HQL2021

# Coherent Elastic Neutrino-Nucleus Scattering

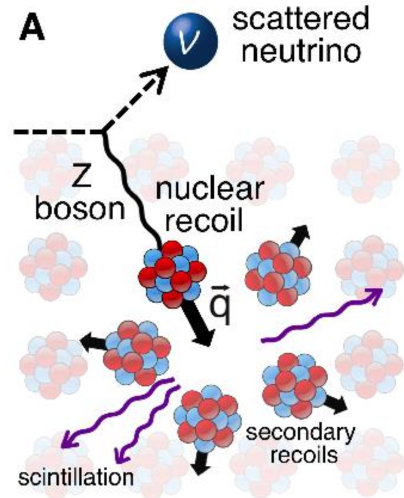
Max Hughes on behalf of the COHERENT collaboration

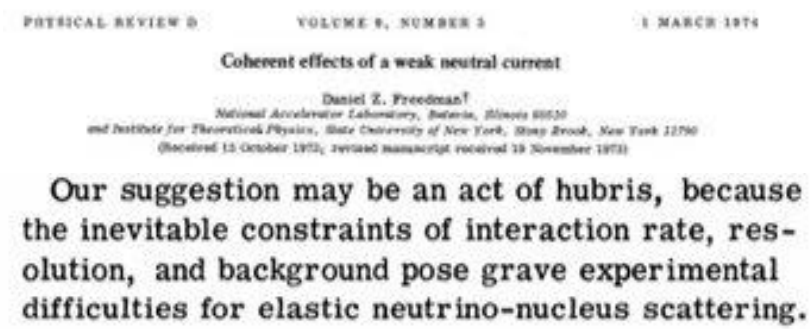
Indiana University Department of Physics

September 17, 2021

# Coherent Elastic Neutrino-Nucleus Scattering

- Neutrino scatters off a nucleus which recoils elastically
  - Neutrino energy up to 50 MeV
  - Cross-section is large
  - Cross-section goes as $\sim N^2 \times F^2(q^2) \times Q_{weak}^2$
  - Recoil energy is at or below 50 keV



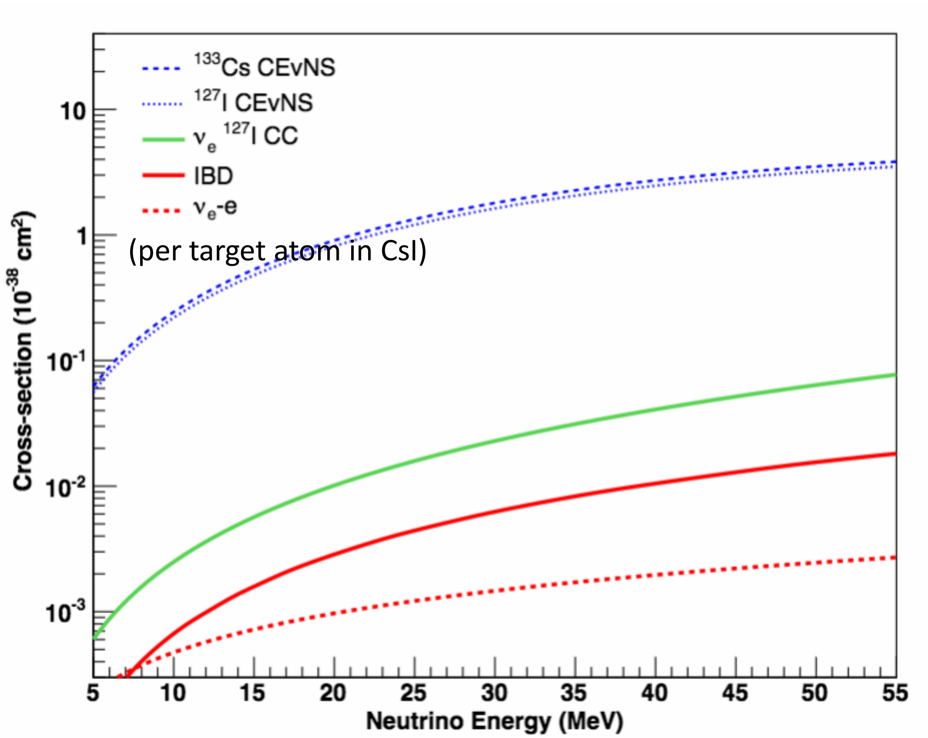


PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

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

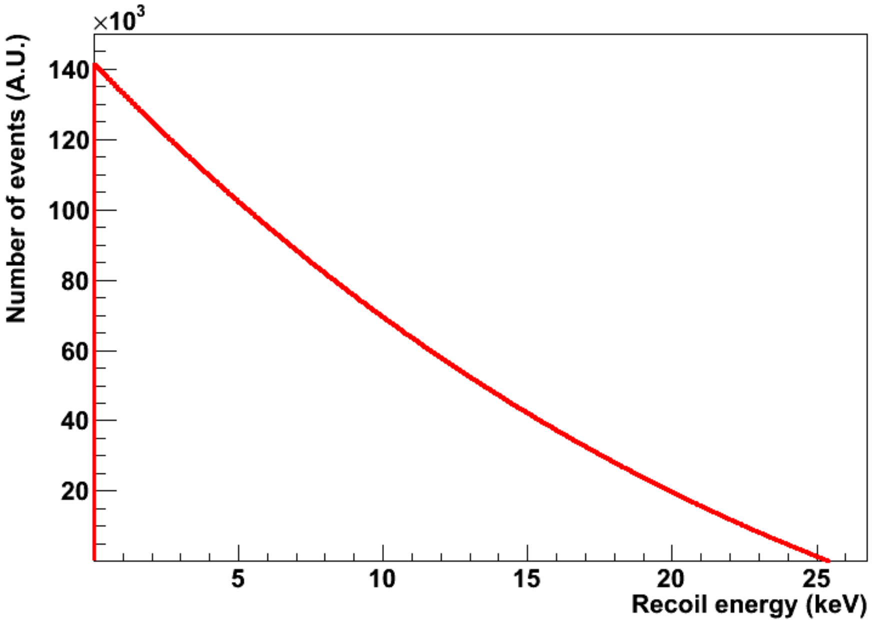
Our suggestion may be an act of hubris, because the inevitable constraints of interaction rate, resolution, and background pose grave experimental difficulties for elastic neutrino-nucleus scattering.

# Cross Section




K. Scholberg, IPA2018

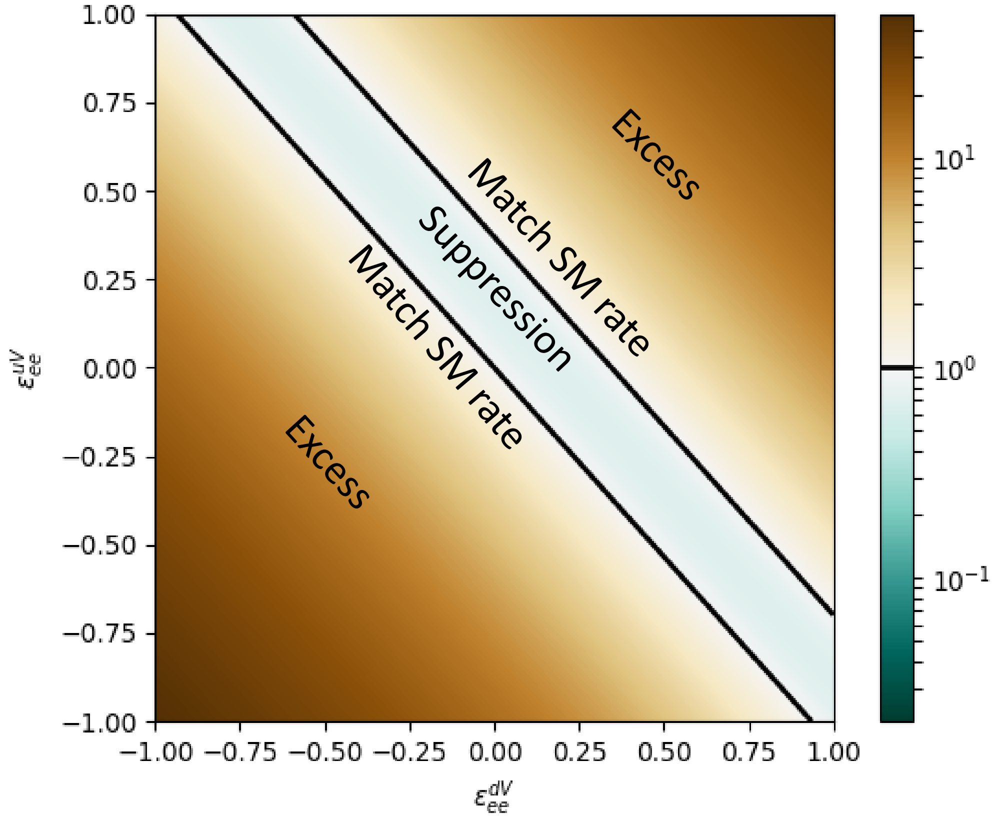
- Cross section is large




- Max recoil energy is ~$2E_\nu^2/M$
  (25 keV for Ge)

# Why Study It

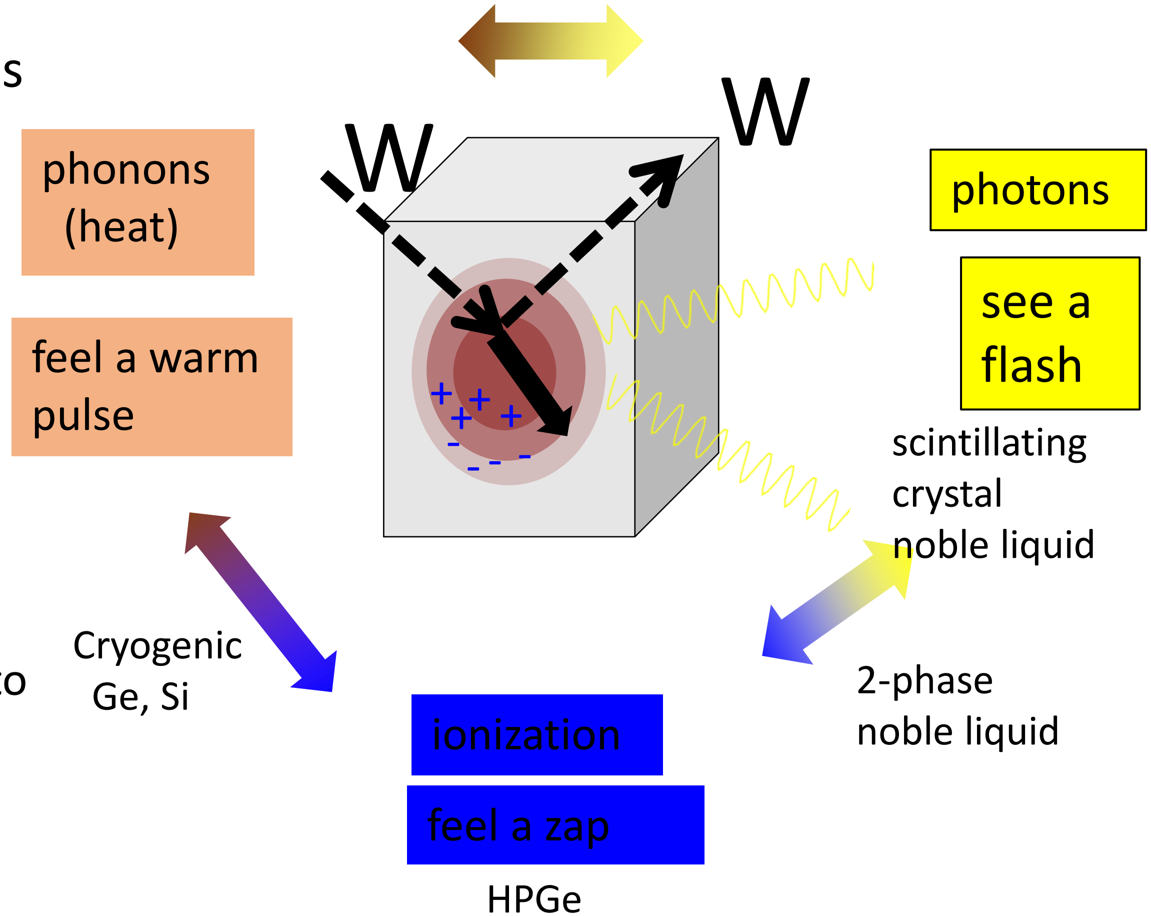
- Precisely described by standard model, so can look for new physics with this process
- Important for WIMP searches
- Sensitive to accelerator produced dark matter
- Sensitive to neutron radius




$$Q_W^2 \rightarrow Q_{\mathrm{NSI}}^2 = 4\left[N\left(-\frac{1}{2} + \boxed{\epsilon_{ee}^{uV} + 2\epsilon_{ee}^{dV}}\right) + Z\left(\frac{1}{2} - 2\sin^2\theta_W + \boxed{2\epsilon_{ee}^{uV} + \epsilon_{ee}^{dV}}\right)\right]^2$$

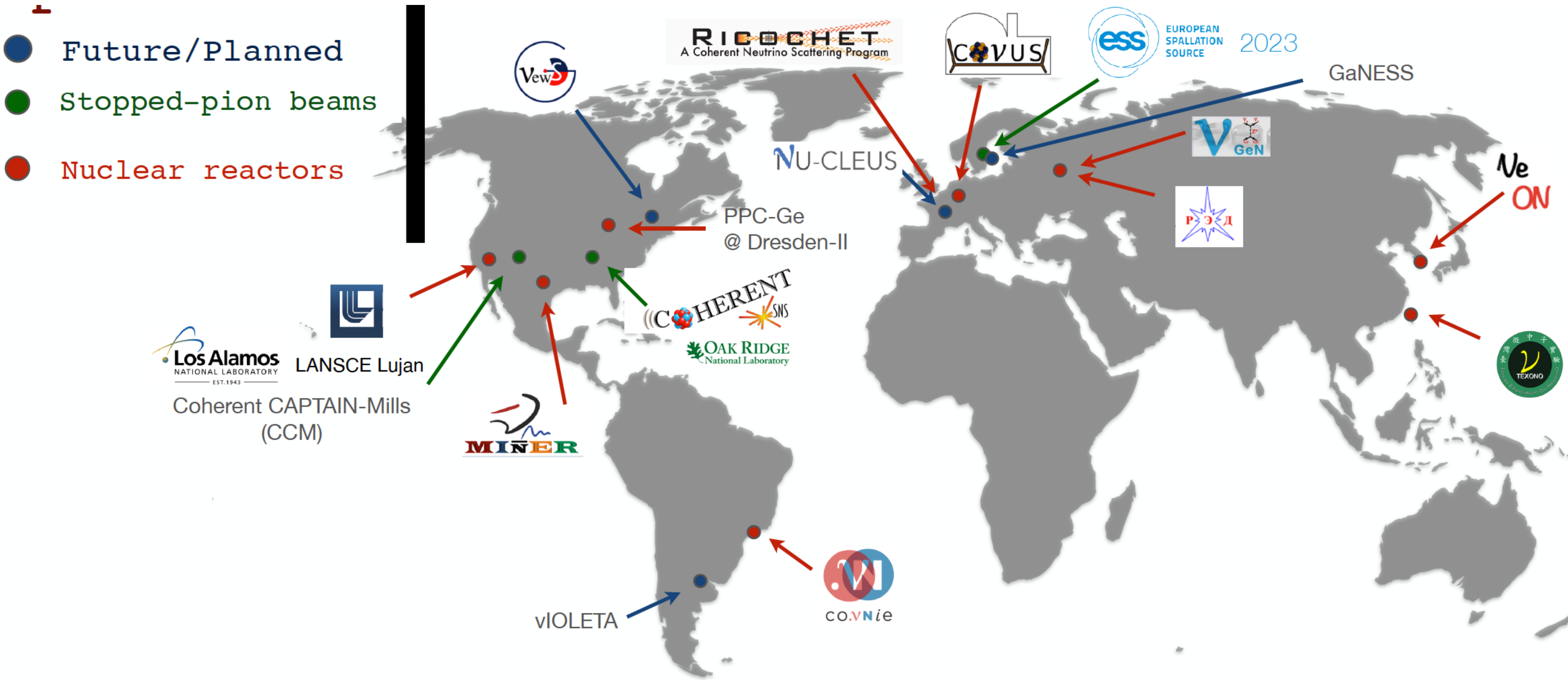
# How to Detect CEvNS

- Need a good source of neutrinos
- Need good rejection of background at low energy
  - Can subtract steady state backgrounds with pulsed sources
- Use low background detector technologies
  - Use different detector materials to map out $\sim N^2$ dependence



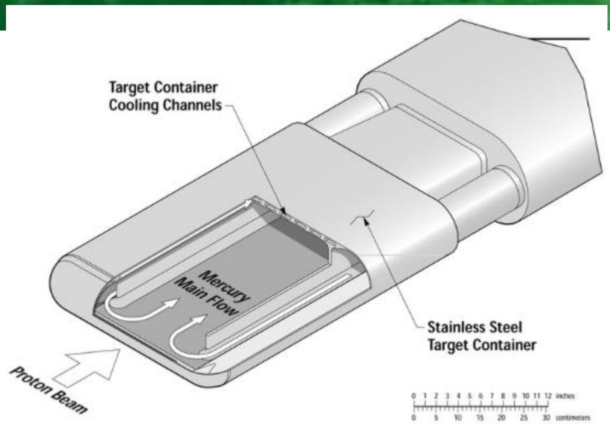

http://dmrc.snu.ac.kr/english/intro/intro1.html

# Different CEvNS Measurement Programs




Bonifazi, TAUP 2021

# Spallation Neutron Source

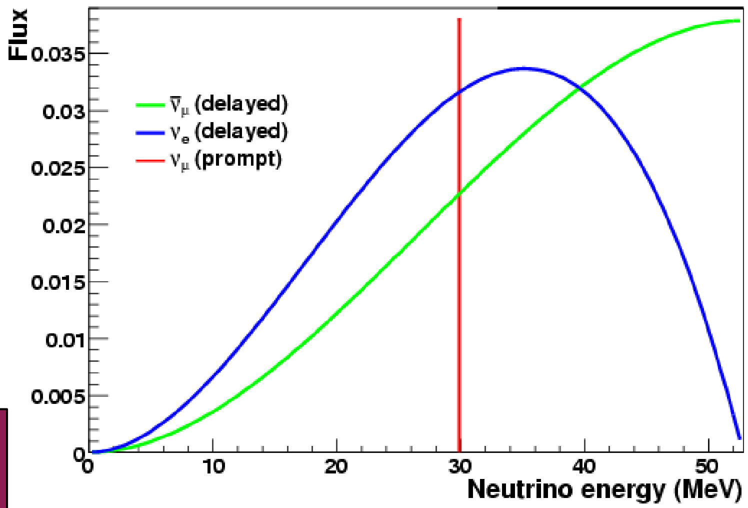



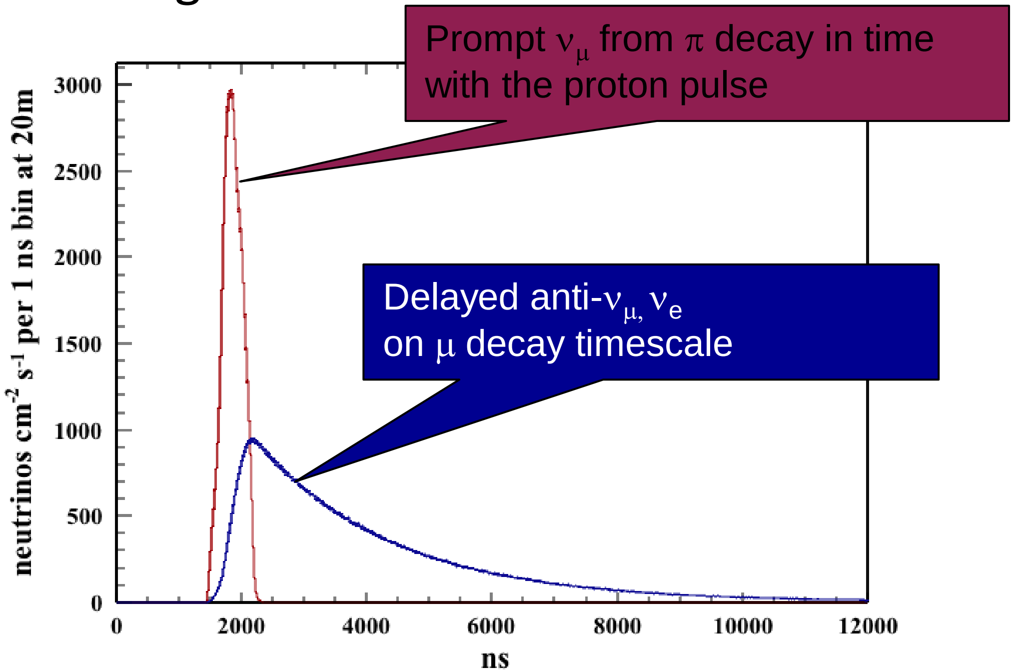

Proton beam energy: 0.9-1.3 GeV
Total power: 0.9-1.4 MW
Pulse duration: 380 ns FWHM
Repetition rate: 60 Hz
Liquid mercury target

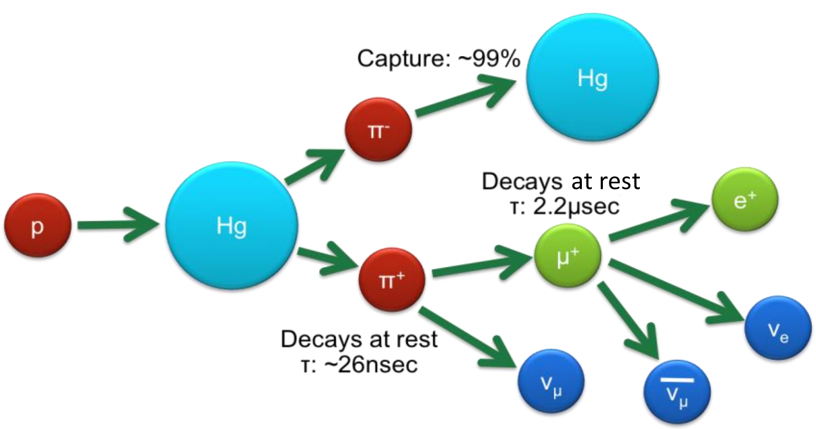
# Spallation "Neutrino" Source

- Spallation creates pions and muons that decay at rest to create two different flavors of neutrinos

- Can reject steady-state backgrounds due to 60 Hz

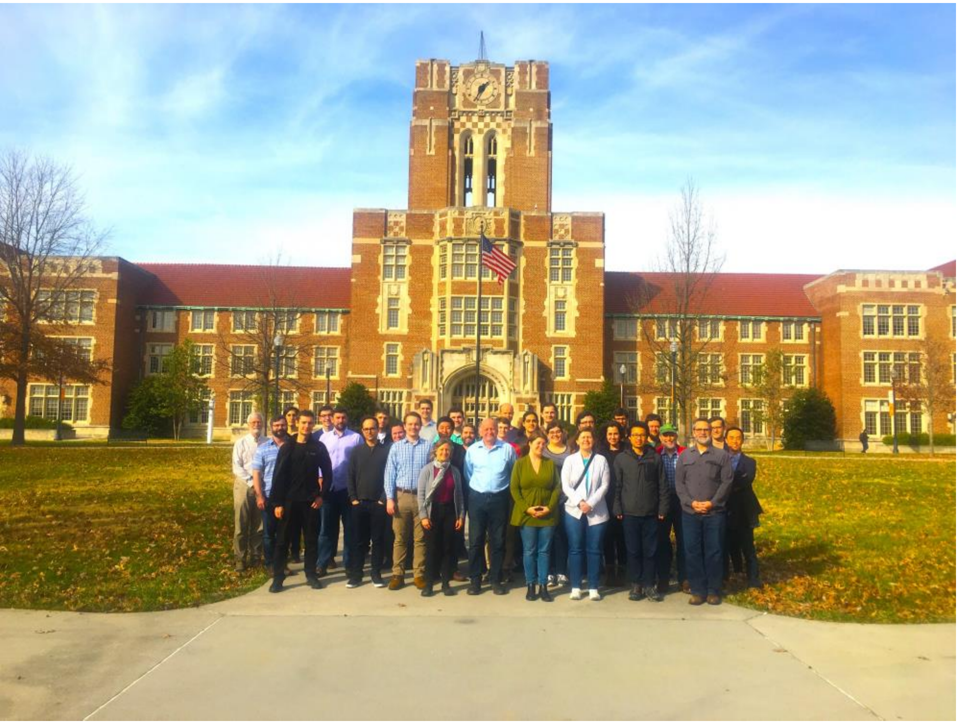


# COHERENT Collaboration

[http://coherent.ornl.gov/](http://coherent.ornl.gov/)



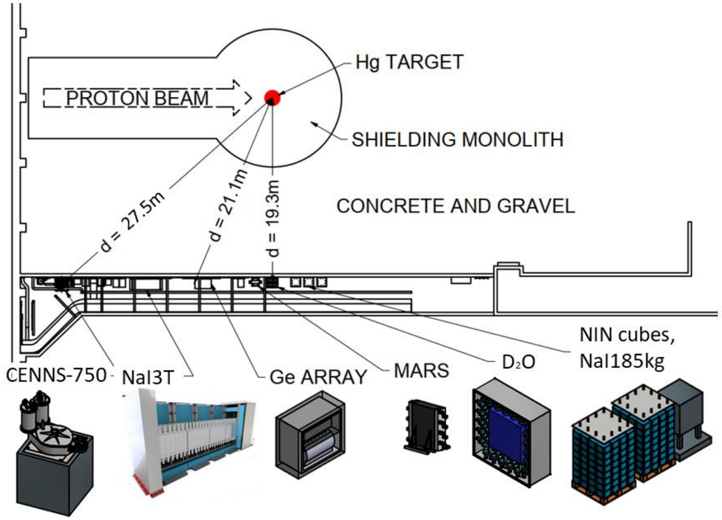
COHERENT
SNS
SPALLATION NEUTRON SOURCE

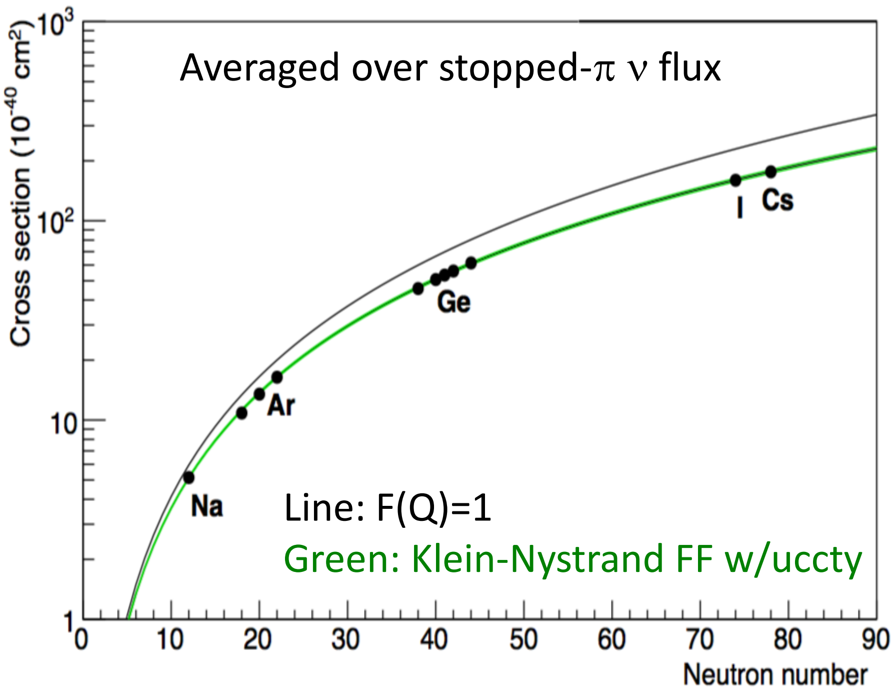
Carnegie Mellon University
Duke University
UF UNIVERSITY of FLORIDA
서울대학교 SEOUL NATIONAL UNIVERSITY
Laurentian University Université Laurentienne
VIRGINIA TECH
Los Alamos NATIONAL LABORATORY EST. 1943
MEPhI
NC Central UNIVERSITY
NC STATE UNIVERSITY
Tufts UNIVERSITY
OAK RIDGE National Laboratory
Sandia National Laboratories
THE UNIVERSITY of TENNESSEE KNOXVILLE
TUNL Triangle Universities Nuclear Laboratory
UNIVERSITY of WASHINGTON
UNIVERSITY OF SOUTH DAKOTA

U.S. DEPARTMENT OF ENERGY
Office of Science
NSF
CONSORTIUM FOR MONITORING TECHNOLOGY AND VERIFICATION
NNSA National Nuclear Security Administration
CNEC

# COHERENT at the Spallation Neutron Source

- In neutron quiet neutrino alley
- Multi-target CEvNS measurement program to map out $\sim N^2$ dependence of cross section
- Current and planned detectors shown below

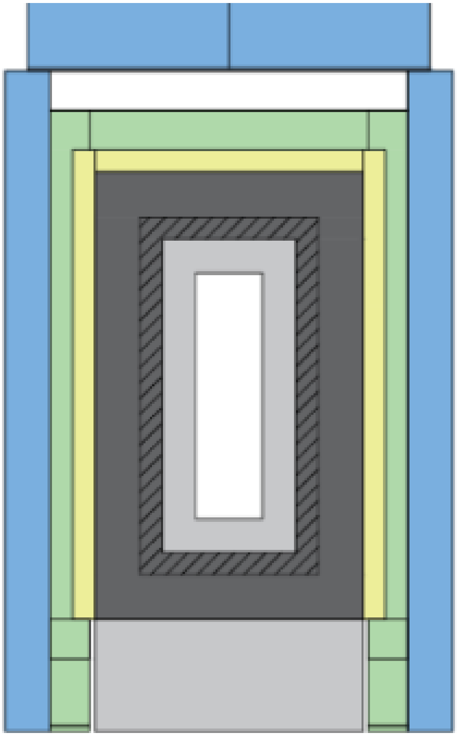


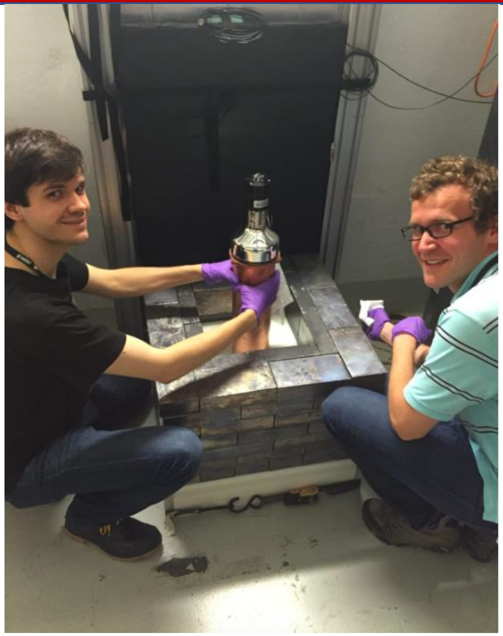




CsI: *Science* 357 (2017) 6356, 1123-1126

LAr: *Phys. Rev. Lett* 126, (2021) 012002

# CsI Detector





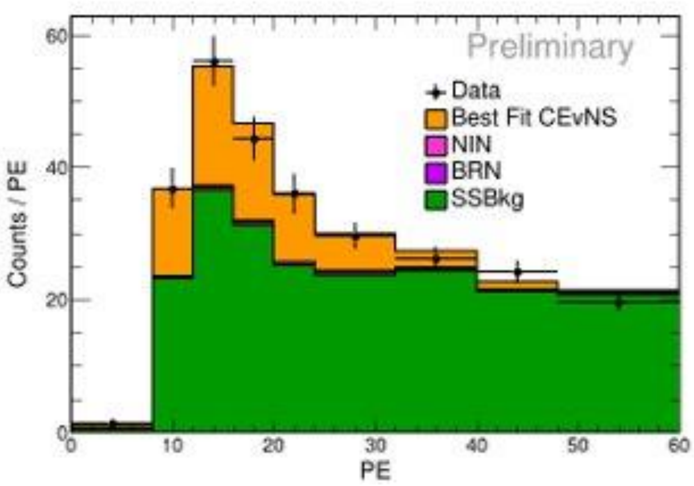
A hand-held detector!

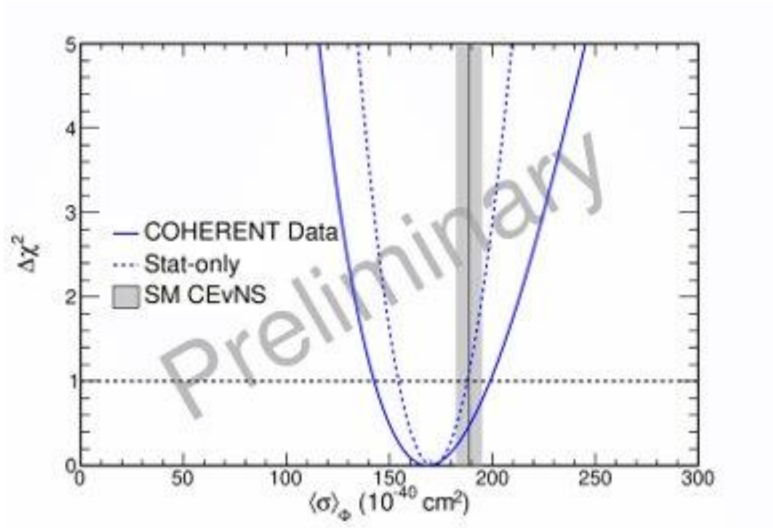
Almost wrapped up...

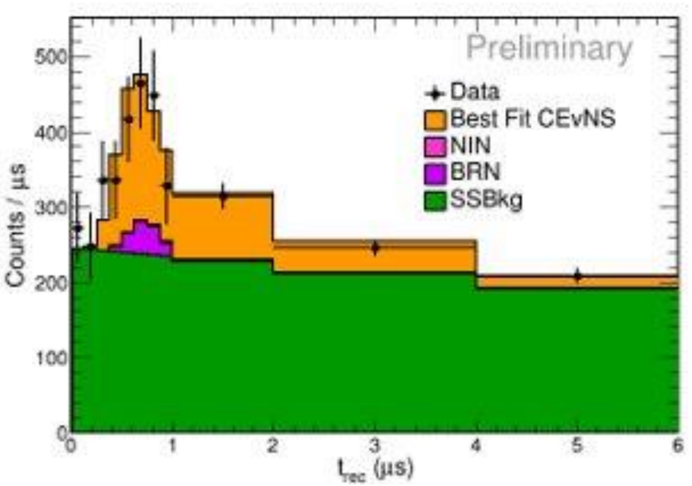
| Layer | HDPE* | Low backg. lead | Lead | Muon veto | Water |
|---|---|---|---|---|---|
| Thickness | 3" | 2" | 4" | 2" | 4" |
| Colour | | | | | |

# CsI Measurement Results

- First part of data set used for first light detection
- Shown are preliminary results for full data set
  - Reject null to 11.6σ
  - Within 1σ of standard model prediction



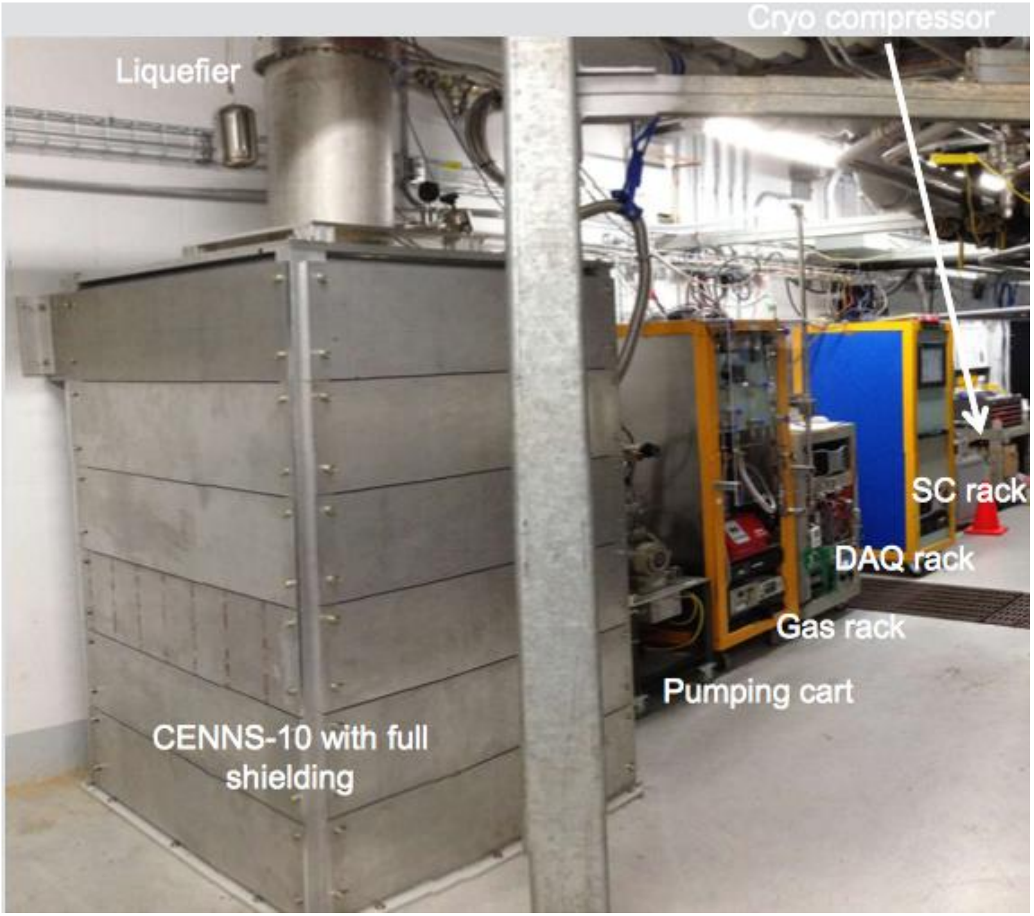



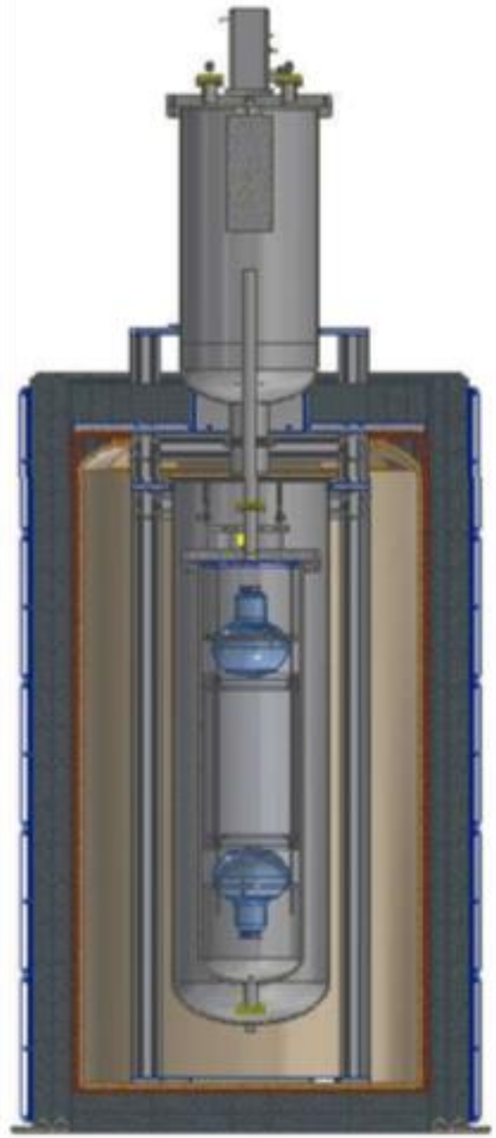




D. Pershey JETP Seminar Dec 11, 2020

# LAr Detector

- Single-phase liquid argon detector
  - 24 kg fiducial volume

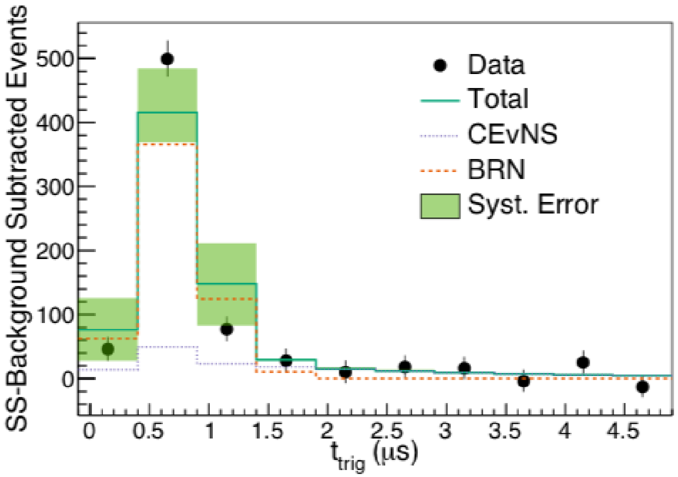


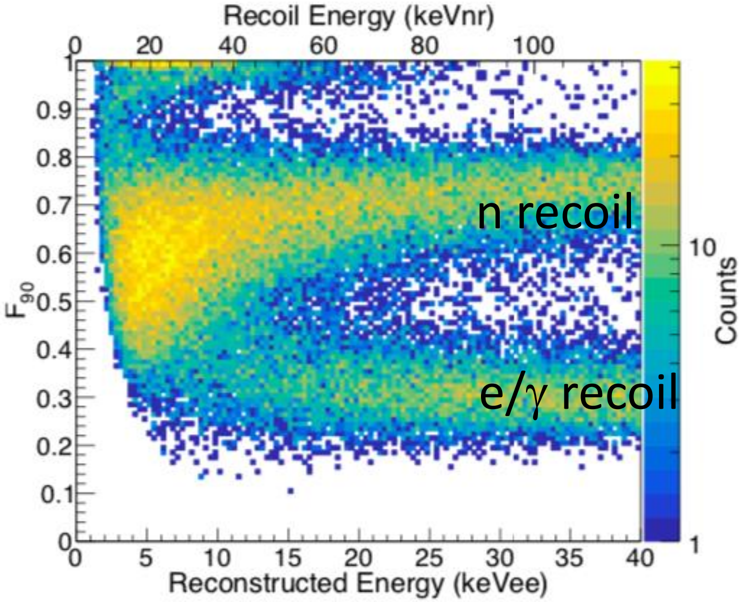



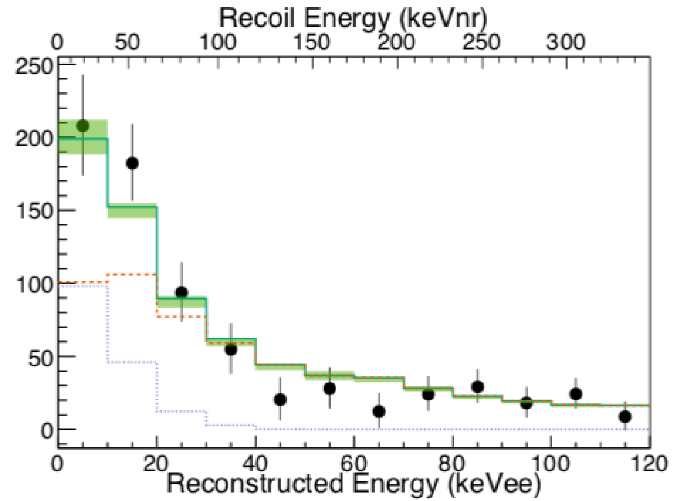
- Shielding
  - 20 cm of water
  - 1.25 cm of copper
  - 10 cm of lead

# LAr First Light Results

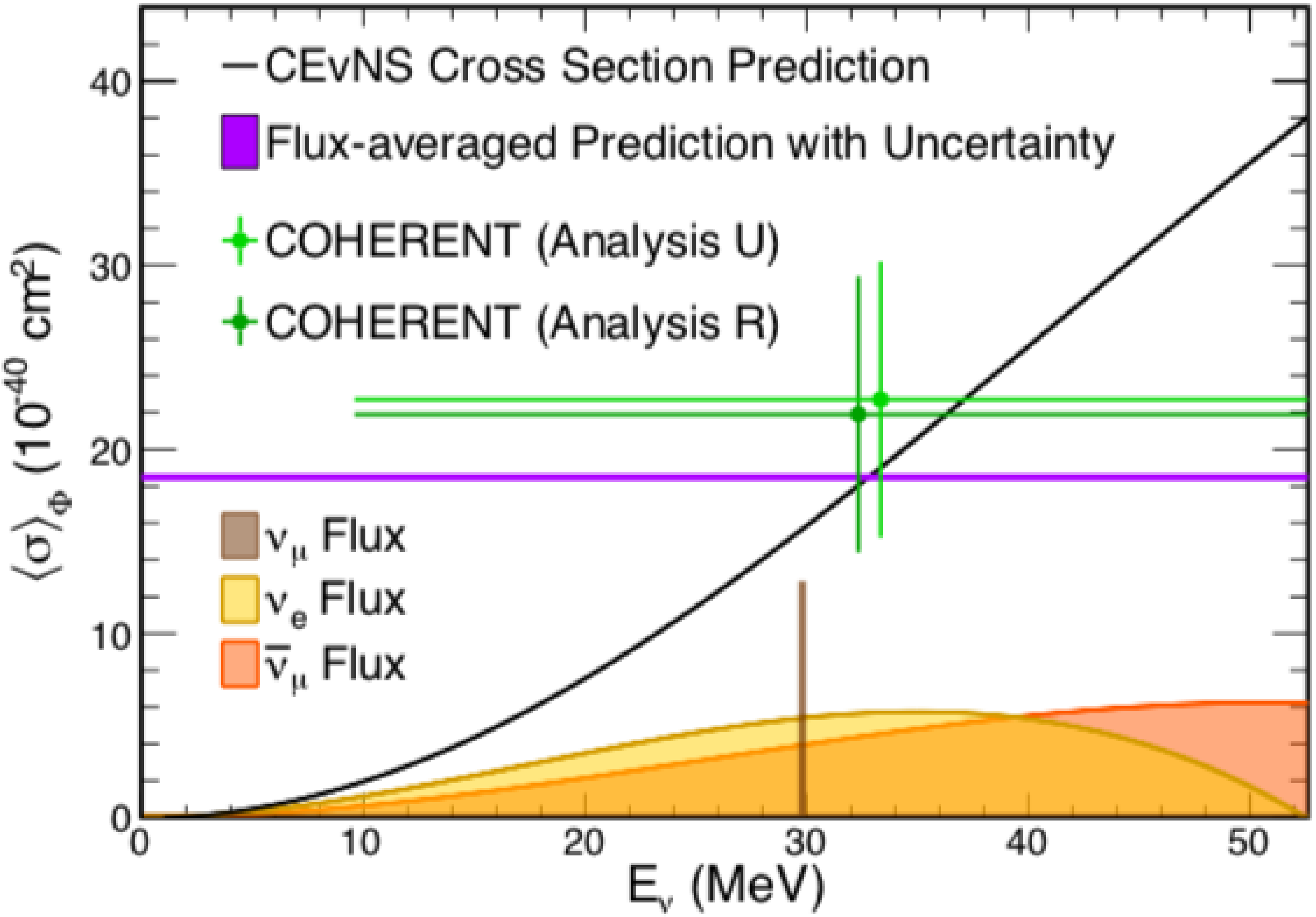
- Apply timing cuts, energy cuts, and pulse shape discrimination cuts to raw data
  - A and B have slightly different cuts for data
- Reject null hypothesis at 3σ



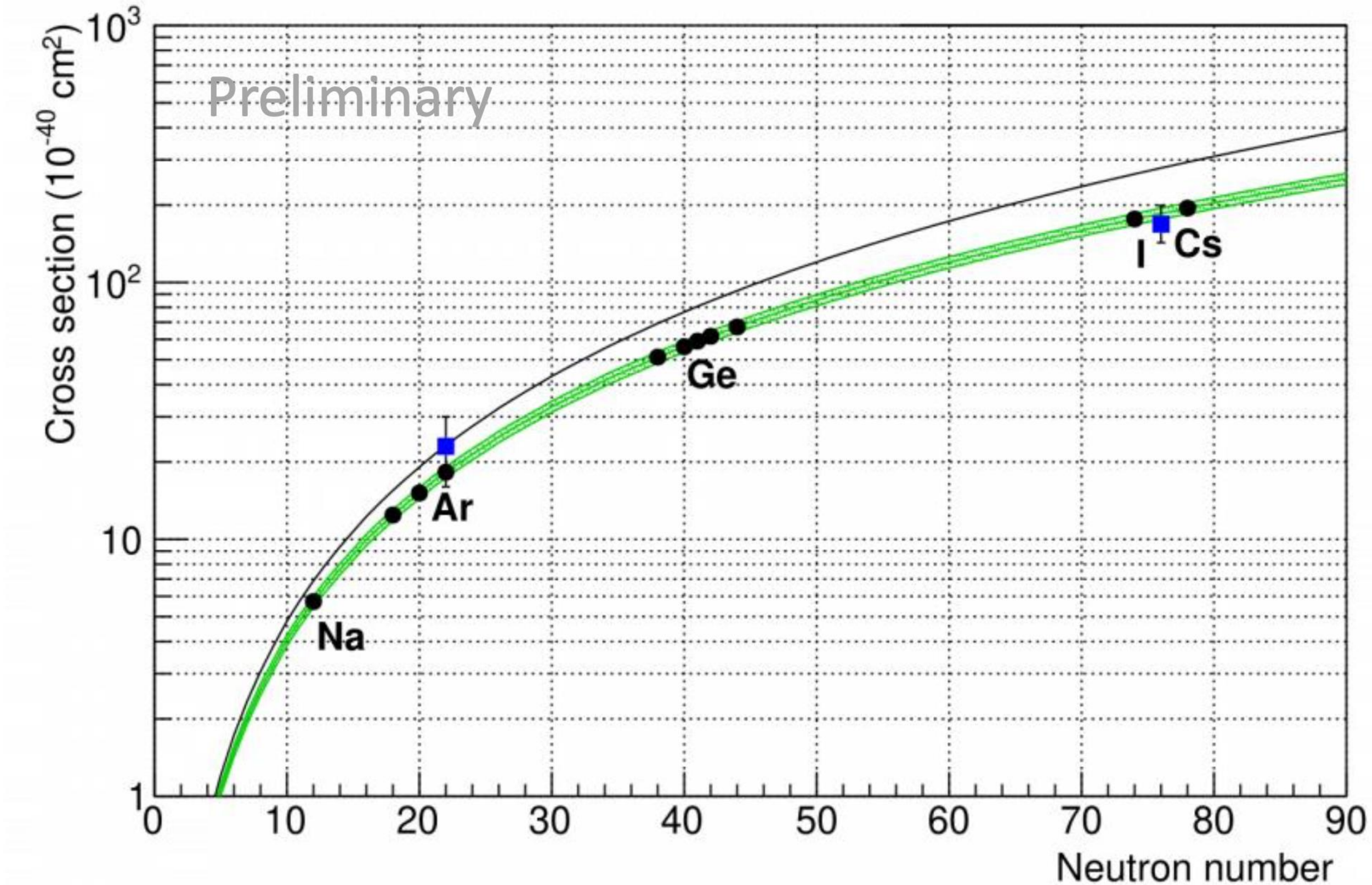



# LAr First Light Results



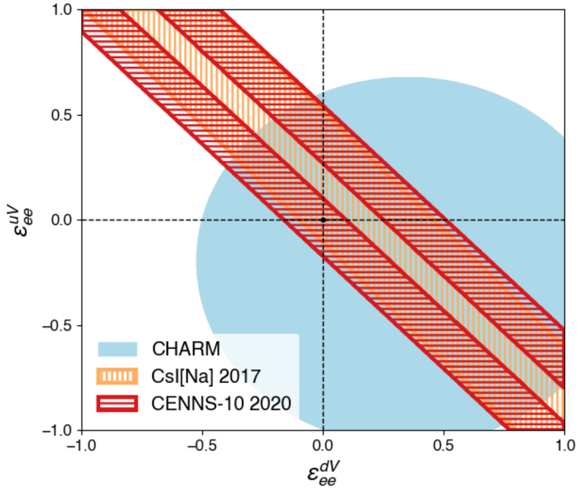
# Flux as a Function of Neutron Number

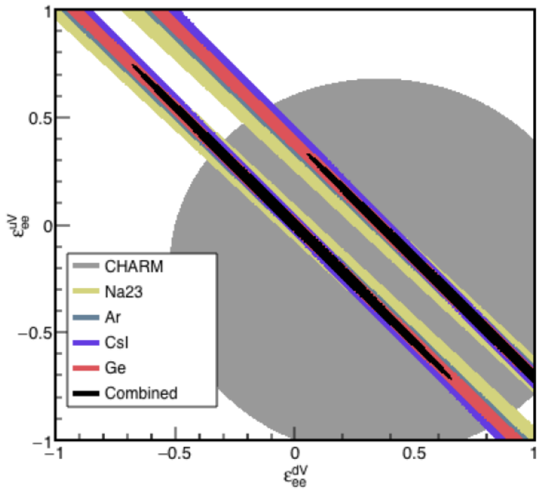


# Non-Standard Interactions

- Multiple targets constrain parameter space of new physics
- Shown are current published constraints
- Will use D2O detector to measure neutrino flux and reduce current 10% uncertainty

  arXiv:2104.09605
- To do a precision measurement beyond a first detection, a larger detector is needed



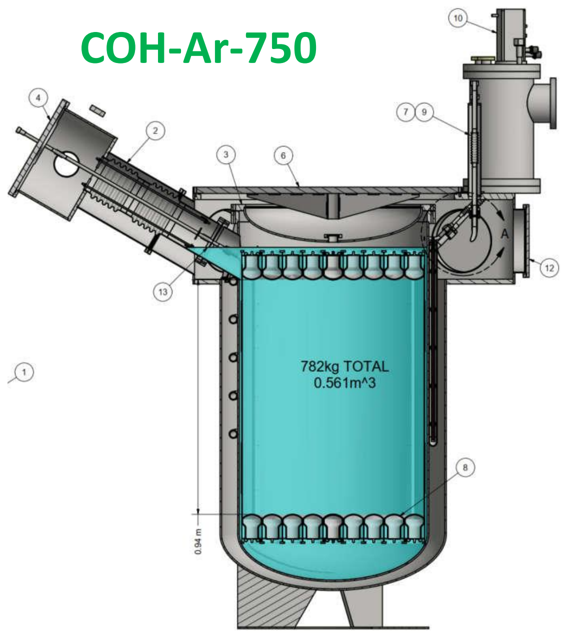



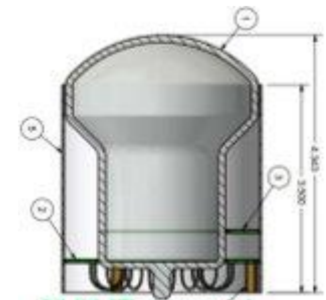

arXiv:1803.09183

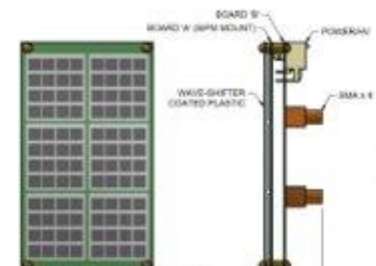
# Next Generation Single-phase Argon Detector

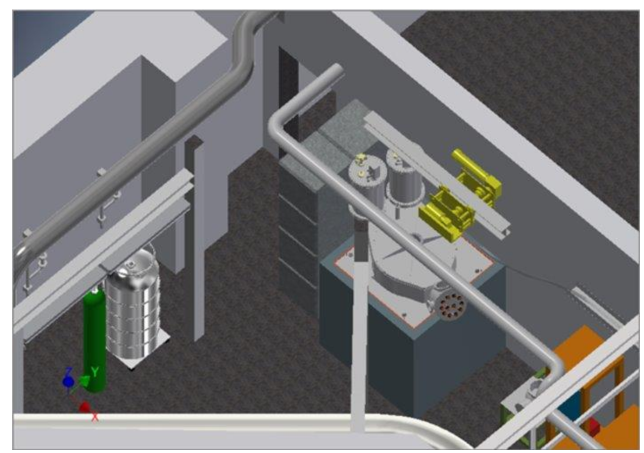
- Single-phase liquid argon calorimeter
- 610 kg fiducial mass
- Designed to hit 20 keVnr threshold or below
- Designed to fit in current LAr detector location
- R & D and simulations underway
- Use current detector as a test bench

COH-Ar-750



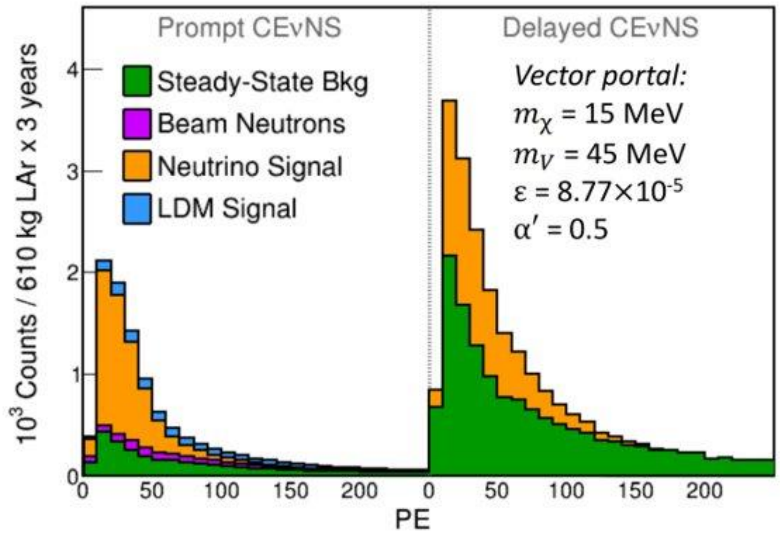


3" PMT assembly


SiPM assembly

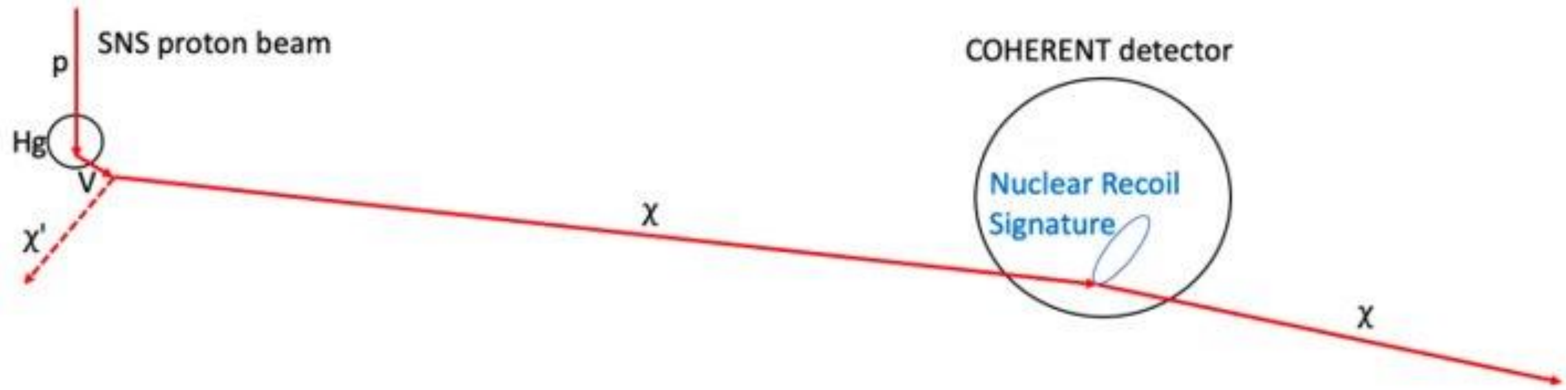


# Sensitivity to Dark Matter

- Vector portal dark matter could be produced by pions in SNS
- Could detect nuclear recoils
- Need great understanding of backgrounds




D. Akimov *et al.*
Phys. Rev. D **102**, 052007



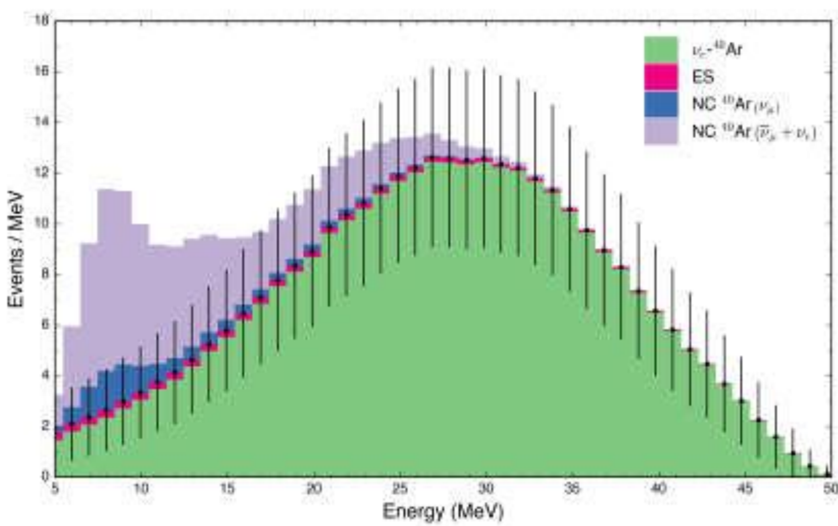
# Summary

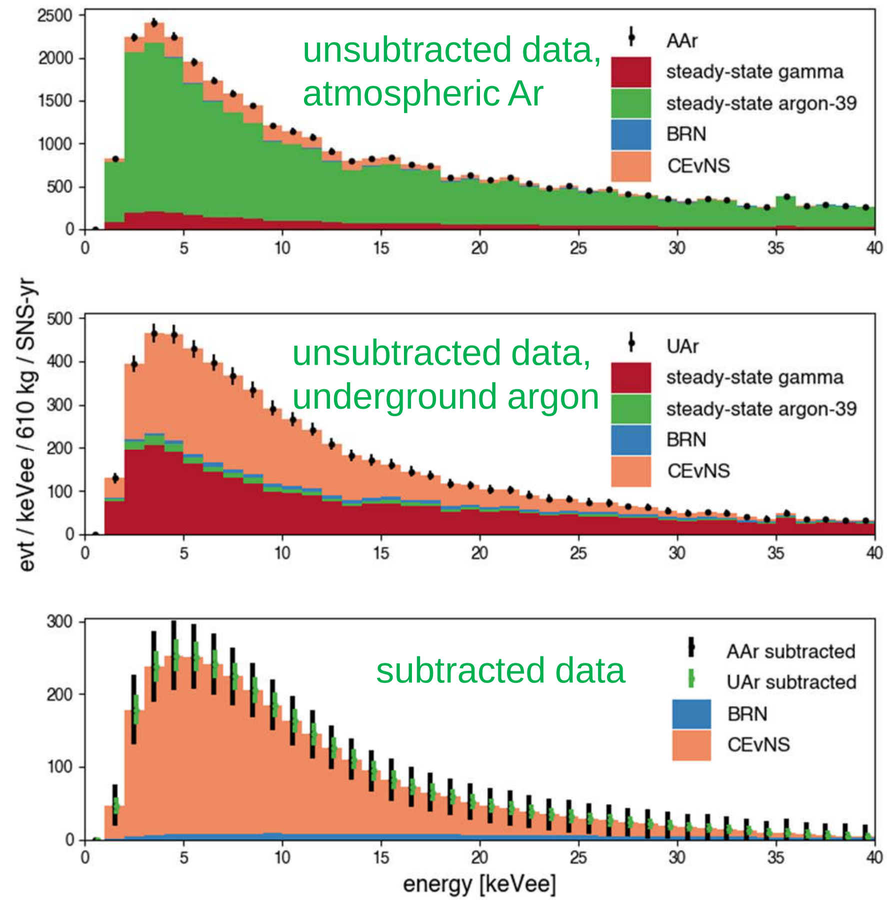
- CEvNS is a well described process that gives a window to interesting physics
- Due to the low recoil energies, a specific set of conditions is needed to measure CEvNS
- Neutrino alley at the Spallation Neutron Source has these conditions
- The COHERENT collaboration has made the first measurement of CEvNS
- Plan to continue mapping out $n^2$ depedence with different detector materials
- Plan on doing precision measurements with larger detectors

# Backups

# Precision Physics with COH-Ar-750

- About 3000 CEvNS events/SNS year
    - 20x rate of current LAr detector
- About 400 inelastic charge current/neutral current events/SNS year




arXiv:1901.10108

# Conclusions and Outlook

- R&D on a tonne-scale liquid argon detector is ongoing and making progress, which could lead to 10 tonne-scale liquid argon detector at SNS second target station