The COHERENT collaboration: an effort to observe coherent, elastic, neutral-current neutrino-nucleus scattering at the Spallation Neutron Source

G.C. Rich for the COHERENT collaboration

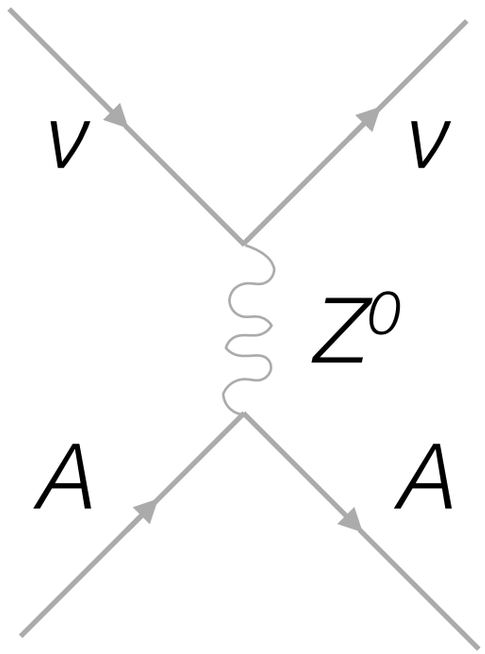
Coherent, elastic neutrino-nucleus scattering (CEvNS)

- 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

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



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

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

Physics from first observations of CEvNS

- Cross section provides a basic test of the standard model
- Measurement of weak mixing angle at ~5% level from ~10% absolute CEvNS cross section measurement
  - Complements measurements by Q_{weak} at JLab; similar momentum transfer in both experiments, very different probes
- Relevant input for extreme astrophysical environments, particularly core-collapse supernovae
  - Tremendous amounts of energy are released from core of collapsing star in the form of neutrinos
  - CEvNS may play a role in the dynamics of the evolution of CCSNe by providing a mechanism for (relatively) efficient coupling of neutrinos to matter

Physics from precision CEvNS measurements

- With very good understanding of systematics and spectral response of detectors, broad new physics horizons are accessible
- Sensitivity to physics beyond the standard model (nonstandard neutrino interactions / vector coupling to quarks)
- Potential for measurement of neutrino magnetic moment
- Unique tool for nuclear structure studies: neutron form factors and density distributions can be extracted

See talk by G. McLaughlin tomorrow (2PM in Kohala 1, abstract MA.00001) for a more in-depth discussion of theoretical implications and impact of CEvNS measurements

The COHERENT collaboration

Overarching goal: observe CEvNS interaction using neutrinos produced by the Spallation Neutron Source (SNS) at Oak Ridge National Lab (ORNL) with **numerous targets**, providing a check on systematic uncertainties and allowing **confirmation of the N^2-dependence of the cross section**

The COHERENT collaboration

- Utilize neutrinos produced by the SNS
  - Pulsed, intense neutrino flux with **very well-defined spectral distribution**
  - 10^{15} ν/s from stopped pions and muons, **no contribution from kaons**
- Take advantage of proven low-background, highly-sensitive detectors
  - Experimentally establish high-precision knowledge of detector response for low-energy nuclear recoils
  - Current candidate detector technologies under strong consideration: Germanium PPC detectors, noble-element detectors, **CsI(Na)**, leveraging knowledge gained from WIMP and 0νββ searches
- Multi-institutional group of researchers with diverse expertise
  - Coalescence of many groups with interest in CEvNS observation

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

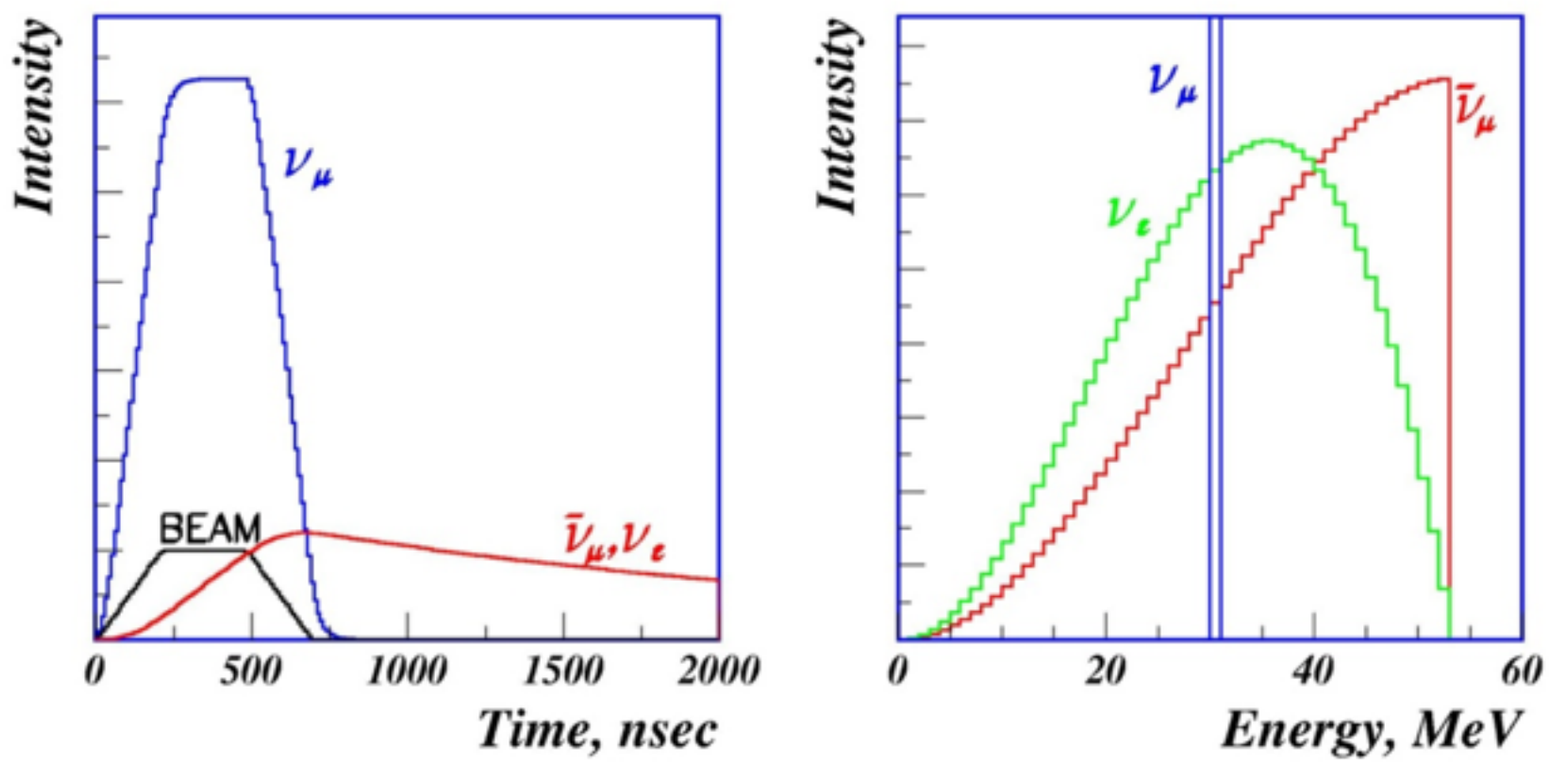


Figure from A. Bolozdynya *et al.*, arXiv:1211.5199 (2012)

CEvNS signals and detectors

$$\frac{d\sigma}{dT}(E,T) = \frac{G_F^2}{2\pi} M \left[2 - \frac{2T}{E} + \left(\frac{T}{E}\right)^2 - \frac{MT}{E^2} \right] \frac{Q_W^2}{4} F^2(Q^2)$$

- CEvNS cross section increases like N^2
- .. *but* heavier nuclei recoil with lower energy
- Target/detector selection and design requires consideration of this balance!
- Interpretation of CEvNS-search results are dependent on knowledge of detector response, *especially* to provide input for neutron distributions, beyond standard model tests, etc

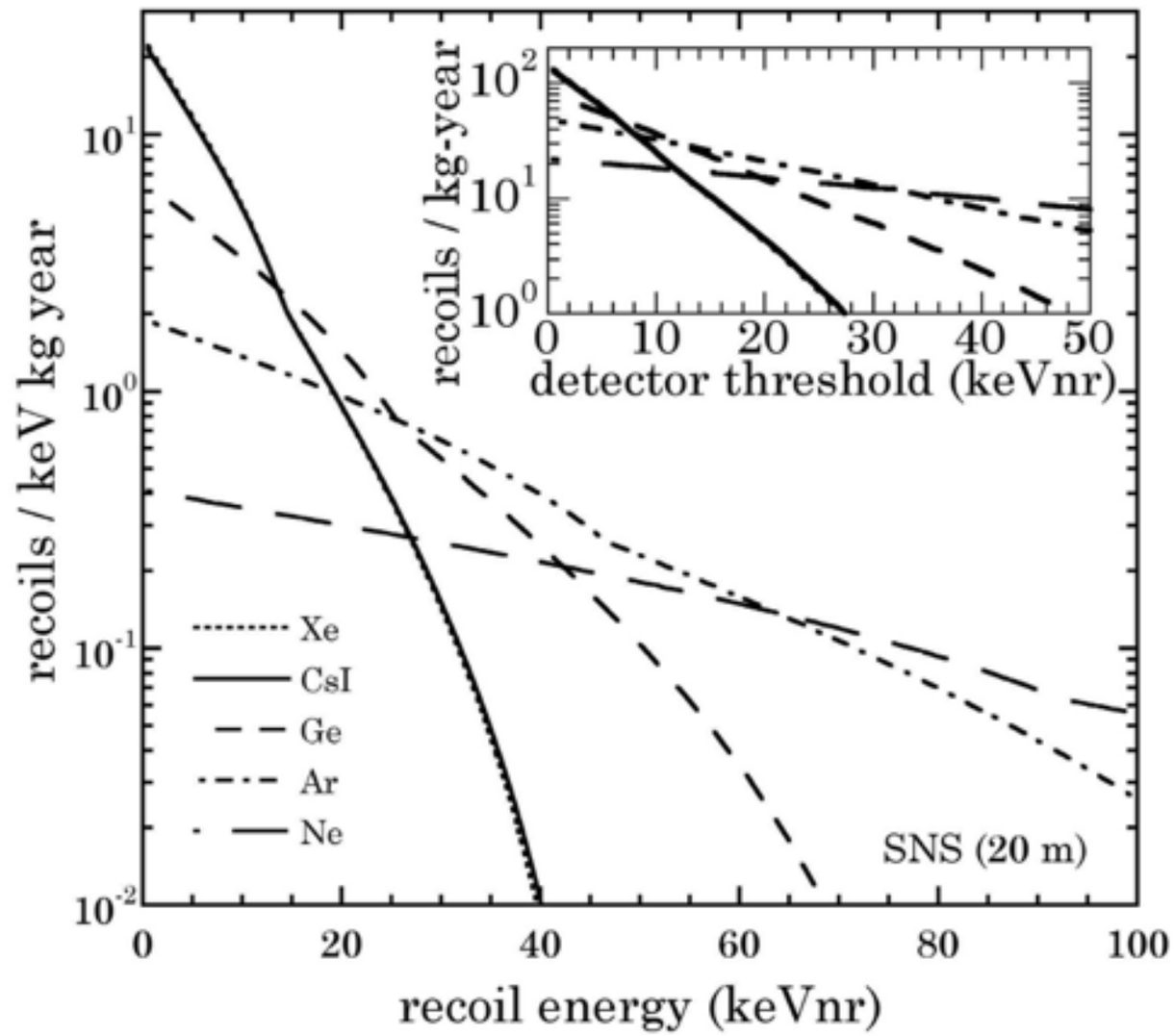
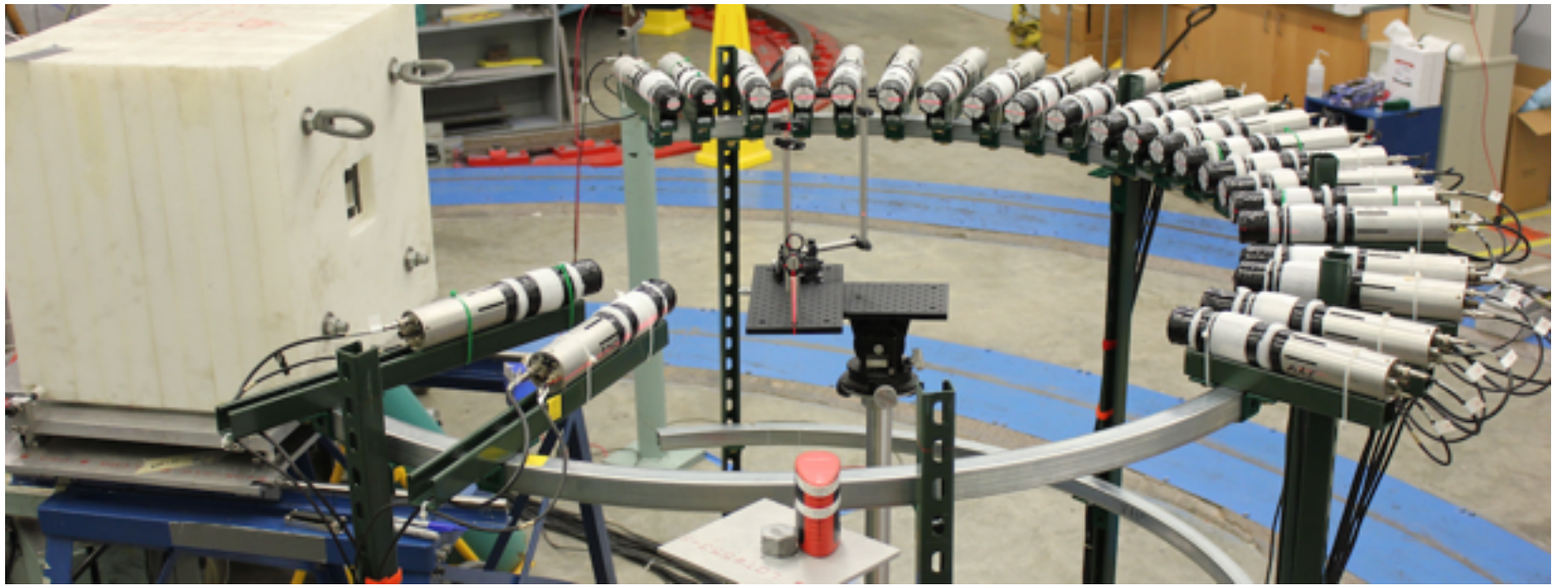
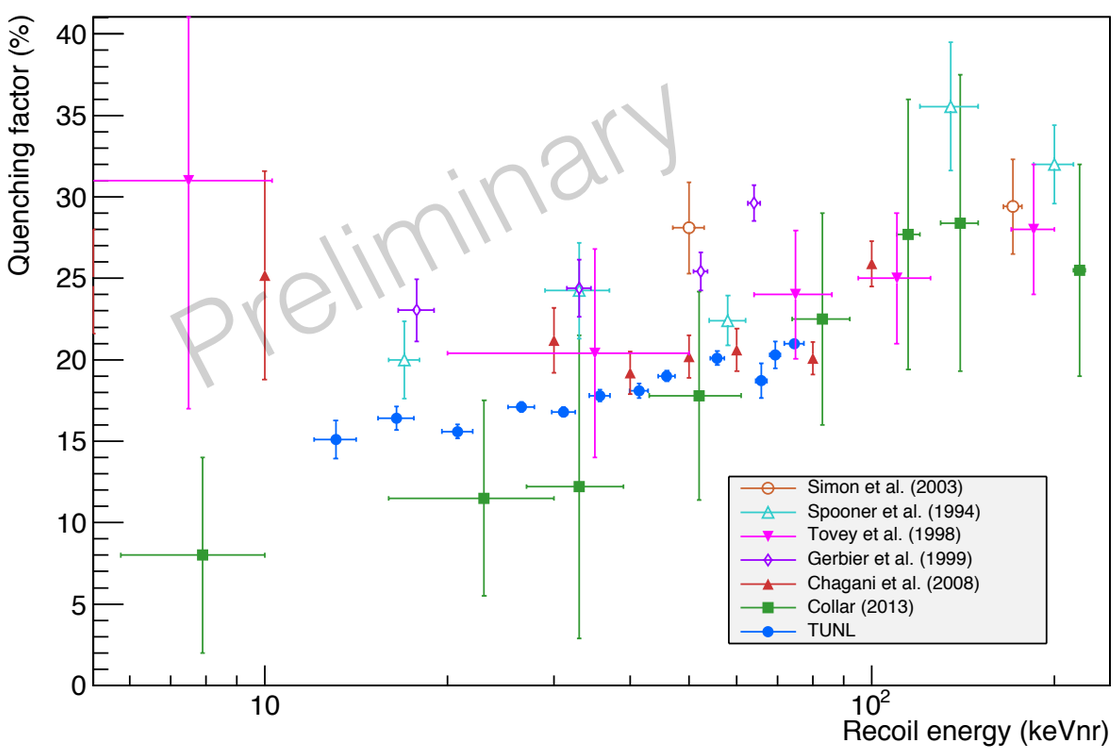


Figure from J.I. Collar *et al.*, arXiv:1407.7524 (2014)

COHERENT detector characterization

- Signals from CEvNS have very low amplitude, interpretation of collected data can be very dependent on understanding of detector response

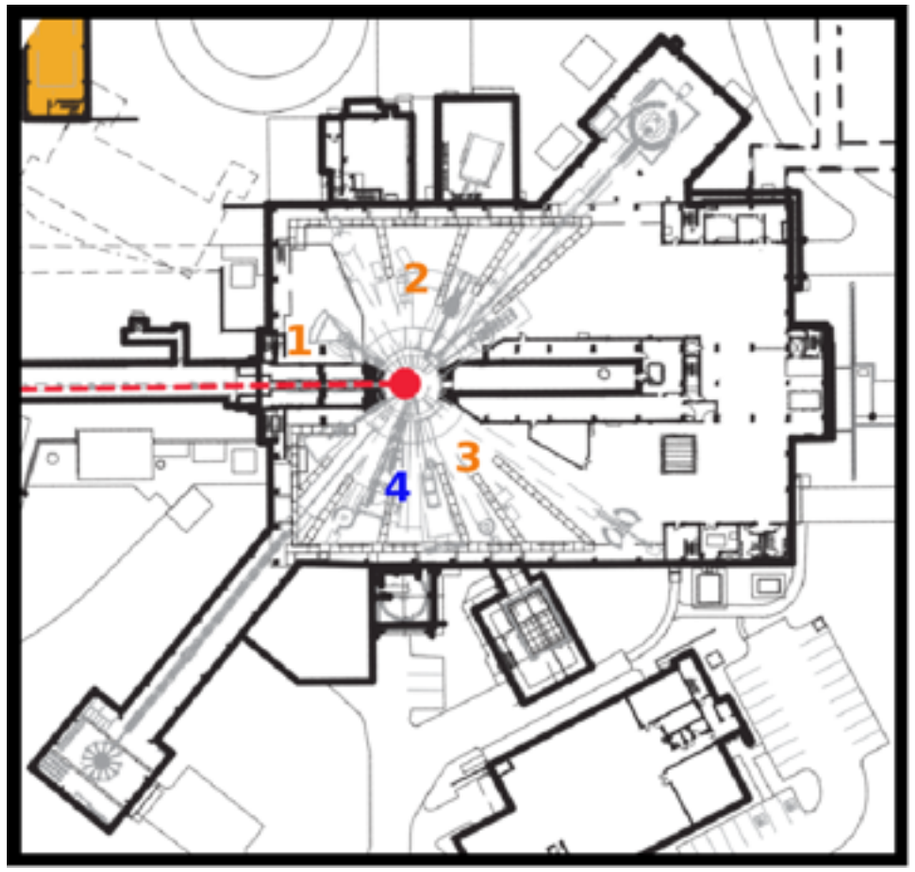




- At TUNL, a facility has been built for **precision measurements** of detector response to low-energy nuclear recoils
- A beam of quasi-monoenergetic neutrons is scattered off of detector, creating low-energy nuclear recoils; signals are measured and correlated with scatters into fixed angles
- First high-precision results for nuclear recoils in NaI(Tl) and CsI(Na) out soon

Siting and backgrounds at the SNS

- CEvNS-searches are subject to familiar backgrounds for other rare-event searches
- Additional, site-specific backgrounds must also be understood and considered
- *Following talk by Jason Newby discusses the continuing campaign of background measurements at various SNS locations*



- Focus for first stages of COHERENT has landed on basement location with overburden and near target
- **A somewhat atypical background became a concern..**

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)
- For CsI(Na) geometry, sited in the SNS basement location, *NINs represent **the** dominant background for a CEvNS measurement*

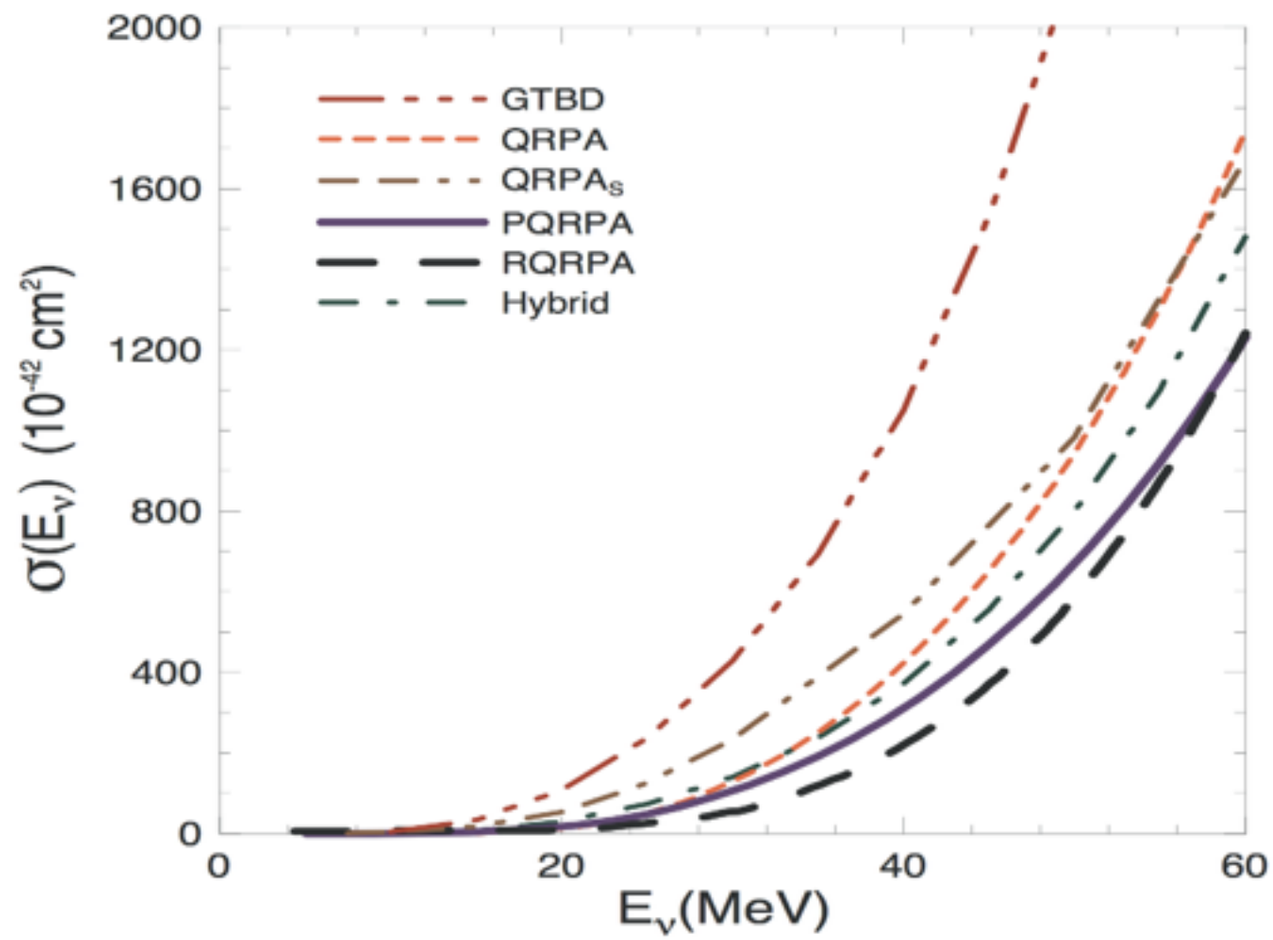


Figure from A.R. Samana and C.A. Bertulani, Phys. Rev. C (2008)

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]

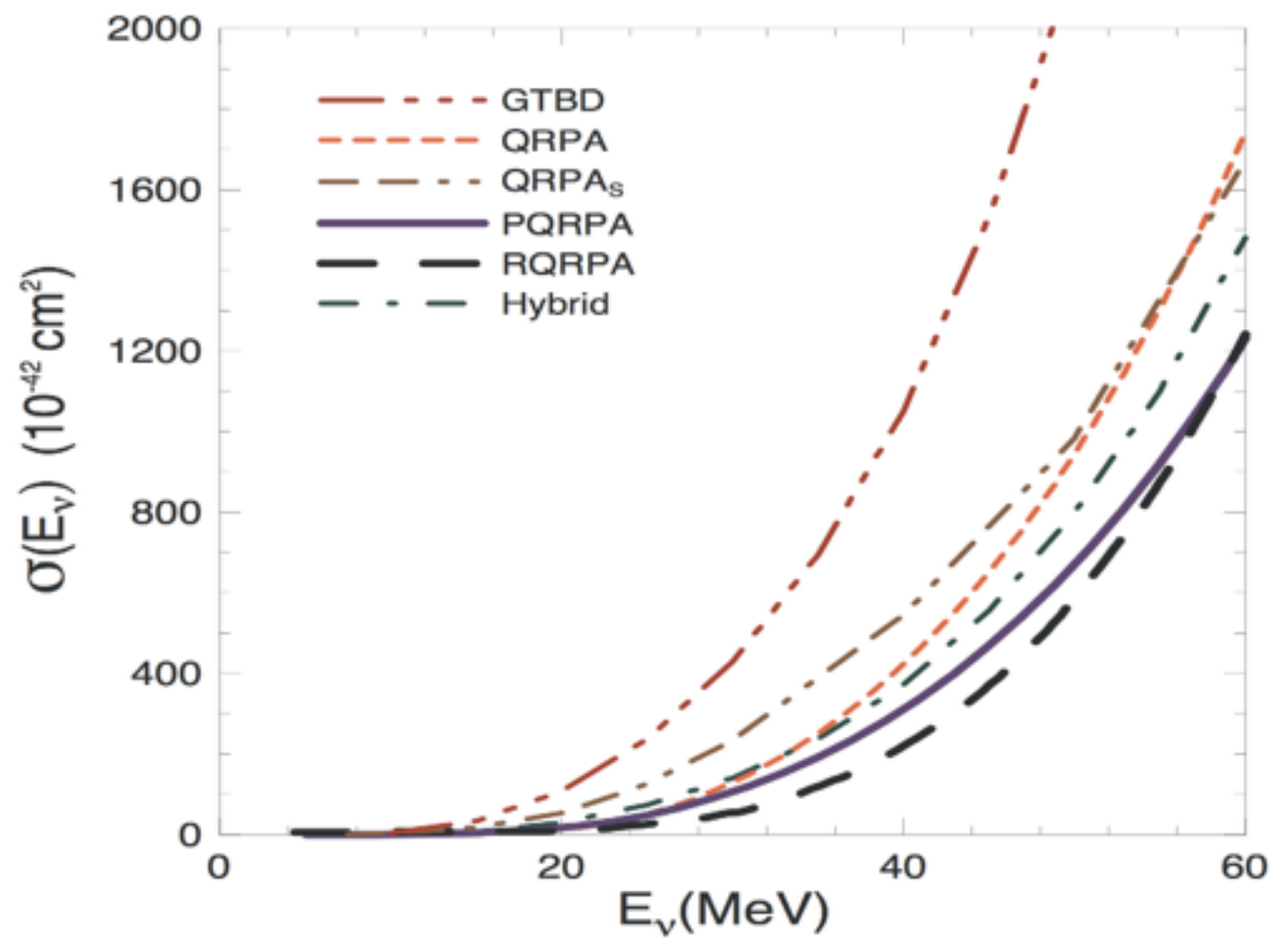
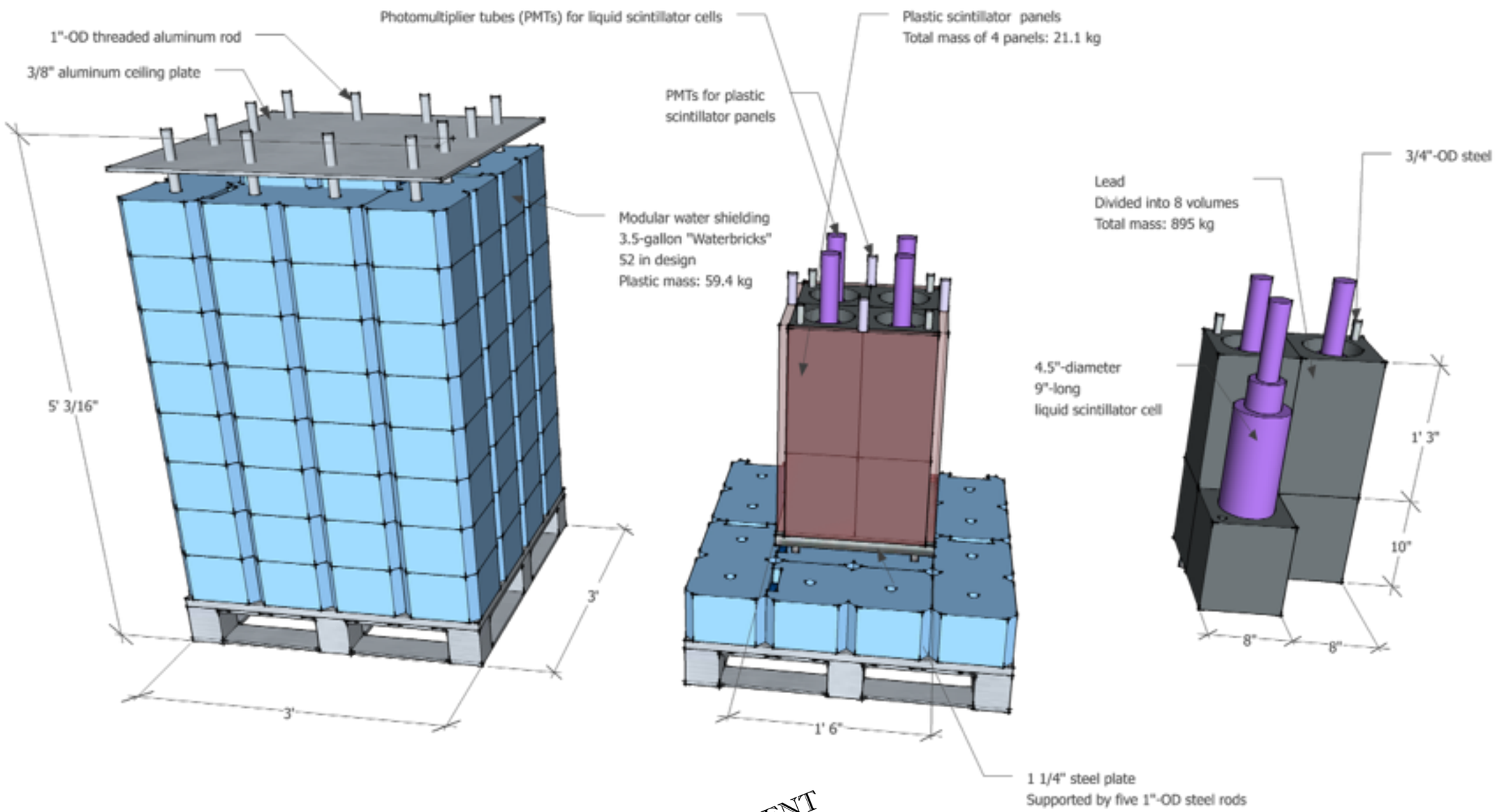


Figure from A.R. Samana and C.A. Bertulani, Phys. Rev. C (2008)

[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

- NIN cross section measurements can be made with dedicated “neutrino cubes”: palletized assemblies which can easily be or loaded with different target materials
- Expect ~2 NIN event detections per day @ 20 m from SNS target with ~800-kg Pb target



COHERENT deployment at SNS

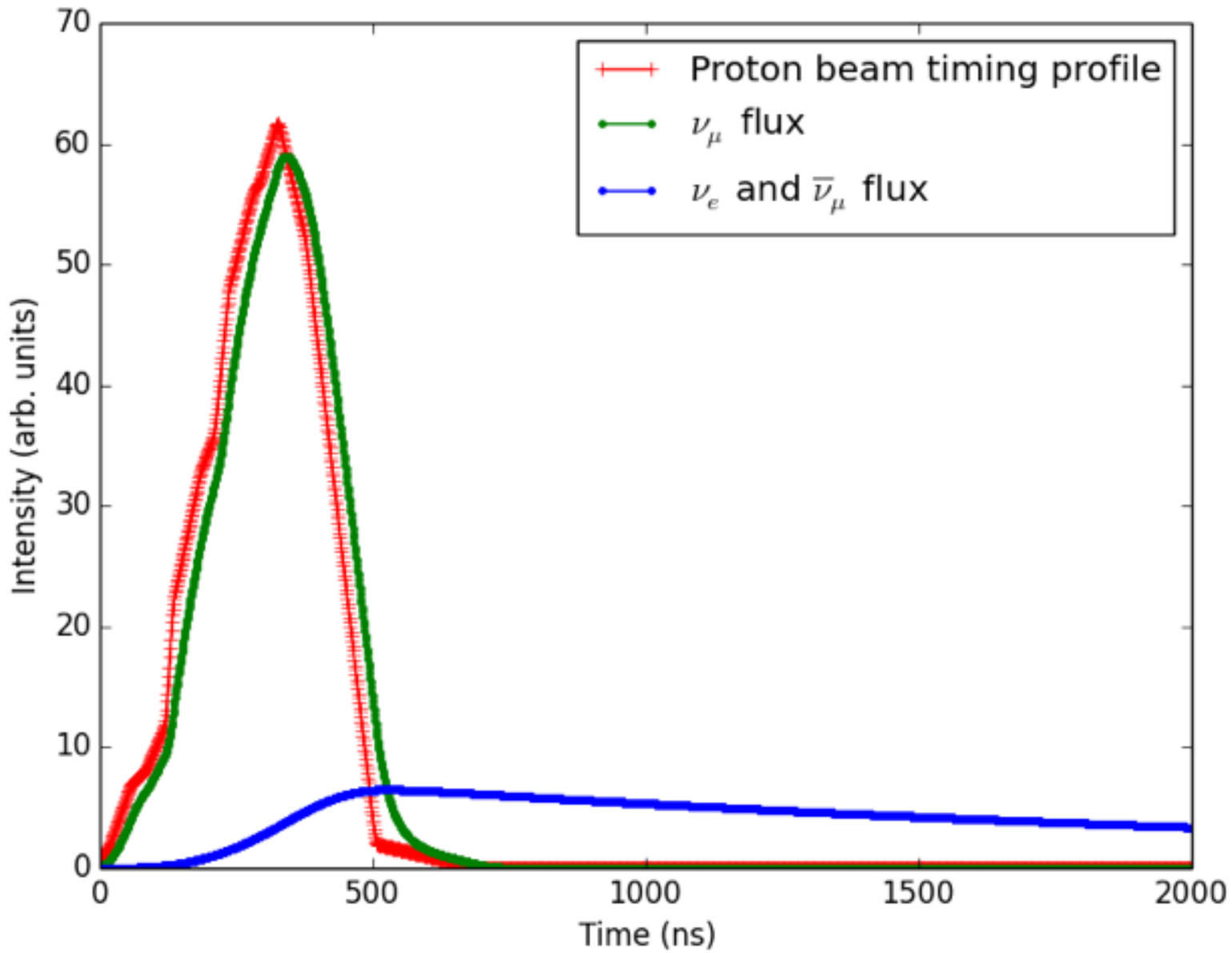
Deployment of neutrino cubes and CsI(Na) shielding assembly took place mid-September 2014. Located in basement, ~20 m from target, with ~8 m.w.e. overburden

- CsI(Na)-detector cavity occupied by liquid scintillator cells for *in situ* background measurement
  - Following background assessment, **CsI(Na) crystal can be installed and CEvNS data can be taken**
- **Neutrino physics events will begin to come in as soon as SNS maintenance is complete**
- NIN results will help inform design of shielding for other technologies ultimately employed by COHERENT for CEvNS measurements

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

Backup

SNS proton beam timing distribution



- Proton-beam timing distribution modeled after data from J. Galambos

Other stopped-pion neutrino sources

Facility	Location	Proton Energy (GeV)	Power (MW)	Bunch Structure	Rate	Target
LANSCE	USA (LANL)	0.8	0.056	600 μs	120 Hz	Various
ISIS	UK (RAL)	0.8	0.16	2×200 ns	50 Hz	Water-cooled tantalum
BNB	USA (FNAL)	8	0.032	1.6 μs	5-11 Hz	Beryllium
SNS	USA (ORNL)	1.3	1	700 ns	60 Hz	Mercury
MLF	Japan (J-PARC)	3	1	$2 \times$ 60-100 ns	25 Hz	Mercury
ESS	Sweden (planned)	1.3	5	2 ms	17 Hz	Mercury
DAEδALUS	TBD (planned)	0.7	$\sim 7 \times 1$	100 ms	2 Hz	Mercury

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