Neutrino Alley, COHERENT Overview

Jason Newby,

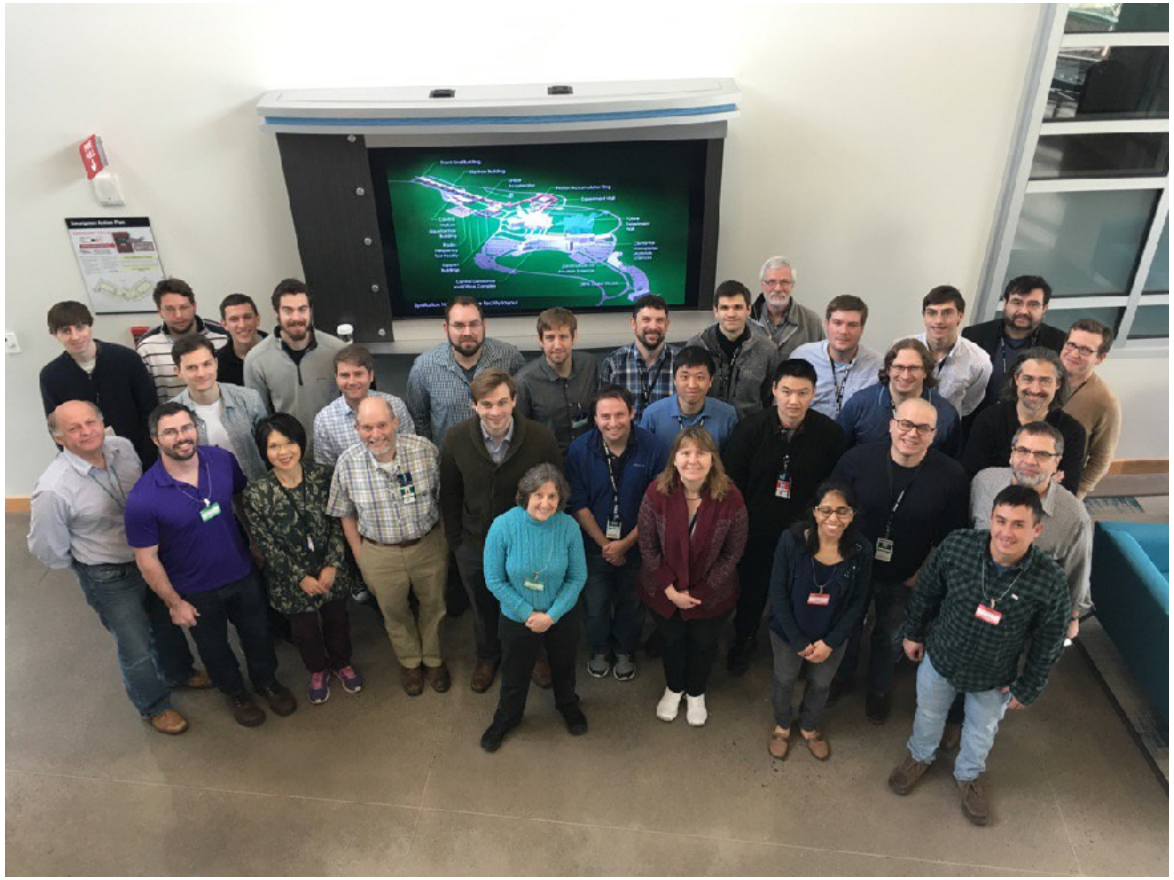
For the COHERENT Collaboration

First Workshop on Fundamental Physics at the Second Target Station

July 26, 2019

Spallation Neutron Source

COHERENT Collaboration



https://coherent.ornl.gov arXiv:1803.09183v2

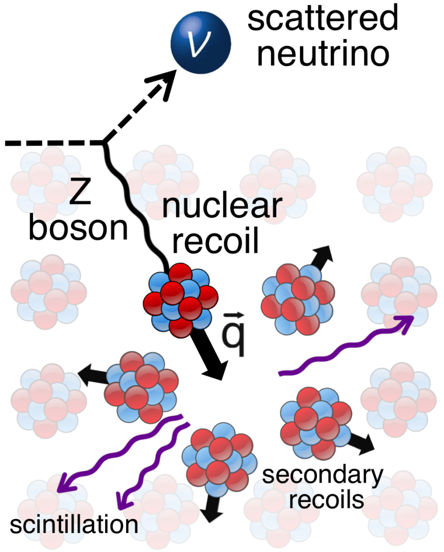
COHERENT
SNS
SPALLATION NEUTRON SOURCE

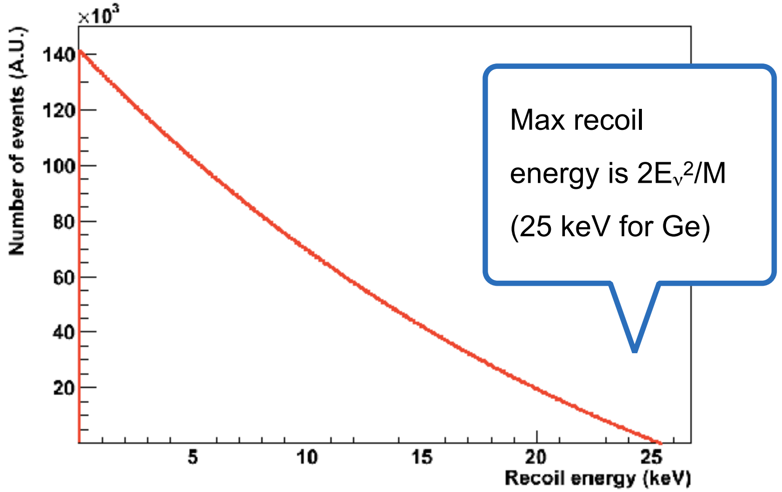
Oak Ridge National Laboratory
Duke University
TUNL
Sandia National Laboratories
The University of Tennessee Knoxville
Los Alamos National Laboratory Est. 1943
NC State University
University of Washington
The University of Chicago
NM State
MEPhI
UF University of Florida The Foundation for The Gator Nation
KAIST
North Carolina Central University Founded 1910
Tufts University
Carnegie Mellon University
Laurentian University Université Laurentienne

CNEC Consortium for Nonproliferation Enabling Capabilities
KICP
NNSA National Nuclear Security Administration
NSF
U.S. Department of Energy

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





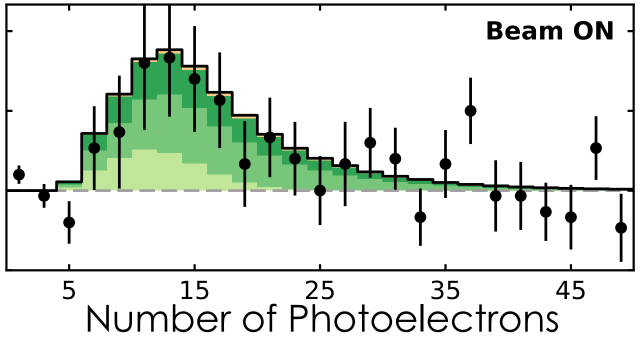
CEvNS cross section is well calculable in the Standard Model

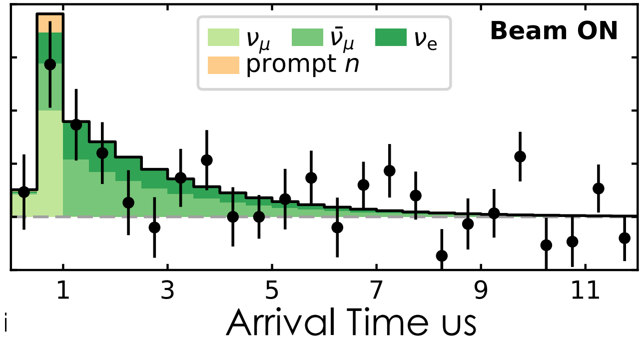
$$\frac{d\sigma}{d\Omega} = \frac{G^2}{4\pi^2} k^2 (1+\cos\theta) \frac{(N-(1-4\sin^2\theta_W)Z)^2}{4} F^2(Q^2)$$

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

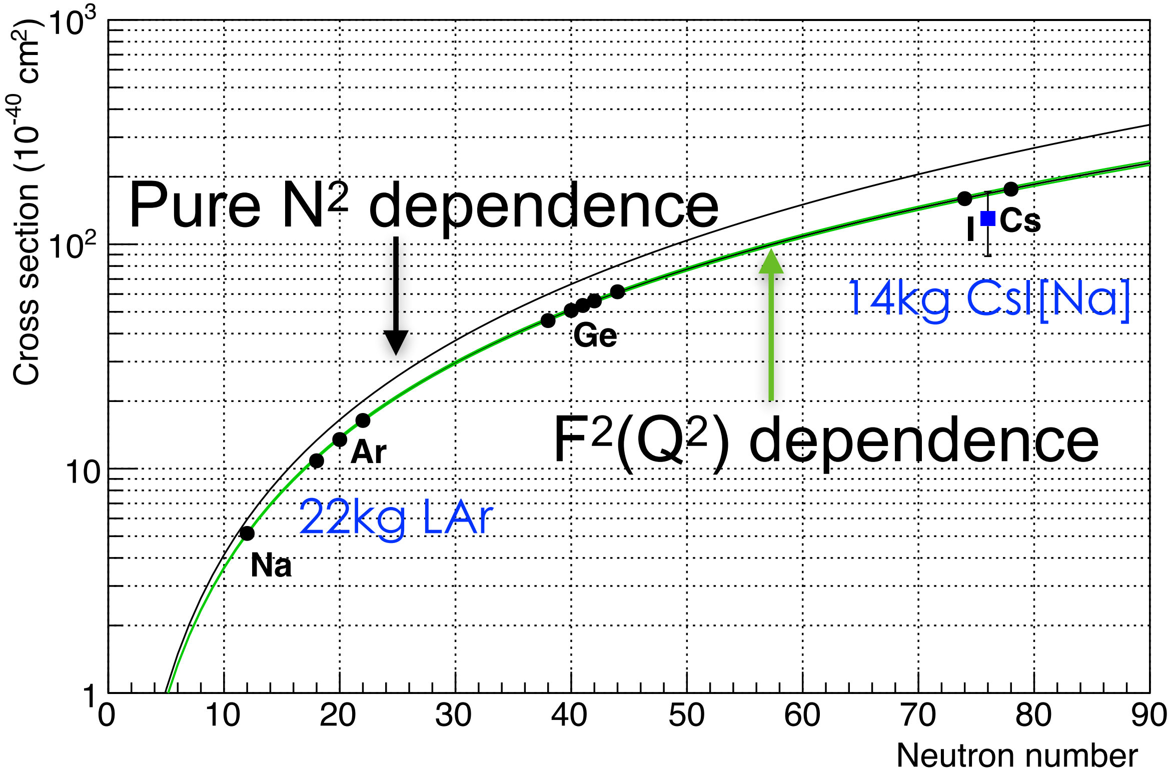
- Predicted in 1974 by D. Freedman
- Interesting test of the standard model
  - Sensitive to **non-standard interactions**
  - Largest cross section in **supernovae** dynamics
  - Background for future **dark matter** experiments
  - Sensitive to nuclear physics, **neutron skin**
- Difficult to observe
  - Need a low threshold detector
  - Need an intense neutrino source

First Observation of CEvNS





Akimov et al. *Science*
Vol 357, Issue 6356
15 September 2017



First light detectors deployed to measure neutron-squared dependence. (Na, Ge in 2019)

High precision measurements enable the full potential of CEvNS scientific impact.

Immediate Scientific Impact

PHYSICAL REVIEW D 96, 115007 (2017)

COHERENT enlightenment of the neutrino dark side

Pilar Coloma,[1,*] M. C. Gonzalez-Garcia,[2,3,4,†] Michele Maltoni,[5,‡] and Thomas Schwetz[6,§]

Contents lists available at ScienceDirect
Physics Letters B
www.elsevier.com/locate/physletb

COHERENT constraints on nonstandard neutrino interactions

Jiajun Liao *, Danny Marfatia

PHYSICAL REVIEW LETTERS 120, 072501 (2018)

Average CsI Neutron Density Distribution from COHERENT Data

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PHYSICAL REVIEW D 97, 033003 (2018)

COHERENT constraints to conventional and exotic neutrino physics

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(Received 4 December 2017; published 15 February 2018)

PROCEEDINGS OF SCIENCE

Constraints on nonstandard neutrino interactions from the COHERENT experiment

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JHEP
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Accepted: June 29, 2018
Published: July 5, 2018

Testing large non-standard neutrino interactions with arbitrary mediator mass after COHERENT data

Peter B. Denton,[a] Yasaman Farzan[b] and Ian M. Shoemaker[c]

PHYSICAL REVIEW D 98, 075018 (2018)

COHERENT analysis of neutrino generalized interactions

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[2]*IFPA, Départment AGO, Université de Liège, Bât B5, Sart Tilman B-4000 Liège 1, Belgium*
[3]*AHEP Group, Instituto de Física Corpuscular, CSIC/Universitat de València, Calle Catedrático José Beltrán, 2 E-46980 Paterna, Spain*

Neutrino Charge Radii from COHERENT Elastic Neutrino-Nucleus Scattering

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A.I. Studenikin**
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(Dated: Monday 15/10/18, 00:27)

Reinterpreting the weak mixing angle from atomic parity violation in view of the Cs neutron rms radius measurement from COHERENT

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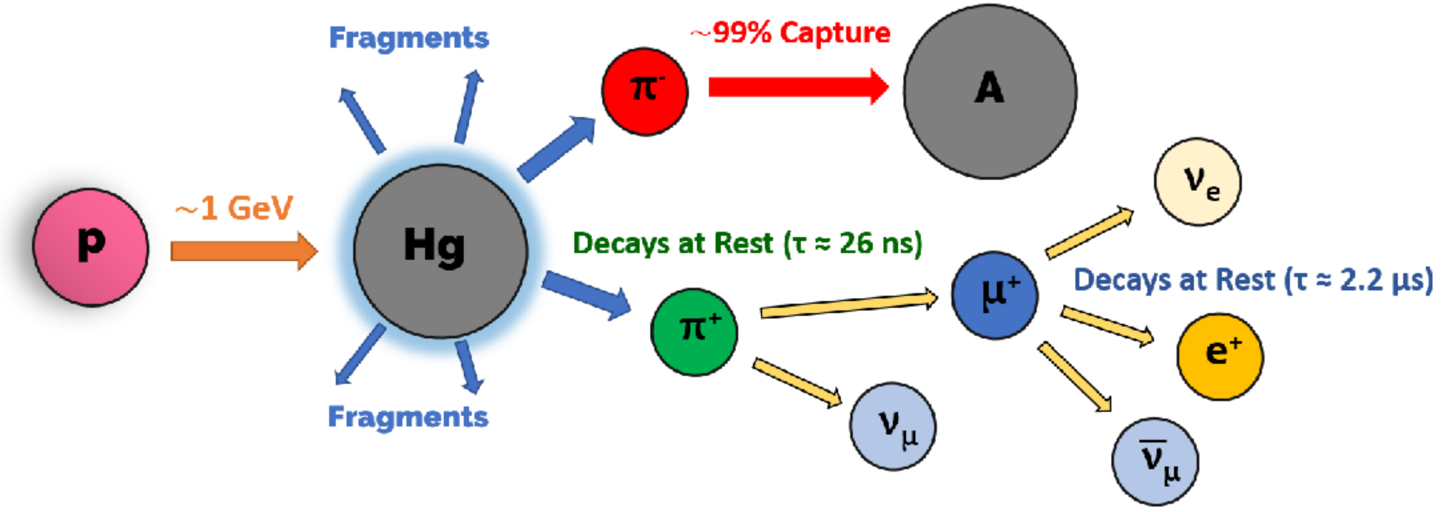
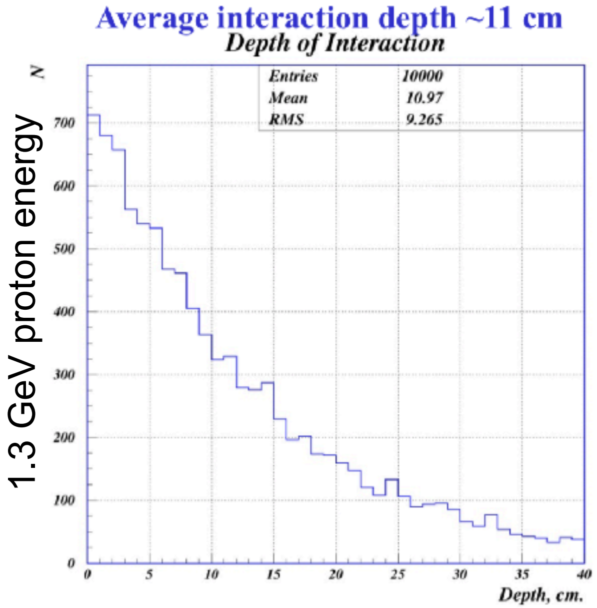
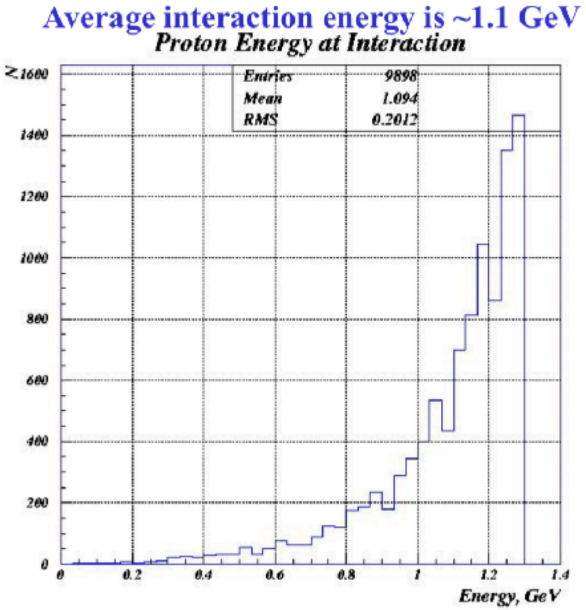
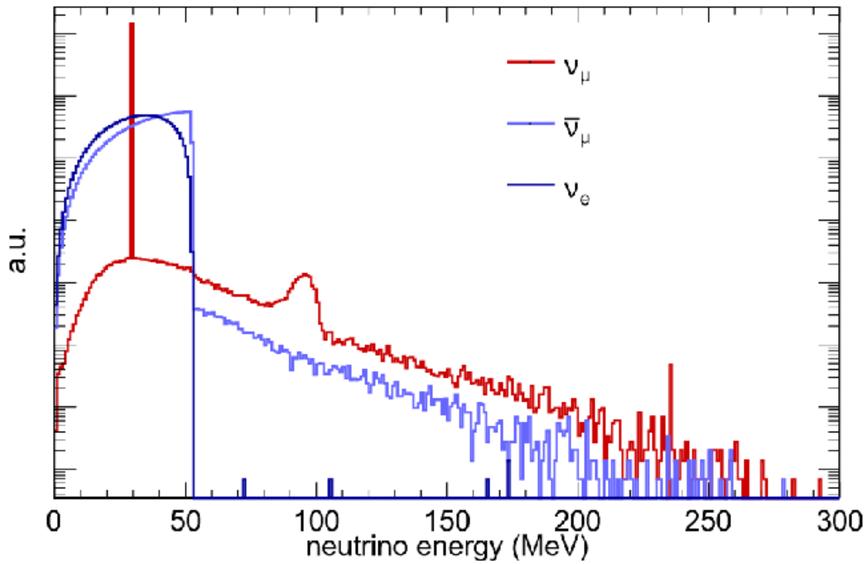
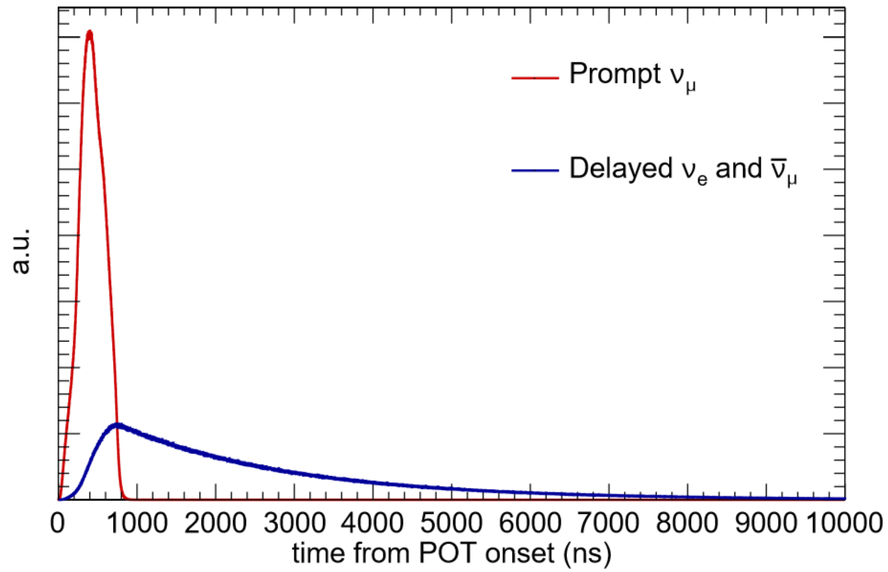
Signal: Neutrino Production via Pion Decay at Rest





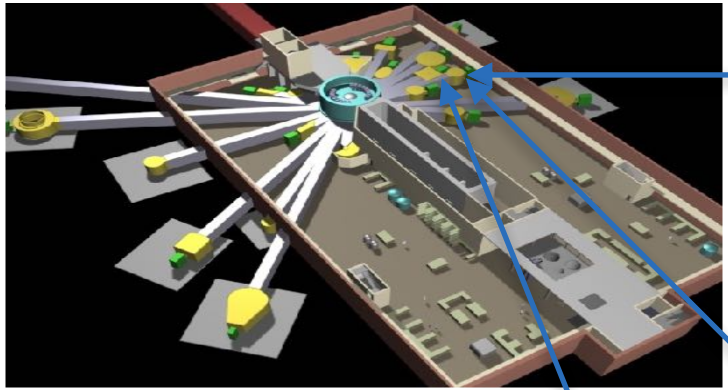




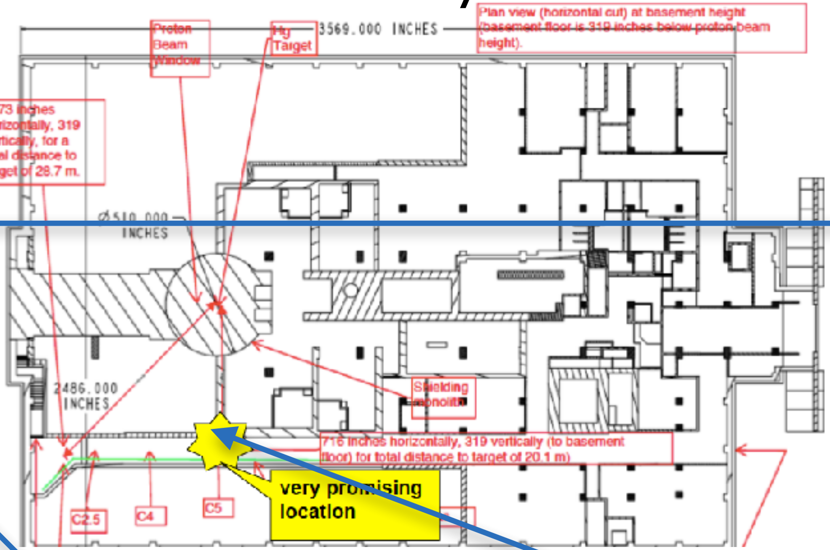


ν flux is approximately 4.3×10^7 ν cm^{-2} s^{-1} at 20 m

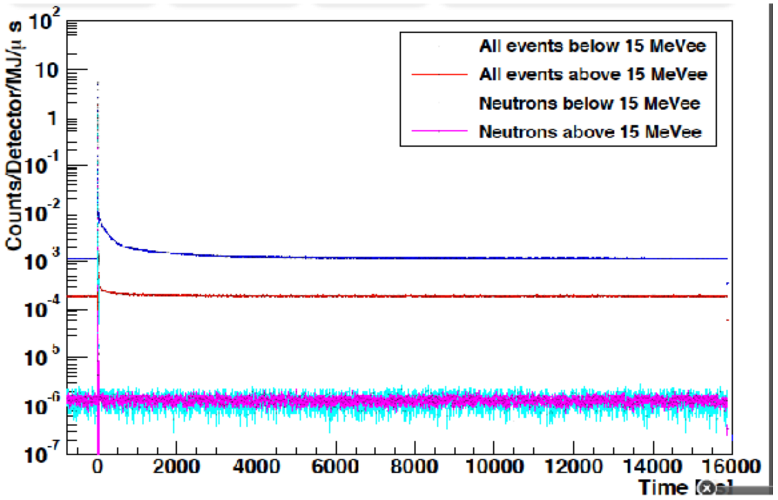
Initial Siting Studies: Choose Wisely

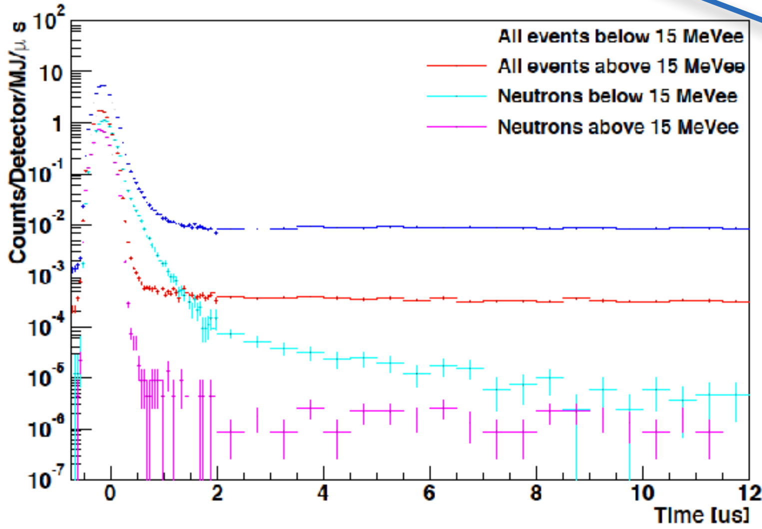


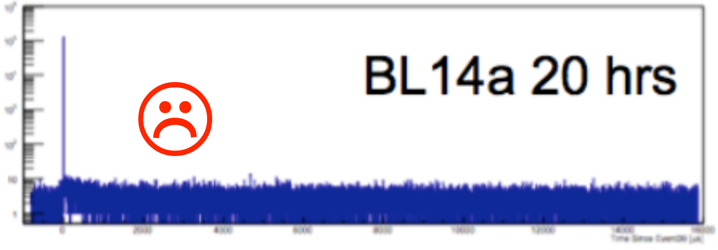
Target Floor

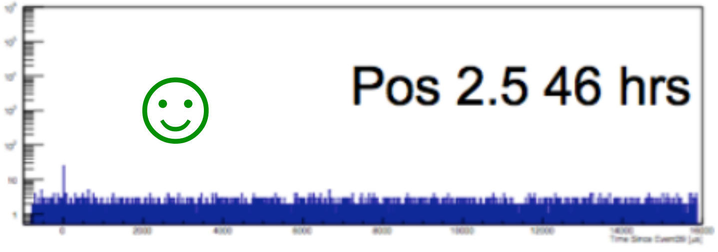


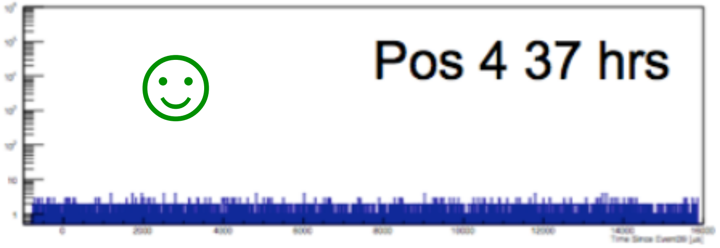
Basement

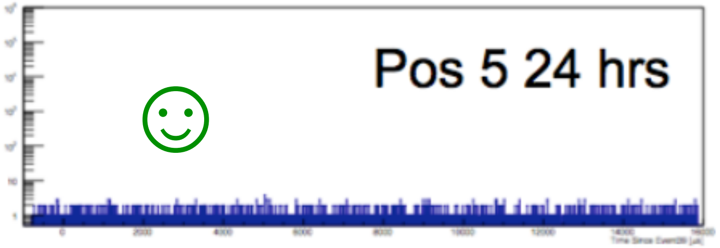




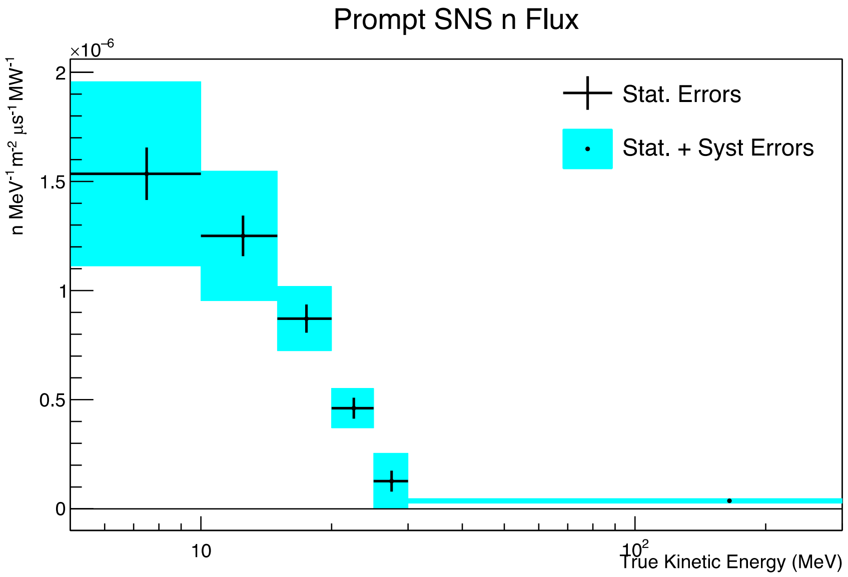


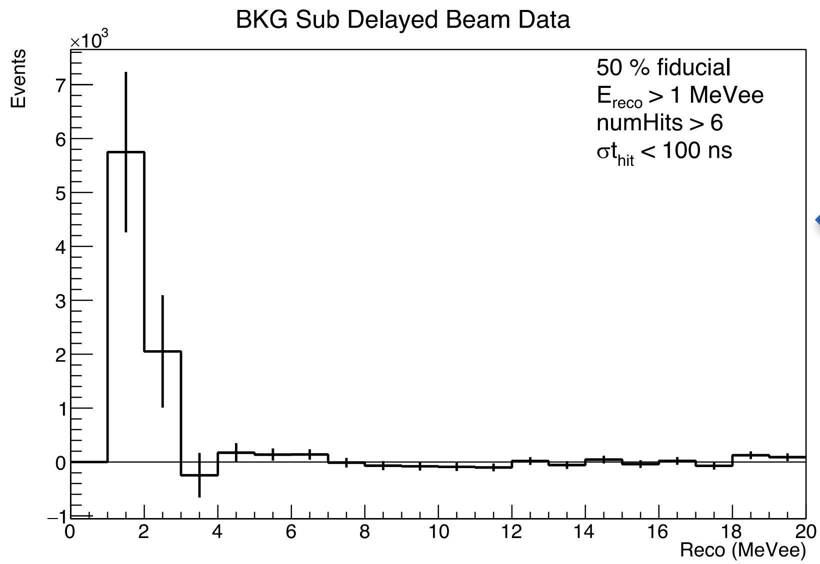




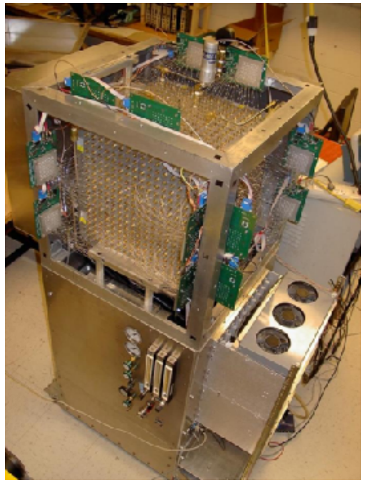


Neutron Flux Measurements in the basement

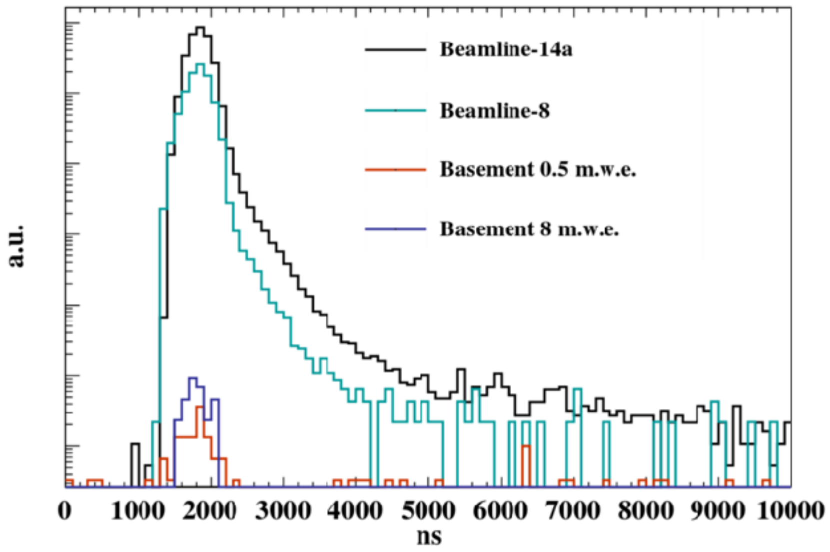


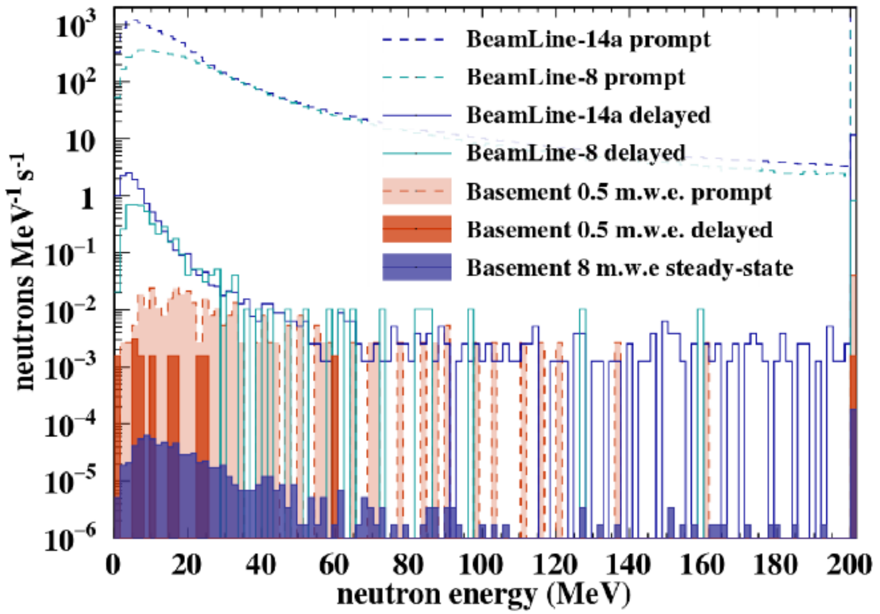


Sandia Scatter Camera



IU SciBath





Converting the service corridor into “Neutrino Alley”

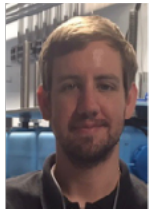
- In 2015, ORNL approved LDRD to prepare service corridor as neutrino laboratory
- May 2016, CENNS-10 22 kg Argon selected for installation
- July 2016, CENNS-10 delivered
- Sept 2016, Electrical, Oxygen Monitoring, FixedBeam Hoist Installed
- Nov 2016, Instrument Readiness Review, Cryogenic Operations Begin
- June 2017, 11 ton Lead Shielding Approved and Installed

- 25 m^2 of equipment floor space
- Limited to 1 m depth (except in alcove)
- The fast neutron shielding provided by the SNS.
- Larger areas are available but Neutron Shielding not provided.

COHERENT Post-docs and Students working at ORNL


Ben Suh
IU


Justin
Raybern
Duke


Sam
Hedges
Duke


Long Li
Duke


Alexander
Kumpan,
MEPhI


Brandon
Becker
UTK


Jacob
Zettlemoyer
IU

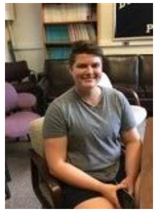

Connor
Awe
Duke


Katrina
Miller
Duke


Hector
Moreno
UNM


Dmitry
Rudik
MEPhI


Rebecca
Rall
CMU


Jes Koros
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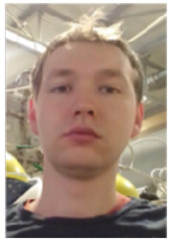
Alexander
Kavner
Chicago

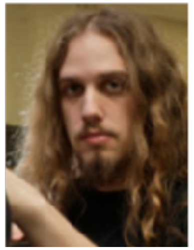

Alexey
Konovalov
MEPhI


Matt
Heath
IU


Alex
Khromov
MEPhI


Gleb
Sinev
Duke


Erin
Conley
Duke


Dan
Salvat
UW
(Postdoc)

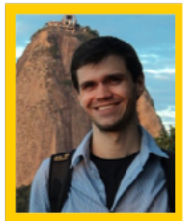

Jacob
Daughhetee
UTK
(Postdoc)


Mayra
Cervantes
Duke
(Postdoc)

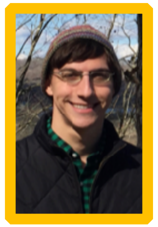

Ivan
Tolstukhin
IU
(Postdoc)


Josh
Albert
IU
(Postdoc)

First three PhD dissertations completed


Bjorn Scholz
U of Chicago


Grayson Rich
Duke
2018 DNP Dissertation Award


Matthew Heath
Indiana University

ORNL/SNS Support at every level

- Day-to-day support from research mechanics, target operations, and SNS scientists.
- Research Accelerator Division
  - Enthusiastic support from Director Kevin Jones and now Director Fulvia Pilat
- PPU Upgrades Office Director - John Galambos
- Neutron Sciences Directorate - Paul Langan (ALD)
- Physics Division
  - David Dean (now ALD), David Radford (GL), Marcel
- Nuclear Security & Isotope Technology Division - Cecil Parks
- Deputy Director for S&T - Michelle Buchanan

01.03.18

2017's Top Stories from the Office of Science

Our Most Popular Articles of the Year

National Laboratory Articles

The Office of Science's 10 national laboratories report on their latest research news with timely press releases and features. They also profile scientists to highlight the passion and commitment behind the research.

Top five national laboratory articles:

- New Studies of Ancient Concrete Could Teach Us to Do As the Romans Did (Lawrence Berkeley National Laboratory)
- New Evidence for a Water-Rich History on Mars (Lawrence Berkeley National Laboratory)
- World's Smallest Neutrino Detector Finds Big Physics Fingerprint (Oak Ridge National Laboratory)
- Research Led by PPPL Provides Reassurance that Heat Flux Will Be Manageable in ITER (Princeton Plasma Physics Laboratory)
- Chemical "Dance" of Cobalt Catalysis Could Pave Way to Solar Fuels (Argonne National Laboratory)

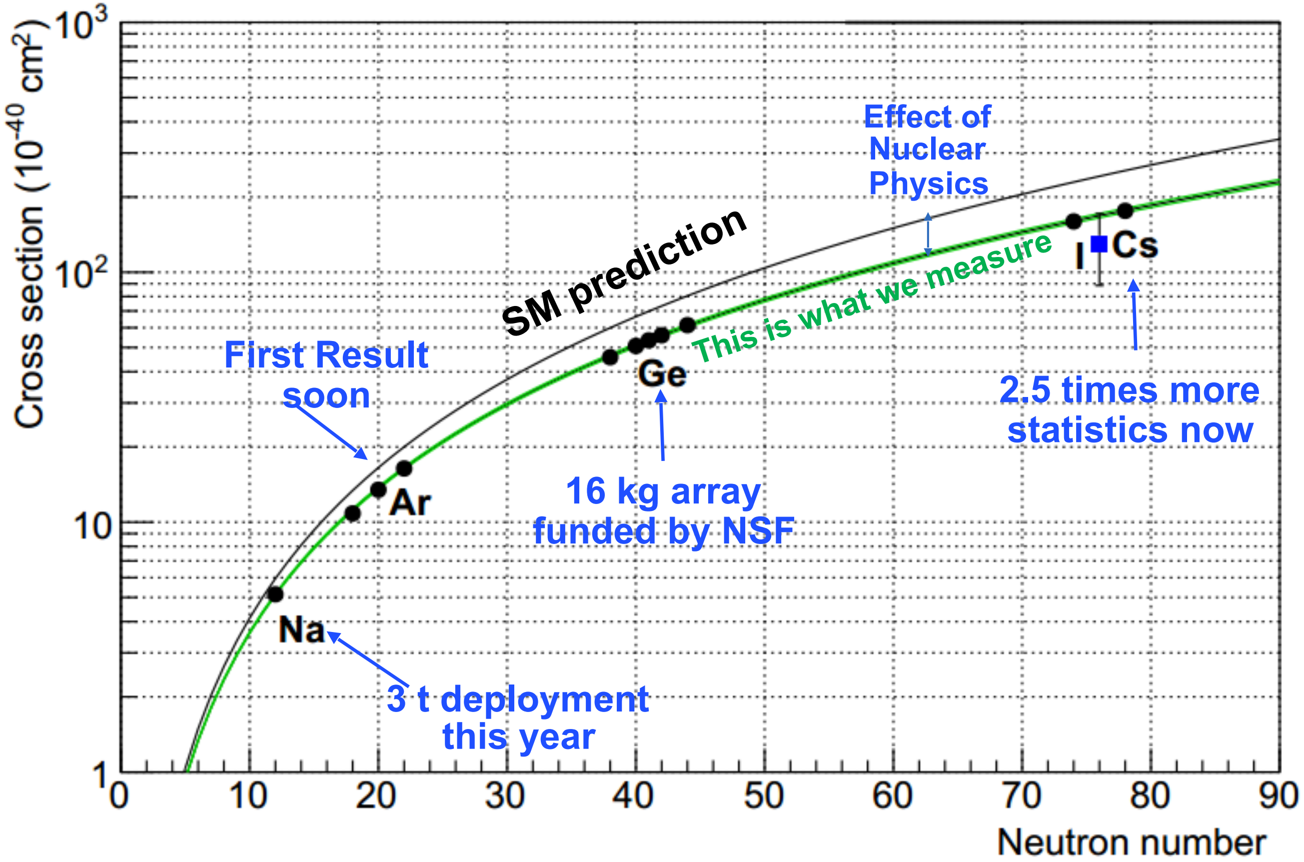
https://science.energy.gov/news/featured-articles/2018/01-03-18/

Many thanks from COHERENT to all above!

ORNL has invested over $1.2M in the Neutrino Program at the SNS

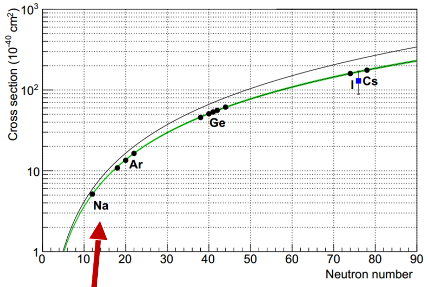
OS/HEP support of ORNL COHERENT staff at 0.4 FTE since 2015

Activities In Neutrino Alley



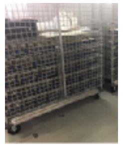
- **Nubes Pb/Fe Targets**
  - Neutrino Induced Neutron Production
- **CsI**
  - Completed operation and disassembled in June
  - Finalizing analysis of complete dataset
- **CENNS-10**
  - 22 kg LAr detector
  - Engineering Run: new CEvNS limits
  - Production Run: Advanced analysis stage
- **NaI 185kg**
  - Charged Current $\nu_e + {}^{127}\mathrm{I} \rightarrow {}^{127}\mathrm{Xe} + \mathrm{e}^-$
  - Study backgrounds for Na CEvNS
- **MARS**
  - Fast Neutron Background Monitoring
- **HPGe**
  - NSF Grant Awarded, to begin late 2019

Preparations for NaI upgrade



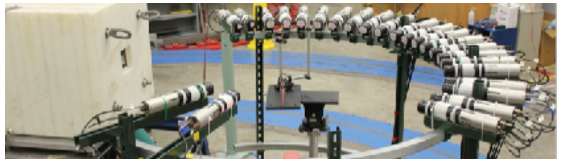
Transition from 185 kg to multi-ton array of NaI detectors

100s of detectors available



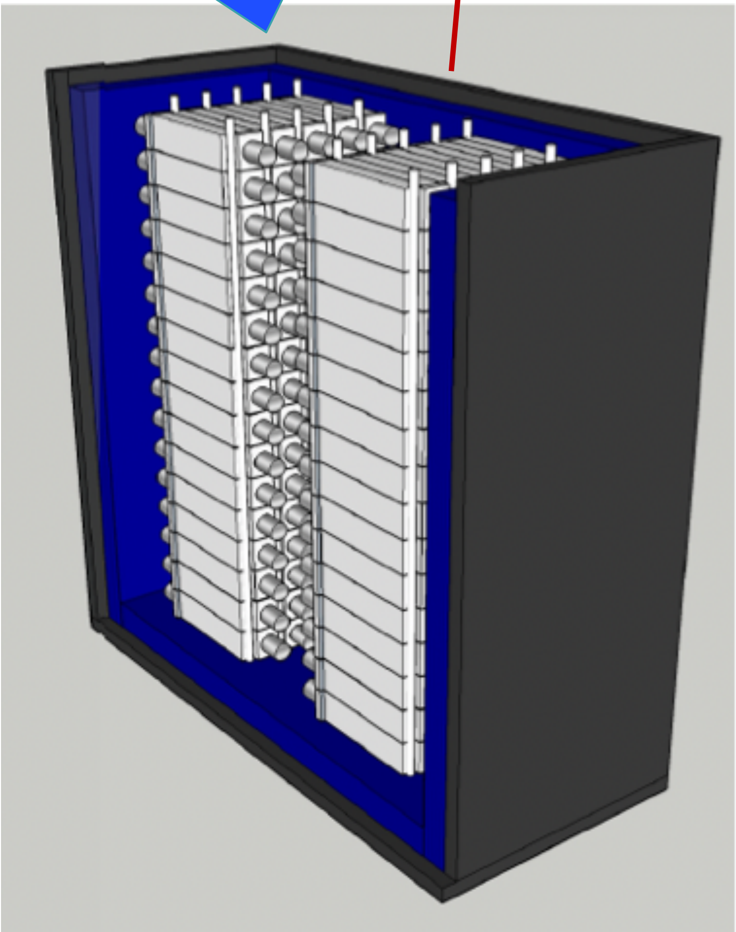
Need dual gain bases
(final tests of prototypes)

Program to measure Quenching Factors is ongoing at TUNL

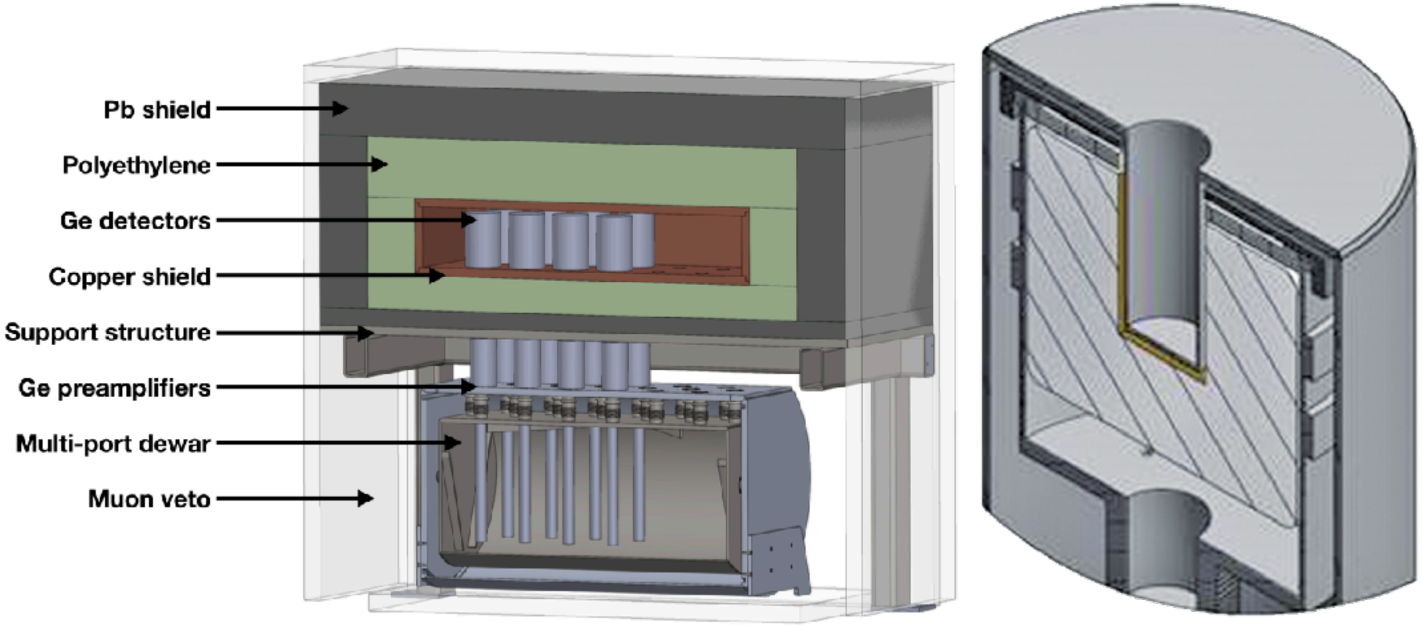


Readout Electronics and HV

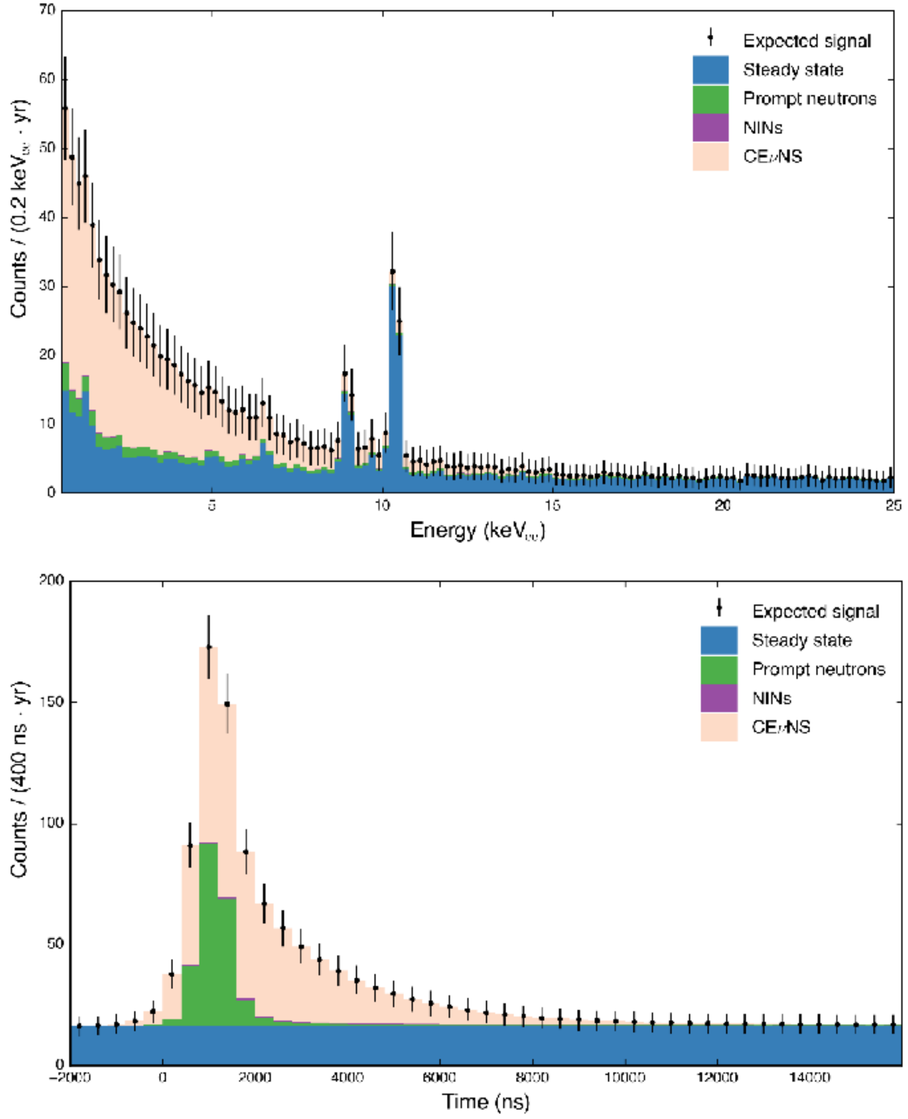
Simultaneously, measure both CEvNS and CC reactions



Preparations for Ge Detector Array

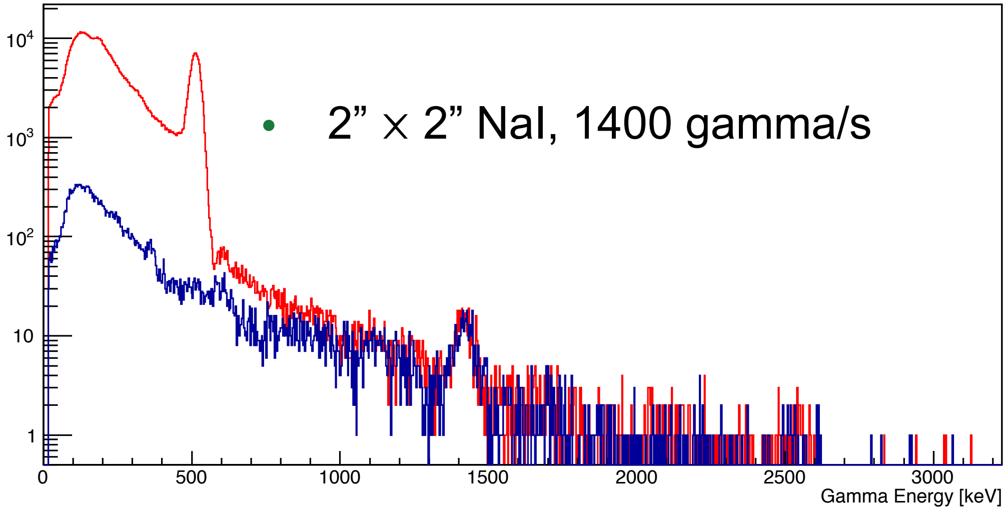


- 16 kg array of PPC Ge detectors placed in compact shielding using multi-port dewar that has already been procured.
- Expectation of 500-600 CEvNS events in defined ROI with a predicted signal-to-background ratio of 3.5 per year of SNS operation.
- Improved sensitivity for BSM physics: ν electromagnetic properties, non-standard interactions, sterile oscillations, DM, etc.

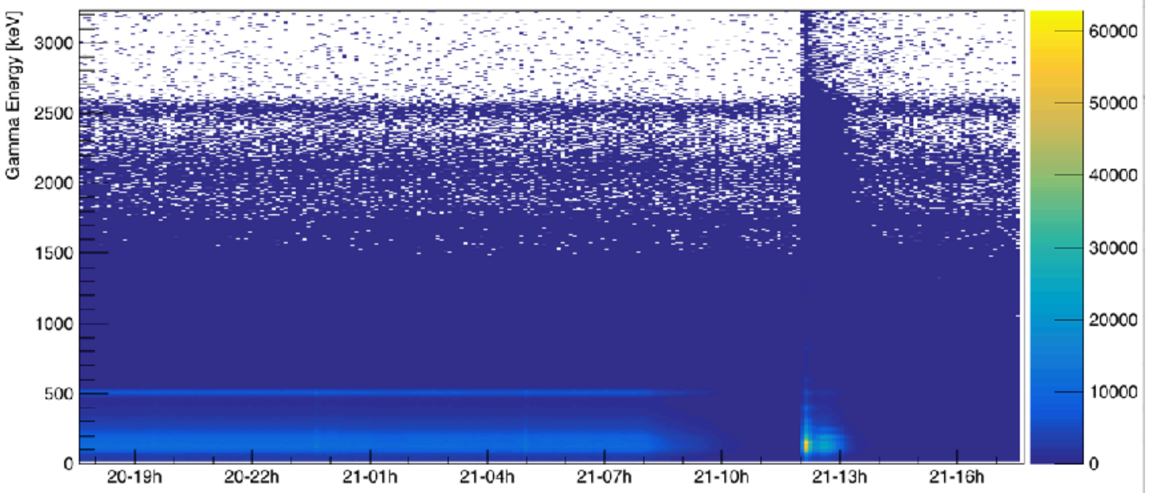


The expected CEvNS signal in a 14.4kg PPC germanium detector array in 1 year of SNS operation.

Steady State Backgrounds



MOTS Flush



- 10,000 Curies of ^{11}C per year from target moderator system exhausted through 6” Hot Off Gas pipe
- Lot’s of 511 gammas to be shielded at every detector location
- Backgrounds for cosmic vetos
- Mitigated to ambient rates with 1 Inch lead collar
- First10 ft section to be installed in August 2019

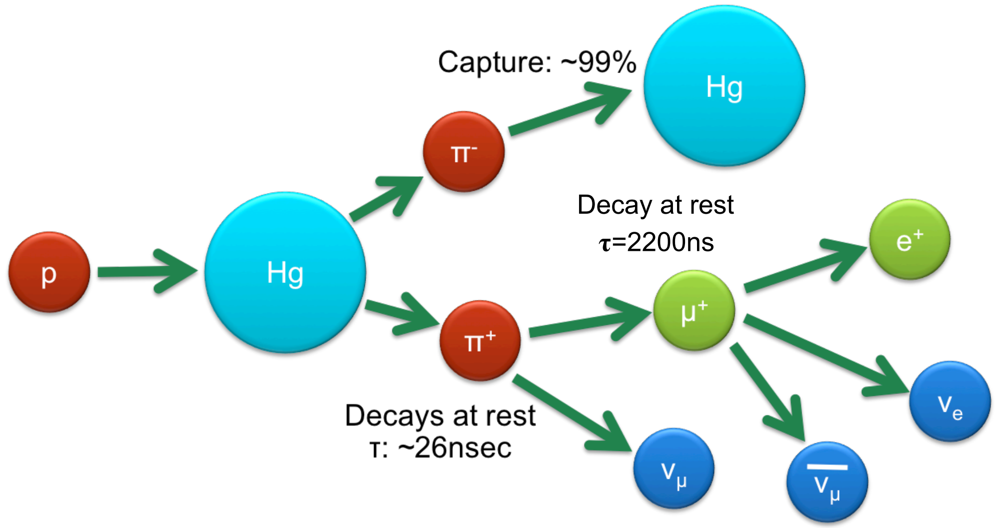
OAK RIDGE National Laboratory Jason Newby, STS Workshop 2019

Beyond First Light Measurements …

Uncertainties on CsI signal and background predictions	
Event selection (signal acceptance)	5%
Form Factor	5%
Neutrino Flux	10%
Quenching factor	25%
Total uncertainty on signal	**28%**

All uncertainties except neutrino flux are detector specific and could be much less for other technologies

SNS produces pions via π decay at rest



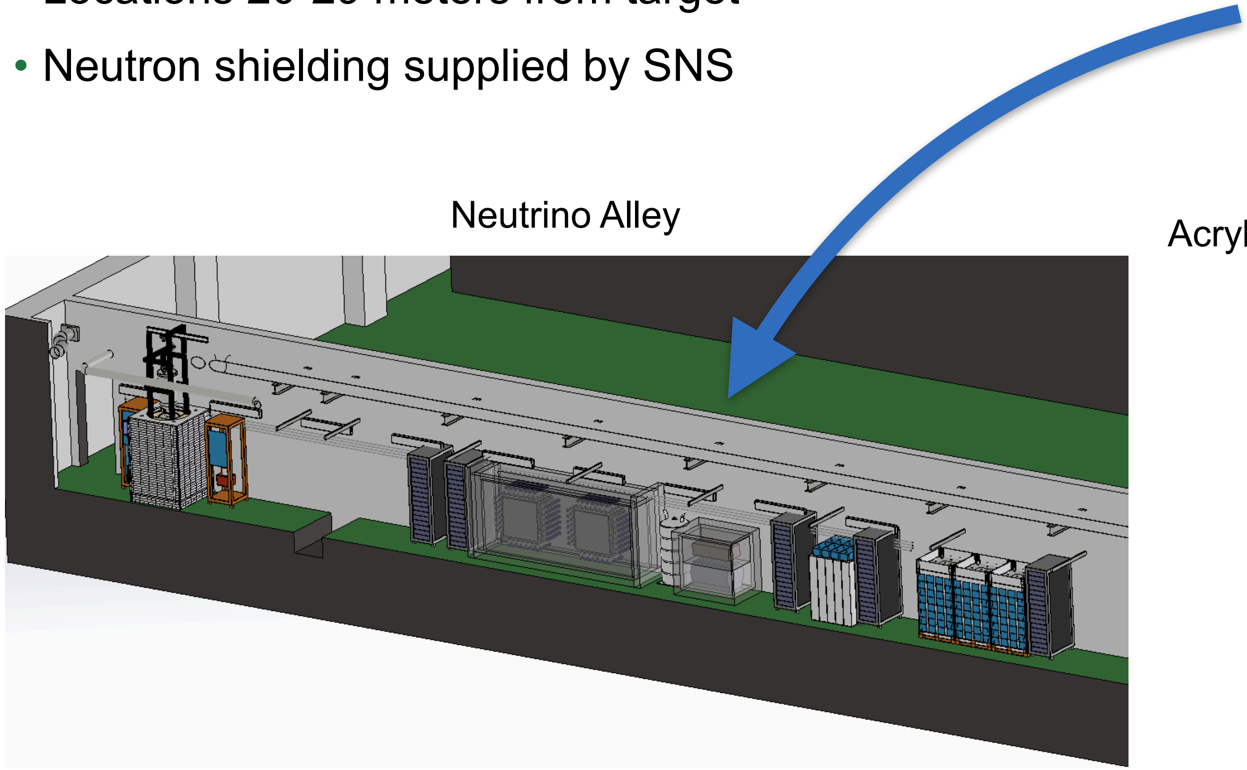
- Largest uncertainty is pion production from p+Hg
- 10% discrepancy between Bertini and LAHET calculations

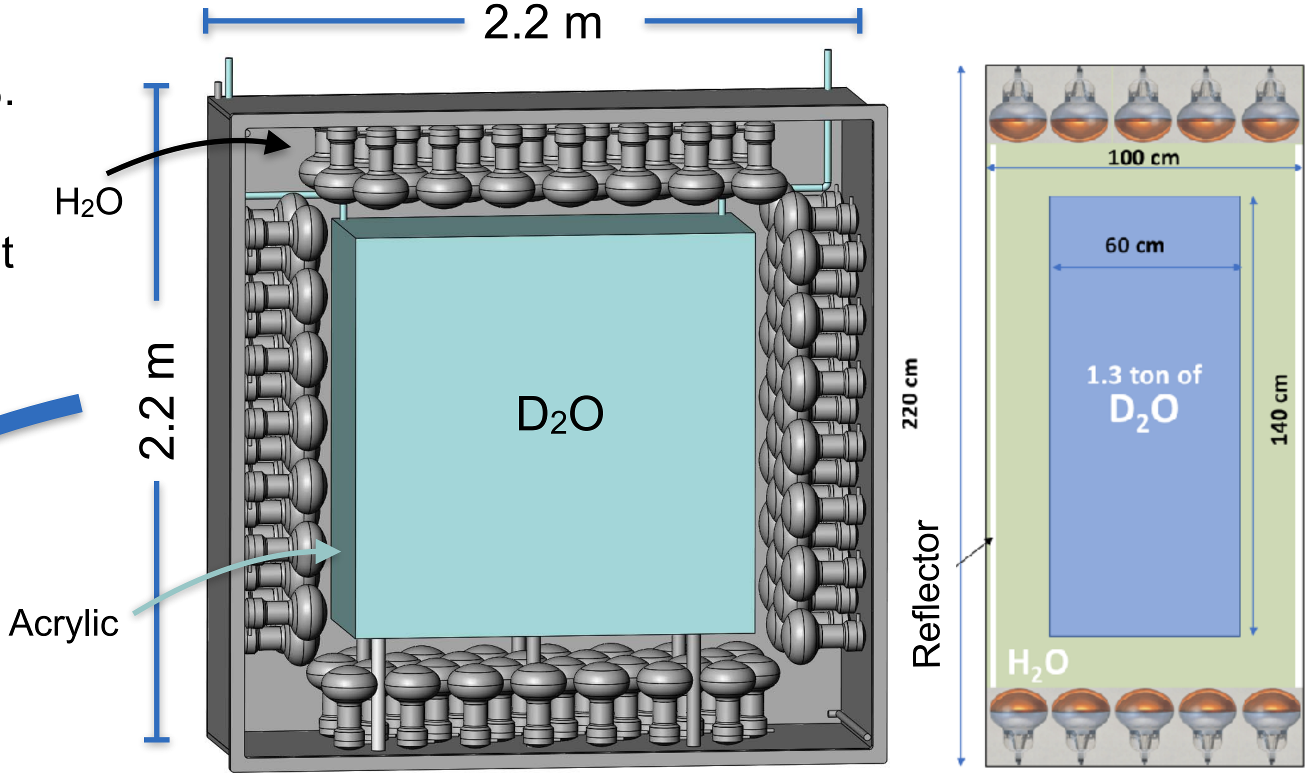
To unlock high precision CEvNS program, we need to calibrate SNS neutrino flux

1-ton Heavy Water Detector

- Charged current ν_e-d cross section known to about 2-3%.
  S.Nakamura et. al. Nucl.Phys. A721(2003) 549
- Neutrino Alley space constraints: 1m depth x 2.3m height x 3m width
- Locations 20-29 meters from target
- Neutron shielding supplied by SNS

Neutrino Alley



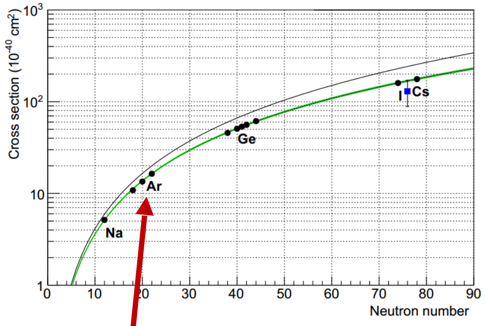


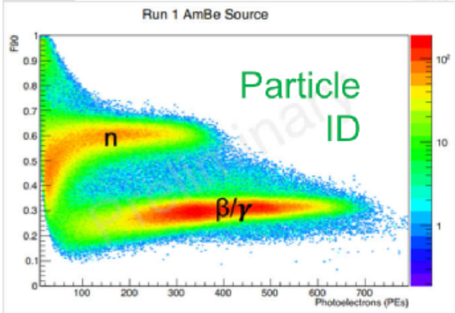
Darryl Dowling, ORNL

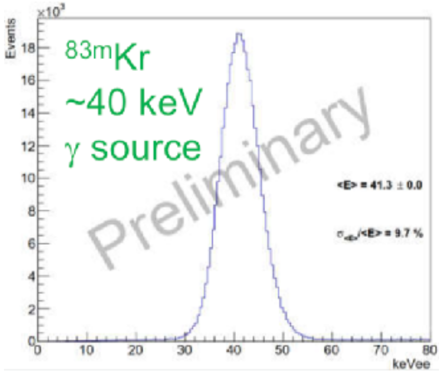
- 1.3 tons D_2O within acrylic inner vessel
- H_2O "tail catcher" for high energy e^-
- Outer light water vessel contains PMTs, PMT support structure, and optical reflector.
- Outer steel vessel to support shielding and veto

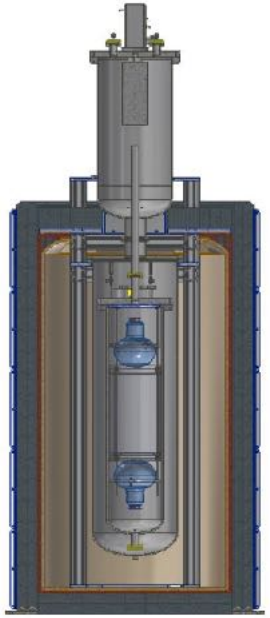
Future 1 ton LAr detector

Need high statistics low background measurements of CEvNS









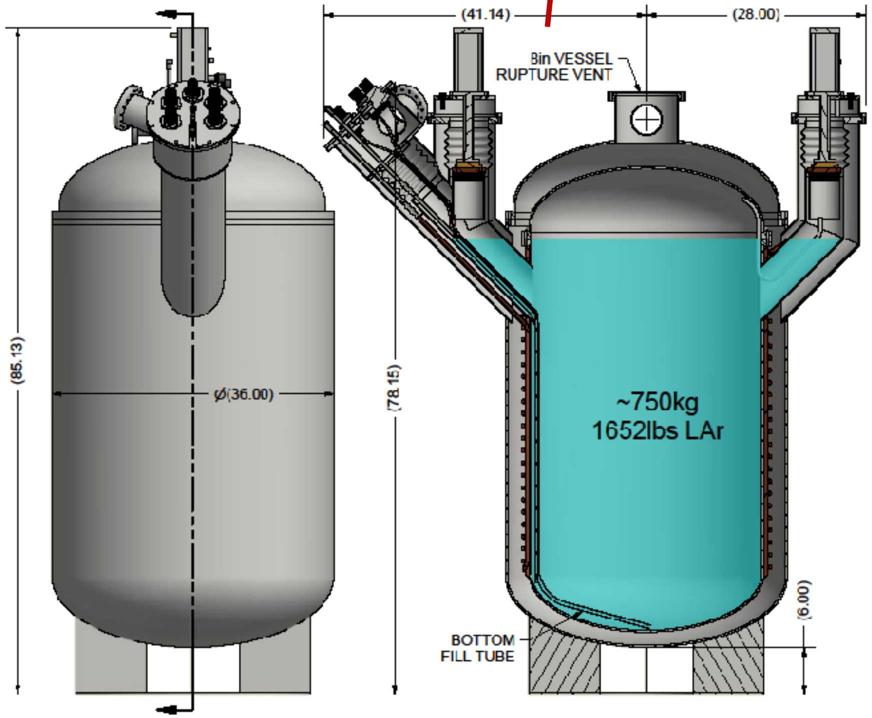
Transition from 22 kg to 1 ton LAr detector.

Can fit at the same place where presently 22 kg detector is sitting

Will reuse part of existing infrastructure

Potentially use depleted Argon; piggyback on DarkSide investments

Will see thousands of CEvNS events per year + CC



Physics Overview

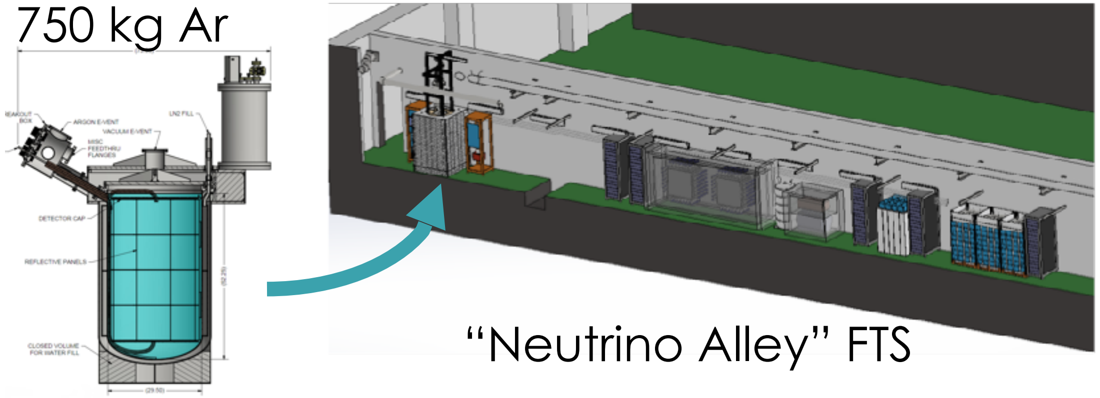
Topic	CsI	Ar	NsI	Ge	Nubes	D_2O
Non-standard neutrino interactions	✓	✓	✓	✓		
Weak mixing angle	✓	✓	✓	✓		
Accelerator-produced dark matter	✓	✓	✓	✓		
Sterile oscillations	✓	✓	✓	✓		
Neutrino magnetic moment		✓	✓	✓		
Nuclear form factors	✓	✓	✓	✓		
Inelastic CC/NC cross-section for supernova		✓			✓	✓
Inelastic CC/NC cross-section for weak physics		✓	✓		✓	✓

The sum is greater than the individual measurements (green shading)

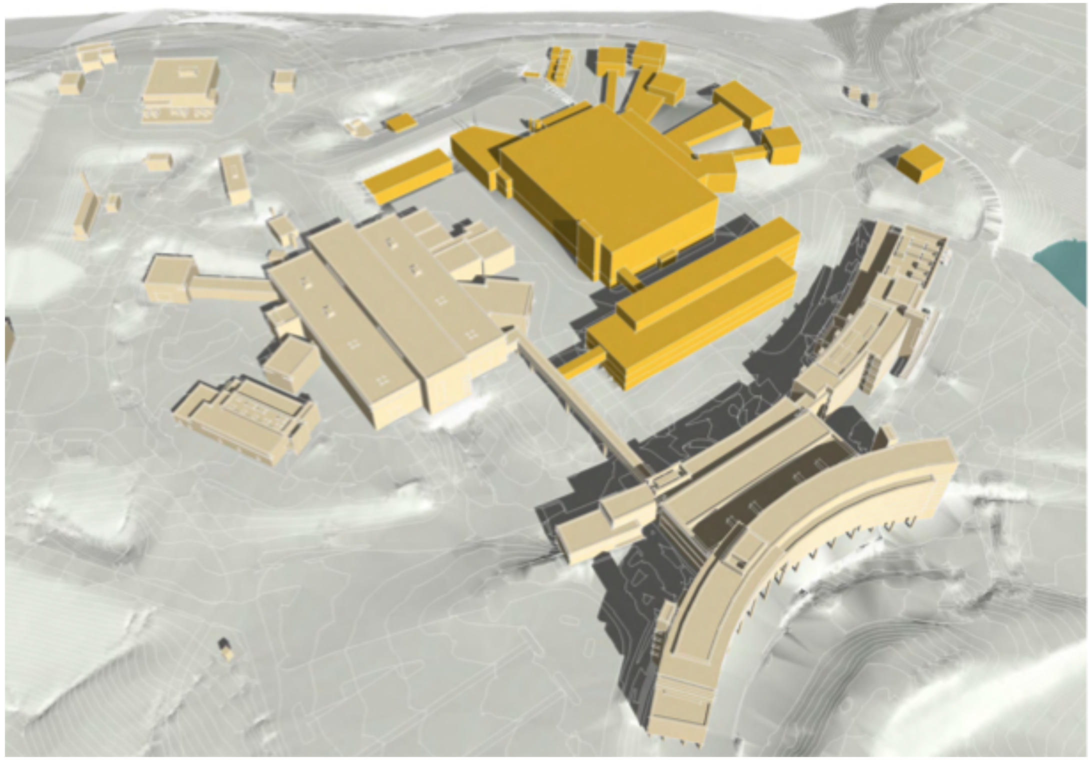
All measurements benefit from neutrino flux normalization (grey shading)

Rare physics requires even larger detectors

- Basement corridor in First Target Station is ideal location for small compact **neutrino** detectors up to 1-ton mass.



- **Dark Matter** detection will require 10-ton detector mass.
- Basement area of STS is an attractive possibility: near source and well shielded.
- Locations with current STS design could accommodate large detectors.
- Dedicated engineering effort required to ensure a feasible experiment is compatible with BES mission and facility operations.



- FTS "Neutrino Alley"
  - 1 x 25 m^2 of equipment floor space
  - Detectors limited to 1 m width
- STS required footprint of 5 x 10 m^2

Summary

- The Spallation Neutron Source is currently the cleanest, most intense stopped pion neutrino source with stable operation planned for decades.
- Multiple targets (Ar, Ge, Na, Cs, I, D) deployed by the COHERENT collaboration in neutrino alley has created a rich neutrino physics program.
- Neutrino Alley at the First Target Station is an ideal location for small compact neutrino detectors up to 1-ton mass.
- The Second Target Station basement is an attractive possibility for new physics requiring 10-ton mass scales: near source and well shielded.

Acknowledgements

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