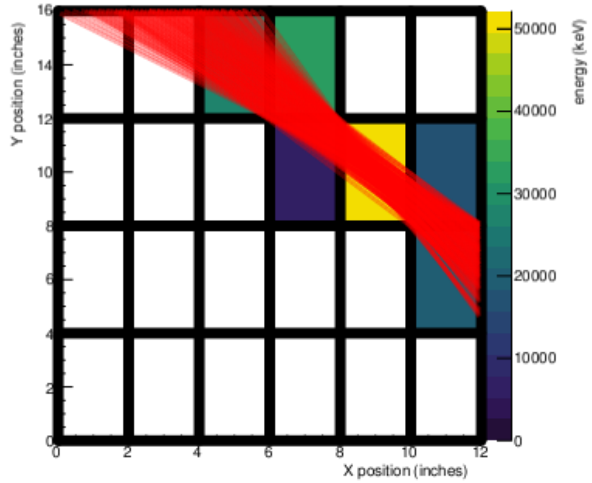
Background Reduction Through Muon Tracking

- Hough transform parameterizes straight lines in (ρ, θ) 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

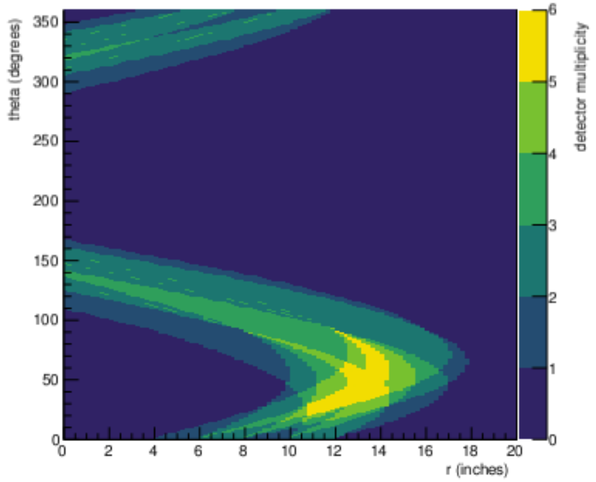


Duda, Richard O. and Hart, Peter E., Commun. ACM 15(11) 1972

Energy of signals in event

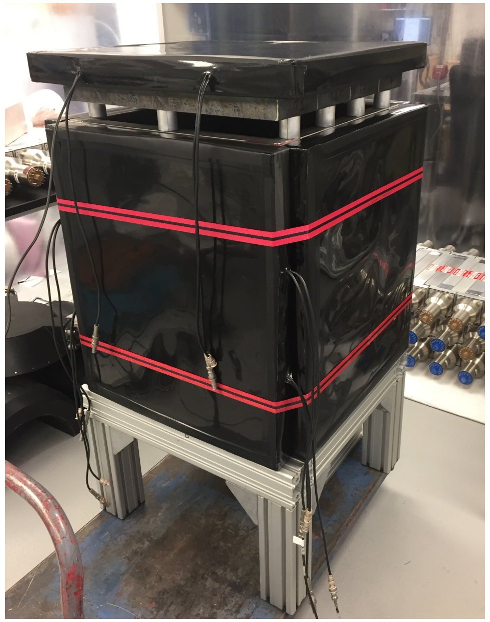


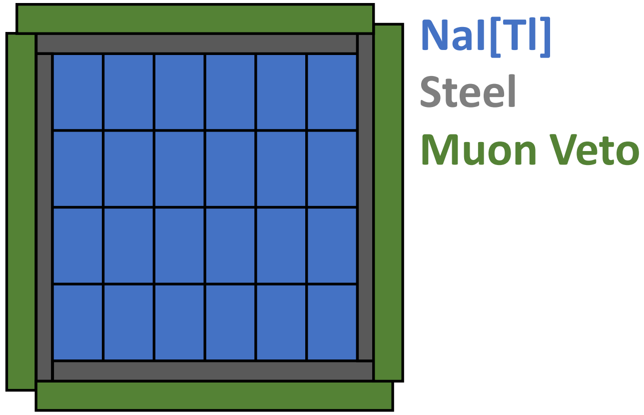
Hough Accumulator plot



NaIνE-185 Upgrade

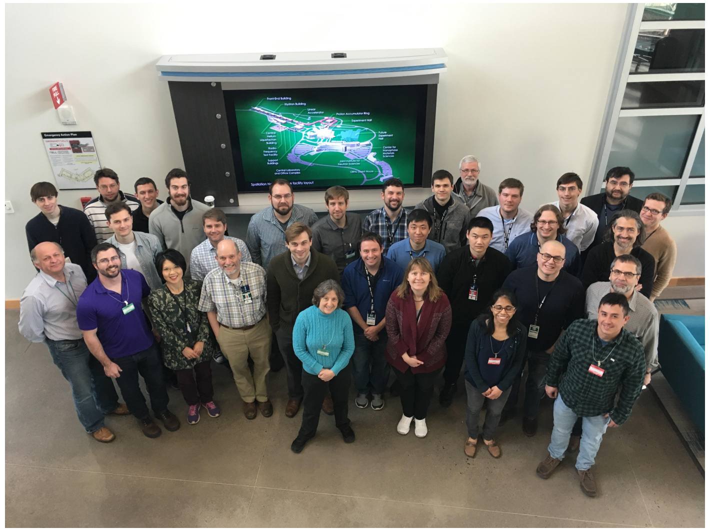
- Veto panels will reduce muon background
- 1.5" steel shielding between veto and detectors to avoid vetoing signal
- Muon vetos operating in similar triggering configuration, allow for study of muon physics in NaI[Tl] detectors
- Construction complete, testing now, planned deployment in November





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

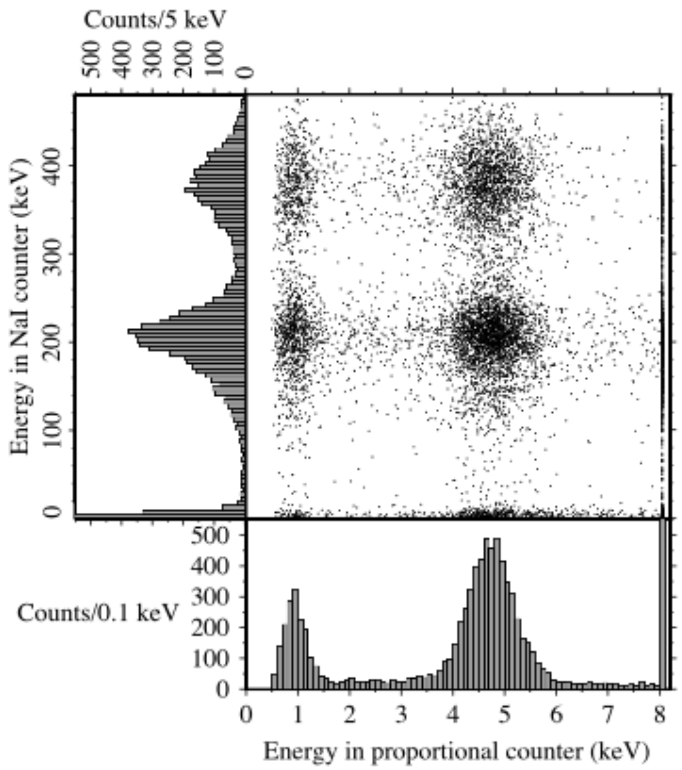
- Radiochemical approach at LAMPF measured flux-averaged cross section of

  $\sigma = 2.84 \pm 0.91\ (stat) \pm 0.25\ (sys) \times 10^{-40}\ \text{cm}^2$

- ^{127}Xe decays exclusively to excited ^{127}I states:

$$^{127}\text{Xe} \rightarrow {}^{127}\text{I}^* + \gamma\ (203,\ 375\ \text{keV})$$
$$^{127}\text{I}^* \rightarrow {}^{127}\text{I} + e^{-}\ (\sim 0.9,\ 4.7\ \text{keV})$$

- 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)



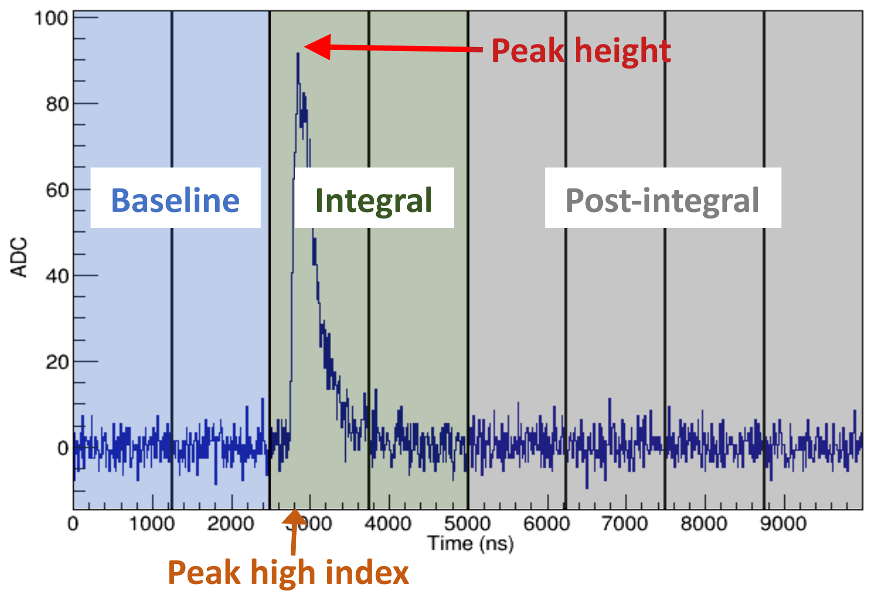
J. R. Distel, B. T. Cleveland, K. Lande, C. K. Lee, P. S. Wildenhain, G. E. Allen, and R. L. Burman Phys. Rev. C 68, 054613 2003

Dual Output Bases

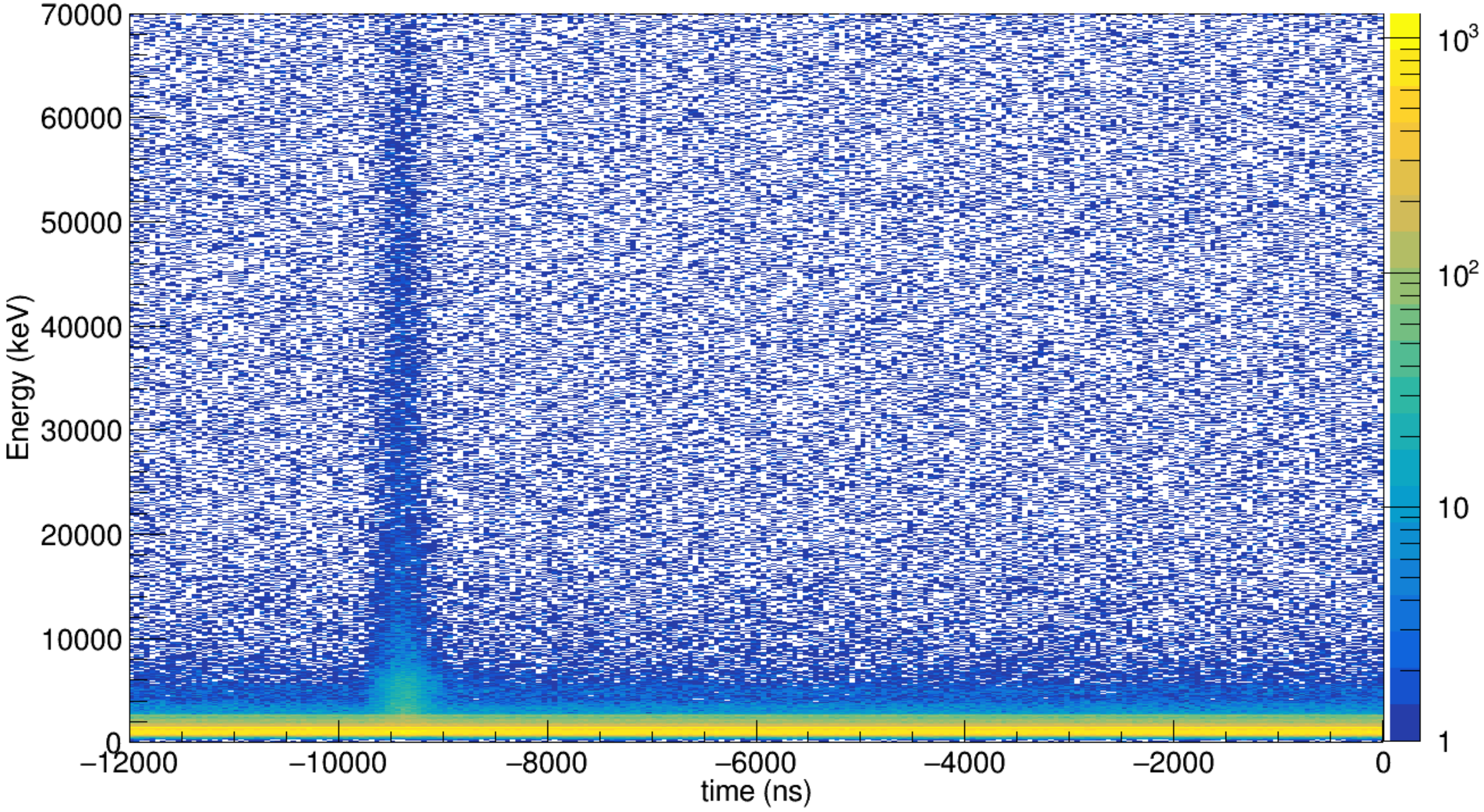
- PMTs begin to saturate, see non-linear light output above a certain energy (voltage-dependent)
- Solution is to use a dual-output base designed by Lorenzo Fabris at ORNL
  - With base, have achieved target thresholds for Na CEνNS recoils (3-40 keVee) in low-energy output while avoiding saturation effects up to 60 MeV in high-energy output

NaIνE-185 Data Acquisition

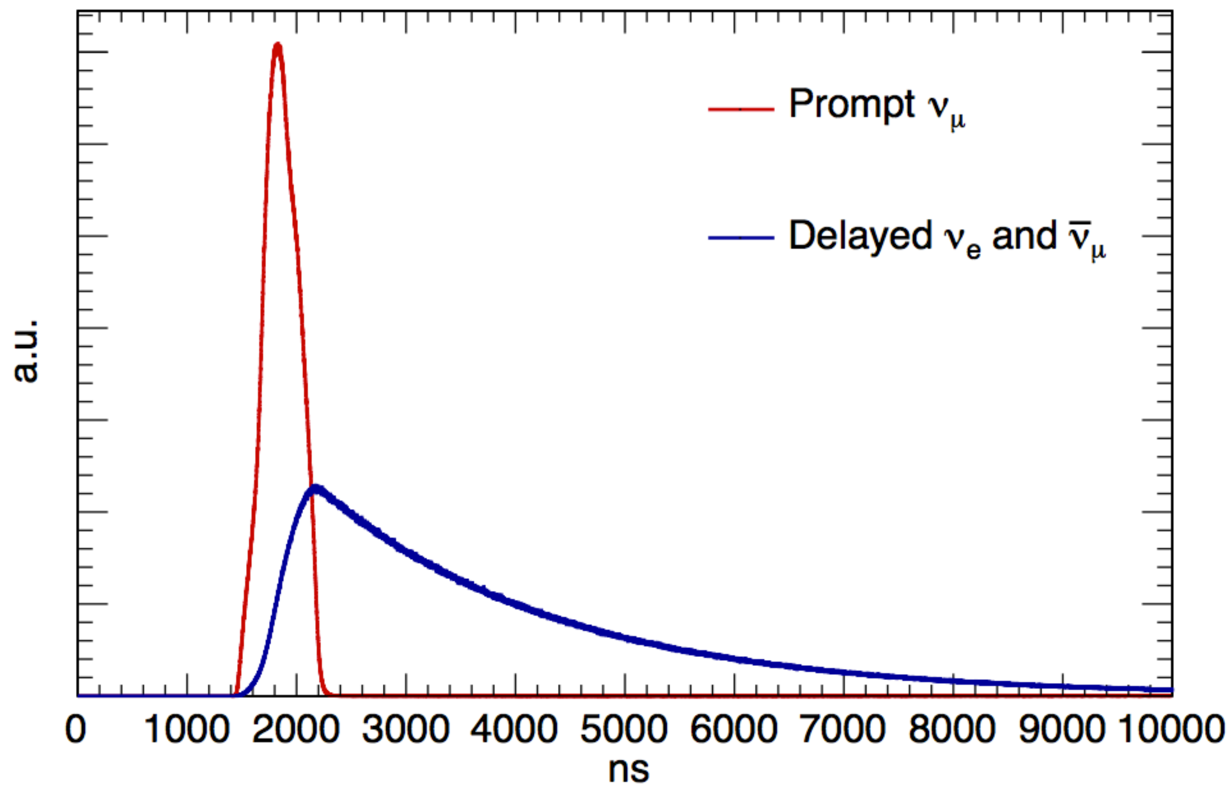
- Use internal digitizers trigger to record signals (regardless of beam presence)
- Separately digitize timing signals from SNS to look for beam-correlated events
- Eight 1250ns accumulator windows used for calculating integral, detecting pile-up of signals
- Peak height, peak high index, pile-up flag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



Prompt Signals in NaIνE



Neutrino Timing Distribution



D. Akimov, et al., arXiv:1509.08702, 2015