# The COHERENT experiment

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on behalf of the COHERENT Collaboration

Moscow, ICPPA-2024

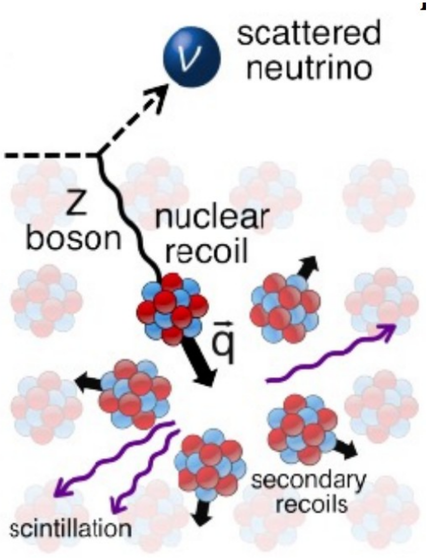
# Coherent elastic neutrino nucleus scattering


Coherent elastic neutrino nucleus scattering (CEvNS) – is a fundumental process proposed more then 50 years ago but observed in 2017 by the first time

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

10.1126/science.aao0990

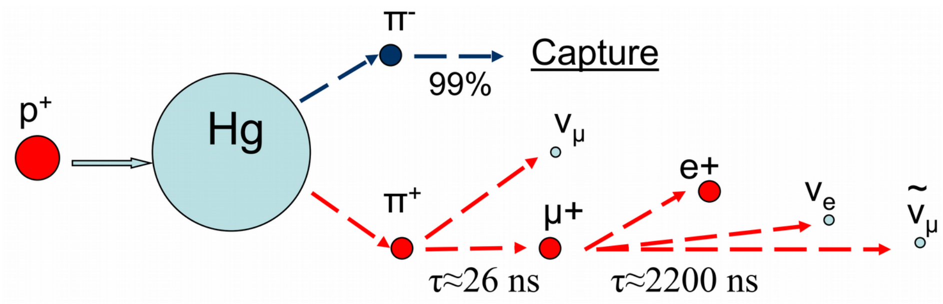
- Cross-section enhancement ~ $N^2$
- CEvNS is most probable interaction process for neutrinos of a low energy region (≤ 50 MeV) with medium and heavy nuclei
- Difficult detection signal from small nuclear recoil energies



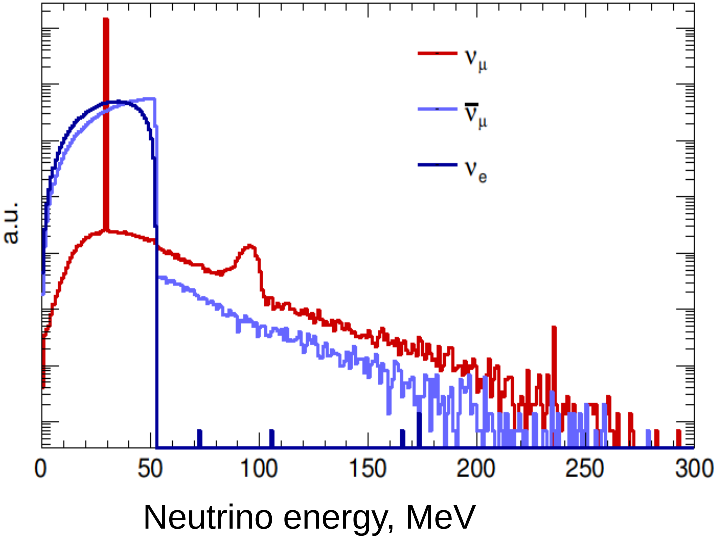
# Collaboration

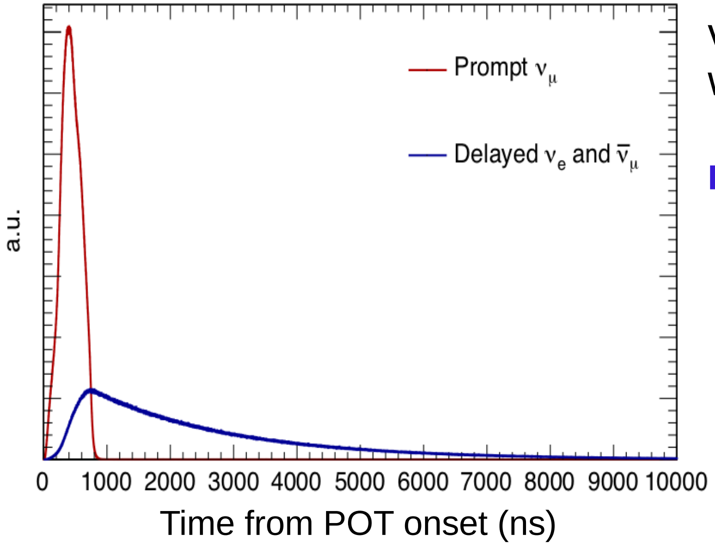

~ 100 people from 28 institutions from 5 countries

# SNS facility at ORNL




- Bunches of ~1 GeV protons on the Hg target with 60 Hz frequency
- Proton bunch time profile with FWHM of ~350 ns
- Total neutrino flux of 4.3·107 $cm^{-2}*s^{-1}$ at 20m

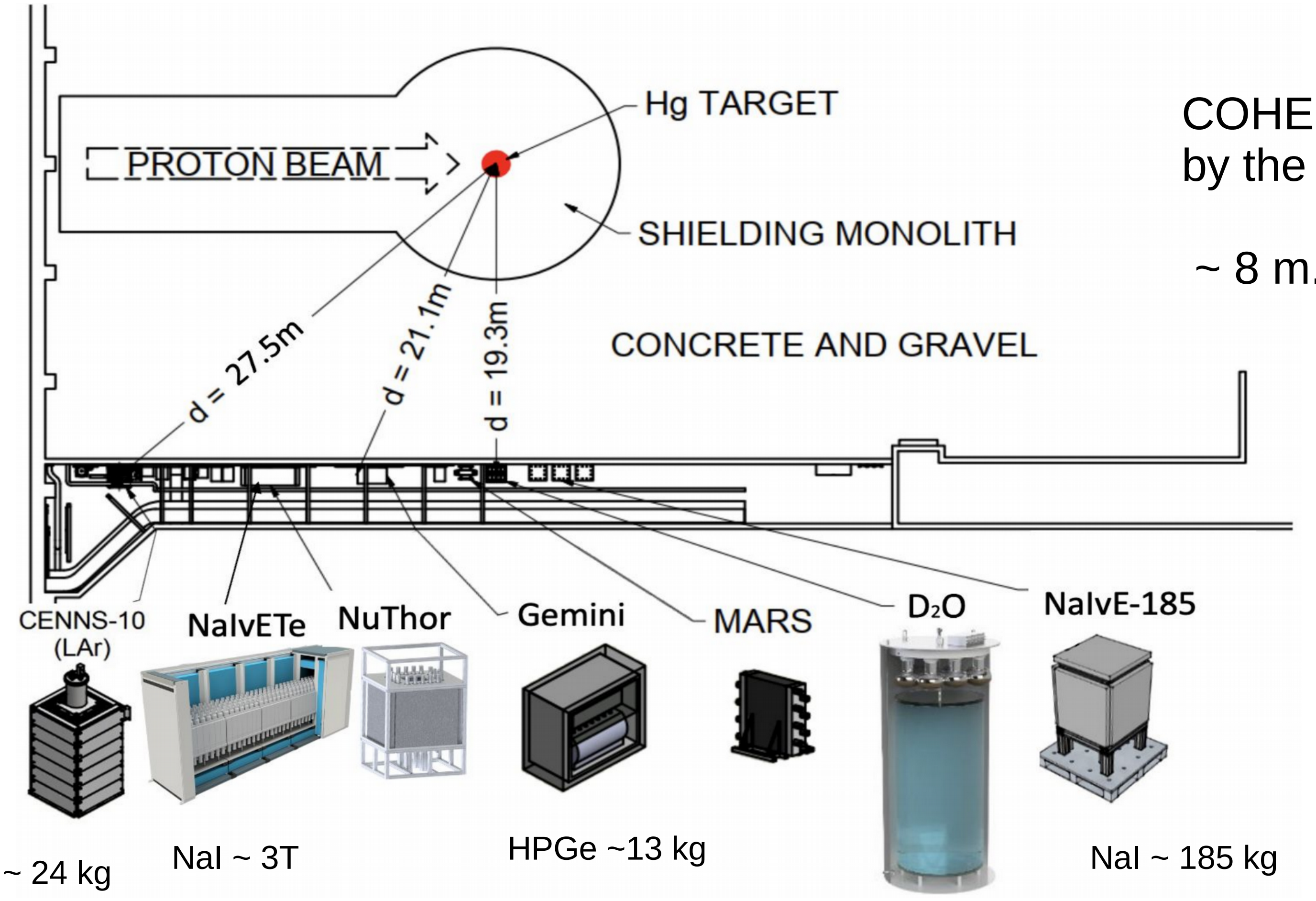



ν energy and timing suit well for CEνNS search:

**PRD 106, 032003 (2022)**

# Neutrino Alley




~ 24 kg

NaI ~ 3T

HPGe ~13 kg

2 x ~ 592 kg

NaI ~ 185 kg

COHERENT detectors are hosted by the target building basement:

~ 8 m.w.e. vertical overburden

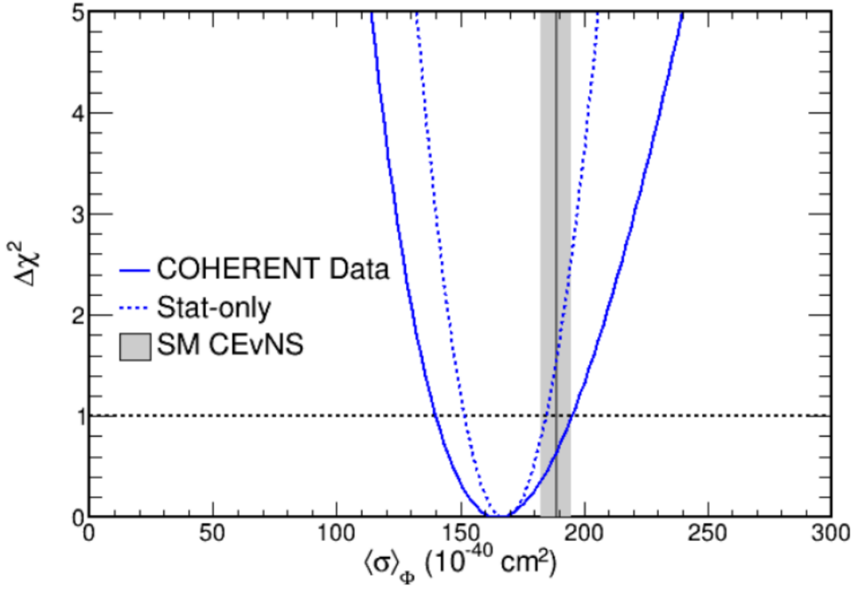
20 m of steel, concrete and gravel with no voids in the direction of the target

# COHERENT experiment: first results

Target: CsI[Na], 14.6 kg

2015-2017: 6.5σ first observation
Science vol. 357 iss. 6456 (2017)

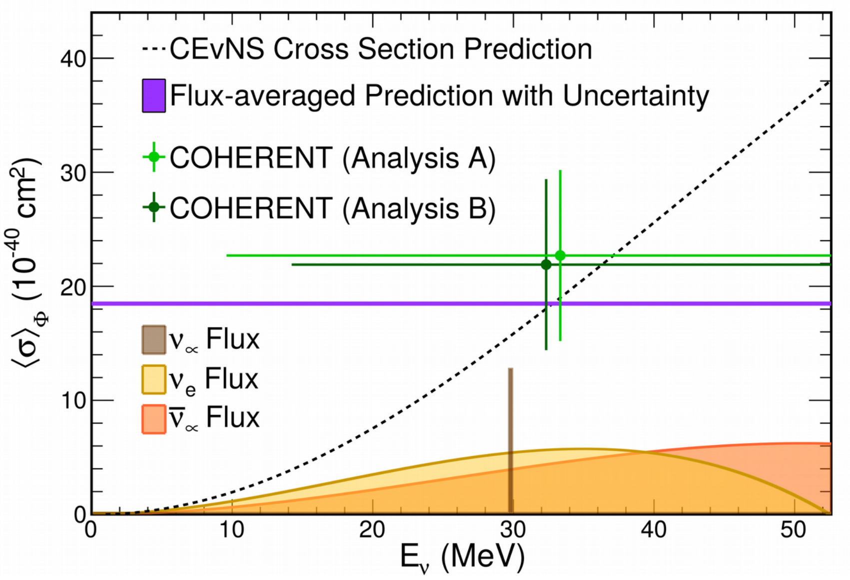
2015-2019: 11.6σ at full statistics
PRL vol. 129 081801 (2022)




Target: LAr, ~ 24 kg (CENNS-10)

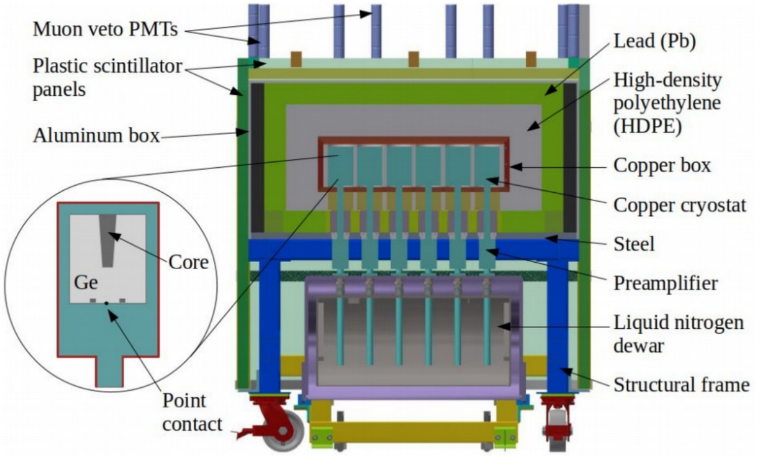
2017: limit ~4 times SM (90% CL )
PRD vol. 100 115020 (2019)

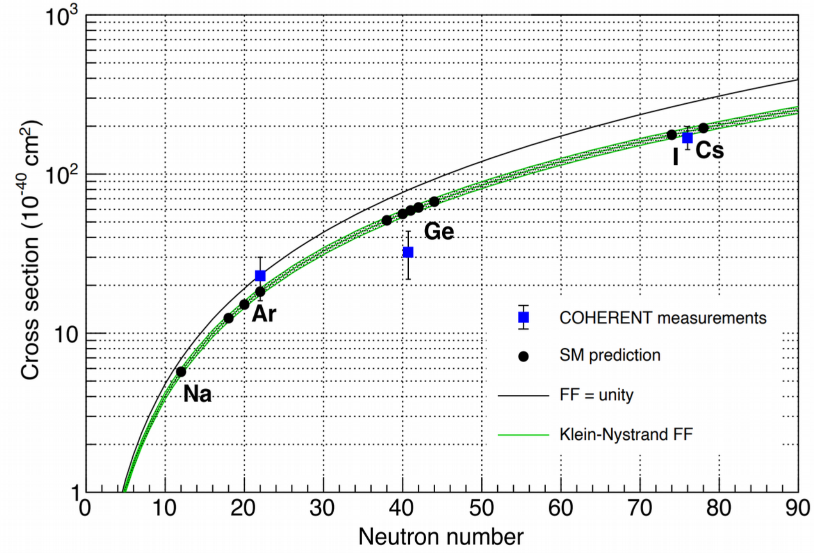
2017-2018: observation at 3.1σ
PRL vol. 126 012002 (2021)

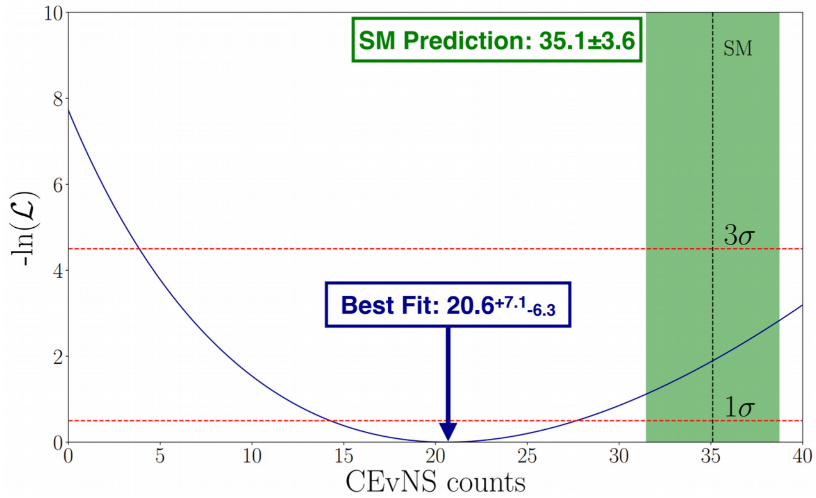


# COHERENT results: Ge-Mini

- 8 x 2.2 kg inverted coaxial P-Type Point Contact (PPC) Ge Detectors
- Noise resolution: < 500 eV
- CEvNS threshold: < ~3 $keV_{nr}$
- Compact Copper, HDPE, Pb shield
- Plastic Scintillator muon veto
- **arXiv:2406.13806**



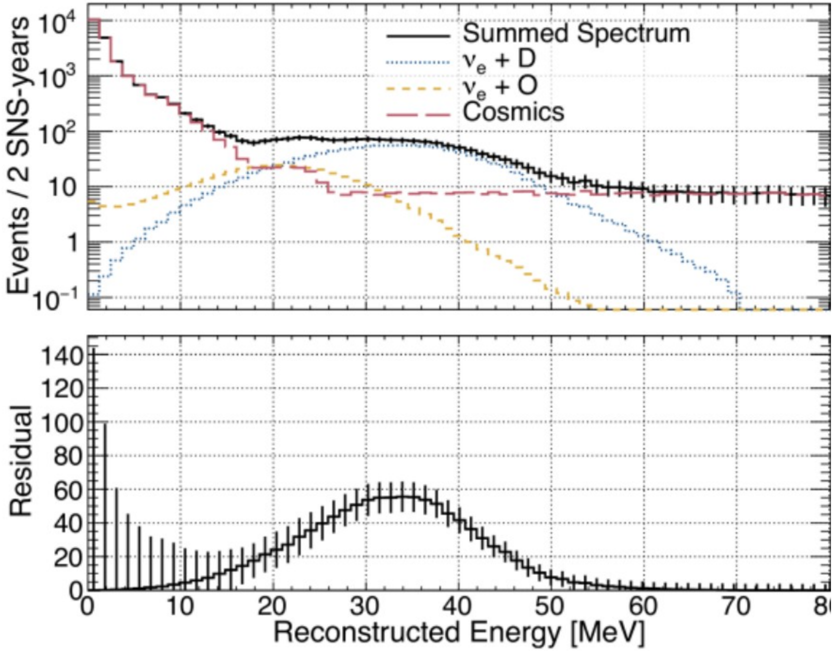



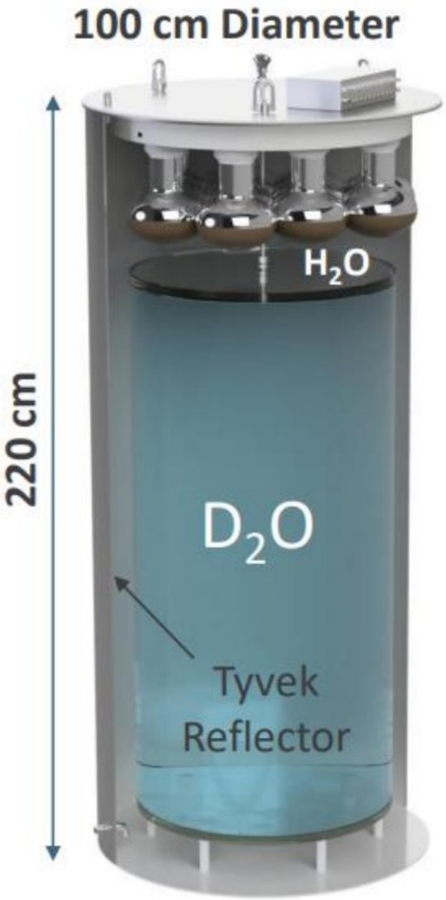
# COHERENT detectors: $D_20$

Dominant systematic effect in COHERENT is neutrino flux uncertanty.
The idea: to measure $\nu_e$ flux with $\nu_e + d \rightarrow p + p + e^-$

- 2 modules 590 kg $D_2O$ $H_2O$ in acrylic tank
- 12 PMTs for Cherenkov radiation
- Reflective Tyvek covers inner wall of steel vessel
- Outside: lead shielding + muon veto panels




COHERENT, JINST 16 P08048 (2021)




First module is deployed!

# Neutrino induced neutrons

Measuring inelastic neutrino induced neutrons:

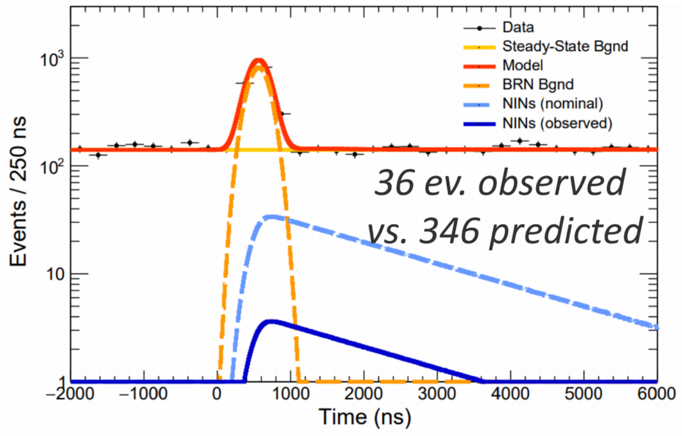
$$\nu_e + {}^{208}Pb \rightarrow e^- + {}^{208}Bi^*,$$

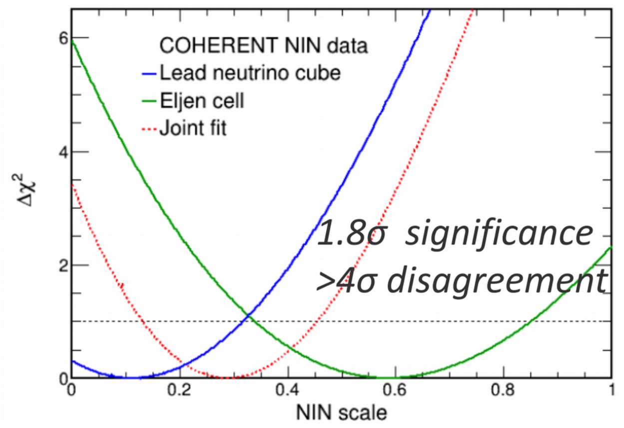
$$\nu + {}^{208}Pb \rightarrow \nu + {}^{208}Pb^*$$

- 900 kg lead target
- EJ-301 liquid scintillator
- Plastic scintillator muon veto panels against the sides and the top
- Water shielding to reduce environmental and BRN background

- Can be used for supernova neutrino detection
- Can be a background for CEvNS

**PRD 108, 072001 (2023)**



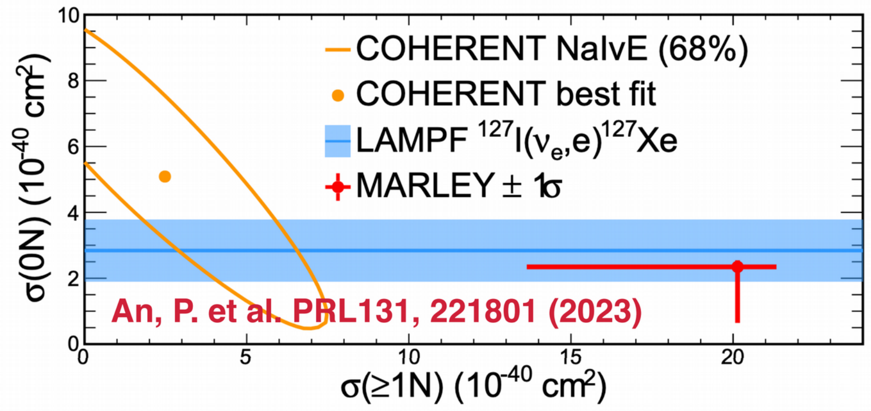

Neutrino cube

# CEvNS detectors: NaIvE

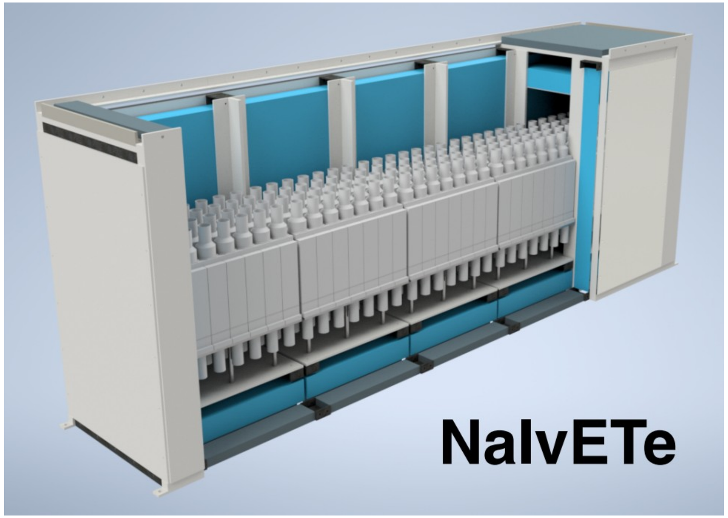
## NaIvE-185

$\nu_e + {}^{127}I \rightarrow e^- + {}^{127}Xe^*$ for solar $^7Be\ \nu_e$

- Repurposed Advanced Spectroscopic Portal program NaI detectors;
- Detector: 24×7.7 kg NaI[Tl] crystals
- Signal: 10-55 MeV electrons in the delayed neutrino window
- Exposure: ~5 years 5.8σ CC signal (541 events), but 41% lower than MARLEY prediction




PRL vol. 131 221801 (2023)



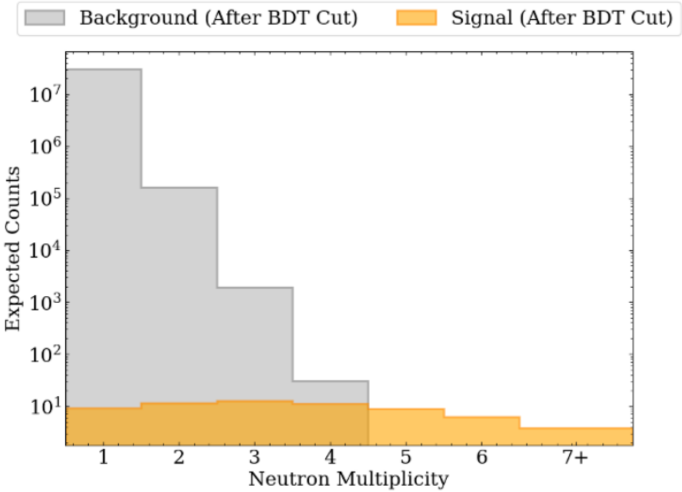

- NaI[Tl]: 2.4T → 3.4T
- 1 crystal = 7.7 kg,
- 1 module = 63 crystals,
- 5->7 modules planned [3 currently deployed]
- Sensitivity: 3σ in 3 years (3.4 T), $E_{thr}$=13 $keV_{nr}$

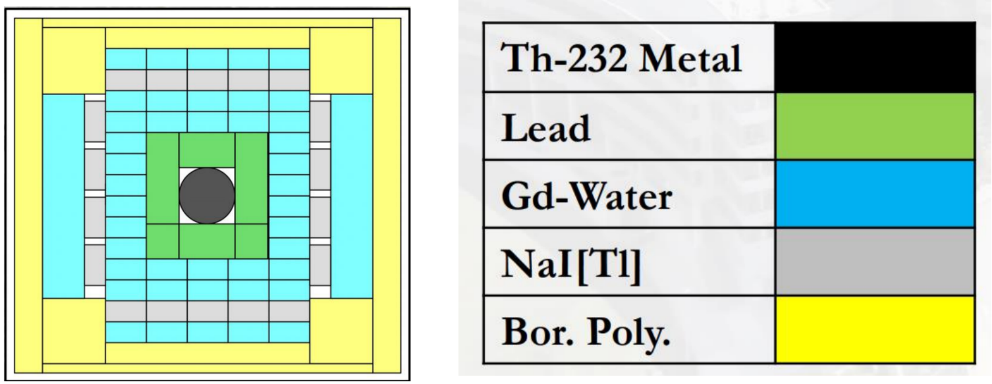
# COHERENT detectors: NuThor

Looking for neutrino-induced thorium fission – predicted in 1971, but not observed yet

$$\nu_e + {}^{232}\mathrm{Th} \rightarrow e^- + {}^{232}\mathrm{Pa}^*$$

$${}^{232}\mathrm{Pa}^* \rightarrow \mathrm{FF}_1 + \mathrm{FF}_2 + x\mathrm{n} + y\gamma$$



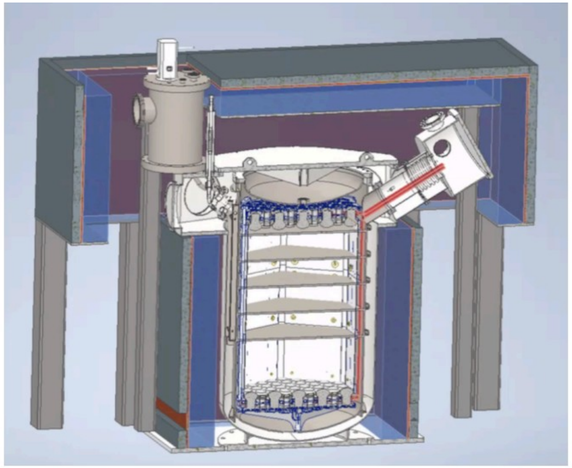



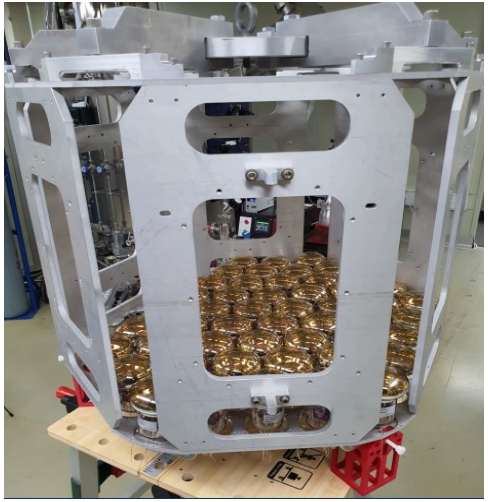

- 52 kgs of thorium
- 800 kgs of lead shielding
- Water Bricks doped with Gadolinium Nitrate
- 36 NaI[Tl] Scintillators
- Borated Polyethylene neutron shielding

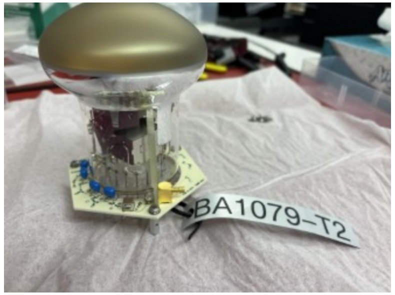
More than 3,000 beam hours of data collected as of now.

# CEvNS future: COH-Ar-750 (LAr)

- 750 kg of LAr in total
- 2x61 3” Hamamatsu R14374 PMTs
- TPB for wavelength shifting
- Expected:
  - ~3000 detected CEvNS events per year
  - ~500 inelastic CC interactions per year
- Potential use of underground Ar for lower $^{39}$Ar backgrounds
- **Phase I detector funded**
- Commissioning late 2024
- First data: 2025

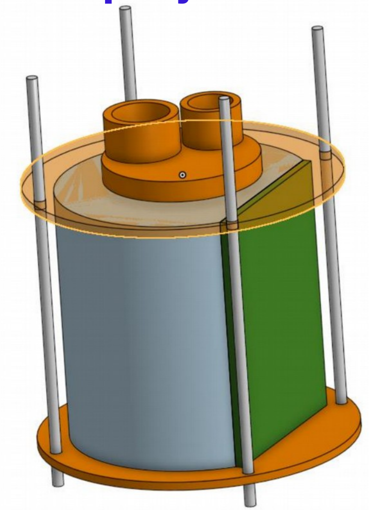






# Cryogenic undoped CsI and LAr plans

**The project funded**



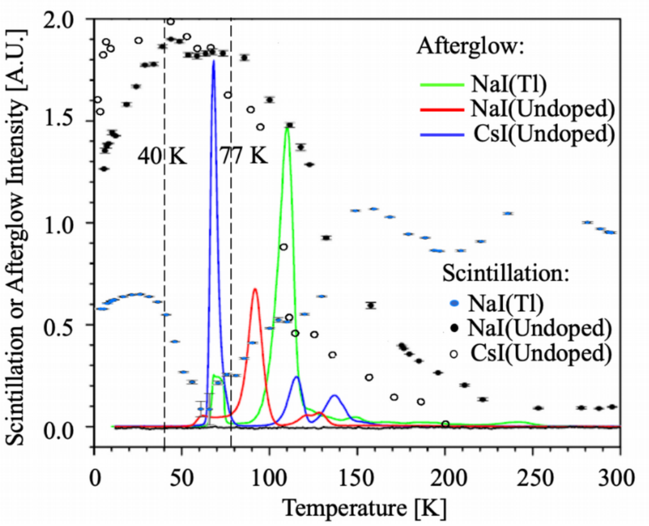
Like CsI[Na], but better:

1. Higher ligh yield at or below 77 K

2. Use SPMs

SIPMs advantages:

- high QE
- no Cherenkov radiation
- low dark count rate

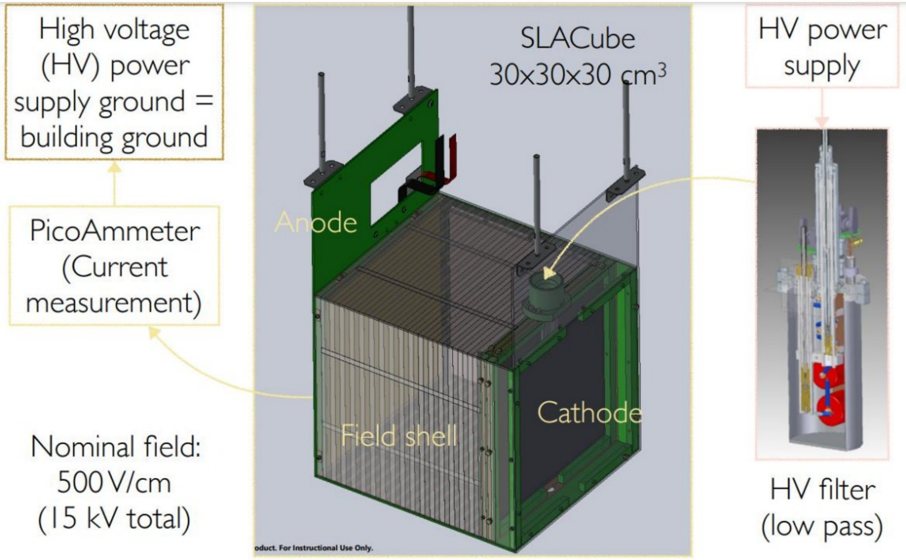



**PRD 109, 092005 (2024)**

Proposal:

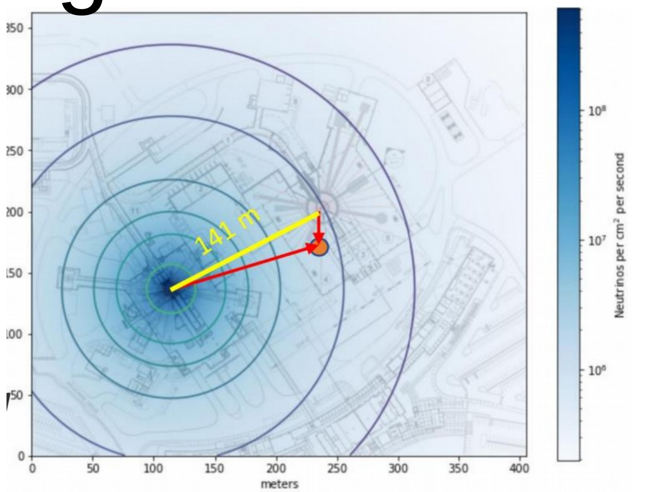
250 kg LAr TPC for DUNE-like CC detection

Main background is cosmic muons



# Physics reach at Second Target Station

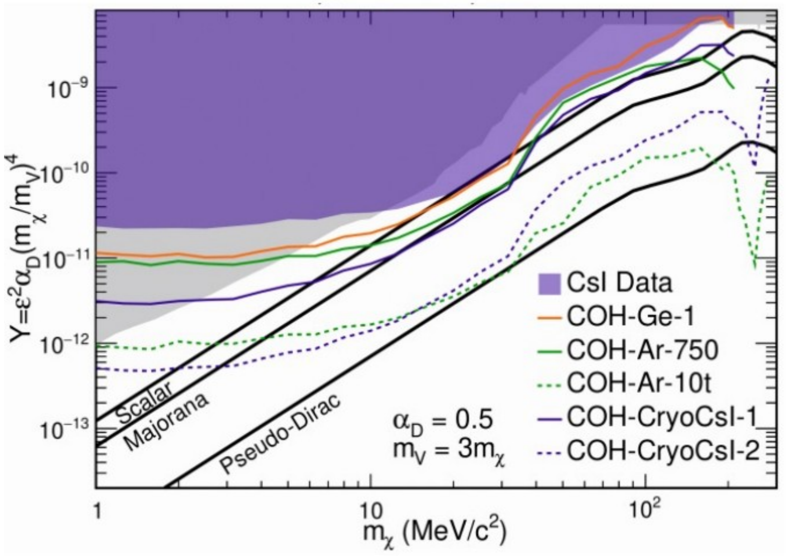
Second target station of SNS will be constricterd at around 2030s – 1 detector, 2 beams.



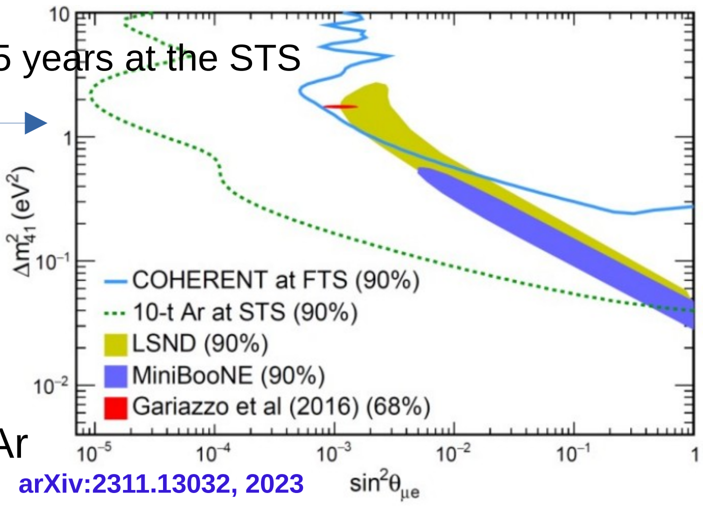

Search for scalar Dark Matter particles and sterile neutrinos produced at the SNS.

**PRL 130, 051803 (2023)** **PRD 106, 052004 (2022)**

Accelerator DM, 5 years at the STS




Sterile neutrinos, 5 years at the STS



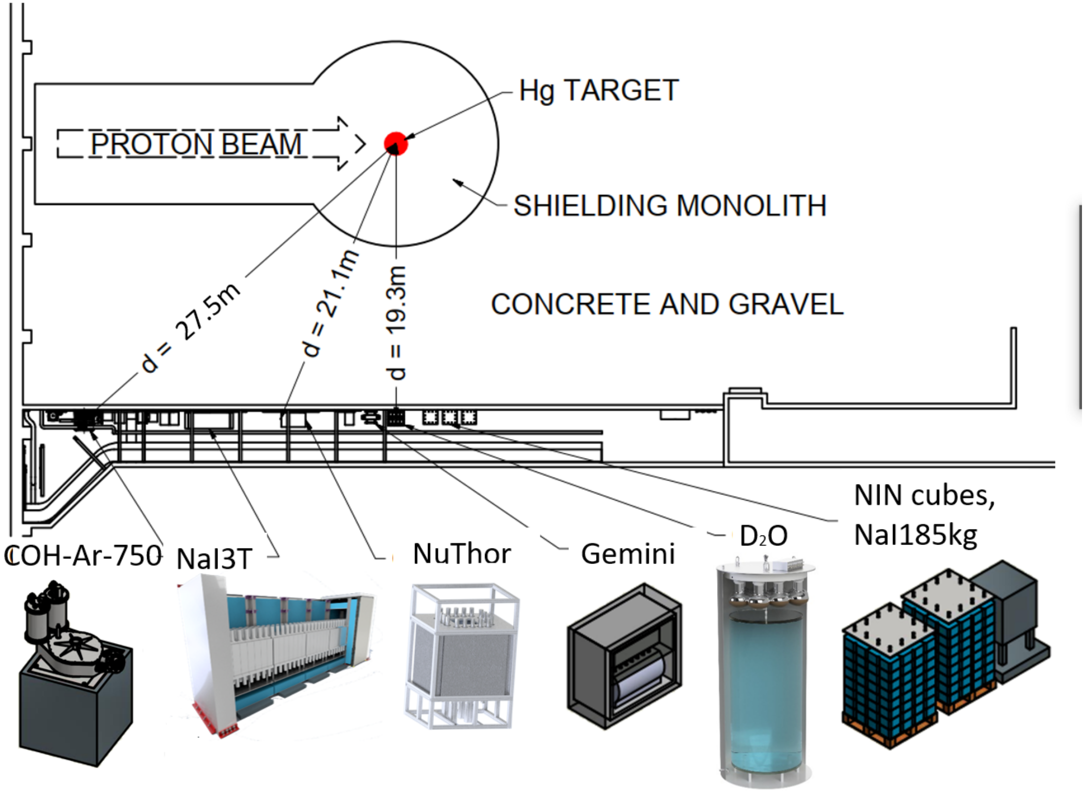

$L_{STS}$ = 20 m
$L_{FTS}$ = 121 m
Consider 10T LAr

**arXiv:2311.13032, 2023**

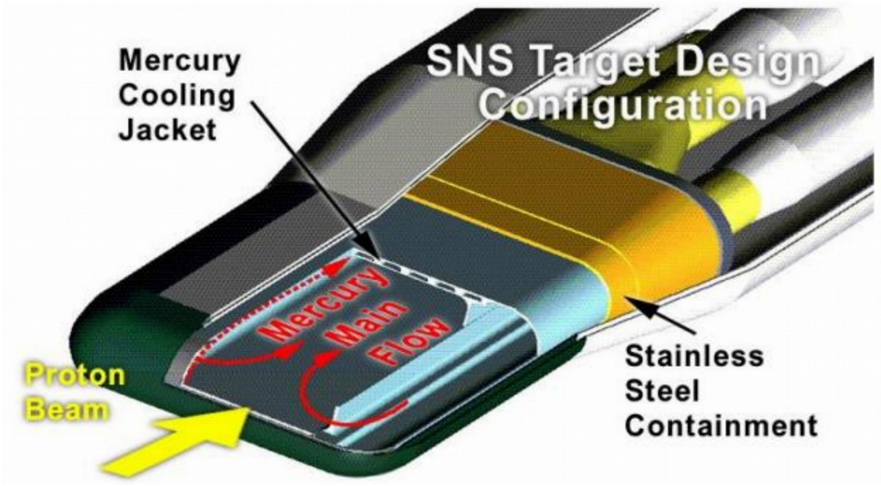
# Summary

- COHERENT continues to measure CEvNS and Inelastic neutrino scattering on multiply targets.
- D2O campaign underway, 1-st module is deployed, second is under construction – improve neutrino flux precidion.
- Beyond CEvNS – measure of inelastic neutrino induced neutrons and neutrino-induced thorium fission.
- Large scale detectors are coming.
- Proton power source upgrade and building of STS are accelerating COHERENT progress.

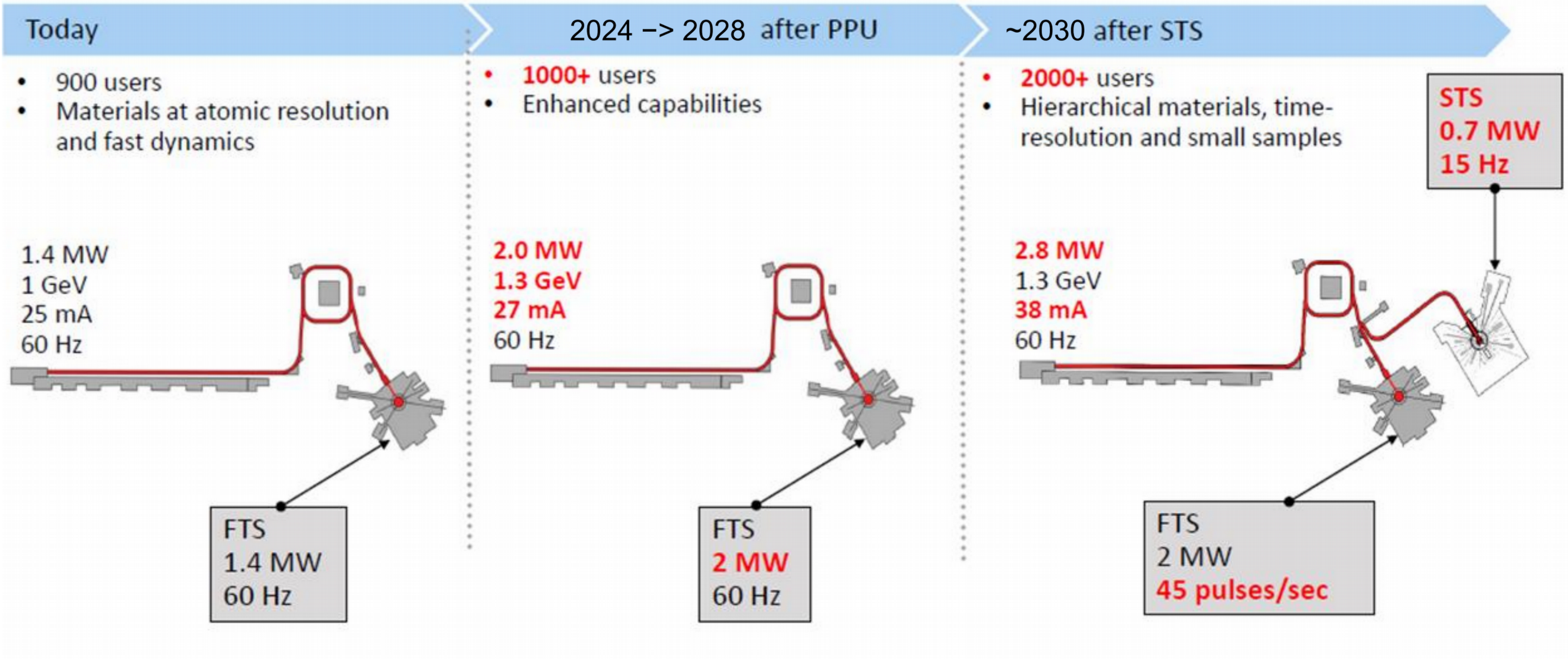
# COHERENT: future detectors



# Spallation Neutron Source



# SNS upgrade


Today
2024 –> 2028 after PPU
~2030 after STS
900 users
Materials at atomic resolution and fast dynamics
1000+ users
Enhanced capabilities
2000+ users
Hierarchical materials, time-resolution and small samples
STS
0.7 MW
15 Hz
1.4 MW
1 GeV
25 mA
60 Hz
2.0 MW
1.3 GeV
27 mA
60 Hz
2.8 MW
1.3 GeV
38 mA
60 Hz
FTS
1.4 MW
60 Hz
FTS
2 MW
60 Hz
FTS
2 MW
45 pulses/sec

# Beam-related backgrounds