Measuring Charged-Current Neutrino-Nucleus Cross Section on Oxygen

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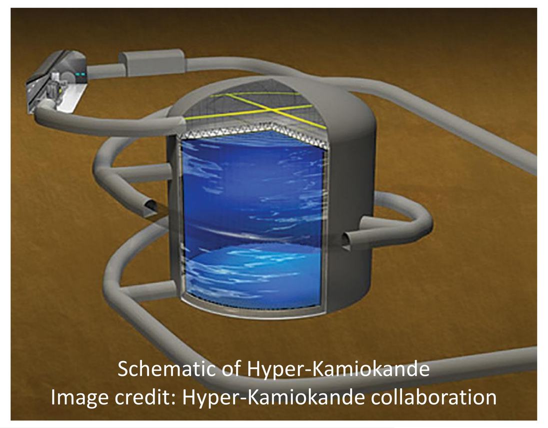
Applications in Supernova Detection and Testing Nuclear Physics Theory

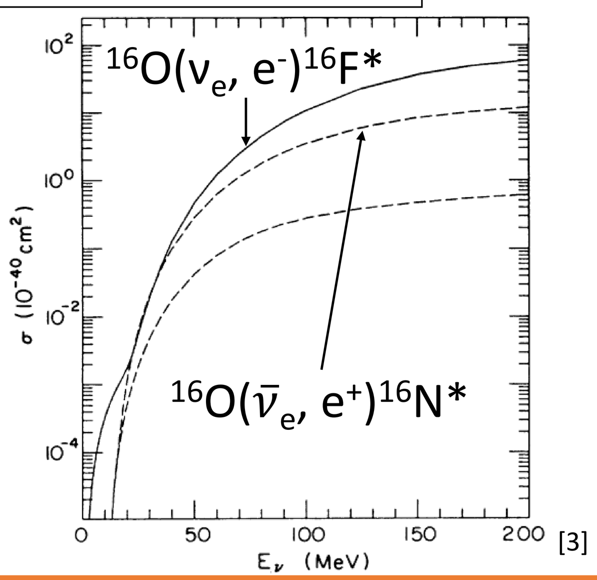
The SNS produces neutrinos in similar energy ranges (E_ν < 53 MeV) to core collapse supernovae.



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

From SN 1987A:
- Kamiokande detected **11 ν**
- Super-Kamiokande *would have* detected **~120 ν**
- Hyper-Kamiokande *would have* detected **~1,000 ν**

The νO interaction cross section predictions made in 1987 have never been tested below 100 MeV.

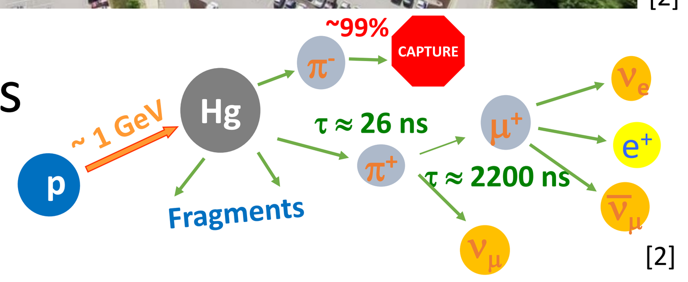


[3]

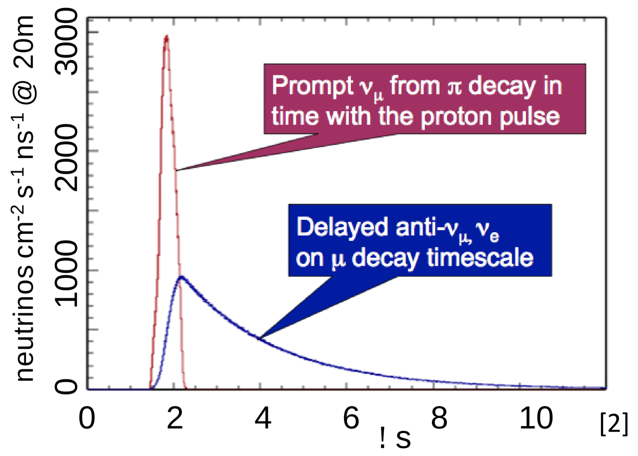
The Spallation Neutron Source is an Ideal Source of Neutrinos for CC ν_eO

[2]

Sub μs-scale pulses of 1 GeV p⁺ collide with a Hg target, making sharp pulses of ν_e, ν_μ, and $\bar{\nu}_\mu$. Most ν arise from decay at rest of π or μ, thus ν spectra are well known [1].



[2]



[2]

CC ν_eO Interactions will be Measured in a Water Cherenkov Detector

A 549 kg heavy water Cherenkov detector was installed at the SNS, roughly 90⁰ off-axis and 20 m from the Hg target. This detector will primarily use the ν_e-deuterium reaction in D_2O to measure the neutrino flux from the p + Hg collision; we will also use it to measure CC ν_eO [1].

Initial detector deployment, without heavy water or shielding, occurred in summer 2022. Complete deployment occurred in July 2023.

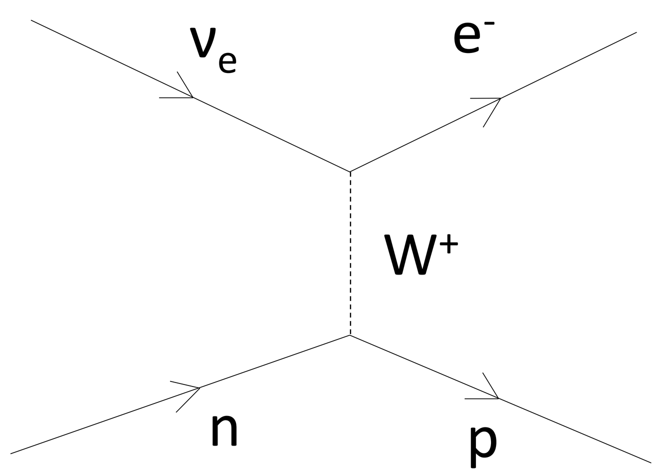
This detector is the first of two planned modules to ultimately measure the neutrino flux to 2-3% uncertainty [1].

[1]

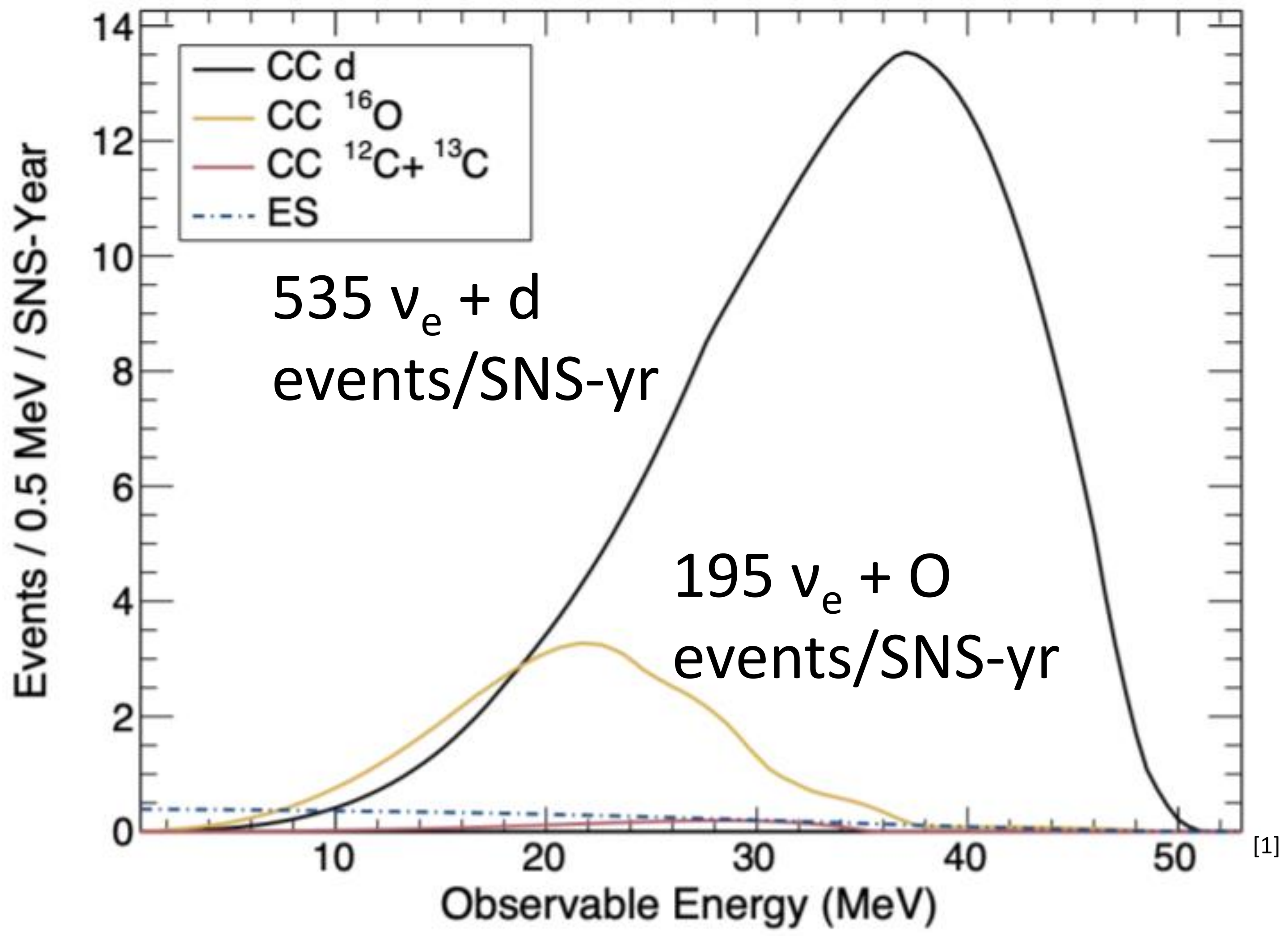
D_2O detector is covered by:
- 5.08 cm thick lead shielding
- 2.54 cm muon veto panels

Our Only Significant Background is from Neutrino Interactions on Deuterium

Sharply pulsed neutrino flux allows constant backgrounds to be easily subtracted, but SNS ν_e will also scatter off deuterons (d) in D_2O. CC ν_ed cross section is very well understood [1], so we can measure total spectrum above 30 MeV, where CC ν_ed dominates, and extrapolate CC ν_ed spectrum below that threshold.



CC ν_ed: $\nu_e + d \rightarrow e^- + p + p$



[1]

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

We Plan to Measure CC ν_eO Cross Section with Uncertainty as Low as 12%

$$\sigma = \frac{Num.\,of\ Events}{(Num.\,of\ Atoms)(Flux)(DE)}$$

- Very low error in number of oxygen atoms in detector
- Will measure neutrino flux to better than 5% uncertainty in two SNS-yrs [1]
- DE = Detection Efficiency; uncertainty in DE will contribute to uncertainty in σ
- Uncertainty in cross section depends on length of time that we run the experiment – our goal is to collect enough statistics to achieve uncertainty of about 15%.

References

[1] COHERENT collaboration *et al* 2021 *JINST* **16** P08048

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

[3] Haxton, W C 1987 Phys. Rev. D **36** 2283

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