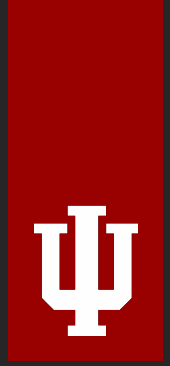


Daniel J Salvat

3 Dec 2020 Snowmass NF09 Workshop

COHERENT: Physics, Hardware, and Upgrades

INDIANA UNIVERSITY BLOOMINGTON

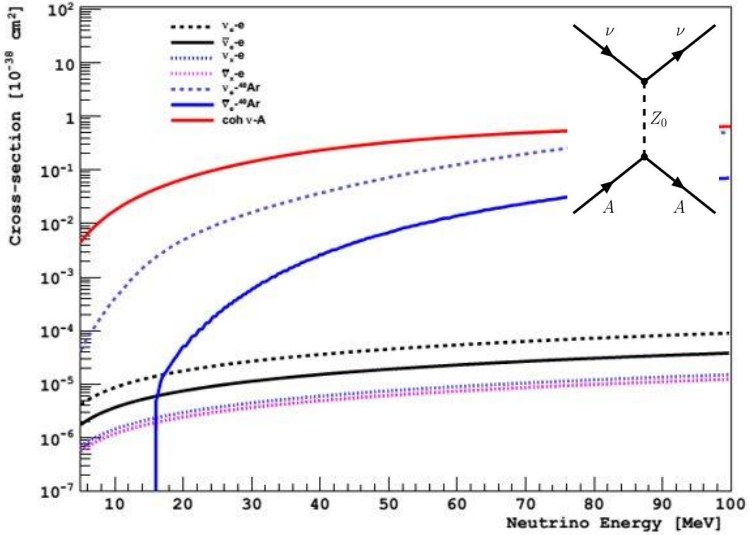
Magnificent CEvNS

https://indico.cern.ch/event/943069/overview


COHERENT Physics

Coherent Elastic Neutrino-Nucleus Scattering

$$\lambda = \frac{\hbar}{p} = \frac{1200\ \text{MeV fm}}{50\ \text{MeV}} \sim 25\ \text{fm}$$



$$\frac{d\sigma}{dT}_{coh} = \frac{G_f^2 M}{2\pi} G_V^2 \left[1 + \left(1 - \frac{T}{E_\nu}\right)^2 - \frac{MT}{E_\nu^2}\right]$$

$$G_V = (g_V^p Z + g_V^n N) F_{\text{nucl}}^V(Q^2)$$

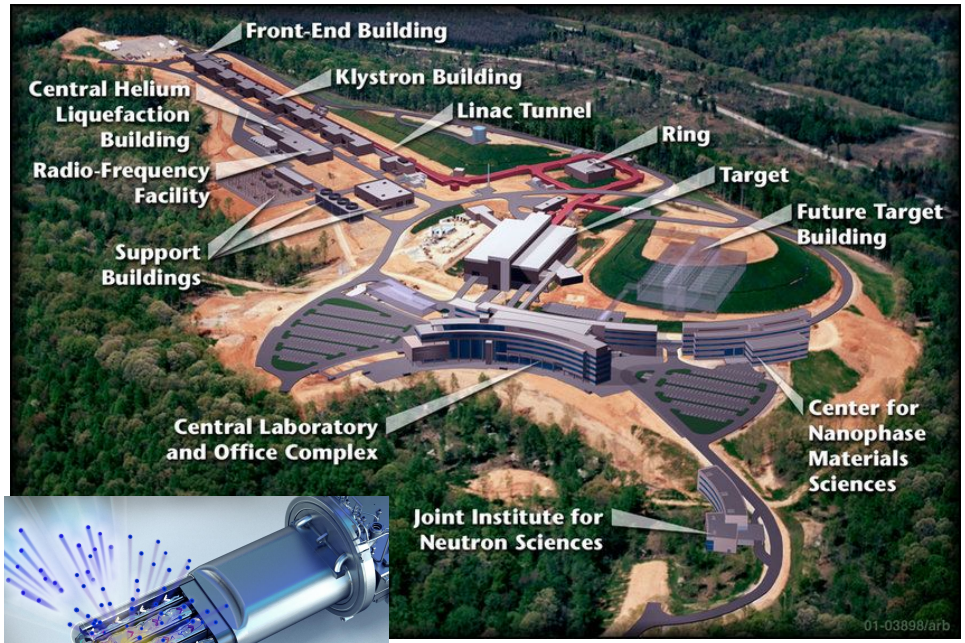
small proton weak charge

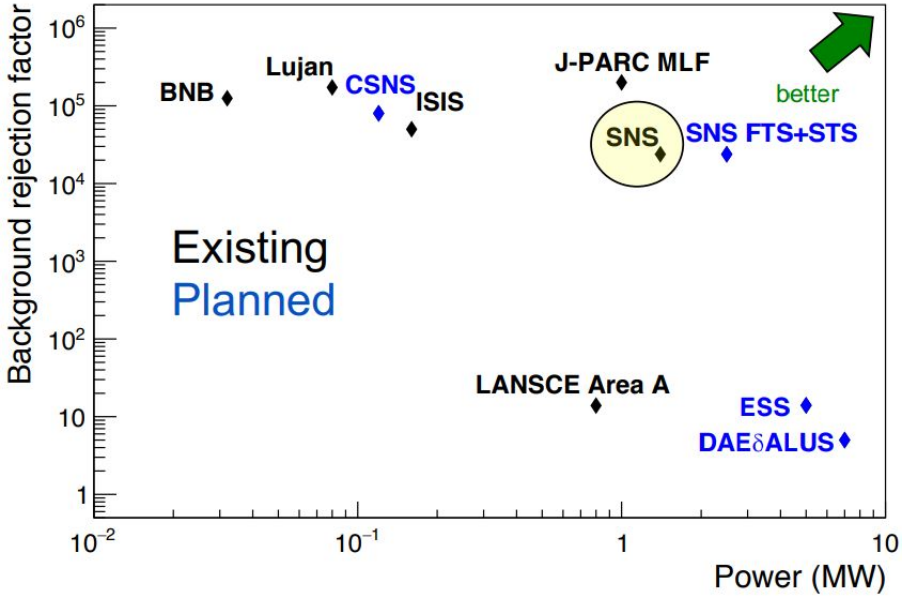
$\sigma \sim N^2$

~few-% uncertainty

What do we want? *neutrinos!*

When do we want 'em? *60 times a second!*

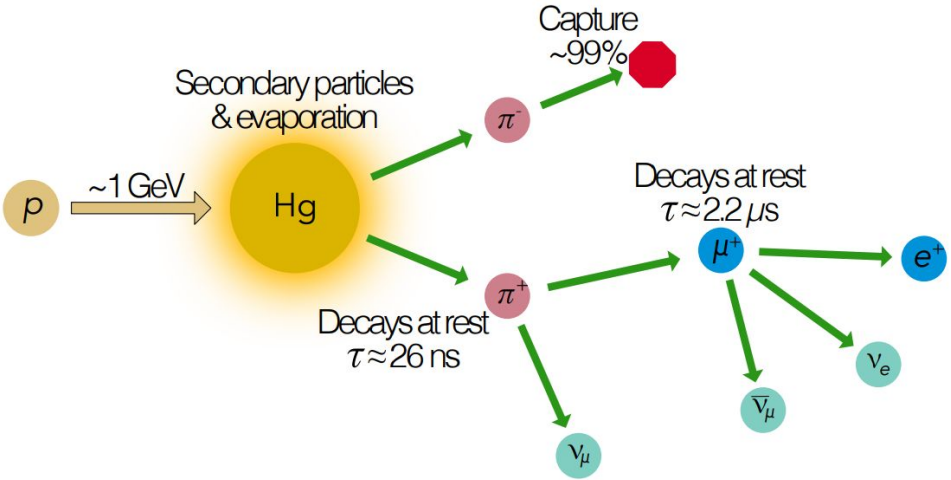


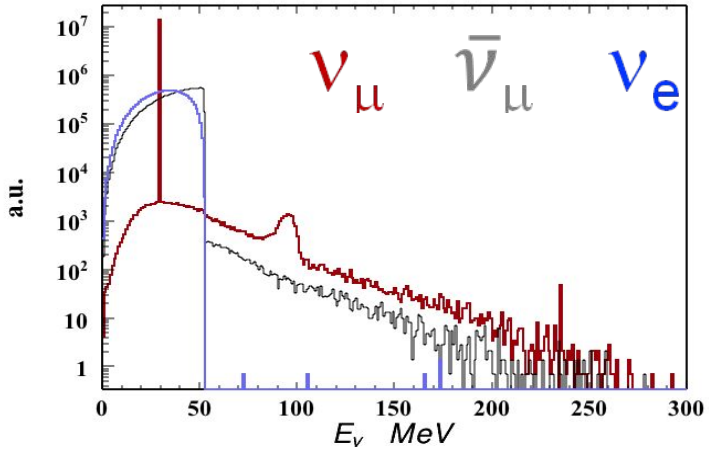


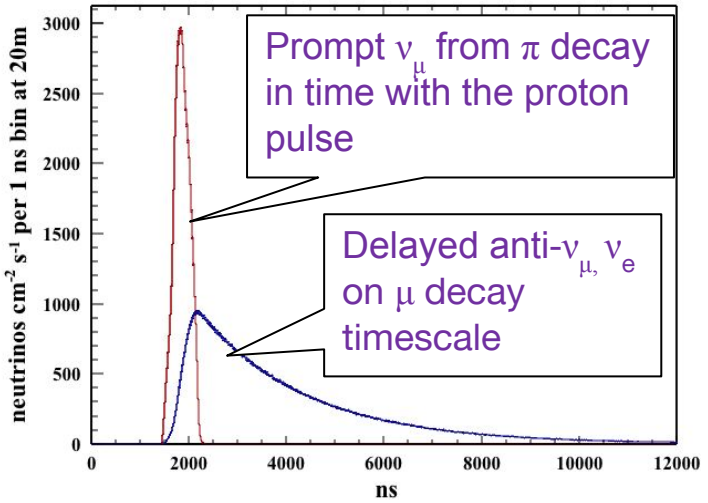
- 60 Hz-pulsed ~1 GeV protons
- 1.4 MW on liquid Hg target
- Future upgrades for higher power

The SNS neutrino flux

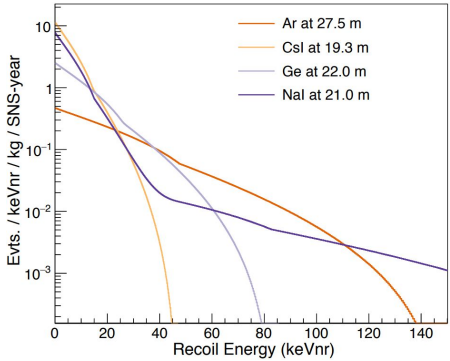
- $1x10^7$ ν / flavor / cm^2 / s 20 m from target
- 0.09 ν per proton-on-target
- ~10,000-fold background suppression







CEvNS cross section measurements



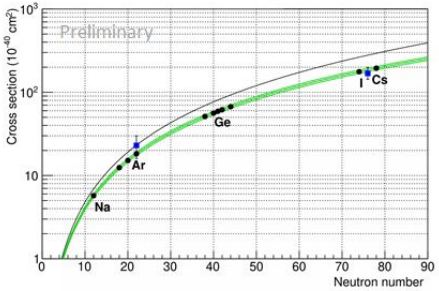
$$\frac{d\sigma}{dT}(T,t) = \frac{\text{events vs. } T,t,...}{(\text{exposure})\,(\text{acceptance})\,(\text{flux})}$$

CEvNS cross section measurements

SM prediction, $\sin^2\theta_W$, vector non-standard interactions, ...

S/T forces, *Z'* models, EM properties, neutron radius ....

prompt and **delayed** flux: flavor dependence

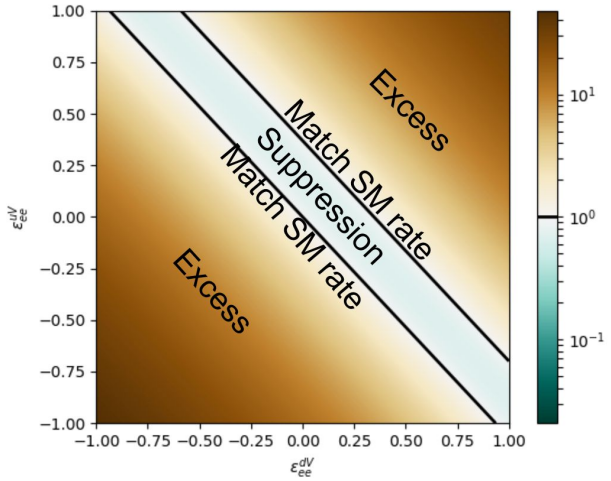


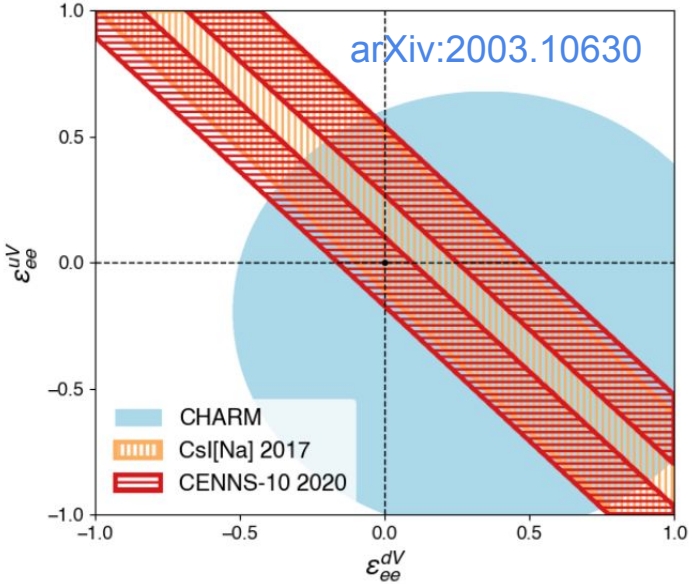
$$\frac{d\sigma}{dT}(T,t) = \frac{\text{events vs. } T,t,\ldots}{(\text{exposure})\,(\text{acceptance})\,(\text{flux})}$$

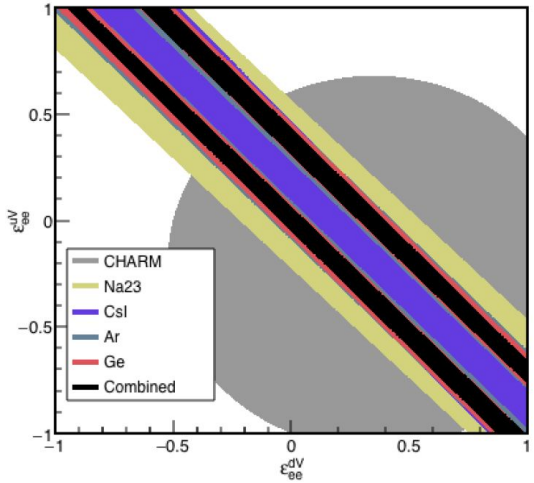
Non-standard interactions

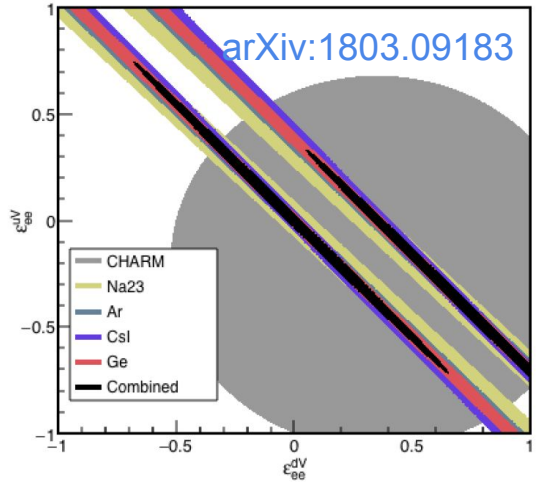
$$\mathcal{L}_{\rm NSI} = -2\sqrt{2}G_F \sum_{f,P,\alpha,\beta} \epsilon^{f,P}_{\alpha\beta}(\bar{\nu}_\alpha \gamma^\mu P_L \nu_\beta)(\bar{f}\gamma_\mu P f)$$

$$Q_W^2 \to Q_{\rm NSI}^2 = 4\left[N\left(-\frac{1}{2}+\epsilon_{ee}^{uV}+2\epsilon_{ee}^{dV}\right)+Z\left(\frac{1}{2}-2\sin^2\theta_W+2\epsilon_{ee}^{uV}+\epsilon_{ee}^{dV}\right)\right]^2 + 4\left[N(\epsilon_{e\tau}^{uV}+2\epsilon_{e\tau}^{dV})+Z(2\epsilon_{e\tau}^{uV}+\epsilon_{e\tau}^{dV})\right]^2 .$$





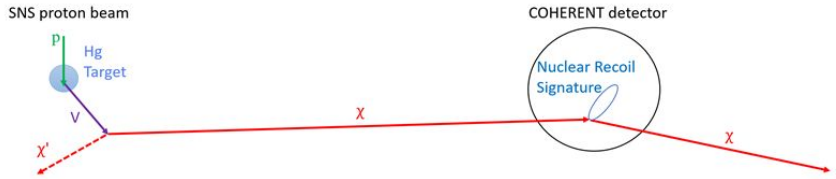


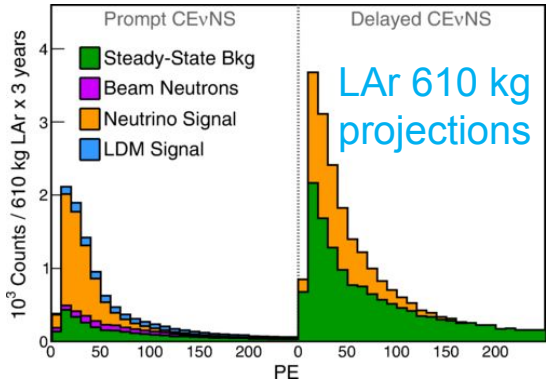


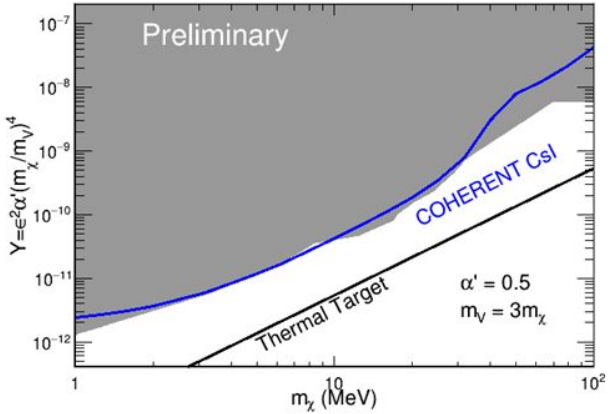
See also: O.G. Miranda, *et al.* arXiv:2003.12050v3 (2020)

Accelerator-produced dark matter

- Vector-portal dark matter from neutral mesons in target
- Recoil spectrum depends upon mediator mass, *different recoil spectrum from CEvNS*
- Coherent nuclear enhancement
- New CsI results push constraints for DM mass near 9 MeV







Sensitivity of the COHERENT experiment to accelerator-produced dark matter

D. Akimov *et al.*
Phys. Rev. D **102**, 052007 – Published 29 September 2020

CEvNS cross section measurements

$$\frac{d\sigma}{dT}(T,t) = \frac{\text{events vs. } T,t,...}{(\text{exposure})\,(\text{acceptance})\,(\text{flux})}$$

CEvNS cross section measurements

Accelerator timing

Energy calibration, quenching factor measurements

e.g. pulse-shape discrimination

$$\frac{d\sigma}{dT}(T,t) = \frac{\text{events vs. } T, t, \ldots}{(\text{exposure})(\text{acceptance})(\text{flux})}$$

Count beam triggers after quality cuts

Establish cut efficiencies, threshold, check w/ Monte Carlo...

At the SNS: *0.090 ± 0.009* neutrinos per POT per flavor

CEvNS cross section measurements

Accelerator timing

Energy calibration, quenching factor measurements

e.g. pulse-shape discrimination

$$\frac{d\sigma}{dT}(T,t) = \frac{\text{events vs. } T, t, \ldots}{(\text{exposure})(\text{acceptance})(\text{flux})}$$

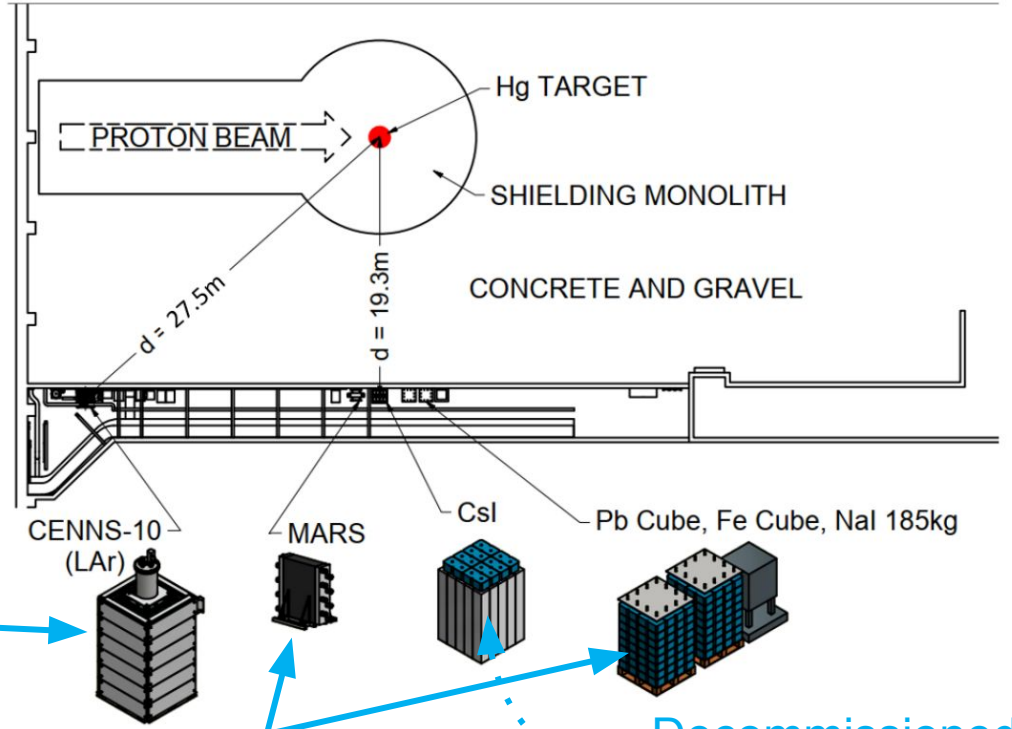
Count beam triggers after quality cuts

Establish cut efficiencies, threshold, check w/ Monte Carlo...

At the SNS: *0.090 ± 0.009* neutrinos per POT per flavor

COHERENT Hardware

Neutrino alley today



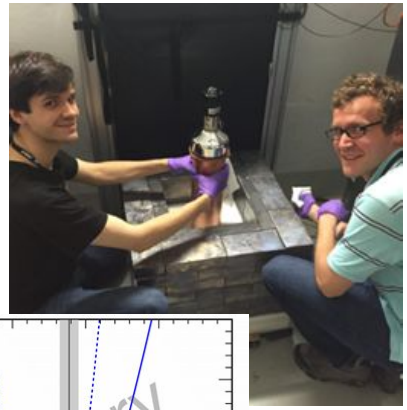
Results early 2020, continued acquisition

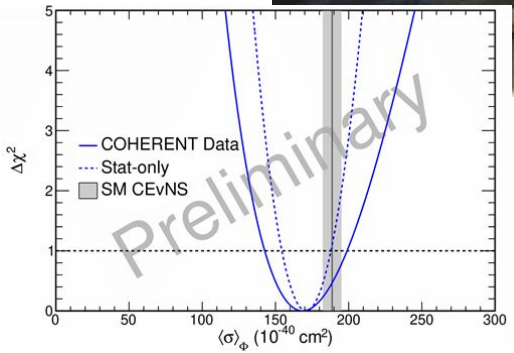
Acquisition and analysis underway

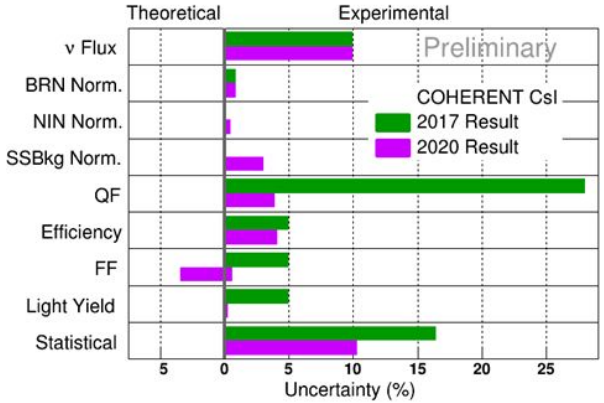
Decommissioned, prelim. final results

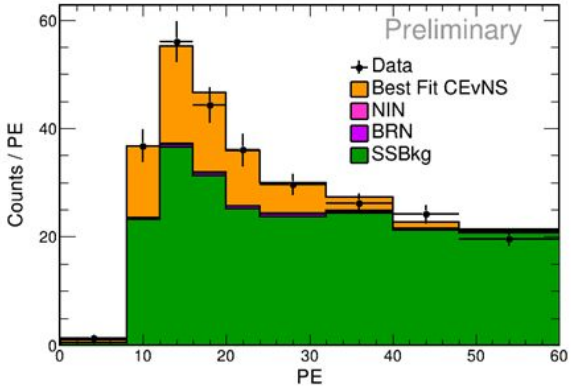
14.6 kg CsI scintillator

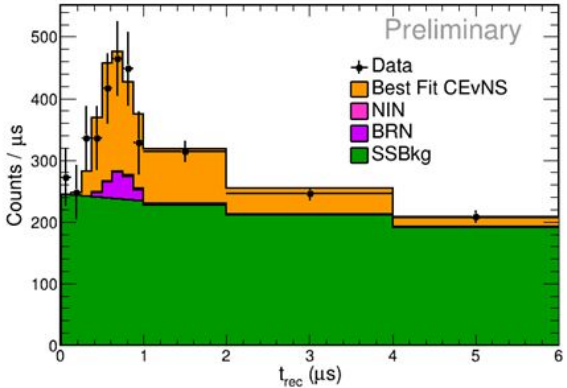
- New results at Mag7s workshop! (D. Pershey)
- Improved analysis (A. Konovalov)
- Improved CsI quenching factor
- Good agreement with SM





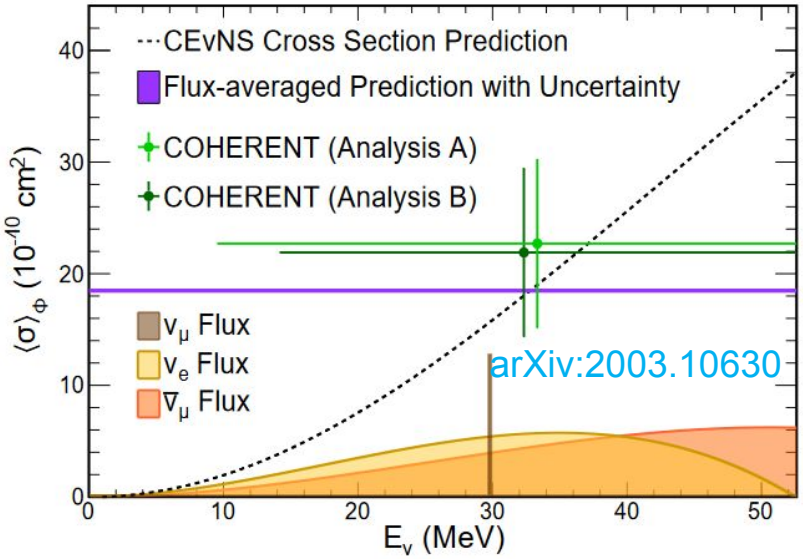


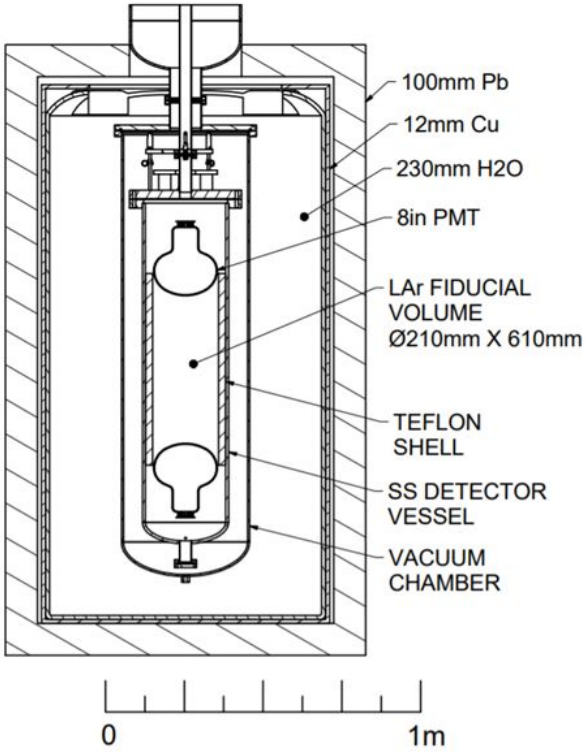


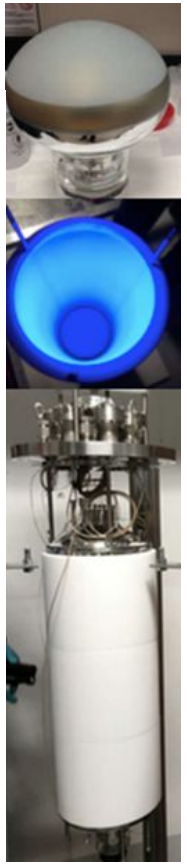


COH-Ar-10 single phase LAr scintillator

- 20 keVnr threshold, 4.5 p.e. per keVee
- First results earlier this year: arXiv:2003.10630
- >2x more data acquired, analysis underway
- ^{83m}Kr cal. source: arXiv:2010.11258

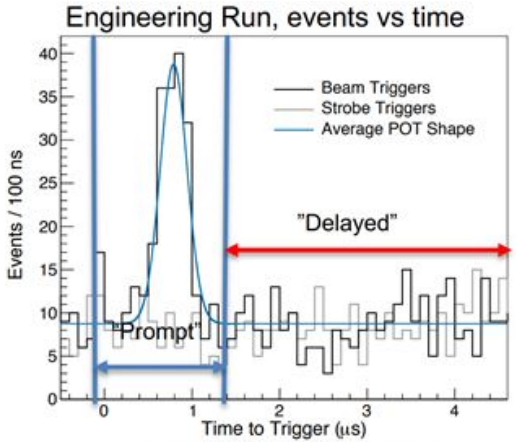




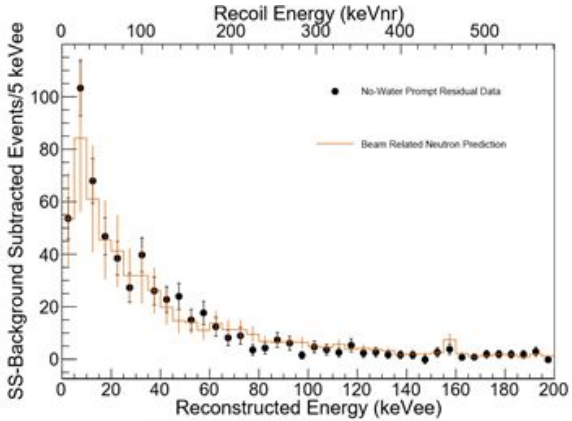


COH-Ar-10 beam-related neutrons

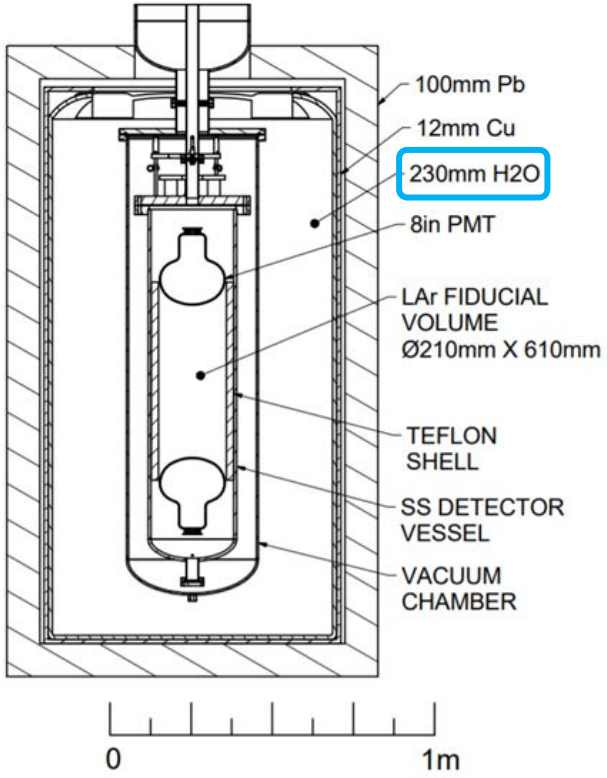
- Drain water shielding -- increase BRN by ten-fold
- Use “no-water” data to tune GEANT4 simulation
- Data-driven simulation used to estimate contribution to CEvNS background



M.R. Heath PhD thesis (IU 2019)
Phys. Rev. D 11 115020 (2019)

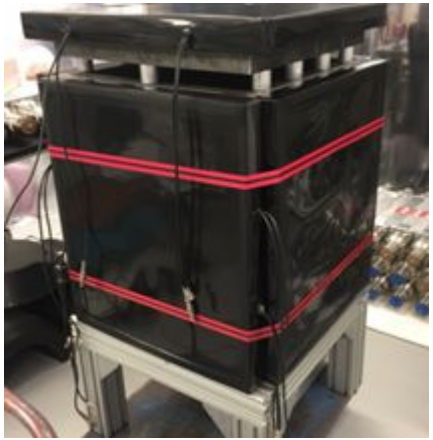


Neutron runs are ultimately used to tune GEANT4 simulation.



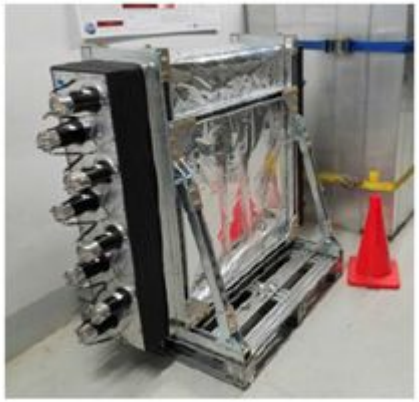
Background studies and CC-interactions

- NaIvE -- 185 kg NaI array
- Search for $^{127}I(\nu,e)^{127}Xe^{*}$
- Test-bed for future ton-scale NaI



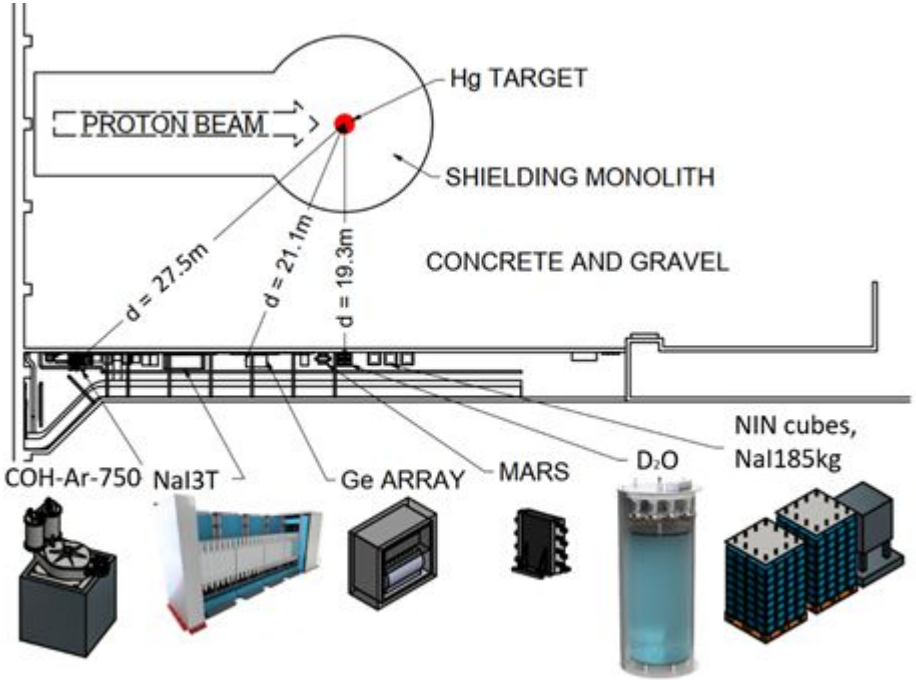
- "Neutrino cubes"
- Liquid scintillator surrounded by heavy shielding
- Search for fast *n* from CC interactions in Pb/Fe/Cu
- Detection scheme for SN *ν*'s

- MARS
- Layered plastic scintillator w/ Gd paint
- capture-gated fast *n* detection



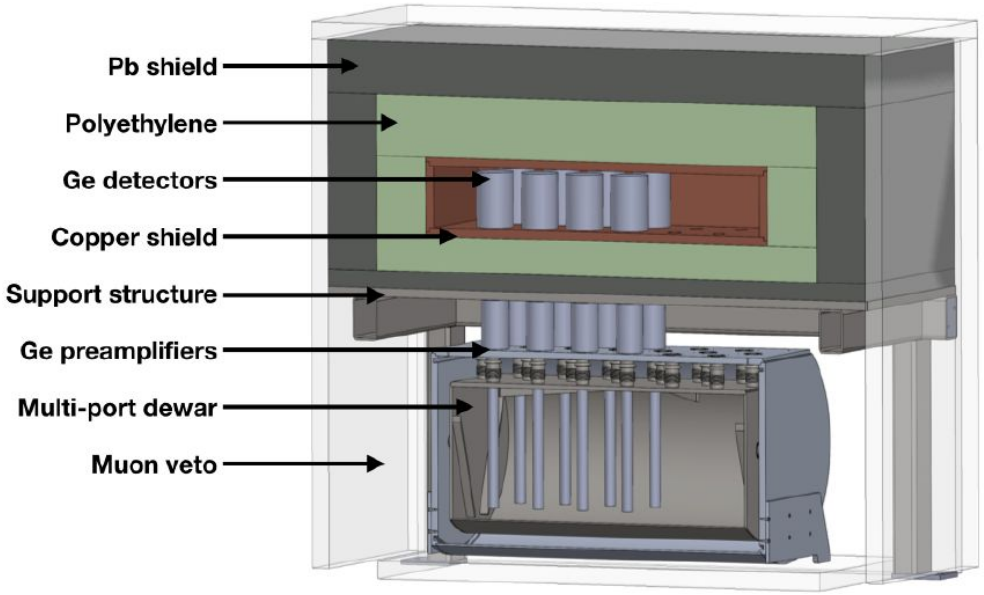
COHERENT Upgrades

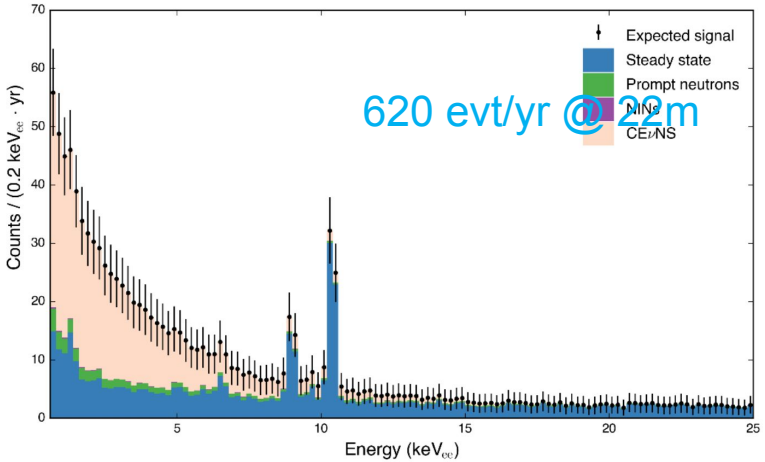
Neutrino alley future

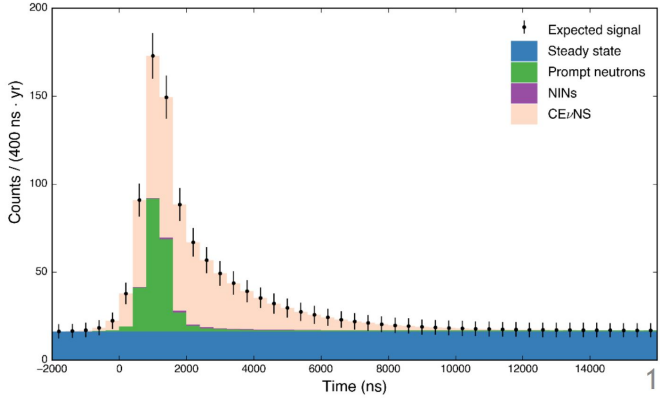


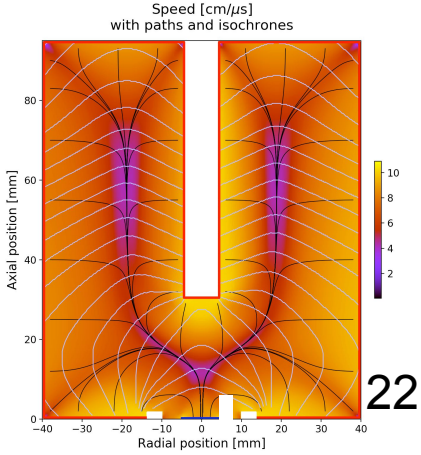
Coh-Ge-16

- 16 kg of PPC Ge (>2 kg each)
- ~2.5 keVnr CEvNS threshold
- ~150 eV FWHM pulser resolution
- Low-background cryostat
- Ge delivery ~March 2021
- Commission/acq. summer 2021!



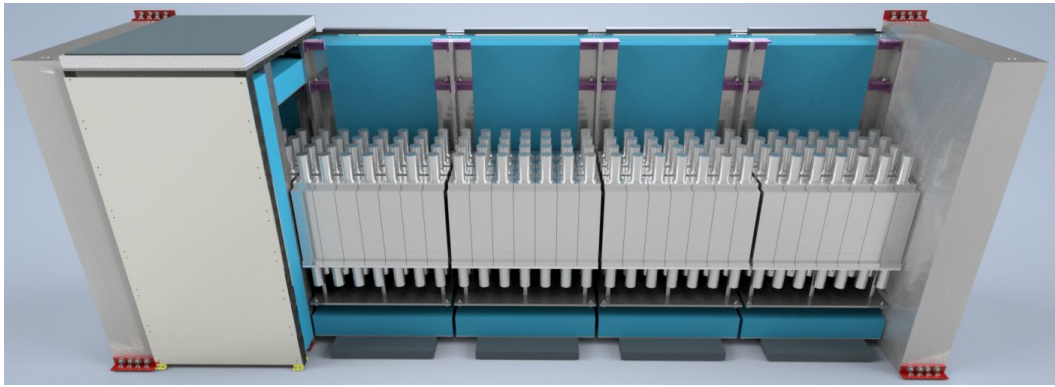


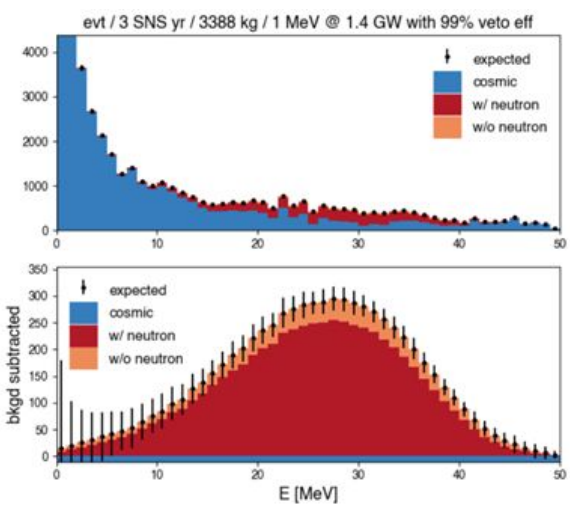


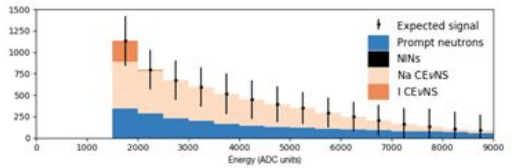


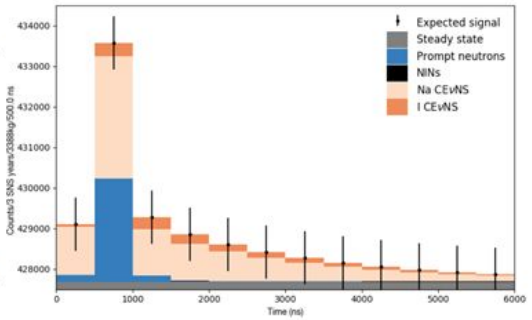
Multi-ton NaI array

- 13 keVnr threshold on ^{23}Na
- 485 kg shielded modules
- Finalizing design/shielding
- Dual-gain readout for low-energy CEvNS measurement, high energy ^{127}I inelastic measurement
- Detector module characterization underway



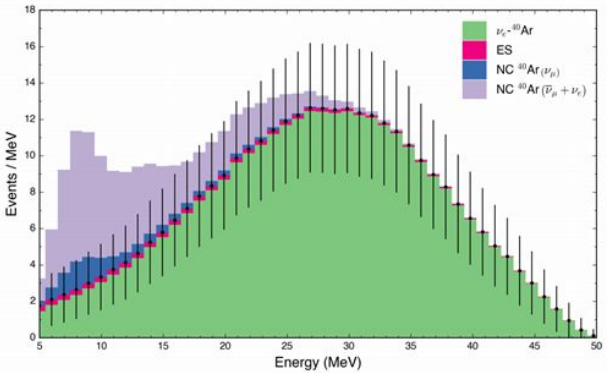


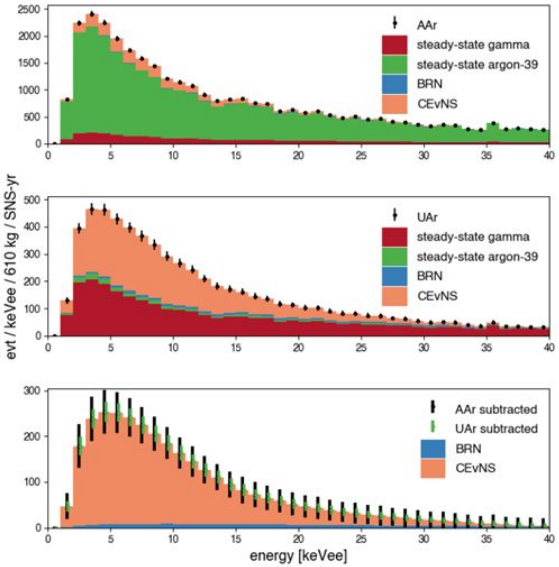


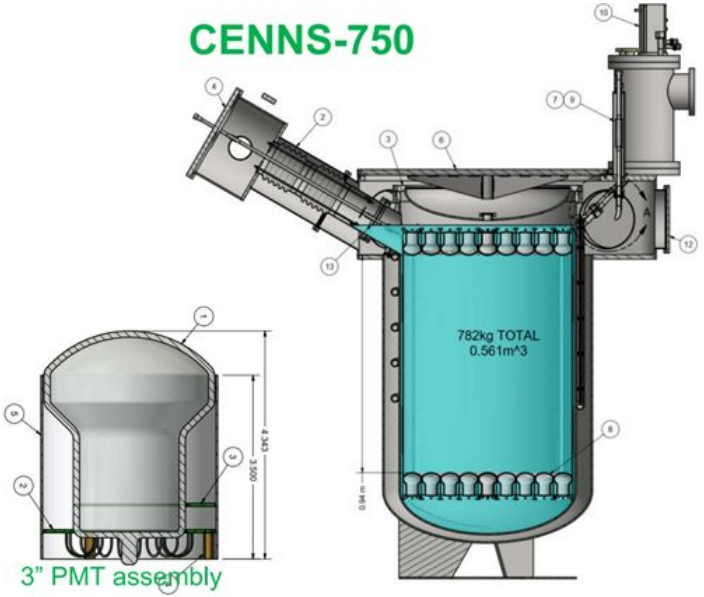


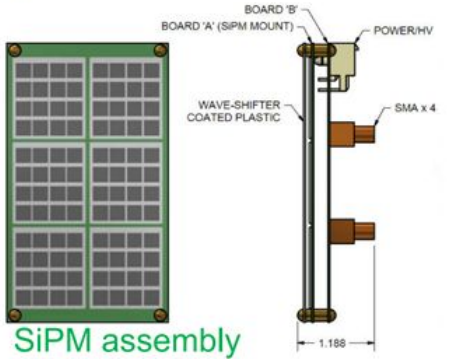
COH-Ar-750

- 610 kg fiducial volume
- Attain same ~20 keVnr threshold
- 3000 CEvNS per SNS-year
- ~400 CC/NC inelastic events per SNs-year
- R&D of cryostat, photodetectors
- Exploring ^{39}Ar-depleted underground argon





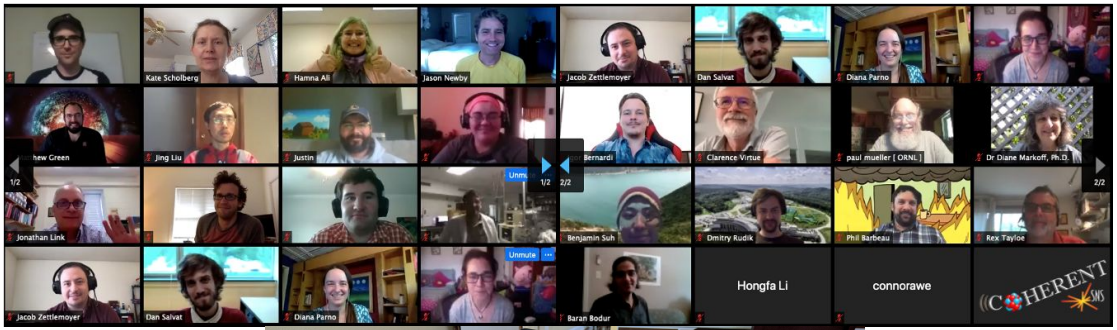


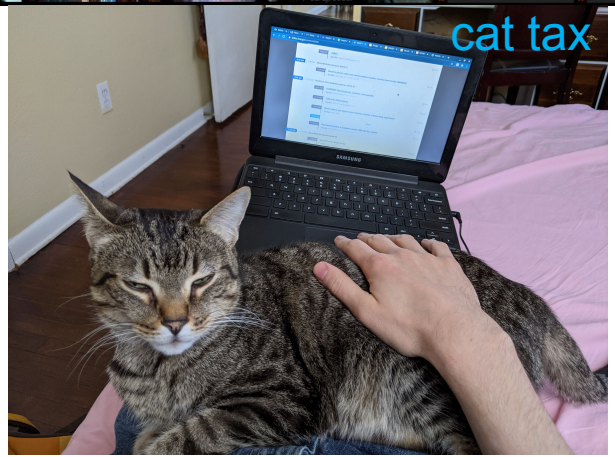


Outlook

- CEvNS is a rich source of standard model tests, **BSM physics**, **nuclear physics**
- We use an array of detector technologies to **test N^2 dependence** in many nuclei
- Dedicated **background** studies, improved **QF measurements** ongoing
- Future large-scale upgrades will lead to **high-precision** measurements of CEvNS recoils
- Potential for **CC/NC inelastic** cross section measurements in I, Ar, Pb, etc…
- Improve upon now-dominant 10% flux uncertainty!
  - See talk by **D. Parno**
- Discuss full potential of **SNS second target station**, power upgrades

The COHERENT collaboration





4 countries, 21 institutions, ~80 members