COHERENT
at the Spallation Neutron Source

Yu.Efremenko – University of Tennessee
\[
\frac{d\sigma}{dT_A} = \frac{G_F^2}{4\pi} m_A \left[ Z \left( 1 - 4\sin^2 \theta_W \right) - N \right]^2 \left[ 1 - m_A \frac{T_A}{2E^2_v} \right] F^2(Q^2)
\]

\[
\sigma_{\text{tot}} = \frac{G_F^2 E^2_v}{4\pi} \left[ Z \left( 1 - 4\sin^2 \theta_W \right) - N \right]^2 F^2(Q^2)
\]

- \( m_A \) – nucleus mass
- \( T_A \) – kinetic energy of recoil nucleus
- \( E_v \) – neutrino energy
- \( Z \) – nucleus charge
- \( N \) – number of neutrons in the nucleus
- \( F \) is nucleus form factor

\( E_v < 50\text{MeV} \)

Horowitz et al. astro-ph/0302071
Why we do not see it yet?

Cross Section is Large !!!

But the Signal is Hard to Detect

\[ \sigma, \text{ cm}^2 \]

\[ E_{\nu}, \text{ MeV} \]

\[ E_{\text{recoils}}, \text{ MeV} \]
CEvNS from natural neutrinos creates ultimate background for direct DM search experiments

Understand nature of background (& detector response)
CEvNS is cleanly predicted in the SM, so any deviation could represent new physics

Example: sensitivity to **Non-Standard Interactions (NSI)** of neutrinos and quarks; could get ~factor of 10 beyond existing limits with current-generation CEvNS experiment
CEvNS is important in supernova models and supernova neutrino detection

J.R. Wilson, PRL 32, 849 (1974)
C. Horowitz et al., PRD 68, 02005 (2003)
Clean SM prediction for the rate $\rightarrow$ measure $\sin^2\theta_{\text{w eff}}$;

\[ \sigma \sim \frac{G_f^2 E^2}{4\pi} (N - (1 - 4\sin^2\theta_W)Z)^2 \]

deviation probes
new physics

Example: hypothetical dark Z mediator
(explanation for g-2 anomaly)

CEvNS sensitivity is @ low Q;
need sub-percent precision to compete w/ electron scattering & APV, but new channel

Plot based on arXiv: 1411.4088
Neutrino magnetic moment

Signature is **distortion at low recoil energy** $E$

$$\frac{d\sigma}{dE} = \frac{\pi \alpha^2 \mu^2 Z^2}{m_e^2} \left( \frac{1 - E/k}{E} + \frac{E}{4k^2} \right)$$

- requires low energy threshold

See also new paper: Kosmas et al., arXiv:1505.03202
Solar neutrinos: rule out sterile oscillations using CEvNS (NC)

Supernova neutrinos: ~ handful of events per tonne @ 10 kpc: sensitive to all flavor components of the flux

Billard et al., arXiv:1409.0050
Horowitz et al., PRD68 (2003) 023005

Also note: tone-scale underground detectors can do astrophysics
A practical application in nuclear safeguards:

P. Huber, talk at NA/NT workshop, Manchester, May 2015

Presence of **plutonium breeder blanket** in a reactor has $\nu$ spectral signature

$$^{238}\text{U} + n \rightarrow ^{239}\text{U} \xrightarrow{\beta} ^{239}\text{Np} \xrightarrow{\beta} ^{239}\text{Pu}$$

$\nu$ spectrum is below IBD threshold

$\rightarrow$ accessible with CEvNS, but require low recoil energy threshold
Radioactive sources

$^{144}\text{Ce}$, 75 kCi

Practical distance between source and detector is $\sim$2 m
$E_\nu \sim 1.5$ MeV

Nuclear Reactors

3 GW
Distance $\sim$20 m
$E_\nu \sim 3$ MeV

Stopped Pion Facilities

1 MW
Distance $\sim$15 m
$E_\nu \sim 30$ MeV
Reactor Neutrinos

The graph shows the distribution of reactors' neutrino energy (in keV) with the corresponding detector gains (in 1/keV). The detectors used are He, Si, Xe, and Ge. The isotopes U-235, Pu-239, U-238, and Pu-241 are also indicated.
Proton beam energy – 0.9 - 1.3 GeV
Intensity - $9.6 \cdot 10^{15}$ protons/sec
Pulse duration - 380ns (FWHM)
Repetition rate - 60Hz
Total power – 0.9 – 1.4 MW
Liquid Mercury target
LINAC: \[ \cdots \times 1000 \cdots \]

Accumulator Ring: \[
\]

Repeat 60/sec.

1.0 GeV
Number of protons on target for 1.1 mA at 1.3 GeV is $0.687 \cdot 10^{16} \text{ sec}^{-1}$

Number of each flavor neutrino produced by one proton is 0.13

SNS is operational 2/3 part of the year

Number of each flavor of neutrinos produced at SNS is $1.9 \cdot 10^{22} \text{ year}^{-1}$

Caveat:
There is larger flux of antineutrinos from decay of radioactivity in the target
However, their energy is at a few MeV and almost continues in time.
**Stopped-Pion (πDAR) Neutrinos**

- **3-body decay**: range of energies between 0 and $m_\mu/2$
  - DELAYED (2.2 μs)

- **2-body decay**: monochromatic 29.9 MeV $\nu_\mu$
  - PROMPT

\[ \begin{align*}
\pi^+ & \rightarrow \mu^+ + \nu_\mu \\
\mu^+ & \rightarrow e^+ + \bar{\nu}_\mu + \nu_e
\end{align*} \]
The SNS has large, extremely clean DAR $\nu$ flux

Note that contamination from non $\pi$-decay at rest (decay in flight, kaon decay, $\mu$ capture...) is down by several orders of magnitude

SNS flux (1.4 MW): $430 \times 10^5 \nu/\text{cm}^2/\text{s}$
@ 20 m

BNB off-axis flux (32 kW): $5 \times 10^5 \nu/\text{cm}^2/\text{s}$
@ 20 m (CENNS)
Comparison of pion decay-at-rest ν sources from duty cycle

$\propto \nu \text{ flux}$
The COHERENT collaboration

arXiv:1509.08702

<table>
<thead>
<tr>
<th>Institution</th>
<th>Board Member</th>
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<tr>
<td>University of California, Berkeley</td>
<td>Kai Vetter</td>
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<tr>
<td>University of Chicago</td>
<td>Juan Collar</td>
</tr>
<tr>
<td>Duke University</td>
<td>Kate Scholberg</td>
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<tr>
<td>University of Florida</td>
<td>Heather Ray</td>
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<td>Indiana University</td>
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<td>Institute for Theoretical and Experimental Physics, Moscow</td>
<td>Dmitri Akimov</td>
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<td>Lawrence Berkeley National Laboratory</td>
<td>Ren Cooper</td>
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<td>Los Alamos National Laboratory</td>
<td>Steve Elliott</td>
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<tr>
<td>National Research Nuclear University MEPhl</td>
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<td>New Mexico State University</td>
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<tr>
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<td>Matt Green</td>
</tr>
<tr>
<td>Oak Ridge National Laboratory</td>
<td>Jason Newby</td>
</tr>
<tr>
<td>Sandia National Laboratories</td>
<td>David Reyna</td>
</tr>
<tr>
<td>University of Tennessee, Knoxville</td>
<td>Yuri Efremenko</td>
</tr>
<tr>
<td>Triangle Universities Nuclear Laboratory</td>
<td>Phil Barbeau</td>
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<tr>
<td>University of Washington</td>
<td>Jason Detwiler</td>
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</table>

- Collaboration: ~65 members, 16 institutions (USA+ Russia)
- Spokesperson: K. Scholberg
- ORNL PI: J. Newby
- Technical coordinator/PM: D. Reyna
Potential Locations for Neutrino Experiment at the SNS

Multiple sites are available at a distance 15-20 m.

“Green field” is outside of the target building distance is more than 30 m.

sites inside target building

protons
Background Measurements at SNS

“Out-of-beam” events, primarily muons.

“In-Beam” events, considerably more neutron events (and 16x less “live time”).

Started in Sept 2013.
## COHERENT detectors and Status

<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>6.5</td>
<td>9/2015; 3σ in 2 yr</td>
</tr>
<tr>
<td>Ge</td>
<td>HPGe PPC</td>
<td>10</td>
<td>22</td>
<td>5</td>
<td>Fall 2016</td>
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<tr>
<td>LAr</td>
<td>Single-phase</td>
<td>35</td>
<td>29</td>
<td>4</td>
<td>Fall 2016</td>
</tr>
<tr>
<td>NaI</td>
<td>Scintillating crystal</td>
<td>85*</td>
<td>29</td>
<td>TBD</td>
<td>*high-threshold deployment done last week</td>
</tr>
</tbody>
</table>

- Measurements indicate **SNS basement is neutron-quiet**
- CsI installed July 2015
- Three more detectors to be deployed summer/fall 2016
Expected signals

- CsI delayed (20 m, 14 kg)
- CsI prompt
- Ge delayed (22 m, 10 kg)
- Ge prompt
- LAr delayed (29 m, 35 kg)
- LAr prompt
- Na delayed (29 m, 2 T NaI)
- Na prompt

Graph showing counts (keVnr y⁻¹) vs. recoil energy (keVnr) for different detectors and conditions.
Other potential neutrino physics at the SNS

Neutrino oscillations – Test of the LSND claim

Search for Sterile Neutrinos

Neutrino Magnetic moment

Measurement of Neutrino Spectra from Muon Decay

Cross section Measurements
Destruction of massive star initiated by the Fe core collapse
- $10^{53}$ ergs of energy released
- 99% carried by neutrinos
- A few happen every century in our Galaxy, but the last one observed was over 300 years ago

Dominant contributor to Galactic nucleosynthesis

Neutrinos and the weak interaction play a crucial role in the mechanism, which is not well understood

SN neutrino spectra, 0.1 s post-bounce
Never been measured.
There are only theoretical calculations

This reaction on Lead is used by HALO experiment in the SNOlab,

Fitting the annual modulation in DAMA with neutrons from muons and neutrinos

Jonathan H. Davis

1Institute for Particle Physics Phenomenology, Durham University, Durham, DH1 3LE, United Kingdom
j.h.davis@durham.ac.uk

author explain DAMA seasonal modulations by solar neutrino induced interactions in the DAMA shielding

In this article authors believe that J.Davis is wrong by >6 orders of magnitude.

Comment on “Fitting the annual modulation in DAMA with neutrons from muons and neutrinos”


aDepartment of Physics, Duke University,
Durham, NC 27708 USA
bDepartment of Physics, University of Chicago,
Chicago, IL 60637 USA
*University of Tennessee, Knoxville, TN 37996 USA
*Corresponding author. E-mail: schol@phy.duke.edu
NIN measurement in SNS basement

- Scintillator inside CsI detector lead shield (now)
- Liquid scintillator surrounded by lead (swappable for other NIN targets) inside water shield
Measurement of Neutrino Induced Neutrons

It is First Neutrino Experiment at the SNS

Liquid Scintillator detectors inside Lead, Poly, Cd, Water shield with muon veto

(Expected 3 events per day)

On the next day after we finished installation, SNS got water leak in the accelerator, then target failed.

It has been fixed

No we are running for one full year.

Have a statistics.
Data are being analyzed
Conclusion

It is time to measure COHERENT neutrino scattering !!!

Appropriate technology and sources are available

SNS is the best place for the first observation of CEvNS

Reach neutrino program at SNS is being developed