CsI[Na] for CEνNS detection at the SNS

NCSU CEνNS workshop, Jan 2015

J.I. Collar, UC
“Tendons”

San Onofre Unit 3 core 20m that way

LN2 generation and auto-transfer

30 mwe

Everyone needs a hobby

BaDAss (Background Detector Assembly)
Everyone needs a hobby

Giorgio dixit: “first to put CEνNS signal and backgrounds on a lin-lin plot…”
Why CsI[Na]? (NIM A773 (2014) 56)

- Large $N^2 \Rightarrow$ large x-section.
- Cs and I surround Xe in Periodic Table: they behave much like a single recoiling species, greatly simplifying understanding the NR response.
- Quenching factor in energy ROI sufficient for ~7 keVnr threshold (we have measured this).
- Statistical NR/ER discrimination is possible at low-E (but will need further improved signal-to-background).
- Sufficiently low in intrinsic backgrounds (U, Th, K-40, Rb-87, Cs-134,137) Measurements in complete SNS shield and 6 m.w.e. indicate we are ready
- Practical advantages: High light yield (64 ph/keVee), optimal match to bialkali PMTs, rugged, room temperature, inexpensive ($1/g), modest afterglow (CsI[Tl] not a viable option for surface experiment).
- Expect ~550 $\nu$ recoils/year in 14 kg detector under construction.

(boule grown at AMCRYS, detector already at UC)
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CsI[Tl] not an option due to excessive afterglow
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Simultaneous ER and NR low-E response measured via Compton scattering and D-D neutron gun (see PRC 88(2013)035806)
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Highlights of feasibility study

- Study of backgrounds with 2 kg detector within a full shield (except n moderator) at 6 m.w.e. (~similar to SNS basement).
- Threshold ~7 keVnr (4 PE) demonstrated.
- Clear CENNS excess expected following a 2-3 year run with 14 kg detector. Some ~550 ev/year expected in 4-20 PE region. Measured steady-state backgrounds are sufficiently low (but further improvements seem possible → neutron moderator, fancier treatment of discrimination against afterglow).
- GEANT simulation (transport of target neutrons to basement) using UC cluster. CPU-intensive! Several sanity checks performed. Confirms that basement location should keep target neutrons at bay.
- $\nu_e$ CC reaction in Pb provides largest foreseeable background. Several ways to discriminate CENNS and this reaction.
- Should we measure $^{208}$Pb($\nu_e$,e)$^{208}$Bi first? Advantages: 1) quick measurement eliminates this unknown, 2) a first $\nu$ physics result at the SNS at hand → useful for HALO, traction with agencies.
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Preliminaries: *in situ* NIN measurement
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- If x-sections are what is expected, we should have a measurement of CC (+ perhaps NC) NIN production in Pb within the next few months.

- Main purpose of ongoing measurement is to educate CsI[Na] shield design. We plan a much higher statistics measurement with dedicated NIN detectors (“NIN-cubes”), also using other targets (G. Rich talk tomorrow)

- We need theory help already!
1) A best effort at calculating CC NIN x-section specifically for SNS ν energies. We should be able to distinguish between predictions from different nuclear models.

Low-energy neutrino scattering measurements at future spallation source facilities

<table>
<thead>
<tr>
<th></th>
<th>10</th>
<th>20</th>
<th>50</th>
<th>ρ (g cm⁻³)</th>
<th>⟨σ⟩_{DAR}</th>
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<tr>
<td>¹²C (in C₁₂H₁₈)</td>
<td>1.47</td>
<td>3.84</td>
<td>63</td>
<td>0.992</td>
<td>\approx 0.14 [10, 13]</td>
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<tr>
<td>¹⁶O (in water)</td>
<td>998</td>
<td>261</td>
<td>43</td>
<td>1.0</td>
<td>0.131 [56]</td>
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<td>⁴⁰Ar</td>
<td>8.86</td>
<td>2.31</td>
<td>380</td>
<td>1.43</td>
<td>2.56 [44]</td>
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<td>⁵⁶Fe</td>
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<td>2.33</td>
<td>377</td>
<td>7.87</td>
<td>3.53 [56]</td>
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<tr>
<td>¹⁰⁰Mo</td>
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<td>4.42</td>
<td>716</td>
<td>10.28</td>
<td>11.95 [56]</td>
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<tr>
<td>²⁰⁸Pb</td>
<td>13.49</td>
<td>3.82</td>
<td>1430</td>
<td>11.34</td>
<td>49.6 [56]</td>
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<td>2.40</td>
<td>677</td>
<td>23.5</td>
<td>23.5 [28]</td>
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<tr>
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<td>2.40</td>
<td>390</td>
<td>13.5</td>
<td>13.5 [28]</td>
</tr>
</tbody>
</table>

Situation for Fe, very similar for Pb

(this is what is used for the expectations in previous transparency, post corrections <- checked with authors)
Dangling ends desperately needing theory input:

2) Best effort at calculating spectrum of neutron emission energies. Presently using a simple spallation spectrum in Pb as a place holder (NIMA 354 (1995) 553). We should be able to eventually deconvolve this emission spectrum with data from a high-statistics run using the NIN-cubes (G. Rich talk tomorrow).

3) Is the assumption of isotropic neutron emission correct?

FIG. 6. Neutron energy spectrum produced by the charged-current \( (\nu_e, e^-) \) reaction on \( ^{208}\text{Pb} \). The calculation has been performed for different supernova neutrino spectra characterized by the parameters \((T, \alpha)\). Note that the cross sections for \((T, \alpha) = (4,0)\) and \((3,3)\) neutrinos have been scaled by a factor of 5.
Dangling ends desperately needing theory input:

4) NC NINs are prompt, but in principle only a ~10% fraction of CC NINs. We may be able to measure these too, or to at least place an upper limit to the x-section. Best effort needed to calculate $\nu_\mu$ NIN x-section at exactly 29.9 MeV (resonances could make a significant difference). We plan to run with detectors outside Pb, to help disentangle NC NINs from POT neutrons.

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FIG. 3. Excitation spectrum of the $^{208}$Pb nucleus for photoabsorption (upper part) in comparison to the spectrum excited by neutral current neutrino scattering (lower part), which is decomposed into the dominant multipole contributions.