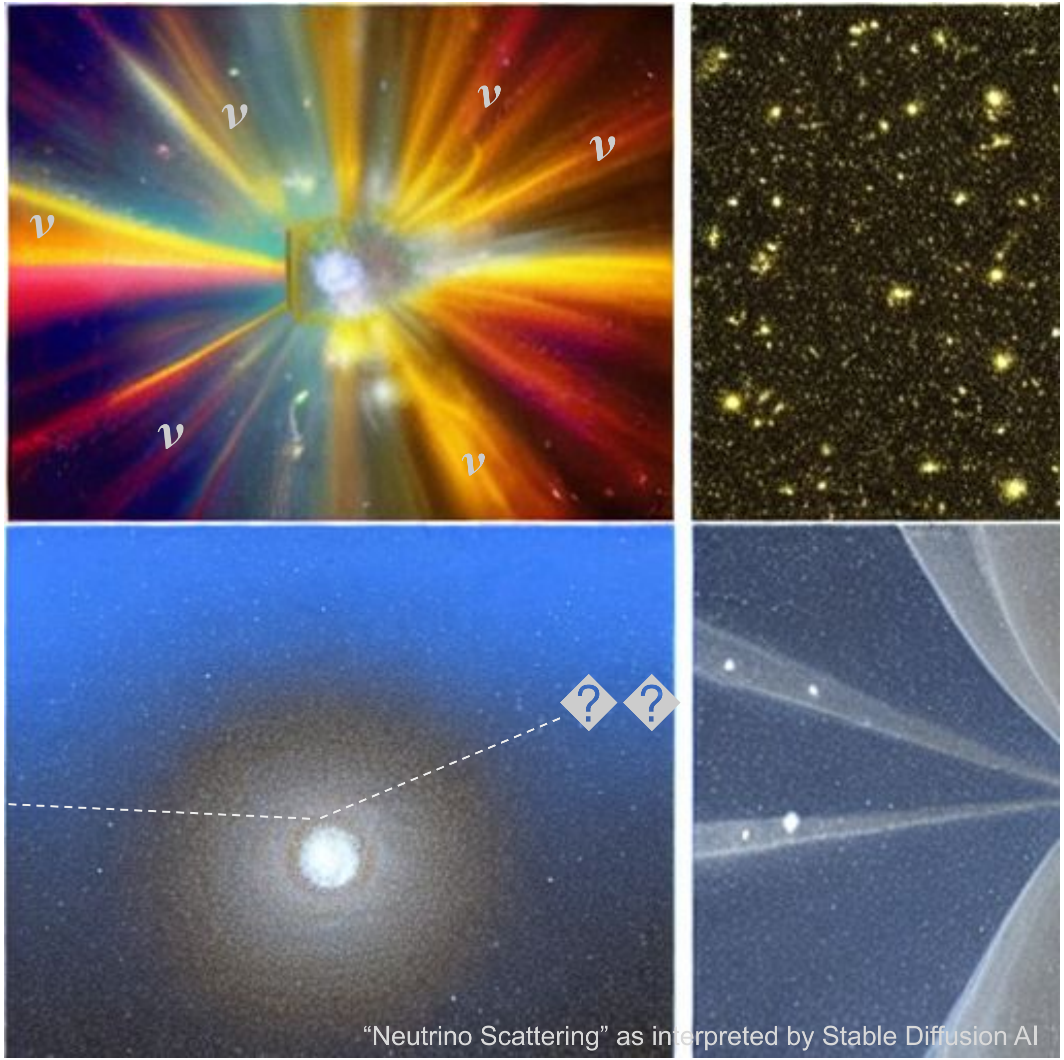
Status of the COHERENT Experiment

41st PIC Symposium
September 7, 2022

Taritree Wongjirad
Tufts University

QUARK - LEPTON
Tbilisi, Georgia, September 5-9, 2022



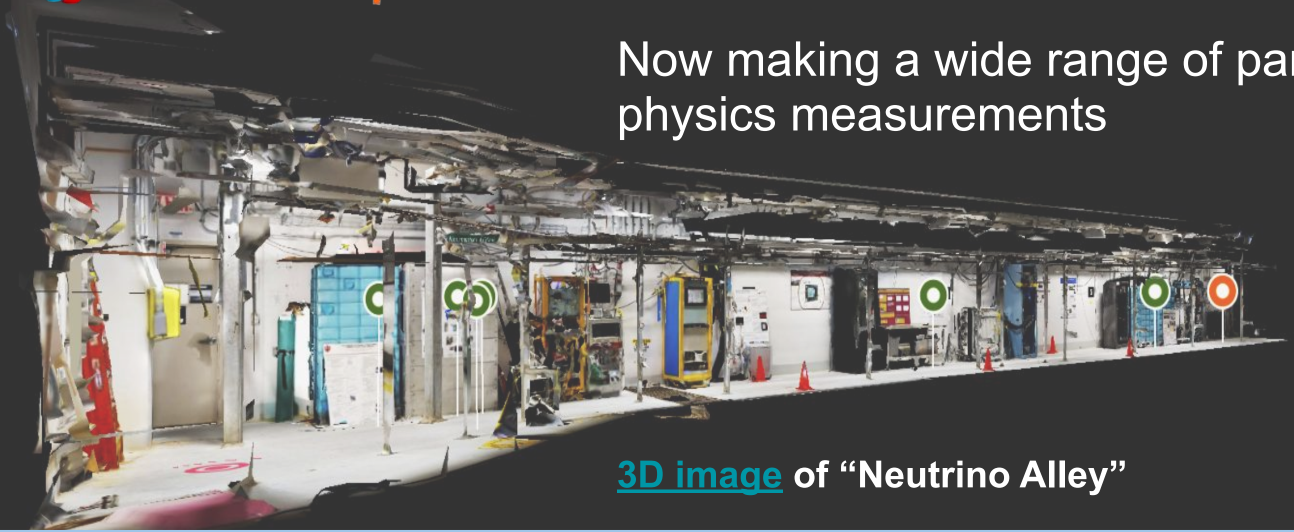
“Neutrino Scattering” as interpreted by Stable Diffusion AI

COHERENT

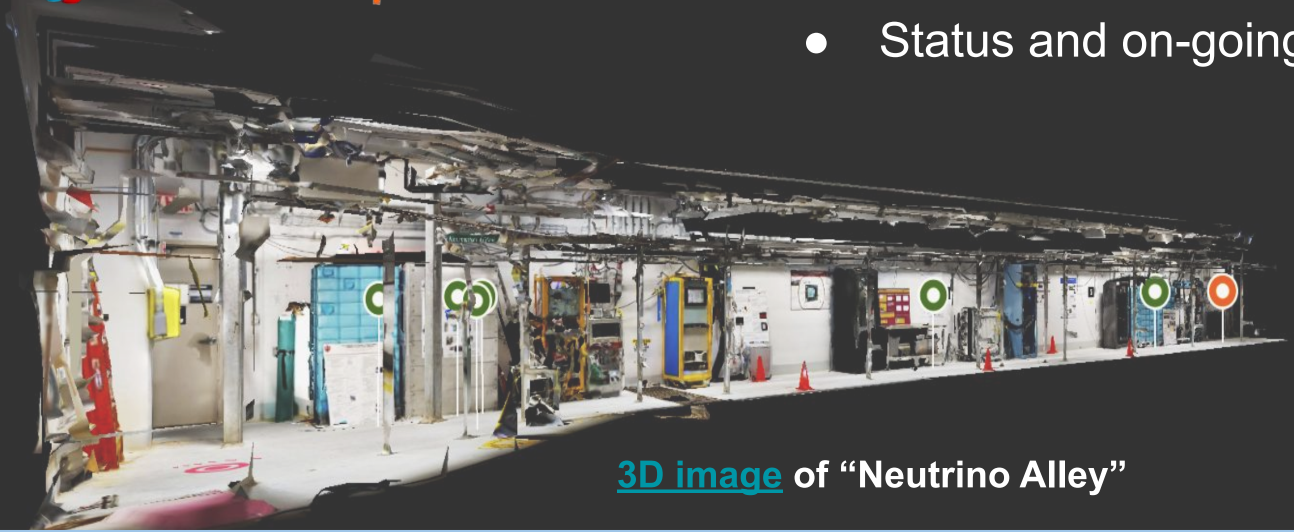
The COHERENT collaboration operates a suite of detectors at Oak Ridge National Laboratory

Originally formed to measure coherent elastic neutrino interactions (cevens)

Now making a wide range of particle and nuclear physics measurements



3D image of "Neutrino Alley"



Outline

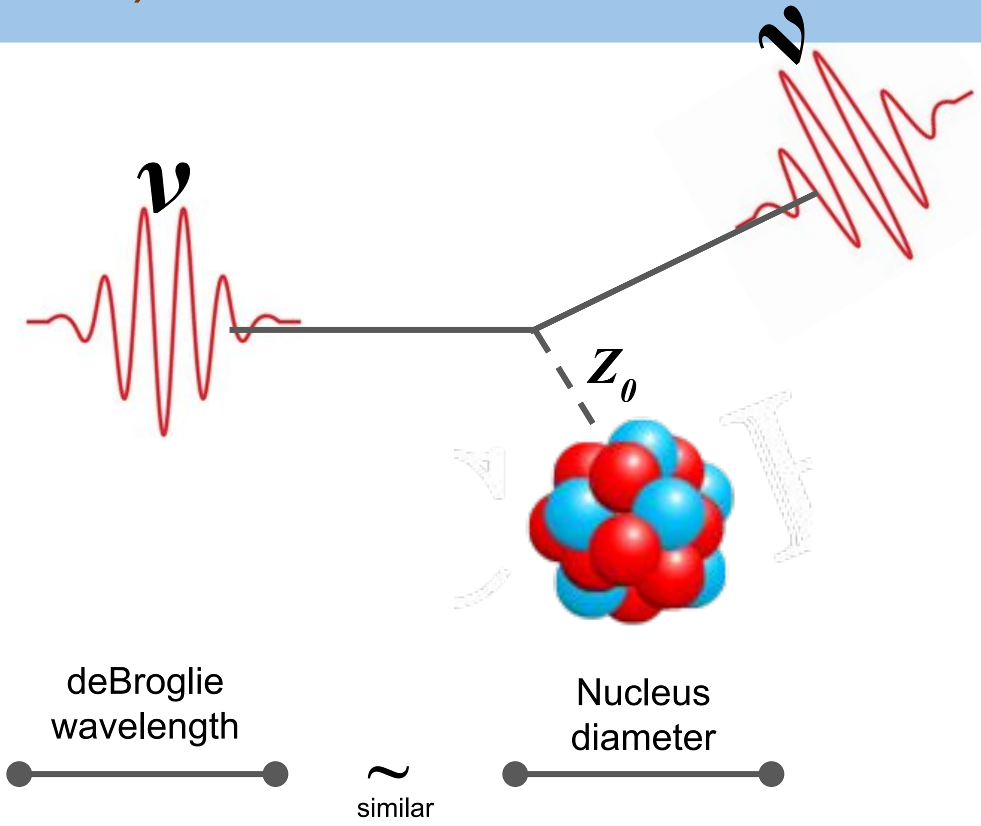
- Overview of experiment
- Recent results
- Status and on-going work

3D image of "Neutrino Alley"

CEVENS (pronounced “sevens”)

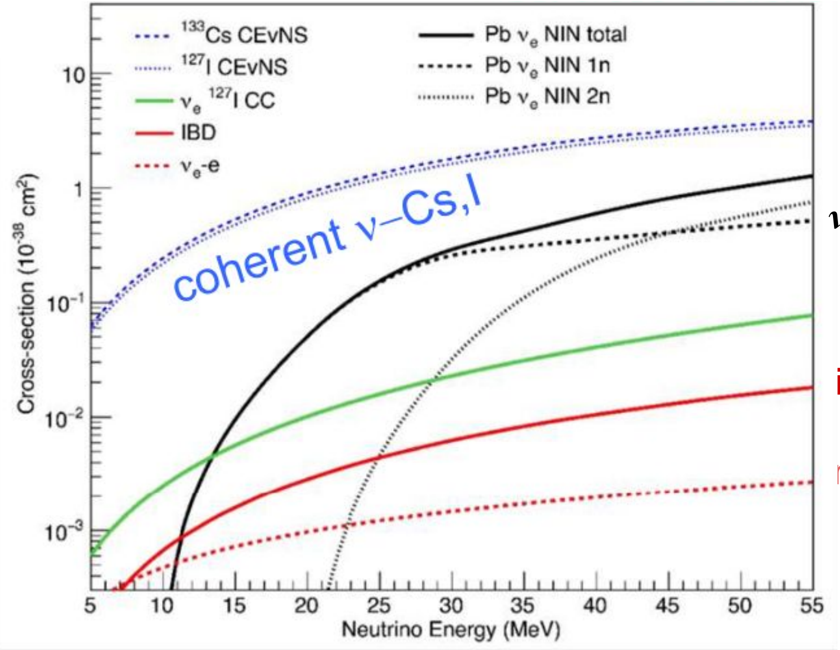
Coherent Elastic Neutrino-Nucleus Scattering

At energies ~10 MeV and below, neutrino probes the nucleus ***coherently***



CEVENS rate

Coherence leads to largest ν-nucleus interaction channel



cevens

ν-induced neutron(s)

inelastic CC

inverse beta-decay

neutrino-electron

CEVENS cross section

Cevens has predicted

… N^2 dependence

Scales as number of neutrons-squared

$$\frac{d\sigma}{dT} \simeq \frac{G_F^2 M}{2\pi} \frac{Q_W^2}{4} F^2(Q) \left(2 - \frac{MT}{E_\nu^2}\right)$$

E_ν: neutrino energy
T: nuclear recoil energy
M: nuclear mass
Q = √ (2 M T): momentum transfer

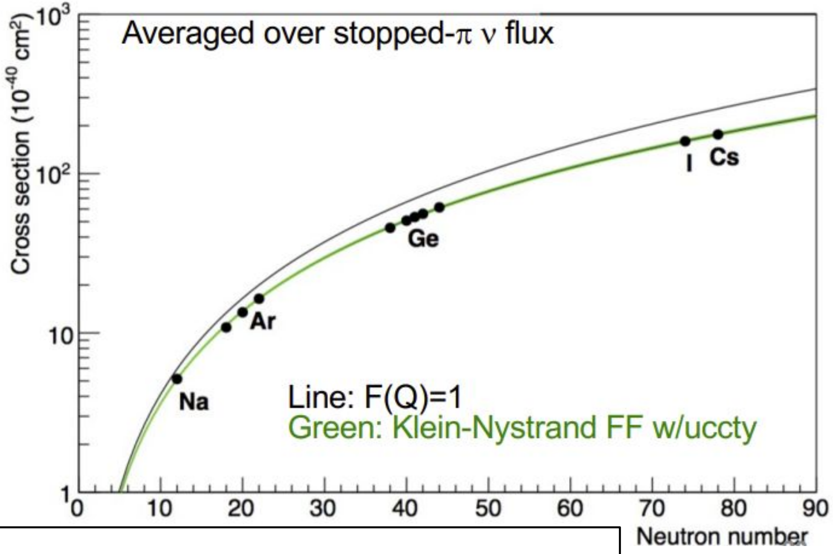
Form factor: F=1 ➔ full coherence

weak nuclear charge

$$Q_W = N - (1 - 4\sin^2\theta_W)Z$$

~zero

… and small theoretical uncertainty ~ 3%

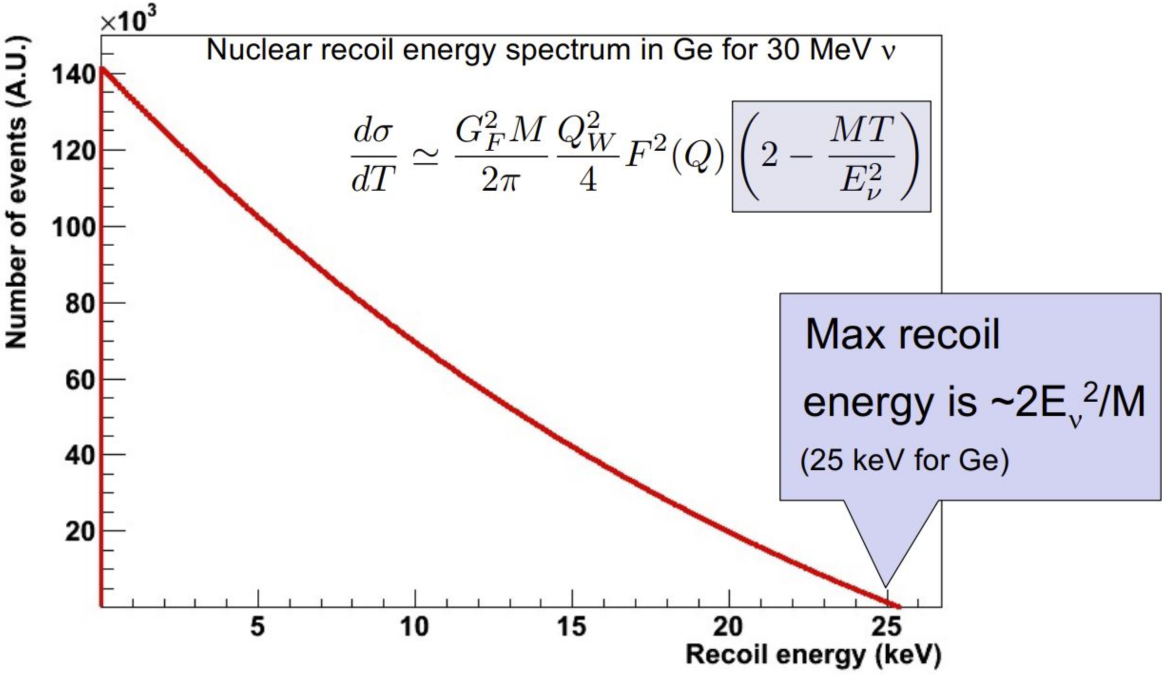


An attractive probe for new physics!

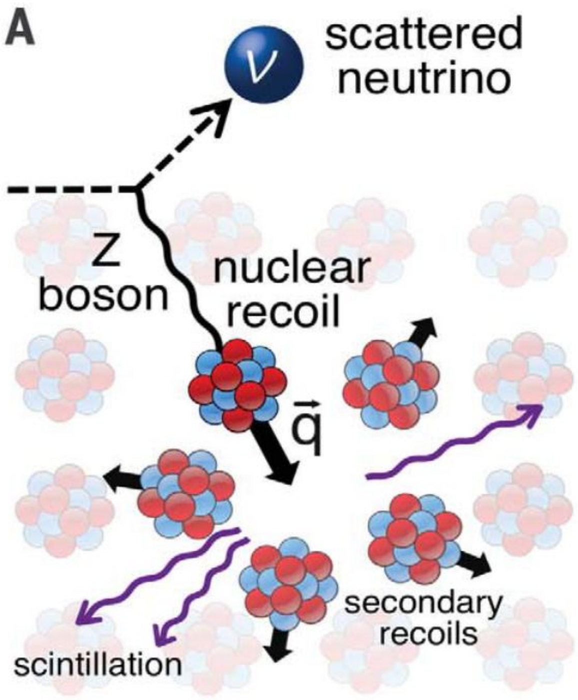
CEVENS Recoil Spectrum

Yes, large cross section (for neutrinos)

..but low recoil energies



CEVENS Signature



Signature is usually small **scintillation** signal from **nuclear recoil**

So need low threshold detectors and high intensity neutrino source

CEVENS at last

After 40+ years since first theorized, able to put together what we need

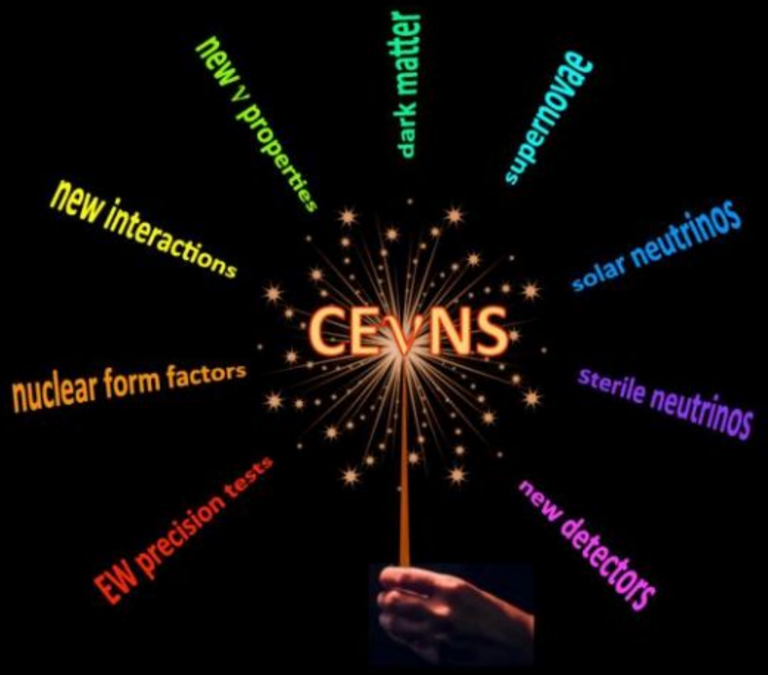
PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

Coherent effects of a weak neutral current

Daniel Z. Freedman†
National Accelerator Laboratory, Batavia, Illinois 60510
and Institute for Theoretical Physics, State University of New York, Stony Brook, New York 11790
(Received 15 October 1973; revised manuscript received 19 November 1973)

Our suggestion may be an act of hubris, because the inevitable constraints of interaction rate, resolution, and background pose grave experimental difficulties for elastic neutrino-nucleus scattering. We will discuss these problems at the end of this note, but first we wish to present the theoretical ideas relevant to the experiments.

Worth the effort!



E Lisi, Neutrino 2018

Measure cevens for (not complete list)

Signatures of new physics

- Non-standard interactions
- Test weak mixing angle: $\sin^2\theta_W$
- ν anomalous magnetic moment
- Sterile oscillation searches

Dark matter

- Cevens important background (nu floor)
- Sensitive to accelerator-produced DM

Supernova

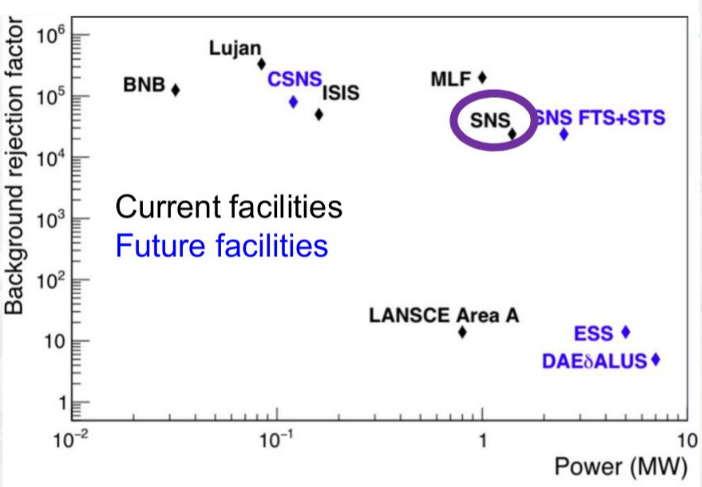
- Largest σ in SN dynamics
- cevens possible detection channel
- Inelastic neutral- and charged-current important channel for DUNE SN detection

COHERENT at Oak Ridge National Lab

Located in state of Tennessee, USA

ORNL Spallation Neutron Source (SNS) is also a powerful ***neutrino*** source

- Intense proton beam: 1.4 MW, 1 GeV
- Narrow Pulse: 60 Hz, 600 ns spill time



Neutrinos from the SNS

Neutrinos from **decay-at-rest** pions in the beam target

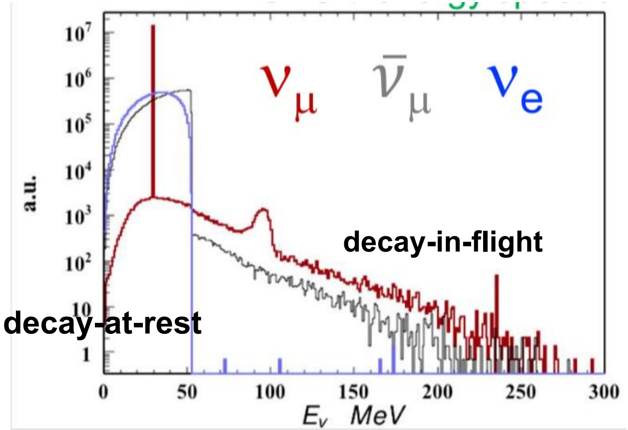
$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

2-body decay: monochromatic 29.9 MeV ν_μ
PROMPT

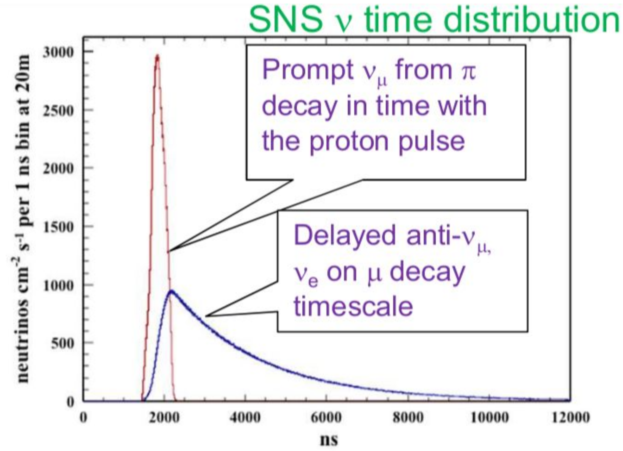
$$\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e$$

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

Well known energy spectrum *shape*



And useful timing distribution

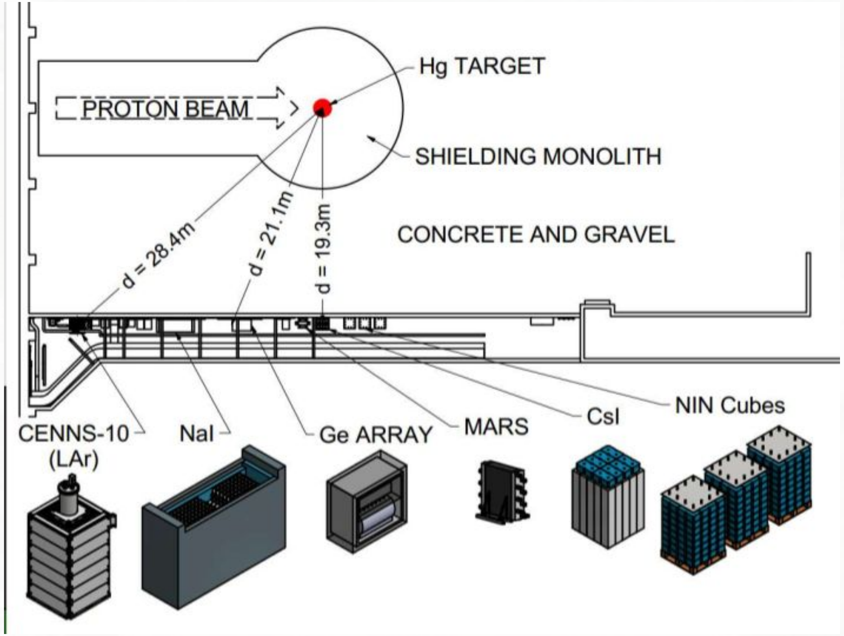


Tight timing allows for *in situ* measurement of steady-state backgrounds

COHERENT Detectors

SNS Target Building

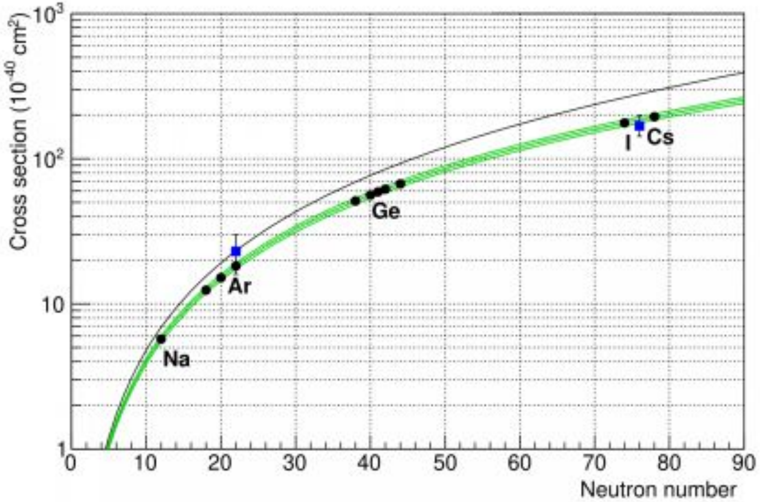
- **Suite of Detectors** in Neutrino Alley
- 20-29 m from target in repurposed basement hallway of target building
- Path from target to alley filled with steel, gravel, concrete shielding
- Concrete overburden
- Low beam-related backgrounds



COHERENT Strategy

Phase 1:
Observe cevens for first time and measure N2 dependence with multiple detector technologies

- First measurements made (CsI in 2017, Ar in 2019)
- Precision of about ~10%



Blue points are measurements

Phase 2:
Precision measurements of cevens (and related) physics
With larger/upgraded targets and detectors

- Measure flux normalization uncertainty with dedicated detector

CsI[Na]

CsI[Na] Scintillating Crystal

- 14.6 kg sodium-doped CsI
- High light yield: 13.35 pe/keVee
- Manufactured by Amcrys-H
- Single R877-100 PMT

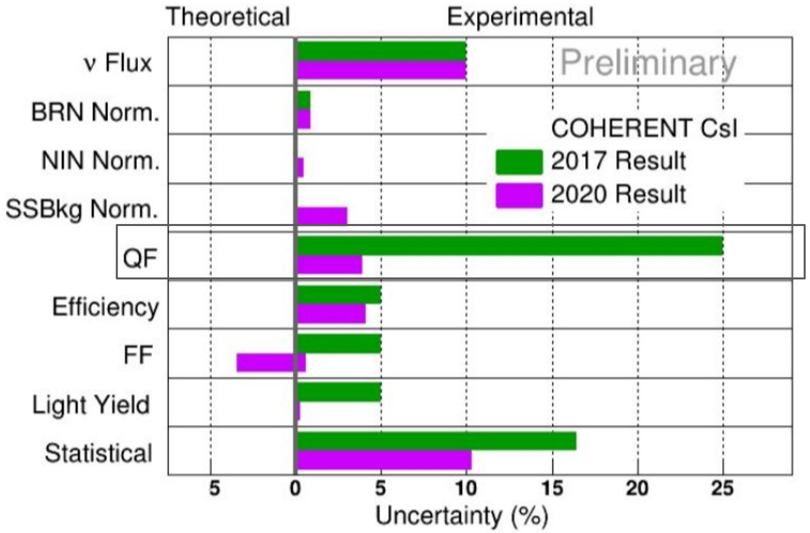
Updated result with 2.2x more data (w/r/t 2017 result)

- More POT
- Analysis improvements
- New quenching factor (QF) measurements
- Over reduced uncertainties

"First Light" - 2017

- 6.7σ discovery of cevens
- Consistent w/ SM w/in 1σ

Science 357 (2017) 6356, 1123-1126

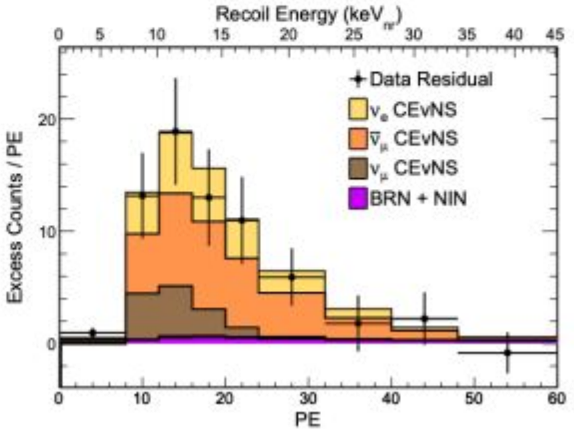


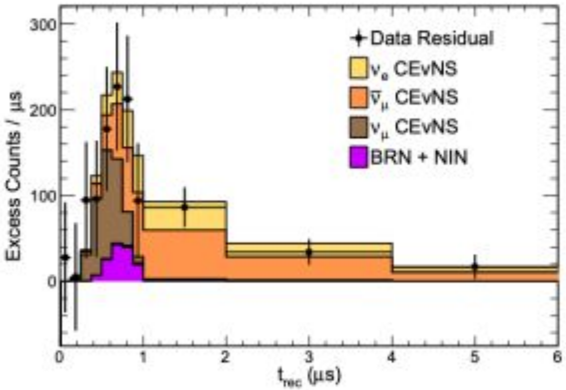
CsI[Na] Updated Result

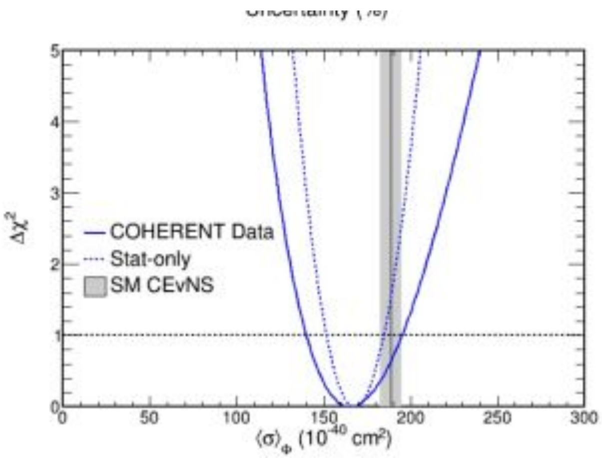
Latest Result:

- Data disfavor null hypothesis at **11.6σ**
- See 1σ agreement with SM cevens prediction
- Largest source of uncertainty is neutrino flux, ~10%
- Enough stats to fit neutrino flavor components

PRL 129, 081801 (2022)

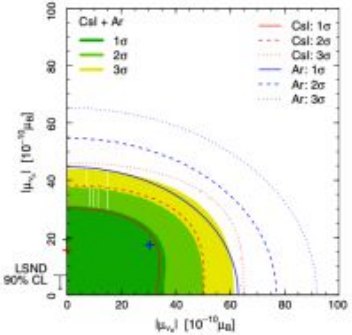






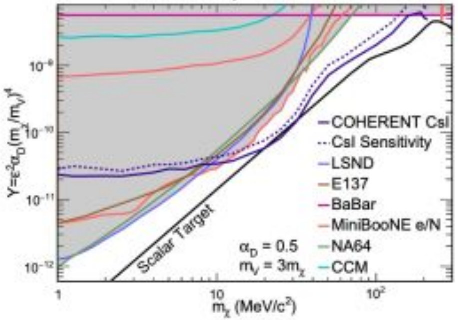
Measurement Impact

Neutrino magnetic moments



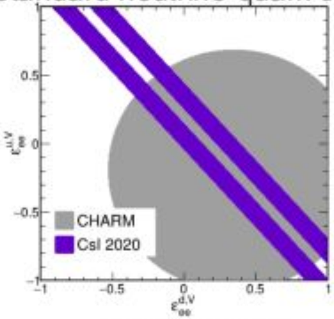
[arXiv:2005.01645]

Accelerator-produced DM



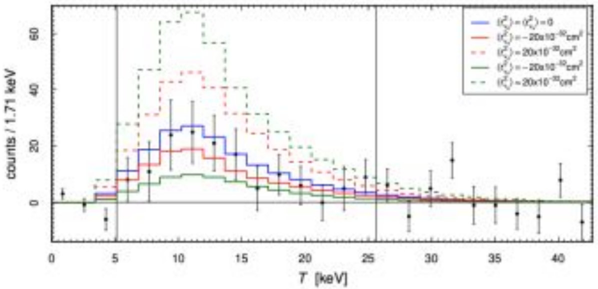
[arXiv: 2110.11453.05022]

Non-standard neutrino-quark couplings



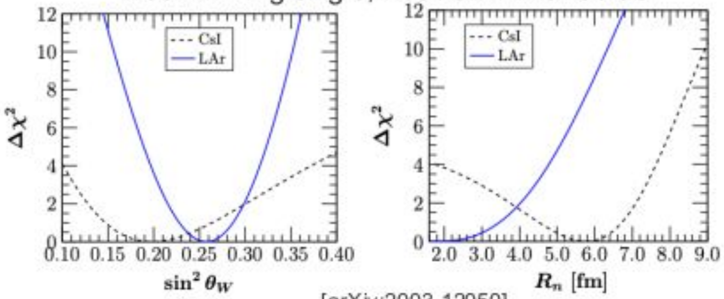
[arXiv:2110.07730]

Neutrino charge radius



[arXiv:1810.05606]

Weak mixing angle, neutron RMS radius



[arXiv:2003.12050]

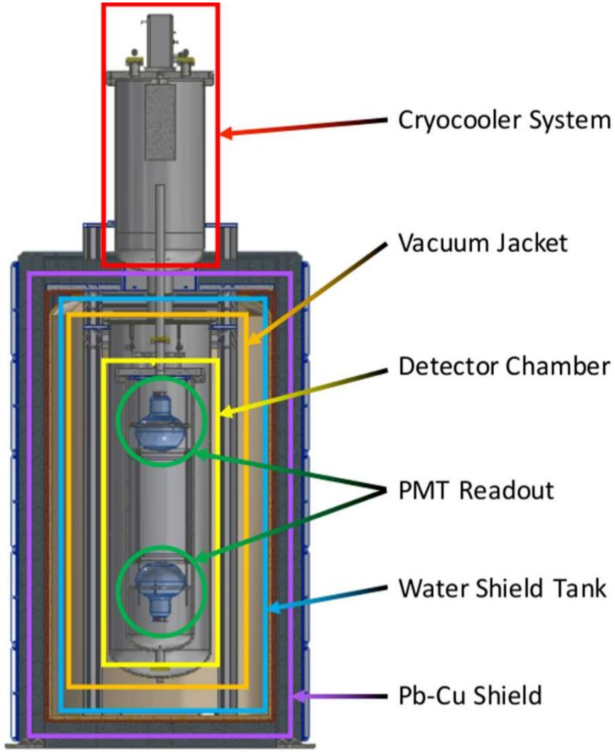
CENNS10: Argon Measurement

Single-phase argon detector

- 24 kg fiducial volume
- 28 m from target
- Energy threshold: 20 keVnr
- Expect ~140 cevens events/SNS-year
- Built by Fermilab (J. Yoo)

Initial results from 2017-2019 data

- Full ~3 year run result to come

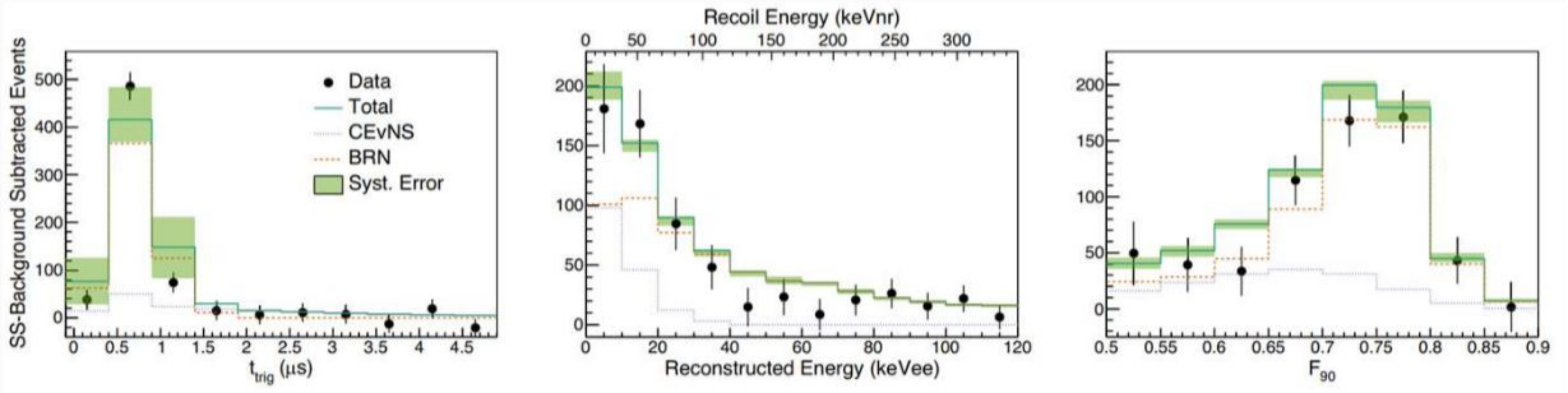


Argon Measurement

Initial Result

- Evidence of cevens on LAr at > 3σ
- Agrees with SM within 1σ
- Two analyses performed as cross-check

10.1103/PhysRevLett.126.012002
JINST 16 (2021) 04, P04002

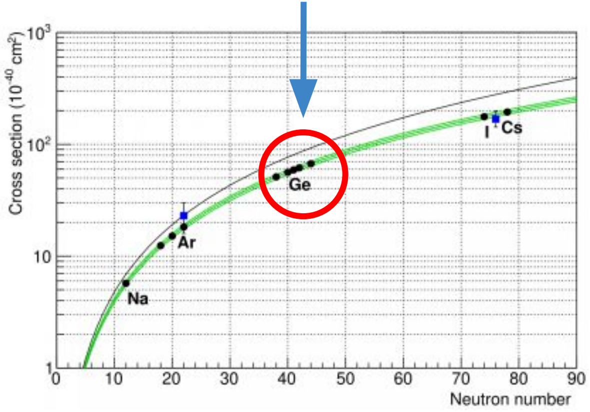


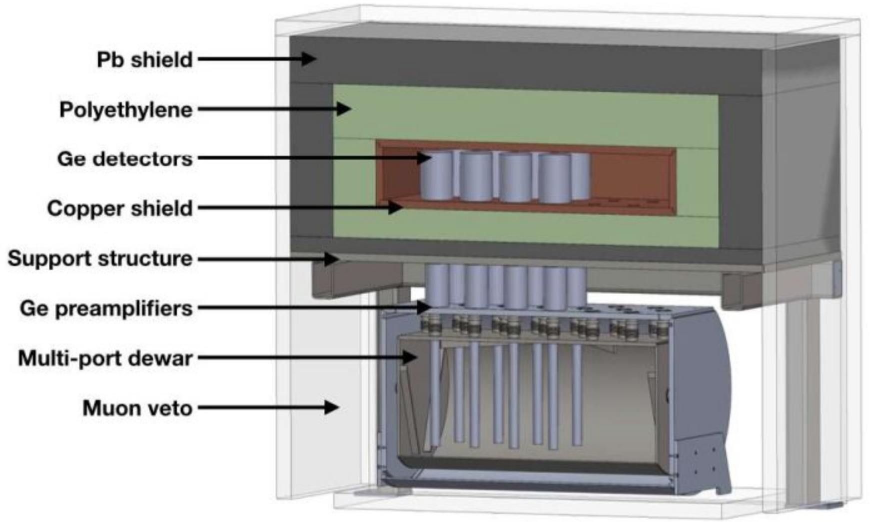
What's Next!

Gemini

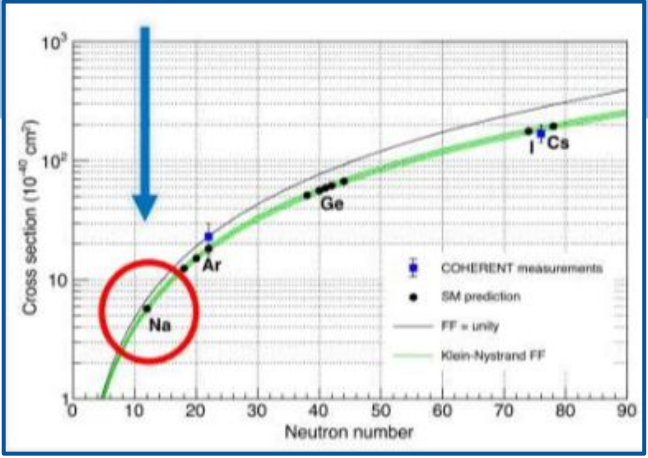
Eight ~2kg p-type point contact Ge detectors

- Good energy resolution
- Threshold of ~3keVnr
- Low-background targets, cryostat
- Commissioning/Deployment underway
- Expect 500-600 cevens events/year





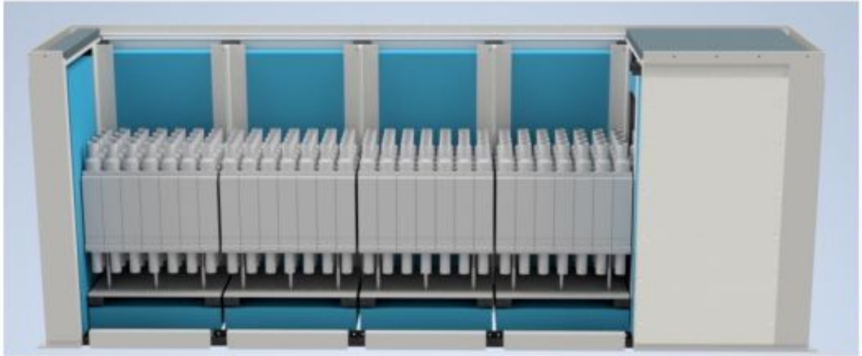
NaIνE-185/NaIνETe



NaIνE-185 (NaI Neutrino Experiment)

- Studying inclusive charged-current electron neutrino cross section on ^{127}I
- ^{127}I a potential target for solar neutrino detection
- By measuring electromagnetic energy deposition, may be able to test nuclear models including gA quenching at ~30 MeV momentum transfer
- Collecting data since 2016

$$\nu_e + {}^{127}\mathrm{I} \rightarrow e^- + {}^{127}\mathrm{Xe}^*$$



NaIνETe (NaI Neutrino Experiment TonnE-scale)

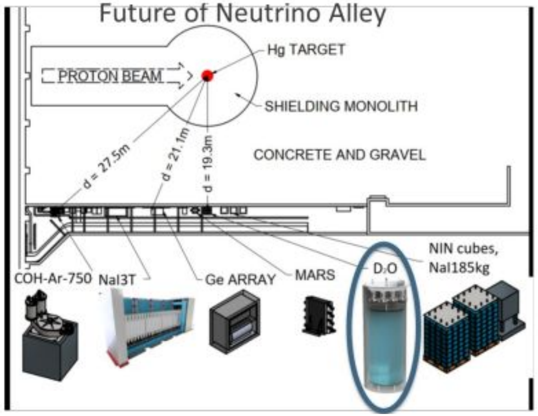
- Measure CEνNS on 23Na, COHERENT's lightest target
- Unpaired proton in ^{23}Na gives potential to measure axial contributions to CEνNS cross section
- Take advantage of detector segmentation to reject backgrounds spanning multiple crystals
- Module one (of five) current deployed
- Full deployment of 2425.5-kg

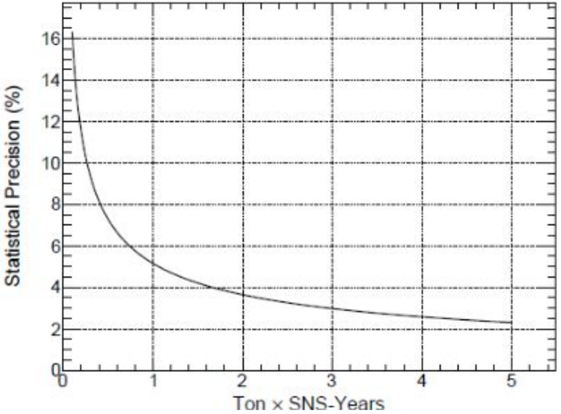
D2O

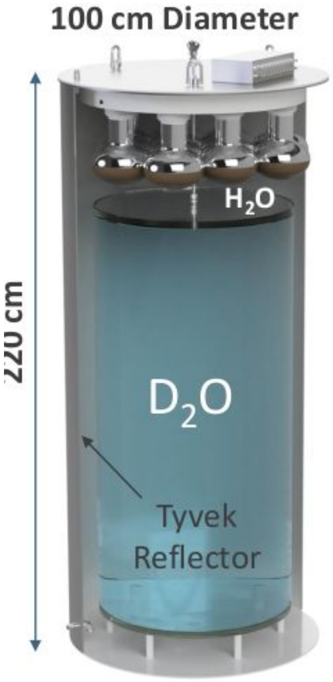
Concept paper: 2021 JINST 16 P08048

D2O Flux Monitor

- Largest systematic uncertainty from neutrino production (~10%).
- Use well known D2O IBD cross-section to measure flux normalization
- Reduce Neutrino flux uncertainty: As low as 2% after a few years.
- ~1000 events/2 years







D2O Status

Engineering Run has begun

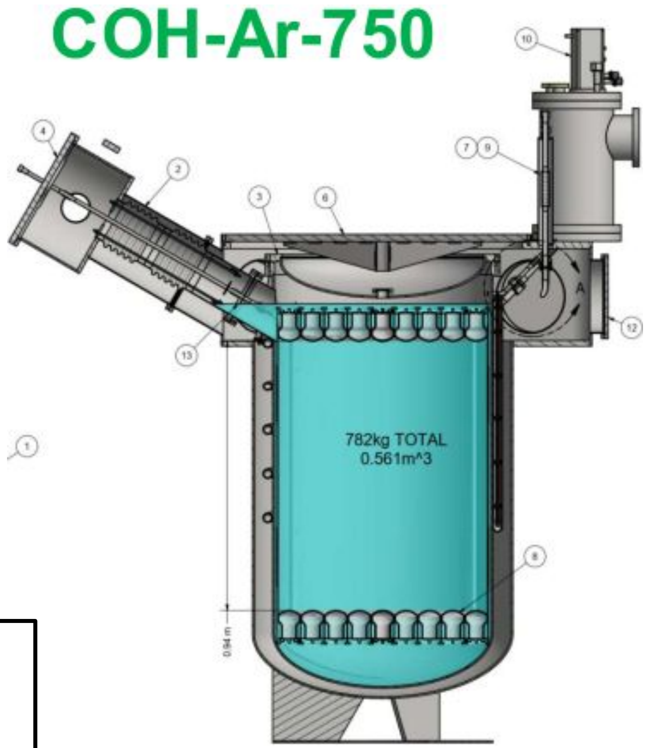
- D2O acquired
- Acrylic vessel (for heavy water) installed in 2023
- Data acquisition started on light water

Tonne-Scale LAr

Tonne-scale Single Phase LAr Scintillator

- 750 kg total/610 kg fiducial
- Light collection: array of 3" PMTs with VUV/VIS SiPMS being studied
- Goal of eventual use of underground argon to reduce dominant ^{39}Ar background
- **3000 events events/year**
- **400 inelastic CC/NC events/year**
- Capable of very strong dark matter limits [arXiv:1911.06422]

Collaborators at Seoul National University recently awarded funds for construction of the detector!



Upgrade to SNS + Beyond Neutrino Alley

Proton Power Upgrade

PPU project: Double the power of the existing accelerator structure

- First Target Station (FTS) is optimized for thermal neutrons
- Increases the brightness of beams of pulsed neutrons
- Provides new science capabilities for atomic resolution and fast dynamics
- Provides a platform for STS

Larger Neutrino Experimental Hall Possible at STS: 2 10-ton Detectors

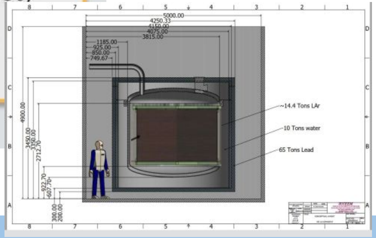
Second Target Station

STS project: Build the second target station with initial suite of beam lines

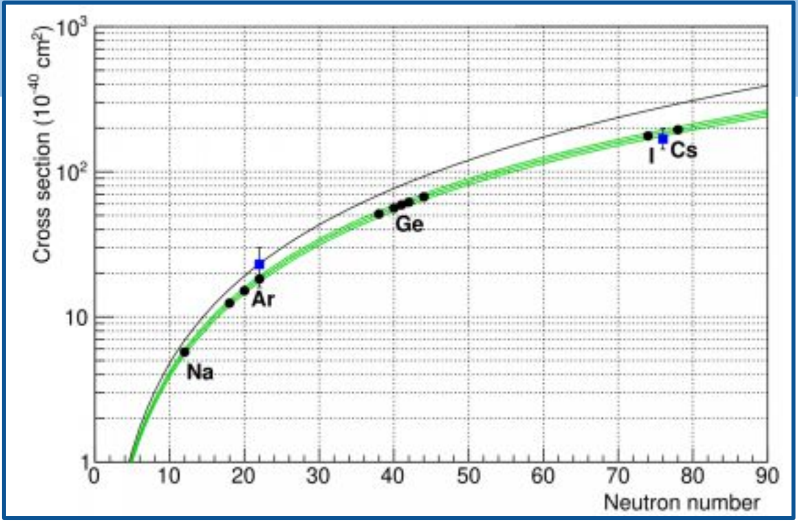
- Optimized for cold neutrons
- World-leading peak brightness
- Provides new science capabilities for measurements across broader ranges of temporal and length scales, real-time, and smaller samples

Slide from Ken Herwig, Workshop on Fundamental Physics at the Second Target Station (FPSTS18)

Potential space for larger neutrino detectors!
E.g. 10t LAr



Summary



- First measurements of cevens on CsI[Na] and Ar have been made at the SNS
- Robust physics program motivates next phase of experiments on more targets and increased precision to few percent
- Next up:
  - NaI, Ge, Tonne-scale LAr
  - D2O flux monitor – key to reducing flux normalization uncertainty
  - Potential increase in neutrinos at ORNL!
  - And other efforts I did not have time to mention
- Want to note: Other collaborations worldwide are also out measuring cevens with different technologies and from other sources!

COHERENT Collaboration

~80 Members, ~20 institutions, 4 countries

OAK RIDGE National Laboratory
Duke UNIVERSITY
TUNL TRIANGLE UNIVERSITIES NUCLEAR LABORATORY
KAIST
LaurentianUniversity UniversitéLaurentienne
Los Alamos NATIONAL LABORATORY EST. 1943
NC STATE UNIVERSITY
UNIVERSITY of WASHINGTON
UNIVERSITY OF SOUTH DAKOTA
THE UNIVERSITY of TENNESSEE KNOXVILLE
Sandia National Laboratories
THE UNIVERSITY OF CHICAGO
MEPhI
Carnegie Mellon University
UF UNIVERSITY of FLORIDA
NCCentral UNIVERSITY
Tufts UNIVERSITY

Thanks!

Thank you for your attention!

Additional thank you to funding agencies!

Backups