The current status of the

COHERENT experiment

Diana Parno
Carnegie Mellon University

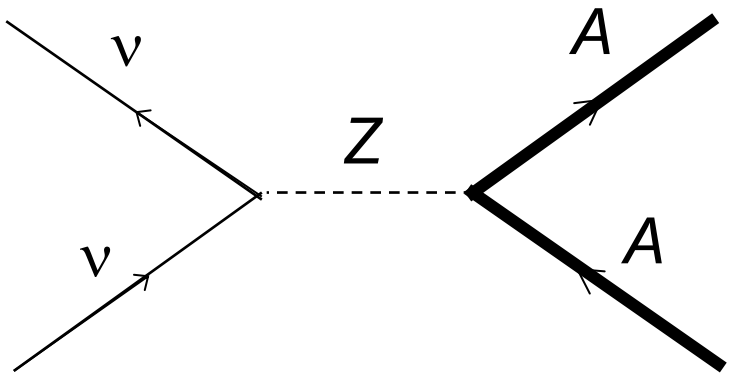
Magnificent CEvNS 2024, Valencia, Spain

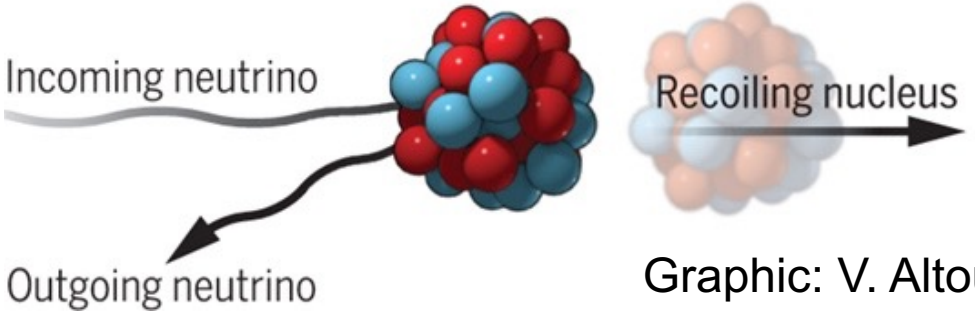
Outline

- Experimentalist's guide to CEvNS
- COHERENT basics and CEvNS summary
- Backgrounds and flux normalization
- Future plans
- Bonus physics: inelastics & dark matter

Experimentalist's Guide to CEvNS

- **C**oherent **E**lastic ν-**N**ucleus **S**cattering
  - Predicted in Standard Model in 1974
  - Not observed until 2017 (by COHERENT)



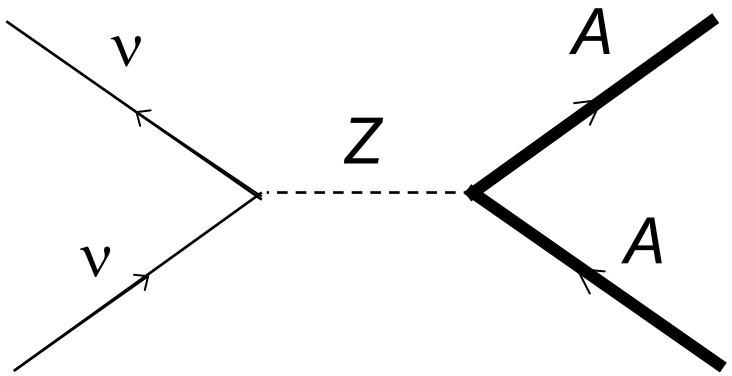


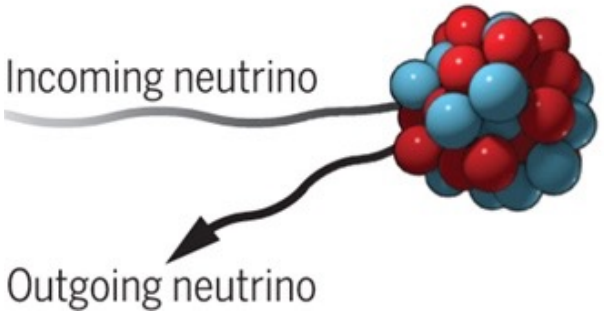
Graphic: V. Altounian, *Science*

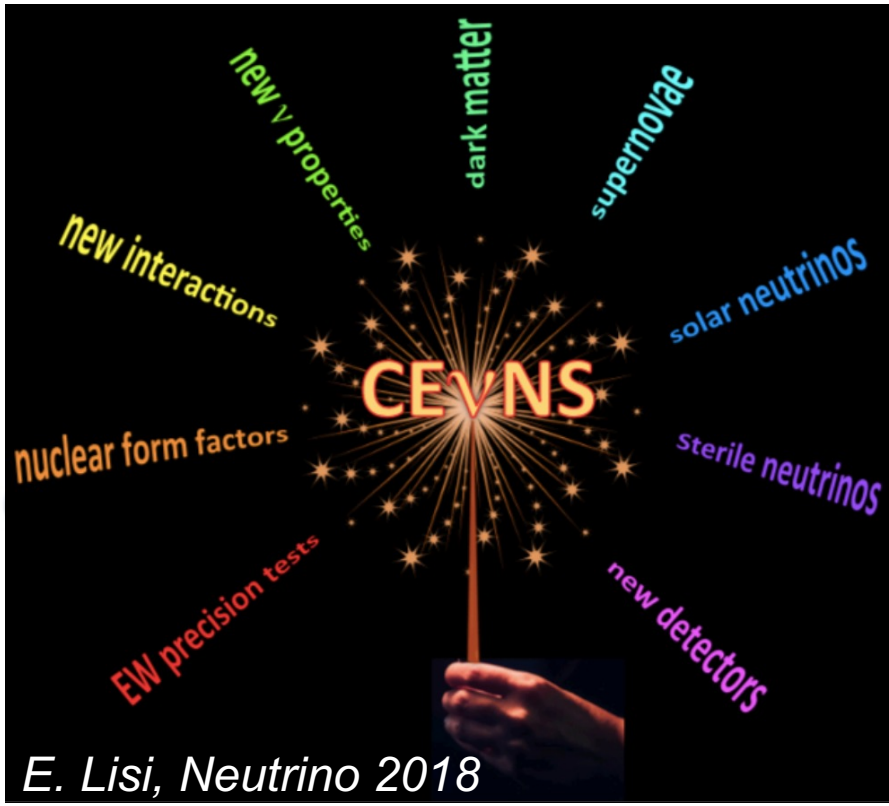
- ν interacts coherently and elastically with entire nucleus
  - Cross-section enhancement
  - No nuclear excitation
  - Unlocks exciting physics!

Experimentalist's Guide to CEvNS

- **C**oherent **E**lastic ν-**N**ucleus **S**cattering
  - Predicted in Standard Model in 1974
  - Not observed until 2017 (by COHERENT)







- ν interacts coherently and elastically with entire nucleus
  - Cross-section enhancement
  - No nuclear excitation
  - Unlocks exciting physics!

> 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.

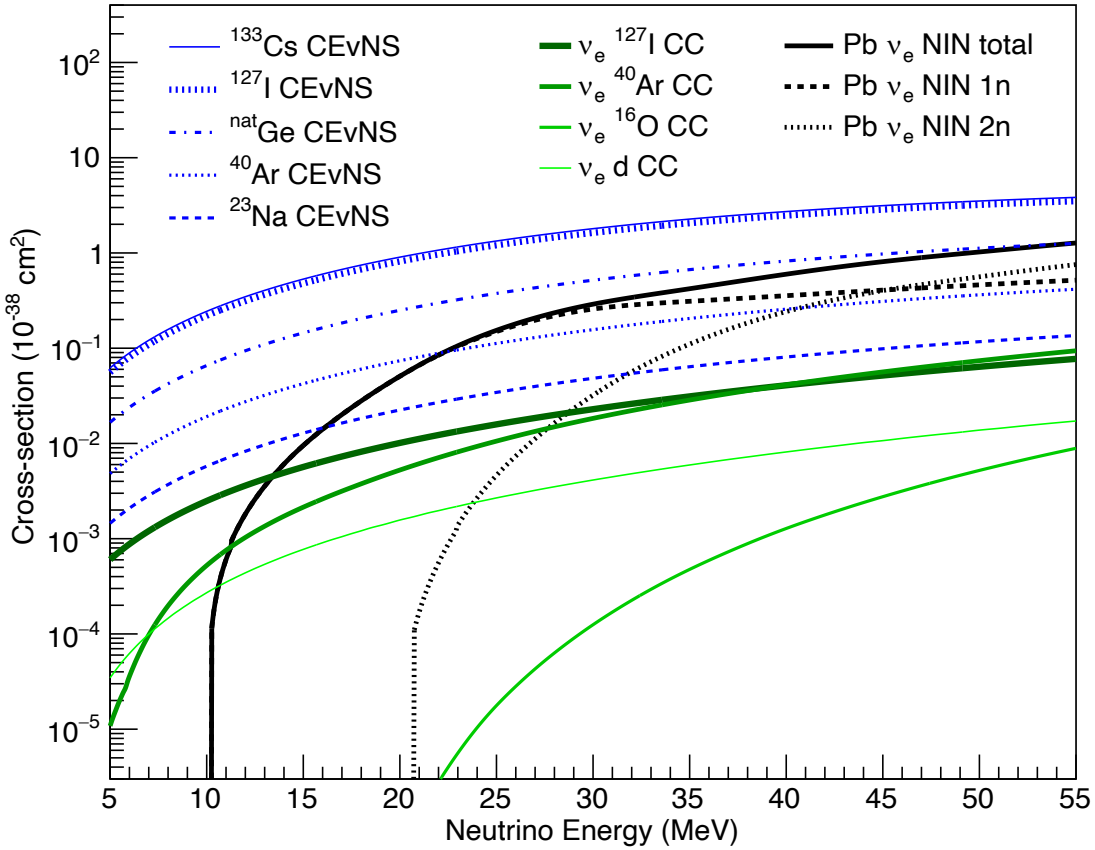
*- D.Z. Freedman, Phys. Rev. D **9** (1974) 1389*

CEvNS Detection Recipe

- $E_\nu \lesssim 50$ MeV to permit coherent interaction

CEvNS Detection Recipe

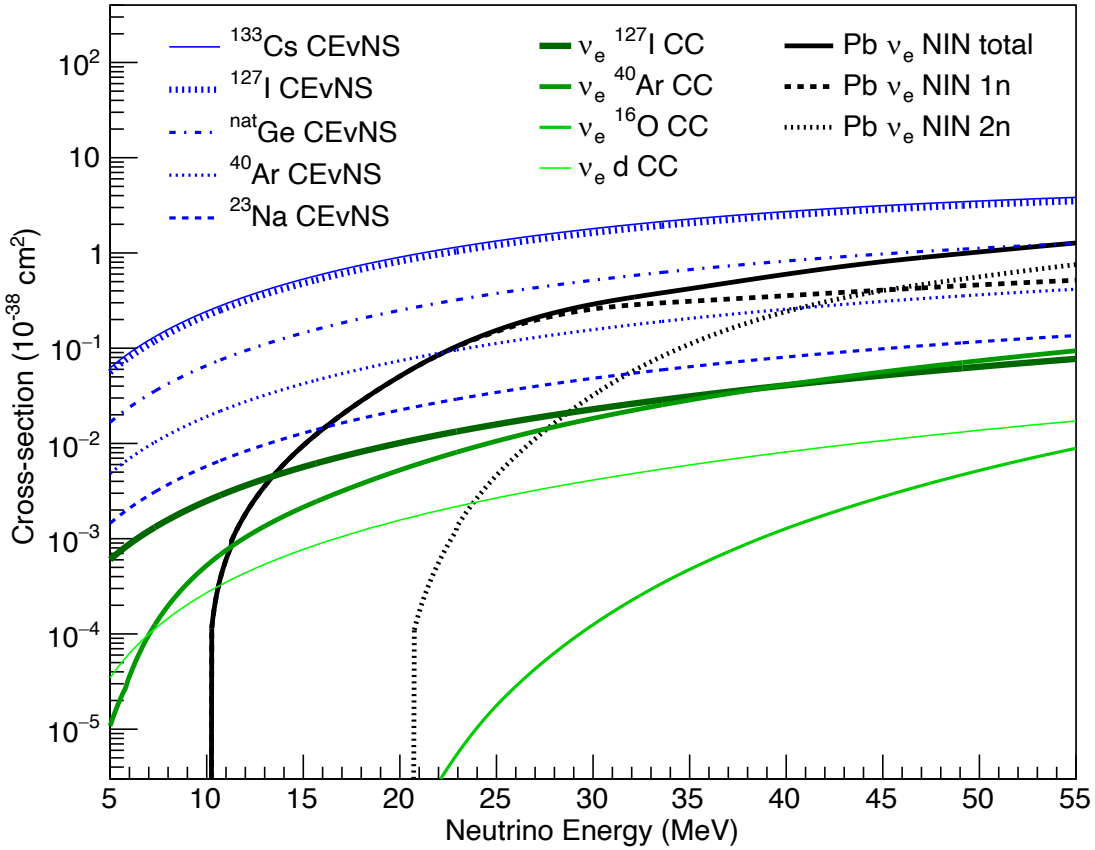
- $E_\nu \lesssim 50$ MeV to permit coherent interaction
- Sensitivity to small cross section ~ 10^{-39} cm^2
  - Low backgrounds
  - Lots of neutrinos



Barbeau, Efremenko, and Scholberg,
Ann. Rev. Nucl. Part. Sci. 73 (2023) 41

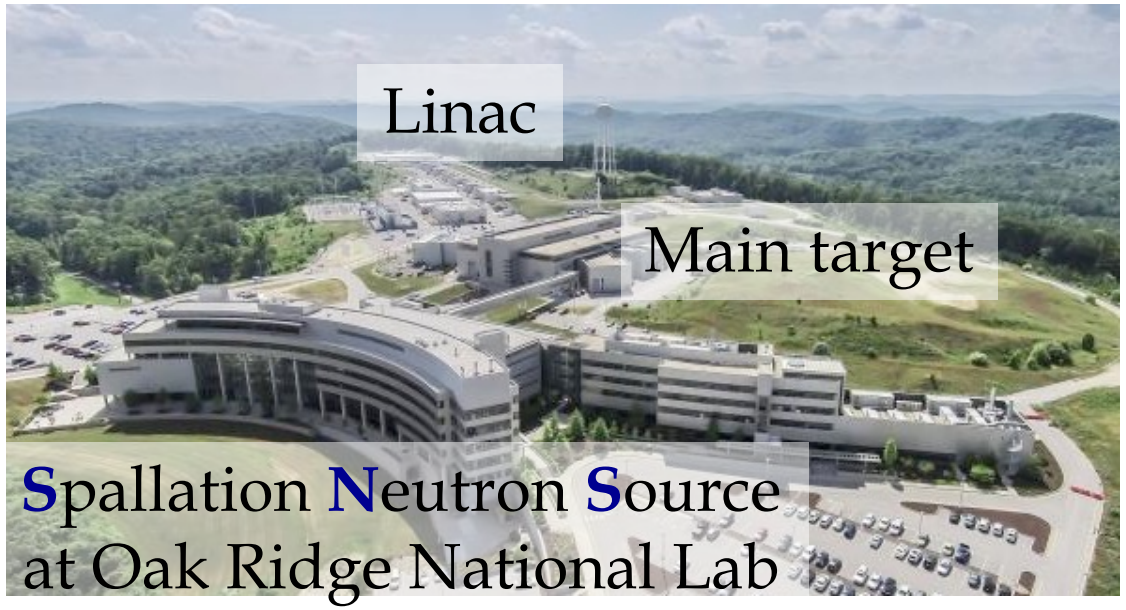
CEvNS Detection Recipe

- $E_\nu \lesssim 50$ MeV to permit coherent interaction
- Sensitivity to small cross section ~ 10^{-39} cm^2
  - Low backgrounds
  - Lots of neutrinos
- Sensitivity to tiny nuclear recoils

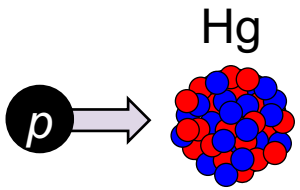


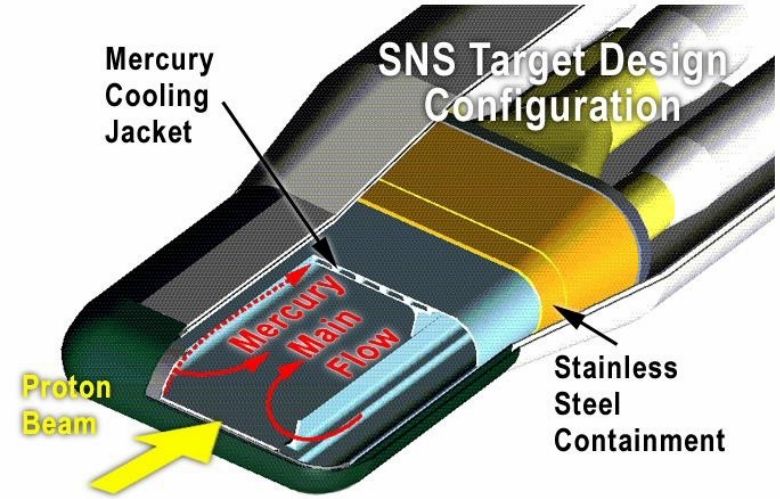
Barbeau, Efremenko, and Scholberg,
Ann. Rev. Nucl. Part. Sci. 73 (2023) 41

The Spallation Neutron Source

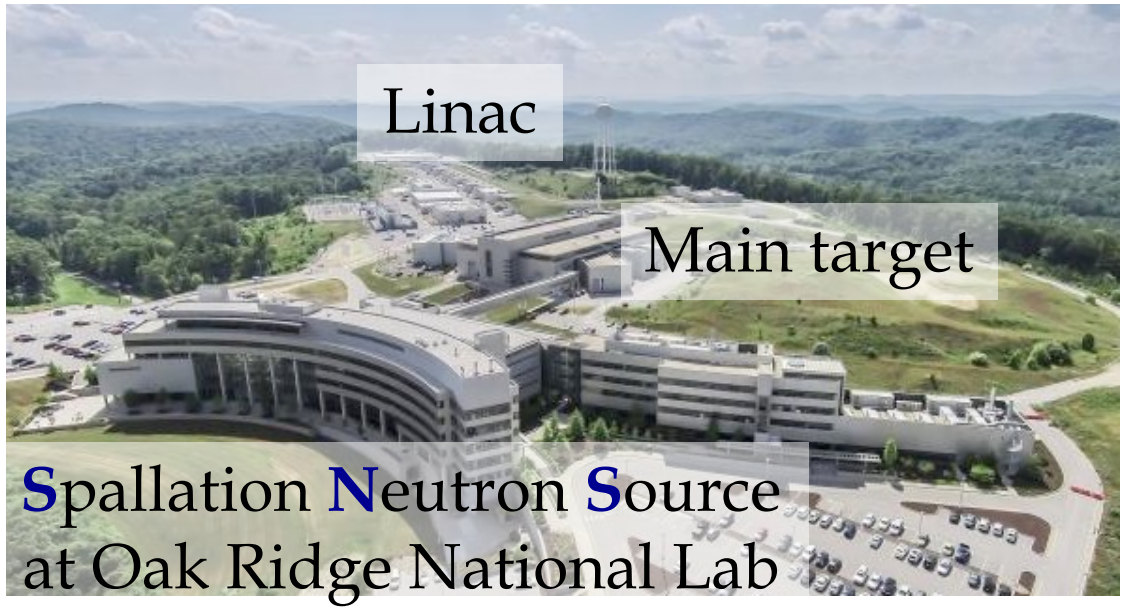


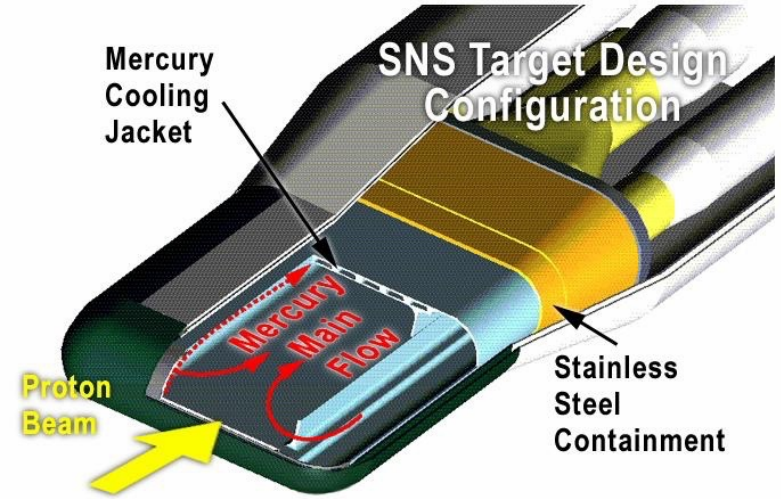
- Provides neutrons for materials science, life science, basic physics research
- Proton beam strikes liquid Hg target at ~1 GeV



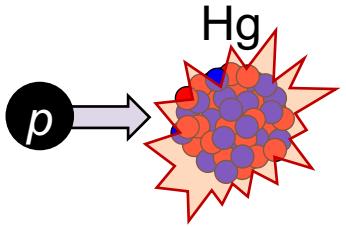


The Spallation Neutron Source

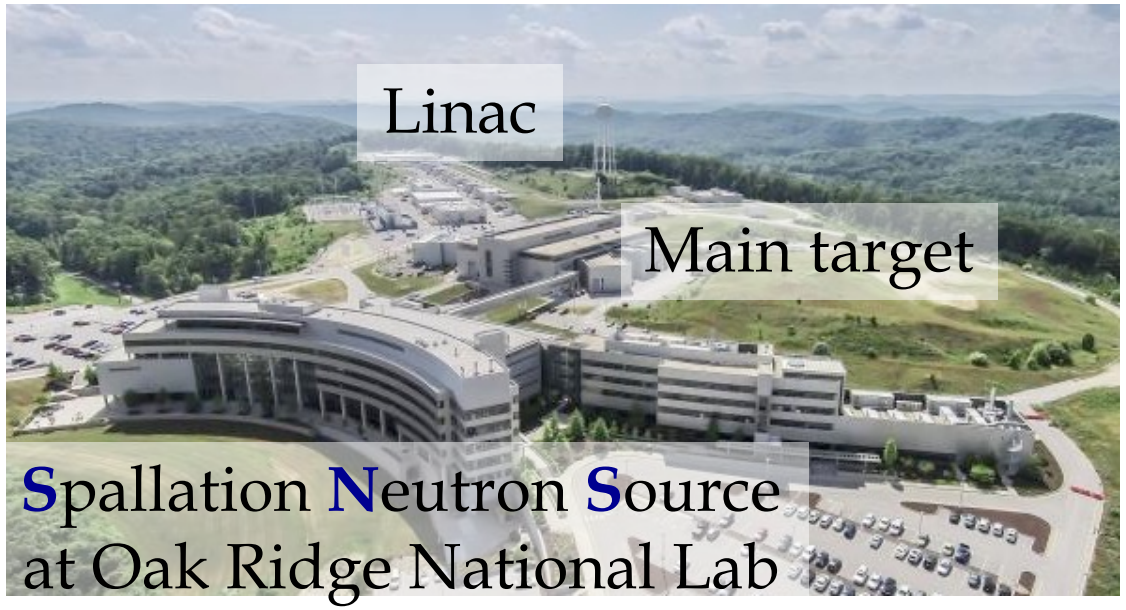




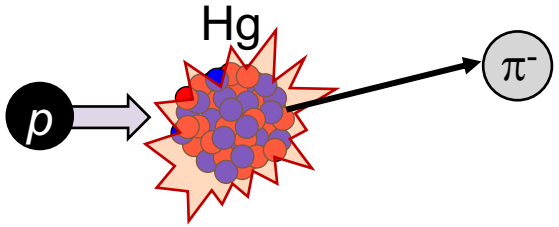
- Provides neutrons for materials science, life science, basic physics research
- Proton beam strikes liquid Hg target at ~1 GeV

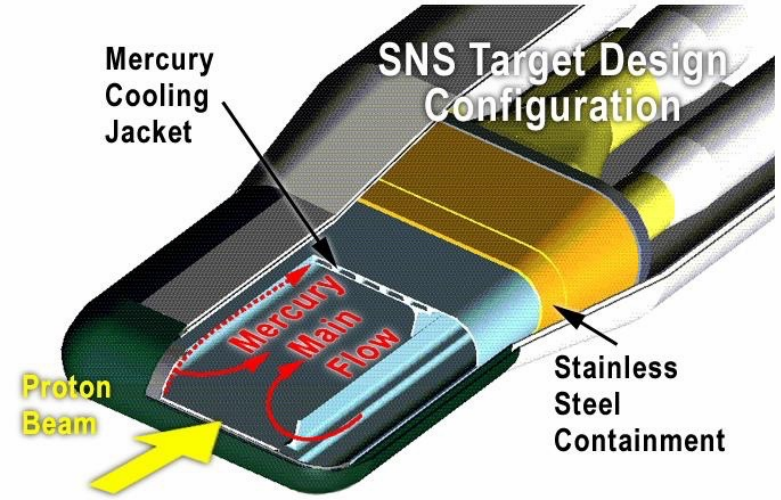


The Spallation Neutron Source

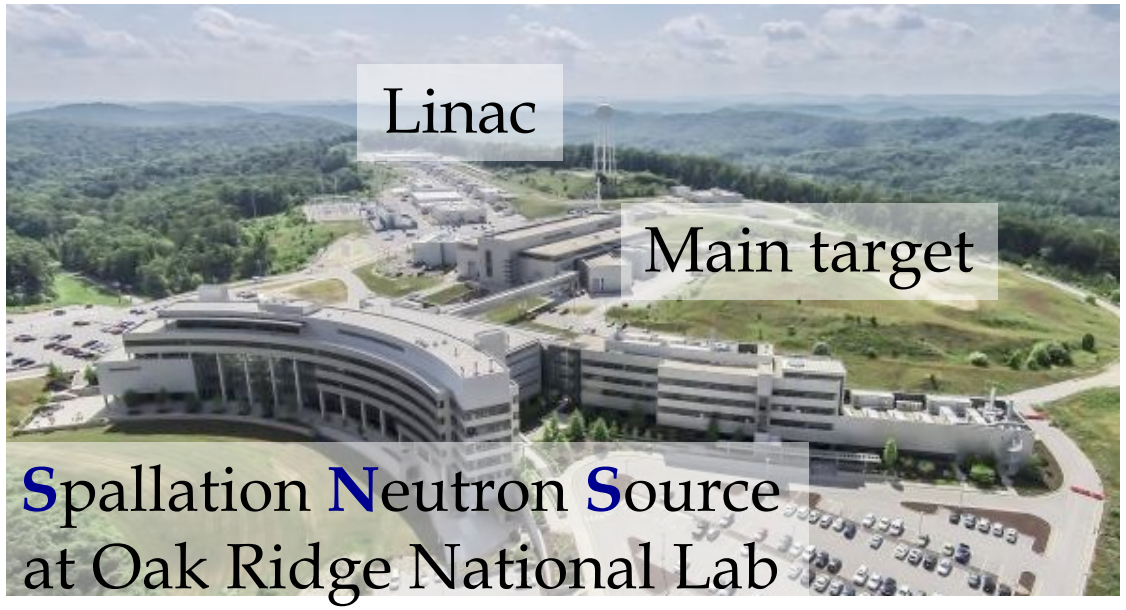


- Provides neutrons for materials science, life science, basic physics research
- Proton beam strikes liquid Hg target at ~1 GeV

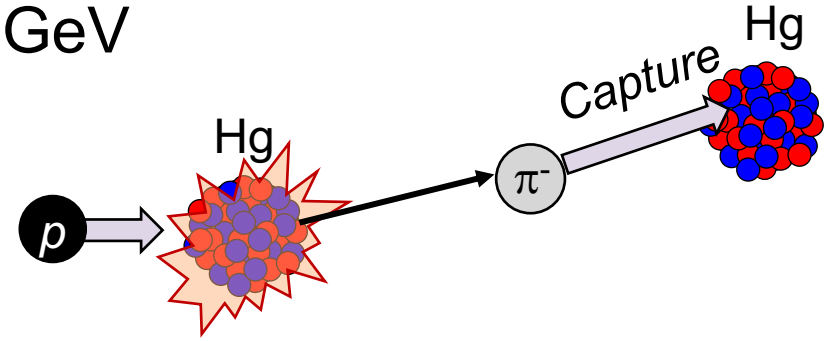


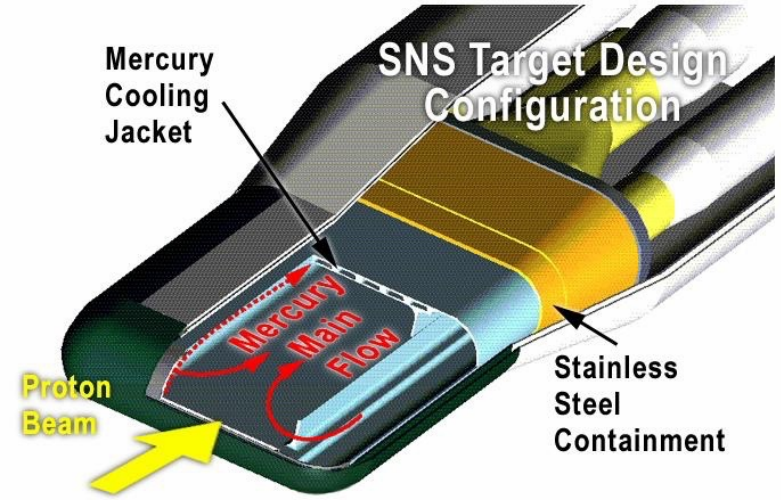


The Spallation Neutron Source

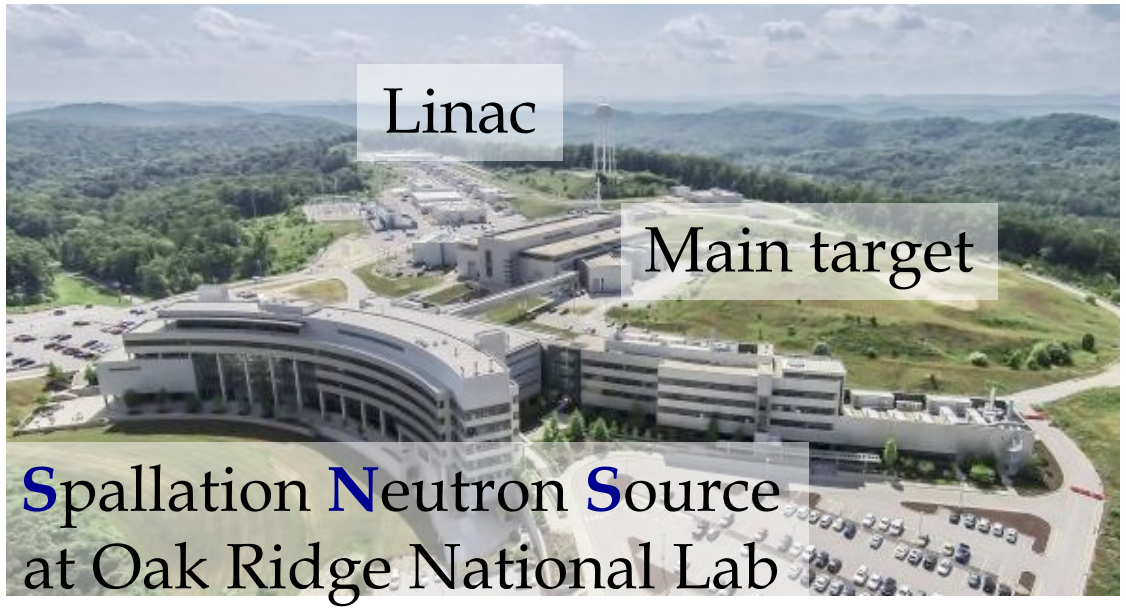


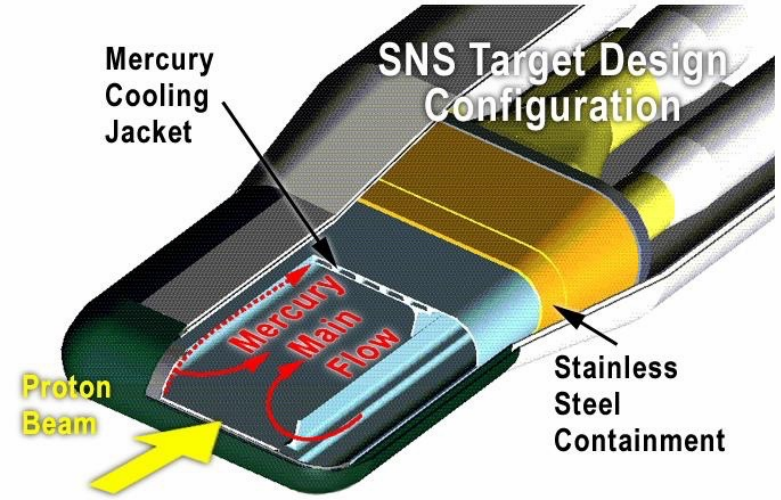
- Provides neutrons for materials science, life science, basic physics research
- Proton beam strikes liquid Hg target at ~1 GeV



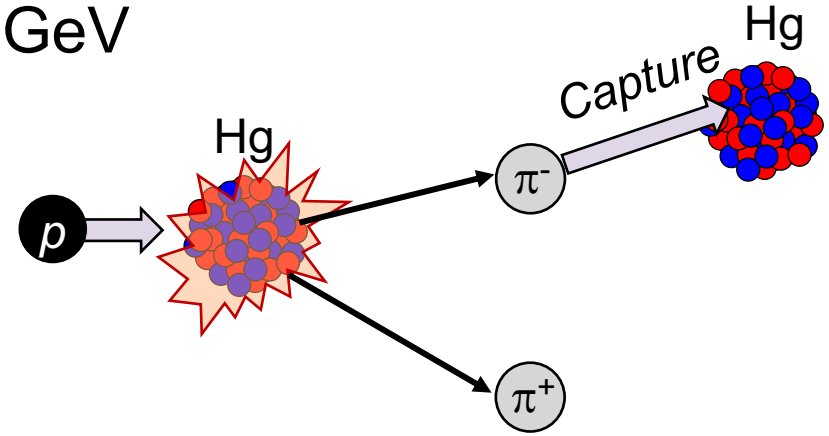


The Spallation Neutron Source





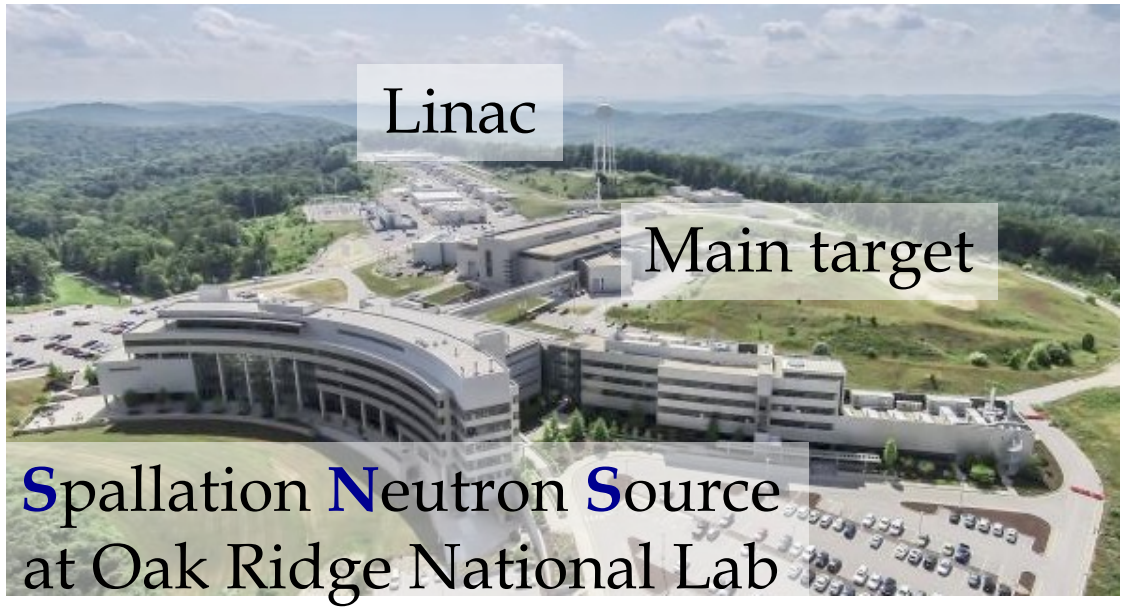
- Provides neutrons for materials science, life science, basic physics research
- Proton beam strikes liquid Hg target at ~1 GeV

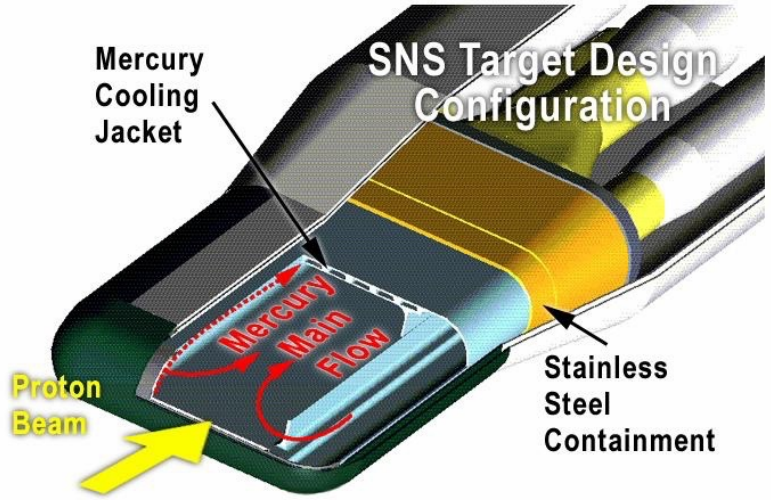


Decay at rest

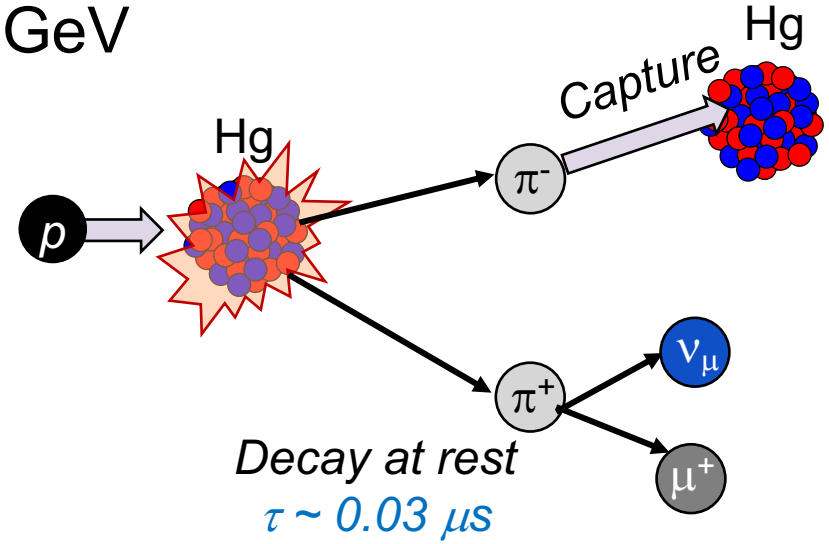
$\tau \sim 0.03\ \mu s$

The Spallation Neutron Source

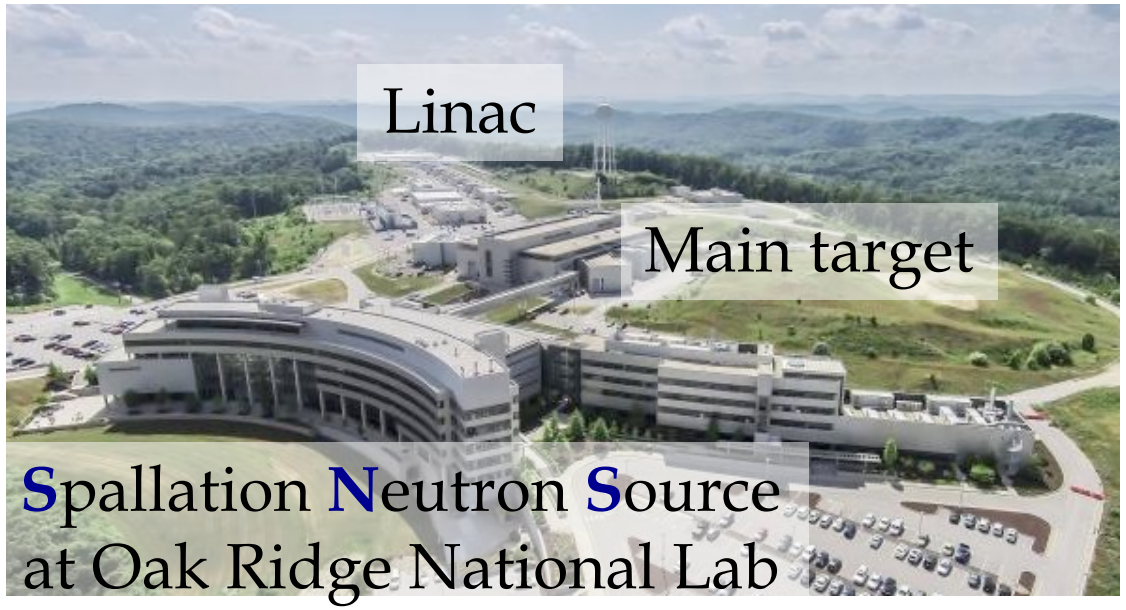


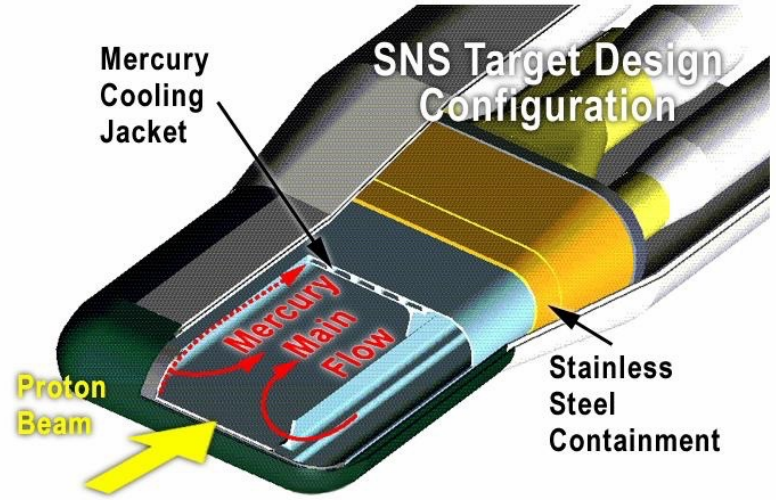


- Provides neutrons for materials science, life science, basic physics research
- Proton beam strikes liquid Hg target at ~1 GeV

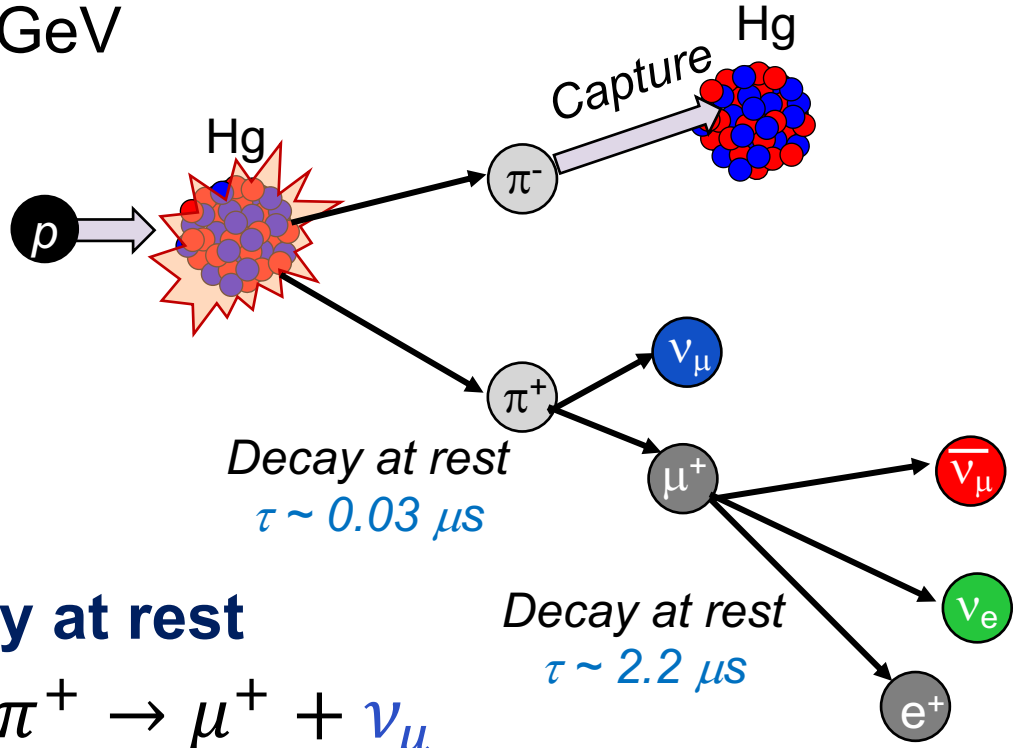


The Spallation Neutron Source





- Provides neutrons for materials science, life science, basic physics research
- Proton beam strikes liquid Hg target at ~1 GeV

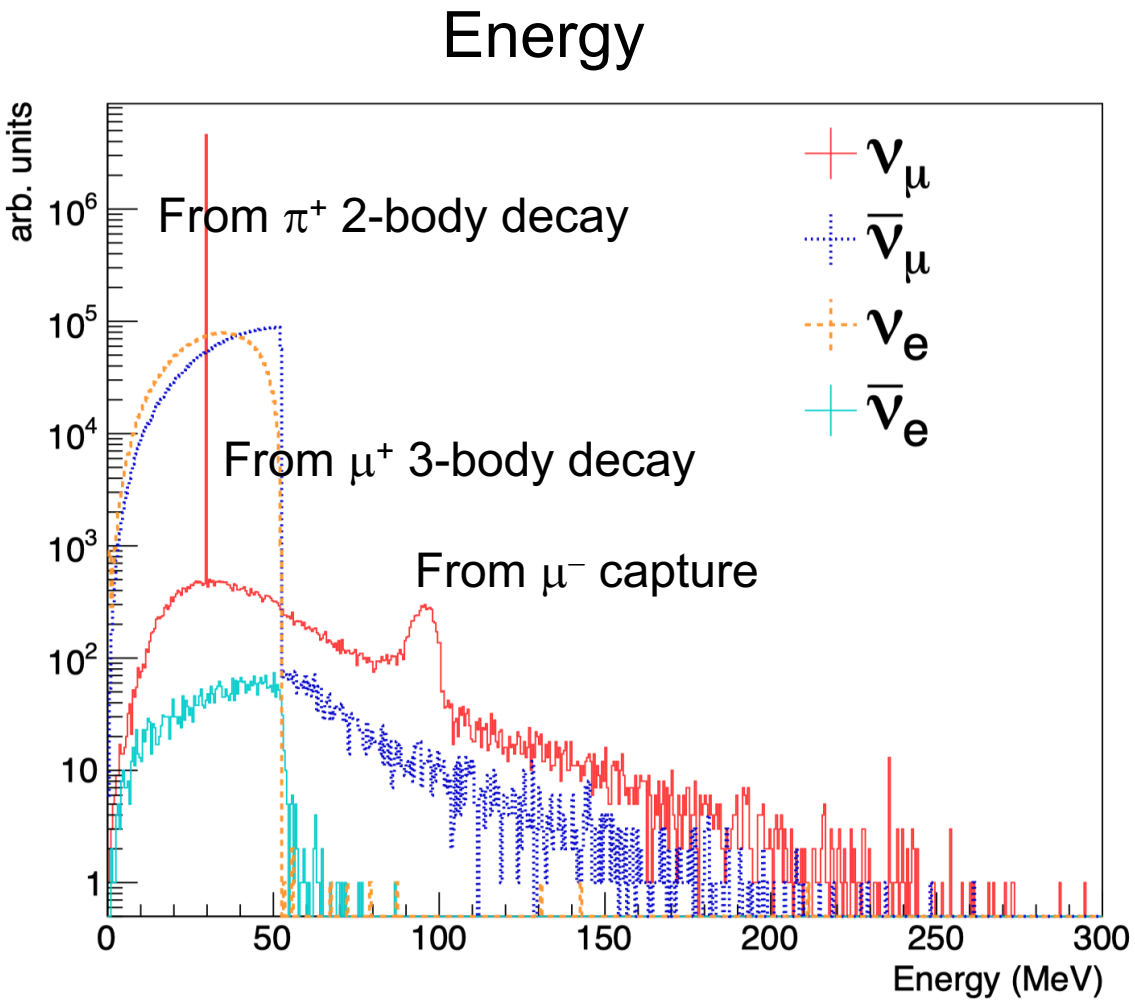


Pion decay at rest

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

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

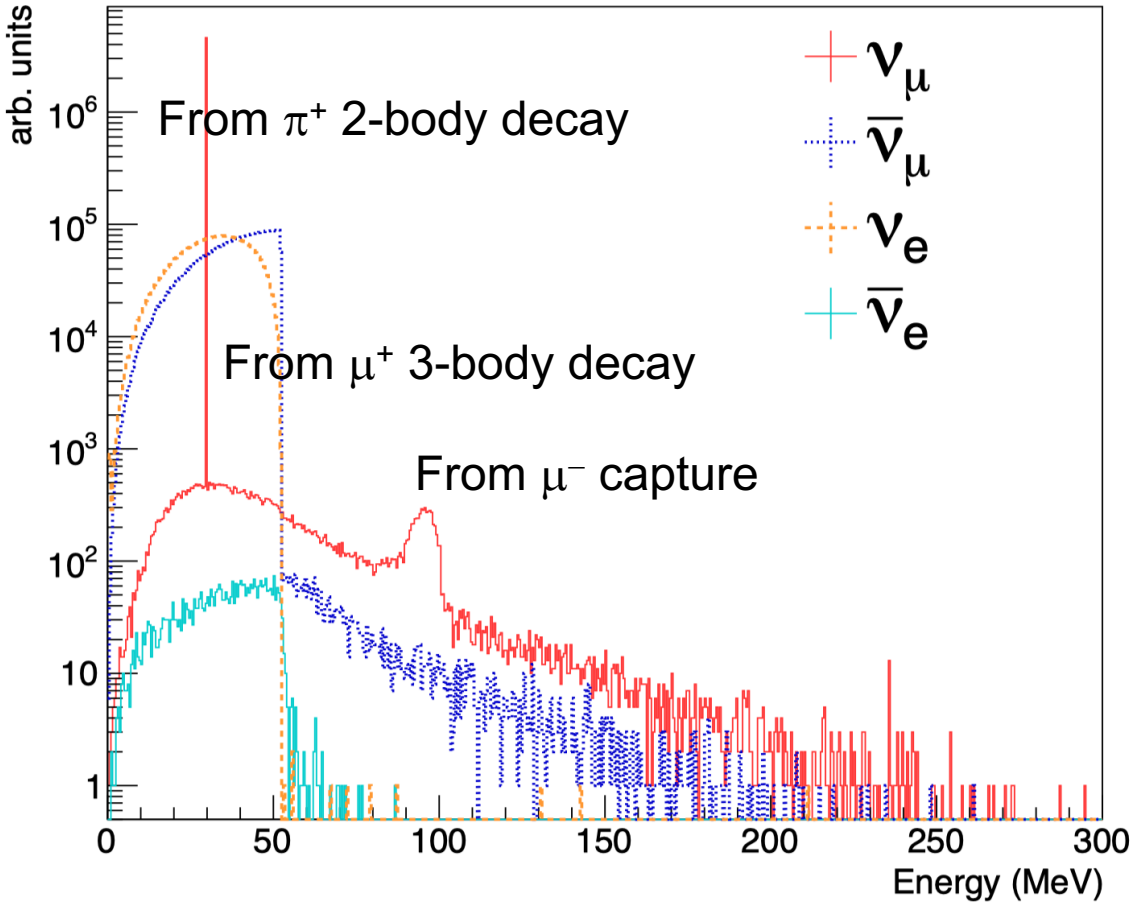
Spallation Neutron + Neutrino Source



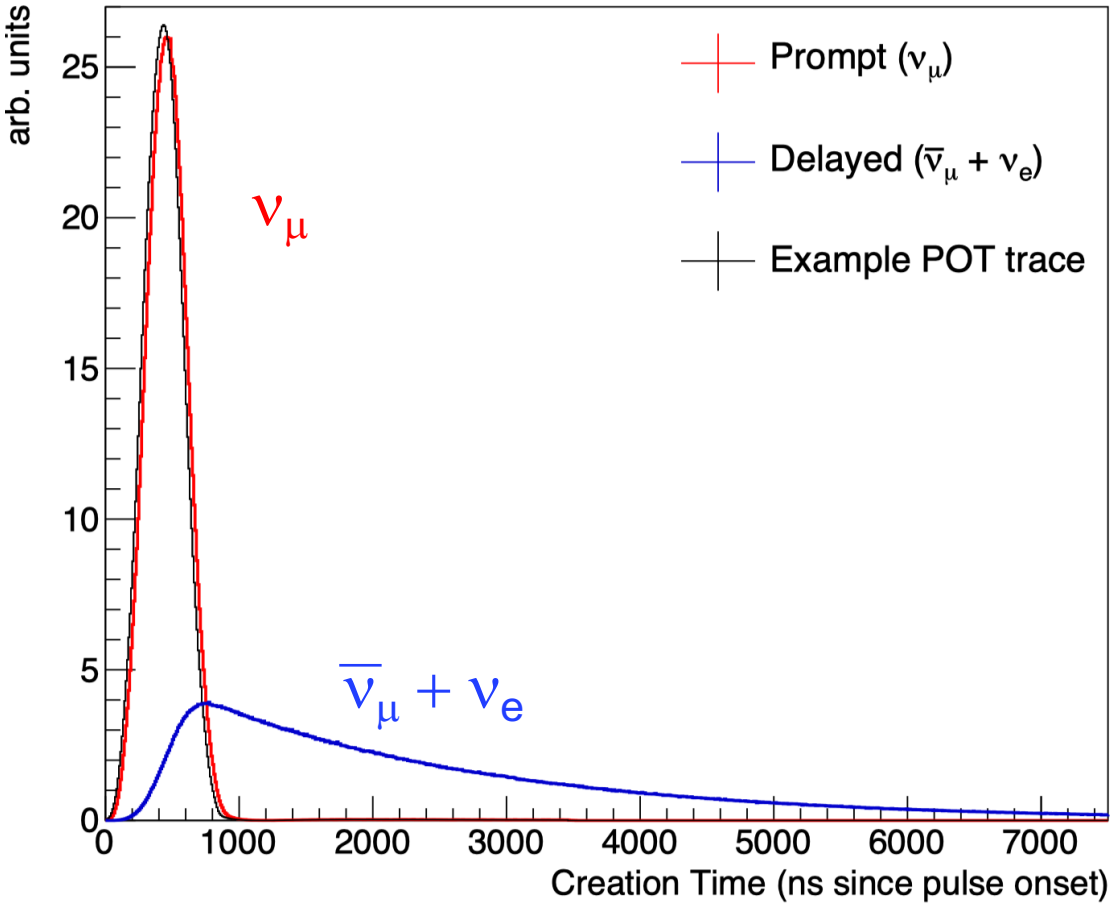
COHERENT, Phys. Rev. D **106** (2022) 032003

Spallation Neutron + Neutrino Source

Energy



Timing



COHERENT, Phys. Rev. D **106** (2022) 032003

The SNS as a Neutrino Source

Pulsed beam

- 2.28 x 10^{-5} duty factor, 60 Hz repetition rate
- Simple to subtract steady-state backgrounds

The SNS as a Neutrino Source

Pulsed beam

- 2.28 x 10^{-5} duty factor, 60 Hz repetition rate
- Simple to subtract steady-state backgrounds

Basement location with >20 m gravel+concrete fill

- Significant reduction of beam-related neutrons

The SNS as a Neutrino Source

Pulsed beam

- 2.28 x 10^{-5} duty factor, 60 Hz repetition rate
- Simple to subtract steady-state backgrounds

Basement location with >20 m gravel+concrete fill

- Significant reduction of beam-related neutrons

Proton power upgrade underway

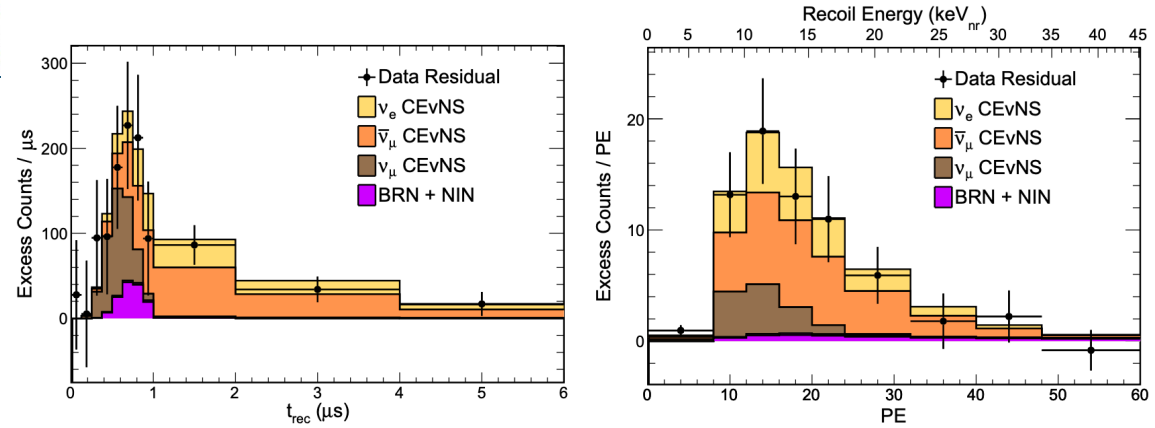
- Average beam current: 26 mA → **38 mA**
- Average beam energy: 0.97 GeV → **1.3 GeV**

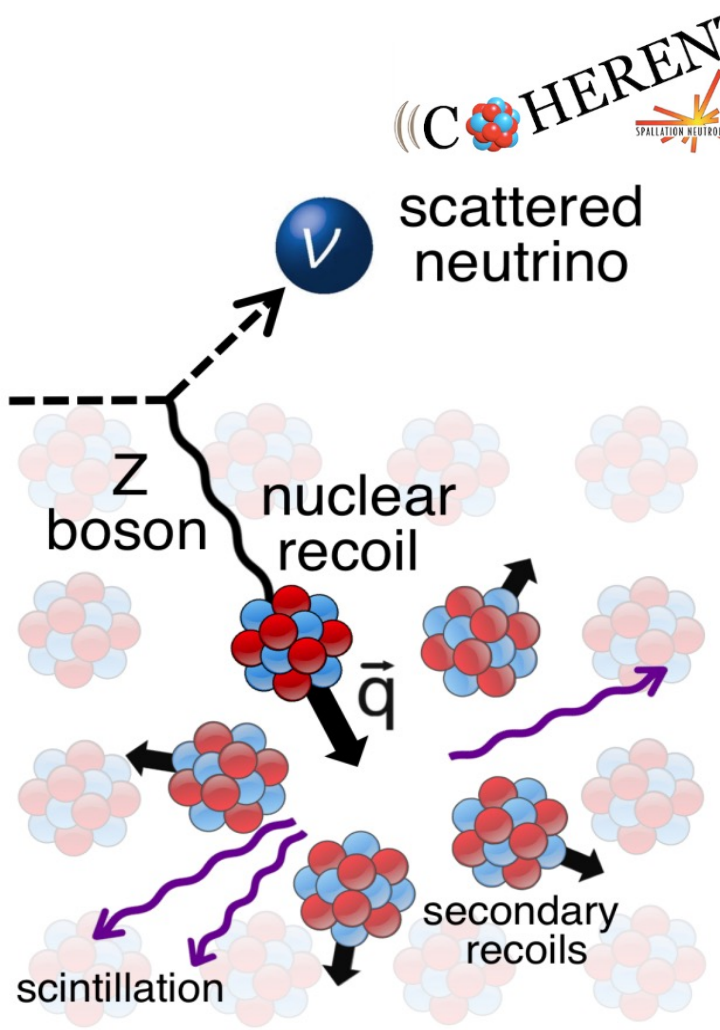
The SNS as a Neutrino Source

- Pulsed beam
  - 2.28 x 10^{-5} duty factor, 60 Hz repetition rate
  - Simple to subtract steady-state backgrounds
- Basement location with >20 m gravel+concrete fill
  - Significant reduction of beam-related neutrons
- Proton power upgrade underway
  - Average beam current: 26 mA → **38 mA**
  - Average beam energy: 0.97 GeV → **1.3 GeV**
- Just a little bit cramped …

CEvNS on CsI

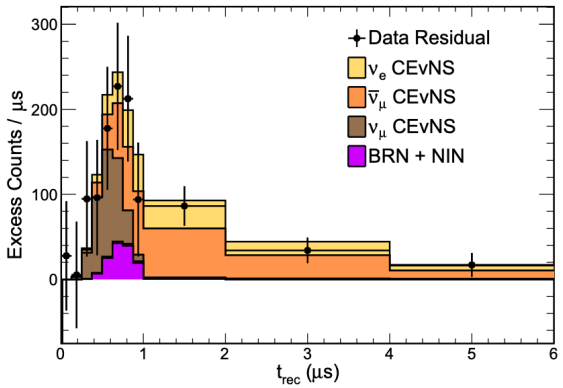
*COHERENT, PRL **129** (2022) 081801*

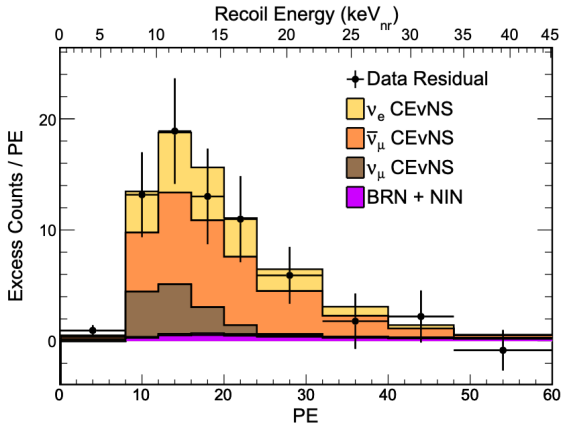




CEvNS on CsI

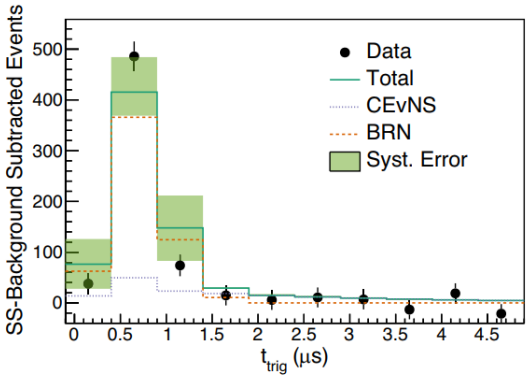
*COHERENT, PRL **129** (2022) 081801*

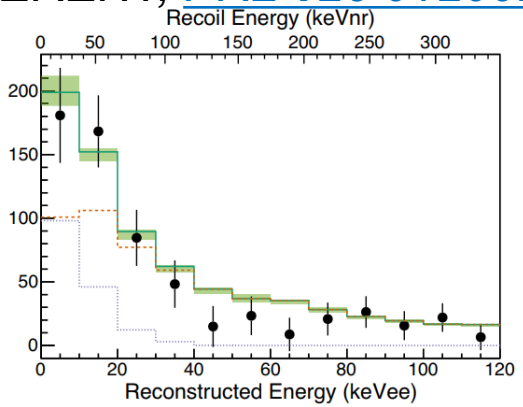


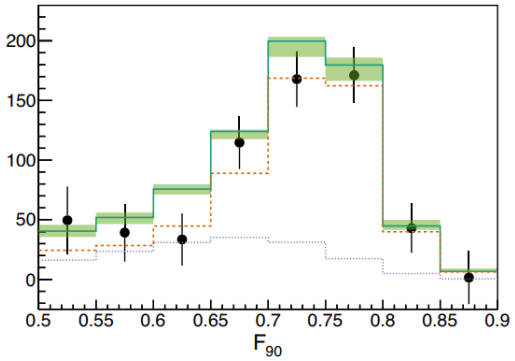


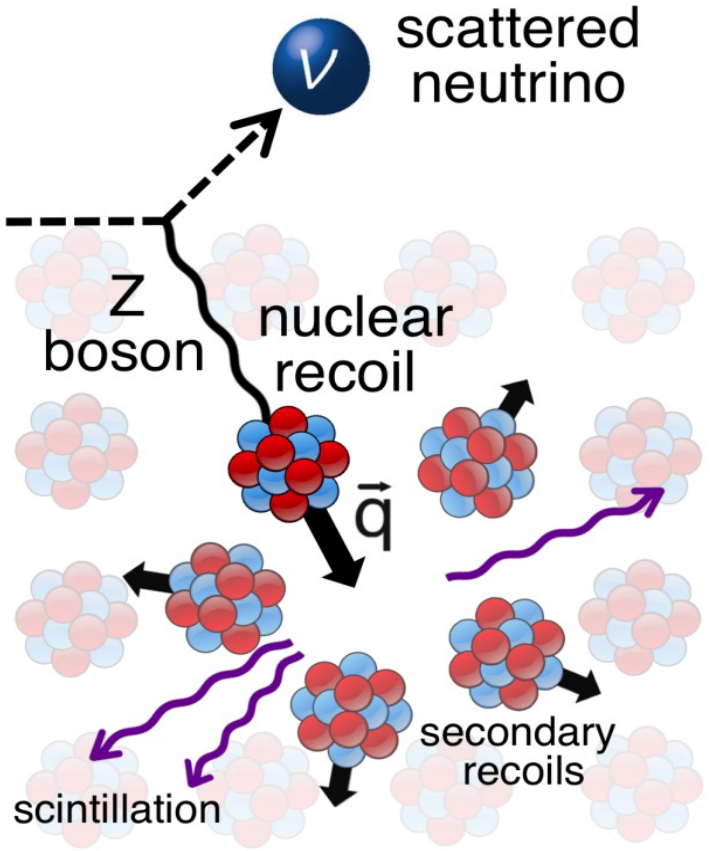
CEvNS on Ar

*COHERENT, PRL **126** 012002 (2021)*



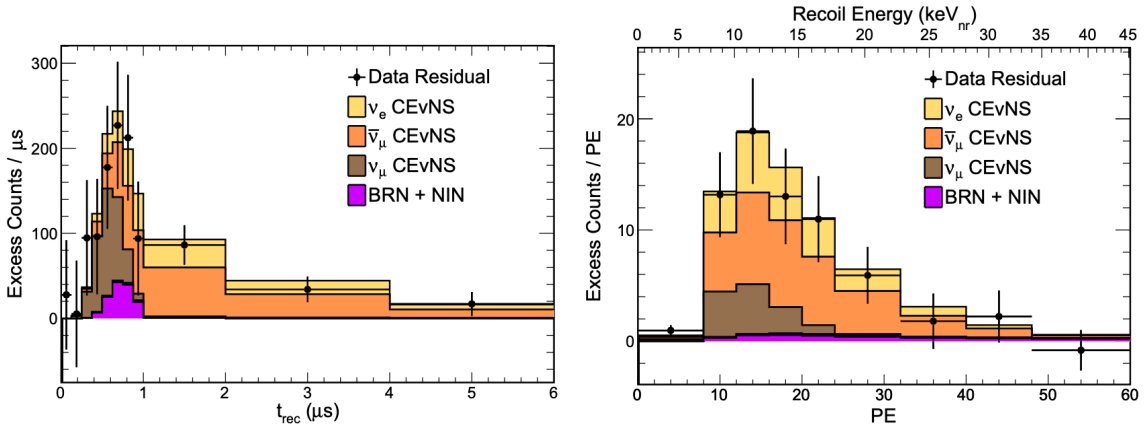






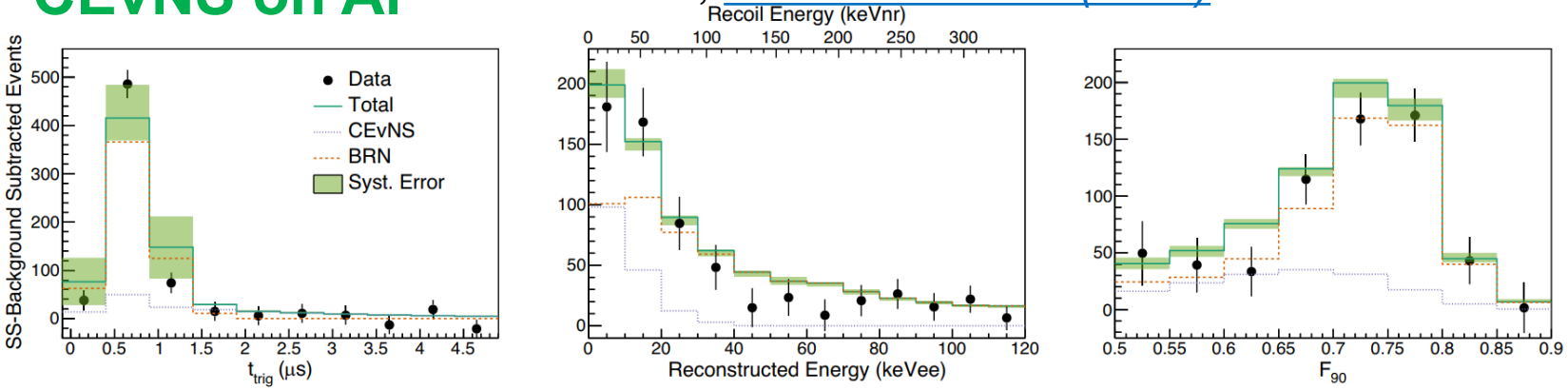
CEvNS on CsI

*COHERENT, PRL **129** (2022) 081801*



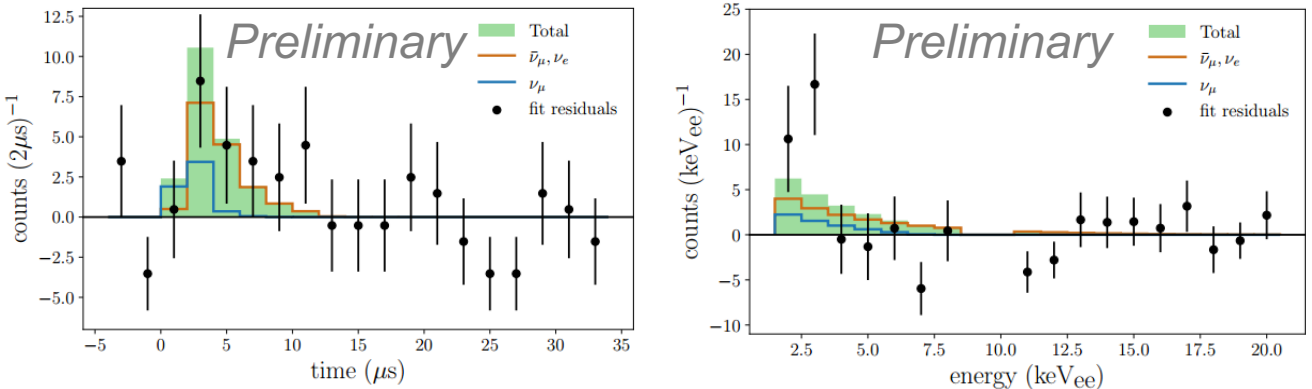
CEvNS on Ar

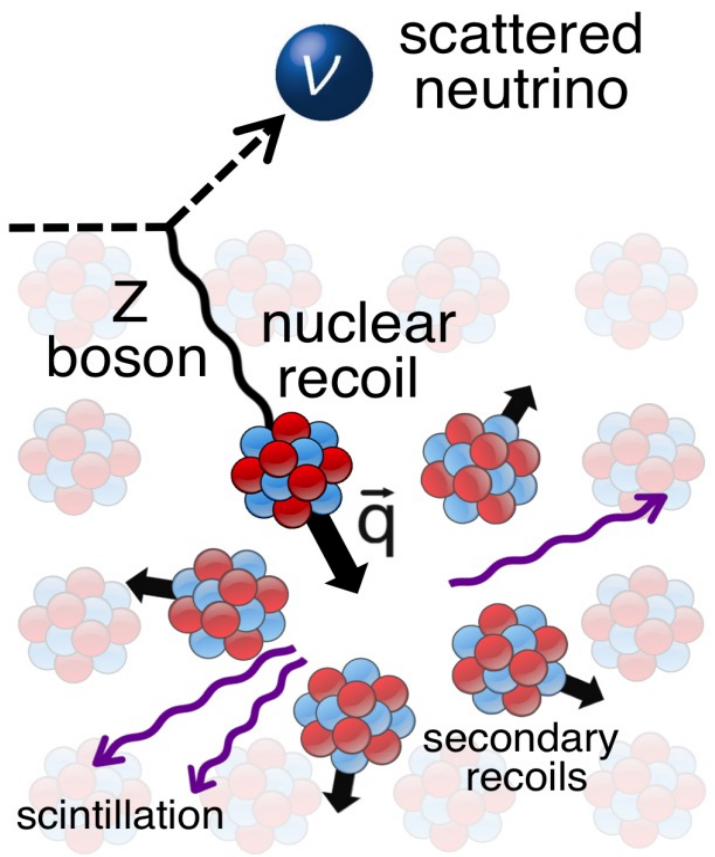
*COHERENT, PRL **126** 012002 (2021)*



CEvNS on Ge

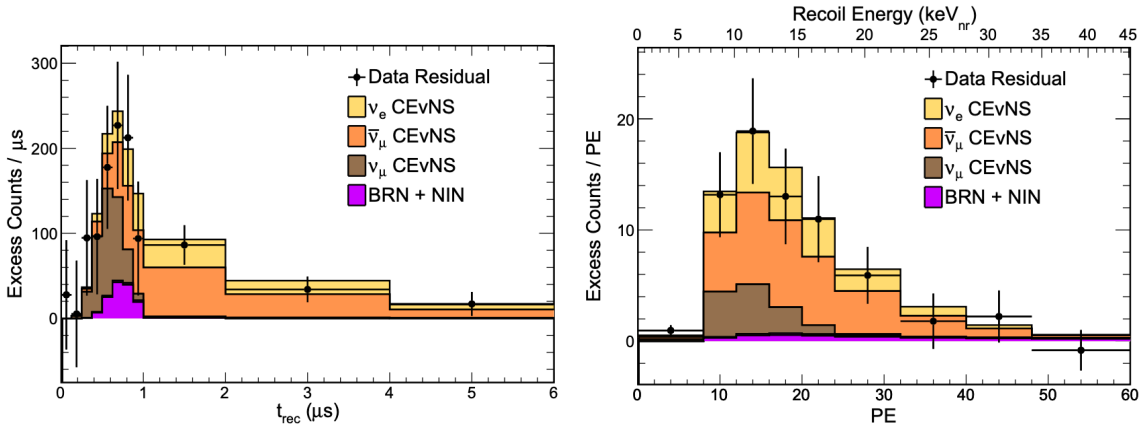
Paper in preparation





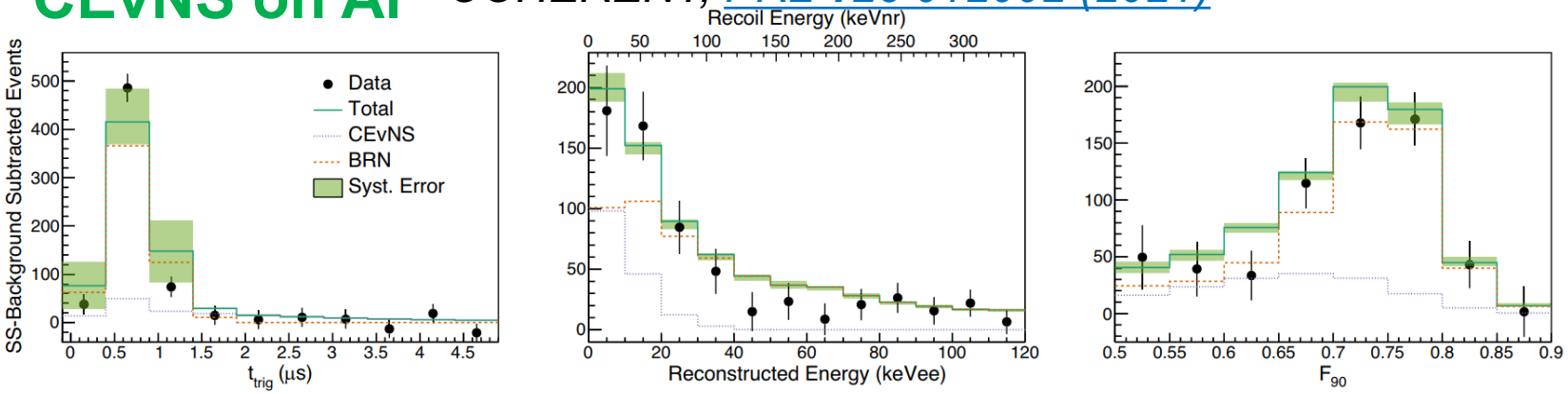
CEvNS on CsI

*COHERENT, PRL **129** (2022) 081801*



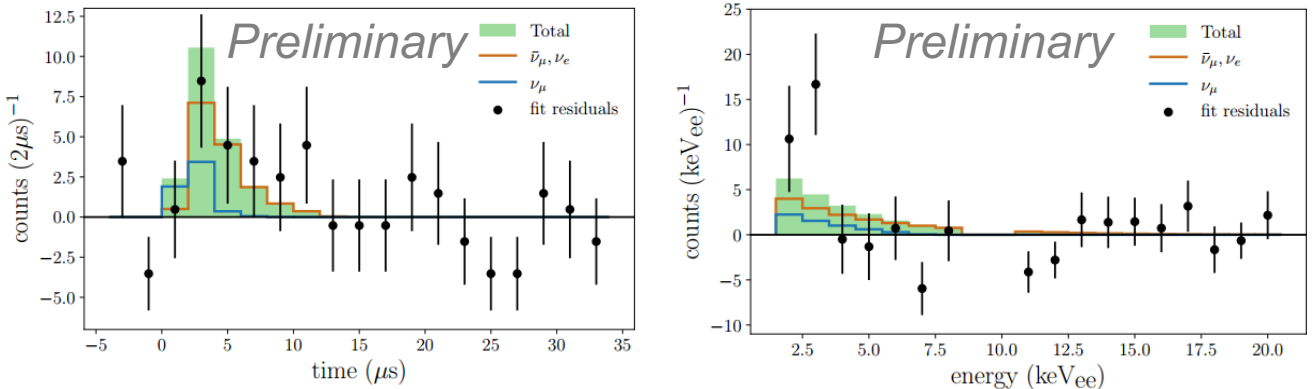
CEvNS on Ar

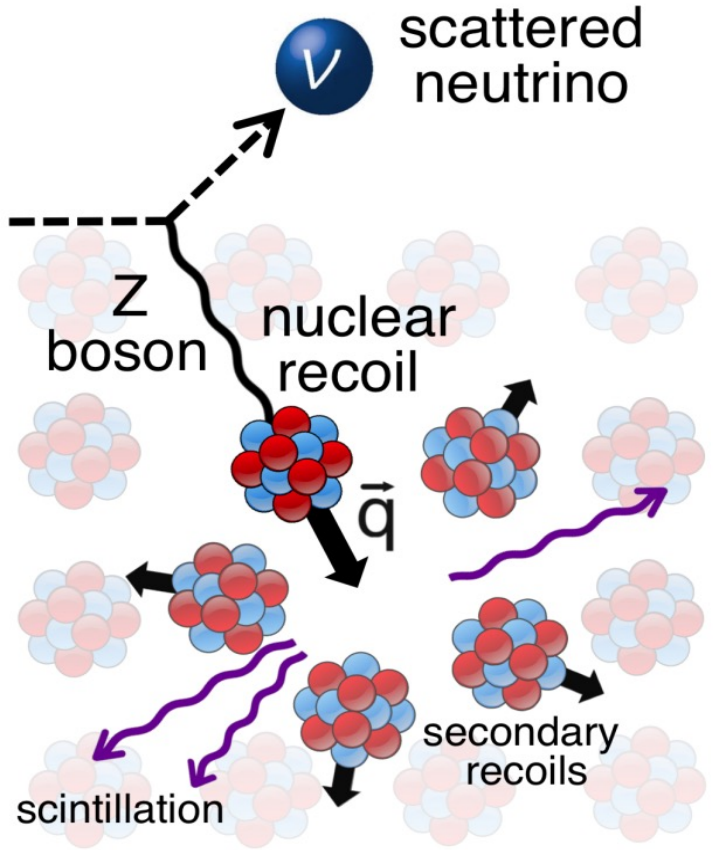
*COHERENT, PRL **126** 012002 (2021)*



CEvNS on Ge

Paper in preparation



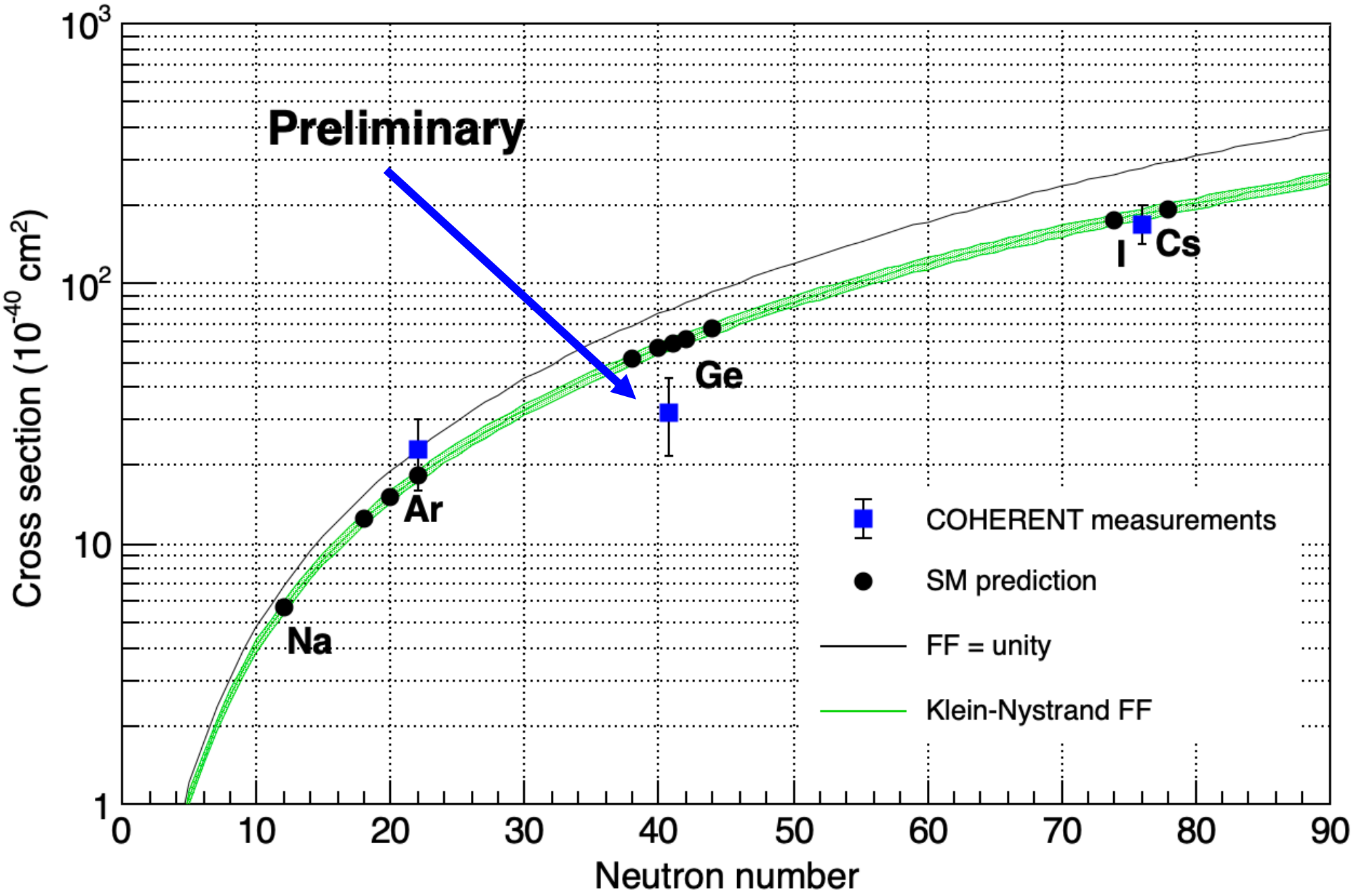


Next Talk

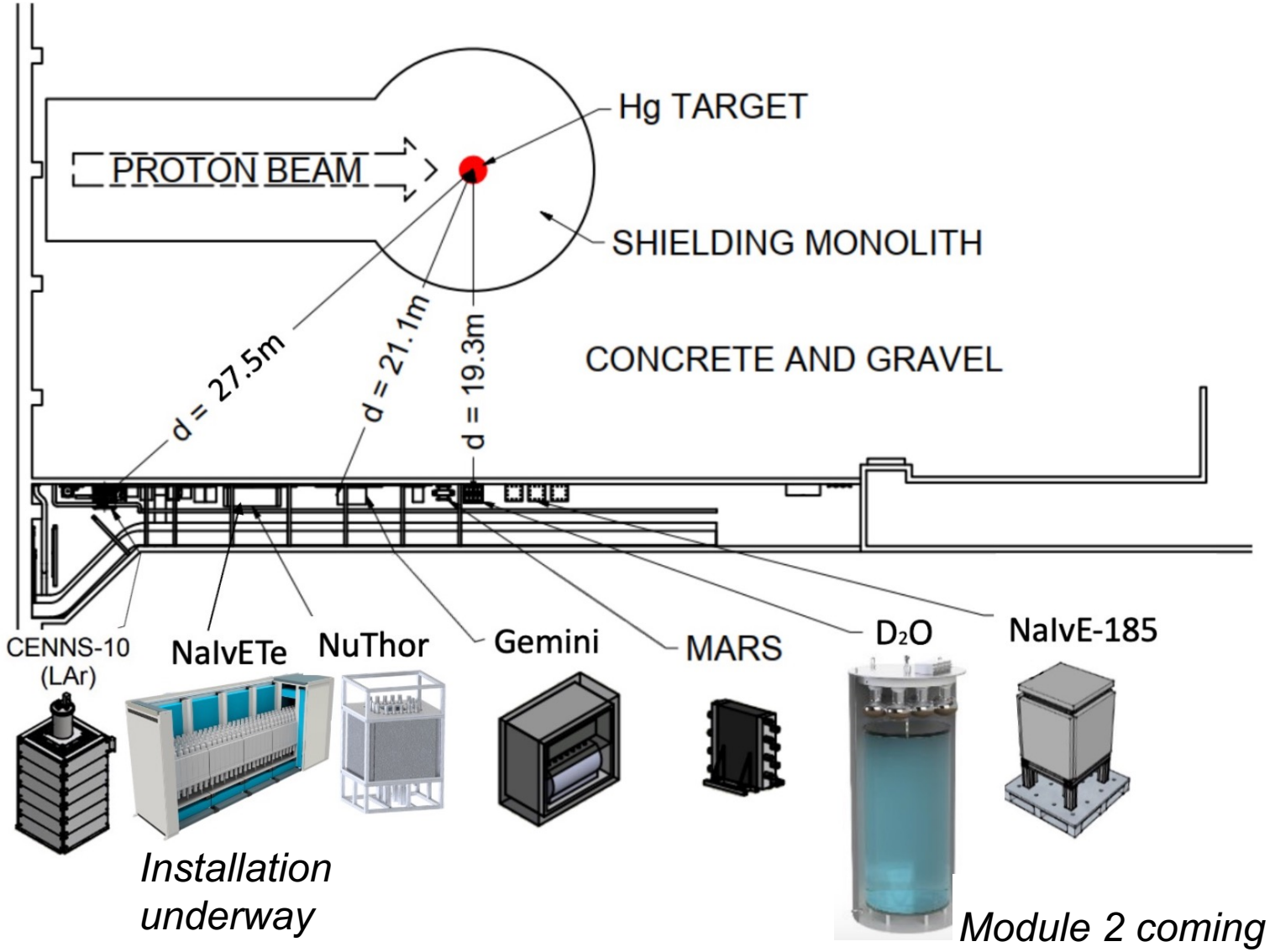
Ryan Bouabid

Poster

Emma van Nieuwenhuizen


Preliminary
Cross section (10^{-40} cm^2)
Neutron number
Na
Ar
Ge
I
Cs
COHERENT measurements
SM prediction
FF = unity
Klein-Nystrand FF

Neutrino Alley 2024

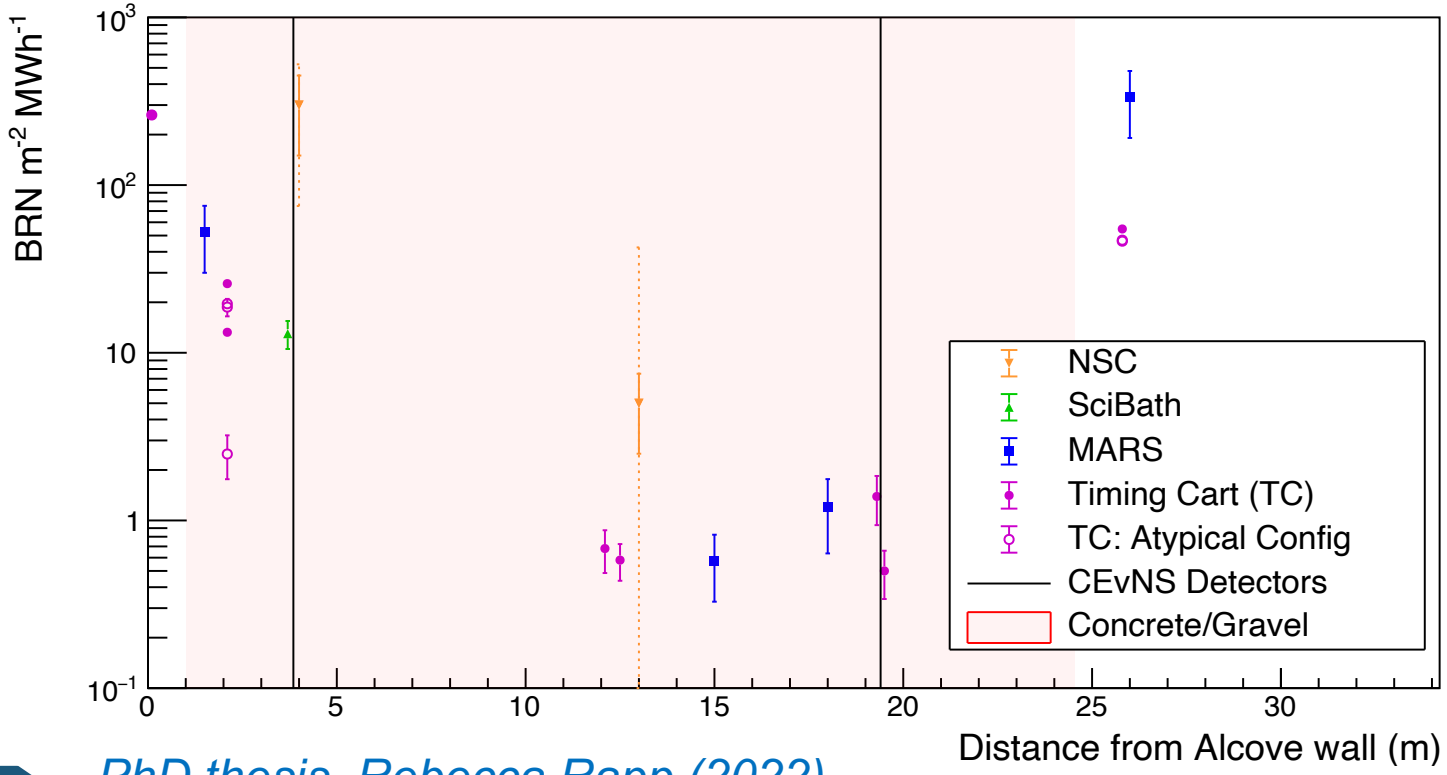


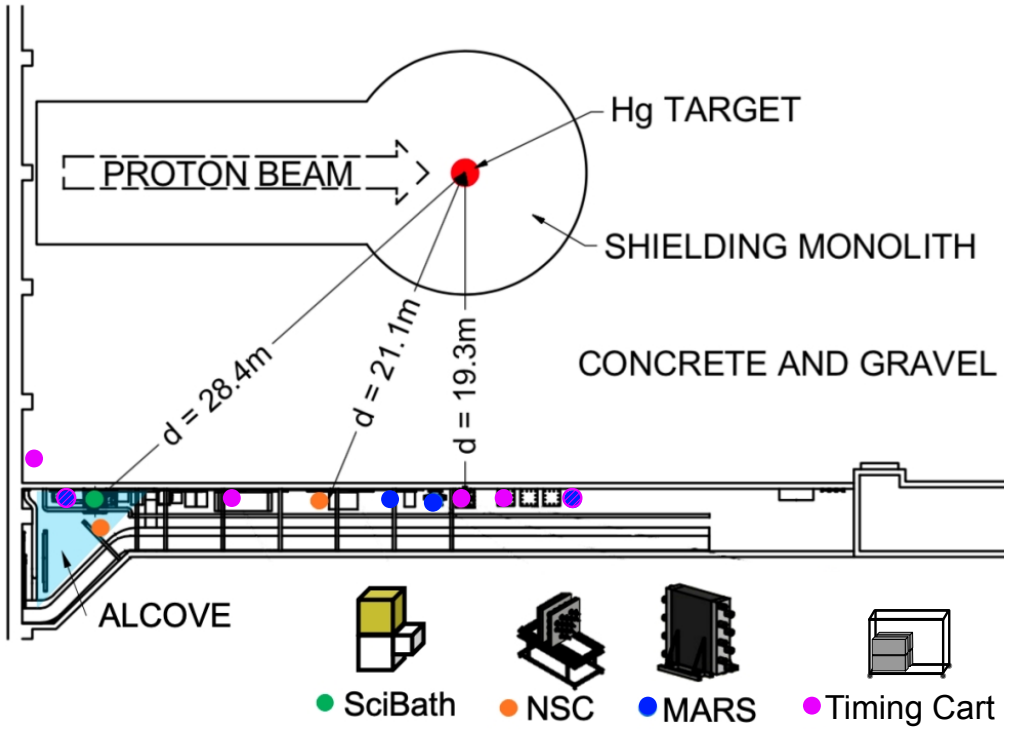
Installation underway

Module 2 coming soon

SNS Backgrounds

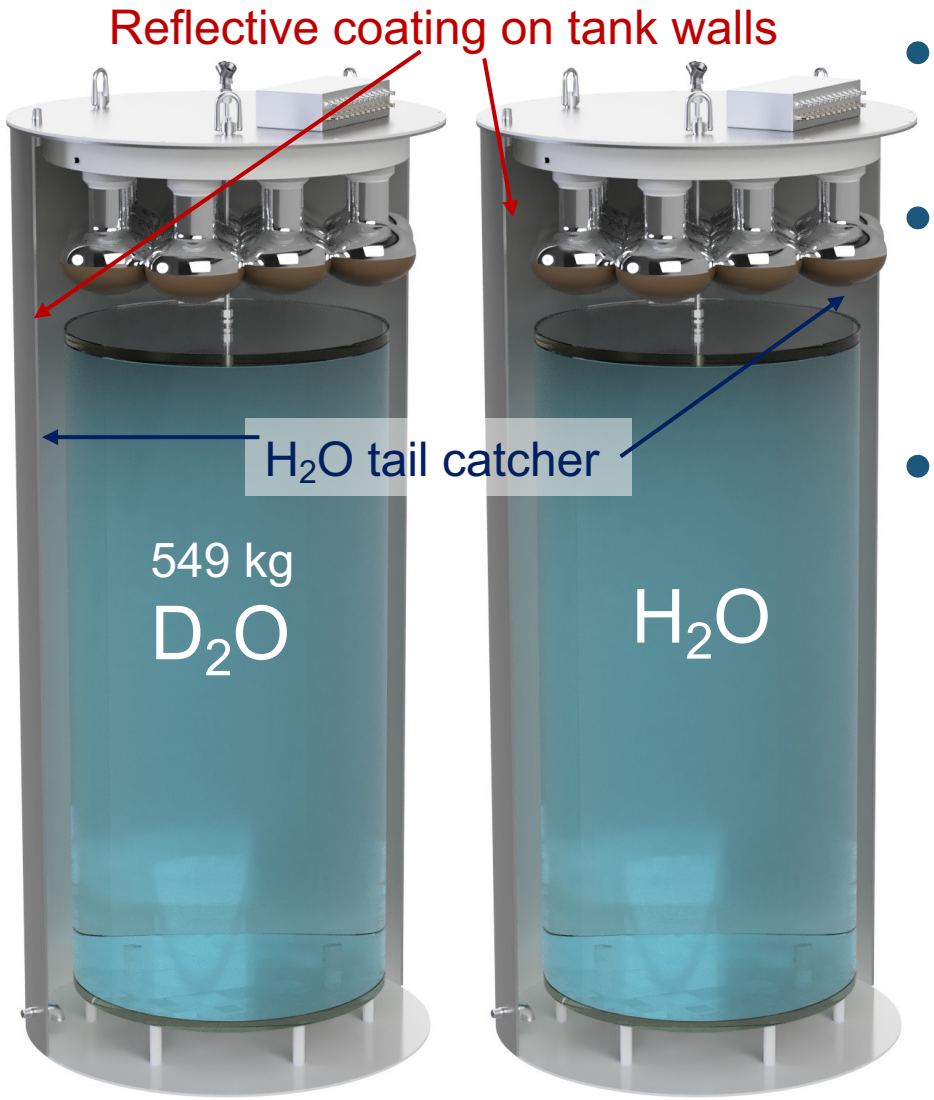
- **Steady-state**: Cosmic-ray muons, 511-keV γs, environmental radioactivity
- **Beam-related neutrons**
  - Measured in several locations with multiple detectors
  - Flux depends strongly on location in Neutrino Alley



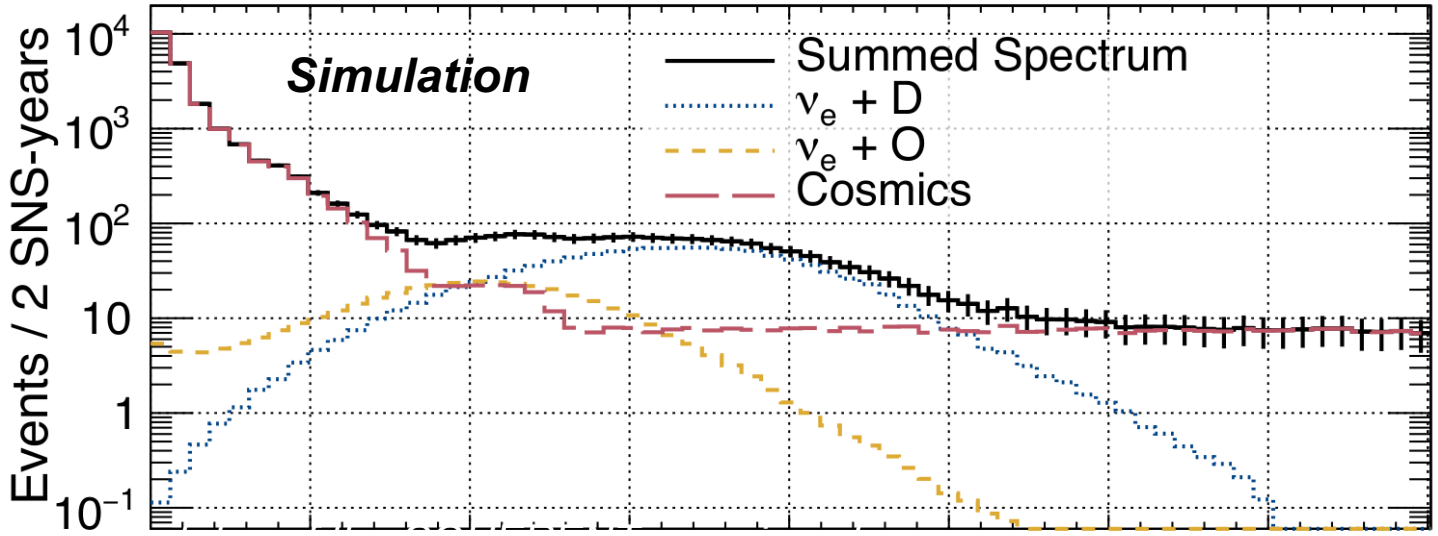


PhD thesis, Rebecca Rapp (2022)

COH-R²D₂O: Neutrino Flux



- Neutrino flux is a shared ~10% systematic across all ν-interaction measurements!
- Use $\nu_e + d \rightarrow p + p + e^-$ reaction to benchmark actual SNS ν flux
  - Theoretical cross-section uncertainty 2-3%
- With two modules, control CC-O backgrounds and detector response



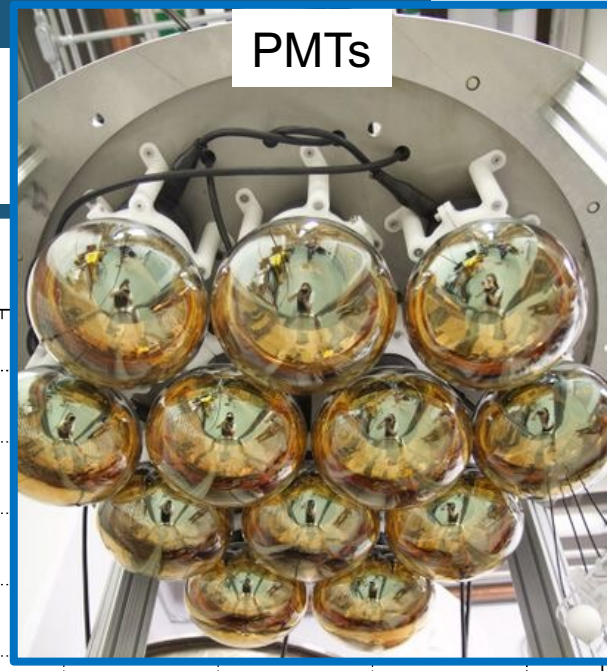
*COHERENT, JINST **16** P08048 (2021)*

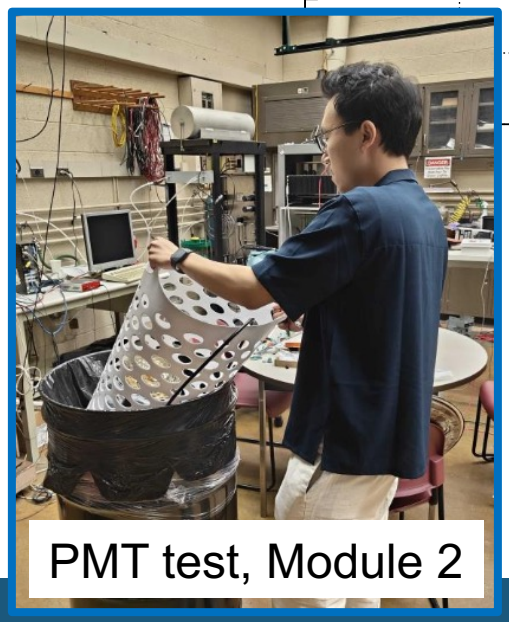
COH-R²D₂O Status

- Module 1 deployed summer 2023!
- Module 2 under construction
  - PMTs tested (wet+dry)
  - Deployment planned this summer

Module 1


LED calibration system

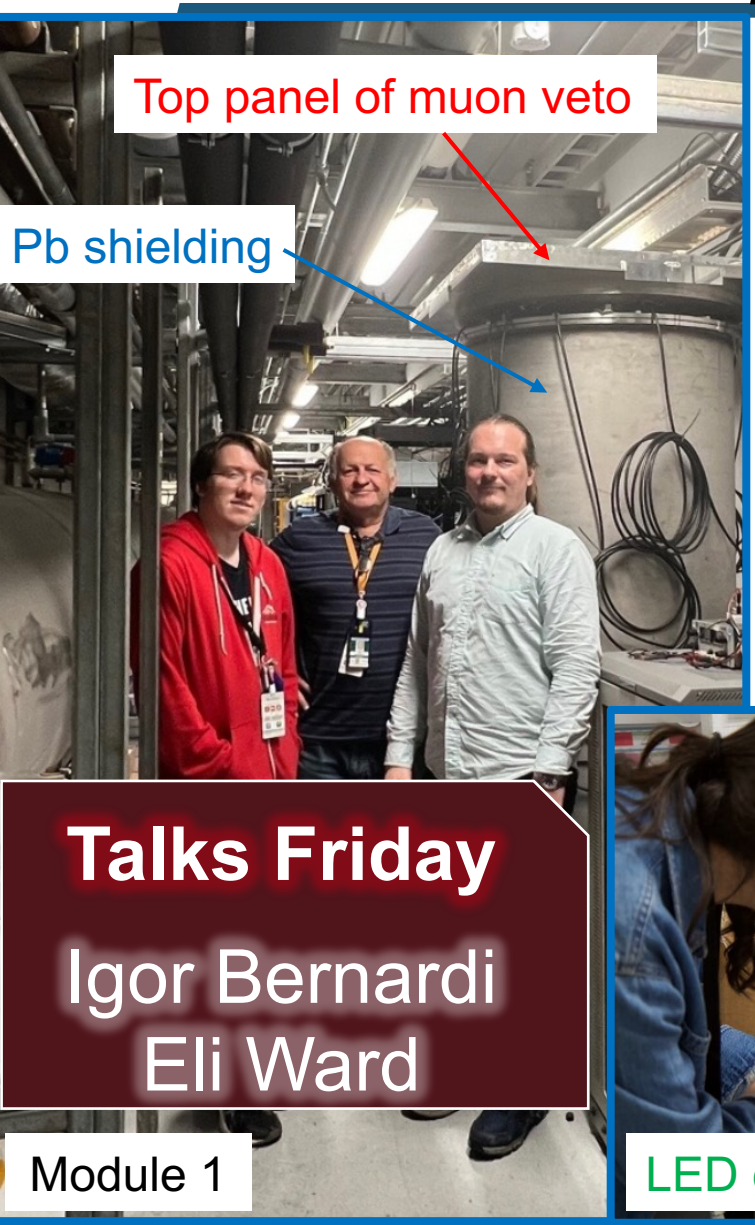

PMTs

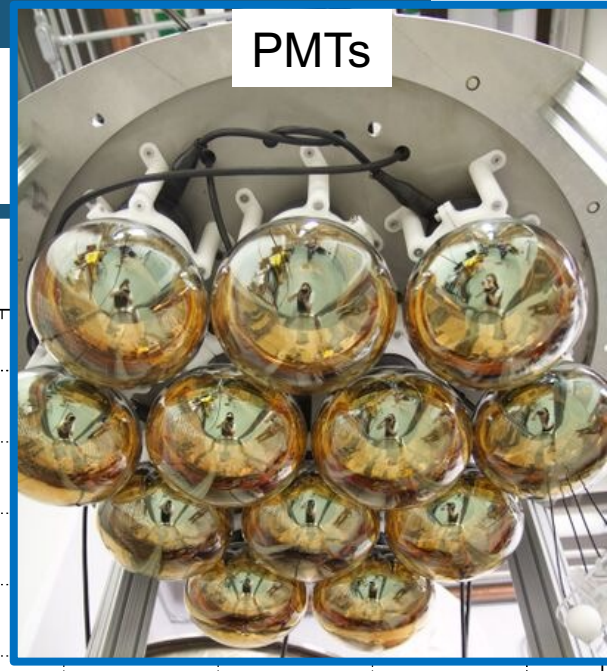

PMT test, Module 2


Cable assembly, Module 2

COH-R²D₂O Status

- Module 1 deployed summer 2023!





Talks Friday

Igor Bernardi
Eli Ward

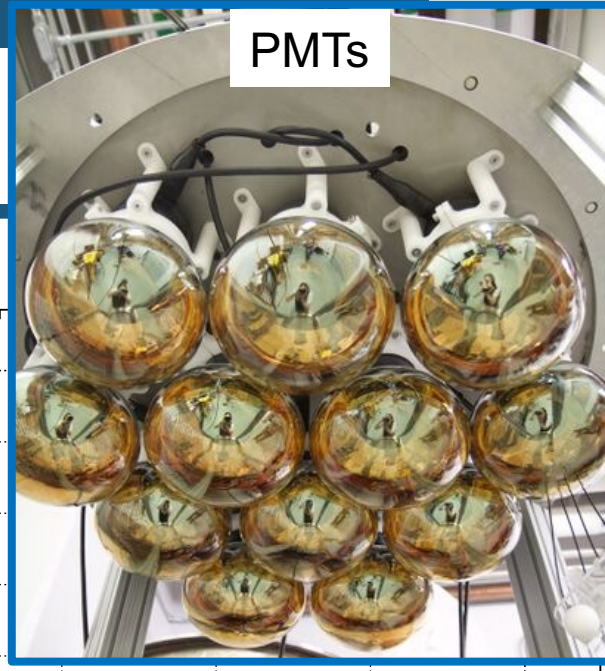
COH-R²D₂O Status

- Module 1 deployed summer 2023!
- Module 2 under construction
  - PMTs tested (wet+dry)
  - Deployment planned this summer

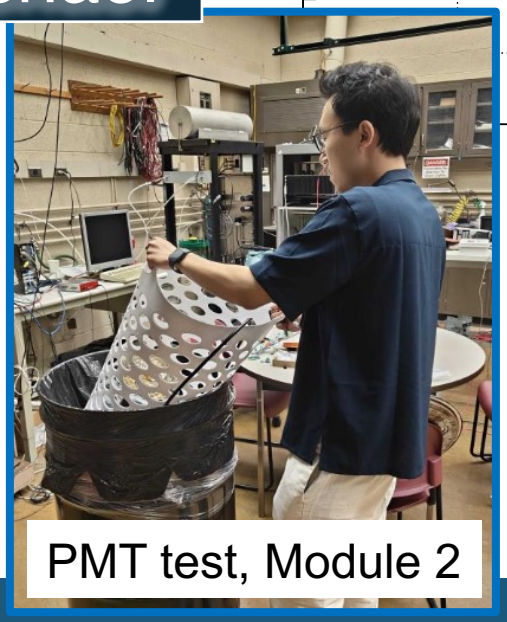
Module 1

Poster
Gen Li + Kirsten McMichael

Talks Friday
Igor Bernardi
Eli Ward


PMTs

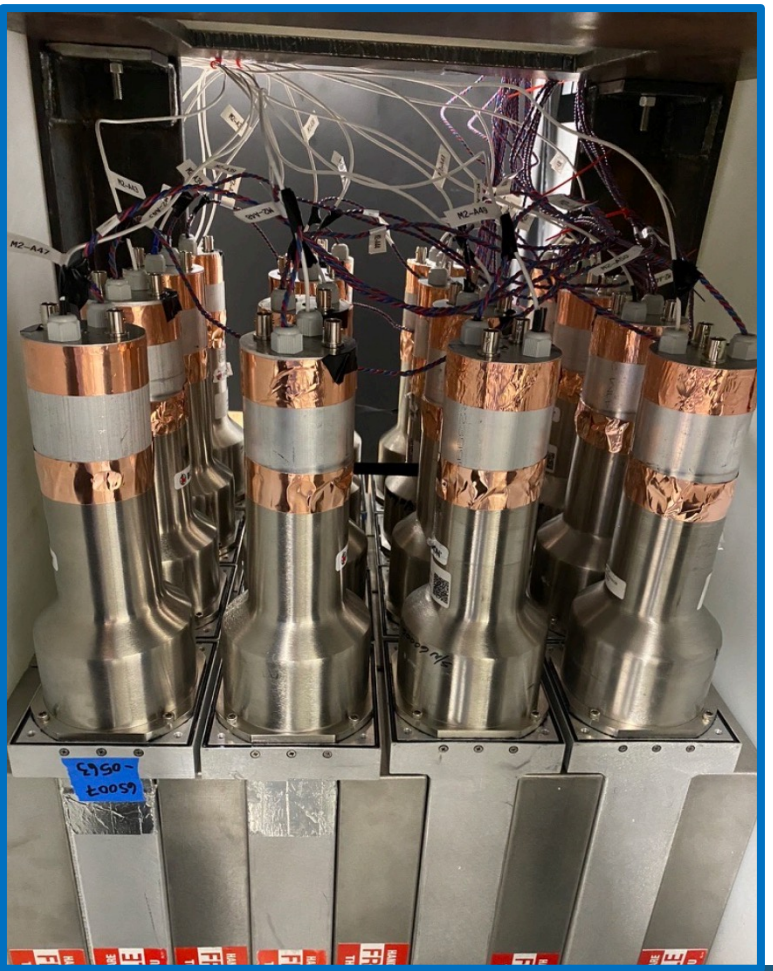

LED calibration system


PMT test, Module 2


Cable assembly, Module 2

Coming Soon: COH-NaIvETe

- 2425 kg of NaI crystals, partially deployed!
  - Plan: dual-gain running for both CEvNS and CC measurements



- Commissioning and analysis underway in CEvNS mode
- More modules to be deployed Summer 2024

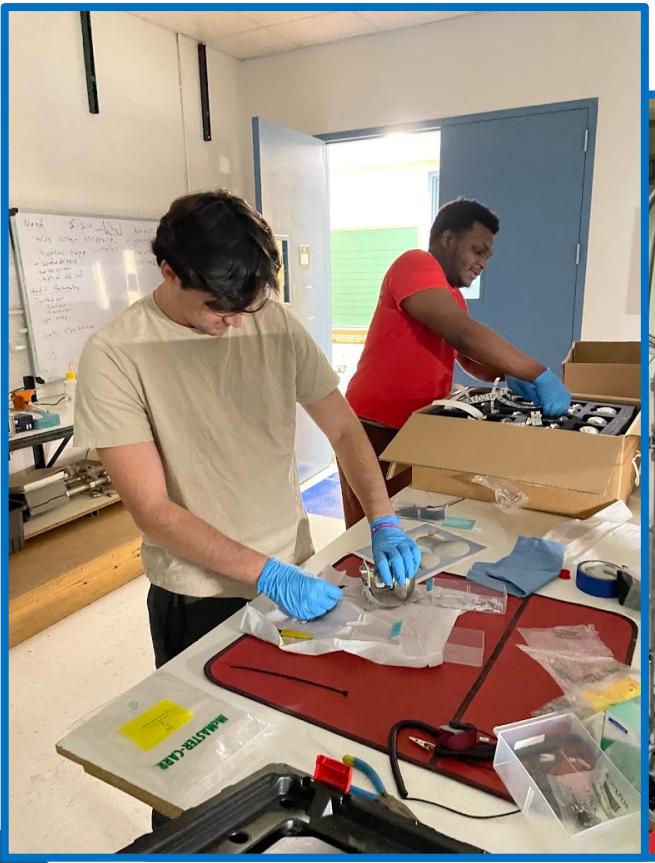
Poster
Nixon Ogoi

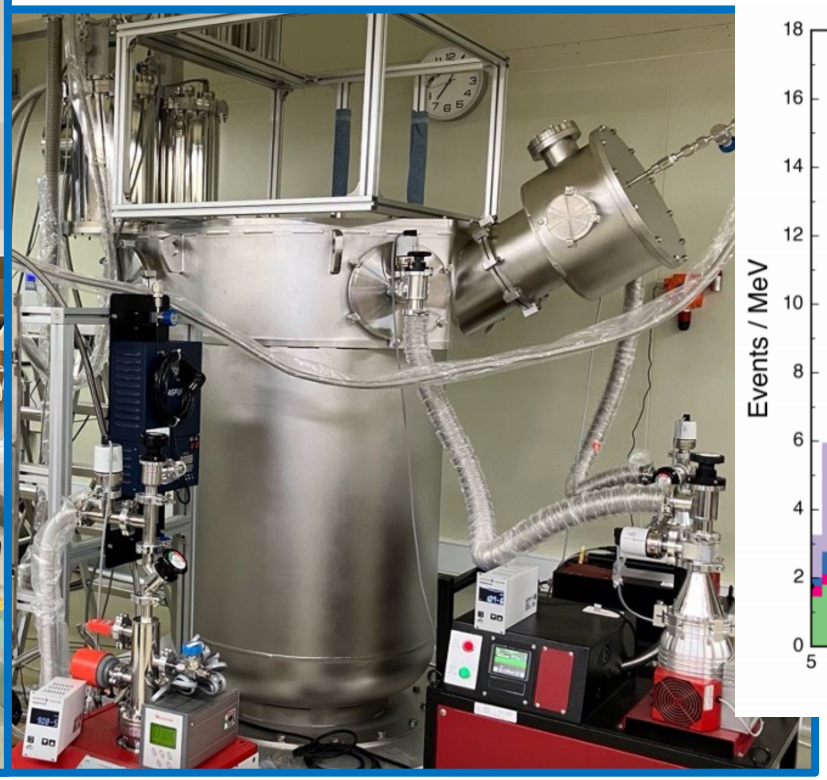
Coming Soon: Next-Generation LAr

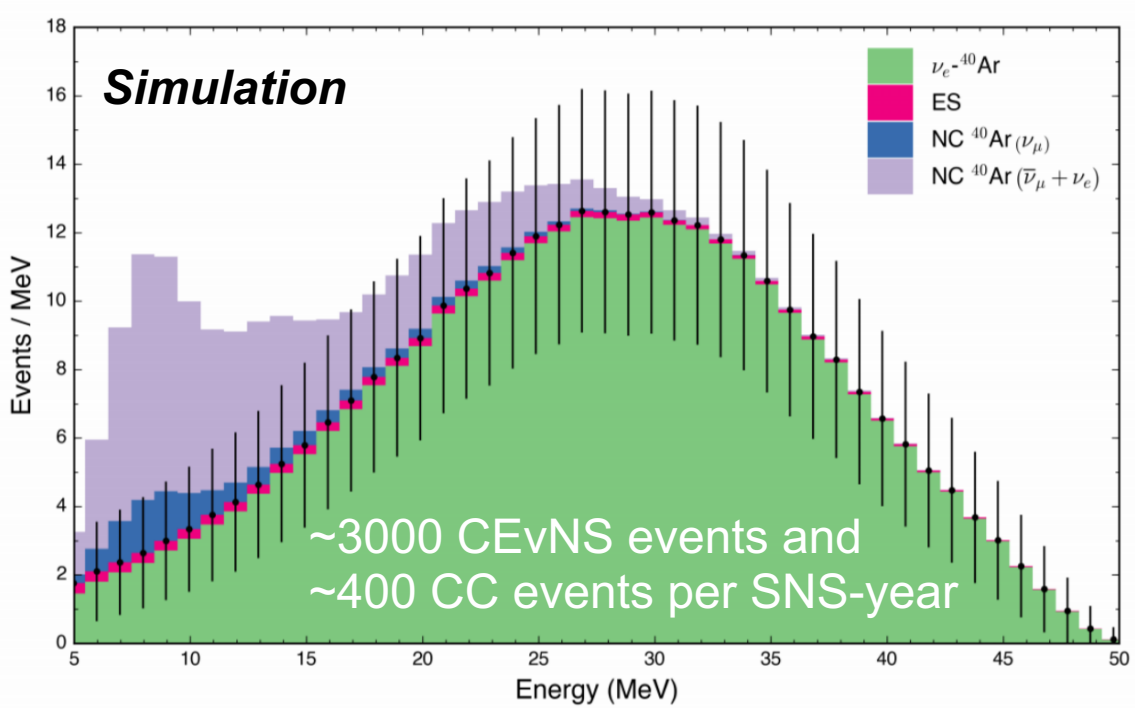
- While COH-Ar-10 final dataset is being analyzed (22 kg, 2 PMTs)…
- …A new LAr detector with 600kg fiducial volume and 122 PMTs is under construction in South Korea and the USA!

Coming Soon: Next-Generation LAr

- While COH-Ar-10 final dataset is being analyzed (22 kg, 2 PMTs)…
- …A new LAr detector with 600kg fiducial volume and 122 PMTs is under construction in South Korea and the USA!



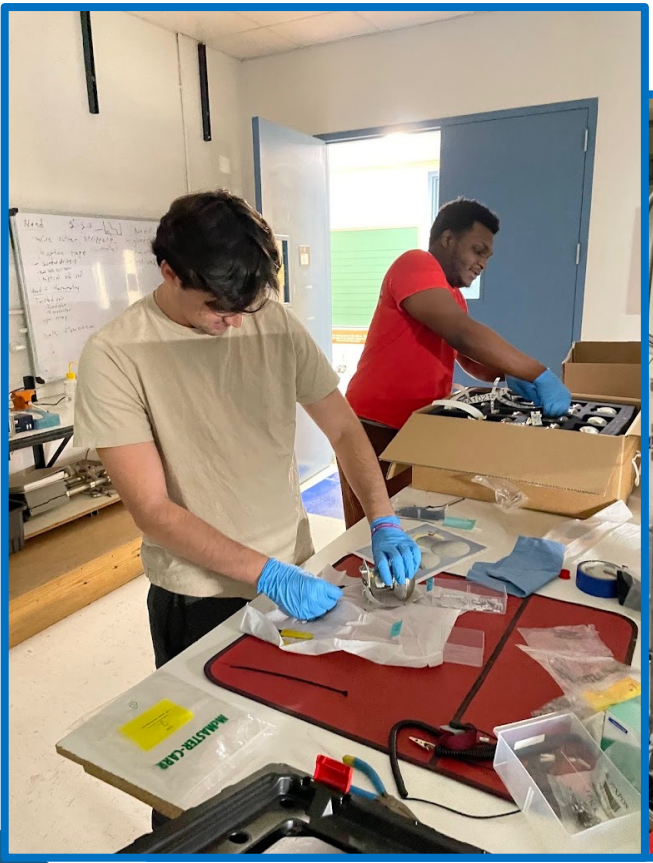


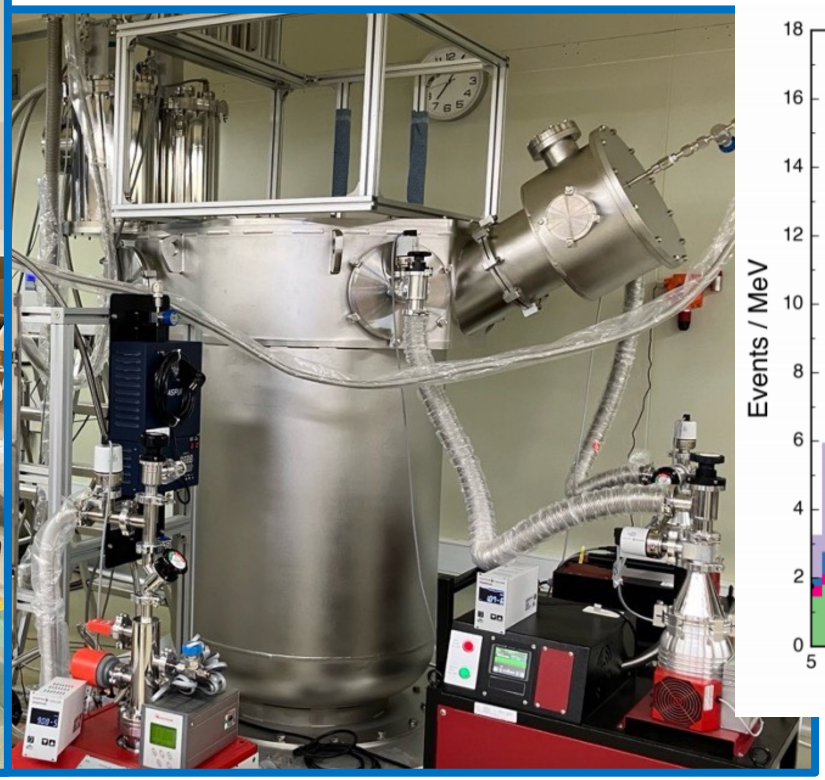


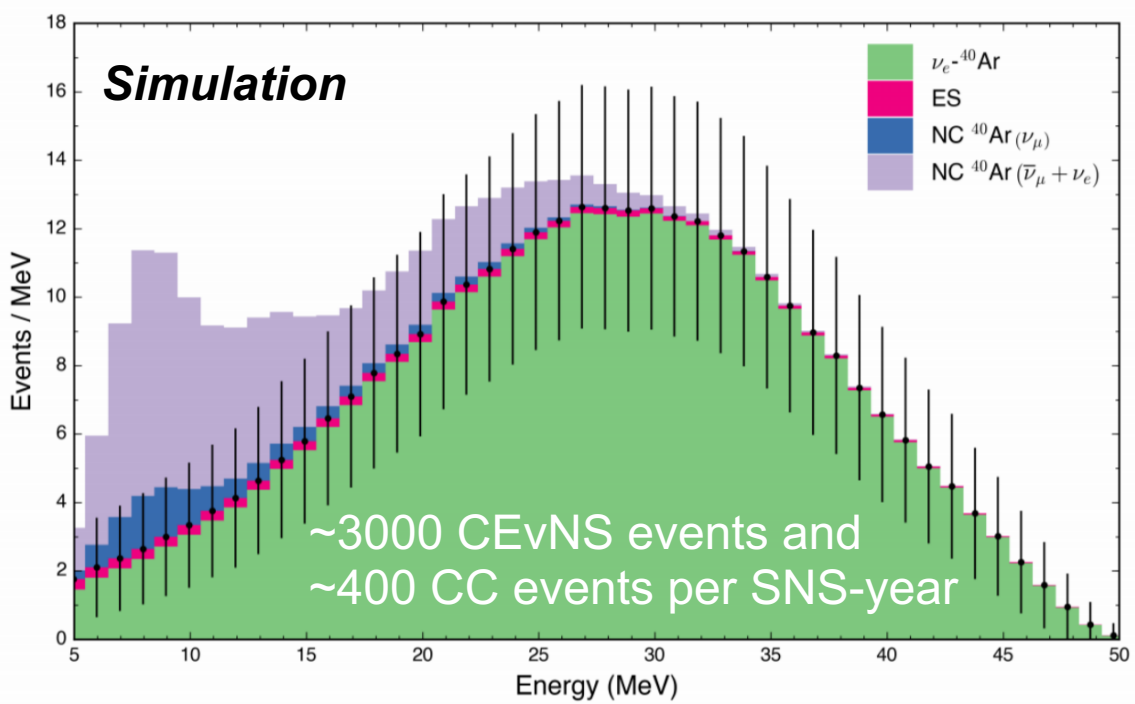
COHERENT, 2204.04575 (Snowmass white paper)

Coming Soon: Next-Generation LAr

- While COH-Ar-10 final dataset is being analyzed (22 kg, 2 PMTs)…
- …A new LAr detector with 600kg fiducial volume and 122 PMTs is under construction in South Korea and the USA!
- Future upgrade possibility: underground argon







COHERENT, 2204.04575 (Snowmass white paper)

Planning: Cryo-CsI

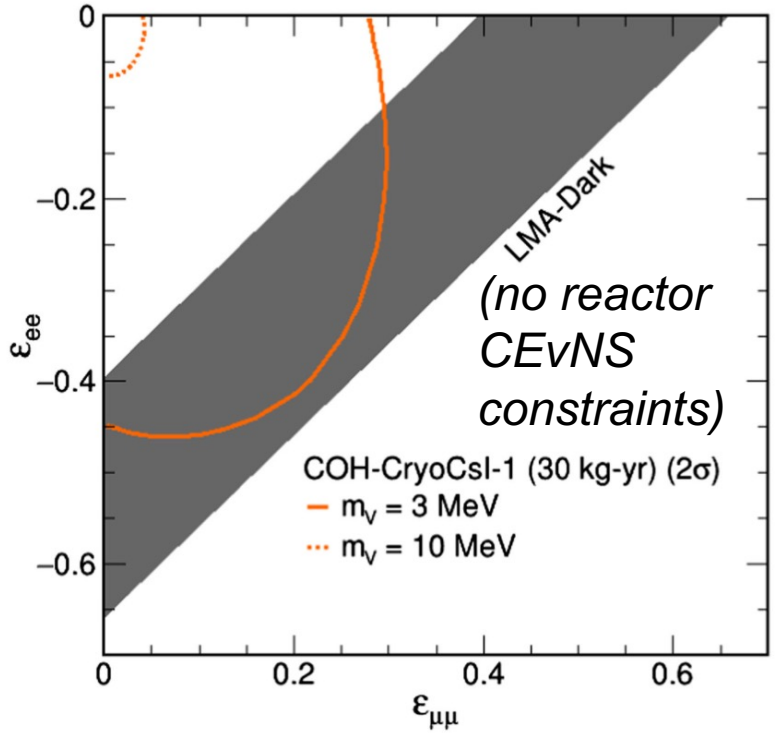
- Original CsI results limited by Cherenkov radiation in PMT quartz window
- Proposed next-generation detector:
  - 10 kg undoped CsI at ~40K with SiPMs
  - First proof-of-concept: *Ding et al.*, *Eur. Phys. J. C **82**, 344 (2022)*
  - Physics reach: Phys. Rev. D 109 092005 (2024)

Poster
Charles Prior

Planning: Cryo-CsI

- Original CsI results limited by Cherenkov radiation in PMT quartz window
- Proposed next-generation detector:
  - 10 kg undoped CsI at ~40K with SiPMs
  - First proof-of-concept: *Ding et al.*, *Eur. Phys. J. C* ***82***, *344 (2022)*
  - Physics reach: Phys. Rev. D 109 092005 (2024)

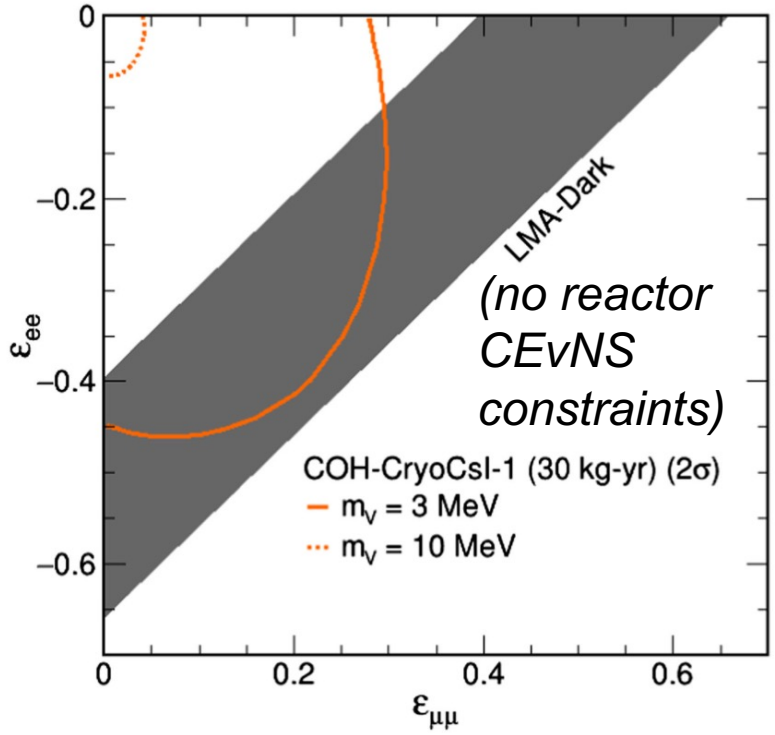
Poster
Charles Prior

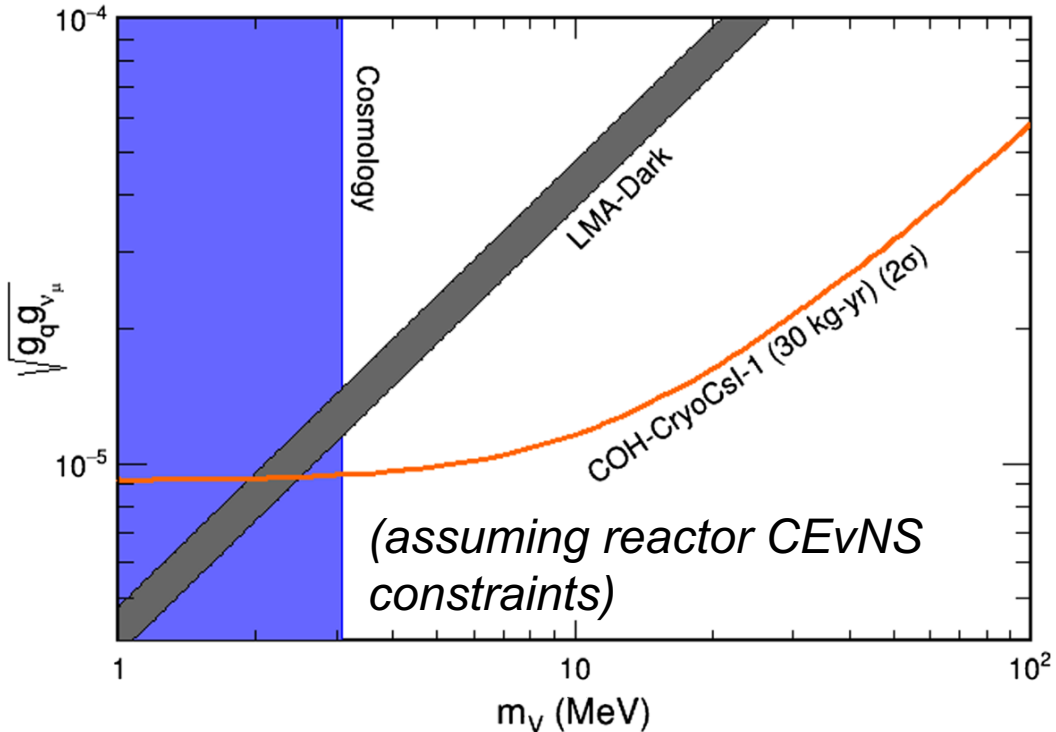


Planning: Cryo-CsI

- Original CsI results limited by Cherenkov radiation in PMT quartz window
- Proposed next-generation detector:
  - 10 kg undoped CsI at ~40K with SiPMs
  - First proof-of-concept: *Ding et al.*, *Eur. Phys. J. C* ***82***, *344 (2022)*
  - Physics reach: Phys. Rev. D 109 092005 (2024)

Poster
Charles Prior





- The cu

Bonus Physics: Inelastics

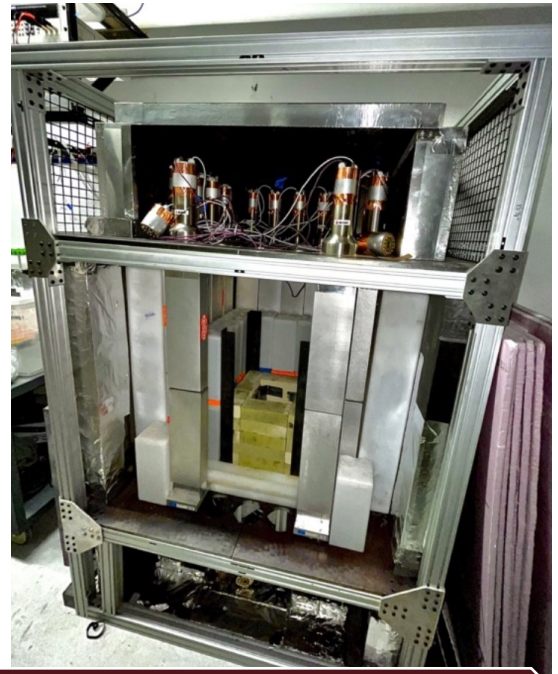
- SNS neutrino energies match supernova neutrinos and probe nuclear physics!

Bonus Physics: Inelastics

- SNS neutrino energies match supernova neutrinos and probe nuclear physics!

NUSTHOR

ν-induced fission



Talk Friday

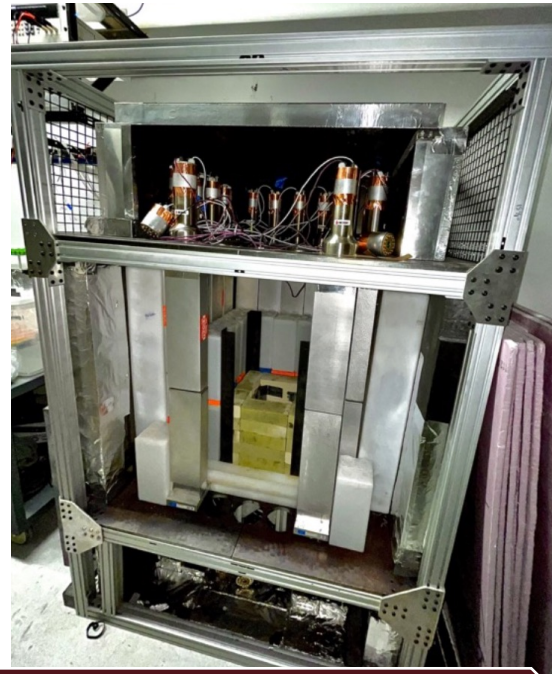
Tyler Johnson

Bonus Physics: Inelastics

- SNS neutrino energies match supernova neutrinos and probe nuclear physics!

NUTHOR

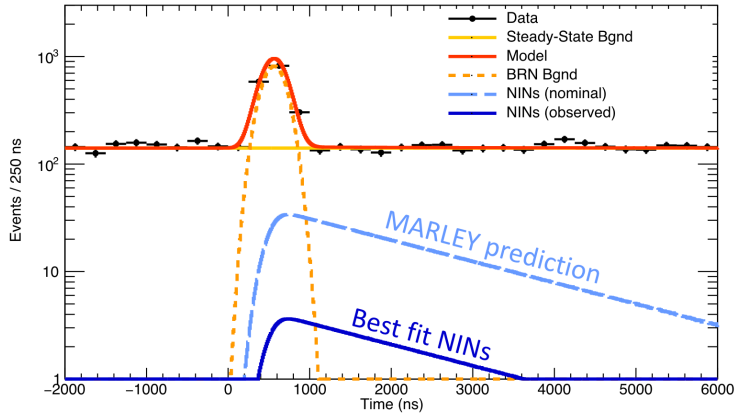
ν-induced fission



Talk Friday

Tyler Johnson

ν–induced n from ν+Pb



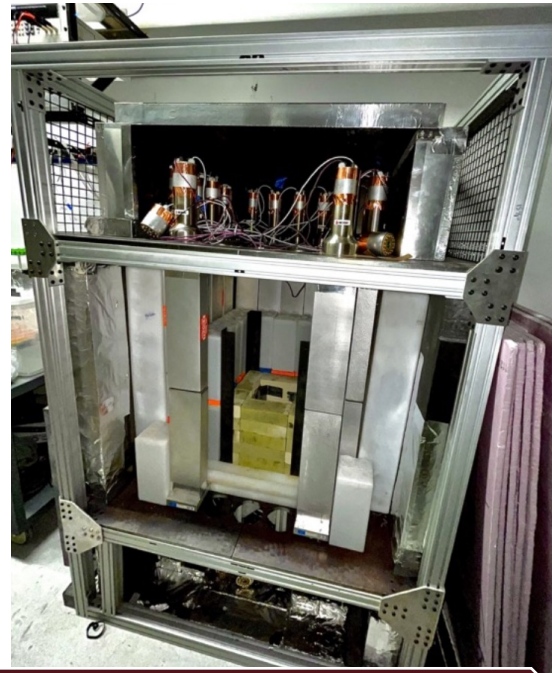
PRD **108** 072001 (2023)

Bonus Physics: Inelastics

- SNS neutrino energies match supernova neutrinos and probe nuclear physics!

NUTHOR

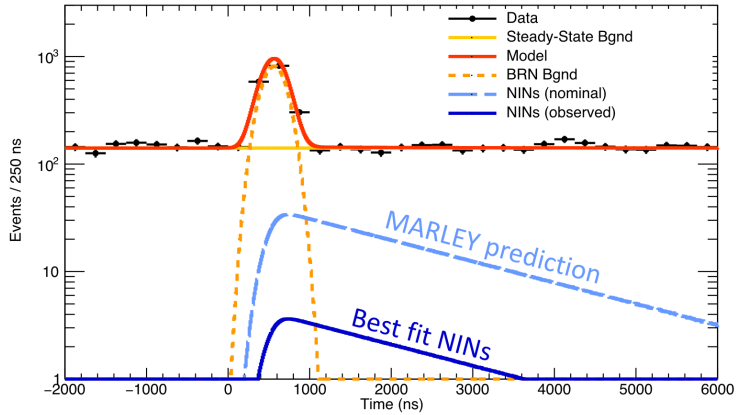
ν-induced fission



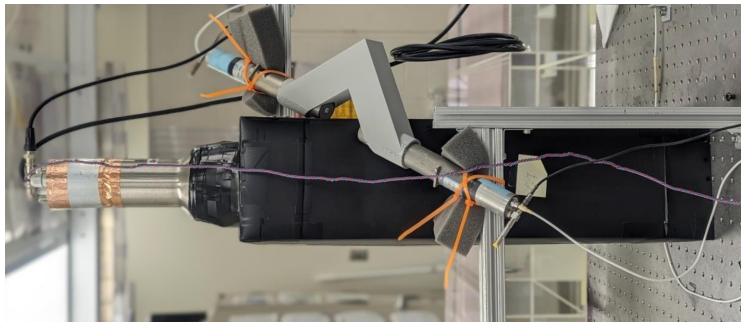
Talk Friday

Tyler Johnson

ν–induced n from ν+Pb



PRD **108** 072001 (2023)



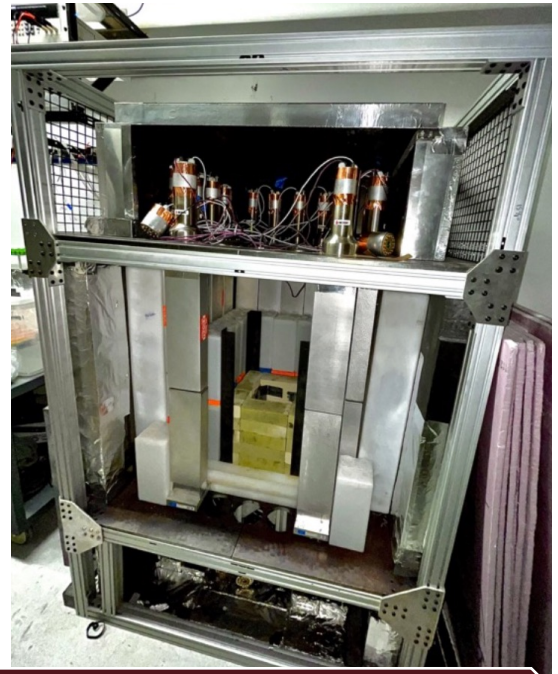
Follow-up Pb glass detector

Bonus Physics: Inelastics

- SNS neutrino energies match supernova neutrinos and probe nuclear physics!

NUTHOR

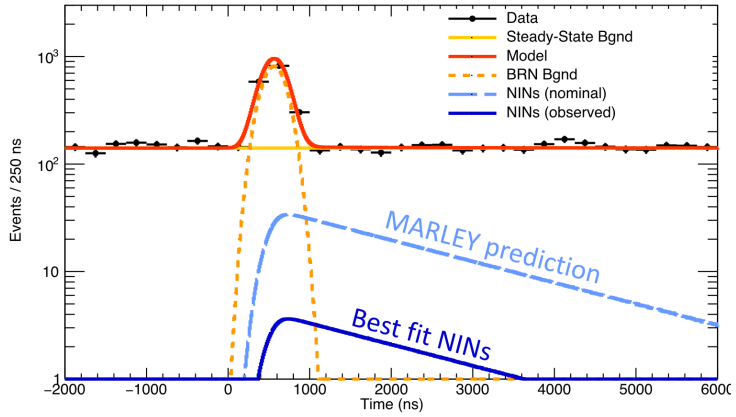
ν-induced fission



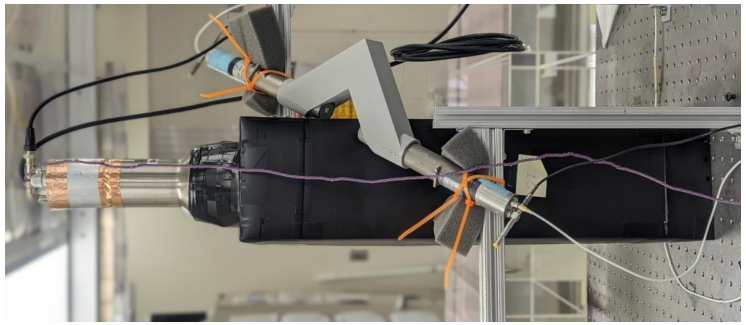
Talk Friday

Tyler Johnson

ν–induced n from ν+Pb



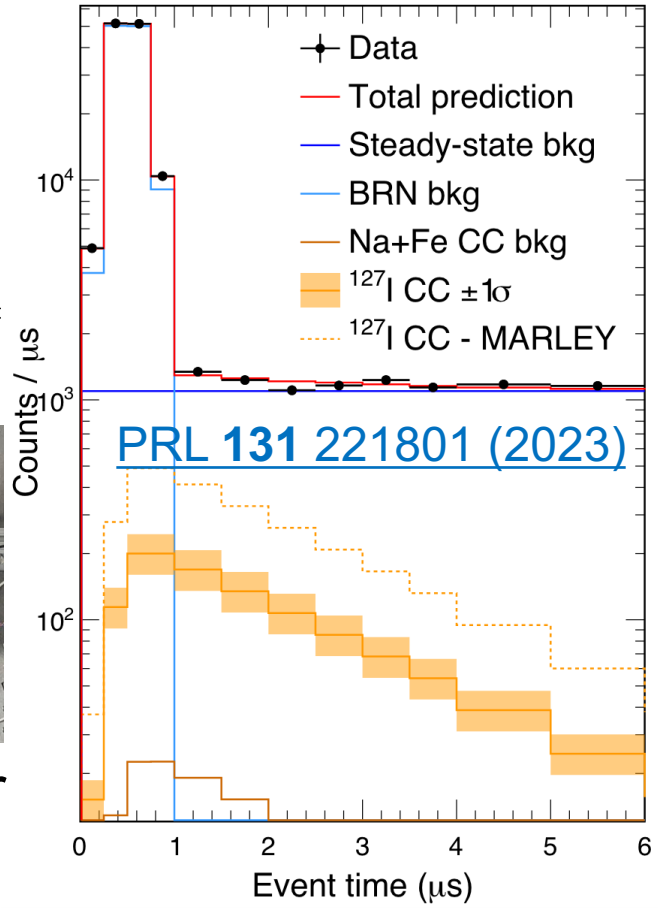
PRD **108** 072001 (2023)



Follow-up Pb glass detector

CC ν–^{127}I

NaIvE, NaIvETe



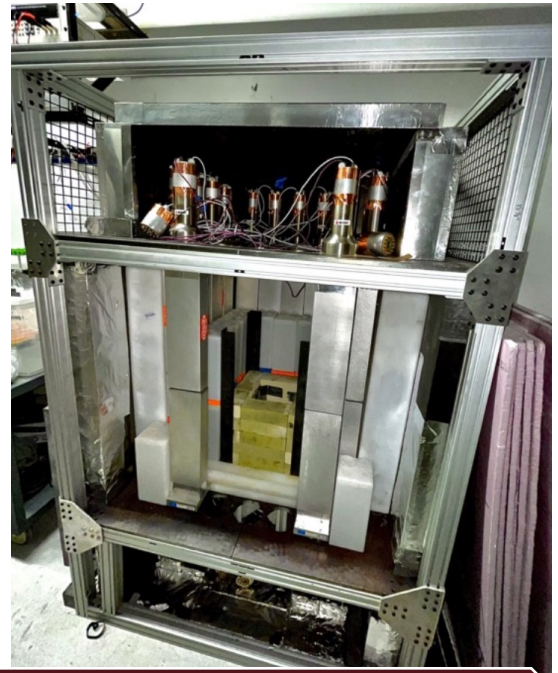
PRL **131** 221801 (2023)

Bonus Physics: Inelastics

- SNS neutrino energies match supernova neutrinos and probe nuclear physics!

NUTHOR

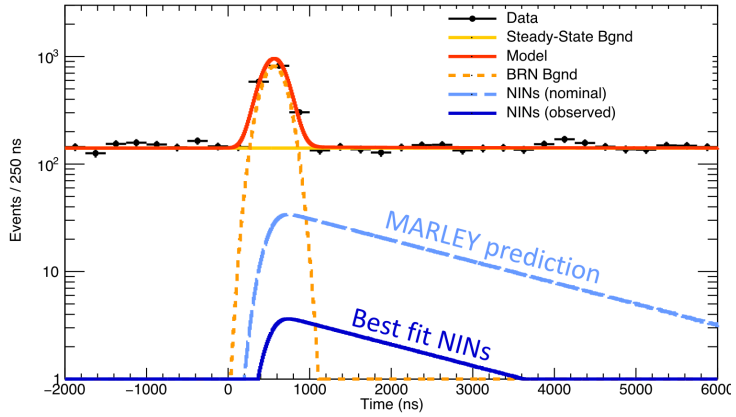
ν-induced fission



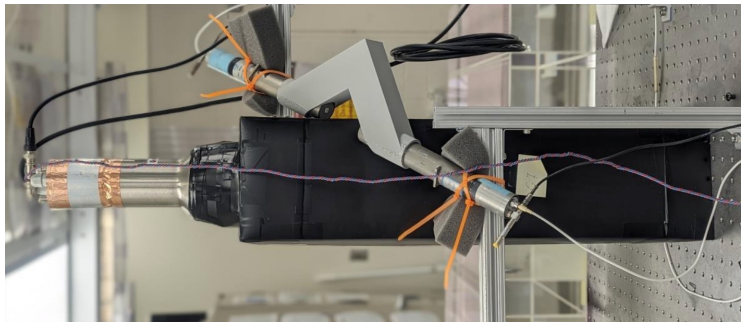
Talk Friday

Tyler Johnson

ν–induced n from ν+Pb



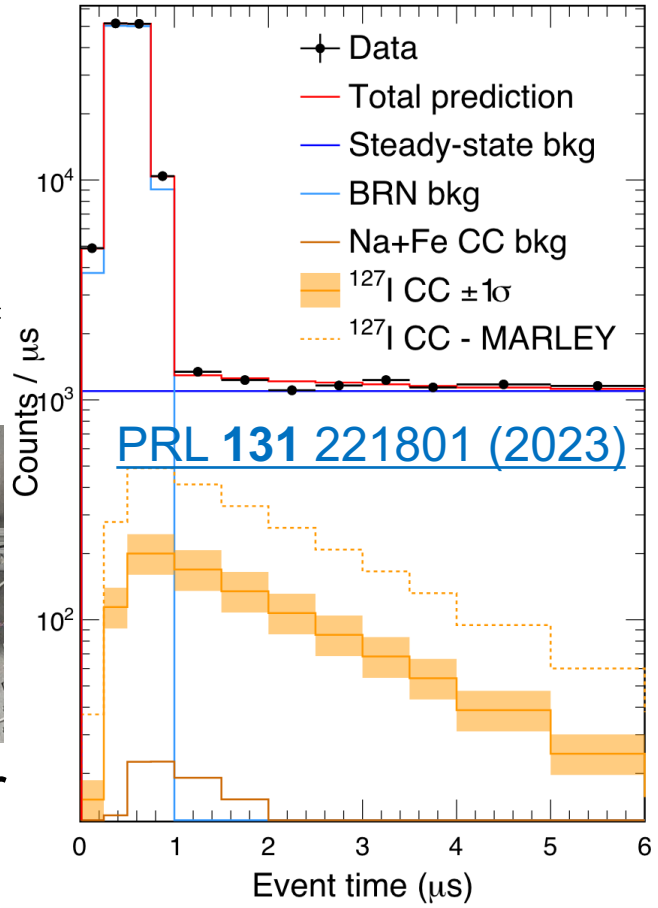
PRD **108** 072001 (2023)



Follow-up Pb glass detector

CC ν–^{127}I

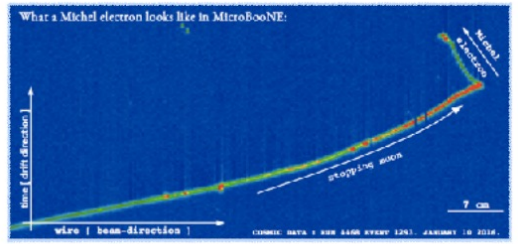
NaIvE, NaIvETe

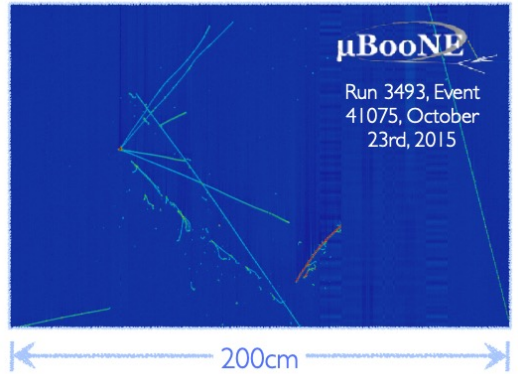


PRL **131** 221801 (2023)

CC ν–^{40}Ar

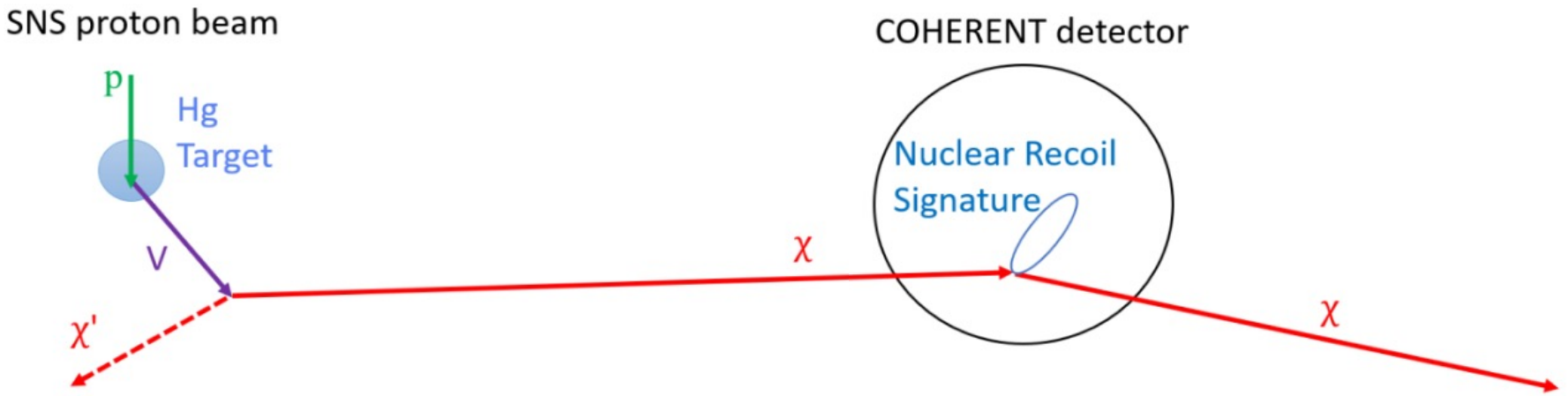
LArTPC (~250 kg)





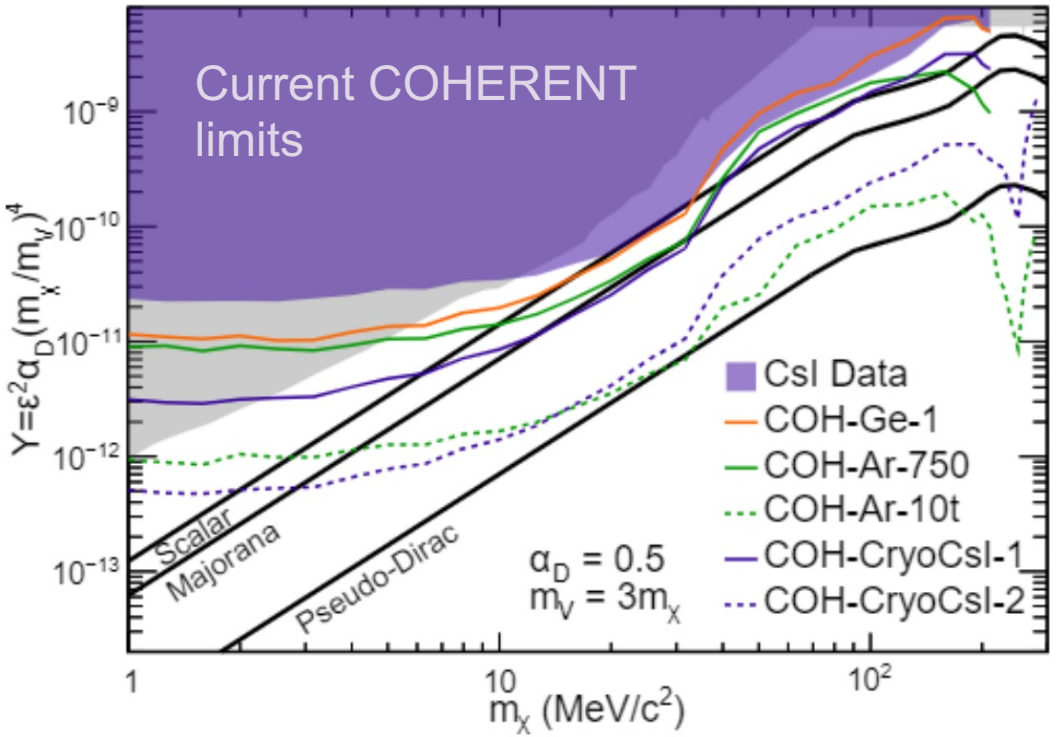
Bonus Physics: Dark Matter

- SNS delivers more than 1.58×10^{23} protons to the Hg target each year
  - Tremendous opportunity for producing vector-portal dark matter!

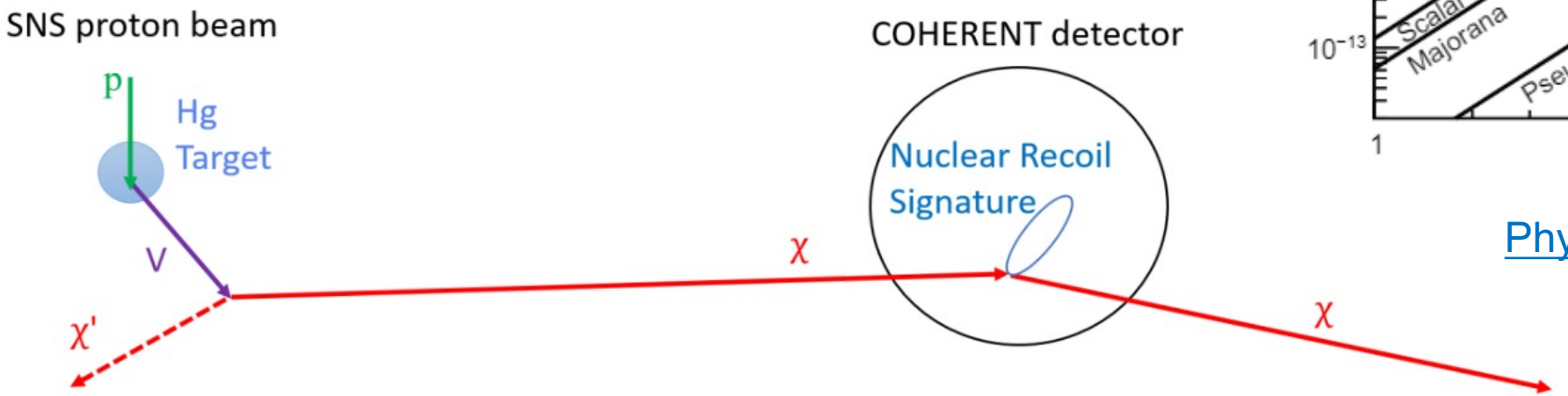


Bonus Physics: Dark Matter

- SNS delivers more than 1.58×10^{23} protons to the Hg target each year
  - Tremendous opportunity for producing vector-portal dark matter!
- Two searches with existing CsI data:
  - Leptophobic DM: PRD **106** 052004 (2022)
  - Scalar DM: PRL **130** 051803 (2023)
- Sensitivity studies for future detectors



Phys. Rev. D 109 092005 (2024)



The COHERENT Collaboration

Canadian Nuclear Laboratories
Laboratoires Nucléaires Canadiens
Carnegie Mellon University
CONCORD U
Duke University
UF UNIVERSITY of FLORIDA
Florida State University 1851
ICRR Institute for Cosmic Ray Research University of Tokyo
Kyoto University Kyoto Japan Founded 1897
Laurentian University Université Laurentienne
Los Alamos National Laboratory EST. 1943
MEPhI
NCCentral University
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
東京大学
Tufts University
TUNL Triangle Universities Nuclear Laboratory
VIRGINIA TECH
Washington & Jefferson College
NSF
NRF 한국연구재단 National Research Foundation of Korea
U.S. Department of Energy | Office of Science
NNSA National Nuclear Security Administration
Consortium for Monitoring Technology and Verification

Conclusion

- The SNS at Oak Ridge National Lab is a powerful tool for CEvNS and other low-energy neutrino interactions
  - Current and planned upgrades increase its potential

Conclusion

- The SNS at Oak Ridge National Lab is a powerful tool for CEvNS and other low-energy neutrino interactions
  - Current and planned upgrades increase its potential
- Studies of beam-related neutrons and neutrino flux are bringing them under control

Conclusion

- The SNS at Oak Ridge National Lab is a powerful tool for CEvNS and other low-energy neutrino interactions
  - Current and planned upgrades increase its potential
- Studies of beam-related neutrons and neutrino flux are bringing them under control
- COHERENT has seen CEvNS on three nuclear targets (CsI, Ar, Ge) with Na taking data
  - CsI – new detector proposed
  - Ar
    - Remaining COH-Ar-1 dataset under analysis.
    - New detector under construction
  - Ge – more data to be acquired this summer

Conclusion

- The SNS at Oak Ridge National Lab is a powerful tool for CEvNS and other low-energy neutrino interactions
  - Current and planned upgrades increase its potential
- Studies of beam-related neutrons and neutrino flux are bringing them under control
- COHERENT has seen CEvNS on three nuclear targets (CsI, Ar, Ge) with Na taking data
  - CsI – new detector proposed
  - Ar
    - Remaining COH-Ar-1 dataset under analysis.
    - New detector under construction
  - Ge – more data to be acquired this summer
- Active, competitive DM searches and inelastics measurements

Conclusion

- The SNS at Oak Ridge National Lab is a powerful tool for CEvNS and other low-energy neutrino interactions
  - Current and planned upgrades increase its potential
- Studies of beam-related neutrons and neutrino flux are bringing them under control
- COHERENT has seen CEvNS on three nuclear targets (CsI, Ar, Ge) with Na taking data
  - CsI – new detector proposed
  - Ar
    - Remaining COH-Ar-1 dataset under analysis.
    - New detector under construction
  - Ge – more data to be acquired this summer
- Active, competitive DM searches and inelastics measurements

Thank you!

Backup

SNS Schedule Until Sep. 2027

FY24

24	Apr-24	May-24	Jun-24	Jul-24	Aug-24	Sep-24
				PPU 2MW Target Ramp to 1.7 MW @ 1.3 GeV for 1250 hr KPP		

FY25

	Oct-24	Nov-24	Dec-24	Jan-25	Feb-25	Mar-25	Apr-25	May-25	Jun-25	Jul-25	Aug-25	Sep-25
SNS		FY25A			1.7 MW Operations				FY25B		1.8 MW Operations	

FY26

	Oct-25	Nov-25	Dec-25	Jan-26	Feb-26	Mar-26	Apr-26	May-26	Jun-26	Jul-26	Aug-26	Sep-26
SNS	1.8 MW Operations		FY26A		1.9 MW Operations				FY26B		1.9 MW Operations	

FY27

	Oct-26	Nov-26	Dec-26	Jan-27	Feb-27	Mar-27	Apr-27	May-27	Jun-27	Jul-27	Aug-27	Sep-27
SNS	2MW Operations		FY27A		2MW Operations				FY27B		2MW Operations	

Second Target Station: The Basics

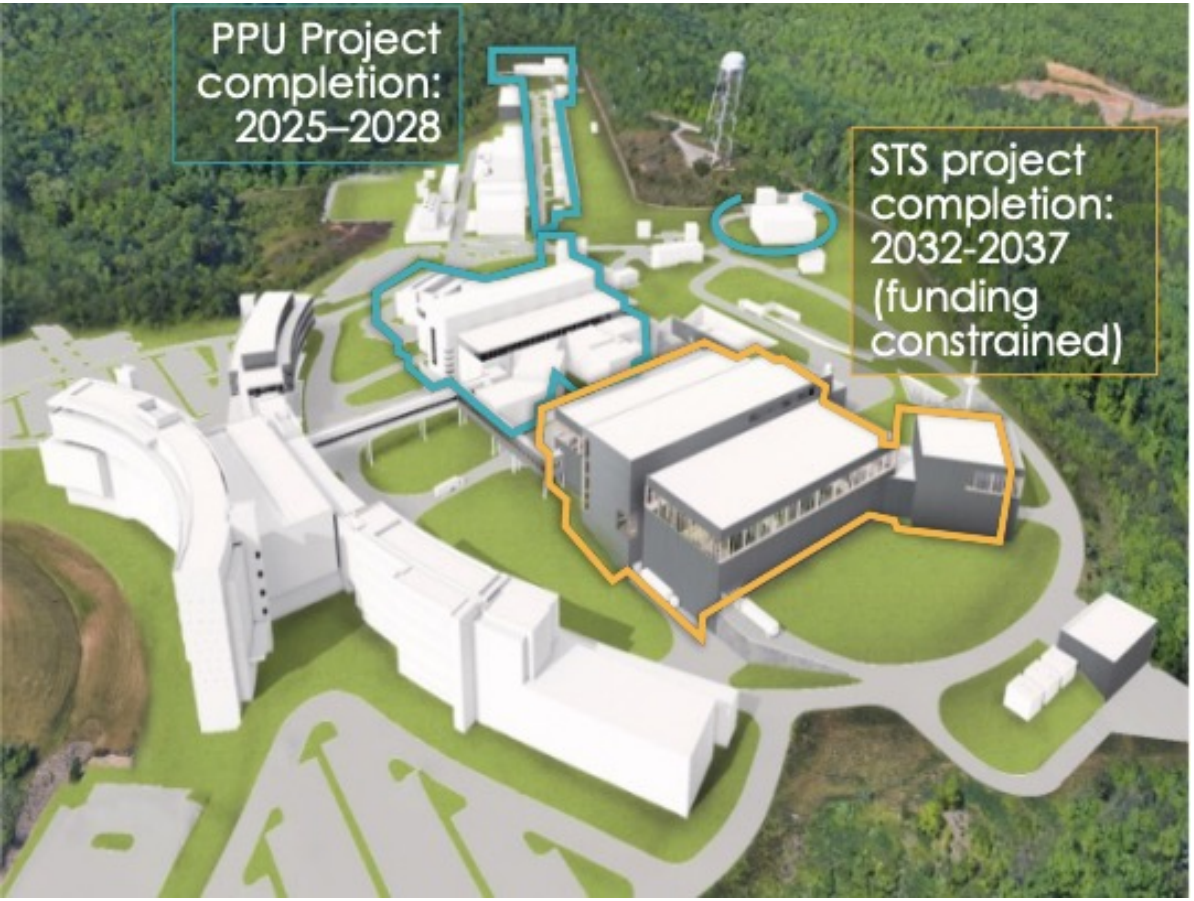
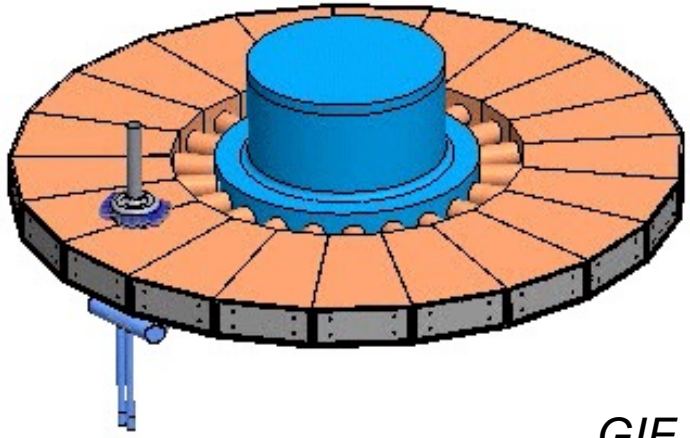


Image from Ken Herwig

- Rotating wheel of tungsten wedges
- Receives ¼ proton pulses (15 Hz)
  - First target station gets ¾ proton pulses (45 Hz)
- Optimized to produce cold neutrons



GIF from ORNL