Status of the CENNS-10 Liquid Argon Detector for COHERENT

Jacob Zettlemoyer, for the COHERENT Collaboration
DOE SCGSR Fellow
Indiana University, Bloomington
2017 Fall Meeting of the APS Division of Nuclear Physics
Pittsburgh, PA
October 27, 2017
Coherent Elastic Neutrino-Nucleus Scattering (CEvNS)

- Process where the neutrino scattering off the nucleus coherently with low momentum transfer

- Large cross section!
  - For heavier nuclei at low neutrino energies, the largest channel

- Cross section goes as $N^2$

\[ E_{\nu} \lesssim \frac{\hbar c}{R_N} \approx 50 \text{ MeV} \]

\[ E_{\nu}^{\text{max}} \approx \frac{2E_{\nu}^2}{M} \approx 50 \text{ keV} \]

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

nu-Ar interactions

CEvNS on Ar

[Diagram of CEvNS process]
Physics with CEvNS/COHERENT

- Supernova neutrinos
- Dark Matter Backgrounds
- Weak mixing angle
- Neutrino Charged Current Interactions
  - Important in LAr for DUNE
- Accelerator Produced sub-GeV DM

\[
\frac{d\sigma}{dE} = \frac{G_F^2}{4\pi} \left[ (1 - 4 \sin^2 \theta_W) Z - (A - Z) \right]^2 M \left( 1 - \frac{ME}{2E'_\nu} \right) F(Q^2)^2
\]
The COHERENT Detector Suite

<table>
<thead>
<tr>
<th>Nuclear Target</th>
<th>Technology</th>
<th>Mass (kg)</th>
<th>Distance from source (m)</th>
<th>Recoil threshold (keVr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CsI[Na]</td>
<td>Scintillating Crystal</td>
<td>14.6</td>
<td>19.3</td>
<td>6.5</td>
</tr>
<tr>
<td>Ge</td>
<td>HPGe PPC</td>
<td>10</td>
<td>22</td>
<td>5</td>
</tr>
<tr>
<td>LAr</td>
<td>Single-phase</td>
<td>22</td>
<td>29</td>
<td>20</td>
</tr>
<tr>
<td>NaI[Tl]</td>
<td>Scintillating crystal</td>
<td>185*200</td>
<td>28</td>
<td>13</td>
</tr>
</tbody>
</table>

Focus of this talk!

First observation of CEvNS!
D. Akimov et al., Science 10.1126/science.aao0990 (2017) 134 ± 22 CEvNS events
The CENNS-10 Detector

- Built 2012-2015 by team at FNAL for the CENNS effort at FNAL led by J. Yoo, A. Lathrop, R. Davila, and others
- Moved to SNS October 2016
- First run December 2016-May 2017
  - “Spring 2017” Data
  - 35 kg fiducial volume
  - 2x Hamamatsu R5912-MOD02 8” PMT
    - 18% QE at 400 nm
  - CAEN V1720 digitizer based DAQ
  - TPB coated acrylic sides/disks backed by Teflon
    - Expected threshold ~ 100 keVnr
  - $\text{H}_2\text{O}/\text{Cu}$ shielding
First Look at Data – Spring 2017 Data

1. Analysis method is:
   - Fit single PE waveform with template
   - Fit singlet light
   - For triplet contribution, subtract scaled singlet template waveform
   - Integrate triplet light

Channel 1 (Voltage 1475)

Single PE distribution

LED Voltage: 3.5 V

\[ \mu = 0.06 \pm 0.00 \]

PE calibrate $= 55.55 \pm 2.46$

\[ \sigma = 29.84 \pm 2.56 \]

\[ \chi^2 / \text{NDF} = 184.54 / 144 \]

Data Ped Int: 8604.00
Fit Ped Int: 8465.03
Ratio (data/fit): 1.02

137Cs data compared to GEANT4 MC

Estimate $\sim 0.5$ pe/keVee

\[ \langle E \rangle = 113.6 \pm 0.7 \]

\[ \sigma_{\text{MC}} = 13.7 \pm 0.3 \]

\[ \sigma_{\text{MC}} / \langle E \rangle = 12.1 \% \]

\[ \chi^2 / \text{NDF} = 213 / 150 \]

\[ \langle E \rangle = 384.2 \pm 0.4 \]

\[ \sigma_{\text{MC}} = 27.2 \pm 0.4 \]

\[ \sigma_{\text{MC}} / \langle E \rangle = 7.1 \% \]

\[ \chi^2 / \text{NDF} = 118 / 111 \]
1. With singlet and triplet time constant sufficiently different and differing triplet decay fractions between neutron and electron recoils, pulse shape discrimination is possible

   - Standard parameter is $F_{90} = \text{light in first 90 ns}$
Upgraded CENNS-10 Detector

- Light collection upgrade in June 2017 during SNS shutdown
  - Second run July-December 2017
    - "Summer 2017 Data"
- 22 kg fiducial volume
- TPB coated Teflon side walls, frosted and TPB coated PMT glass
- \( \text{H}_2\text{O}/\text{Cu}/\text{Pb} \) shielding
- Quenching factor ~25%
- Expected threshold ~ 20 keV
- Expected 140 CEvNS events/yr
- Very stable operation!
Light Collection Upgrade

1. TPB coated acrylic parts → TPB coated Teflon/PMTs
2. Electronics Upgrade to clean up PMT signals
3. Expected threshold: 100 keVnr → 20 keVnr
Summer 2017 Data

1. Energy of main $^{57}$Co gamma = 122 keV

2. Singlet light yield of detector – Estimate 1.3 pe/keVee
   - Fit mean = 154 PEs

3. For singlet + triplet light yield estimate ~4 pe/keVee currently
   - Fit mean = 470 PEs
   - Still tuning triplet light algorithm but should be similar to this with expected triplet contribution
Expected Signal/Background Rate (After Upgrade)

- After upgrades, threshold ~ 20 keVnr
- beam-unrelated backgrounds
  - $^{39}$Ar (1 Bq/kg), environmental $\gamma$ assumed negligible with shielding, PSD, and background subtraction
- beam-related backgrounds:
  - Neutrons in time with beam measured – 60 events/yr
- CEvNS signal
  - estimate 60 prompt/80 delayed events/yr
    - Prompt – within 1 $\mu$s after SNS beam spill
    - Delayed – 1-10 $\mu$s after SNS beam spill
Future Liquid Argon Program

1. Test chambers for future LAr ton-scale detector R&D work under construction at IU/ORNL
   - Readout electronics, other WLS methods

2. WLS tests underway at IU/ORNL/ITEP(Moscow, Russia) for optimization of techniques for future LAr
Future Liquid Argon Program

1. Current CENNS-10 detector
   - More upgrades during 5 month SNS shutdown 1/18-6/18, options include
     - Improved WLS from studies
     - Depleted Ar (~1 mBq/kg $^{39}$Ar)
     - More electronics upgrades
     - LXe doped LAr

2. Long term
   - Ton scale LAr detector
     - Good charged current interaction measurement
     - Better CEvNS measurement
   - LXe, LNe

Search for accelerator produced low mass dark matter
Summary/Acknowledgements

1. The CENNS-10 detector is a 22 kg liquid argon detector built at Fermilab currently running at the SNS at ORNL
   - Upgraded for better light collection in June 2017 during SNS shutdown after completion of first run in May 2017
   - Should provide the first CEvNS measurement on liquid argon with current data run of upgraded detector

2. There are current plans for studies and tests for a future large scale detector and a long term liquid argon program at the SNS

3. Ideas/Interest welcome!

4. Thank you to DOE Office of Science, Oak Ridge National Laboratory, and the NSF for sponsoring this work!
   - This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists, Office of Science Graduate Student Research (SCGSR) program. The SCGSR program is administered by the Oak Ridge Institute for Science and Education (ORISE) for the DOE. ORISE is managed by ORAU under contract number DE-SC0014664
The COHERENT Collaboration

http://sites.duke.edu/coherent

arXiv:1509.08702

~80 members,
18 institutions
4 countries
Backups/ Extras
Triplet Lifetime

Pre-Doping

Post-Doping

- As data quality check introduce N\textsubscript{2} after spring run
- Introduce \textasciitilde25 ppm N\textsubscript{2}
- Triplet lifetime changed from \textasciitilde1.2\,\mu s to 0.20\,\mu s
  - Correspond to 1 ppm and 20 ppm respectively\textsuperscript{2}
- Verified with LDetek8000 N\textsubscript{2} monitor readings

Importance of Purity
LAr Quenching Factor