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On behalf of the COHERENT collaboration
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The COHERENT collaboration
http://sites.duke.edu/coherent

~80 members, 21 institutions, 4 countries
Coherent elastic neutrino-nucleus scattering

- Condition for coherence: low momentum transfer $q << 1/(\text{nucleus radius})$, effectively bounds neutrino energies $E_\nu <= 50 \text{ MeV}$
- Largest of all Standard Model low-energy neutrino interaction cross-sections, enhanced by $N^2$
  \[
  \frac{d\sigma}{dE} = \frac{G_F^2}{4\pi} \left[ (1 - 4\sin^2 \theta_W)Z - (A - Z) \right]^2 M \left( 1 - \frac{M E}{2E_\nu^2} \right) F(Q^2)^2
  \]
- Flavor blind: any neutrino can do it.

... The idea is very simple: If there is a weak neutral current, elastic neutrino-nucleus scattering should exhibit a sharp coherent forward peak characteristic of the size of the target just as electron-nucleus elastic scattering does...
Coherent effects of a weak neutral current

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(Received 15 October 1973; revised manuscript received 19 November 1973)
What makes CEνNS interesting?
For the Neutrino Physics community:

• Non-standard Neutrino Interactions
  
  P. Coloma et al., JHEP 12 021 (2005)
  J. Barranco et al., PRD 76 073008 (2007)
  M. Masud, P. Mehta, arxiv:1603.01389 (2016)

• Sensitive tool for Sterile neutrino searches
  
  A.J. Anderson et al., PRD86 013004 (2012)

• Neutron distribution functions
  
  K. Patton et al., PRC 86, 024216 (2012)

• Neutrino Magnetic Moments
  
  A. C. Dodd, et al., PLB 266 (91), 434
What makes CE$\nu$NS interesting?

Beyond the Neutrino Physics community:

- **Irreducible background for WIMP searches**
- **Major role in Supernovae dynamics**
  - J.R. Wilson, PRL 34 113 (1974)
  - D.N. Schramm, W.D. Arnett, PRL 34, 113 (1975)
- **Potential application in reactor monitoring**
- **Astrophysical signals (solar and SN)**

Measure CE$\nu$NS to understand nature of background (& detector response, DM interaction)
CEνNS signature: low-energy nuclear recoils

- Both CEνNS cross-section and maximum recoil energy increase with neutrino energy.
- Want energy as large as possible while satisfying coherence condition: \( q \lesssim \frac{1}{R} \)

Maximum recoil energy for Ge is \( \frac{2}{A} \left( \frac{E_\nu}{1\text{MeV}} \right)^2 \text{keV} \approx 25\text{keV} \)

Nuclear recoil energy spectrum in Ge for 30 MeV \( \nu \)

40Ar target

30 MeV \( \nu \)'s from stopped \( \pi \)

3 MeV \( \nu \)'s from reactors for same flux
Spallation Neutron Source as a Neutrino Source

Proton beam energy: 0.9-1.3 GeV
Total power: 0.9-1.4 MW
Pulse duration: 380 ns FWHM
Repetition rate: 60 Hz
Liquid mercury target

The neutrinos are free!
Neutrinos at the SNS

- Decay-at-Rest Neutrino source
- \( \nu \) flux \( 4.3 \times 10^7 \, \nu \, \text{cm}^{-2} \, \text{s}^{-1} \) at 20 m
- Pulses 800 ns full-width at 60 Hz

\[ \pi^+ \rightarrow \mu^+ + \nu_\mu \quad \text{PROMPT: monochromatic 29.9 MeV } \nu_\mu \]
\[ \mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_e \quad \text{DELAYED (2.2 \, \mu s): range of energies between 0 and } m_\mu/2 \]

Neutrino energy

- \( \nu_\mu \)
- \( \nu_e \)
- \( \bar{\nu}_\mu \)

Timing energy

Time structure enables:
- \( 10^3-10^4 \) steady-state background rejection
- steady-state characterization
Neutrino Alley

- **Quiet basement location**: extensive BG program determined that intermediate energy (10-100 MeV) beam neutron rates are ~5 orders of magnitude lower than on the experimental hall.

- Steady-state background rate also lower due to ~8 m.w.e. overburden.

- Alley is 20-30 meters from the target.

Neutron measurement data from various SNS locations.
First CEνNS observation with 14.6-kg CsI[Na]

- Beam OFF: 153.5 live-days
- Beam ON: 308.1 live-days, 7.48 GWhr

- Still collecting data with CsI detector
- More than twice statistics accumulated
Signal, background, and uncertainty

<table>
<thead>
<tr>
<th>Event Type</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam ON coincidence window</td>
<td>547 counts</td>
</tr>
<tr>
<td>Anticoincidence window</td>
<td>405 counts</td>
</tr>
<tr>
<td>Beam-on bg: prompt beam neutrons</td>
<td>7.0 ± 1.7</td>
</tr>
<tr>
<td>Beam-on bg: NINs (neglected)</td>
<td>4.0 ± 1.3</td>
</tr>
<tr>
<td>Signal counts, single-bin counting</td>
<td>136 ± 31</td>
</tr>
<tr>
<td><strong>Signal counts, 2D likelihood fit</strong></td>
<td><strong>134 ± 22</strong></td>
</tr>
<tr>
<td><strong>Predicted SM signal counts</strong></td>
<td><strong>173 ± 48</strong></td>
</tr>
</tbody>
</table>

**Uncertainties on signal and background predictions**

<table>
<thead>
<tr>
<th>Source</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Event selection (signal acceptance)</td>
<td>5%</td>
</tr>
<tr>
<td>Flux</td>
<td>10%</td>
</tr>
<tr>
<td>Quenching factor (QF)</td>
<td>25%</td>
</tr>
<tr>
<td>Form factor</td>
<td>5%</td>
</tr>
<tr>
<td><strong>Total uncertainty on signal</strong></td>
<td><strong>28%</strong></td>
</tr>
</tbody>
</table>

For any detector technology, a high-precision CEvNS program requires:

- calibrate SNS neutrino flux
- high-precision QF measurement
To untangle effects of nuclear form factors we need measurements at the wide range of target masses: Light, Middle, and Heavy.

To have handle on axial current it is interesting to have close targets with different spins. Example $^{40}\text{Ar}$ $s=0$ and $^{23}\text{Na}$ $s=3/2$. 

**COHERENT: multi-target CEνNS program**

- LAr
- NaI
- Ge
- CsI
- NIN cubes

**X-section ($10^{-40}$ cm$^2$)**

- Black: $F(q) = 1$
- Green: Klein-Nystrand FF

**Counts keVnr$^{-1}$ y$^{-1}$**

- CsI delayed (20 m, 14 kg)
- CsI prompt
- Ge delayed (22 m, 10 kg)
- Ge prompt
- LAr delayed (29 m, 35 kg)
- LAr prompt
- Na delayed (29 m, 2T NaI)
- Na prompt
Neutrino Alley
Initial activities

Several Neutrino and Background detectors deployed at various times:

- Beam Delivered
- Neutron Scatter Camera (BG Neutrons)
- LS in CsI Shield (NINs)
- CsI (CEvNS)
- SciBath (BG Neutrons)
- Pb Nube (NINs)
- NaI (CC)
- CENNS-10 (CEvNS)
- Fe Nube (NINs)

Graph showing the timeline and number of protons on target from Jan 2014 to Jul 2017.
Neutrino alley
Current activities

Single phase Liquid Argon detector CENNS-10
Since December 2016 (more next)

185 kg of NaI since July 2016
• taking data in high-threshold mode for $\nu_e$CC on $^{127}$I
• PMT base modifications to enable low-threshold CE$\nu$NS running

Pilot deployment for 2T array

Neutron background monitoring (2017)
Plastic scintillator and Gd layers, no shielding. Affected by high 511-keV gammas BG from hot off-gas pipe, considering shielding.

Study of Neutrino Induced Neutrons (NIM) on Lead and Iron (2016).
NINs are background for CE$\nu$NS and signal for Supernovae neutrino detectors (HALO)
Working on upgrade using PROSPECT Li loaded scintillator.
Single-Phase Liquid Argon

- 22 kg fiducial mass
- TPB coated teflon side reflectors
- 8in TPB-coated PMT readout
- $E_{\text{thres}} \sim 20$ keVnr enough to see CE$\nu$NS
- Running since 12/16, anticipate 6.5GWhr by 12/18
- ~100 detected CE$\nu$NS expected

Detector from FNAL, previously built (J. Yoo et al.) for CENNS@BNB
Neutrino alley
Planned activities

1 ton LAr detector
Need high statistics low background measurements of CEnNS

Transition from 22 kg to 1 ton LAr detector.

Can fit at the same place where presently 22 kg detector is sitting

Will reuse part of existing infrastructure

Potentially use depleted Argon; piggyback on DarkSide investments

Will see thousands of CEνNS events per year + higher-energy NC/CC interactions
Neutrino alley
Planned activities

Transition from 185 kg to 2 ton array of NaI detectors

Detectors are available

Need dual gain bases (prototypes have been built)

Program to measure Quenching Factors is ongoing at TUNL

Need electronics and HV; some funds are secure

Potential to detect both CEνNS and CC reactions
New Germanium Target

- Use state-of-the-art PPC Ge technology to perform a *precision* measurement of CEνNS. >800 events/yr from 10 kg array, with signal/background of ~15 (this was ~1/4 for CsI[Na] result).

- Demonstrated analysis threshold of 120 eVee/600 eVnr allows measurement of full CEνNS recoil spectrum. Accompanying ongoing effort in quenching factor characterization.

- Two first detectors (6 kg) funded at University of Chicago through DARPA and NSF. Shield will be designed to accommodate additional two units. Support from ORNL/NSCU on shield design and installation.


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Neutrino alley
Planned activities

- Improved sensitivity to ν electromagnetic properties, non-standard ν interactions, MiniBooNE/LSND anomaly (steriles), DM models…

Present µν limit (LSND)

Present µν limit (LBNL)

Present µν limit (LSND)

Present µν limit (LBNL)

Present µν limit (LBNL)

Present µν limit (LBNL)
Neutrino Flux Calibration

Presently we assume that neutrino flux at SNS is known within 10%

Well defined D$_2$O mass constrained by acrylic tank.

10 cm of light water tail catcher for high energy e-

Outer dimensions 2.3 * 2.3 * 1.0 m$^3$

For 1 t fiducial mass detector ~ thousand interactions per year

Detector calibration with Michel Electrons (same energy range)

Neutrino Flux Calibration

Cross sections of neutrino interaction with Deuterium are known with 2-3% accuracy:


Prompt NC $\nu_\mu + d \rightarrow 1.8 \times 10^{-41}$ cm$^2$

Delayed NC $\nu_{\mu-bar} + d \rightarrow 6.0 \times 10^{-41}$ cm$^2$

Delayed CC $\nu_e + d \rightarrow 5.5 \times 10^{-41}$ cm$^2$

$v$ Flux calibration and CC measurements on Oxygen
Present goals - after first CEνNS observation with CsI[Na]:
  • Accumulate more statistics with CsI[Na]
  • CEνNS detection with multiple targets: expecting LAr
  • NINs detection for Lead and Iron

Next goals - new deployments:
  • Deploy low-threshold Ge detectors
  • Measure SNS ν flux
  • High precision CEνNS studies. Look for physics beyond SM.
  • Measure ν CC to support Supernovae physics and Weak interaction physics (Lead, Argon, Oxygen, Iodine)