Detector Technologies for the COHERENT Experiment

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Coherent Elastic Neutrino Nucleus Scattering (CEvNS)

- Neutrino recoils coherently and elastically off entire nucleus via $Z$ exchange
  - Coherent up to $E_\nu \lesssim \frac{\hbar c}{R_N} \approx 50$ MeV
- Predicted 41 years ago, yet to be observed
- Large predicted SM cross section with $N^2$ dependence

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

- So why not observed?
  - Low recoil energy $E_r^{\text{max}} \approx \frac{2E^2}{M} \approx 50$ keV
  - Detectors just now becoming sensitive to these recoil energies

Accessible Physics with CEvNS Measurement

- Sensitive to supernova neutrinos from core-collapse SN, largest SN cross section
- Background for WIMP dark matter searches
- Standard Model tests
- Nuclear Form Factors
- Non-Standard Neutrino Interactions

K. Patton et al., PRC86 (2012) 024612
Neutrinos at the SNS

- High intensity, clean pulsed $\pi$-decay at rest neutrino source ($10^7$/cm$^2$/s at 20m)
- Ideal proton beam energy (0.9-1.3 GeV)
- Multiple neutrino flavors
- Pulsed 60 Hz timing structure
- Good background rejection of few x $10^{-4}$ due to pulsed structure of beam
COHERENT at the SNS ("Neutrino Alley")

- Background measurements began in 2013 to determine lowest background feasible location at SNS for COHERENT

  - Location in SNS target building basement ("Neutrino Alley")

    - 20-29 m from source
COHERENT Background Measurements

- Campaign to measure steady-state backgrounds and backgrounds related to the beam pulse
  - SciBath (Indiana Univ.) and Neutron Scatter Camera (Sandia) for beam related neutrons → basement neutron quiet
  - Ortec HPGe detector for environmental gammas from concrete and “hot off gas” pipe (source of 511 keV gammas)
  - “Neutrino Cubes (Nubes)” for Neutrino Induced Neutrons
    - Pb shielding interacts with $\nu_e$ and break up into 1 or 2 neutrons

Neutron Scatter Camera results (various locations in SNS target building)
COHERENT Deployment Program

- Unambiguous detection of CEvNS via $N^2$ dependence of cross section in above targets
- 100’s of events expected/year
- Must control backgrounds, have low thresholds, and understand quenching factors
- Also measure Neutrino Induced Neutrons (NINs) on Pb, Fe

<table>
<thead>
<tr>
<th>Nuclear Target</th>
<th>Technology</th>
<th>Mass (kg)</th>
<th>Target Distance (m)</th>
<th>Recoil threshold (keVr)</th>
<th>Data-taking start date; CEvNS detection goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>CsI[Na]</td>
<td>Scintillating Crystal</td>
<td>14</td>
<td>20</td>
<td>6.5</td>
<td>Sept. 2015; 3σ in 2 yr</td>
</tr>
<tr>
<td>Ge</td>
<td>HPGe PPC</td>
<td>10</td>
<td>22</td>
<td>5</td>
<td>Early 2017</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>
</tr>
</tbody>
</table>

* high-threshold deployment summer 2016
CsI[Na]

- 14 kg CsI[Na] crystal
  - Na doping reduces afterglow seen in more common Tl doping
- Commissioned at SNS in July 2015
- Shielding structure includes lead, water, and plastic
- Quenching factor measurements performed
- Steady-state backgrounds at SNS installation site 10-20% of measurements taken at Univ. of Chicago
  - Neutrino-Induced-Neutrons reduced to ~4% of CEvNS including HDPE shielding
- ~1 calendar year of data has been taken
  - Analysis underway
**NaI[Tl] - NaI Ve**

- Acquired many ~7kg NaI crystals from discontinued DHS program
- 185 kg prototype to begin
  - Commissioned at SNS site in July 2016
  - Measure CC $\nu_e$ interaction on $^{127}$I (see B. Suh poster L1.00006 for more details)
- 2 ton deployment planned for CEvNS measurement
- Up to 9 tons available
LAr – CENNS-10

- 35 kg fiducial-volume single-phase detector built by J. Yoo at Fermilab for CEvNS effort
- Readout is 2 Hamamatsu R5912-02MOD 8" cryogenic, high-gain PMT
- Neutron/electron recoil pulse shape discrimination measured by miniCLEAN
- Quenching factor well measured by SCENE collaboration
- $^{39}$Ar controllable via PSD and beam duty factor
- Shielding structure of lead, copper, and water to control steady state backgrounds
- Tested at Indiana Univ. in the summer of 2016 for feasibility
- Commissioned at SNS in December 2016

HPGe

• HPGe PPC
• Excellent energy resolution at low energies
• Well measured quenching factor
• First deployment: ~10 kg PPC detector array
  • Repurpose on-hand Majorana Demonstrator/LANL natGe detectors
  • Shielding structure of Lead, Copper, and Poly along with plastic scintillator muon veto
  • Installation in early 2017
• Potential next deployment: Larger mass (C4-style) PPC detectors
Summary

• SNS provides clean $\pi$-DAR neutrino source for CEvNS measurement

• COHERENT is deploying 4 different detector technologies to make an unambiguous discovery of CEvNS via $N^2$ dependence of cross section

• COHERENT anticipates a rich neutrino program with different detector technologies and reach of a wide variety of physics