Search for CEvNS at the SNS with the COHERENT experiment

Ivan Tolstukhin

(Indiana University)

For the COHERENT collaboration

Coherent Elastic Neutrino-Nucleus Scattering - CEvNS

- First predicted in 1974 by D. Freedman
- Neutrino scatters off via exchange a Z-boson (νA → νA)
  - Nucleus recoils as a whole
  - Coherent up to E_ν ~ 50 MeV

PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

Coherent effects of a weak neutral current

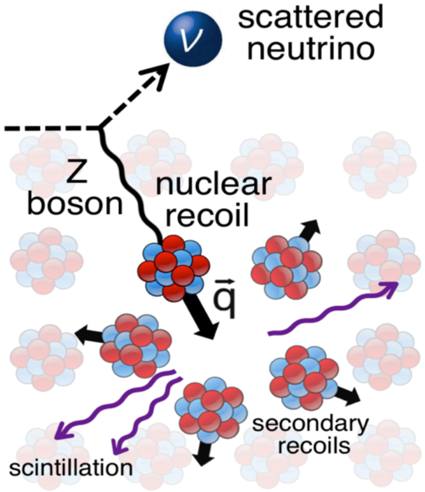
Daniel Z. Freedman†
National Accelerator Laboratory, Batavia, Illinois 60510
and Institute for Theoretical Physics, State University of New York, Stony Brook, New York 11790
(Received 15 October 1973; revised manuscript received 19 November 1973)

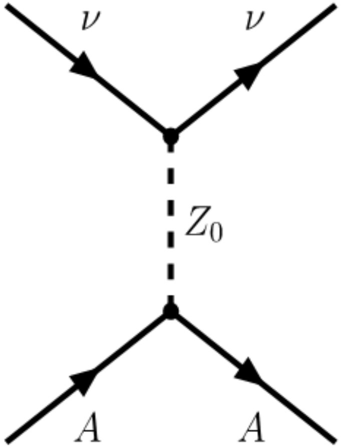
- Standard Model calculation
  - Dependence on neutron number

$$\frac{d\sigma}{dE} \propto N^2$$

- Experimental signature – nuclear recoil
  - Low energy signals

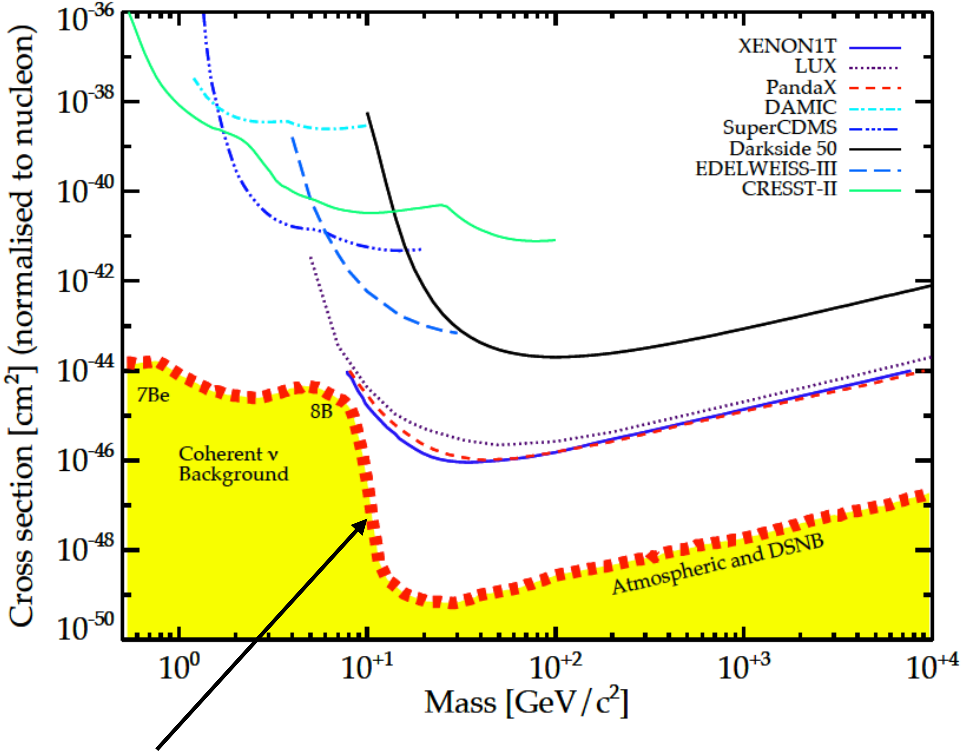
$$E_r^{\max} \simeq \frac{2E_\nu^2}{M} \simeq 50 \text{ keV}$$





Physics of CEvNS

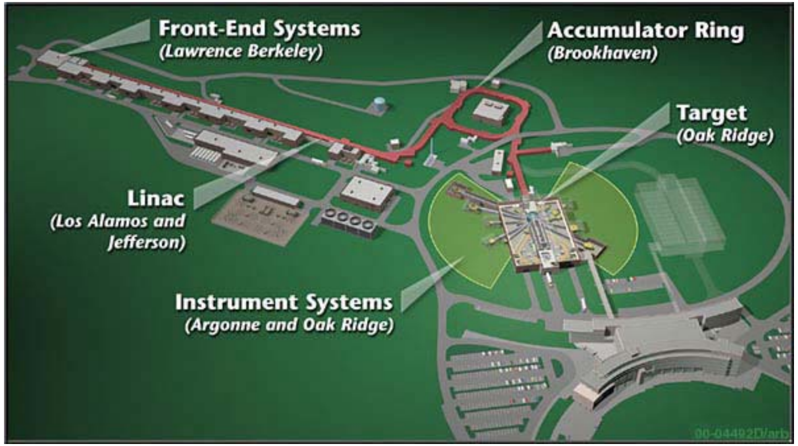
- Standard model tests
  - Proton weak charge ($\sin^2(\theta_W)$)
  - Non-standard interactions of neutrinos
  - Neutrino magnetic moment
- Supernova Neutrino detection channel
- Nuclear Form Factors
- Reactor Monitoring
- Dark Matter (DM)
  - CEvNS is important background for ton-scale direct searches



Coherent neutrino background

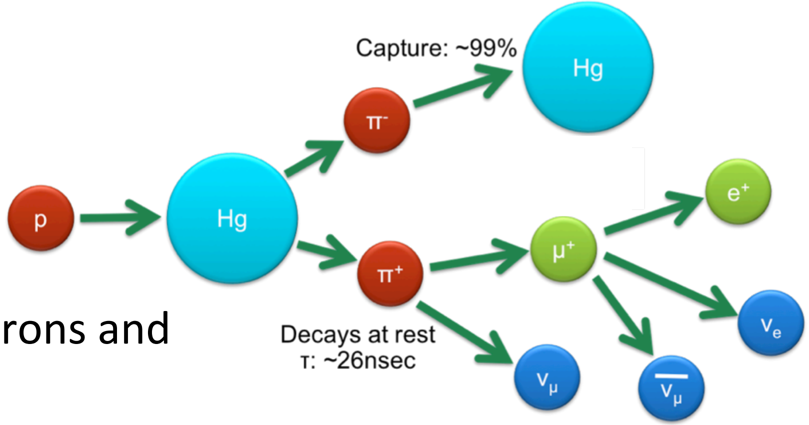
COHERENT program

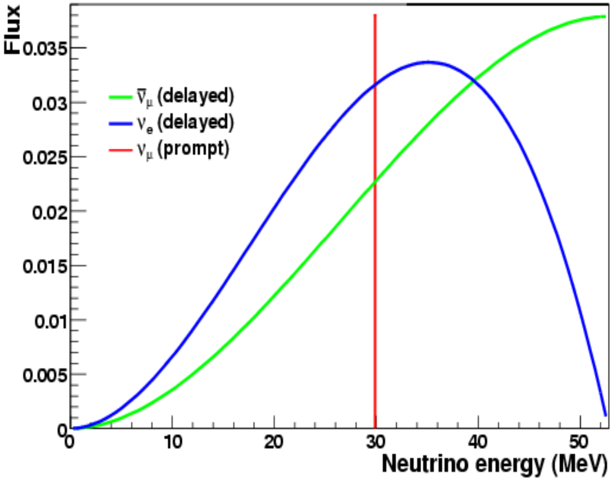
- Neutrino source
  - pulsed proton beam on a mercury target at the ORNL Spallation Neutron Source (SNS)
- Several detector subsystems for N^2 dependence
  - Low threshold detectors
- Well characterized and reduced background
  - Low energy neutrons in the detectors can produce similar recoil spectra as neutrino scattering signal



Spallation Neutron Source (SNS) at Oak Ridge

- Pulsed Proton Beam
  - ~1 MW power
  - 60 Hz, 600 ns spill
  - Pulsing allows natural background rejection for factor ~ 10^4
  - Proton collisions with mercury create neutrons and neutrinos (~ 10^7 $cm^{-2}s^{-1}$ per flavor).





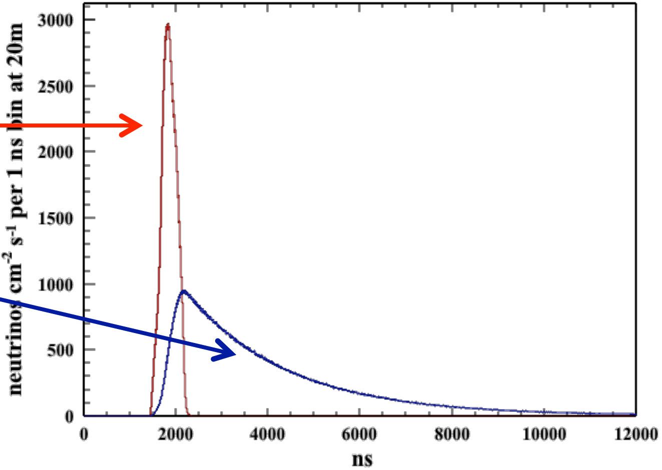
Prompt monochromatic
29.2 MeV

$$\pi^+ \longrightarrow \mu^+ + \upsilon_\mu$$

$$\downarrow$$

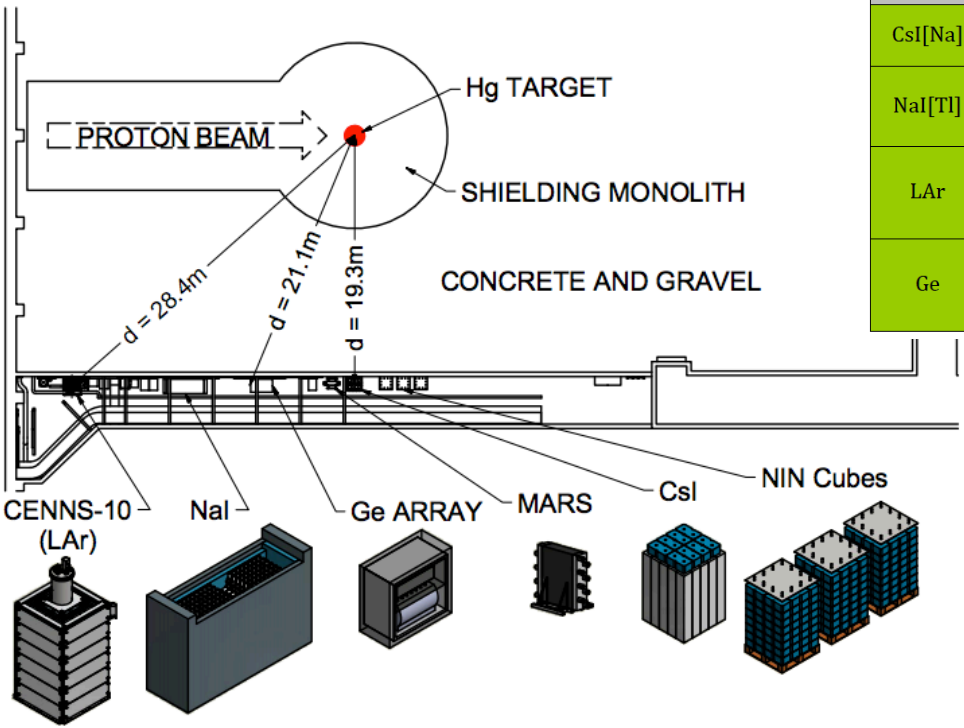
$$\mu^+ \longrightarrow e^+ + \bar{\upsilon}_\mu + \upsilon_e$$

$0 < E < m_\mu/2$
2.2 μs delayed



COHERENT Detectors

SNS “Neutrino-alley”

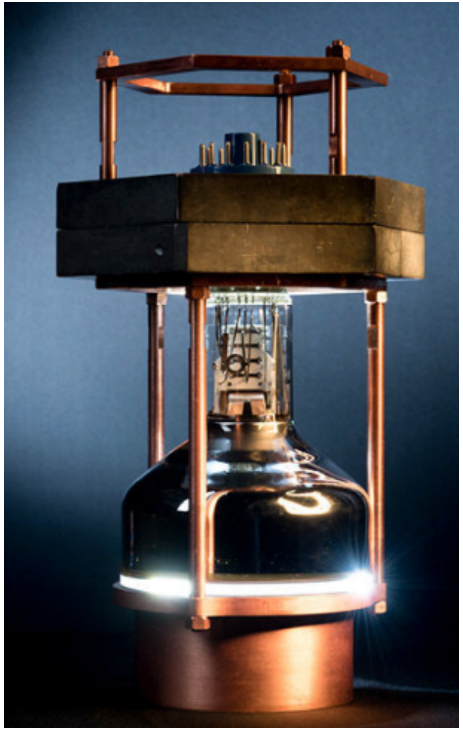


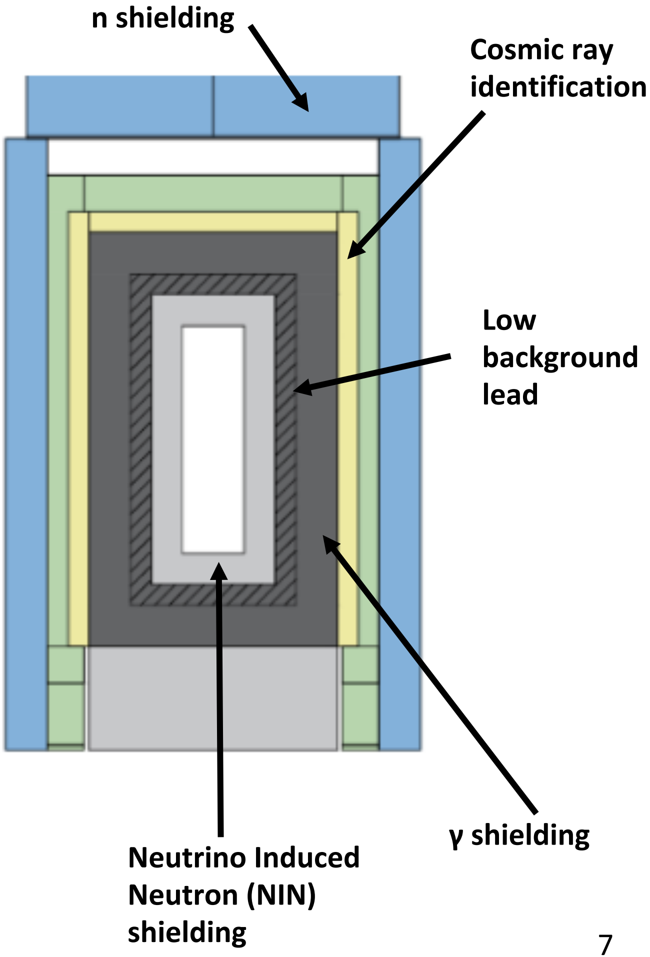
Nuclear Target	Technology	Mass (kg)	Distance from source (m)	Recoil threshold (keVr)	Start data-taking	Possible Future
CsI[Na]	Scintillating crystal	14.6	20	6.5	09/2015	Continue data-taking
NaI[Tl]	Scintillating crystal	185* /2000	28	13	*high-threshold deployment summer 2016	Expansion to 2 tonne
LAr	Single-phase	22	29	20	12/2016, Upgraded 07/2017	Expansion to ~ 1 tonne scale
Ge	HPGe PPC	10	22	5	2018	Ge expansion w/ lower threshold

- COHERENT non-CEvNS detectors
  - Neutron background
    - Sandia Neutron Scatter Camera (deployed 2014-2016)
    - SciBath (deployed 2015)
    - MARS (deployed 2017 – now)
  - Neutrino induced neutron
    - Lead Nube (see G08.08 talk)
    - Iron Nube

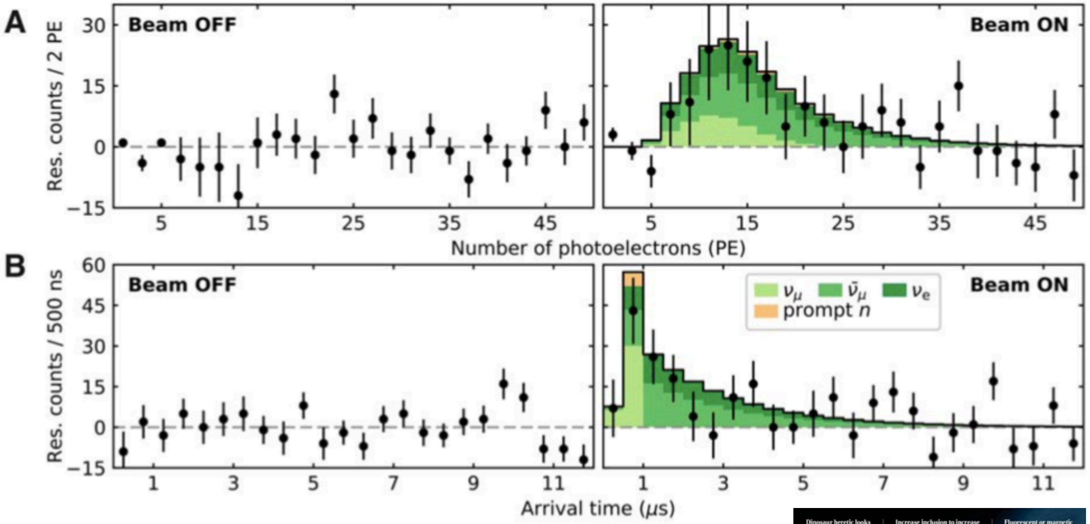
Detector Subsystem - CsI

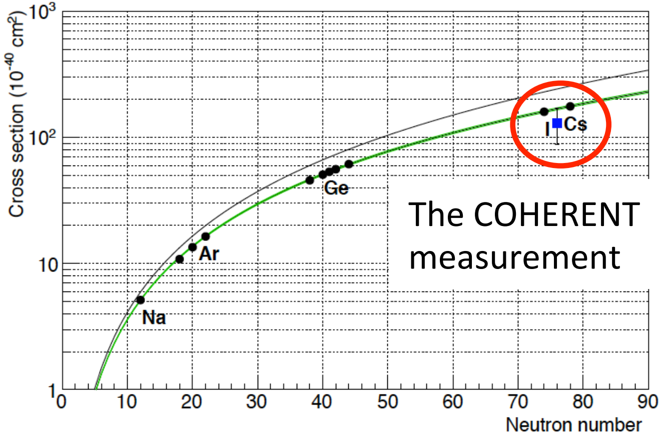
- Installed in summer 2015 in the SNS “neutrino-alley”
- 14.6 kg sodium doped CsI inorganic crystal
- High light yield
- Low intrinsic background
- Room temperature operation





First CEvNS observation





- 134 ± 22 observed events
- Standard model prediction 173 ± 48 events
- No CEvNS rejected at 6.7σ
- Consistent with SM within 1σ

- new constraints on NSIs (see D08.04)

Observation of coherent elastic neutrino-nucleus scattering

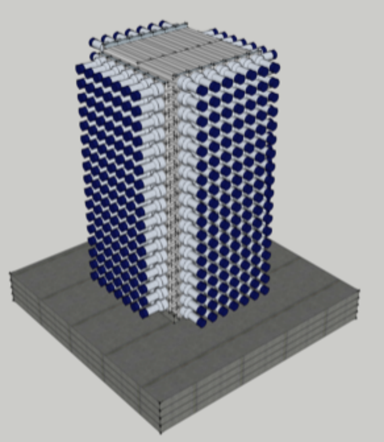
D. Akimov[1,2], J. B. Albert[3], P. An[4], C. Awe[4,5], P. S. Barbeau[4,5], B. Becker[6], V. Belov[1,2], A. Brown[4,7], A. Bolozdy...
+ See all authors and affiliations

Science 03 Aug 2017:
eaao0990
DOI: 10.1126/science.aao0990

Peer Reviewed

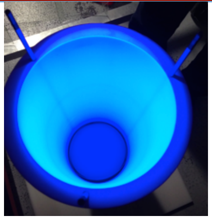
NaI(Tl) for COHERENT

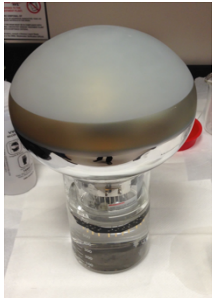
- Thallium doped sodium iodide scintillating inorganic crystal
  - Scintillation process very similar to CsI scintillation
- Currently 185 kg total
  - 24 7.7 kg detectors
- Currently not sensitive to CEvNS
  - Being used for a different neutrino measurement
    - Charged current interaction on ^{127}I
  - Background characterization for ton-scale upgrade

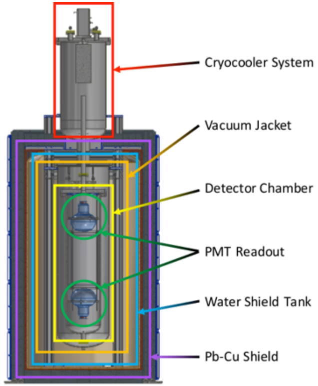


LAr for COHERENT

- CENNS-10 detector
- 2x Hamamatsu R5912-MOD02 PMTs
- Wavelength shifter tetraphenyl butadiene (TPB) coated Teflon side walls
- ~ 22 kg fiducial volume
- 20 keVnr energy threshold
- Installed at SNS late 2016
- Upgraded in June 2017 to improve light collection capabilities
- More details – D08.02 talk



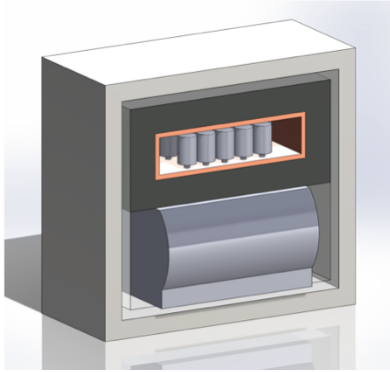


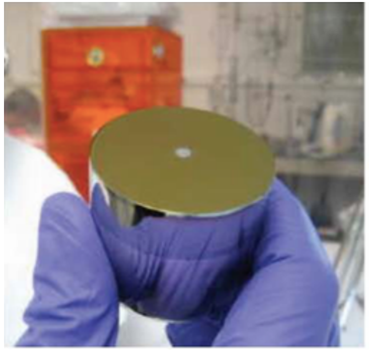


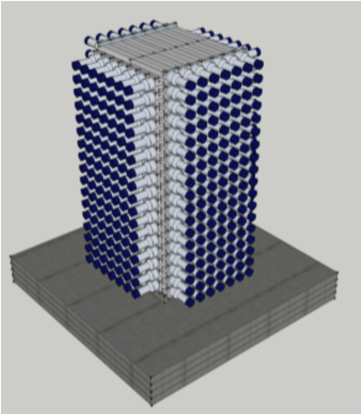
- Full shielding since August 2017
  - Lead 4’’
  - Copper 0.5’’
  - Water 9’’

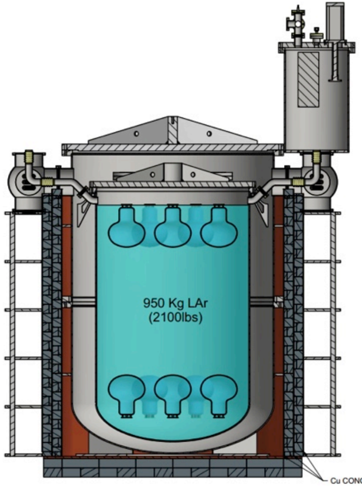
Future COHERENT

- Improved background studies
- 10 kg Ge, w/ future upgrade to state-of-the-art tech → study e.m. properties
  - See G08.05 talk
- NaI: 2-ton CEvNS sensitive upgrade → have multiple tons in hand and available for a multi-ton deployment
- Further neutrino induced neutron studies
- LAr: expansion to ~ 1 tonne scale
- Several prospects for additional target nuclei

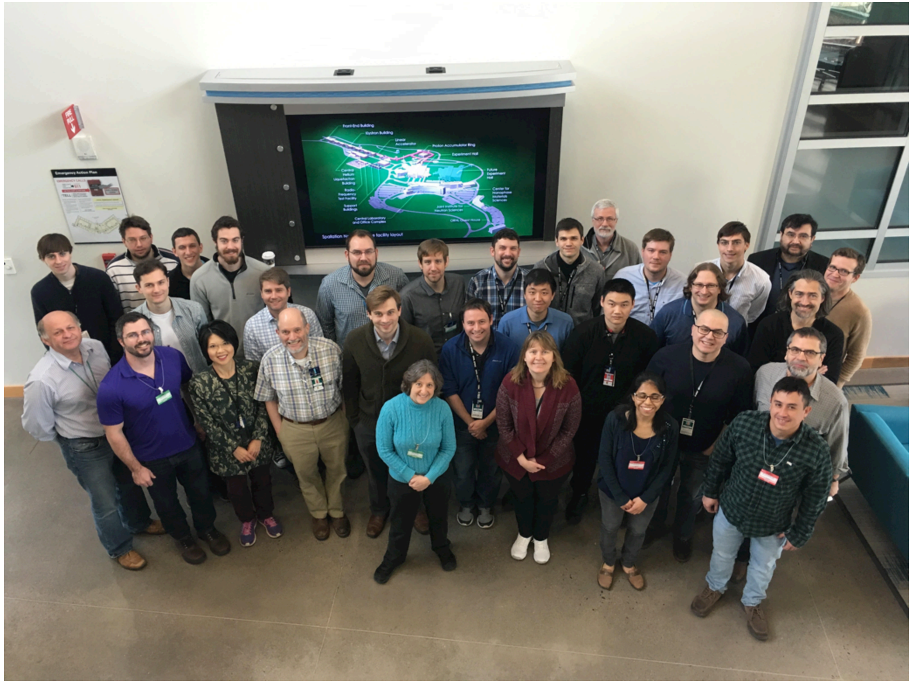








COHERENT collaboration



~80 members, 18 institutions 4 countries

Summary

- Search for CEvNS at SNS and measure the coherent neutrino-nucleus cross section in multiple nuclei
- SNS is a great source for a CEvNS measurement due to pulsed beam and beam power
- First CEvNS observation in CsI (August 2017) made by COHERENT collaboration
- Multiple target material detectors (NaI, LAr, Ge) taking data and under development to show N^2 dependence. Other target materials under consideration for feasibility.
- Working towards ton-scale detectors to increase sensitivity

Backup

Neutron Background

- 100 keV – 1 MeV neutrons can produce similar signal
- Neuron flux measured at different positions with multiple detector technologies:
  - Sandia Scatter Camera – multiplane liquid scintillator
  - SciBath - WLS fiber + liquid scintillator
- Low neutron background in the SNS basement
- Prompt neutron flux ~10^{-7} neutrons/cm^2/s
- Expected rates in detector below CEvNS signal