OAK RIDGE National Laboratory | SPALLATION NEUTRON SOURCE

June 10, 2026, Oak Ridge National Laboratory

New Opportunities for Neutrino Physics

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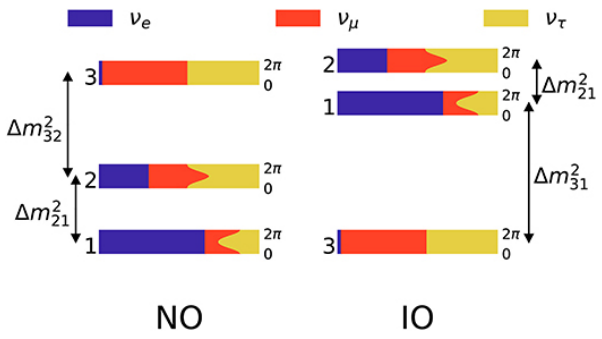
Oak Ridge National Laboratory

U.S. DEPARTMENT OF ENERGY

ORNL IS MANAGED BY UT-BATTELLE LLC
FOR THE US DEPARTMENT OF ENERGY

Why study neutrinos?

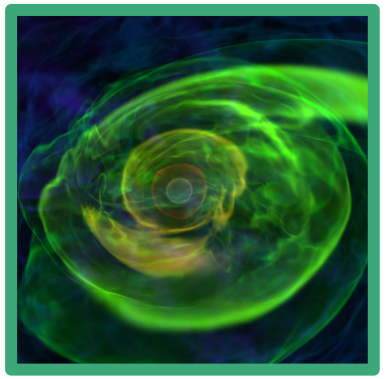
Standard Model is incomplete



Neutrino oscillations requires non-zero mass at odds with SM.

- Precision tests of standard model are required to elucidate how to expand the theory.
- Properties: Size, Magnetic Moment, Majorana, Sterile candidates
- Interactions: Quark-lepton couplings, flavor dependent radiative corrections, axial couplings

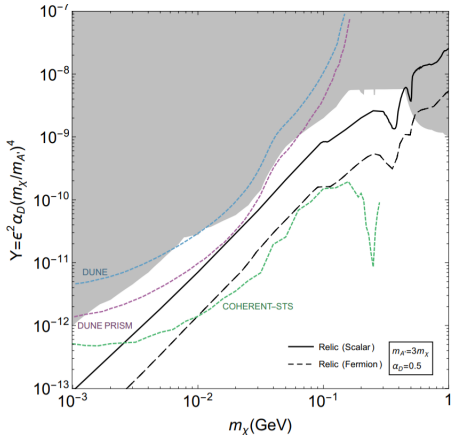
Evolution of the Universe



Core-collapse Supernova

- Neutrinos play critical role in SN dynamics
- Neutrino detection essential for testing models.
- Neutrino cross sections below 50 MeV never measured in critical targets: argon, oxygen

Related BSM Searches

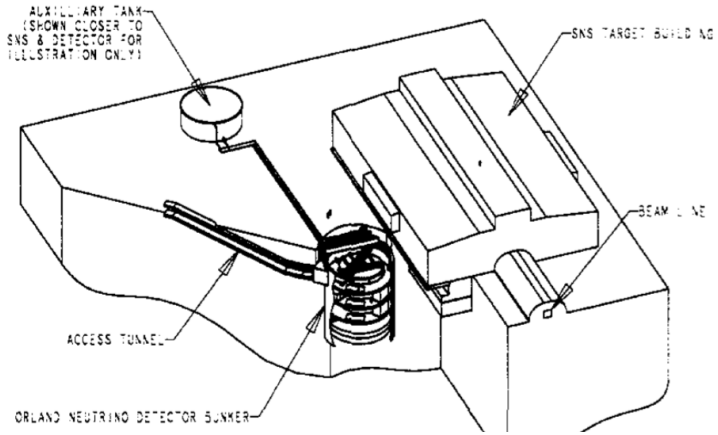


Dark Matter Searches

- SNS is an intense source of pions and photons that could couple to dark sector
- Light DM, Leptophobic Models, QCD Axion, Axion-like particles
- Right-handed neutrinos, heavy neutral leptons (HNLs) JHEP 09 (2023) 1

Many scientists envisioned a thriving neutrino program at the SNS

Year 2000

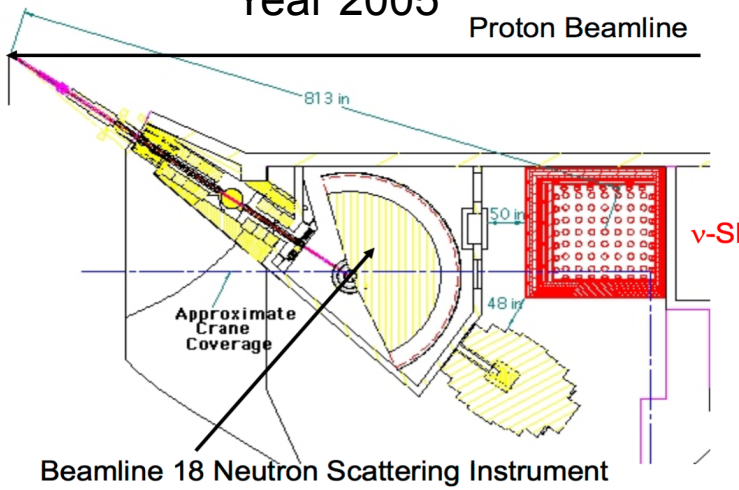


ORLaND: A Proposed Facility to Investigate Neutrino Properties Relevant to Astrophysics

F. T. Avignone III[a], L. Chatterjee[b,c,d], Yu. Efremenko[b,c], V. Gudkov[a] and M. Strayer[c]

2000-ton Cherenkov Detector

Year 2005



νSNS

20-ton Liquid Scintillator Detector
20-ton Solid-target Gas Detectors

Y. Efremenko (*ex-officio*)
F.E. Bertrand
J. Blackmon
V. Cianciolo
T.A. Gabriel
U. Greife
W.R. Hix
E. Hungerford
G. McLaughlin

- SNS construction completed in 2006 and began neutron scattering program in 2007.
- In 2009, CLEAR proposed to install 0.5-ton detector 46 m from source.

Workshop at ORNL in 2013 considered what could be done with a ~10kg detector.

COHERENT Collaboration

- 120 members, 28 institutions
- Formed in 2013 to observe CEvNS in multiple nuclear targets to measure N^2-scaling of cross section
- Spallation Neutron Source (SNS) at Oak Ridge National Laboratory (ORNL) is also a perfect source of neutrinos.
- Intense flux of low-energy pulsed neutrinos also useful for studying inelastic neutrino-nucleus interactions
- Intense proton pulses also useful for dark sector searches

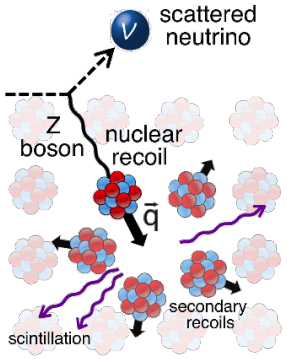
https://sites.duke.edu/coherent/ arXiv:2204.04575v1

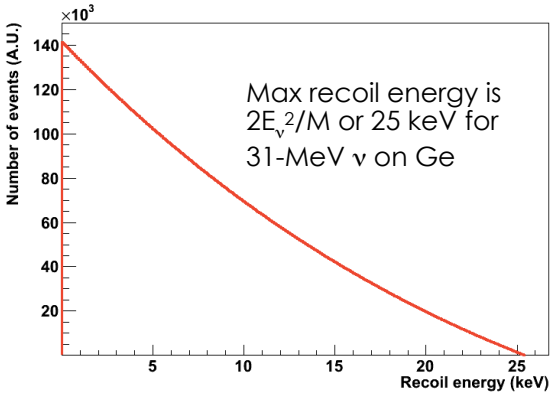
COHERENT Collaboration - May 2023

Canadian Nuclear Laboratories / Laboratoires Nucléaires Canadiens
Carnegie Mellon University
CONCORDIA
Duke University
UF UNIVERSITY of FLORIDA
Florida State University
ICRR Institute for Cosmic Ray Research University of Tokyo
Kyoto University Founded 1897
MEPhI
Laurentian University / Université Laurentienne
Los Alamos National Laboratory Est. 1943
東京大学
NC State University
Oak Ridge National Laboratory
岡山大学 Okayama University
Sandia National Laboratories
서울대학교 Seoul National University
SLAC National Accelerator Laboratory
University of South Dakota
The University of Tennessee Knoxville
NCCentral University
Tufts University
TUNL Triangle Universities Nuclear Laboratory
Virginia Tech
Washington & Jefferson College

Coherent elastic neutrino-nucleus scattering (CEvNS)

A neutrino scatters on a nucleus via exchange of a Z, and the nucleus recoils as a whole; **coherent** up to $E_\nu \sim 50$ MeV

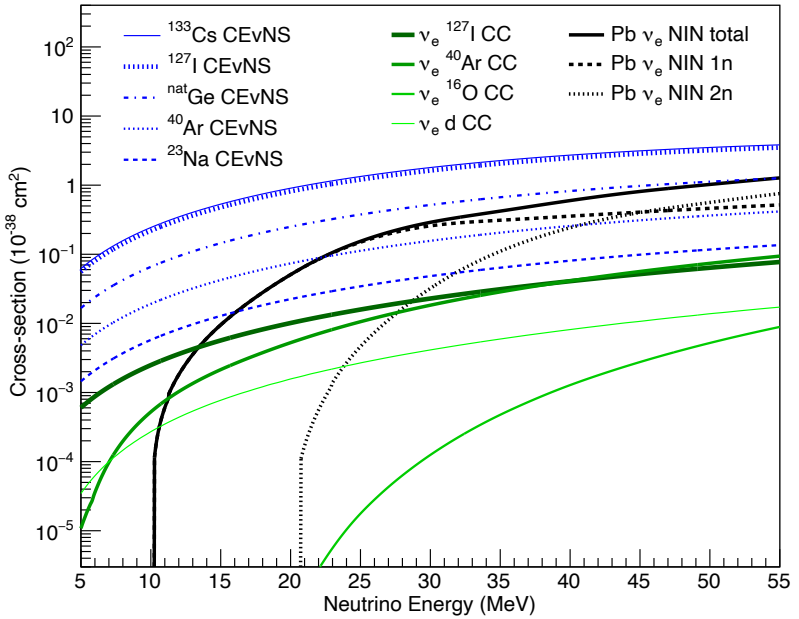




CEvNS cross section is well calculable in the Standard Model

- Sensitive to **non-standard interactions**
- Largest cross section in **supernovae** dynamics
- Background for future **dark matter** experiments
- Sensitive to nuclear physics, **neutron skin** (neutron star radius)

- Predicted in 1974 by D. Freedman
- Interesting test of the standard model, but difficult to detect, "act of hubris".

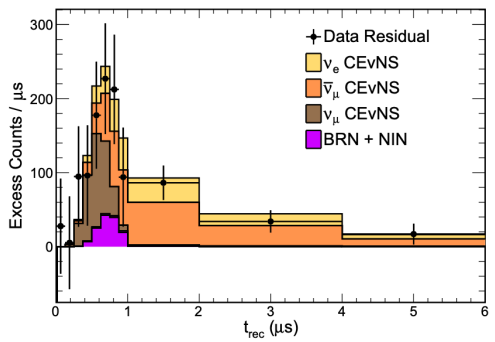


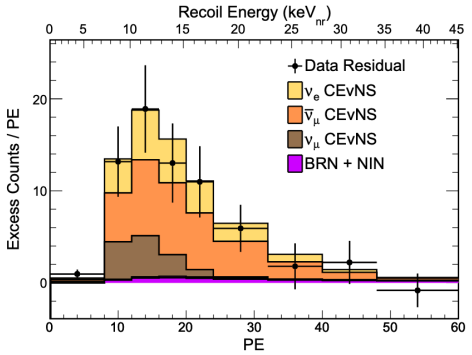
P.S. Barbeau, Y. Efremenko and K. Scholberg, COHERENT at the Spallation Neutron Source, Annual Reviews of Nuclear and Particle Science

CEvNS cross section is large! $\propto N^2$

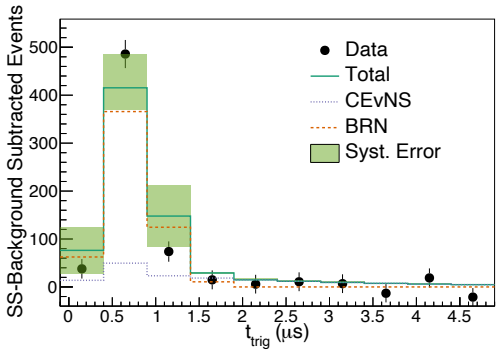
Completing the N-squared Cross Section Dependence

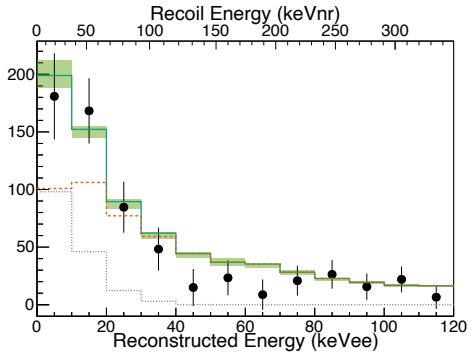
CsI



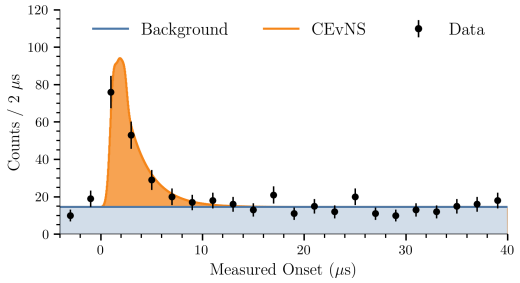


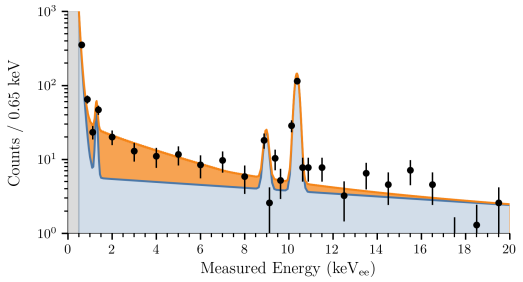
Ar

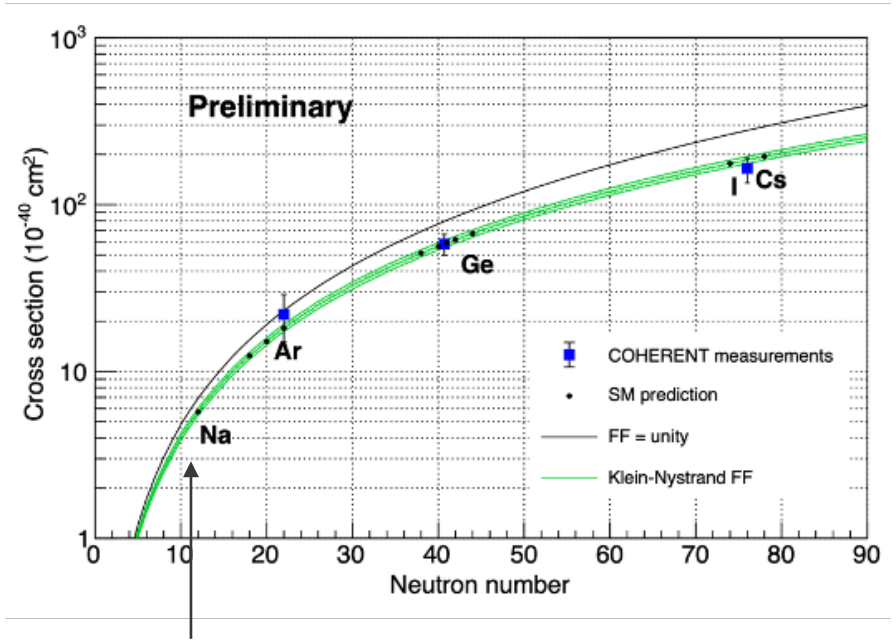




Ge







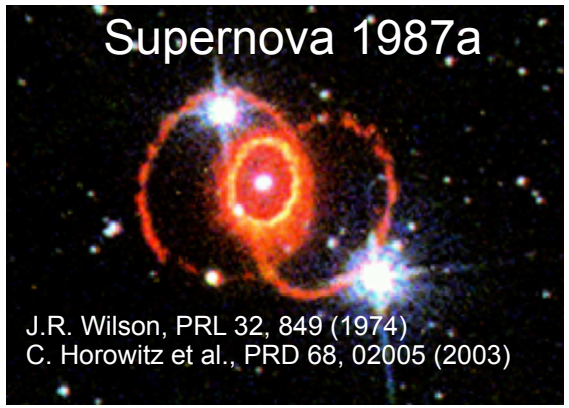
Future CEvNS Measurement Planned

Sodium (NaI)

- *Lightest-Nucleus*
- 3.4 ton NaI Array
- 3σ CEvNS/yr
- 2 of 5 modules installed for commissioning

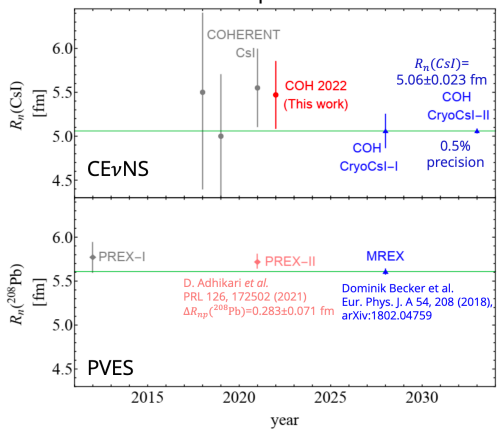
Broad Impact of Future π-DAR CEvNS Studies

Largest σ in Supernovae dynamics

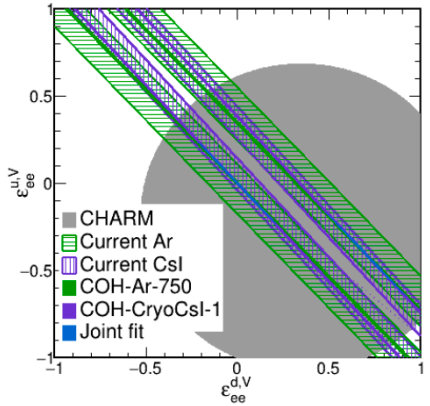


Nuclear Form Factors

Matteo Cadeddu presentation M7s '23

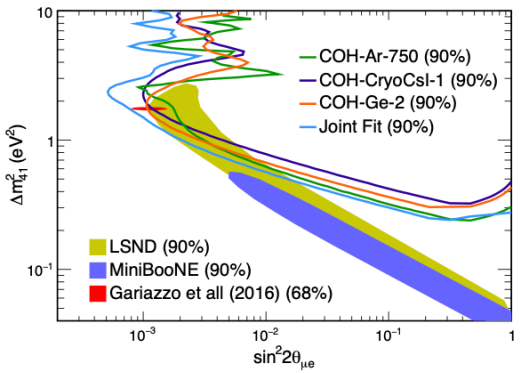


Non-Standard Interactions



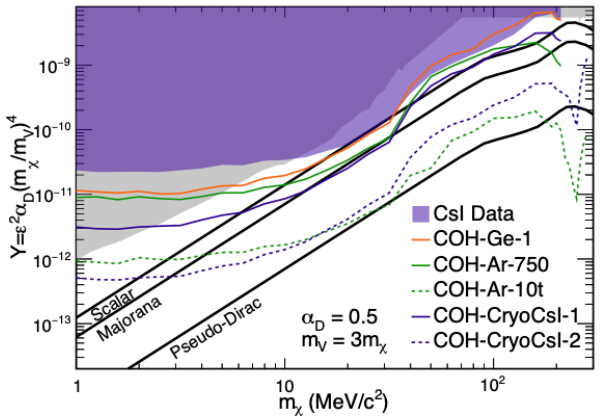
COHERENT Snowmass whitepaper 2022

Sterile Searches



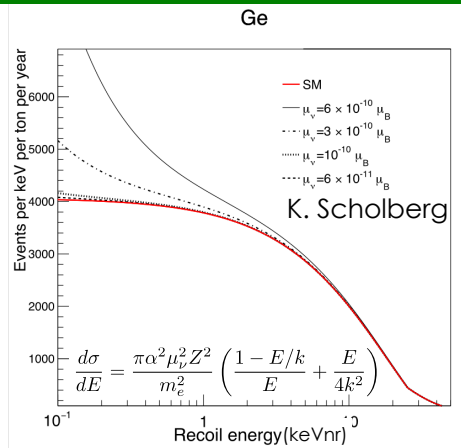
COHERENT Snowmass whitepaper 2022

Accelerator DM searches



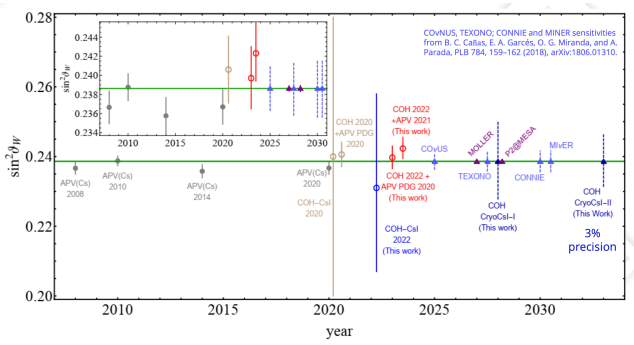
COHERENT Snowmass whitepaper 2022

Neutrino Magnetic Moment



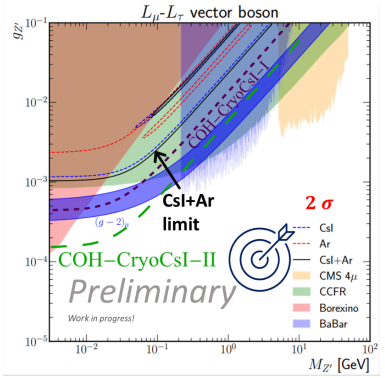
See also Kosmas et al., arXiv:1505.03202

Weak Mixing Angle



Matteo Cadeddu presentation M7s '23

BSM light mediator searches



Mattia Attori Corona presentation M7s '23

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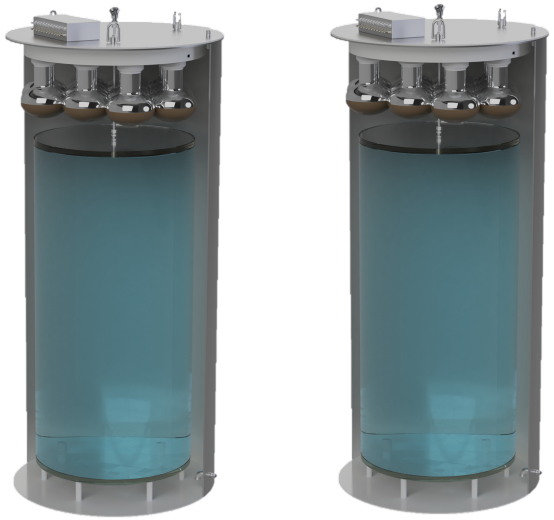
arXiv:2204.04575v1

COHERENT Precision Program now underway

Precise Flux Normalization



Module 1 Module 2

UTK/CMU/VT/ORNL

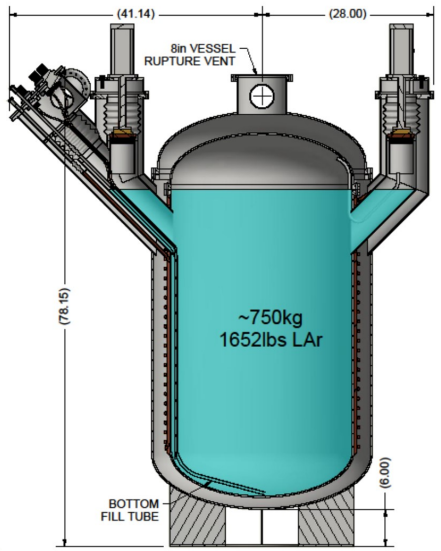
- Deuteron Charged Current
  $\nu_e + d \rightarrow p + p + e^-$
- 2-3% Theoretical Uncertainty*
- Calorimetry: no Ring Imaging
- 2.5% Statistical in 2 yrs
- Module 1 now operating

COHERENT 2021 JINST 16 P08048

US-Japan Workshop on Measurements for Supernova Neutrino Detection, ORNL Mar 2023

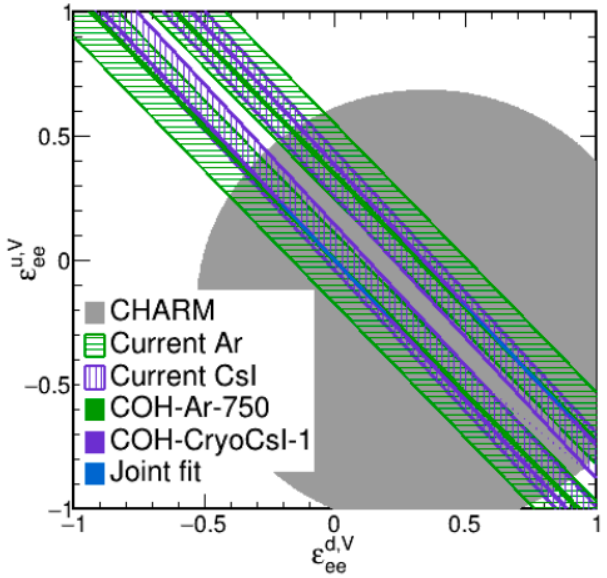
*S.Nakamura et. al. Nucl.Phys. A721(2003) 549

High Statistics CEvNS

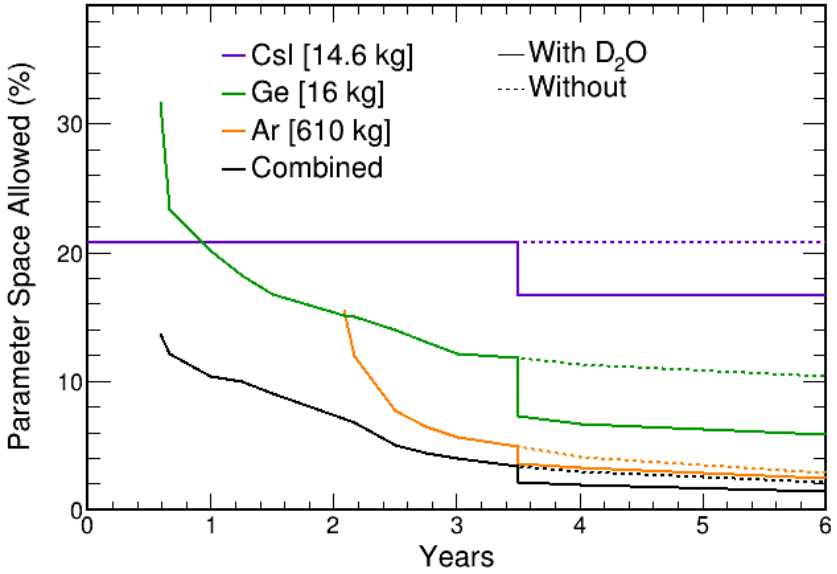


Walt Fox, IU

- 750kg LAr
- Single phase
- Light Collection Options
  - 3” PMT TPB
  - SiPM, Xenon Doping, …
- ~3000 CEvNS/yr
- Fabrication underway @ Seoul and IU

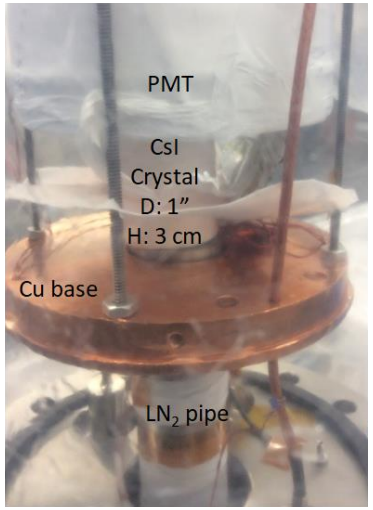


Significantly Improve NSI Constraints



Future COHERENT Detectors

Cryogenic Scintillating Crystals

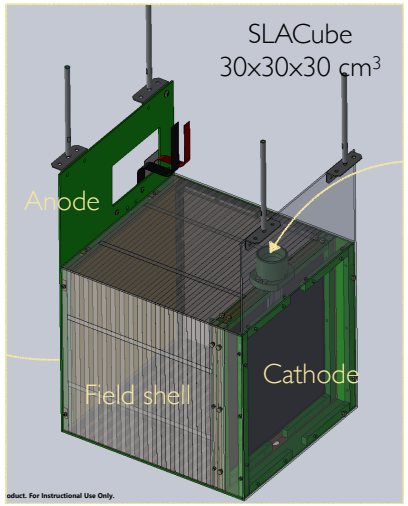


USD, Prototype

COH-CryoCsI

- Undoped CsI
- Maximal Light Yield, Minimal Afterglow at 77K
- Well matched for SiPM readout
- ~0.4 keVnr thresholds possible
- 10kg and 750kg concepts

Time Projection Chambers



Concept Yun-Tse Tsai, SLAC

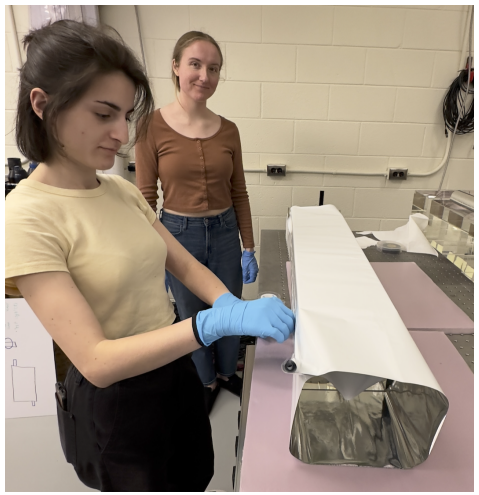
SLACube

- Compact LAr TPC Design
- LArPix Readout
- ν_e Charged Current

Gas TPC

- CEvNS recoil direction

Lead Glass



Prototype NCCU, TUNL, DUKE

Lead Glass Array

- 40 kg Module
- Duel ended light readout
- ν_e- Pb Charged Current
- Multi-ton in Neutrino Alley
- Deploy in 2025

Neutrino Alley limited to 1-ton, 1-meter width deployments

Beyond Neutrino Alley in STS Era

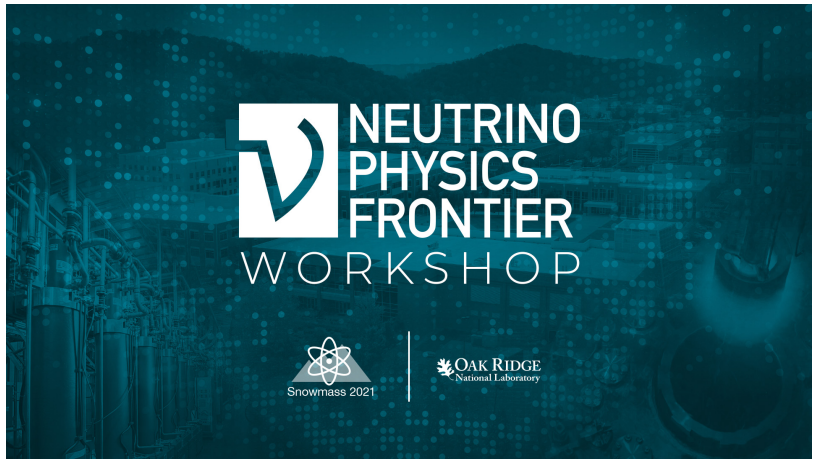
Snowmass 2021 Decadal Planning Exercise Began in April 2020

- 2020 Jul 10 Discussion with STS Project Team
- 2020 Sep Snowmass LOI ORNL/NScD Senior Mgmt
- 2021 Jan 21 Briefing of ORNL Deputy Directory
- 2021 Jan 21 ORNL email to BES Director
- 2021 Jan 22 Briefing with OHEP Director
- 2021 Feb 9 First STS Nu Working group meeting
- 2021 Apr 13 STS Nu Briefing of STS Project Team
- 2021 Jul 13 STS Project Neutrino Charrette

- 2021 Dec 14 Joint Briefing of BES and HEP
- 2022 Sep 22 STS Project Director confirms Neutrino Laboratory to be considered in Preliminary Design

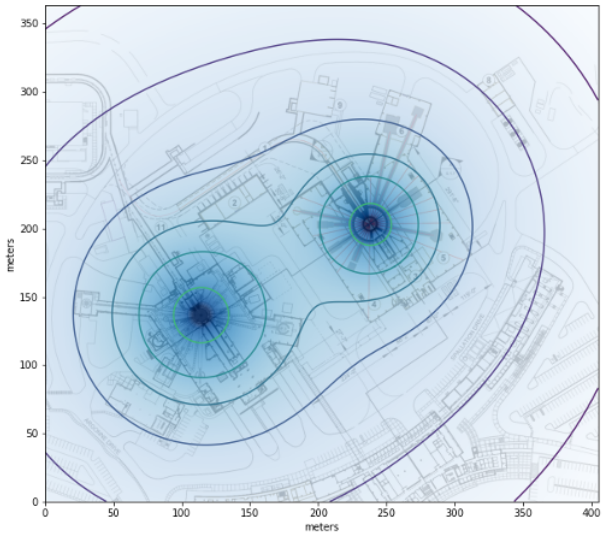
STS Nu Working Group (Chair Kate S.)

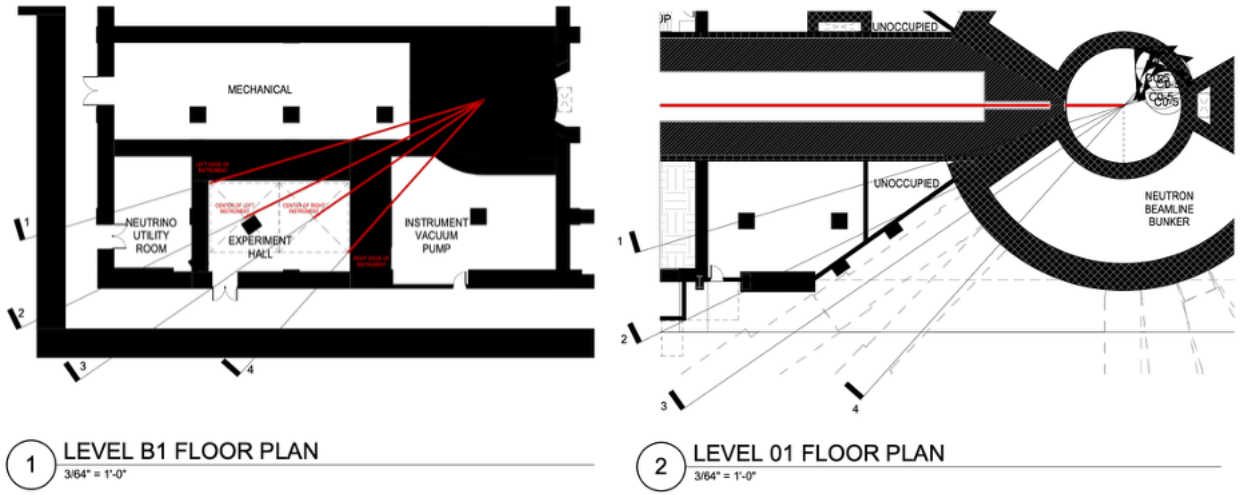
- COHERENT Institutions, SLAC, UT-Arlington, TAMU
- Weekly Meetings to Consider
  - Science Program
  - Detector Technologies
  - Distance & Proton Beam Angle
  - Shielding
  - Installation Constraints
  - Utilities

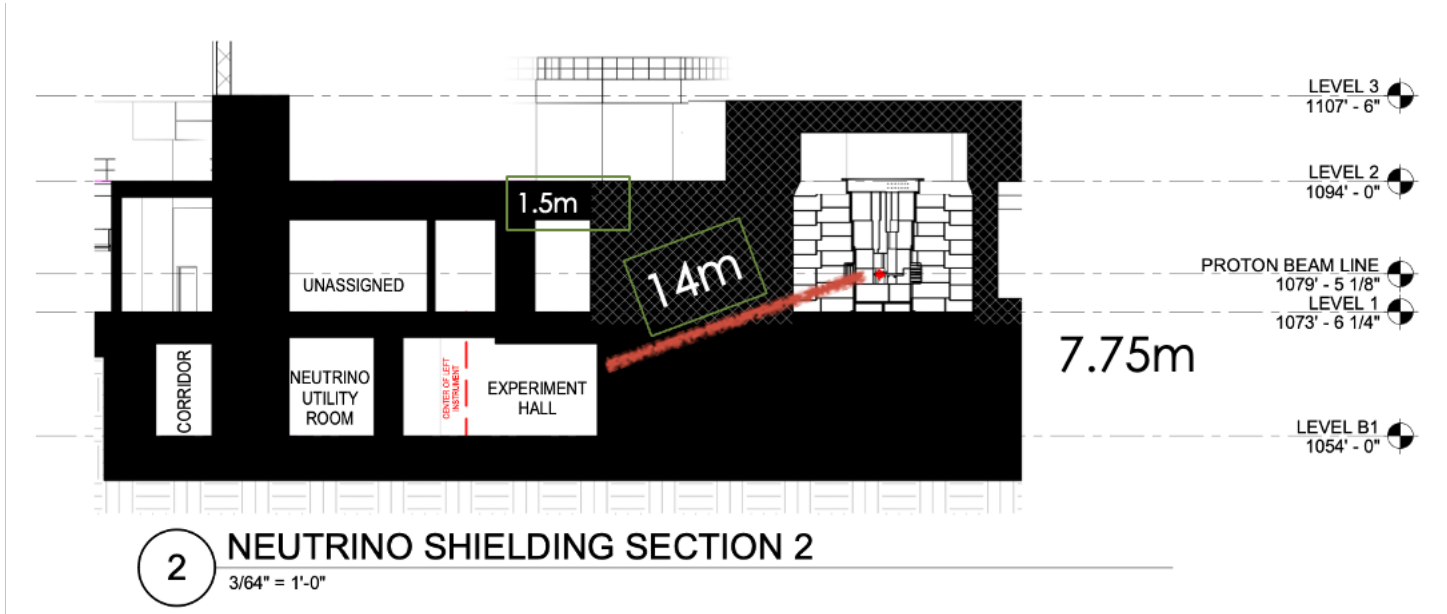


Second Target Station Opportunities

- Neutrino Laboratory approved for STS Project Preliminary Design in 2021
- STS Basement concept location offered facility integrated neutron shielding for 2 10-ton scale detectors and adjacent utility room



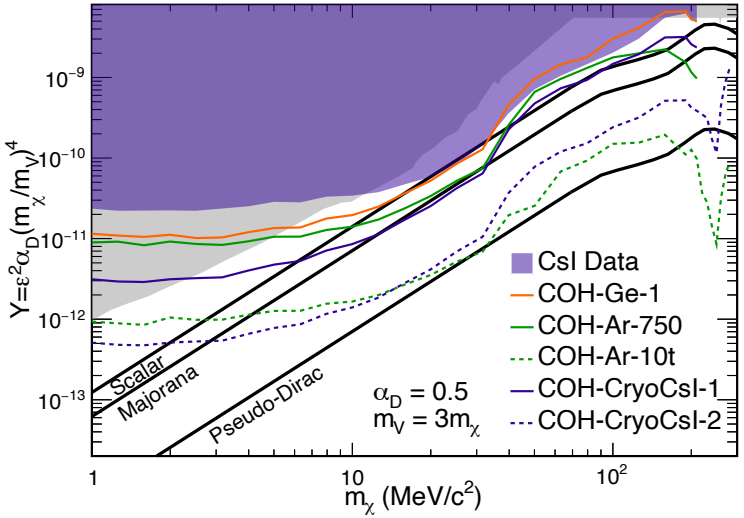




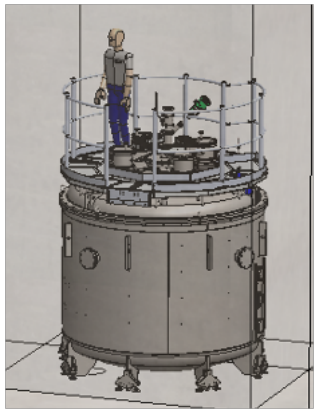
Science Capability of Second Target Station

Physics Opportunities in the ORNL Spallation Neutron Source Second Target Station Era

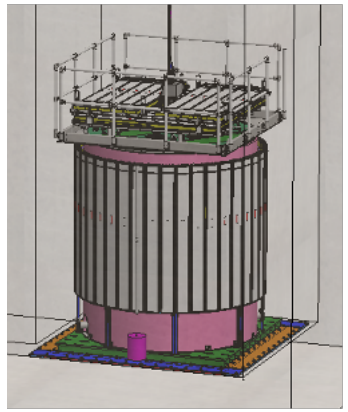
J. Asaadi,[1] P.S. Barbeau,[2,3] B. Bodur,[2] A. Bross,[4] E. Conley,[2] Y. Efremenko,[5,6] M. Febbraro,[6] A. Galindo-Uribarri,[6,5] S. Gardiner,[4] D. Gonzalez-Diaz,[7] M.P. Green,[3,6,8] M.R. Heath,[6] S. Hedges,[2,3] J. Liu,[9] A. Major,[2] D.M. Markoff,[10,3] J. Newby,[6] D.S. Parno,[11] D. Pershey,[2] R. Rapp,[11,*] D.J. Salvat,[12] K. Scholberg,[2,†] L. Strigari,[13] B. Suh,[12] R. Tayloe,[12] Y.-T. Tsai,[14] S.E. Vahsen,[15] T. Wongjirad,[16] and J. Zettlemoyer[4]



Dark Matter Searches

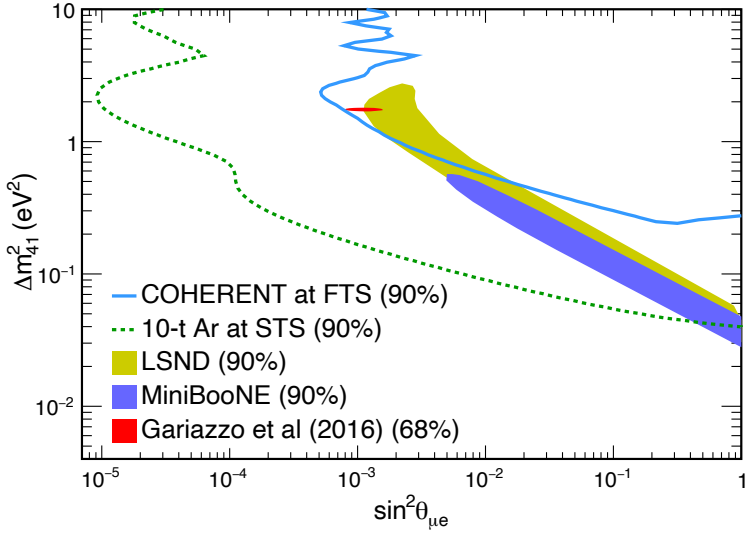


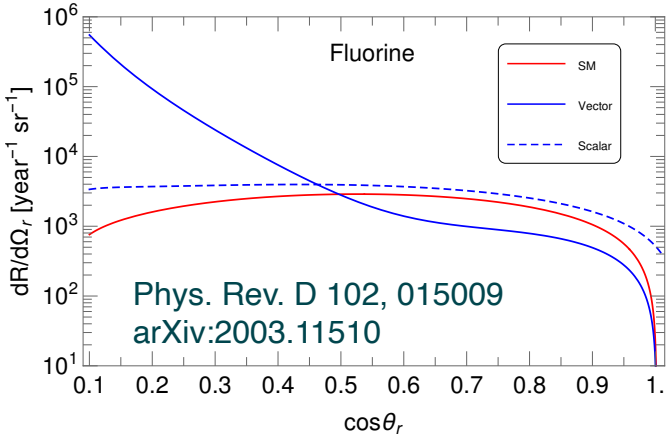
10-ton LAr
FSD Bern



10-ton WbLS
EOS (LBNL)

Sterile Searches





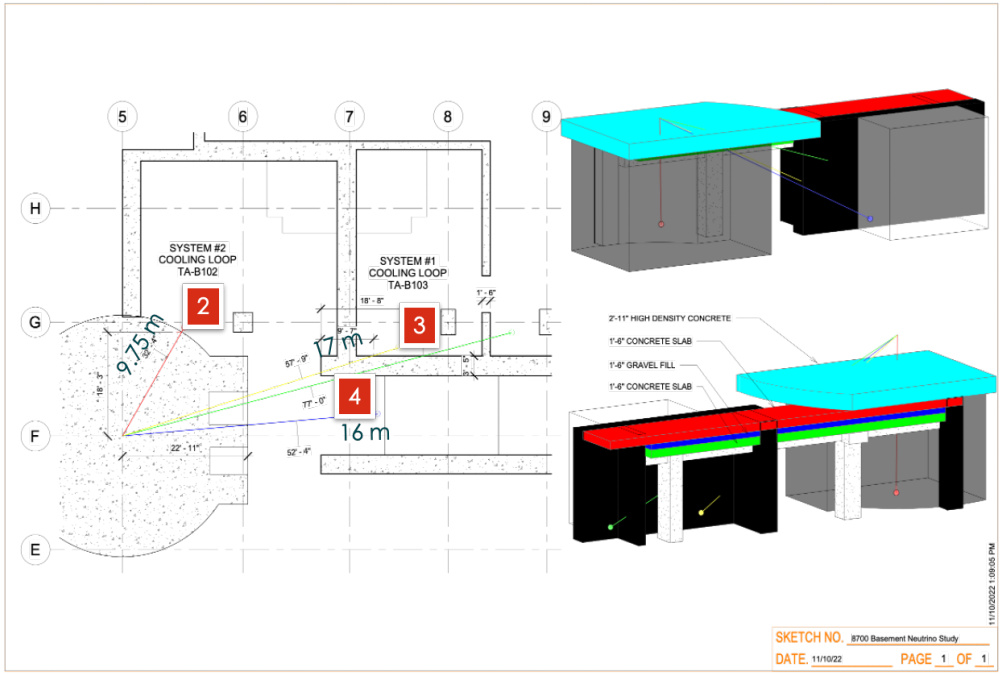
Directional CEvNS with GasTPCs sensitive to light/vector mediators

Broad International Interest in SNS/STS Science Program

Exploring First Target Station Opportunities for Larger Detectors

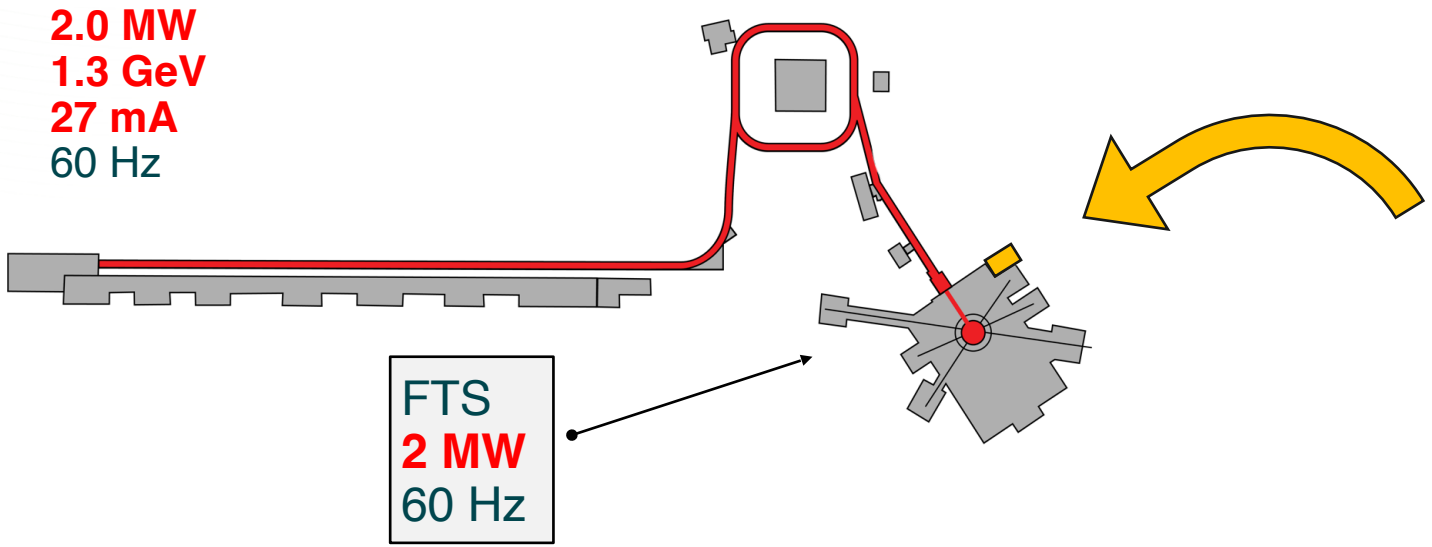
ORNL LDRD 2022-2023 to consider FTS spaces

- Neutrino flux at FTS a factor of 3 higher than STS
- SNS Engineering and Operations identified additional 4 candidate spaces with facility integrated shielding for neutrino experiments.
- Overburden and cosmic ray reduction similar to Neutrino Alley.
- Locations 10-17 meters from the target.
- Beam related neutron backgrounds are the critical unknown to establish viability.
- Limited to ton-scale detectors
- Modest facility infrastructure required in these locations.

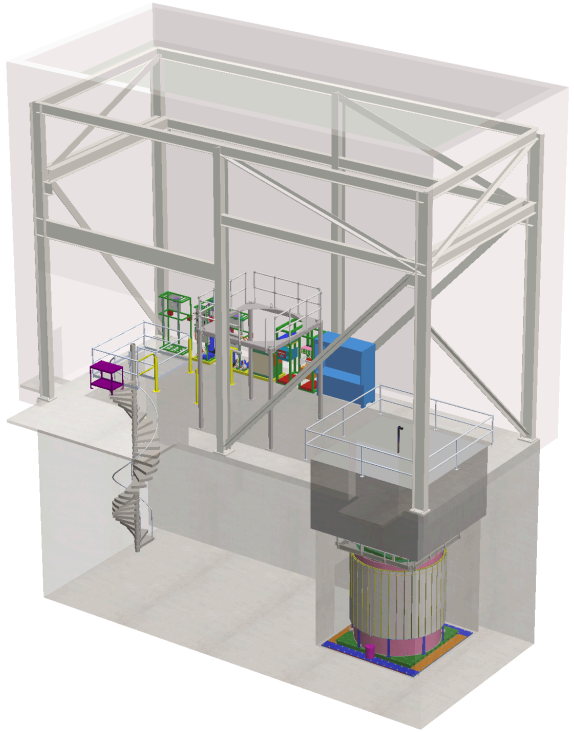


ORNL initiative to explore modest facility upgrades to enable new capabilities

SNS First Target Station



Neutrino Detector Hall



Concept by John Ramsey

First Target Station ramped to 2.0 MW in 2026

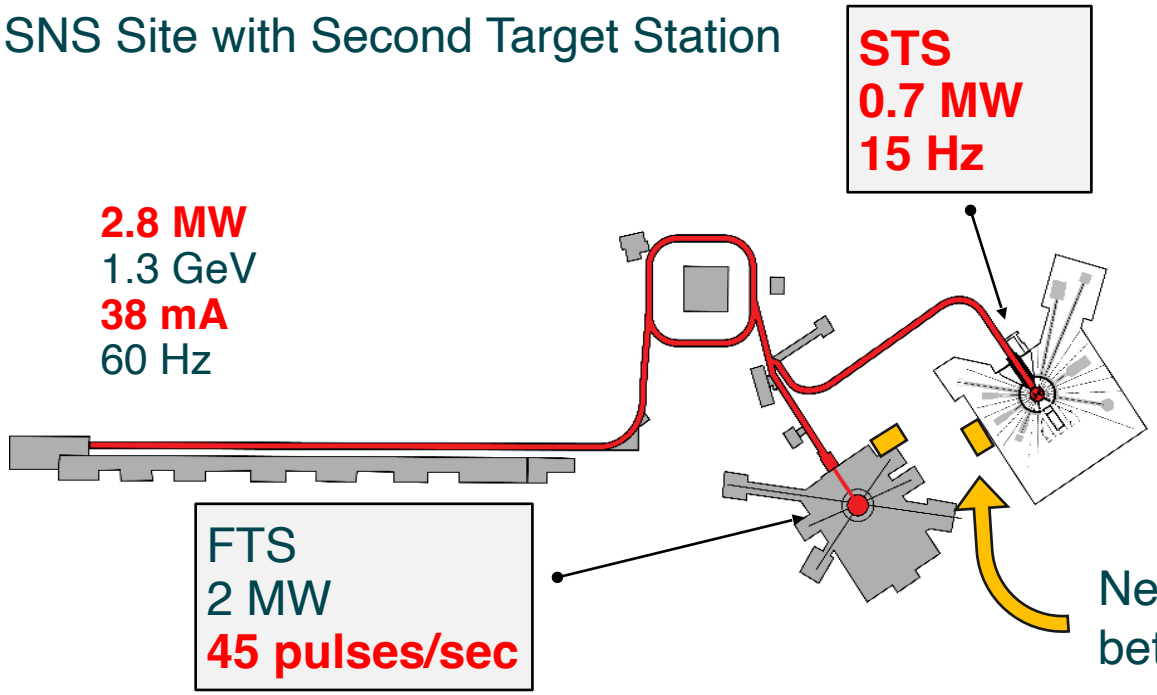
ORNL FY24 LDRD explored feasibility and cost of dedicated neutrino laborato

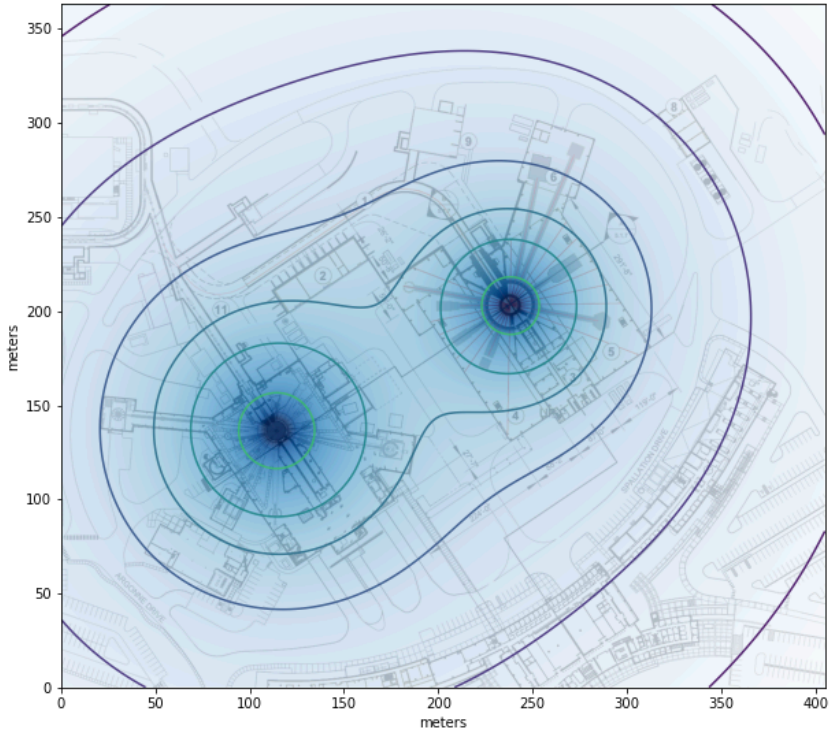
- Subterranean pit 45 meters from neutrino source: 3.8 m x 3.8 m x 4.3 m
- 8 ft of overburden cosmic shielding.
- Accommodate EOS WbLS or 10-ton LArTPC, or both simultaneously to be evaluated in preliminary design

STS Site Construction cost for March 2025 authorization and December 2028 closeout: $6.3M including 25% contingency

Exploring science opportunities in Second Target Station Era

SNS Site with Second Target Station





Dueling Neutrinos Sources
K. Scholberg

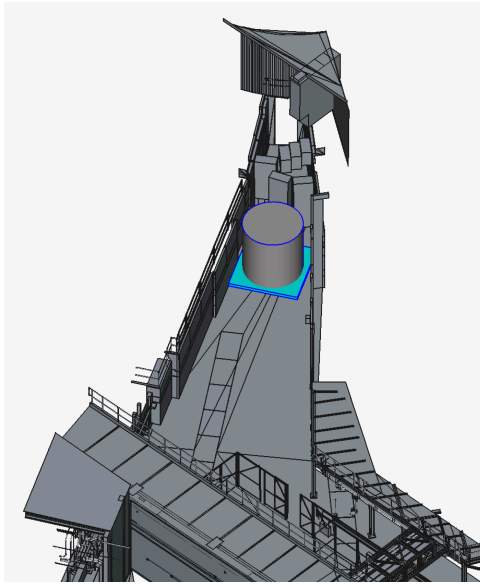
Neutrino Program inclusion in STS Project Preliminary Design phase approved by BES-HEP

Similar neutrino laboratory design at STS could benefit from STS construction mobilization and allow single detector to simultaneously observed two pion-decay-at-rest neutrino sources at different baselines.

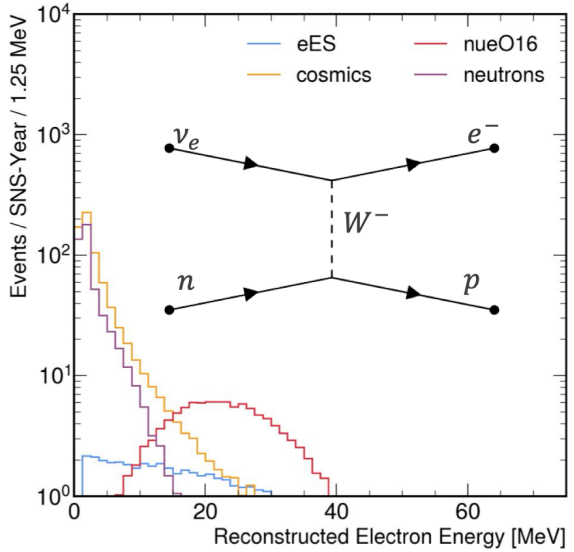
See Snowmass STS Whitepaper https://arxiv.org/abs/2209.02883

Neutrino Oxygen Cross-Section Measurement with EOS at FTS
Inelastic cross sections Ar, O essential for DUNE, HK Supernova Physics

EOS - Hybrid Water-Scintillator
Candidate tech for DUNE Module 4
NNSA/DNN - $10M Instrument
Construction Complete in 2024



SNS – Beamline 8
5-Year+ Window For Neutrinos
ORNL funded by DNN for feasibility study



EOS @ SNS Sensitivity
Simulations indicate backgrounds are manageable at surface – 5% in 3 years
Informs future Argon TPC at 10-ton scale

NNSA-funding identified for transportation and installation in June 2027
DOE HENP funding is under negotiation for operations 2027-2029

If BL8 or similar location identified at FTS, broader interest in DUNE LArTPC 2.4T, PbGlass 20T

Summary

- The Low Energy Neutrino Program at ORNL is a highly productive, user-facing international effort utilizing a globally-unique DOE user facility to create a “national landmark for neutrino science” - HEP Comparative Review 2024
- The COHERENT experiment addresses all three P5 science themes and is well-aligned with Office of High Energy Nuclear Physics priorities.
- Inelastic neutrino cross-section measurements at ORNL have direct impact on DUNE for supernova and low energy science.
- Partnership of NScD and Physics Division has been significantly strengthened in the past year with programmatic, engineering, and operational integration for planning future detector deployments.
- ORNL engagement with the HEP community has identified compelling new initiatives to expand the impact of the Low Energy Neutrino Program to the HEP mission.

Neutrino and BSM Physics Opportunities at SNS Workshop planned for October 26-31