Observation of CEvNS at SNS

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**Coherent elastic neutrino-nucleus scattering**

- Neutral weak current process
- Low momentum transfer, $\lambda_z = 1/q < R_N$
- Identical initial and final states

The process was predicted about four decades ago:


Largest of all Standard Model low-energy neutrino interactions cross-section

$$
\frac{d\sigma}{d\Omega} = \frac{G^2}{4\pi^2} k^2 (1 + \cos \theta) \left( N - (1 - 4\sin^2 \theta_W) Z \right)^2 F^2(Q^2)
$$

where $G$ – Fermi constant, $Z$ – number of protons, $N$ – number of neutrons, $F(Q^2)$ – nuclear form factor, $Q$ – momentum transfer, $k$ – neutrino energy
Spallation Neutron Source (SNS) accelerator at ORNL

Dumping bunches of ~1 GeV protons on the Hg target with 60 Hz frequency

Full width of a bunch time profile ~800 ns

\[ \pi^- + \text{Hg} \rightarrow \text{Capture} \]

\[ \pi^+ \rightarrow \mu^+ + \nu_\mu \]

\[ \tau \approx 26 \text{ ns} \]

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

\[ \tau \approx 2200 \text{ ns} \]

Total neutrino flux

\[ 4.3 \times 10^7 \text{ cm}^{-2}\text{s}^{-1} \text{ at 20m} \]
The $\text{CsI}[\text{Na}]$ detector

$\text{CsI}[\text{Na}]$ cylindrical crystal manufactured by Amcrys-H, Ukraine

Crystal dimensions:
diameter – 11 cm,
length - 34 cm,
weight – 14.5 kg

Light collection by R877-100 PMT
Light yield of 13.35 PE/keV

Shielding design:

<table>
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<tr>
<th>Layer</th>
<th>HDPE*</th>
<th>Low backg. lead</th>
<th>Lead</th>
<th>Muon veto</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thickness</td>
<td>3”</td>
<td>2”</td>
<td>4”</td>
<td>2”</td>
<td>4”</td>
</tr>
<tr>
<td>Colour</td>
<td></td>
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Neutron backgrounds

“Neutrino alley”:
SNS basement with 8 m.w.e. overburden
-> reduction of CR background
20 m of concrete and gravel to the SNS target
-> reduction of prompt neutron flux
Steady state background reduction (pulsed source): $\sim 10^3$ (for CsI[Na])

Prompt neutron flux measurements:
• Measurements with Scibath and Sandia Camera
• In situ measurements within the CsI[Na] shielding prior to installation (Liquid Scint.)
• Limits coming from the absence of peak from the $^{127}$I(n,n’$\gamma$) reaction in the CEvNS search data
Neutrino induced neutrons (NINs)

In situ measurement with LS was also used to constrain NINs rate

Fitting of the arrival times of neutron-like signals

First indication of NINs detection
(1.7 times below theory prediction)

Prompt neutron and NINs rates estimates were used in the final analysis

This process can be important in many stellar environments

**DAQ and analysis approach**

Recording of 70 μs waveforms with 500 MHz sampling of CsI and veto channels

Around 2 billions of waveforms were recorded!

**Scheme:** look into ROI → find the first pulse → integrate for 3 μsec

\[
\text{C ROI (after trigger)} - \text{AC ROI (before trigger)} = \text{CEvNS} + \text{Beam correlated background} + \text{Fluctuations of steady state background}
\]
Results

Spectra of integrals and arrival times of signals appearing in ROI
Results: residual spectra

Residual spectra of integrals and arrival times of signals appearing in ROI

The significant excess in both spectra for BEAM ON only periods is observed
The formation of excess is strongly correlated with the accumulated Beam Power.
Results: significance

The ML fit for the CEvNS signal including contributions from the prompt neutrons and the steady state backgrounds taken from the anti-coincidence window

6.7σ significance!

Agreement with the SM prediction to within 1σ

**CEvNS and NSI**

Model independent parameterization of NS contributions to neutrino-quark interactions

Considering only $\varepsilon_{ee}^{uV}, \varepsilon_{ee}^{dV}$ to have non-zero values

First result can improve constraints on non-universal interactions

**Systematics**

- Uncertainty in the CsI[Na] QF (~25%)
- SNS neutrino flux (~10%)
- Signal acceptance (~5%)
- Form-factor uncertainty (~5%)

Total: 28%
Activities and perspectives

• CENNS-10 LAr detector (single phase, 22 kg) aiming for CEvNS
• “NIN cubes” to measure NINs production on lead, iron and copper
• NaIve (NaI[Tl], 185 kg → 2T) to measure CC and NC on $^{127}$I, CEvNS on Na
• P-Type Point Contact HPGE detector to be deployed soon to hunt for CEvNS
• Scibath, Sandia Camera and MARS to measure neutron backgrounds
• Small CsI[Na] crystal to repeat the QF measurements at TUNL
• CsI[Na] continues acquiring statistics

Hope to see new exciting results soon!
Backup 1: QF measurements at TUNL

- D(D,n) generator (3.8 MeV)
- shield to attenuate off-axis neutrons
- scatterer under investigation (not shown)
- twelve backing detectors
- zero-degree beam monitor

Two independent measurements with the ~100 g CsI[Na] crystal from the same manufacturer as 14.5 kg one

The Na concentration is the same for both crystals
Backup 2: QF

![Graph showing quenching factor vs. nuclear recoil energy](image-url)
Backup 3: CsI[Na] stability
Backup 4: $^{252}\text{Cf}$ calibration and $^{127}\text{l}(n,n'\gamma)$
Backup 5: light yield $^{241}$Am calibration

![Graph showing light yield versus distance from PMT window (cm)](image)
Backup 6: risetimes cut
Backup 7: the parallel analysis results

Separately dealing with the data already at the digitized trace level

The results are consistent with the first analysis and the prediction of the Standard Model
Backup 8: AC (on) – AC (off) residuals
Backup 9: why SNS
Backup 10: cuts efficiency
Backup 11: $^{133}\text{Ba}$ calibration

The maximum single scattering angle for a coincidence signal is $\theta \sim 12^\circ$

Corresponding energy – up to 6.2 keV

Goal:

to have a dataset with few to few tens phe events to “train” cuts on $^{133}\text{Ba}$ gammas

BrilLanCe crystal to trigger on forward scattered gammas
Backup 12: Motivation

CEvNS can be used as a tool to investigate:

• Sterile neutrino existence
  A.J. Anderson et al., PRD 86 013004 (2012)

• Neutron distribution functions
  K. Patton et al., PRC 86, 024216 (2012)

• Weak mixing angle at tens MeV scale

• NSI interactions relevant for LBL CP violation experiments
  P. Coloma et al., JHEP 12 021 (2005)
  J. Barranco et al., PRD 76 073008 (2007)
  M. Masud, P. Mehta, arxiv:1603.01389 (2016)

CEvNS also plays major role in the supernovae dynamics

J.R. Wilson, PRL 34 113 (1974)
D.N. Schramm, W.D. Arnett, PRL 34, 113 (1975)

Potential application: nuclear power plant monitoring!