Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

SAND2018-11502 C

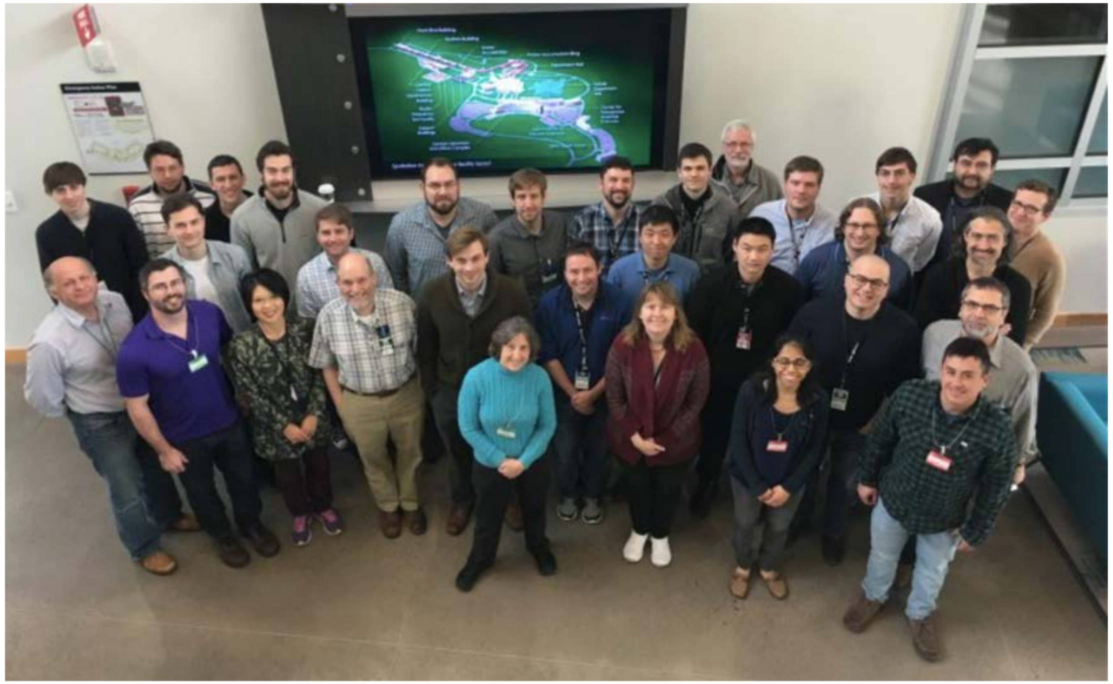
Belkis Cabrera-Palmer, Sandia National Laboratories
On behalf of the COHERENT collaboration

October 11, 2018

Applied Antineutrino Physics 2018

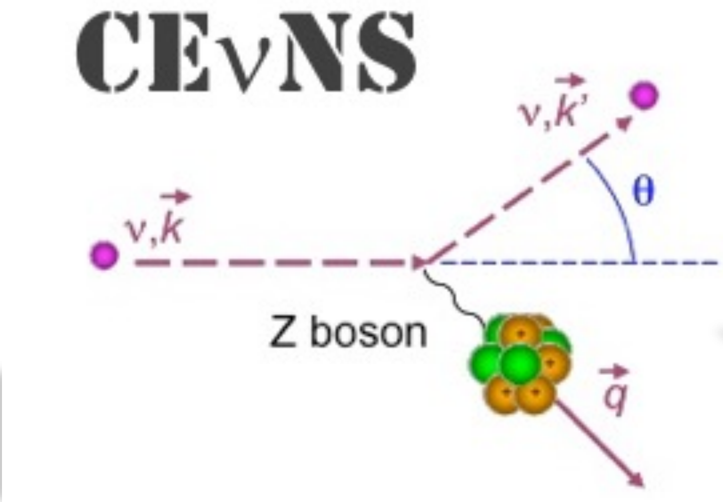
The COHERENT collaboration

http://sites.duke.edu/coherent



~80 members, 21 institutions, 4 countries

Coherent elastic neutrino-nucleus scattering



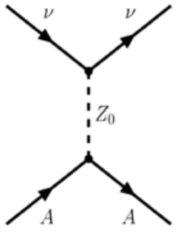
PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

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)

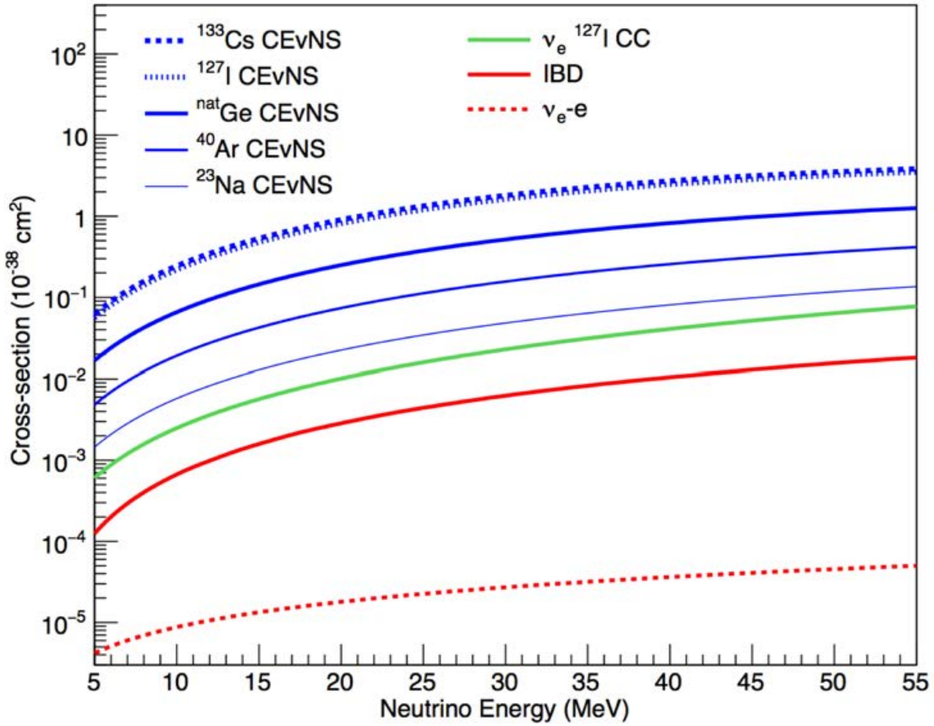
. . . The idea is very simple: If there is a weak neutral current, elastic neutrino-nucleus scattering should exhibit a sharp coherent forward peak characteristic of the size of the target just as electron-nucleus elastic scattering does. . .

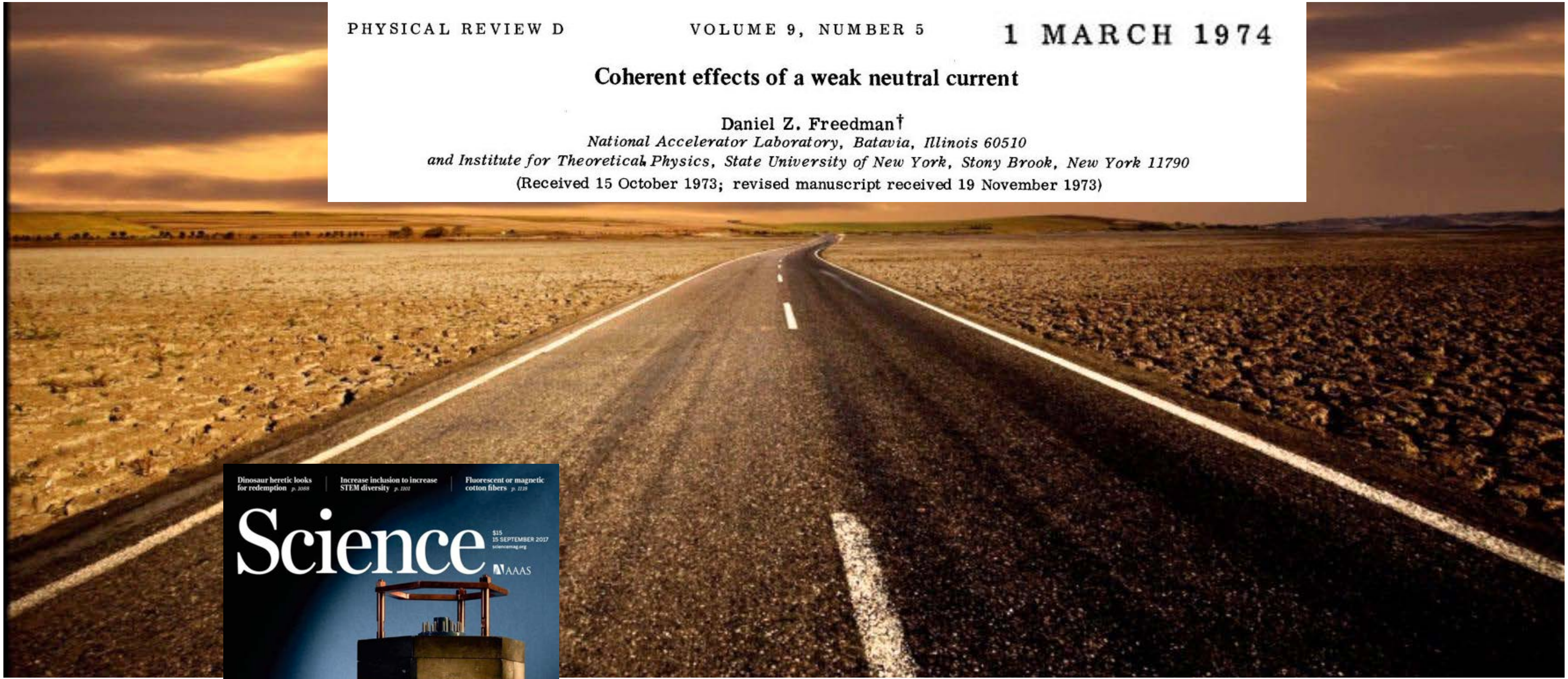
- Condition for coherence: low momentum transfer ***q*** << 1/(nucleus radius), effectively bounds neutrino energies E_ν<~ 50 MeV
- Largest of all Standard Model low-energy neutrino interaction cross-sections, enhanced by N^2



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

- Flavor blind: any neutrino can do it.





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)

SUMMER 2017:
First observation

What makes CEνNS interesting?

For the Neutrino Physics community:

- Non-standard Neutrino Interactions

P. Coloma et al., JHEP 12 021 (2005)
K. Scholberg, PRD 73 033005 (2006)
J. Barranco et al., PRD 76 073008 (2007)
P. Coloma, T. Schwetz, PRD 94 055005 (2016)
M. Masud, P. Mehta, arxiv:1603.01389 (2016)

- Neutron distribution functions

K. Patton et al., PRC 86, 024216 (2012)

- Sensitive tool for Sterile neutrino searches

A.J. Anderson et al., PRD86 013004 (2012)
A. Drukier & L. Stodolsky, PRD 30 2295 (1984)

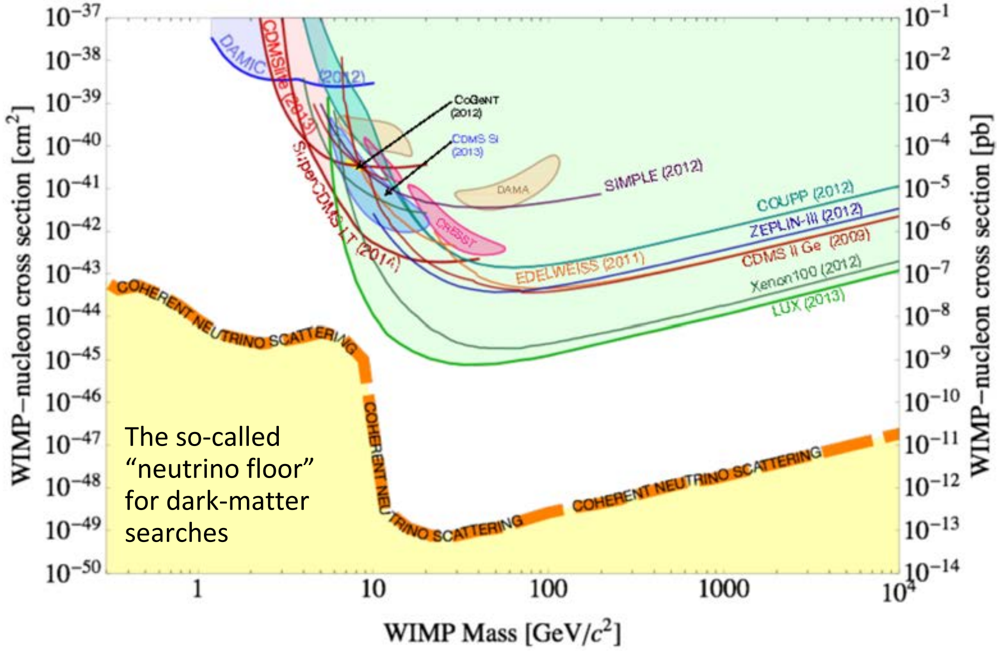
- Neutrino Magnetic Moments

A. C. Dodd, et al,. PLB 266 (91), 434

What makes CEνNS interesting?

Beyond the Neutrino Physics community:

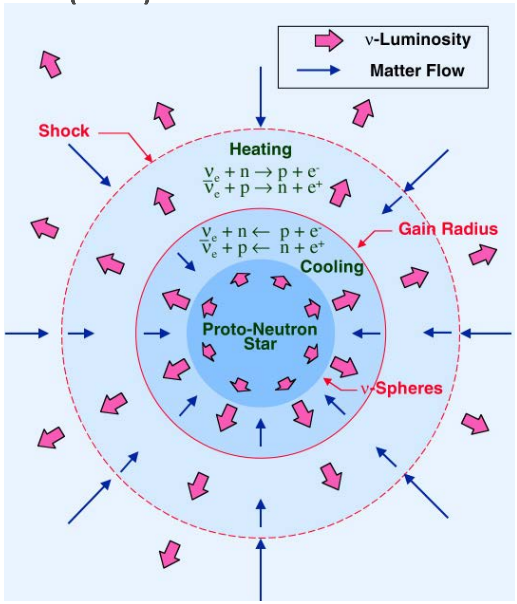
- Irreducible background for WIMP searches



Measure CEνNS to understand nature of background
(& detector response, DM interaction)

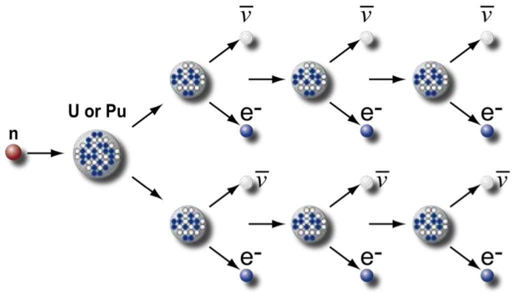
- Major role in Supernovae dynamics

J.R. Wilson, PRL 34 113 (1974)
D.N. Schramm, W.D. Arnett, PRL 34, 113 (1975)

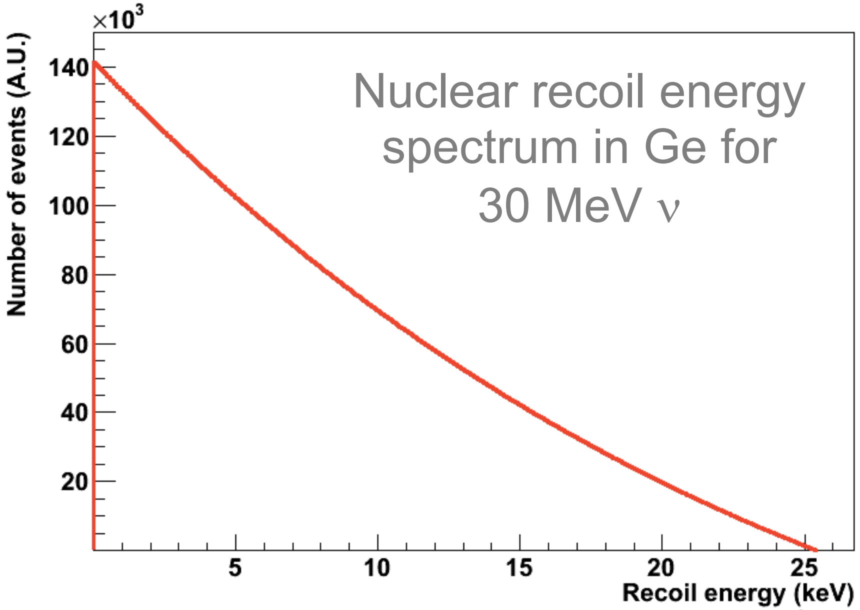


- Astrophysical signals (solar and SN)

- Potential application in reactor monitoring

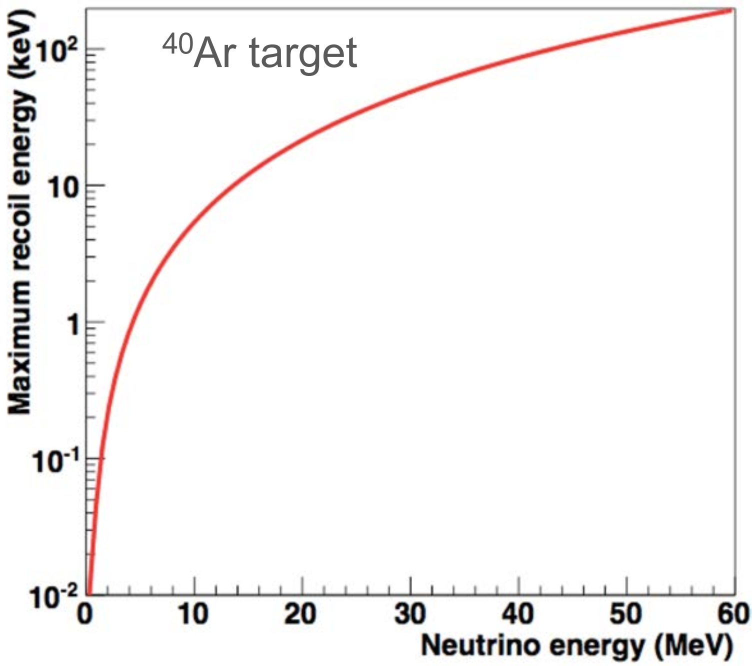


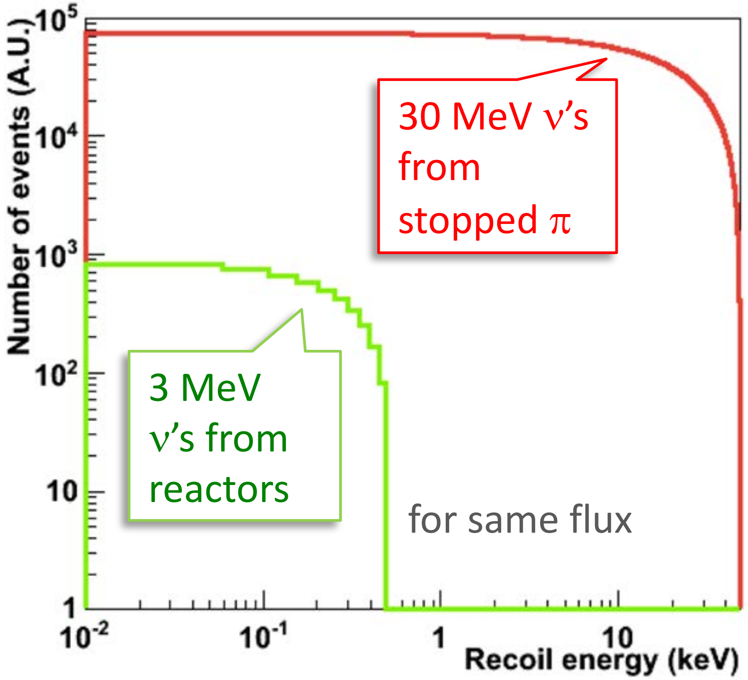
CEνNS signature: low-energy nuclear recoils



Maximum recoil energy for Ge is $\frac{2}{A}\left[\frac{E_{\nu}}{1MeV}\right]^{2} keV \sim 25\ keV$

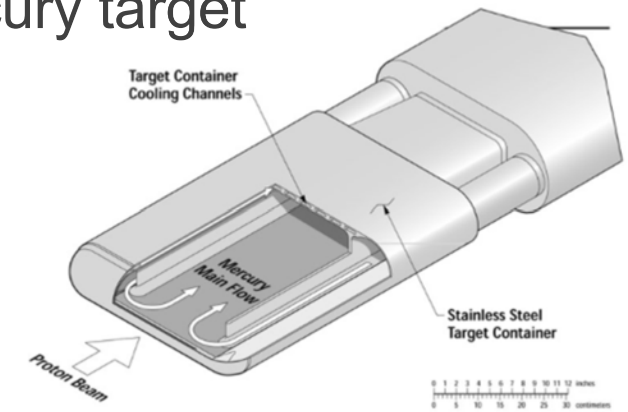
- Both CEνNS cross-section and maximum recoil energy increase with neutrino energy.
- Want energy as large as possible while satisfying coherence condition: $q \lesssim \frac{1}{R}$

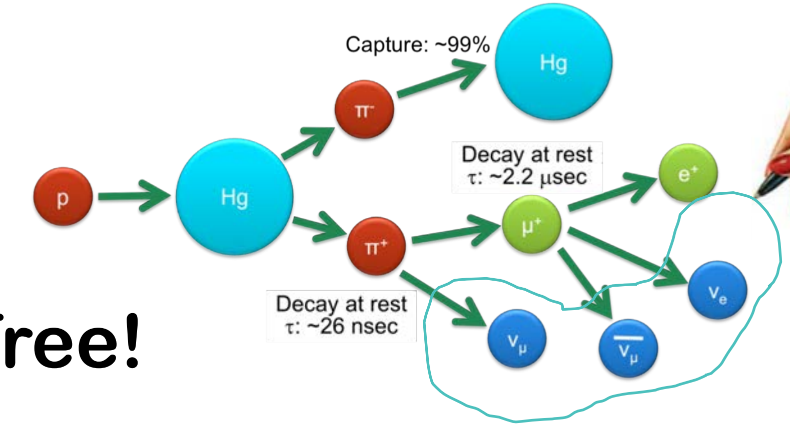




Spallation Neutron Source as a Neutrino Source

Proton beam energy: 0.9-1.3 GeV
Total power: 0.9-1.4 MW
Pulse duration: 380 ns FWHM
Repetition rate: 60 Hz
Liquid mercury target





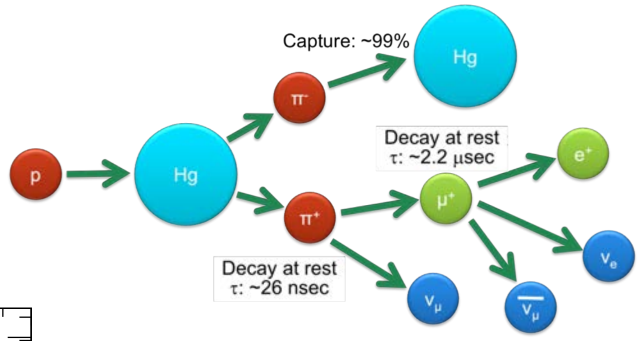
The neutrinos are free!

Neutrinos at the SNS

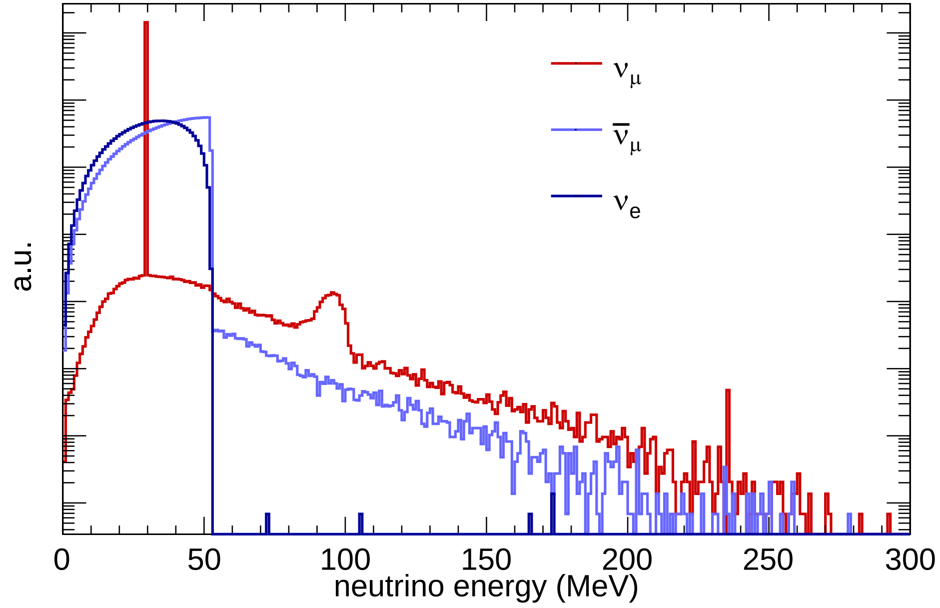
- Decay-at-Rest Neutrino source
- ν flux 4.3×10^7 ν cm^{-2} s^{-1} at 20 m
- Pulses 800 ns full-width at 60 Hz

$\pi^+ \rightarrow \mu^+ + \nu_\mu$ PROMPT: monochromatic 29.9 MeV ν_μ

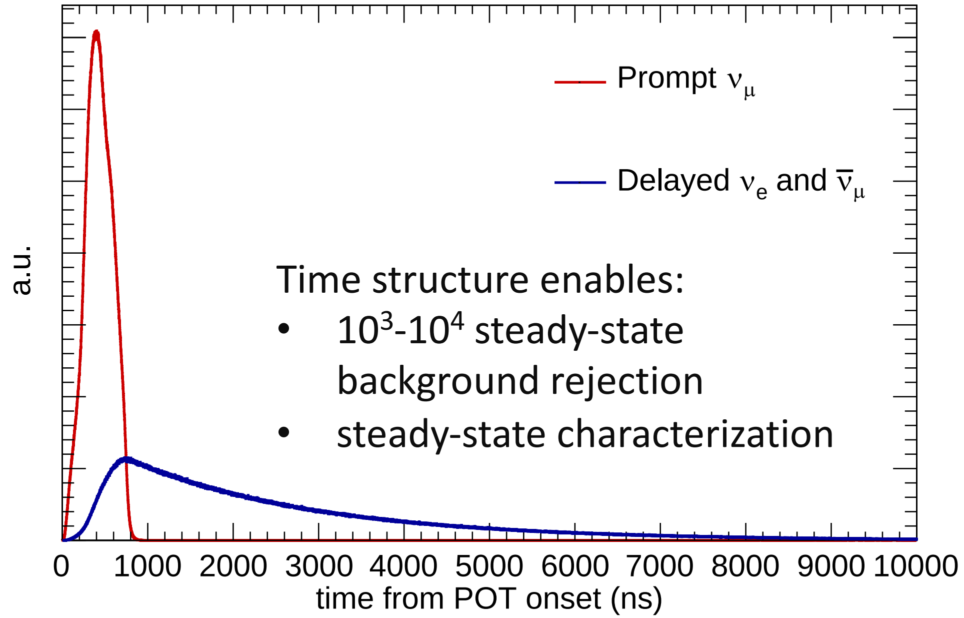
$\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e$ DELAYED (2.2 μs): range of energies between 0 and $m_\mu/2$



Neutrino energy



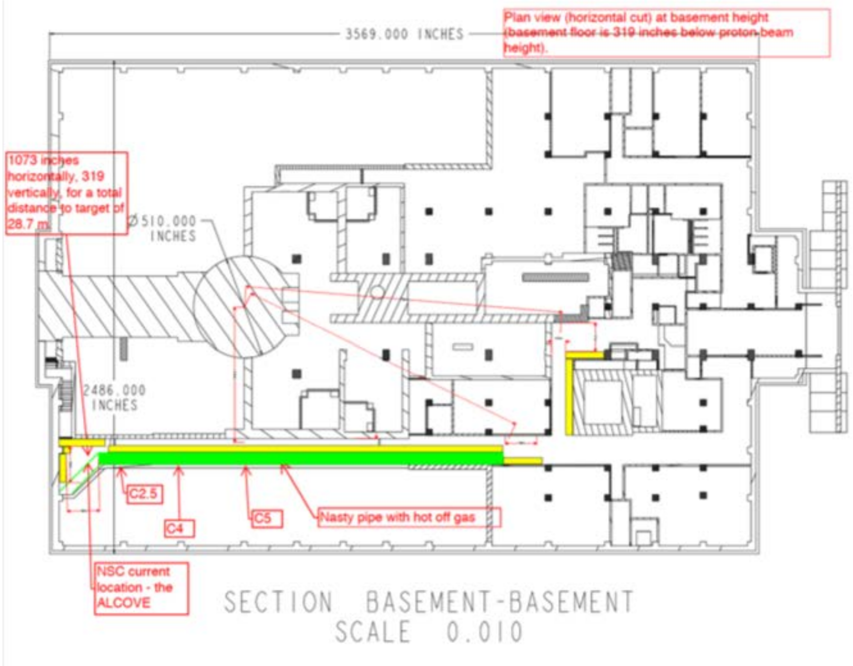
Timing energy

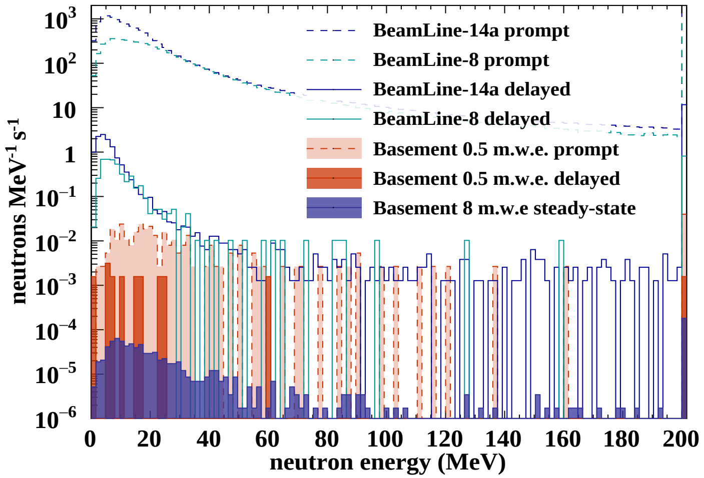


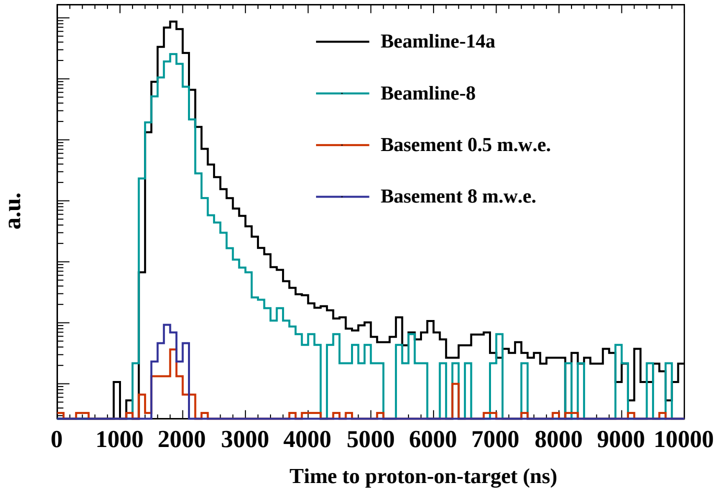
Time structure enables:
- 10^3-10^4 steady-state background rejection
- steady-state characterization

Neutrino Alley

- **Quiet basement location**: extensive BG program determined that intermediate energy (10-100 MeV) beam neutron rates are ~5 orders of magnitude lower than on the experimental hall.
- Steady-state background rate also lower due to ~ 8 m.w.e. overburden.
- Alley is 20-30 meters from the target.

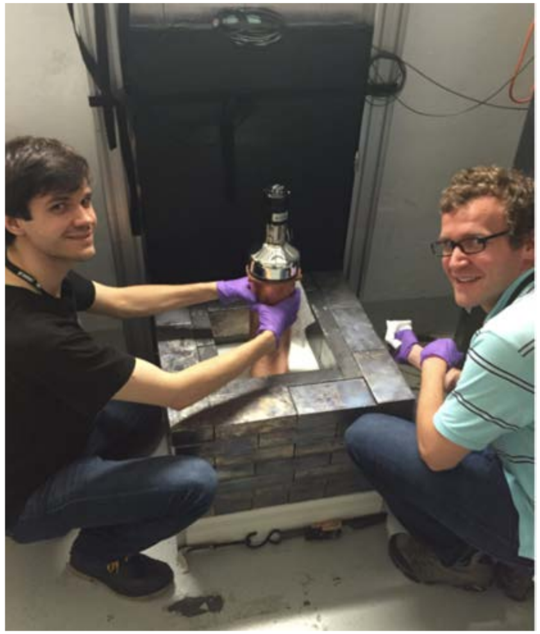


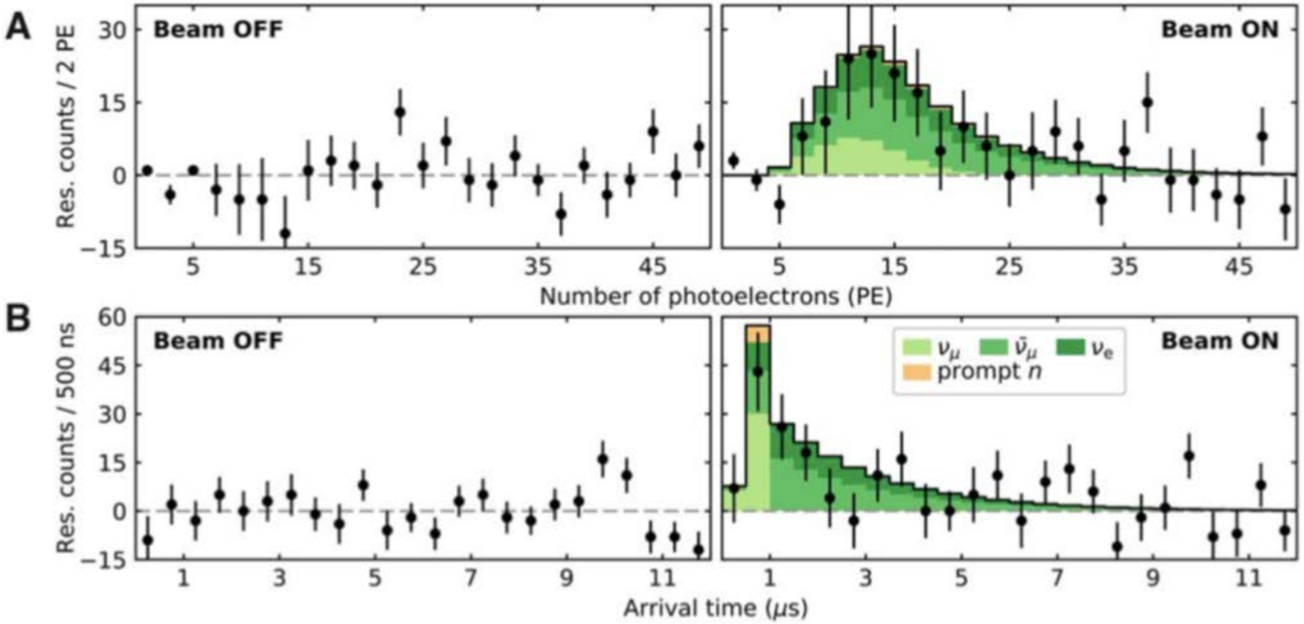




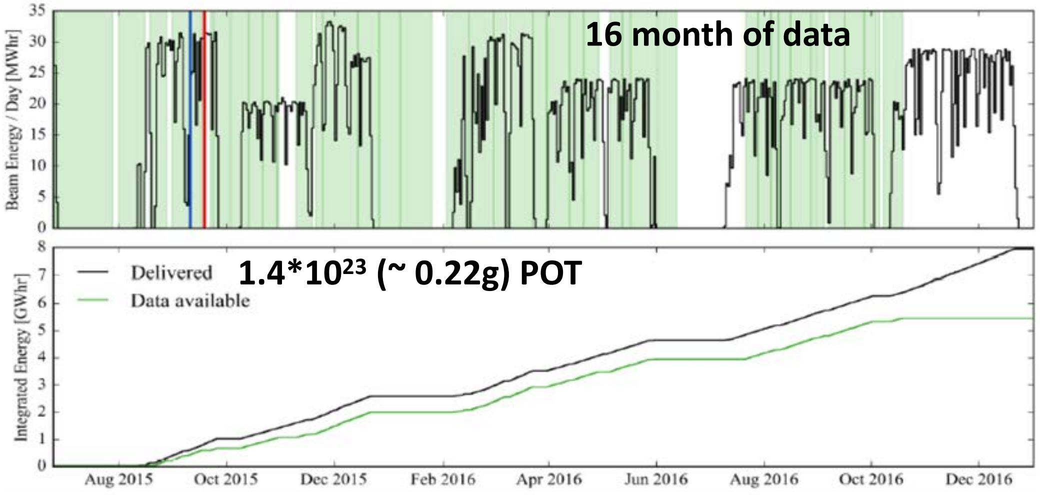
Neutron measurement data from various SNS locations.

First CEνNS observation with 14.6-kg CsI[Na]





August 2017

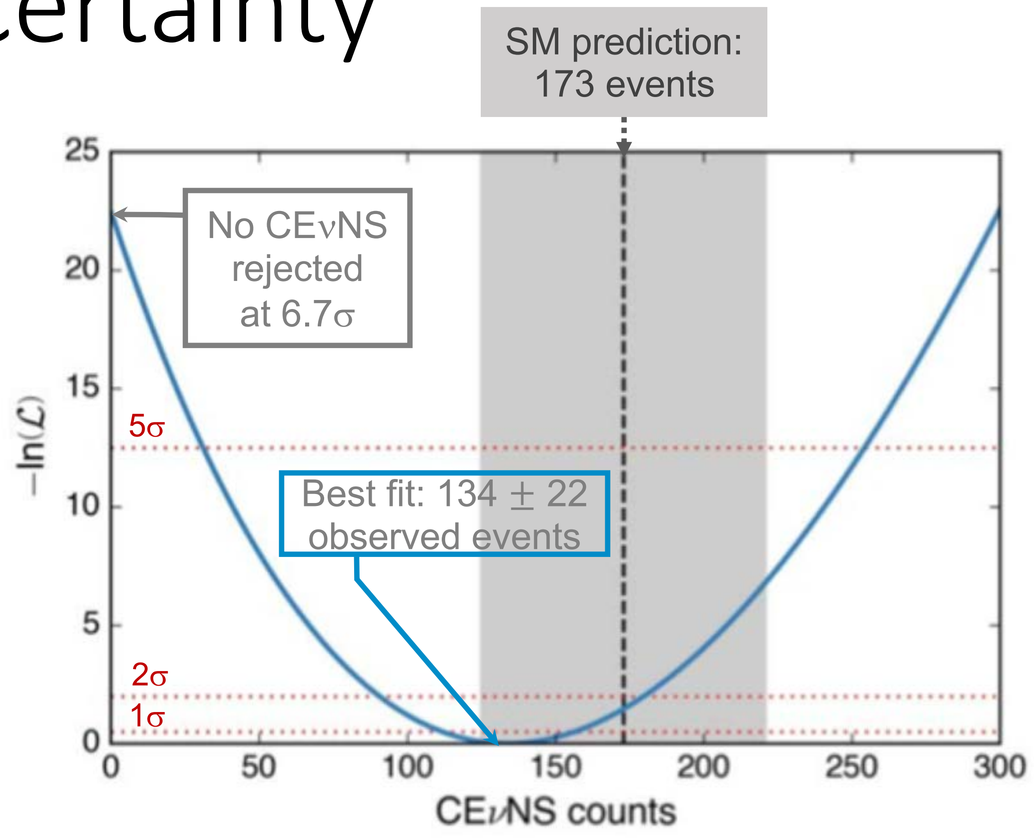


- Beam OFF: 153.5 live-days
- Beam ON: 308.1 live-days, 7.48 GWhr

- Still collecting data with CsI detector
- More than twice statistics accumulated

Signal, background, and uncertainty

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**

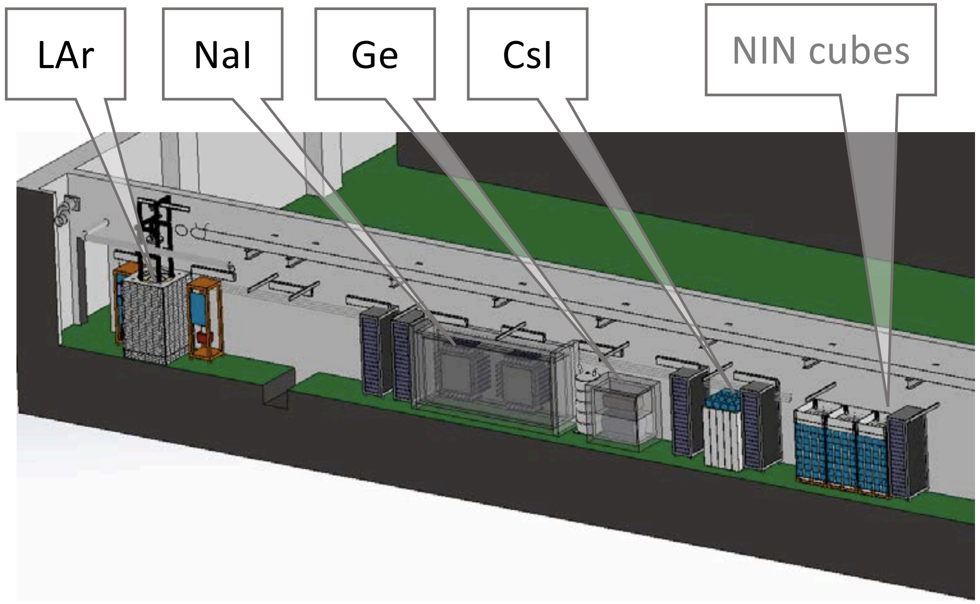


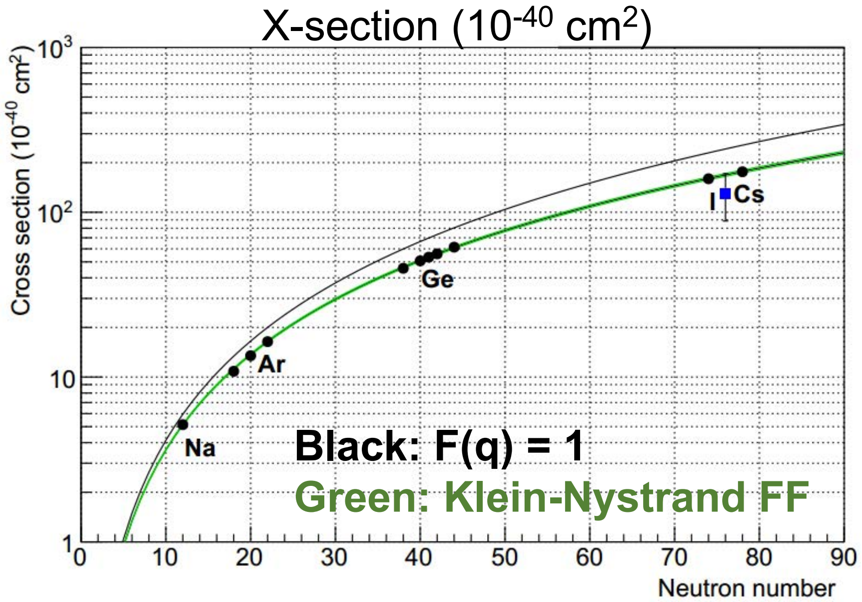
Uncertainties on signal and background predictions	
Event selection (signal acceptance)	5%
Flux	10%
Quenching factor (QF)	25%
Form factor	5%
Total uncertainty on signal	**28%**

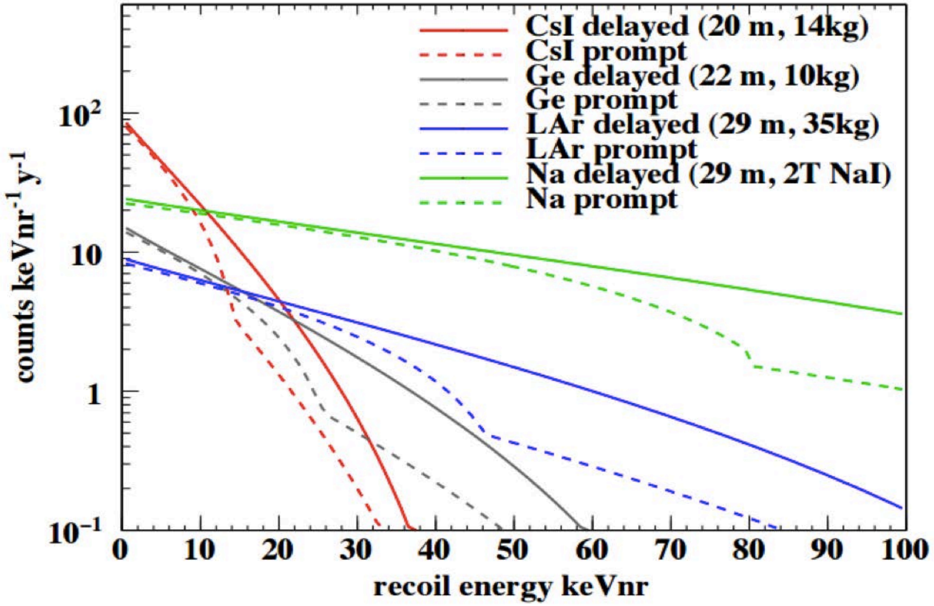
For any detector technology, a high-precision CEvNS program requires:

- **calibrate SNS neutrino flux**
- **high-precision QF measurement**

COHERENT: multi-target CEνNS program





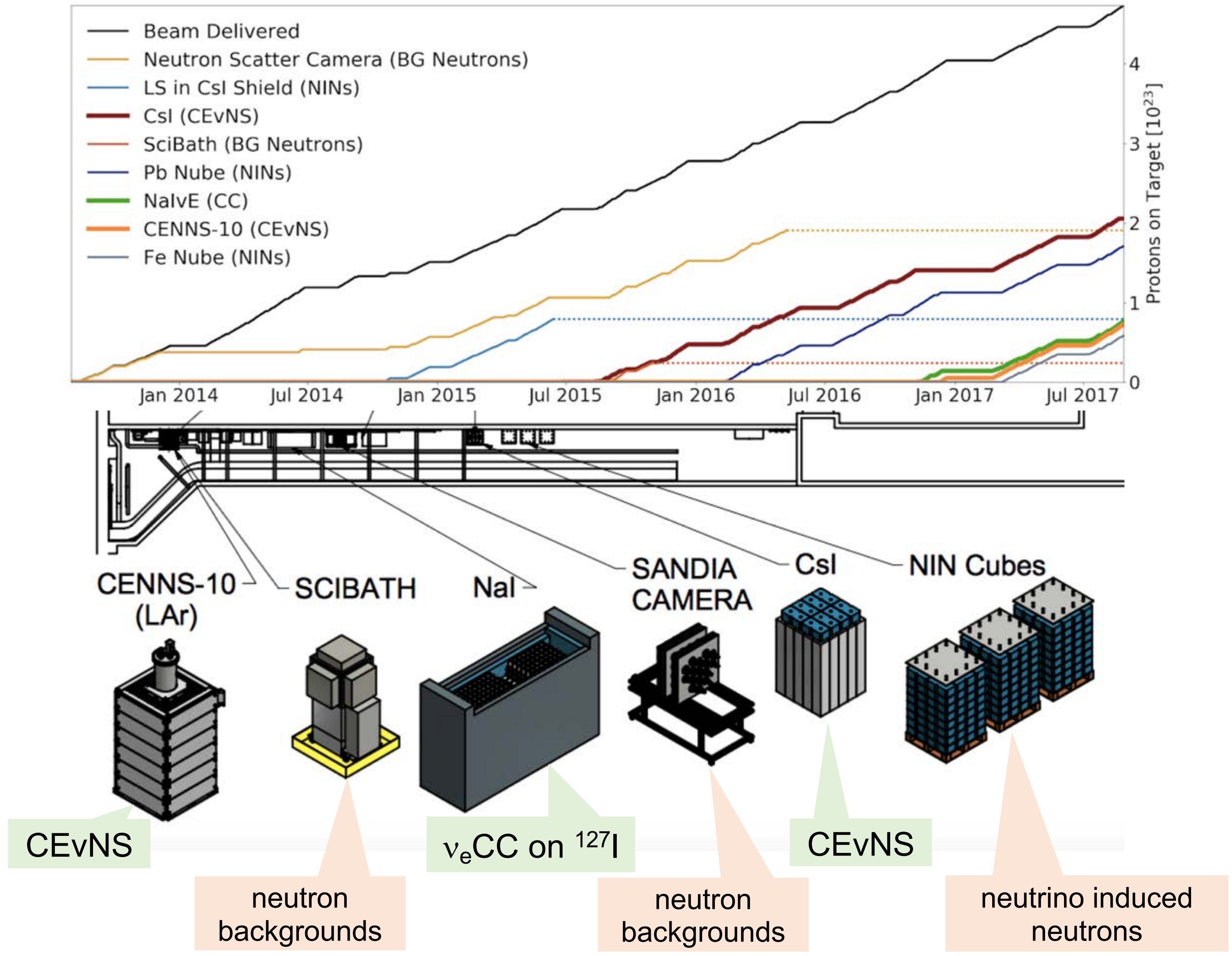


To untangle effects of nuclear form factors we need measurements at the wide range of target masses: Light, Middle, and Heavy

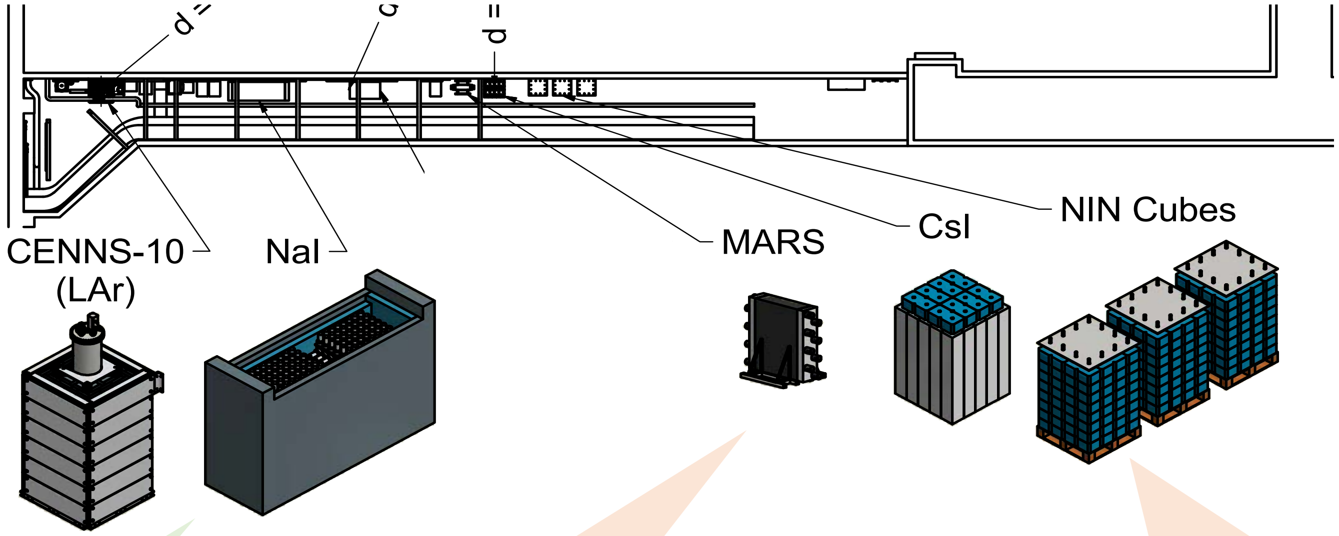
To have handle on axial current it is interesting to have close targets with different spins. Example ^{40}Ar s=0 and ^{23}Na s=3/2

Neutrino Alley
Initial activities

Several Neutrino and Background detectors deployed at various times:



Neutrino alley
Current activities

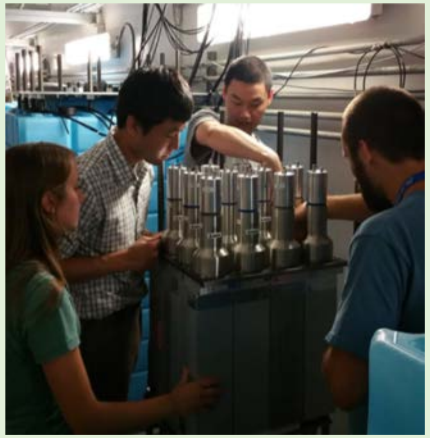


Single phase Liquid Argon detector CENNS-10

Since December 2016 (more next)

185 kg of NaI since July 2016

- taking data in high-threshold mode for ν_eCC on ^{127}I
- PMT base modifications to enable low-threshold CEνNS running



Pilot deployment for 2T array

Neutron background monitoring (2017)

Plastic scintillator and Gd layers, no shielding.
Affected by high 511-keV gammas BG from hot off-gas pipe, considering shielding.

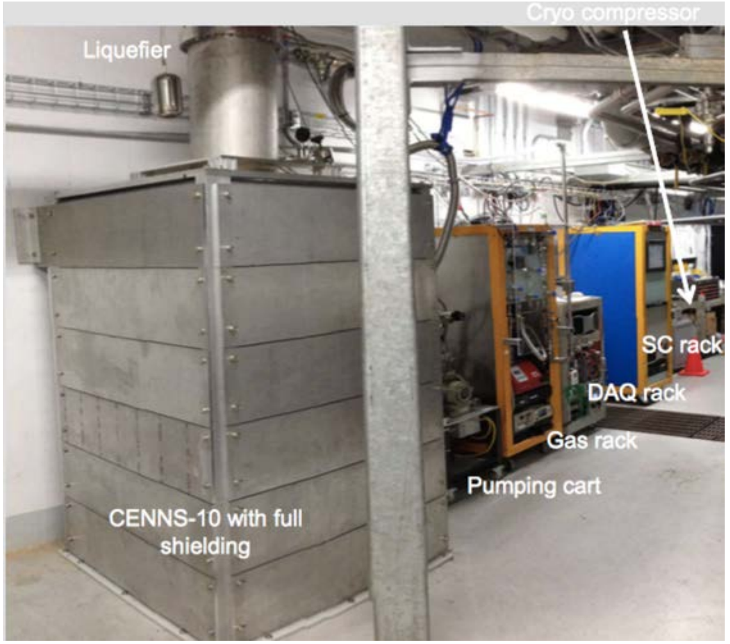
Study of Neutrino Induced Neutrons (NIM) on Lead and Iron (2016).

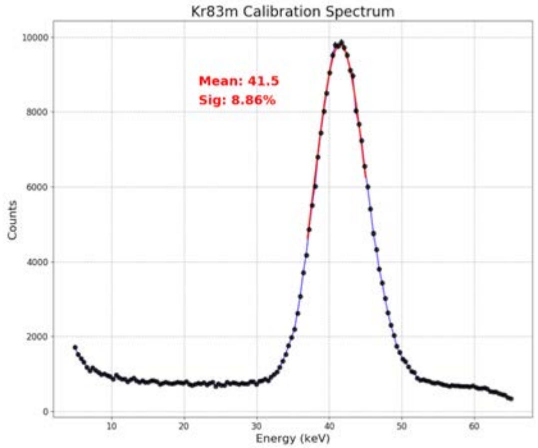
NINs are background for CEvNS and signal for Supernovae neutrino detectors (HALO)

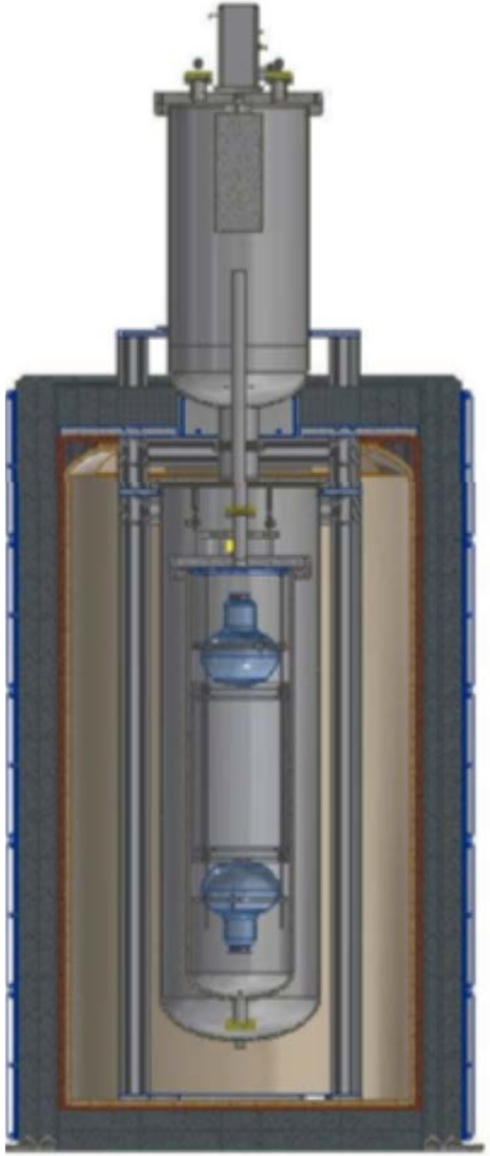
Working on upgrade using PROSPECT Li loaded scintillator.

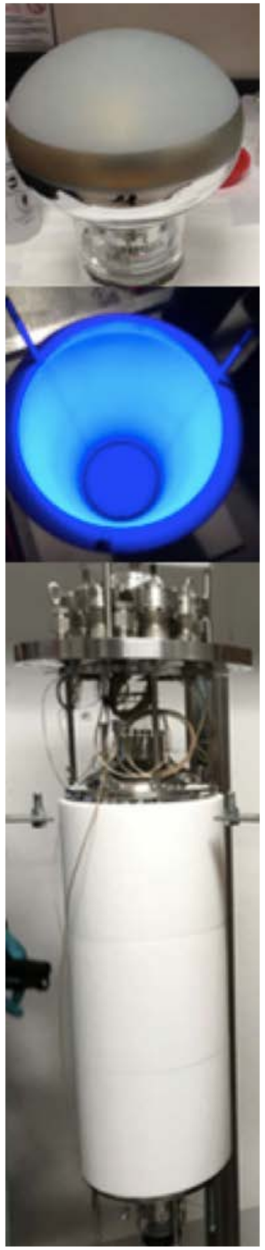
Single-Phase Liquid Argon

- 22 kg fiducial mass
- TPB coated teflon side reflectors
- 8in TPB-coated PMT readout
- E_{thresh} ~ 20 keVnr enough to see CEνNS
- Running since 12/16, anticipate 6.5GWhr by 12/18
- ~100 detected CEνNS expected







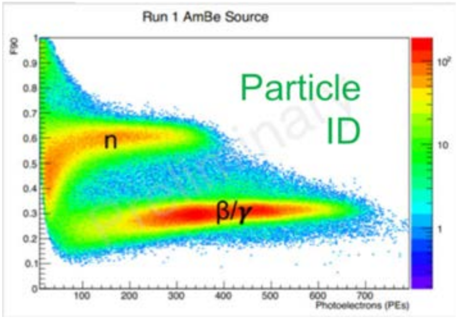


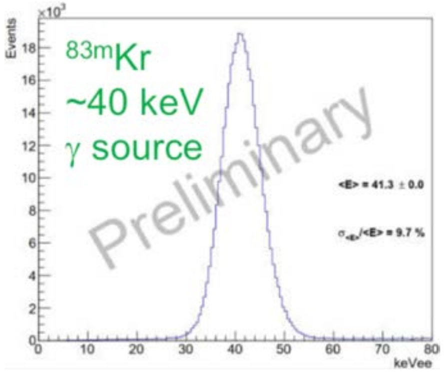
Detector from FNAL, previously built (J. Yoo et al.) for CENNS@BNB
(S. Brice, Phys.Rev. D89 (2014) no.7, 072004)

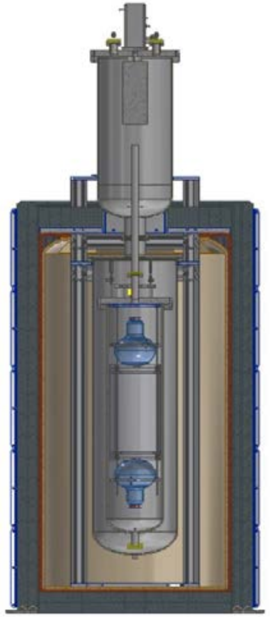
Neutrino alley
Planned activities

1 ton LAr detector

Need high statistics low background measurements of CEnNS







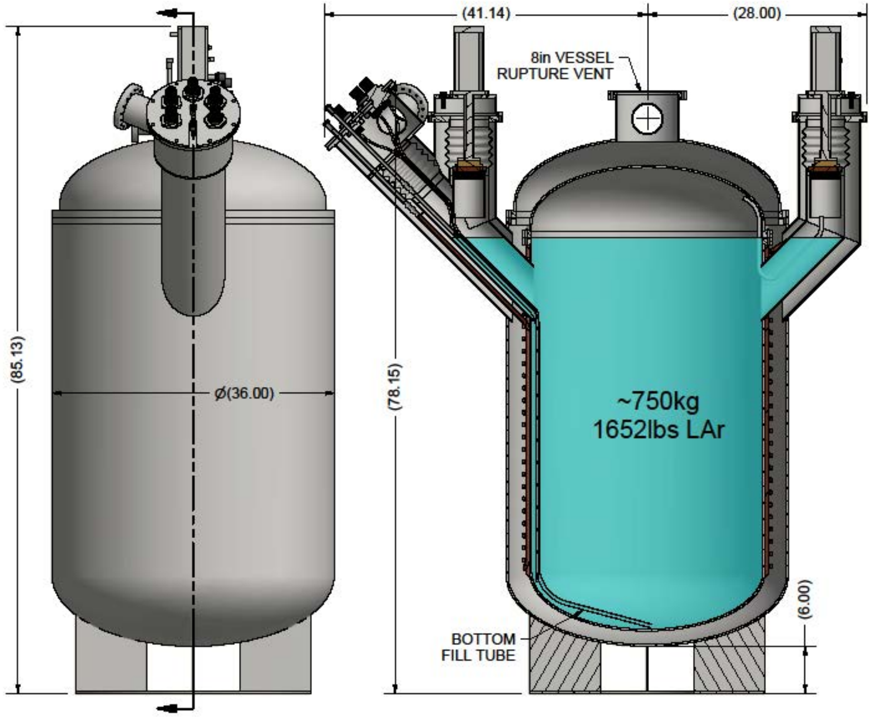
Transition from 22 kg to 1 ton LAr detector.

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 CEνNS events per year + higher-energy NC/CC interactions



Neutrino alley
Planned activities

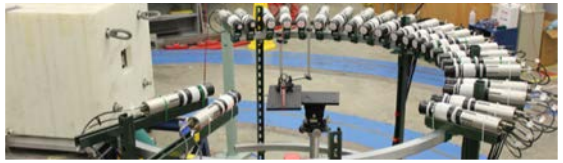
2t NaI detector array

Transition from 185 kg to 2 ton array of NaI detectors

Detectors are available

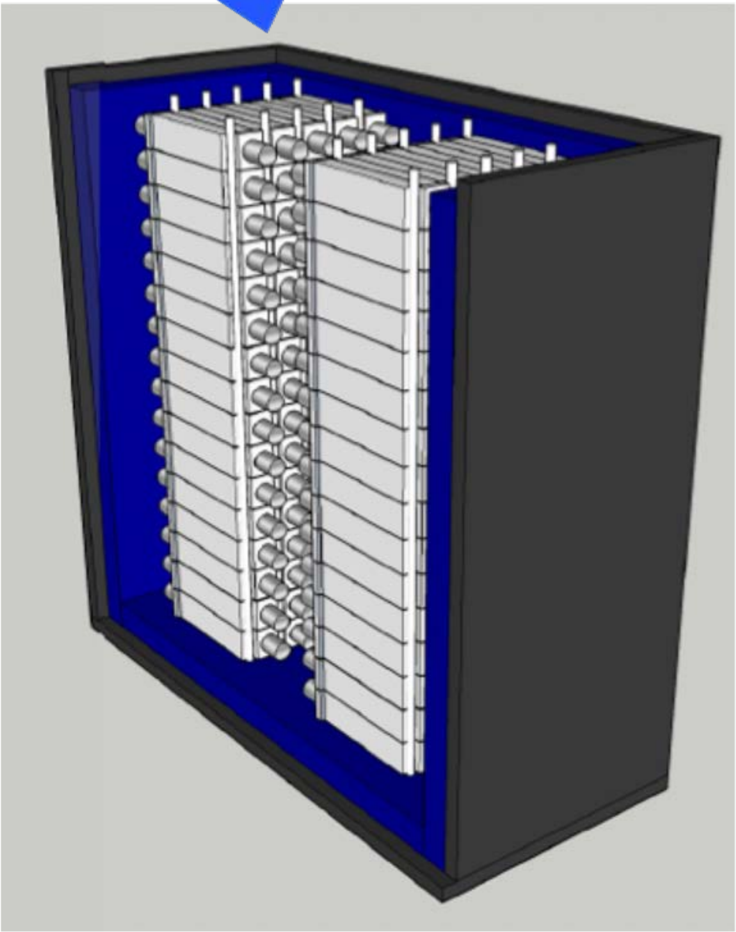
Need dual gain bases
(prototypes have been build)

Program to measure Quenching Factors is ongoing at TUNL



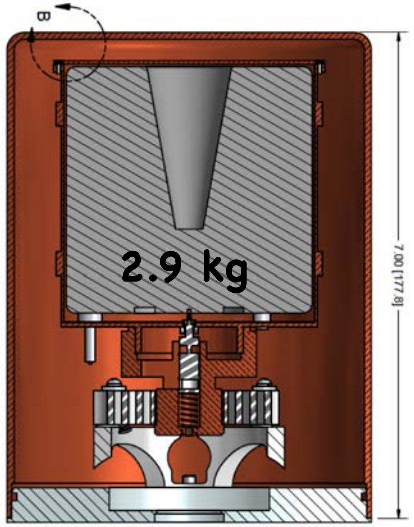
Need electronics and HV; some funds are secure

Potential to detect both CEνNS and CC reactions

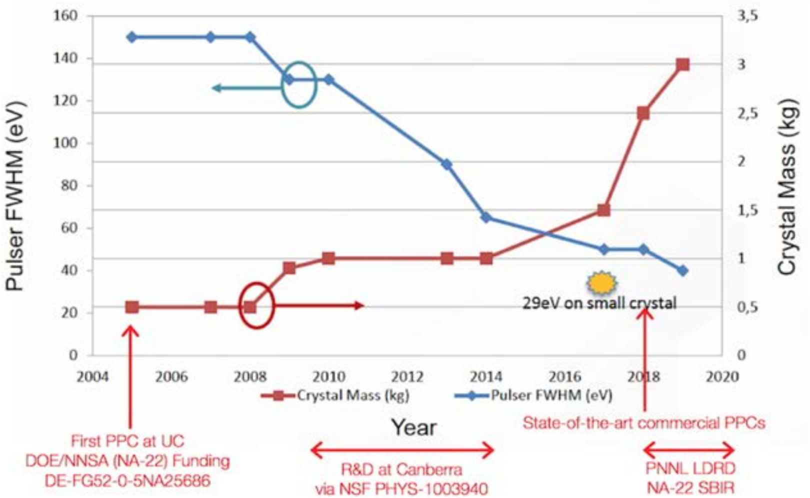


Neutrino alley Planned activities

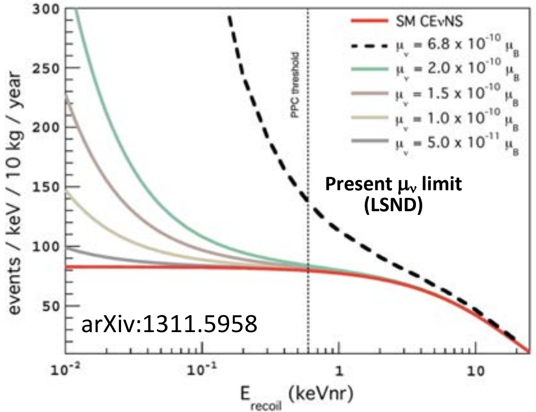
New Germanium Target



- 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] result).
- Demonstrated analysis threshold of 120 eVee/600 eVnr allows measurement of full CEνNS recoil spectrum. Accompanying ongoing effort in quenching factor characterization.
- 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.
- Demonstration of threshold and background in 2018. Start of data-taking at SNS during first quarter of 2019.



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



Neutrino alley Planned activities

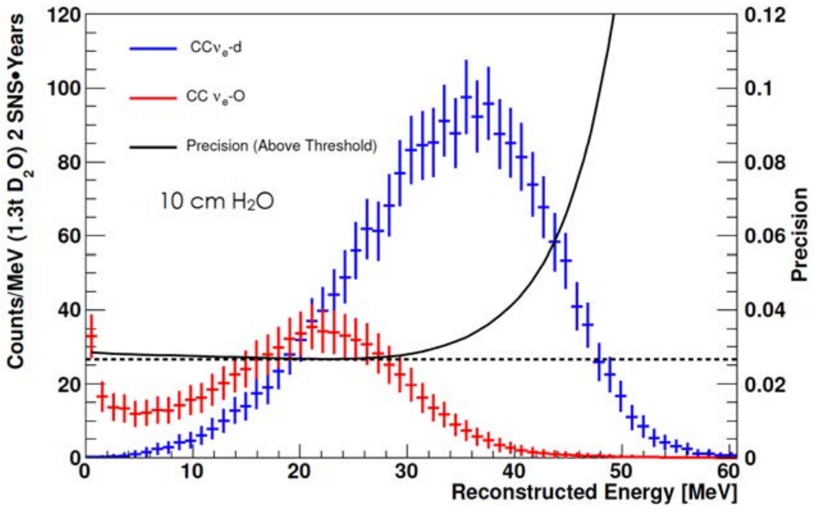
Neutrino Flux Calibration

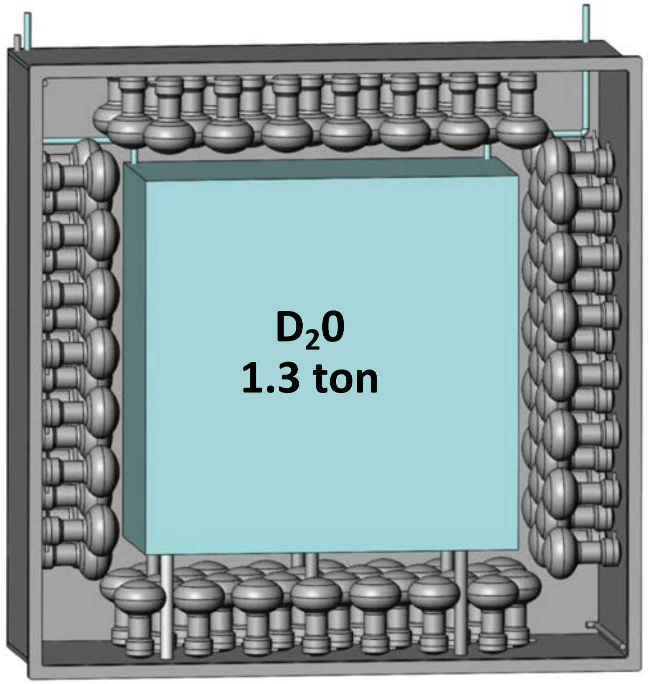
Presently we assume that neutrino flux at SNS is known within 10%

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





ν Flux calibration and CC measurements on Oxygen

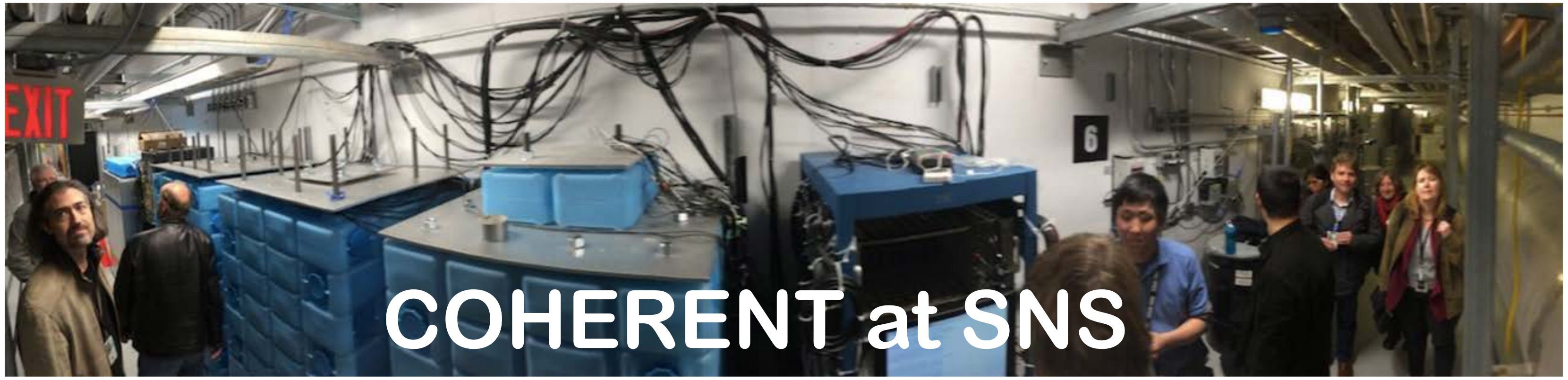
Well defined D_2O mass constrained by acrylic tank.

10 cm of light water tail catcher for high energy e-

Outer dimensions 2.3 * 2.3 * 1.0 m^3

For 1 t fiducial mass detector ~ thousand interactions per year

Detector calibration with Michel Electrons (same energy range)



Present goals - after first CEνNS observation with CsI[Na]:

- Accumulate more statistics with CsI[Na]
- CEνNS detection with multiple targets: expecting LAr
- NINs detection for Lead and Iron

Next goals - new deployments:

- Deploy low-threshold Ge detectors
- Measure SNS ν flux
- High precision CEvNS studies. Look for physics beyond SM.
- Measure ν CC to support Supernovae physics and Weak interaction physics (Lead, Argon, Oxygen, Iodine)


EXTRA!