Neutrino Interaction Measurements for Supernova Detection at the Spallation Neutron Source

Jason Newby - Oak Ridge National Laboratory
for the Workshop Organizers (https://indico.phy.ornl.gov/event/217/)

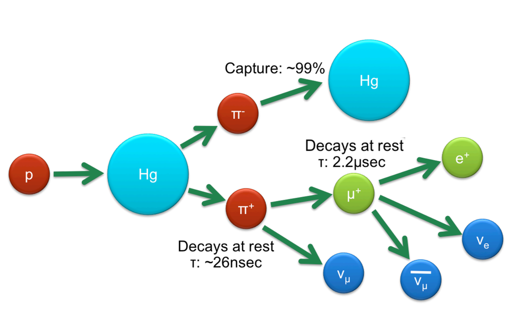
Abstract: The intense pulsed neutrinos at the Spallation Neutron Source (SNS) present a unique opportunity to measure low-energy neutrino interactions on 16-O including inelastic charged-current and neutral-current interactions in the few tens of MeV range. While these interactions have never been measured at this energy, they are of great importance for supernova detection in Super-Kamiokande and Hyper-Kamiokande, for which signals will be highly complementary to those of DUNE. The COHERENT collaboration is deploying a heavy water detector optimized for a neutrino flux normalization using the charge current interactions on the deuteron. While the instrument will have some sensitivity for such a cross section measurement on oxygen, a precision measurement could be made with a larger, more optimally instrumented detector at the upgraded SNS First Target Station or at the future Second Target Station that would further enable the disentangling of the subdominant electron neutrino and neutral current components from the inverse beta decay interactions in the large water-based experiments.

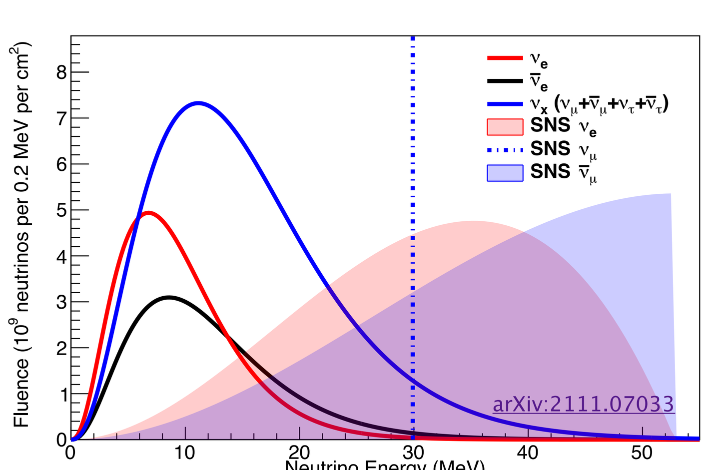
Workshop on Neutrino Interaction Measurements for Supernova Detection was hosted at Oak Ridge National Laboratory under the U.S.-Japan Science and Technology Cooperation Program in High Energy Physics [LAB 22-2607]

Scientific Organizers: M. Demarteau, Y. Efremenko, M. Ikeda, Y. Hino, Y. Koshio, Y. Nakajima, J.Newby, D. Parno, K. Scholberg, H. Sekiya, R.Wendell

70 Registered participants, 42 In-person
18 International Participants Attending

Low Energy Neutrinos at the SNS



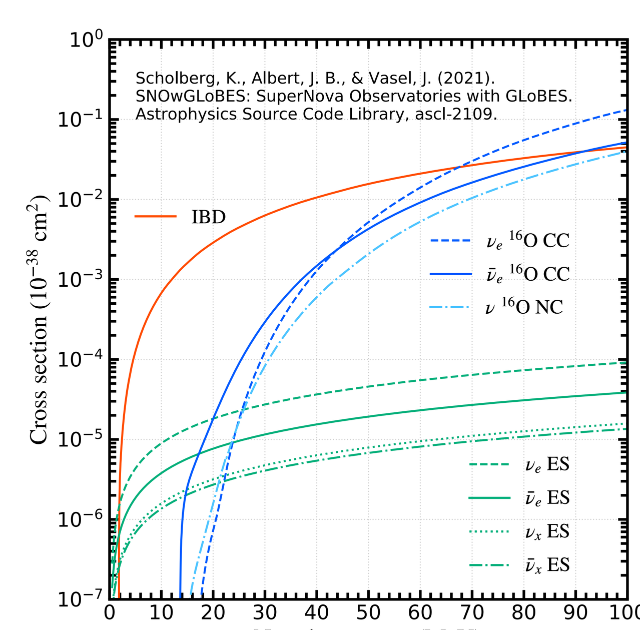


$\pi^+ \rightarrow \mu^+ + \nu_\mu$ 2-body decay: monochromatic 29.9 MeV ν_μ PROMPT

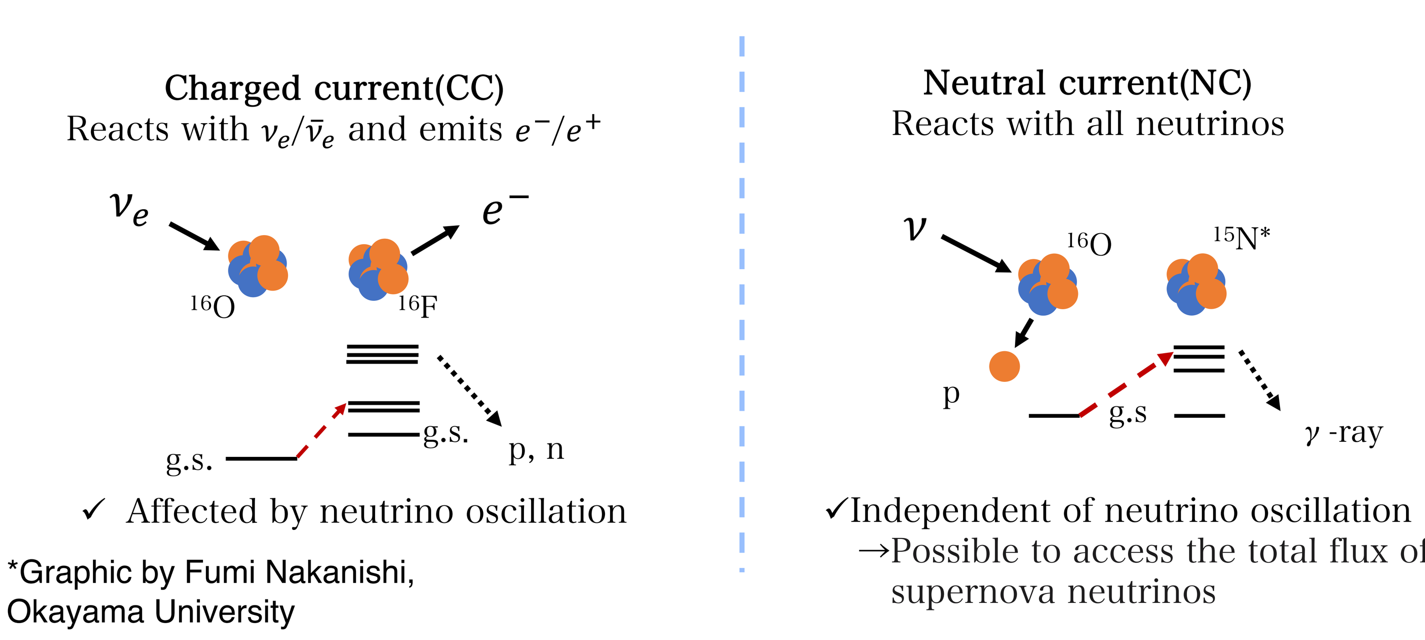
$\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e$ 3-body decay: range of energies between 0 and $m_\mu/2$ DELAYED (2.2 µs)

- High Intensity (2.8×10^{14} /cm²/flavor/SNSYear @ 20m)
- Multiple Neutrino Flavors: ν_e, (anti) ν_μ
- Prompt & delayed neutrinos provide additional handle for systematic errors
- Excellent Time Structure (Short Proton Pulses 370 ns full-width half max)
- **The SNS is a clean, intense neutrino source to study low energy interactions.**
- **Neutrino capability demonstrated by successful COHERENT experimental program.**

Oxygen Interaction in Supernova Neutrinos

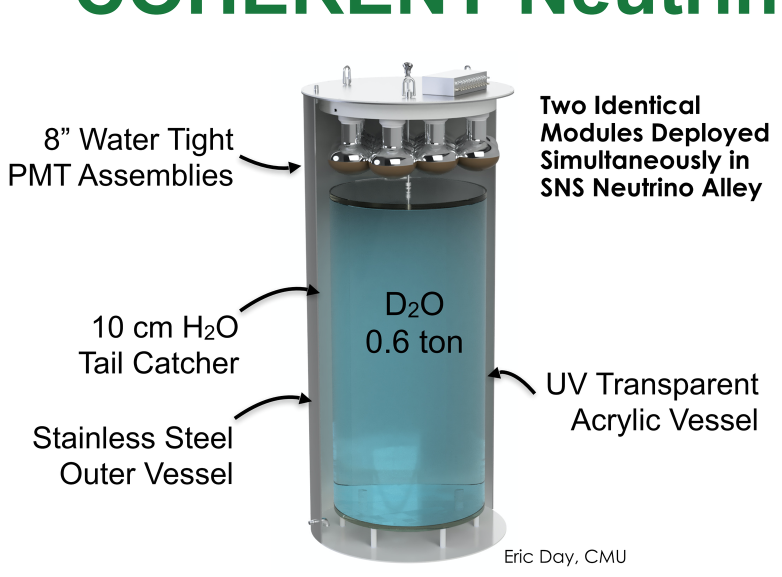


- For large water Cherenkov detectors, such as Super-Kamiokande and Hyper-Kamiokande, the primary interactions channel of supernova neutrinos is the Inverse Beta Decay ($\overline{\nu_e} + p \rightarrow e^+ + n$) and therefore primarily sensitive to the electron antineutrino flux.
- In order to exploit the full explosion mechanism of supernovae, it is essential to measure the flux of all flavors.
- Charged current and Neutral Current cross-sections on oxygen have never been measured and theoretical predictions have large uncertainties.
- Complementary to detectors worldwide, including DUNE



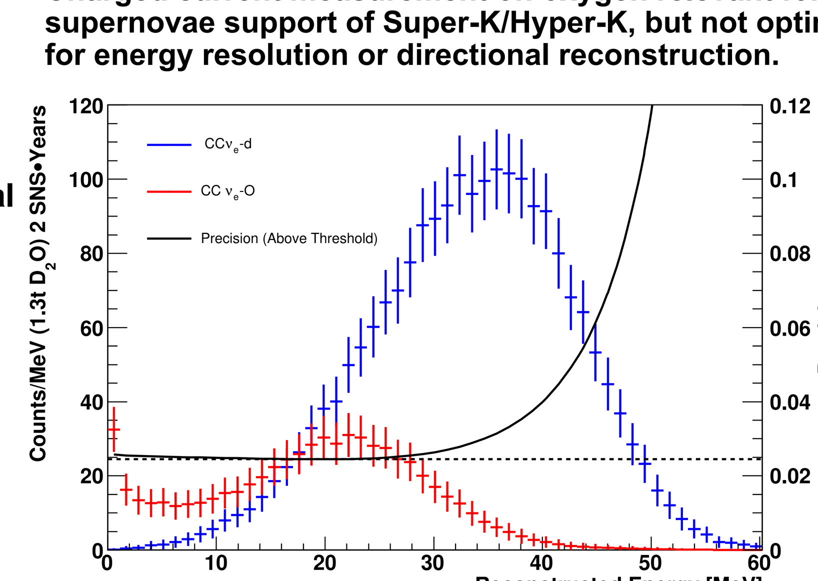
*Graphic by Fumi Nakanishi, Okayama University

COHERENT Neutrino Flux Normalization



- SNS ν flux is currently known to about 10% uncertainty.
- Charged current cross section of ν_e-deuteron is known to 2-3%. Nucl.Phys. A721(2003) 549
- Ton-scale heavy water Cherenkov detector in Neutrino Alley to normalize ν flux with high accuracy.
  - 1.3 tons D_2O within acrylic inner vessel
  - H_2O "tail catcher" for high energy e^-
  - Outer light water vessel contains 12 PMTs, PMT support structure, and optical reflector.
  - Outer steel vessel to support shielding and veto
- **Charged current measurement on oxygen relevant for supernovae support of Super-K/Hyper-K, but not optimized for energy resolution or directional reconstruction.**

In this simulated detector response, a 2.5% statistical precision on the SNS neutrino flux would be achieved in 2 SNS years.

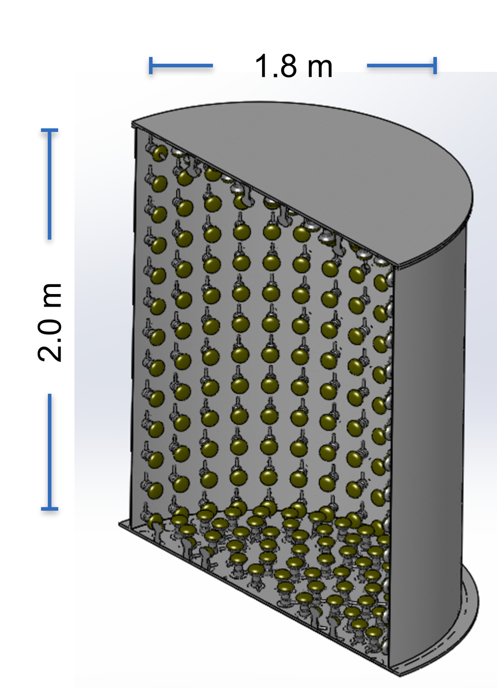


Module 1 deployed with H2O in June 2022
with D2O June 2023

Module 2 to be deployed in 2024

Future Oxygen Measurements at the SNS

- A fully instrumented water Cherenkov detector at the SNS could provide high precision neutrino cross section measurements in 2-3 years.
- Spallation Neutron Source Proton Power Upgrade will complete in 2024 to deliver 2.0 MW at the First Target Station.
- ORNL LDRD to characterize locations at First Target Station to accommodate multi-ton water instruments less than 20 meters from target
- Expanded opportunities for larger instruments at dedicated neutrino laboratory at the SNS Second Target Station



A 6-ton Water Cherenkov Detector with 3 inch photomultiplier tubes would provide excellent energy resolution and directional information for charge current interactions within a footprint feasible at First Target Station.

This material is based upon work supported by the U.S. Department of Energy, Office of Science, Office of High Energy Physics, under contract number DE-AC05-00OR22725.

Oak Ridge National Laboratory — U.S. Department of Energy, Office of Science