Detector Technologies for the COHERENT Experiment

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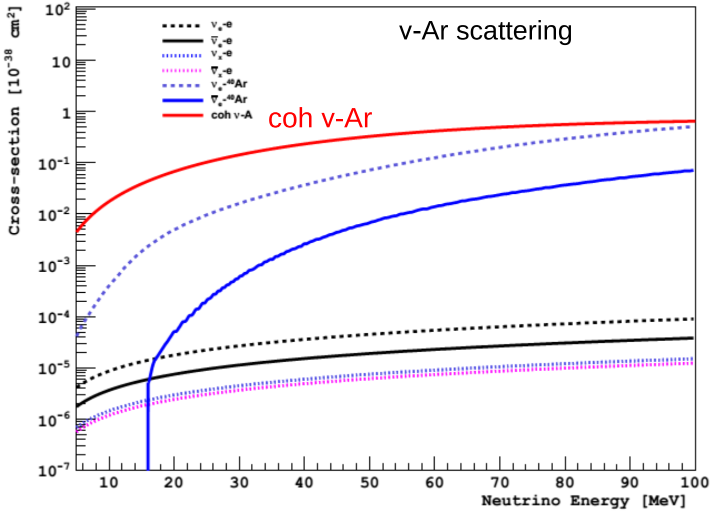
2017 APS April Meeting, Washington, D.C.
January 28, 2017

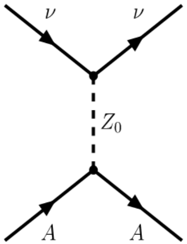
Coherent Elastic Neutrino Nucleus Scattering (CEvNS)

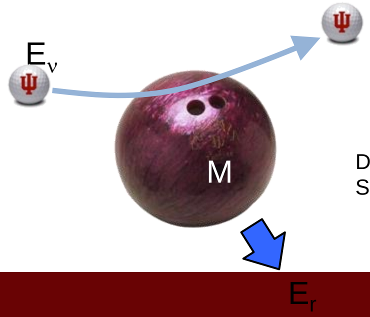
- Neutrino recoils coherently and elastically off entire nucleus via Z exchange
  - Coherent up to $E_\nu \lesssim \frac{hc}{R_N} \cong 50 \text{ MeV}$
- Predicted 41 years ago, yet to be observed
- Large predicted SM cross section with N^2 dependence

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

- So why not observed?
  - Low recoil energy $E_r^{\max} \simeq \frac{2E_\nu^2}{M} \simeq 50 \text{ keV}$
  - Detectors just now becoming sensitive to these recoil energies



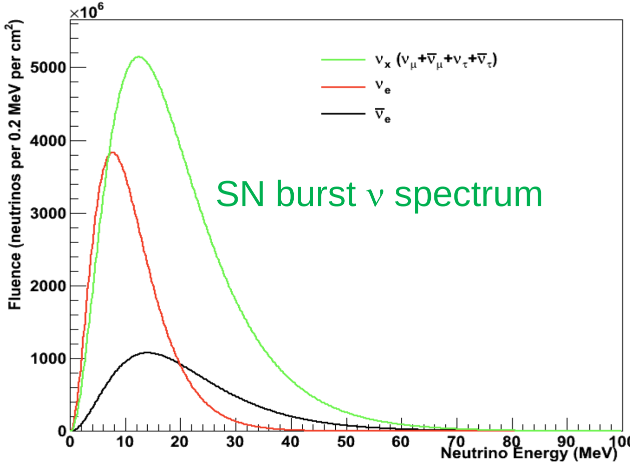


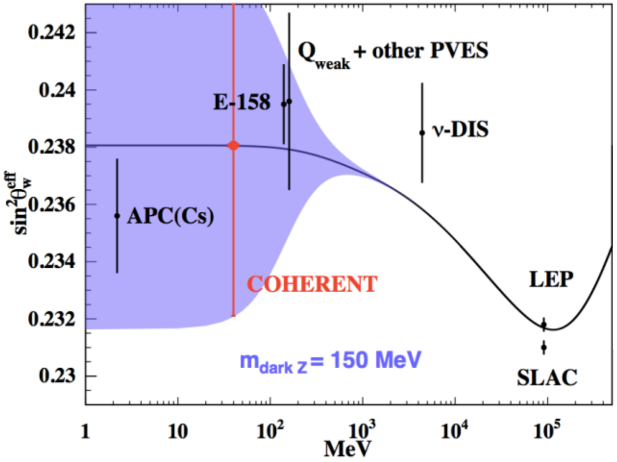


D.Z. Freedman. Phys. Rev. D9, 1389 (1974)
S.J. Brice et al. Phys. Rev. D 89, 072004 (2014)

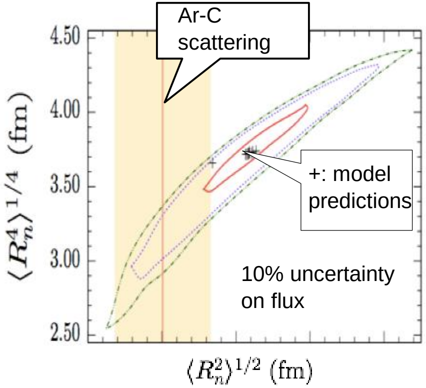
Accessible Physics with CEvNS Measurement

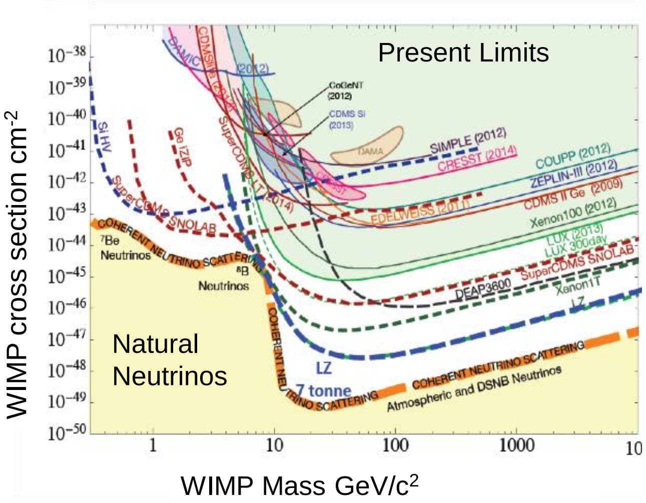
- Sensitive to supernova neutrinos from core-collapse SN, largest SN cross section
- Background for WIMP dark matter searches
- Standard Model tests
- Nuclear Form Factors
- Non-Standard Neutrino Interactions





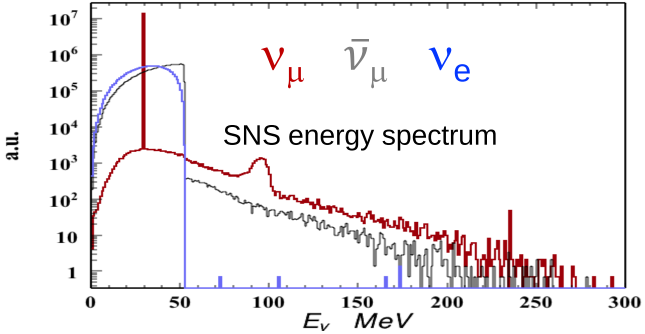
K. Patton et al., PRC86 (2012) 024612

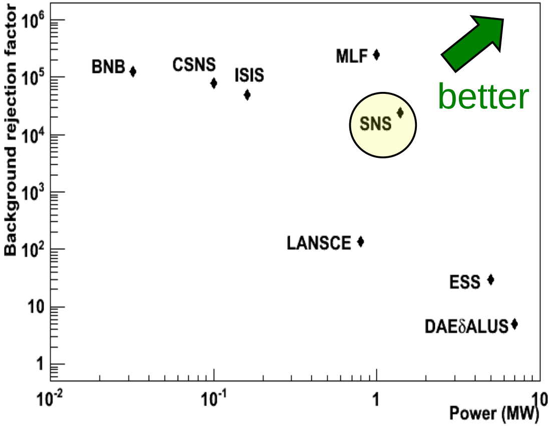


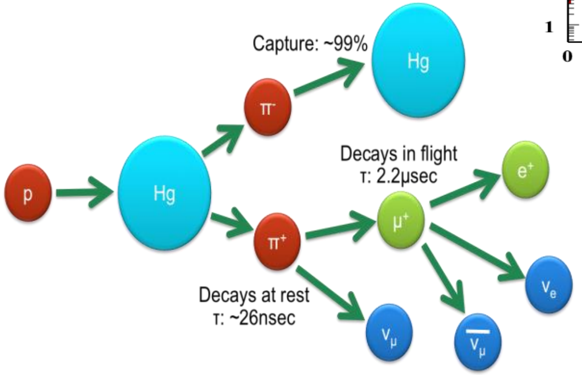


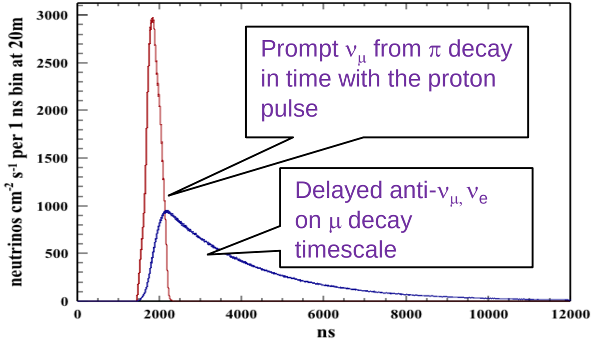
Neutrinos at the SNS

- High intensity, clean pulsed π-decay at rest neutrino source (10^7/cm^2/s at 20m)
- Ideal proton beam energy (0.9-1.3 GeV)
- Multiple neutrino flavors
- Pulsed 60 Hz timing structure
- Good background rejection of few x 10^{-4} due to pulsed structure of beam



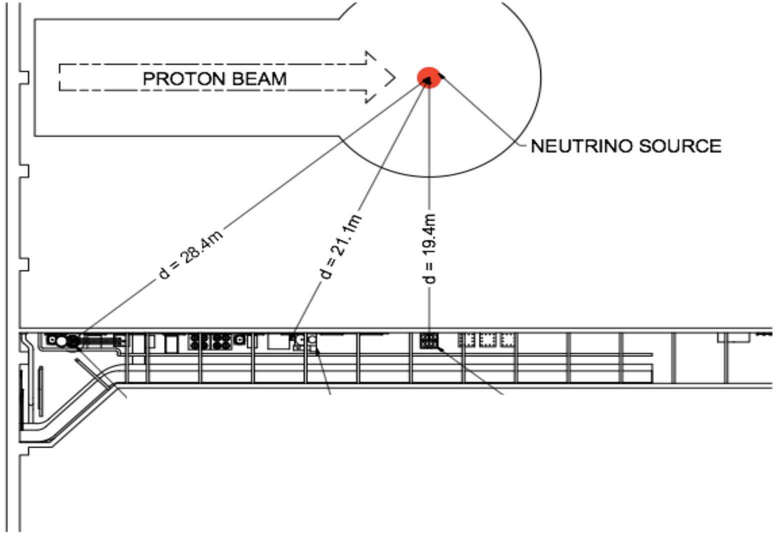


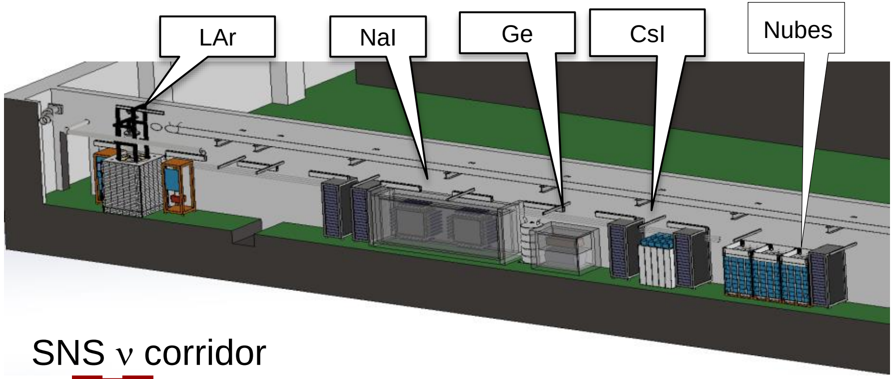




COHERENT at the SNS ("Neutrino Alley")

- Background measurements began in 2013 to determine lowest background feasible location at SNS for COHERENT
    - Location in SNS target building basement ("Neutrino Alley")
        - 20-29 m from source

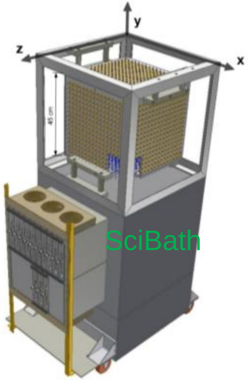


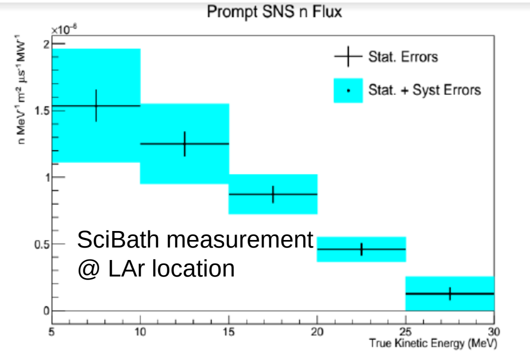


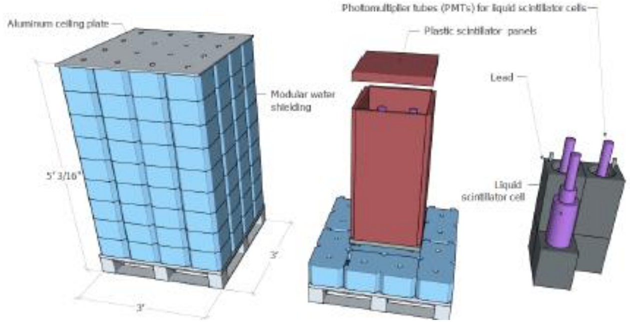
SNS ν corridor

COHERENT Background Measurements

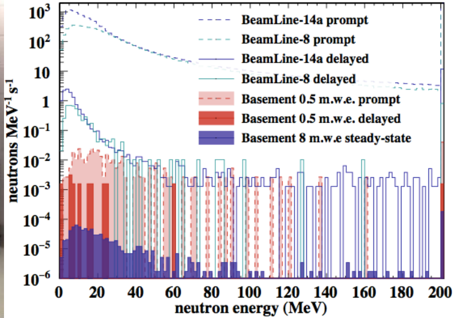
- Campaign to measure steady-state backgrounds and backgrounds related to the beam pulse
  - SciBath (Indiana Univ.) and Neutron Scatter Camera (Sandia) for beam related neutrons $\rightarrow$ basement neutron quiet
  - Ortec HPGe detector for environmental gammas from concrete and "hot off gas" pipe (source of 511 keV gammas)
  - "Neutrino Cubes (Nubes)" for Neutrino Induced Neutrons
    - Pb shielding interacts with ν_e and break up into 1 or 2 neutrons

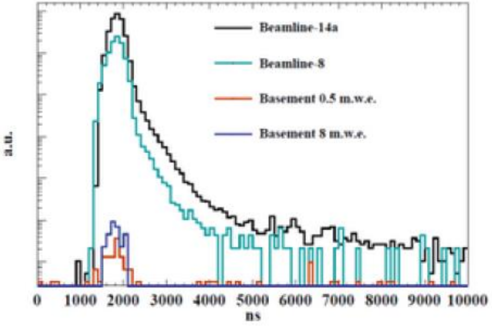


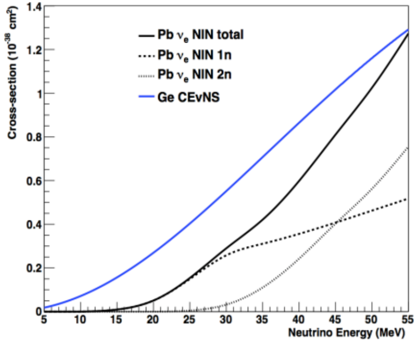




Neutron Scatter Camera results (various locations in SNS target building)

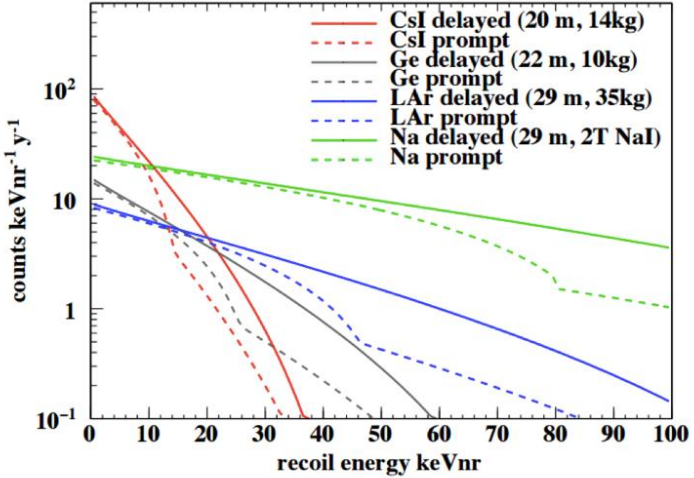




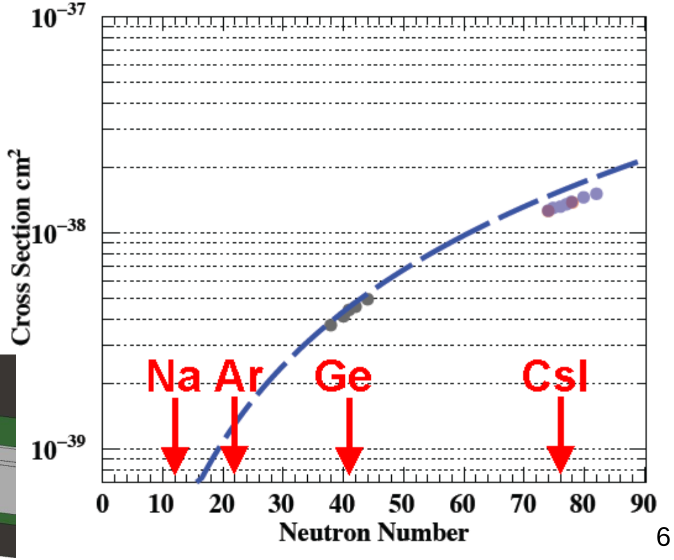


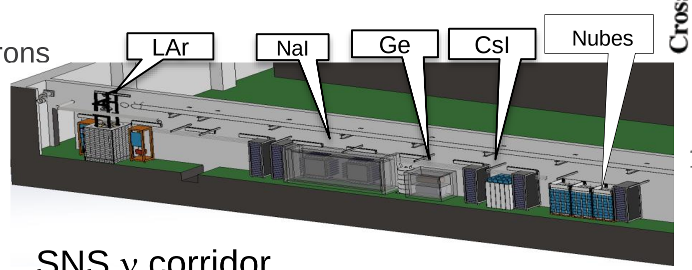
COHERENT Deployment Program

Nuclear Target	Technology	Mass (kg)	Target Distance (m)	Recoil threshold (keVr)	Data-taking start date; CEvNS detection goal
CsI[Na]	Scintillating Crystal	14	20	6.5	Sept. 2015; 3σ in 2 yr
Ge	HPGe PPC	10	22	5	Early 2017
LAr	Single-phase	35	29	20	Dec. 2016
NaI[Tl]	Scintillating crystal	185*/2000	28	13	*high-threshold deployment summer 2016



- Unambiguous detection of CEvNS via N^2 dependence of cross section in above targets
- 100's of events expected/year
- Must control backgrounds, have low thresholds, and understand quenching factors
- Also measure Neutrino Induced Neutrons (NINs) on Pb, Fe

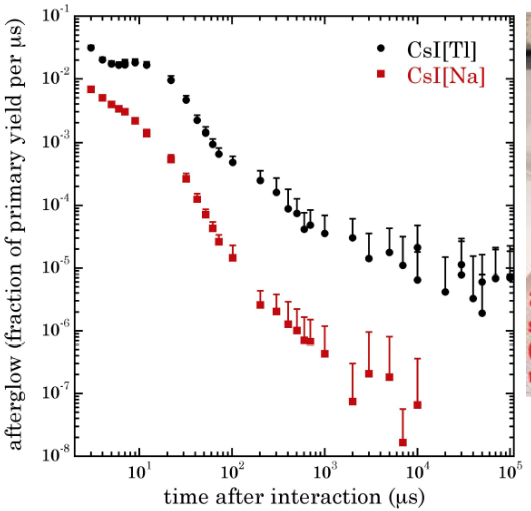


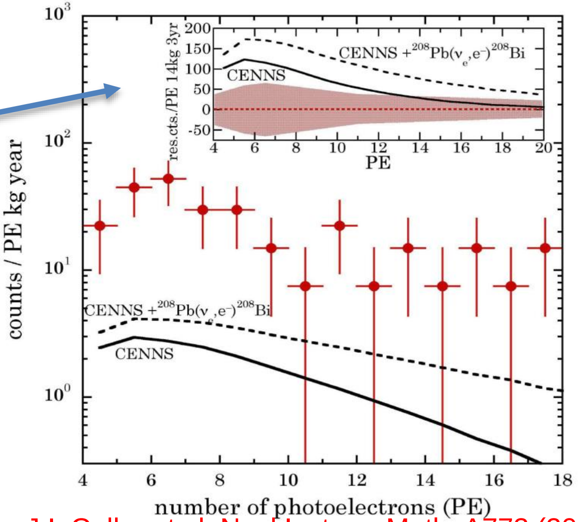


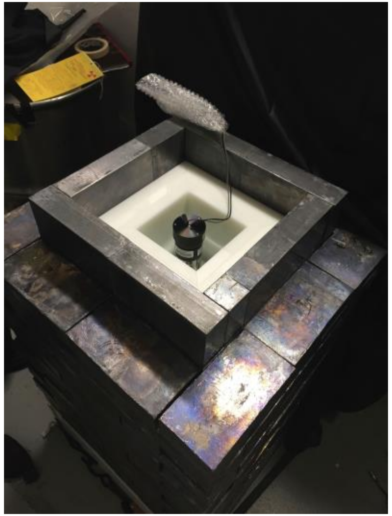
SNS ν corridor

CsI[Na]

- 14 kg CsI[Na] crystal
  - Na doping reduces afterglow seen in more common Tl doping
- Commissioned at SNS in July 2015
- Shielding structure includes lead, water, and plastic
- Quenching factor measurements performed
- Steady-state backgrounds at SNS installation site 10-20% of measurements taken at Univ. of Chicago
  - Neutrino-Induced-Neutrons reduced to ~4% of CEvNS including HDPE shielding
- ~1 calendar year of data has been taken
  - Analysis underway



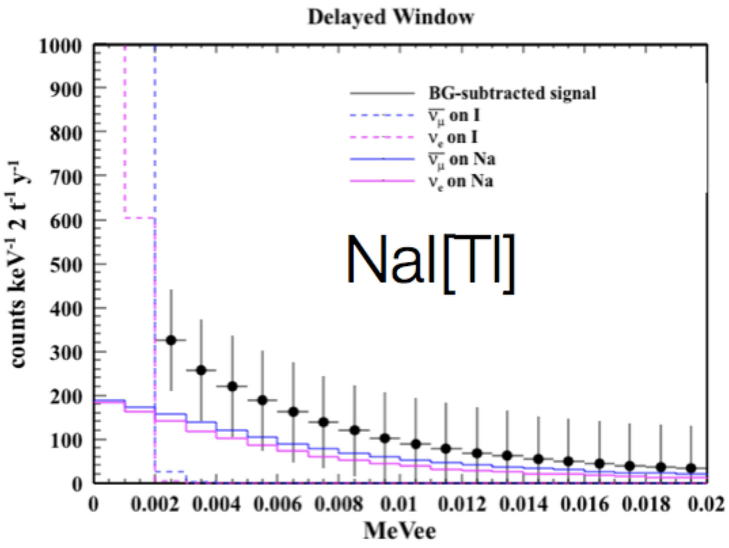


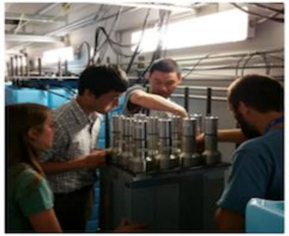


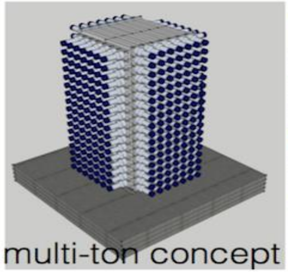
J.I. Collar et al. Nucl.Instrum.Meth. A773 (2015) 56-65

NaI[Tl] - NaIVe

- Acquired many ~7kg NaI crystals from discontinued DHS program
- 185 kg prototype to begin
  - Commissioned at SNS site in July 2016
  - Measure CC ν_e interaction on ^{127}I (see B. Suh poster L1.00006 for more details)
- 2 ton deployment planned for CEvNS measurement
- Up to 9 tons available

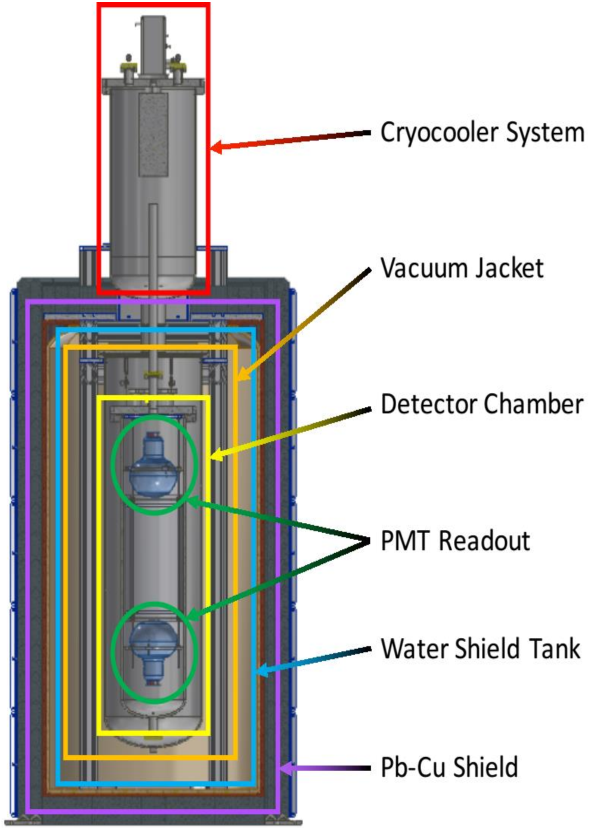


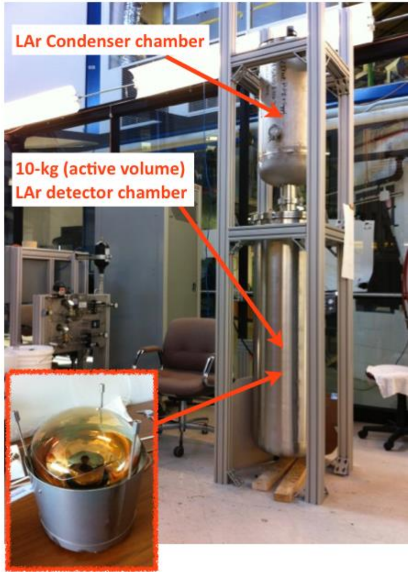


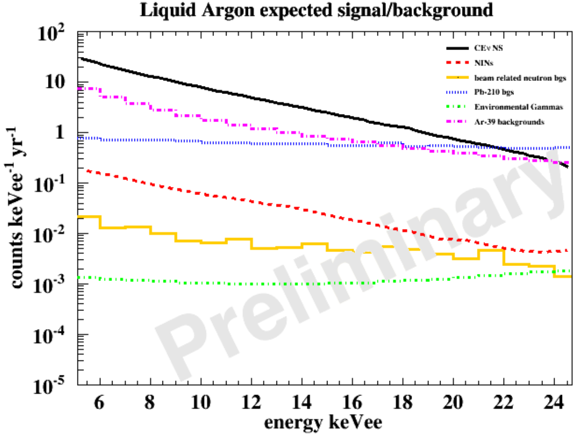


LAr – CENNS-10

- 35 kg fiducial-volume single-phase detector built by J.Yoo at Fermilab for CEvNS effort
- Readout is 2 Hamamatsu R5912-02MOD 8” cryogenic, high-gain PMT
- Neutron/electon recoil pulse shape discrimination measured by miniCLEAN
- Quenching factor well measured by SCENE collaboration
- ^{39}Ar controllable via PSD and beam duty factor
- Shielding structure of lead, copper, and water to control steady state backgrounds
- Tested at Indiana Univ. in the summer of 2016 for feasibility
- Commissioned at SNS in December 2016





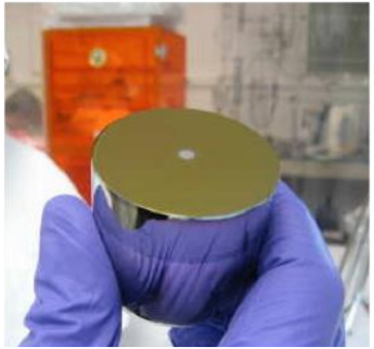


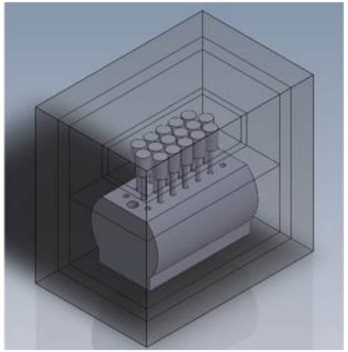
S.J. Brice et al. Phys. Rev. D 89, 072004 (2014)

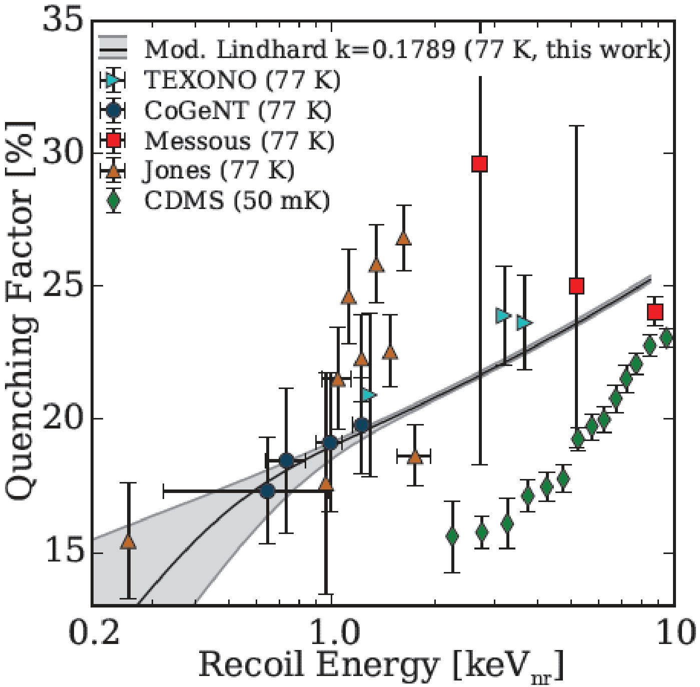
H. Cao et al., SCENE Collaboration, *Phys. Rev.* **D91** (2015) 092007.

HPGe

- HPGe PPC
- Excellent energy resolution at low energies
- Well measured quenching factor
- First deployment: ~10 kg PPC detector array
    - Repurpose on-hand Majorana Demonstrator/LANL ^{nat}Ge detectors
    - Shielding structure of Lead, Copper, and Poly along with plastic scintillator muon veto
    - Installation in early 2017
- Potential next deployment: Larger mass (C4-style) PPC detectors







Summary

- SNS provides clean π-DAR neutrino source for CEvNS measurement
- COHERENT is deploying 4 different detector technologies to make an unambiguous discovery of CEvNS via N^2 dependence of cross section
- COHERENT anticipates a rich neutrino program with different detector technologies and reach of a wide variety of physics

The COHERENT collaboration

arXiv:1509.08702

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Acknowledgments We are grateful for logistical support and advice from SNS (a DOE Office of Science facility) and ORNL personnel. Much of the background measurement work was done using ORNL SEED funds, as well as Sandia Laboratories Directed Research and Development (LDRD) and NA-22 support. The RED-100 xenon detector has been developed and constructed under the contract of NRNU MEPhI with Ministry of Education and Science of Russian Federation No. 11.G34.31.0049 from October 19, 2011. Xenon detector deployment is supported by ORNL LDRD funds. We thank Pacific Northwest National Laboratory colleagues for CsI[Tl] detector contributions and Triangle Universities Nuclear Laboratory for making resources for various detector components available. COHERENT collaborators are supported by the U.S. Department of Energy Office of Science, the National Science Foundation, and the Sloan Foundation.