Search for CEvNS at the SNS with the COHERENT experiment

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For the COHERENT collaboration
Coherent Elastic Neutrino-Nucleus Scattering - CEvNS

- First predicted in 1974 by D. Freedman
- Neutrino scatters off via exchange a Z-boson (νA → νA)
  - Nucleus recoils as a whole
  - Coherent up to $E_\nu \sim 50$ MeV

- Standard Model calculation
  - Dependence on neutron number
    $$ \frac{d\sigma}{dE} \propto N^2 $$

- Experimental signature – nuclear recoil
  - Low energy signals
    $$ E_{r,\text{max}} \simeq \frac{2E^2_\nu}{M} \simeq 50 \text{ keV} $$
Physics of CEvNS

- Standard model tests
  - Proton weak charge ($\sin^2(\theta_W)$)
  - Non-standard interactions of neutrinos
  - Neutrino magnetic moment
- Supernova Neutrino detection channel
- Nuclear Form Factors
- Reactor Monitoring
- Dark Matter (DM)
  - CEvNS is important background for ton-scale direct searches
• Neutrino source
  • pulsed proton beam on a mercury target at the ORNL Spallation Neutron Source (SNS)

• Several detector subsystems for $N^2$ dependence
  • Low threshold detectors

• Well characterized and reduced background
  • Low energy neutrons in the detectors can produce similar recoil spectra as neutrino scattering signal
Spallation Neutron Source (SNS) at Oak Ridge

- Pulsed Proton Beam
  - ~1 MW power
  - 60 Hz, 600 ns spill
  - Pulsing allows natural background rejection for factor ~ $10^4$
  - Proton collisions with mercury create neutrons and neutrinos (~ $10^7$ cm$^{-2}$s$^{-1}$ per flavor).

**Prompt monochromatic 29.2 MeV**

\[
\pi^+ \rightarrow \mu^+ + \nu_\mu \\
\downarrow
\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e
\]

$0 < E < m_\mu/2$

2.2 μs delayed
COHERENT Detectors

SNS “Neutrino-alley”

- COHERENT non-CEvNS detectors
  - Neutron background
    - Sandia Neutron Scatter Camera (deployed 2014-2016)
    - SciBath (deployed 2015)
    - MARS (deployed 2017 – now)
  - Neutrino induced neutron
    - Lead Nube (see G08.08 talk)
    - Iron Nube

<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>
<th>Start data-taking</th>
<th>Possible Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>CsI[Na]</td>
<td>Scintillating crystal</td>
<td>14.6</td>
<td>20</td>
<td>6.5</td>
<td>09/2015</td>
<td>Continue data-taking</td>
</tr>
<tr>
<td>NaI[Tl]</td>
<td>Scintillating crystal</td>
<td>185* /2000</td>
<td>28</td>
<td>13</td>
<td>*high-threshold deployment summer 2016</td>
<td>Expansion to 2 tonne</td>
</tr>
<tr>
<td>LAr</td>
<td>Single-phase</td>
<td>22</td>
<td>29</td>
<td>20</td>
<td>12/2016, Upgraded 07/2017</td>
<td>Expansion to ~ 1 tonne scale</td>
</tr>
<tr>
<td>Ge</td>
<td>HPGe PPC</td>
<td>10</td>
<td>22</td>
<td>5</td>
<td>2018</td>
<td>Ge expansion w/ lower threshold</td>
</tr>
</tbody>
</table>
Detector Subsystem - CsI

- Installed in summer 2015 in the SNS “neutrino-alley”
- 14.6 kg sodium doped CsI inorganic crystal
- High light yield
- Low intrinsic background
- Room temperature operation
First CEvNS observation

- 134 ± 22 observed events
- Standard model prediction 173 ± 48 events
- No CEvNS rejected at 6.7σ
- Consistent with SM within 1σ
- New constraints on NSIs (see D08.04)
• Thallium doped sodium iodide scintillating inorganic crystal
  • Scintillation process very similar to CsI scintillation

• Currently 185 kg total
  • 24 7.7 kg detectors

• Currently not sensitive to CEvNS
  • Being used for a different neutrino measurement
    • Charged current interaction on $^{127}$I
  • Background characterization for ton-scale upgrade
**LAr for COHERENT**

- CENNS-10 detector
- 2x Hamamatsu R5912-MOD02 PMTs
- Wavelength shifter tetraphenyl butadiene (TPB) coated Teflon side walls
- ~ 22 kg fiducial volume
- 20 keVnr energy threshold
- Installed at SNS late 2016
- Upgraded in June 2017 to improve light collection capabilities

- More details – D08.02 talk

- Full shielding since August 2017
  - Lead 4’’
  - Copper 0.5’’
  - Water 9’’
Future COHERENT

- Improved background studies

- 10 kg Ge, w/ future upgrade to state-of-the-art tech → study e.m. properties
  - See G08.05 talk

- NaI: 2-ton CEvNS sensitive upgrade → have multiple tons in hand and available for a multi-ton deployment

- Further neutrino induced neutron studies

- LAr: expansion to ~ 1 tonne scale

- Several prospects for additional target nuclei
COHERENT collaboration

~80 members, 18 institutions 4 countries
Summary

• Search for CEvNS at SNS and measure the coherent neutrino-nucleus cross section in multiple nuclei

• SNS is a great source for a CEvNS measurement due to pulsed beam and beam power

• First CEvNS observation in CsI (August 2017) made by COHERENT collaboration

• Multiple target material detectors (NaI, LAr, Ge) taking data and under development to show N^2 dependence. Other target materials under consideration for feasibility.

• Working towards ton-scale detectors to increase sensitivity
Backup
Neutron Background

• 100 keV – 1 MeV neutrons can produce similar signal

• Neutron flux measured at different positions with multiple detector technologies:
  • Sandia Scatter Camera – multiplane liquid scintillator
  • SciBath - WLS fiber + liquid scintillator

• Low neutron background in the SNS basement
• Prompt neutron flux $\sim 10^{-7}$ neutrons/cm$^2$/s

• Expected rates in detector below CEvNS signal