First steps for an experimental neutrino program at the Spallation Neutron Source

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on behalf of D. Hornback
on behalf of the COHERENT collaboration

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Coherent, elastic neutrino-nucleus scattering (CEvNS)

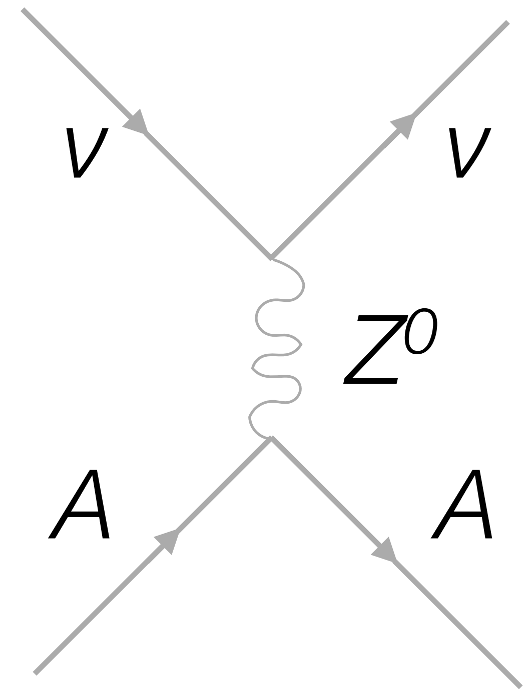
- Neutral-current (flavor-independent) process postulated by D.Z. Freedman in 1974 [1]

- In a CEvNS interaction, a neutrino scatters off of a nucleus whose nucleons recoil *in phase*, resulting in an enhanced cross section; total cross section scales approximately like N^2 [2]

- Expectation of existence is uncontroversial, but the process has never been detected

$$\sigma \approx \frac{G_F^2 N^2}{4\pi} E_\nu^2$$

[1] D.Z. Freedman, Phys. Rev. D (1974)
[2] A. Drukier and L. Stodolsky, Phys. Rev. D (1984)



Very hard to observe experimentally

- Intense neutrino source needed with appropriate energy distribution (coherence is lost with higher energy)

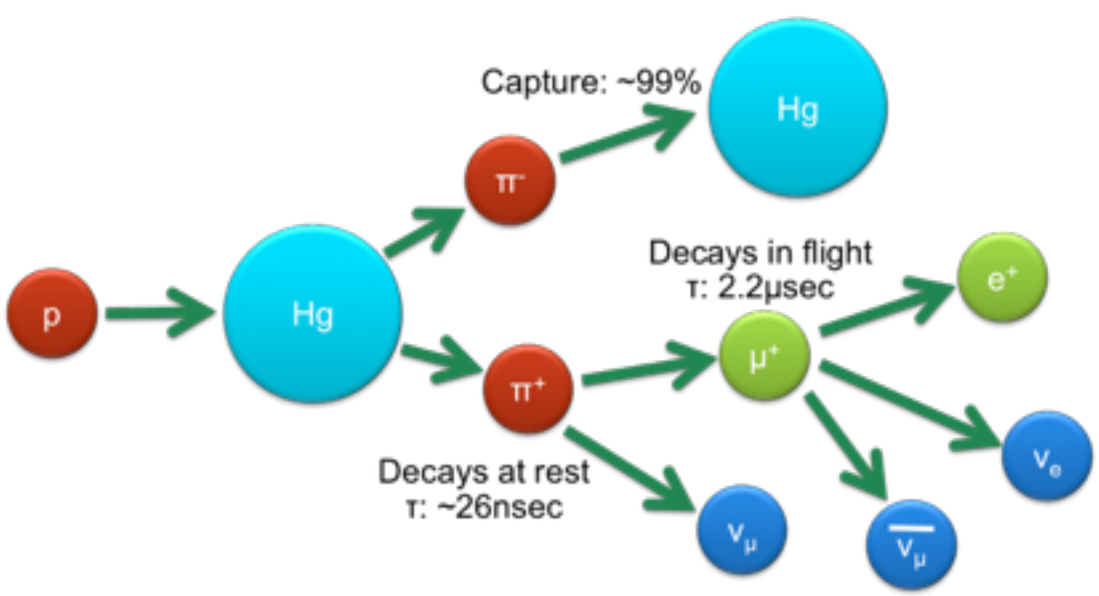
- Signature of interaction is a nucleus recoiling with low (order 10 keV) energy, necessitating low-threshold, low-background detectors

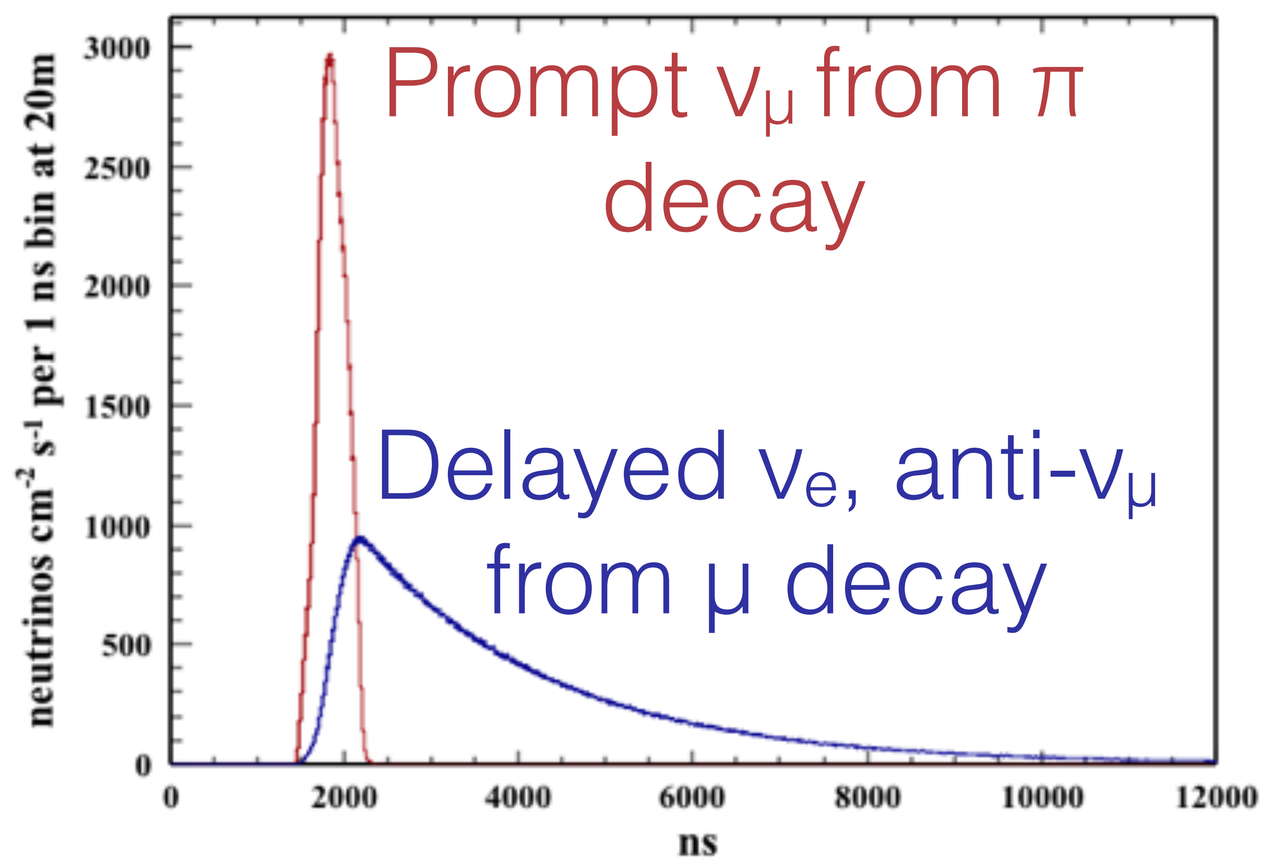
Physics from CEvNS

- Cross section provides a basic test of the standard model
- This interaction is relevant in extreme astrophysical environments, particularly core-collapse supernovae, where it may play a role in explosion dynamics
- Solar neutrinos and CEvNS will be an irreducible background in WIMP dark matter searches
- CEvNS also allows measurement of weak mixing angle, nuclear form factors and neutron distributions of nuclei, and is sensitive to non-standard neutrino interactions and neutrino magnetic moment
- As a neutral-current process, CEvNS is a natural candidate for use in searches for sterile neutrinos

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





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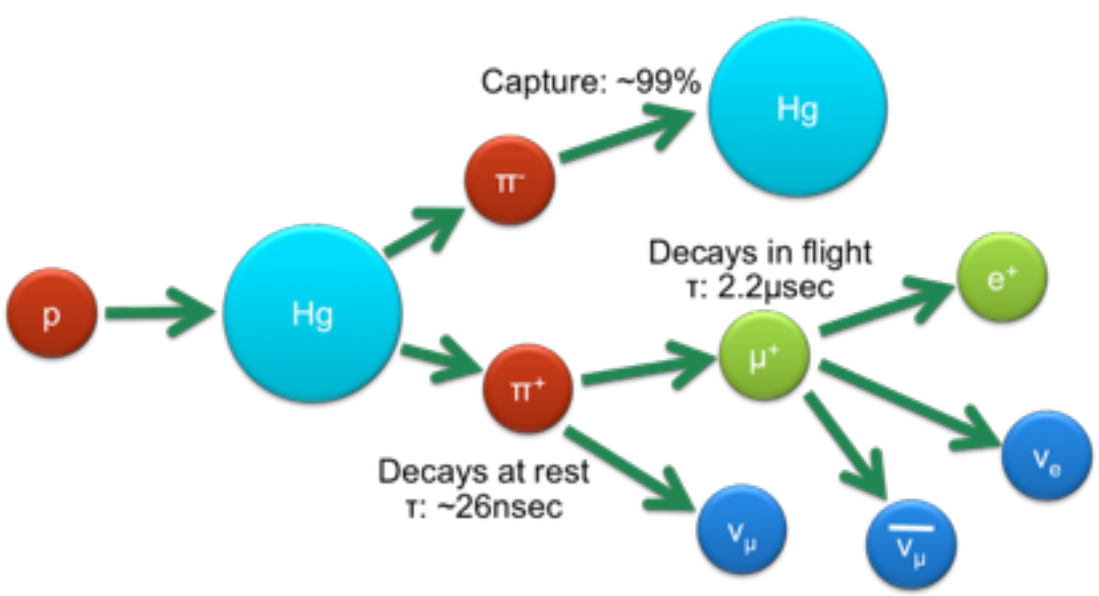
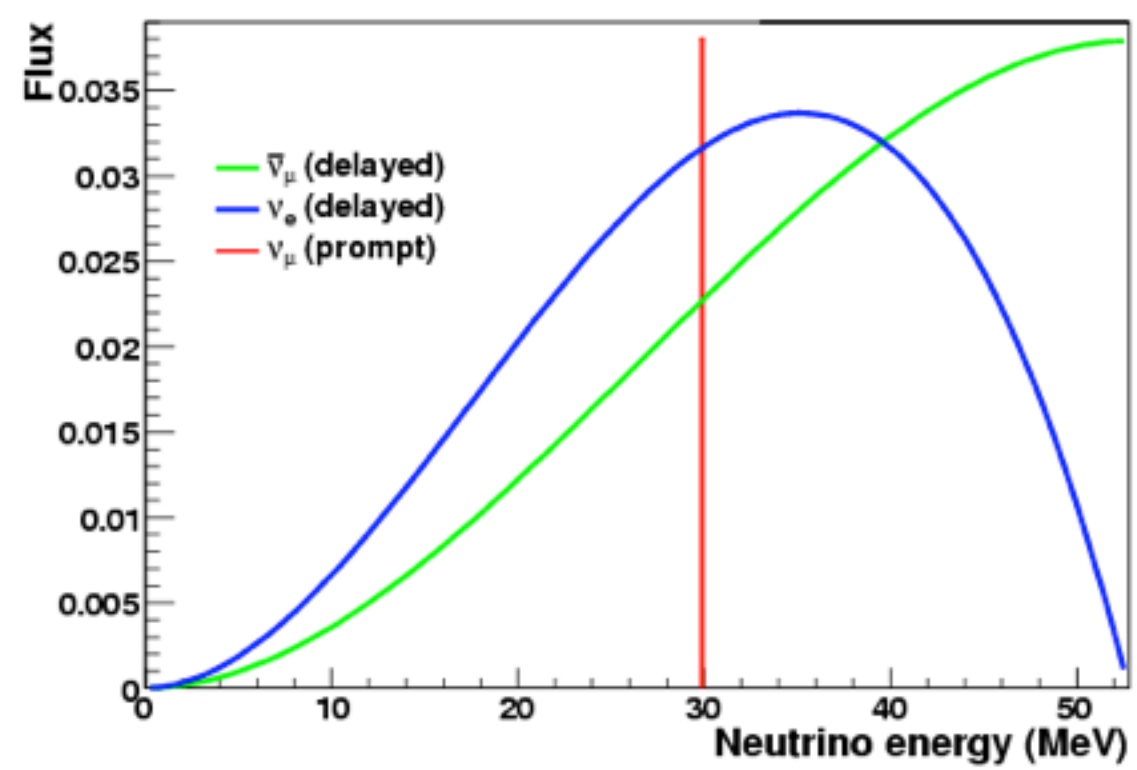


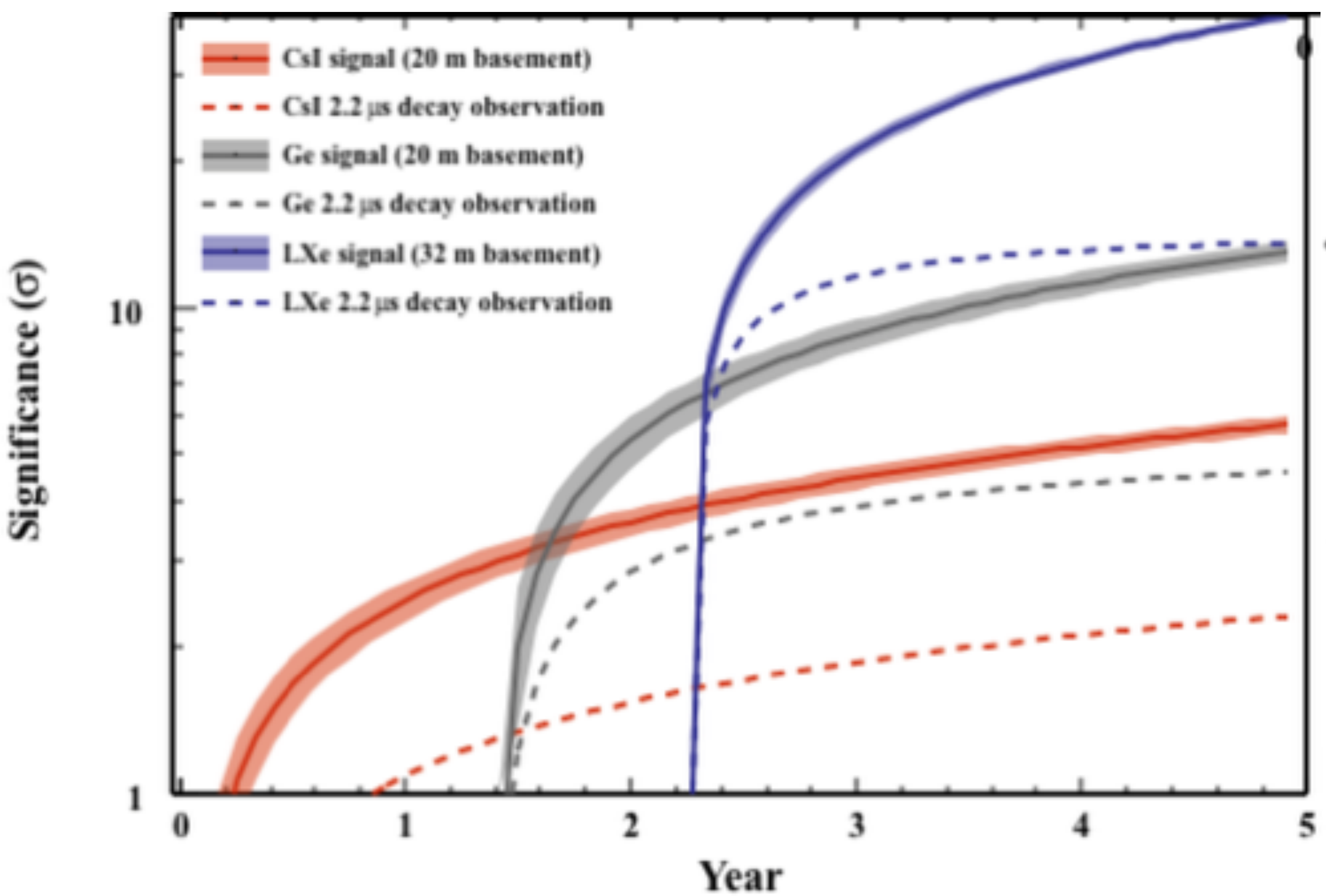


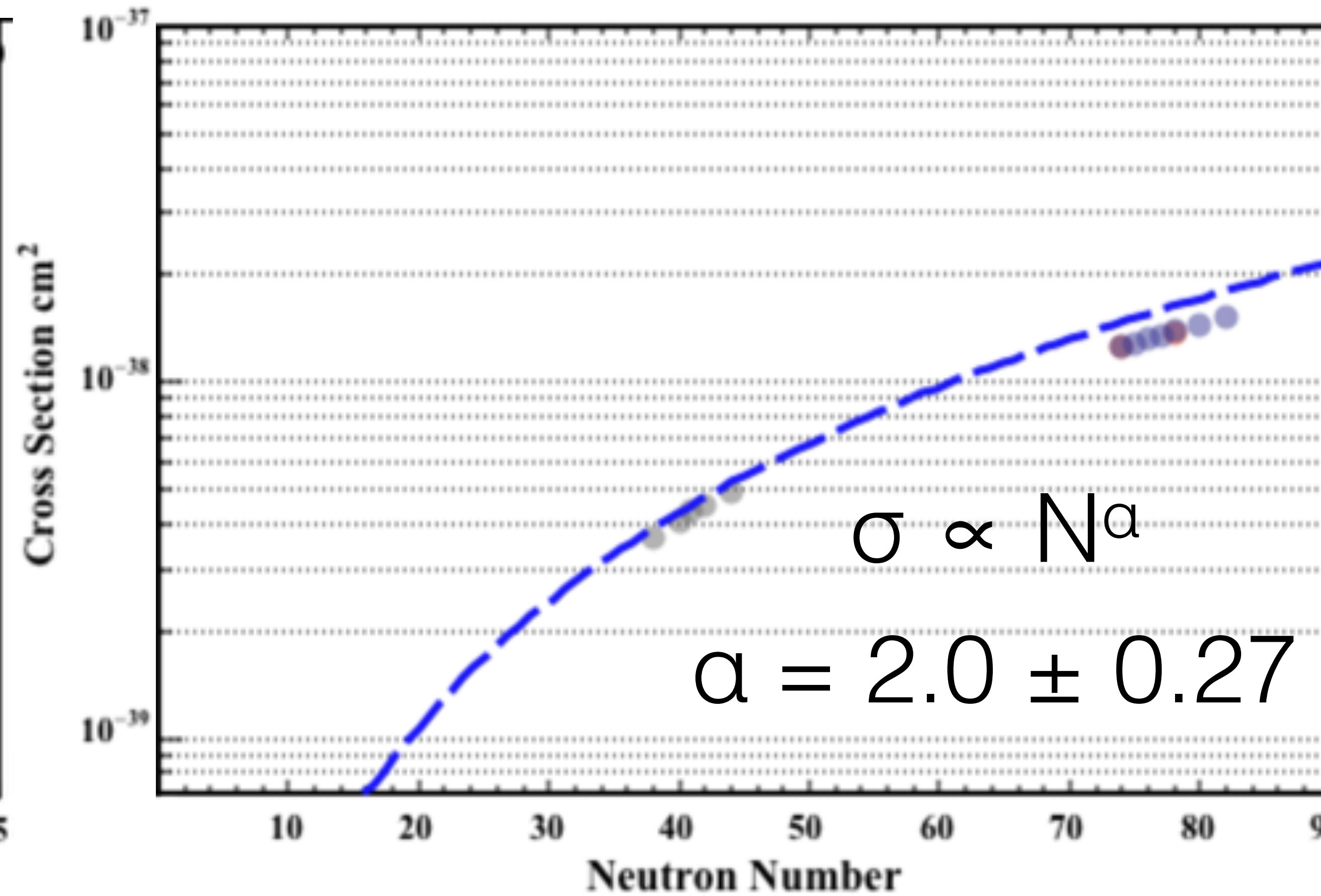
Multiple detector technologies within COHERENT

- Current scope includes CsI(Na), germanium p-type point contact detectors (PPCs), and dual-phase xenon
- By using all of these technologies/targets as part of the COHERENT effort, an very unambiguous first observation of CEvNS can be produced



Unambiguous discovery of CEvNS through multiple detector technologies

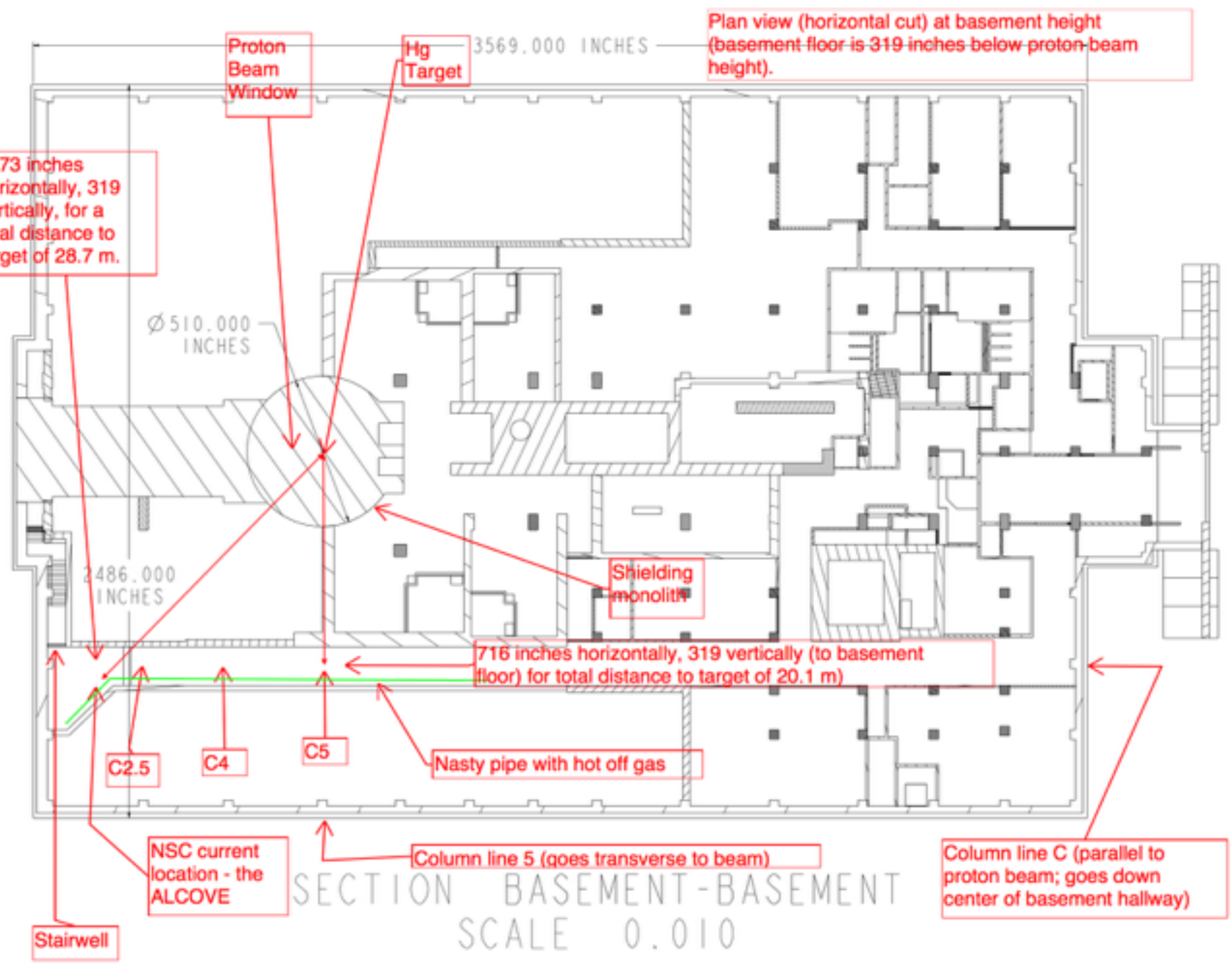




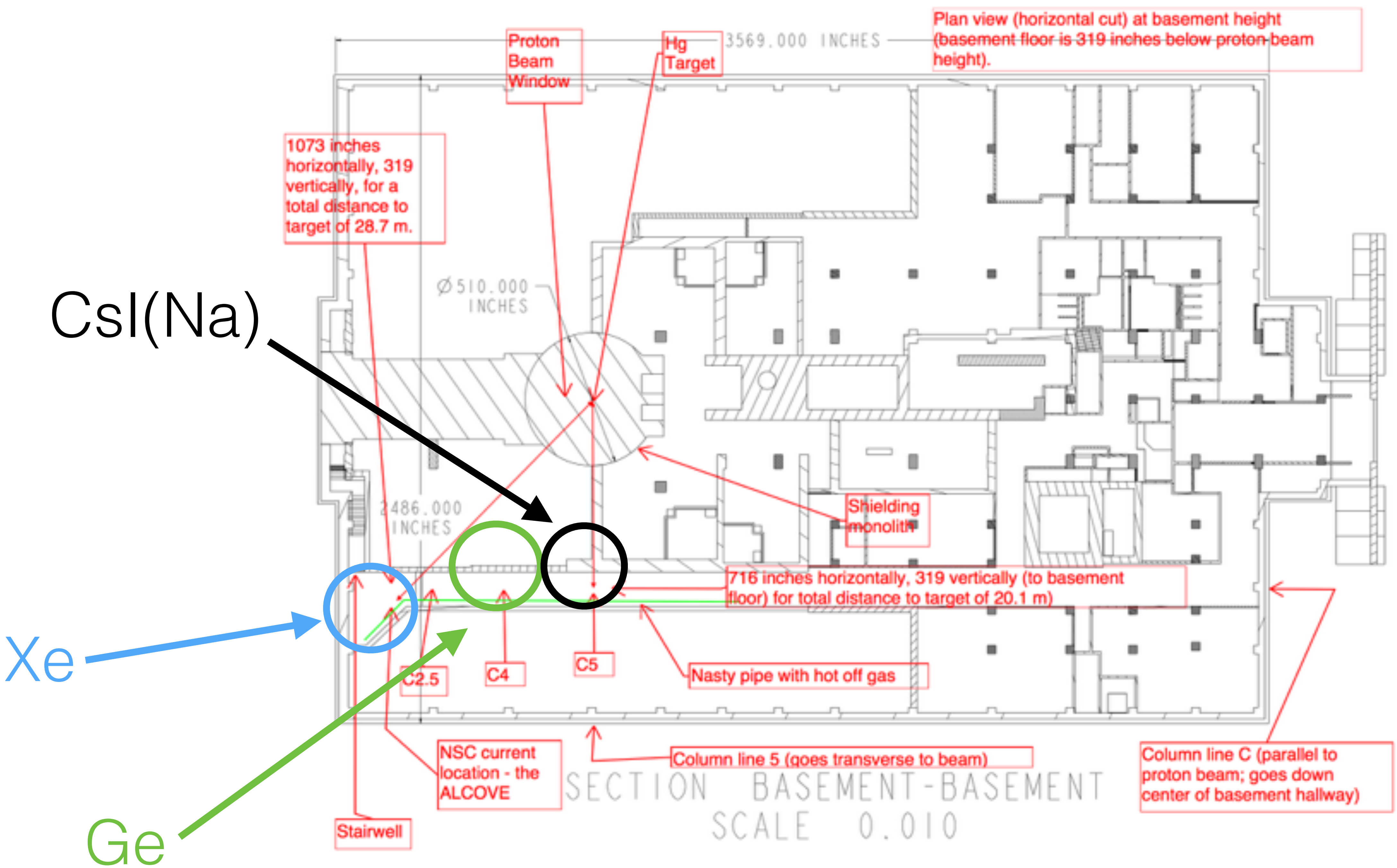
- Observation of SNS-beam-coincident signal excess confirms *beam related*
- Observation of 2.2-μs decay time confirms *neutrino related*
- The use of multiple targets enables observation of N^2-dependence of cross section, characteristic of a coherent, neutral-current interaction

Neutrons at the SNS

- Backgrounds depend on siting at SNS
- Detectors will all tentatively be located in a basement hallway
    - ~8 m.w.e. overburden
    - 20-m from target at C5



Neutrons at the SNS



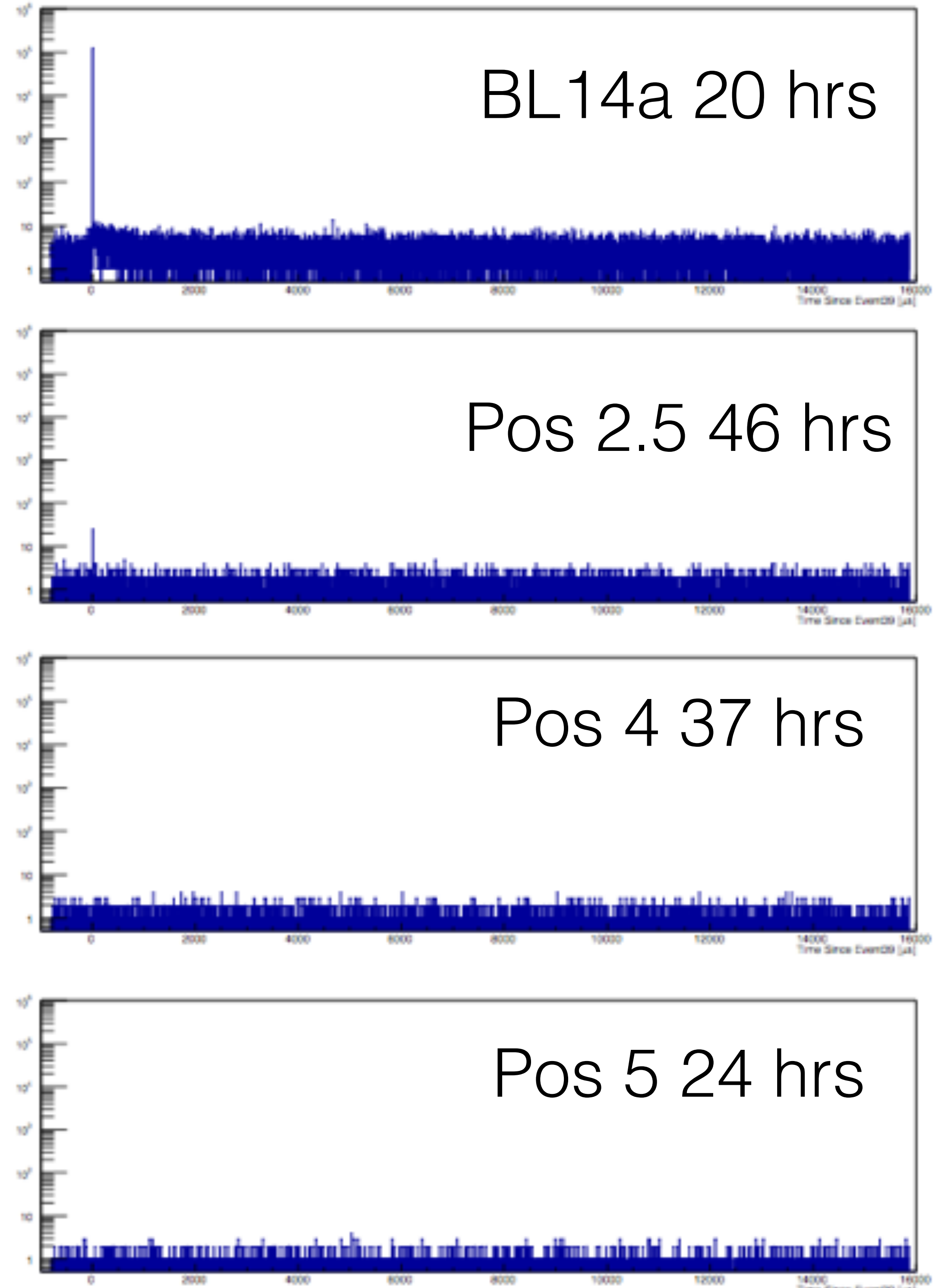
Neutrons at the SNS

Data taken in all 3 site locations in the basement using 5-L EJ-301 LS cells

Xe

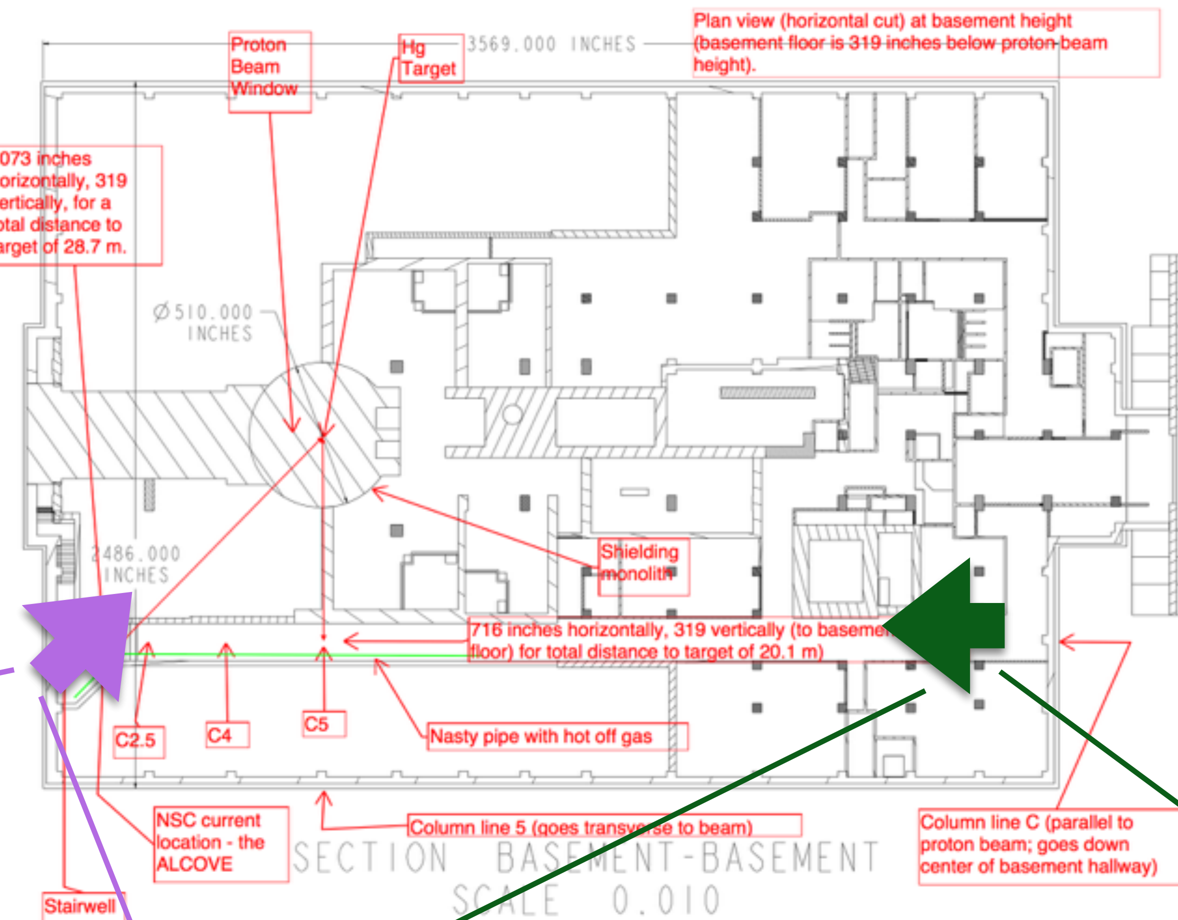
Ge

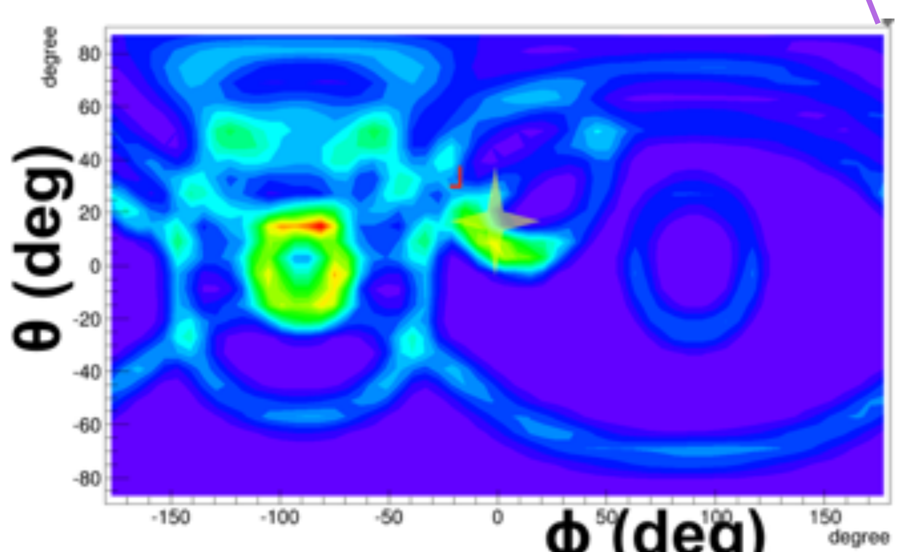
CsI(Na)

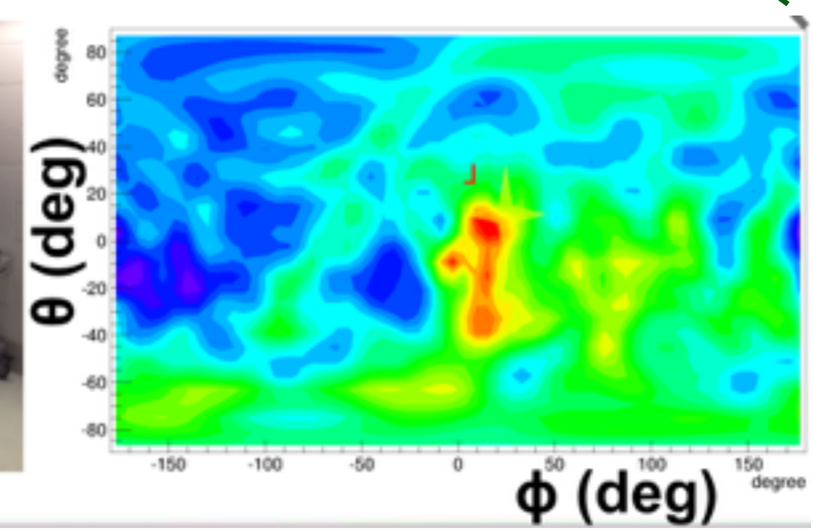


Neutrons at the SNS

Sandia neutron-scatter camera has been deployed in basement locations

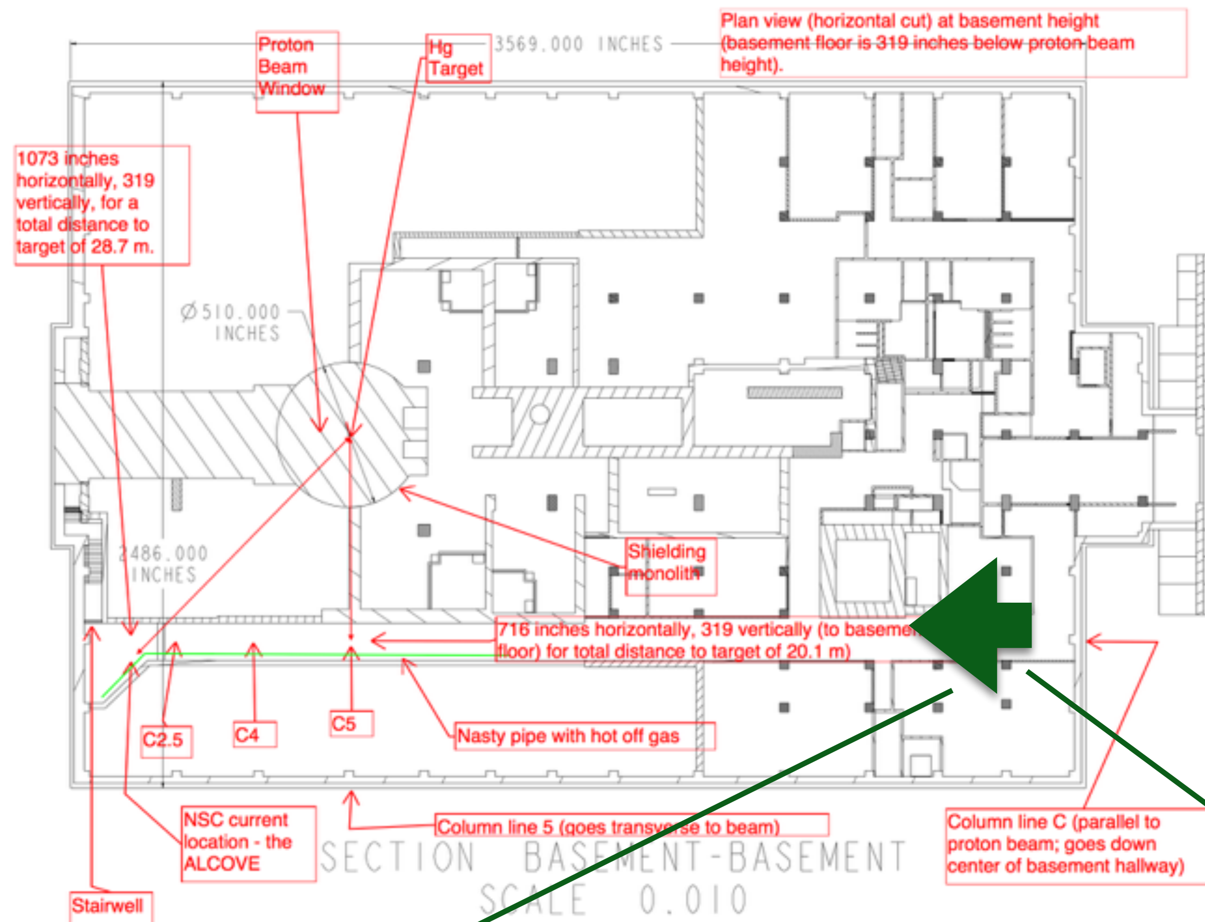


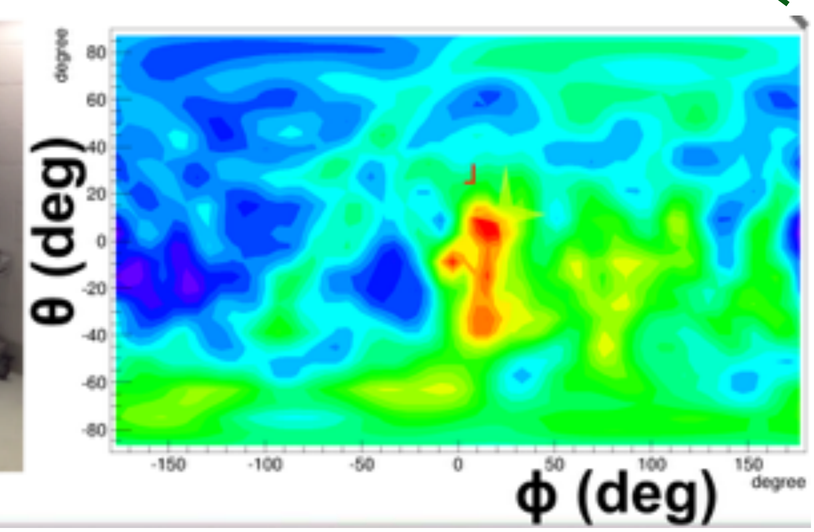




Neutrons at the SNS

- Fast neutron backgrounds correlated strongly with SNS beam pulse
- Large reduction in neutron backgrounds by using a window delayed 2.2 μs relative to SNS beam
    - Delayed neutrons lower energy, easier to shield
    - Delayed window still allows focus on neutrinos from muon-decay





Neutrino-induced neutrons (NINs)

- Neutrinos incident on shielding material can result in the emission of neutrons

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

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

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

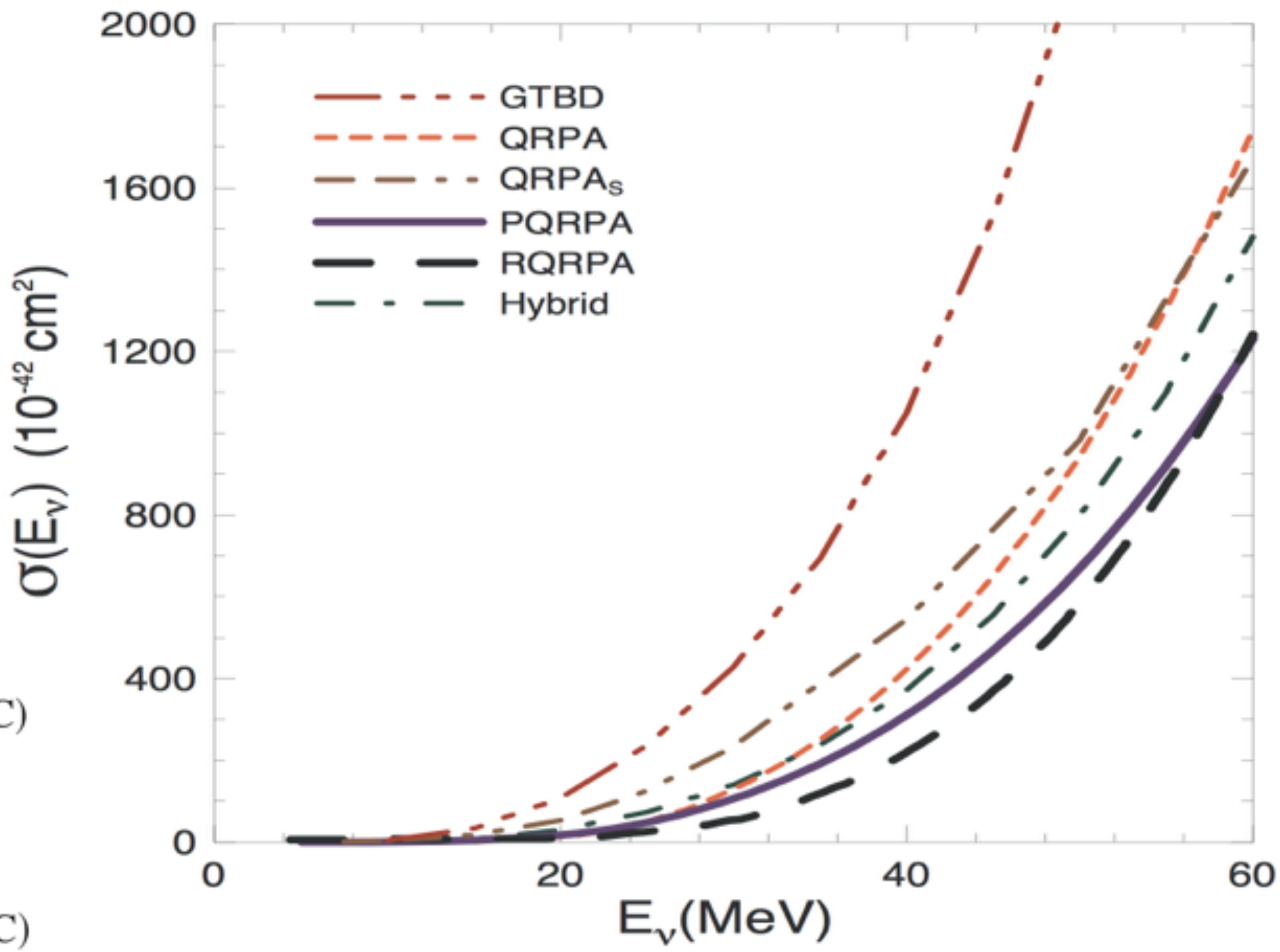


Figure from A.R. Samana and C.A. Bertulani, Phys. Rev. C (2008)

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]

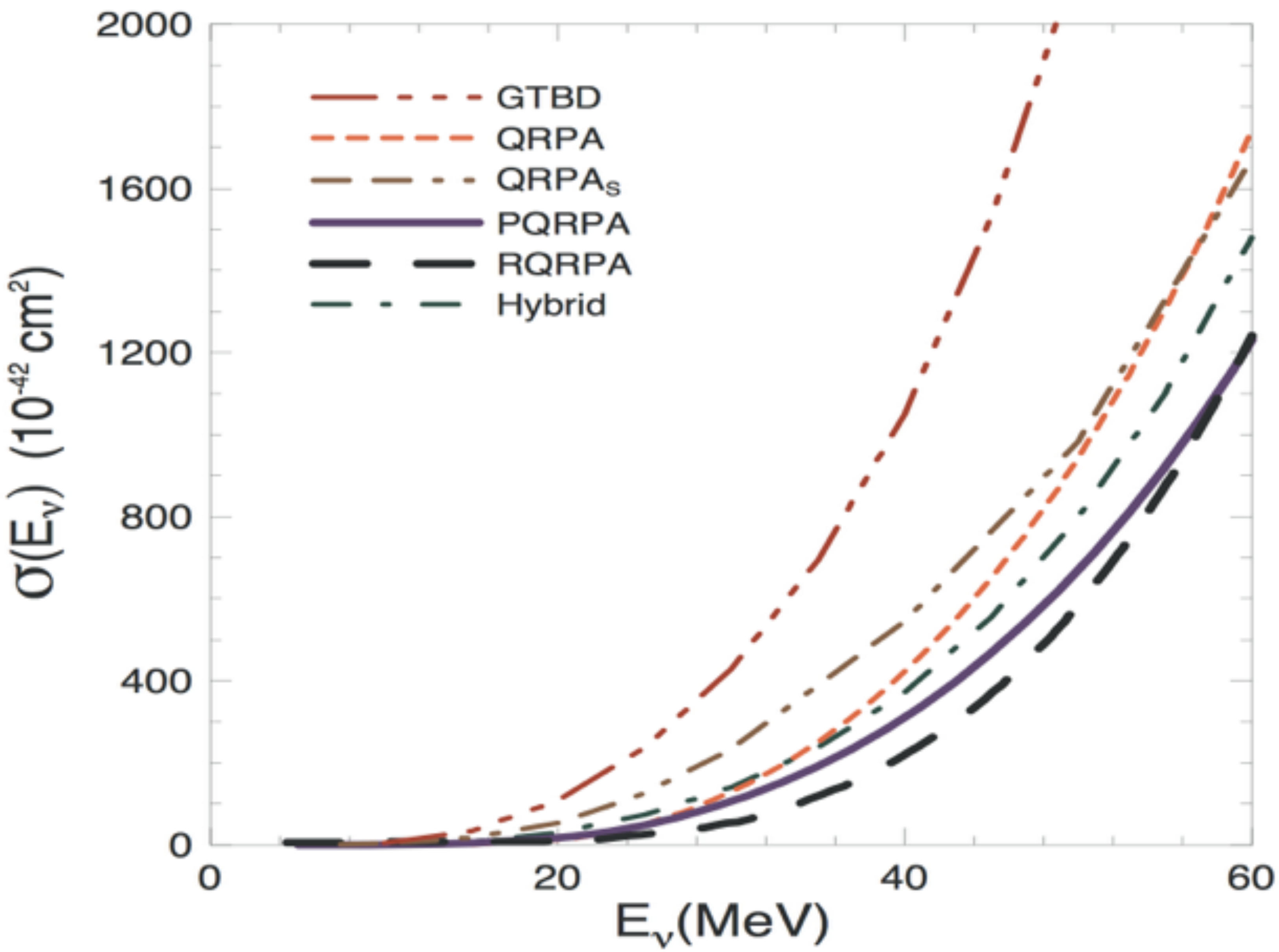
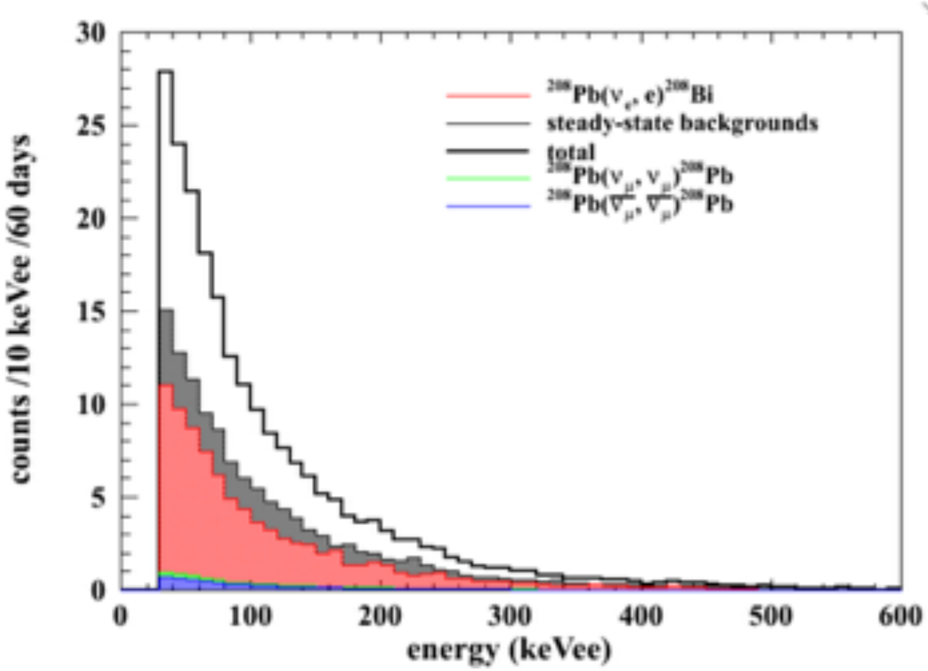


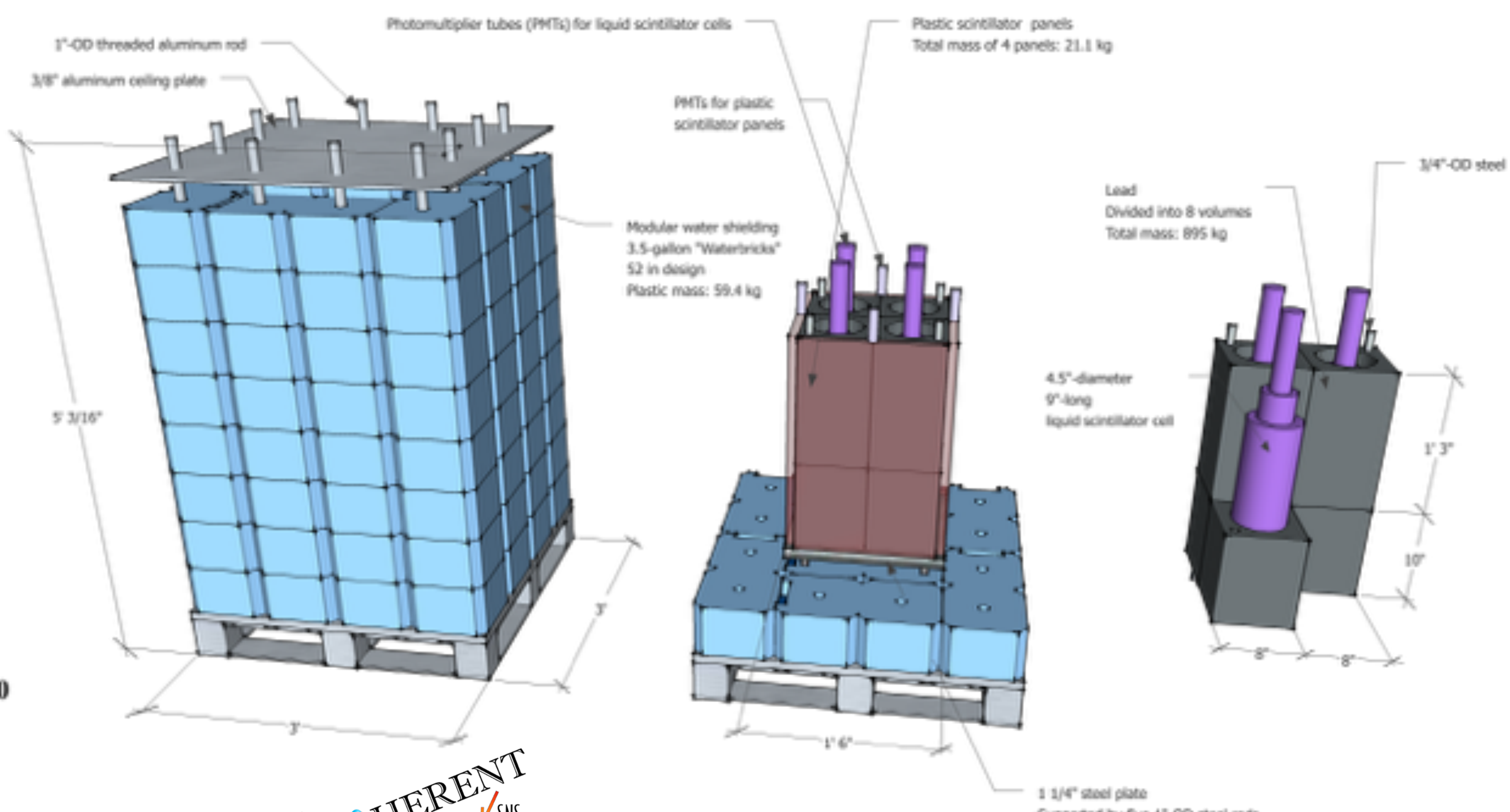
Figure from A.R. Samana and C.A. Bertulani, Phys. Rev. C (2008)

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

Measuring NINs at the SNS

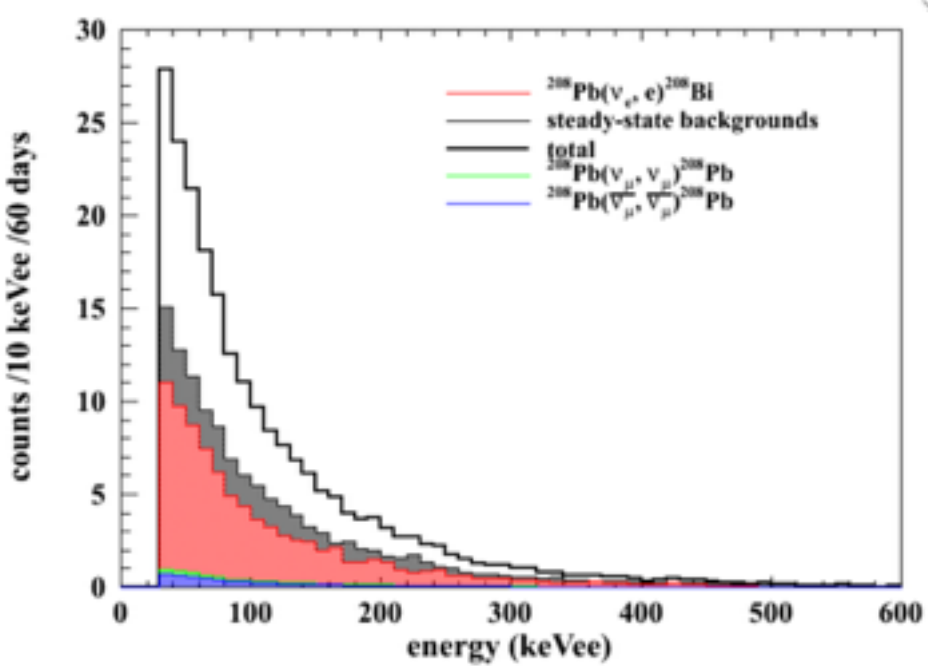
- Two complementary efforts
  - *In situ* measurement inside CsI(Na) crystal cavity using LS cells
  - Dedicated, higher-statistics measurement using “neutrino cubes”
- LS cells in CsI(Na) shield are taking data now; neutrino cubes nearing readiness

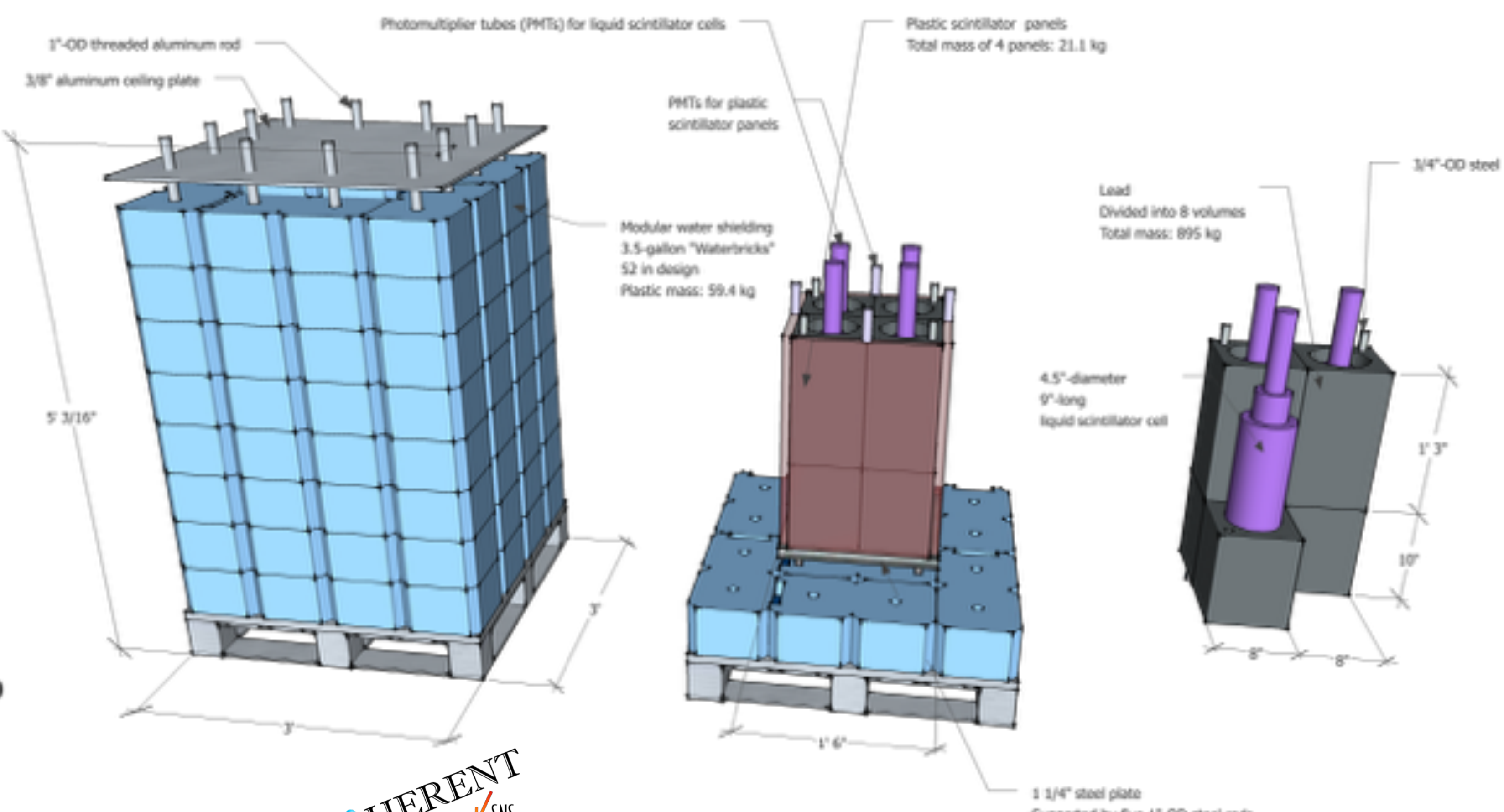




Measuring NINs at the SNS

Preliminary indication from *in situ* background measurement for CsI(Na) suggests fast neutrons associated with beam will be few (< 1 n/day) and tightly correlated with SNS timing

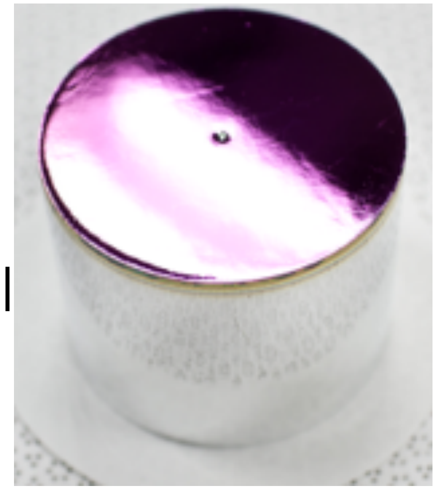




Tentative COHERENT timeline

CsI(Na)

- Shielding already in position at SNS
- Deploy 14.6-kg crystal mid-late 2015



Germanium PPCs

- Possible deployment late 2016
- Anticipate 226 CEvNS events / 10 kg / yr

2016 2017 2018

Next phases
NSI
Standard model tests
Neutron distributions

NIN measurements

- Ongoing in CsI(Na) shield
- Pb and Fe neutrino cubes beginning soon

RED-100 dual-phase Xe

- Possible deployment mid 2017
- > 1000 CEvNS counts per year: high-statistics CS and 2.2-us decay observation quickly obtained

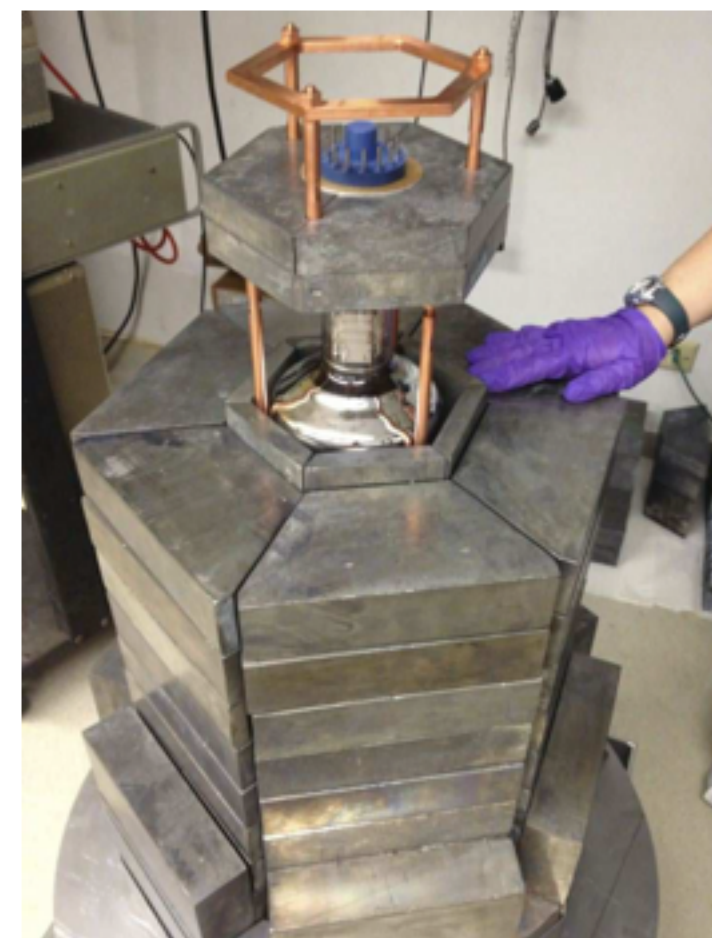
COHERENT: neutrino scattering at the SNS

- Backgrounds in basement locations are increasingly-well understood; fast neutron contributions significantly lower in time window associated with neutrinos from μ decay
- Path toward unambiguous observation of CEvNS process with multiple proven and available detector technologies
  - CsI(Na) should begin taking CEvNS data by the end of 2015
  - Ge PPCs and dual-phase Xe to follow

J. Adam, D. Akimov, P. Barbeau, P. Barton, A. Bolozdyna, B. Cabrera-Palmer, J. Collar, Robert Cooper, Ren Cooper, C. Cuesta, D. Dean, J. Detweiler, Y. Efremenko, S. Elliott, N. Fields, M. Foxe, A. Galindo-Uribarri, M. Gerling, M. Green, G. Green, D. Hornback, T. Hossbach, E. Iverson, L. Kaufman, 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

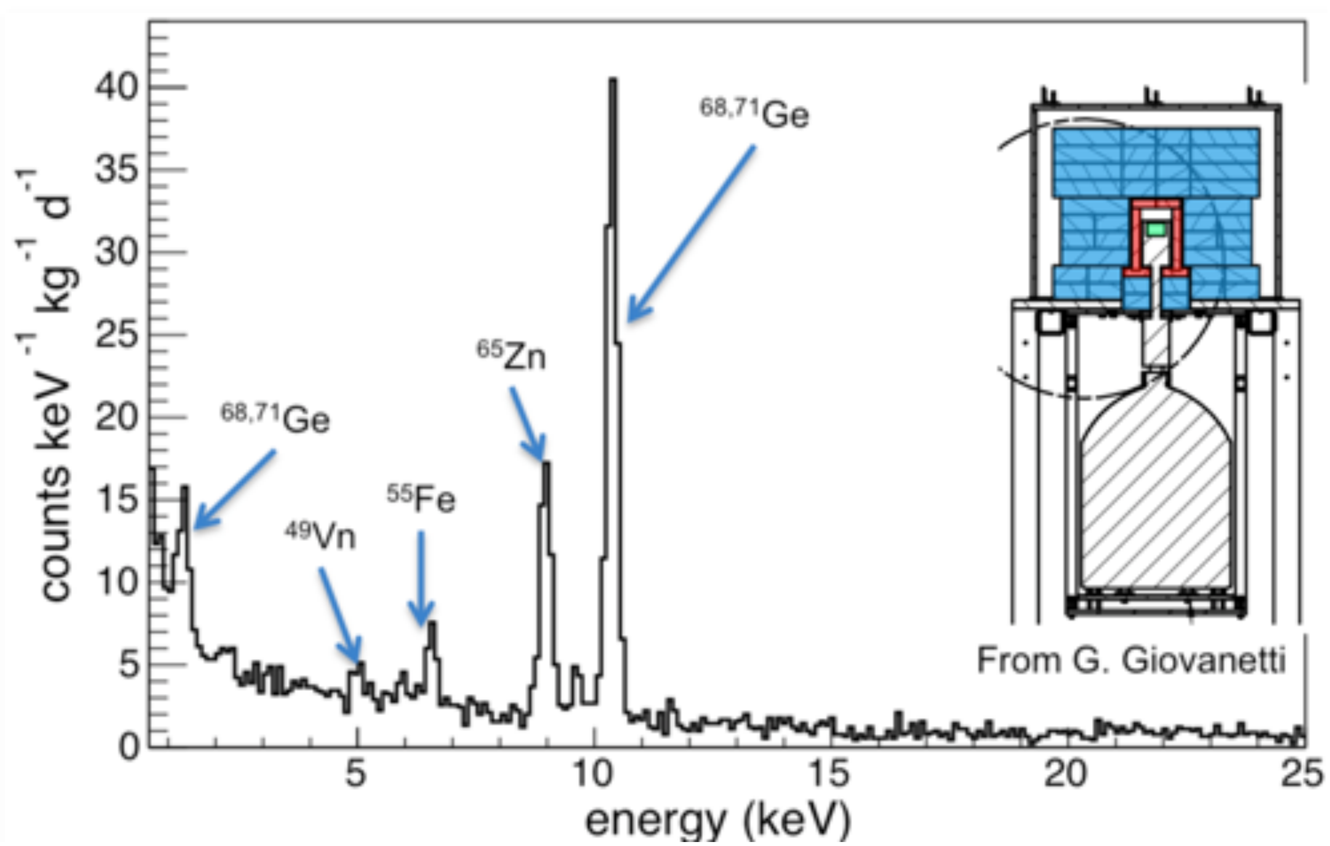
CEvNS with CsI(Na)

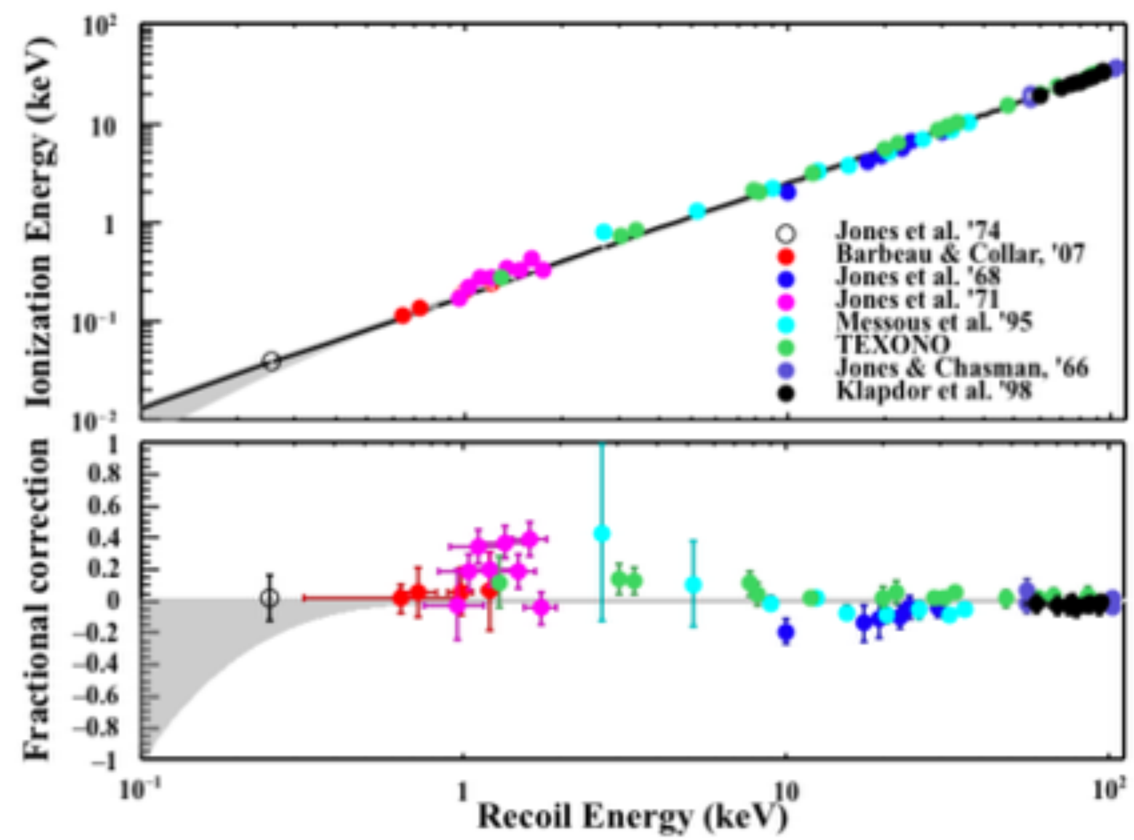
- CsI(Na) response to low-energy nuclear recoils has been measured by members of the COHERENT collaboration
- With a 2-kg crystal, data taken at ~6 m.w.e. indicate sufficiently low backgrounds for CEvNS search @ 20 m from SNS target
- 14.6-kg crystal, now located at University of Chicago, has been characterized (good uniformity of light yield along length)



CEvNS with PPCs

- Ge PPC technology offers very-high energy resolution and systems can be very-low background
- Signal (ionization) yield for CEvNS-relevant nuclear-recoil energies has been measured extensively; data agree well with theoretical predictions
- MAJORANA Executive Committee has endorsed the use of components from the MAJORANA Demonstrator (MJD), following decommissioning in Spring 2015, by COHERENT; working group led by R. Cooper (LBL)





CEvNS with dual-phase xenon

- RED-100 detector built by COHERENT collaborators at MEPhI (Moscow); working group led by Yu. Efremenko (UTK)
- Advances in dual-phase xenon technology have been driven by WIMP community: response
- 200-kg total mass, 120-kg fiducial
- Engineering test of completely-assembled detector anticipated by end of 2015
- > 1000 CEvNS counts/yr; S/N 10:1

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

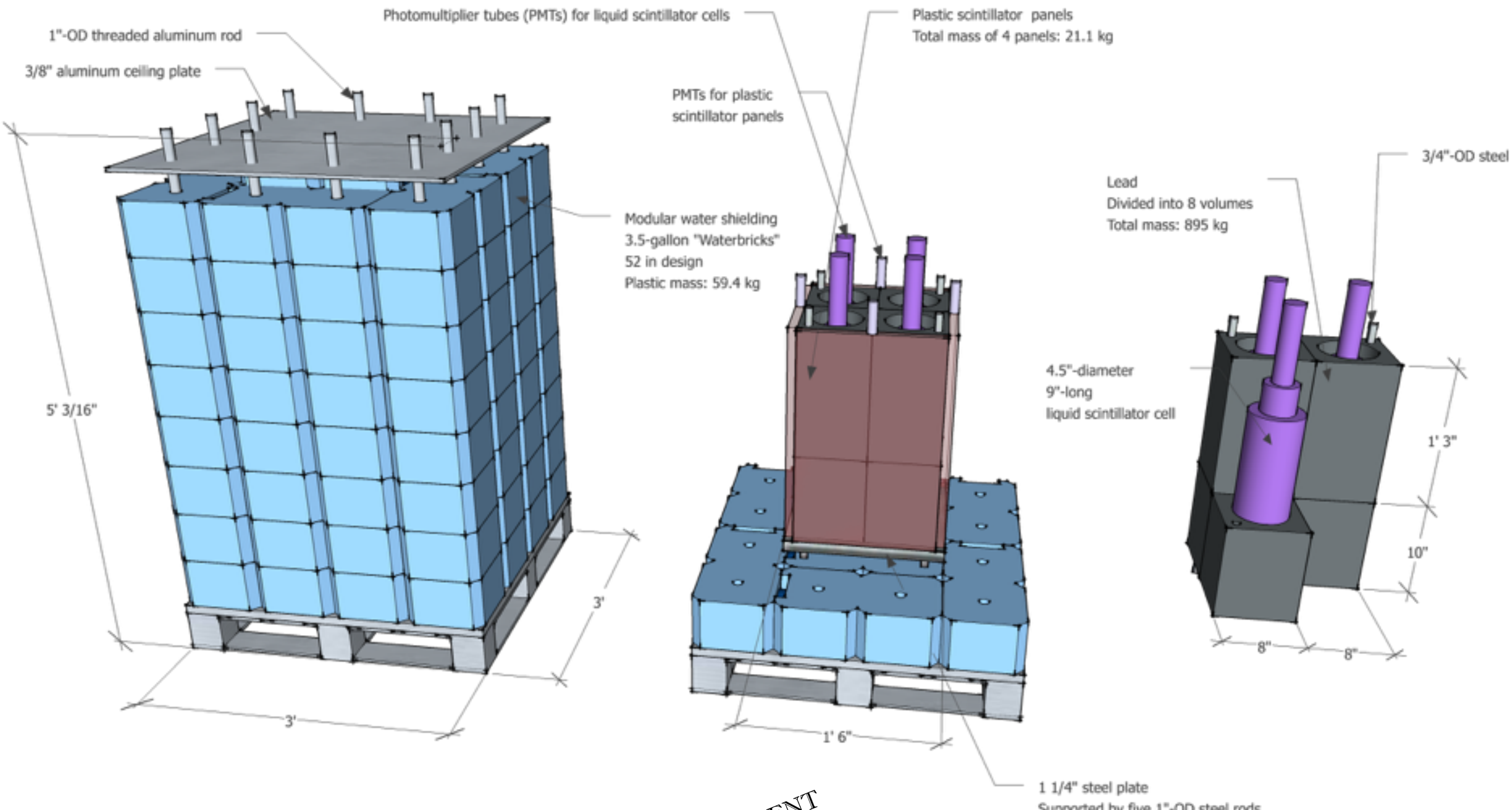
- Two liquid scintillator cells are in place within the detector cavity, allowing *in situ* measurement of gamma and neutron backgrounds for the CsI(Na) CEvNS search and an initial measurement of the NINs cross section

- MCNP-PoliMi simulation suggests a ~4.4% efficiency for production of nuclear recoils in by neutrons spalled from Pb

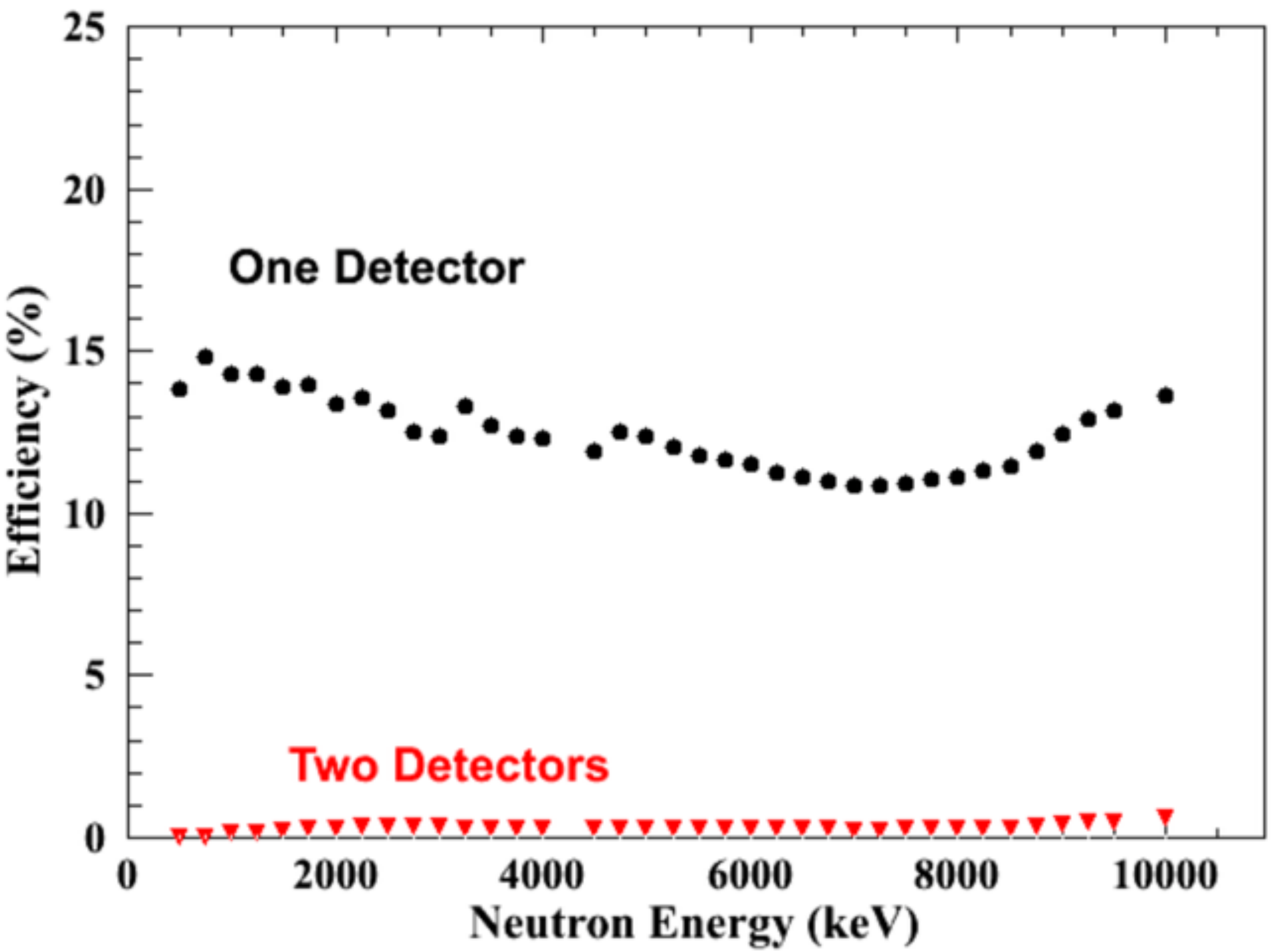
As J. Collar showed: this system is presently collecting data

NIN measurements at the SNS: 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

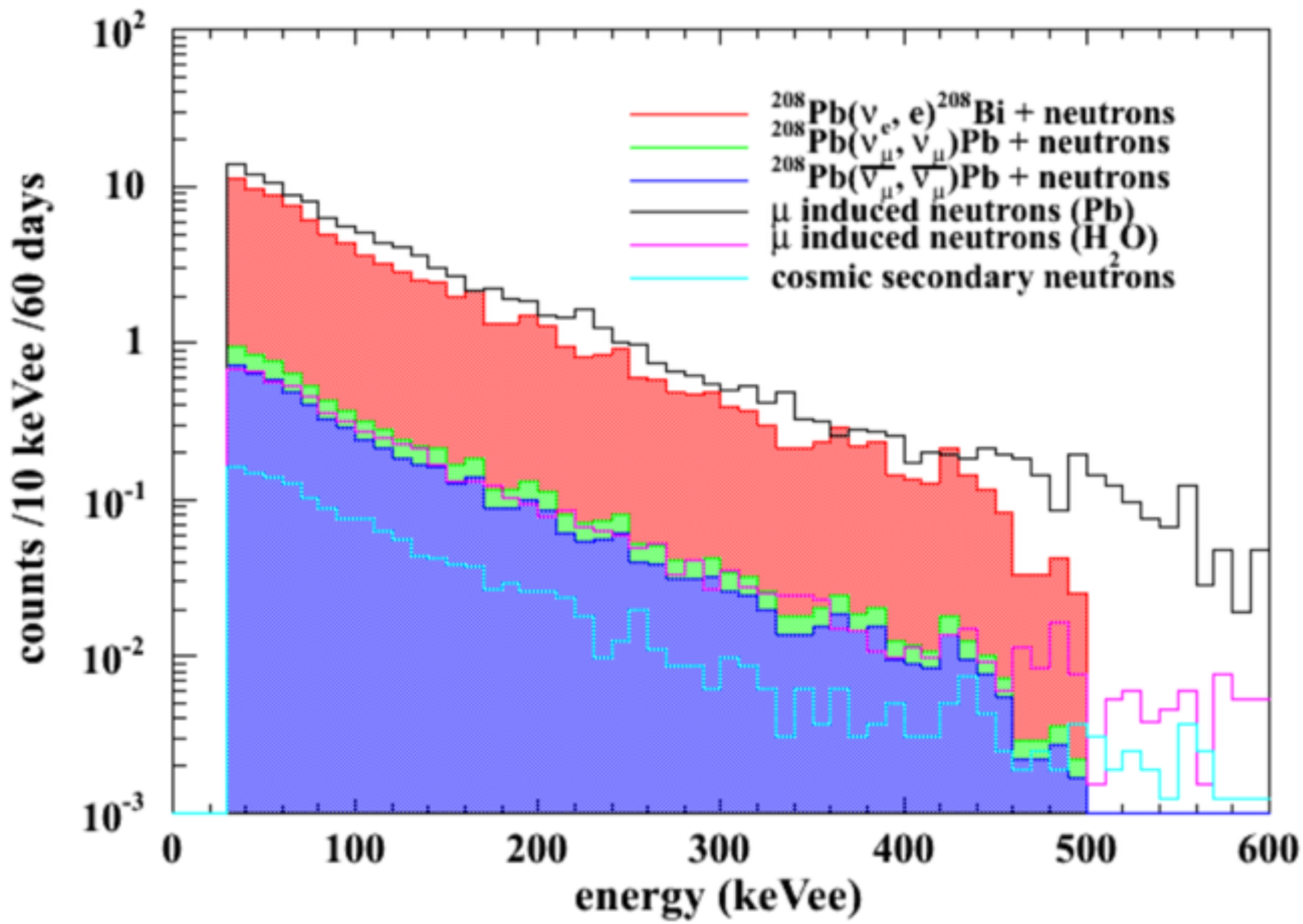


NIN measurements at the SNS: Neutrino cubes



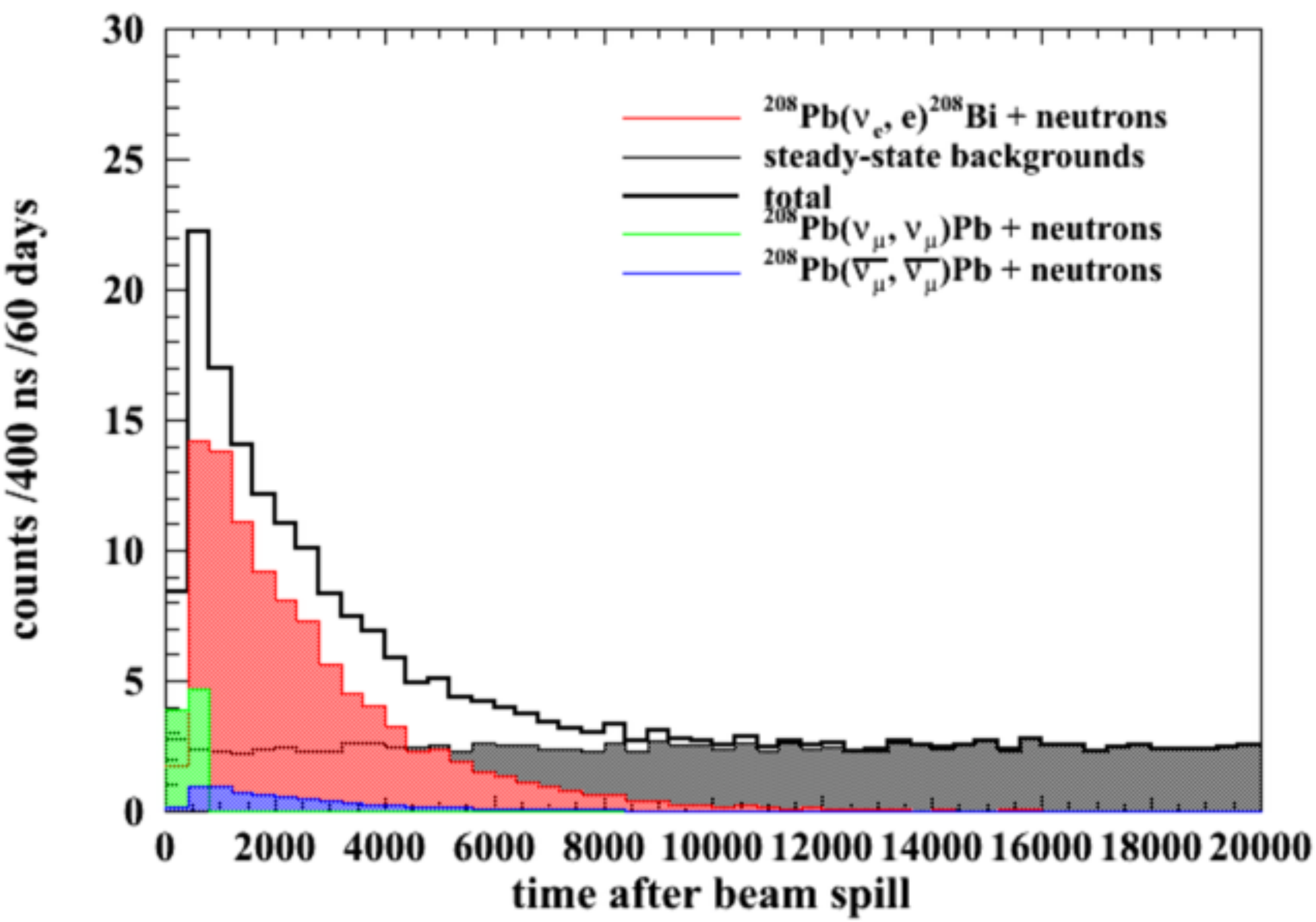
Neutrino cubes with a lead target have a well-behaved efficiency for a wide range of initial neutron energies. Above ~7 MeV, neutron multiplication in the target volume begin to influence efficiency and observed multiplicity.

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

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

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