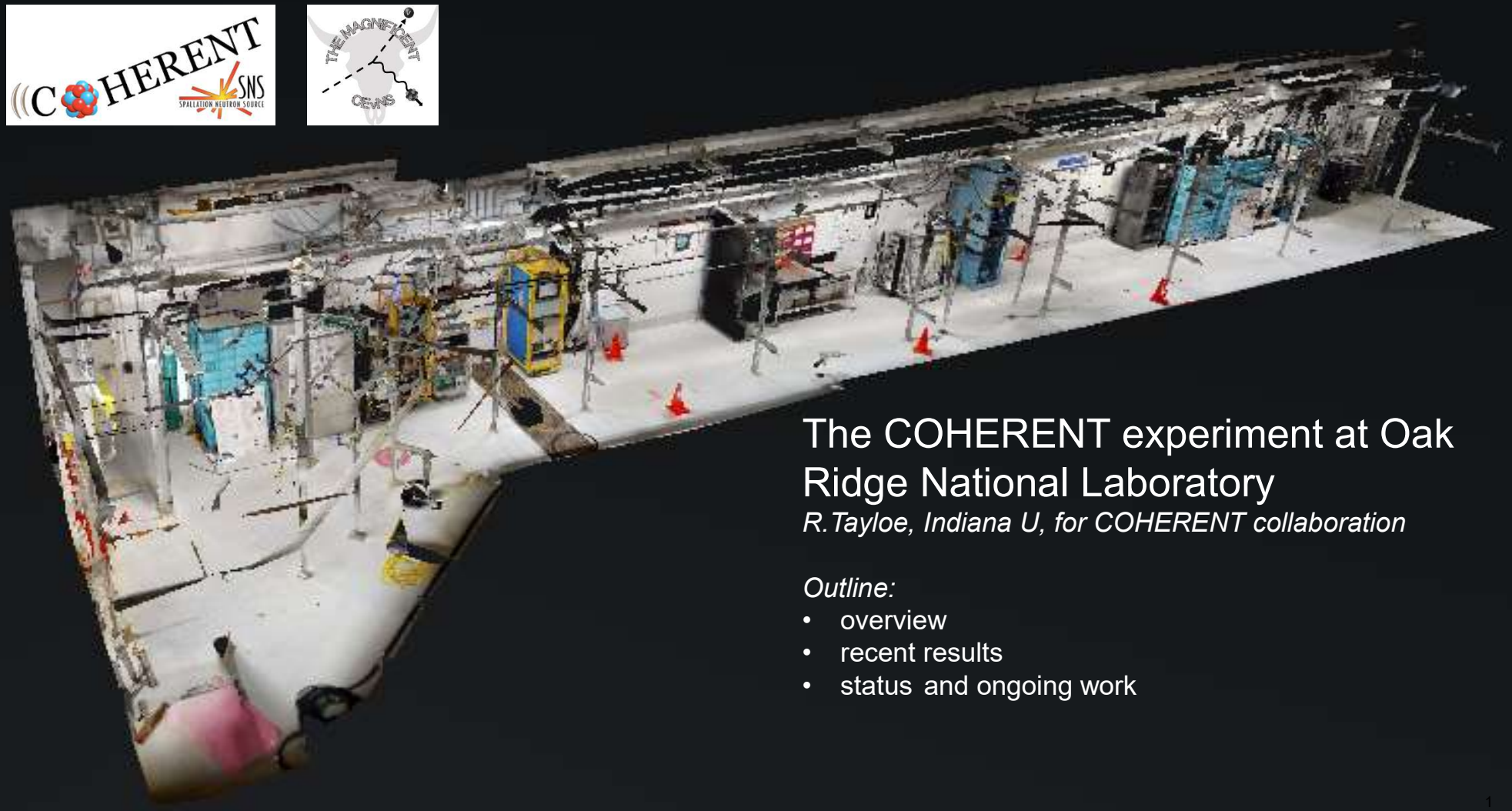


The COHERENT experiment at Oak Ridge National Laboratory

R.Tayloe, Indiana U, for COHERENT collaboration

Outline:

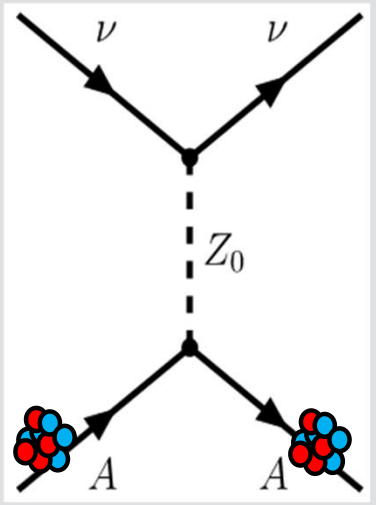
- overview
- recent results
- status and ongoing work

CEvNS: Coherent Elastic ν-Nucleus Scattering: νA→νA

CEvNS probes the nucleus coherently, yielding clear tests of the standard model weak interaction with the nucleus.

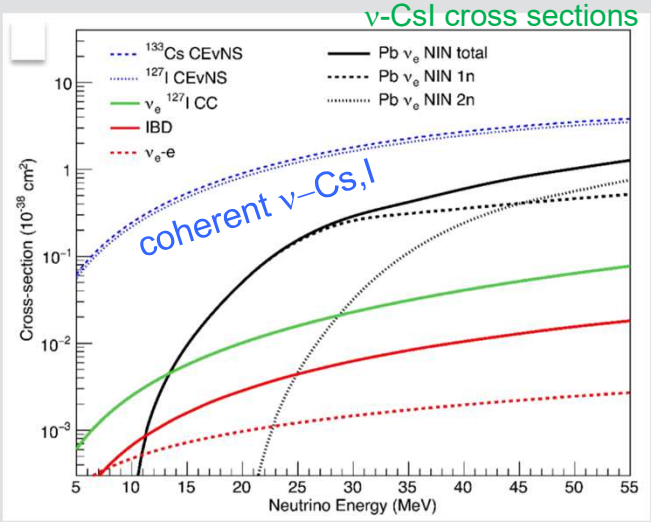
CEvNS total cross section:

$$\sigma \approx \frac{G_F^2}{4\pi}(N-(1-4\sin^2\theta_W)Z)^2E_\nu^2$$



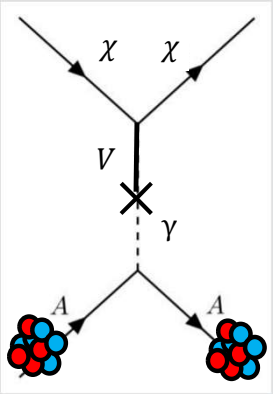
…CEvNS is largest ν channel at ~10 MeV on nuclei, eg Cs,I, Ar

ν-CsI cross sections



Also:

- coupling to other neutral particles possible (eg accelerator darkmatter)

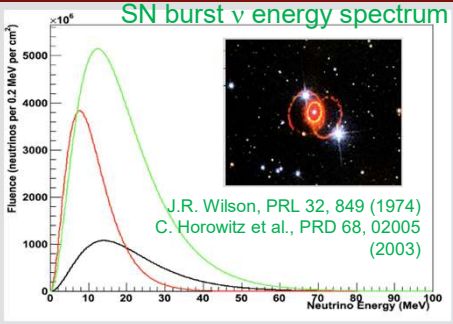


Coherent Elastic ν-Nucleus Scattering:

Physics reach of CEvNS (and related)

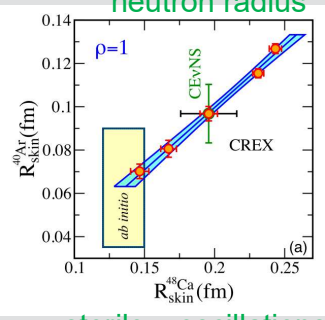
- Supernovae (SN)
  - Largest σ in SN dynamics
  - possible SN detection channel
- Nuclear Physics: nuclear form factors
- Standard Model tests:
  - non-standard interactions (NSI)
  - weak mixing angle: $\sin^2\theta_w$
  - ν magnetic moment
- ν oscillations: Sensitive to sterile ν
- Dark Matter:
  - Important background for 10-ton direct searches
  - detectors sensitive for accelerator produced DM
- And other related low-energy processes
  - neutrino-induced neutrons (NINs)
  - inelastic neutral-, charged-current events

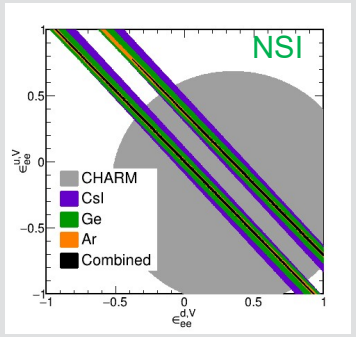
SN burst ν energy spectrum



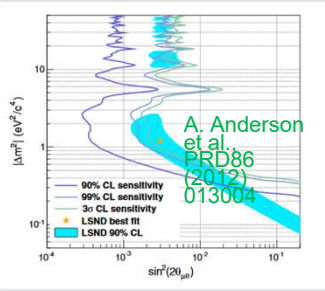
J.R. Wilson, PRL 32, 849 (1974)
C. Horowitz et al., PRD 68, 02005 (2003)

neutron radius

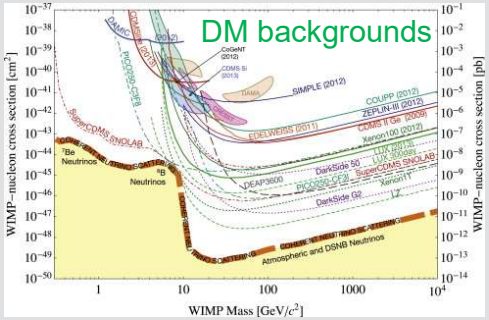


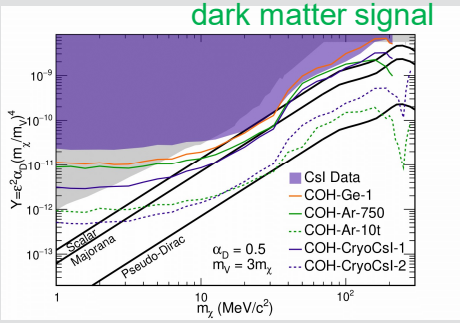


sterile ν oscillations



A. Anderson et al., PRD86 (2012) 013004

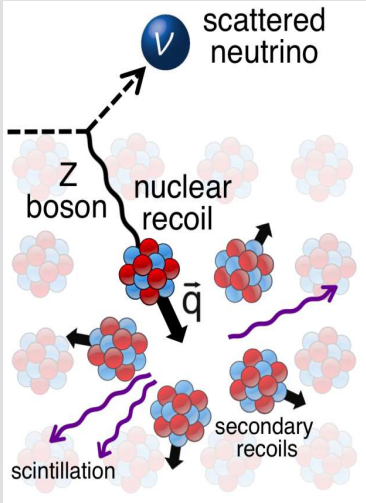




Coherent Elastic ν-Nucleus Scattering:

However, detection of the CEvNS process is a challenge:
- At $E_\nu \approx 10$MeV recoil energy of nucleus is quite small:

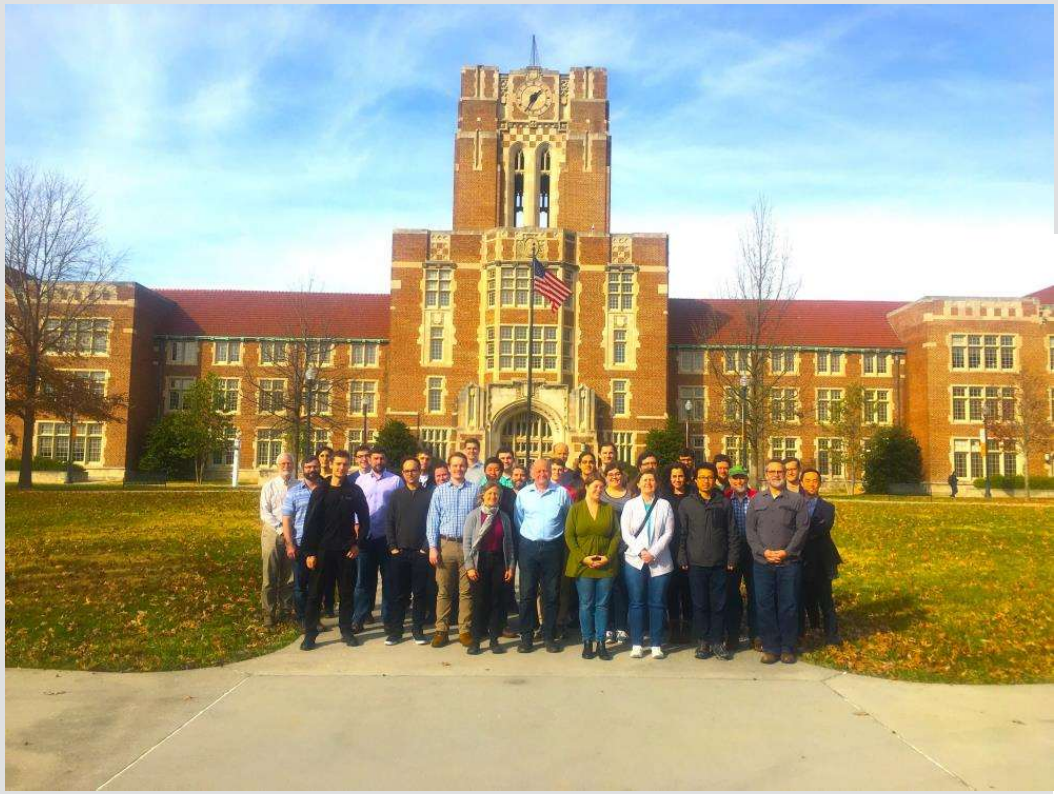
$$E_r^{\max} \simeq \frac{2E_\nu^2}{M} \simeq 50 \text{ keV}$$



And so, the CEvNS process has only recently been observed†… and, so far, in only one experiment.

†COHERENT collab, Science 3 Aug, 2017.

The COHERENT collaboration



~80 members,
~20 institutions
4 countries

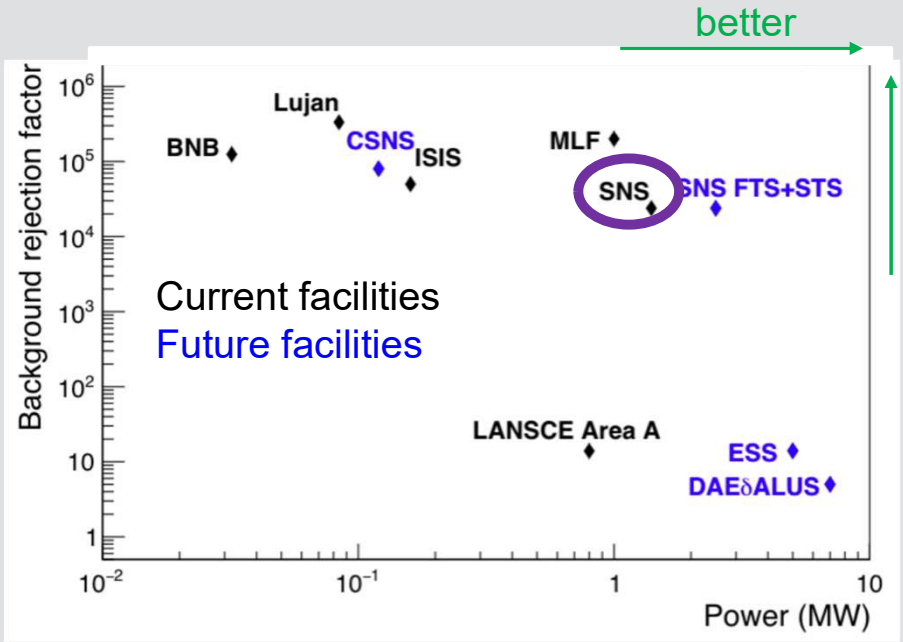
Carnegie Mellon University
Duke University
UF University of Florida
KAIST
Laurentian University / Université Laurentienne
Virginia Tech
Los Alamos National Laboratory, Est. 1943
MEPhI
NC Central University
NC State University
Tufts University
Oak Ridge National Laboratory
Sandia National Laboratories
The University of Tennessee, Knoxville
TUNL Triangle Universities Nuclear Laboratory
University of Washington
University of South Dakota

http://coherent.ornl.gov/

COHERENT experiment at SNS/ORNL

ORNL Spallation Neutron Source (SNS)

- intense proton beam (~1.4 MW, 1 GeV)
- pulsed (60 Hz, 600ns spill time)…



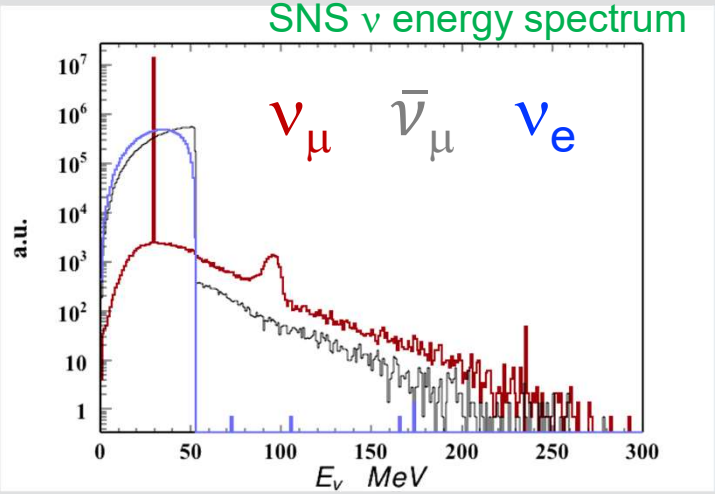
COHERENT experiment at SNS/ORNL

ORNL Spallation Neutron Source (SNS) is also a world-class ν source:

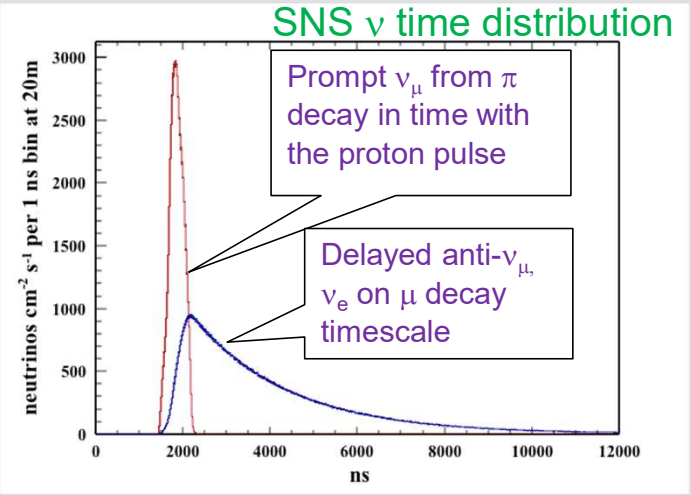
- intense proton beam (~1.4 MW, 1 GeV)
- pulsed (60 Hz, 600ns spill time)…
- ~7000 MWhr/year, ~1.5E23 protons/year

- yielding intense neutrino flux with excellent energy and timing for neutrino experiments.

SNS ν energy spectrum

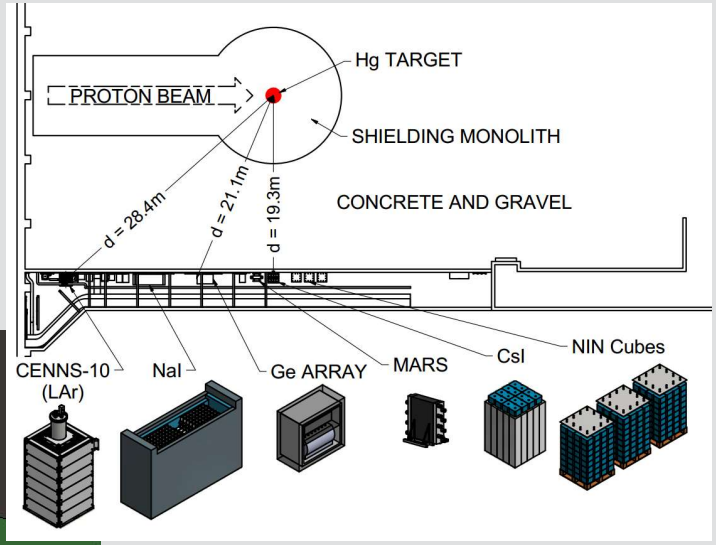


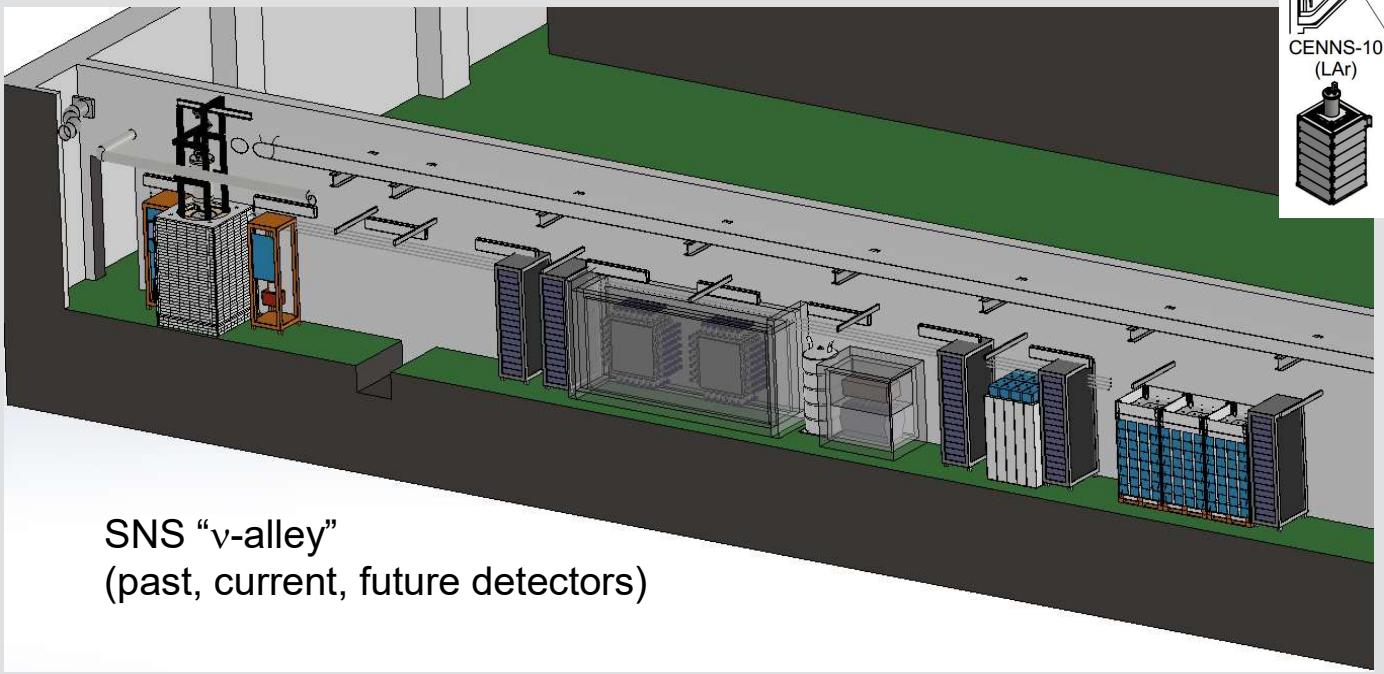
SNS ν time distribution



COHERENT experiment at SNS/ORNL

- in “neutrino alley”
- with low beam-related backgrounds
- 20-29 m from target





SNS “ν-alley”
(past, current, future detectors)

COHERENT experimental strategy at SNS/ORNL

Phase 1:

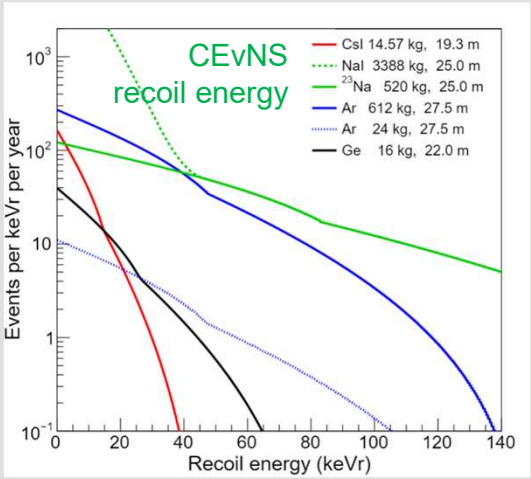
Observe CEvNS process and measure N^2 dependence

with multiple targets/detector technologies

Phase 2:

Precision measurements of CEvNS (and related) physics

with larger/upgraded targets/detectors



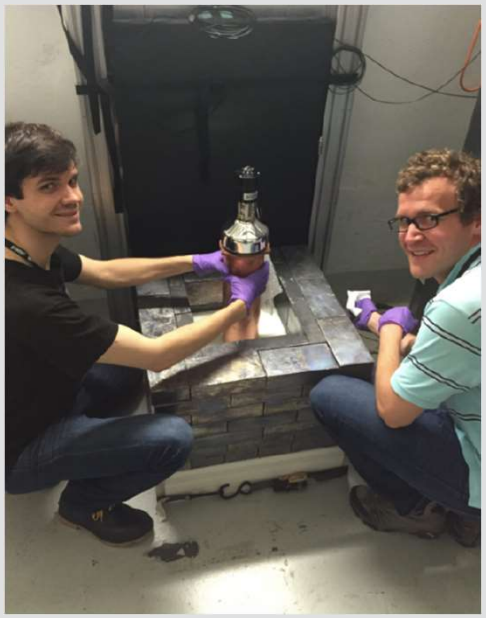
COHERENT past, current, future detectors

Target	Technology	Fid. Mass (kg)	Threshold (keV_{nr})	Commission dates	Pubs/status
CsI[Na]	Scintillation	14.6	6.5	2015	1st result, 2017: 10.1126/science.aao0990 updated results in press, detector removed
Liquid Ar	Scintillation	24.4/610	20	2017/2024	1st result, 2019: 10.1103/PhysRevLett.126.012002, currently running
Ge	Ionization	16	1-2	2022	commissioning: 2022
NaI[Tl]	Scintillation	185/3000	13	2016/2022	commissioning: 2022

COHERENT with CsI[Na]

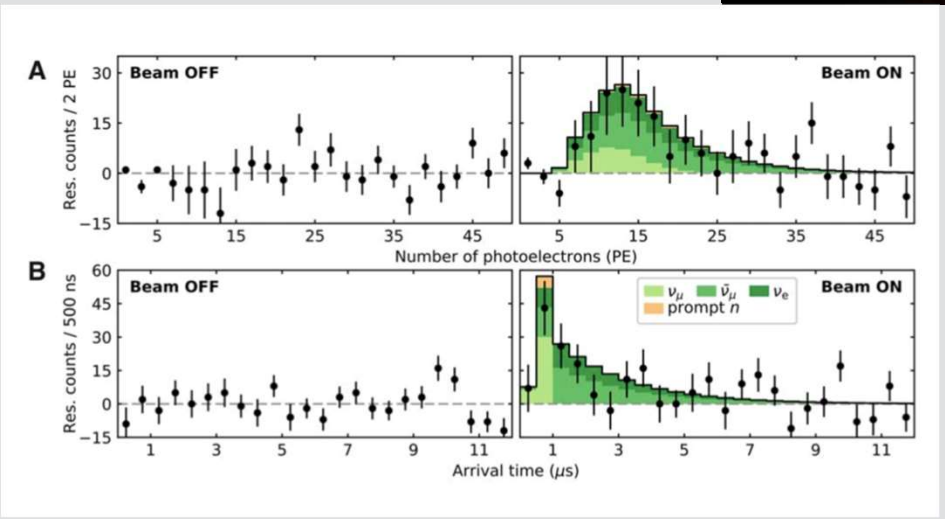
CsI[Na] scintillating crystal:

- 14.6 kg sodium-doped CsI
- high light yield (13.35 pe/keVee)
- Manufactured by Amcrys-H
- Single R877-100 PMT



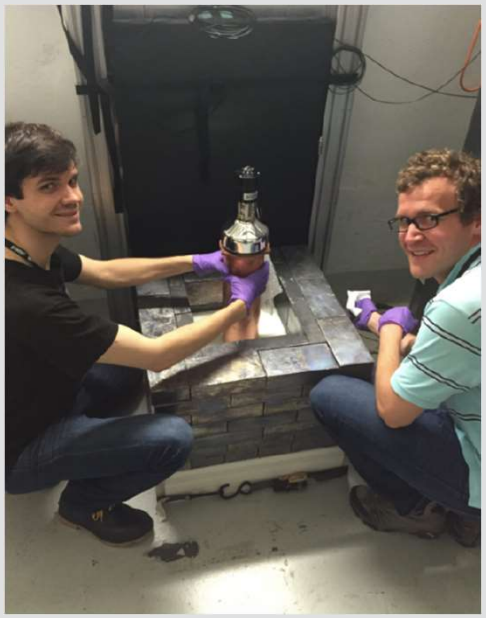
2017 results (~1.5yrs of data)

- 6.7σ discovery of CEvNS
- consistent w/SM within 1σ

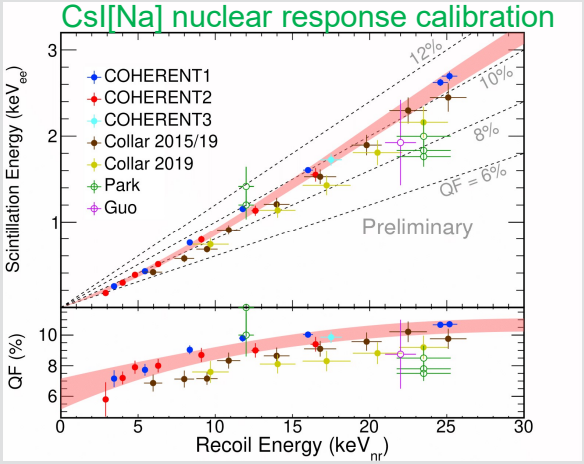


COHERENT with CsI[Na]

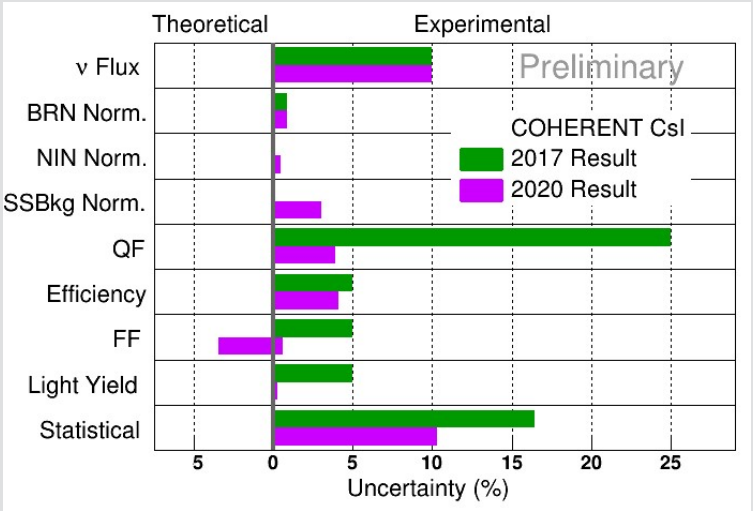
- recently updated results with 2.2x more data (compared to 2017 result)
- analysis improvements
- new quenching factor (nuclear response) measurements/analysis
- resulting in reduced errors



CsI[Na] nuclear response calibration

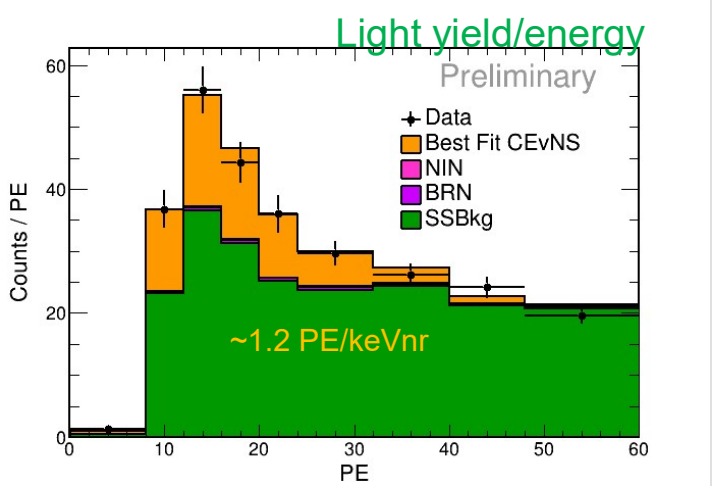


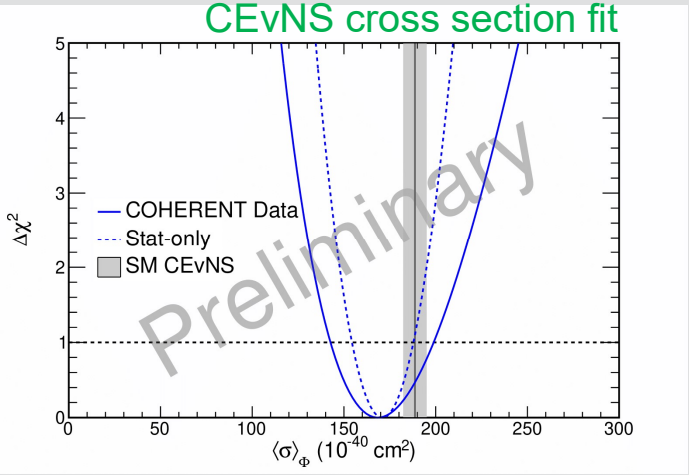
CsI[Na] uncertainties comparison

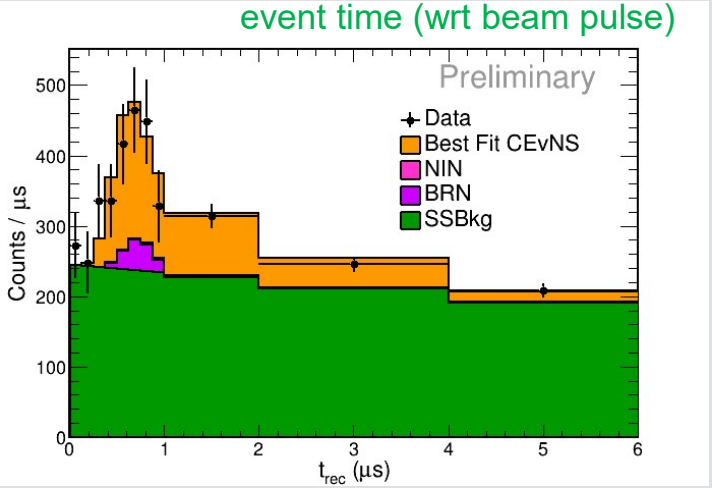


COHERENT, updated CsI results:

Best-fit results	
Steady-state background	1273
Beam-related neutrons	17
Neutrino-induced neutrons	5
CEvNS	306







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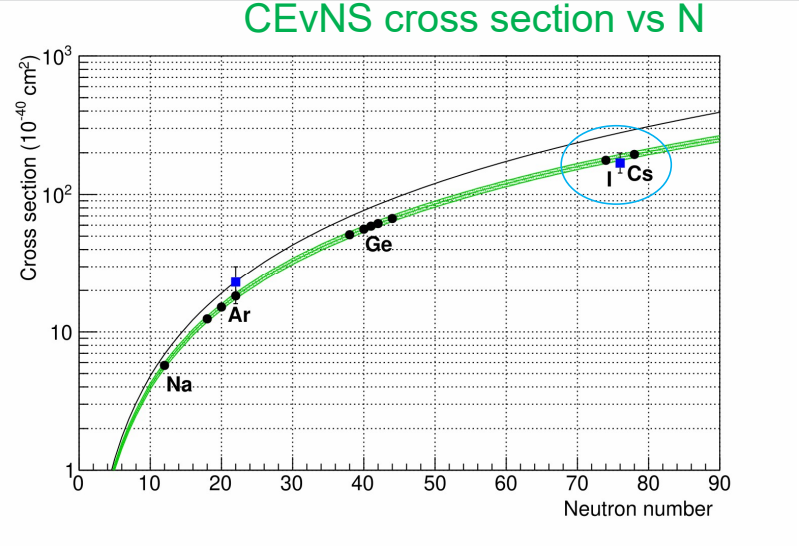
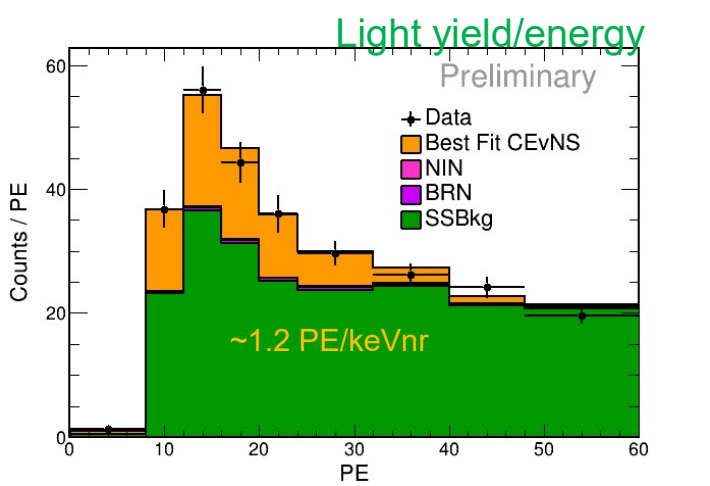
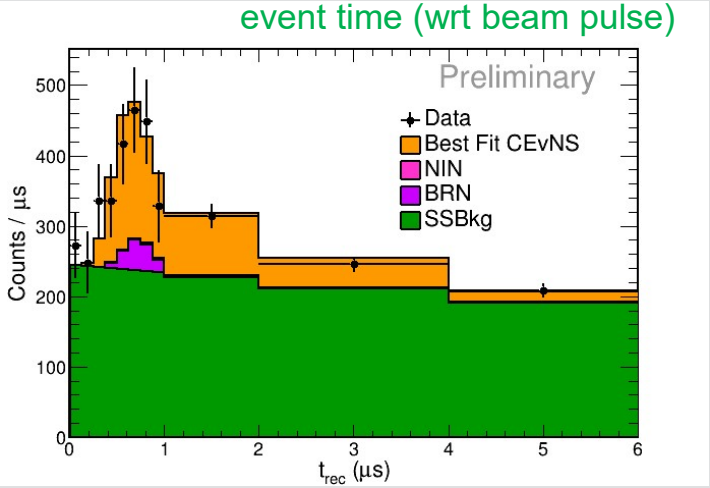


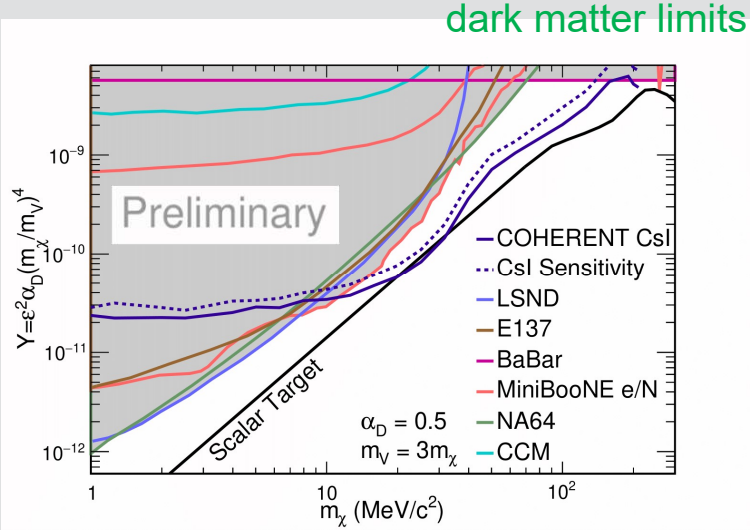




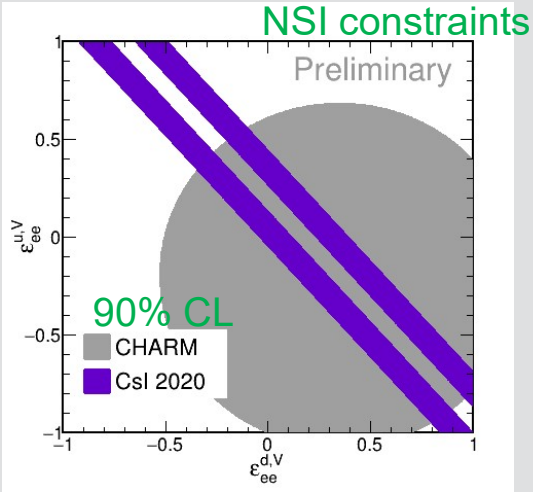
COHERENT, updated CsI results, physics:

- Updated CsI data improves upon previous non-standard interaction (NSI) constraints
- Separately measured ν_μ /ν_e cross sections as allowed in NSI scenarios.
- New limits on sub-GeV accelerator-produced dark matter. First result with limit beyond scalar target (matching DM relic abundance)
- Papers on CsI cross section, dark matter, and quenching factors imminent

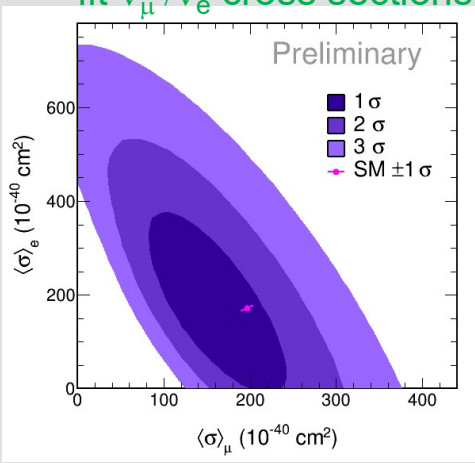
dark matter limits



NSI constraints



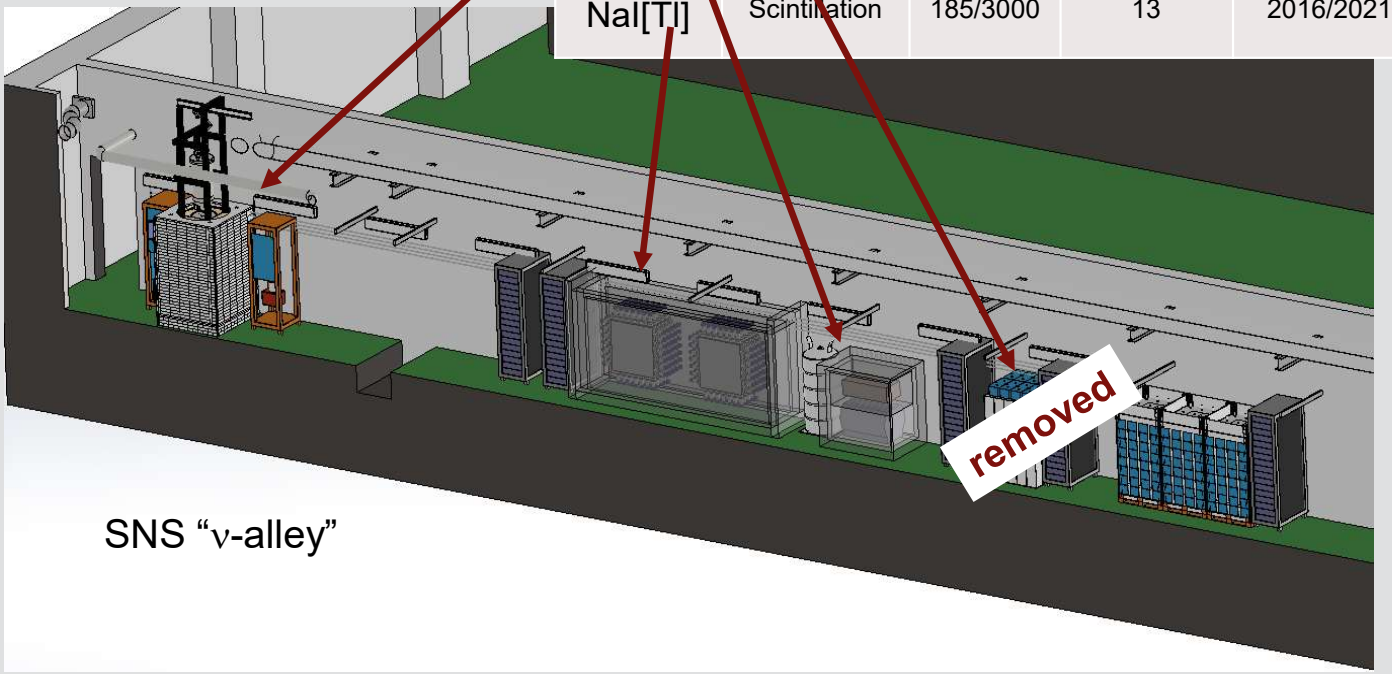
fit ν_μ /ν_e cross sections



(more) COHERENT detectors

COHERENT program continues with additional detectors

Target	Technology	Fid. Mass (kg)	Threshold (keV_{nr})	Commission dates
CsI[Na]	Scintillation	14.6	6.5	2015
Liquid Ar	Scintillation	24.4/610	20	2017/≈2023
Ge	Ionization	16	1-2	2021
NaI[Tl]	Scintillation	185/3000	13	2016/2021



SNS "ν-alley"

(more) COHERENT detectors

COHERENT program continues with additional detectors

Target	Technology	Fid. Mass (kg)	Threshold (keV_{nr})	Commission dates
CsI[Na]	Scintillation	14.6	6.5	2015
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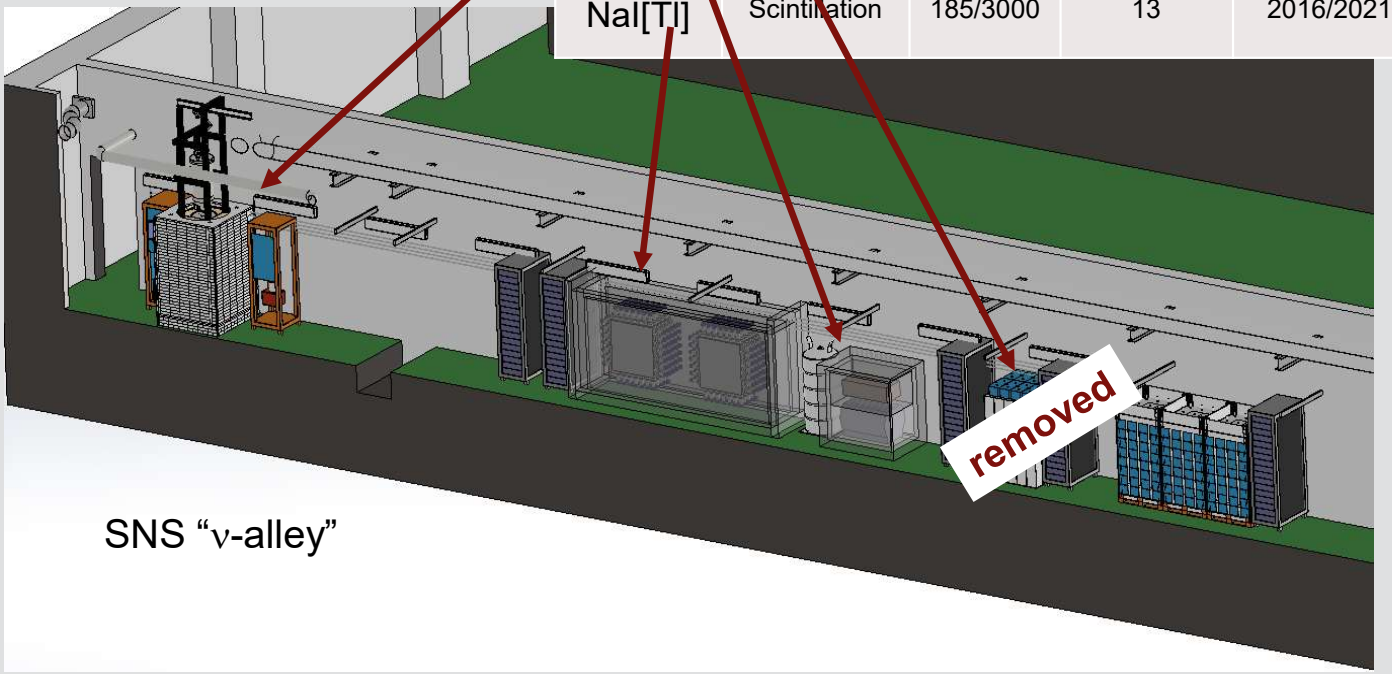
NaI[Tl]	Scintillation	185/3000	13	2016/2021

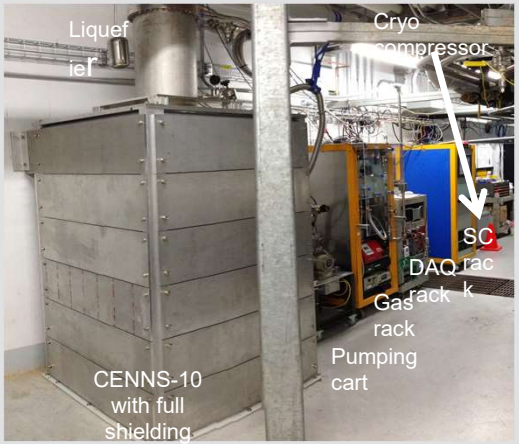


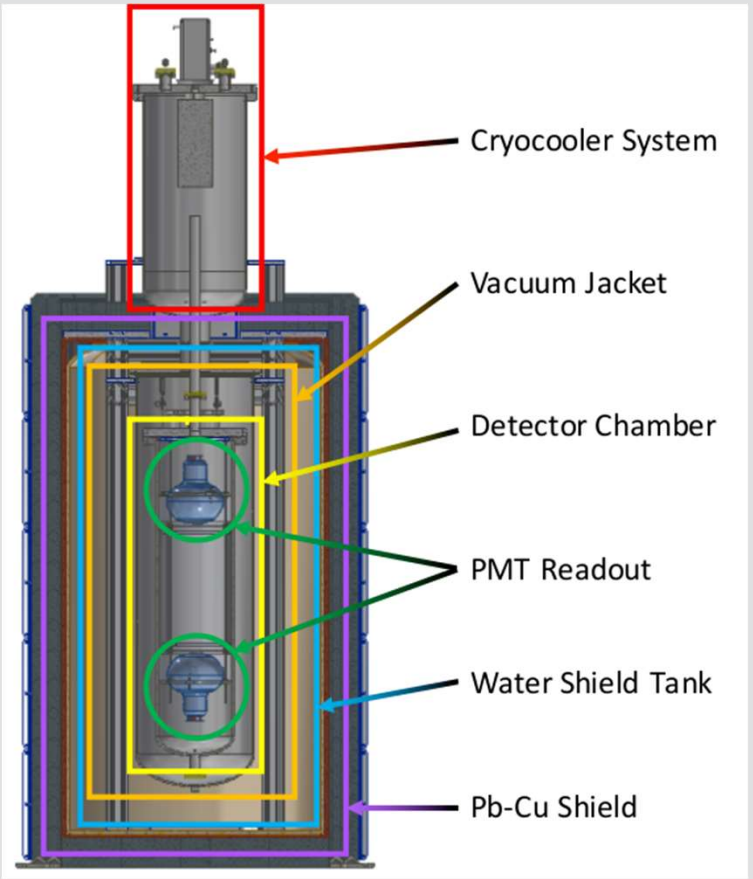
SNS "ν-alley"

The CENNS-10 (CohAr-10) Detector:

Specs:

- 24 kg LAr fiducial volume
- 2 × Hamamatsu 8”PMTs w/QE=18%@400 nm
- TPB-coated PMTs/teflon side walls
- Energy threshold ≈ 20keVnr
- CAEN 1420 (250MHz, 12-bit) digitizer
- 90W single-stage pulse-tube cold head
- SAES MonoTorr gas purifier for ~1 ppm purity
- Pb/Cu/H2O shield
- Expect ≈140 CEvNS events/SNS-year (7GWhr)
- Running in current configuration since July ‘17

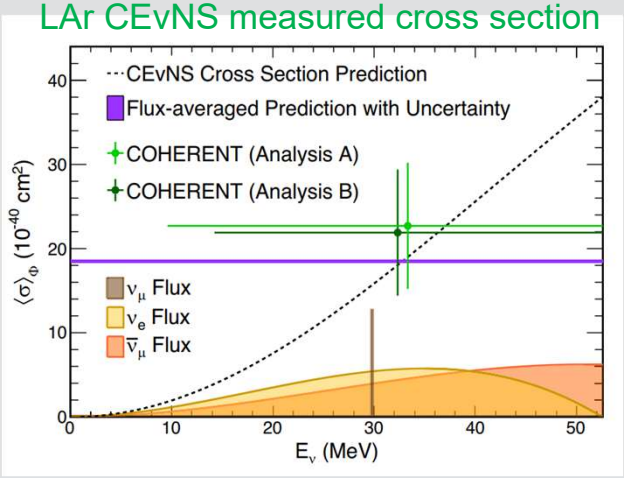




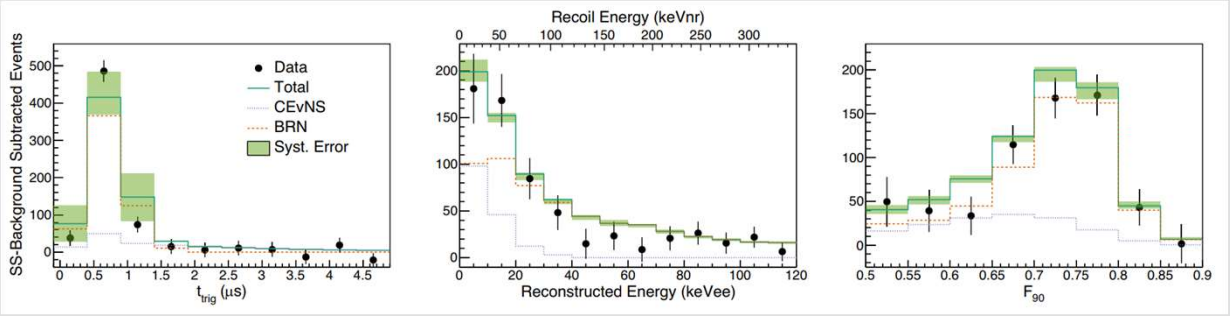
COHERENT LAr results:

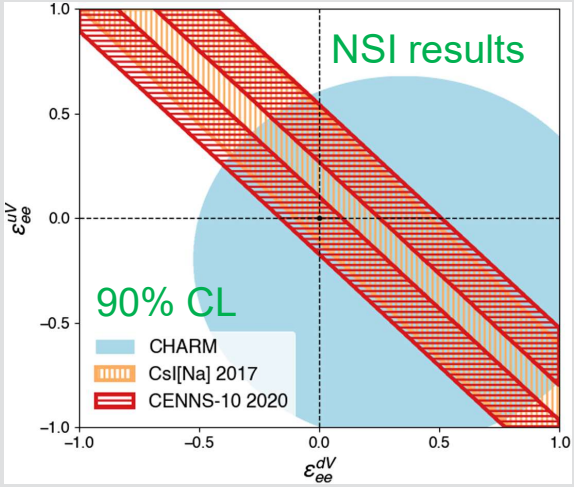
- Evidence for CEvNS in LAr at >3σ
- Measured cross section agrees between 2 analyses and with standard model within 1σ
- NSI parameters further constrained
- See DOI: 10.1103/PhysRevLett.126.012002 and *JINST* 16 (2021) 04, P04002
- data set has since increased by ~3x, updated results soon

LAr CEvNS measured cross section



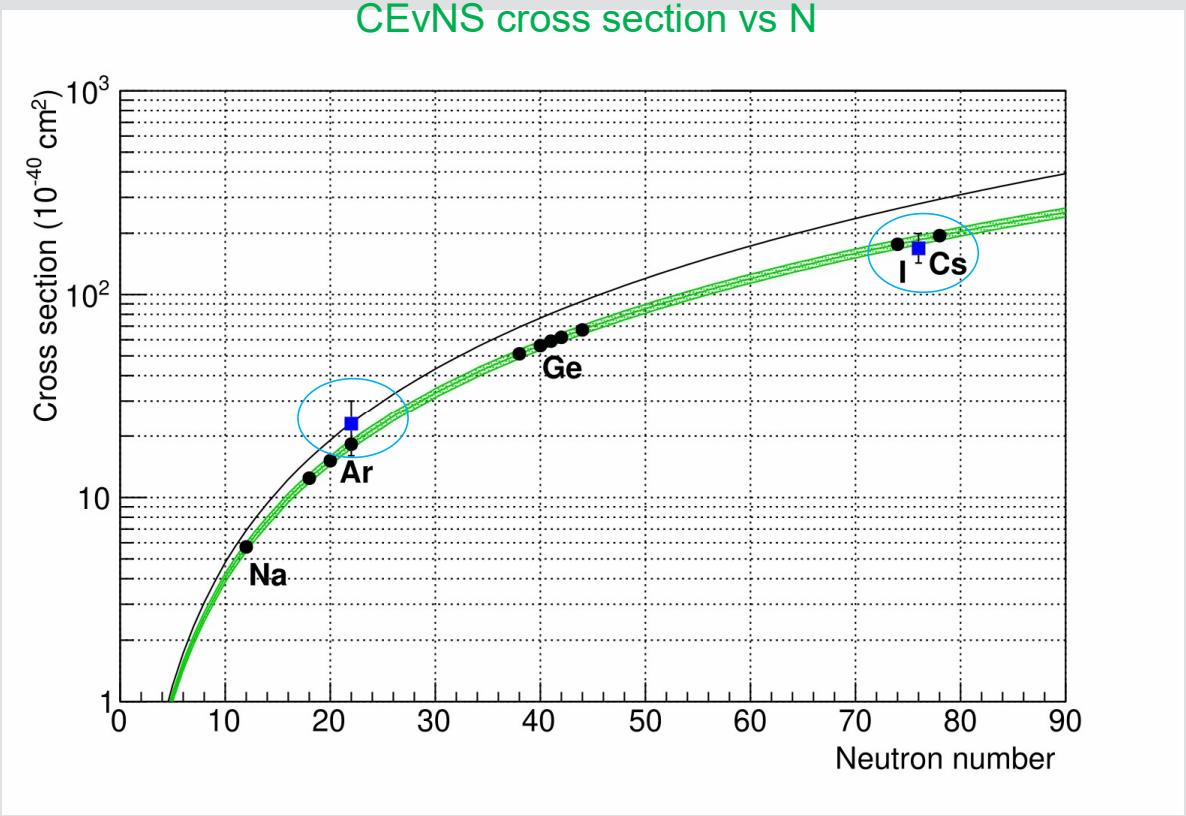
LAr CEvNS fit results





COHERENT LAr analysis:

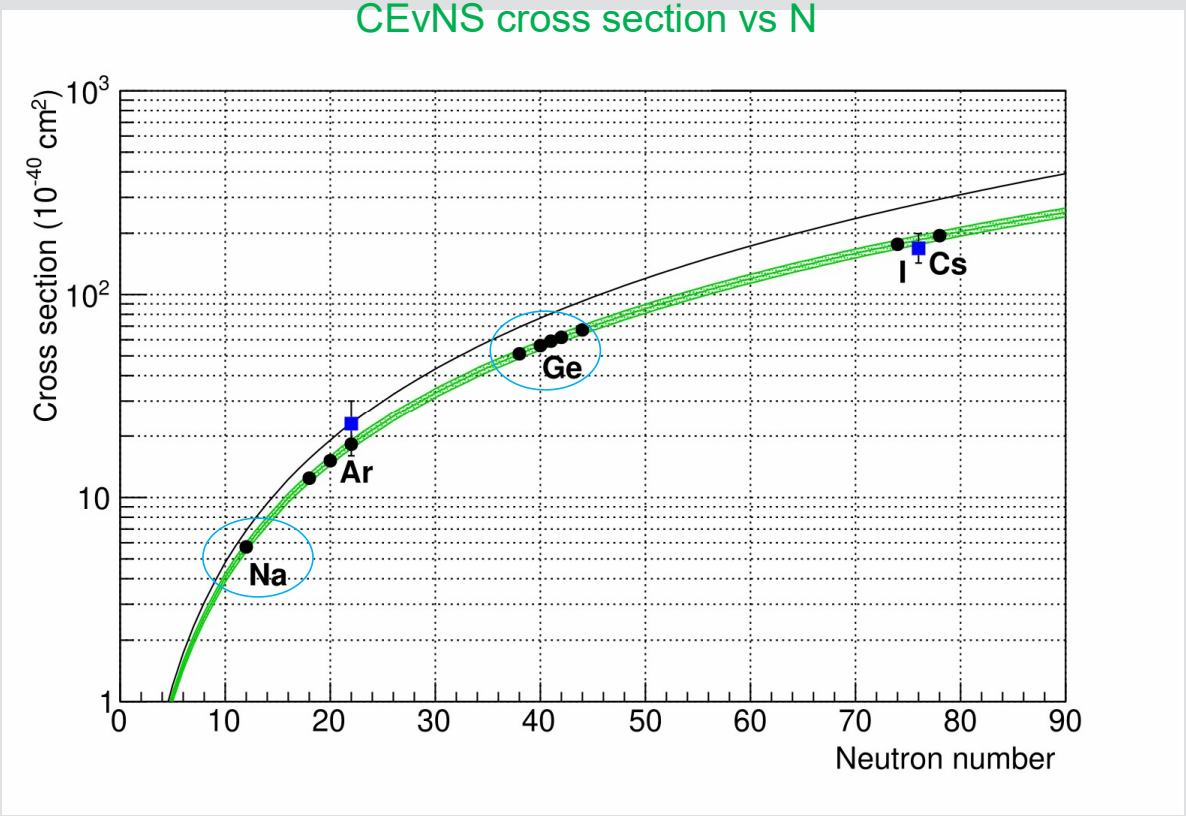
- with LAr result, together with CsI, have measured N^2 - dependence of CEvNS



near-future COHERENT detectors:

- with LAr result, together with CsI, have measured N^2 - dependence of CEvNS

- but continuing work to improve this…



near-future COHERENT activities:

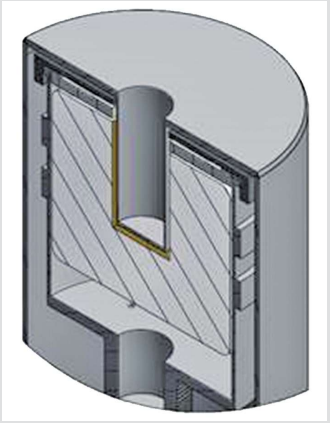
2022: 2 new CEvNS detectors/nuclear targets: Ge, NaI

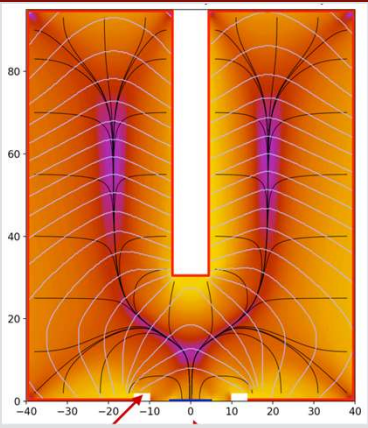
Target	Technology	Fid. Mass (kg)	Threshold (keV_{nr})	Commission dates	Pubs/status
CsI[Na]	Scintillation	14.6	6.5	2015	1st result, 2017: 10.1126/science.aao0990 updated results in press, detector removed
Liquid Ar	Scintillation	24.4/610	20	2017/≈2023	1st result, 2019: 10.1103/PhysRevLett.126.012002, currently running
Ge	Ionization	16	1-2	2022	commissioning: 2022
NaI[Tl]	Scintillation	3000	13	2022	commissioning: 2022

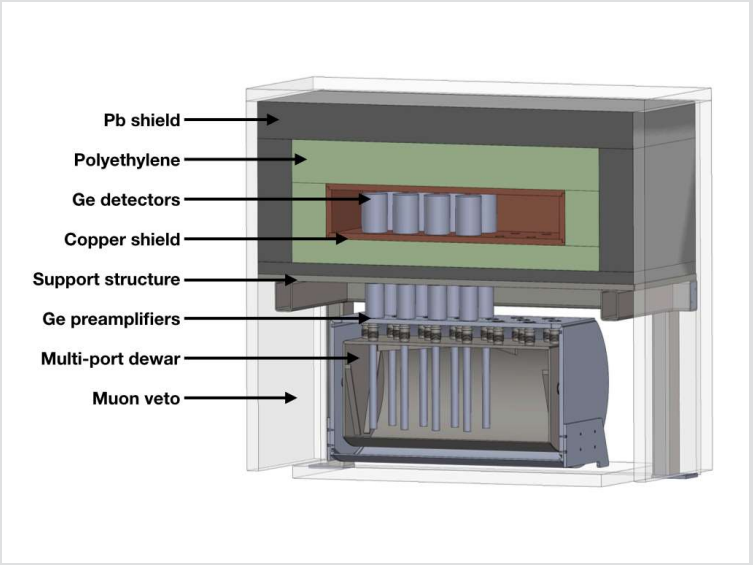
near-future COHERENT activities:

Germanium:

- P-Type Point Contact Ge detectors well-suited to precision CEvNS measurements
- 8 >2kg detectors , all delivered!
- deployment work in progress
- commissioning in 2022



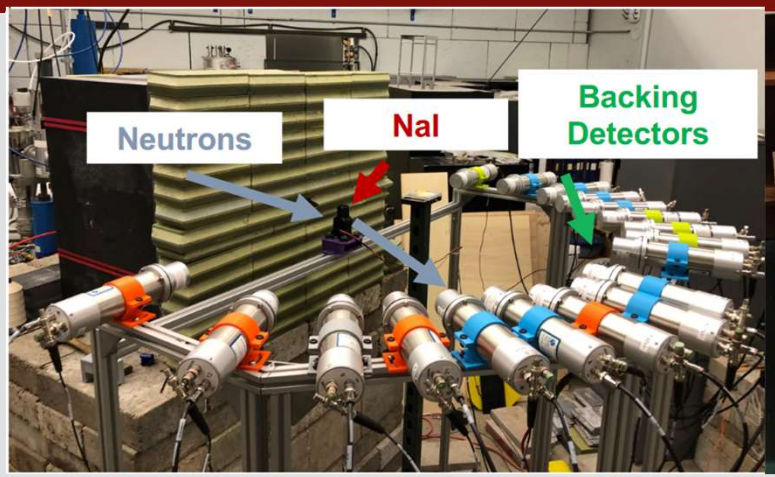


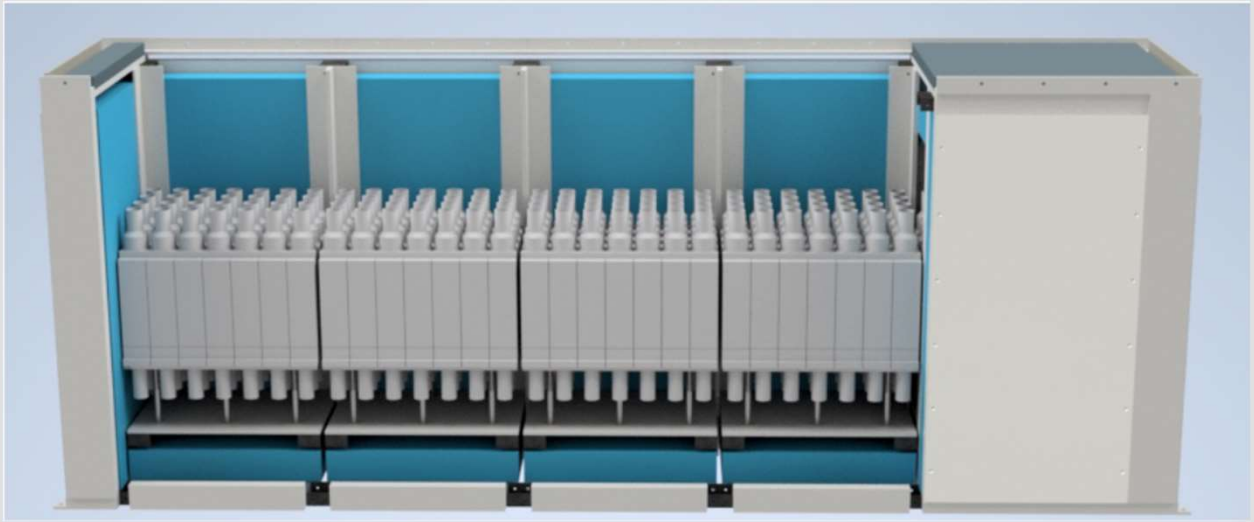


near-future COHERENT activities:

Sodium-Iodide:

- Multi-ton array of ~8kg NaI crystals
- detectors on-hand
- deployment work in progress
- commissioning in 2022

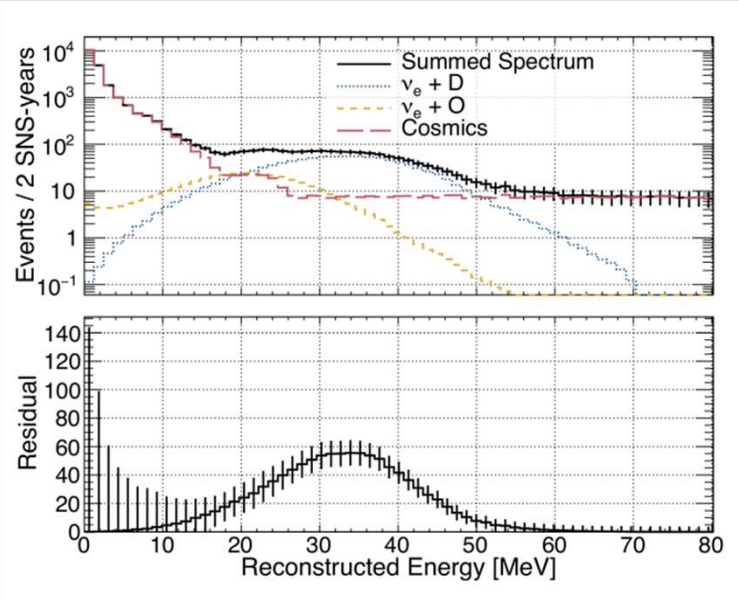


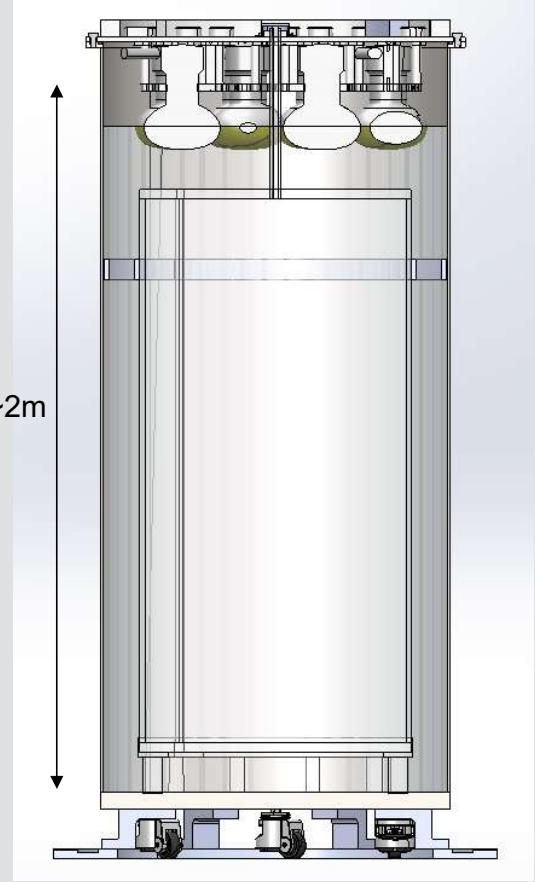


Important new addition to COHERENT :

D2O flux normalization detector:

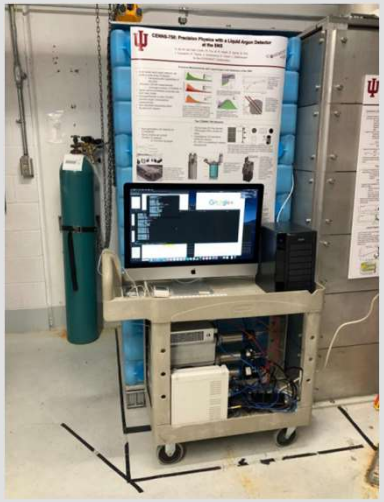
- reduce current 10% flux error to 2-3% from known ν-d CC cross section allowing more precise measurements from absolute measurements.
- Light collection with PMT's on one endcap
- 670kg heavy water fiducial volume in acrylic vessel
- D_2O , PMTs acquired , other components in progress
- *JINST* 16 (2021) 08, 08.

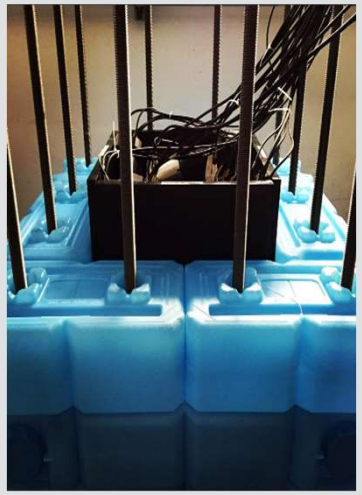




additional COHERENT activities:

detector/ activity	effort began	detector/tools	
NUBEs	2016	Scintillator encased in Pb/Fe, which is surrounded by water to moderate outside neutrons	Measure neutrino-induced neutron production cross sections on Pb and Fe which is a background to CEvNS detectors and a detection channel for supernova burst neutrinos for HALO
NaIvE	2016	185 kg of NaI scintillating crystals	Assess backgrounds for future NaI CEvNS detector, measure ^{127}I inelastic cross sections, a background for 0νββ searches with Xe
MARS	2017	Scintillator covered with Gd paint to observe neutron captures	Mobile neutron flux calorimeter taking measurements throughout neutrino alley
neutron studies	2020	4 x 10 liter scintillator cells	Map the timing of the neutron flux through neutrino alley, determine how neutrons from the target hall are sneaking in
flux work	2010	simulation time	optimized calculation of neutrino flux, assessment of errors from model/data comparisons, submitted to JINST, e-Print: 2109.11049 [hep-ex]

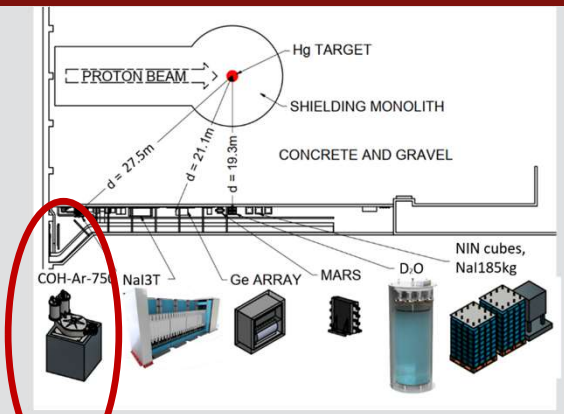


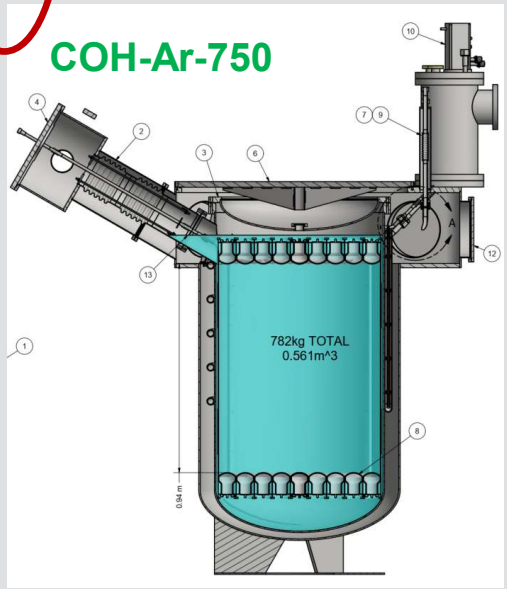


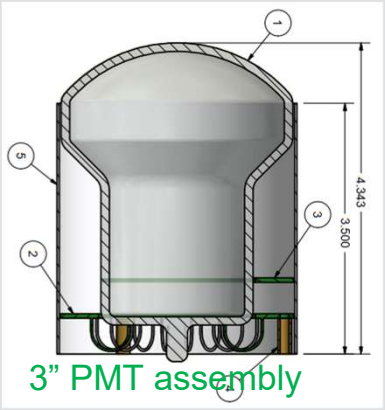
Future ton-scale argon detector: COH-Ar-750

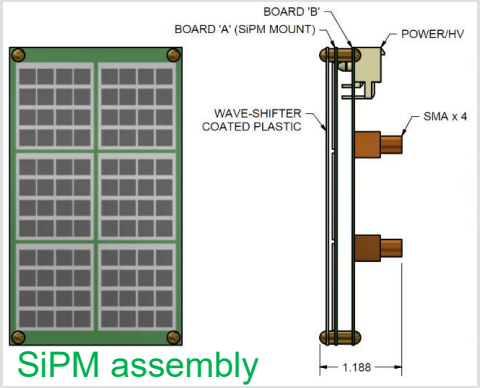
- Single-phase LAr (scintillation-only) calorimeter, 750/**610kg** total/**fiducial**
- Purpose-designed cryostat w/LN2 precool, and dual cryocooler for liquification/gas purification.
- Light collection: 3”PMTs or VUV/VIS SiPMs w/optimal WLS scheme
- Eventual use of underground (low ^{39}Ar) argon.

- ⇒ 3000 CEvNS, 440 inelastic CC/NC events/yr ! to further physics reach of COHERENT









Beyond neutrino alley, at SNS:

Proton Power Upgrade

PPU project: Double the power of the existing accelerator structure

- First Target Station (FTS) is optimized for thermal neutrons
- Increases the brightness of beams of pulsed neutrons
- Provides new science capabilities for atomic resolution and fast dynamics
- Provides a platform for STS

Larger Neutrino Experimental Hall Possible at STS: 2 10-ton Detectors

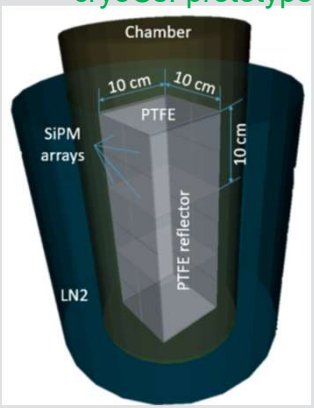
Second Target Station

STS project: Build the second target station with initial suite of beam lines

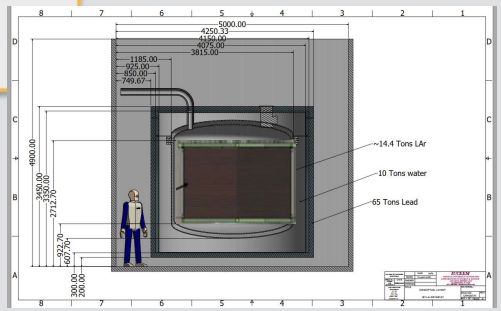
- Optimized for cold neutrons
- World-leading peak brightness
- Provides new science capabilities for measurements across broader ranges of temporal and length scales, real-time, and smaller samples

Slide from Ken Herwig, Workshop on Fundamental Physics at the Second Target Station (FPSTS18)

cryoCsI prototype



10ton LAr



- Discussions in progress for neutrino experiment hall in STS
- possible detectors: ~10LAr calorimeter, TPC, cryoCsI

Summary

- First measurements of CEvNS on CsI, Ar have been made with COHERENT at the SNS!
- Multiple physics motivations drive further work on additional/larger detectors for more precise measurements in neutrino alley and beyond.

Thanks to ORNL/SNS, Fermilab, NSF, DOE.
and to COHERENT collaboration for excellent work (and material for this talk!)…