The COHERENT collaboration: an effort to observe coherent, elastic, neutral-current neutrino-nucleus scattering at the Spallation Neutron Source

G.C. Rich for the COHERENT collaboration
Coherent, elastic neutrino-nucleus scattering (CEνNS)

- Neutral-current (flavor-independent) process postulated by D.Z. Freedman in 1974 [1]

- In a CEνNS interaction, a neutrino scatters off of a nucleus whose nucleons recoil in phase, resulting in an enhanced cross section; total cross section scales approximately like \( N^2 \) [2]

- Expectation of existence is uncontroversial, but the process has never been detected

\[
\sigma \approx \frac{G_F^2 N^2}{4\pi} E_\nu^2
\]


Very hard to observe experimentally

- Intense neutrino source needed with appropriate energy distribution (coherence is lost with higher energy)

- Signature of interaction is a nucleus recoiling with low (order 10 keV) energy, necessitating low-threshold, low-background detectors
Physics from first observations of CEvNS

• Cross section provides a basic test of the standard model

• Measurement of weak mixing angle at ~5% level from ~10% absolute CEvNS cross section measurement
  
  • Complements measurements by $Q_{\text{weak}}$ at JLab; similar momentum transfer in both experiments, very different probes

• Relevant input for extreme astrophysical environments, particularly core-collapse supernovae
  
  • Tremendous amounts of energy are released from core of collapsing star in the form of neutrinos

• CEvNS may play a role in the dynamics of the evolution of CCSNe by providing a mechanism for (relatively) efficient coupling of neutrinos to matter
Physics from precision CEvNS measurements

• With very good understanding of systematics and spectral response of detectors, broad new physics horizons are accessible

• Sensitivity to physics beyond the standard model (nonstandard neutrino interactions / vector coupling to quarks)

• Potential for measurement of neutrino magnetic moment

• Unique tool for nuclear structure studies: neutron form factors and density distributions can be extracted

See talk by G. McLaughlin tomorrow (2PM in Kohala 1, abstract MA.00001) for a more in-depth discussion of theoretical implications and impact of CEvNS measurements
The COHERENT collaboration

Overarching goal: observe CEvNS interaction using neutrinos produced by the Spallation Neutron Source (SNS) at Oak Ridge National Lab (ORNL) with numerous targets, providing a check on systematic uncertainties and allowing confirmation of the $N^2$-dependence of the cross section.
The COHERENT collaboration

- Utilize neutrinos produced by the SNS
  - Pulsed, intense neutrino flux with **very well-defined spectral distribution**
  - $10^{15}$ neutrinos/s from stopped pions and muons, no contribution from kaons
- Take advantage of proven low-background, highly-sensitive detectors
  - Experimentally establish high-precision knowledge of detector response for low-energy nuclear recoils
- Current candidate detector technologies under strong consideration: Germanium PPC detectors, noble-element detectors, CsI(Na), leveraging knowledge gained from WIMP and 0νββ searches
- Multi-institutional group of researchers with diverse expertise
- Coalescence of many groups with interest in CEvNS observation
Neutrinos from the SNS

• The SNS bombards a liquid Hg target with a 1.3-GeV proton beam pulsed at 60 Hz; pulse is ~700 ns wide

• Neutrinos are produced by decay of stopped pions and muons, resulting in flux with well-defined spectral and timing characteristics

Figure from A. Bolozdynya et al., arXiv:1211.5199 (2012)
CEvNS signals and detectors

- CEvNS cross section increases like $N^2$
- \textit{.. but} heavier nuclei recoil with lower energy
- Target/detector selection and design requires consideration of this balance!
- Interpretation of CEvNS-search results are dependent on knowledge of detector response, especially to provide input for neutron distributions, beyond standard model tests, etc

Figure from J.I. Collar \textit{et al.}, arXiv:1407.7524 (2014)
COHERENT detector characterization

- Signals from CEvNS have very low amplitude, interpretation of collected data can be very dependent on understanding of detector response

- At TUNL, a facility has been built for precision measurements of detector response to low-energy nuclear recoils

- A beam of quasi-monoenergetic neutrons is scattered off of detector, creating low-energy nuclear recoils; signals are measured and correlated with scatters into fixed angles

- First high-precision results for nuclear recoils in NaI(Tl) and CsI(Na) out soon
Siting and backgrounds at the SNS

- CEvNS-searches are subject to familiar backgrounds for other rare-event searches

- Additional, site-specific backgrounds must also be understood and considered

- Following talk by Jason Newby discusses the continuing campaign of background measurements at various SNS locations

- Focus for first stages of COHERENT has landed on basement location with overburden and near target

- A somewhat atypical background became a concern..
Neutrino-induced neutrons (NINs)

- Both neutral- and charged-current reactions contribute

- Theoretical predictions of cross section are strongly model dependent (plot at right shows total CC cross section for $^{56}$Fe)

- For CsI(Na) geometry, sited in the SNS basement location, NINs represent the dominant background for a CEvNS measurement

Figure from A.R. Samana and C.A. Bertulani, Phys. Rev. C (2008)
Neutrino-induced neutrons (NINs)

- Measurements of these cross sections have implications beyond background assessment
- NINs from Pb are fundamental mechanism for detection in HALO supernova neutrino detector [1]
- NIN interactions may influence nucleosynthesis in certain astrophysical environments [2]

Figure from A.R. Samana and C.A. Bertulani, Phys. Rev. C (2008)

NIN measurements at the SNS

• NIN cross section measurements can be made with dedicated “neutrino cubes”: palletized assemblies which can easily be or loaded with different target materials

• Expect ~2 NIN event detections per day @ 20 m from SNS target with ~800-kg Pb target
COHERENT deployment at SNS

Deployment of neutrino cubes and CsI(Na) shielding assembly took place mid-September 2014. Located in basement, ~20 m from target, with ~8 m.w.e. overburden

- CsI(Na)-detector cavity occupied by liquid scintillator cells for *in situ* background measurement
  - Following background assessment, CsI(Na) crystal can be installed and CEνNS data can be taken

- Neutrino physics events will begin to come in as soon as SNS maintenance is complete

- NIN results will help inform design of shielding for other technologies ultimately employed by COHERENT for CEνNS measurements
Backup
SNS proton beam timing distribution

- Proton-beam timing distribution modeled after data from J. Galambos
## Other stopped-pion neutrino sources

<table>
<thead>
<tr>
<th>Facility</th>
<th>Location</th>
<th>Proton Energy (GeV)</th>
<th>Power (MW)</th>
<th>Bunch Structure</th>
<th>Rate</th>
<th>Target</th>
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<tbody>
<tr>
<td>LANSCE</td>
<td>USA (LANL)</td>
<td>0.8</td>
<td>0.056</td>
<td>600 $\mu$s</td>
<td>120 Hz</td>
<td>Various</td>
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<td>ISIS</td>
<td>UK (RAL)</td>
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<td>0.16</td>
<td>$2 \times 200$ ns</td>
<td>50 Hz</td>
<td>Water-cooled tantalum</td>
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<td>BNB</td>
<td>USA (FNAL)</td>
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<td>0.032</td>
<td>1.6 $\mu$s</td>
<td>5-11 Hz</td>
<td>Beryllium</td>
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<tr>
<td>SNS</td>
<td>USA (ORNEL)</td>
<td>1.3</td>
<td>1</td>
<td>700 ns</td>
<td>60 Hz</td>
<td>Mercury</td>
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<td>MLF</td>
<td>Japan (J-PARC)</td>
<td>3</td>
<td>1</td>
<td>$2 \times 60$-100 ns</td>
<td>25 Hz</td>
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<tr>
<td>ESS</td>
<td>Sweden (planned)</td>
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<td>17 Hz</td>
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<td>DAEDALUS</td>
<td>TBD (planned)</td>
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<td>$\sim 7 \times 1$</td>
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