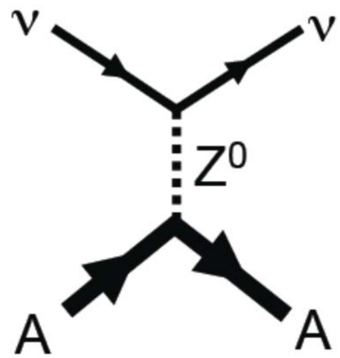
# *Background Neutron Studies for Coherent Elastic Neutrino-Nucleus Scattering Measurements at the SNS*

D. Markoff
(NC Central University, Triangle Universities Nuclear Laboratory)
For the COHERENT Collaboration

# COHERENT: Measure CEvNS

$$\nu + A \rightarrow \nu + A$$




A neutrino ‘smacks’ a nucleus via exchange of a Z, and the nucleus recoils as a whole; coherent up to $E_\nu$ ~ 50 MeV

Motivation – reach of first measurement program

- Largest $\sigma$ in Supernovae dynamics. We should measure it to validate the models
- CEvNS is an irreducible background for WIMP searches, and should be measured in order to validate background models and detector responses.
- By measuring the relative rates on several nuclear targets we dramatically extend the sensitivity of searches for Non-Standard **ν** Interactions

Detection observable – measure low-energy nuclear recoil.

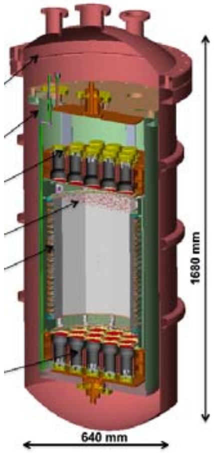
# COHERENT Detection Program

## NEUTRINO SOURCE

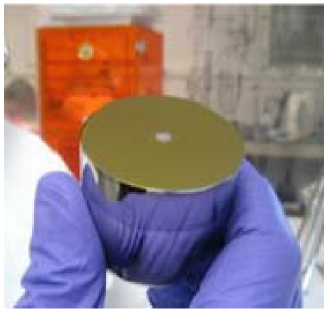
Spallation Neutron Source at ORNL

## DETECTION SUBSYSTEMS

Low-Background CsI[Na]



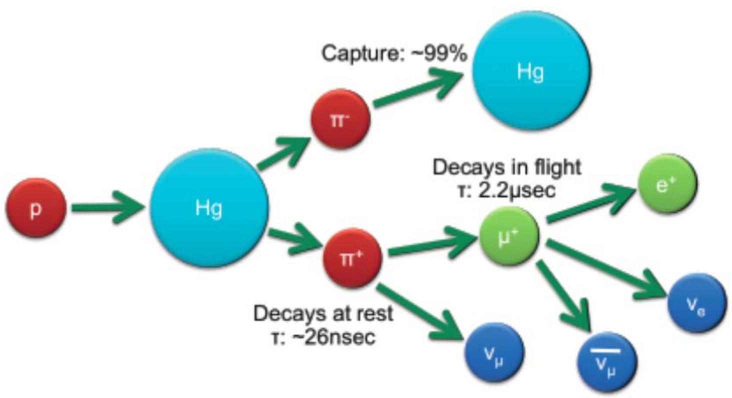

2-Phase Xe



P-Type Point Contact HPGe

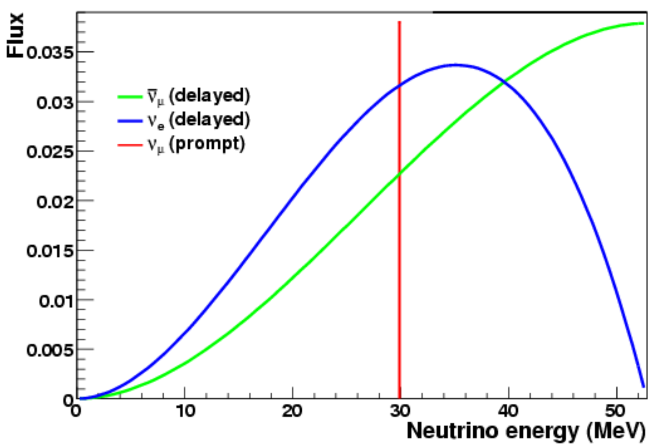
Described in more detail in previous talk
M. Green PD-1

# SNS Neutrino Beam Timing Profile




60 Hz timing protons on target
Produces sharply pulsed time structure

Prompt $\nu_\mu$ with delayed $\nu_\mu$–bar and $\nu_e$




$$\pi^+ \to \mu^+ + \nu_\mu$$

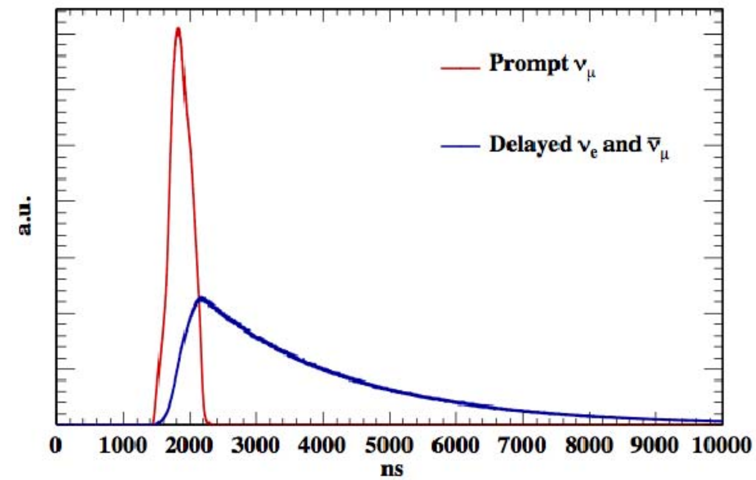
2-body decay: monochromatic 29.9 MeV $\nu_\mu$
PROMPT

$$\downarrow$$

$$\mu^+ \to e^+ + \bar{\nu}_\mu + \nu_e$$

3-body decay: range of energies between 0 and $m_\mu/2$
DELAYED (2.2 µs)

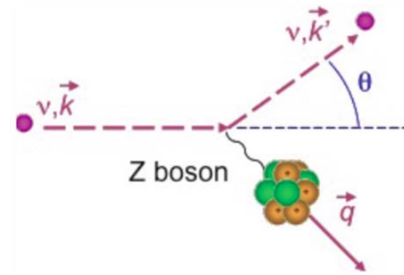
# SNS Neutrino Beam Timing for Background Rejection




Timing structure enables background rejection

- Use timing window to reduce steady-state backgrounds by factor of $10^3 – 10^4$
  – radioactivity and cosmogenics
- Precise characterization of backgrounds unrelated to the beam
  – measure outside prompt and delayed timing window – neutrino emission

# Neutron Background



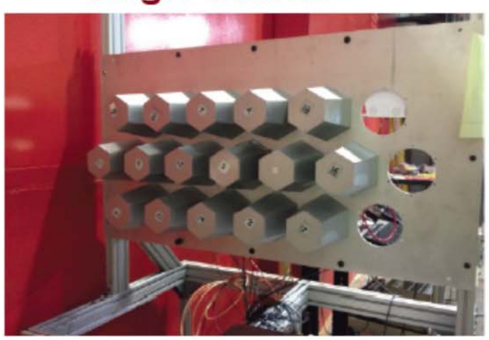

- Our signal is based on low-energy recoiling nuclei with no visible incoming our outgoing particles
  - Energy deposition characteristics can exclude other interactions (for example, timing cuts)
- Neutrons can create the same nuclear recoil
  - ~100 keV – 1 MeV neutrons in the detector can produce similar recoil spectra as our neutrino scattering signal
- Shielding helps and hurts
  - Easily stop low-energy neutrons
  - Creates showers of low-energy neutrons from incoming high-energy neutrons
  - Inelastic scattering of neutrinos in lead produces neutrons

Fast neutrons (10-100 MeV) coincident with the beam are the largest concern.

# Neutron Background Studies

- Leveraged unique skills/capabilities of neutron diagnostics and imaging capabilities of collaborators at ORNL, SNL, IU
- Combination of multiple technologies and complementary analysis by multiple groups provides confidence in background results
- Initial studies show reduction in neutron background by 4 orders of magnitude in the basement compared to the experimental hall level
- Systems available for monitoring:

**Single Plane Single Scatter**

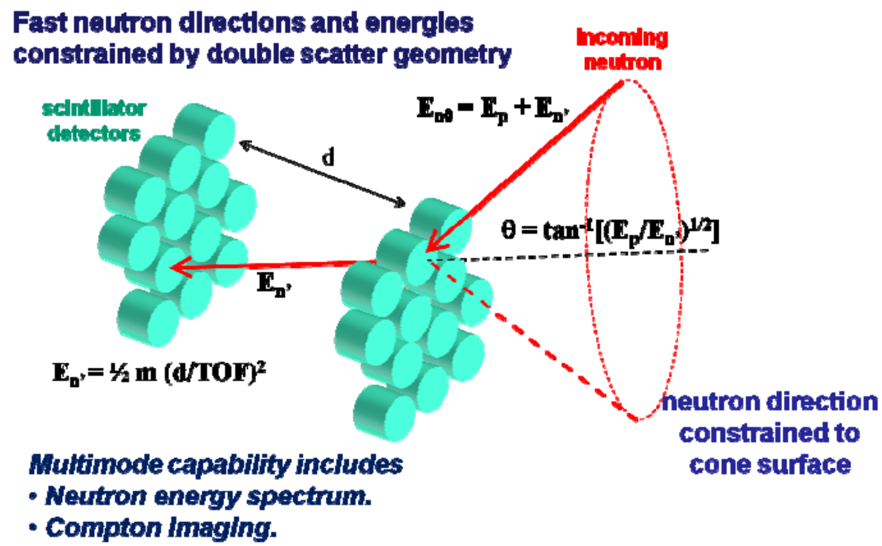


**Portable 5L LS Cells**

**Coded-aperture Imager**

**Neutron Scatter Camera**

# Scatter Camera Measurement



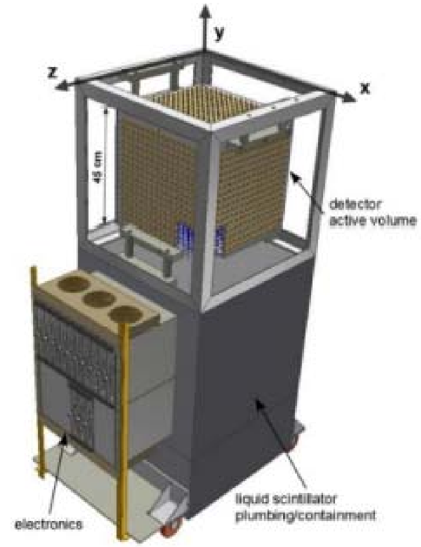

- Fast neutron imaging spectrometer developed under NNSA and DNDO support
- Sandia National Laboratory
- Two-plane liquid scintillator detector with good energy resolution and some directionality
- Variable plane separation allows tradeoff of effective area, image resolution

# SciBath Measurement

- Courtesy of IU Neutrino Group
- Liquid scintillator with 3 sets of mutually orthogonal, parallel arrays of wavelength-shifting optical fibers

  3D fiber grid gives fine position resolution and accurate directional spectra
- Timing resolution ~20ns

- Basement of SNS-Anticipated LXe location
- Measure neutron background rates for COHERENT - Measure flux in energy/time
- Large detector volume (80L) gives high rates
  - ~30 beam related neutrons/day detected
  - Expect ~1700 events by run's end
- Also measuring cosmic muon flux




# Neutron Background Studies at the SNS Basement

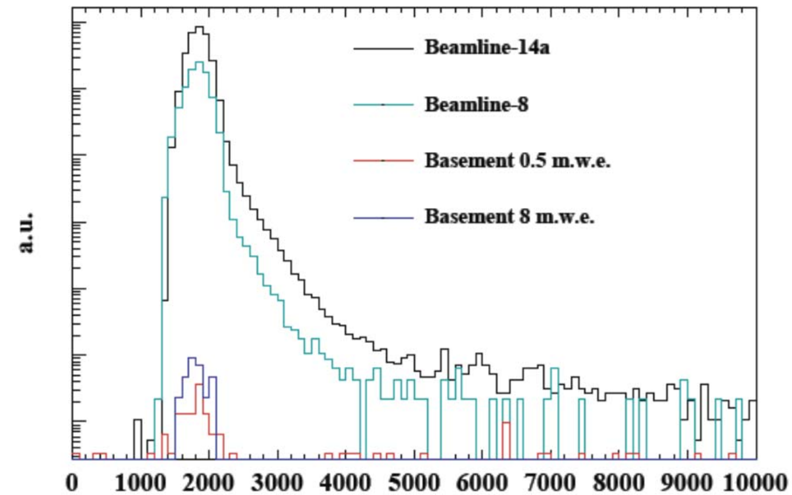
Fast neutron backgrounds in the basement are clearly associated with 800 ns protons on target

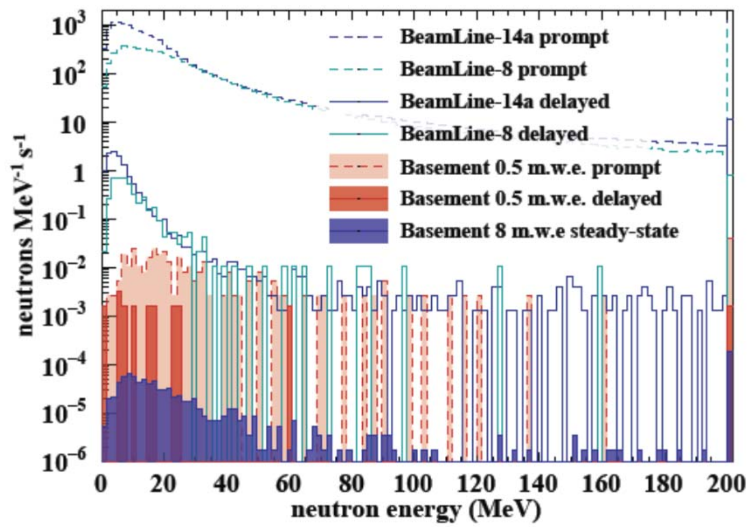
A 2.2 $\mu$s window after the beam would highlight muon decay neutrinos ($\nu_\mu$-bar, $\nu_e$)

Neutron backgrounds reduced by at least an order of magnitude in the delayed window compared to prompt

Neutrons in the delayed window are significantly lower in energy and therefore relatively easier to shield.

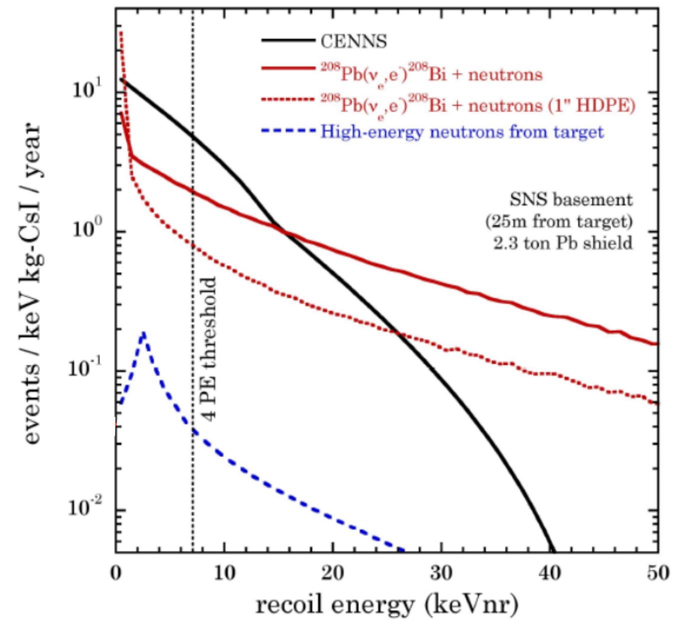
Scatter-camera data (SNL)
Consistent with earlier Portable LS Cells data (ORNL)
Confirmation with initial data from SciBath imager (IU)



# New Background: $\boldsymbol{\nu}$-induced neutrons (NINs)

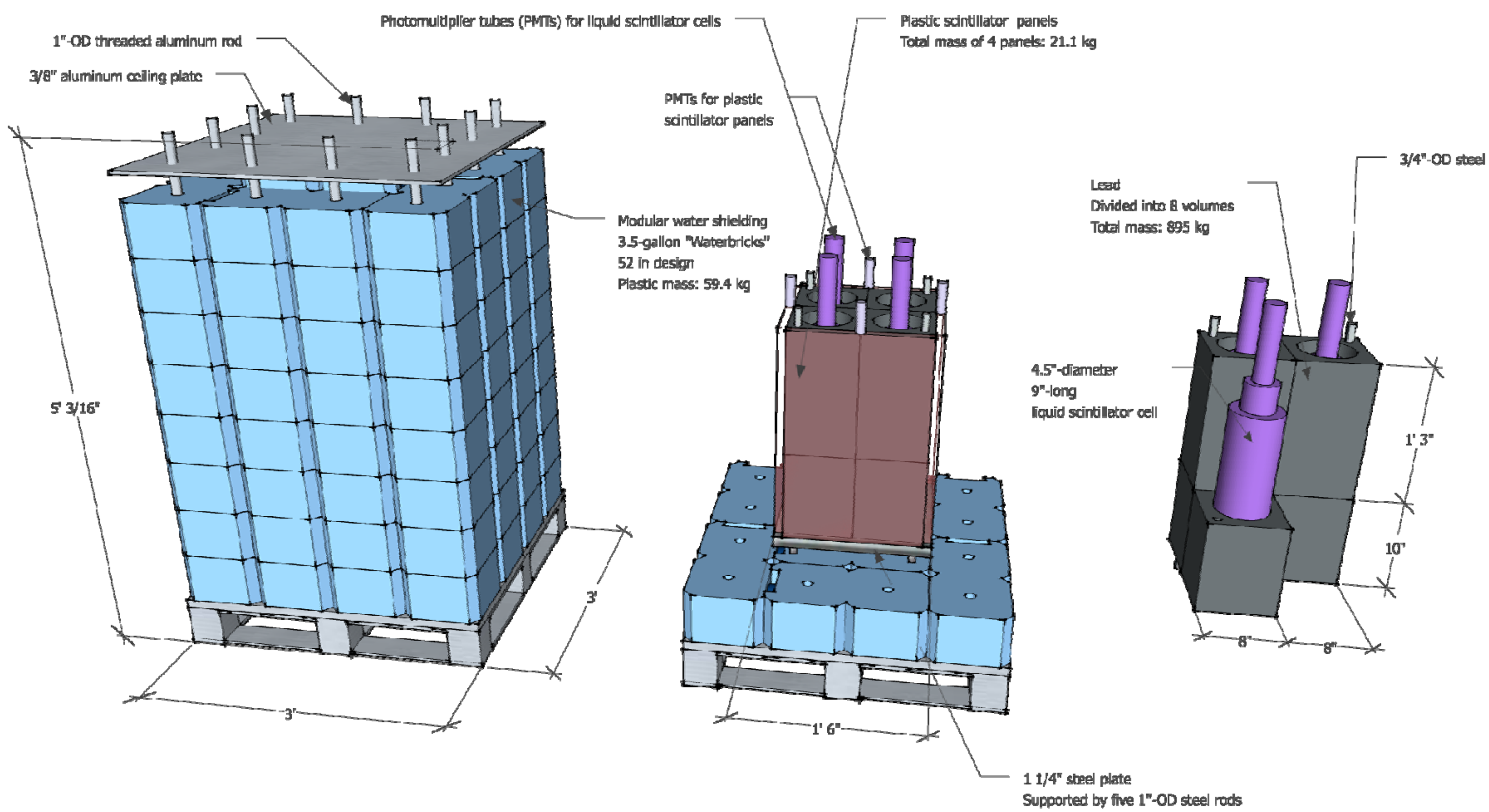
- The detector shields use several tons of lead
- Neutrons can be produced near the detectors. They will be pulsed, and share the 2.2 μs decay time of the neutrinos
- Need to measure this cross section and optimize the shields
- Important for HALO (Helium and Lead Observatory)
- Nucleosynthesis of heavy elements in supernovae – from n spallation




$$\nu_e +^{208} Pb \Rightarrow {}^{208}Bi^* + e^- \qquad (CC)$$
$$\Downarrow$$
$$^{208-y}Bi + x\gamma + yn$$

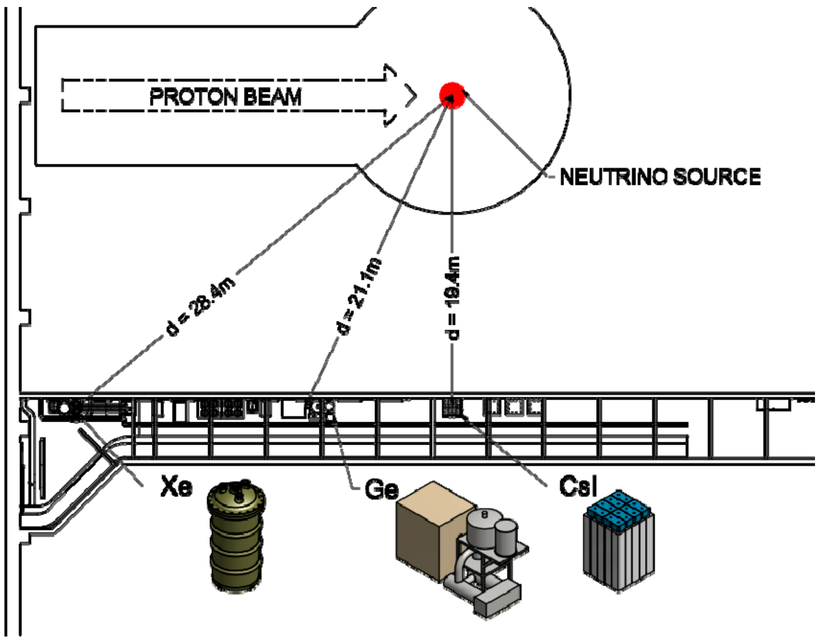
$$\nu_x +^{208} Pb \Rightarrow {}^{208}Pb^* + \nu_x' \qquad (NC)$$
$$\Downarrow$$
$$^{208-y}Pb + x\gamma + yn.$$

# Measuring the $\boldsymbol{\nu}$-induced Neutrons




- Several palletized (mobile) targets with LS detectors delivered to the SNS
- Will measure neutrino-induced-neutrons on Pb, Fe and Cu

# Final Configuration




Viable locations for detector deployment that do not impact SNS operations and in areas that are 'neutron quiet' – SNS basement

Continuous monitoring of backgrounds will be critical – employ multiple detector systems for cross-check and confidence – use advantages of each system

Neutron flux reduced and energy spectrum favorable in delayed neutrino window in the basement area

Background low enough for a successful measurement of CEvNS

# Collaboration

CEvNS Detection Program
arXiv:1509.08702