Neutrino Oxygen Charged-Current Interactions in COHERENT's Heavy Water Cherenkov Detector

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Our Neutrino Source:
The Spallation Neutron Source at ORNL

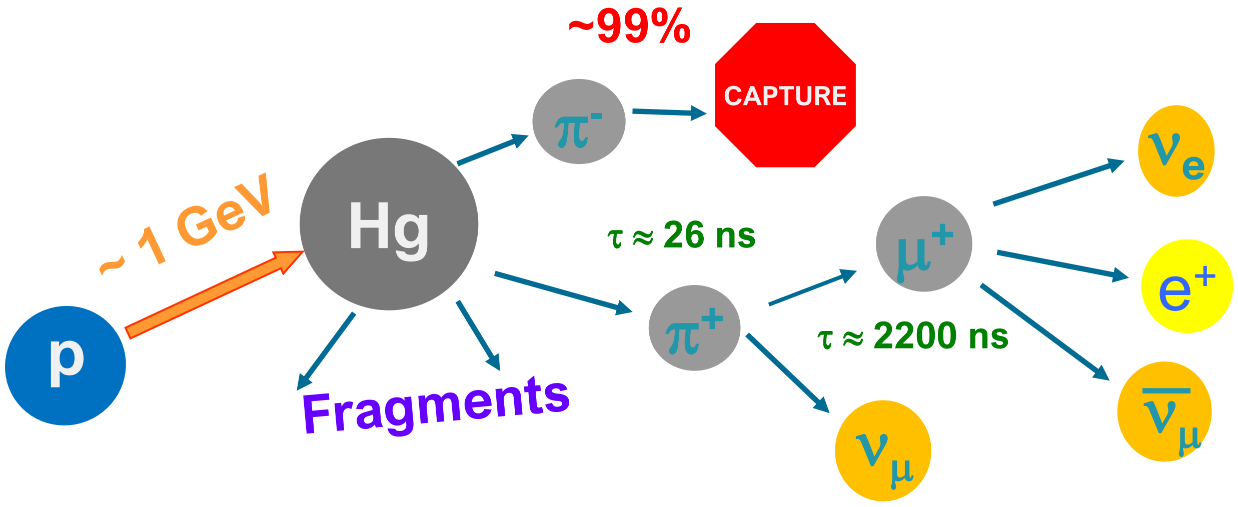
1.3 GeV Protons, 2 MW Beam

60 Hz, ~400 ns Wide Pulses

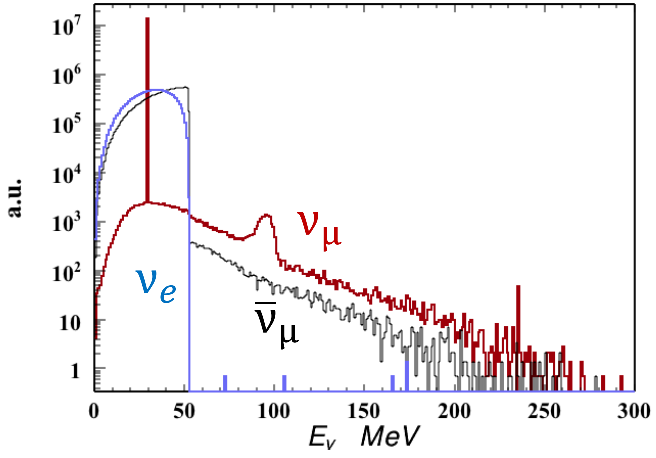
Hg Target

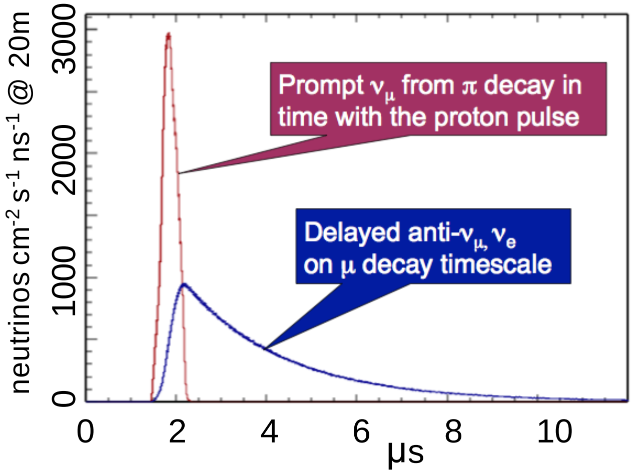
Efremenko, Y. (2020). What we can learn from CEvNS? (Coherent Elastic neutrino Nucleus Scattering) [PowerPoint presentation]. 5 th International Conference on Particle Physics and Astrophysics, Moscow, Russia.

Spallation Neutron Source – ν Production



- Largest ν production is ν_μ from rapid decay-at-rest of π^+
  - This creates narrow ν_μ pulse, with time structure determined by proton pulse width
- ν_e and $\bar{\nu}_\mu$ produced from slower decay of μ^+, with E_ν < 53 MeV, i.e., half of mass of μ^+
  - All detected ν interactions should follow this wider time distribution



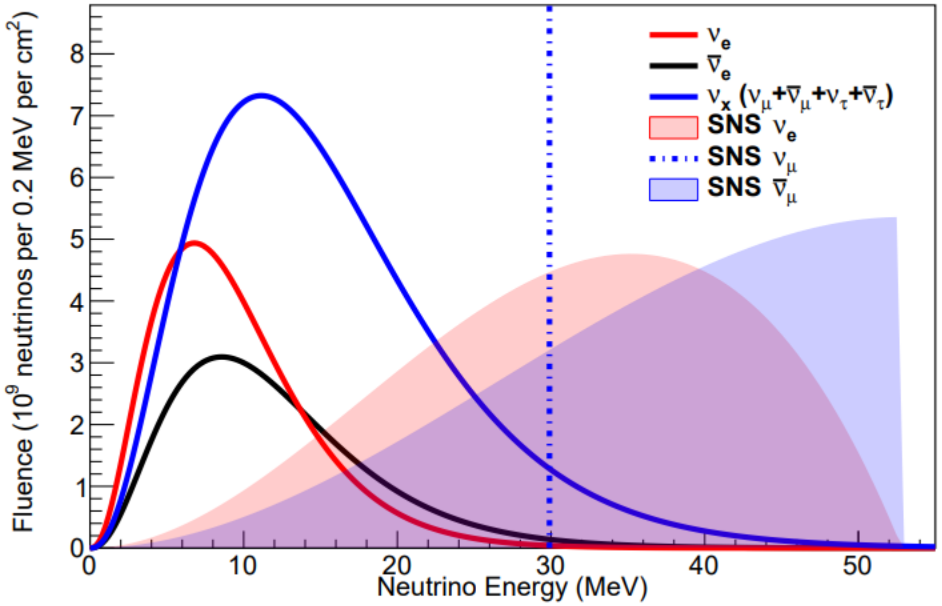


Y. Efremenko, "Coherent neutrino scattering status and perspectives," Lomonosov-2021, August 25, 2021.

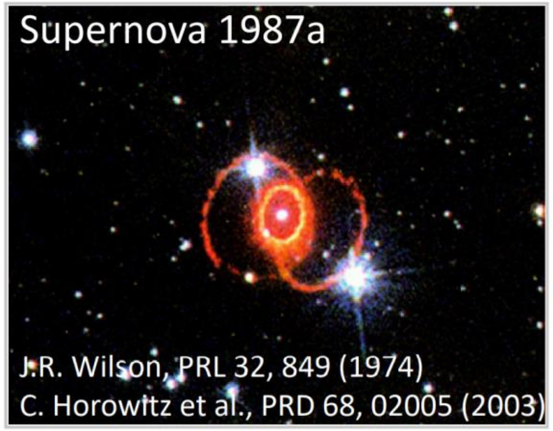
P. S. Barbeau, Y. Efremenko, and K. Scholberg, "COHERENT at the Spallation Neutron Source," Nov. 2021. arXiv: 2111.07033 [hep-ex].

Applications in Supernova Neutrino Detection

The SNS produces neutrinos in an energy range similar to that of core-collapse supernovae (tens of MeV)



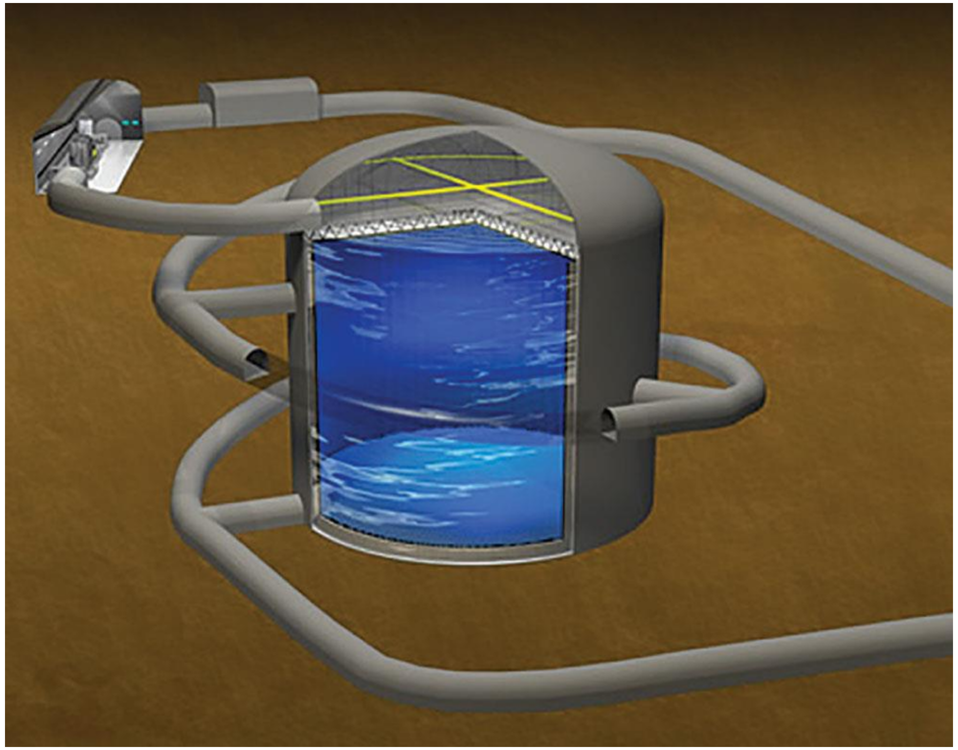
Understanding the cross section of these neutrinos scattering on oxygen is critical for accurately measuring these supernova neutrino fluxes in water Cherenkov detectors such as Super-Kamiokande and Hyper-Kamiokande



P. S. Barbeau, Y. Efremenko, and K. Scholberg, “COHERENT at the Spallation Neutron Source,” Nov. 2021. arXiv: 2111.07033 [hep-ex].

Supernova Neutrinos & Water Cherenkov Detectors

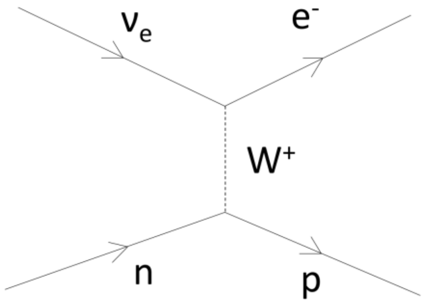
- SN 1987A is thus far the only source of detected supernova neutrinos
- Kamiokande detected **11 ν** from this event
- Super-Kamiokande would have detected **~120 ν** from SN 1987A if had been operational at the time
- Hyper-Kamiokande would have detected **~1,000 ν** from SN 1987A
- Some fraction of these neutrino events will be detected via neutrino-oxygen interactions
- Understanding this neutrino-oxygen cross section will help these very large detectors to interpret signals from future supernovae
  - E.g., by determining which events were from neutrino-oxygen scattering and which were from inverse beta decay or neutrino-electron scattering



Schematic of Hyper-Kamiokande
Image credit: Hyper-Kamiokande collaboration

Observation of a Neutrino Burst from the Supernova SN 1987a
Kamiokande-II Collaboration • K. Hirata (Tokyo U., ICEPP) et al.

Charged-Current Neutrino-Oxygen Interaction

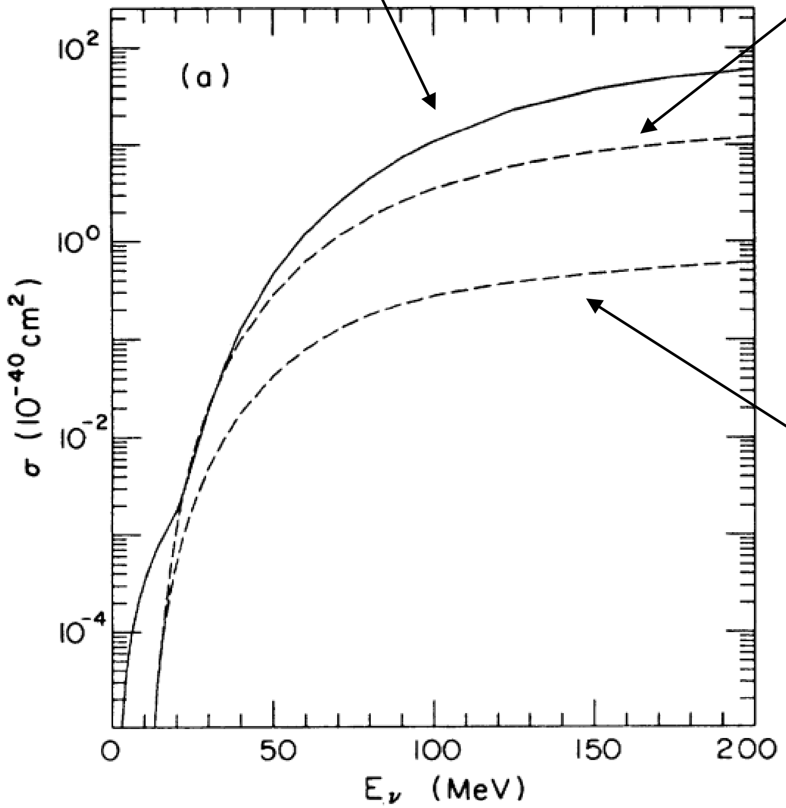


$$\nu_e + {}^{16}O \rightarrow e^- + {}^{16}F^*$$

- ν_e of interest are in the energy range of tens of MeV
- On the right are theoretical predictions made by Wick Haxton in 1987 for the cross section between O nuclei and $\nu_e/\bar{\nu}_e$
- These cross section predictions have never been tested at this energy range

${}^{16}O(\nu_e, e^-){}^{16}F^*$

${}^{16}O(\bar{\nu}_e, e^+){}^{16}N^*$

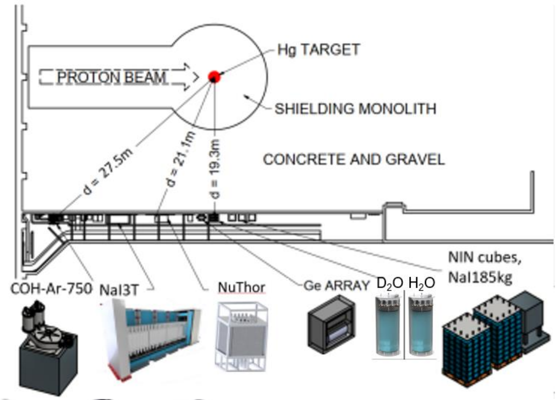


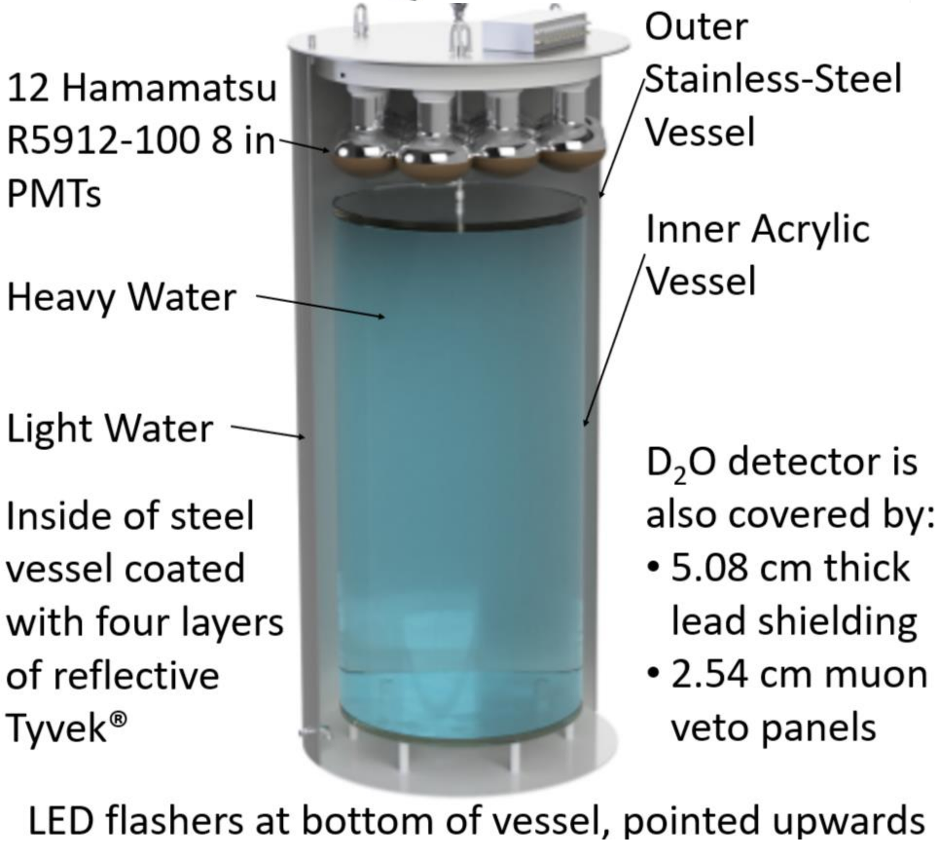
$\bar{\nu}_e$ cross section proceeding to 2^-, 0^-, 3^-, and 1^- particle-bound states

Haxton, W C 1987 Phys. Rev. D 36 2283

Heavy Water Cherenkov Detector

- 550 kg heavy water Cherenkov detector installed roughly 20 m from SNS target, 90º off the proton beam axis
- The primary purpose of this detector will be to measure the neutrino flux from the p + Hg collision via CC ν-deuterium channel
- Detector will also be used to measure CC νO cross section
- Plan to measure neutrino flux to better than 5% uncertainty in two SNS-years of collecting data





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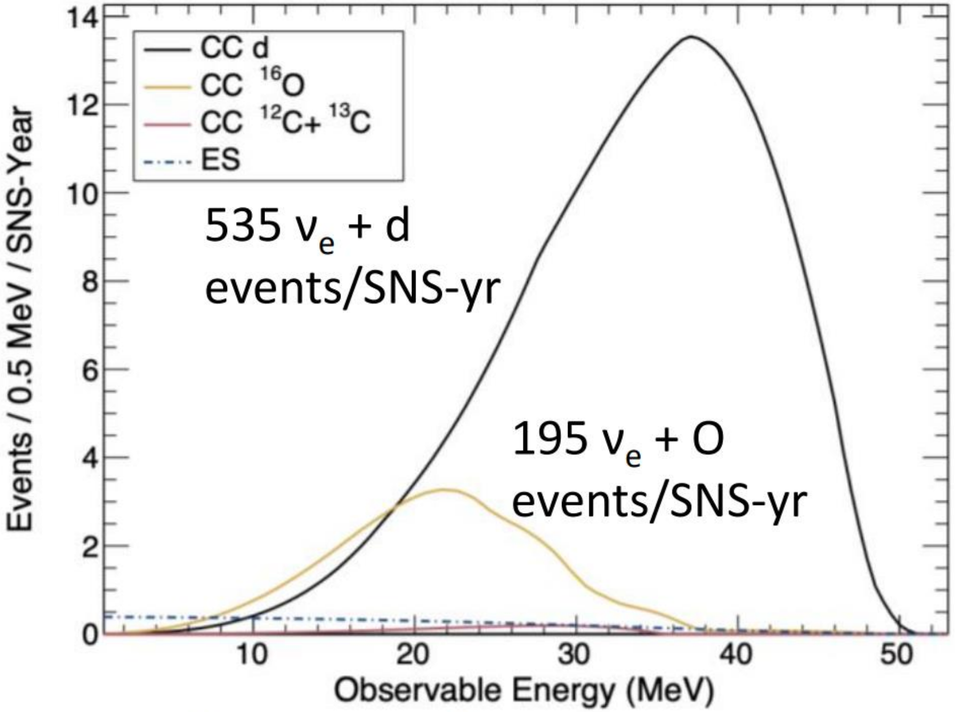
Neutrino-Deuterium Background

- Sharply pulsed neutrino flux allows constant backgrounds to be easily subtracted
- Thus, only significant background is ν_e scattering off deuterium in D_2O
- Neutrino-deuterium cross section is very well understood, but also much larger than neutrino-oxygen cross section
- We plan to run pure light water detector for pure neutrino-oxygen measurement

$\nu_e + d \rightarrow e^- + p + p$



$\nu_e + {}^{16}O \rightarrow e^- + {}^{16}F^*$

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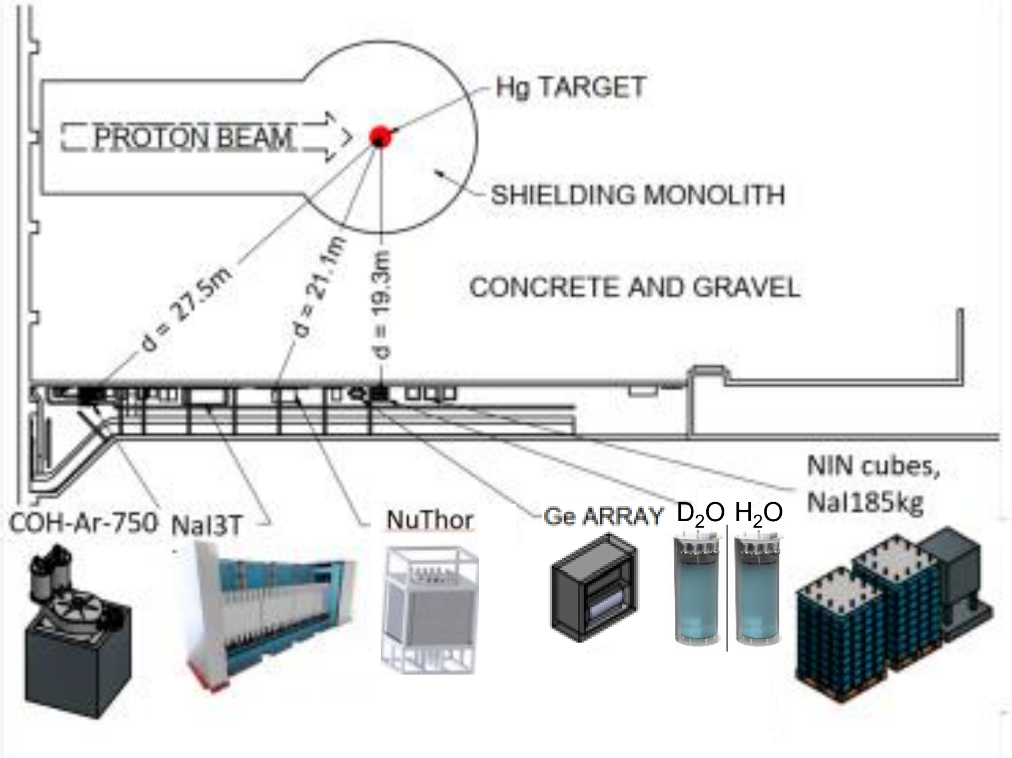
Second Water Cherenkov Detector Module

- Second water Cherenkov detector is currently under construction
- To be placed next to current heavy water Cherenkov detector
- Will initially be filled with light water only
  - Design otherwise identical to first module
- All major components for detector are ready; we expect deployment in the next few months



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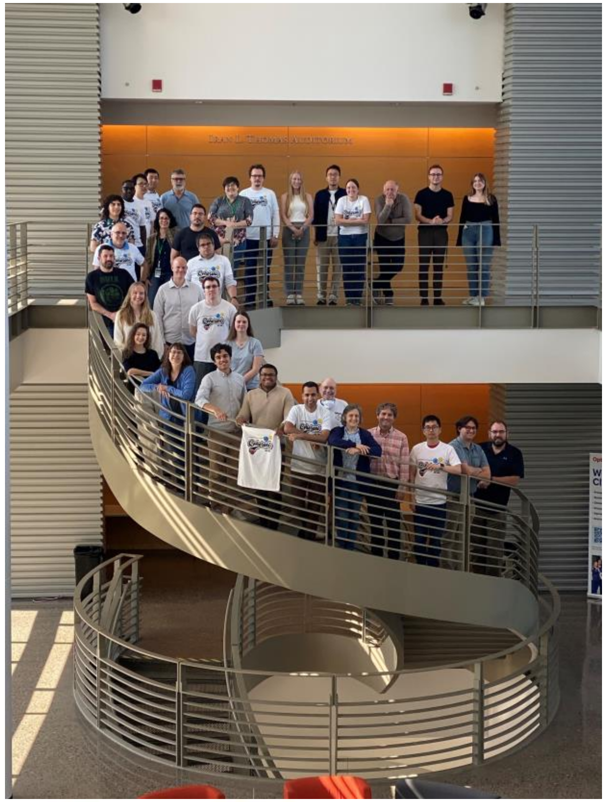
The COHERENT SNS Collaboration



- Canadian Nuclear Laboratories / Laboratoires Nucléaires Canadiens
- Carnegie Mellon University
- Chinese Academy of Sciences
- Concordia University
- Duke University
- UF University of Florida
- Florida State University
- ICRR Institute for Cosmic Ray Research, University of Tokyo
- Indiana University
- Kyoto University
- Laurentian University / Université Laurentienne
- Los Alamos National Laboratory
- MEPhI
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- NC State University
- Oak Ridge National Laboratory
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Summary

- Charged-current neutrino-oxygen scattering is important for measuring supernova neutrino fluxes in large water-based neutrino detectors.
- This neutrino-oxygen cross section has never been measured in the supernova neutrino energy range.
- The SNS is an ideal source of sharply pulsed electron neutrinos in the energy range of supernova neutrinos.
- The possibility of this measurement has sparked great interest from the Super-Kamiokande and Hyper-Kamiokande collaborations.
  - There is a proposal from people at S-K and H-K to deploy an even bigger light water detector at the SNS.