The COHERENT experiment

Janina Hakenmüller for the COHERENT collaboration

Duke UNIVERSITY

AAP 2024 Aachen, 30th of October

Coherent elastic neutrino nucleus scattering (CEvNS) at SNS

Spallation Neutron Source (SNS), Oak Ridge National Laboratory, Tennesse, USA

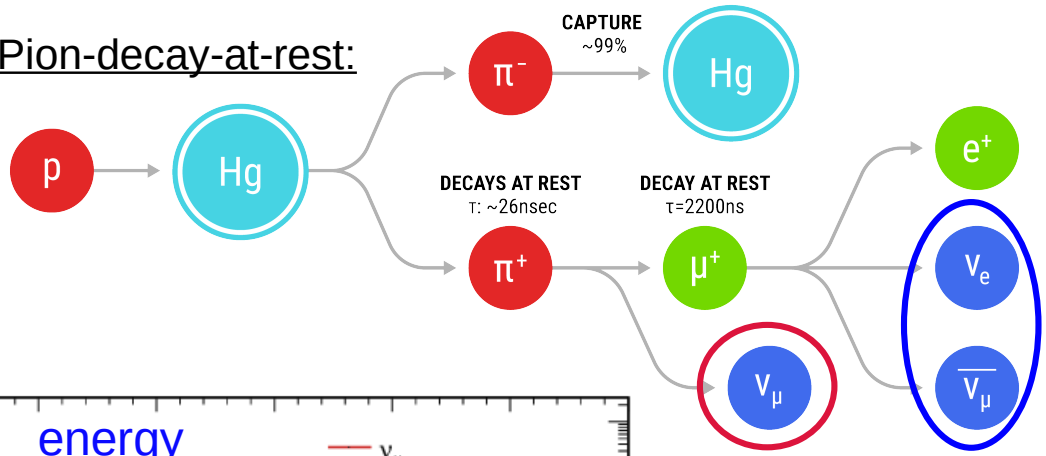
COHERENT collaboration

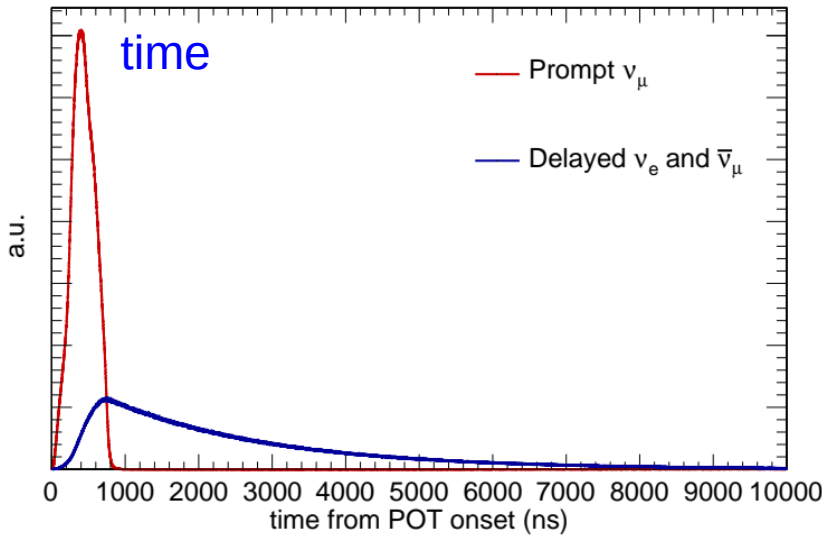
Neutrino spectra from SNS

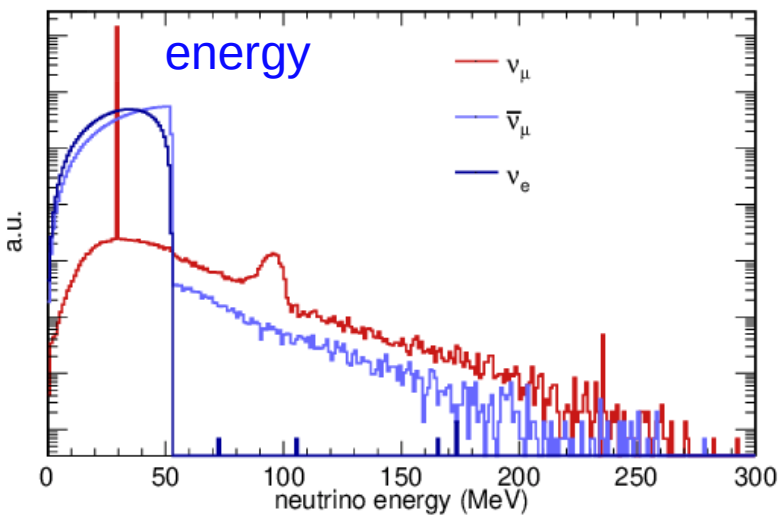
Pulsed proton beam with 60Hz:

- up to 1.7 MW power since this summer, ~10^{20} protons on target/d
  → ~0.3 ν per proton on target
- background rejection factor by beam time structure

Pion-decay-at-rest:

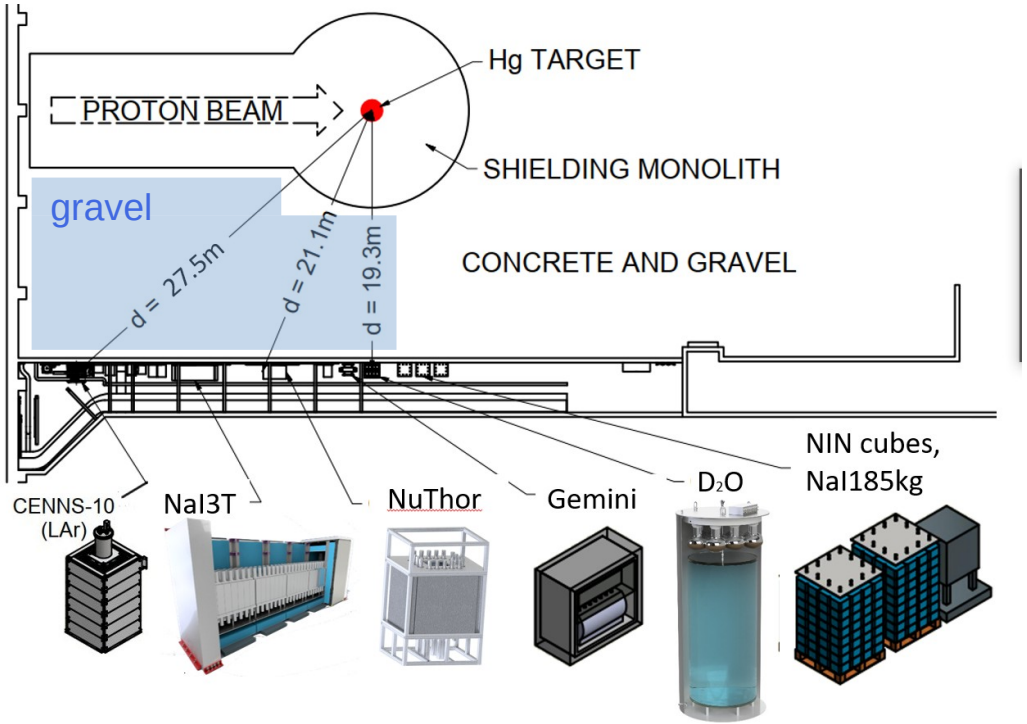






D. Akimov et al., Science 10.1126/science.aao0990, 2017

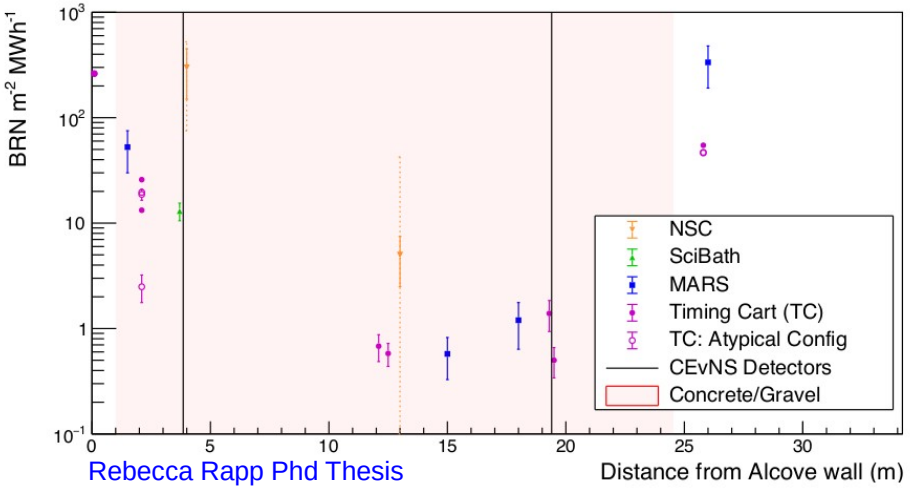
today



several types of detectors → N^2 dependence

Beam-related backgrounds:

- beam-related neutron (BRN) measurements:



Rebecca Rapp Phd Thesis

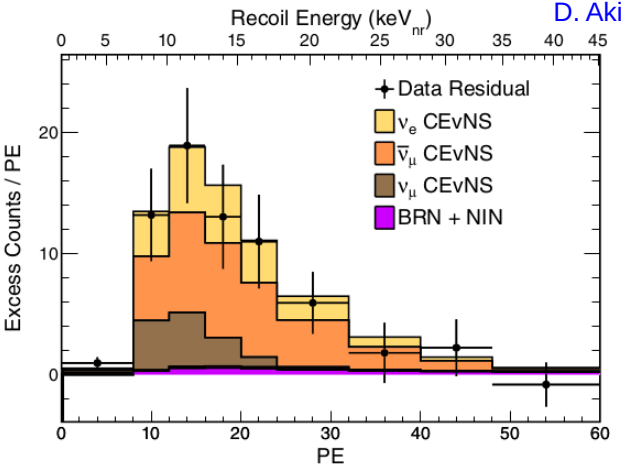
- neutrino-induced neutrons (NINs)

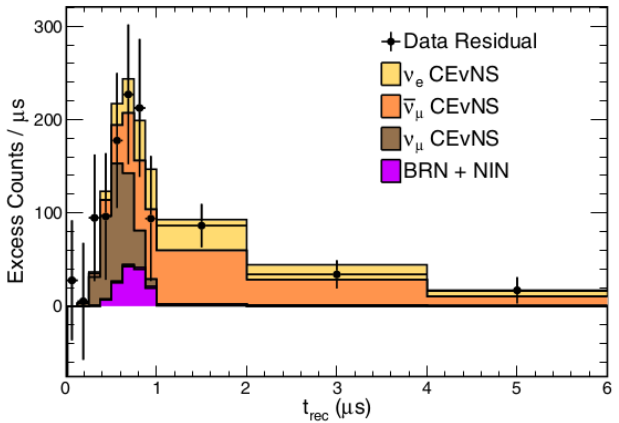
Steady-state:

- cosmic ray background → 7 m w.e. overburden
- gamma ray background from environment and hot-off gas pipe (511 keV)

CsI and LAr results

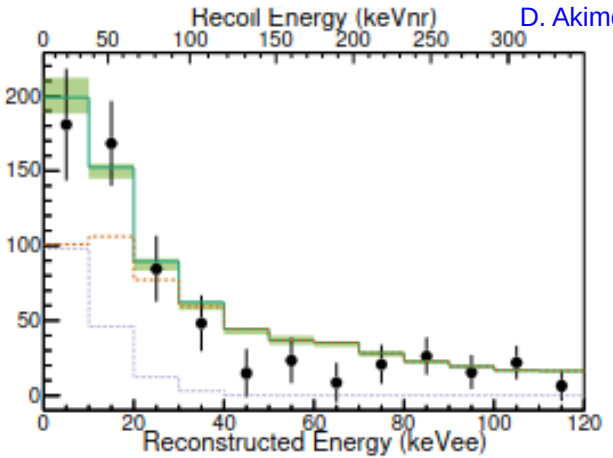
D. Akimov et al. Phys. Rev. Lett. 129, 081801,2022

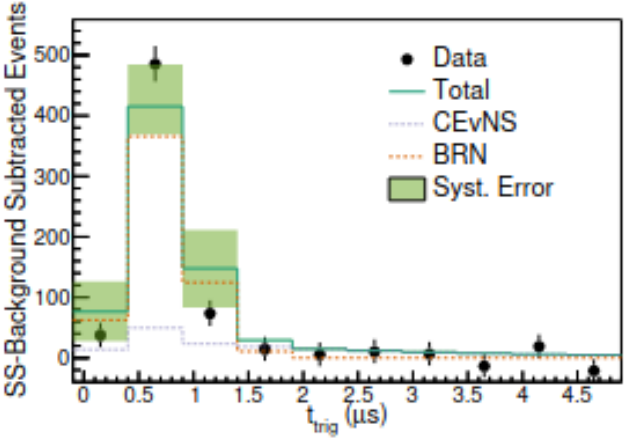




Mass: 14.6 kg
Threshold: 5 keV$_{nr}$
Significance: 11.6 σ (final)

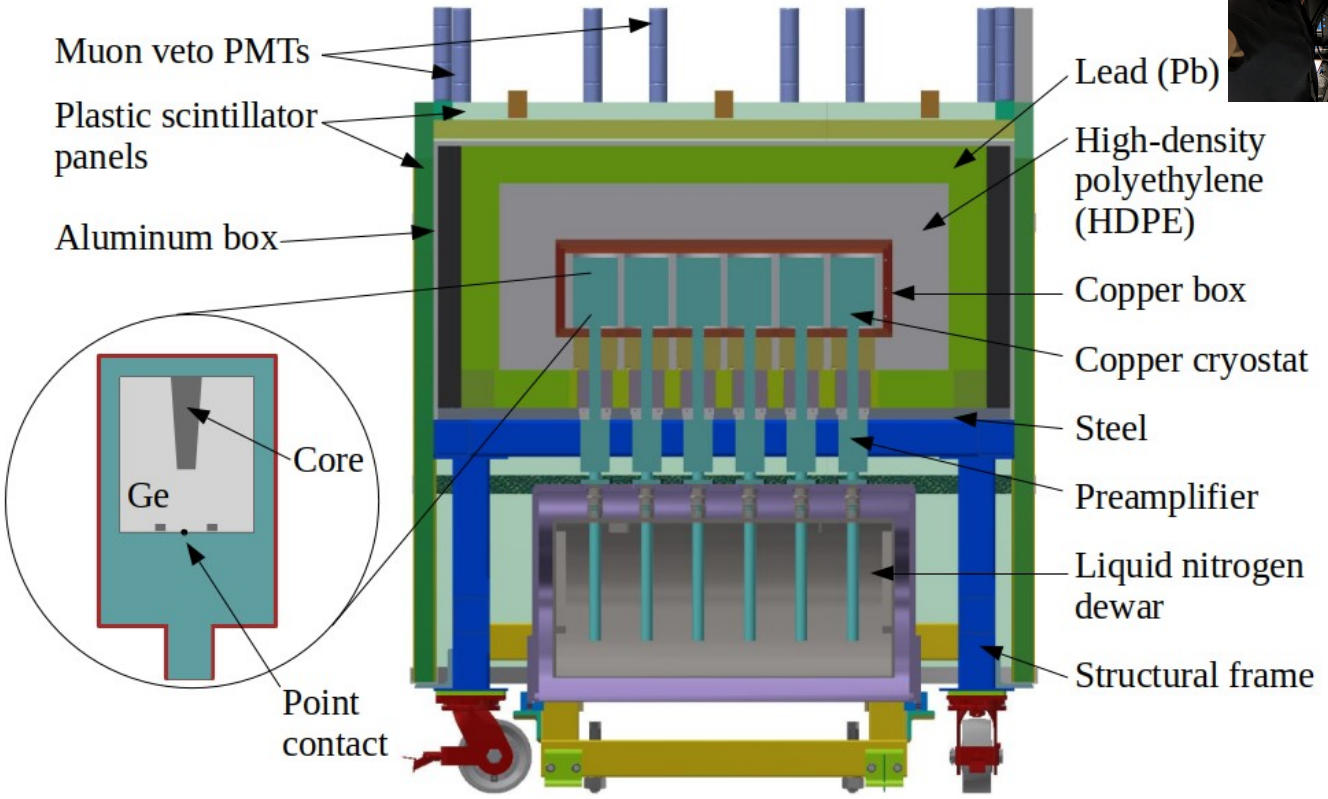
D. Akimov et al. Phys. Rev. Lett. 126, 012002, 2021

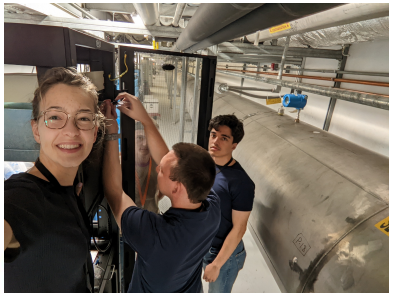


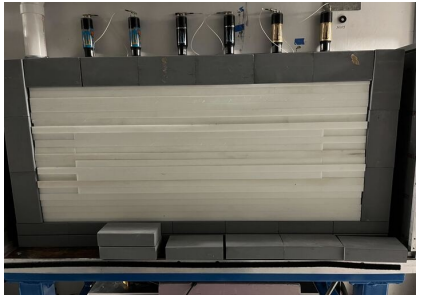


Mass: 24 kg
Threshold: 20 keV$_{nr}$
Significance: 3.5 σ
→ three times more statistics collected

Ge-Mini







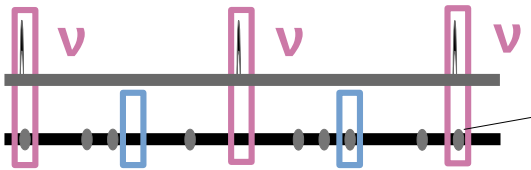
distance to target: (19.2+-0.1)m, former CsI location
in total 8 detectors with ~2.2 kg each

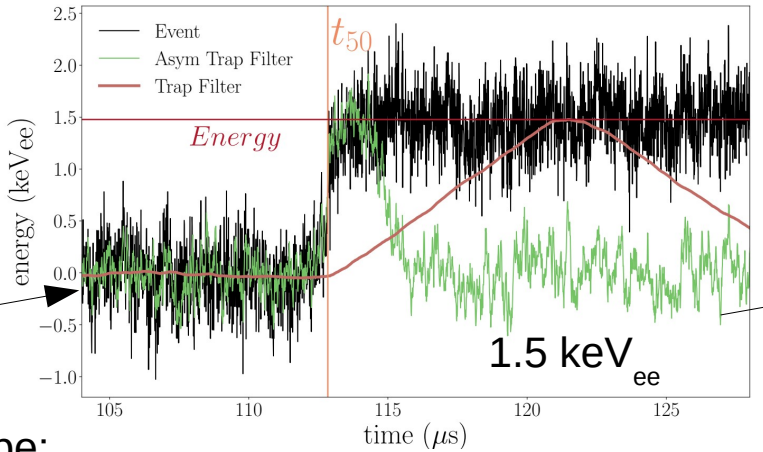
Ge-Mini analysis

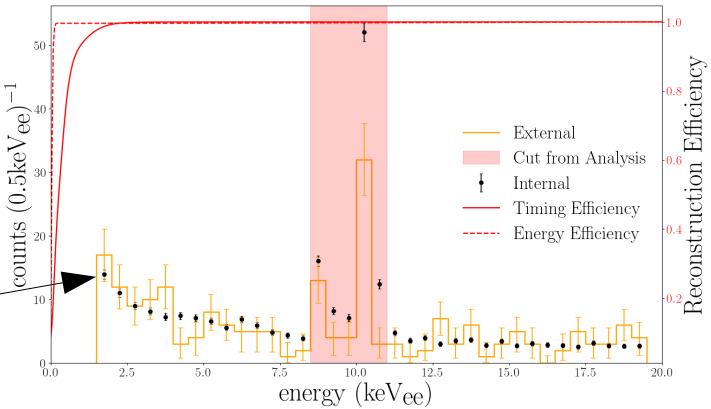
Campaign-2 physics run: 6/21/23 - 8/15/23

internally triggered: calibration

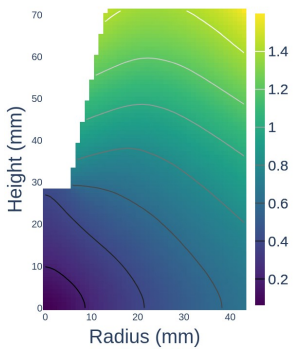
externally triggered: 120 Hz

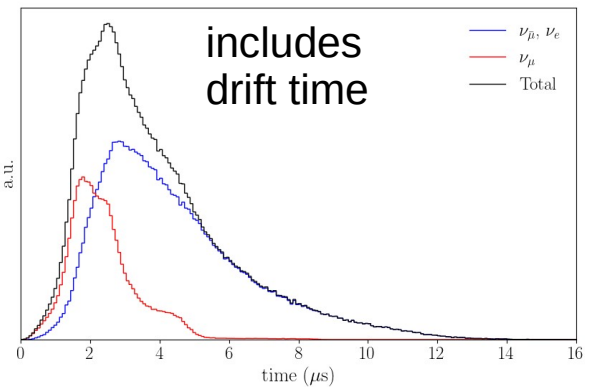


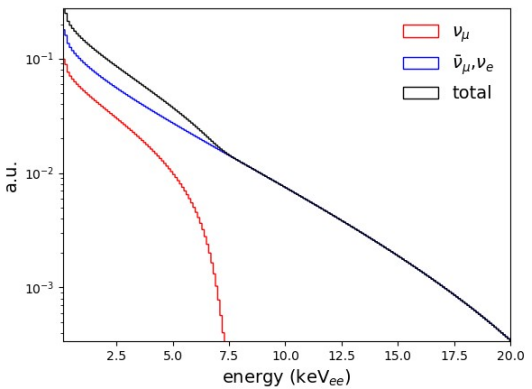




Signal expectation and shape:



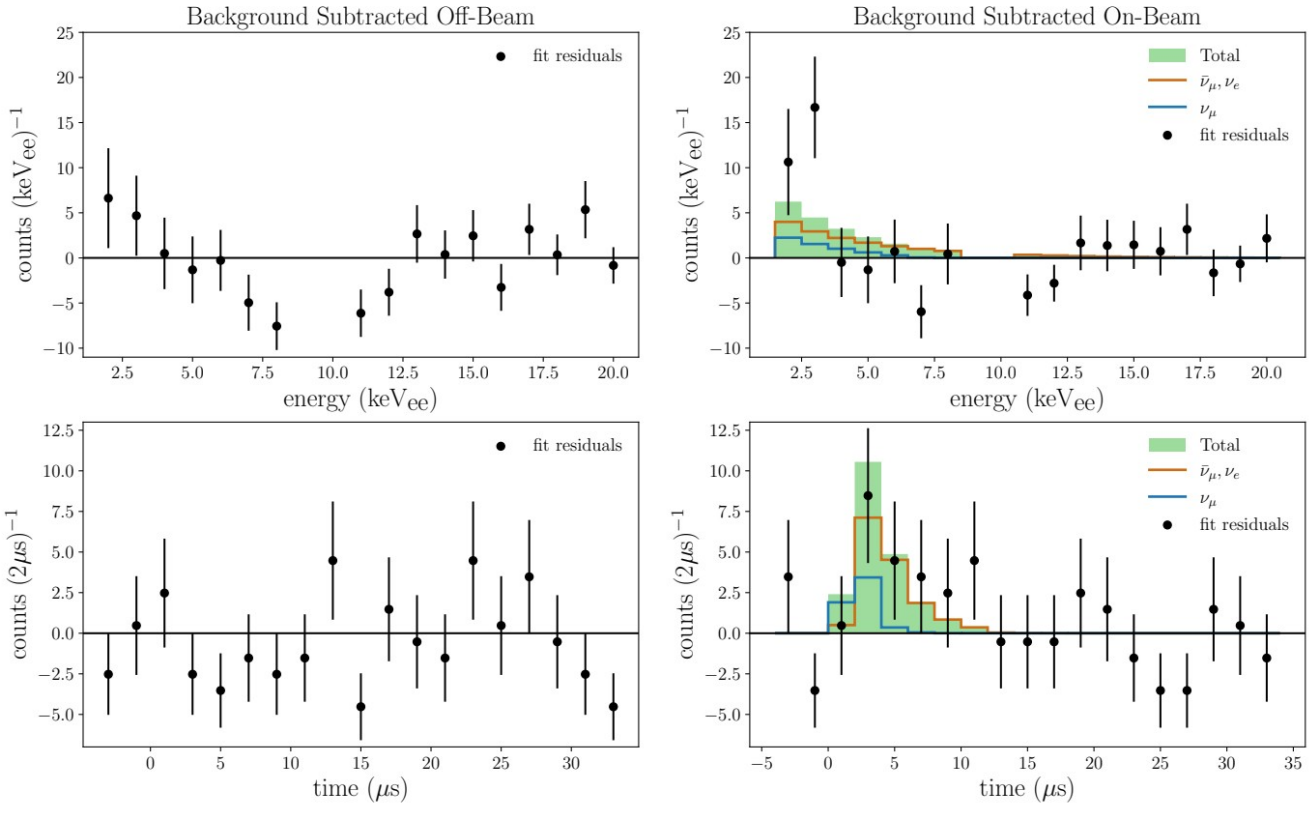




includes quenching
(Lindhard theory, k=0.157)
includes form factor
(~32% reduction of rate)

Ge-Mini result

arXiv:2406.13806 (2024)



Total mass in analysis: 11.07 kg

Unbinned likelihood fit

CEvNS:	20.6 -6.3 +7.1
BRN:	0.7 ±0.3
Background:	161.7 -9.1 +9.5
SM expectation:	35.1 ±3.6

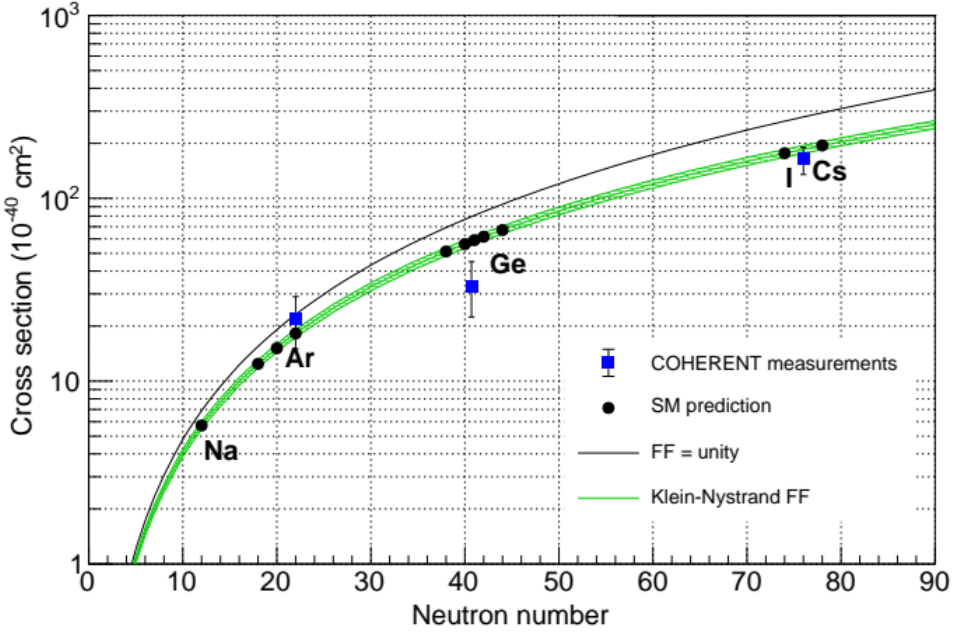
*Null hypothesis rejected by **3.9** sigma!*

Uncertainty	contribution
flux	10%
distance	0.5%
energy calibration	1%
active mass	2%
form factor	1%
quenching Ge	negligible
all	10.3%

+30% statistical uncertainty

First CEvNS detection on germanium!

Towards precision CEvNS detection



precise measurement of neutrino flux: D_2O

- Cherenkov heavy water:
  charged current deuteron scattering
  → well known cross section
- great reduction on neutrino flux uncertainty:
  ~10% → 2% (5 SNS years)
- one module operating,
- second under construction
- charged current neutrino oxygen scattering cross section (supernova detection)

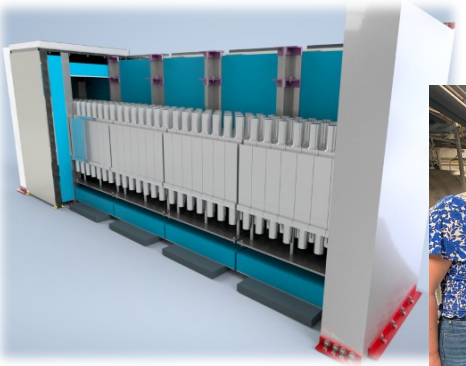
COHERENT collaboration
2021 JINST 16 P08048

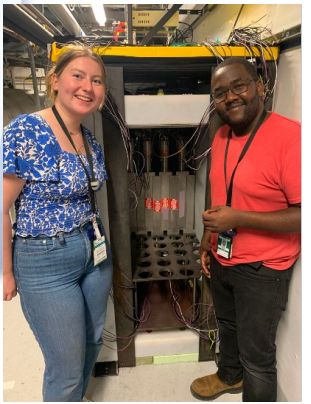
COH-Ar-750 and NaIvETe

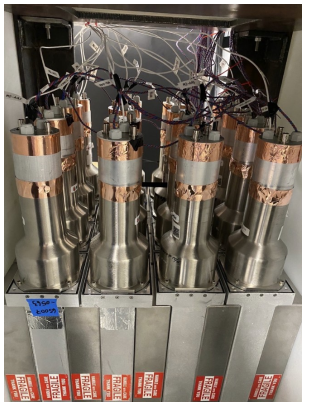
More mass!

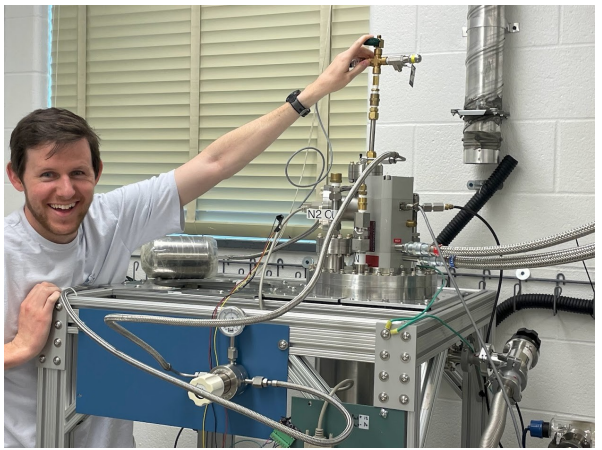
COH-Ar-750: ton-scale (~480 kg)

- 3” PMTs with cryogenic photocathode, TPB coated reflectors → <20 keV$_{nr}$ threshold
  => **~5000** CEvNS events per year,
  ~500 inelastic events/year
- PMT characterization and TPB coating
- working cryostat in place summer 2025









NaI scintillating crystals (Tl doped):

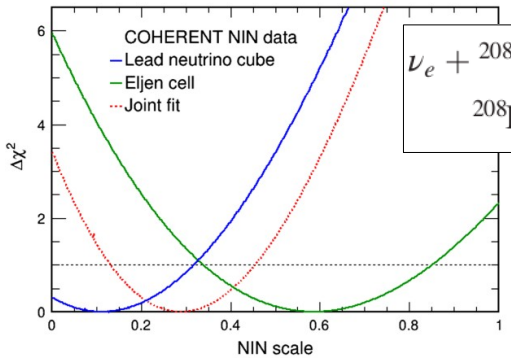
- since 2016: NaIvE 185 kg
  → increase to 3.4t → **NaIvETe**
  → CEvNS on Na (lighter isotope, unpaired proton probes axial vector coupling), I
- completion of modules 2025,
  DAQ upgrade, background studies

Charged current & neutrino-induced fission

Higher energies!

Neutrino Cubes (Pb, Fe):

- neutrino-induced neutrons on Pb



$$\nu_e + {}^{208}\mathrm{Pb} \rightarrow e^- + {}^{208}\mathrm{Bi}^*$$
$${}^{208}\mathrm{Bi}^* \rightarrow {}^{208-X}\mathrm{Bi} + \mathrm{X}n + \mathrm{Y}\gamma$$

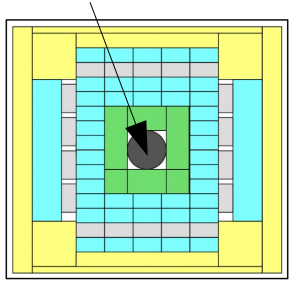
~29% of nominal Marley prediction

P. An et al., Phys. Rev. D 108, 072001

NuThor:

neutrino induced fission

52 kg thorium metal

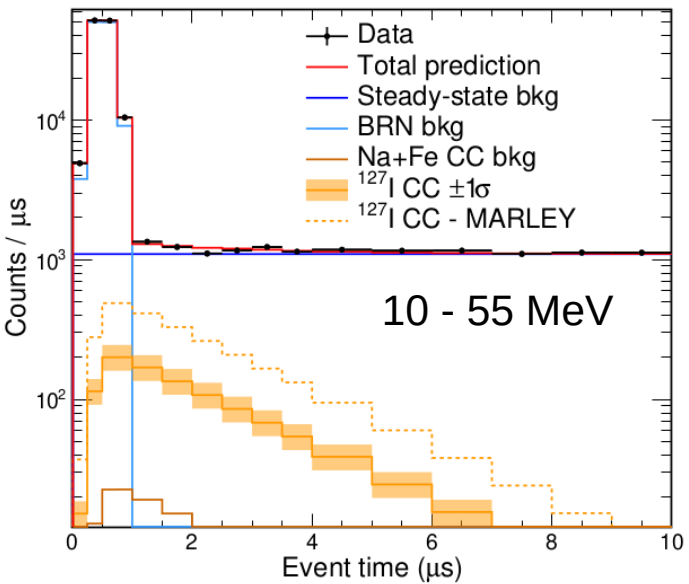


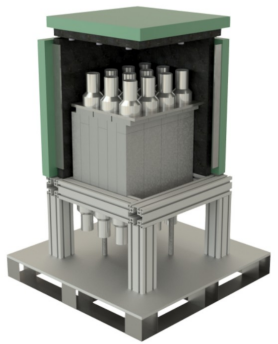
NaIvE (deployed in 2016-2024)

- 185 kg NaI(Tl) scint. Crystals
- charged current on I: $^{127}\mathrm{I}(\nu_e,e^-)^{127}\mathrm{Xe}$

  → 5.8 σ evidence

  ~41% of nominal Marley prediction (with supplied GT strength)





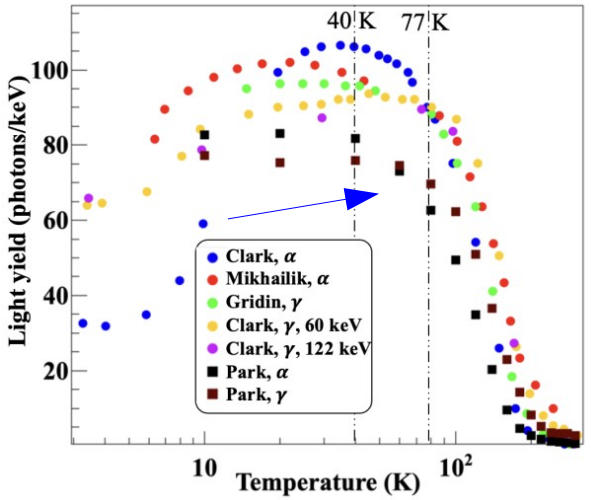
P. An, et al., Phys. Rev. Lett. 131, 221801 (2023)

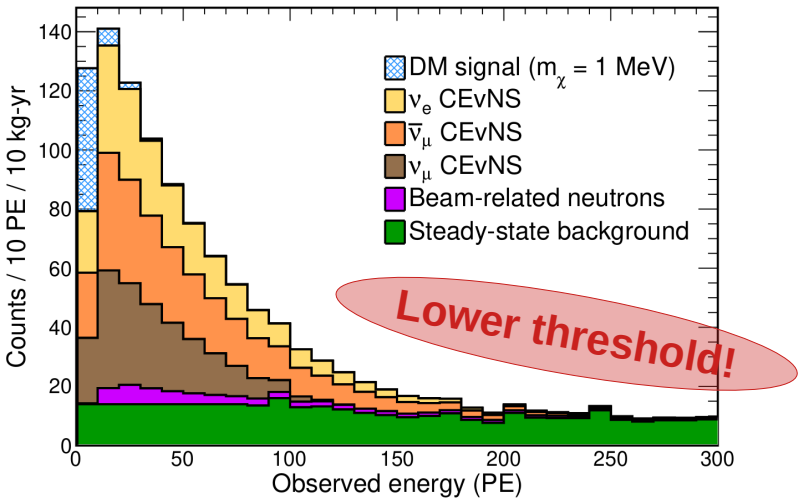
CryoCsI & Cherenkov detector

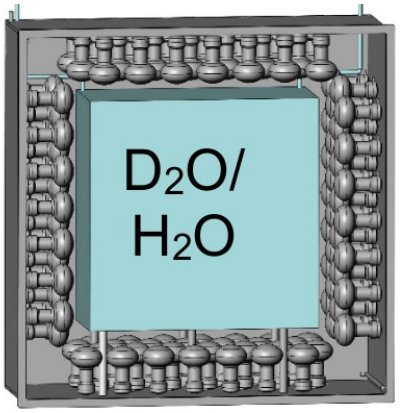
COH-CryoCsI

- doped CsI → undoped CsI
- cryo: maximal light yield, minimal afterglow at 40 K
- ~1.4keV$_{nr}$ threshold in reach
- mass: 10kg concept, extension to 750kg

https://arxiv.org/abs/2311.13032

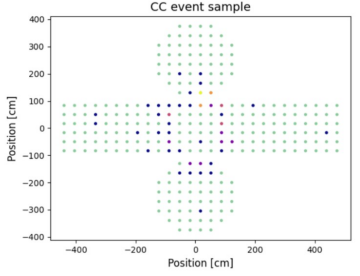




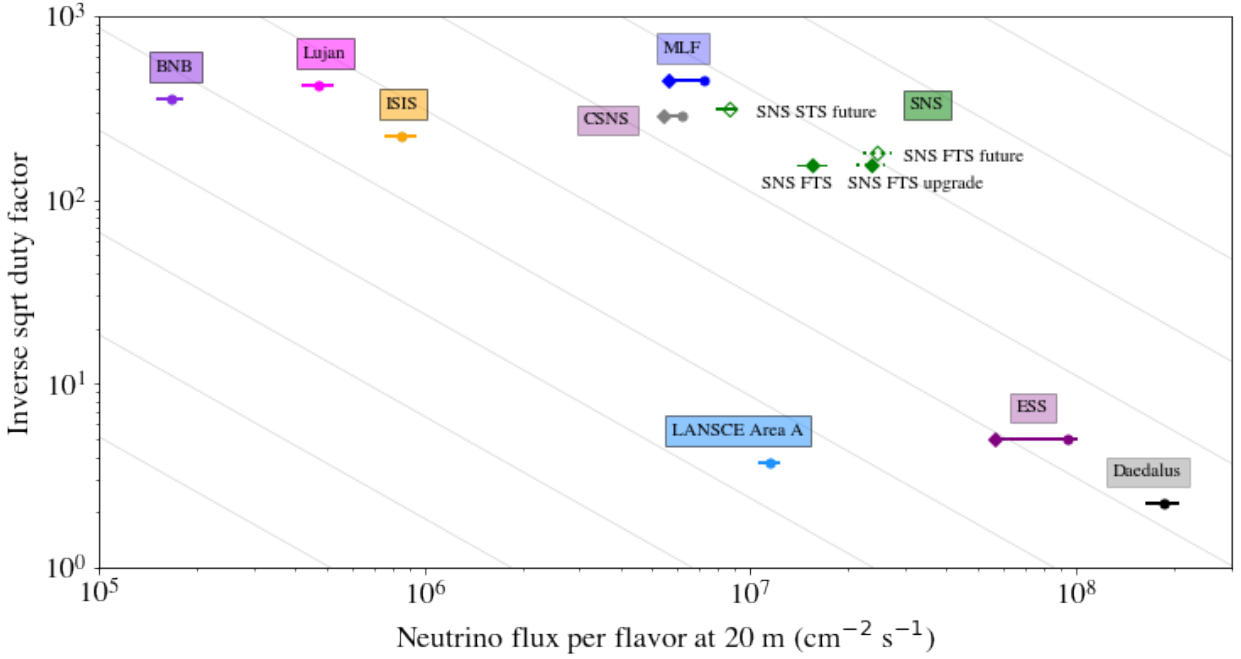


Fully instrumented water Cherenkov detector

- ton-scale, high light collection, ring reconstruction → directional Information
- ν_e charged current differential cross section
- fully characterize interaction response for supernova detection



SNS future



- **exploration of new locations**
- **Proton Power Upgrade (PPU)**
  beam energy: 1.0 GeV → 1.3 GeV, beam power: 1.4 MW → 2.0 MW
- **Second Target Station (STS)** (expected completion: **early 2030s**)

Summary and outlook

Coherent elastic neutrino-nucleus scattering (CEvNS) at SNS (pion-decay-at-rest)

→ coherency condition fullfilled (<50MeV)

→ 60 Hz pulsed beam => backgroud suppression

COHERENT at SNS:

detection 2017 with CsI (first ever)

detection 2021 with LAr

2023 (Ge-Mini): First detection of CEvNS on germanium!

rejection of null hypothesis at 3.9 sigma

upcoming:

more statistics: COH-Ar-10, GeMini; improved precision: D2O

more mass: NaIvETe, COH-Ar-750; lower threshold: CryoCsI

else: power upgrade of SNS, Second Target Station,…

inelastics campaign: argon, D_2O,...

Thank you for your attention!