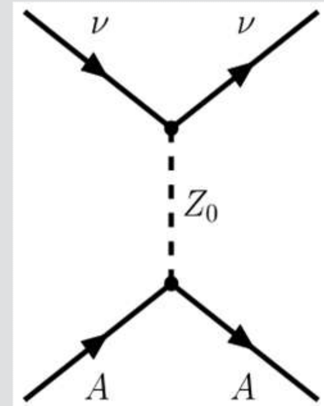
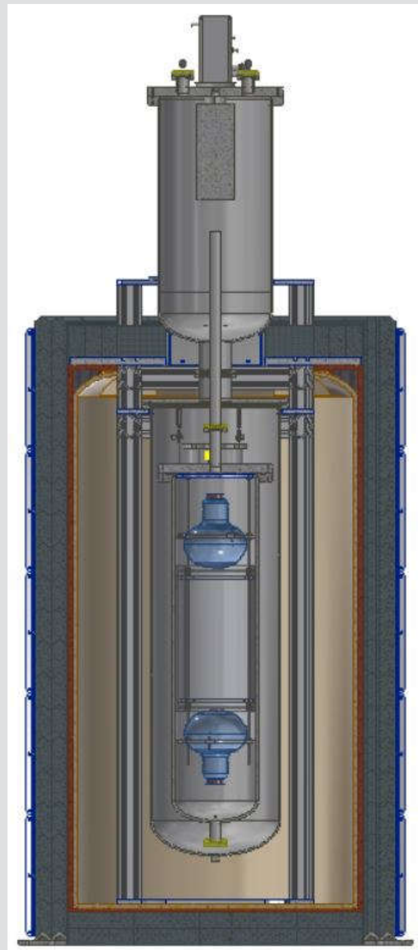
LOW-RADIOACTIVITY UNDERGROUND ARGON Low-Radioactivity Underground Argon Workshop

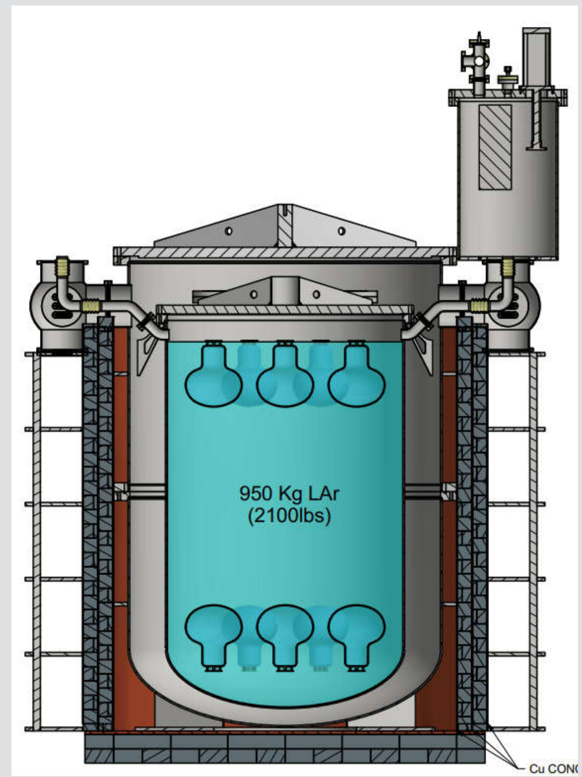
19-20 March 2018
Pacific Northwest National Laboratory

CEvNS with a liquid argon scintillation detector

R. Tayloe, Indiana U.
for the COHERENT collaboration

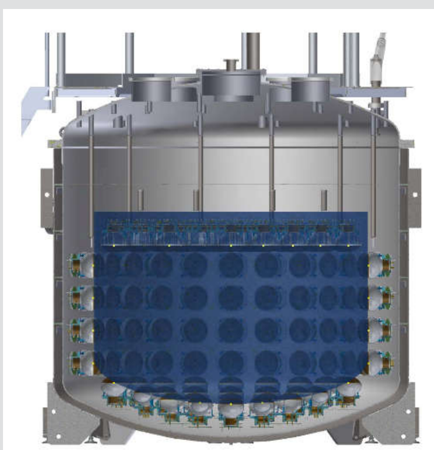






<u>Outline:</u>

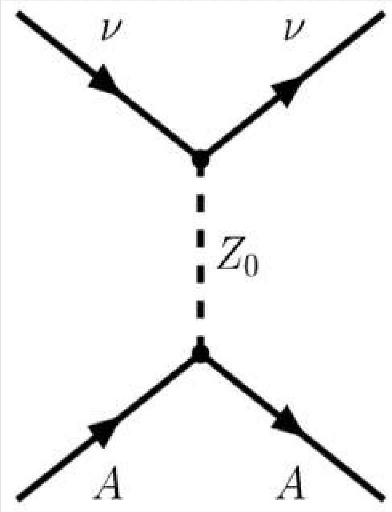
- physics of CEvNS
- COHERENT at ORNL/SNS
- Results from CENNS-10 detector
- Future
- Argon requirements



Coherent Elastic ν-Nucleus Scattering:

"CEvNS":

Coherent Elastic ν-Nucleus Scattering: $\nu A \rightarrow \nu A$

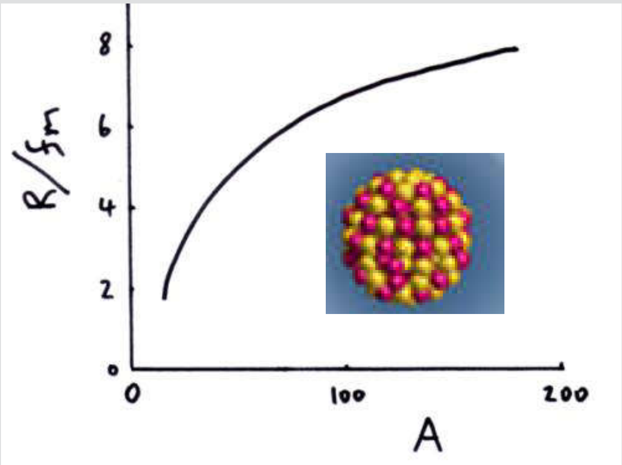


Coherent = neutrino "sees" (interacts with) nucleus (A) as a whole, not the individual constituents (eg: nucleons, quarks)

For a large nucleus, R ~ 5 fm (10^{-15} m), and coherence obtained for E_ν < 50 MeV .

de Broglie wavelength for 50 MeV neutrino:

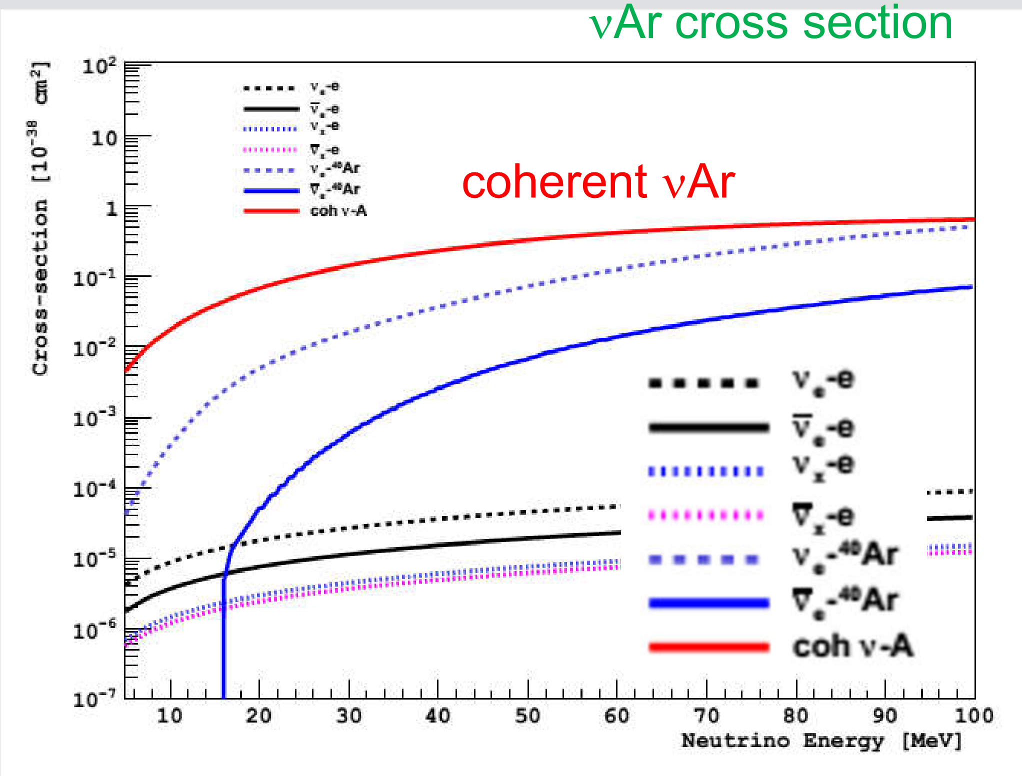
$$\lambda = \frac{h}{p} = \frac{hc}{E} = \frac{1200 \text{ eV fm}}{50 \text{ MeV}} \sim 25 \text{ fm}$$



(more accurately, relevant wavelength is that for the ν-A momentum transfer, q, but the scale is same)

<u>Coherent Elastic ν-Nucleus Scattering:</u>

Cross section (interaction probability) for CEvNS is large…
in fact largest ν channel at
10s of MeV
on heavier nuclei, eg Ar



and, since weak charge of proton is small, there is distinctive N^2 (neutron-squared) dependence

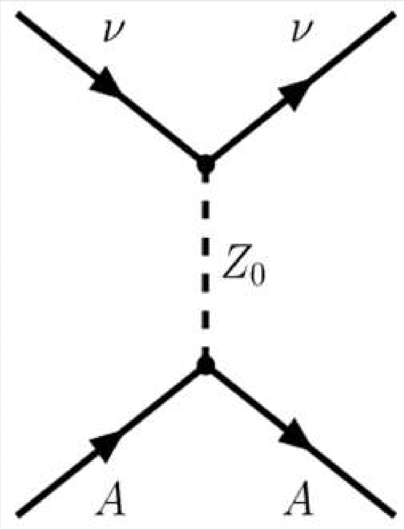
CEvNS differential cross section:

$$\frac{d\sigma}{dE} = \frac{G_F^2}{2\pi}[\underbrace{(1/2 - 2\sin^2\theta_w)Z}_{\text{weak charge of proton} \sim 0} - \underbrace{(1/2)}_{\text{weak charge of neutron}}N]^2(1 - \frac{ME}{2E_\nu^2})F(Q^2)^2$$

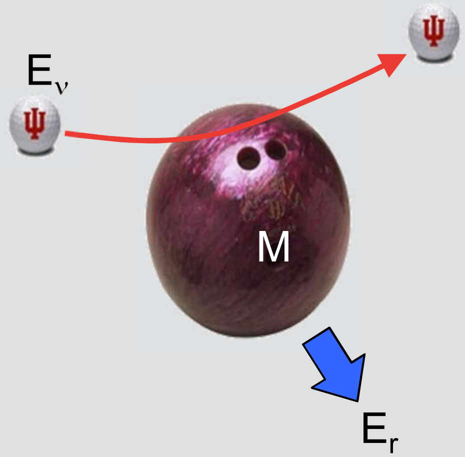
Coherent Elastic ν-Nucleus Scattering:

However, detection is a challenge:

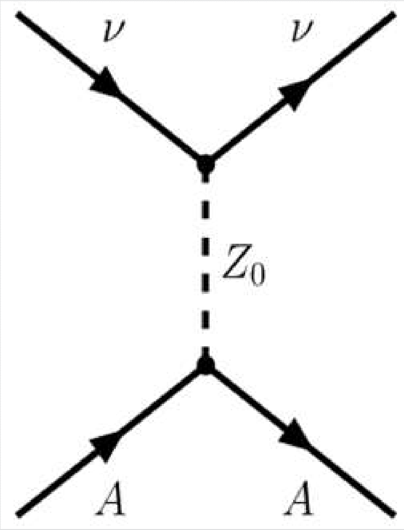
- no signal from neutrino and recoil energy is quite small:



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



Coherent Elastic ν-Nucleus Scattering:



However, detection is a challenge:

- no signal from neutrino and recoil energy is quite small:

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

only recently

And so, the CEvNS process has ^ ~~never~~ been observed…

40 years after its prediction...

PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

Coherent effects of a weak neutral current

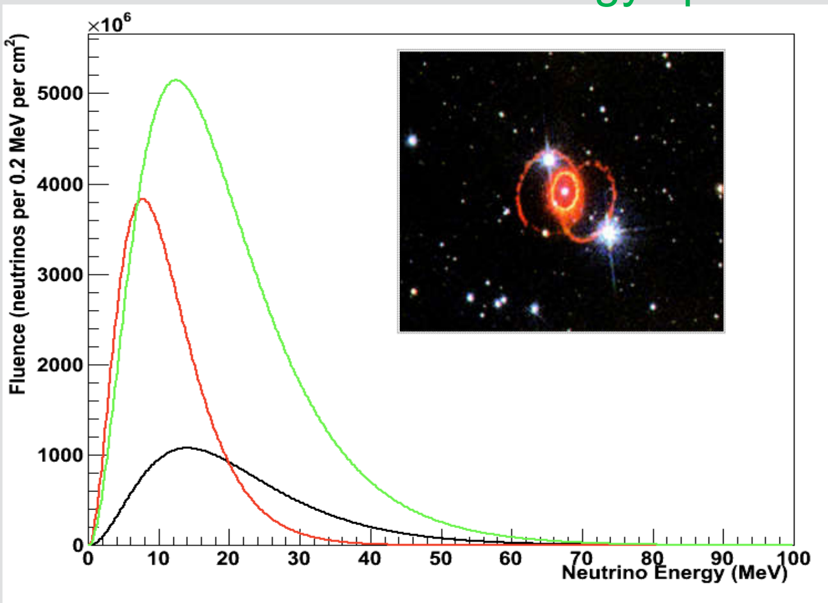
Daniel Z. Freedman†
National Accelerator Laboratory, Batavia, Illinois 60510
and Institute for Theoretical Physics, State University of New York, Stony Brook, New York 11790
(Received 15 October 1973; revised manuscript received 19 November 1973)

Coherent Elastic ν-Nucleus Scattering:

Physics reach of CEvNS:

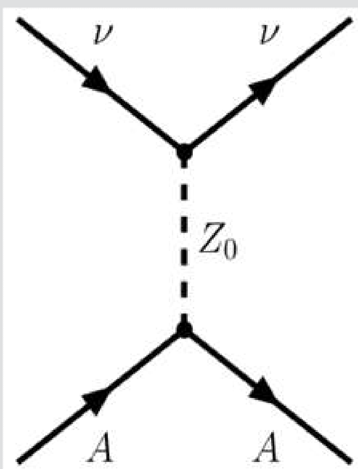
- Understanding supernovae (SN):
  - Expected to be important in core-collapse SN and
  - possible SN detection channel.
- Standard Model tests, eg: NSI, $\sin^2\theta_W$, neutrino magnetic moments
- Nuclear Physics: nuclear form factors
- ν oscillations: A possible ν_s detection channel
- reactor monitoring (non-proliferation)
- Dark Matter:
  - Important background for 10-ton direct searches
  - detectors sensitive for accelerator produced DM

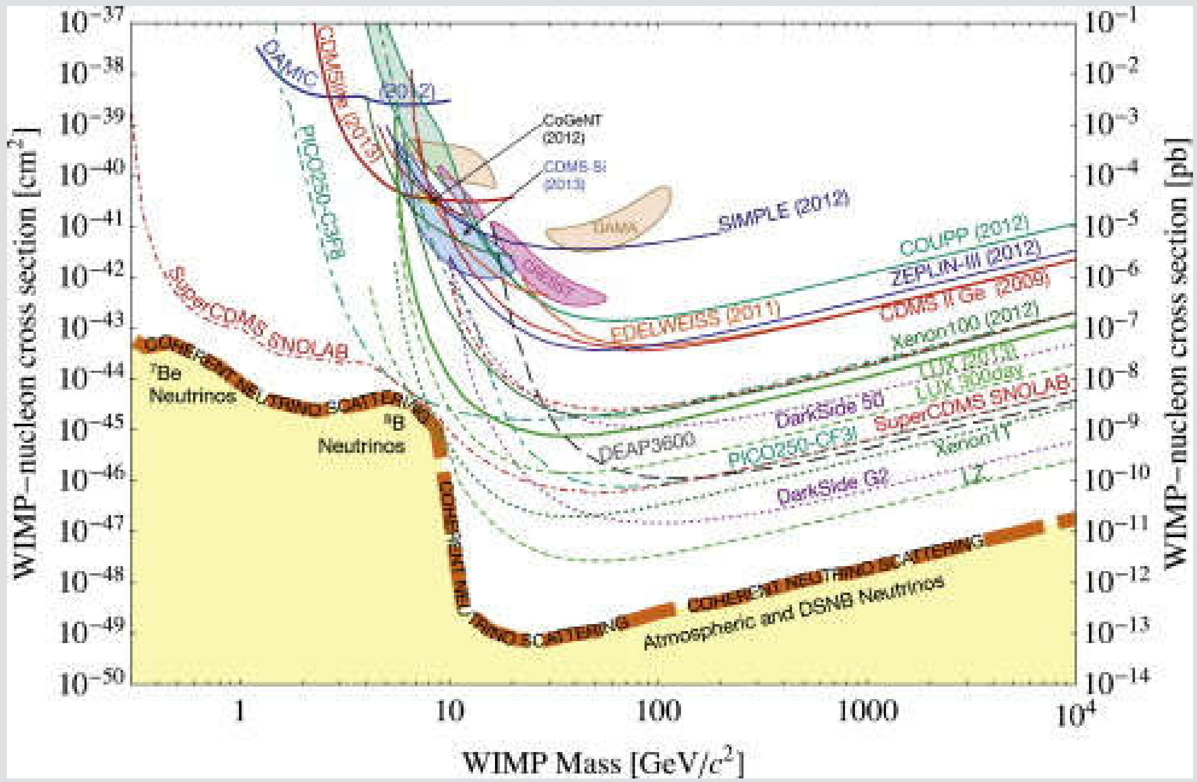
SN burst ν energy spectrum



CEvNS physics:

- Dark Matter: CEvNS from solar, atmospheric ν is irreducible background for O(10-ton) direct DM searches
- A CEvNS measurement test those background assumptions (in similar detectors)

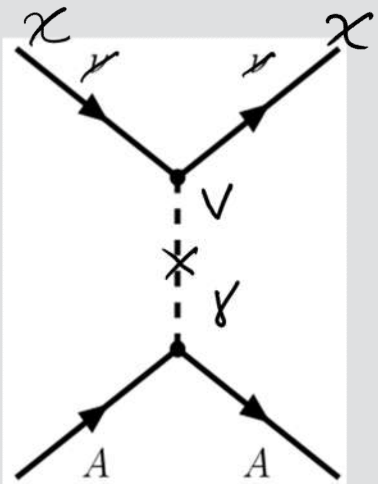




J. Billard, E. Figueroa-Feliciano, and L. Strigari, arXiv:1307.5458v2 (2013).

CEvNS physics:

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



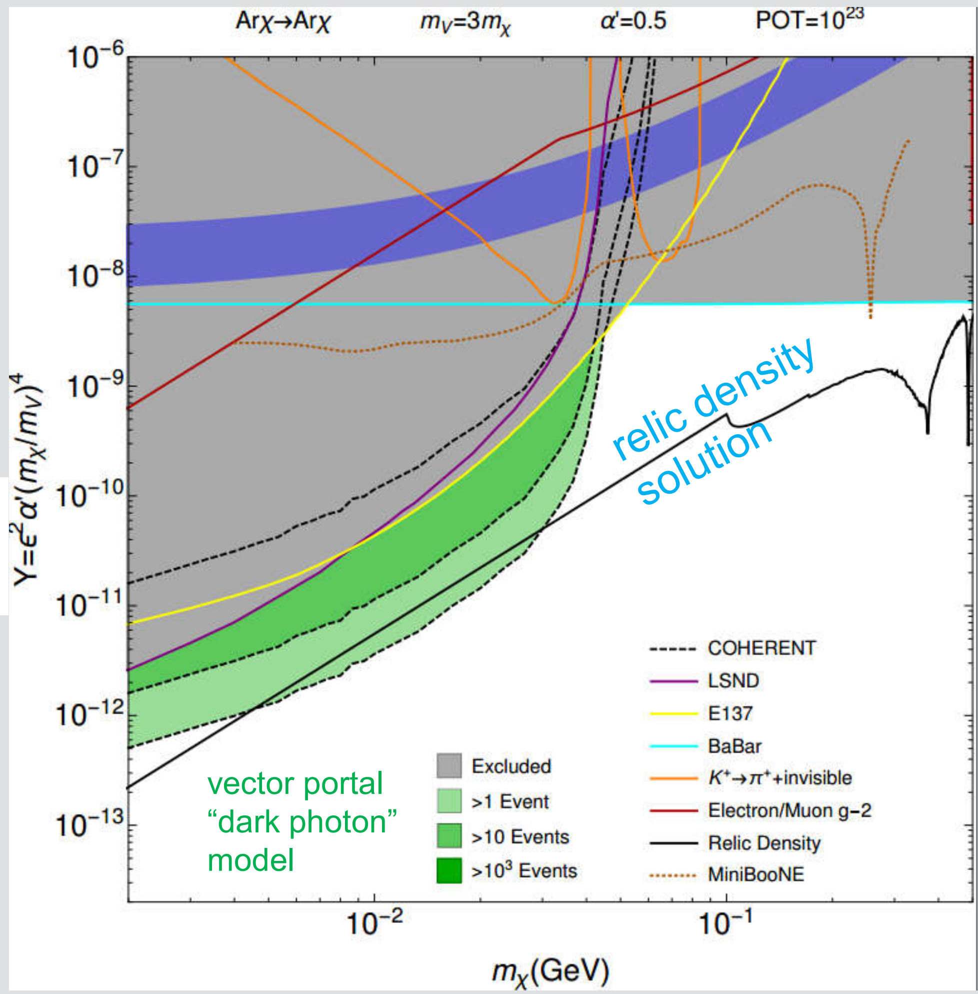
Light new physics in coherent neutrino-nucleus scattering experiments

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)

1 ton-year LAr SNS DM sensitivity



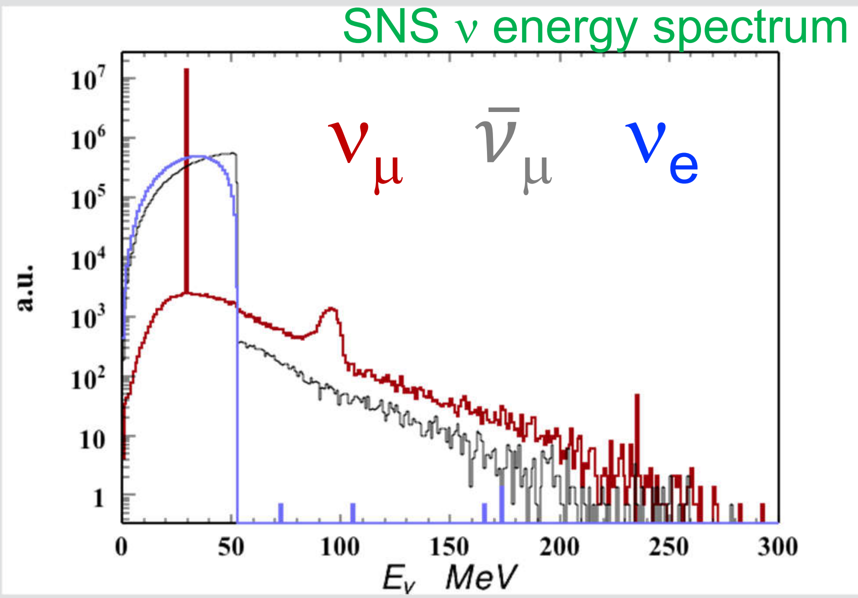
To realize these physics topics, require:

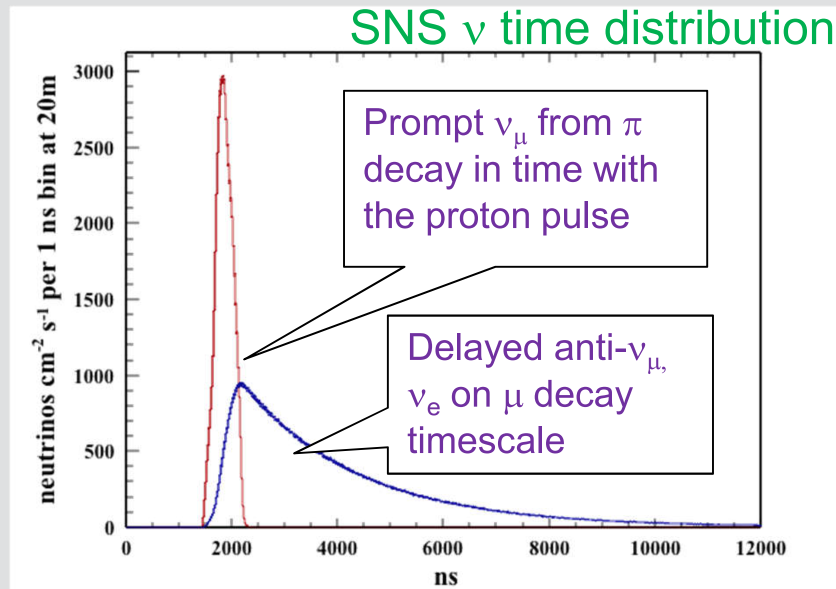
- intense ν source
- low bckgrd location
- low threshold detector(s)

COHERENT experiment at SNS/ORNL

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

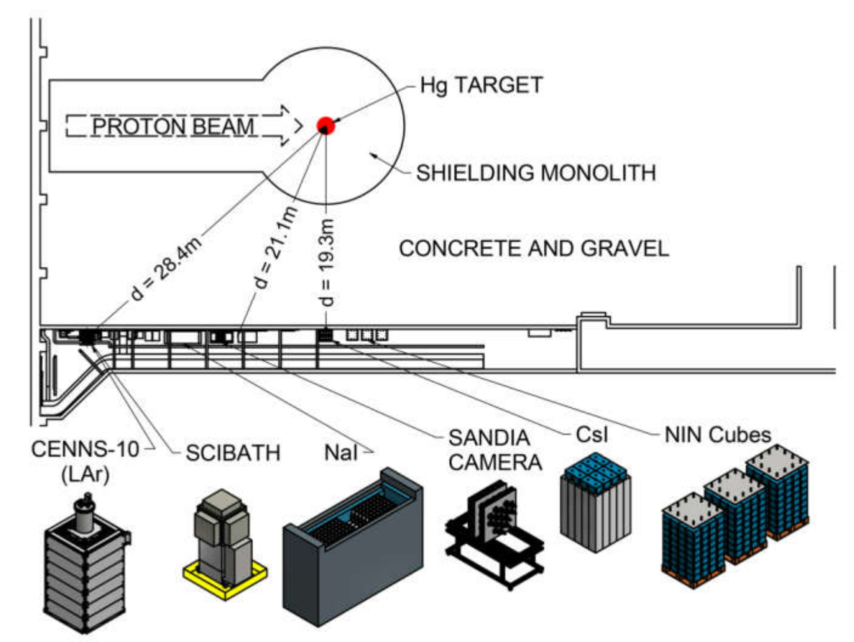
- intense proton beam (~1MW, 1 GeV)
- pulsed (60 Hz, 600ns spill time)…
- ~ 5000MWhr/year
- ~ 2E23 POT!

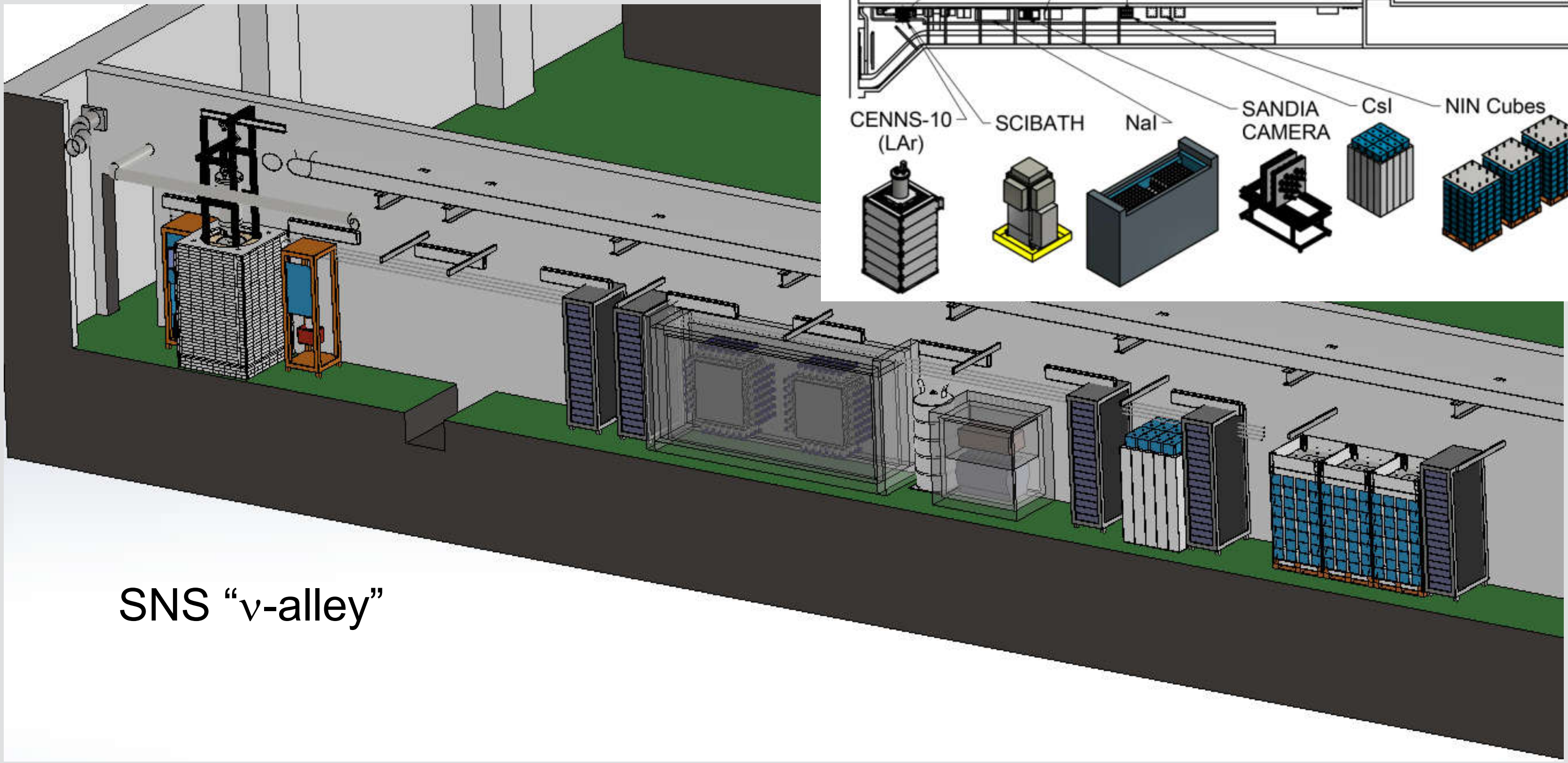




COHERENT experiment at SNS/ORNL

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





SNS "ν-alley"

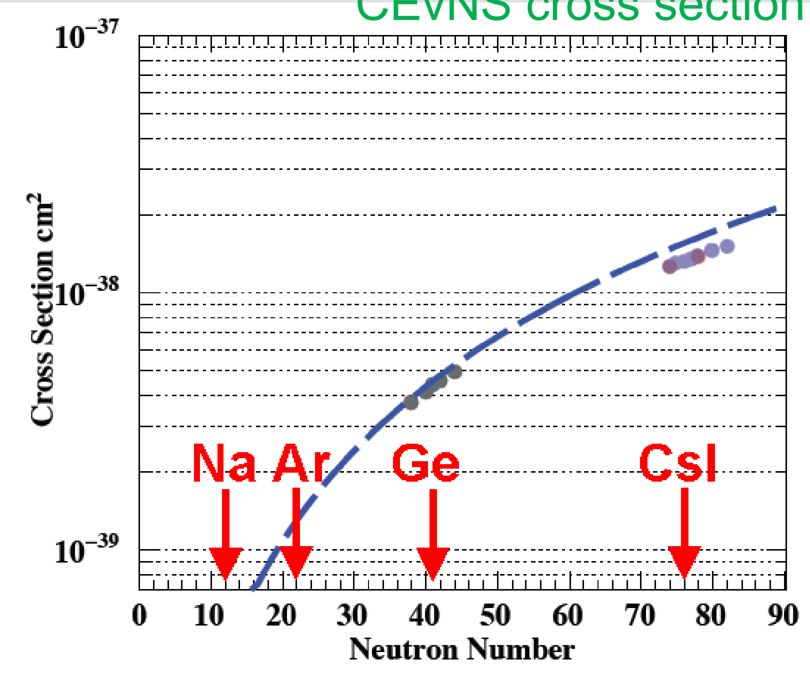
COHERENT experimental strategy at SNS/ORNL

Measure N^2 dependence of CEvNS process

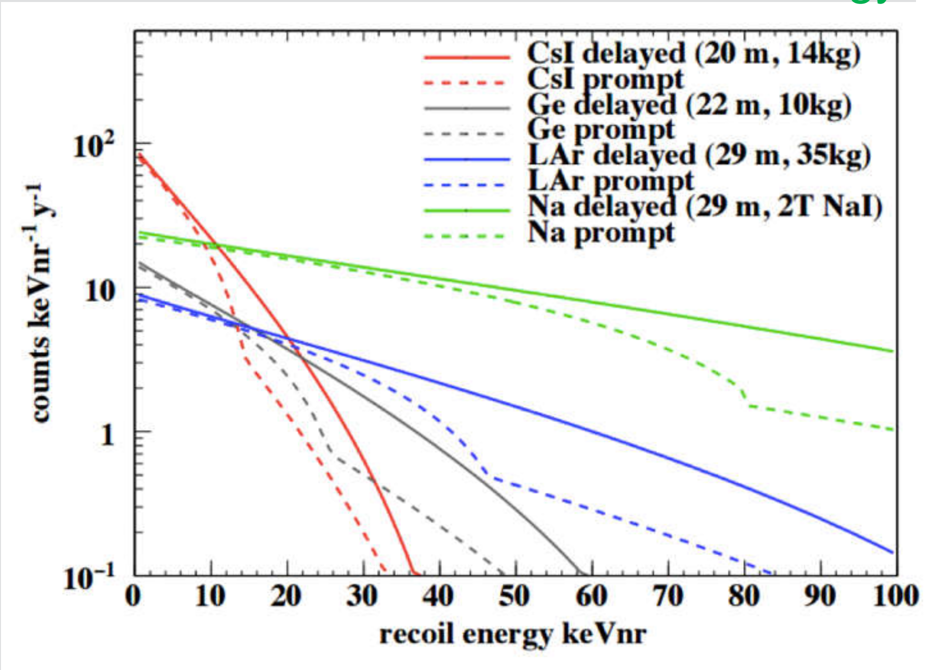
with multiple targets/detector technologies

- (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

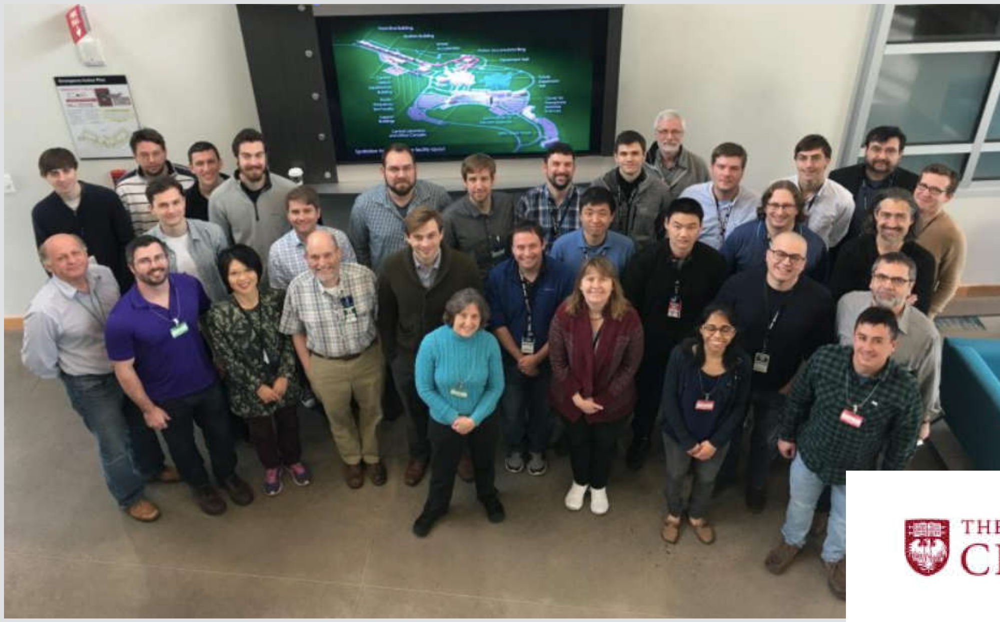


CEvNS recoil energy



The COHERENT collaboration

http://sites.duke.edu/coherent



~80 members,
18 institutions
4 countries

arXiv:1509.08702

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

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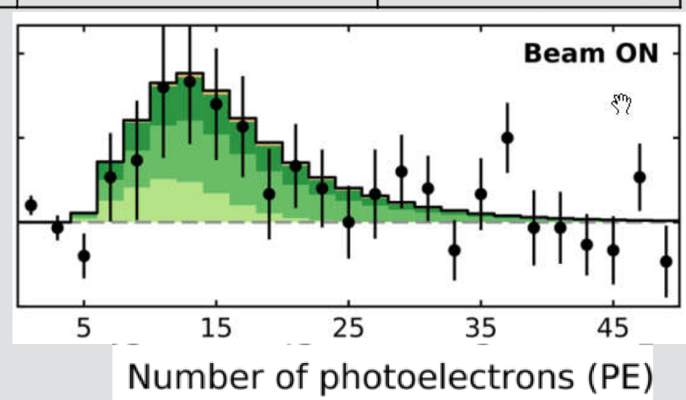
- recent observation of CEvNS
- D. Akimov *et al.*, *Science* 10.1126/science.aao0990 (2017)
- 134 ± 22 CEvNS events



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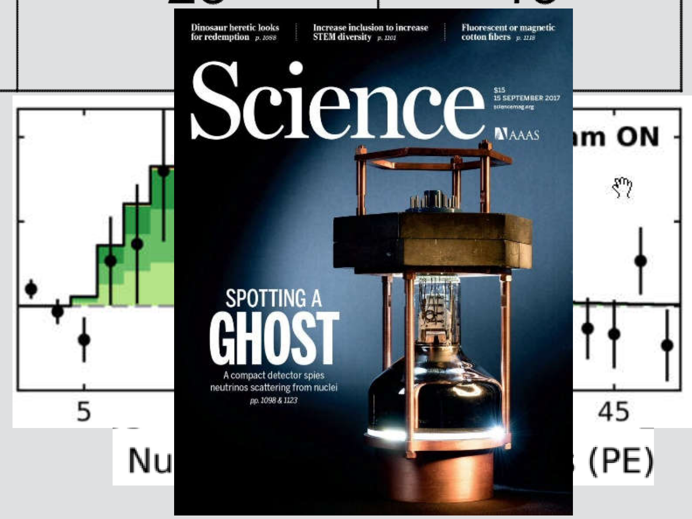


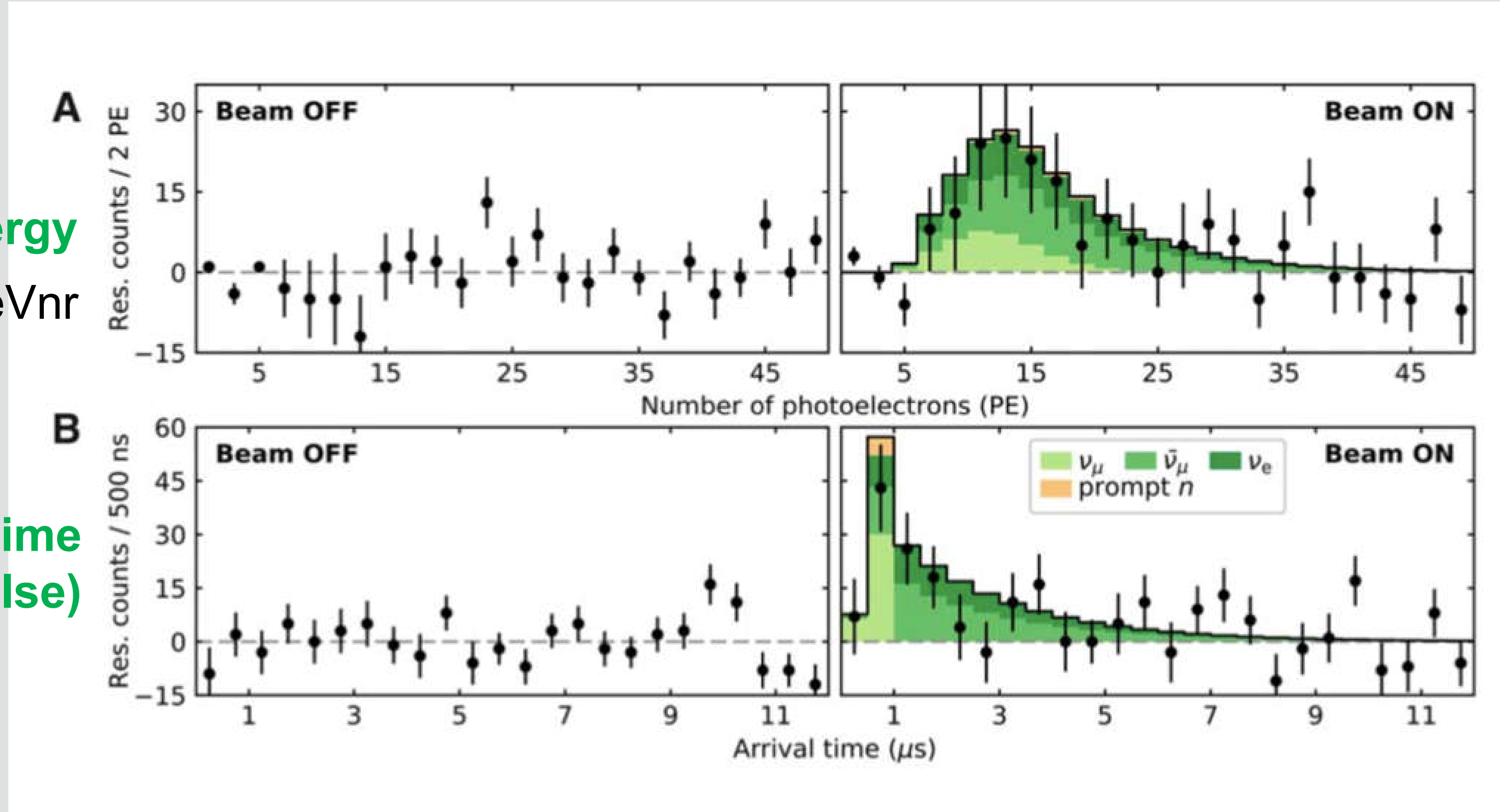
COHERENT, CsI results:

Steady-state-background subtracted data:

~Energy

~1.2 PE/keVnr

time
(wrt ν pulse)

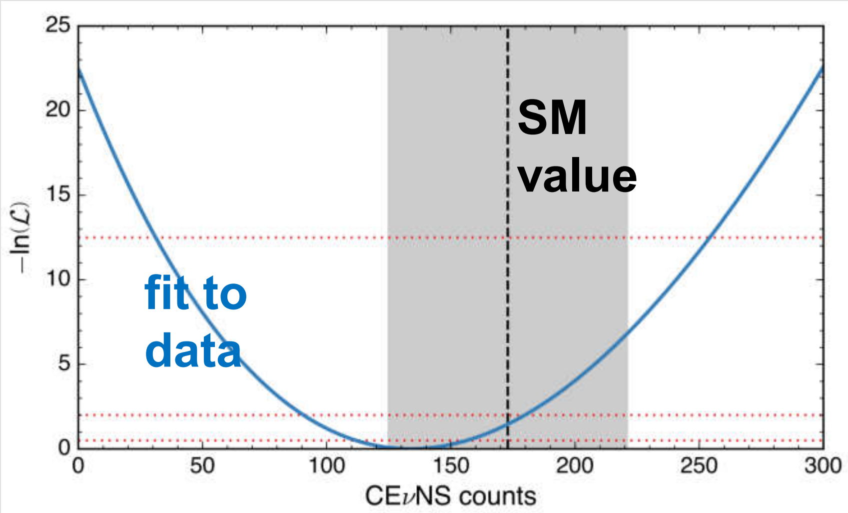


1.76 x10^{23} POT, 7.5 GWhr, ~1.5 SNS-yrs)

COHERENT, CsI results:

Likelihood analysis: 2D in energy (pe) and time

- best fit of data: 134 ± 22 CEvNS events
- SM prediction: 173 ± 48 CEvNS events
- Null hypothesis (=no CEvNS) rejected at 6.7σ
- consistent w/SM within 1σ



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, single-bin counting	136 ± 31
Signal counts, 2D likelihood fit	**134 ± 22**
Predicted SM signal counts	**173 ± 48**

$6 \leq PE \leq 30$, $0 \leq t \leq 6000$ ns

Uncertainties on signal and background predictions	
Event selection	5%
Flux	10%
Quenching factor	25%
Form factor	5%
Total uncertainty on signal	**28%**
Beam-on neutron background	25%

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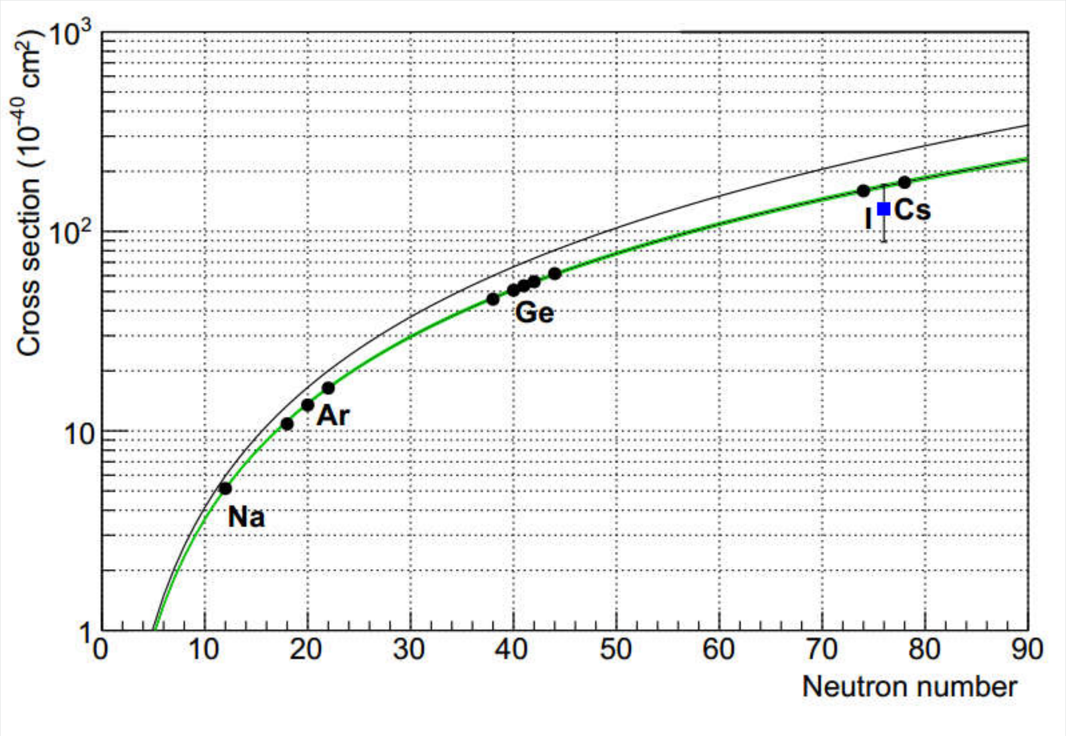

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- future

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- today

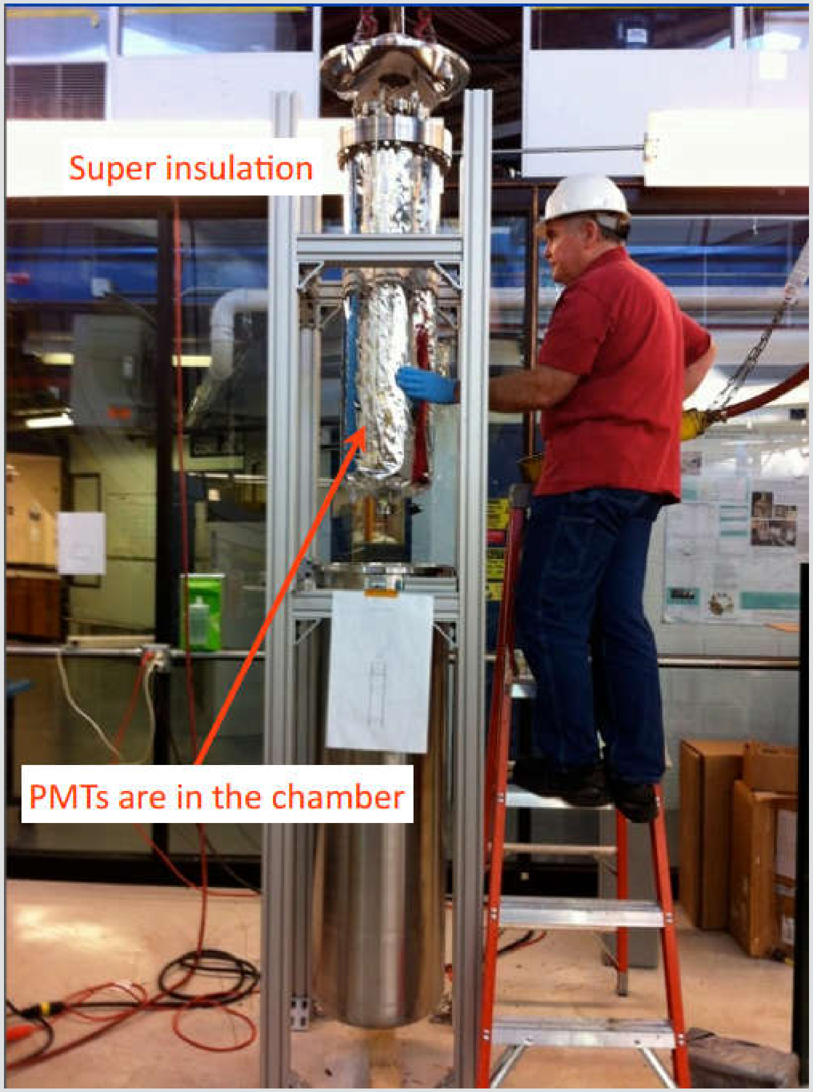
The CENNS-10 detector

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

- (2015) moved to Indiana U. for commissioning, upgrades, neutron tests

- (2016) installed at SNS for COHERENT



The CENNS-10 (LAr) Detector:

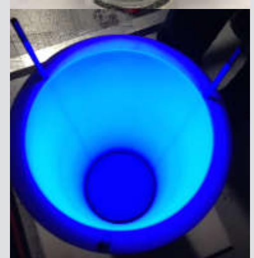
CENNS-10 SNS timeline:

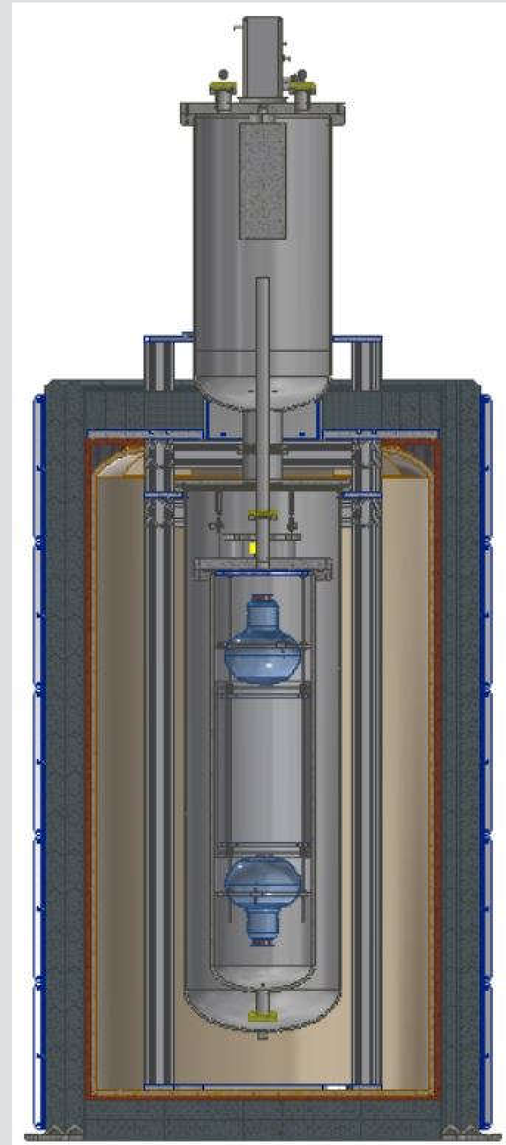
- 10-12/2016: (re)build detector at SNS

- 12/16, 3-5/17: run with TPB-acrylic parts, E_{thresh}~100keVnr
  "Spring17" data:
  CEvNS measurement not possible, will constrain beam-related bckgrds

- 6/17: upgrade: TPB-Teflon reflectors, new TPB-coated PMTs, added 4" Pb shielding

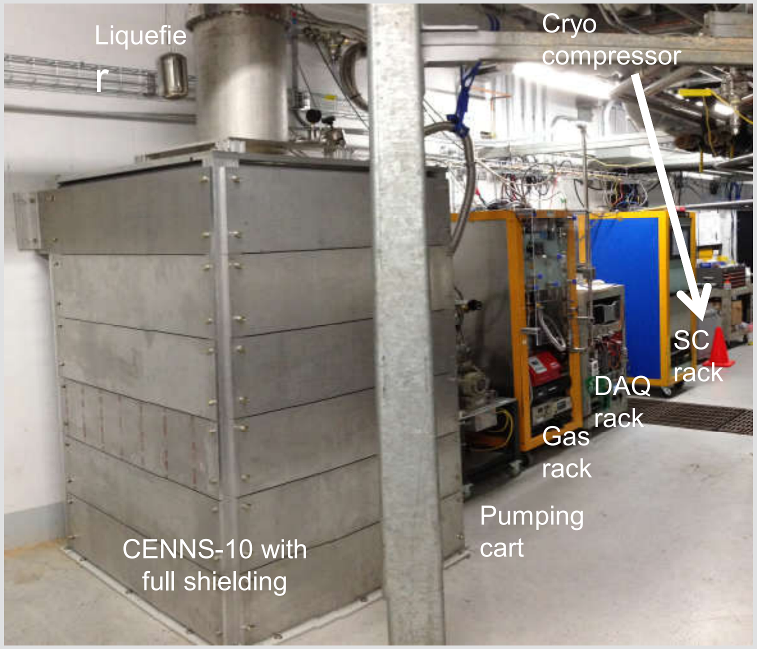
- 7/17-12/17: ran in upgraded mode, E_{thresh}~20keVnr
  "Summer17" data:
  2.8GWhr collected

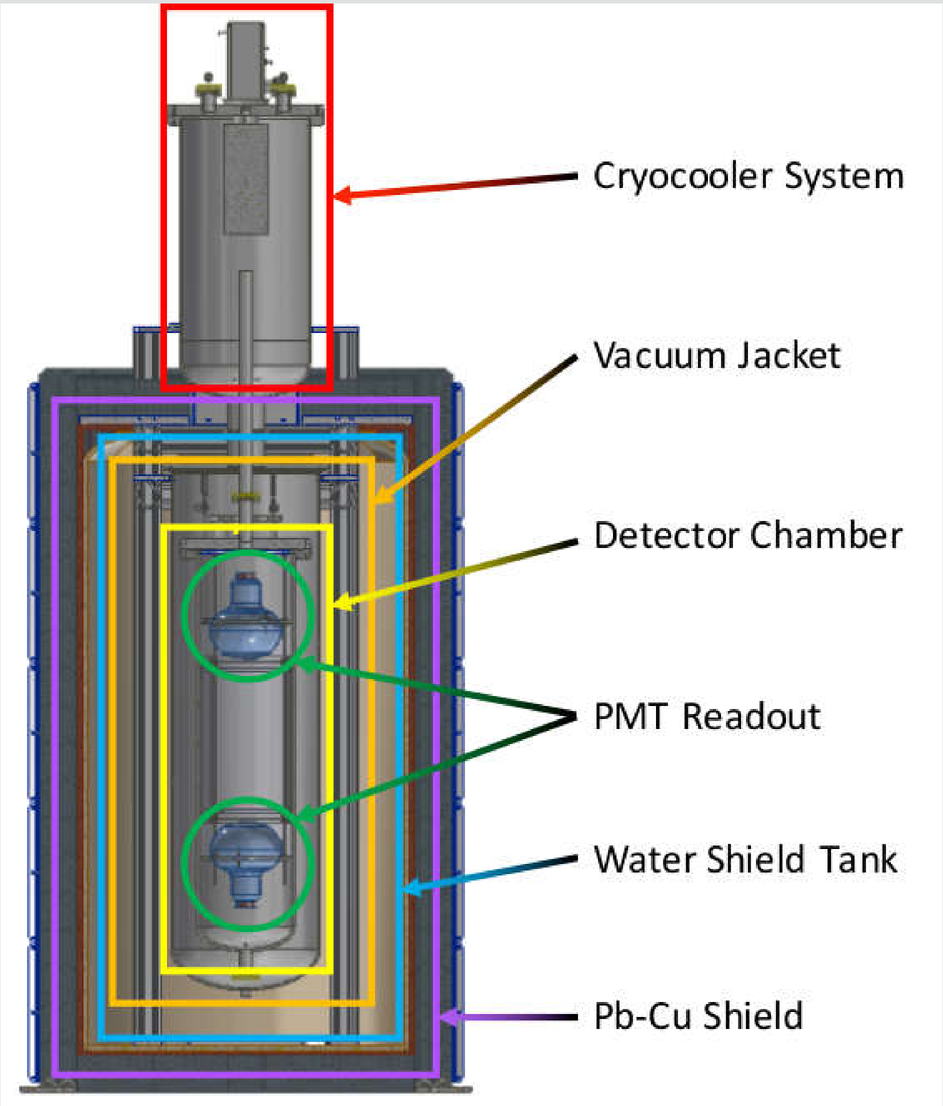




The CENNS-10 (LAr) Detector:

Specs:
- 22 kg LAr fiducial volume
- 2 × Hamamatsu 8”PMTs w/QE=18%@400 nm
- TPB-coated PMTs/teflon side walls
- Energy threshold ≈ 20keVnr
- CAEN 1420 (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

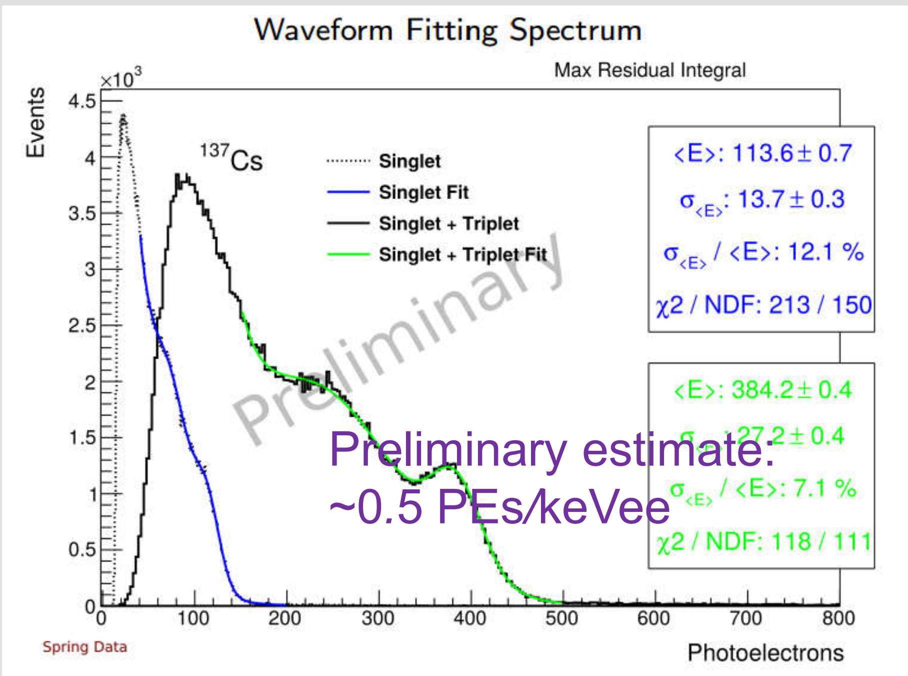




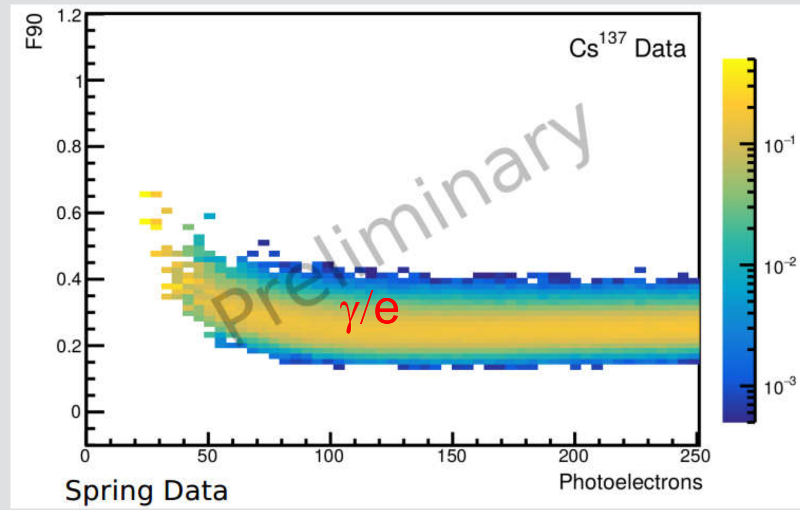
The CENNS-10 (LAr) Detector

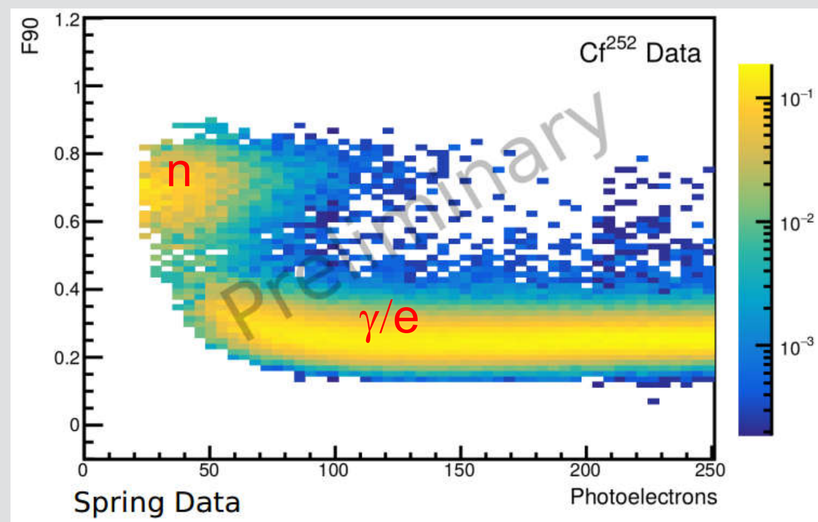
Preliminary data analysis: Spring17 data

137Cs spectrum



Preliminary estimate:
~0.5 PEs/keVee





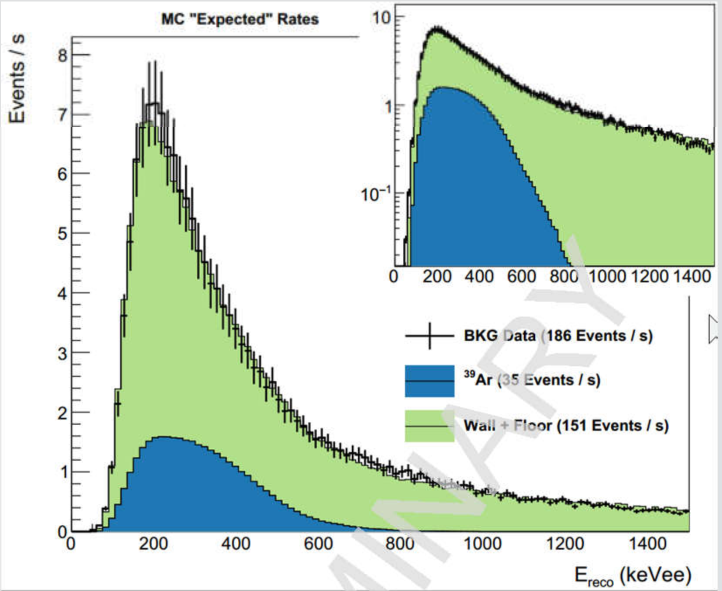
IU grad
Matt Heath's
analysis

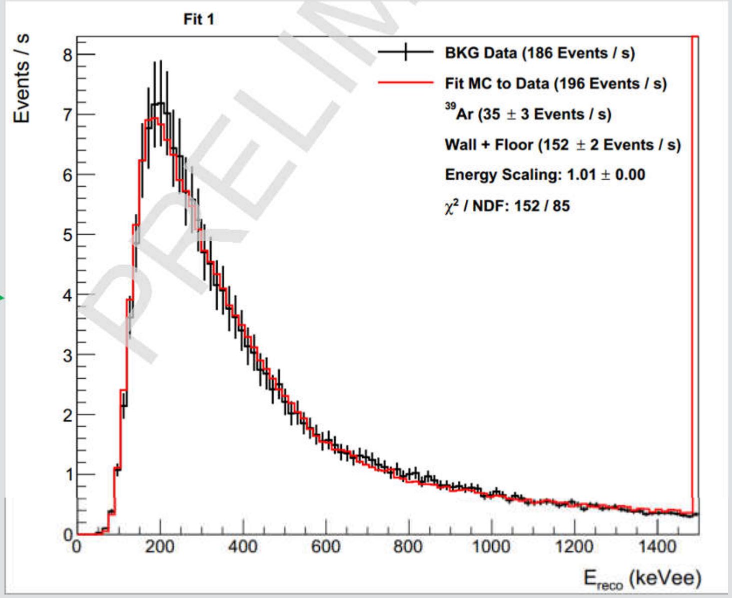
^{39}Ar in Spring '17 data:

- from CENNS-10, stage 1 config: TPB-acrylic sides, no Pb shielding, beam-off (lower 511keV γ rate)
- background-collection threshold ~100 keVee
- ~0.5 PE/keV $\Rightarrow$ E threshold ~ 80keVnr

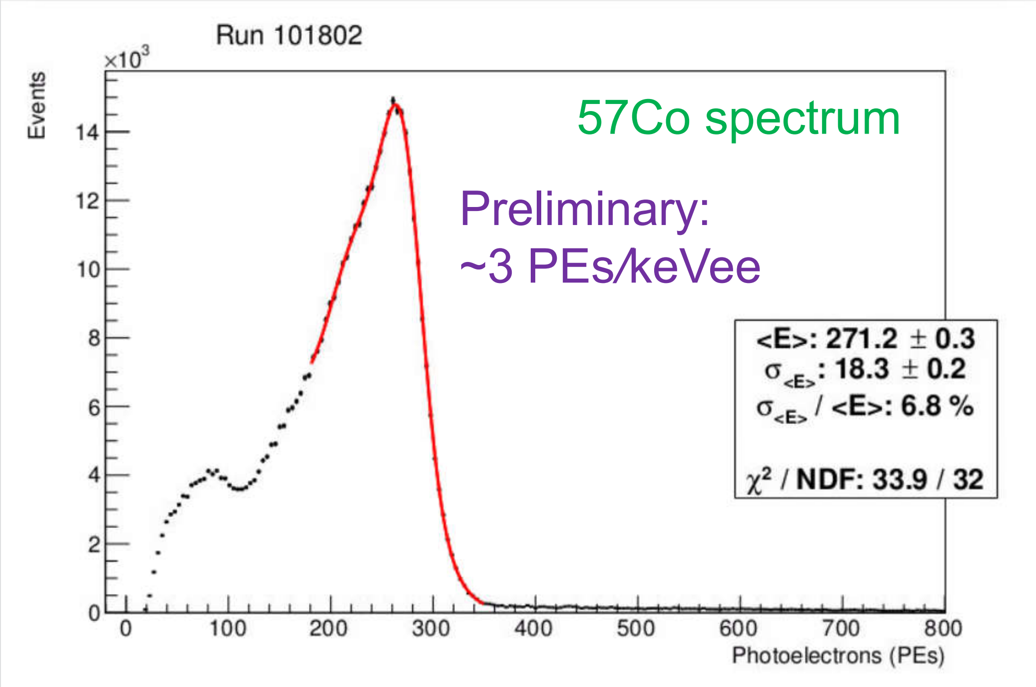
- comparison to expected rates from environmental γ measurements + 1 Bq/kg ^{39}Ar + detector/shielding MC, very good agreement to expected

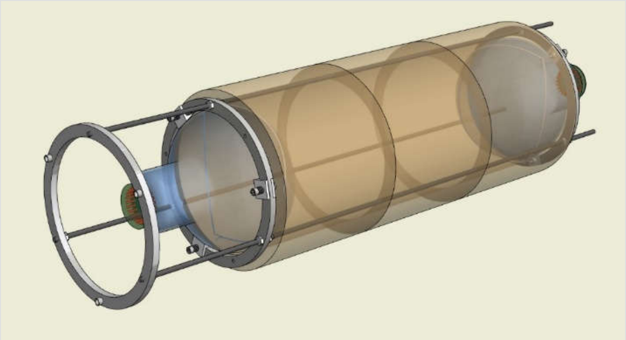
- fit with background allowed to float $\Rightarrow$ 1 Bq/kg ^{39}Ar $\pm$ 10%





Upgrade, in Summer'17 to get more light





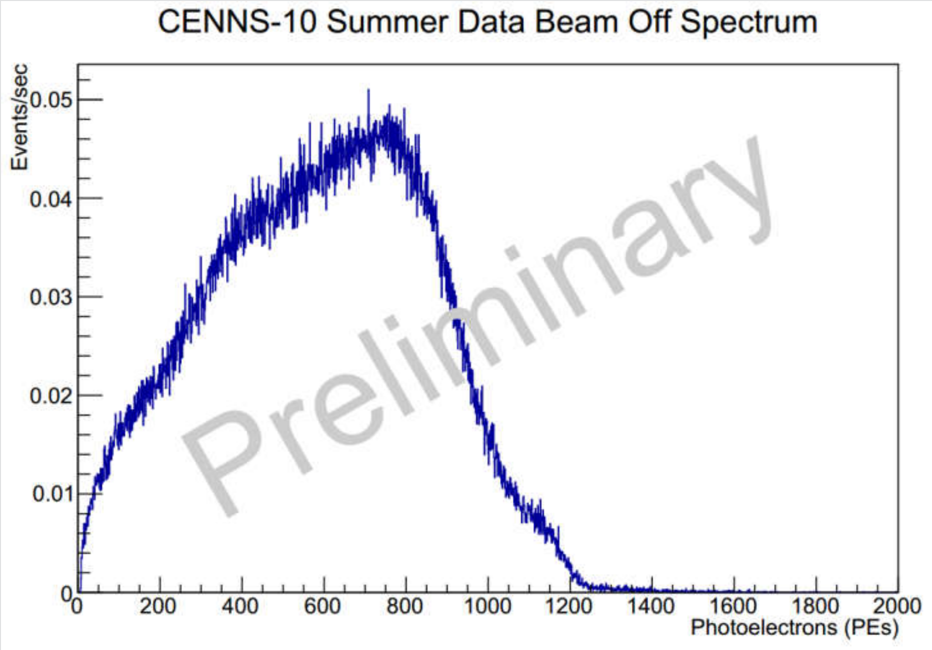
IU grad
Jacob Zettlemoyer's
analysis

^{39}Ar in Summer '17 data:

- from CENNS-10, upgraded config: TPB-Teflon sides, full Pb shielding, beam-off
- background-collection threshold ~20 keVee
- ~3 PE/keV $\Rightarrow$ E threshold ~ 20keVnr

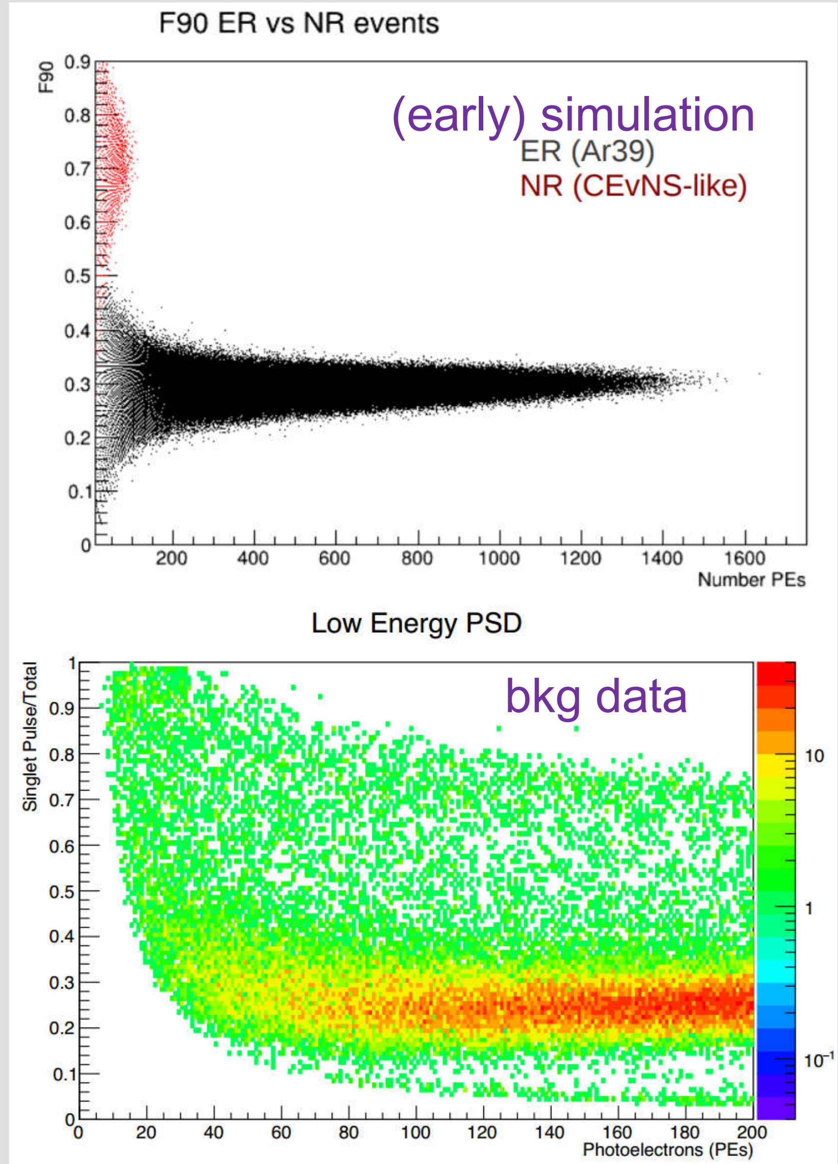
- observed spectrum consistent with ~1 Bq/kg, negligible envir. γ rate

- energy calibration, MC tuning, etc in progress



^{39}Ar in Summer '17 data:

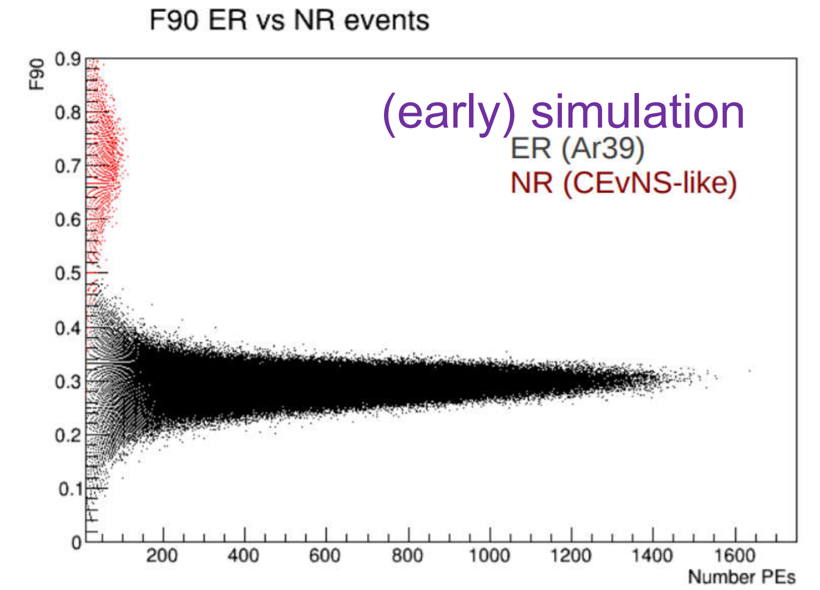
- PSD separates ^{39}Ar from CEvNS signal
- initial simulations show that separation is adequate and ^{39}Ar background can be completely suppressed.
- However, real events may prove more challenging and we are currently understanding that in the data

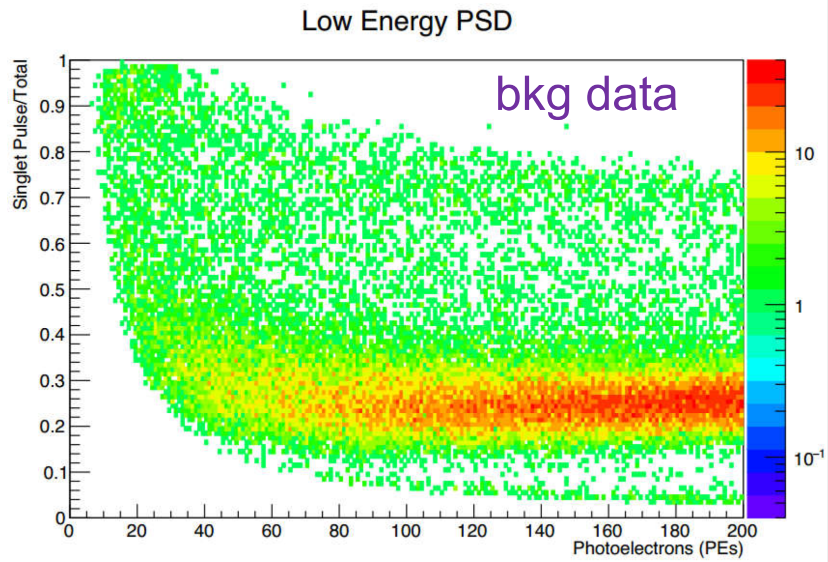


^{39}Ar in CEvNS data:

Some (rough) rate calculations:

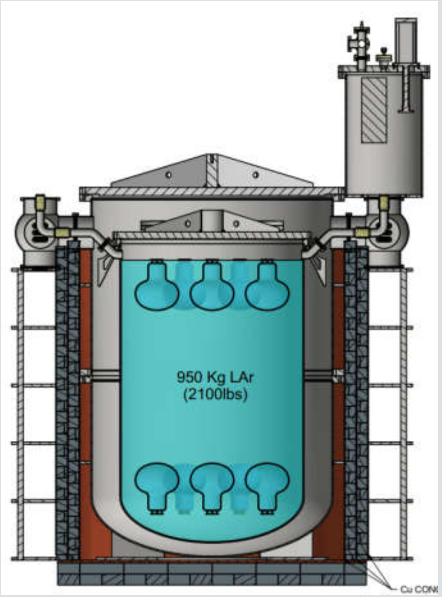
- 100 CEvNS events/ SNS yr in 20kg with 20 keVnr threshold
- beam-on livetime = 200 mins (10μs window x 60 Hz)
- 1Bq/kg 39Ar $\Rightarrow$
  240k events in 1 SNS-yr
  ~50k in ROI (20-200 PE)
- reduce to 500 evs backgnd (as with CsI data set)
- then PSD requirements are:
  - atmos. Ar: 1% leakage
  - underground Ar w/20x reduction, 20% leakage allowed
  - if 100x ^{39}Ar suppression, then S:B = 5:1 before any PSD
- A powerful improvement, esp with larger detectors!

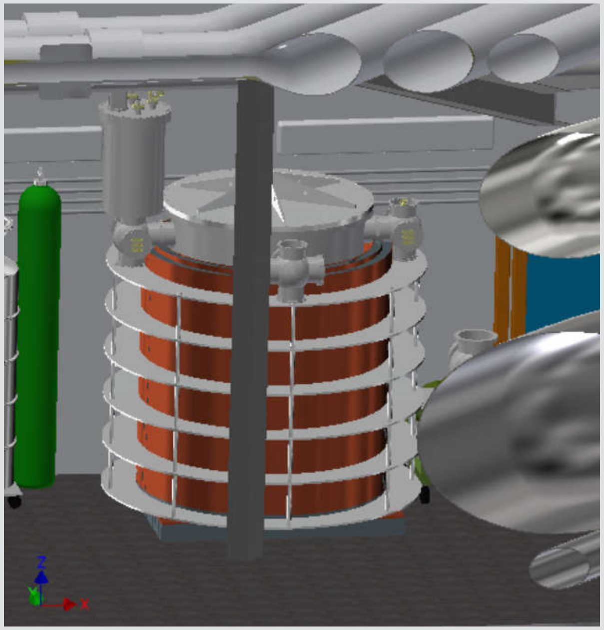




Future for LAr w/COHERENT

- summer '17 data set (7-12/17)
  should provide 1st CEvNS LAr signal
- currently in 5-month shutdown: ^{83}Kr calibration + misc improvements, will run CENNS-10, 2018-19
- working on proposal for larger detector(s) w/
  - O(1 ton) LAr
  - depleted Ar
  - LXe, LNe

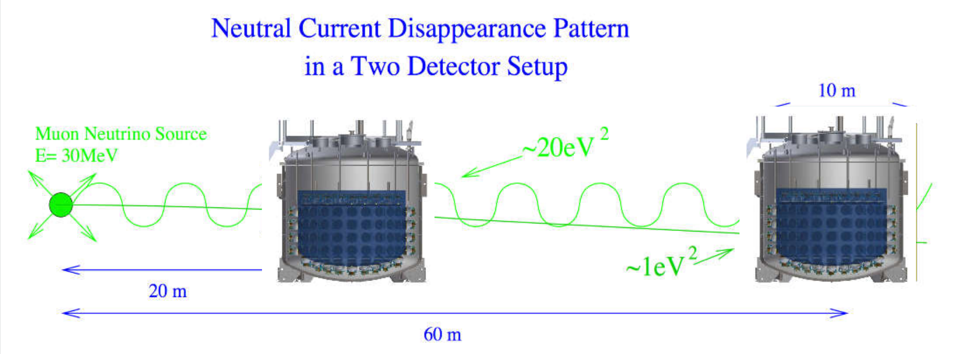




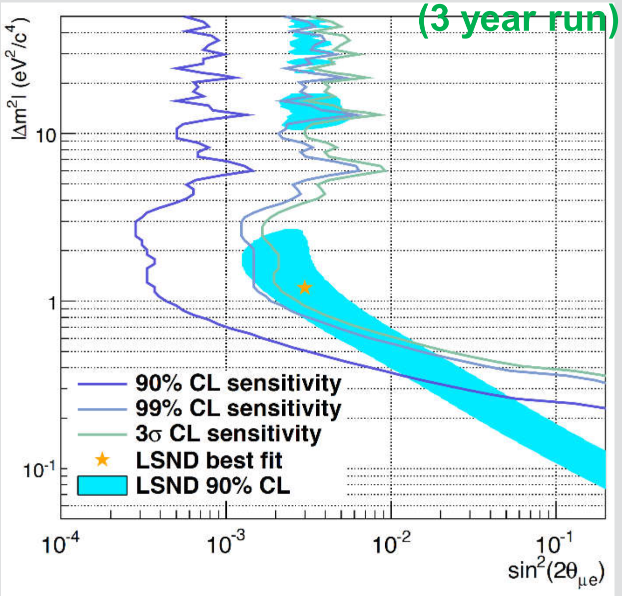
Another effort with LAr for CEvNS detection

CAPTAIN-MILLS at
LANL-Lujan neutron source:

- 7 ton fiducial LAr volume
- initial tests summer ‘18
- underground Ar highly desirable



3+1 Sterile Neutrino Oscillation Fits
(3 year run)

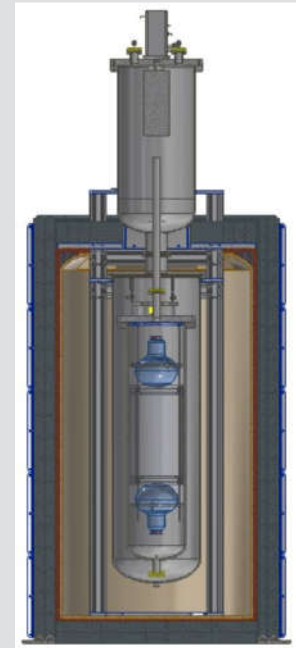


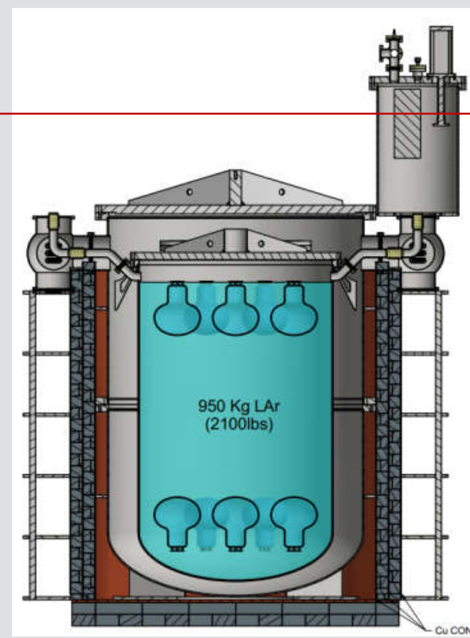
Summary of possible underground LAr for CEvNS

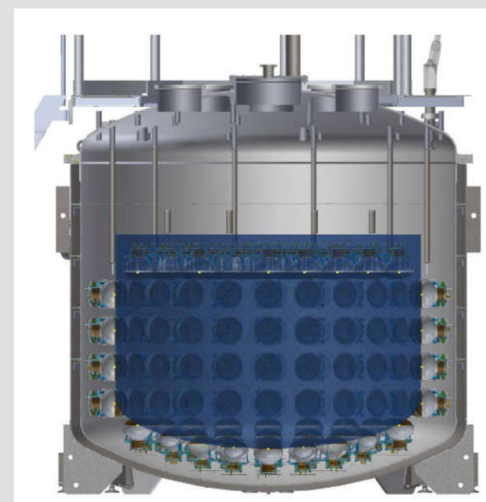
- for π DAR ν sources (eg: SNS, LANL)
  20-100x ^{39}Ar is desireable

- Timescale/quantities req'd for program described here:
  - 2019: ~100kg for CENNS-10 at SNS/COHERENT
  - 2020: ~1 t for new LAr detector at SNS/COHERENT
  - 2020: ~10 t for CAPTAIN-MILLS at LANL/Lujan

Would enable background-free* CEvNS measurements!
* (beam-unrelated)







LOW-RADIOACTIVITY UNDERGROUND ARGON

Low-Radioactivity Underground Argon Workshop

19-20 March 2018
Pacific Northwest National Laboratory

PNNL Underground Argon workshop
R. Tayloe, Indiana U.
for the COHERENT collaboration

CEvNS with a liquid argon scintillation detector

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. 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, performance, and backgrounds of the CENNS-10 detector will be presented.