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COHERENT at the Spallation Neutron Source

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on behalf of the COHERENT Collaboration

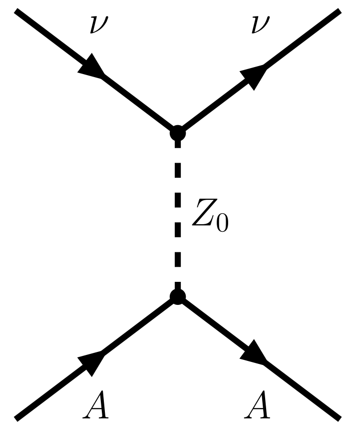
CEνNS (pronounced sevens)

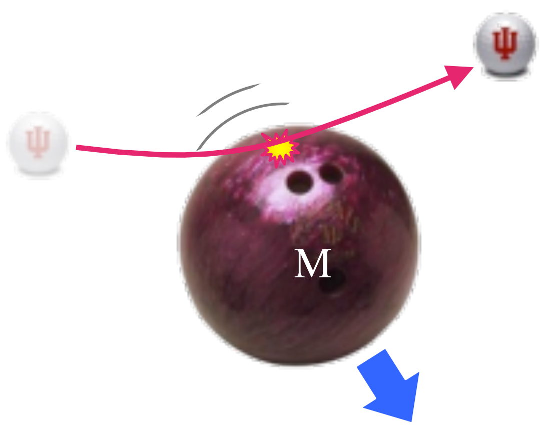
- Coherent Elastic Neutrino Nucleus Scattering
- Flavor blind Neutral Current process that scatters the entire nucleus as a whole
- To probe a "large" nucleus (few × 10^{-15} m)

$$E_\nu \lesssim \frac{hc}{R_N} \cong 50 \text{ MeV}$$

- Recoiling nucleus is detection signature

$$E_r^{\max} \simeq \frac{2E_\nu^2}{M} \simeq 50 \text{ keV}$$





PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

Coherent effects of a weak neutral current

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(Received 15 October 1973; revised manuscript received 19 November 1973)

Structure CEνNS Signal

- Standard Model Prediction

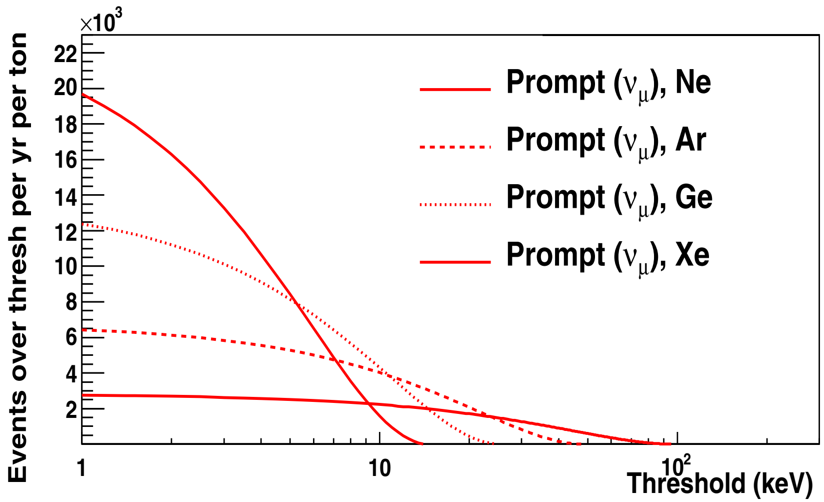
$$\frac{d\sigma}{dE} = \frac{G_F^2}{4\pi}\left[\left(1 - 4\sin^2\theta_w\right)Z - N\right]^2 M\left(1 - \frac{ME}{2E_\nu^2}\right) F(Q^2)^2$$

≈ 0 → protons have small effect

square of sum → part of coherence condition

nuclear form factor → distribution of neutrons

Detection Rate [ton^{-1} year^{-1}][1]

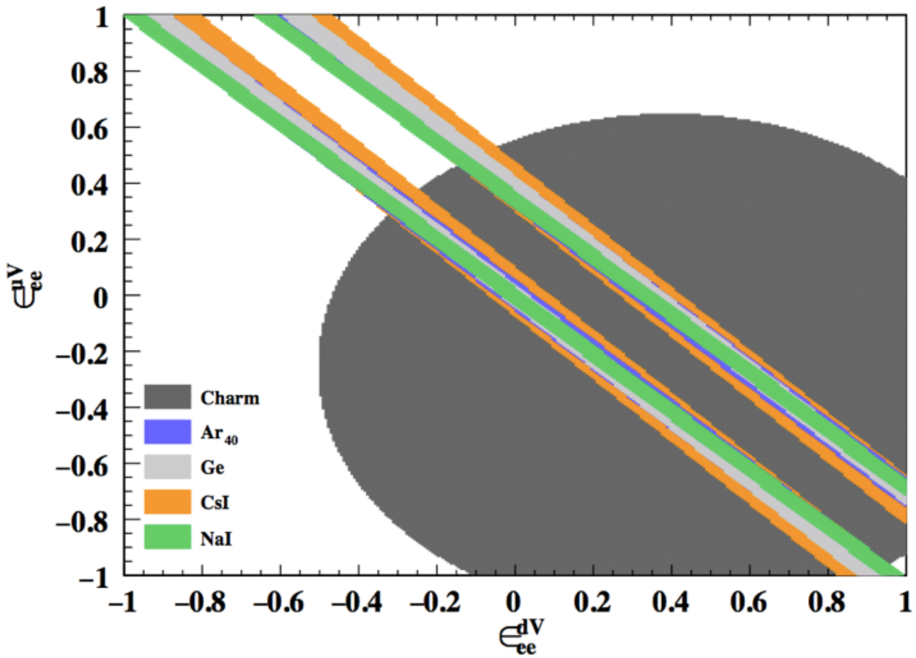


- Recoil energy (M^{-1}) and rate (N^2)

[1] K. Scholberg, *Phys. Rev.* **D73** (2006) 033005. arXiv:hep-ex/0511042.

Physics Motivations for CEνNS

- Non-Standard Interactions
- Multiple targets can greatly improve CHARM experiment limits on NSI
- Meaningful limits can be set with first generation experiments
- NSI may have significant influence in DUNE CP-violation search[1]



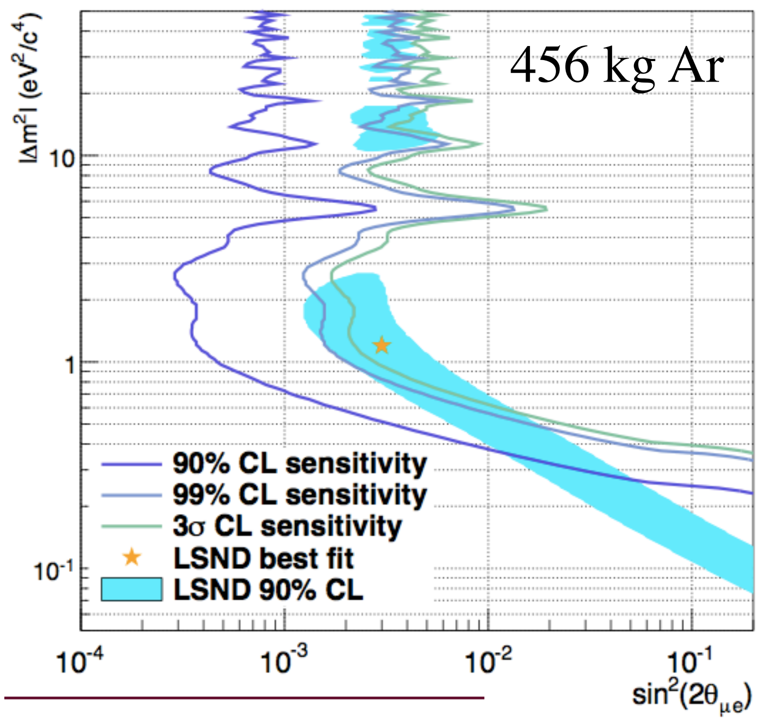
$$\mathcal{L}_{\nu H}^{NSI} = -\frac{G_F}{\sqrt{2}} \sum_{\substack{q=u,d \\ \alpha,\beta=e,\mu,\tau}} [\bar{\nu}_\alpha \gamma^\mu (1-\gamma^5)\nu_\beta] \times (\varepsilon_{\alpha\beta}^{qL}[\bar{q}\gamma_\mu(1-\gamma^5)q] + \varepsilon_{\alpha\beta}^{qR}[\bar{q}\gamma_\mu(1+\gamma^5)q])$$

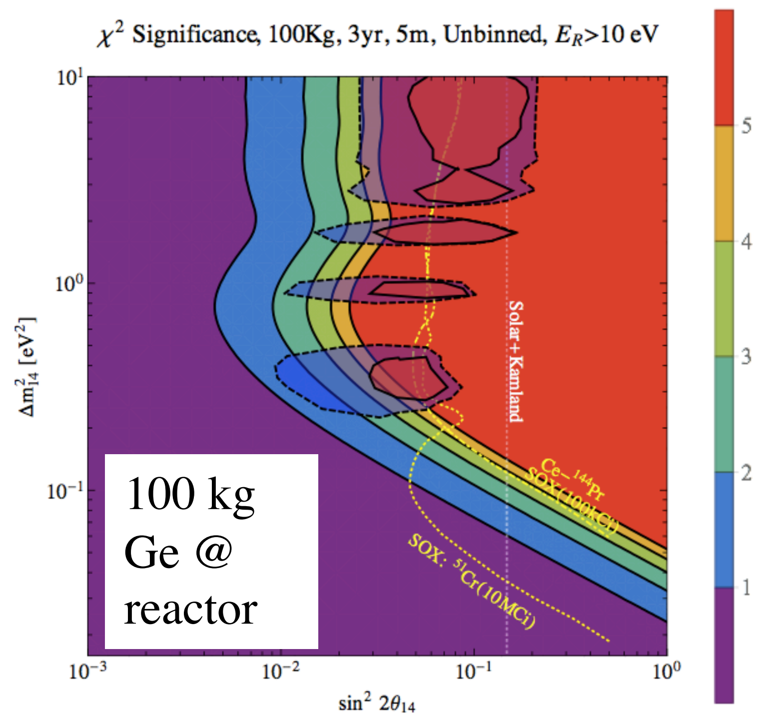
(Plot) K. Scholberg, *Phys. Rev.* **D73** (2006) 033005. arXiv:hep-ex/0511042.

[1]M. Masud, A. Chatterjee, P. Mehta, arXiv:1510.08261 [hep-ph].

Physics Motivations for CEνNS

- Neutrino oscillations can use NC, flavor-blind CEνNS interaction to look for *L/E* shape distortions and disappearance

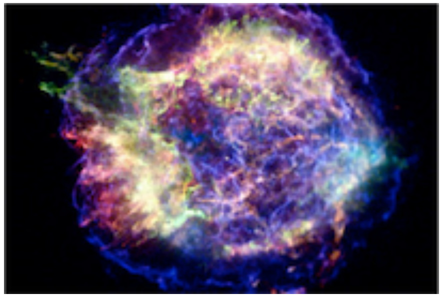


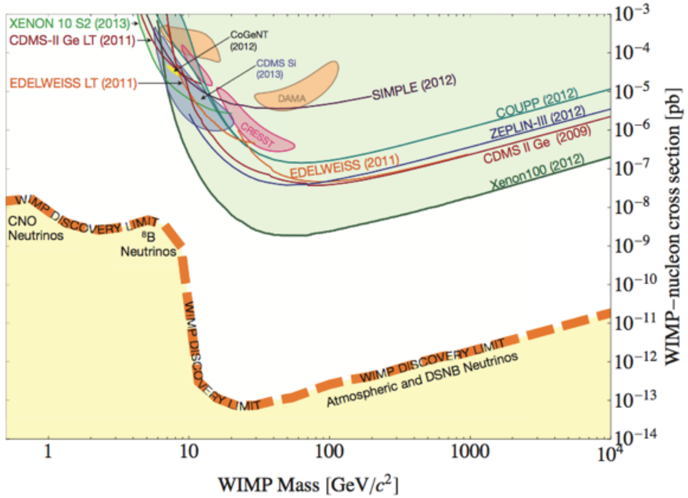


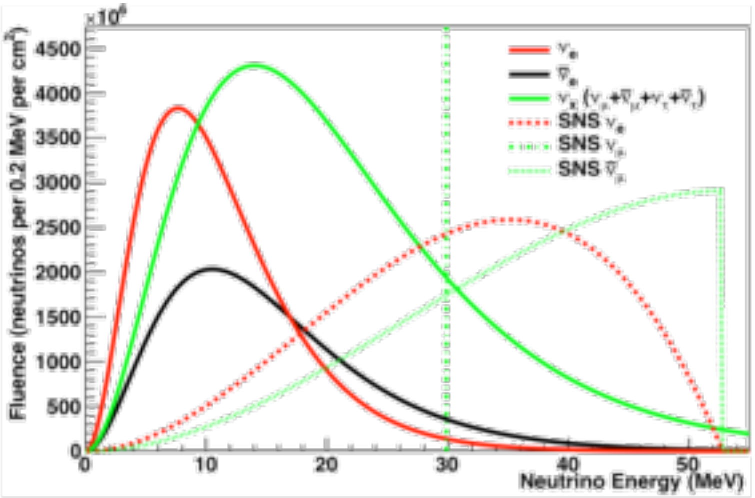
(Left Plot) A.J. Anderson et al., *Phys. Rev.* **D86** (2012) 013004. arXiv:1201.3805 [hep-ph].
(Right Plot) J. Dutta et al., arXiv:1511.02834 [hep-ph].

Physics Motivations for CEνNS

- CEνNS is irreducible background for deep underground WIMP Dark Matter searches
- Supernova cross sections (or direct detection) via CEνNS



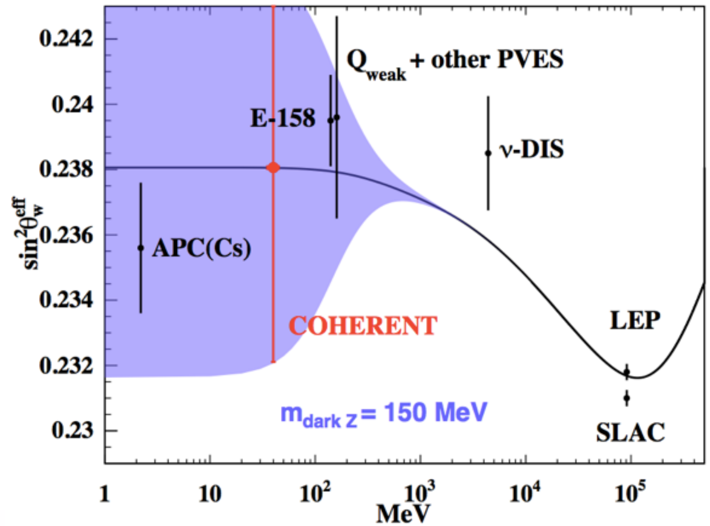


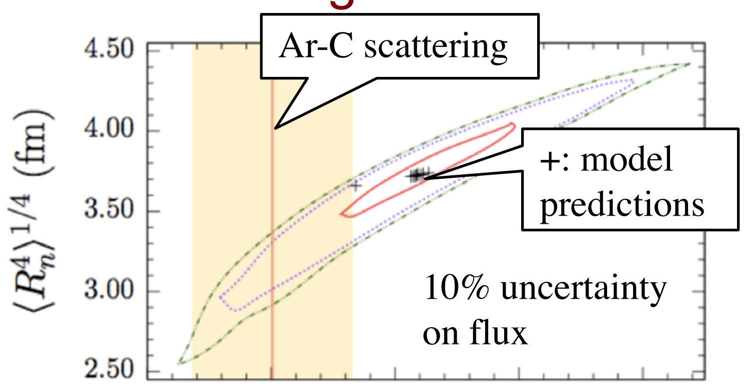


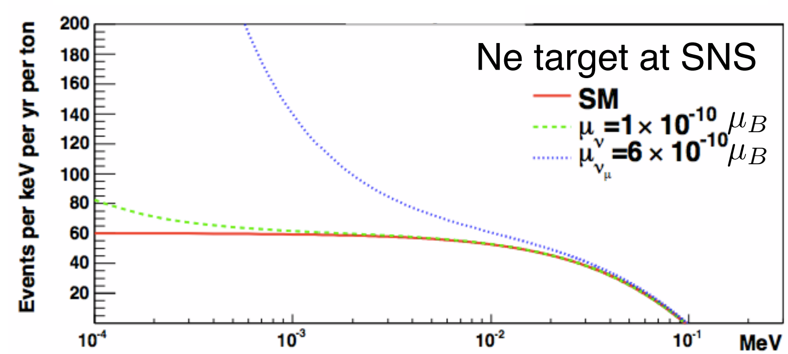
(Left Plot) J. Billard, E. Figueroa-Feliciano, L. Strigari. arXiv:1307.5458 [hep-ph].
(Right Plot) K. Scholberg, *Phys. Rev.* **D73** (2006) 033005. arXiv:hep-ex/0511042.
[1]A. Drukier and L. Stodolsky, *Phys. Rev.* **D30** (1984) 2295.

More Physics Motivations for CEνNS

- Method to measure $\sin^2 \theta_W$
- Neutrino magnetic moment distorts recoil spectrum
- Low-mass Dark Matter searches
- Nuclear physics form factors
- Nuclear safeguards







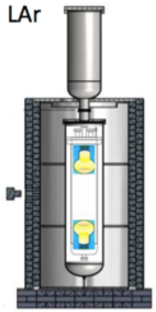
(Bottom-Left Plot) K. Patton et al., *Phys. Rev.* **C86** (2012) 024612 arXiv:1207.0693 [nucl-th].
(Bottom-Right Plot) Horowitz et al, *Phys. Rev.* **D86** (2012) 013004. arXiv:1201.3805 [hep-ph].

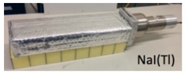
Physics Goals for COHERENT

- Measure N^2 dependence across multiple targets
- Deploy detectors in low-neutron-background basement area
- Measure relevant neutrino-induced neutrons and quenching factors

Nuclear Target	Technology	Mass (kg)	Distance from source (m)	Recoil threshold (keVnr)	Data-taking start date; CEνNS detection goal
CsI[Na]	Scintillating Crystal	14	20	6.5	9/2015; 3σ in 2 yr
Ge	HPGe PPC	10	22	5	Fall 2016
LAr	Single-phase scintillation	35	29	20	Fall 2016
NaI[Tl]	Scintillating crystal	185* /2000	28	13	*high-threshold deployment started July 2016







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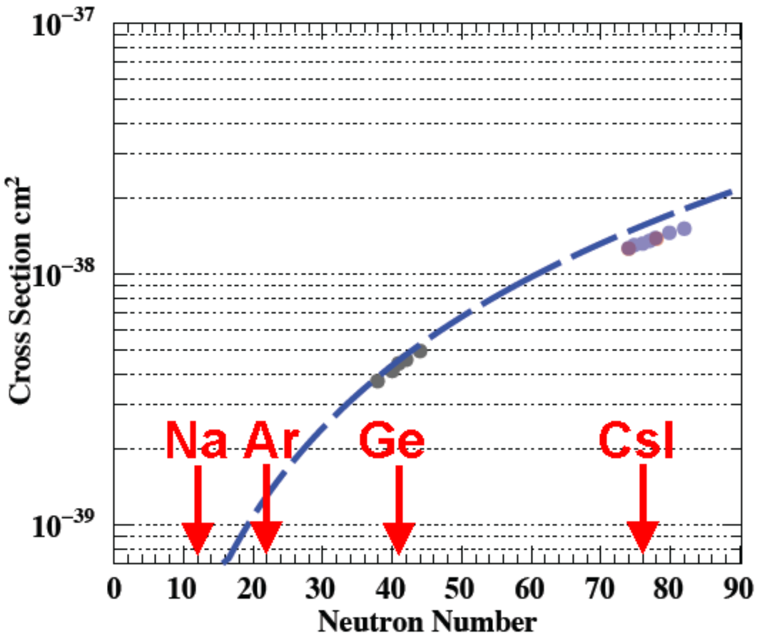

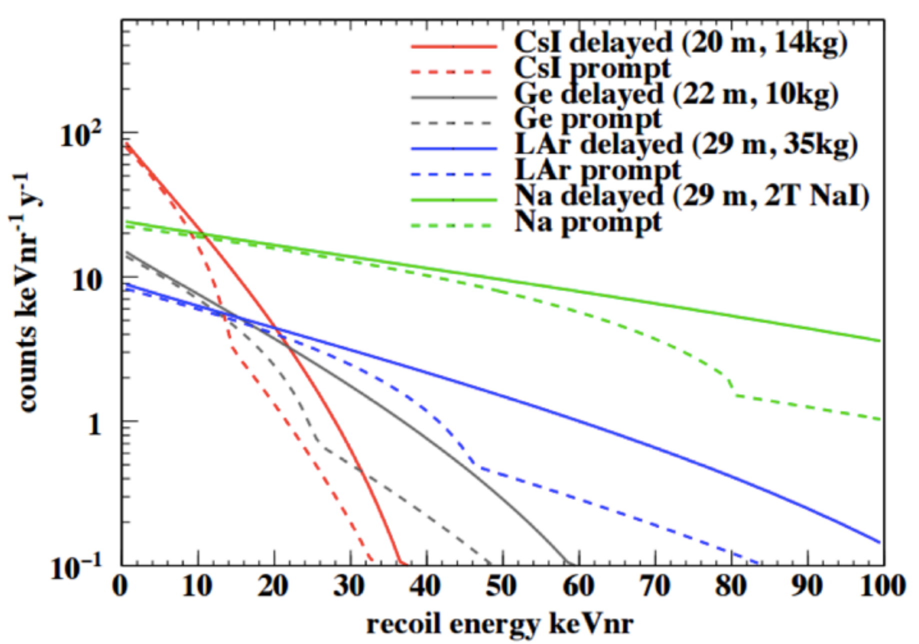

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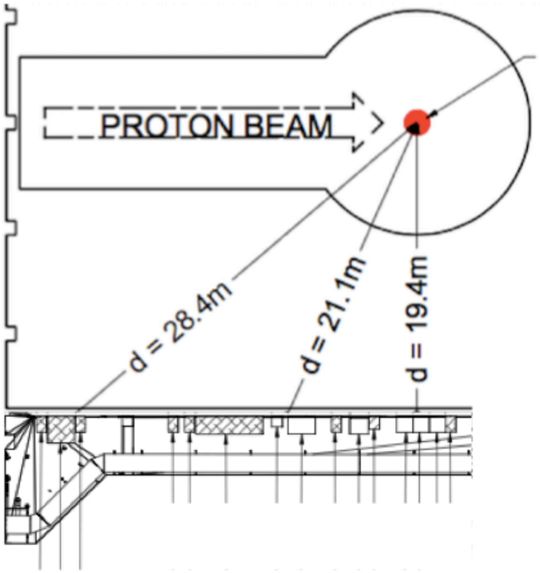
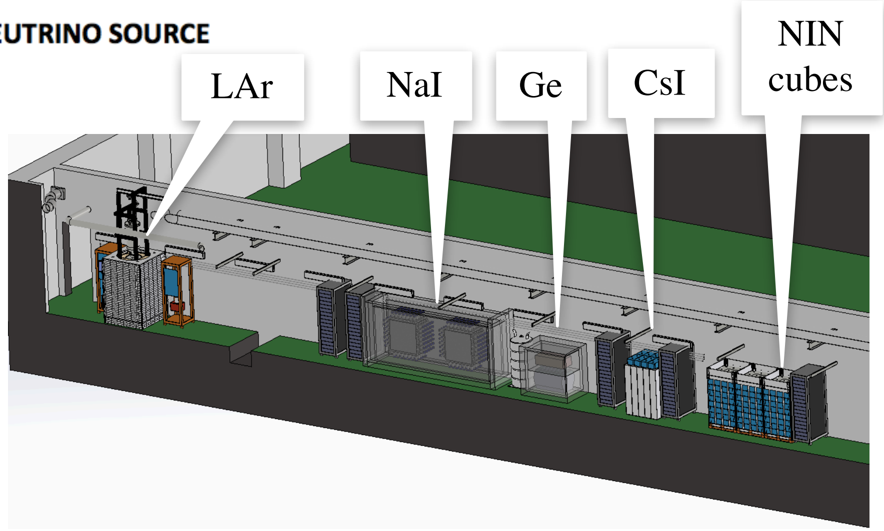
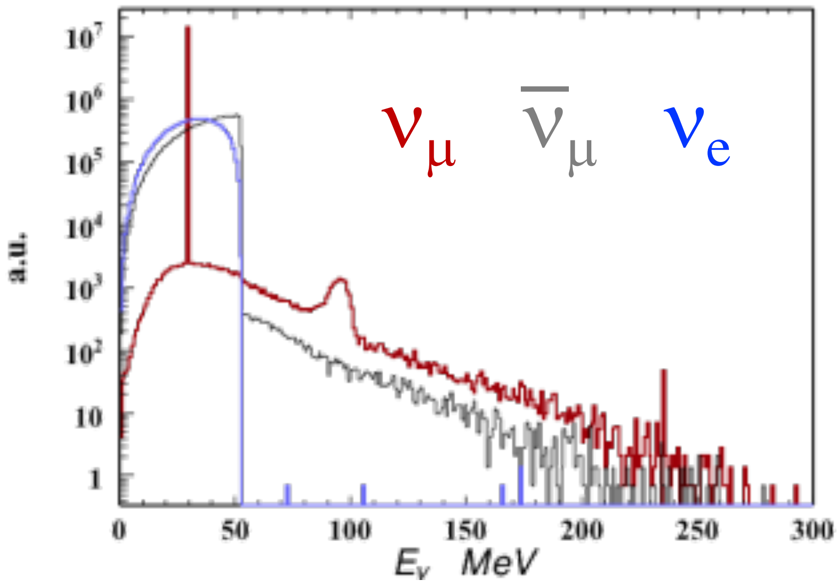




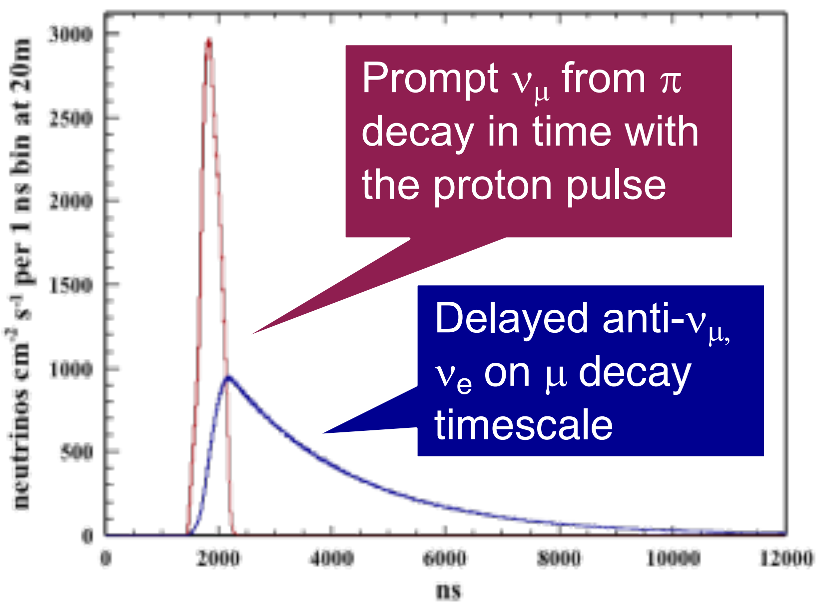
Neutrino Production at the SNS

- 0.9-1.3 GeV protons on liquid mercury target produces π^+
- Total power: 0.9–1.4 MW

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$
$$\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e$$

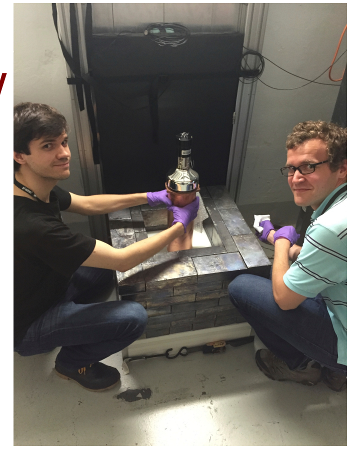


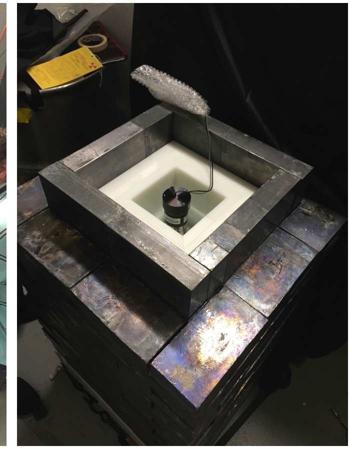
- Pulsed at 60 Hz for ~400 ns → few × 10^{-4} duty (steady-state background reduction)
- 43×10^6 ν/cm^2/s 20 m at SNS maximum power (1.4 MW)

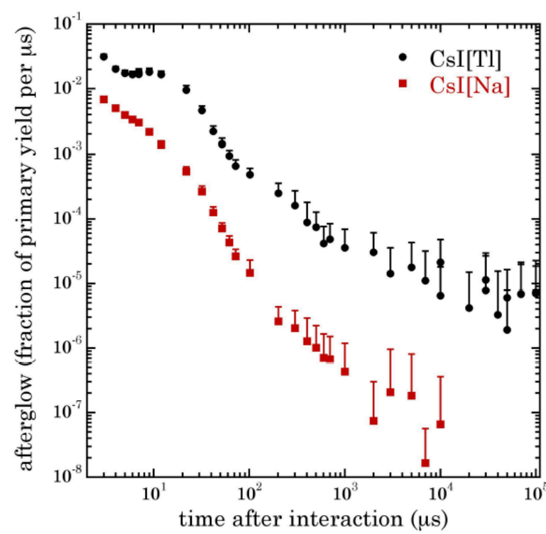


Detector Subsystems: CsI[Na]

- Na doping reduces afterglow seen in common Tl doping
  - Tl doping insufficient for near-surface experiment
- Cs and I surround Xe in periodic table, very similar nuclear recoil response
- Statistical nuclear-/electron-recoil separation
- Quenching factors measured → 5 keVnr is easily achieved



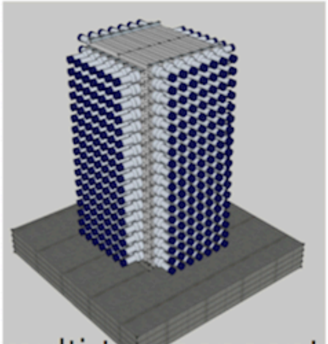




[1]J.I. Collar et al., *Nucl. Instrum. Meth.* **A773** (2014) 56.

Detector Subsystems: NaI[Tl]

- 185 kg prototype for initial deployment
- 2 ton next phase deployment
- Up to 9 tons available
- NC CEνNS interaction
- Also CC interaction with ν_e
- https://twitter.com/NaIvE_SNS



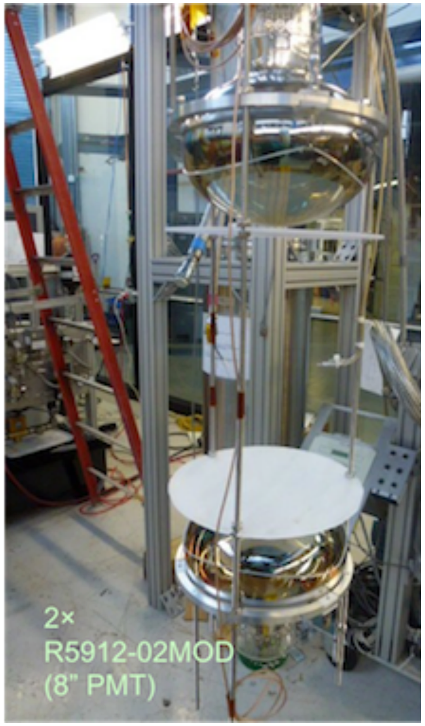
multi-ton concept

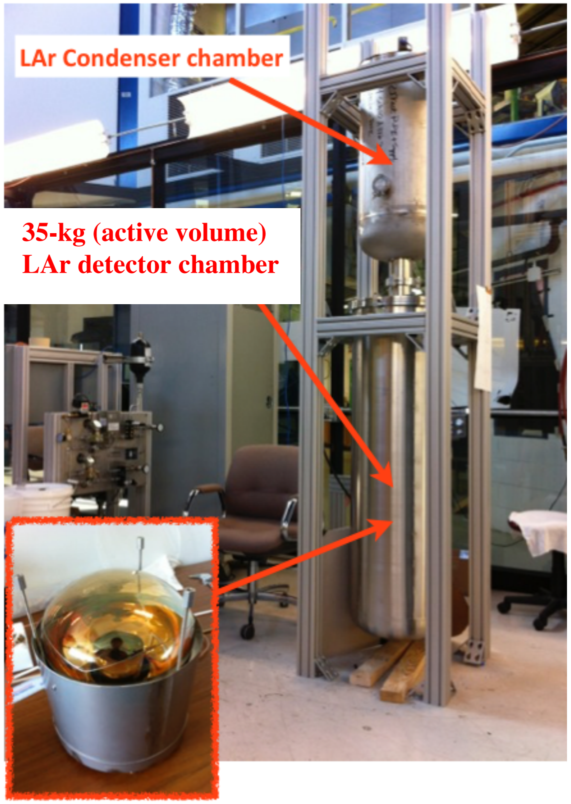
^{56}Fe	^{56}Fe$(\nu_e, e^-)^{56}$Co	Stopped π/μ	KARMEN	256 ± 108(stat) ± 43(sys)	264 [Shell] (Kolbe *et al.*, 1999a)
^{71}Ga	^{71}Ga$(\nu_e, e^-)^{71}$Ge	^{51}Cr source	GALLEX, ave.	0.0054 ± 0.0009(tot)	0.0058 [Shell] (Haxton, 1998)
		^{51}Cr	SAGE	0.0055 ± 0.0007(tot)	
		^{37}Ar source	SAGE	0.0055 ± 0.0006(tot)	0.0070 [Shell] (Bahcall, 1997)
^{127}I	^{127}I$(\nu_e, e^-)^{127}$Xe	Stopped π/μ	LSND	284 ± 91(stat) ± 25(sys)	210-310 [Quasi-particle] (Engel *et al.*, 1994)

[1] J.A. Formaggio and G. Zeller, *Rev. Mod. Phys.* **84** (2012) 1307.

Detector Subsystems: Liquid Argon

- Single-phase, scintillation only
- 35-kg fiducial volume
- Readout is 2 × Hamamatsu R5912-02MOD PMT (8" cryogenic, high-gain)
- Excellent nuclear-/electron-recoil PSD demonstrated by miniCLEAN
- SCENE has measured quenching factors[1]
- ^{39}Ar controllable with PSD and duty factor

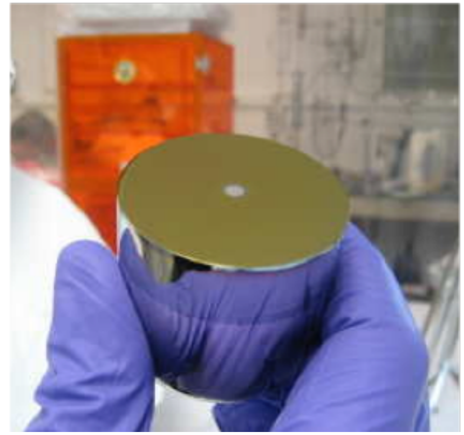


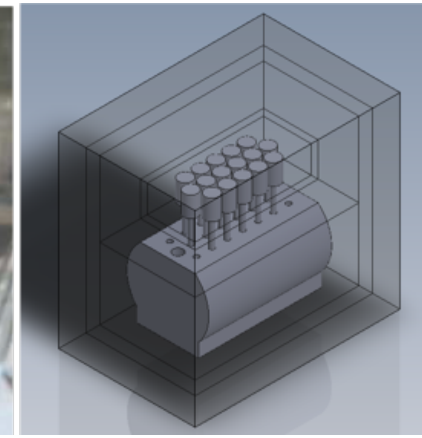


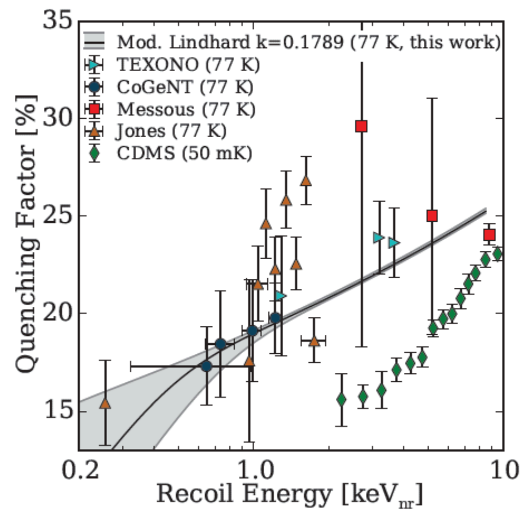
[1]H. Cao et al., SCENE Collaboration, *Phys. Rev.* **D91** (2015) 092007. arXiv:1406.4825 [physics.ins-det].

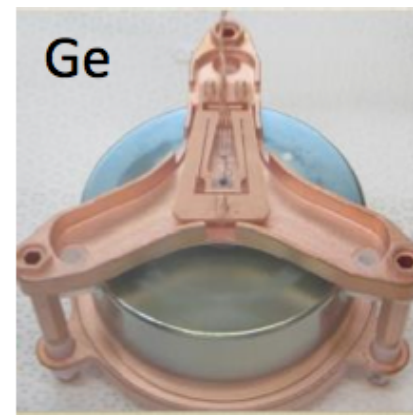
Detector Subsystems: Germanium

- HPGe PPC type that have excellent low-energy resolution and low threshold
- Repurposing of Majorana Demonstrator and LANL ^{nat}Ge detectors
- First phase is 5-10 kg of existing BeGe detectors in a copper, lead, and polyethylene shielding system
- Second phase could add more detector mass with larger (C4-style) detectors
- Quenching factors well known



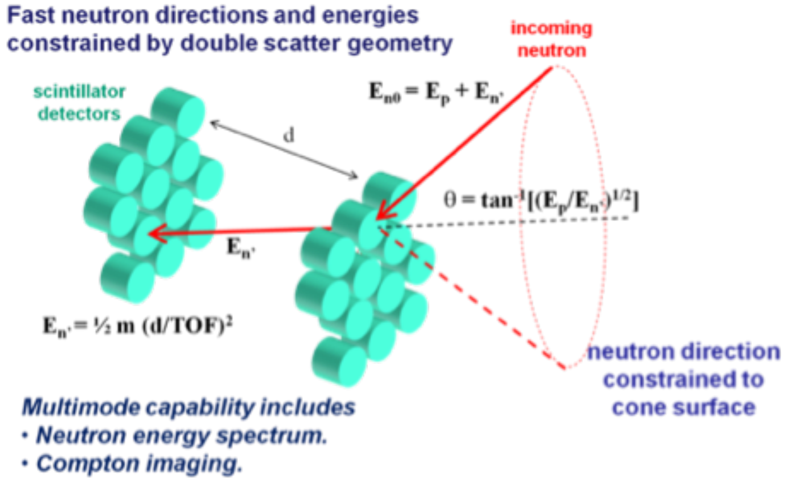


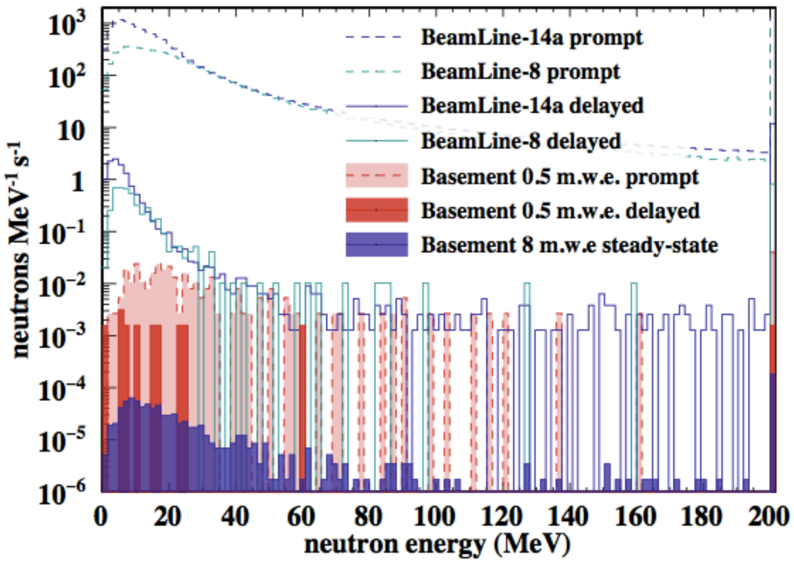




Neutron Backgrounds: Sandia NSC

- Sandia Neutron Scatter Camera
- Neutron imager from neutron double scatter
- Measured neutrons across SNS complex
- Basement is very neutron quiet

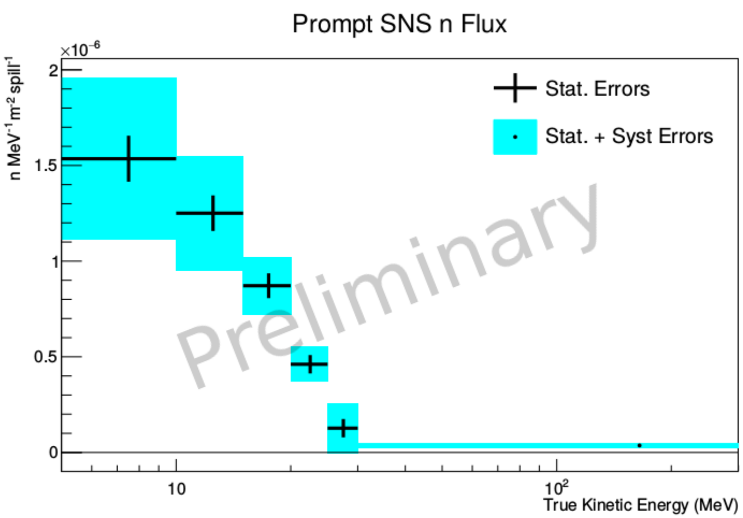


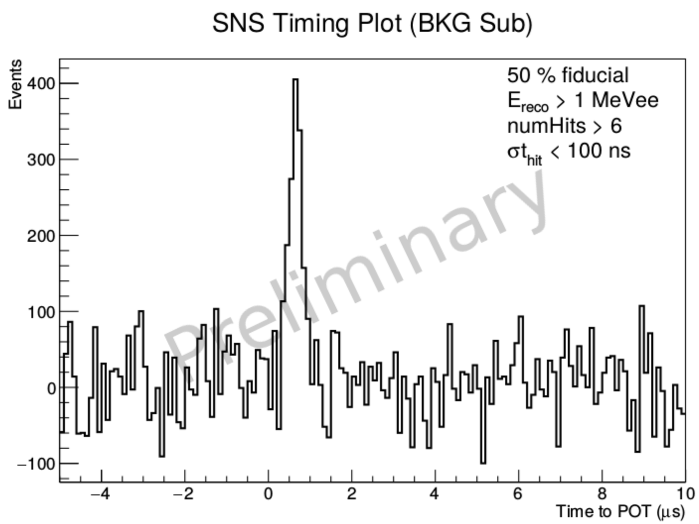


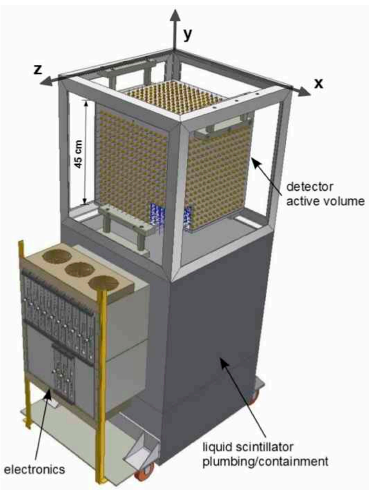
[1]N. Mascarenhas et al., *IEEE Trans. Nucl. Sci.* **56** (20109) 1269.

Neutron Backgrounds: SciBath

- 80 L volume of liquid scintillator read out by 768 wavelength shifting fiber → high-energy event topology
- Measured at LAr site in SNS Neutrino Alley
- Low-energy neutrons prompt observed, delayed neutrons not observed and a delayed neutron rate limit is being set



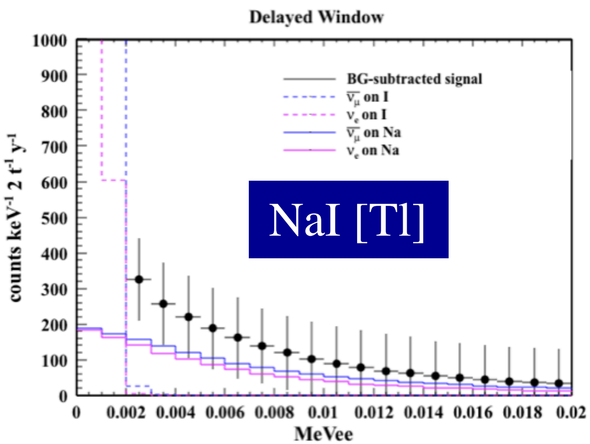


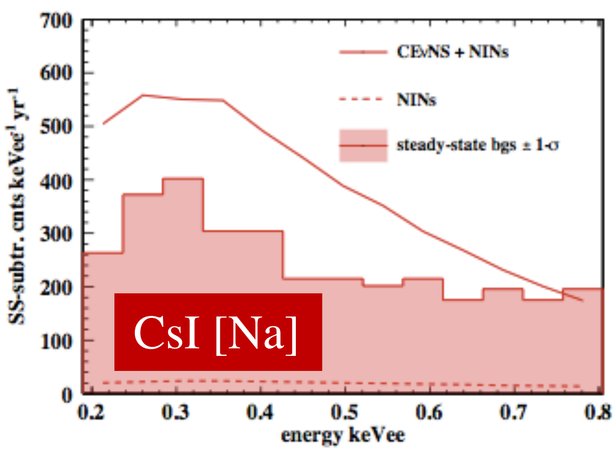


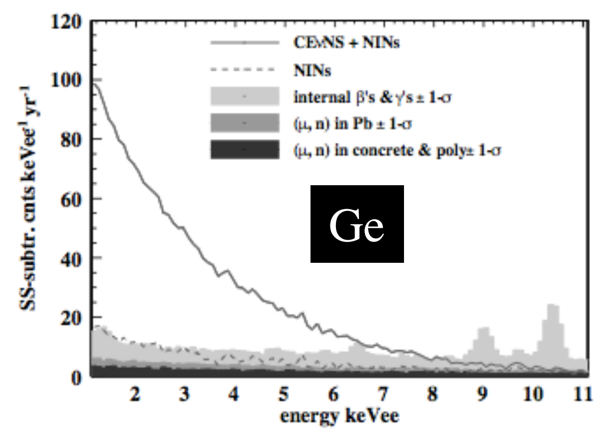
[1]R. Tayloe, *Nucl. Instrum. Meth.* **A562** (2006) 198.

Conclusions

- COHERENT is deploying a suite of detector technologies in the neutron-quiet SNS basement
- First light measurement to test N^2 dependence
- Sensitivities shown below (LAr is being completed)
- LAr expects ~300/700 events on ~100/900 steady-state backgrounds in a year in prompt/delayed region



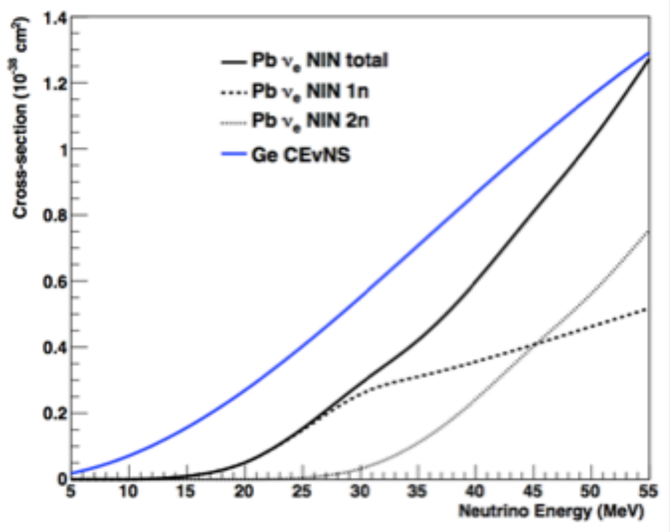


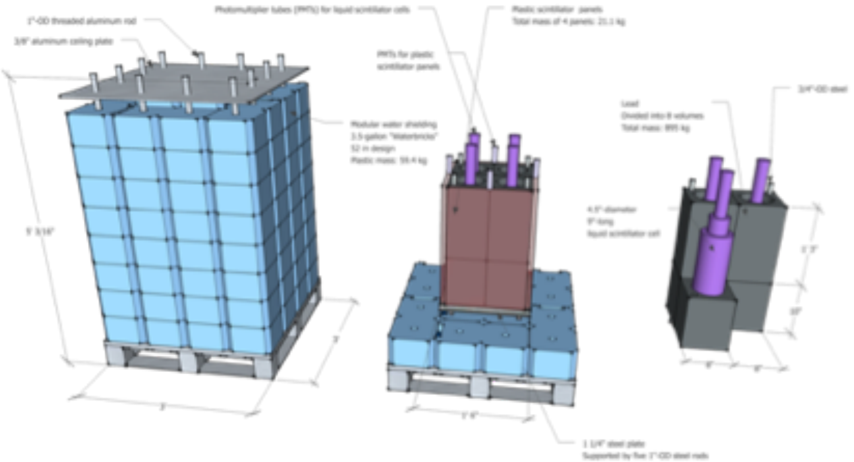


BACKUPS

Neutrino Induced Neutrons (NINs)

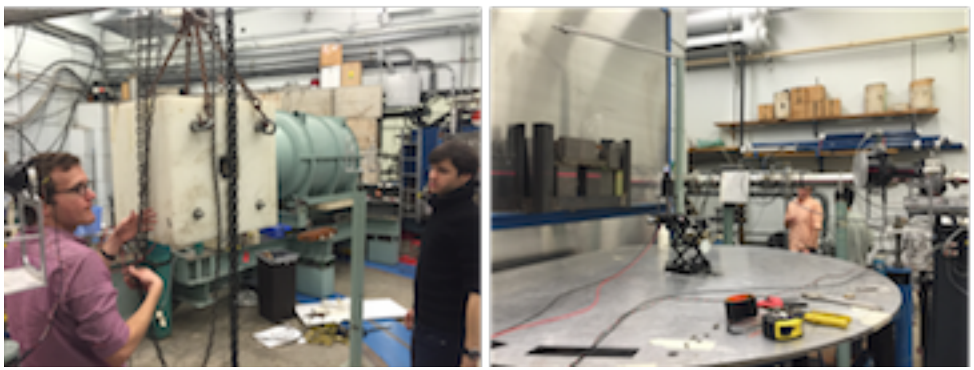
- Pb shielding interacts with ν_e and can break-up to 1 n or 2 n
- Shield can give CEνNS backgrounds
- "Neutrino Cubes" testing neutron production from Pb, Fe inside water shield
- https://twitter.com/theLeadNube



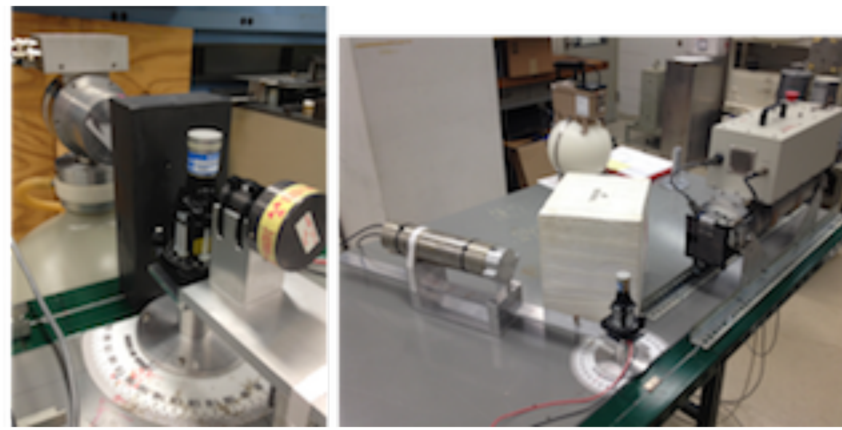


Quenching Measurements

- Chicago has used commercial D-D neutron generator
- Duke group at TUNL have created a tunable p-^{7}Li and D-D neutron sources to test low-energy nuclear recoils for quenching factor measurements



TUNL Setup



Chicago Setup