CEvNS with liquid argon scintillation detector(s)
R. Tayloe, Indiana U.
for the COHERENT collaboration

Outline:
• COHERENT at SNS
• CEvNS with LAr
• status/future of LAr detectors for CEvNS

SNS “v-alley”
COHERENT experiment in SNS $\nu$-alley

- Low-background area
- near (20-28 m) SNS target with
- 1.4MW, 5000MWhr/yr, 1.5E23POT/yr,
- pulsed beam (FWHM≈350 ns) at 60Hz

SNS “$\nu$-alley”

SNS $\nu$ energy spectrum

SNS $\nu$ time distribution

Prompt $\nu_\mu$ from $\pi$ decay in time with the proton pulse

Delayed anti-$\nu_\mu$, $\nu_e$ on $\mu$ decay timescale
COHERENT experiment

First detection of CEvNS with CsI!

Cross section ($10^{-40}$ cm$^2$) vs. Neutron number

- Ar
- Na
- Ge
- Cs

without/with nuclear FF

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COHERENT experiment

- Next goal, demonstrate $N^2$ dependence of CEvNS
- with CENNS-10 (liquid argon, LAr), currently running…
LAr for CEvNS

Liquid argon (LAr) is:

- Complementary to heavier Cs and I
  - Map out low $N \sigma(CEvNS)$
  - Lower $\sigma$ but more energetic recoils

- Large scintillation yield
  - 40 photons/keVee

- Quenching factor well-measured

- Pulse Shape Discrimination (PSD) for particle ID!
  - Argon scintillates with 2 time constants
    1. Singlet light: $\sim$6 ns
    2. Triplet light: $\sim$1.6 $\mu$s
  - Electronic Recoils mostly triplet light
  - Nuclear Recoils mostly singlet light
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COHERENT LAr: CENNS-10

CENNS-10 detector currently running at SNS

timeline:
• 2012-15: built at Fermilab (J. Yoo et al) for CENNS@Fermilab effort, commissioned/upgraded at Indiana U.

• late 2016: moved to SNS, installed, shielding built

• early 2017: run with TPB-acrylic parts, $E_{\text{thresh}} \sim 80\text{keVnr}$
  “Engineering Run”: 1.8GWhr collected, CEvNS rate low, constrain beam-related bckgrds, analysis finished

• mid-17: upgrade: TPB-Teflon reflectors, new TPB-coated PMTs, added 4” Pb shielding

• mid-17-present: run in upgraded mode, $E_{\text{thresh}} \sim 20\text{keVnr}$
  “Production Run”: 6.1 GWhr collected, blind, 2 parallel, analyses in progress in US and Moscow
The CENNS-10 (LAr) Detector:

**Specs:**
- 22 kg single-phase LAr fiducial volume
- $2 \times 8''$ PMTs TPB-coated, w/QE=18%@400 nm
- TPB-coated PMTs/teflon side walls
- Energy threshold $\approx 20$keVnr
- CAEN 1720 (250MHz, 12-bit) digitizer
- 90W single-stage pulse-tube cold head
- SAES MonoTorr gas purifier for $\sim 1$ ppm purity
- Pb/Cu/H2O shield
- Expect $\approx 140$ CEvNS events/SNS-year
- Running in current configuration since July ‘17
CENNS-10 Analysis for CEvNS:

Analysis Overview:

- Calibrate! Calibrate! Calibrate! with variety of sources

- Characterize expected backgrounds in rate/time/energy
  - Steady-state bkg from beam-off triggers
  - Beam-related neutrons with other neutron detectors and CENNS-10 no-water runs

- Optimize energy/PID/time cuts on signal/noise

- Verify bkg subtraction with ‘pre-beam’ data

- “Open the Box”:
  1. Counting exp’t: prompt and delayed
  2. Full likelihood analysis

SNS neutrino time distribution

Eng. run: steady-state bckgnd rate vs energy
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CENNS-10 Engineering run results:

blind analysis CENNS-10 Engineering run results:

- event excess in time with beam is consistent with expected prompt beam-related neutron rate
CENNS-10 Engineering run results:

blind analysis CENNS-10 Engineering run results:

- event excess in time with beam is consistent with expected prompt beam-related neutron rate
- no event excess observed in delayed window with 0.5 events expected →
  - limit on delayed neutron backgrounds
  - limit on CEvNS cross section
CENNS-10 Engineering run results:

blind analysis CENNS-10 Engineering run results:

- from full likelihood analysis:
  - cross section limits
  - non-standard interaction constraints

work of
IU PhD Student:
Matthew Heath
\cite{Heath:2019jpj}
corresponding NSI regions

Eng. run CEvNS cross section limits
CENNS-10 Production run:

Production runs, 7/17-now:
- light yield improved to ~4.5 PE/keV
- Particle ID (PSD), energy resolution/threshold sufficient for observation of CEvNS in $^{40}\text{Ar}$
- SM prediction ~130 CEvNS events in this data set
- analyses in end stages, results soon!

Indiana U, Phd Student: Jacob Zettlemoyer

ITEP/MEPHI (Moscow), Phd Students: Dmitry Rudik, Alex Kumpan.
COHERENT future, next steps

Physics reach of CEvNS:

• Understanding supernovae (SN):
  • Expected to be important in core-collapse SN and
  • possible SN detection channel.

• Nuclear Physics: nuclear form factors

• Standard Model tests, eg: NSI, $\sin^2 \theta_w$, neutrino magnetic moments

• $\nu$ oscillations: Investigation of $\nu_{\text{sterile}}$ oscillations

• reactor monitoring (non-proliferation)

• Dark Matter:
  • Important background for O(10-ton) direct searches
  • detectors sensitive for accelerator produced DM.
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COHERENT future, in ν-alley

- 16kg Ge array, coming soon
- multi-ton NaI, shielding/veto configuration to be finalized
- ton-scale LAr (CENNS-750), funding pending
- D$_2$O for flux normalization
- also NIN cubes
- neutron background measurements
COHERENT future, large LAr detector

CENNS-750:

• Based on our experience with CENNS-10 detector, running since 2017.
• Single-phase LAr (scintillation-only) calorimeter, 750/610 kg total/fiducial
• Purpose-designed cryostat w/LN2 precool, and dual cryocooler for liquefication/gas purification.
• Light collection: TPB coated reflectors combined with 3” PMTs/SiPMs
• Eventual use of underground (low $^{39}$Ar) argon.

⇒ 3000 CEvNS, 440 inelastic CC/NC events/yr!
COHERENT future, large LAr detector

CENNS-750:
It fits into \( \nu \)-alley (barely)
CENNS-750 LAr detector

Event rates in 610kg fiducial LAr detector:

~3000 CEvNS events/year

Simulated CEvNS + background rates

~440 inelastic CC/NC events/yr

Estimated inelastic CC/NC CEvNS rates
**COHERENT future**

Search for accelerator-produced, low-mass, dark matter

Via:

\[ p \rightarrow \text{Hg} \rightarrow \pi^0, \pm \]

\[ \pi^0 \rightarrow \gamma + V^{(*)} \rightarrow \gamma + \chi^\dagger + \chi \]
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Search for accelerator-produced, low-mass, dark matter

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COHERENT future

Search for accelerator-produced, low-mass, dark matter

10-ton LAr or ~2-ton cryogenic NaI detector downstream from high power neutron target, eg SNS

Will enable other CEvNS physics as well!
Summary:

- First measurement of CEvNS in COHERENT CsI[Na] at the SNS!
- More results, demonstrating N^2 dependence, with LAr (and others) coming soon.
- High potential physics output of CEvNS is driving further work on improved/larger detectors
- Thanks to COHERENT collaboration!
Backups
COHERENT future, beyond $\nu$-alley

Sterile oscillation search with large CEvNS detector at SNS