COHERENT Overview

Yu. Efremenko
August 15, 2018

COHERENT collaboration

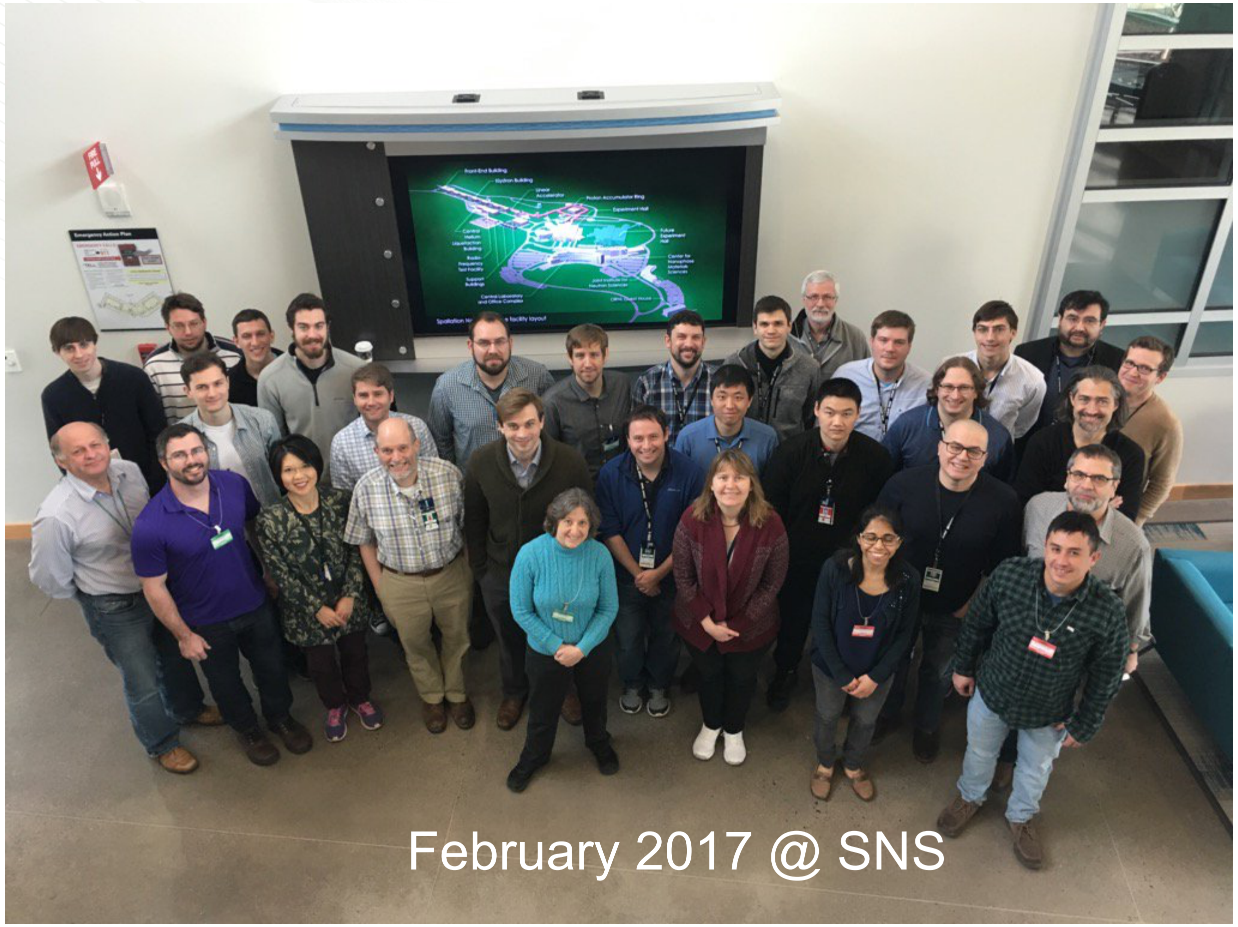
Why did we choose SNS?

COHERENT status and present activities

Future plans

COHERENT Collaboration

Prime goal of the collaboration is to detect and study Coherent Elastic neutrino Nucleus Scattering → CEvNS

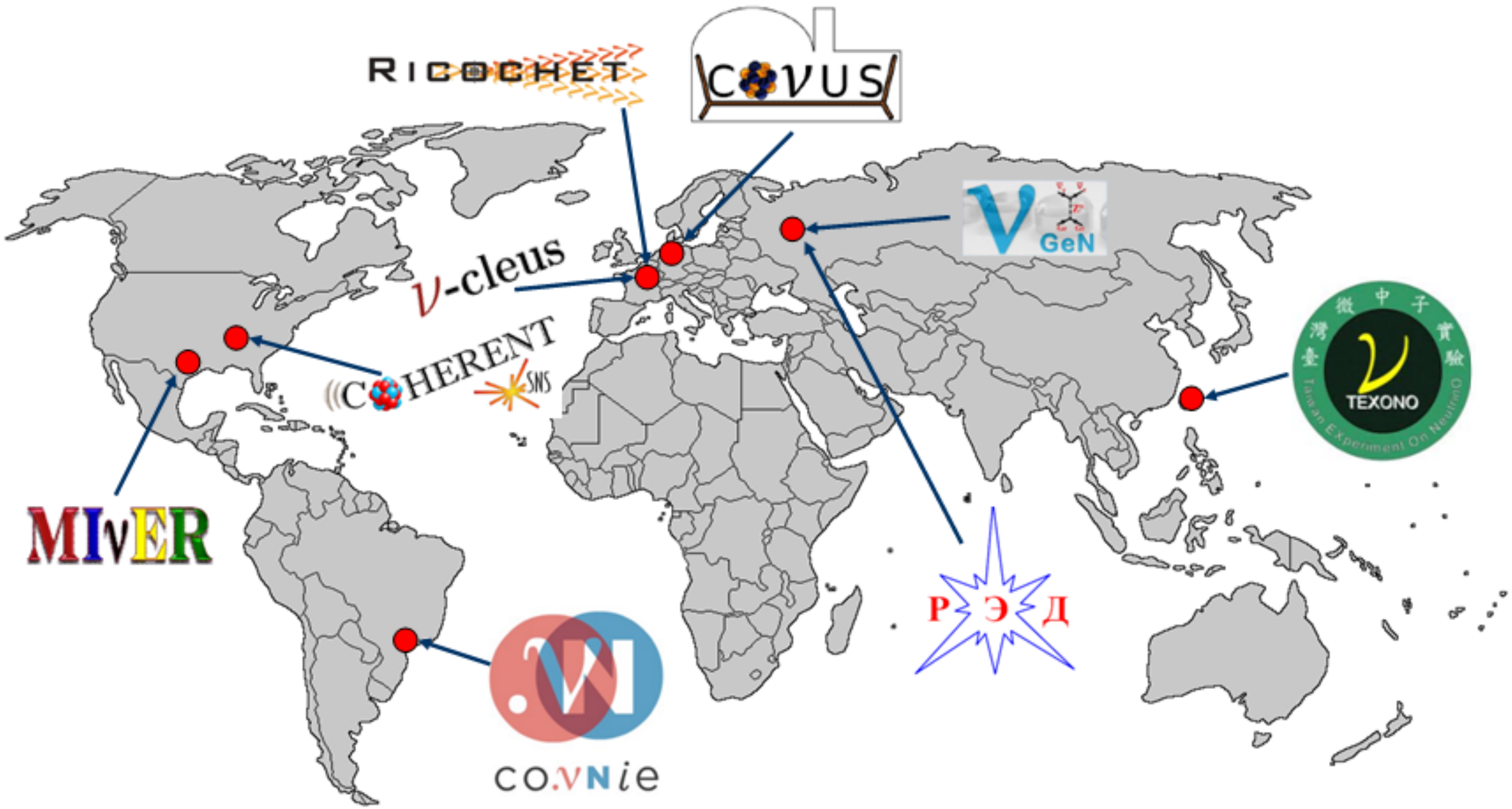


February 2017 @ SNS

Carnegie Mellon University, The University of Chicago, Duke University, University of Florida, Indiana University, KAIST, Laurentian University / Université Laurentienne, Los Alamos National Laboratory, MEPhI, North Carolina Central University, NC State University, NM State University, Oak Ridge National Laboratory, Sandia National Laboratories, The University of Tennessee Knoxville, TUNL, University of Washington

18 Institutions (USA, Russia, Canada, Korea)

World Wide Efforts to Detect CEvNS



Except COHERENT, all other collaboration attempt to use nuclear reactors as a neutrino source

Nuclear reactors give large flux, but low energy neutrinos with a constant flux

Why SNS?

- **It is world most powerful pulsed neutrino source. Presently it delivers 7 · 10^{20} POT daily**
  ~9% of protons produce 3 neutrinos
- **Neutrino energies at SNS are ideal to study CEvNS and Supernovae related neutrino cross sections.**
  For most of neutrinos E_ν < 53 MeV
- **Decay At Rest from pions and muons (DAR) gives very well defined neutrino spectra**
- **Fine duty factor let suppression of steady background by a factor of 2000.**
  It is like being at the 1000 m.w.e underground
- **There is a nice place at the SNS basement with protection from SNS produced neutrons and hadronic component of cosmic rays.**
- **Neutrinos, space, and utilities are provided**

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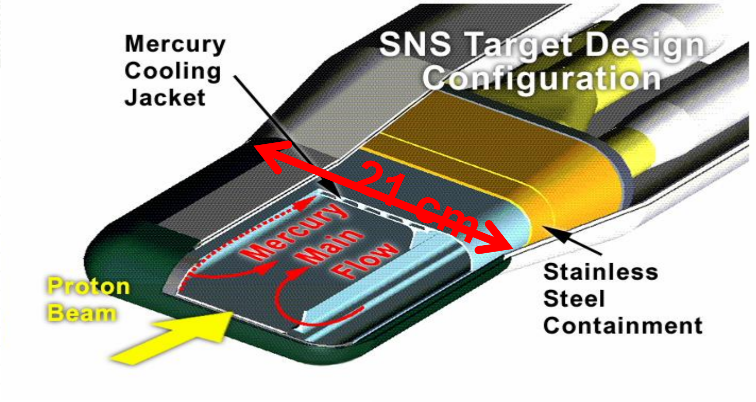
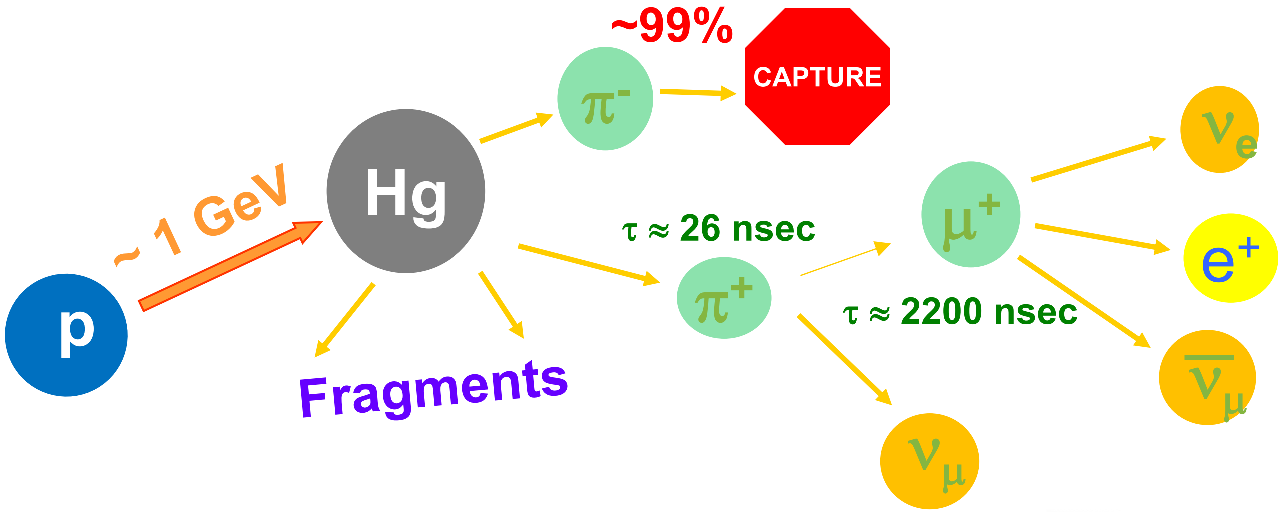
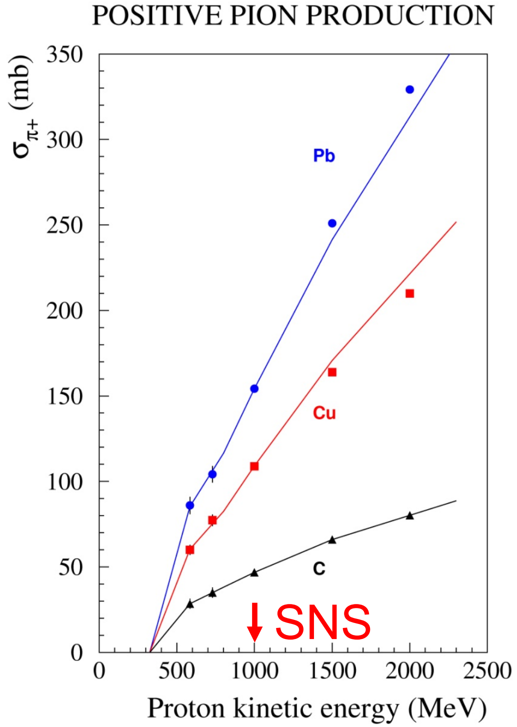
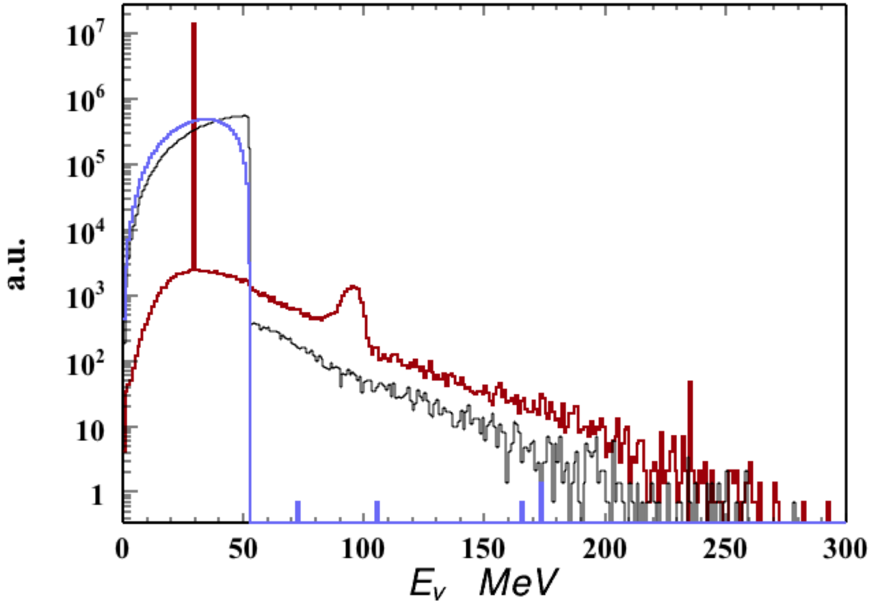
Neutrino Production at the SNS



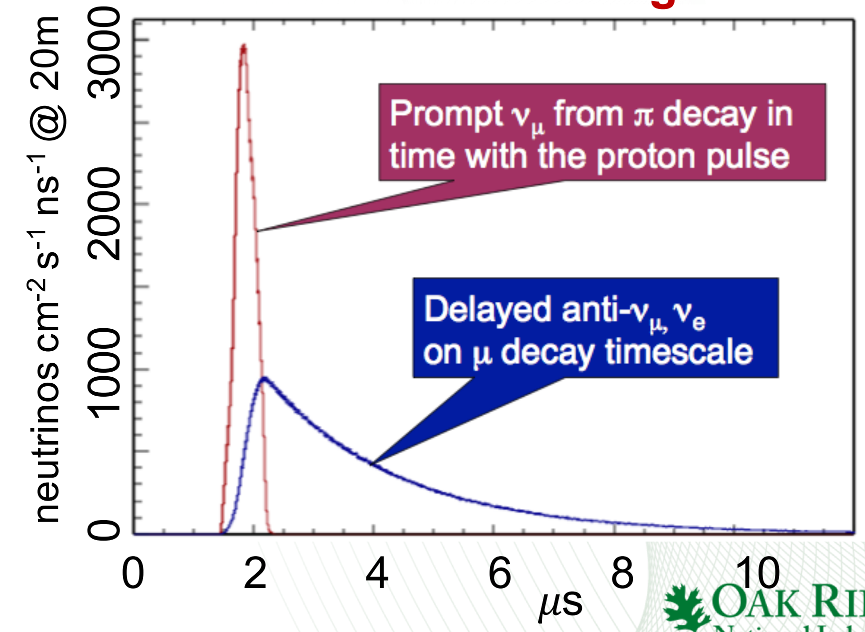




Neutrino Energy



Neutrino Timing



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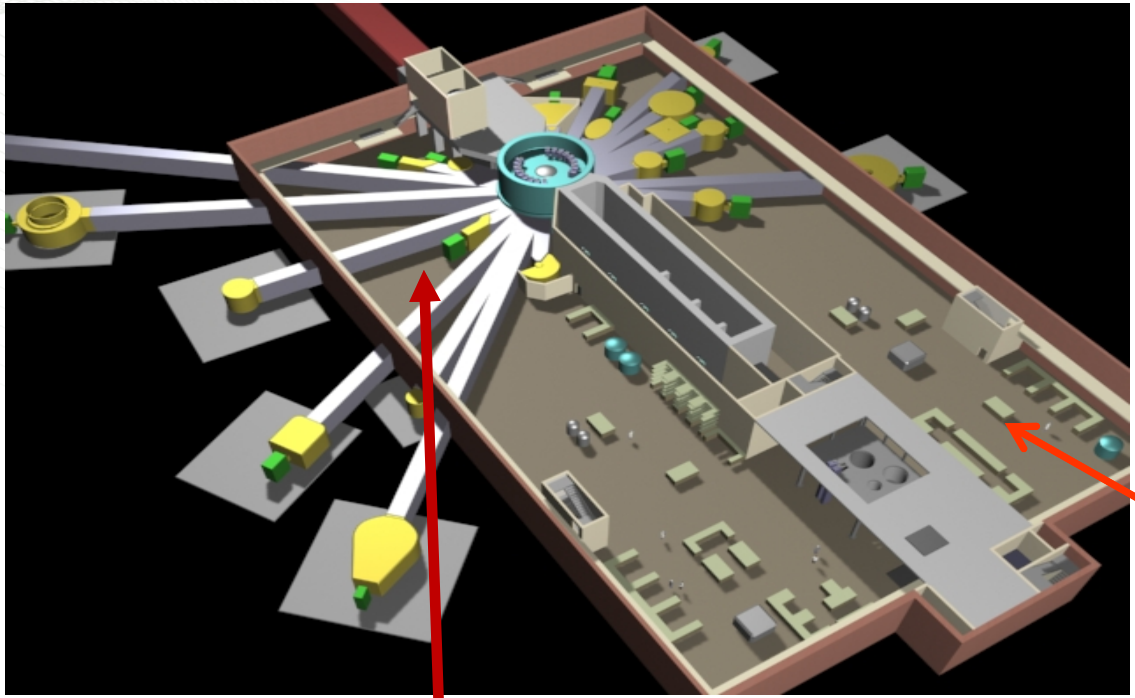
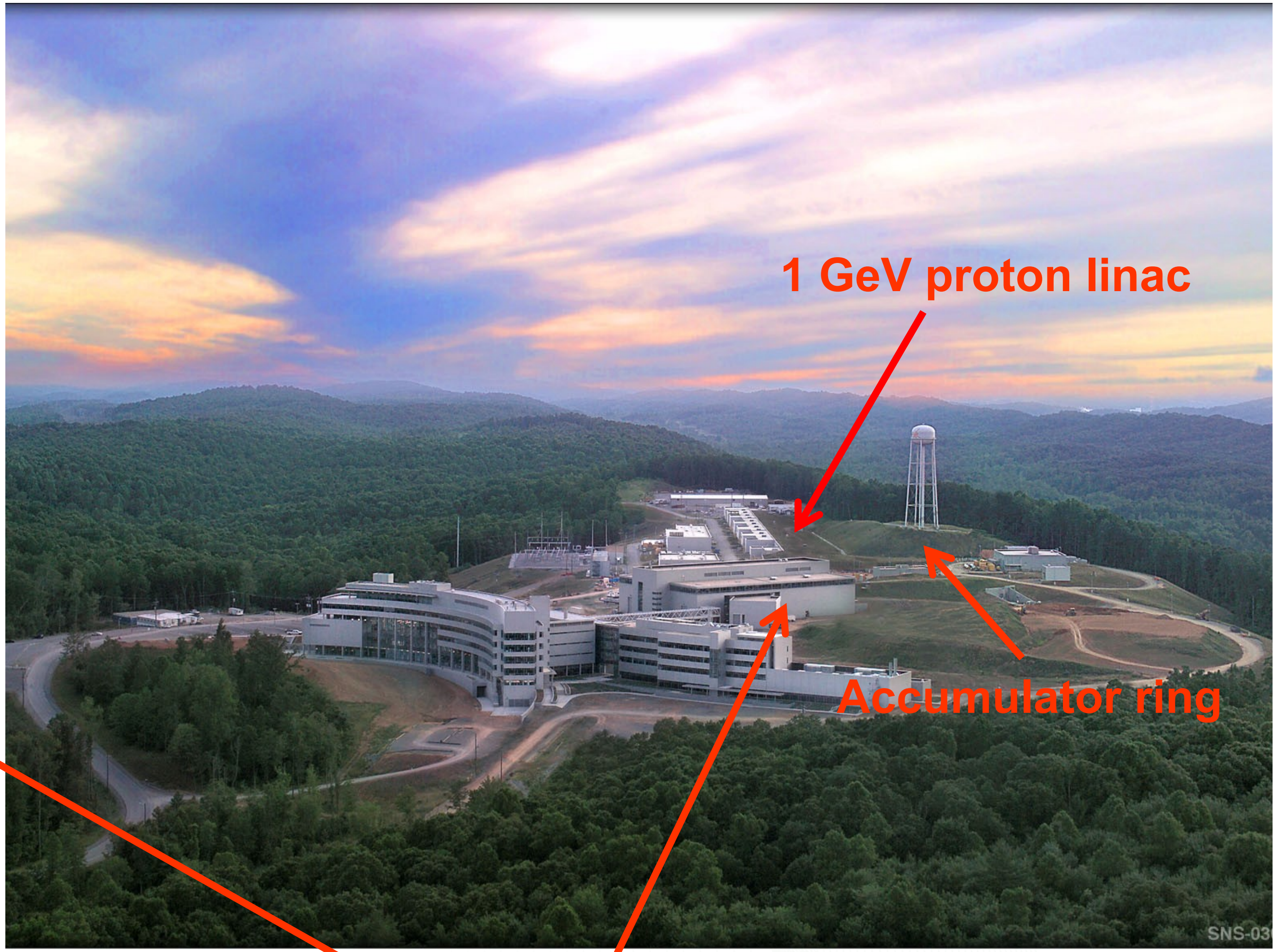
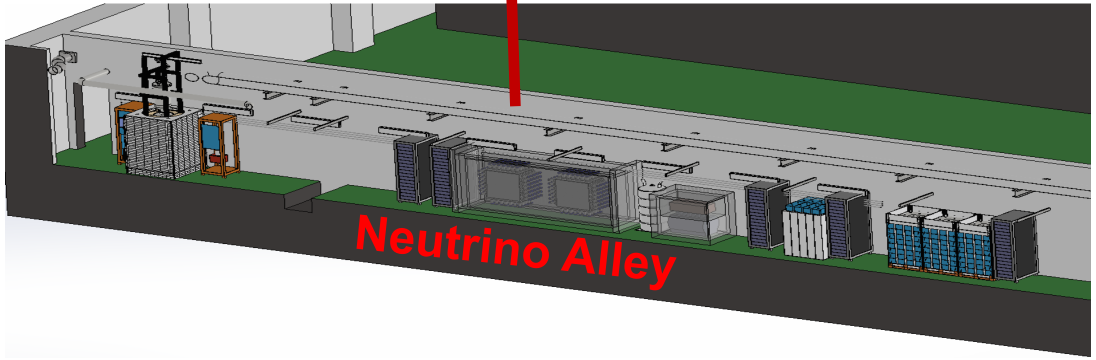
Neutrino Alley Location

After extensive BG program study we find a well protected location





Target Building



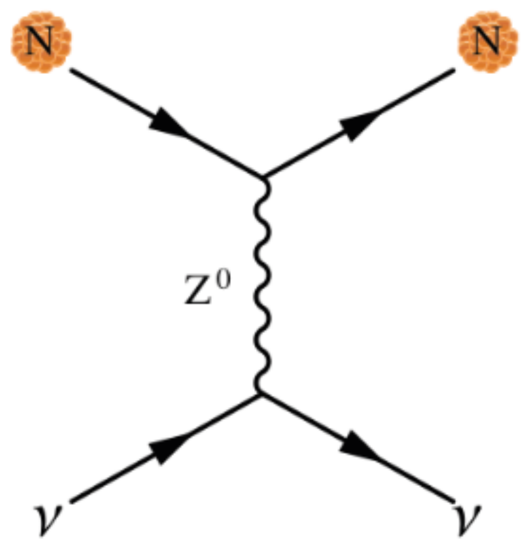
Alley is 20-30 meters from the target.
Space between target and alley is filled with steel, gravel and concrete

There are extra 10 MWE from above

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_ν~ 50 MeV



D.Z. Freedman PRD 9 (1974)

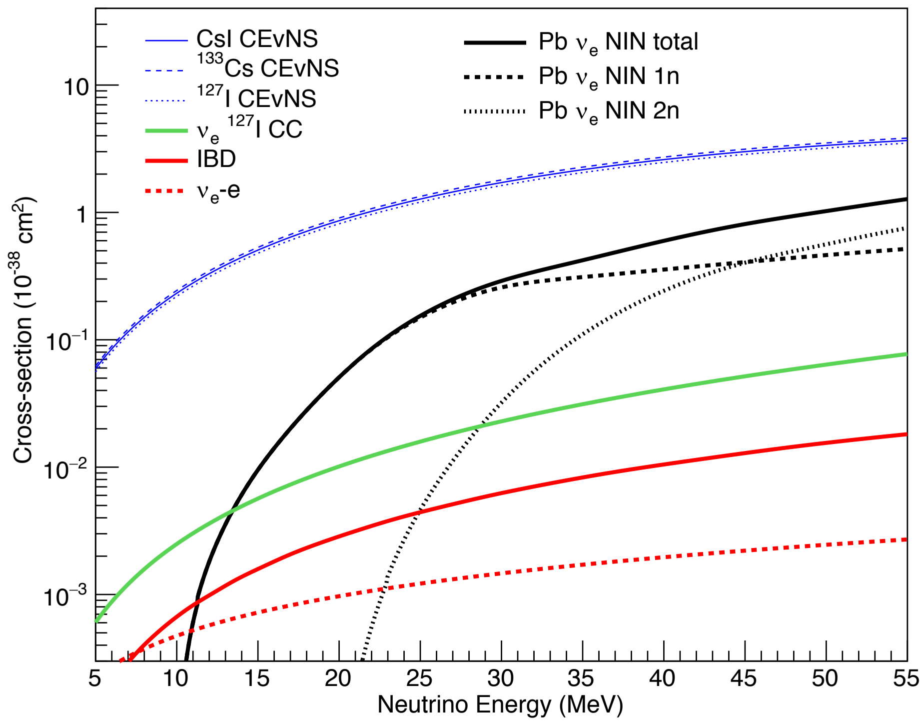
Submitted Oct 15, 1973

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.

V.B.Kopeliovich & L.L.Frankfurt

JETP Lett. 19 (1974)

Submitted Jan 7, 1974



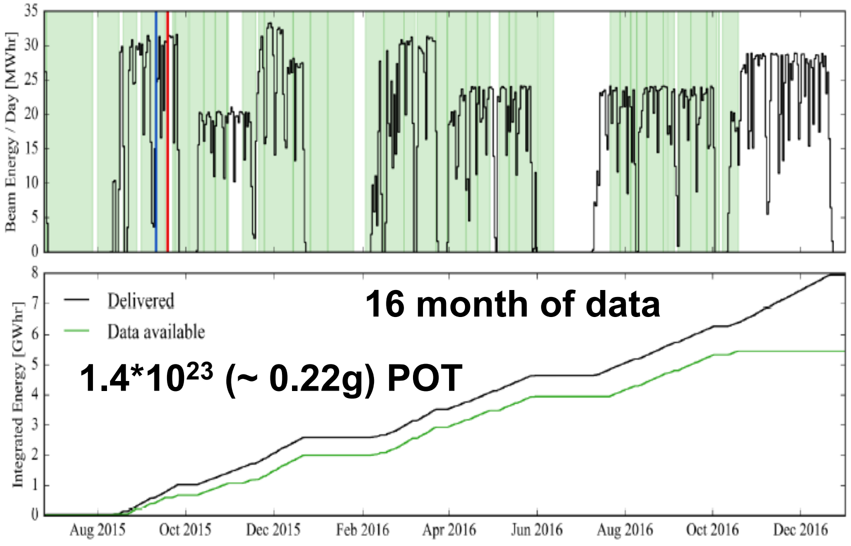
CEvNS cross-section is large!

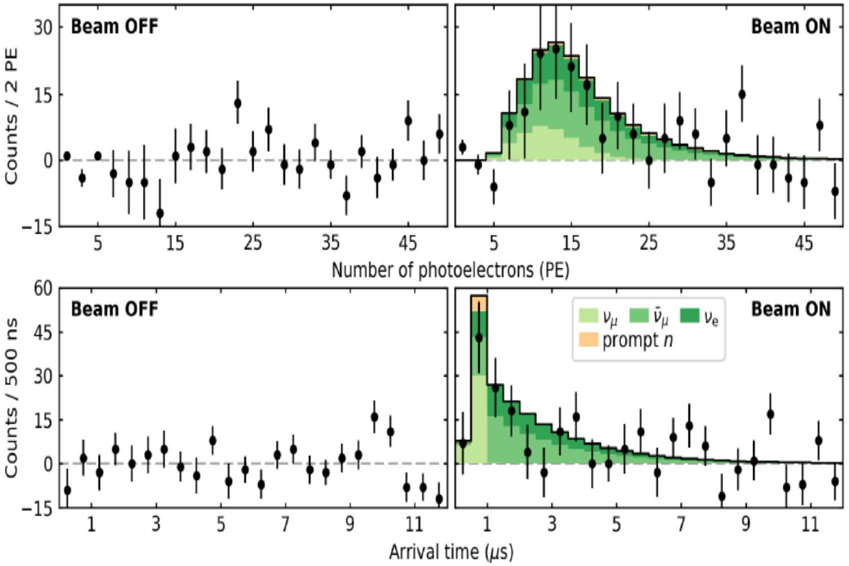
$$\frac{d\sigma}{d\Omega} = \frac{G^2}{4\pi^2} k^2 (1+\cos\theta) \frac{(N-(1-4\sin^2\theta_W)Z)^2}{4} F^2(Q^2) \qquad \propto N^2$$

CEvNS cross section is well calculated in the Standard Model

First Detection of CEvNS with CsI detector

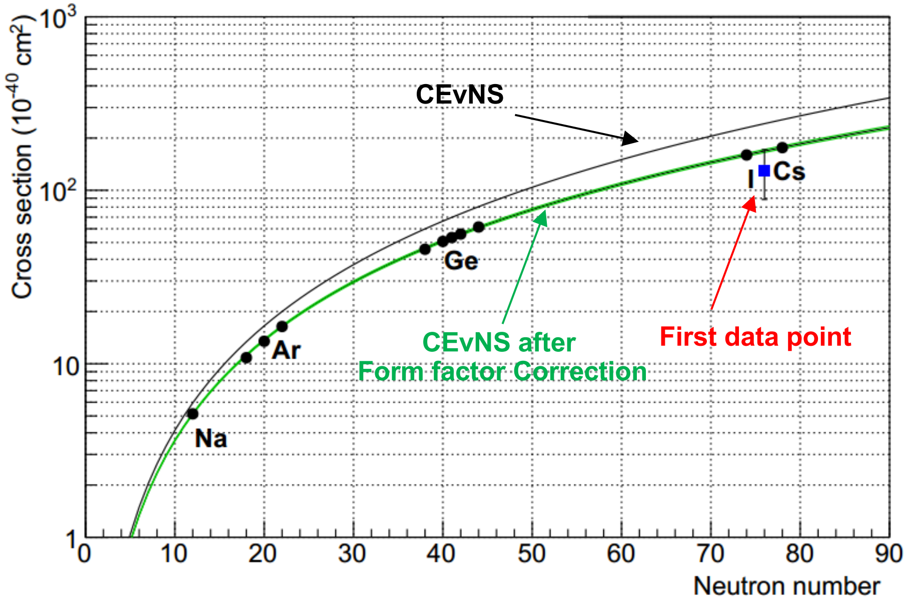
First working hand held neutrino detector -14kg!!!





We continue to take data with CsI detector

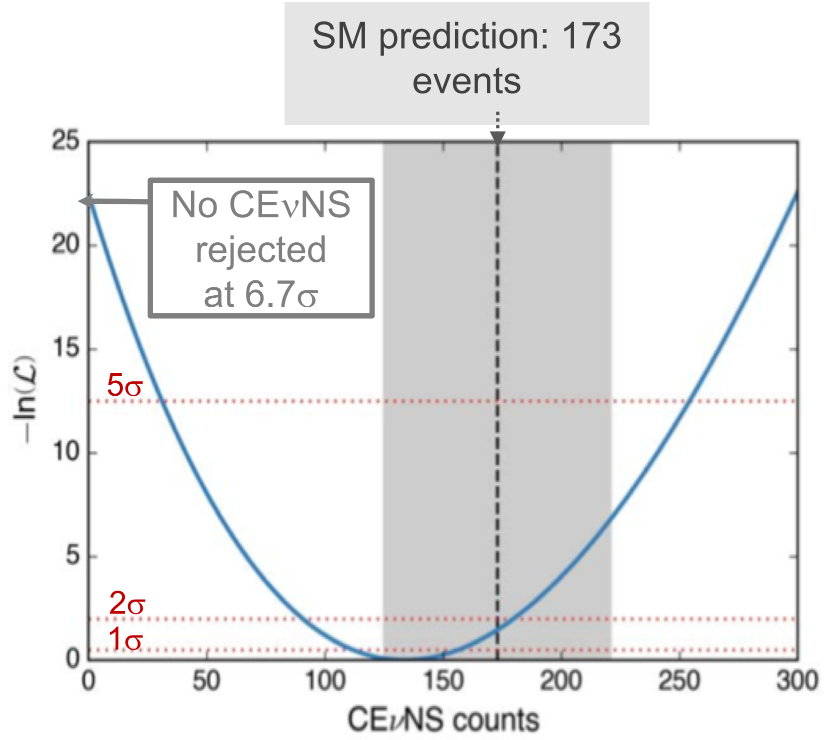
Now it is twice more statistics compare to the first publication



Some Details About the First CEvNS Detection

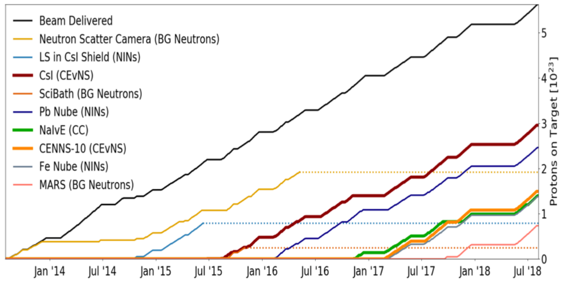
Beam ON coincidence window	547 counts
Anticoincidence window	405 counts
Beam-on bg: prompt beam neutrons	7.0 ± 1.7
Beam-on bg: NINs (neglected)	4.0 ± 1.3
Signal counts, 2D likelihood fit	134 ± 22 (16%)
Predicted SM signal counts	173 ± 48 (28%)

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

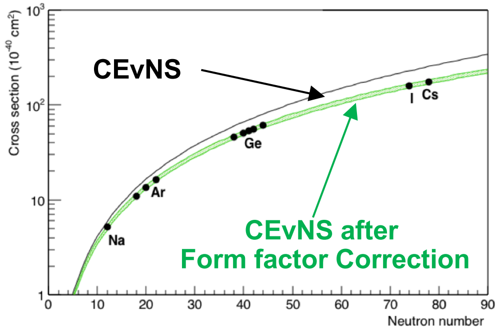


All uncertainties except neutrino flux are detector specific and could be much less for other technologies

To unlock high precision CEvNS program we need to calibrate SNS neutrino flux and measure QF well



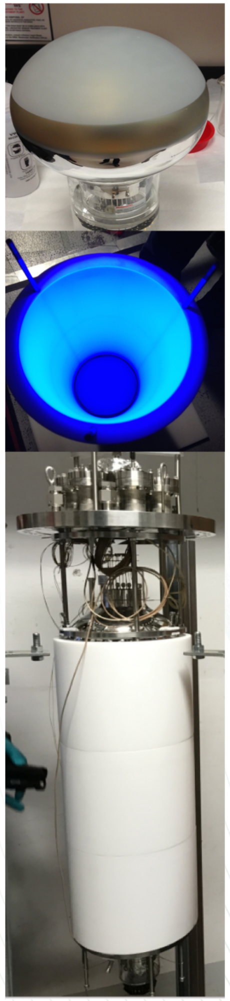
Ongoing Neutrino Alley Activities

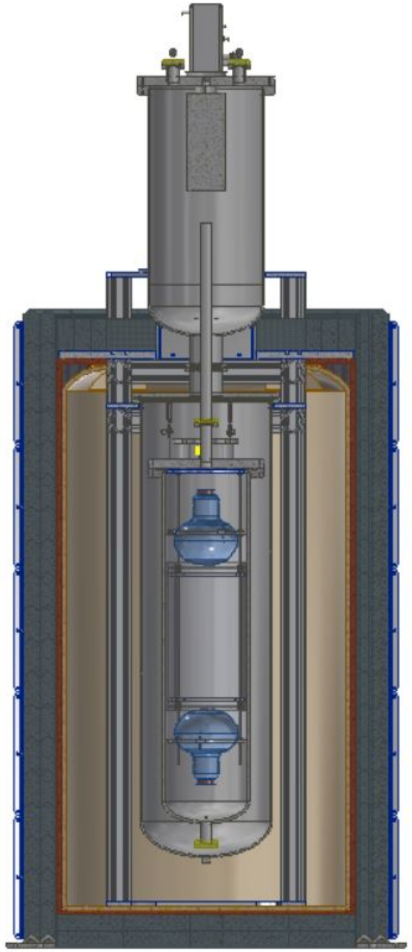


Single Phase Liquid Argon Detector CENNS-10

Aim is to detect CEvNS for very different target

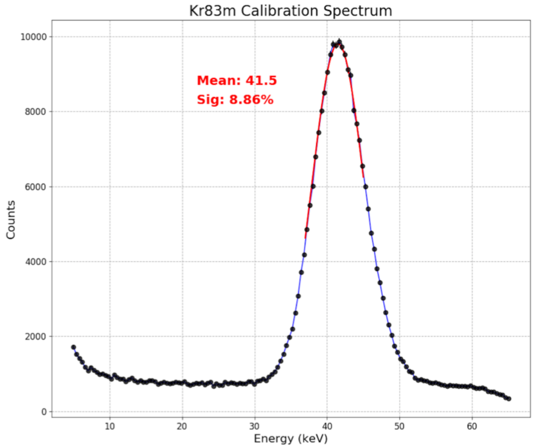
Hardware borrowed from FNAL



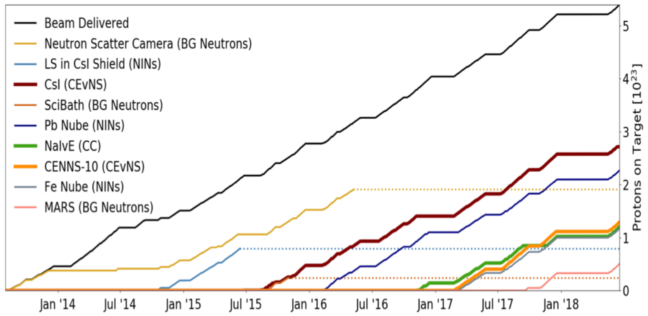


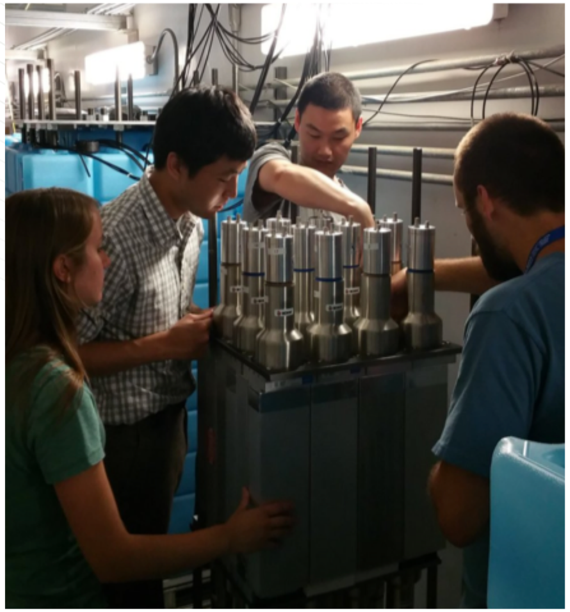
CENNS-10 SNS timeline:

- 10-12/2016: (re)build, commission and deployed detector at SNS
- 12/16 - 5/17: “Run -0”. Poor light collection, E_{thresh}~100keVnr
  Test of hardware.
- 7/17- now: “Run 1” Rebuild detector. Light collection increase by a factor of 10! It should be enough to see CEvNS. E_{thresh}~20keVnr
  Presently accumulated statistics is ~4.1 GWhr (~1*10^{23} POT)
- We implemented blind analysis by looking on the data between beam spills only.
  Planning to open box soon!!!!

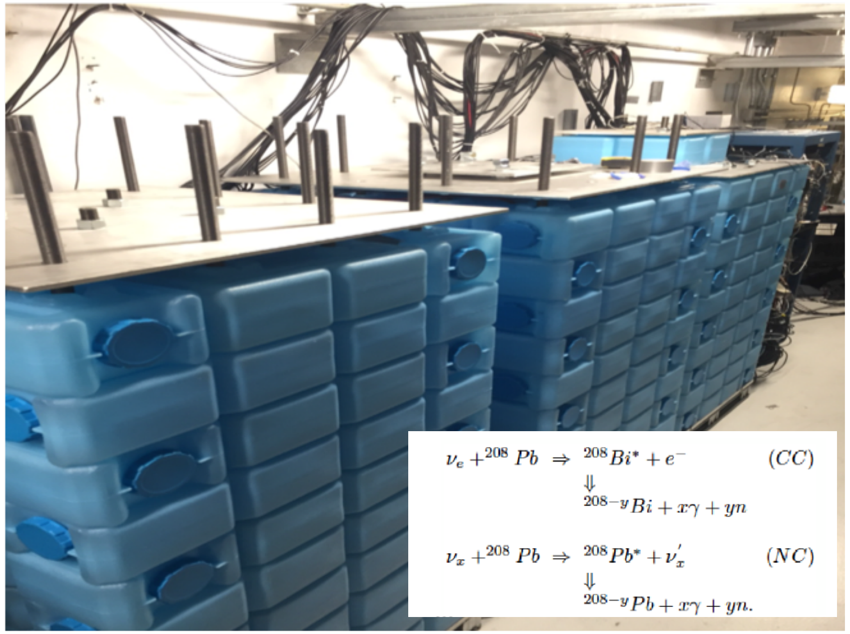


Ongoing Neutrino Alley Activities





Taking data with 185 kg array of NaI detectors. Pilot deployment for 2t array



$$\nu_e + {}^{208}Pb \Rightarrow {}^{208}Bi^* + e^- \qquad (CC)$$
$$\Downarrow$$
$$ {}^{208-y}Bi + x\gamma + yn$$
$$\nu_x + {}^{208}Pb \Rightarrow {}^{208}Pb^* + \nu_x' \qquad (NC)$$
$$\Downarrow$$
$$ {}^{208-y}Pb + x\gamma + yn.$$

Study of Neutrino Induced Neutrons on Lead and Iron

Important for evaluation of backgrounds for CEvNS detectors and for Supernovae neutrino detectors (HALO)

Working on upgrade using PROSPECT Li loaded scintillator

Study of Neutron Backgrounds at Neutrino Alley

MARS detector to monitor neutrons is installed in Neutrino Alley. Initial commissioning and calibration ongoing

What Did We Learn So far?

CEvNS does exists
However, nobody doubt that !!!

“It’s a real thrill that something that I predicted 43 years ago has been realized experimentally,”

Daniel Freedman

SNS is beautiful low energy pulsed neutrino source with “Neutrino Alley”

We know how to detect CEvNS

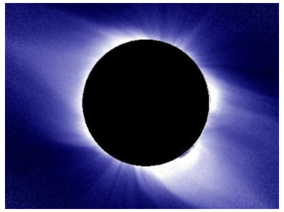
So far we have a binary answers “*YES*”

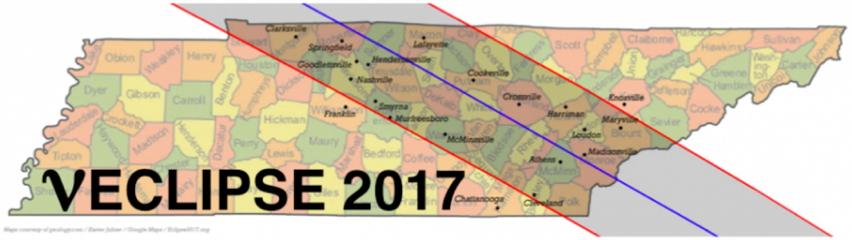
Next step is precision measurements of CEvNS cross sections to search for anomalies

Workshop on Neutrino Physics at the SNS

Baha Balantekin: Neutrino Magnetic Moment
Phil Barbeau: Directional Experiments at the SNS
David Caratelli: LArTPC Electron Reconstruction
Robert Cooper: Dark Photon/Dark Matter Measurements with CEvNS Detectors
Yuri Efremenko: COHERENT Results
Juan Estrada: CONNIE
James Dent: CEvNS as Dark Matter Background
Sam Hedges: CC Interactions at the SNS
Chuck Horowitz: NuEclipse Overview
Jim Kneller: Neutrino NSI in Supernovae
Rupak Mahapatra: MINER
Chris Grant: Low-Energy Interactions in Argon
Gail McLaughlin: Nuclear Physics from SNS Neutrinos
Bob Michaels: PREX/CREX
Yuri Efremenko: Neutrino Production at the SNS
Bronson Messer: Neutrino Signatures from 3D Multi-Physics Models of Core-Collapse Supernovae
Sowjanya Gollapinni: LArTPC Reconstruction Challenges
Natalie Jachowicz: CEvNS and NC/CC Inelastic Cross Sections in a Hartree-Fock CRPA Approach on Various Targets
Saori Pastore: gA Quenching Information from Neutrino Scattering
Kelly Patton: Nuclear Form Factors from Neutrino Scattering
David Radice: Supernova Neutrinos in 2D Models
Shayne Reichard: Supernova Detection via CEvNS
Shu Liao: BSM with CEvNS
Daniel Salvat: MuSun
Raimund Strauss: Nu-cleus
Louis Strigari: CEvNS Theory Overview
Irene Tamborra: Neutrino Signatures from 3D Models of Core-Collapse Supernovae
Clarence Virtue: Neutrino-Induced Neutrons: Experiment

August 21





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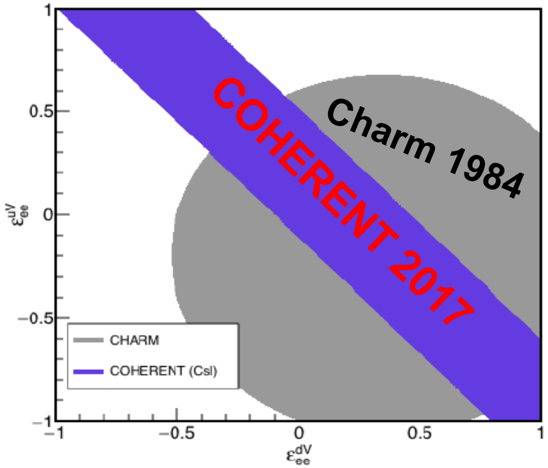
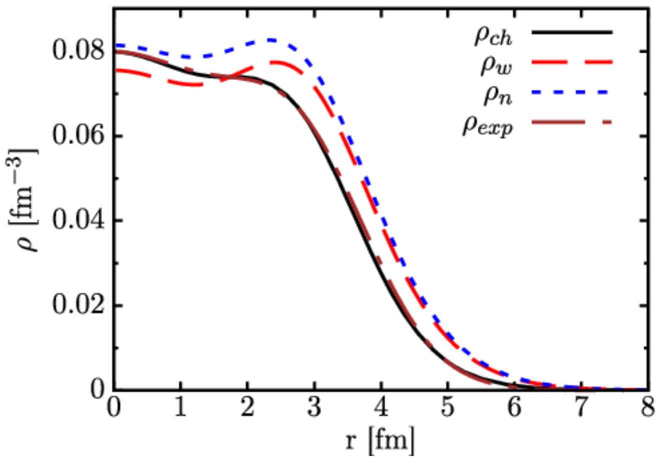
Future Physics for COHERENT

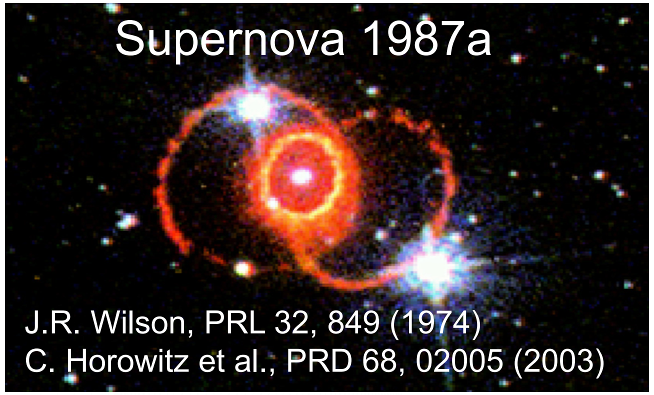
Non-Standard v Interactions: Test of the SM, DM



Nuclear Physics Form Factors, Axial Currents



Supernovae Cross Sections and E_W Measurements



See Kate's Talk

Those studies become important if we do measurements with a very good accuracy

To do so we need multiple detectors able to accumulate large statistics with accurate measurements of recoil spectra

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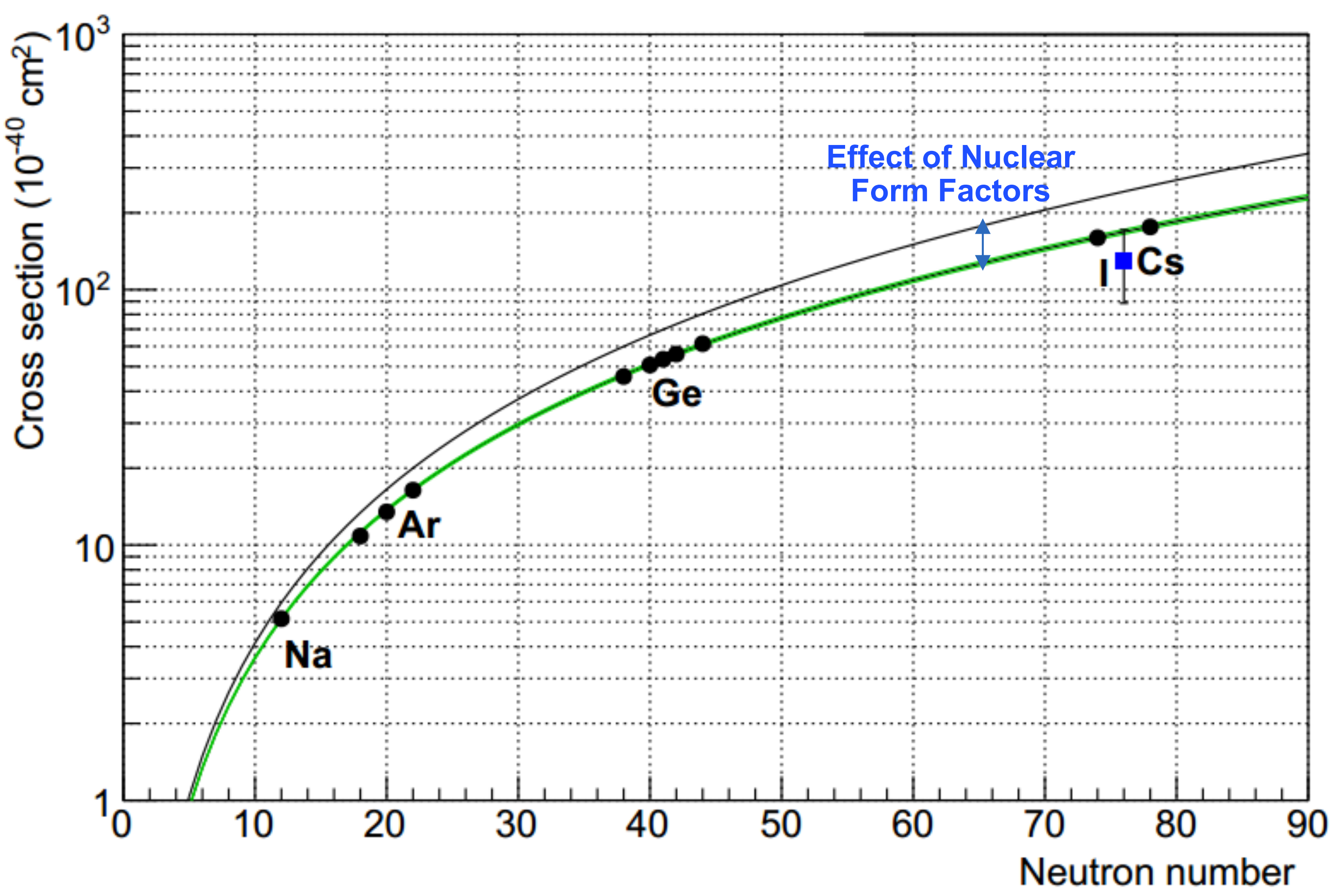
We Need Large Detectors With Various Targets



To untangle effects of nuclear form factors we need measurements at the wide range of target masses: Light, Middle, and Heavy

To have handle on axial current it is interesting to have close targets with different spins.
Example ^{40}Ar s=0 and ^{23}Na s=3/2

Targets near neutrino less double beta decay isotopes (e.g. Ge) are of special interest.

Future Activities – SNS calibration

Presently we assume that neutrino flux at SNS is known within 10%

Cross sections of neutrino interaction with Deuterium are known with 2-3% accuracy

S.Nakamura et. al. Nucl.Phys. A721(2003) 549

Prompt NC ν_μ +d → $1.8 \cdot 10^{-41}$ cm^2
Delayed NC $\nu_{e\mu\text{-bar}}$ + d → $6.0 \cdot 10^{-41}$ cm^2
Delayed CC ν_e + d → $5.5 \cdot 10^{-41}$ cm^2

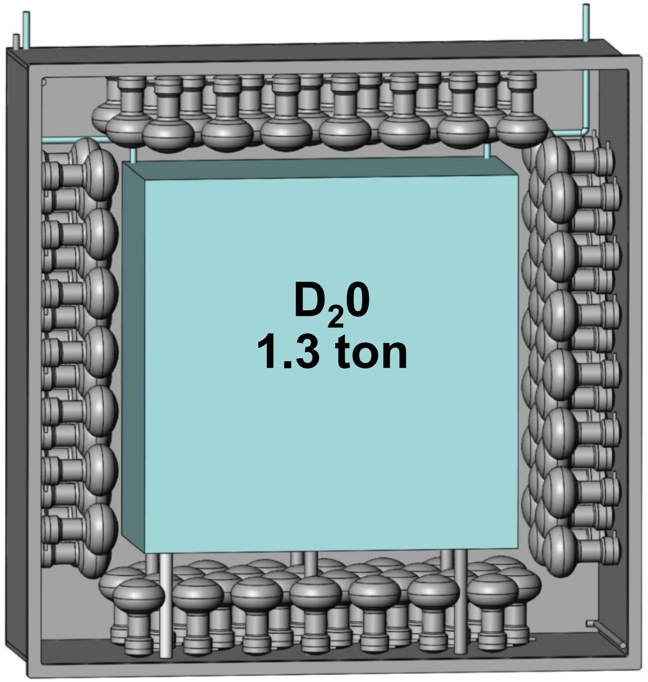
For 1 t fiducial mass detector ~ thousand interactions per year

Detector calibration with Michel Electrons (same energy range)

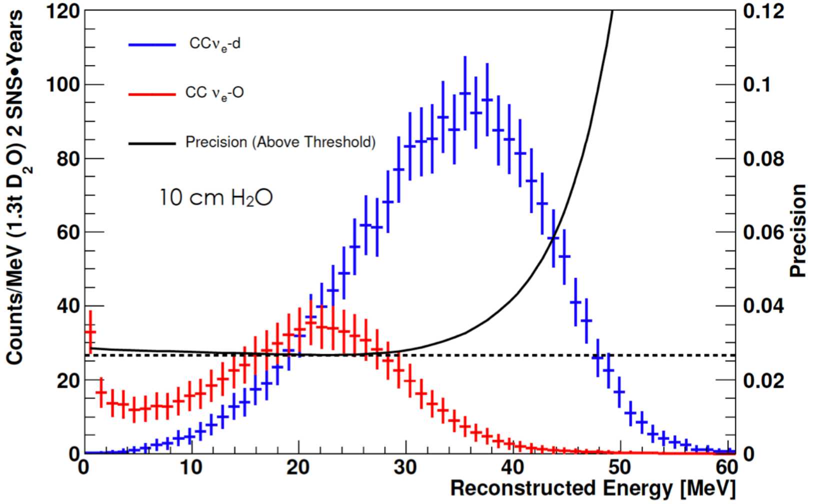
Well defined D_2O mass constrained by acrylic tank

10 cm of light water tail catcher

Outer dimensions 2.3 * 2.3 * 1.0 m^3

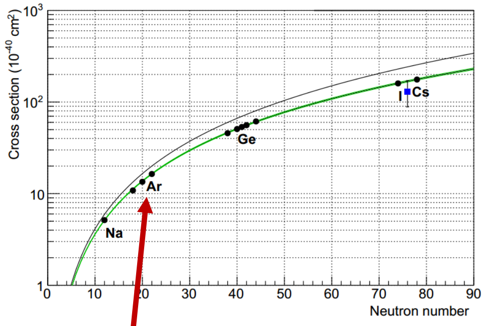


See Jason's Talk

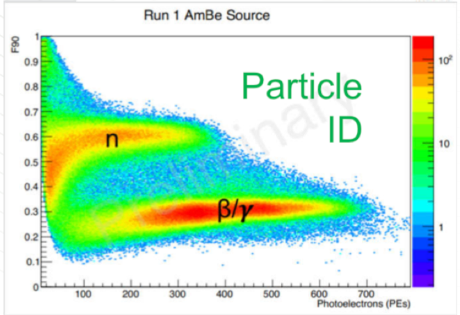


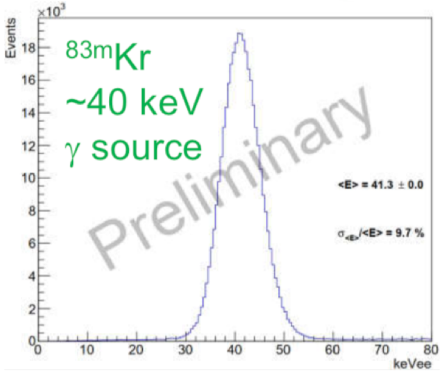
SNS calibration and CC measurements on Oxygen

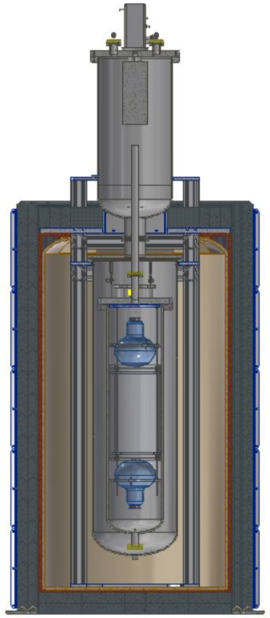
Future Activities - 1 ton LAr detector



Need high statistics low background measurements of CEvNS







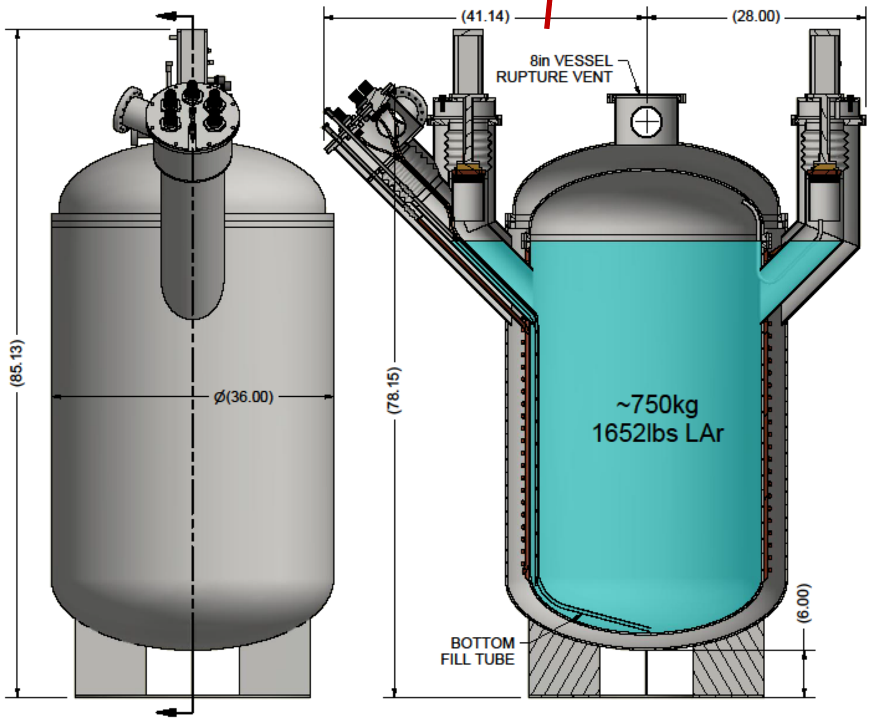
Transition from 22 kg to 1 ton LAr detector.

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



See Rex's Talk

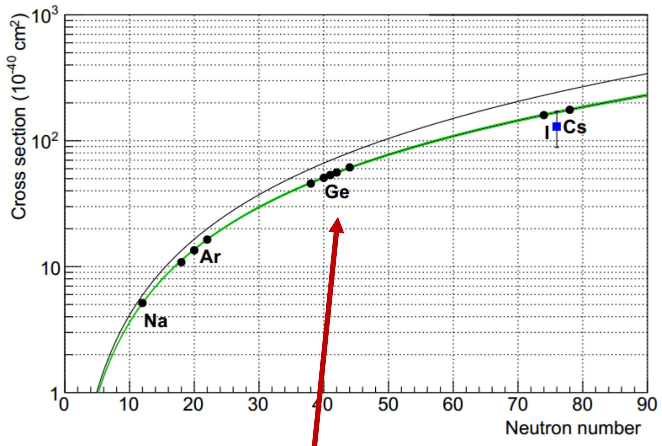
New Germanium Target for COHERENT

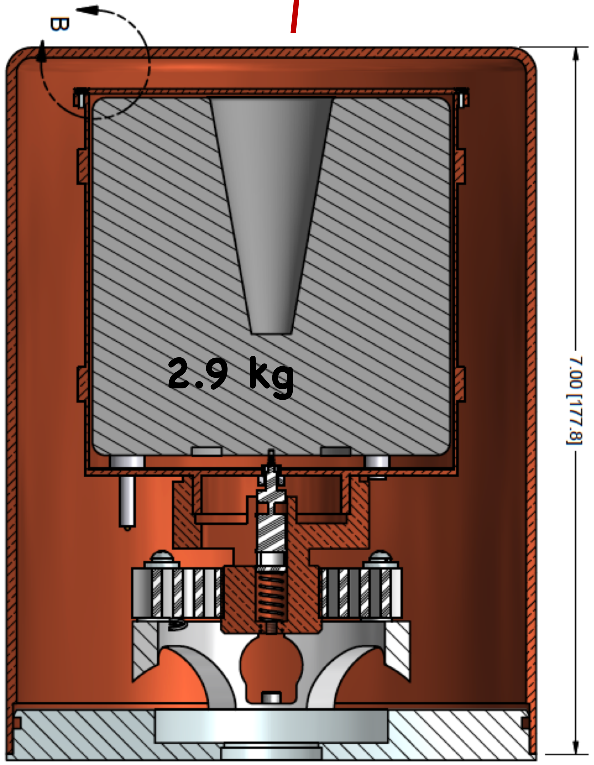
• Use state-of-the-art PPC Ge technology to perform a *precision* measurement of CEνNS. **>800 events/yr from 10 kg** array, with signal/background of ~15 (this was ~1/4 for CsI[Na] first COHERENT result).

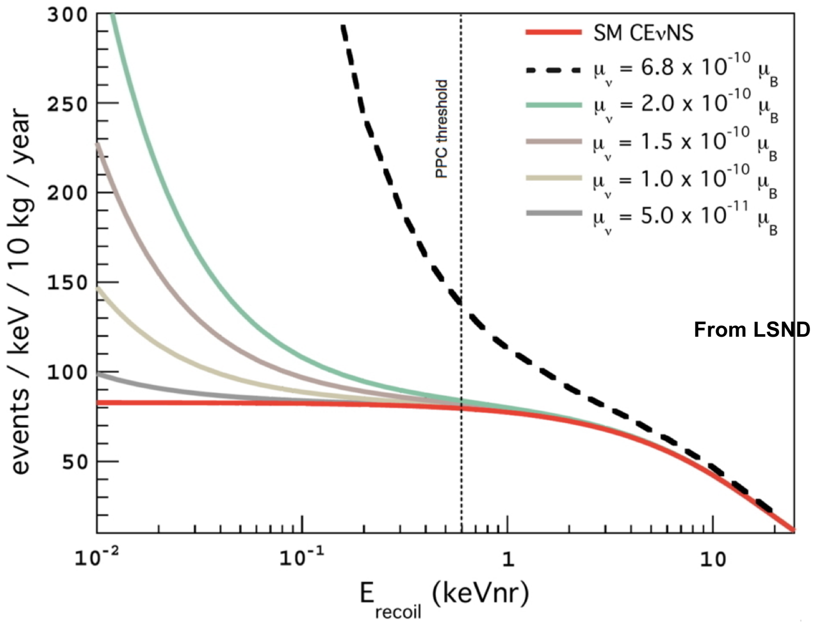
• Demonstrated analysis **threshold of 120eVee/600eVnr** (>70% SA, no false positives) allows measurement of full CEνNS recoil spectrum. Accompanying ongoing effort in quenching factor characterization.

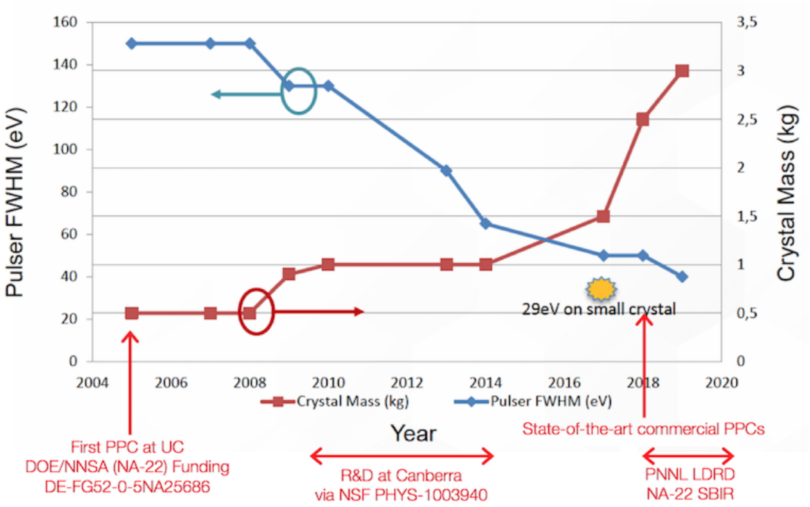
• Improved sensitivity to ν electromagnetic properties, non-standard ν interactions, MiniBooNE/LSND anomaly (steriles), DM models…

• **Two first detectors (6 kg) funded at University of Chicago through DARPA and NSF**. Shield will be designed to accommodate additional two units. **Support from ORNL/NSCU on shield design and installation is necessary**. Demonstration of threshold and background in 2018. **Start of data-taking at SNS during first quarter of 2019.**









See Juan's Talk

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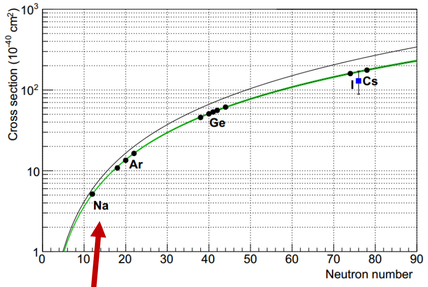
Future Activities - 2t NaI detectors array

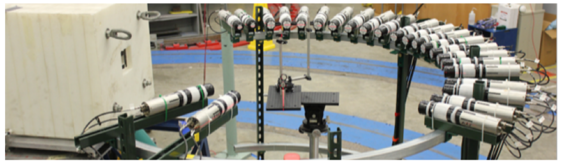


Transition from 185 kg to 2 ton array of NaI detectors

Detectors are available

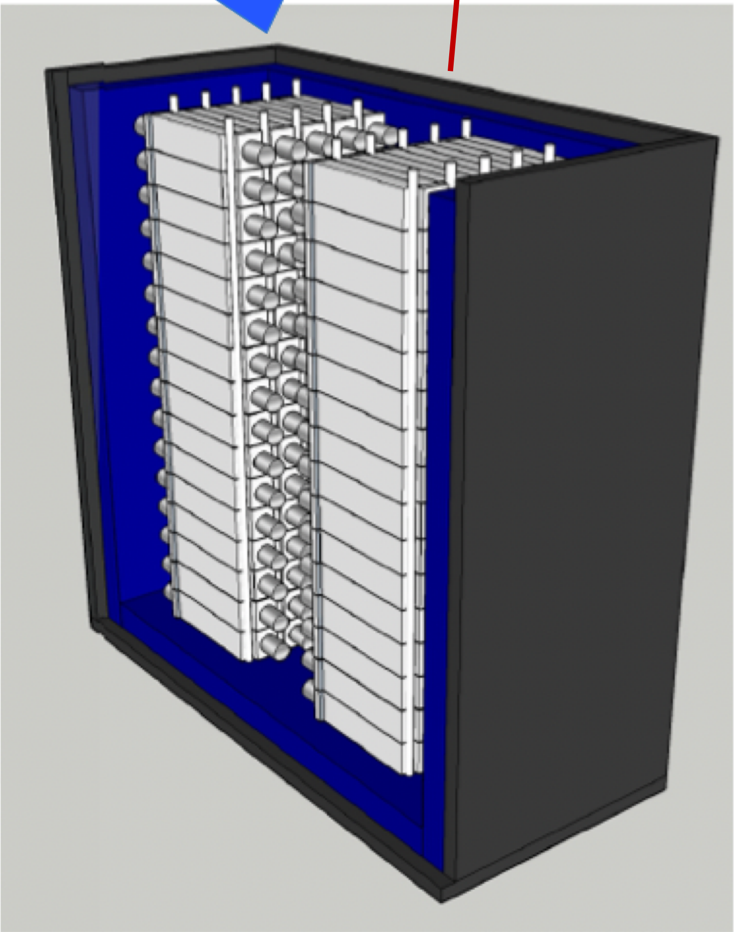
Need dual gain bases (prototypes has been build)

Program to measure Quenching Factors is ongoing at TUNL



Need electronics and HV; some funds are secure

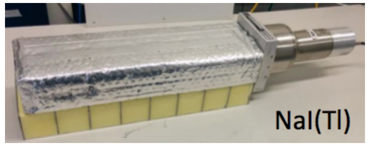
Potential to detect both CEvNS and CC reactions

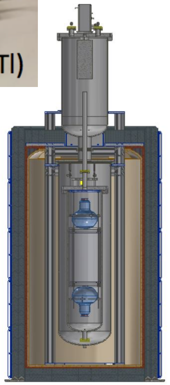


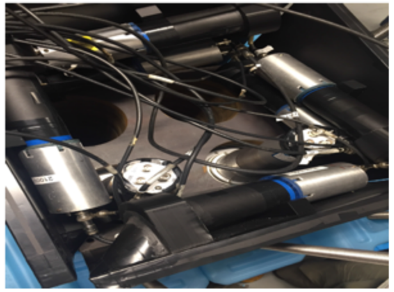
See Phil's Talk

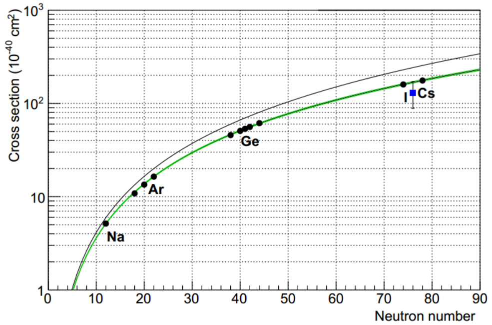
COHERENT Collaboration Steps

Present: First Light



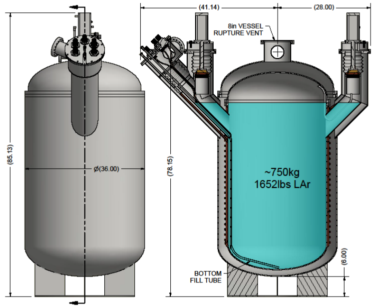


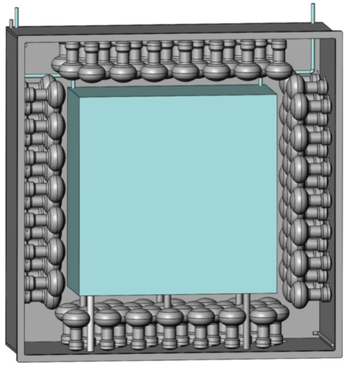


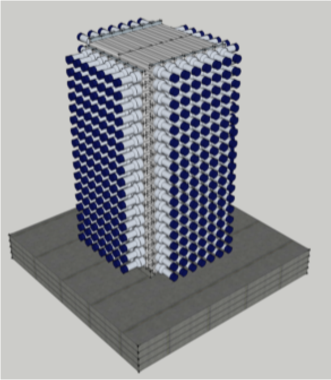


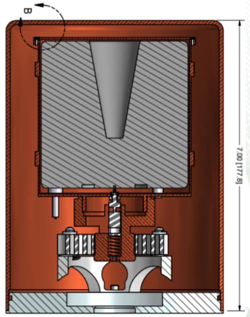
- Detect CEvNS
- Measure CEvNS for heavy and light nuclei
- Detect NINs

Next Step: New Deployments



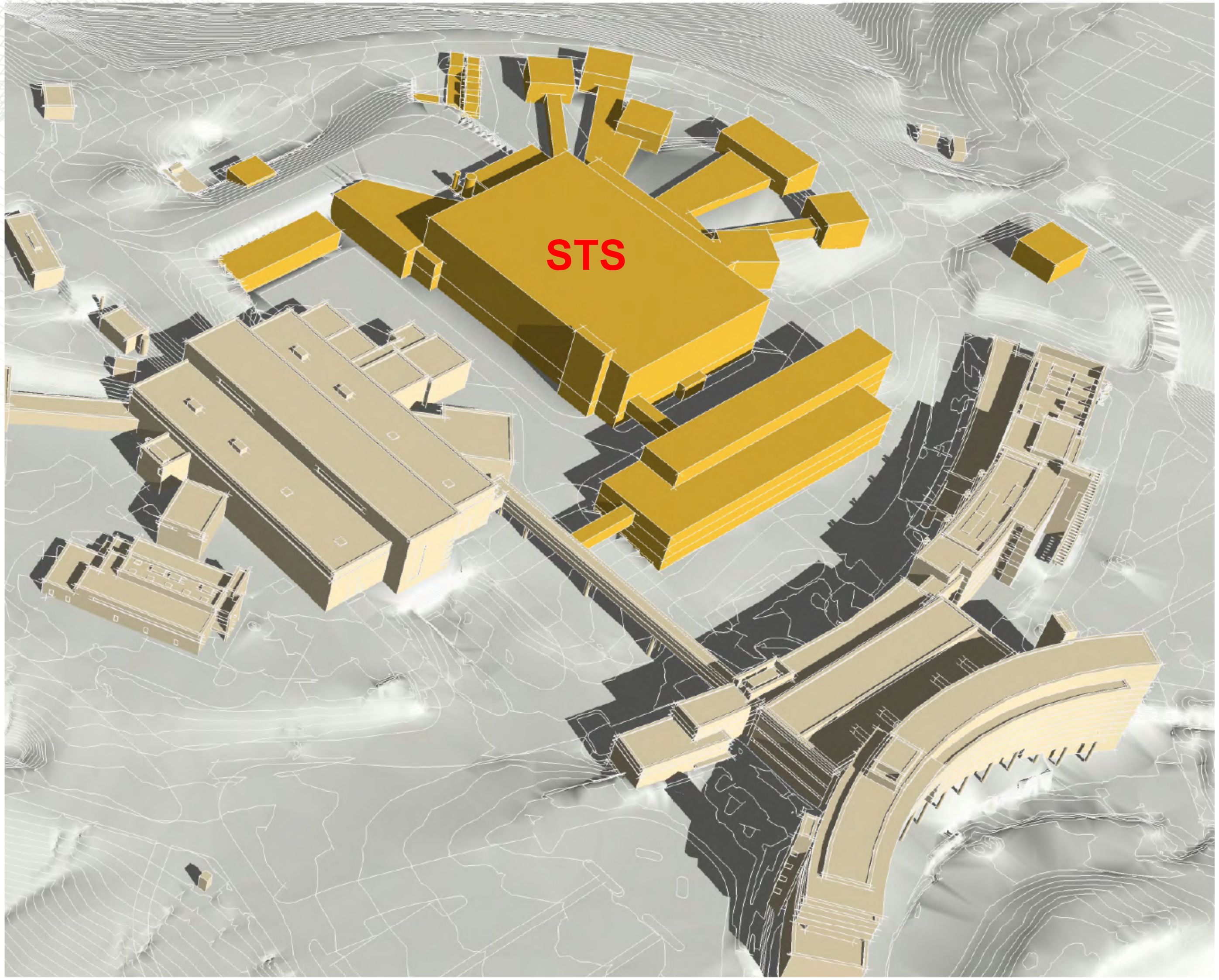






- Deploy low threshold Ge detectors
- Calibrate SNS neutrino flux
- High precision CEvNS studies. Look for physics beyond SM. Eliminate Dark Sector as degeneracy for DUNE
- Measure neutrino CC to support Supernovae physics, and Weak interaction physice
  (Lead, Argon, Oxygen, Iodine)

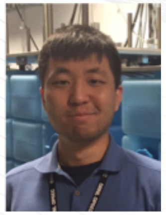
Future Dreams: SNS - STS



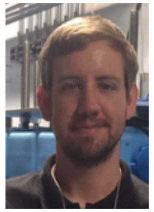
SNS Second Target Station

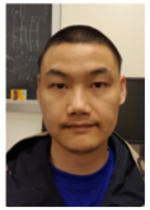
- 1.3 GeV
- Tungsten Target
- 0.8 MW
- 15 Hz
- 600 nsec proton pulse
- Neutrino room with a significant size could be available at the STS basement

Young COHERENT members


Ben Suh
IU

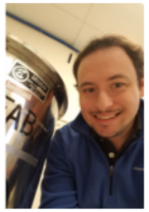

Justin
Raybern
Duke


Sam
Hedges
Duke


Long Li
DUKE

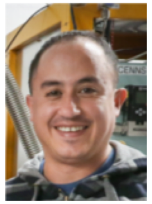

Alexander
Kumpan,
MEPhI


Brandon
Becker
UT


Jacob
Zettlemoyer IU

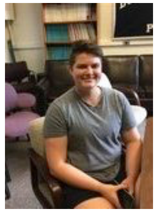

Connor
Awe
Duke


Katrina
Miller
Duke


Hector
Moreno
UNM


Dmitry
Rudik
MEPhI

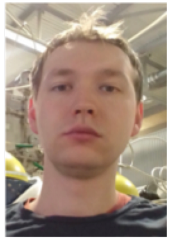

Rebecca
Rall
CMU


Jes Koros
Duke


Alexander
Kavner
Chicago

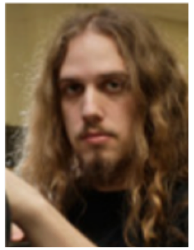

Alexey
Konovalov
MEPhI


Matt Heath
IU


Alex
Khromov
MEPhI


Gleb Sinev
Duke


Erin
Conley
Duke


Dan Salvat
UW
(Postdoc)

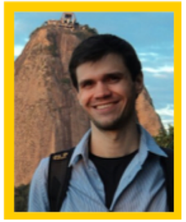

Jacob
Daughhetee
UT (Postdoc)


Mayra
Cervantes
Duke
(Postdoc)


Ivan
Tolstukhin
IU
(Postdoc)

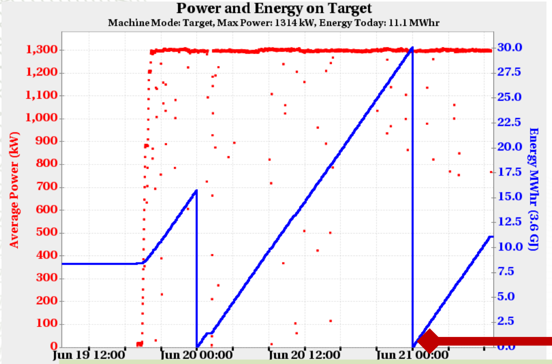

Josh
Albert
IU
(Postdoc)

First two PhD dissertations completed

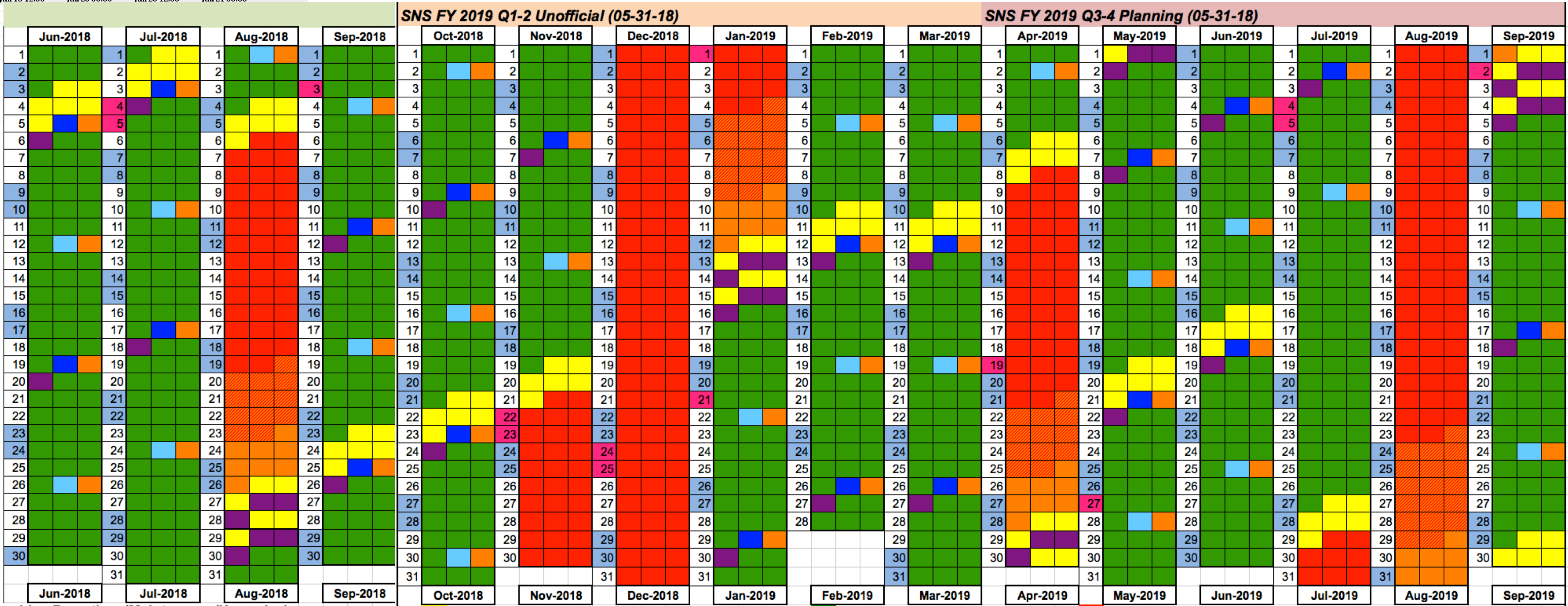

Bjorn Scholz
U of Chicago


Grayson Rich
Duke

SNS Schedule



1.4 MW



achine Downtime (Maintenance/Upgrades)
lanned Outages (background color is original plan)
achine Downtime (Tunnels Closed for Equipment Tests)

- Accelerator Physics
- Accelerator Startup/Restore
- Accelerator Physics/Maintenance Periods
- Scheduled Maintenance (starts at 06:30)
- Neutron Production
- Transition to Neutron Production
- Planned Machine Downtime (Maintenance/Upgrades)
- Major Unplanned Outages (background color is original plan)
- Planned Machine Downtime (Tunnels Closed for Equipment Tests)

Summary

COHERENT is continued to take and analyzed data from deployed detectors

We are running QF measurement program at TUNL to support CsI, Ge and NaI detectors

Preparation are on the way to build and deploy ~6 kg Ge detectors and 2t NaI detectors

Collaboration is aiming to submit proposal for 1t LAr and 1t D_2O detectors and to support axillary efforts in the fall of this year

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Collaboration is planning to deliver:

- **Data on precision tests of SM at new channels**
- **Inputs into Nuclear Physics Theory**
- **CC and NC measurement for O, Ar, I, and Pb for E_ν <50 MeV**

A new portal to (non)standard particle and nuclear physics

… small but multicolor !

Slide from the opening talk at the Neutrino 2018 by Prof. Eligio Lisi, INFN