Status of COHERENT and new physics opportunities at SNS
Collaboration

~85 people, 21 institutions from 4 countries

Looking for new physics using coherent elastic $\nu$–nucleus scattering (CEvNS) ...but not only!
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 $4.3 \times 10^7$ cm$^{-2} \cdot$s$^{-1}$ at 20 m

Capture

\[ \pi^- \rightarrow \mu^+ + \nu_\mu \]
\[ \tau \approx 26 \text{ ns} \]

\[ \pi^+ \rightarrow e^+ + \nu_e \]
\[ \tau \approx 2200 \text{ ns} \]

$\nu$ energy and timing suit well for CEvNS search

PRD 106, 032003 (2022)
“Neutrino alley”

**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

**Neutrino alley virtual tour**

(click me)
**CEvNS detectors: pioneers**

**CsI[Na], 14.6 kg**

6.7σ first observation

11.6σ at full statistics

**LAr, 24 kg (CENNS-10)**

limit ~4 times SM (90% CL)

onobservation at 3.1σ

The end of exposure in 2019

The full data (2017-2021) analysis is ongoing
CEvNS detectors: Ge-Mini

HPGe PPC
6 detectors deployed, ~13 kg active mass, 100-150 eV FWHM pulser resolution, expected threshold of $2.5 \text{ keV}_{nr} \approx 0.4 \text{ keV}_{ee}$

About a month of BEAM ON data acquired -> Initial results this fall
CEvNS detectors: NaIvETe

**NaI[TI]: 2.4T→3.4T**

1 crystal = 7.7 kg,
1 module = 63 crystals,
5→7 modules planned [3 deployed ATM]

**Sensitivity: 3σ per year (3.4 T), E_{thr} = 13 keV_{nr}**
CEvNS detectors: future – CENNS-750 (LAr)

750 kg total (610 kg fid.), 3000 CEvNS/year
128 PMTs, TPB for wavelength shifting

Cryostat nearly complete, PMTs acquired

Planned to be deployed and running by 2025
Like CsI[Na], but better:

1. Higher light yield at or below 77 K
2. SiPMs:
   - high QE
   - no Cherenkov radiation
   - low dark count rate (low T)

R&D:
- detector shape and size: ~10 kg, 6”x 6” cylinder
- cooling: LN or cryocooler
- QF measurements at TUNL
- about 1.4 keV_{nr} threshold planned
Complementarity for NSI

Vector-like $v-q$ NSI, $Q^2_\alpha = \left[ Z \left( g^V_p + 2\varepsilon^{u}_{\alpha\alpha} + \varepsilon^{d}_{\alpha\alpha} \right) + N \left( g^V_n + \varepsilon^{u}_{\alpha\alpha} + 2\varepsilon^{d}_{\alpha\alpha} \right) \right]^2$, see JHEP 12 (2005) 021

Different nuclei $\rightarrow$ Different $Z/N = $ Different $u$ to $d$ quark ratio

Testing multiple techniques to identify optimal: sensitivity/scalability/price
Physics reach: $\sin^2 \theta_W$

From CsI[Na]

$$\sin^2 \theta_W = 0.220^{+0.028}_{-0.026}$$

Future: ~2% comparable to PV

EW couplings running with the scale
Low energy inelastic $\nu$-N scattering

An interesting alternative way of $\nu$ detection:

- **larger cross sections (vs. IBD & $\nu$-e)**
- **denser targets**
- **different detector technologies**

SNS gives an opportunity to test this alternative channel!
Inelastic neutrino interactions: inclusive $\nu_e$ CC on $^{127}$I

Motivation:
1. Initial: $\nu_e + ^{127}$I $\rightarrow$ $e^- + ^{127}$Xe$^*$ for solar $^7$Be $\nu_e$
2. Cross section depends on $g_A$ (at $\sim$10s MeV Q)

Detector: 24×7.7 kg NaI[Tl] crystals  
Exposure: $\sim$5 years  
Signal: 10-55 MeV electrons in the delayed neutrino window

5.8σ CC signal (541 events), but 41% lower than MARLEY prediction

If deconvolved to 0N and $\geq$1N by energy deposition, data suggests lack of events with neutron emission

$\langle \sigma \rangle \Phi = 9.2^{+2.1}_{-1.8} \times 10^{-40}$ cm$^2$

$|g_{A,\text{eff}}| < 0.97$
Inelastic neutrino interactions: NINs from Pb

\[ \nu_e + ^{208}\text{Pb} \rightarrow e^- + ^{208}\text{Bi}^* \]  
\[ \nu + ^{208}\text{Pb} \rightarrow \nu + ^{208}\text{Pb}^* \]

Motivation:
1. Can be a background for CEvNS \((M_{\text{shield}} >> M_{\text{det}})\)
2. Can be used for supernova neutrino detection (HALO)

factor \(0.29^{+0.17}_{-0.17}\) suppression vs. MARLEY
in combination with LS in the CsI shielding

900 kg lead

36 ev. observed vs. 346 predicted

1.8σ significance >4σ disagreement
NuThor and plans for LAr

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

52 kg metal Thorium deployed, looking for high neutron multiplicity events

CENNS-750: ~340 v CC and 100 NC per SNS year

LAr TPC: 250 kg LAr to for DUNE-like CC detection

R&D, prototype operation
Leading syst. right now: ±10% on the neutrino flux

Idea: measure flux with $\nu_e + d \rightarrow p + p + e$

Two modules, 592 kg $D_2O$ each

Down to ~5% flux unc-ty with a single module for 2 SNS-years of operation

First module deployed!

Bonus: charge current (CC) on oxygen for supernova $\nu$ in Super/Hyper-Kamiokande
## SNS Schedule

### FY23

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The Second Target Station (STS) provides more dedicated neutrino physics space. COHERENT is in contact with ORNL on this matter (space/background level optimization).
Physics reach: the dark matter of Oak Ridge

«V kinetic mixing with $\gamma$»  
\[ \text{PRL 130, 051803 (2023)} \]

«leptophobic»  
\[ \text{PRD 106, 052004 (2022)} \]

**First to probe beyond the scalar target!**

\[ Y = e^{2\alpha_D(m_\chi/m_\nu)^4} \]

\[ m_\chi (\text{MeV/c}^2) \]

\[ \alpha_D = 0.5 \]

\[ m_\nu = 3m_\chi \]

**5 years at STS**

\[ Y = e^{2\alpha_D(m_\chi/m_\nu)^4} \]

\[ m_\chi (\text{MeV/c}^2) \]

\[ \alpha_D = 0.5 \]

\[ m_\nu = 3m_\chi \]
Physics reach: sterile neutrino

Consider disappearance:

\[ 1 - P(\nu_e \rightarrow \nu_s) = 1 - \sin^2 2\theta_{14} \cos^2 \theta_{24} \cos^2 \theta_{34} \sin^2 \frac{\Delta m_{41}^2 L}{4E} \]

\[ 1 - P(\nu_\mu \rightarrow \nu_s) = 1 - \cos^4 \theta_{14} \sin^2 2\theta_{24} \cos^2 \theta_{34} \sin^2 \frac{\Delta m_{41}^2 L}{4E} \]

We need a prior constraint on \( \theta_{34} \), take from 3-flavor oscillations

Neutrino energy from 10 to 53 MeV, distances from 19 to 28 m \( \rightarrow \Delta m_{41}^2 \) between 0.4 and 3.4 eV$^2$

Sensitivity estimates (FTS - 3 years, STS - 5 years)

Consider 10T LAr

\( L_{STS} = 20m, \quad L_{FTS} = 121m \)

1 detector, 2 beams!
Collaboration operates multiple detectors in the «Neutrino Alley» at SNS

Wide physics reach

- CEvNS
- $\sin^2 \theta_W$
- Nuclear FF
- Inelastic $\nu$ interactions (CC, NC)
- $\nu$-q NSI
- DM
- Steriles

Thank you for your attention!