Search for CEvNS with a liquid argon scintillation detector
R. Tayloe, Indiana U.
for the COHERENT collaboration

Outline:
• physics of CEvNS
• COHERENT at ORNL/SNS
• CENNS-10 detector:
  • history/design
  • deployment
  • preliminary data
  • projections
• summary

LIDINE 2017: Light Detection In Noble Elements
Coherent Elastic $\nu$-Nucleus Scattering:

"CEvNS":

Coherent Elastic $\nu$-Nucleus Scattering: $\nu A \rightarrow \nu A$

Neutrino scatters with low momentum transfer coherently, elastically from entire nucleus. For large nucleus, $R_N \approx \text{few fm}$, and:

$$E_\nu \lesssim \frac{\hbar c}{R_N} \approx 50 \text{ MeV}$$
Coherent Elastic $\nu$-Nucleus Scattering:

Cross section is large... in fact largest $\nu$ channel at $O(10 \text{ MeV})$ on heavier nuclei, eg Ar

and has distinctive $N^2$ dependence

$$\frac{d\sigma}{dE} = \frac{G_F^2}{4\pi} \left[ (1 - 4\sin^2 \theta_w)Z - (A - Z) \right]^2 M \left(1 - \frac{ME}{2E^2_\nu}\right) F(Q^2)^2$$

$vAr$ cross section

coherent $vAr$
Coherent Elastic $\nu$-Nucleus Scattering:

.. but recoil energy is quite small:

$$E_{r}^{\text{max}} \approx \frac{2E_{\nu}^{2}}{M} \approx 50 \text{ keV}$$

And so, the CEvNS process has only recently been observed…
Coherent Elastic $\nu$-Nucleus Scattering:

Physics of CEvNS:

- Supernovae: Expected to be important in core-collapse SN and possible SN detection channel.
- Nuclear Physics: nuclear form factors
- $\nu$ oscillations: A possible $\nu_s$ detection channel
- Standard Model tests, eg: $\sin^2 \theta_w$
- Dark Matter: Important background for 10-ton direct searches
Coherent Elastic $\nu$-Nucleus Scattering:

Physics of CEvNS:

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

To realize this physics, require:
• intense $\nu$ source
• low bckgrd location
• low threshold detector.

1 ton-year LAr SNS DM sensitivity

Tov portal “dark photon” model
COHERENT experiment at SNS/ORNL

ORNLSpallation Neutron Source
(SNS) is also a world-class $\nu$ source:

- intense proton beam (~1MW, 1 GeV)
- pulsed (60 Hz, 600ns spill time)...
- ~ 5000MWhr/year
- ~ $2E23$ POT!

**SNS $\nu$ energy spectrum**

$\nu_\mu$, $\bar{\nu}_\mu$, $\nu_e$

**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 at SNS/ORNL

- a low-background experimental area has been acquired for COHERENT
- 20-29 m from target

SNS “v-alley”
COHERENT experimental strategy at SNS/ORNL
Measure N² dependence of CEvNS process with multiple targets/detector technologies
• (event rate)/kg is high, so relatively small (10-100 kg) detectors sufficient
• radiological background requirements fairly modest, because of pulsed beam
• need low E thresholds!

CEvNS cross section

CEvNS recoil energy
**COHERENT detectors**

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<th>Distance from source (m)</th>
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<td>CsI[Na]</td>
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- recent observation of CEvNS
- 134 ± 22 CEvNS events
### COHERENT detectors

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- recent observation of CEvNS
- D. Akimov *et al.*, *Science*
  10.1126/science.aao0990 (2017)
- $134 \pm 22$ CEvNS events
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<td>Scintillating crystal</td>
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• today
The COHERENT collaboration

~80 members, 18 institutions, 4 countries

arXiv:1509.08702
The CENNS-10 detector timeline:
• (‘12-’15) built at Fermilab for CENNS@Fermilab effort led by J. Yoo (now at KAIST) along with: A. Lathrop, R. Flores, R. Schmidt, E. Voirin, D. Markley, R. Davila, D. Butler, L. Harbacek
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- (2015) moved to Indiana U. for commissioning, upgrades, neutron tests

- (2016) installed at SNS for COHERENT
The CENNS-10 (LAr) Detector:

CENNS-10 SNS timeline:
• 10-12/2016: (re)build detector at SNS

• 12/16, 3-5/17: run with TPB-acrylic parts, $E_{\text{thresh}} \sim 100\text{keVnr}$, “Spring17” data

• 6/17: upgrade: TPB-Teflon reflectors, PMTs, shielding

• 7/17-present: run in upgraded mode, $E_{\text{thresh}} \sim 20\text{keVnr}$, “Summer17” data

• should collect 1/2 SNS-year of data by 12/17 (before 5-month SNS shutdown)
WLS, etc, optical tests:

- a variety of visible, VUV, WLS, reflectance tests have been performed at IU, ORNL, MEPHI, and harvested from literature, details to appear
The CENNS-10 (LAr) Detector:

Specs:
- 22 kg LAr fiducial volume
- 90W single-stage pulse-tube cold head
- SAES MonoTorr gas purifier for ~1 ppm purity
- TPB-coated PMTs/teflon side walls
- 2 × Hamamatsu 8" PMTs w/QE=18%@400 nm
- CAEN 1420 (250MHz, 12-bit) digitizer
- Pb/Cu/H2O shield
- Energy threshold ≈ 20keVnr
- Expect ≈ 140 CEvNS events/SNS-year
- Running in current configuration since July ‘17
The CENNS-10 (LAr) Detector

cryo/gas system:
• 90W single-stage PT90 cold head
• ~50kg total LAr mass, fill (from gas) over ~1 week, extremely stable temps/pressures
• SAES MonoTorr gas purifier for ~1 ppm purity
The CENNS-10 (LAr) Detector

- SAES MonoTorr gas purifier for ~1 ppm purity

![Pre-Doping](image1)

![Post-Doping](image2)

- As data quality check introduce N₂ after spring run
- Introduce ~25 ppm N₂
- Triplet lifetime changed from ~1.2 µs to 0.20 µs
  - Correspond to 1 ppm and 20 ppm respectively\(^2\)
- Verified with LDetek8000 N₂ monitor readings

The CENNS-10 (LAr) Detector

Preliminary data analysis: Spring17 data, Single PE analysis

Single PE waveform: in situ

Plots from IU grad student: M. Heath

Single PE spectrum: test bench

pulse integral

Single PE spectrum: in situ

Data Ped Int: 8604.00
Fit Ped Int: 8465.03
Ratio (data/fit): 1.02
The CENNS-10 (LAr) Detector

Preliminary data analysis: Spring17 data, waveform integration

- fit prompt (singlet) light
- subtract scaled singlet waveform
- integrate delayed (triplet) light

Waveform fit example

137Cs spectrum

Preliminary estimate: ~0.5 PEs/keVee
The CENNS-10 (LAr) Detector

Preliminary data analysis:
Spring17 data, waveform integration

- Fit prompt (singlet) light
- subtract scaled singlet waveform
- integrate delayed (triplet) light
- form F90 ratio (frac of light in 1st 90ns) for PSD (pulse-shape discrimination)
The CENNS-10 (LAr) Detector

Preliminary data analysis:
Summer17 data, after upgrades

57Co spectrum

Preliminary estimate: ~2 PEs/keVee

Plots from IU/SNS grad student: J. Zettlemoyer
CENNS-10 simulations

Geant4 simulation results

<table>
<thead>
<tr>
<th>Simulation Parameter</th>
<th>Value</th>
<th>comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tube QE</td>
<td>18%</td>
<td></td>
</tr>
<tr>
<td>LAr Scintillation Yield ER</td>
<td>40/keV</td>
<td></td>
</tr>
<tr>
<td>Time Constants</td>
<td>6 ns fast, 1.6 us slow</td>
<td></td>
</tr>
<tr>
<td>Quenching Factor</td>
<td>25%</td>
<td></td>
</tr>
<tr>
<td>Scintillation LAr peak</td>
<td>128 nm</td>
<td></td>
</tr>
<tr>
<td>Scintillation WLS peak</td>
<td>450 nm</td>
<td></td>
</tr>
<tr>
<td>TPB Attenuation Length at 400 nm</td>
<td>20 um</td>
<td></td>
</tr>
<tr>
<td>Teflon Reflectivity</td>
<td>95%</td>
<td></td>
</tr>
<tr>
<td>LAr Attenuation Length</td>
<td>2 m LAr, 20 m Vis</td>
<td></td>
</tr>
<tr>
<td>Scintillation Yield Ratio (Fast/Slow)</td>
<td>0.7 NR, 0.25 ER</td>
<td></td>
</tr>
<tr>
<td>TPB Thickness</td>
<td>0.2 mg/cm²</td>
<td></td>
</tr>
<tr>
<td>FV diameter/height</td>
<td>21cm/46cm</td>
<td></td>
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CENNS-10 simulations

Estimated CEvNS signal/backgrounds:
• $E_{\text{thresh}} \sim 20\text{keVnr}$
• beam-unrelated bckgnds:
  • Ar$^{39}$, environmental $\gamma$ reduced with PSD, measured, subtracted, estimated to be negligible
• beam-related bckgnds:
  • neutrons: measured at CENNS-10 location, all prompt, estimate $\sim 60\text{evts/yr}$
• CEvNS signal
  • estimate 60 prompt/ 80 delayed evts/yr

Predictions for:
Summer17 data, after upgrades
Future/Summary for LAr and COHERENT

**Future:**
- current run ends 12/17, should provide 1\textsuperscript{st} CEvNS LAr signal
- 5-month shutdown, in early 2018, possible upgrades:
  - incremental PMT, signal improvements
  - new/better reflectors
  - more/better calibration at low-energy
  - depleted-Ar (?)
- longer term possibilities
  - O(1 ton) LAr
  - depleted Ar, LXe, LNe
- ideas? (let’s talk!)

**Summary:**
- on-track for CEvNS measurement on LAr in next year
- opportunities exist for upgrades to detector and physics program
- Thanks to all who have helped make this happen! IU group, COHERENT collab, Fermilab, SNS, funding agencies, this community
LIDINE’17
Search for CEvNS with a liquid argon scintillation detector

(15min talk)

Abstract:
The COHERENT collaboration is deploying a suite of low-energy detectors in a low-background corridor of the ORNL Spallation Neutron Source (SNS) to measure coherent elastic neutrino nucleus scattering (CEvNS) on an array of nuclear targets employing different technologies. A measurement of CEvNS on different nuclei will test the $N^2$-dependence of the CEvNS cross section and further the physics reach of the COHERENT effort. The first step of this program has been realized recently with the observation of CEvNS in a 14.6 kg CsI detector. Operation and deployment of Ge and NaI detectors are also underway. A 22 kg, single-phase, LAr detector (CENNS-10) started data-taking in Dec. 2016 and will provide results on CEvNS from a much lighter nucleus. The design and performance of the CENNS-10 detector will be presented.