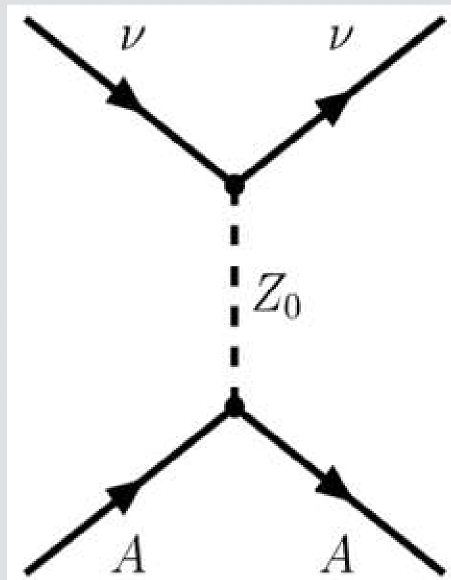
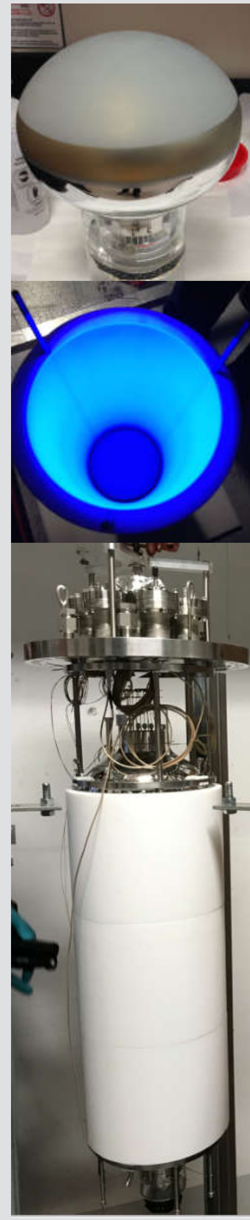
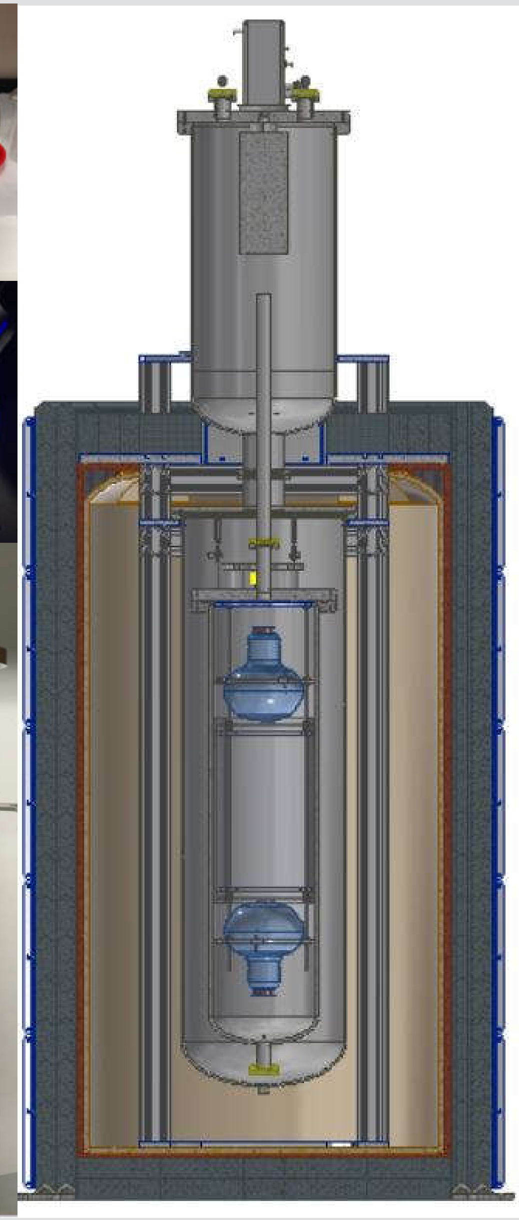
Search for CEvNS with a liquid argon scintillation detector

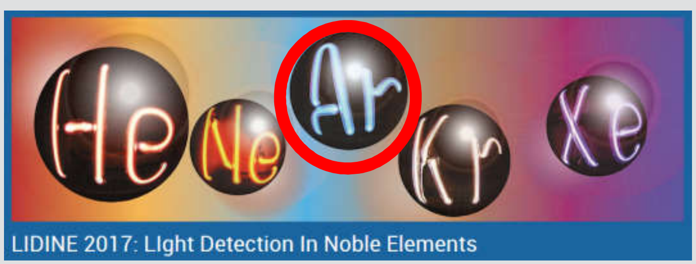
R. Tayloe, Indiana U.
for the COHERENT collaboration







Outline:
- physics of CEvNS
- COHERENT at ORNL/SNS
- CENNS-10 detector:
  - history/design
  - deployment
  - preliminary data
  - projections
- summary



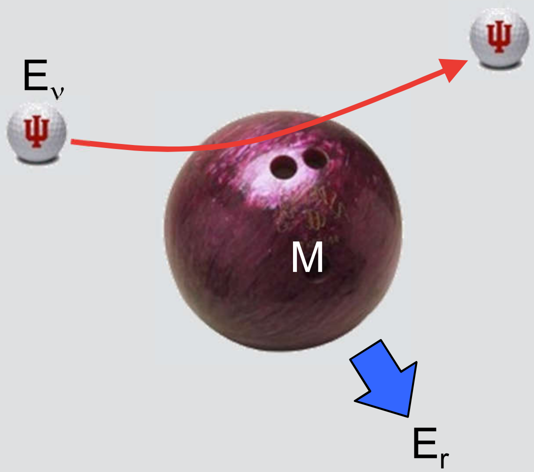
Coherent Elastic ν-Nucleus Scattering:

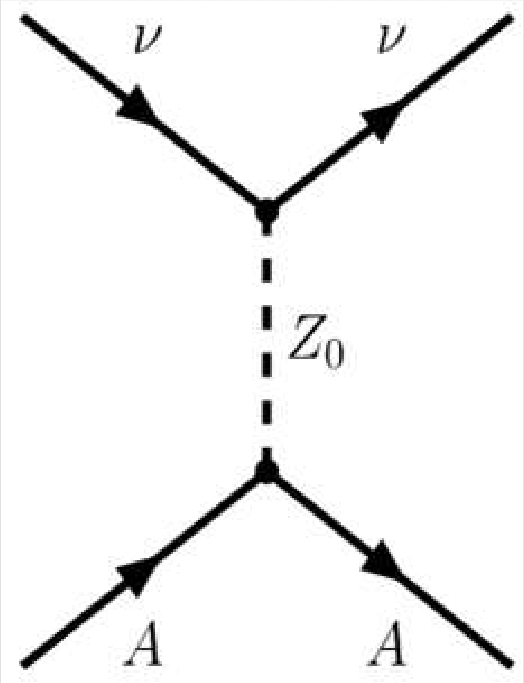
"CEvNS":

Coherent Elastic ν-Nucleus Scattering: νA→νA

Neutrino scatters with low momentum transfer coherently, elastically from entire nucleus. For large nucleus, R_N~few fm, and:

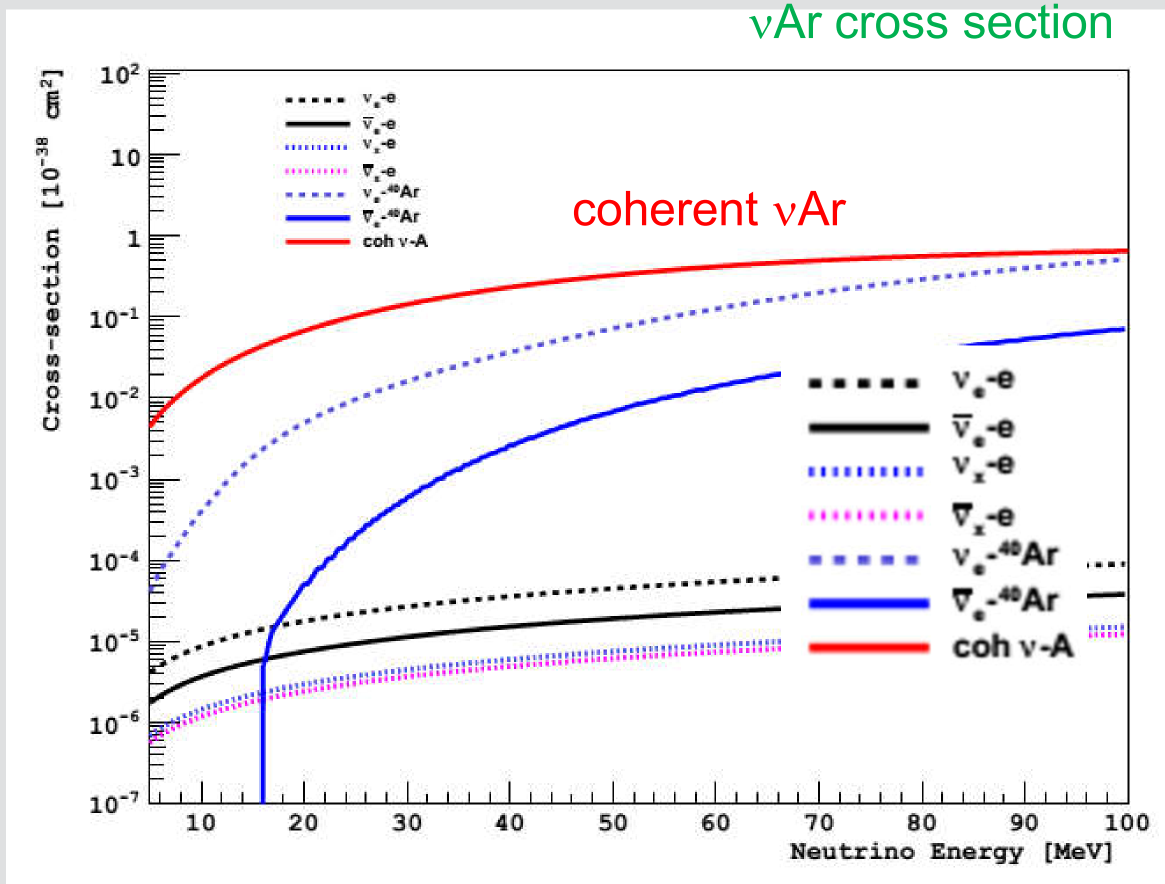
$$E_\nu \lesssim \frac{hc}{R_N} \cong 50 \text{ MeV}$$





Coherent Elastic ν-Nucleus Scattering:

Cross section is large…
in fact largest ν channel
at O(10 MeV) on heavier
nuclei, eg Ar



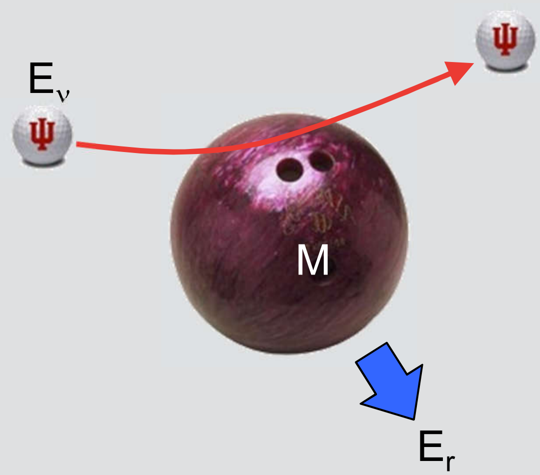
and has distinctive
N^2 dependence

$$\frac{d\sigma}{dE} = \frac{G_F^2}{4\pi}[\underbrace{(1-4\sin^2\theta_w)Z}_{\text{Small}} - \underbrace{(A-Z)]^2}_{N^2} M\left(1-\frac{ME}{2E_\nu^2}\right)F(Q^2)^2$$

Coherent Elastic ν-Nucleus Scattering:

.. but recoil energy is quite small:

$$E_r^{\max} \simeq \frac{2E_\nu^2}{M} \simeq 50 \text{ keV}$$

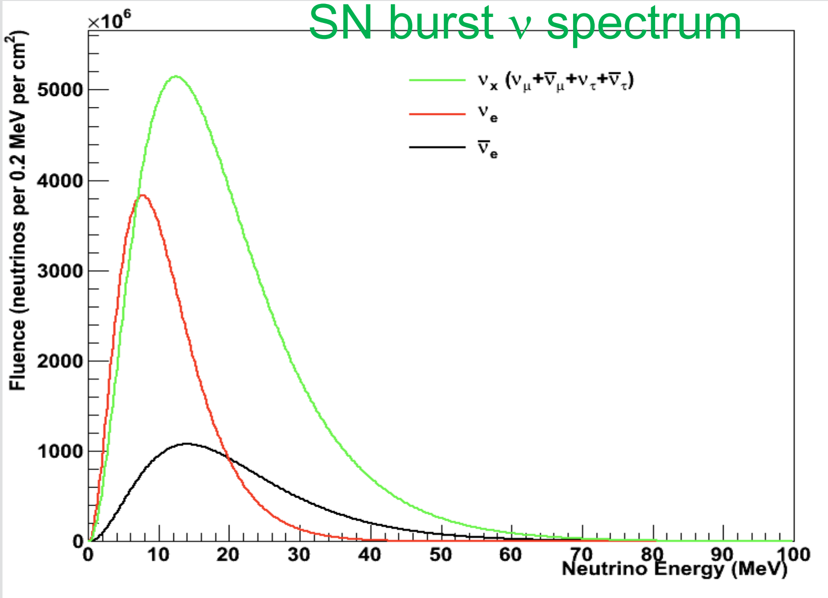


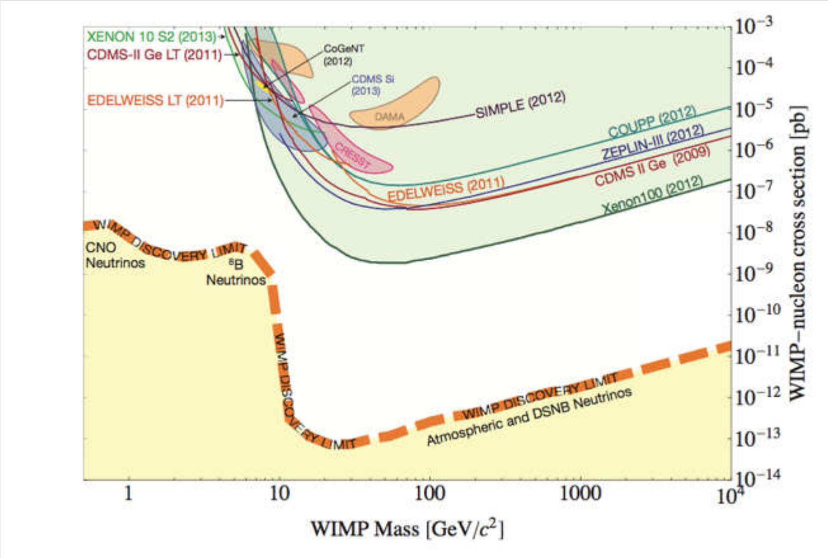
And so, the CEvNS process has ~~yet to be~~ only recently been observed…

Coherent Elastic ν-Nucleus Scattering:

Physics of CEvNS:

- Supernovae: Expected to be important in core-collapse SN and possible SN detection channel.
- Nuclear Physics: nuclear form factors
- ν oscillations: A possible ν_s detection channel
- Standard Model tests, eg: $\sin^2 \theta_W$
- Dark Matter: Important background for 10-ton direct searches

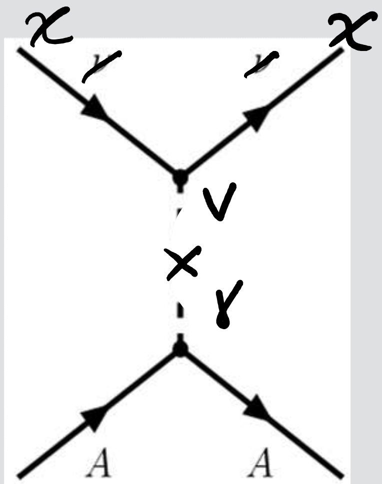




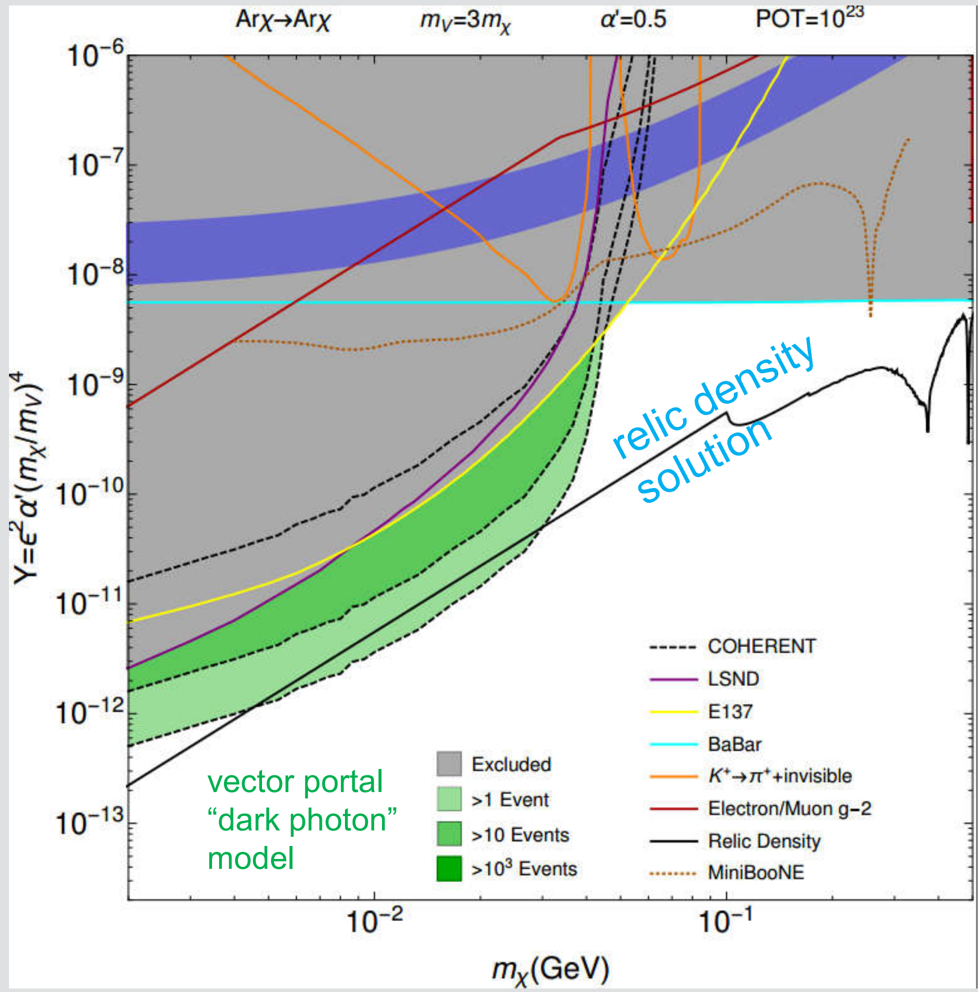
Coherent Elastic ν-Nucleus Scattering:

Physics of CEvNS:

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



1 ton-year LAr
SNS DM sensitivity



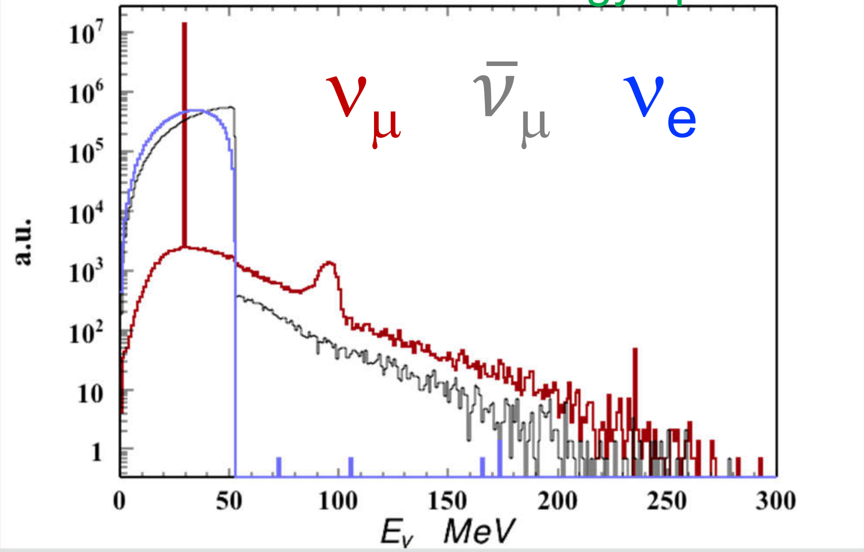
To realize this physics, require:
- intense ν source
- low bckgrd location
- low threshold detector..

COHERENT experiment at SNS/ORNL

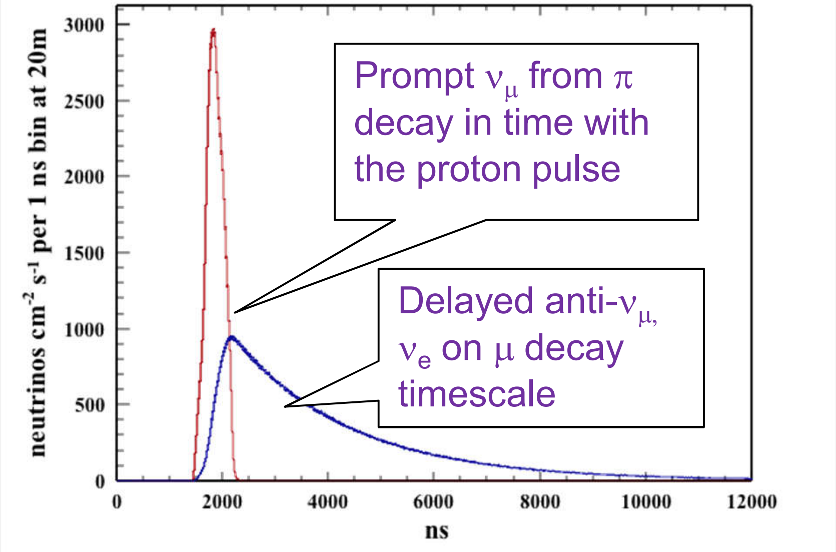
ORNL Spallation Neutron Source (SNS) is also a world-class ν source:

- intense proton beam (~1MW, 1 GeV)
- pulsed (60 Hz, 600ns spill time)…
- ~ 5000MWhr/year
- ~ 2E23 POT!

SNS ν energy spectrum

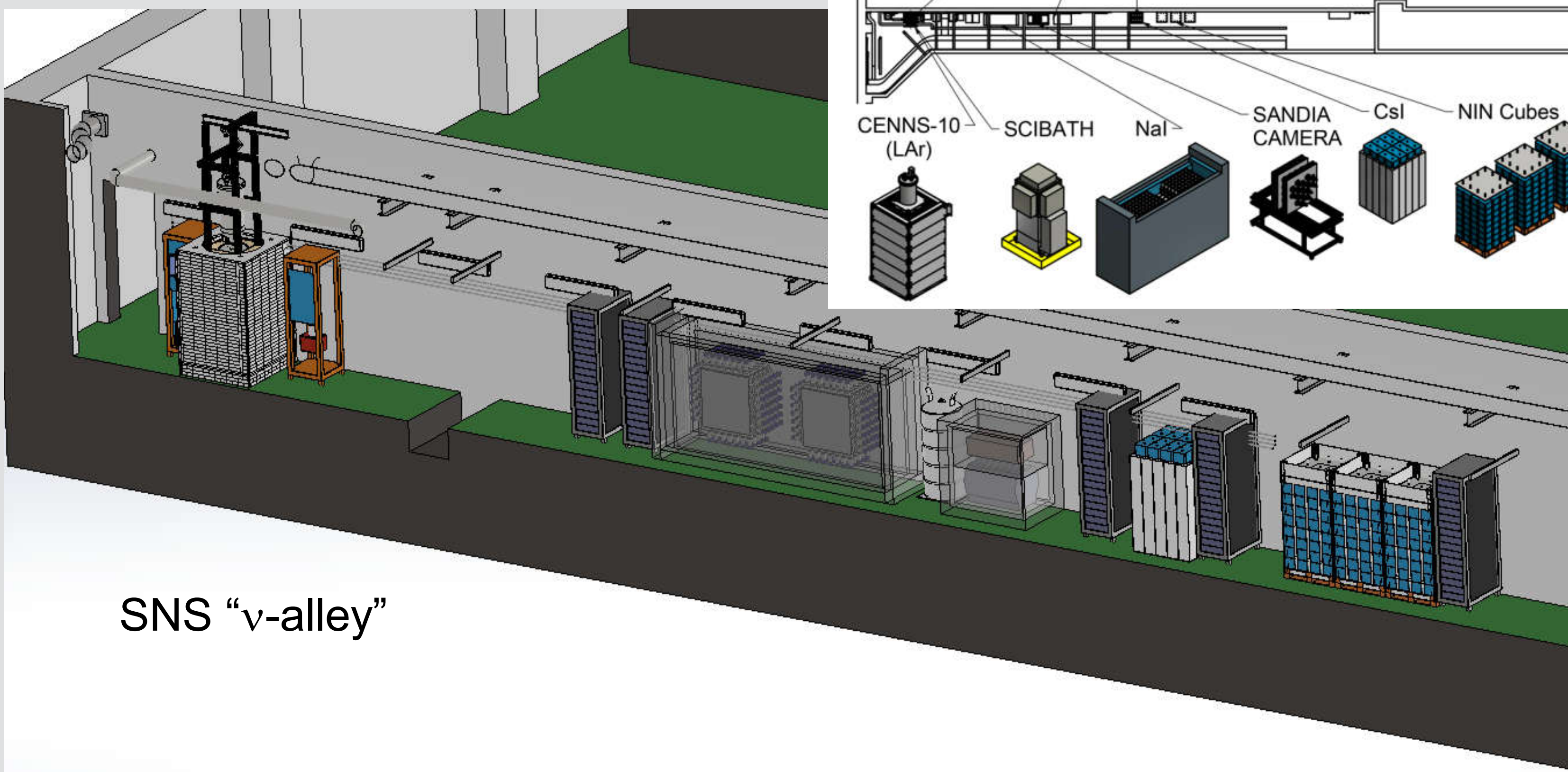


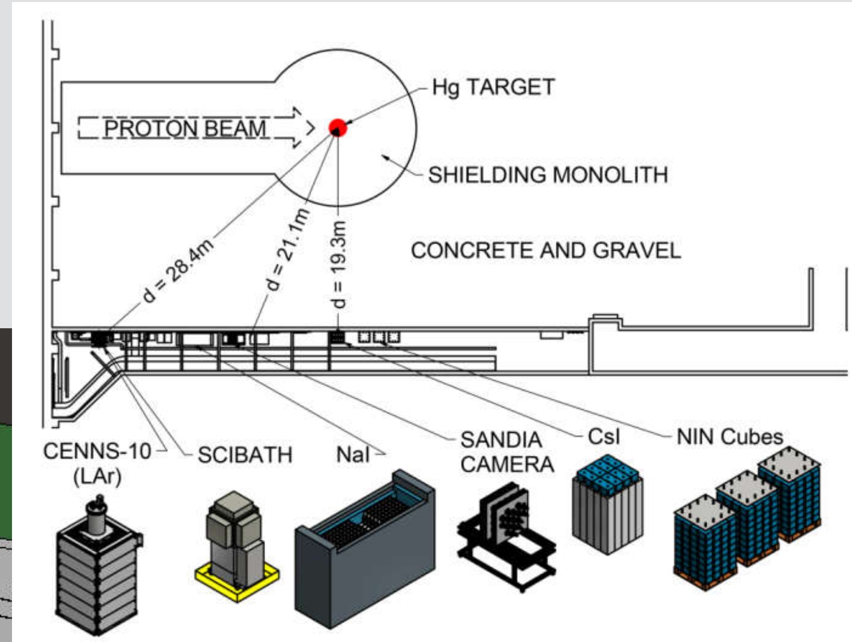
SNS ν time distribution



COHERENT experiment at SNS/ORNL

- a low-background experimental area has been acquired for COHERENT
- 20-29 m from target





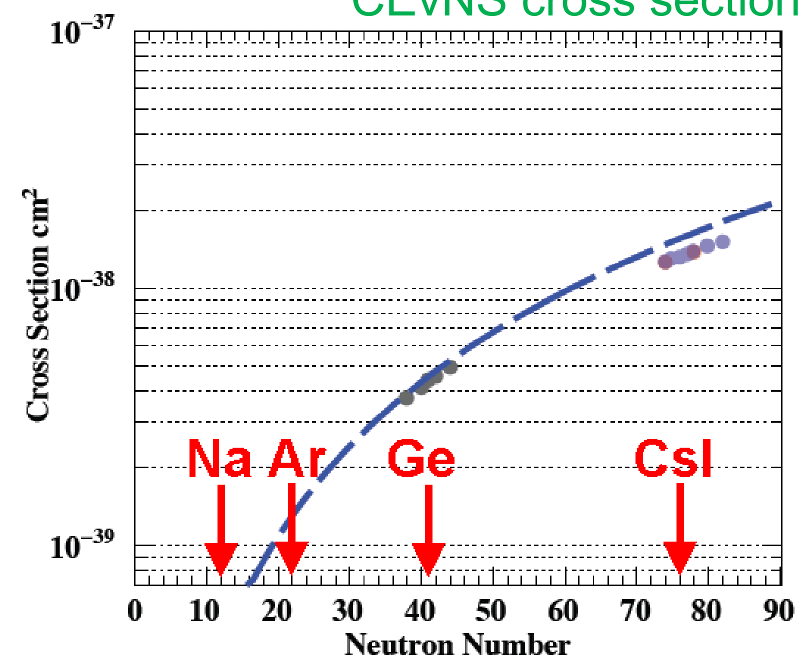
COHERENT experimental strategy at SNS/ORNL

Measure N^2 dependence of CEvNS process

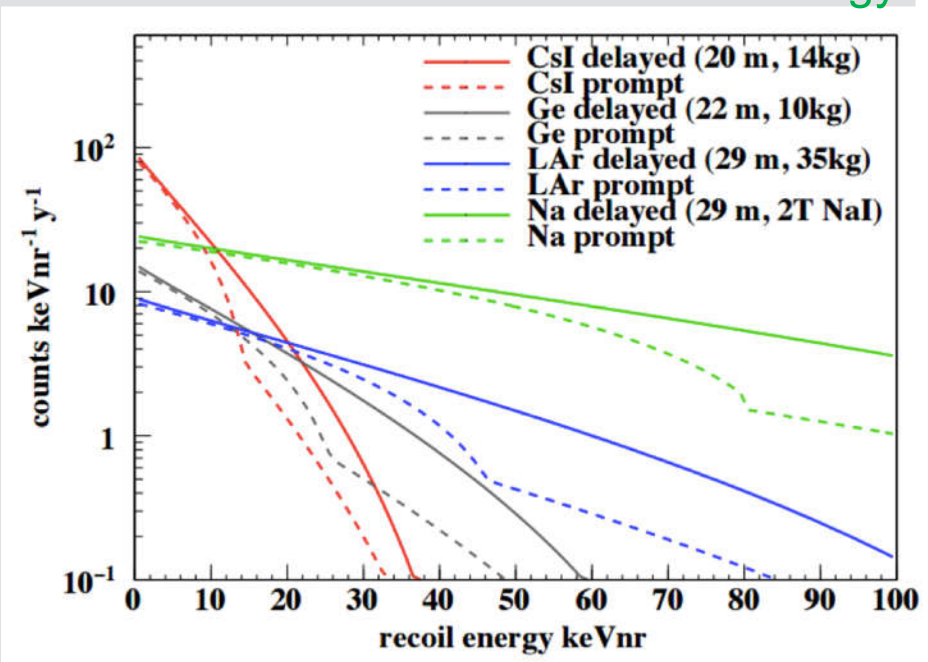
with multiple targets/detector technologies

- (event rate)/kg is high, so relatively small (10-100 kg) detectors sufficient
- radiological background requirements fairly modest, because of pulsed beam
- need low E thresholds !

CEvNS cross section



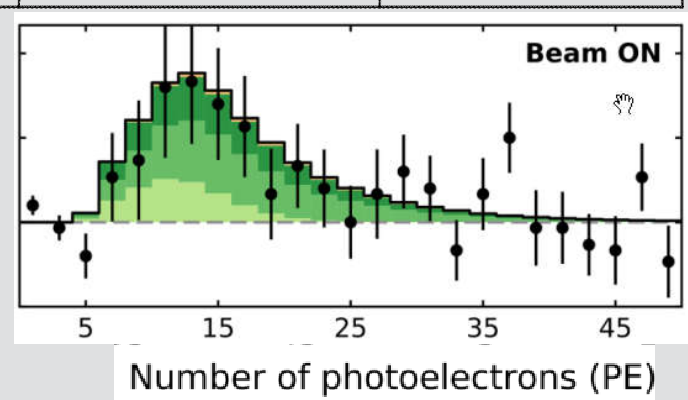
CEvNS recoil energy



COHERENT detectors

Nuclear Target	Technology	Mass (kg)	Distance from source (m)	Recoil threshold (keVr)
CsI[Na]	Scintillating Crystal	14.6	19.3	6.5
Ge	HPGe PPC	10	22	5
LAr	Single-phase	22	29	20
NaI[Tl]	Scintillating crystal	185*/2000	28	13

- recent observation of CEvNS
- D. Akimov *et al.*, *Science* 10.1126/science.aao0990 (2017)
- 134 ± 22 CEvNS events



COHERENT detectors

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- future

COHERENT detectors

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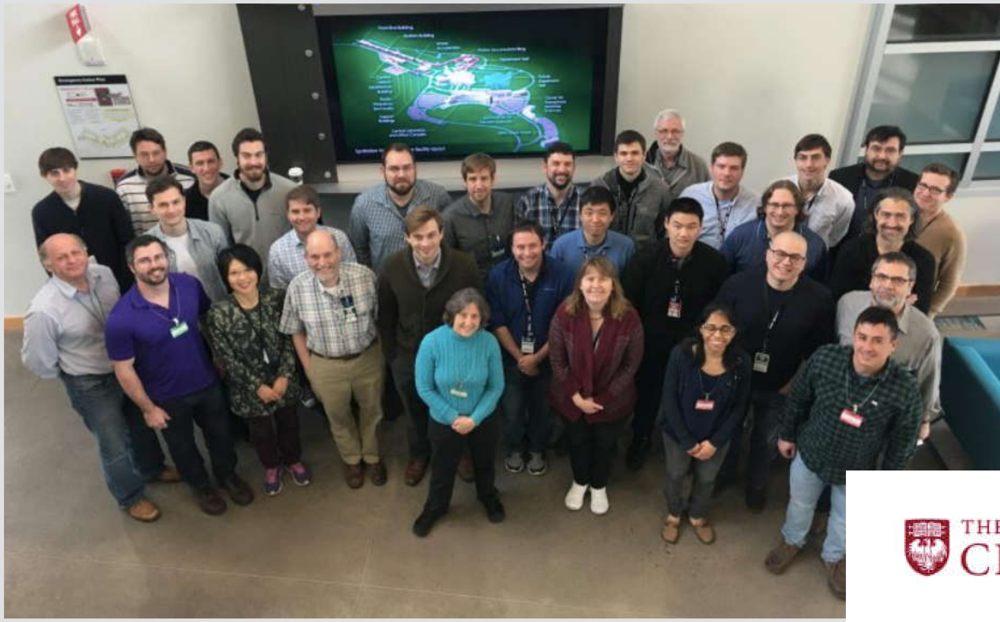
- today

The COHERENT collaboration

http://sites.duke.edu/coherent



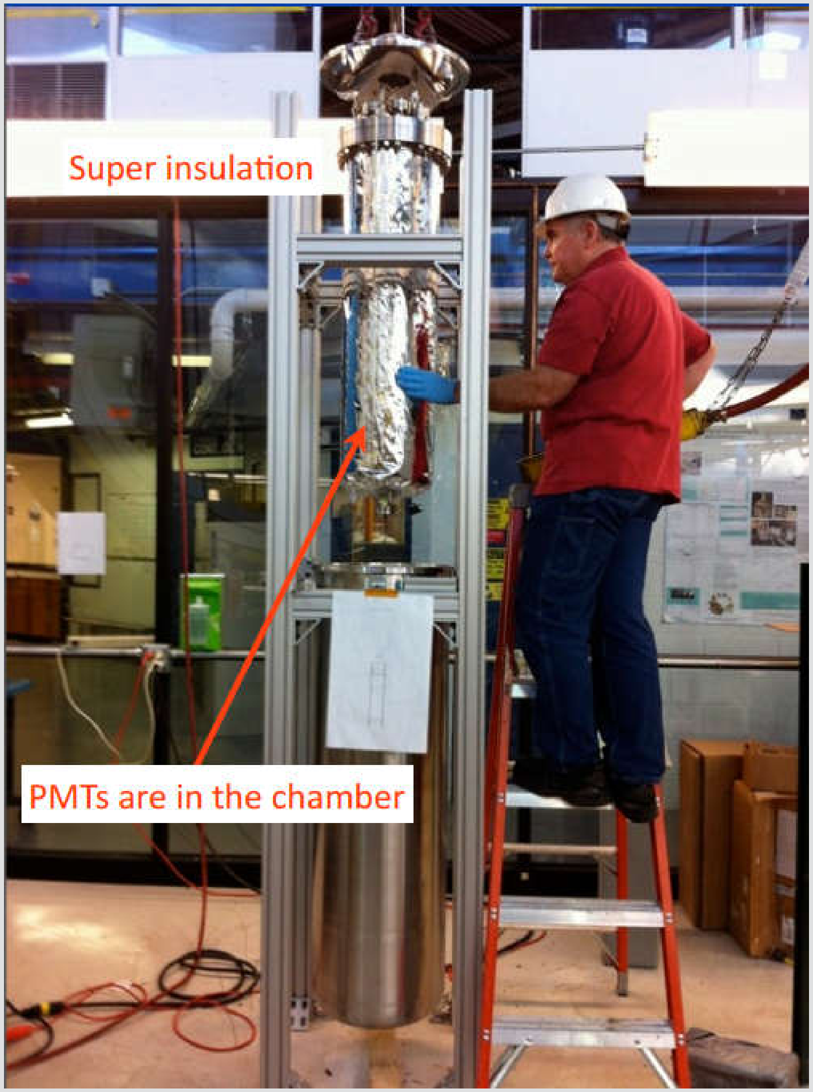
~80 members,
18 institutions
4 countries

arXiv:1509.08702

The CENNS-10 detector

timeline:

- ('12-'15) built at Fermilab for CENNS@Fermilab effort led by J. Yoo (now at KAIST) along with: A. Lathrop, R. Flores, R. Schmidt, E. Voirin, D. Markley, R. Davila, D. Butler, L. Harbacek



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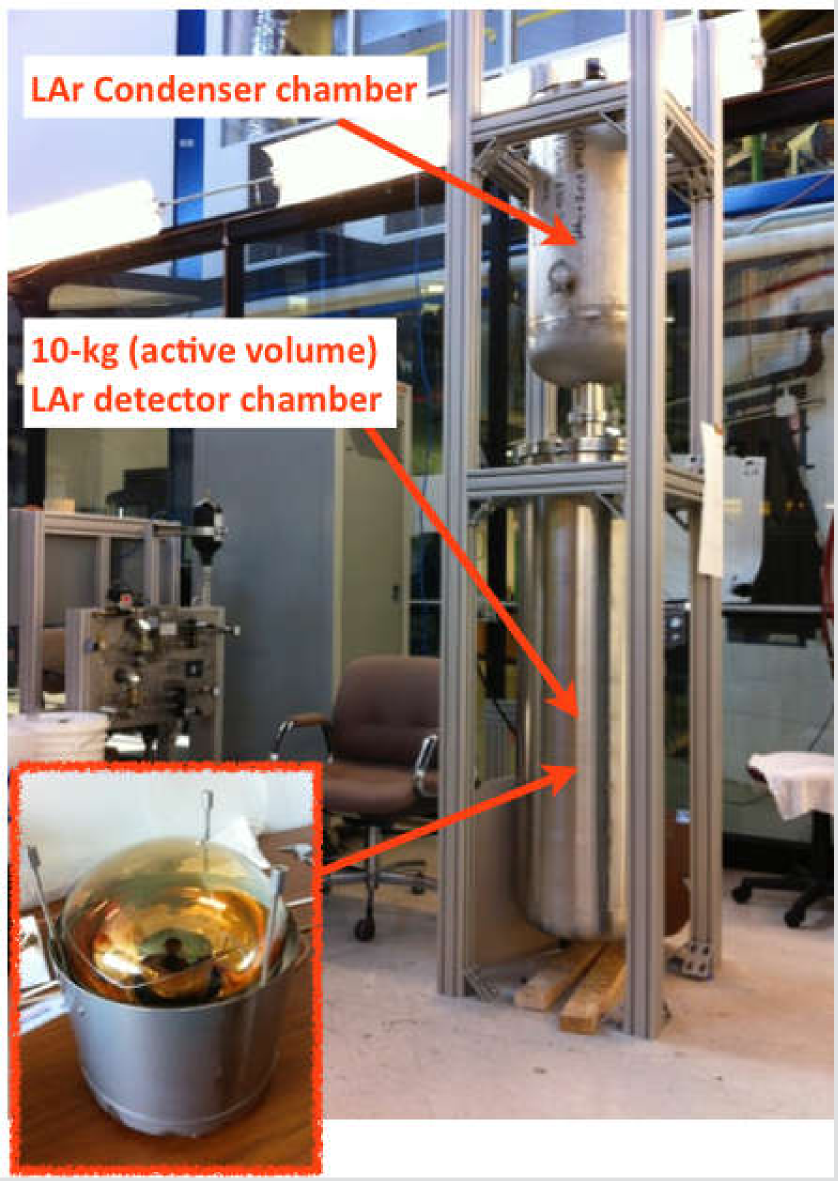
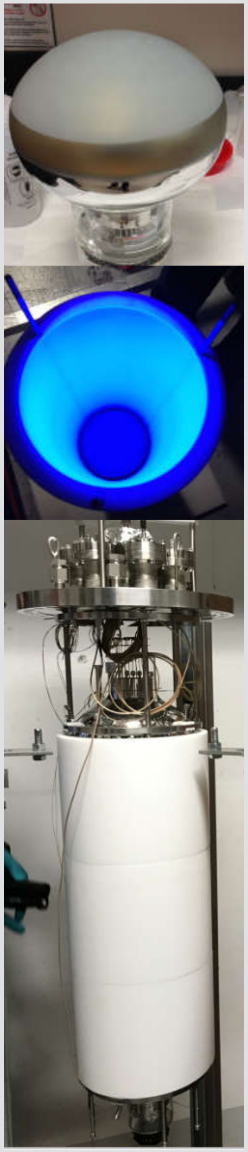
- (2015) moved to Indiana U. for commissioning, upgrades, neutron tests
- (2016) installed at SNS for COHERENT

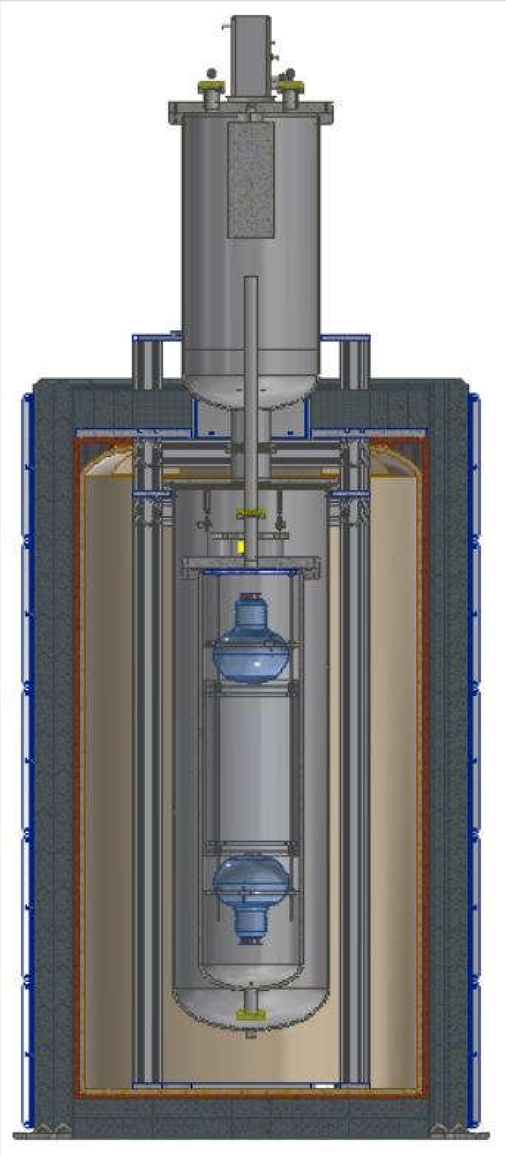


The CENNS-10 (LAr) Detector:

CENNS-10 SNS timeline:

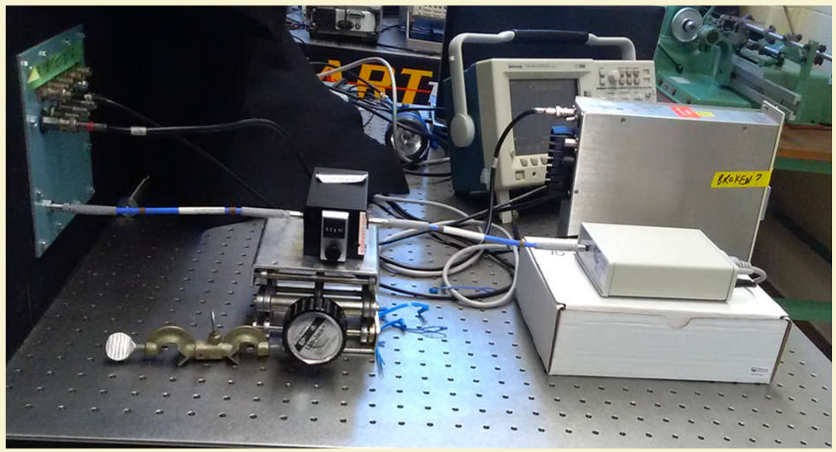
- 10-12/2016: (re)build detector at SNS
- 12/16, 3-5/17: run with TPB-acrylic parts, E_{thresh}~100keVnr, "Spring17" data
- 6/17: upgrade: TPB-Teflon reflectors, PMTs, shielding
- 7/17-present: run in upgraded mode, E_{thresh}~20keVnr, "Summer17" data
- should collect 1/2 SNS-year of data by 12/17 (before 5-month SNS shutdown)

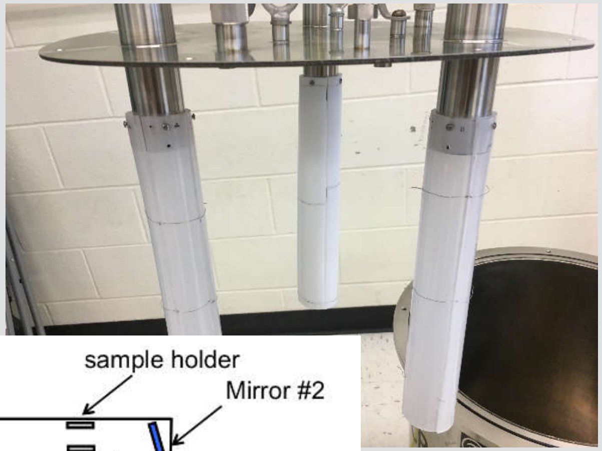


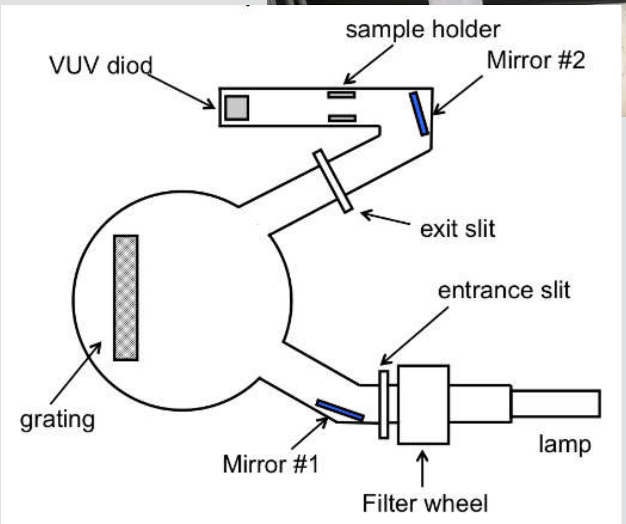


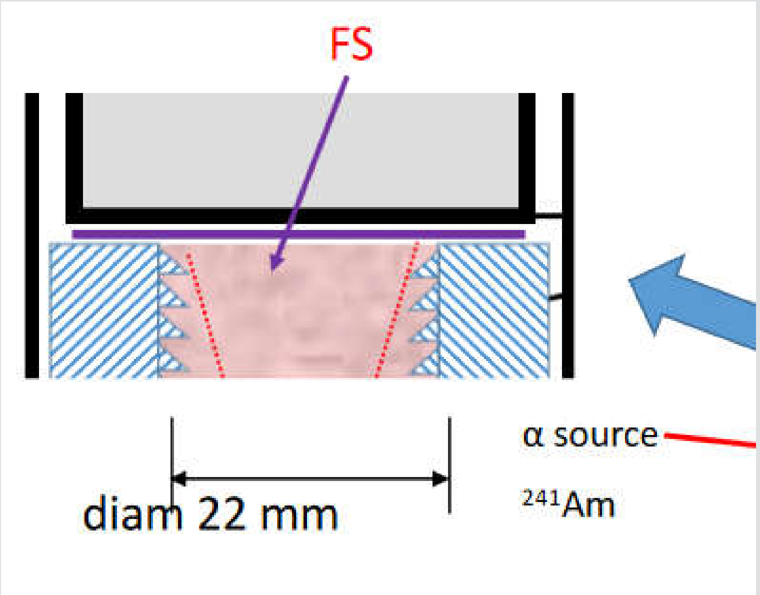
WLS, etc, optical tests:

- a variety of visible, VUV, WLS, reflectance tests have been performed at IU, ORNL, MEPHI, and harvested from literature, details to appear





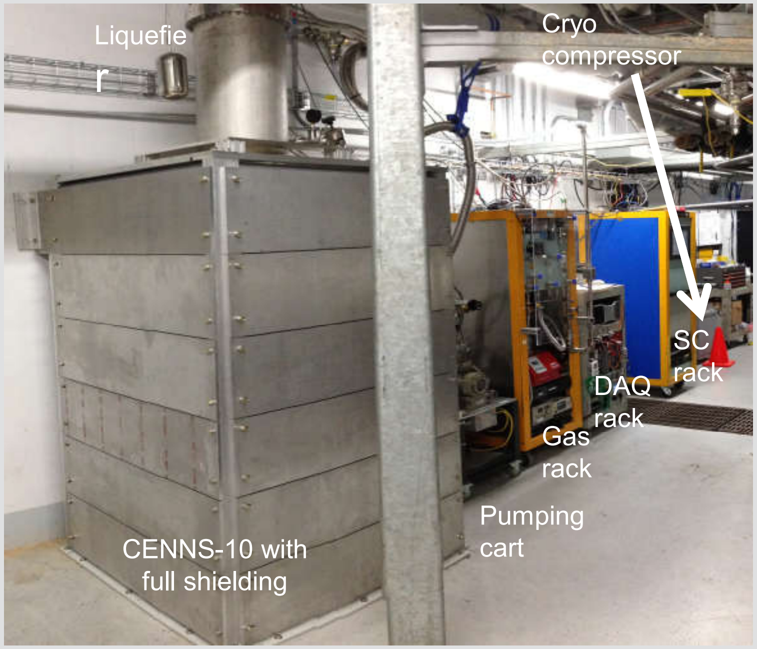


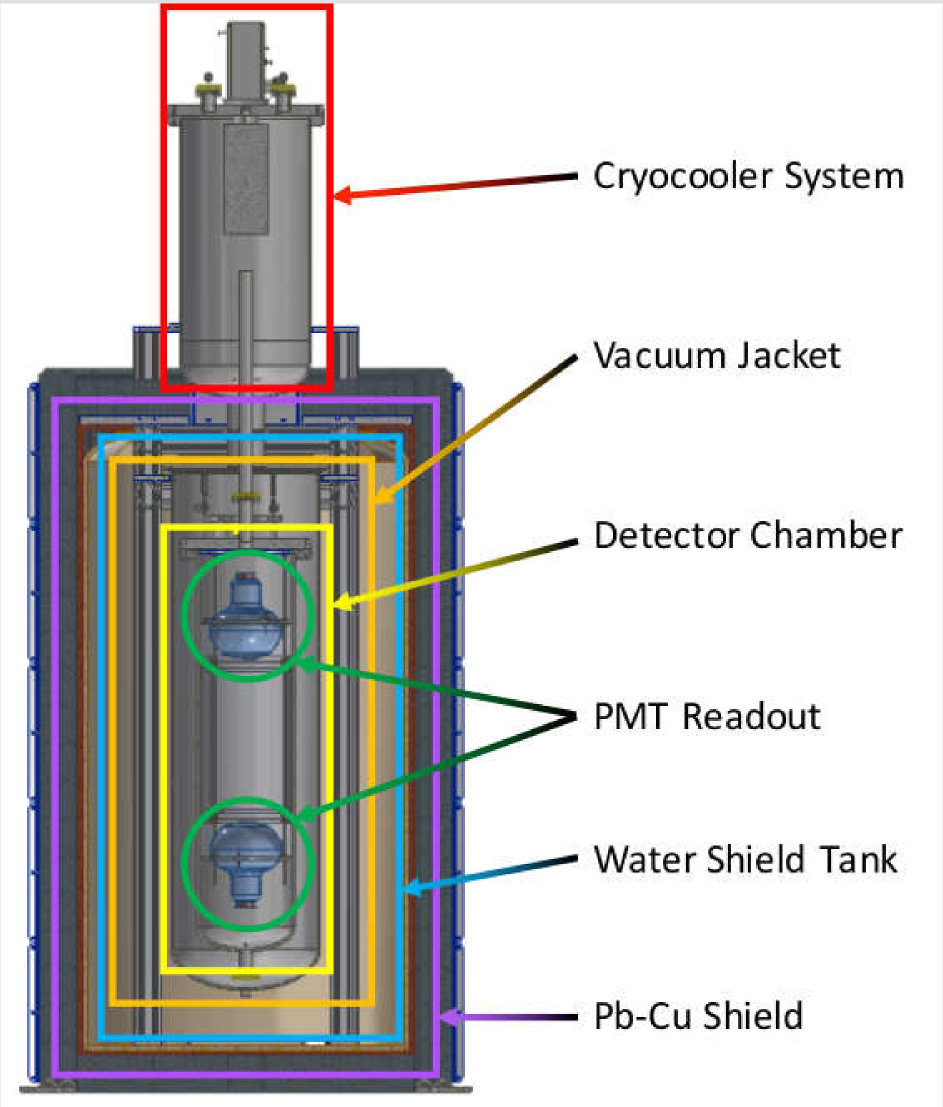


The CENNS-10 (LAr) Detector:

Specs:

- 22 kg LAr fiducial volume
- 90W single-stage pulse-tube cold head
- SAES MonoTorr gas purifier for ~1 ppm purity
- TPB-coated PMTs/teflon side walls
- 2 × Hamamatsu 8"PMTs w/QE=18%@400 nm
- CAEN 1420 (250MHz, 12-bit) digitizer
- Pb/Cu/H_2O shield
- Energy threshold ≈ 20keVnr
- Expect ≈140 CEvNS events/SNS-year
- Running in current configuration since July '17



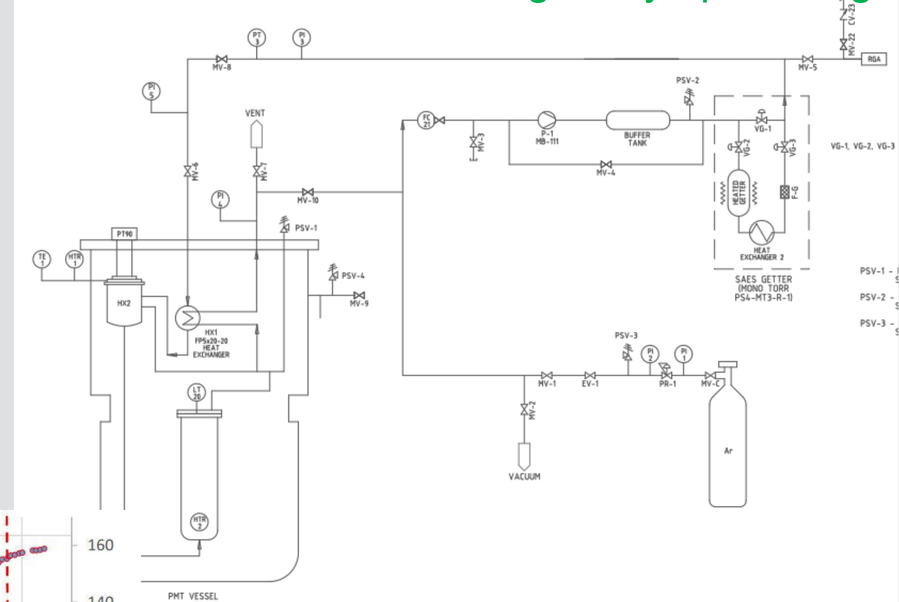


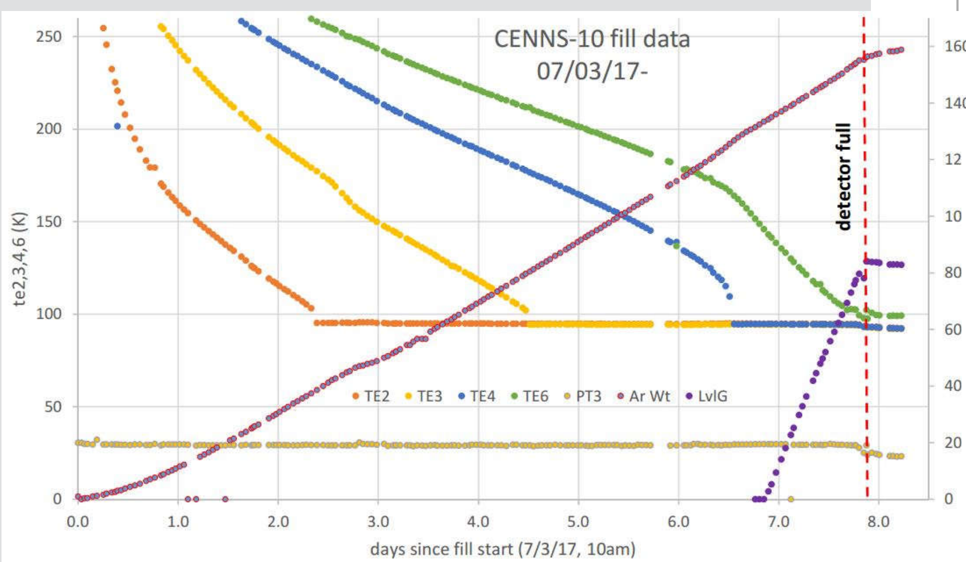
The CENNS-10 (LAr) Detector

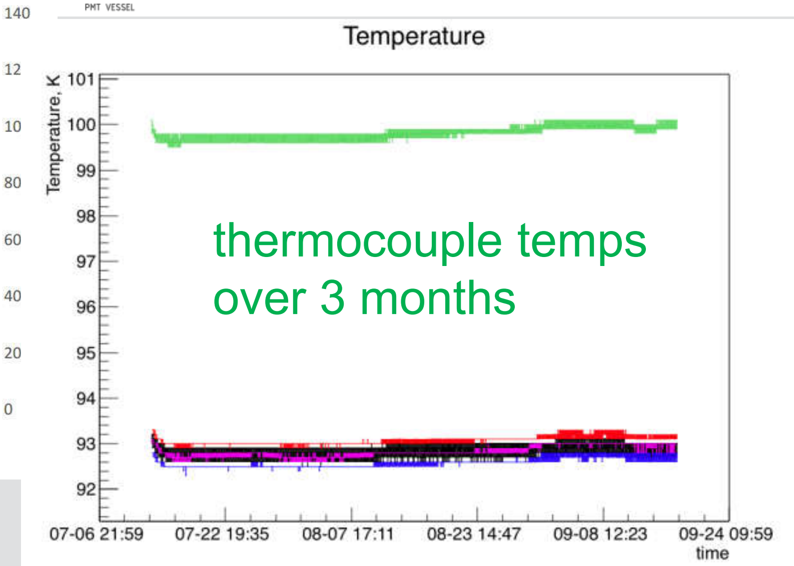
cryo/gas system:

- 90W single-stage PT90 cold head
- ~50kg total LAr mass, fill (from gas) over ~1 week, extremely stable temps/pressures
- SAES MonoTorr gas purifier for ~1 ppm purity

CENNS-10 gas/cryo plumbing



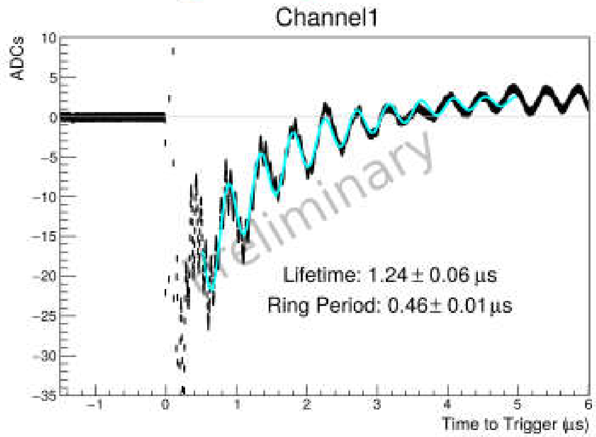




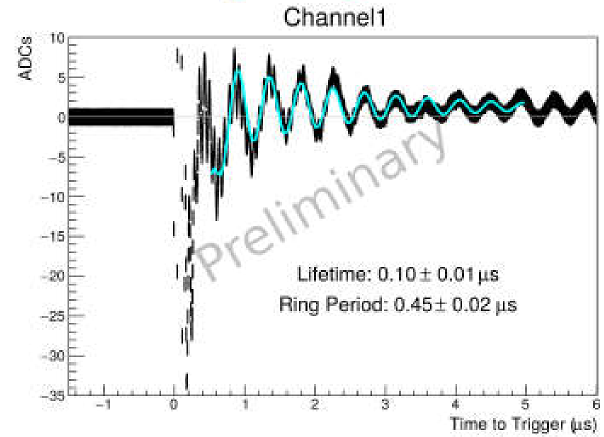
The CENNS-10 (LAr) Detector

- SAES MonoTorr gas purifier for ~1 ppm purity

Pre-Doping



Post-Doping



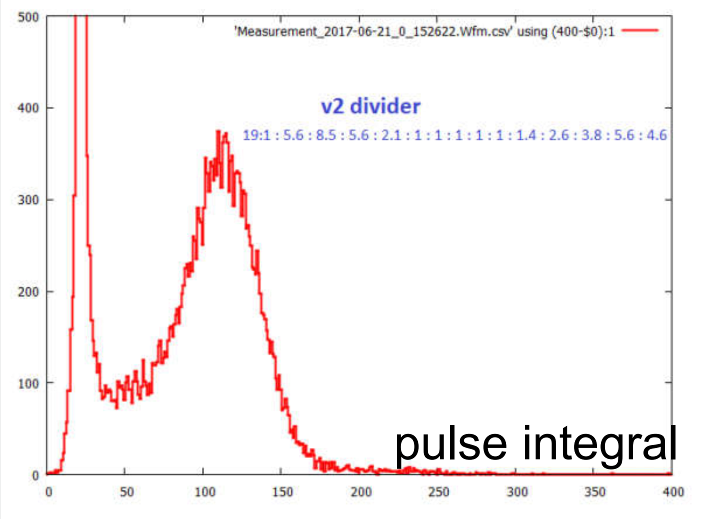
- As data quality check introduce N_2 after spring run
- Introduce ~25 ppm N_2
- Triplet lifetime changed from ~1.2 μs to 0.20 μs
  - Correspond to 1 ppm and 20 ppm respectively[2]
- Verified with LDetek8000 N_2 monitor readings

[2] R. Acciarri et al. Effects of Nitrogen Contamination in Liquid Argon. JINST, 5:P06003, June 2010.

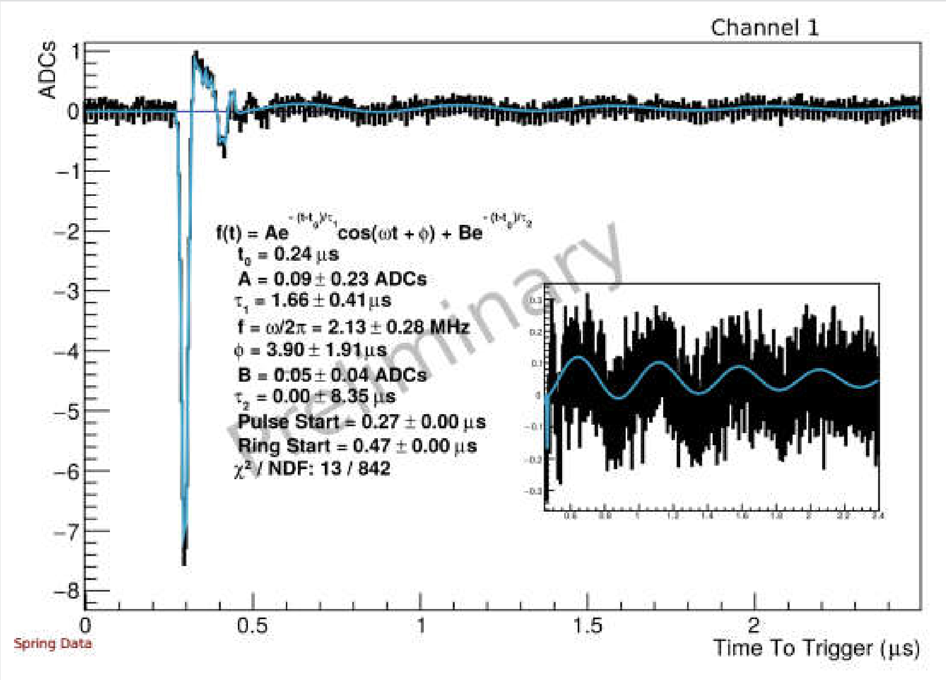
The CENNS-10 (LAr) Detector

Preliminary data analysis:
Spring17 data, Single PE analysis

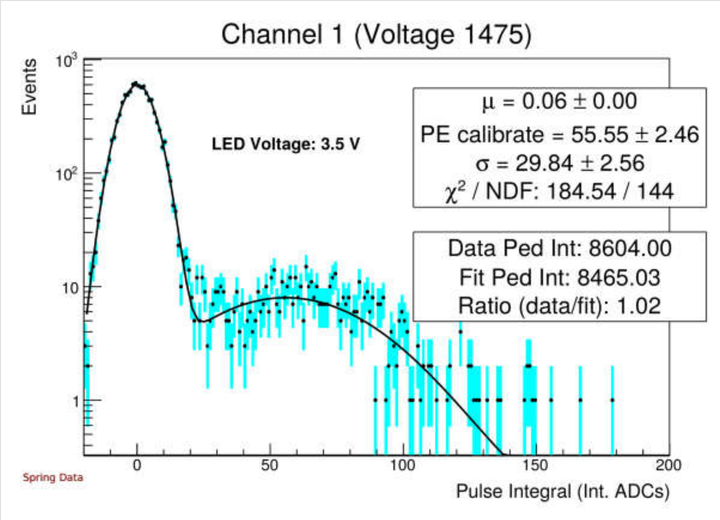
Single PE spectrum: test bench



Single PE waveform: in situ



Single PE spectrum: in situ



Plots from IU grad student: M. Heath

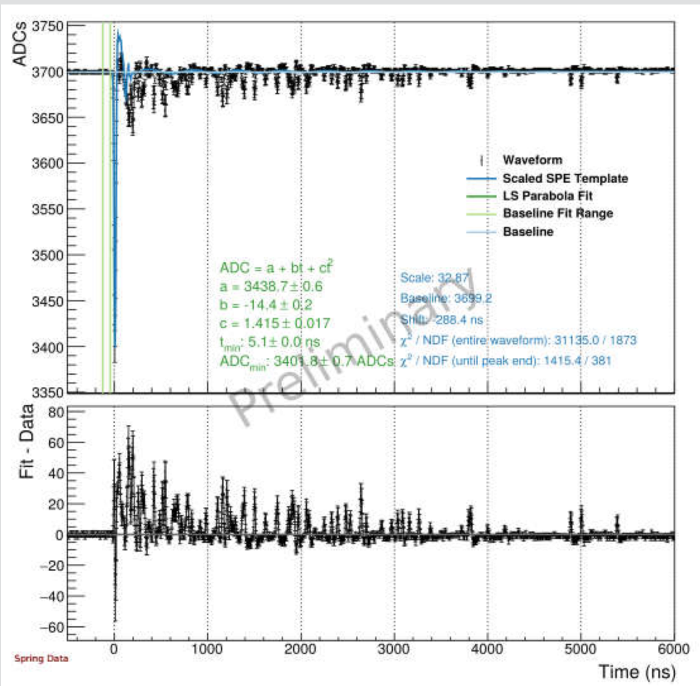
The CENNS-10 (LAr) Detector

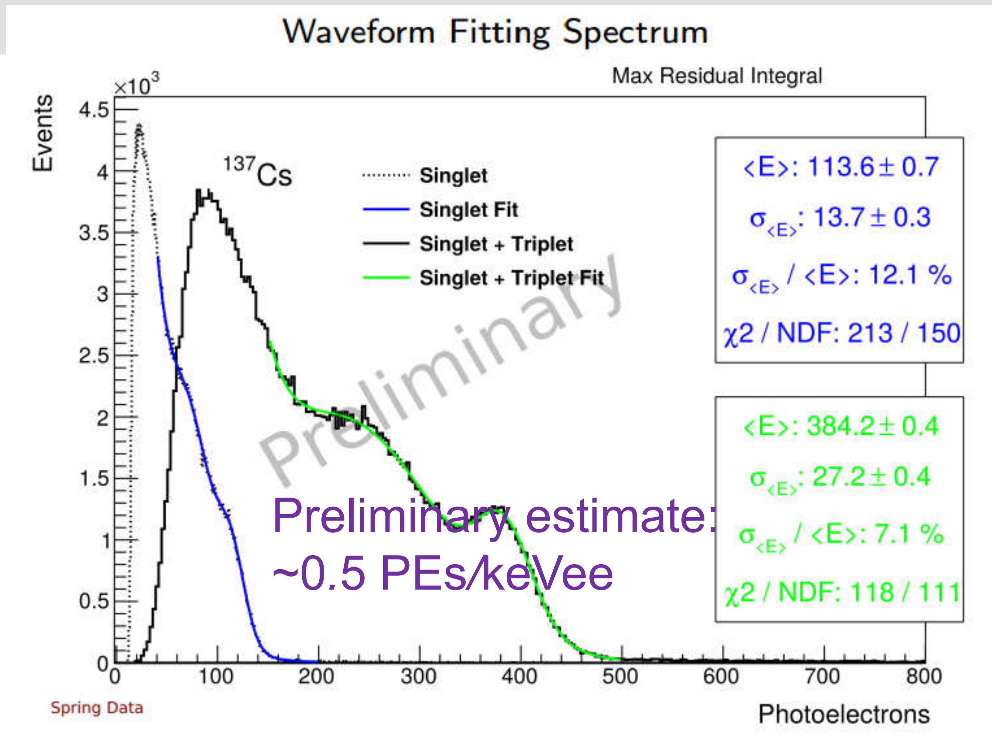
Preliminary data analysis: Spring17 data, waveform integration

- fit prompt (singlet) light
- subtract scaled singlet waveform
- integrate delayed (triplet) light

137Cs spectrum

Waveform fit example

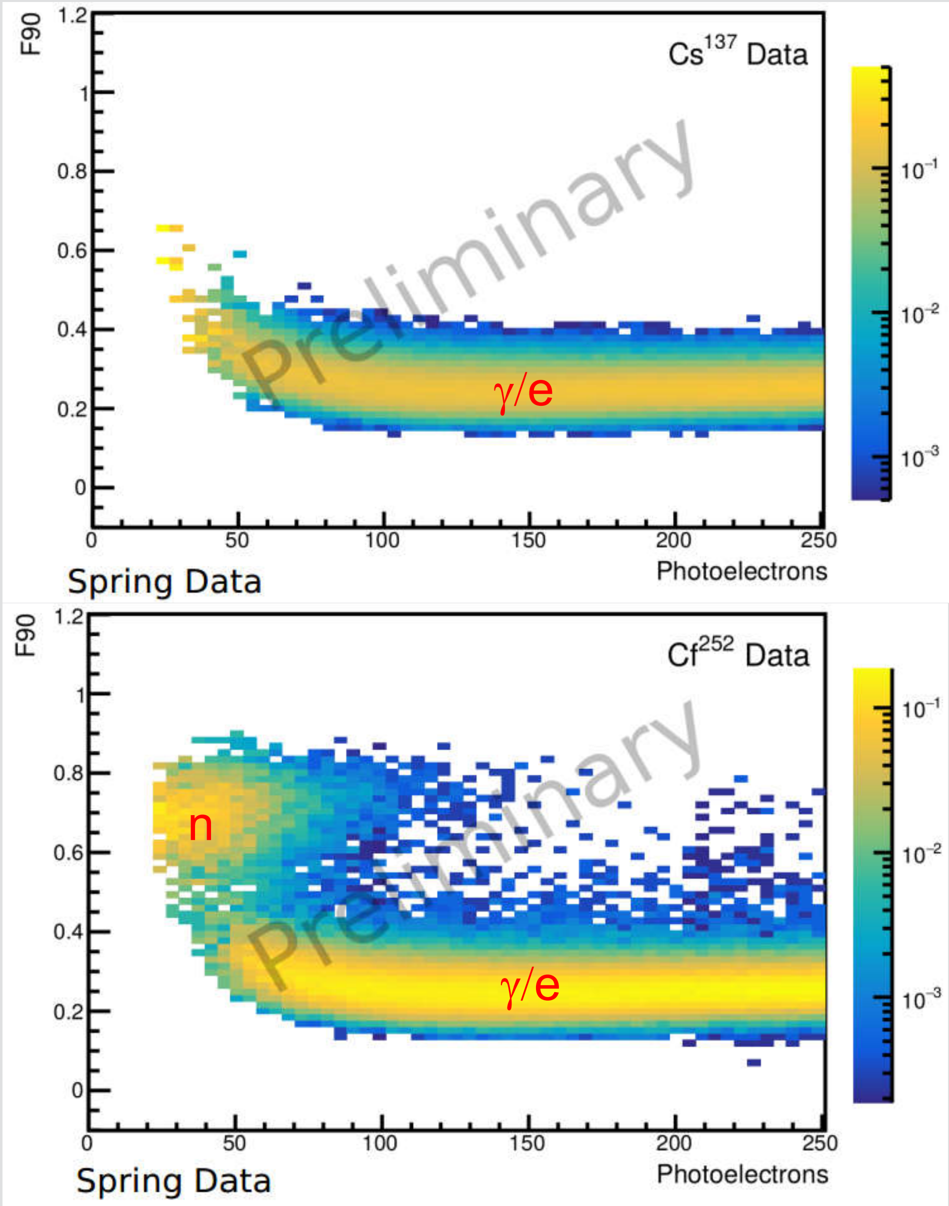




The CENNS-10 (LAr) Detector

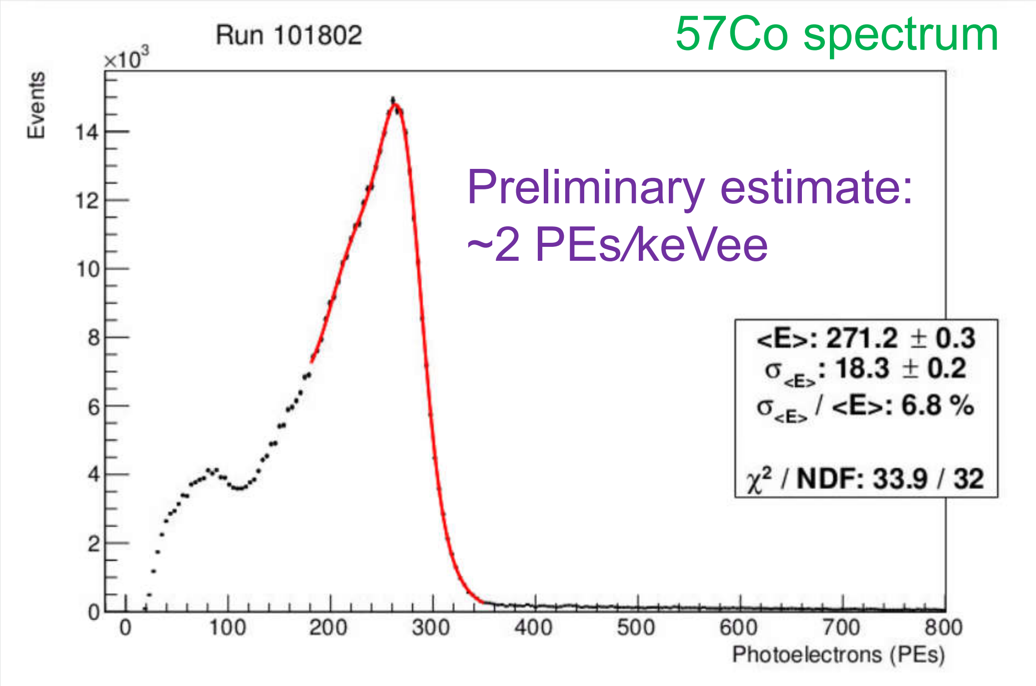
Preliminary data analysis:
Spring17 data, waveform integration

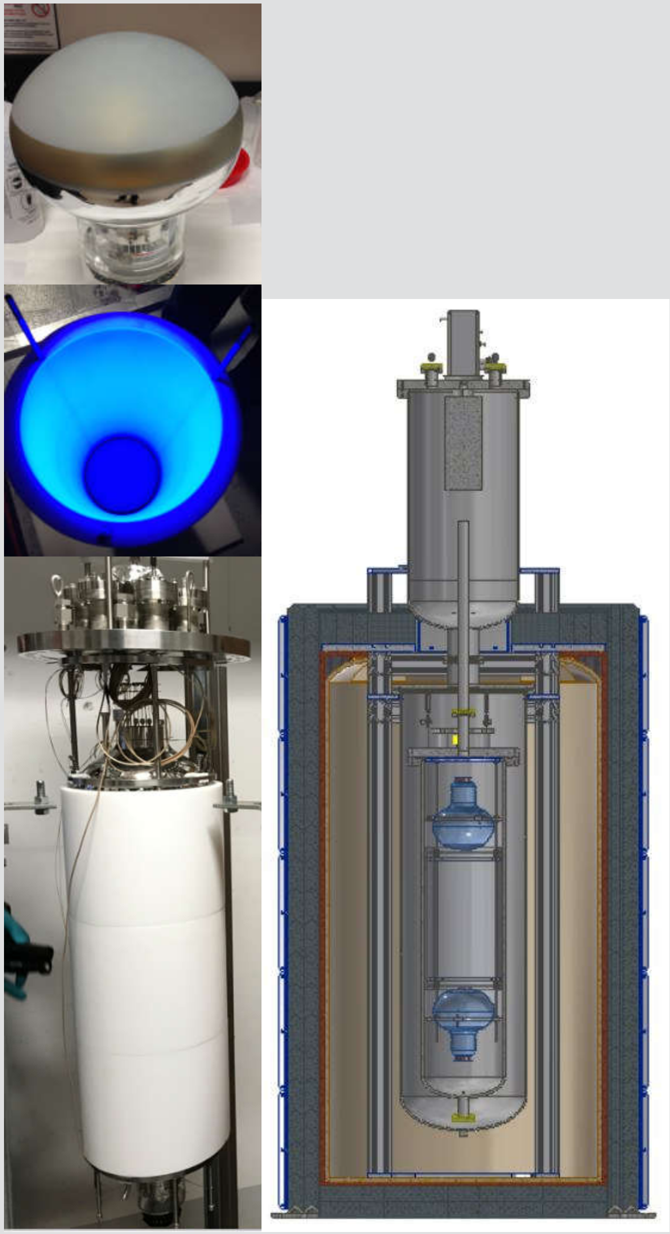
- Fit prompt (singlet) light
- subtract scaled singlet waveform
- integrate delayed (triplet) light
- form F90 ratio (fract of light in 1st 90ns) for PSD (pulse-shape discrimination)



The CENNS-10 (LAr) Detector

Preliminary data analysis:
Summer17 data, after upgrades



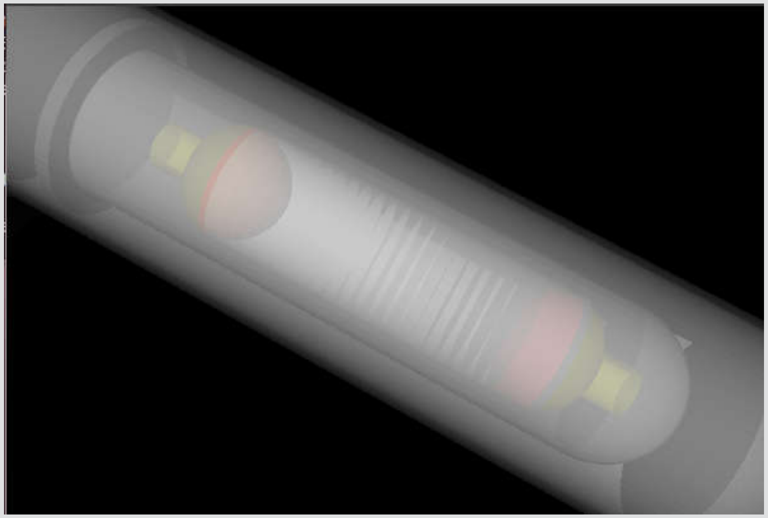


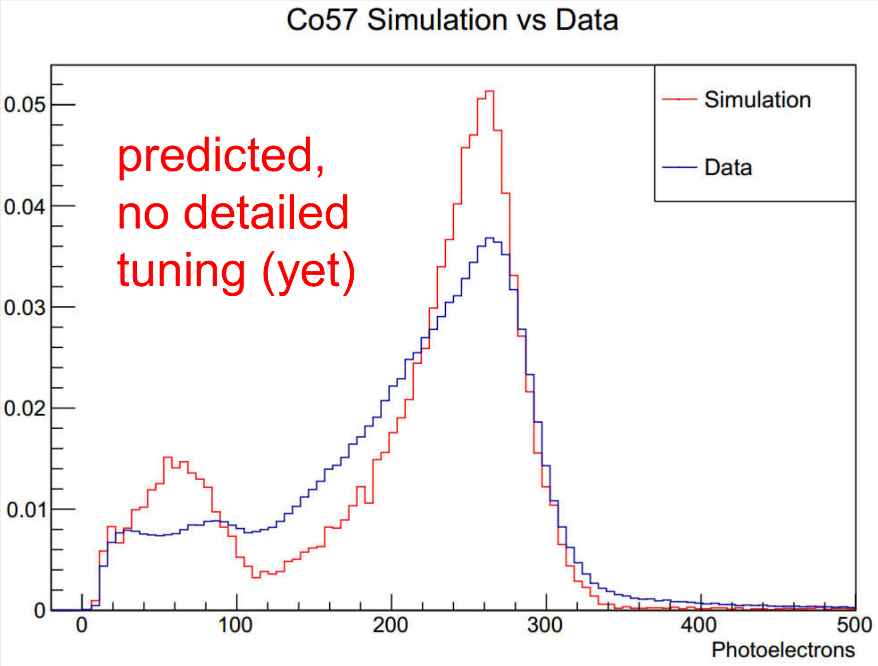
Plots from IU/SNS grad student: J. Zettlemoyer

CENNS-10 simulations

Geant4 simulation results

Simulation Parameter	Value	comment
Tube QE	18%	
LAr Scintillation Yield ER	40/keV	
Quenching Factor	25%	H. Cao et al., SCENE Collaboration, *Phys. Rev.* **D91** (2015) 092007.
Time Constants	6 ns fast, 1.6 us slow	
Quenching Factor	25%	
Scintillation LAr peak	128 nm	
Scintillation WLS peak	450 nm	
TPB Attenuation Length at 400 nm	20 um	
Teflon Reflectivity	95%	
LAr Attenuation Length	2 m LAr, 20 m Vis	
Scintillation Yield Ratio (Fast/Slow)	0.7 NR, 0.25 ER	
TPB Thickness	0.2 mg/cm^2	
FV diameter/height	21cm/46cm	

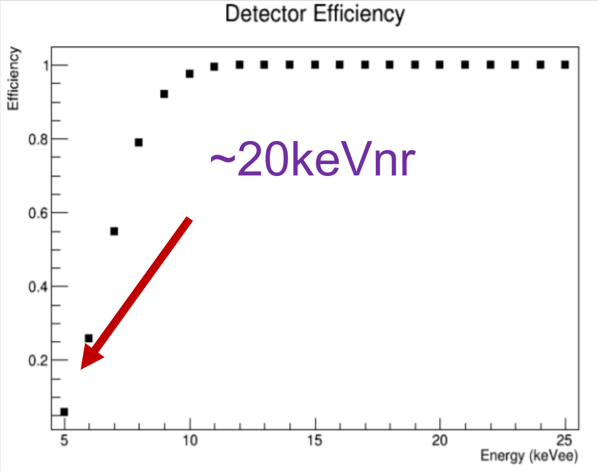


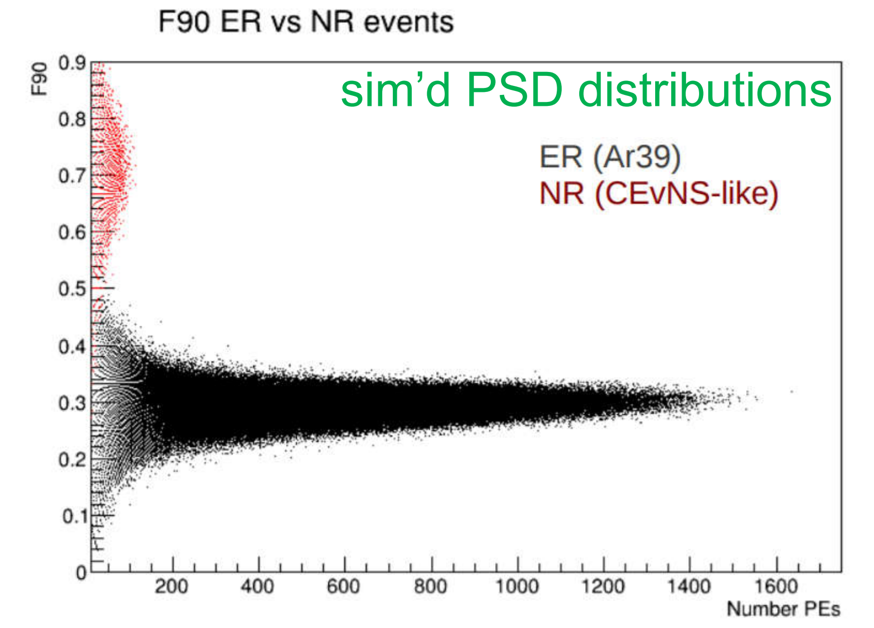


CENNS-10 simulations

Estimated CEvNS signal/backgrounds:

- E_{thresh} ~ 20keVnr
- beam-unrelated bckgnds:
  - Ar39, environmental γ reduced with PSD, measured, subtracted, estimated to be negligible
- beam-related bckgnds:
  - neutrons: measured at CENNS-10 location, all prompt, estimate ~60evts/yr
- CEvNS signal
  - estimate 60 prompt/ 80 delayed evts/yr





Predictions for:
Summer17 data, after upgrades

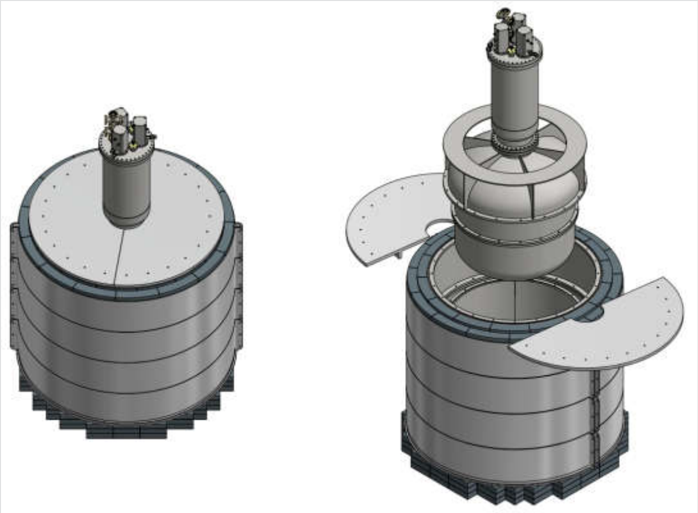
Future/Summary for LAr and COHERENT

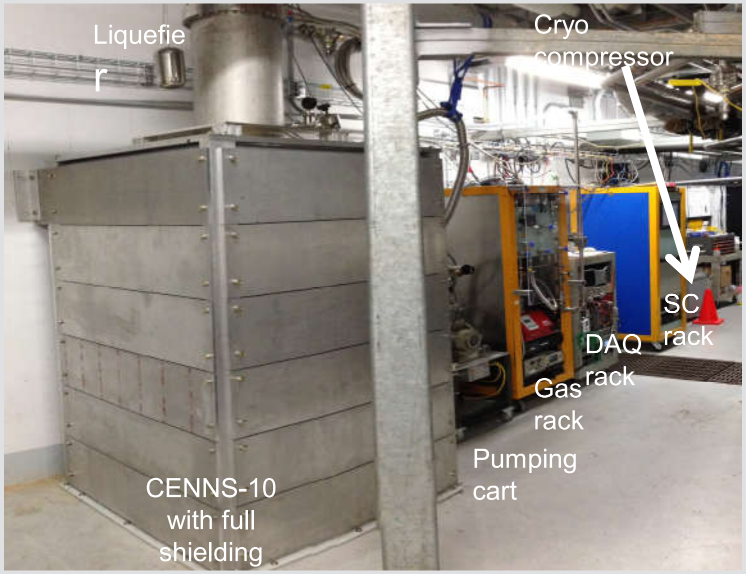
Future:

- current run ends 12/17,
  should provide 1st CEvNS LAr signal
- 5-month shutdown, in early 2018, possible upgrades:
  - incremental PMT, signal improvements
  - new/better reflectors
  - more/better calibration at low-energy
  - depleted-Ar (?)
- longer term possibilities
  - O(1 ton) LAr
  - depleted Ar,
  - LXe, LNe
- ideas? (let's talk!)

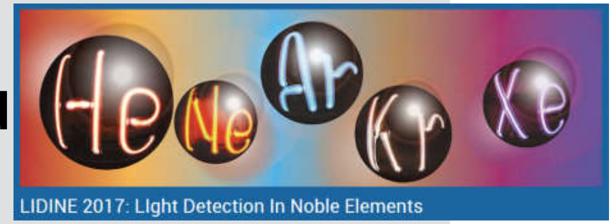
Summary:

- on-track for CEvNS measurement on LAr in next year
- opportunities exist for upgrades to detector and physics program
- Thanks to all who have helped make this happen!: IU group, COHERENT collab, Fermilab, SNS, funding agcys, **this community**





LIDINE’17
Search for CEvNS with a liquid argon scintillation detector



(15min talk)

Abstract:
The COHERENT collaboration is deploying a suite of low-energy detectors in a low-background corridor of the ORNL Spallation Neutron Source (SNS) to measure coherent elastic neutrino nucleus scattering (CEvNS) on an array of nuclear targets employing different technologies. A measurement of CEvNS on different nuclei will test the N^2-dependence of the CEvNS cross section and further the physics reach of the COHERENT effort. The first step of this program has been realized recently with the observation of CEvNS in a 14.6 kg CsI detector. Operation and deployment of Ge and NaI detectors are also underway. A 22 kg, single-phase, LAr detector (CENNS-10) started data-taking in Dec. 2016 and will provide results on CEvNS from a much lighter nucleus. The design and performance of the CENNS-10 detector will be presented.