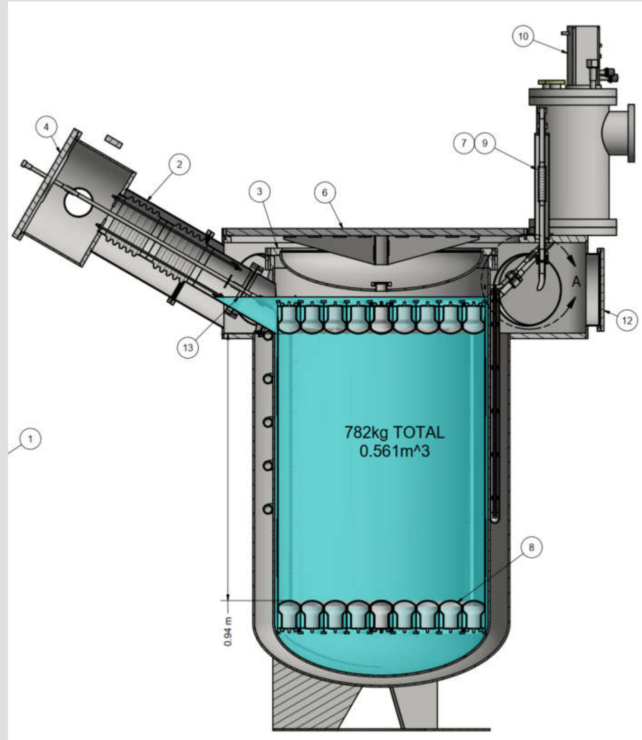
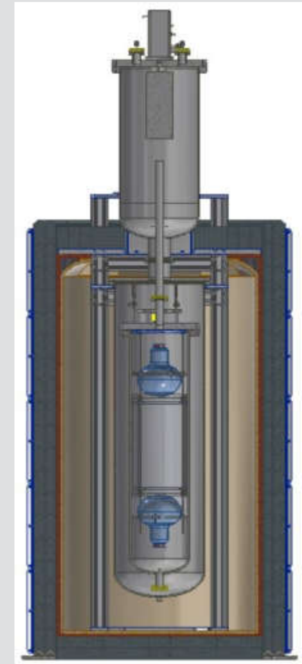
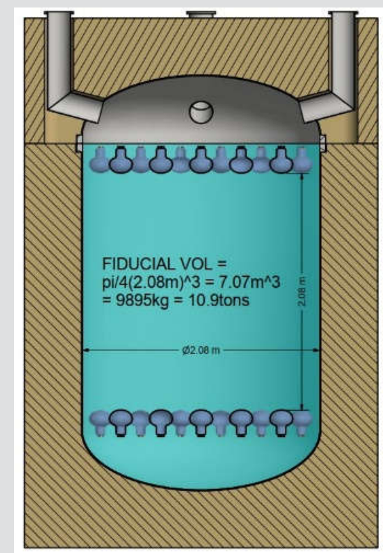
CEvNS with liquid argon scintillation detector(s)

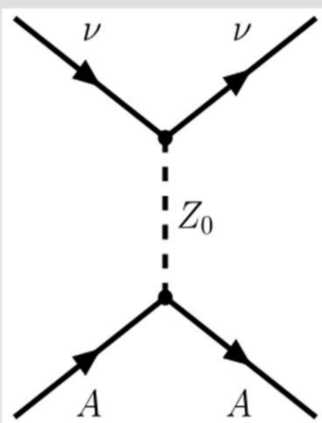
R. Tayloe, Indiana U.
for the COHERENT collaboration

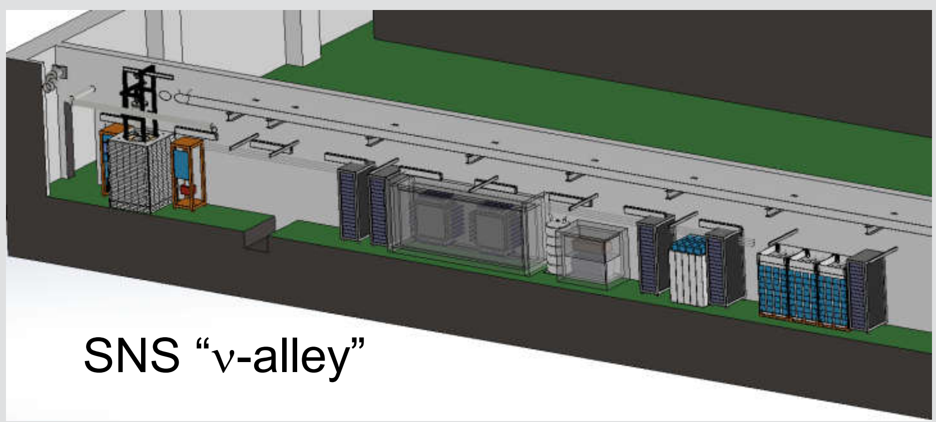




Outline:
- COHERENT at SNS
- CEvNS with LAr
- status/future of LAr detectors for CEvNS



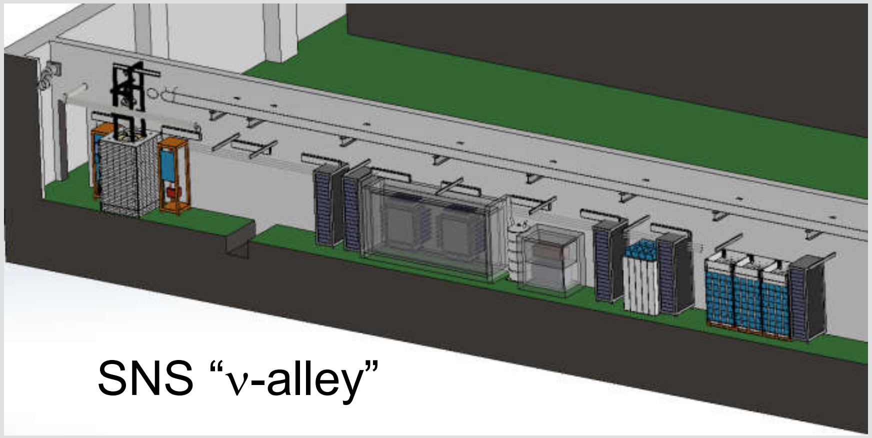




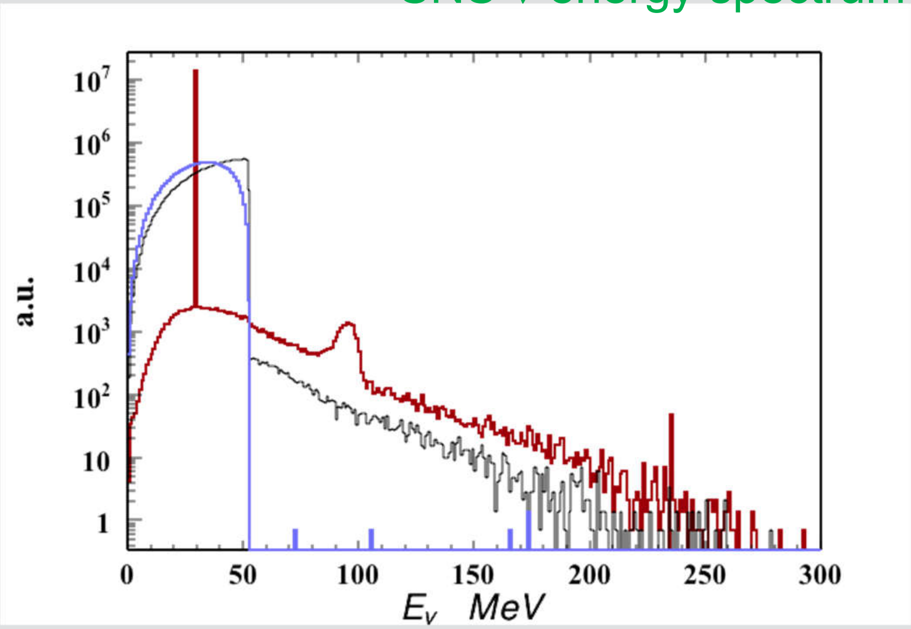
Vf2

COHERENT experiment in SNS ν-alley

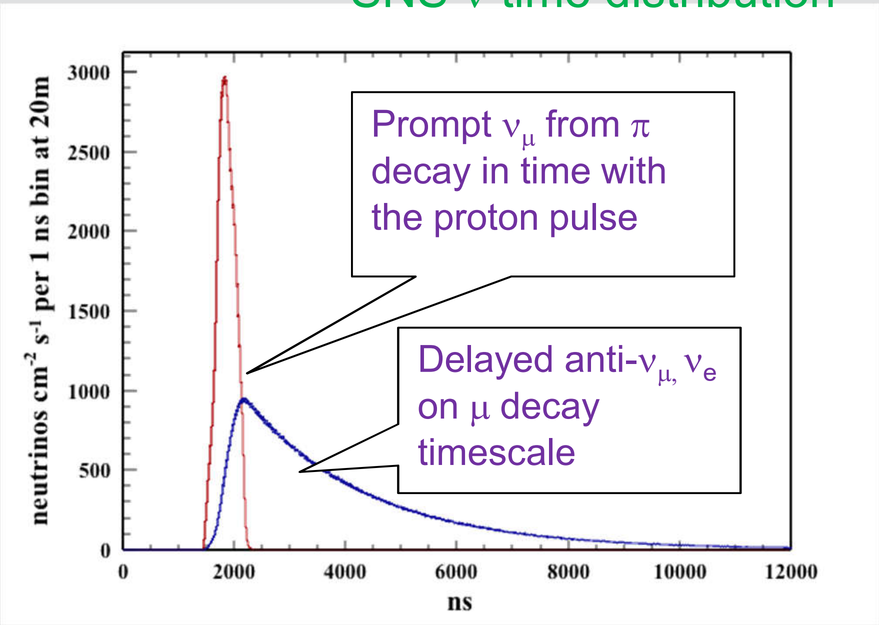
- Low-background area
- near (20-28 m) SNS target with
- 1.4MW, 5000MWhr/yr, 1.5E23POT/yr,
- pulsed beam (FWHM≈350 ns) at 60Hz



SNS ν energy spectrum

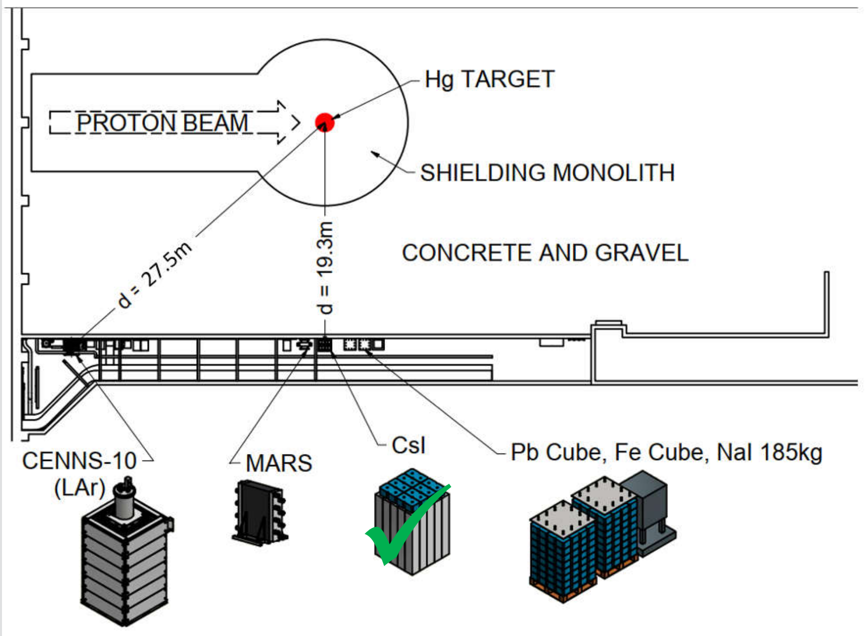


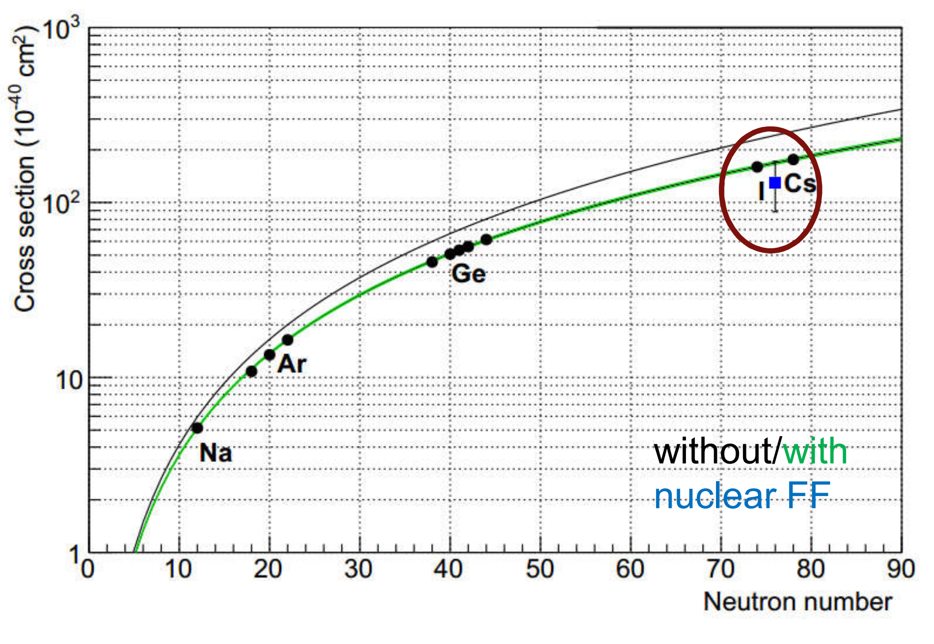
SNS ν time distribution

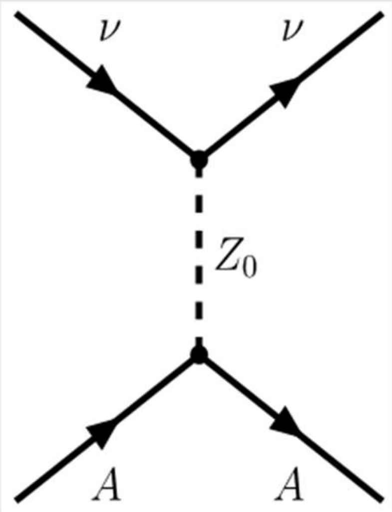


COHERENT experiment

First detection of CEvNS with CsI!

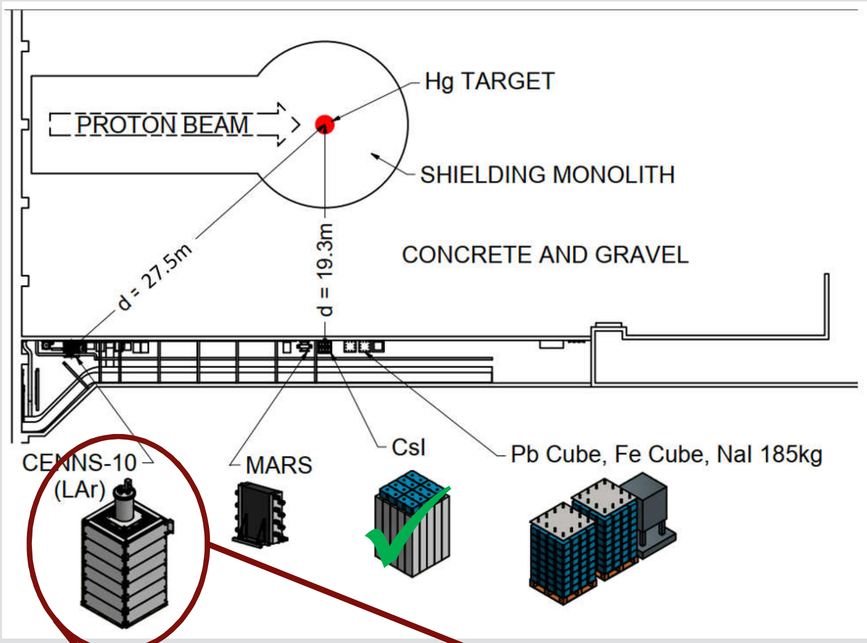


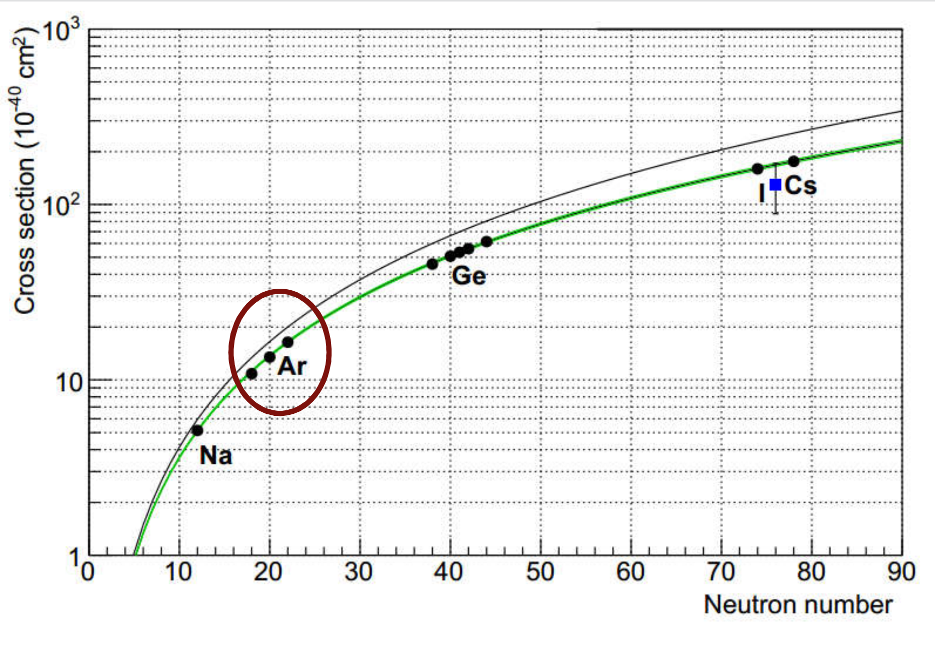


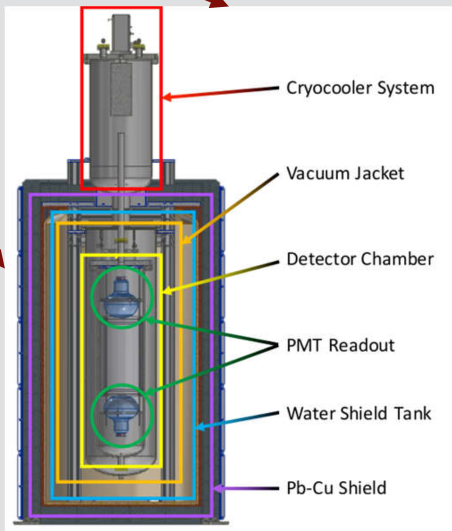


COHERENT experiment

- Next goal, demonstrate N^2 dependence of CEvNS
- with CENNS-10 (liquid argon, LAr), currently running…



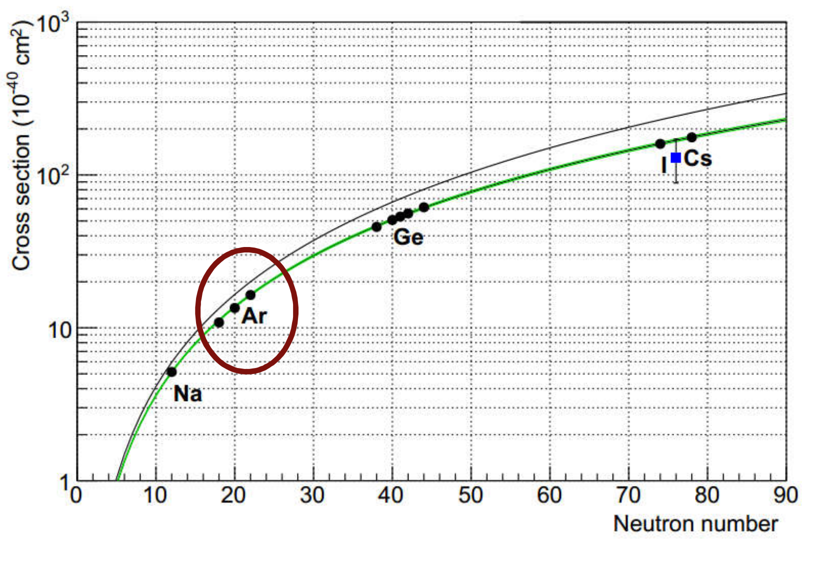




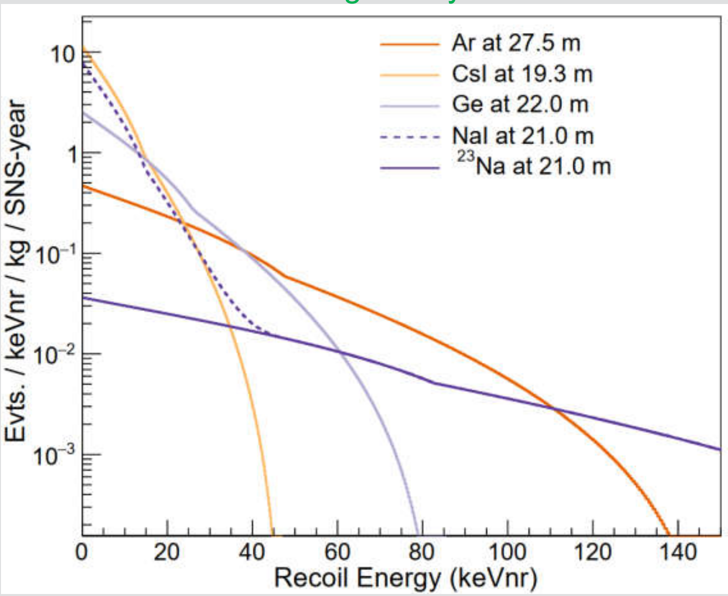
LAr for CEvNS

Liquid argon (LAr) is:

- Complementary to heavier Cs and I
  - Map out low *N σ(CEvNS)*
  - Lower *σ* but more energetic recoils
- Large scintillation yield
  - 40 photons/keVee
- Quenching factor well-measured
- Pulse Shape Discrimination (PSD) for particle ID!
  - Argon scintillates with 2 time constants
    1. Singlet light: ~6 ns
    2. Triplet light: ~1.6 μs
  - Electronic Recoils mostly triplet light
  - Nuclear Recoils mostly singlet light



event rates/kg/SNS-yr for COHERENT



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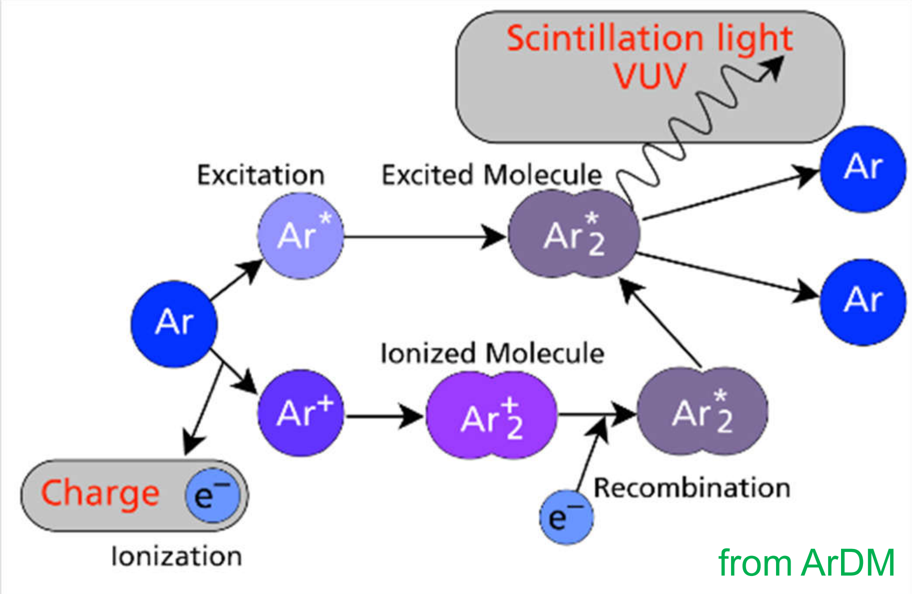
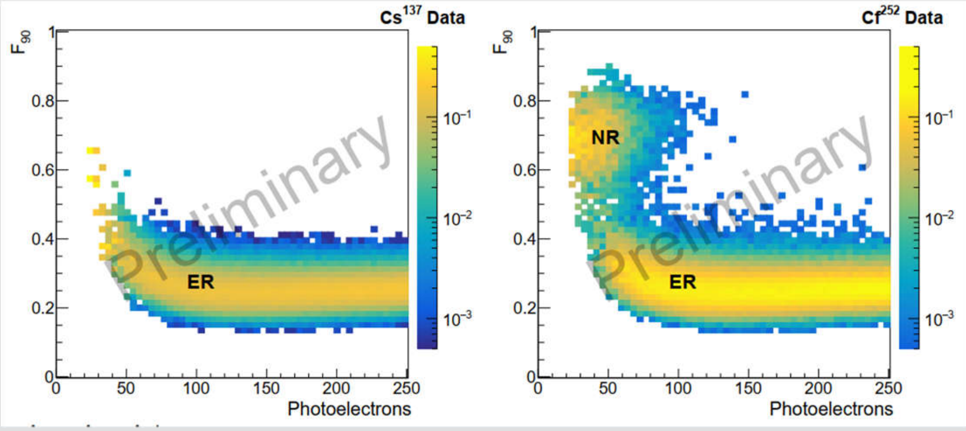
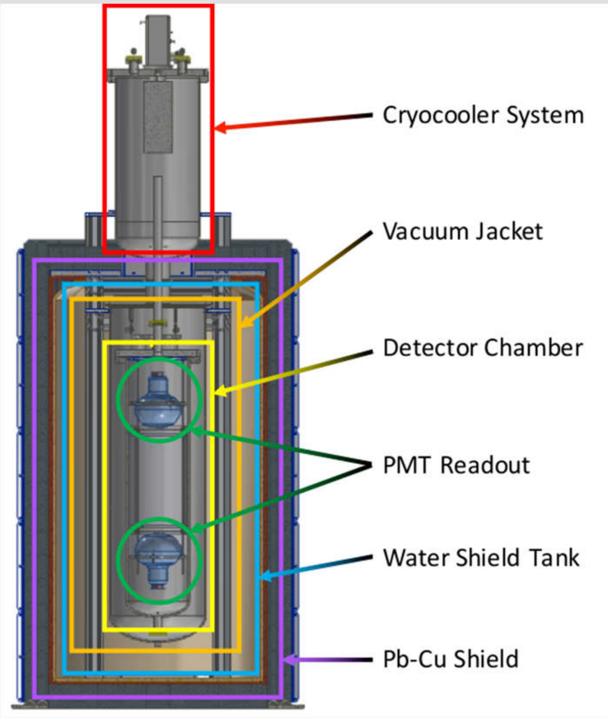


from ArDM



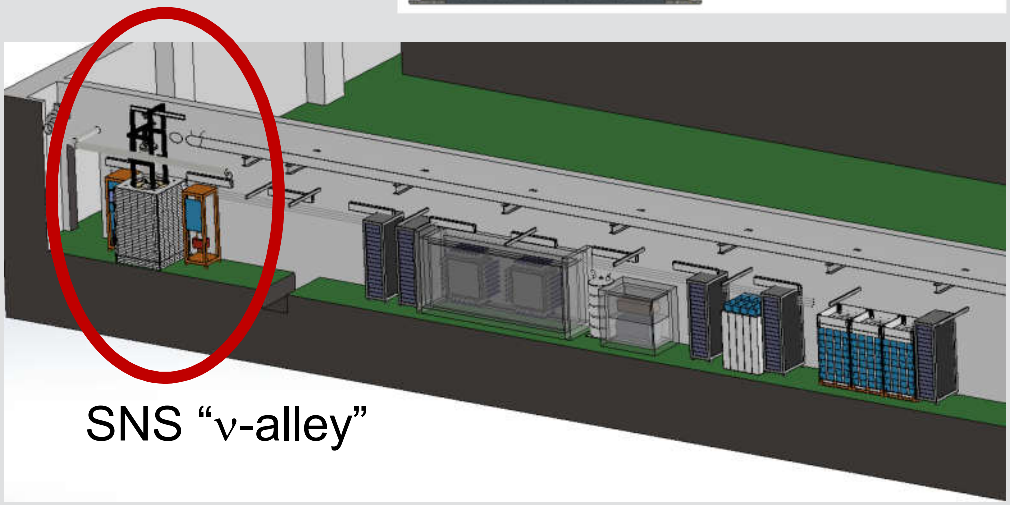
COHERENT LAr: CENNS-10

CENNS-10 detector currently running at SNS



timeline:

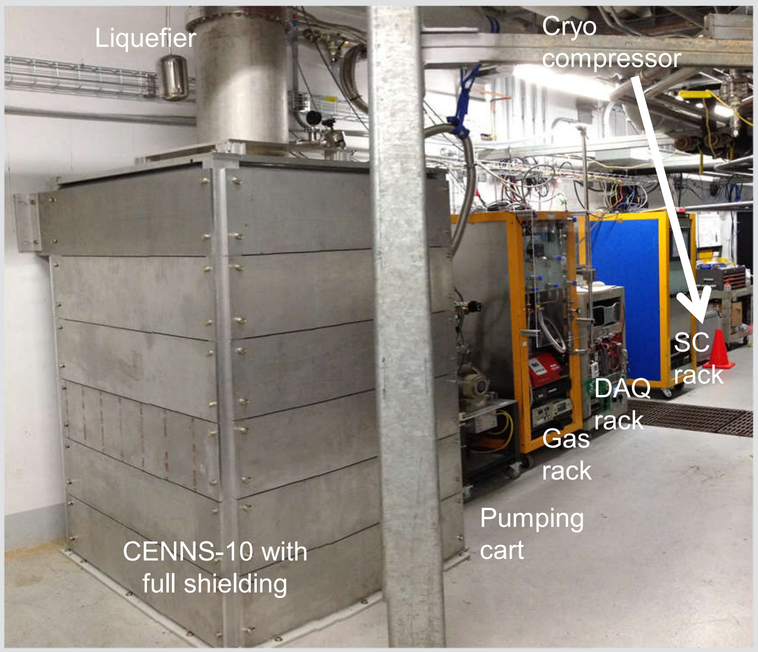
- 2012-15: built at Fermilab (J. Yoo etal) for CENNS@Fermilab effort, commissioned/upgraded at Indiana U.
- late 2016: moved to SNS, installed, shielding built
- early 2017: run with TPB-acrylic parts, E_{thresh}~80keVnr
  "Engineering Run": 1.8GWhr collected, CEvNS rate low, constrain beam-related bckgrds,
  analysis finished
- mid-17: upgrade: TPB-Teflon reflectors, new TPB-coated PMTs, added 4" Pb shielding
- mid-17-present: run in upgraded mode, E_{thresh}~20keVnr
  "Production Run" : 6.1 GWhr collected,
  blind, 2 parallel, analyses in progress in US and Moscow

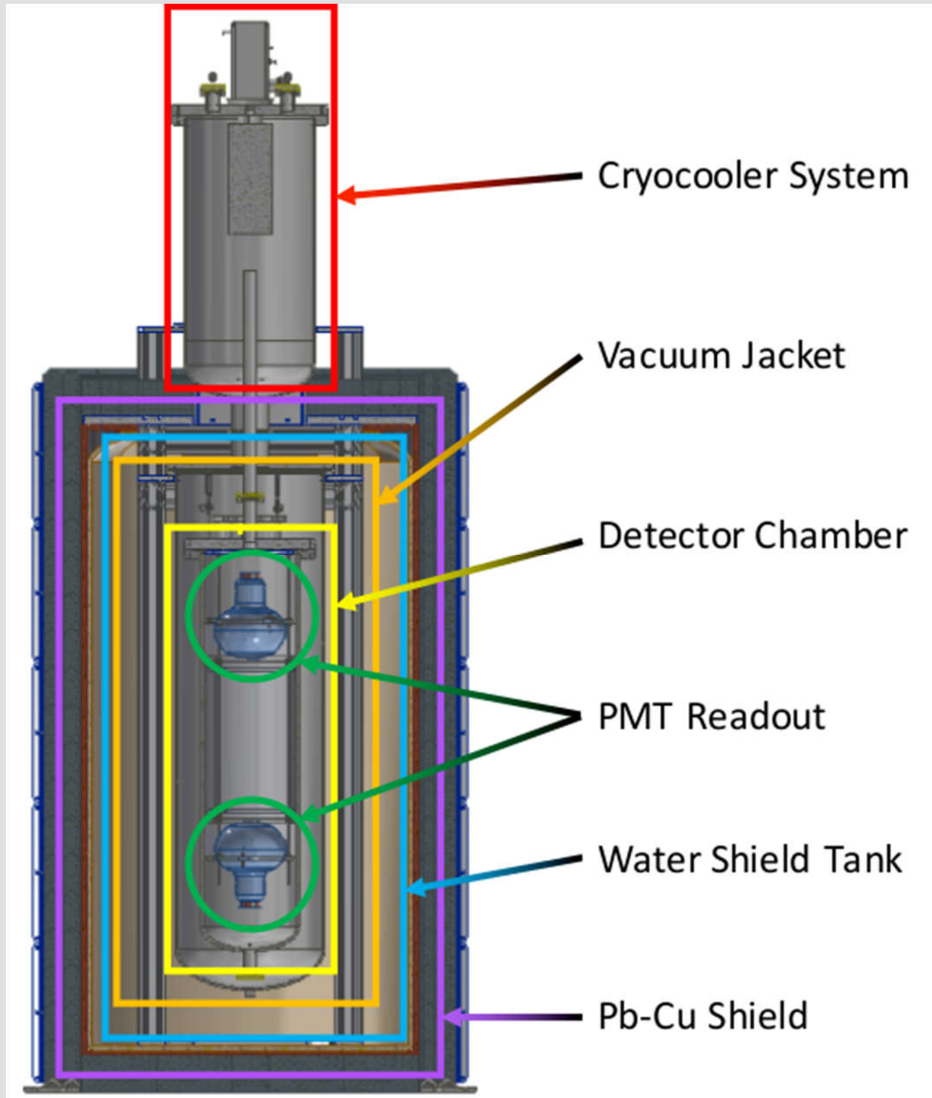


The CENNS-10 (LAr) Detector:

Specs:

- 22 kg single-phase LAr fiducial volume
- 2 × 8”PMTs TPB-coated, w/QE=18%@400 nm
- TPB-coated PMTs/teflon side walls
- Energy threshold ≈ 20keVnr
- CAEN 1720 (250MHz, 12-bit) digitizer
- 90W single-stage pulse-tube cold head
- SAES MonoTorr gas purifier for ~1 ppm purity
- Pb/Cu/H2O shield
- Expect ≈140 CEvNS events/SNS-year
- Running in current configuration since July ‘17

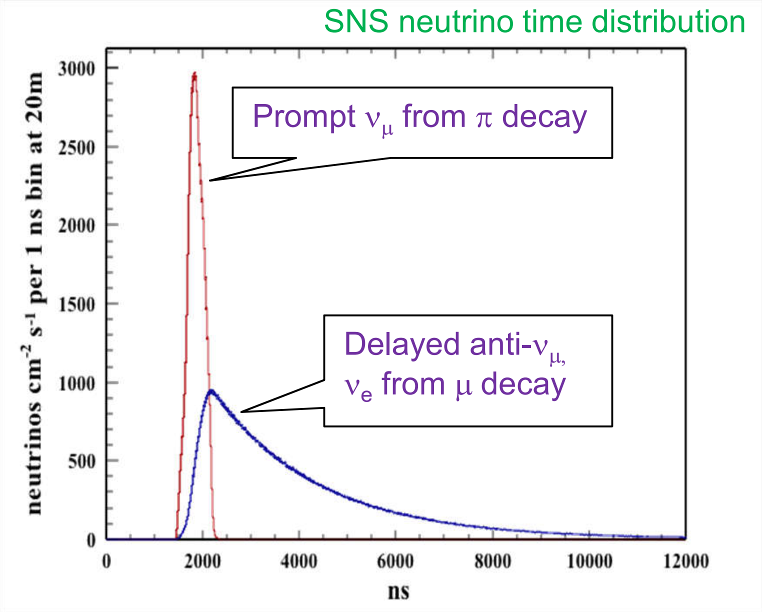


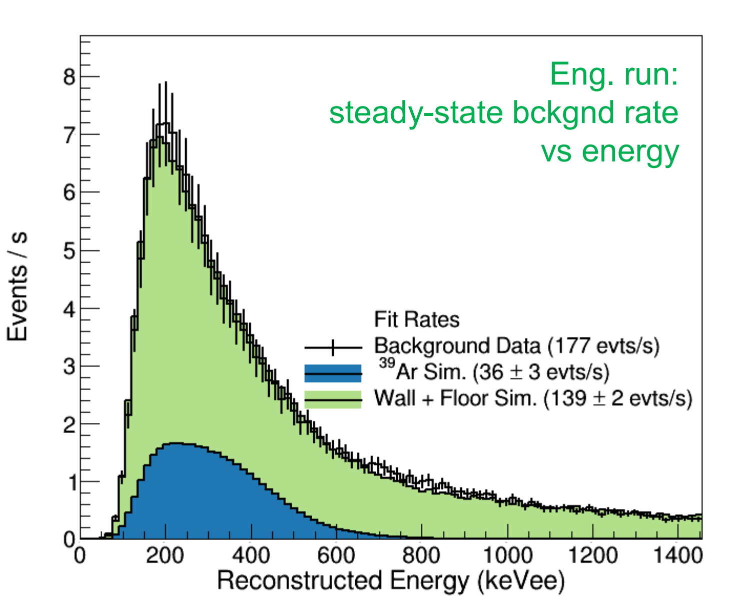


CENNS-10 Analysis for CEvNS:

Analysis Overview:

- Calibrate! , Calibrate!, Calibrate! with variety of sources
- Characterize expected backgrounds in rate/time/energy
  - Steady-state bkg from beam-off triggers
  - Beam-related neutrons with other neutron detectors **and** CENNS-10 no-water runs
- Optimize energy/PID/time cuts on signal/noise
- Verify bkg subtraction with 'pre-beam' data
- "Open the Box":
  1. Counting exp't: prompt and delayed
  2. Full likelihood analysis





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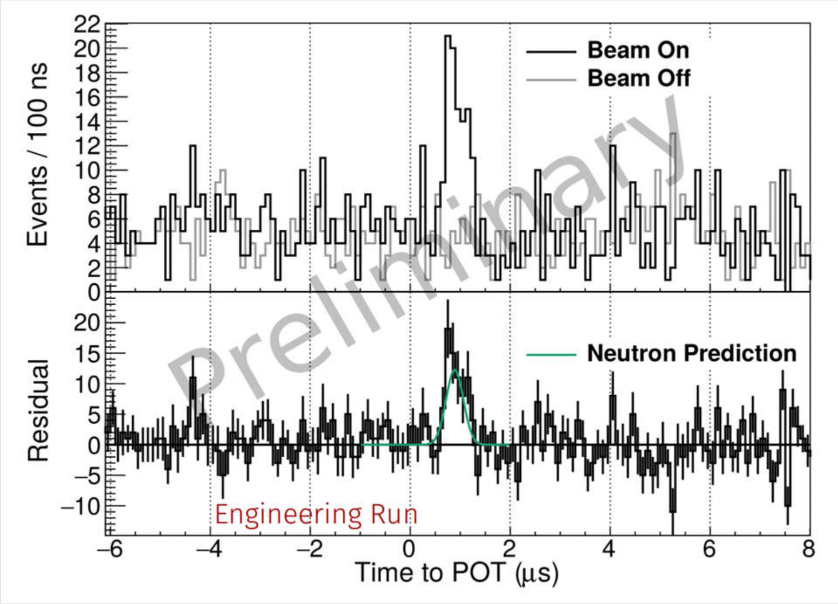
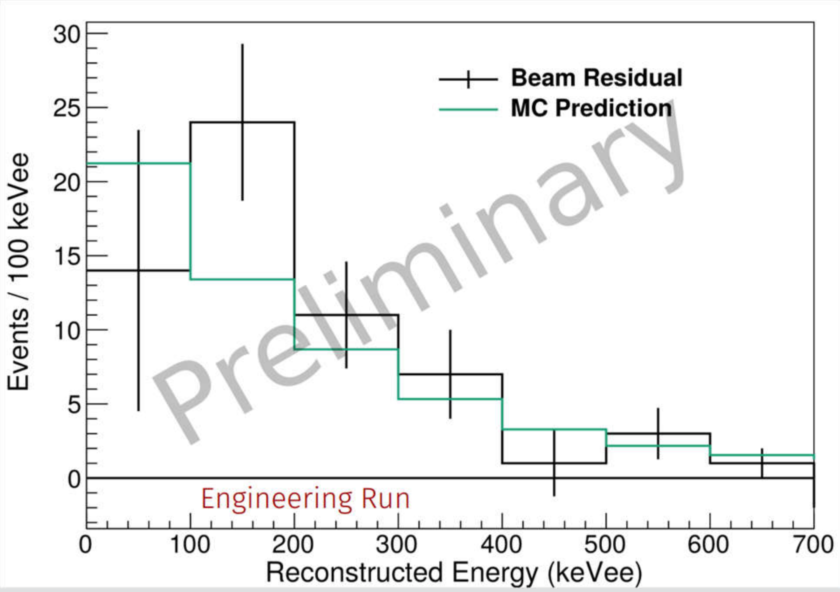


CENNS-10 no-water data

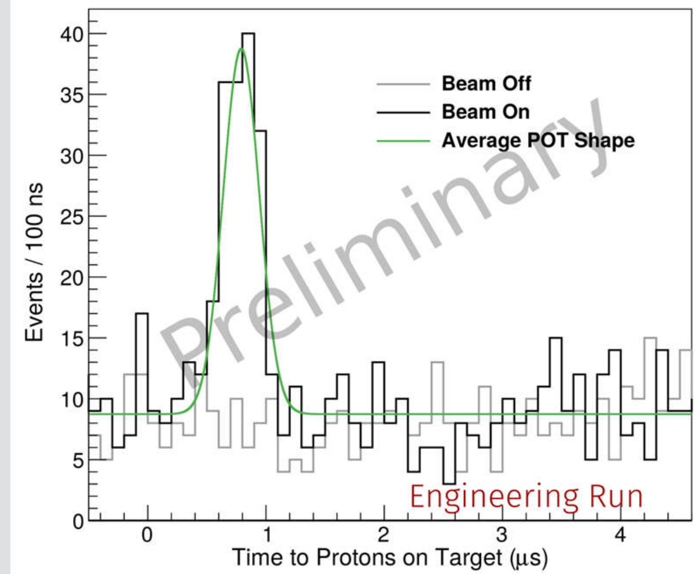


CENNS-10 Engineering run results:

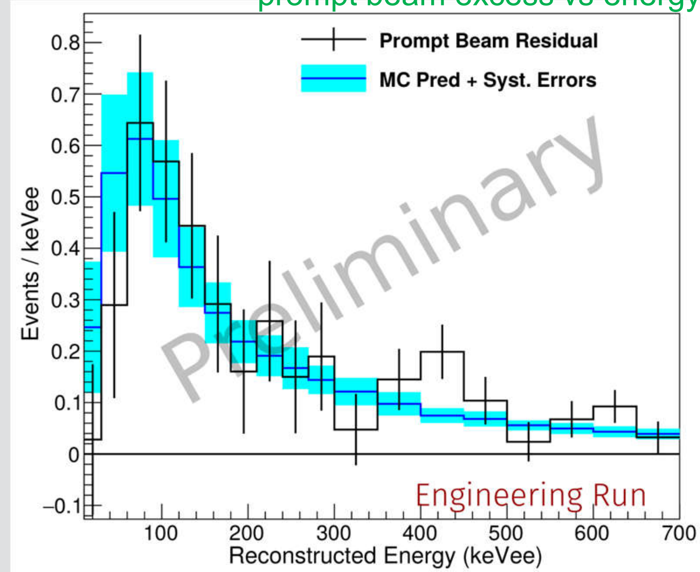
blind analysis CENNS-10 Engineering run results:

- event excess in time with beam is consistent with expected prompt beam-related neutron rate

beam excess vs time



prompt beam excess vs energy

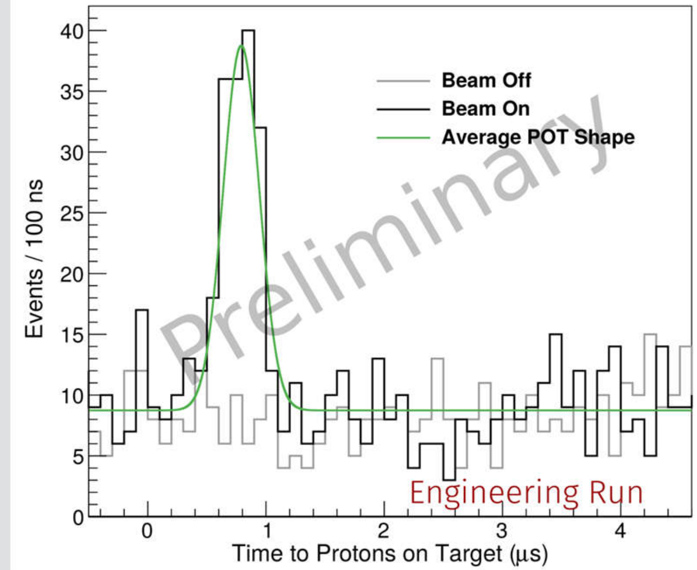


CENNS-10 Engineering run results:

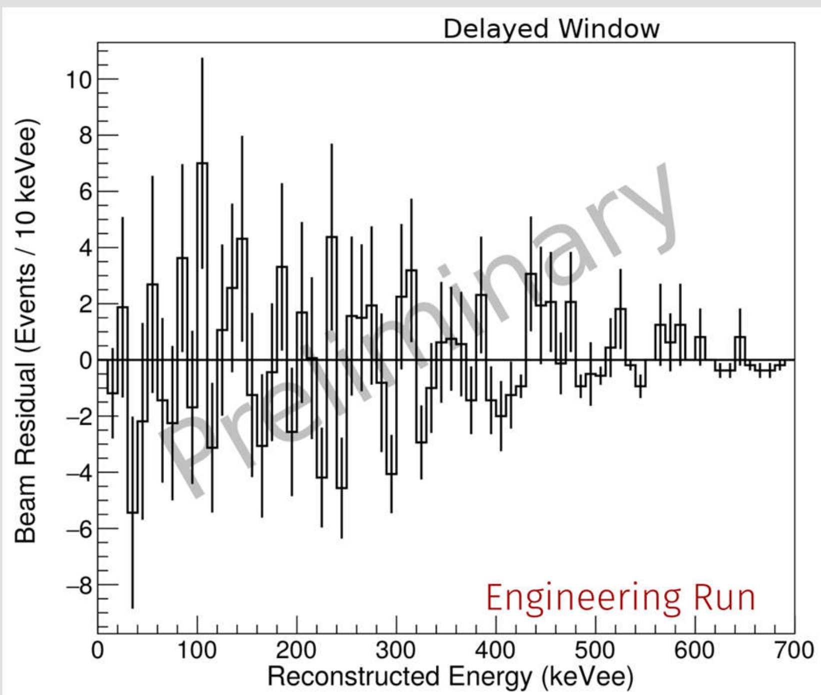
blind analysis CENNS-10 Engineering run results:

- event excess in time with beam is consistent with expected prompt beam-related neutron rate
- no event excess observed in delayed window with 0.5 events expected $\Rightarrow$
  - limit on delayed neutron backgrounds
  - limit on CEvNS cross section

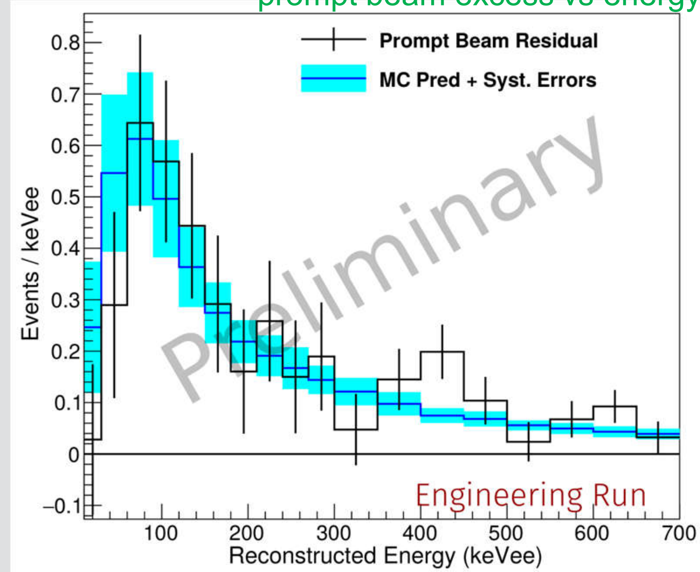
beam excess vs time



delayed beam excess vs energy



prompt beam excess vs energy



CENNS-10 Engineering run results:

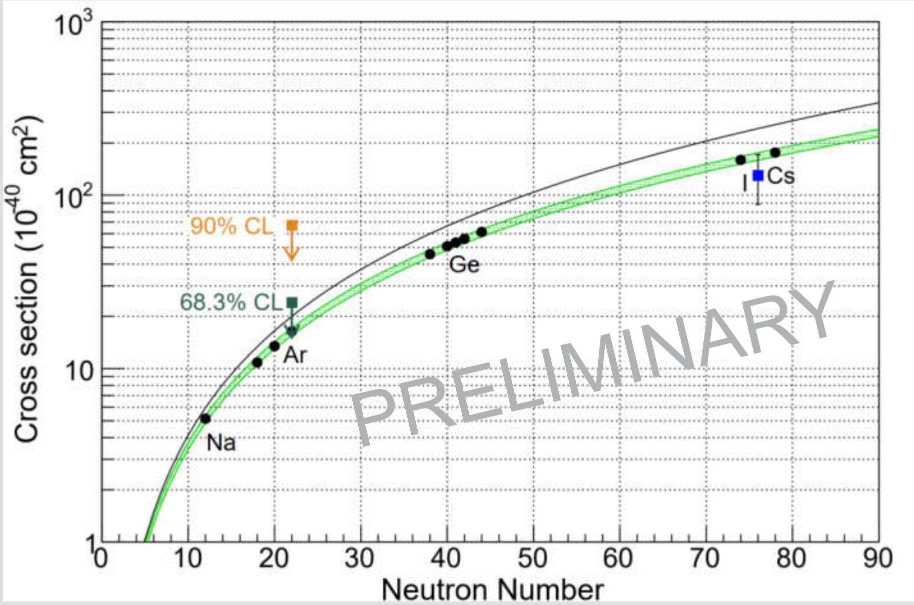
work of
IU PhD Student:
Matthew Heath
\cite{Heath:2019jpj}

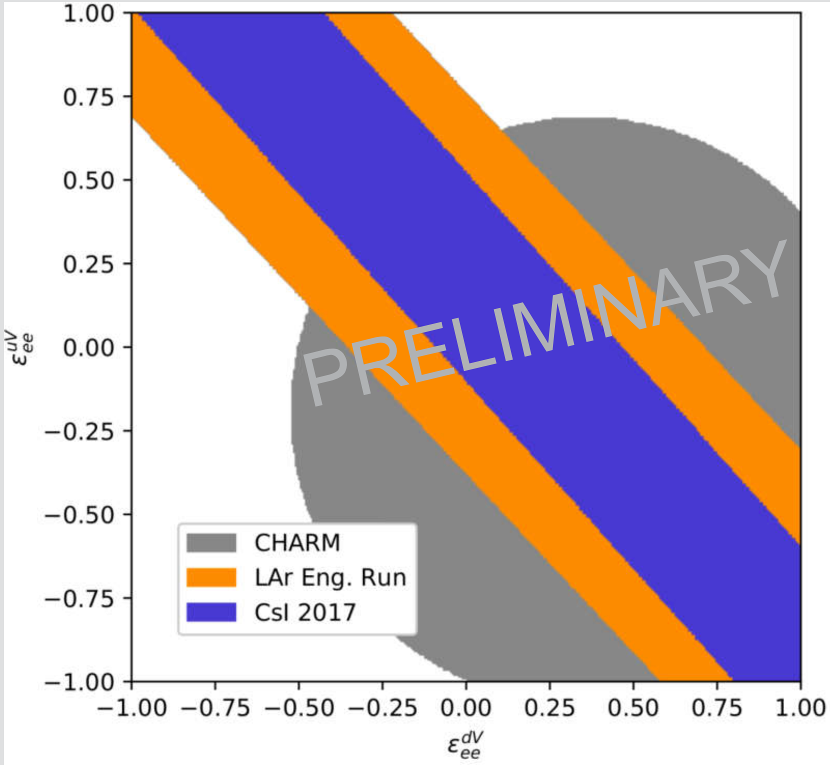
blind analysis CENNS-10 Engineering run results:

- from full likelihood analysis:
  - cross section limits
  - non-standard interaction constraints

corresponding NSI regions

Eng. run CEvNS cross section limits

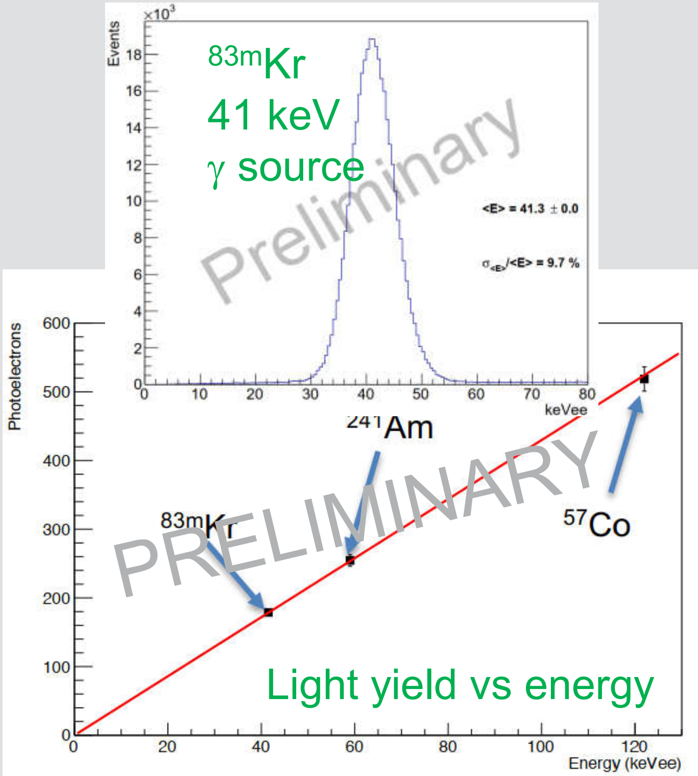


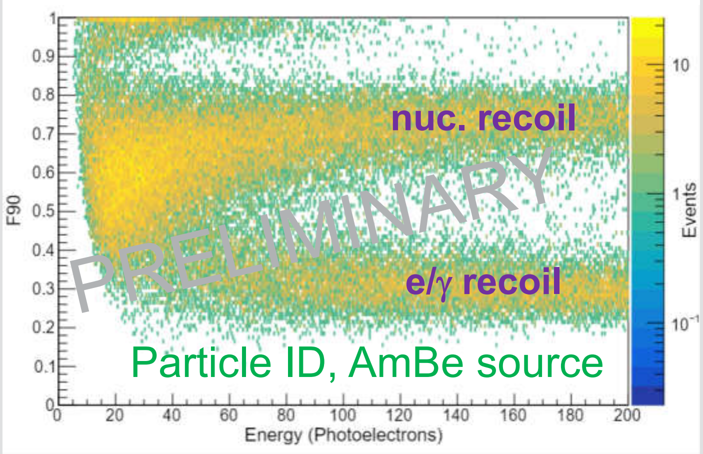


CENNS-10 Production run:

Production runs, 7/17-now:

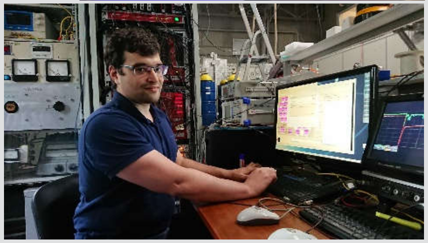
- light yield improved to ~4.5 PE/keV
- Particle ID (PSD), energy resolution/threshold sufficient for observation of CEvNS in ^{40}Ar
- SM prediction ~130 CEvNS events in this data set
- analyses in end stages, results soon!





Indiana U, Phd Student:
Jacob Zettlemoyer

ITEP/MEPHI (Moscow), Phd Students:
Dmitry Rudik, Alex Kumpan,



COHERENT future, next steps

Physics reach of CEvNS:

- Understanding supernovae (SN):
  - Expected to be important in core-collapse SN and
  - possible SN detection channel.

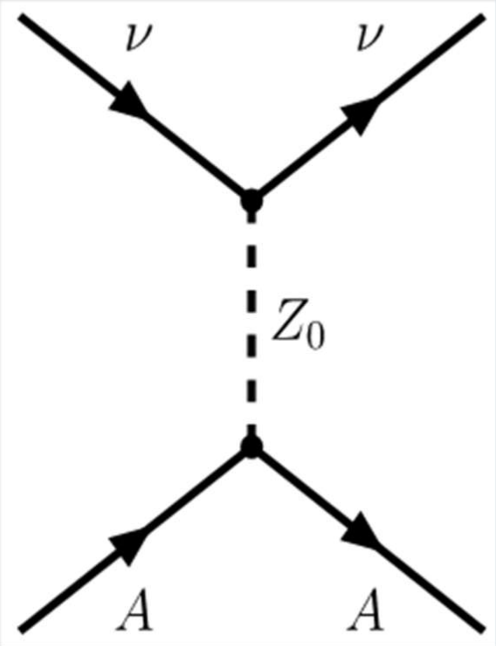
- Nuclear Physics: nuclear form factors

- Standard Model tests, eg: NSI, $\sin^2 \theta_w$, neutrino magnetic moments

- ν oscillations: Investigation of $\nu_{sterile}$ oscillations

- reactor monitoring (non-proliferation)

- Dark Matter:
  - Important background for O(10-ton) direct searches
  - detectors sensitive for accelerator produced DM.



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- Nuclear Physics: nucl
- S
- of $\nu_{sterile}$
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- Dark Matter:
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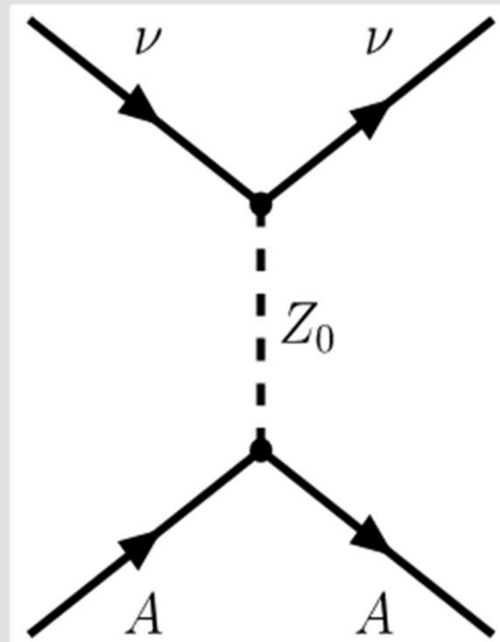
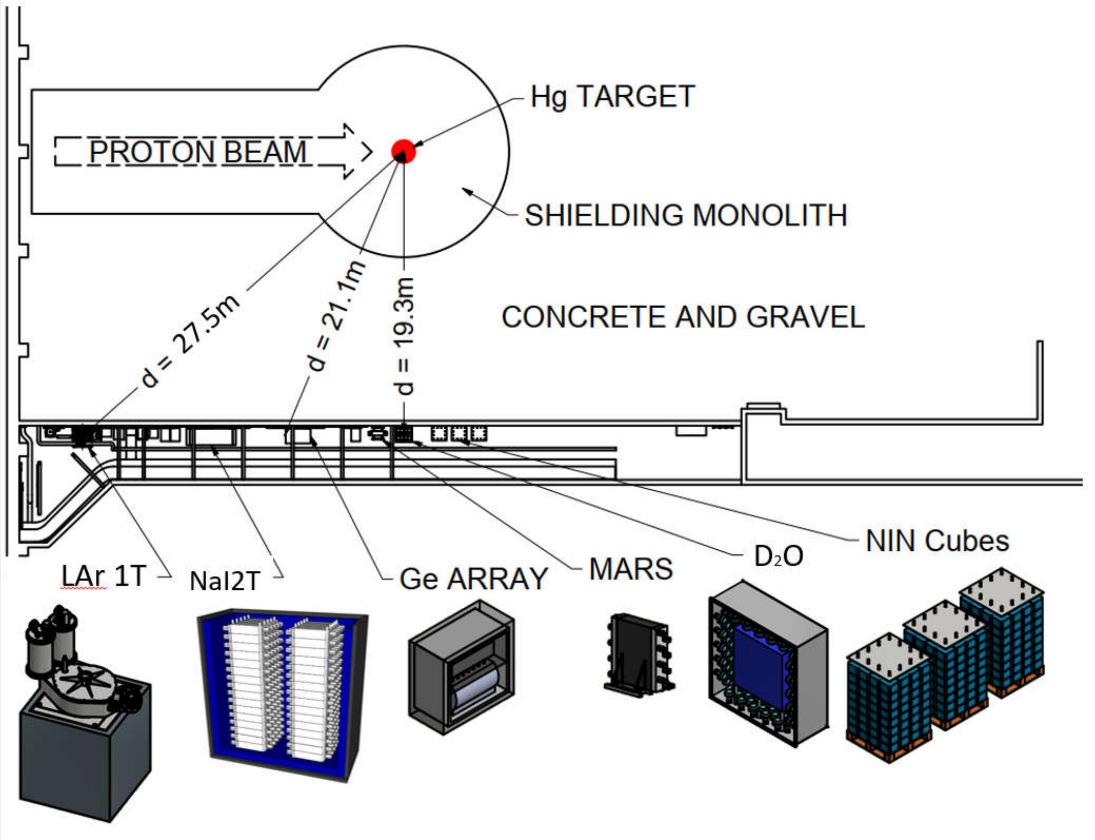
  - detectors sensitive for accelerator produced DM.

For the physics program, require
- higher event rates via larger detetectors, lower thresholds
- reduced systematics via low backgrounds, measured flux



COHERENT future, in ν-alley

- 16kg Ge array, coming soon
- multi-ton NaI, shielding/veto configuration to be finalized
- ton-scale LAr (CENNS-750), funding pending
- D_2O for flux normalization
- also NIN cubes
- neutron background measurements

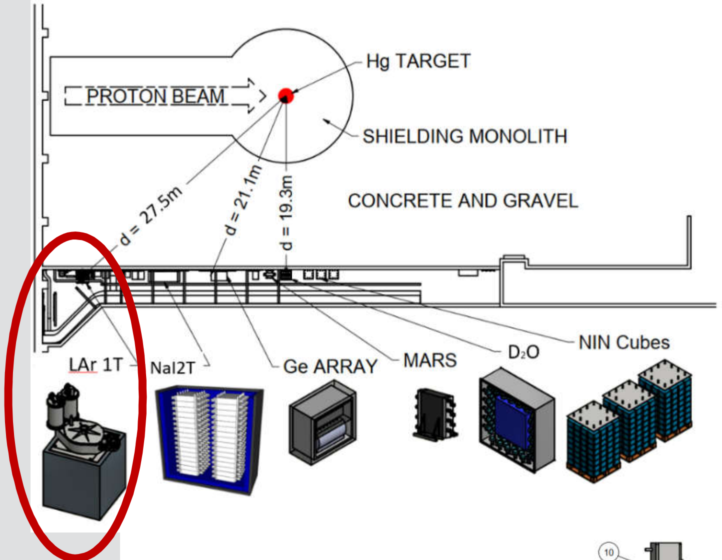


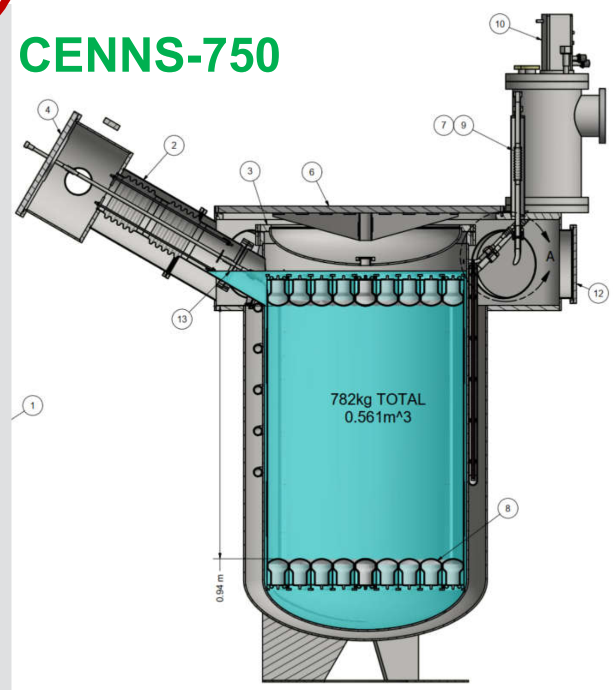
COHERENT future, large LAr detector

CENNS-750:

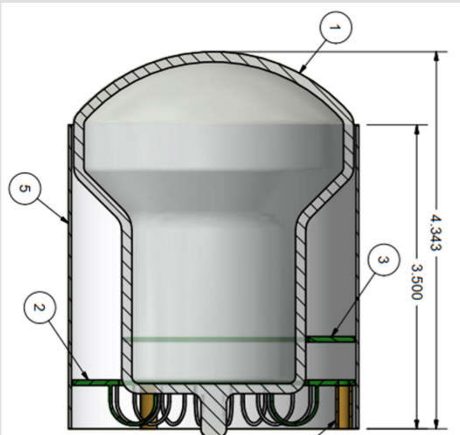
- Based on our experience with CENNS-10 detector, running since 2017.
- Single-phase LAr (scintillation-only) calorimeter, 750/**610kg** total/**fiducial**
- Purpose-designed cryostat w/LN2 precool, and dual cryocooler for liquification/gas purification.
- Light collection: TPB coated reflectors combined with 3"PMTs/SiPMs
- Eventual use of underground (low ^{39}Ar) argon.

- $\Rightarrow$ 3000 CEvNS, 440 inelastic CC/NC events/yr !

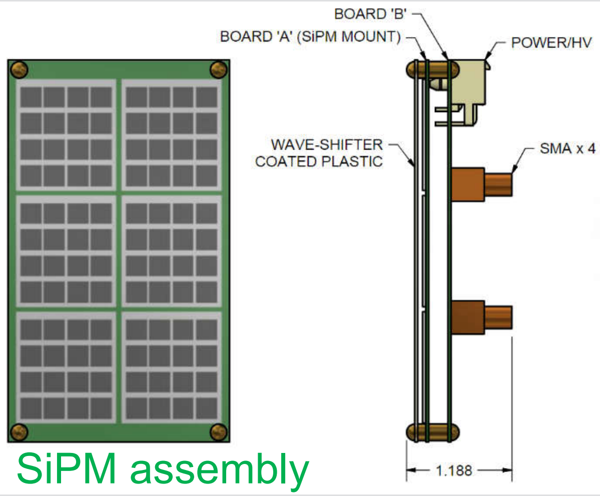




CENNS-750



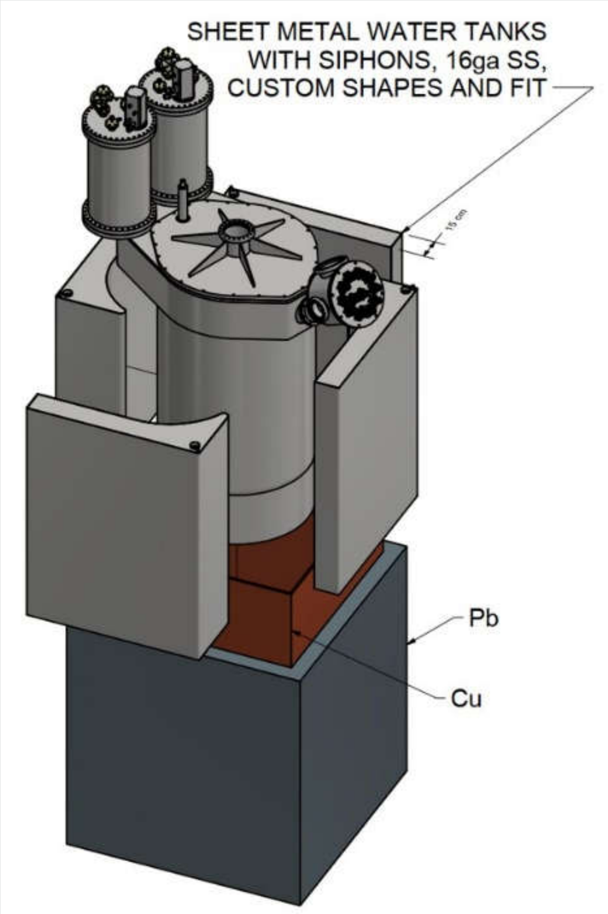
3" PMT assembly

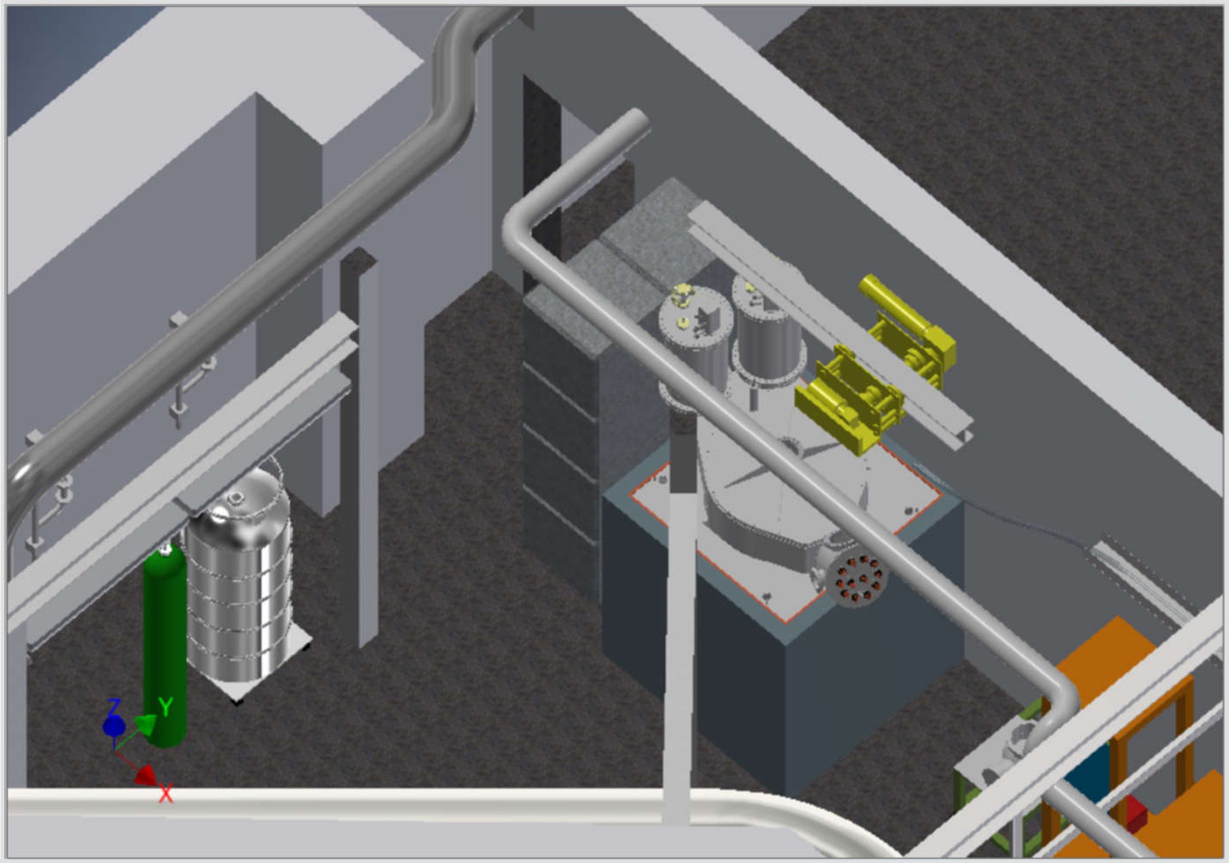


SiPM assembly

COHERENT future, large LAr detector

CENNS-750:
It fits into ν-alley (barely)



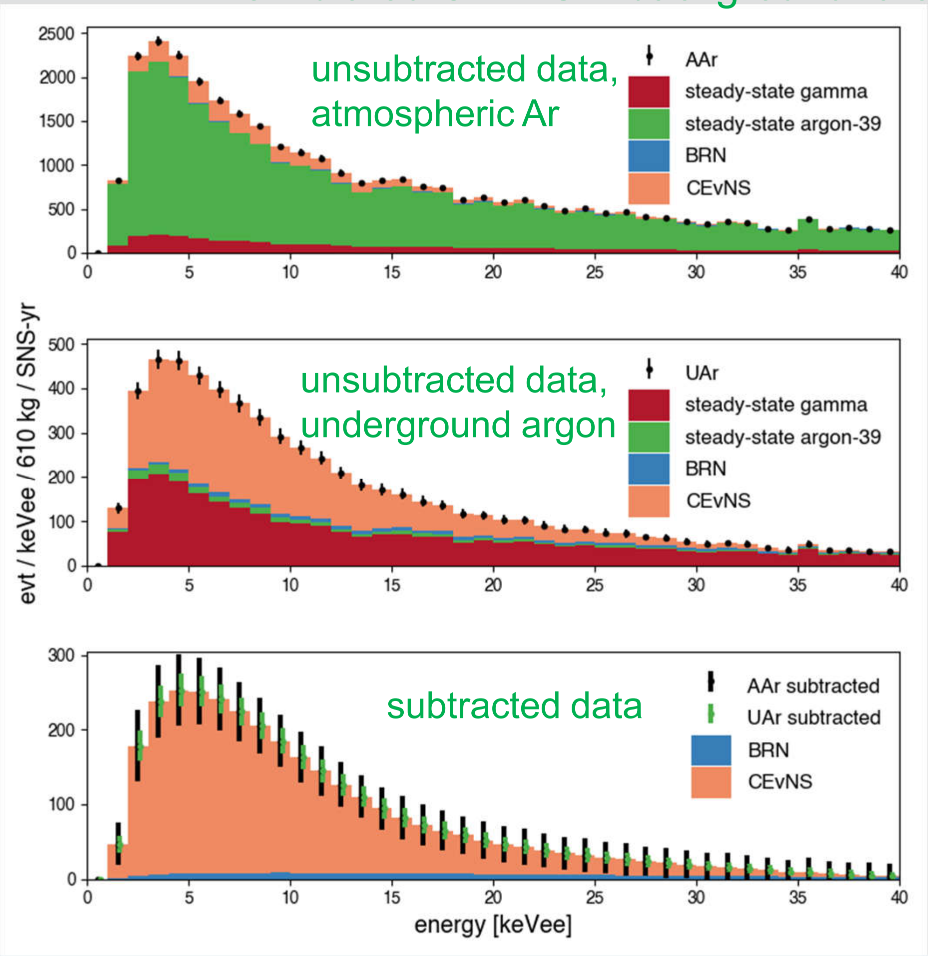


CENNS-750 LAr detector

event rates in 610kg fiducial LAr detector:

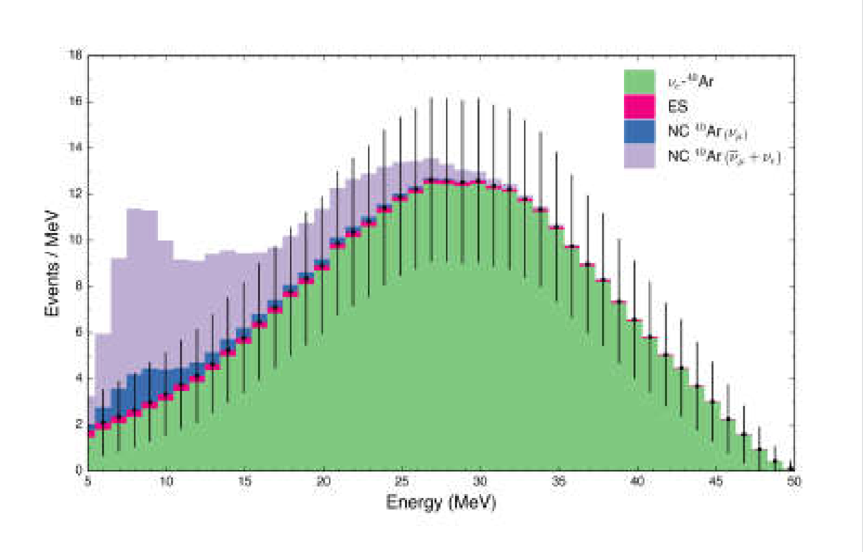
~3000 CEvNS events/year

simulated CEvNS + background rates



~440 inelastic CC/NC events/yr

estimated inelastic CC/NC CEvNS rates



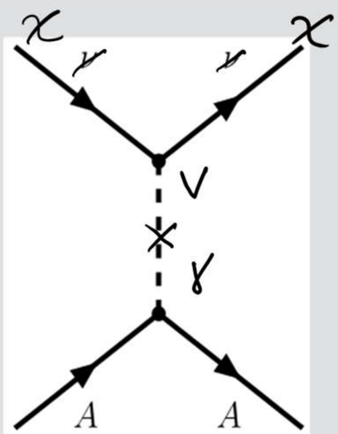
COHERENT future

Search for accelerator-produced, low-mass, dark matter

Via:

$$p \rightarrow \mathrm{Hg} \rightarrow \pi^{0,\pm}$$

$$\pi^0 \longrightarrow \gamma + V^{(*)} \longrightarrow \gamma + \chi^\dagger + \chi$$



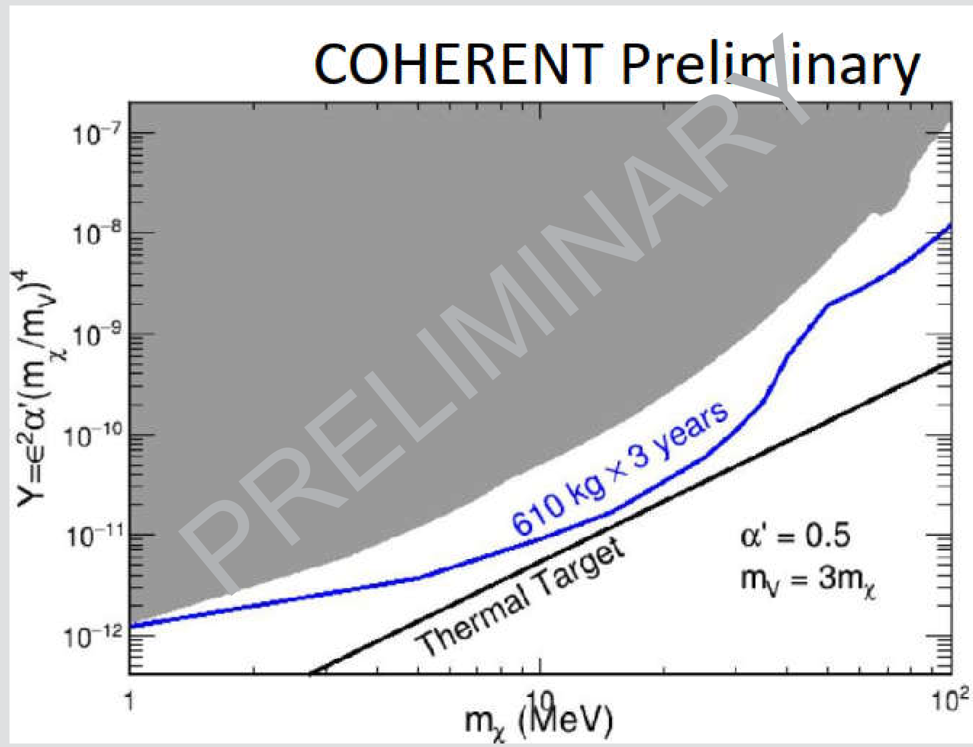
Light new physics in coherent neutrino-nucleus scattering experiments

Patrick deNiverville,[1] Maxim Pospelov,[1,2] and Adam Ritz[1]

[1] Department of Physics and Astronomy, University of Victoria, Victoria, BC V8P 5C2, Canada
[2] Perimeter Institute for Theoretical Physics, Waterloo, ON N2J 2W9, Canada

(Dated: May 2015)

arXiv:1505.07805



D. Pershey, pub in draft

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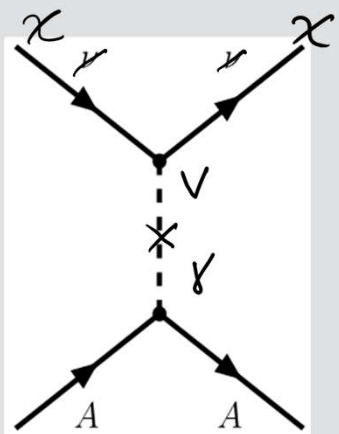
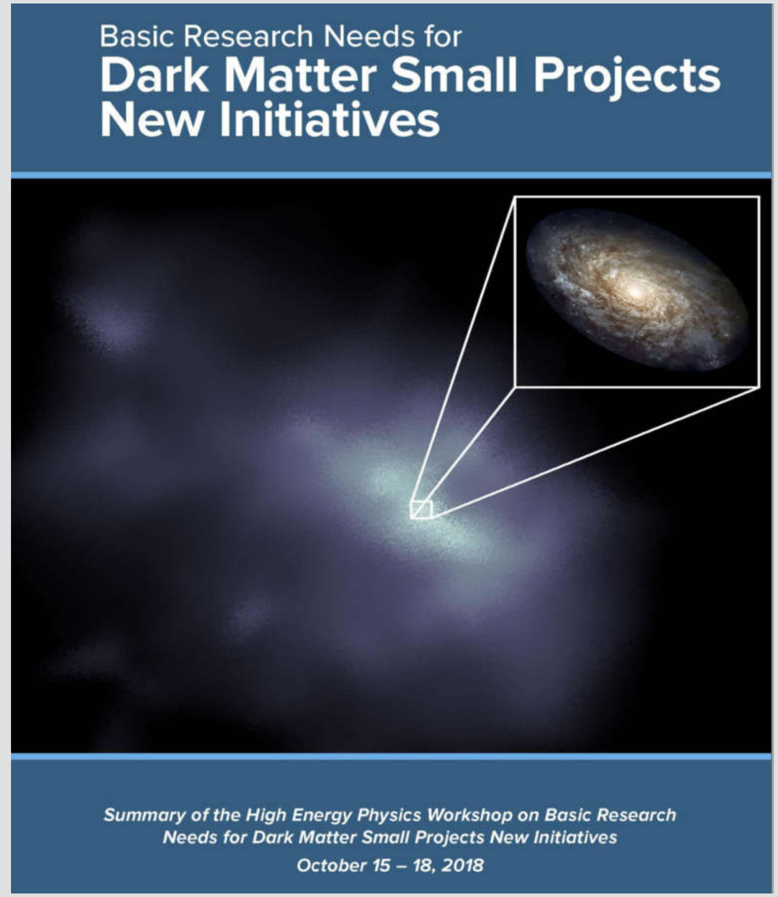
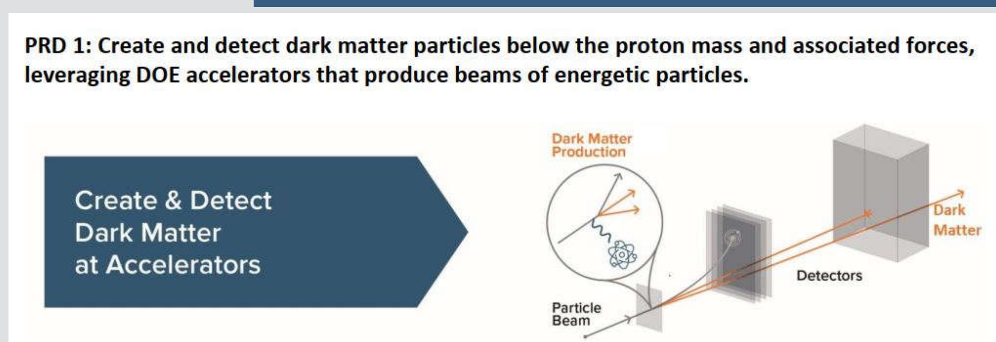


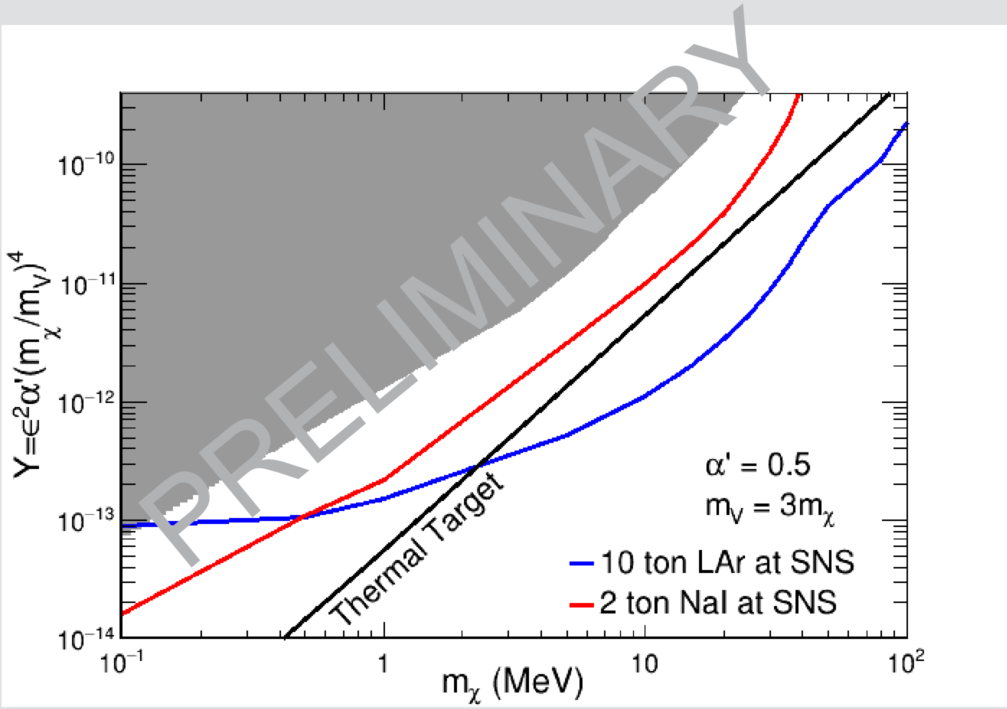


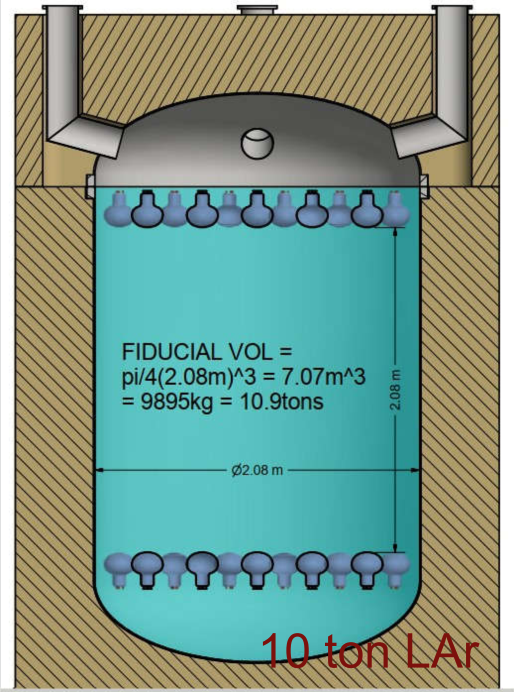


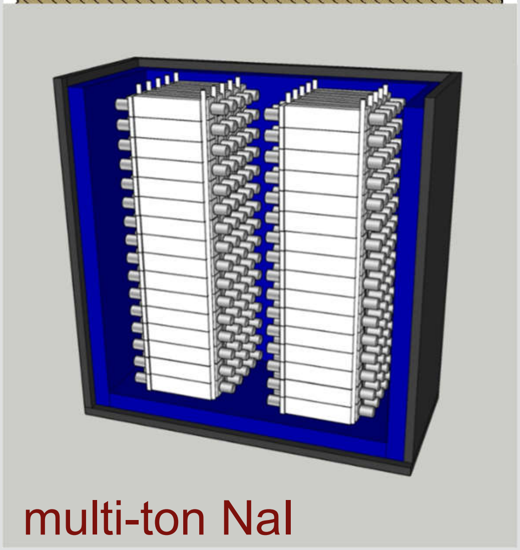
COHERENT future

Search for accelerator-produced, low-mass, dark matter

10-ton LAr or ~2-ton cryogenic NaI detector downstream from high power neutron target, eg SNS





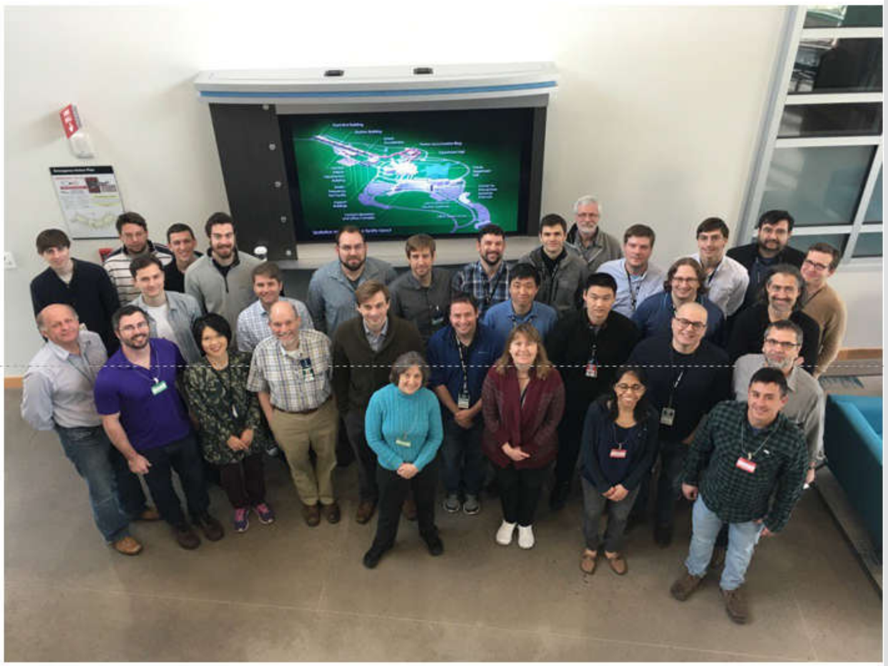


Will enable other CEvNS physics as well!

Summary:

- First measurement of CEvNS in COHERENT CsI[Na] at the SNS!
- More results, demonstrating N^2 dependence, with LAr (and others) coming soon.
- High potential physics output of CEvNS is driving further work on improved/larger detectors
- Thanks to COHERENT collaboration!

postdoc position open!
inspirehep.net/record/1725448



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

Backups

COHERENT future, beyond ν-alley

Sterile oscillation search with large CEvNS detector at SNS