Detectors for CEνNS
“Tendons”

San Onofre Unit 3 core 20m that way

LN2 generation and auto-transfer

30 mwe

BaDAss (Background Detector Assembly)

Everyone needs a hobby
So close, and yet so far

G. Gratta dixit: “first to put CEνNS signal and backgrounds on a linear-linear plot…”

Expected CEνNS signal (resolution folded in)

PPC surface event rejection not known at the time, would have further reduced the background.

However, real impediment was residual electronic noise.

Latest PPCs may be up to snuff (but it won’t be me who tries this again…)

So close, and yet so far

“Tendons”

30 mwe

San Onofre Unit 3 core 20m that way

LN2 generation and auto-transfer

68,71Ge L-shell EC
Other reactor fans:

RICOCHET
Coherent Neutrino Scattering with Cryogenic Crystal Detectors
Other reactor fans:
Fortunately, reactors are not the only game in town:
Fortunately, reactors are not the only game in town:
Enter COHERENT @ SNS:

How to Make an Unambiguous Measurement

- Observe the pulsed $v$ time-structure
- Observe the 2.2 $\mu$s characteristic decay of muon decay $v$'s
- Observe the $N^2$ cross section behavior between targets
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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 ~5 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.

1.7E7 $\nu$/cm$^2$s @20m, e.a. flavor
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CsI[Tl] not an option due to excessive afterglow.
Preliminaries: background studies w/ 2 kg prototype

- 2 kg test crystal.
- Screened salts, electroformed Cu can (PNNL), ULB window and reflector.
- 99.6% measured efficiency muon veto.
- ET 9390UFL Low bkg PMT.
- 300 Hz trigger rate.
- Inner ULB Pb liner (<0.02 Bq Pb-210/kg).
- Incomplete Pb shield (>10 cm in all directions).

Pulsed SNS signal leads to very low bckg.
We improved on prototype background level!
Preliminaries: *in situ* neutron bckg measurements
• Measurements informed final shielding design (3” internal HDPE to reduce NIN signal to 1/25 of CENNS).

• Prompt n’s at this location also not an issue (contained in time, very low flux at ~2 x 10^-8 n/cm²/MeV/s)
Preliminaries: 14.5 kg detector characterization

- Collimated source
- 14.5 kg CsI[Na]
- Small Brilliance crystal

![Graphs showing light yield and signal acceptance vs. distance from PMT and number of photoelectrons.][1]

SA w/ all cuts at SNS
Preliminaries: Quenching factor measurements
Installation of 14.5 kg CsI[Na] June 2015
Installation of 14.5 kg CsI[Na] June 2015

Graph showing beam energy and cumulated beam energy from August 2015 to June 2016.

- Beam Energy [MWhr]
- Cumulated Beam Energy [GWhr]

- Black line: Total energy delivered
- Green line: Data available
<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>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>4.5</td>
<td>9/2015; 5σ in 2 yr</td>
</tr>
<tr>
<td>Ge</td>
<td>HPGe PPC</td>
<td>10</td>
<td>22</td>
<td>5(2)</td>
<td>Fall 2016</td>
</tr>
<tr>
<td>LAr</td>
<td>Single-phase</td>
<td>35</td>
<td>29</td>
<td>20</td>
<td>Fall 2016</td>
</tr>
<tr>
<td>NaI</td>
<td>Scintillating crystal</td>
<td>185*/2000</td>
<td>22</td>
<td>13</td>
<td>*Summer 2016</td>
</tr>
</tbody>
</table>

**COHERENT DETECTORS AND STATUS**

A diagram illustrating a neutrino source with labels for LAr, NaI, Ge, Csl, and NIN cubes. The text details nuclear targets, technologies, masses, distances, recoil thresholds, and data-taking start dates.
CENNS-10 LAr detector for COHERENT

- CENNS-10 detector built at Fermilab, modified by IU-group
- 35kg LAr fiducial mass. NR/ER discrimination.
- Pb, Cu, H2O shielding structure built for SNS neutrino corridor
- ~300/700 (prompt/delayed) CEvNS events/yr on 100/900 est. background evts
- QF measured
**LAr QF measurements**


**FIG. 10.** S1 yield as a function of nuclear recoil energy measured at zero field relative to the light yield of $^{83m}$Kr at zero field, compared to previous measurements[8, 9].
Detector Subsystems: NaI[Tl]

- Initial deployment 185 kgs
- Up to 9 T in hand
- $N = 23$ for Na
- Instrumentation tests underway at Duke and UW
- QF measured by collaboration

https://twitter.com/NalvE_SNS
Nal[Tl]: Two primary measurement goals

- CEvNS on Na

- The electron neutrino Charged & Neutral-Current interaction on $^{127}$I

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Reaction Channel</th>
<th>Source</th>
<th>Experiment</th>
<th>Measurement ($10^{-42}$ cm$^2$)</th>
<th>Theory ($10^{-42}$ cm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^2$H</td>
<td>$^2$H($\nu_e$, $e^-$)pp</td>
<td>Stopped $\pi/\mu$</td>
<td>LAMPF</td>
<td>52 ± 18 (tot)</td>
<td>54 (IA) (Tatara et al., 1990)</td>
</tr>
<tr>
<td>$^{12}$C</td>
<td>$^{12}$C($\nu_e$, $e^-$),$^{12}$N$_{e,e}$</td>
<td>Stopped $\pi/\mu$</td>
<td>KARMEN</td>
<td>9.1 ± 0.5 (stat) ± 0.8 (sys)</td>
<td>9.4 [Multipole](Donnelly and Peccei, 1979)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stopped $\pi/\mu$</td>
<td>E225</td>
<td>10.5 ± 1.0 (stat) ± 1.0 (sys)</td>
<td>9.2 [EPT] (Fukugita et al., 1988)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stopped $\pi/\mu$</td>
<td>LSND</td>
<td>8.9 ± 0.3 (stat) ± 0.9 (sys)</td>
<td>8.9 [CRPA] (Kolbe et al., 1999b)</td>
</tr>
<tr>
<td>$^{12}$C</td>
<td>$^{12}$C($\nu_e$, $e^-$),$^{12}$N$_{e,e}$</td>
<td>Stopped $\pi/\mu$</td>
<td>KARMEN</td>
<td>5.1 ± 0.6 (stat) ± 0.5 (sys)</td>
<td>5.4-5.6 [CRPA] (Kolbe et al., 1999b)</td>
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<tr>
<td></td>
<td></td>
<td>Stopped $\pi/\mu$</td>
<td>E225</td>
<td>3.6 ± 2.0 (tot)</td>
<td>4.1 [Shell] (Hayes and S, 2000)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stopped $\pi/\mu$</td>
<td>LSND</td>
<td>4.3 ± 0.4 (stat) ± 0.6 (sys)</td>
<td></td>
</tr>
<tr>
<td>$^{12}$C</td>
<td>$^{12}$C($\nu_e$, $\nu_\mu$),$^{12}$C$_{\mu}$</td>
<td>Stopped $\pi/\mu$</td>
<td>KARMEN</td>
<td>3.2 ± 0.5 (stat) ± 0.4 (sys)</td>
<td>2.8 [CRPA] (Kolbe et al., 1999b)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Stopped $\pi/\mu$</td>
<td>KARMEN</td>
<td>10.5 ± 1.0 (stat) ± 0.9 (sys)</td>
<td>10.5 [CRPA] (Kolbe et al., 1999b)</td>
</tr>
<tr>
<td>$^{12}$C</td>
<td>$^{12}$C($\nu_e$, $\nu_\mu$)$^{12}$N$_{e,e}$</td>
<td>Decay in Flight</td>
<td>LSND</td>
<td>1000 ± 30 (stat) ± 180 (sys)</td>
<td>1750-1780 [CRPA] (Kolbe et al., 1999b)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1380 [Shell] (Hayes and S, 2000)</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td>1115 [Green’s Function] (Meucci et al., 2004)</td>
</tr>
<tr>
<td>$^{55}$Fe</td>
<td>$^{55}$Fe($\nu_e$, $e^-$)$^{56}$Co</td>
<td>Stopped $\pi/\mu$</td>
<td>KARMEN</td>
<td>256 ± 108 (stat) ± 43 (sys)</td>
<td>264 [Shell] (Kolbe et al., 1999a)</td>
</tr>
<tr>
<td>$^{71}$Ga</td>
<td>$^{71}$Ga($\nu_e$, $e^-$)$^{71}$Ge</td>
<td>$^{51}$Cr source</td>
<td>GALLEX, ave.</td>
<td>0.0054 ± 0.0009 (tot)</td>
<td>0.0058 [Shell] (Haxton, 1998)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$^{51}$Cr</td>
<td>SAGE</td>
<td>0.0055 ± 0.0007 (tot)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>$^{47}$Ar source</td>
<td>SAGE</td>
<td>0.0055 ± 0.0006 (tot)</td>
<td>0.0070 [Shell] (Bahcall, 1997)</td>
</tr>
<tr>
<td>$^{127}$I</td>
<td>$^{127}$I($\nu_e$, $e^-$)$^{127}$Xe</td>
<td>Stopped $\pi/\mu$</td>
<td>LSND</td>
<td>284 ± 91 (stat) ± 25 (sys)</td>
<td>210-310 [Quasi-particle] (Engel et al., 1994)</td>
</tr>
</tbody>
</table>

Detector Subsystems: HPGe PPCs

- Smaller N: 38-44
- Excellent resolution at low energies
- Well-measured quenching factor
- Phase I: 5-10kg PPC Ge detector array:
  - Repurposing on-hand MAJORANA DEMONSTRATOR/LANL natGe detectors.
  - Copper/Lead/Poly shield with Plastic scintillator μ-veto.
  - Installation in Fall 2016
- Potential Phase II: Expansion of target with larger-mass (C4-style) point contact detectors.