Towards the measurement of neutrino-induced neutrons at the SNS

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Neutrinos from the SNS

- The SNS bombards a liquid Hg target with a 1.3-GeV proton beam pulsed at 60 Hz; pulse is ~700 ns wide

- Neutrinos are produced by decay of *stopped pions and muons*, resulting in flux with well-defined spectral and timing characteristics

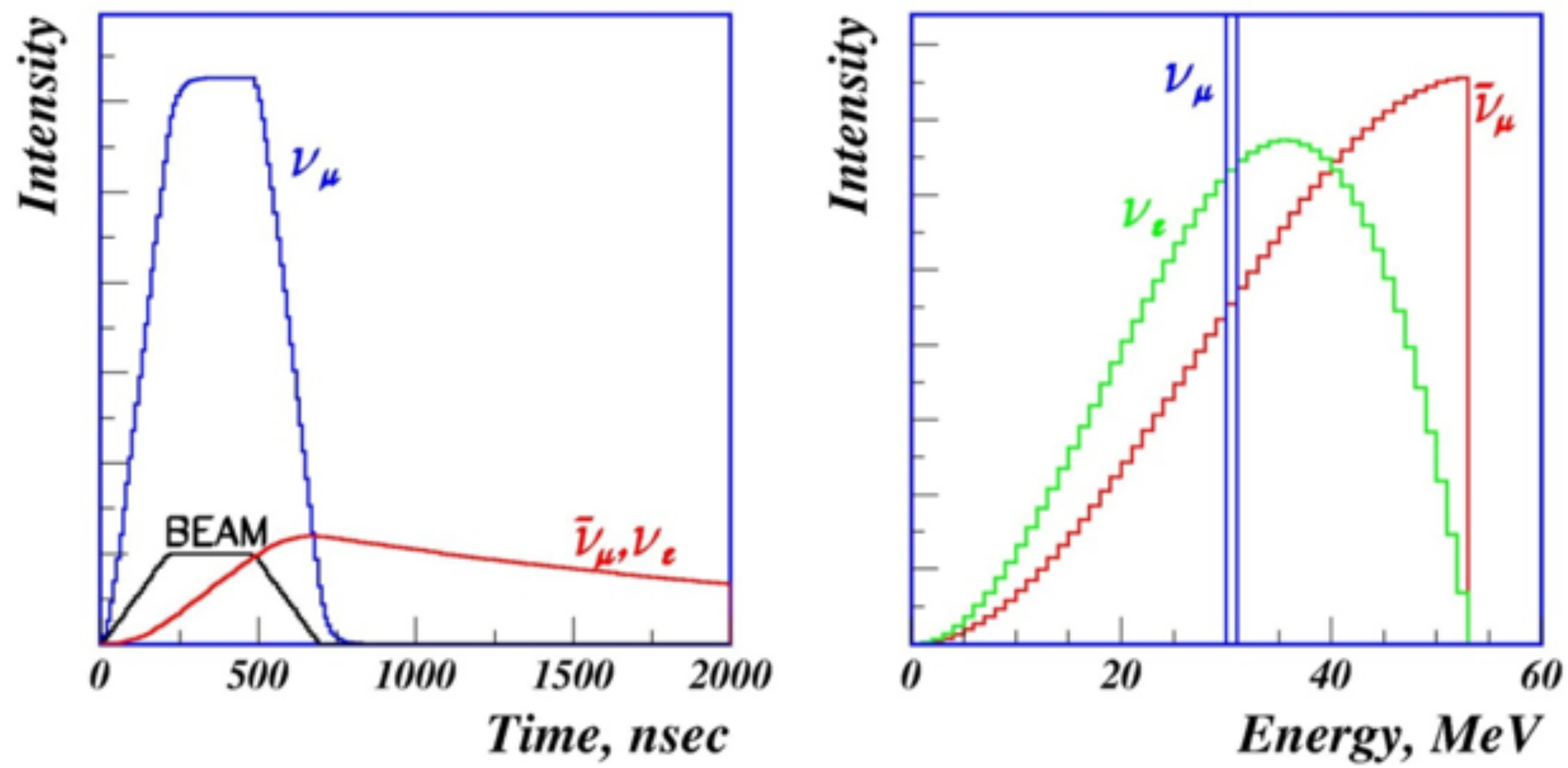
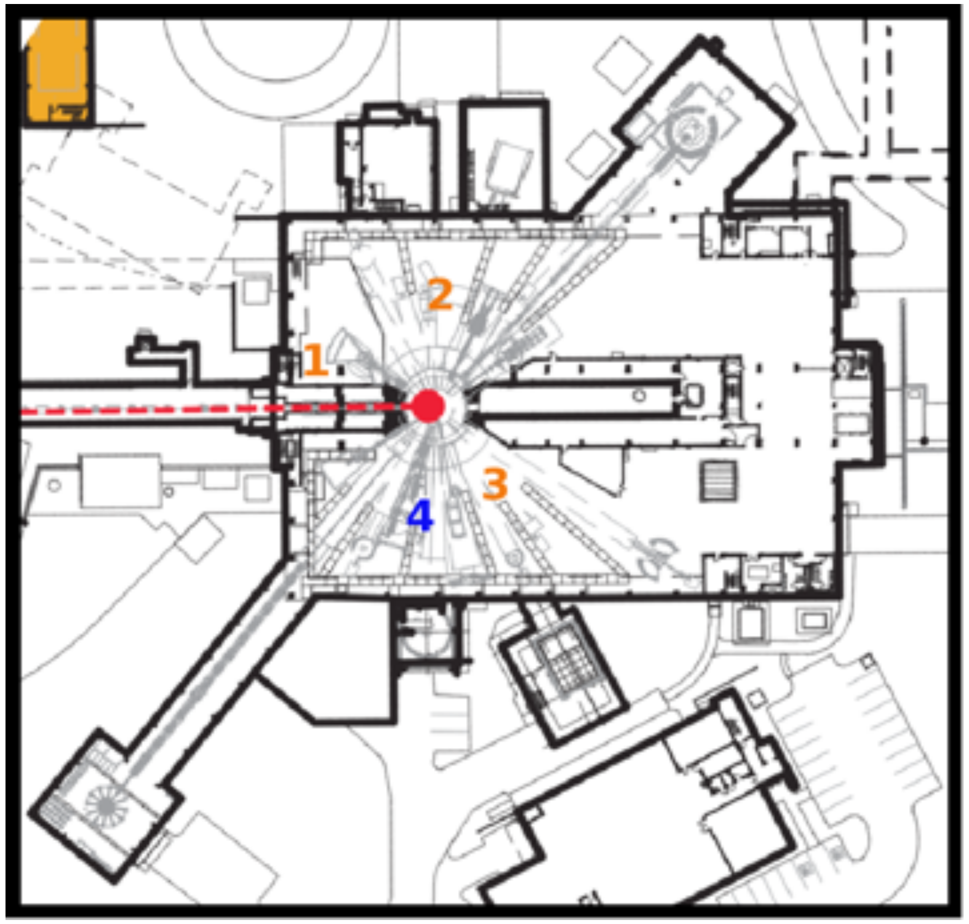


Figure from A. Bolozdynya *et al.*, arXiv:1211.5199 (2012)

Siting and backgrounds at the SNS for COHERENT

- CEvNS-searches are subject to familiar backgrounds for other rare-event searches, but neutrino-induced neutron spallation has been recognized as a prominent source of additional background



- Focus for first stages of COHERENT has landed on basement location with overburden and near target

- For certain experimental designs in this location, neutrino-induced neutrons are one of the most prominent sources of background

Neutrino-induced neutrons (NINs)

- Both neutral- and charged-current reactions contribute

- Theoretical predictions of cross section are strongly model dependent (plot at right shows total CC cross section for ^{56}Fe)

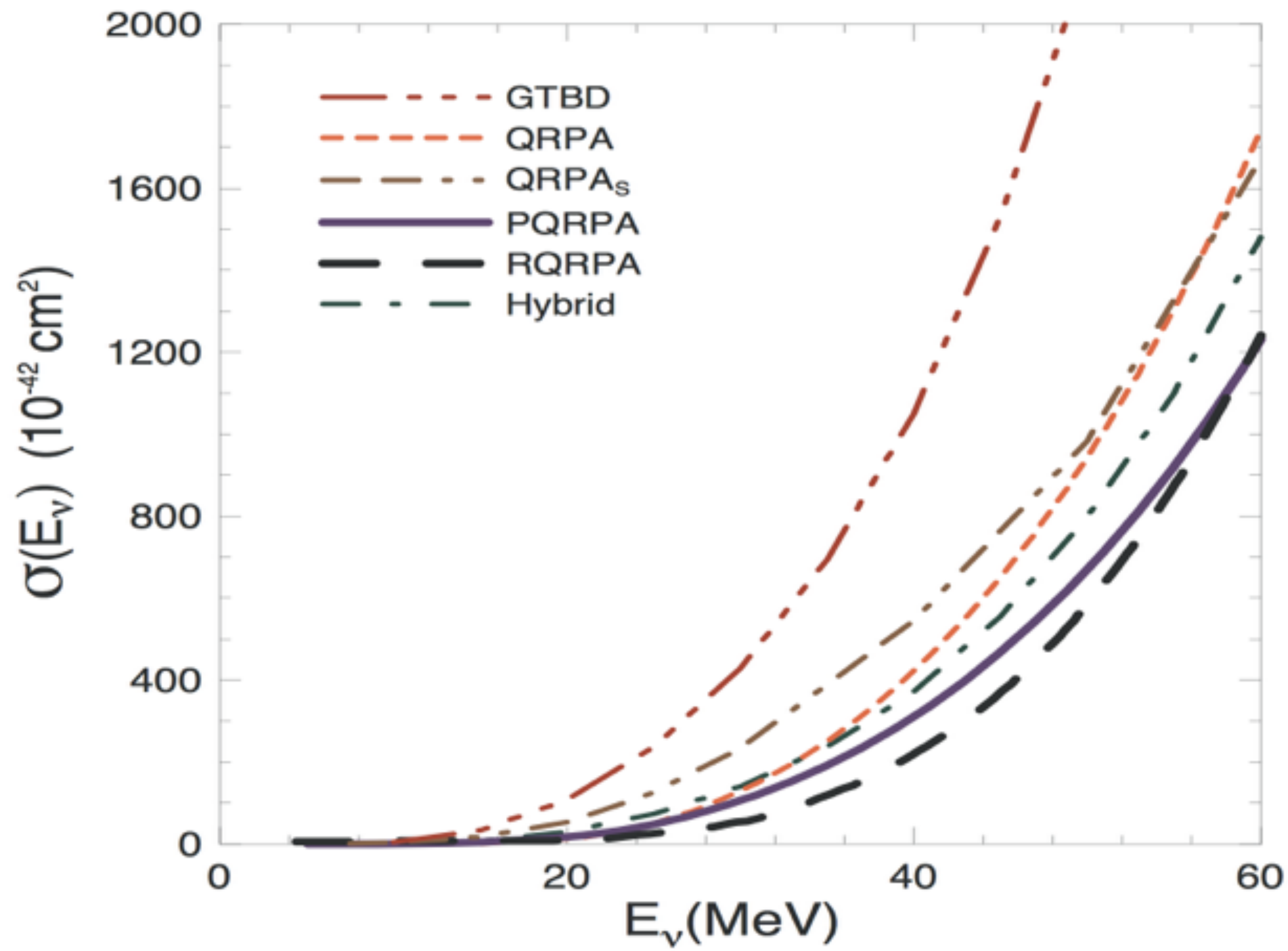


Figure from A.R. Samana and C.A. Bertulani, Phys. Rev. C (2008)

Neutrino-induced neutrons (NINs)

- Measurements of these cross sections have implications beyond background assessment
  - NINs from Pb are fundamental mechanism for detection in HALO supernova neutrino detector [1]
  - NIN interactions may influence nucleosynthesis in certain astrophysical environments [2]

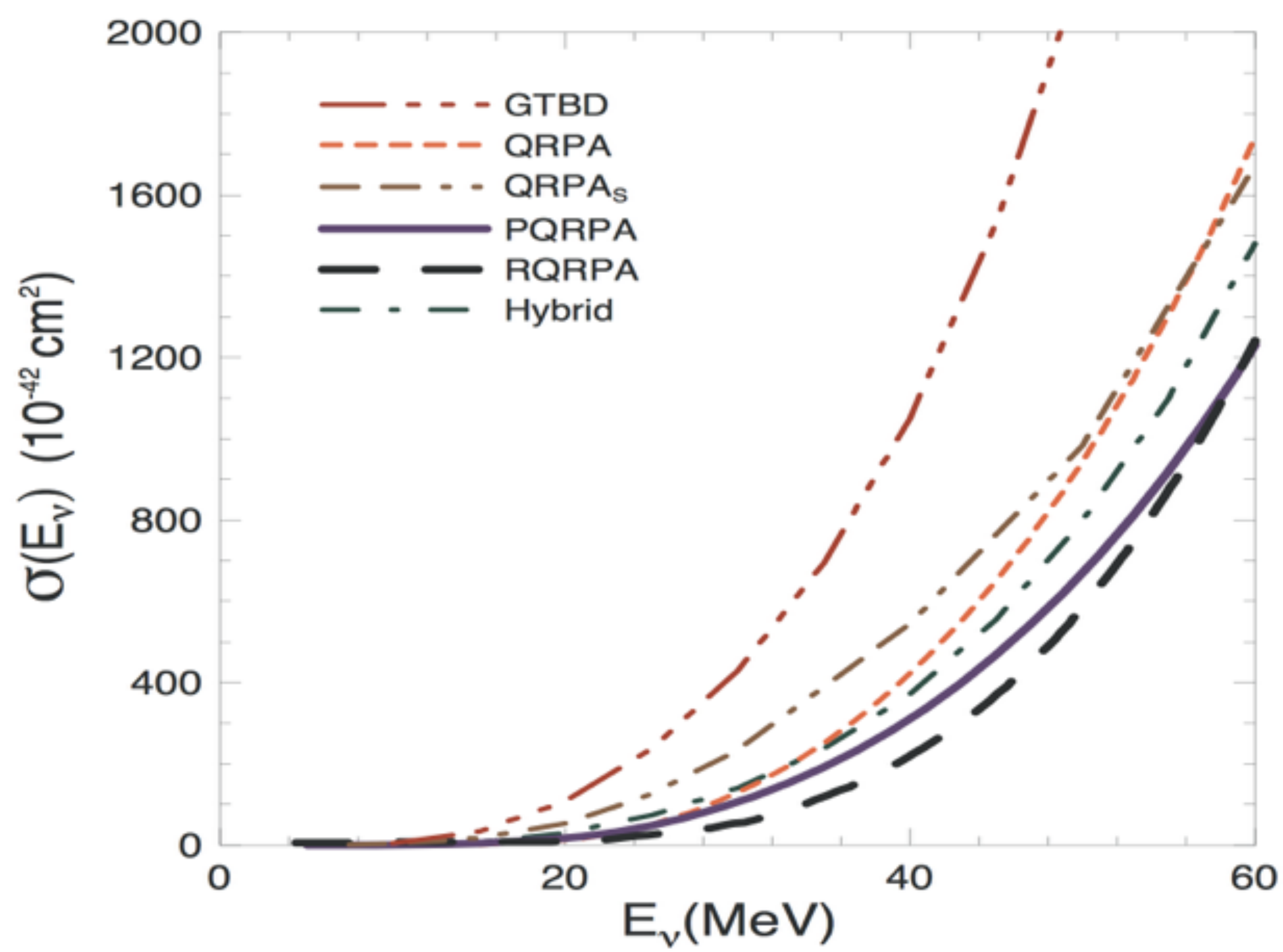


Figure from A.R. Samana and C.A. Bertulani, Phys. Rev. C (2008)

[1] C.A. Duba *et al.* J.Phys.Conf.Series 136 (2008)
[2] Y-Z. Qian *et al.*, Phys. Rev. C 55 (1997)

NIN measurements at the SNS

Two complementary routes within the COHERENT collaboration

Shielding assembly for CsI(Na) CEvNS detector: 2.3 tons of Pb. MCNP-PoliMi simulation suggests a ~4.4% efficiency for production of nuclear recoils in by neutrons spalled from the shield

Neutrino cubes: relatively efficient, modular design capable of holding different target materials (895 kg of lead, ~620 kg of steel, 710 kg of copper)

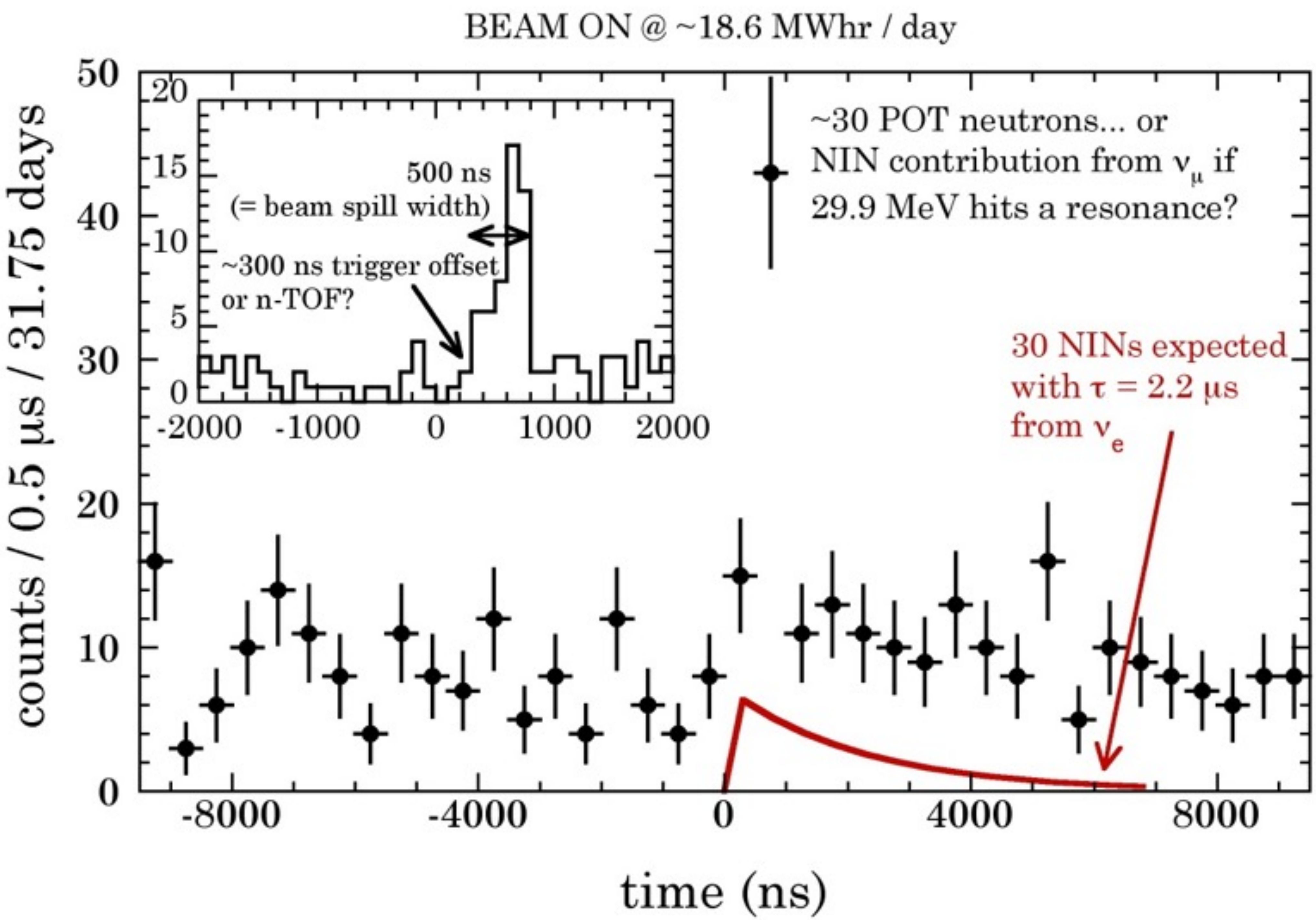
Both systems were installed at the SNS mid-September 2014. Located in the basement at ~20 m from the target with ~8 m.w.e. overburden

NIN measurements at the SNS: CsI(Na) shielding structure

- Lead shielding for the 15-kg CsI(Na) crystal has been moved into place at the SNS - 2.3 tons of lead
- Two liquid scintillator cells are in place within the detector cavity, allowing *in situ* measurement of gamma and neutron backgrounds for the CsI(Na) CEvNS search and an initial measurement of the NINs cross section
- MCNP-PoliMi simulation suggests a ~4.4% efficiency for production of nuclear recoils in by neutrons spalled from Pb

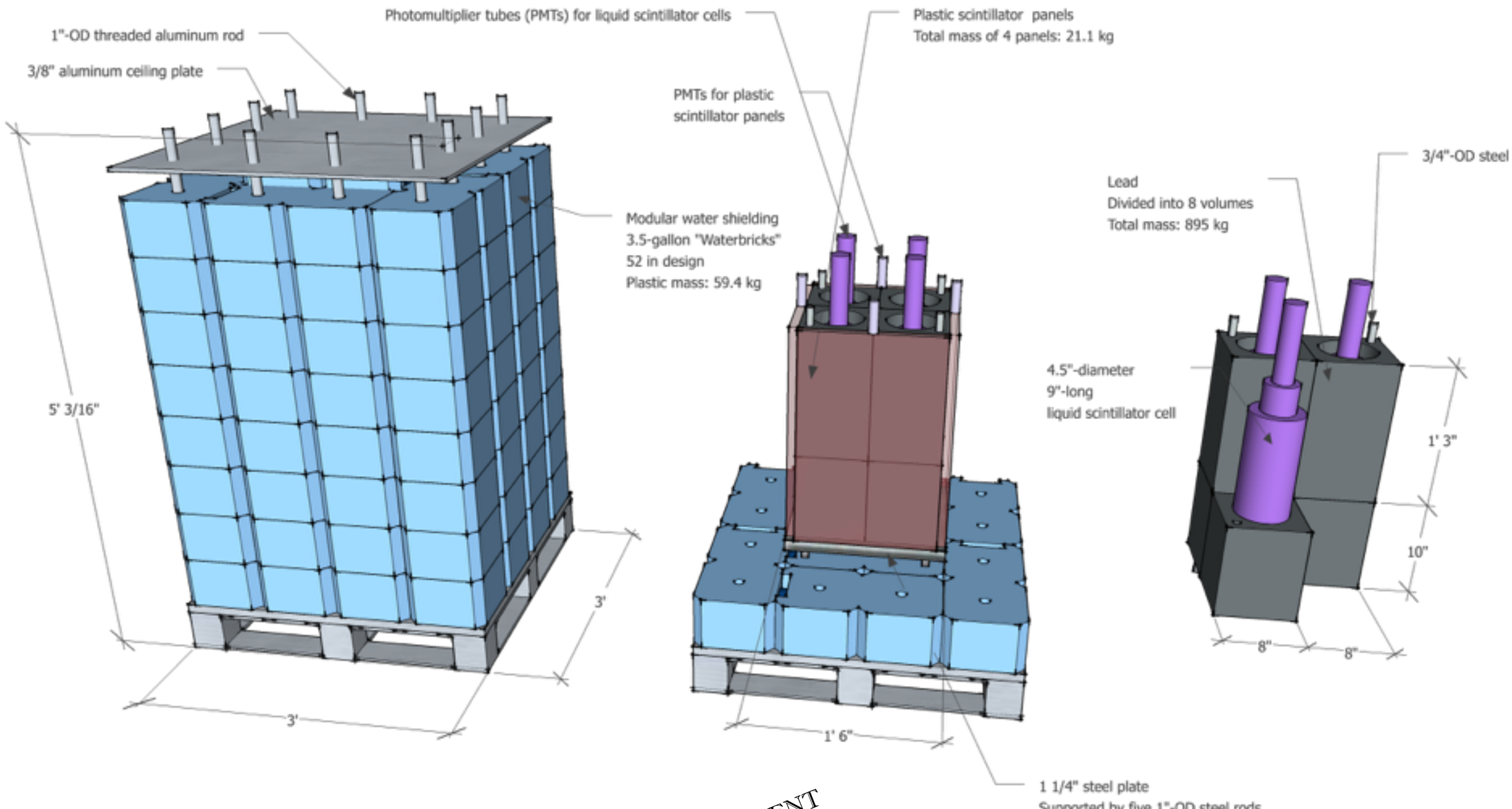
As J. Collar showed: this system is presently collecting data

NIN measurements at the SNS: CsI(Na) shielding structure

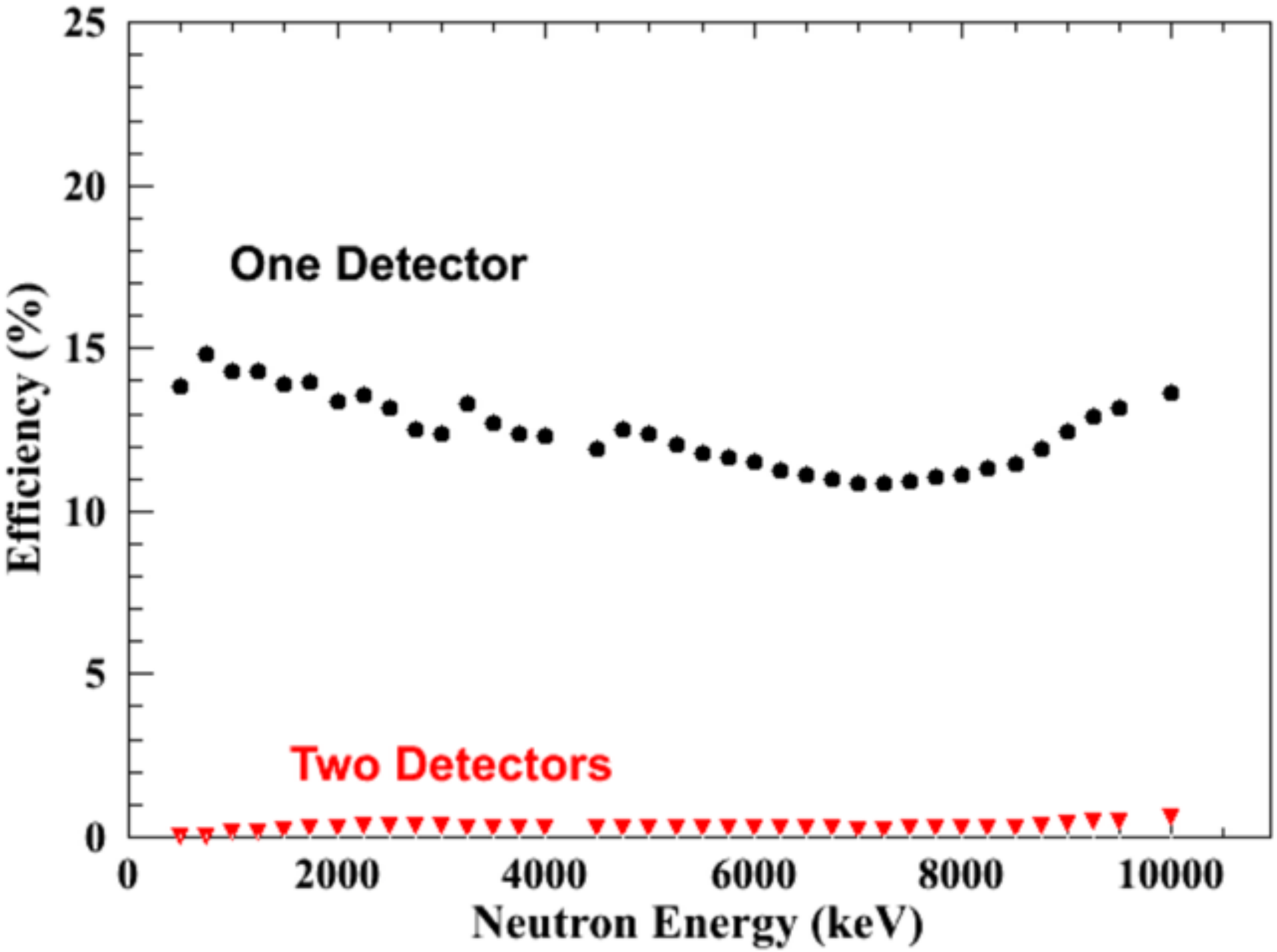


NIN measurements at the SNS: Neutrino cubes

NIN cross section measurements can also be made with dedicated "neutrino cubes", or nubes: palletized assemblies which can easily be moved and/or loaded with different target materials

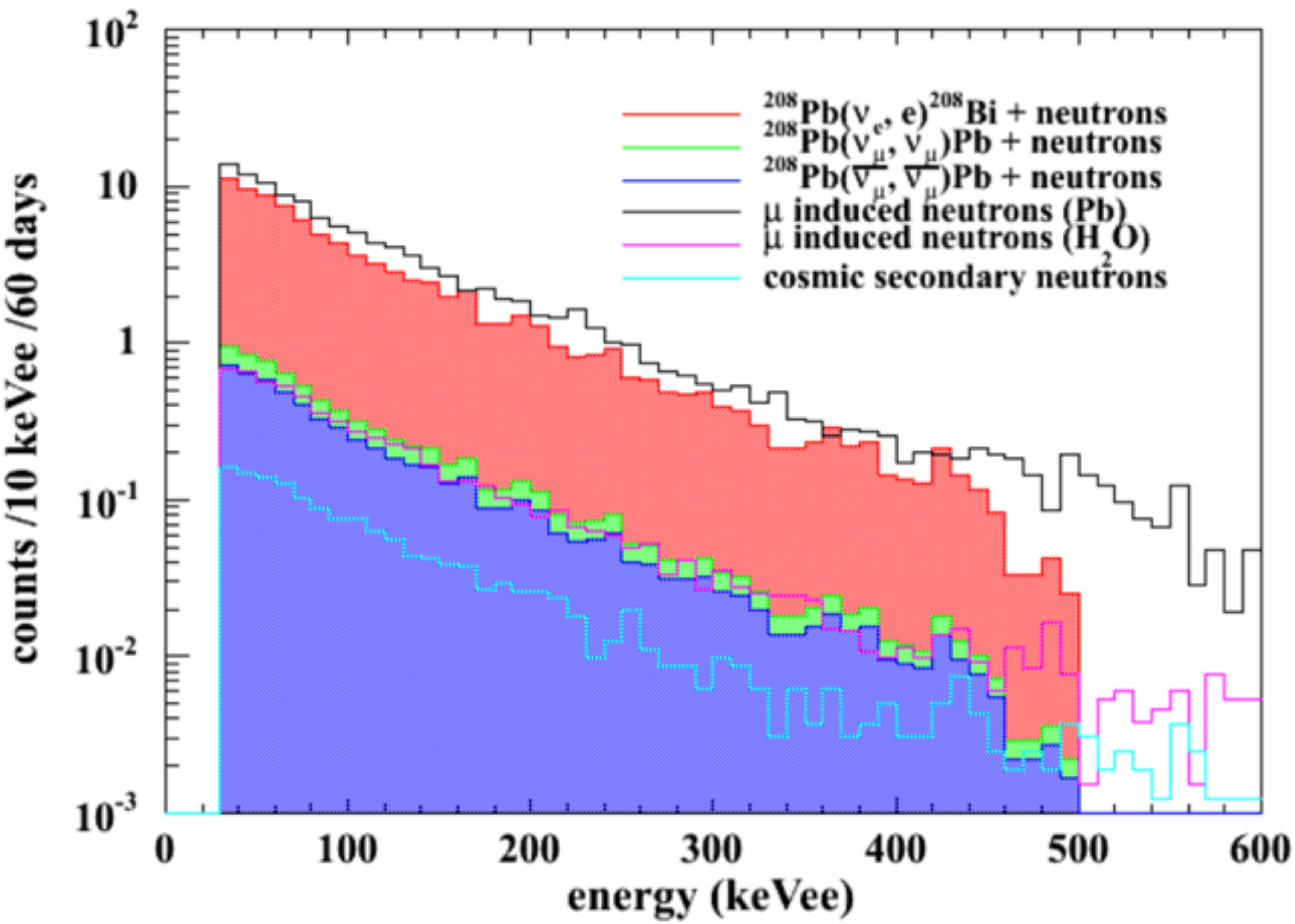


NIN measurements at the SNS: Neutrino cubes



Neutrino cubes with a lead target have a well-behaved efficiency for a wide range of initial neutron energies. Above ~7 MeV, neutron multiplication in the target volume begin to influence efficiency and observed multiplicity.

NIN measurements at the SNS: Neutrino cubes with lead

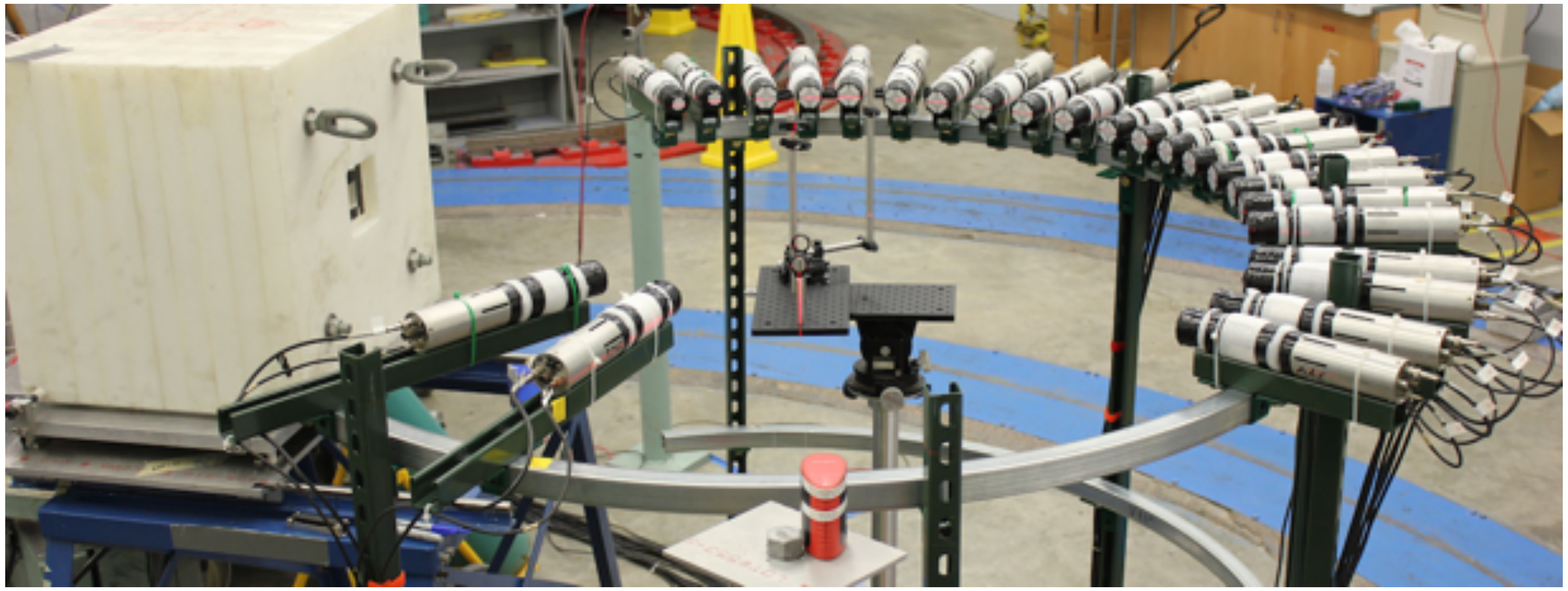


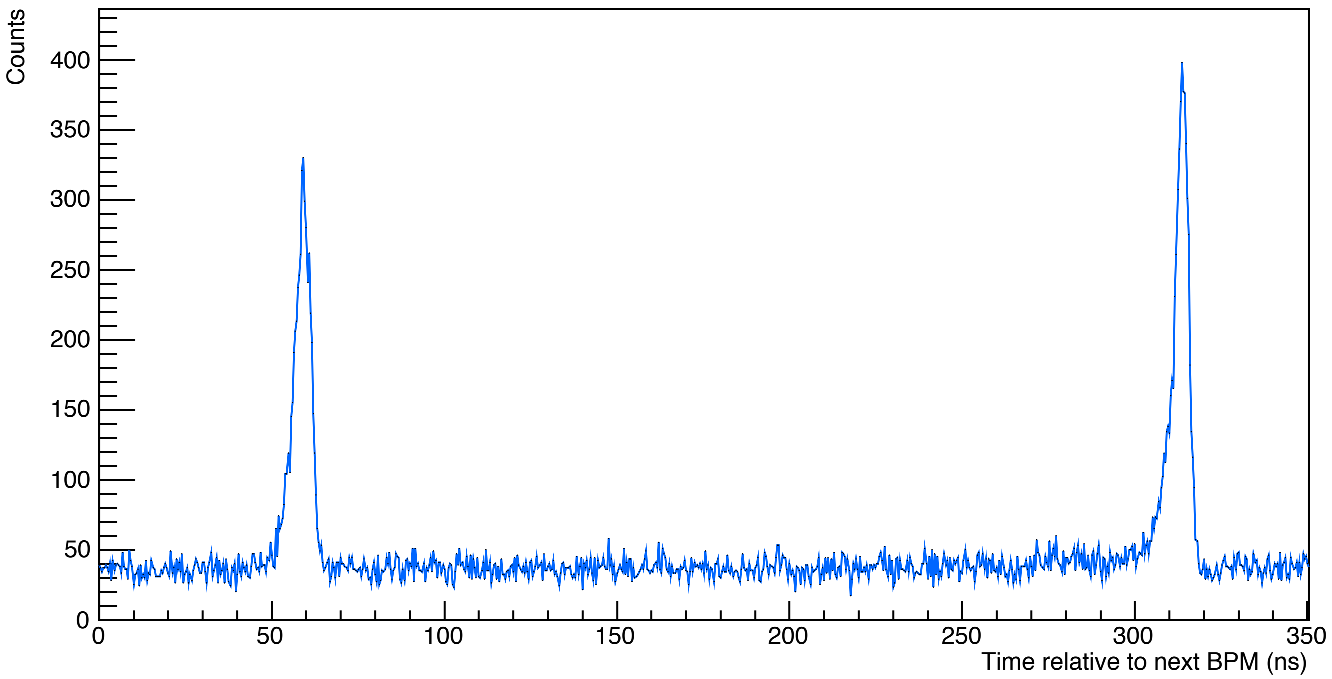
Initial MCNP simulations of the neutrino-cube geometry account for anticipated sources of background neutrons and NINs: many of the interactions result in low-energy (< 100 keVee) recoils in the scintillator, so a low threshold is important to maximize count rate

Detector characterization

- Proton (and carbon) recoils in liquid scintillator cells from NIN interactions are concentrated at low energies

- Characterization of PSD performance in this regime is important to establish threshold





- At TUNL, a facility has been built for **precision measurements** of detector response to low-energy nuclear recoils

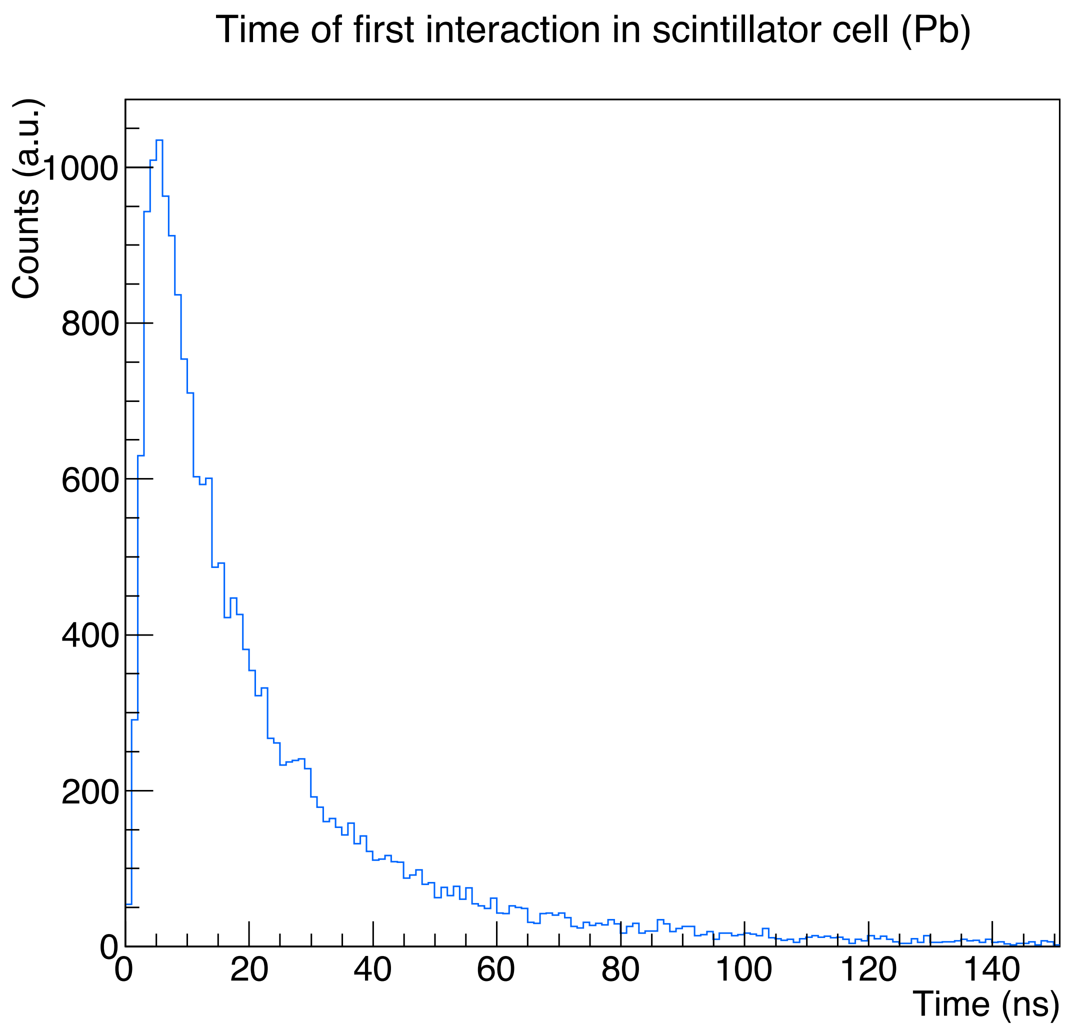
- A tunable, quasi-monoenergetic neutron beam is produced using a thin LiF target and the 7Li(p,n) reaction

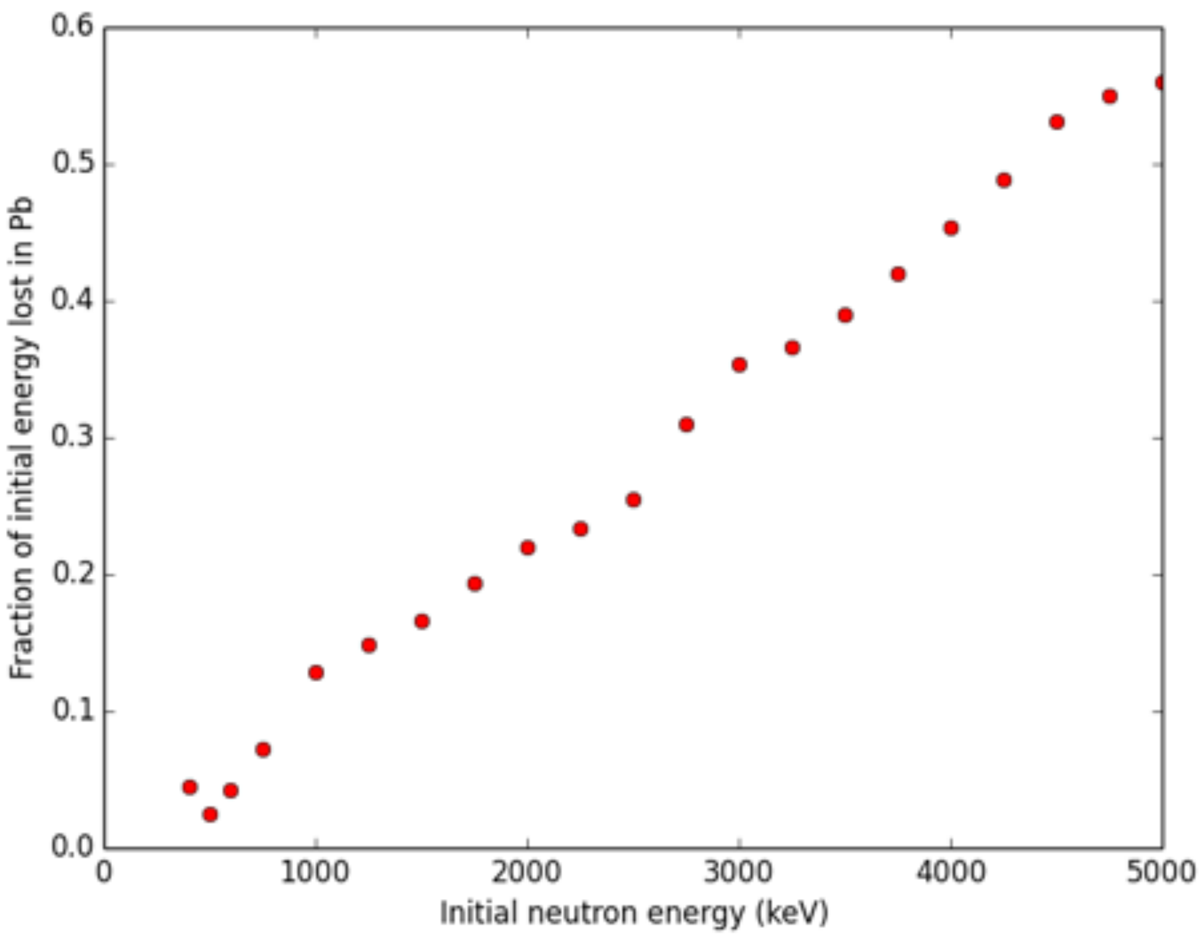
- Efficacy of PSD at recoil energies of 20-30 keVee can reliably be evaluated

NIN measurements at the SNS: Neutrino cubes with lead

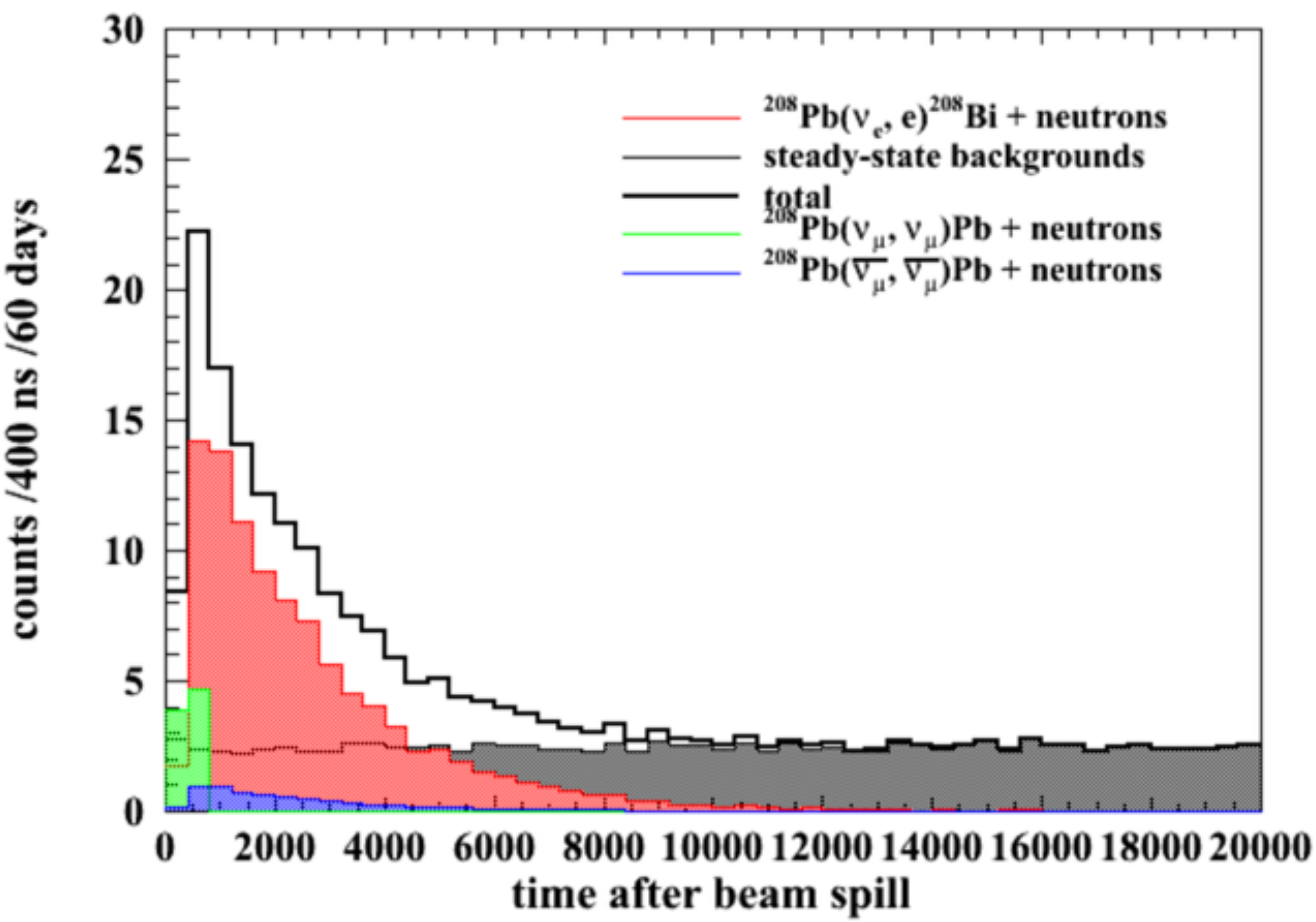
- NIN straggling in the Pb volume is limited
  - This preserves advantages of SNS timing

- Especially for lower energy NINs, the fraction of energy lost prior to interaction in the liquid scintillator cells is small (<~20% for < 2 MeV NINs)
  - It *may* be possible to establish spectral information





NIN measurements at the SNS: Neutrino cubes with lead

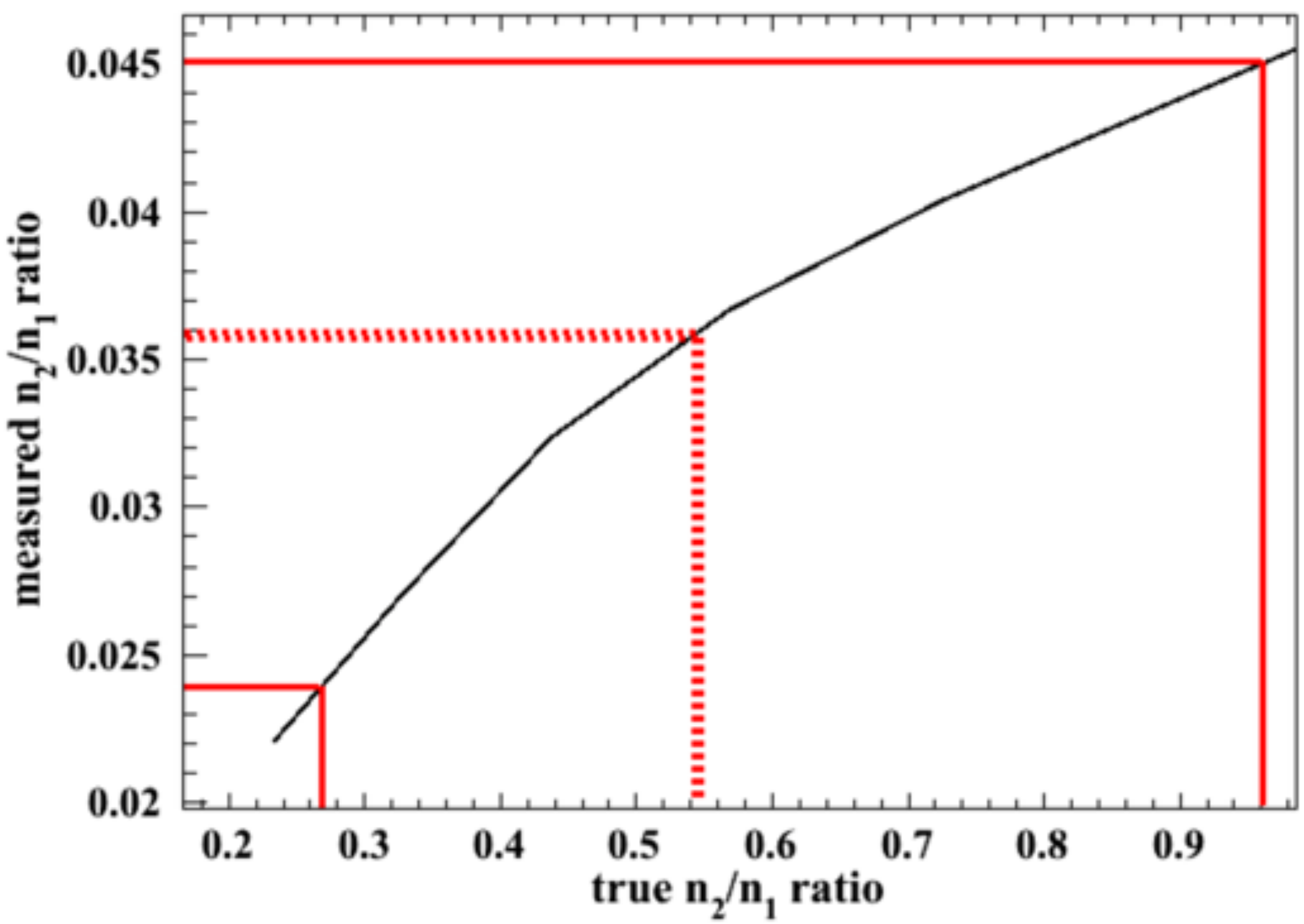


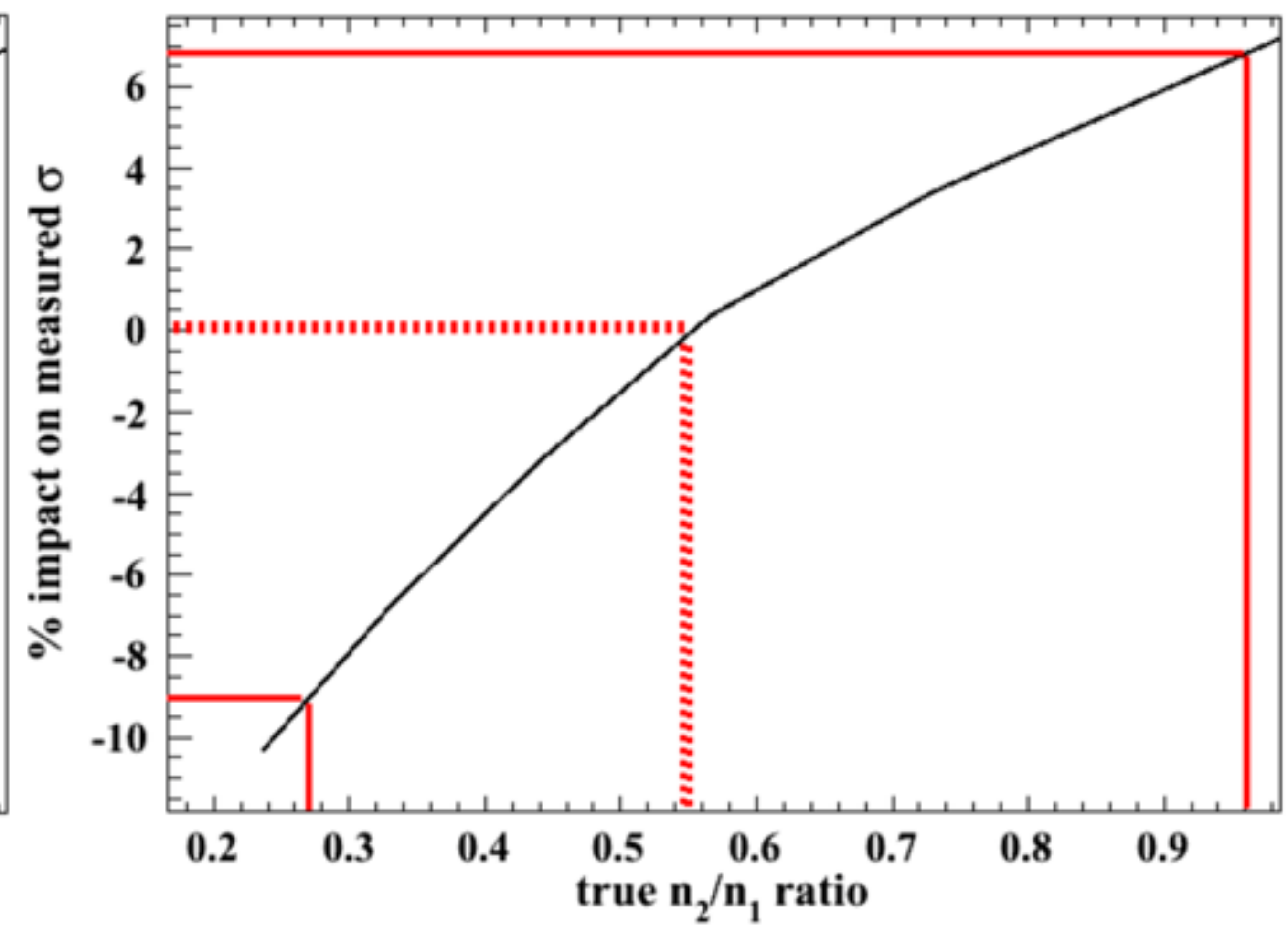
Timing characteristics of the SNS can be utilized to reject steady state, beam-uncorrelated backgrounds.

With high statistics, disentangling of NC and CC NIN contributions might be possible

NIN measurements at the SNS: Neutrino cubes with lead

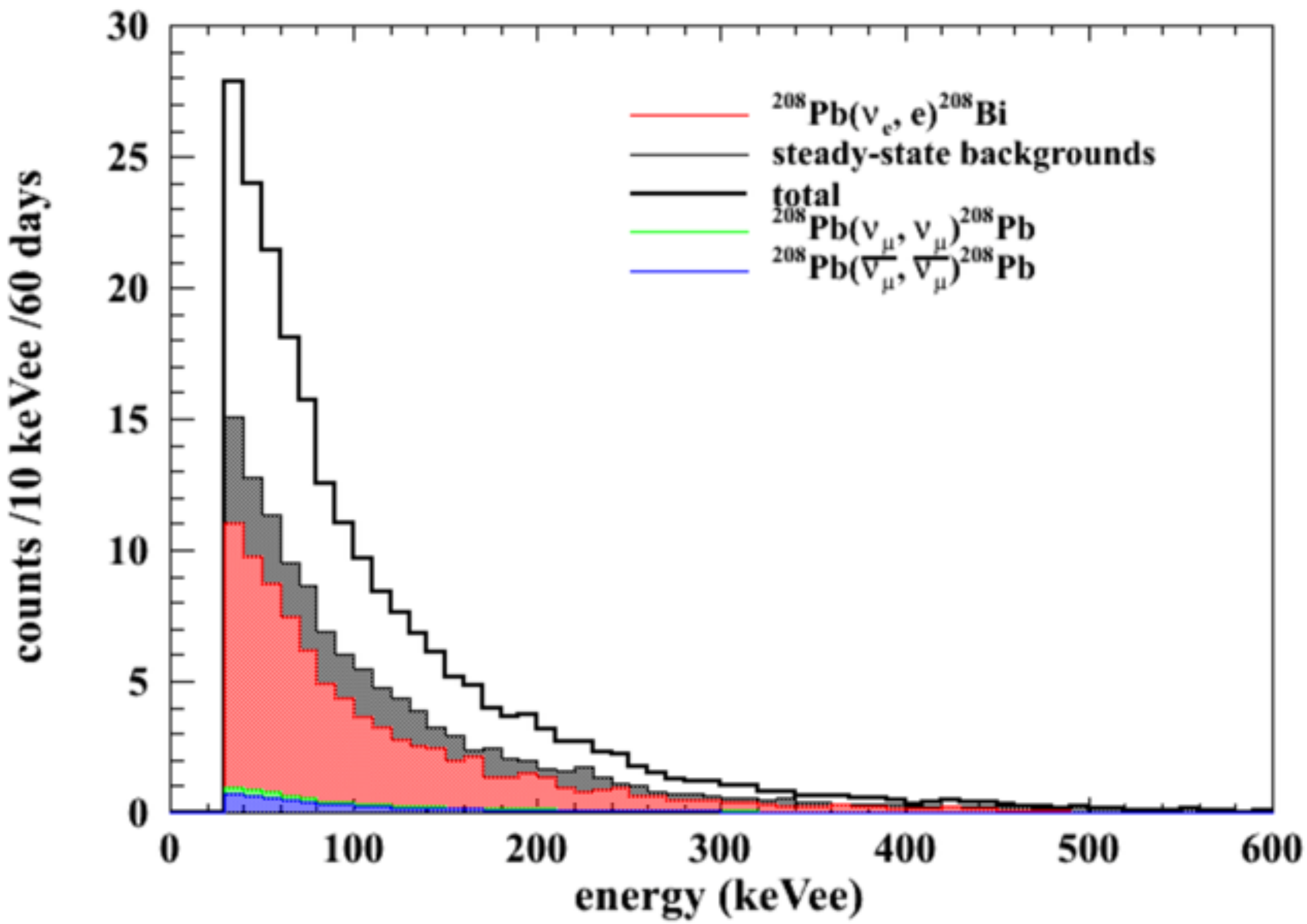
- Initial simulations suggest that the measured two-neutron to one-neutron ratio does not provide a clear window into the *true* ratio
- Mercifully, the true ratio has limited impact on the inferred total cross section for neutron production



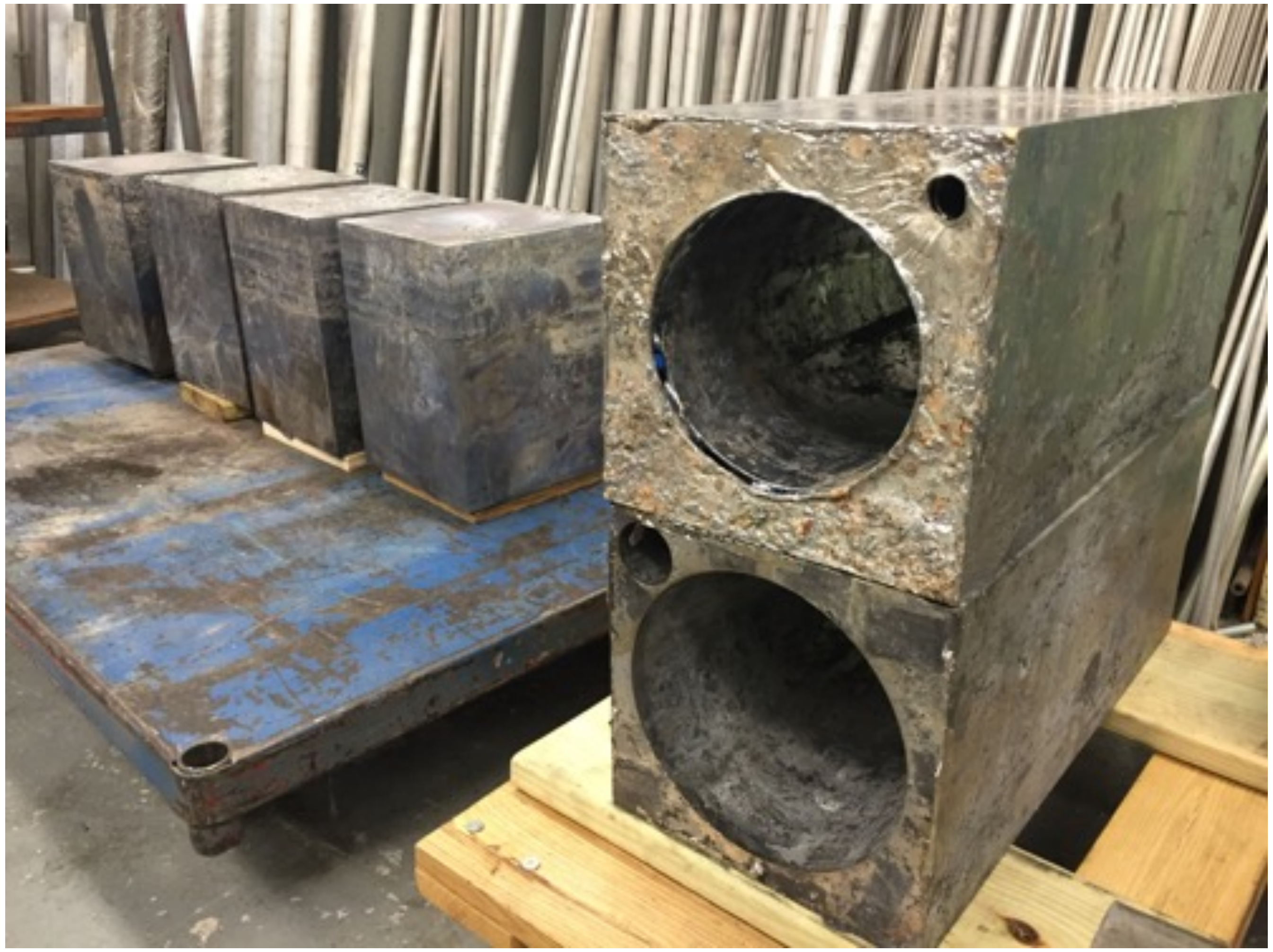


NIN measurements at the SNS: Neutrino cubes with lead

Anticipated NIN count rate in the lead neutrino cube assembly, positioned in its present location at the SNS (~20 m from target, ~8 m.w.e. overburden) and assuming a 30 keVee PSD threshold, is ~100 events in 60 days

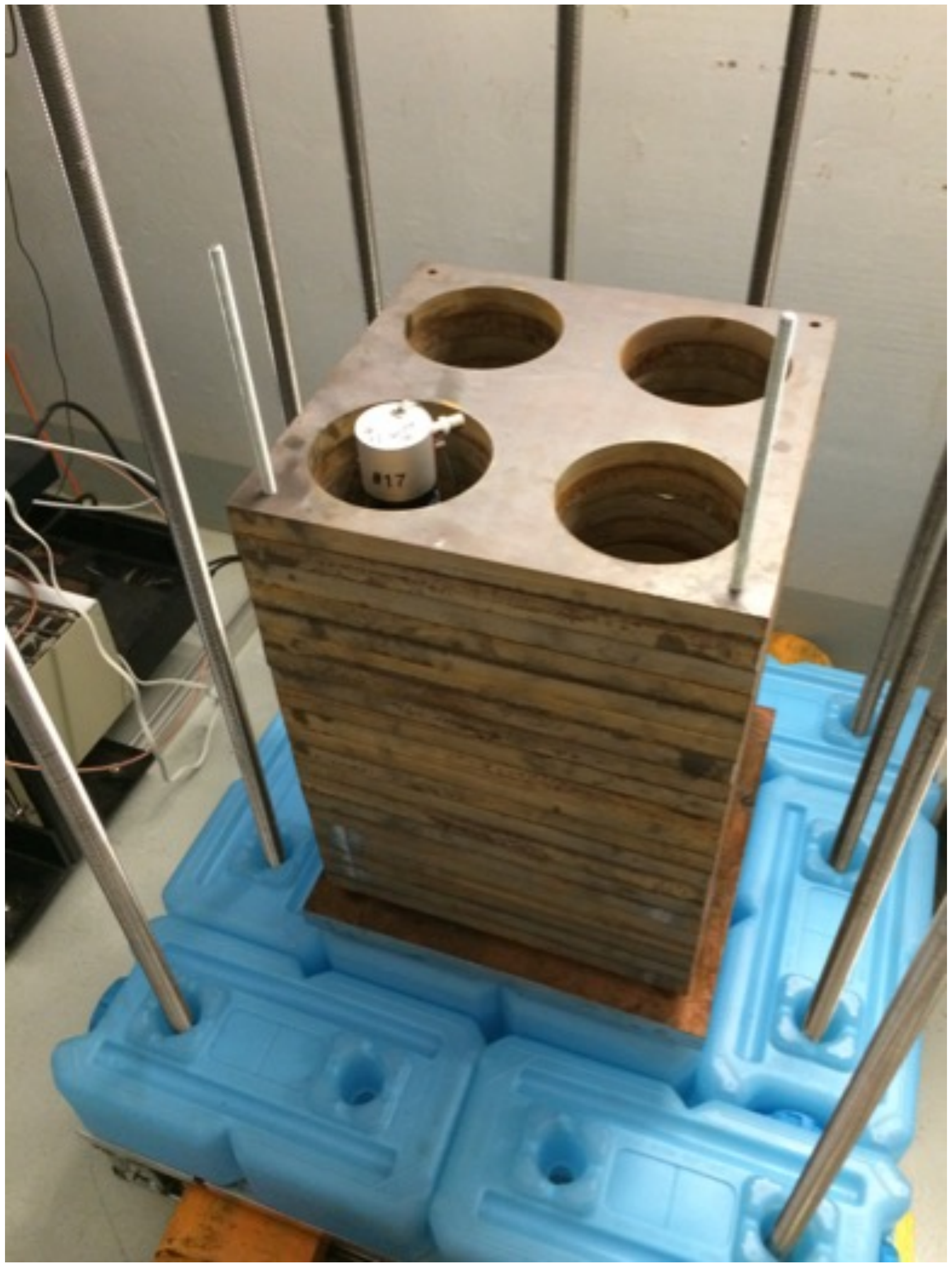


NIN measurements at the SNS: Neutrino cubes with lead



- Lead target assembly being fabricated at Duke Machine Shop
- Muon veto panel assembly should be complete by end of Jan 2015
- Liquid scintillator cells will be characterized at TUNL tandem accelerator over the next week, finished on Jan 20, 2015
- Installation at SNS some time in Q1 2015

Neutrino cubes: “Interchangeable” targets



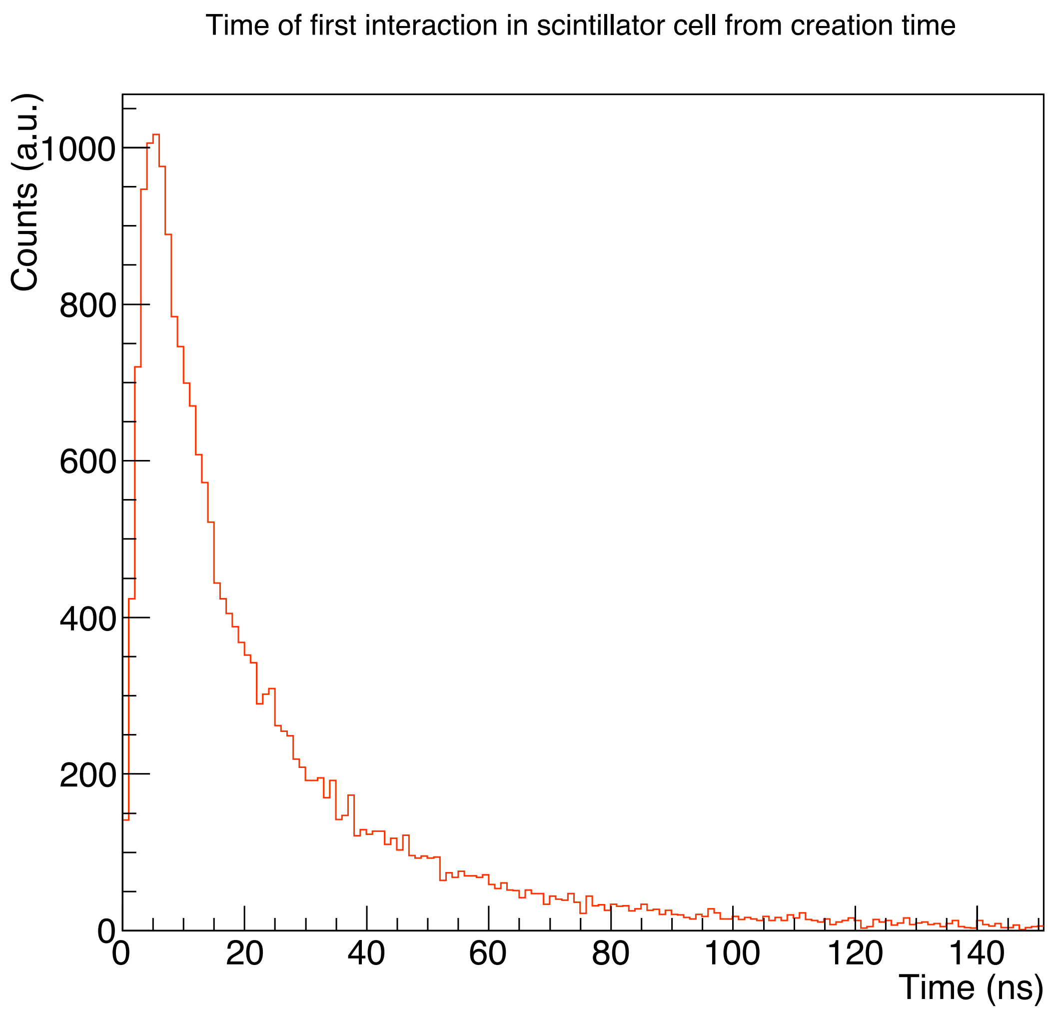
- Neutrino cube design allows for different target materials to be used
- Investigations into NIN cross sections for different materials (especially those commonly used in shielding: Pb, Fe, Cu, W) could be of interest to COHERENT and other (astro)particle physics experiments
- One nube assembly at the SNS is presently loaded with a steel target structure (~620 kg)
- For the same “NIN” energy distribution, Fe assembly efficiency is ~90% that of the Pb assembly
  - NIN cross section is anticipated to be much lower for Fe than Pb, so expected NIN detection rate is very much reduced: ~8 NINs / month

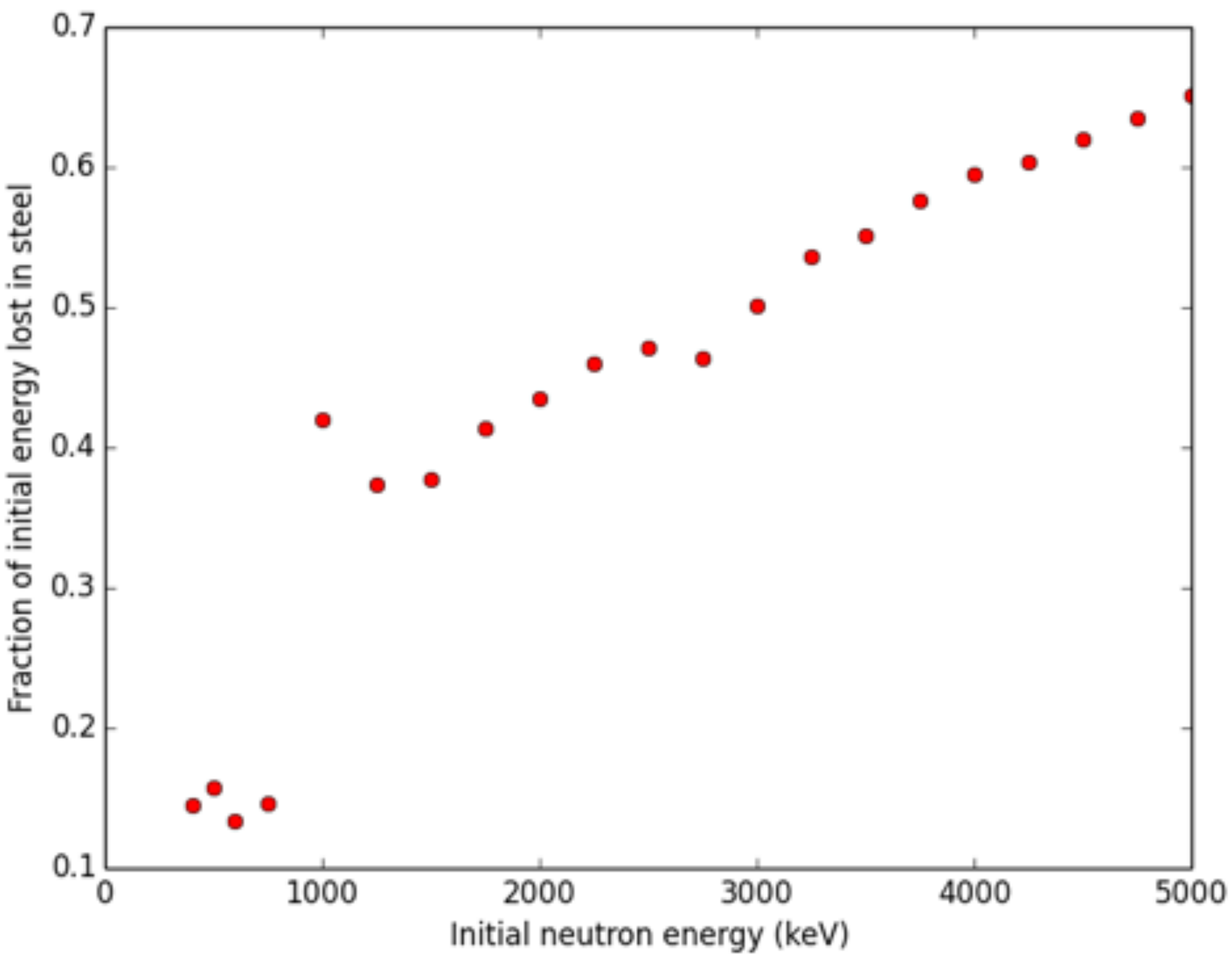
NIN measurements at the SNS: Neutrino cubes with steel

- For steel target, NIN timing information is preserved comparably well to the Pb target

- NIN transport through steel volume has a much more appreciable impact on the energies of the neutrons as they enter the scintillator cells

- Determination of spectral characteristics much more challenging

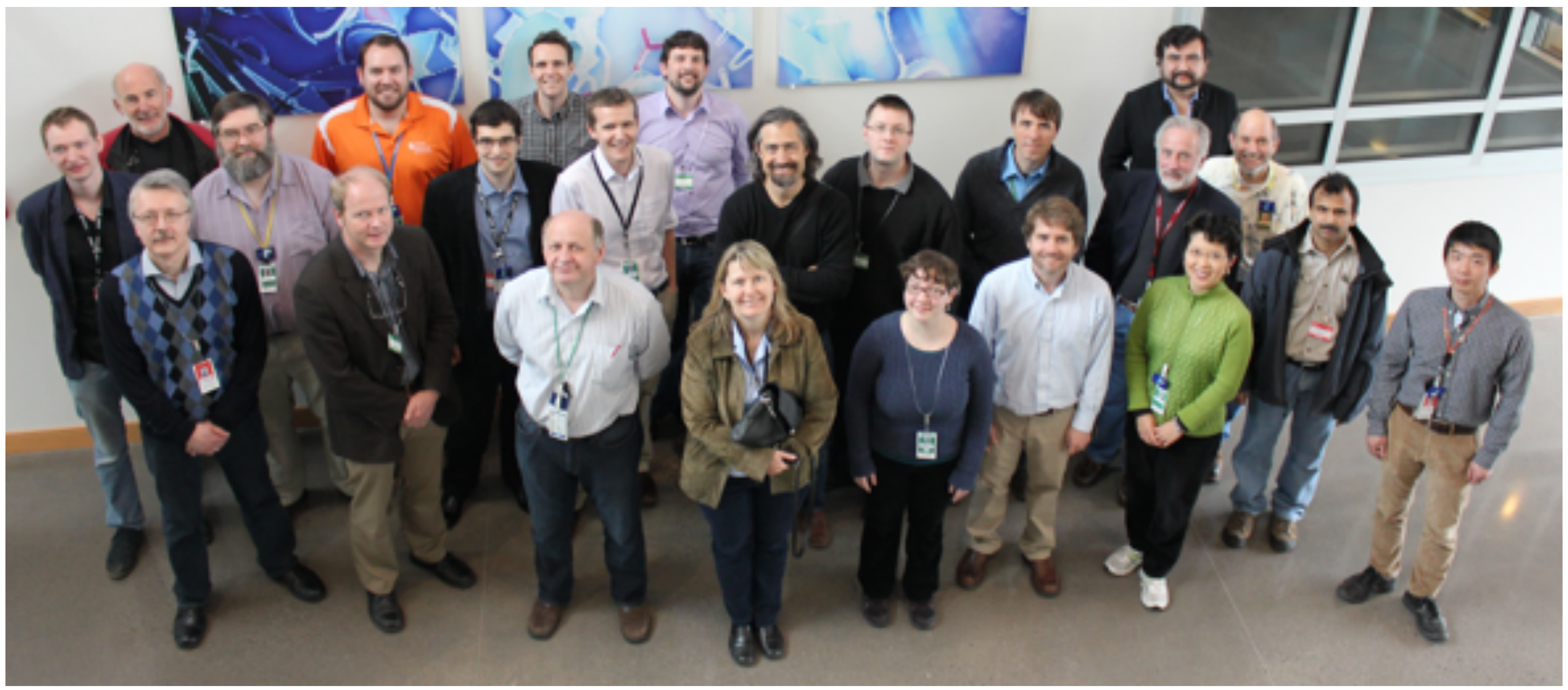




NIN measurements at the SNS

- CsI(Na) shielding is presently collecting NIN data: will provide *in situ* assessment of contribution of NINs to CEvNS search background and a first measurement
- Two neutrino cubes positioned in SNS basement
  - Steel and lead target volumes for neutrino cubes available; first assembly will begin data collection soon
- Total NIN cross section measurements possible for numerous materials
  - Multiplicity measurements seem inaccessible
  - Spectral measurements and Identification of CC and NC NIN cross sections may be possible

COHERENT SNS



J. Adam, D. Akimov, P. Barbeau, P. Barton, A. Bolozdyna, B. Cabrera-Palmer, J. Collar, Robert Cooper, Ren Cooper, D. Dean, Y. Efremenko, S. Elliott, N. Fields, M. Foxe, A. Galindo-Uribarri, M. Gerling, M. Green, G. Green, D. Hornback, T. Hossbach, E. Iverson, A. Khromov, S. Klein, A. Kumpan, W. Lu, D. Markoff, M. McIntyre, P. Mueller, J. Newby, J. Orrell, S. Penttila, G. Perumpilly, D. Radford, J. Raybern, H. Ray, D. Reyna, G. Rich, D. Rimal, K. Scholberg, B. Scholz, S. Suchyta, R. Tayloe, K. Vetter, C.-H. Yu

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