COHERENT in the Near-Term

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Fundamental Physics at the Second Target Station

July 26, 2019

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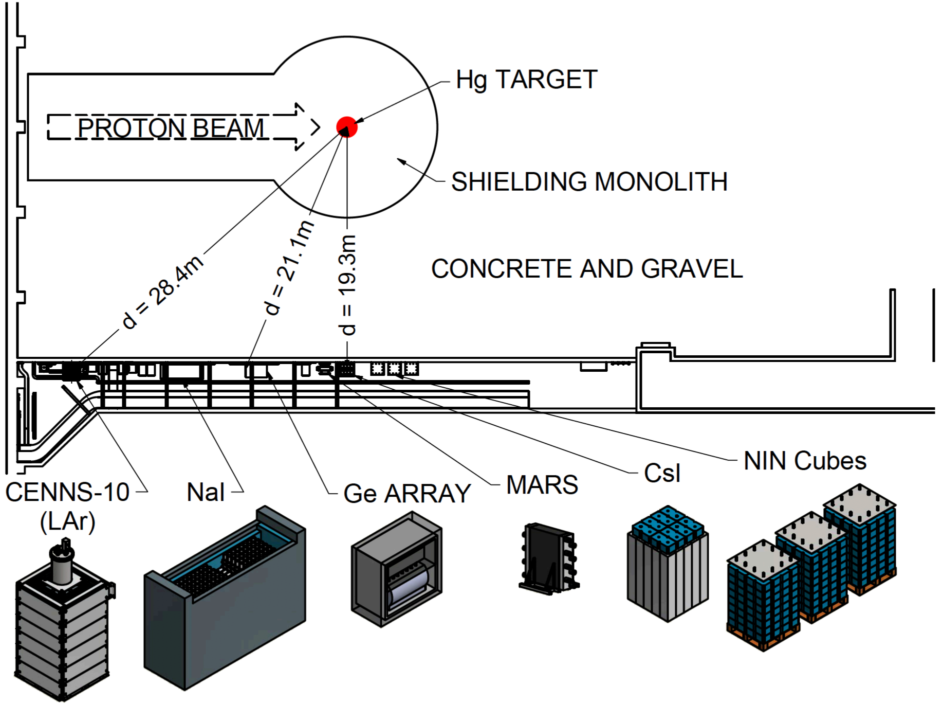
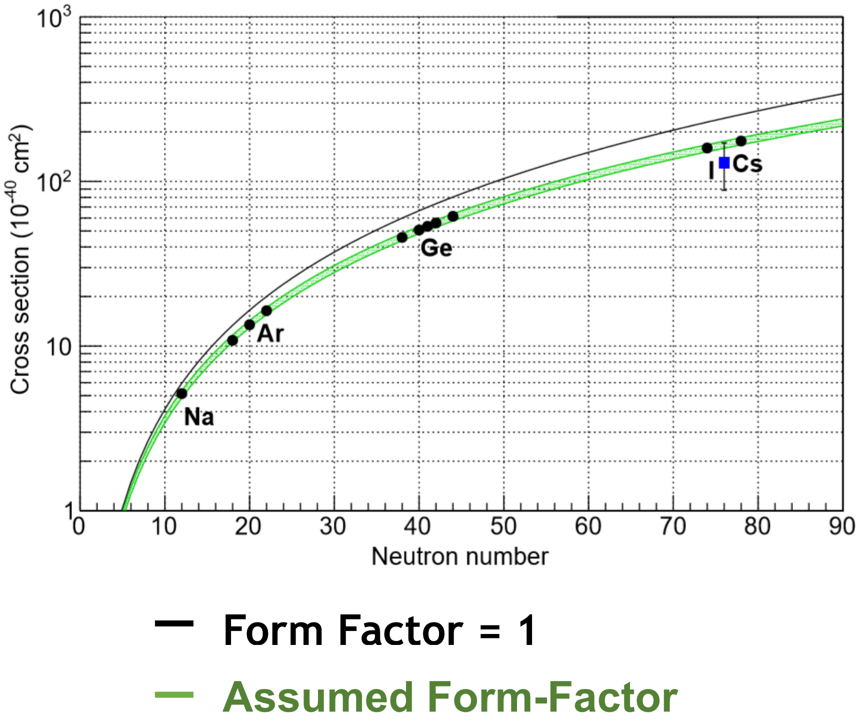
OAK RIDGE National Laboratory
U.S. DEPARTMENT OF ENERGY | Office of Science
NSF

COHERENT Multi-Target Program - Phase I





CsI[Na]: A Hand-held Neutrino Detector

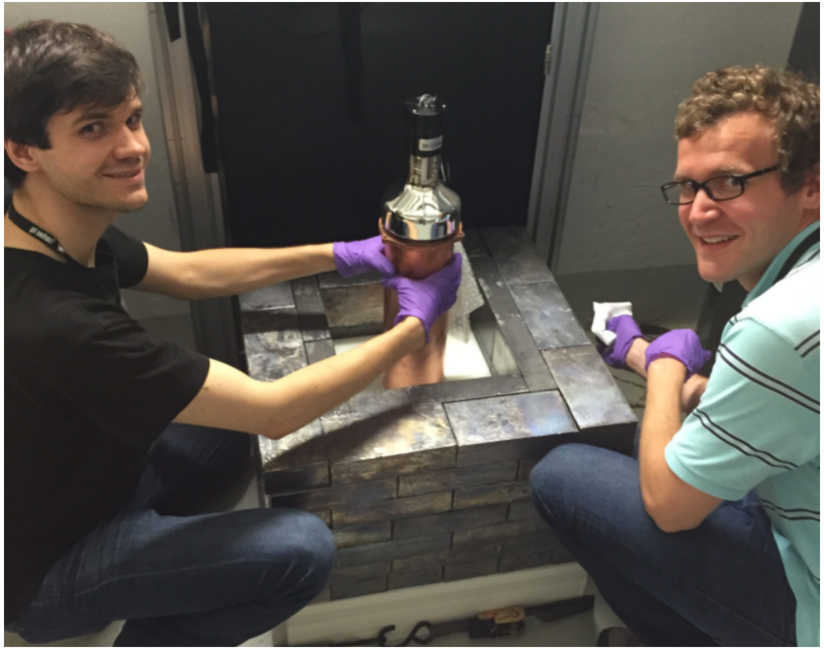
14.6 kg low-background CsI[Na] detector (34cm lg x 4.7cm dia) deployed to Neutrino Alley summer of 2015.

Fabricated from low-background salts, housed in electroformed copper.

Shielded by HDPE(7.5cm), historic low-background Pb (5cm), contemporary Pb (10cm), μ-veto, water

~ 1.2 PE/keVnr after accounting for Quenching Factor for nuclear recoils

CEvNS recoils: 5-30 photoelectrons



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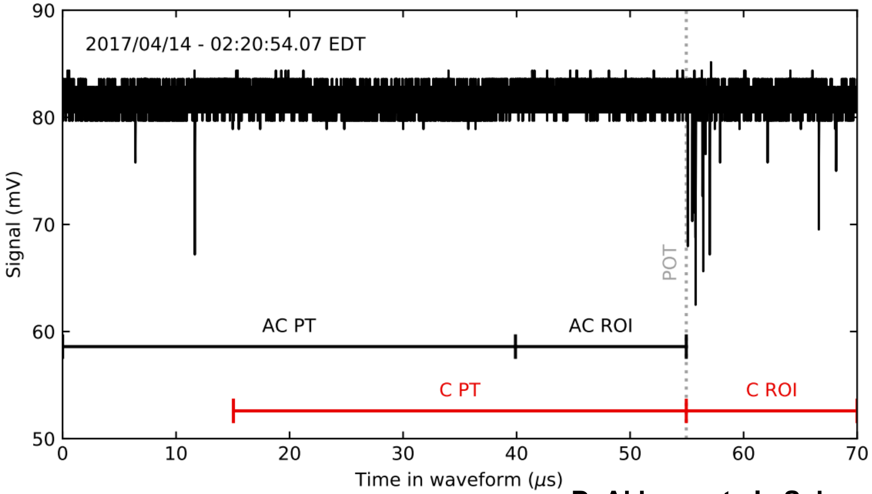
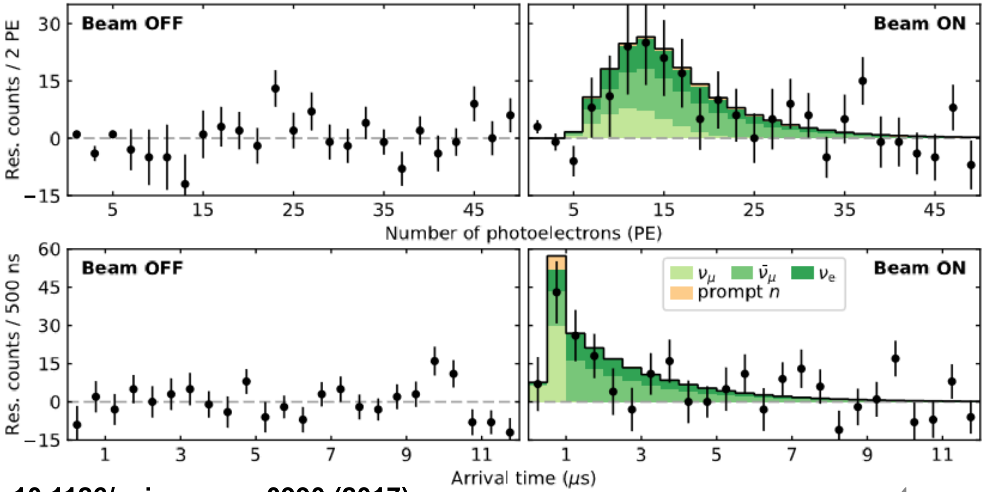
First Observation of CEvNS

- Beam OFF Data: 153.5 days;
- Beam ON Data: 308.1 Days (7.48 GWhr)
- 2D (Energy/Time) profile likelihood analysis





D. Akimov et al., Science 10.1126/science.aao0990 (2017).

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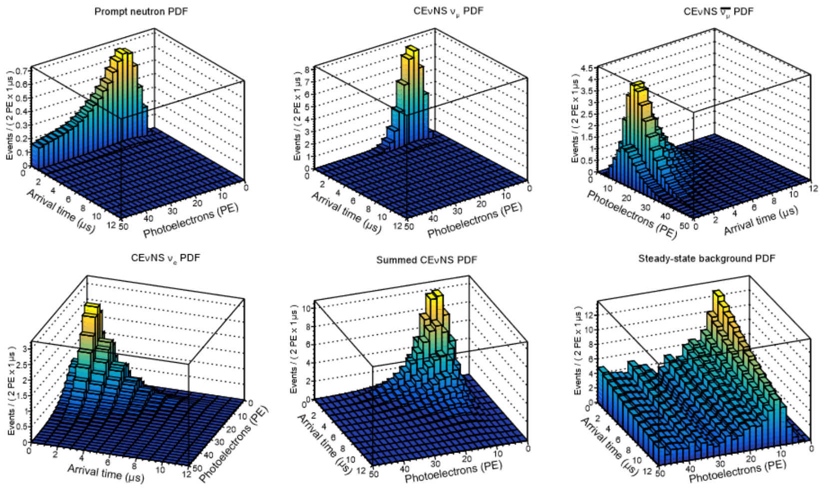

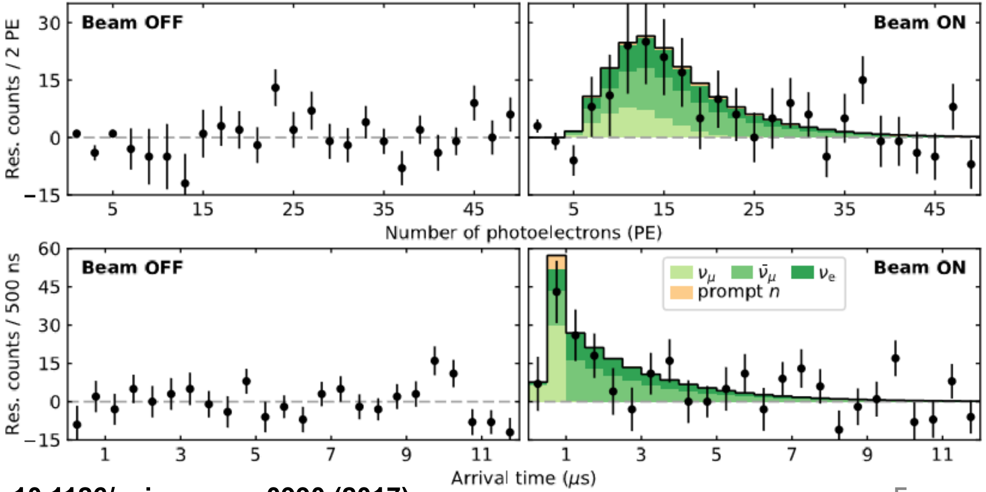

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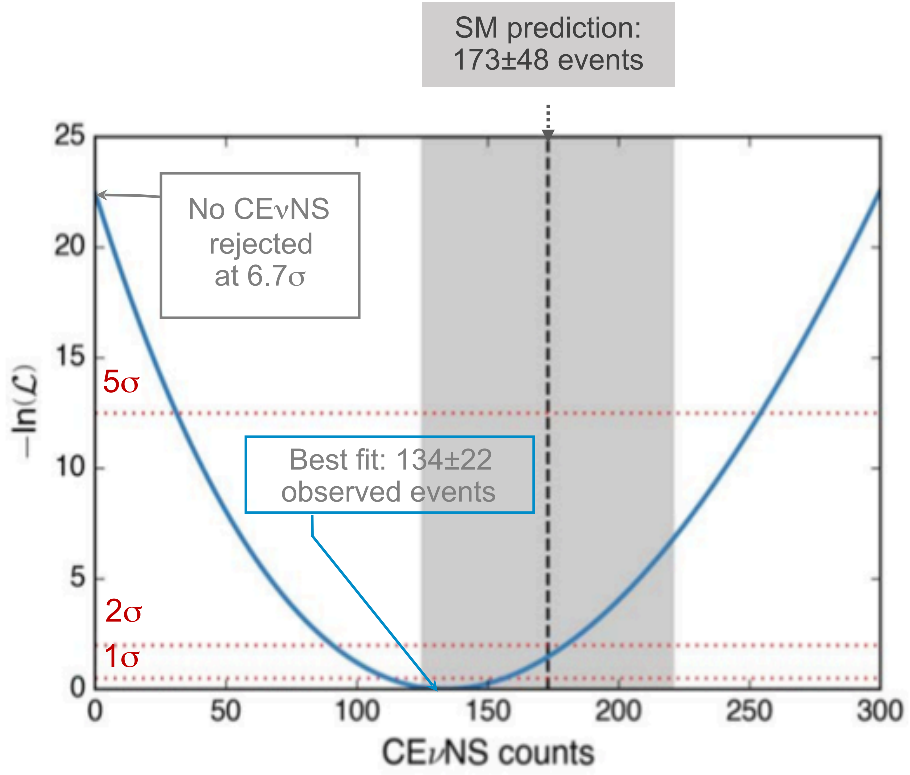

Dominant systematic uncertainties on predicted rates

Quenching factor	25%
ν flux	10%
Nuc. form factor	5%
Analysis acceptance	5%

Uncertainty in this result is dominated by current quenching factor determination; new QF analysis may reduce this significantly.

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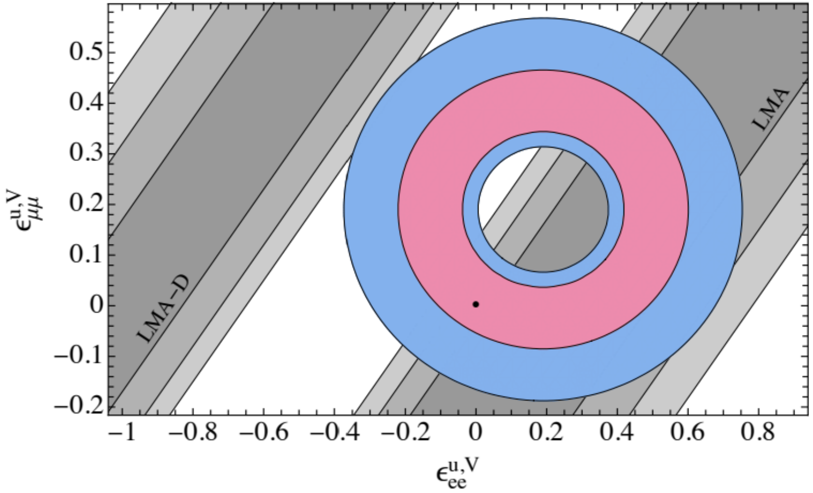
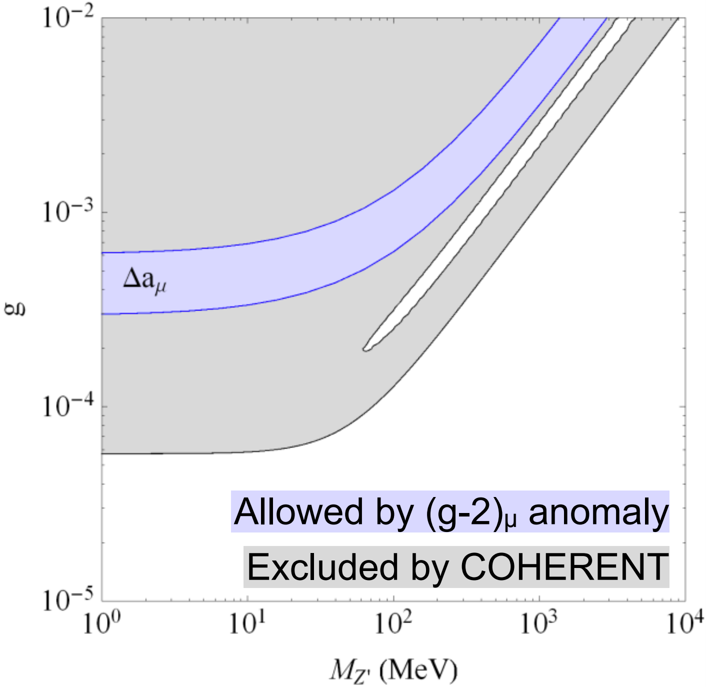
CsI Impact

Current result already rules out (in combination with neutrino oscillation data) the Large Mixing Angle "Dark" solution.



Coloma et al, arXiv:1708.02899v1

Finds tension (at 2 sigma) with a light-mass Z' dark mediator that can explain the $(g\text{-}2)_\mu$ anomaly.



Liao and Marfatia, arXiv:1708.04255v1

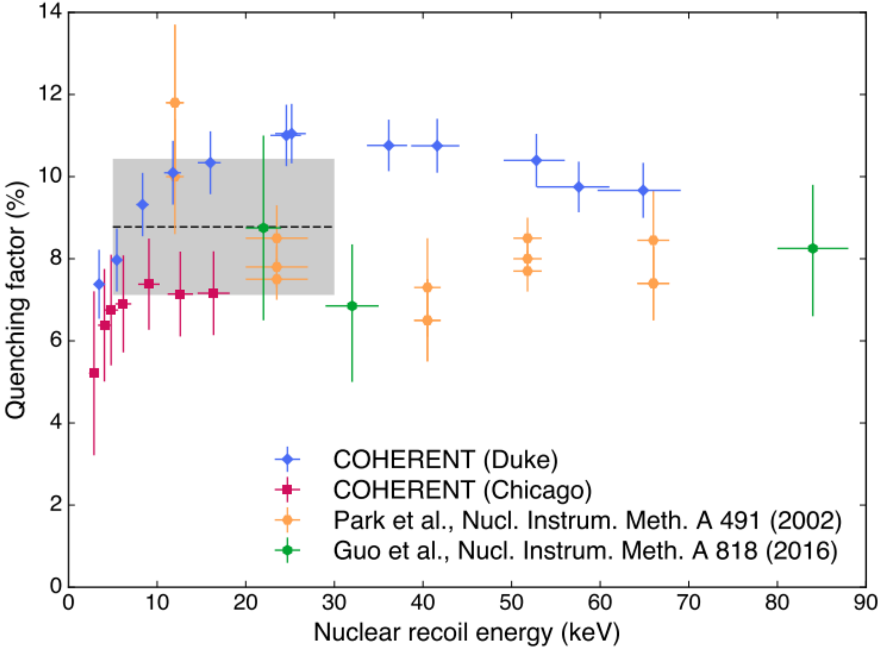
CsI Near-Term Plans

Updated analysis of full dataset:

- Have doubled the exposure since **Science** publication

Quenching Factors:

- Quenching Factor leading source of systematic uncertainty. 25% out of 28%.
- Constant 8.8% (dashed line) assumed for **Science** publication.
- Cause of discrepancy between Chicago, Duke measurements under investigation.



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LAr: CENNS-10

Single-phase liquid Ar scintillation detector

PSD separation of nuclear/electron recoil events

29-kg fiducial volume

Located 28 m from SNS target: 2×10^7 ν/s

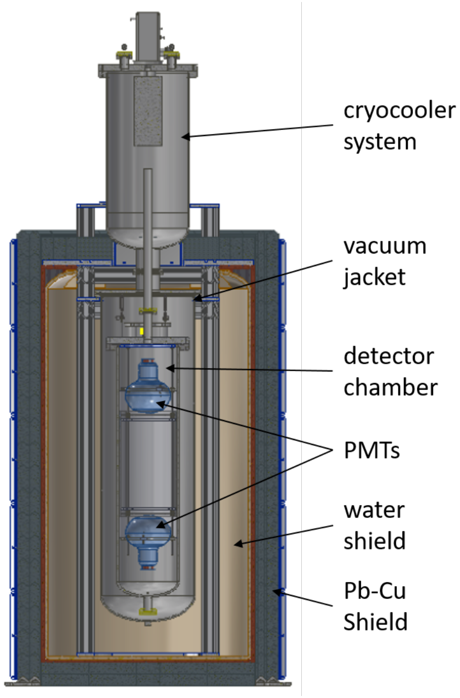
Engineering Run:

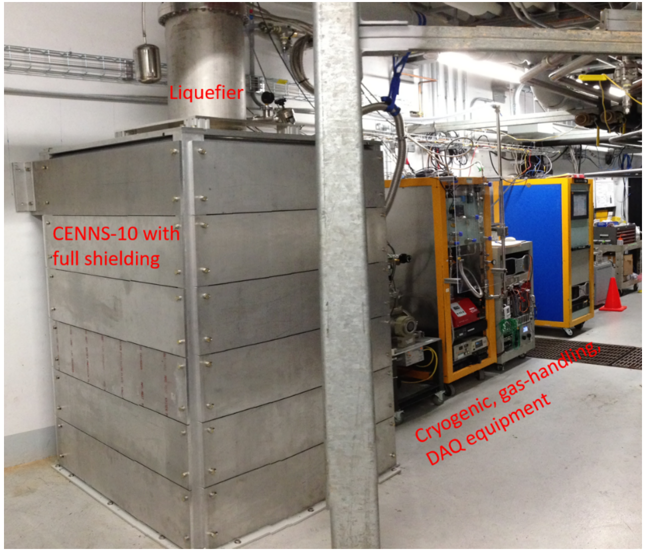
- Dec 2016 -> May 2017
- 1.5 GWhr integrated BP

Summer 2017 upgrade

Production Run:

- Aug 2017 -> Present





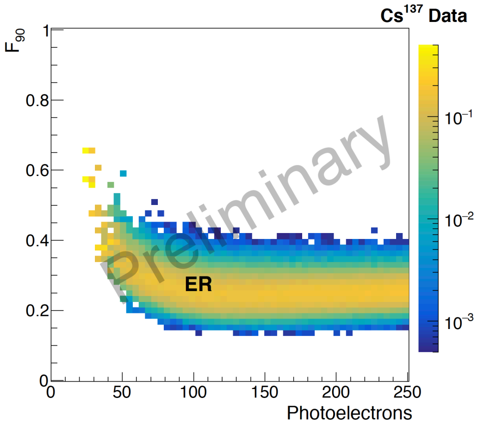
CENNS-10 Engineering Run

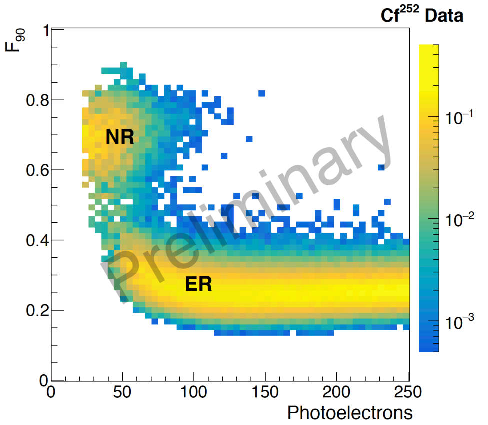
No-shielding run to characterize beam-related neutron backgrounds:

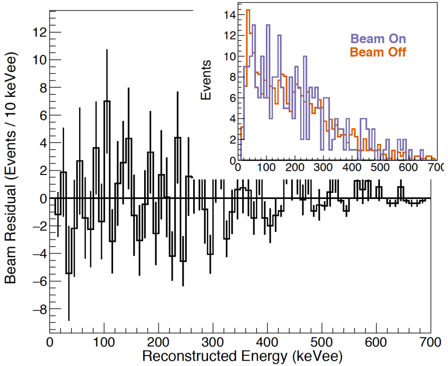
- Prompt neutrons
- Delayed neutron flux consistent with zero.

Full shielding analysis:

- Addition of 20.3 cm H_20, 1.3 cm Cu shielding
- Signal in prompt window consistent with expected neutron background.
- No evidence of neutrons/CEvNS in delayed window
- Counting experiment: Cross section limit: $\sigma_{CEvNS} < 150\times10^{-40}$ cm^2, 8.6x SM prediction
- Likelihood analysis: 3D (Energy, Time, PSD), $\sigma_{CEvNS} < 24\times10^{-40}$ cm^2 (68% CL)

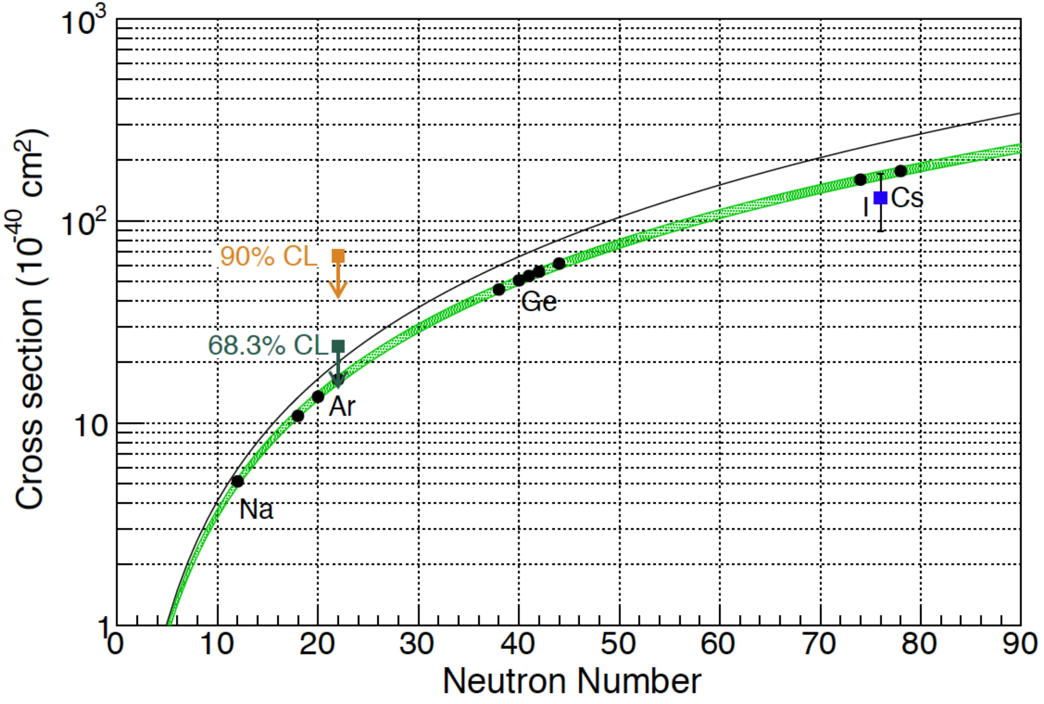


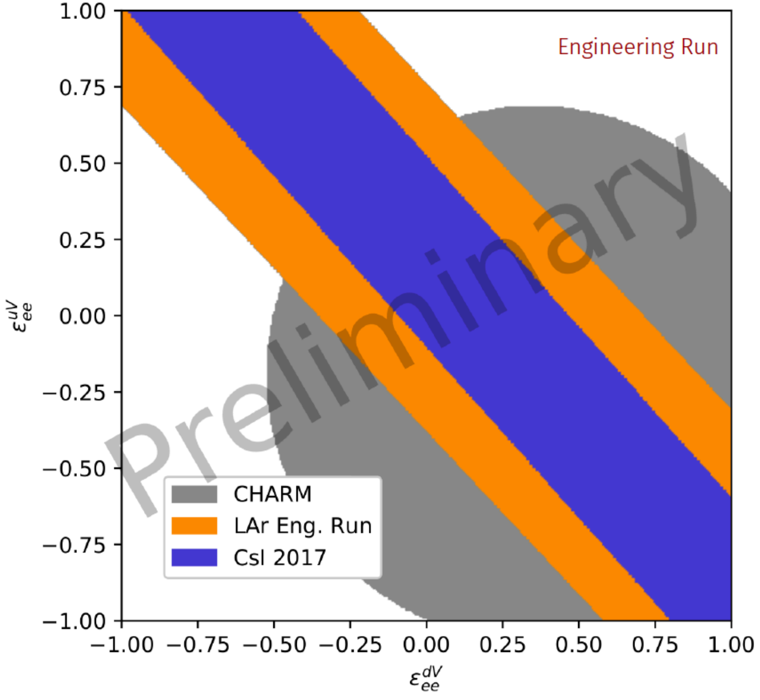




	Delayed BRN	Delayed CEvNS
Beam On	261	11
Beam Off	252	10.3
Residual	9 ± 18	0.7 ± 3.6

CENNS-10 Engineering Run





CENNS-10 Upgrade

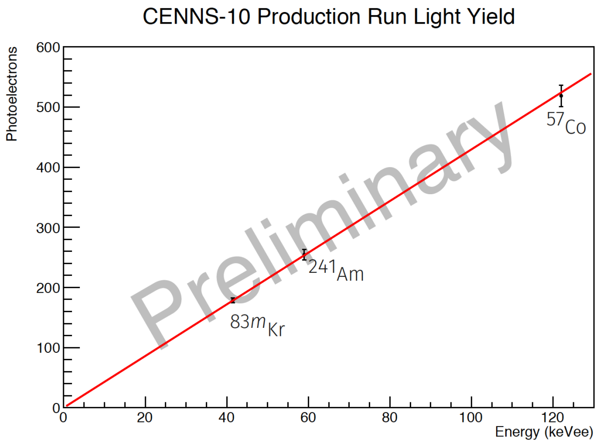
8” PMTs were swapped with PMTs directly coated with TPB; acrylic cylinder replaced with set of 3 TPB coated Teflon cylinders (22.4-kg fiducial volume).

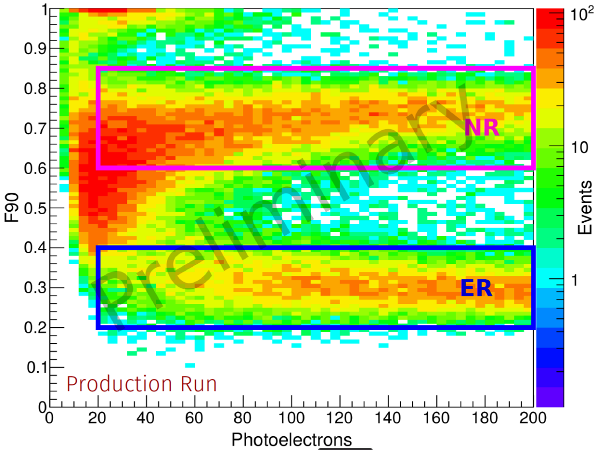
Post-upgrade light yield 4-5 PE/keVee; threshold reduced to ~20 keVnr.

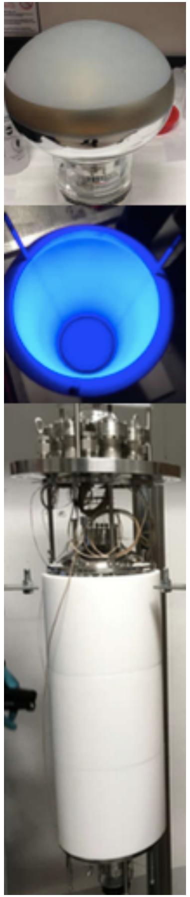
Complete layer of Pb shielding added to reduce environmental gamma backgrounds.

^{83m}Kr calibration source loop added to grant ability for in situ energy calibration at lower energies.

Analysis of 6.1 GWhr of data in the upgraded detector underway.





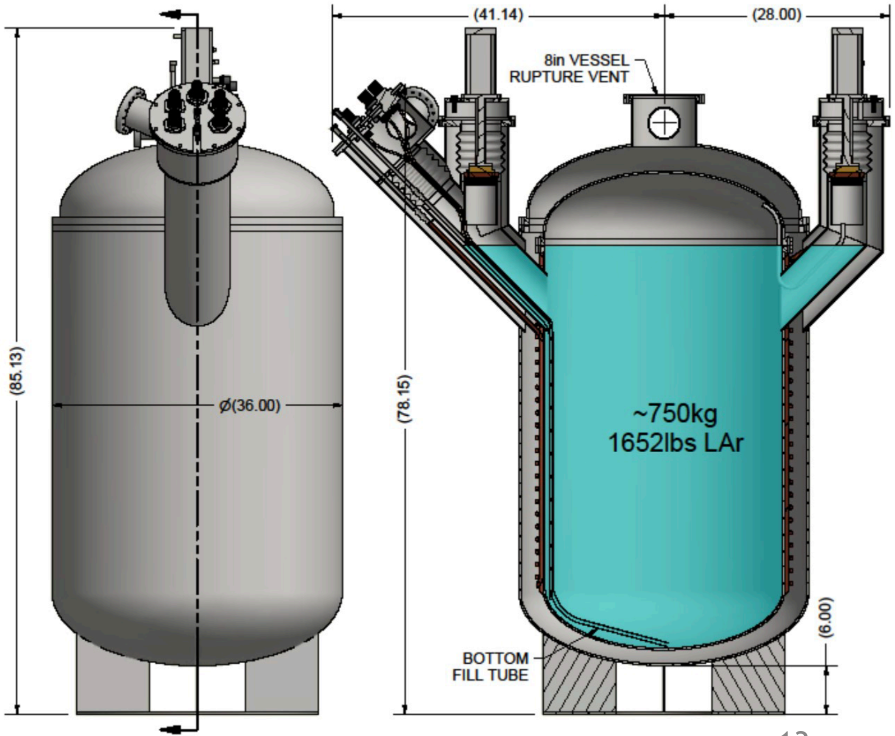


CENNS-10 Future Plans

Possible avenues for improvement:

- 3"PMT and SiPM test assembly
- Xe-doping
- Beam-related neutron mitigation
- Underground Argon

Making way for CENNS-750!



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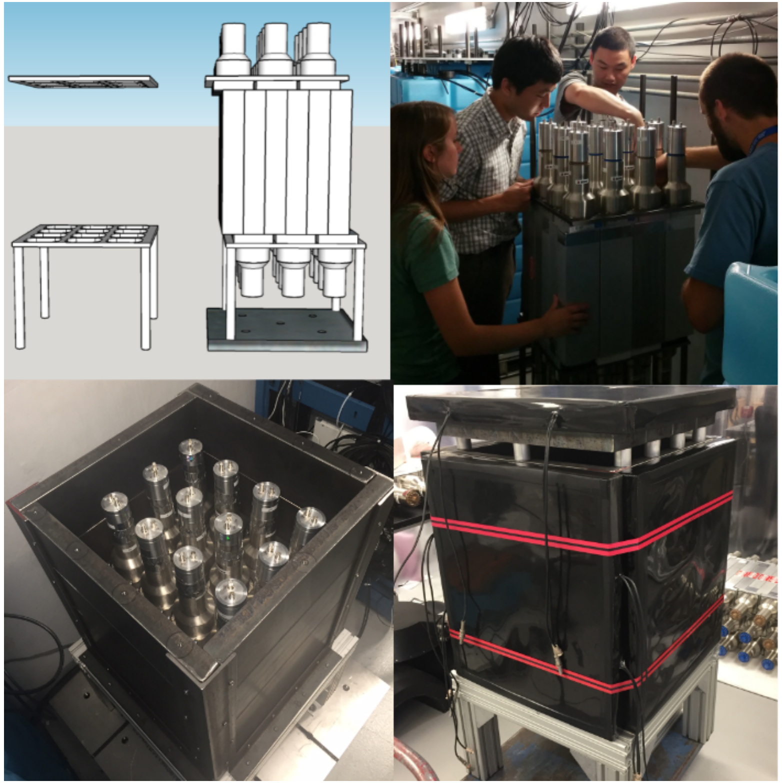
NaIvE Prototype



Several tons of NaI[Tl] detectors available for use after closing of Spectroscopic Portal program (DHS).

Crystals are NOT designed with low-background or threshold

NaIvE prototype: 185kg in 24 modules

Purpose:

- Measurement of CC cross-section on ^{127}I
- Testing of backgrounds for ton-scale deployment optimized for CEvNS

New dual-gain PMT bases being developed at ORNL to allow for both low energy nuclear recoils and high energy CC signals to be observed

Ton-Scale NaI Array

Designs for ton-scale (3.38 tons) NaI array:

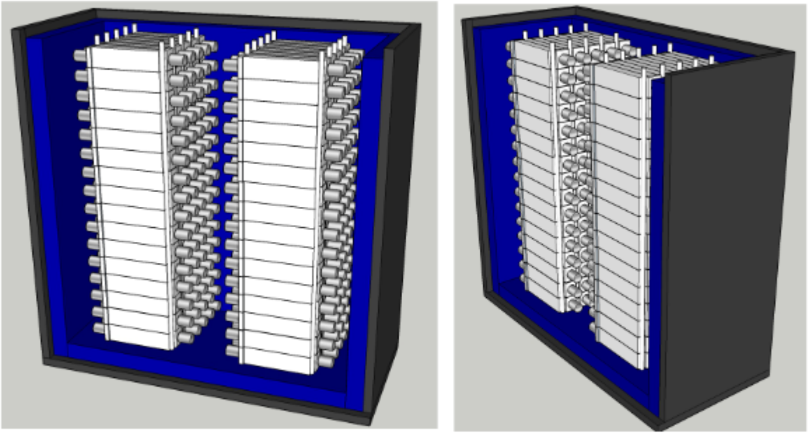
- Two stacks with 144-160 detectors each
- Single continuous array

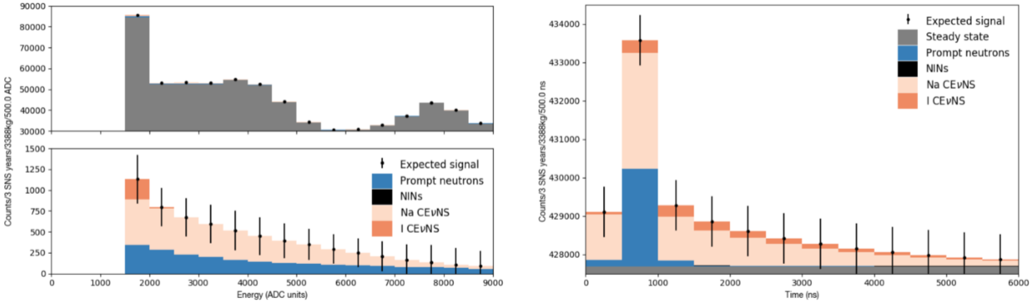
PMT Testing, backgrounds, detector quality for each detector element needed.

Plan for new quenching factor measurements to minimize uncertainty and resolve conflict in existing data.

Physics targets:

- CEvNS on ^{23}Na
- ν_e CC on ^{127}I





Neutrino-Induced Neutrons (NINs)

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

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

Neutrinos can interact in shielding materials to produce energetic neutrons.

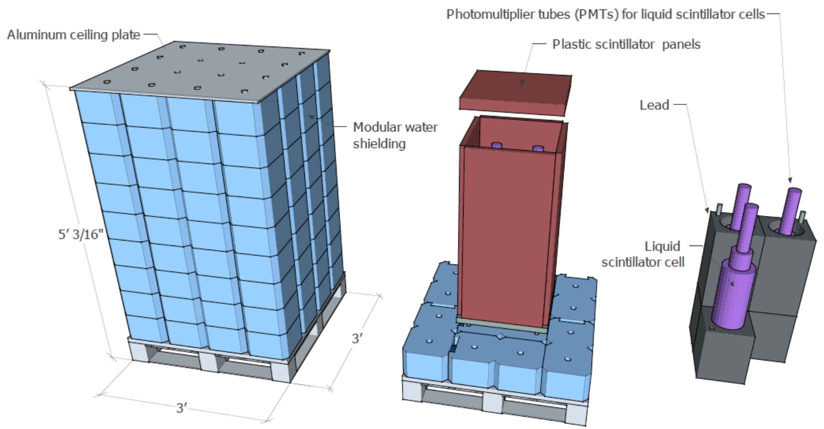
These neutrons can induce nuclear recoils in the detectors mimicking the CEvNS signal!

Cross-section poorly constrained, and a potential important background for COHERENT.

Set of Neutrino Cube detectors (NUBES) seek to observe this process and constrain the potential contribution to CEvNS signal.

Detection mechanism for the HALO supernova observatory.

Currently taking data: Pb (3 years); Fe (2 years)



PPC Germanium Array

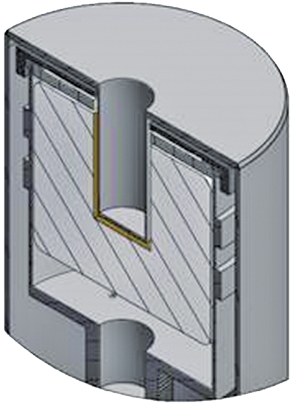
P-Type Point Contact Ge detectors well-suited to precision CEvNS measurements

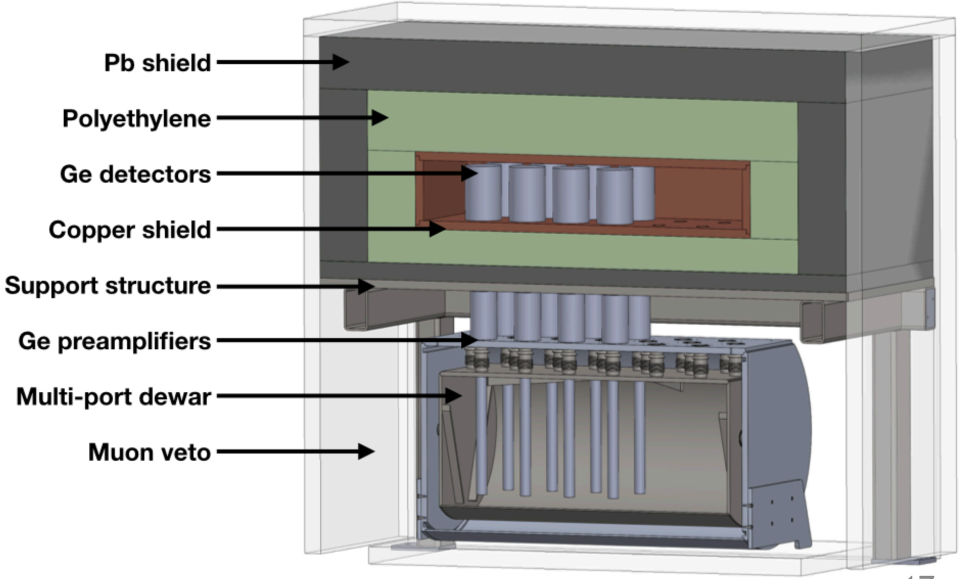
- Excellent energy resolution
- Low thresholds: <1 keVnr
- Intermediate N

Best-understood systematics; energy spectrum faithful to recoil spectrum.

16-kg array of PPC Ge detectors placed in compact shielding using multi-port dewar that has already been procured.

Expectation of 500-600 CEvNS events per year of SNS operation. Predicted signal-to-background ratio of 3.5





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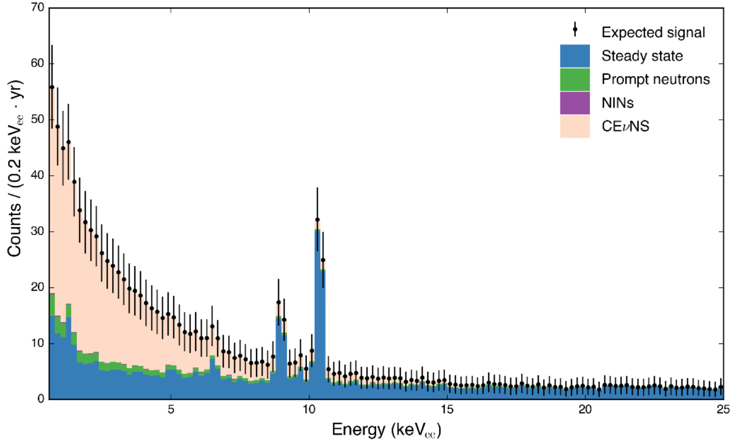
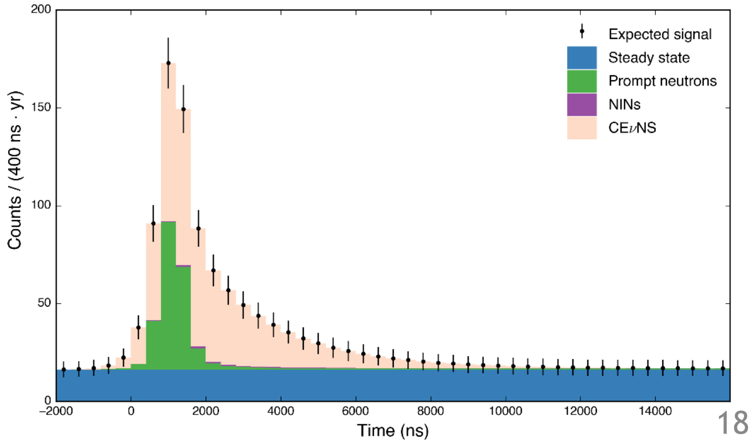
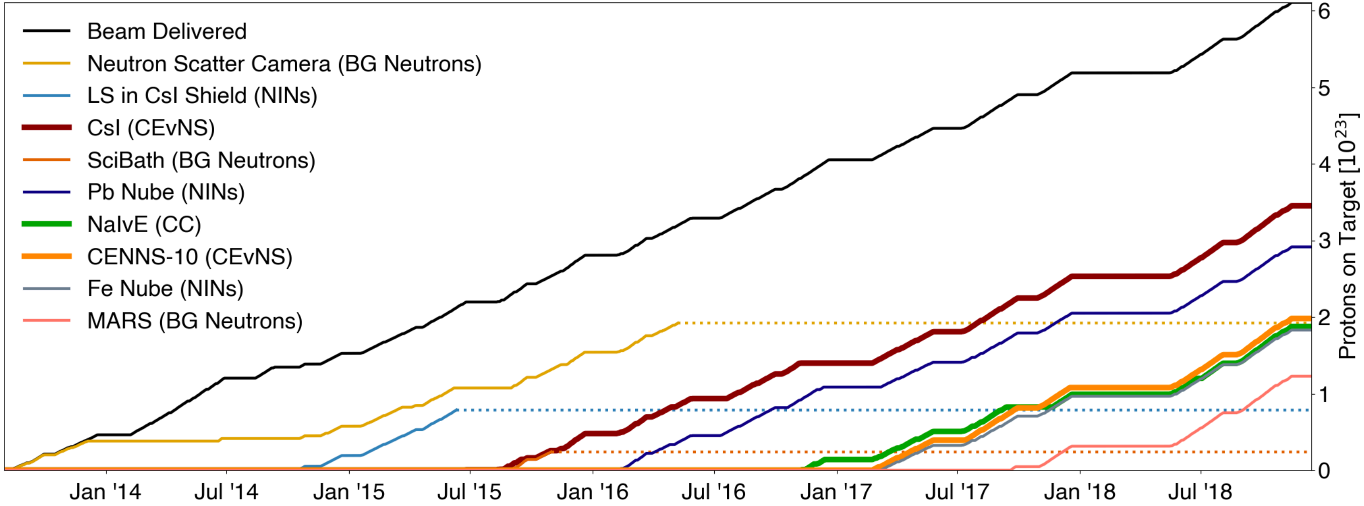




Data Collected - Future Plans



- Several detector systems have begun or finished data taking and characterization of location backgrounds is complete.
- What's next? Bigger detectors and additional targets! Higher statistics and low backgrounds are essential.
- Data from current LAr and NaI detectors essential for informing large-scale detector design.

Summary

Using a CsI detector, the COHERENT collaboration has made the first observation of CEvNS, a long-predicted Standard Model interaction.

CsI[Na]: Data taking complete, detector decommissioned. Analysis of full dataset underway

CENNS-10 LAr: Engineering run completed and analyzed. Production run underway.

NaIvE NaI: 185kg prototype operating since 2016, multi-ton array in development.

Nubes: 3years of Pb data, 2 years of Fe; analysis maturing, unblinding soon.

PPC Ge: Detector procurement in 2020, Deployment at SNS shortly thereafter.