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B. Cabrera-Palmer, Sandia National Laboratories
On behalf of the COHERENT collaboration
December 6th, 2017
Nuclear and Chemical Sciences Colloquium, LLNL

PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

Coherent effects of a weak neutral current

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National Accelerator Laboratory, Batavia, Illinois 60510
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(Received 15 October 1973; revised manuscript received 19 November 1973)

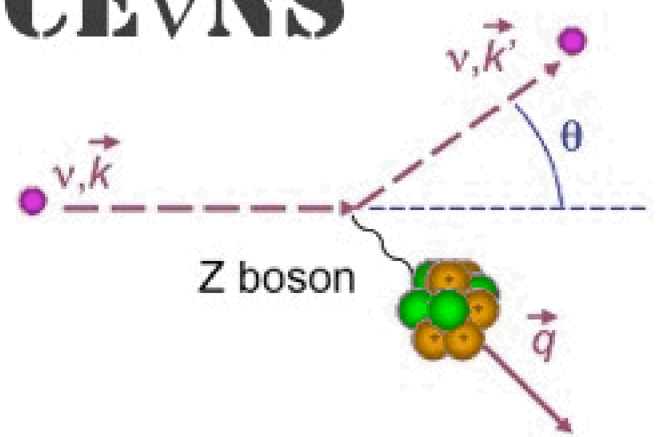
. . . The idea is very simple: If there is a weak neutral current, elastic neutrino-nucleus scattering should exhibit a sharp coherent forward peak characteristic of the size of the target just as electron-nucleus elastic scattering does. . .

SUMMER 2017:
First observation of
Coherent Elastic Neutrino-Nucleus Scattering
- CEνNS -

Coherent elastic neutrino-nucleus scattering

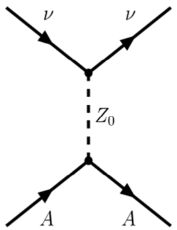
What is CEνNS? Why is it important to measure it?

CEvNS



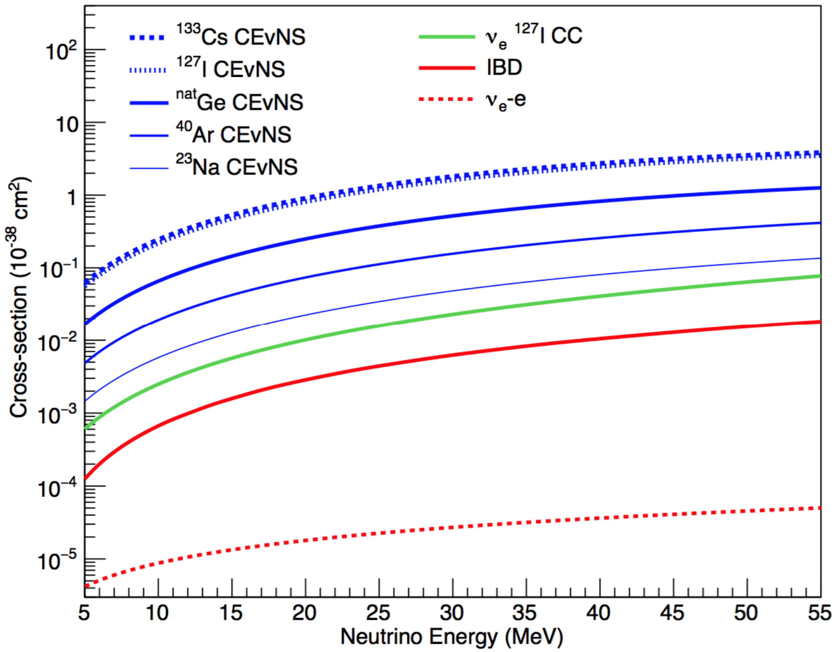
- Condition for coherence: low momentum transfer ***q*** << 1/(nucleus radius),
  bounds neutrino energies E_ν<~ 50 MeV

- Largest of all Standard Model low-energy neutrino interaction cross-sections, enhanced by N^2

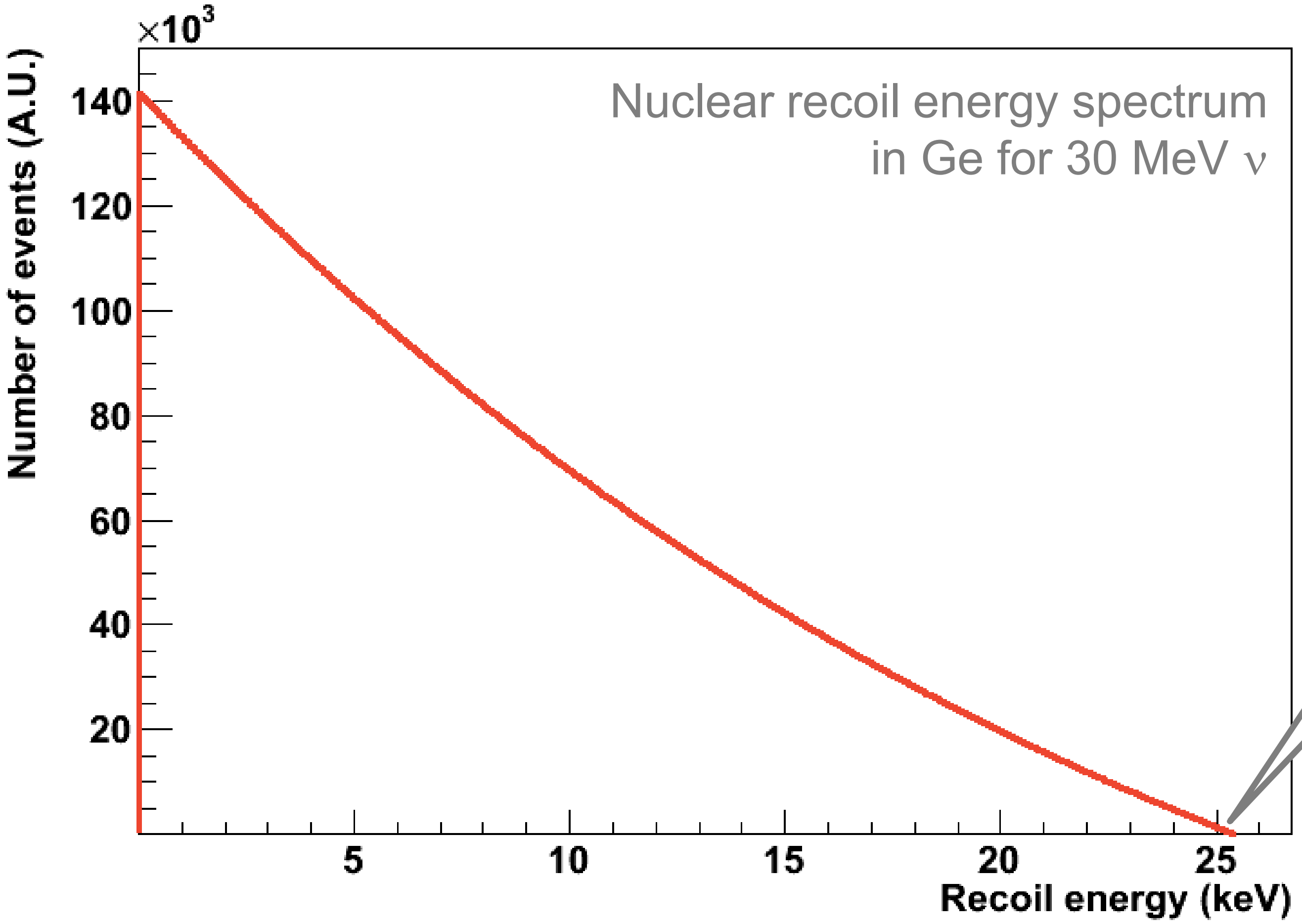


$$\frac{d\sigma}{dE} = \frac{G_F^2}{4\pi}[(1-4\sin^2\theta_w)Z-(A-Z)]^2 M\left(1-\frac{ME}{2E_\nu^2}\right)F(Q^2)^2$$

- Flavor blind: any neutrino can do it.

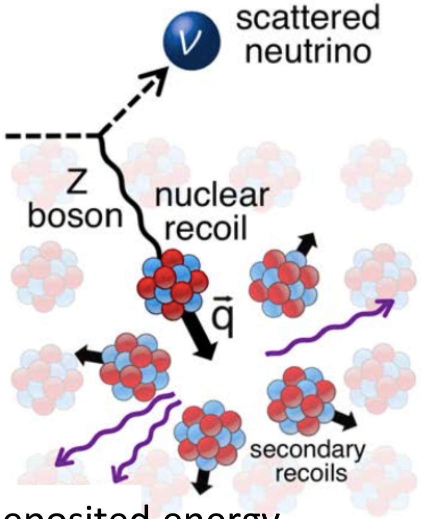


CEνNS signature: low-energy nuclear recoils



Maximum recoil energy for Ge is

$$\frac{2}{A}\left[\frac{E_\nu}{1MeV}\right]^2 keV \sim 25\ keV$$



deposited energy

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)

- Sensitive tool for Sterile neutrino searches

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

- Neutron distribution functions

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

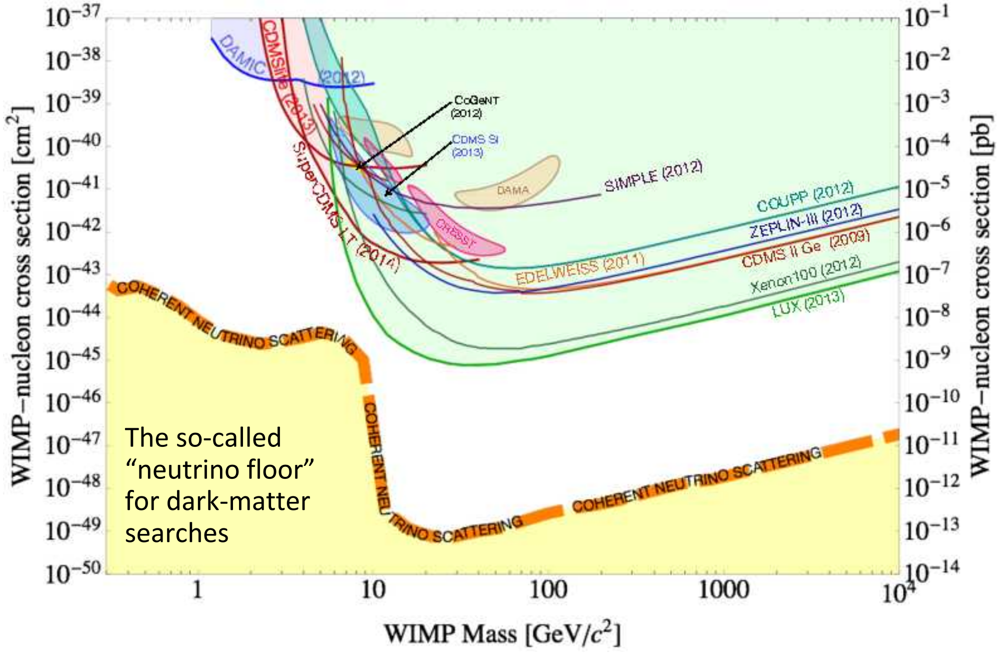
- Neutrino Magnetic Moments

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

What makes CEνNS interesting?

Beyond the Neutrino Physics community:

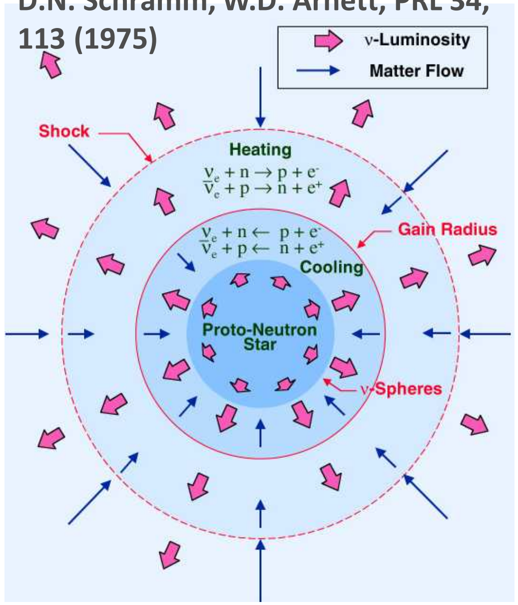
- Irreducible background for WIMP searches



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

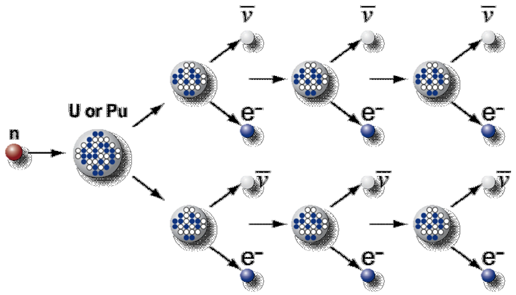
- Major role in Supernovae dynamics

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?

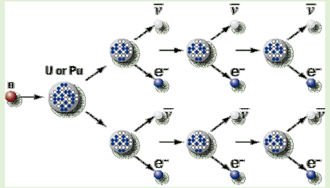
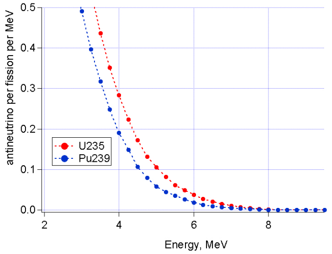
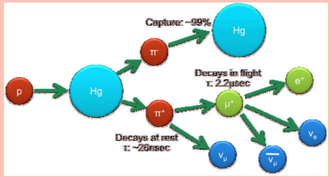
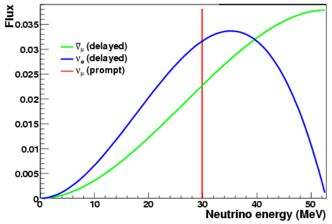


Where to get the neutrinos?

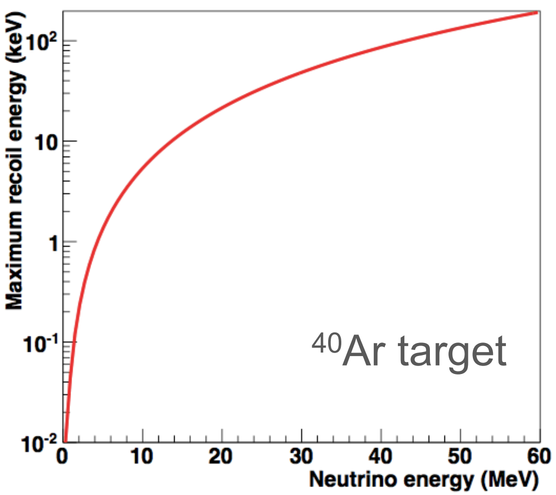
ν sources

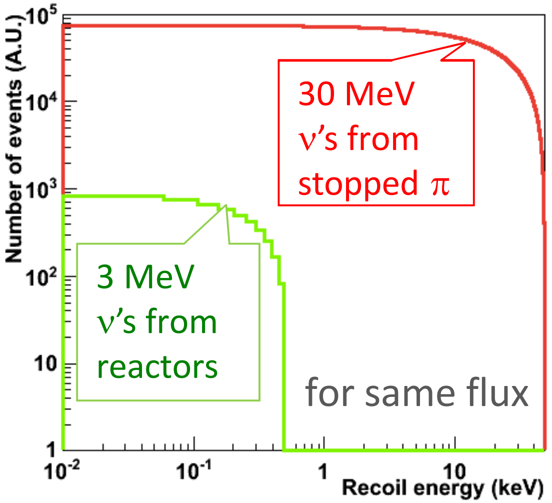
- Natural:
  - supernova burst and relic neutrinos
  - Atmospheric, solar and geo-neutrinos
- Man-made:
  - Nuclear reactors
  - Stopped pion sources
  - Radioactive sources

Reactor vs. Stopped π for CEνNS

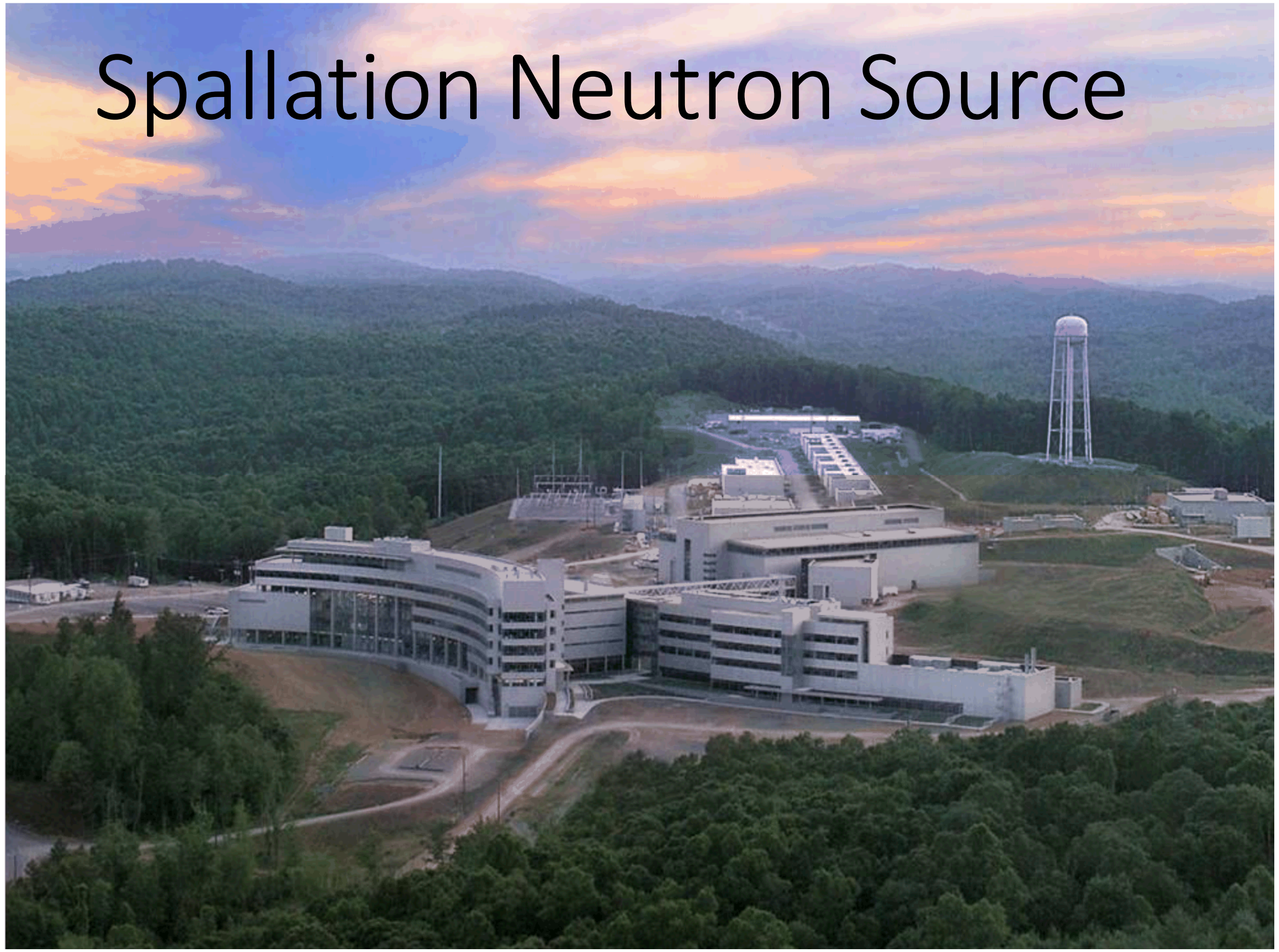
	Pros	Cons
Reactors: $\bar{\nu}_e$ 	High flux: ~10^{20} ν/s	Low E_ν ~ 3 MeV 
Stopped π: $\nu_\mu, \bar{\nu}_\mu, \nu_e$ 	• High E_ν up to ~ 50 MeV  • Pulsed: **background rejection**	Lower flux: ~10^{15} ν/s

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



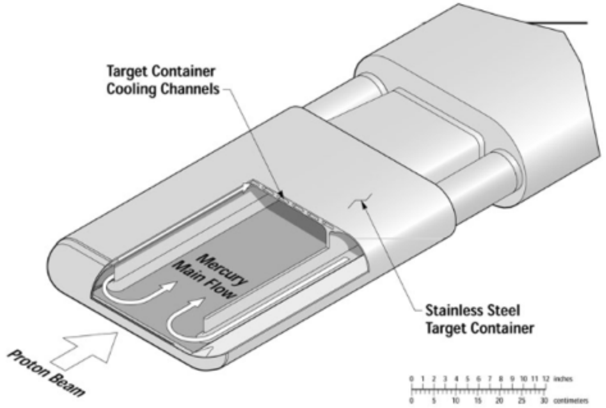


Spallation Neutron Source



Oak Ridge National Laboratory, TN

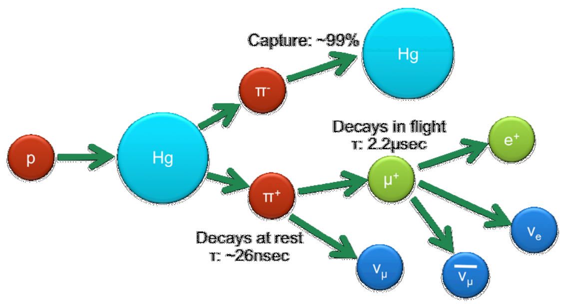
Proton beam energy: 0.9-1.3 GeV
Total power: 0.9-1.4 MW
Pulse duration: 380 ns FWHM
Repetition rate: 60 Hz
Liquid mercury target



The neutrinos are free!

Neutrinos at the SNS

- Pion 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

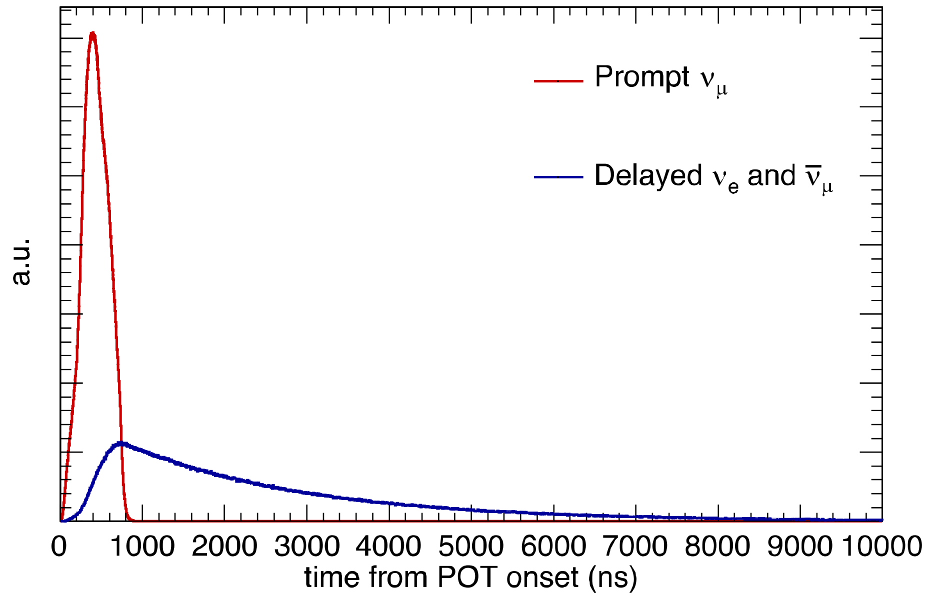


$$\pi^+ \to \mu^+ + \nu_\mu$$ PROMPT: monochromatic 29.9 MeV ν_μ

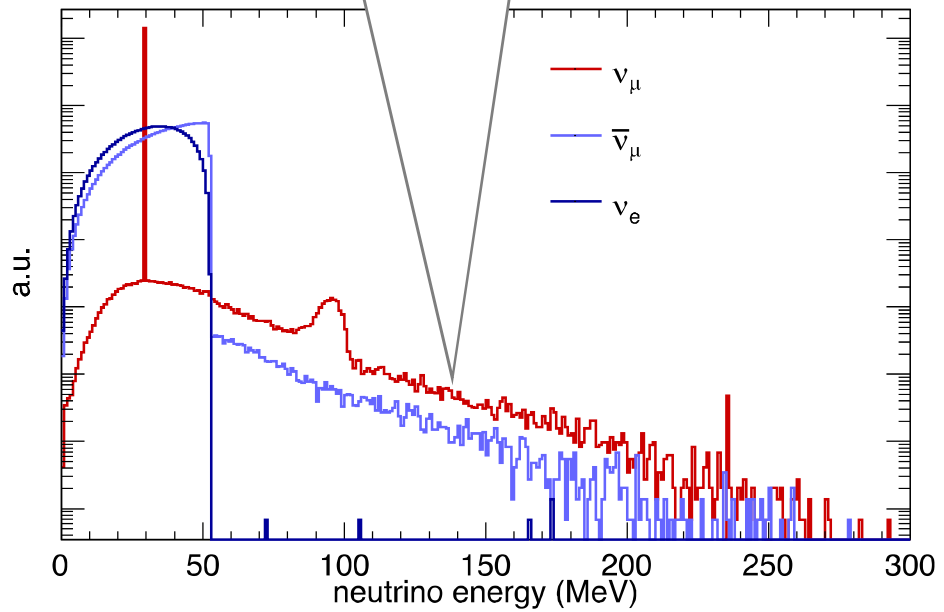
$$\mu^+ \to e^+ + \bar{\nu}_\mu + \nu_e$$ DELAYED (2.2 μs): range of energies between 0 and $m_\mu/2$

Time structure enables:

- 10^3-10^4 steady-state background rejection
- out-beam window for steady-state characterization



< 1% contamination from non-CEνNS scatters



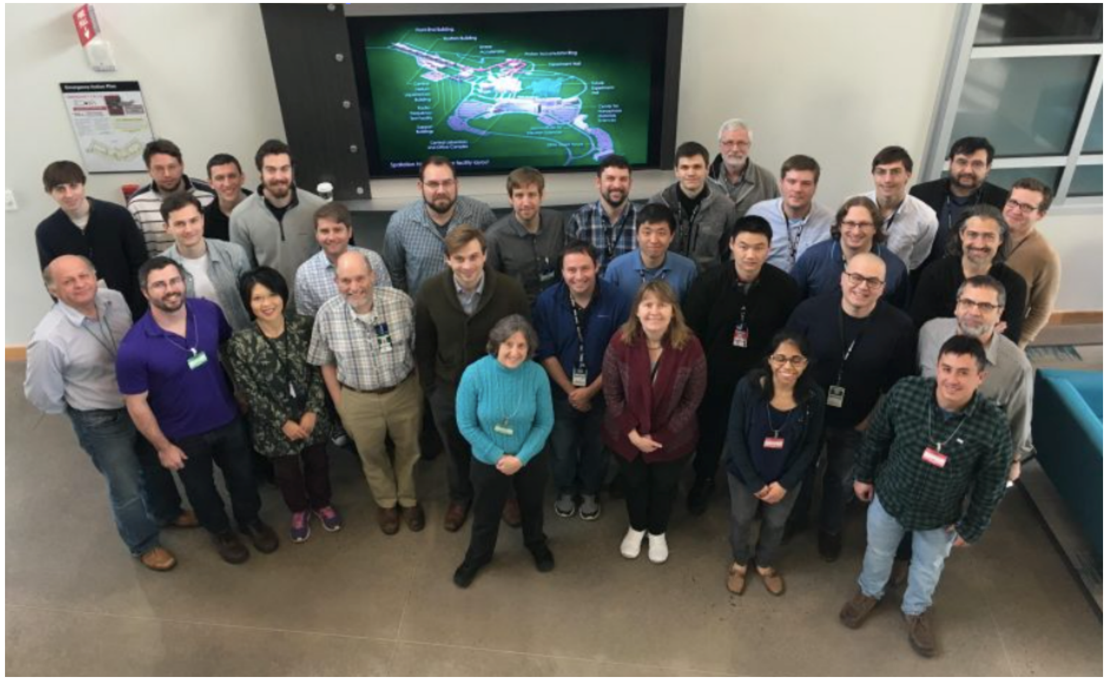
The COHERENT collaboration

COHERENT

SNS SPALLATION NEUTRON SOURCE

~80 members,
19 institutions

http://sites.duke.edu/coherent
arXiv:1509.08702



THE UNIVERSITY OF CHICAGO
Duke UNIVERSITY
UF UNIVERSITY of FLORIDA
KAIST
Laurentian University Université Laurentienne
Los Alamos NATIONAL LABORATORY EST.1943
BERKELEY LAB
MEPhI
NORTH CAROLINA CENTRAL UNIVERSITY FOUNDED 1910
NC STATE UNIVERSITY
NM STATE UNIVERSITY
OAK RIDGE National Laboratory
Sandia National Laboratories
THE UNIVERSITY of TENNESSEE KNOXVILLE
Carnegie Mellon University
W UNIVERSITY of WASHINGTON

CNEC Consortium for Nonproliferation Enabling Capabilities
KICP
NNSA National Nuclear Security Administration
NSF
U.S. DEPARTMENT OF ENERGY

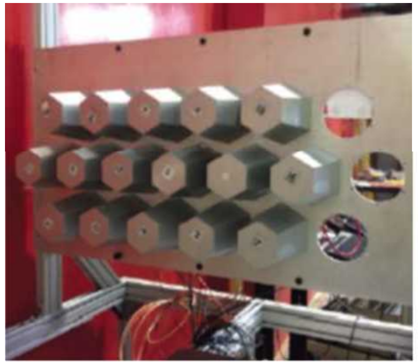
Where should the CEνNS detectors go?

- Backgrounds dictated the answer: since 2013, a suite of neutron detectors were deployed at the SNS to survey for the appropriate and available deployment location.

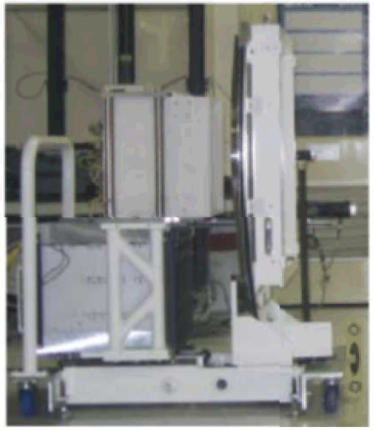
- Intermediate energy neutrons (10-100 MeV) coincident with the beam considered the largest concern:
  - ~100 keV -1 MeV neutrons can create the same nuclear recoil as neutrinos,
  - low-energy neutrons easily shielded … but higher-energy neutrons impinging on the shield can create low-energy neutron showers!

Portable 5L LS Cells

Single Plane Single Scatter



Coded-aperture Imager



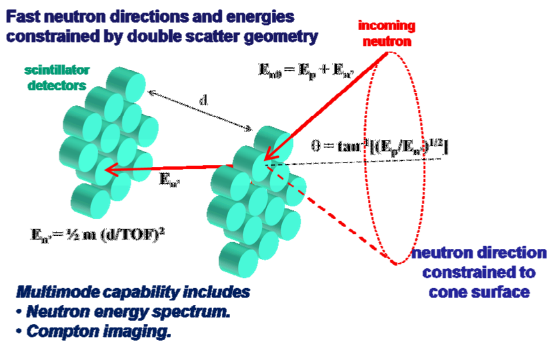
Neutron Scatter Camera

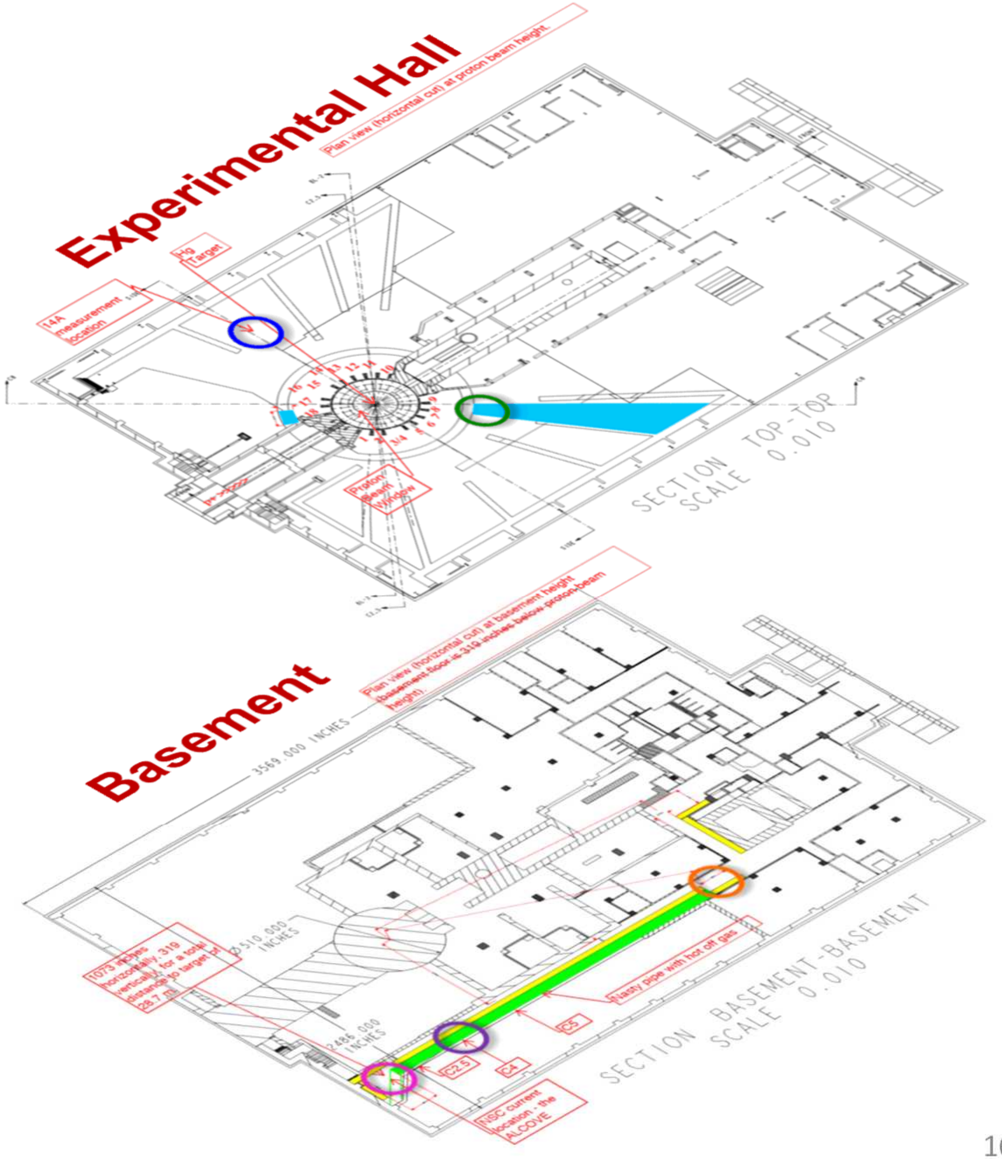
Scibath

Neutron Scatter Camera (NSC) Measurements

- SNL fast neutron imager and spectrometer: not ideal for the intermediate-energy neutron measurements but sufficient to estimate their relative flux rate, timing and direction.

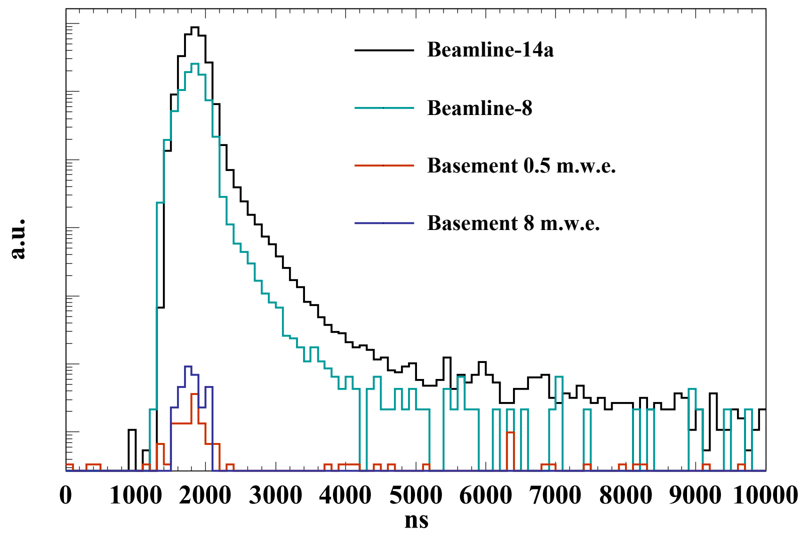
- Background data collected from 2013 to 2015.
- 5 locations surveyed:
  - 2 Experimental Hall Beamlines,
  - 3 Basement positions: each at a different distance from the target, but all behind the shielding monolith, concrete and gravel providing neutron shielding.





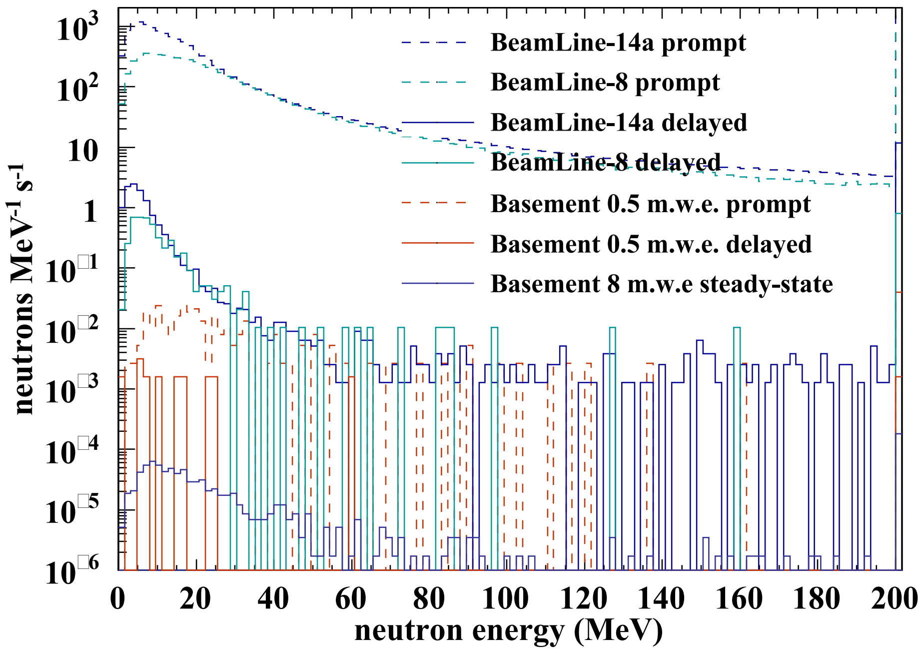
What did the NSC measurements show?

- Timing plot showing the flux of neutrons with respect to the proton-on-target (POT):
  - Prompt ν_e coincident with the beam: most of the neutron backgrounds in the basement clearly from the 800 ns protons on target,
  - Delayed muon-decay ($\bar{\nu}_\mu$, ν_e) in 2.2 µs window after the beam: neutron background reduced at least an order of magnitude compared to the prompt window.



- Intermediate-energy neutron rates at the Experimental Hall prohibitively high: a no-go.

- Basement rates ~5 orders of magnitude lower!
- Steady-state background rate even lower in the basement locations with 8 m.w.e. overburden.
- Deployment location found: **the Neutrino Alley!**



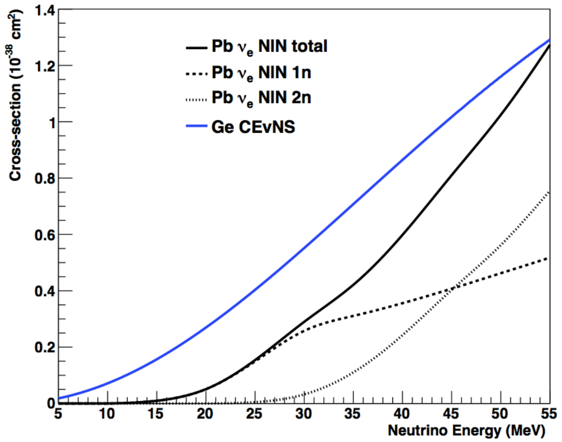
Another background: Neutrinos can make neutrons

Neutrino induced neutrons (NINs) coincident with the CEνNS signal:

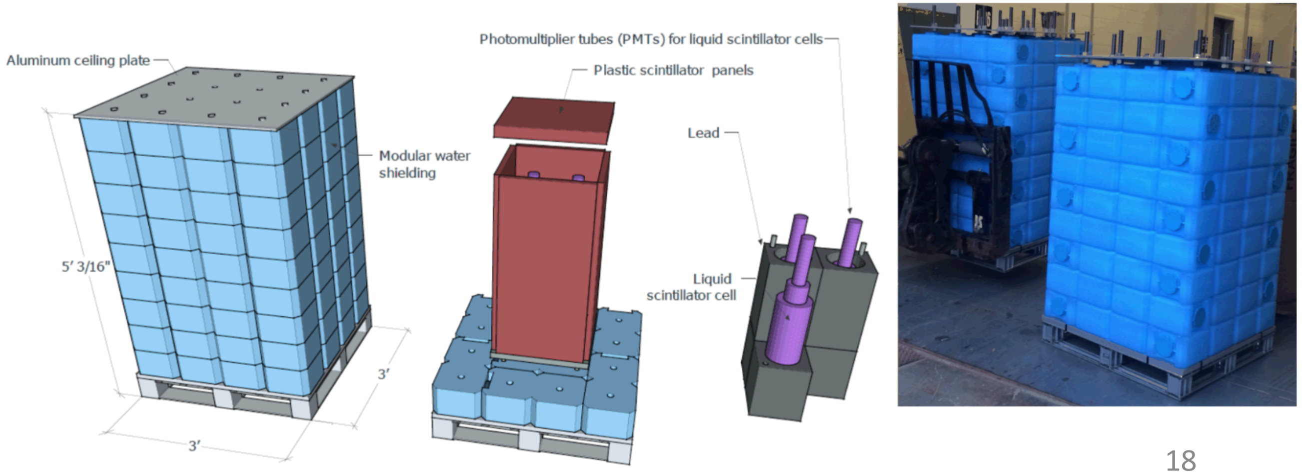
$$\nu_e + {}^{208}Pb \longrightarrow {}^{208}Bi^* + e^-$$
$$\downarrow$$
$${}^{208-y}Bi + x\gamma + yn$$

$$\nu_x + {}^{208}Pb \longrightarrow {}^{208}Pb^* + \nu_x'$$
$$\downarrow$$
$${}^{208-y}Pb + x\gamma + yn$$

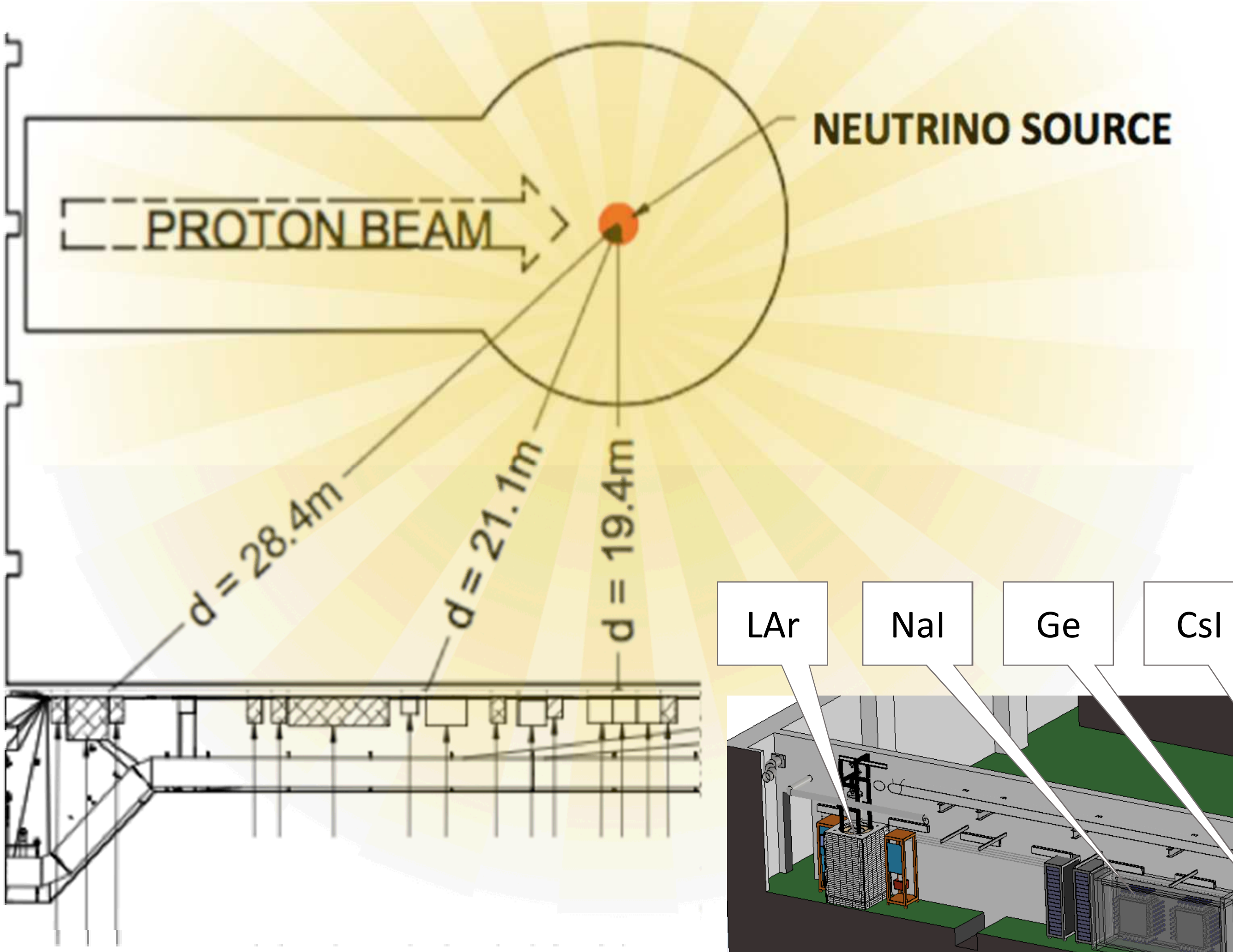
- Produced by neutrinos in Pb shield: requires careful shielding design.
- Cross section is poorly known. A signal in itself in the HALO experiment in the SNOlab to observe Supernovae.
- COHERENT program since September 2014 with Lead (1 ton) and Iron (700 kg) and Cu targets to measure NINs (for background evaluation) and their production cross section (as a physics measurement).

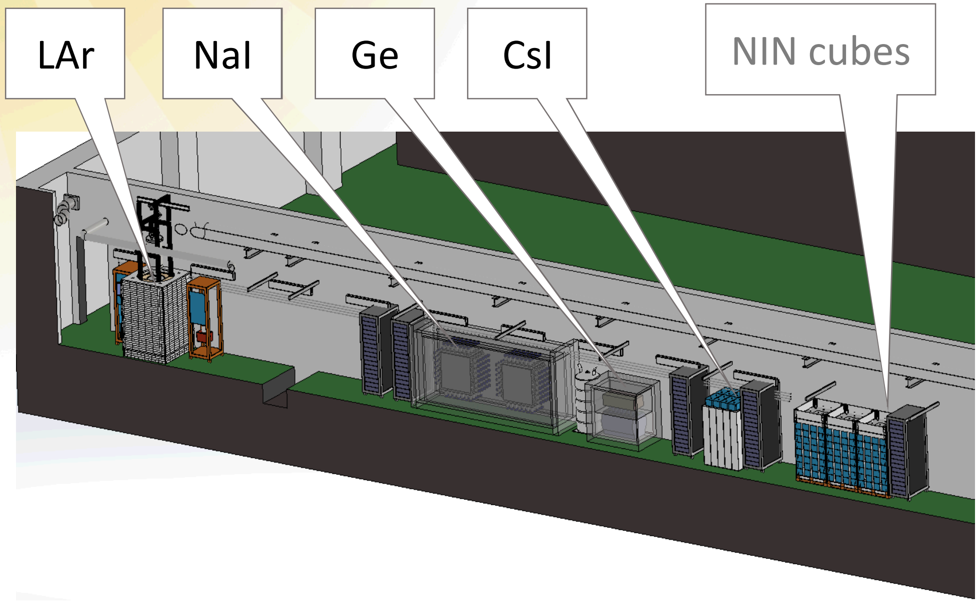


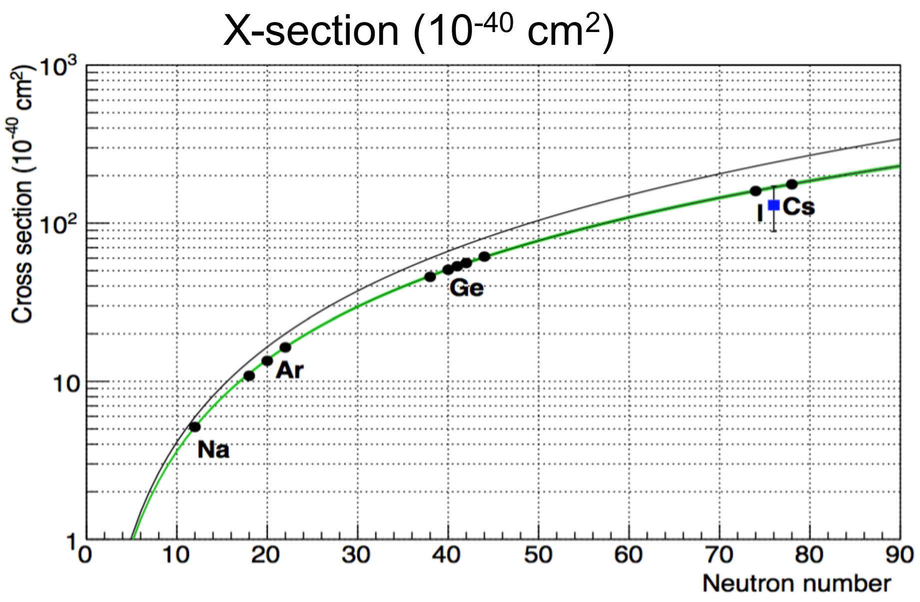
Pb Neutrino Cube
-NUBE-

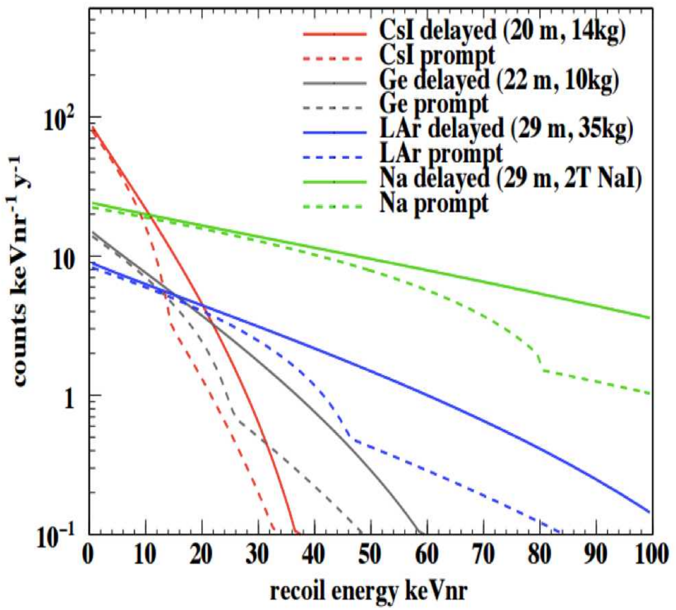


Neutrino Alley: home of a multi-target deployment







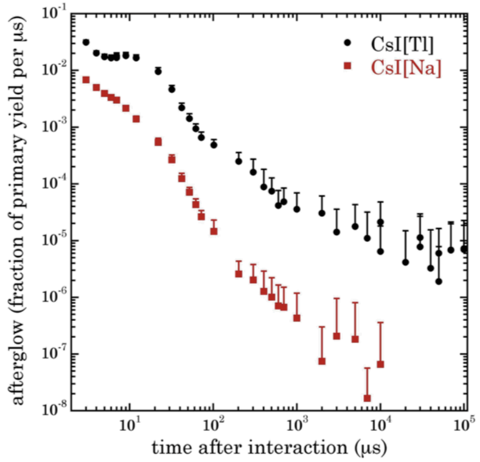


The first COHERENT result

CsI[Na] 14 Kg detector experimental set-up, data collection and analysis.

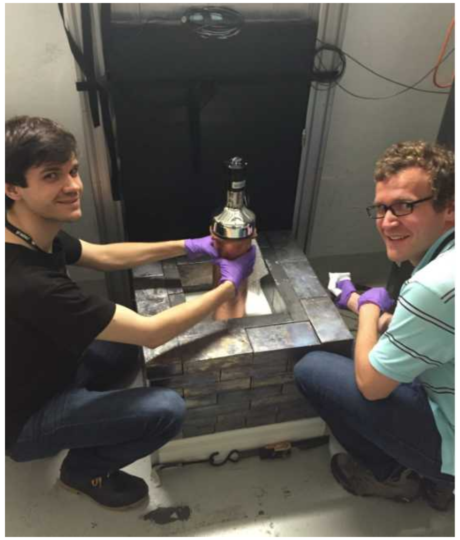
A hand-held neutrino detector

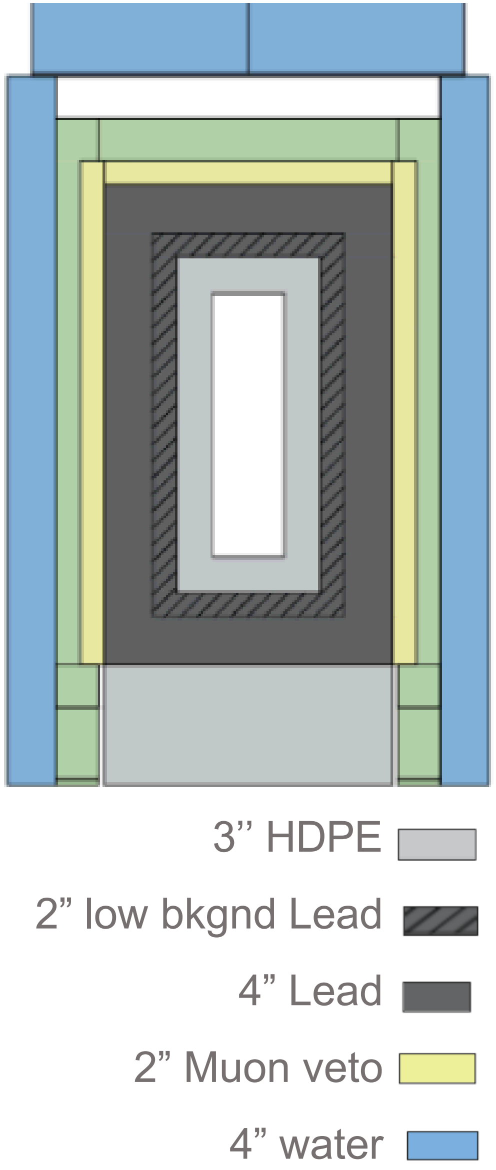
- Led by U. Chicago group
  - 14.6 kg CsI[Na] scintillating crystal
  - Heavy Cs and I with nearly-identical response
  - Low-intrinsic background
  - High light yield (64 photons/keVee)
  - Room temperature and inexpensive
  - Rugged and stable
    - Large afterglow, but suppressed for CsI[Na] compared to CsI[Tl] .



J.I. Collar et al., NIM A773 (2016) 56-67

- Data collection started summer 2015
  - 1.76x1023 POT (7.48 GWhr) delivered since then

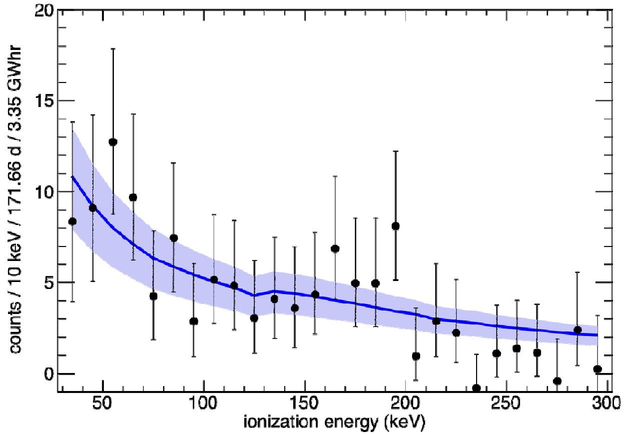


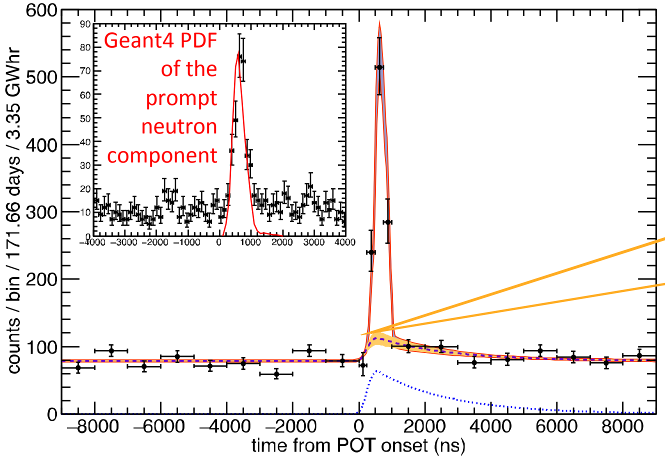


NINs and Prompt neutron specific to the CsI shield

- Prior to CsI[Na] installation, two1.5 liter liquid scintillator (Ej301) cells was deployed at the same location, within the same shielding but without the inner poly layer.
- Data collected from November 2014 to June 2015,

- Ej301 energy spectrum coupled with MCNP-Polimi simulation to estimate the prompt neutron flux and spectral shape.
- Predicted prompt neutron background rate in CsI[Na] detector of 0.92 ± 0.23 events/GWhr: **25 times smaller than expected CEνNS.**





NINs: non-zero component at 2.9σ (factor ~1.7 lower than prediction)

- Fit including: random environmental neutrons, prompt neutrons and ν_e-induced NINs time-profiles.
- Predicted NIN background rate in CsI[Na] detector of 0.54 ± 0.18 events/GWhr: **47 times smaller than expected CEνNS (thus, neglected).**

CsI waveform

40 μs pre-trace windows used for afterglow background removal

Protons on target

Anticoincidence pre-trace

Anticoincidence region of interest

Coincidence pre-trace

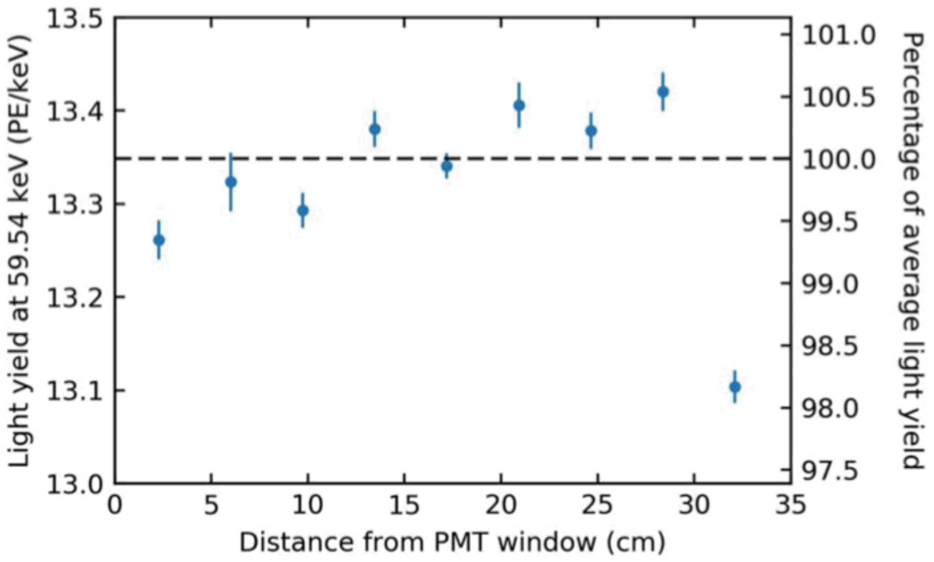
Coincidence region of interest

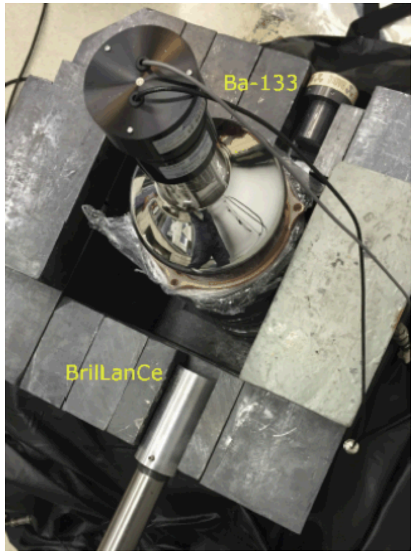
CEνNS + Beam-on Background =
(Event count in C ROI) – (Event count in AC ROI)

Detector Calibrations

14.6-kg detector at U. Chicago

^{241}**Am:** average measured light yield of 13.35 PE/keVee, uniform within ~2%.

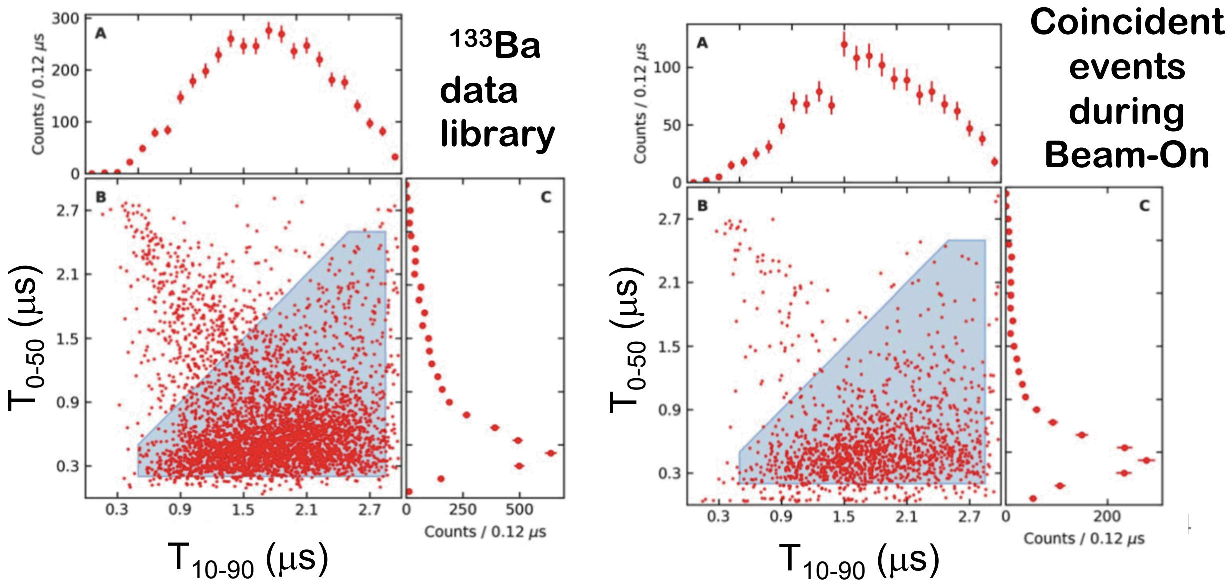




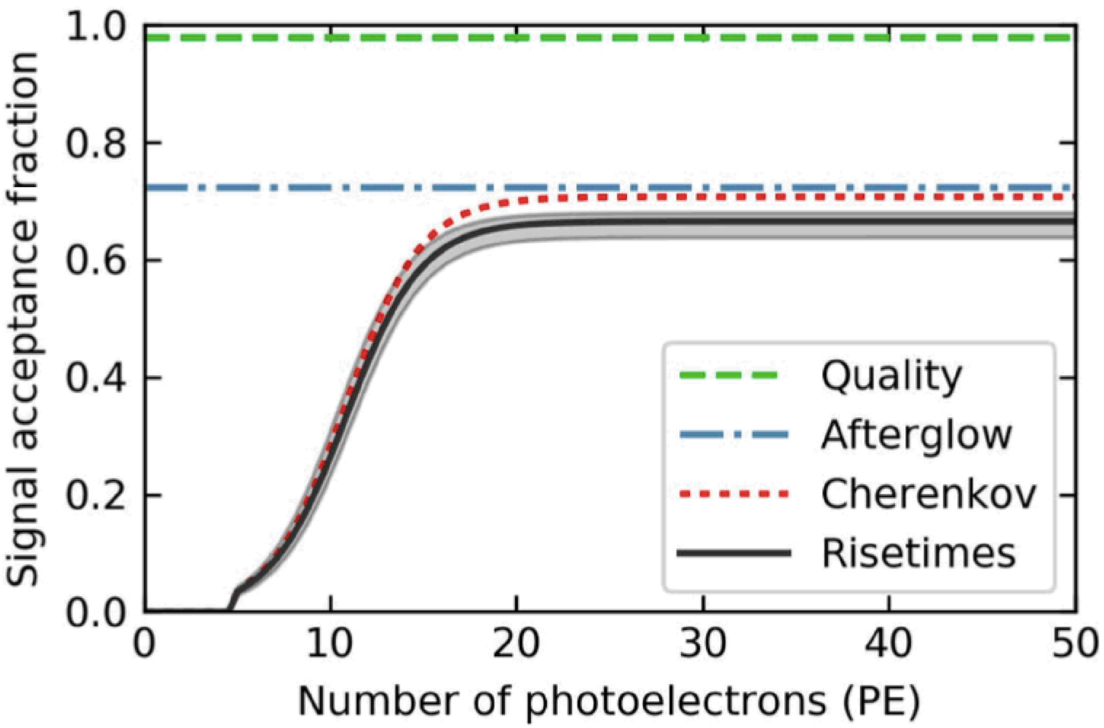
^{133}**Ba:** produced library of low-energy radiation-induced events to train event selection efficiency:

- Risetime cut
- "Cherenkov" cut

Risetime-cut to remove misidentified scintillation onsets

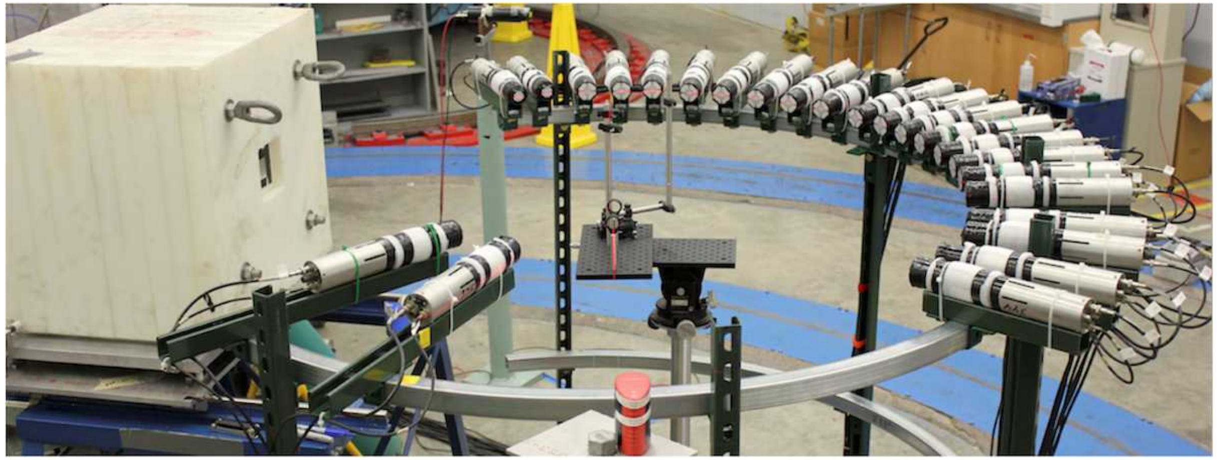


Event selection cut efficiencies

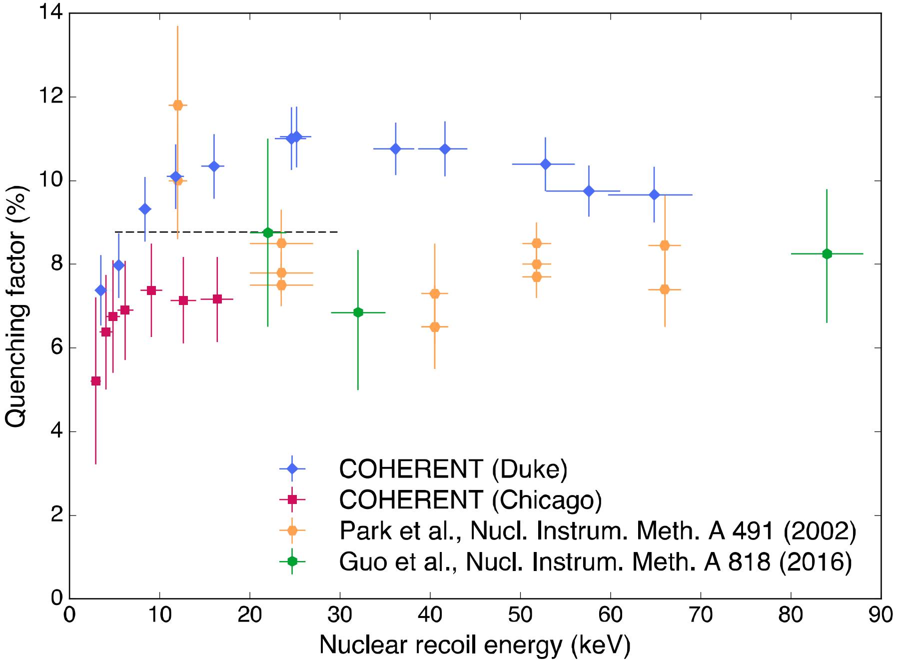


Quality (Beam OFF)	Remove coincidences in muon veto, deadtime from PMT saturation blocking, digitizer range overflow	Selects recoil-like low-energy pulses, reject muons
Afterglow (Beam OFF)	Reject signals with >=4 peaks (typically spe) in pretrace	Removes afterglow (phosphorescence) contamination
"Cherenkov" (^{133}Ba)	Require minimum number of peaks in the scintillation signal	Removes accidental coincidences with Cherenkov emission in PMT window and dark counts/afterglow
Risetime (^{133}Ba)	Pulse-shape based	Removes misidentified scintillator onset, accidental groupings of dark counts, etc.

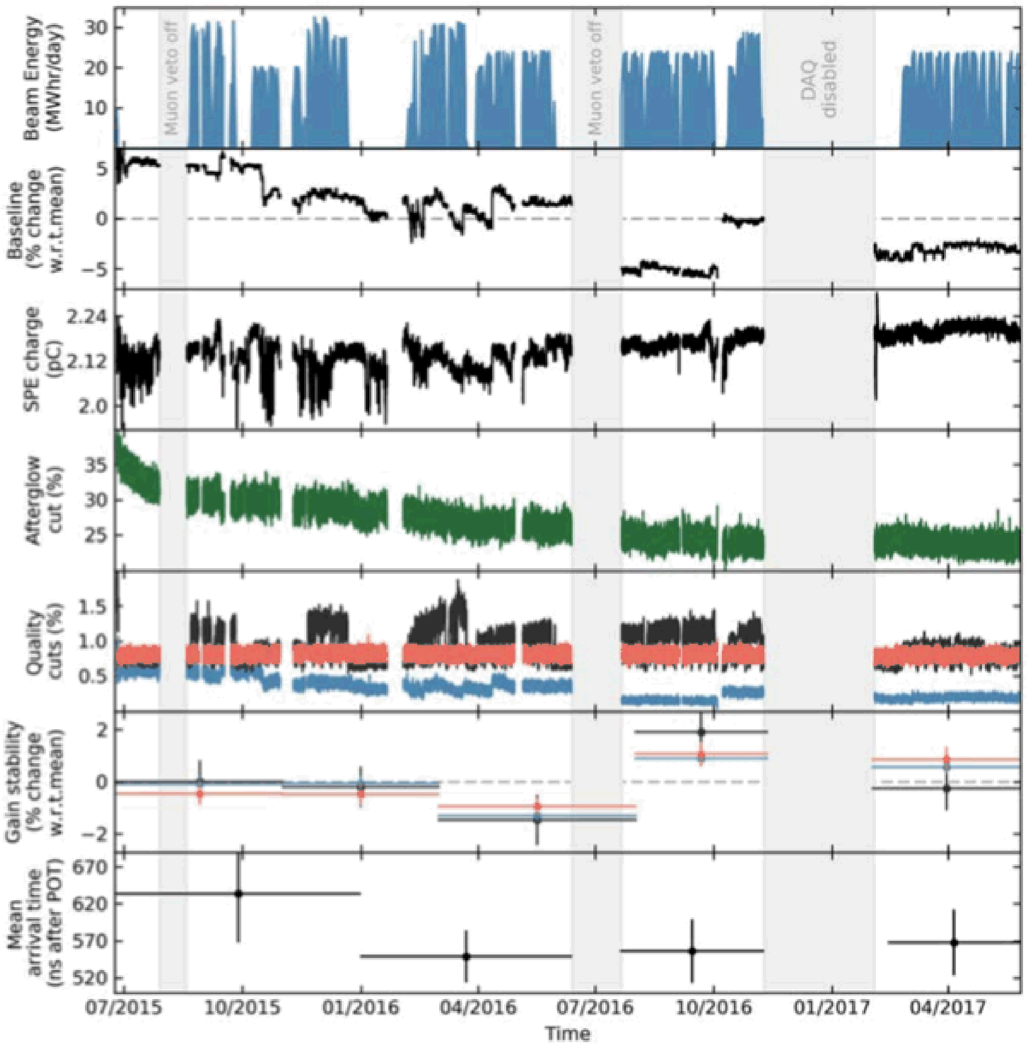
Quenching measurements at TUNL



- CsI Quenching (light yield from nuclear recoils) not very well known
- Two new independent measurements at the Triangle University Nuclear Laboratories, 3.8 MeV DD neutron beam and at the U. Chicago.
- Used 2 kg CsI crystal
- For the first publication, assumed flat quenching of 8.8 % $\pm$ 2.2 %.

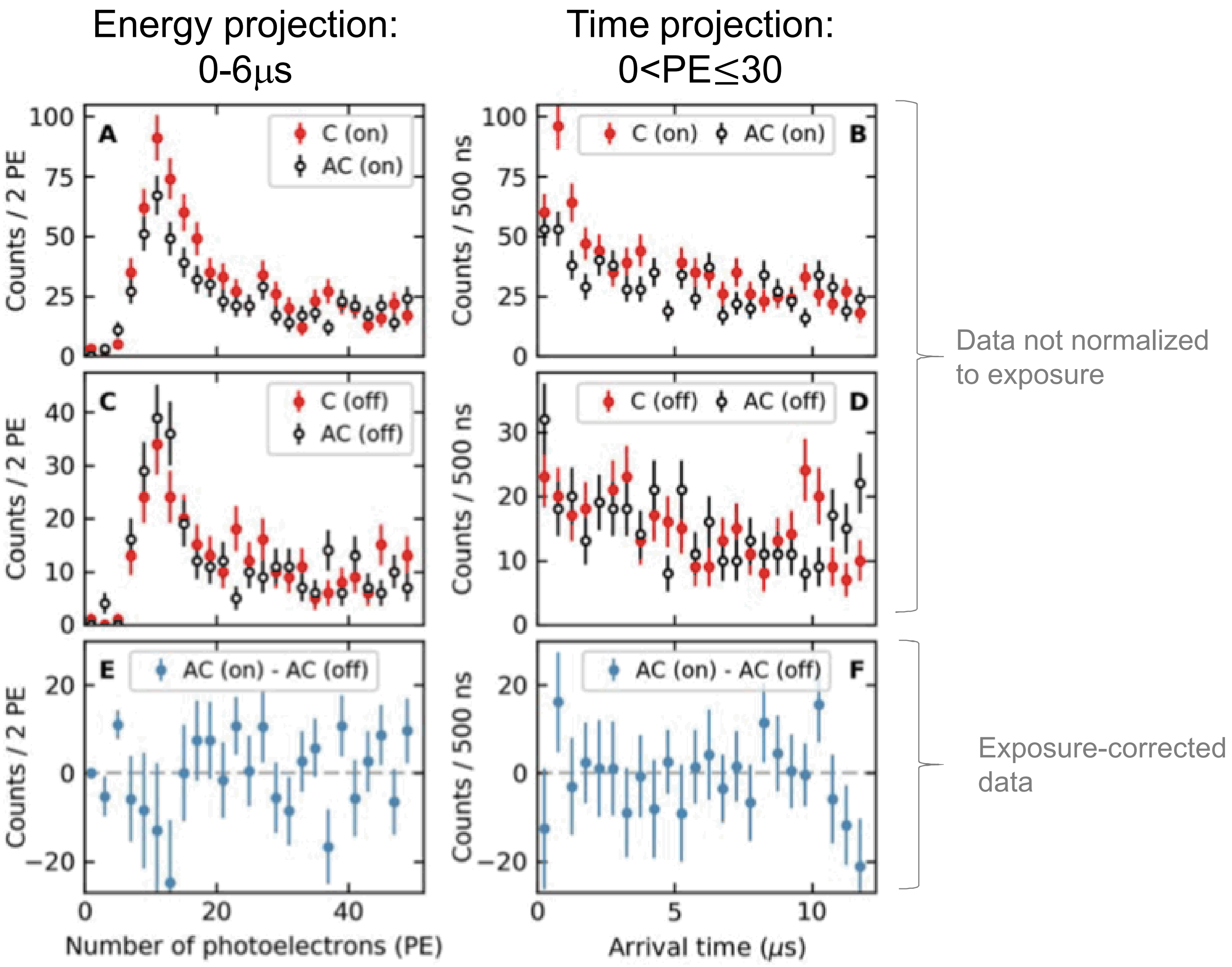


Data quality and stability



Energy to SNS target
CsI channel baseline
PMT SPE mean charge, used for gain fluctuation correction.
Afterglow event removal fraction
Quality cut: Muon veto cut, Linear gate cut, DAQ overflow cut
Gain from internal crystal backgrounds
POT signal stability from muon panel neutron coincidences

After-cuts data



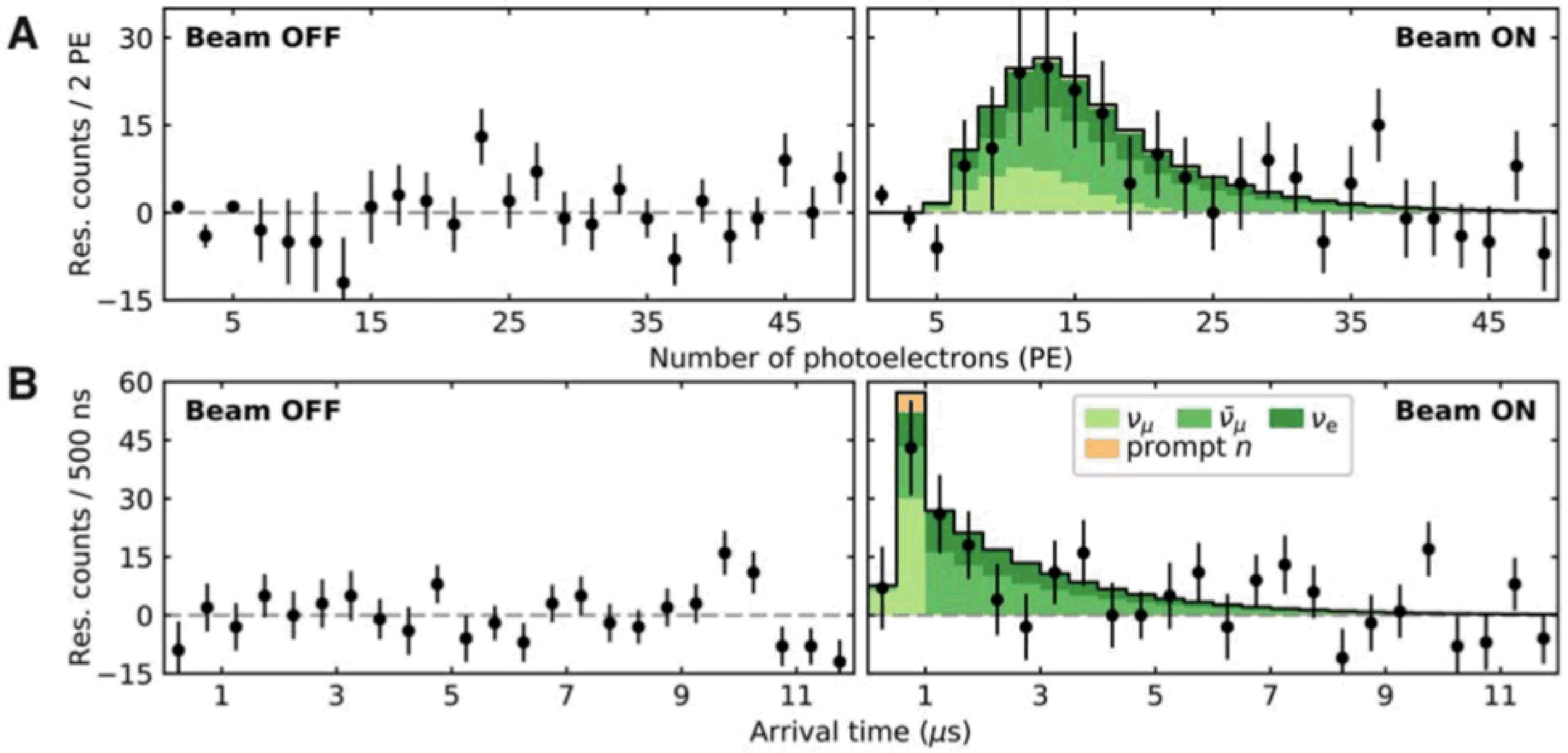
First CEνNs observation with 14.6-kg CsI[Na]

Data points are the **residuals** between CsI[Na] signals in the 12 μs following POT triggers and the 12 μs before:

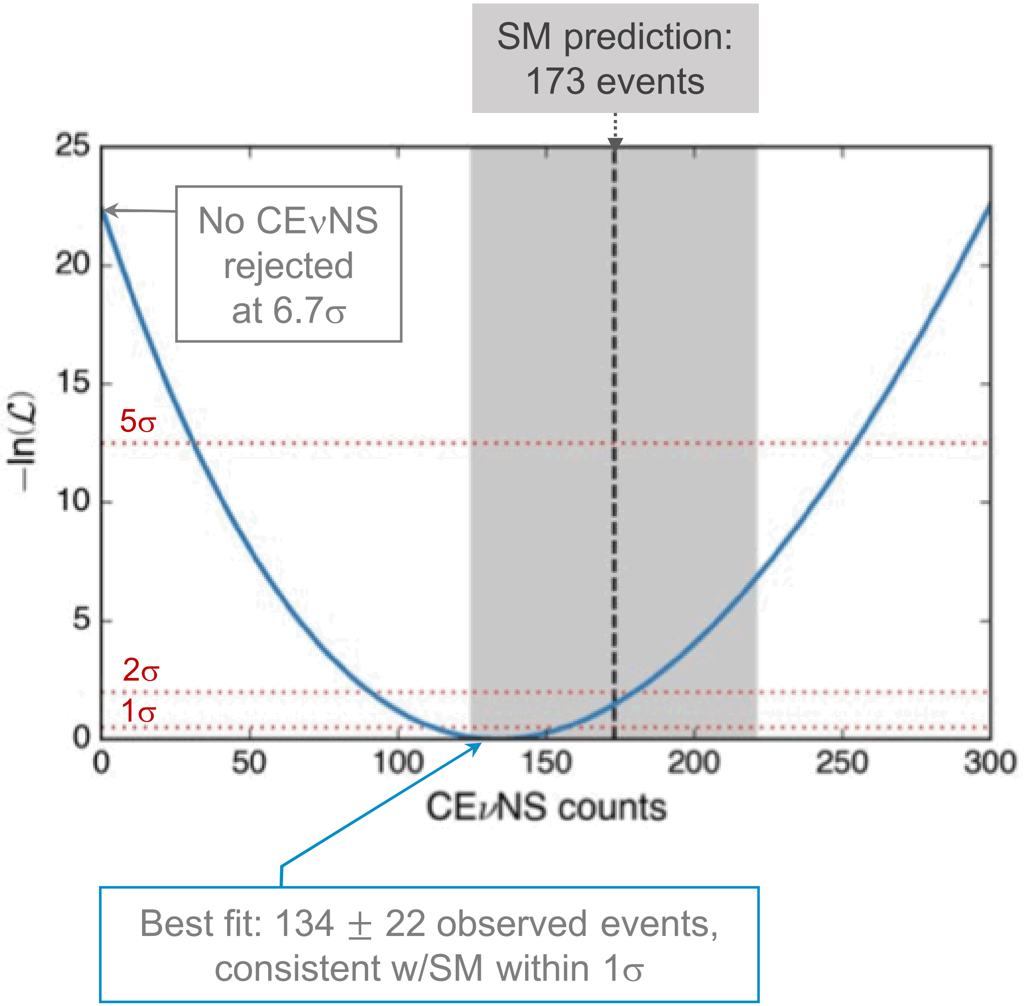
- Beam OFF: 153.5 live-days
- Beam ON: 308.1 live-days, 7.48 GWhr onto the SNS target

Energy

Time



Fitting data to expectation



Using a 2-D energy and time, binned, **maximum likelihood estimator**:

- ROI: $6 \leq \mathrm{PE} < 30, < 6\ \mu s$
- Probability Distribution Functions (PDFs) for:
  - CEνNS signal: convolving simulated neutrino flux with x-section, signal acceptance applied.
  - Prompt neutron background: shape and normalization constraint from *in situ* measurements, signal acceptance applied.
  - Steady-state backgrounds: from anti-coincident data.
- NIN backgrounds neglected: 4 counts spread out over ROI.
- Amplitude of CEνNS signal left unconstraint

Signal, background, and uncertainty

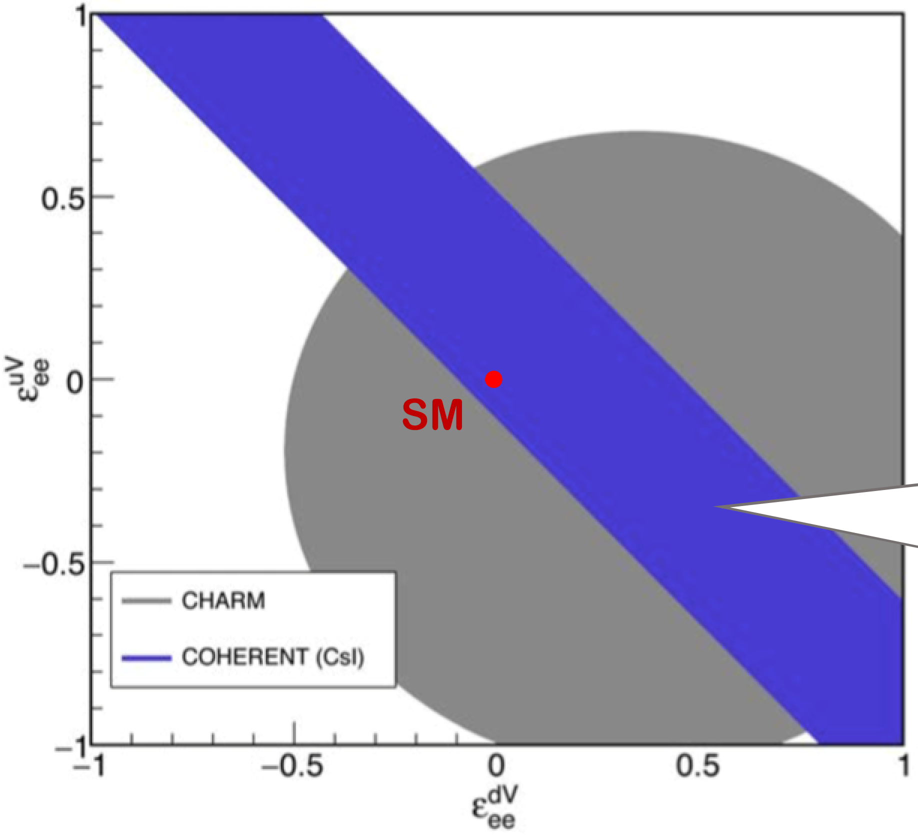
Beam ON coincidence window	547 counts
Anticoincidence window	405 counts
Beam-on bg: prompt beam neutrons	7.0 ± 1.7
Beam-on bg: NINs (neglected)	4.0 ± 1.3
Signal counts, single-bin counting	136 ± 31
Signal counts, 2D likelihood fit	**134 ± 22**
Predicted SM signal counts	**173 ± 48**

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

Data constraints on Non-Standard Neutrino Interactions

$$\mathcal{L}_{\nu H}^{NSI} = -\frac{G_F}{\sqrt{2}} \sum_{\substack{q=u,d \\ \alpha,\beta=e,\mu,\tau}} [\bar{\nu}_\alpha \gamma^\mu (1-\gamma^5)\nu_\beta] \times (\quad \bar{q}\gamma_\mu(1-\gamma^5)q] + \quad \bar{q}\gamma_\mu(1+\gamma^5)q])$$

Davidson et al., JHEP 0303:011 (2004)
Barranco et al., JHEP 0512:021 (2005)



- A first example: simple counting to constrain non-standard interactions (NSI) of neutrinos with quarks
- ε's parameterize new interactions
- Constraint analysis on ε_{ee}^{uV}, ε_{ee}^{dV}, assuming all other ε's zero.
- Parameters describing beyond-the-SM interactions outside this region disfavored at 90%

and more…

Average CsI neutron density distribution from COHERENT data

M. Cadeddu
Dipartimento di Fisica, Università degli Studi di Cagliari, and INFN, Sezione di Cagliari, Complesso Universitario di Monserrato - S.P. per Sestu Km 0.700, 09042 Monserrato (Cagliari), Italy

C. Giunti
INFN, Sezione di Torino, Via P. Giuria 1, I–10125 Torino, Italy

Y.F. Li and Y.Y. Zhang
Institute of High Energy Physics, Chinese Academy of Sciences, and School of Physical Sciences, University of Chinese Academy of Sciences, Beijing 100049, China
(Dated: 10 October 2017)

Using the coherent elastic neutrino-nucleus scattering data of the COHERENT experiment, we determine for the first time the average neutron rms radius of ^{133}Cs and ^{127}I. We obtain the practically model-independent value $R_n = 5.5^{+0.9}_{-1.1}$ fm using the symmetrized Fermi and Helm form factors. We also point out that the COHERENT data show a 2.3σ evidence of the nuclear structure suppression of the full coherence.

9 Aug 2017

FERMILAB-PUB-17-308-T, YITP-SB-17-28, IFT-UAM/CSIC-17-073

A COHERENT enlightenment of the neutrino Dark Side

Pilar Coloma,[1,*] M. C. Gonzalez-Garcia,,[2,3,4,†] Michele Maltoni,,[5,‡] and Thomas Schwetz[6,§]
[1] *Theory Department, Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, IL 60510, USA*
[2] *Departament de Fisíca Quàntica i Astrofísica and Institut de Ciencies del Cosmos, Universitat de Barcelona, Diagonal 647, E-08028 Barcelona, Spain*
[3] *Institució Catalana de Recerca i Estudis Avançats (ICREA), Pg. Lluis Companys 23, 08010 Barcelona, Spain.*
[4] *C.N. Yang Institute for Theoretical Physics, Stony Brook University , Stony Brook, NY 11794-3840, USA*
[5] *Instituto de Física Teórica UAM/CSIC, Calle de Nicolás Cabrera 13–15, Universidad Autónoma de Madrid, Cantoblanco, E-28049 Madrid, Spain*
[6] *Institut für Kernphysik, Karlsruher Institut für Technologie (KIT), D-76021 Karlsruhe, Germany*

COHERENT constraints on nonstandard neutrino interactions

Oct 2017

Jiajun Liao and Danny Marfatia
Department of Physics and Astronomy, University of Hawaii-Manoa, Honolulu, HI 96822, USA

COHERENT constraints to conventional and exotic neutrino physics

T.S. Kosmas [1*] and D.K. Papoulias [1†]
[1] *Theoretical Physics Section, University of Ioannina, GR-45110 Ioannina, Greece*

The process of neutral-current coherent elastic neutrino-nucleus scattering (CEνNS), consistent with the Standard Model (SM) expectation has been recently measured by the COHERENT experiment at the Spallation Neutron Source, Oak Ridge. On the basis of the observed signal and our nuclear calculations for the relevant Cs and I isotopes, the extracted constraints on both conventional and exotic neutrino physics are updated. The present study concentrates on various SM extensions involving vector and tensor non-standard interactions (NSI) as well as neutrino electromagnetic properties with emphasis on the neutrino magnetic moment and the neutrino charge-radius. Furthermore, models addressing a light sterile neutrino state and scenarios with new propagator fields such as vector Z' and scalar bosons are examined, and the corresponding excluded regions by the COHERENT experiment are presented.

MI-TH-1769

Accelerator and reactor complementarity in coherent neutrino scattering

9 Nov 2017

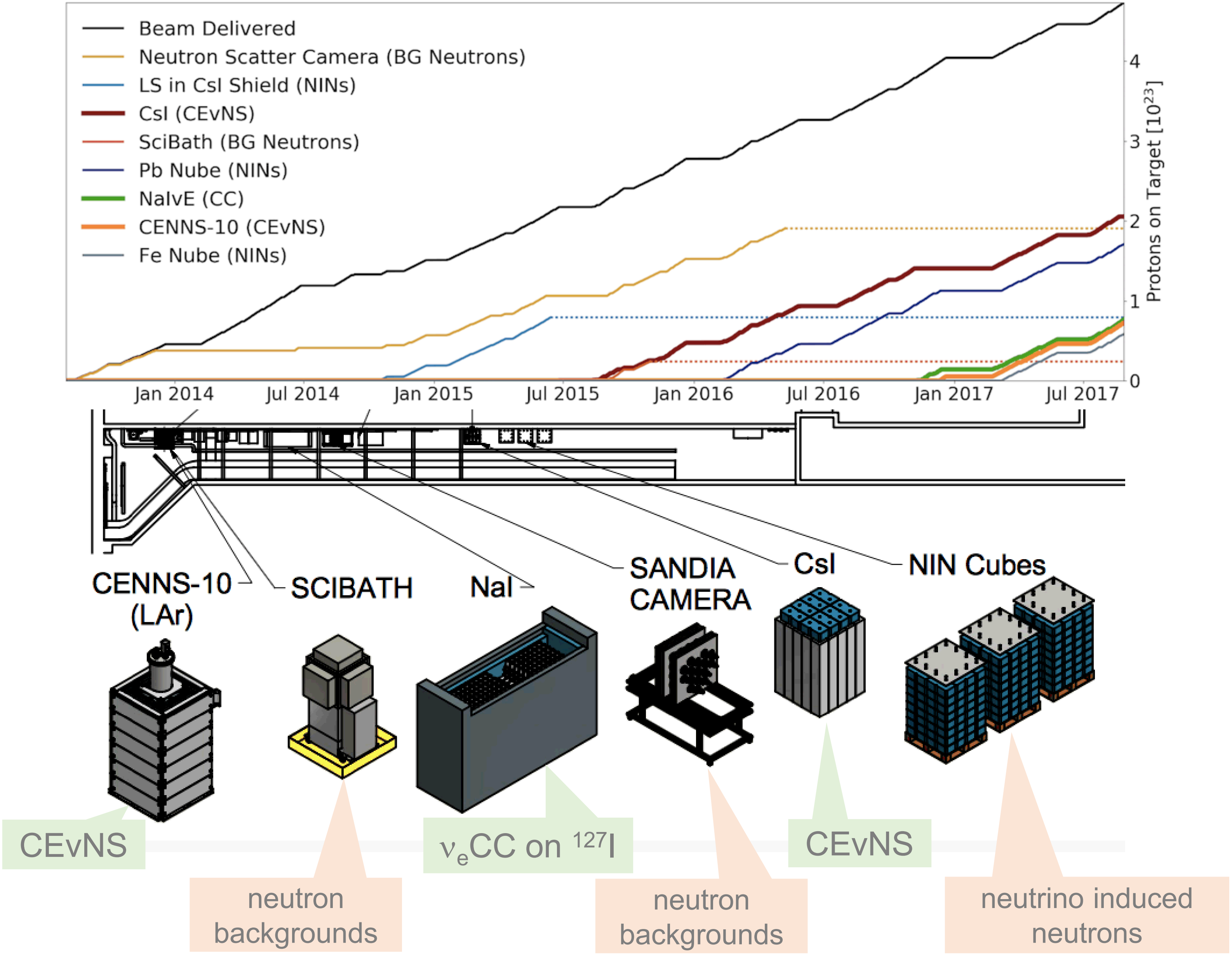
James B. Dent[a], Bhaskar Dutta[b], Shu Liao[b], Jayden L. Newstead[c], Louis E. Strigari[b], and Joel W. Walker[a]
[a] *Department of Physics, Sam Houston State University, Huntsville, TX 77341, USA*
[b] *Mitchell Institute for Fundamental Physics and Astronomy, Department of Physics and Astronomy, Texas A&M University, College Station, TX 77845, USA and*
[c] *Department of Physics, Arizona State University, Tempe, AZ 85287, USA*

Abstract

COHERENT: just the beginning…

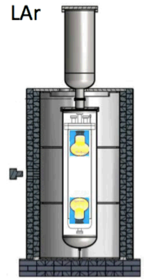
What next? COHERENT current and future activities.

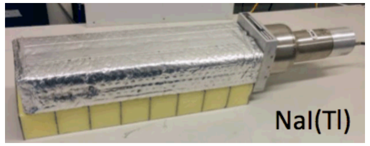
Protons on target delivered so far



COHERENT CEνNS Detector Status

Nuclear Target	Technology	Mass (kg)	Recoil threshold	Distance from source (mm)	Collection start
CsI[Na]	Scintillating crystal	14.6	6.5	20	9/2015
Ge	HPGe PPC	10	5	22	2017
LAr	Single-phase	22	20	29	12/2016
NaI[Tl]	Scintillating crystal	185/2000	13	28	summer 2016

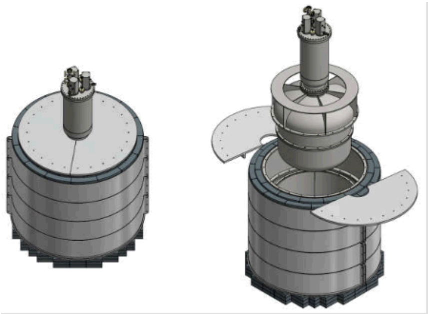


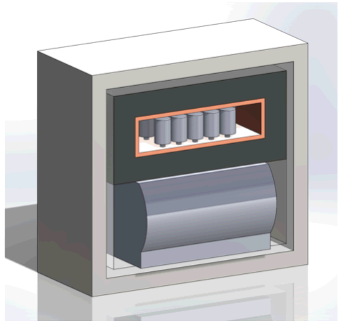


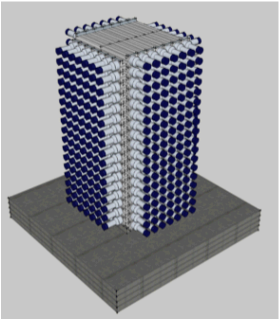
- CsI will continue running
- 185 kg of NaI installed in July 2016
  - taking data in high-threshold mode for CC on ^{127}I
  - PMT base modifications to enable low-threshold CEνNS running
- LAr single-phase detector installed in December 2016
  - upgraded w/TPB coating of PMT & Teflon, running since May 2017
- First Ge detectors to be installed late 2017

COHERENT CEνNS Detector Future

Nuclear Target	Technology	Mass (kg)	Recoil threshold	Distance from source (mm)	Collection start	**Possible Future**
CsI[Na]	Scintillating crystal	14.6	6.5	20	9/2015	Finish data-taking
Ge	HPGe PPC	10	5	22	2017	Additional detectors, 2.5-kg detectors
LAr	Single-phase	22	20	29	12/2016	Expansion to ~1 tonne scale
NaI[Tl]	Scintillating crystal	185/2000	13	28	summer 2016	Expansion to 2 tonne, up to 9 tonnes



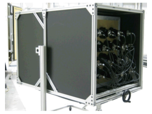
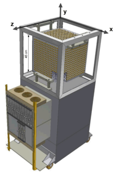


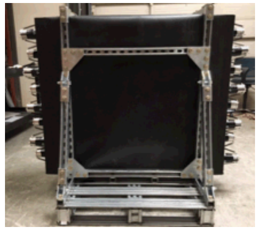
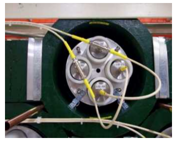


+ concepts for other targets

Non-CEvNS Detectors used/in use by COHERENT

Sandia NSC	Multi-cell liquid scintillator	Neutron background	Deployed 2014-2016
SciBath	WLS fiber + liquid scintillator	Neutron background	Deployed few months during 2015
NaI[Tl]	Scintillating crystal	ν_eCC	High-threshold deployment since summer 2016
Lead Nube	Pb + liquid scintillator	NINs in lead	Deployed since 2016
Iron Nube	Fe + liquid scintillator	NINs in iron	Deployed since 2017
MARS	Plastic scintillator and Gd layers sandwich	Neutron background	Deployed since 2017
Mini-HALO	Pb + NCDs	NINs in lead	In design

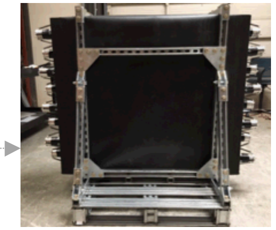
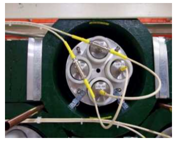



Non-CEvNS Detectors in use by COHERENT

Sandia NSC	Multi-cell liquid scintillator	Neutron background	Deployed 2014-2016
SciBath	WLS fiber + liquid scintillator	Neutron background	Deployed few months during 2015
NaI[TI]	Scintillating crystal	ν_eCC	High-threshold deployment since summer 2016
Lead Nube	Pb + liquid scintillator	NINs in lead	Deployed since 2016
Iron Nube	Fe + liquid scintillator	NINs in iron	Deployed since 2017
MARS	Plastic scintillator and Gd layers sandwich	Neutron background	Deployed since 2017
Mini-HALO	Pb + NCDs	NINs in lead	In design

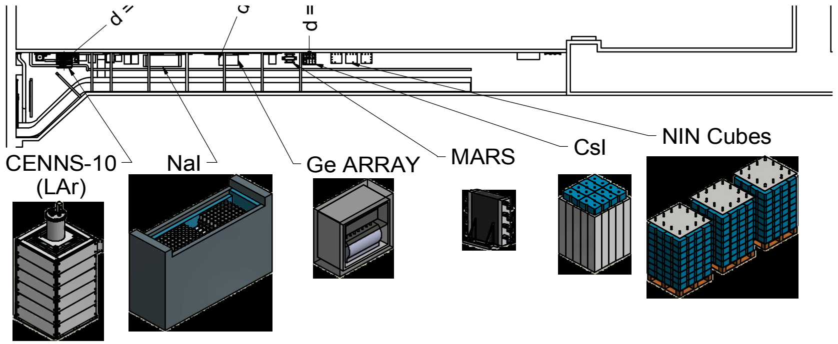


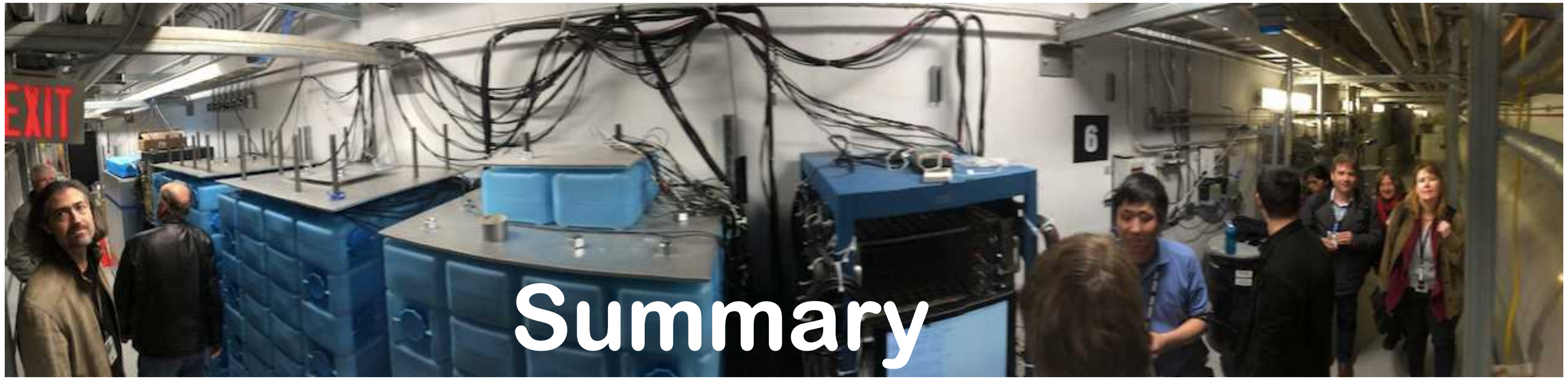



PS + Gd layers detector first developed by N. Bowden

- Planned ν flux normalization: current idea of using D_2O (well known x-scn)
- Independent measurements of quenching factors of COHERENT targets

Neutrino Alley currently





Summary

- CEνNS low-E recoils accessible at SNS with current generation of low-threshold detectors:
    - Non-Standard Interactions, DM background, SM test, astrophysics, nuclear physics, ...

- First measurement by COHERENT CsI[Na] at the SNS.

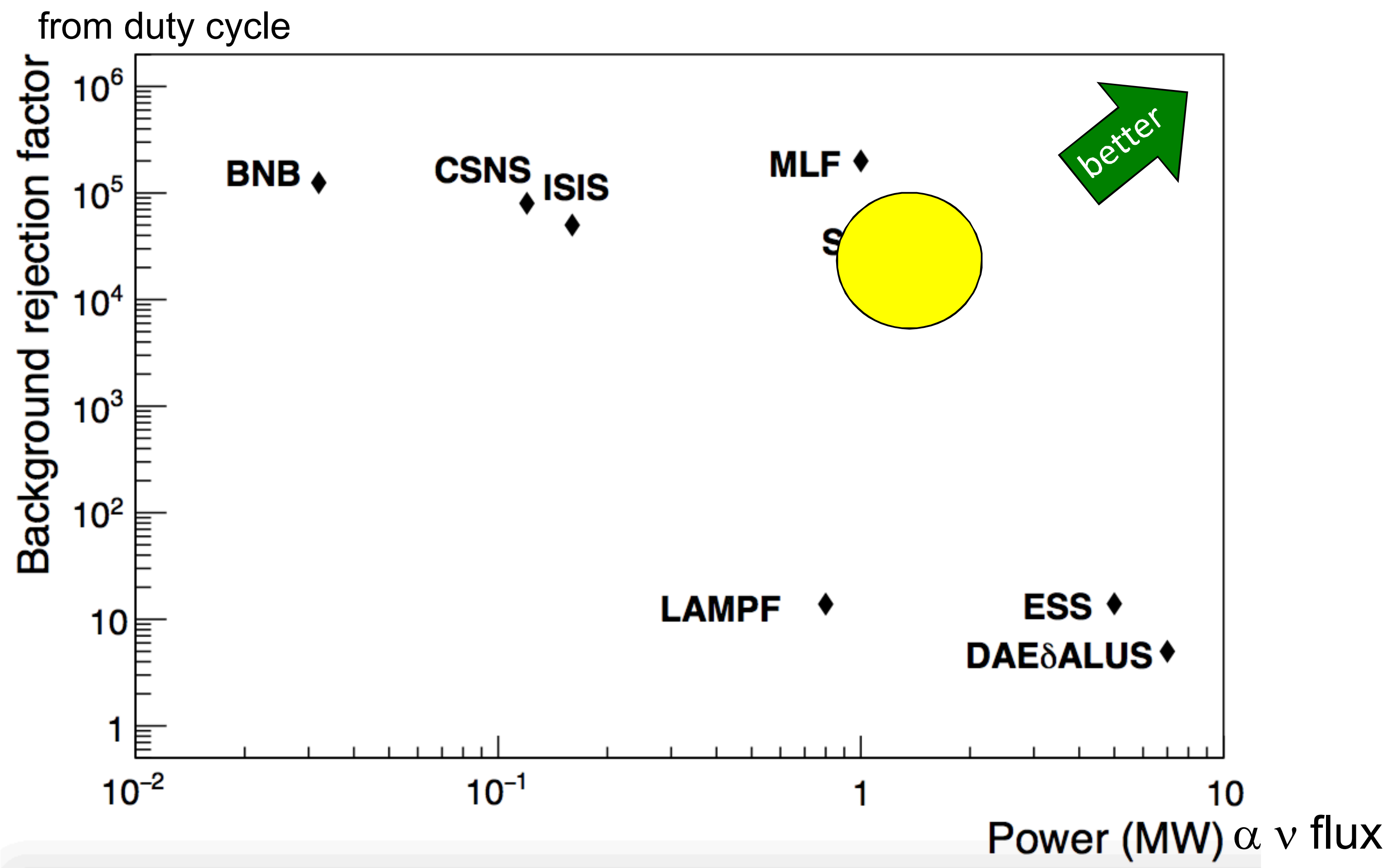
It's just the beginning....

- **Multiple targets (new Ne, Xe,...), upgrades and new ideas in the works!**

- **Other CEνNS experiments will soon join the fun: CONNIE, CONUS, MINER, RED, Ricochet, Nu-cleus...**


EXTRA!

Comparison of pion decay-at-rest ν sources

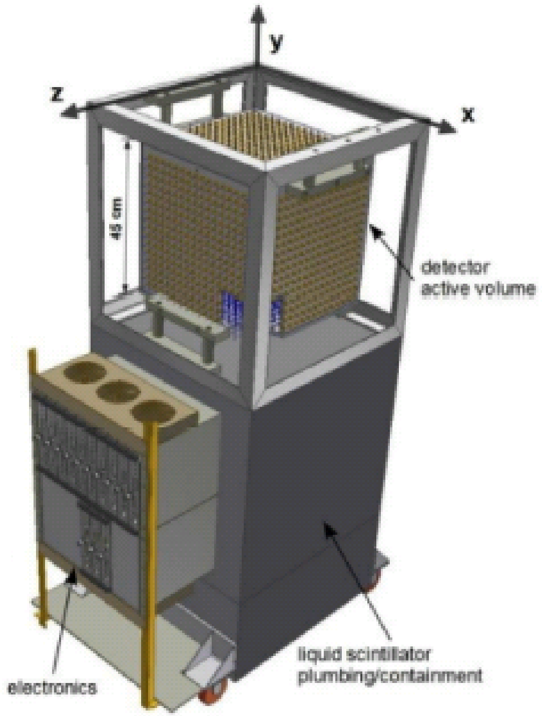


SciBath Neutron Measurement in Neutrino Alley

- Provided ancillary cross-check n the NSC data
- Courtesy of IU Neutrino Group
- Basement of SNS -anticipated LAr location

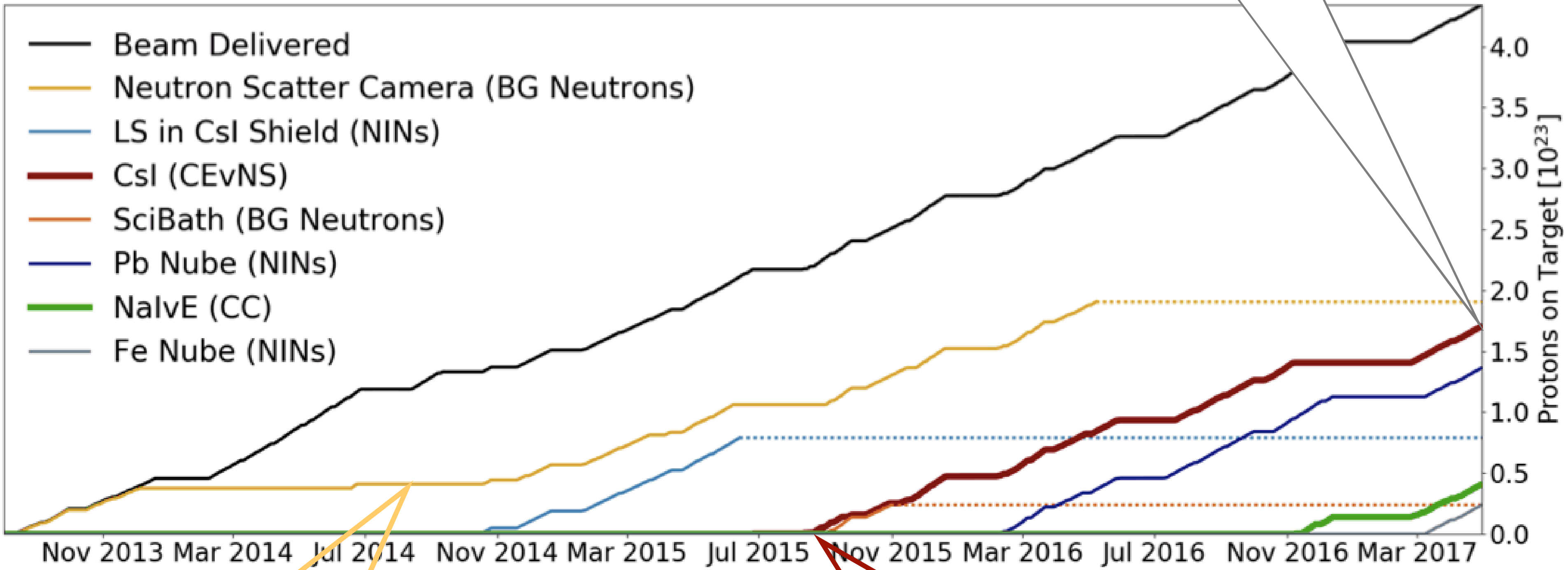
- Large volume (80L) of liquid scintillator with 3 sets of mutually orthogonal, parallel arrays of wavelength-shifting optical fibers: 3D fiber grid gives fine position resolution and accurate directional spectra

- Prompt neutron flux (2.12 ± 0.38) × 10^{-5} n/m^2/spill
- Muon flux (60 ± 3) μ/m^2/s



COHERENT data taking

1.76 x10^{23} POT delivered to CsI (7.48 GWhr)

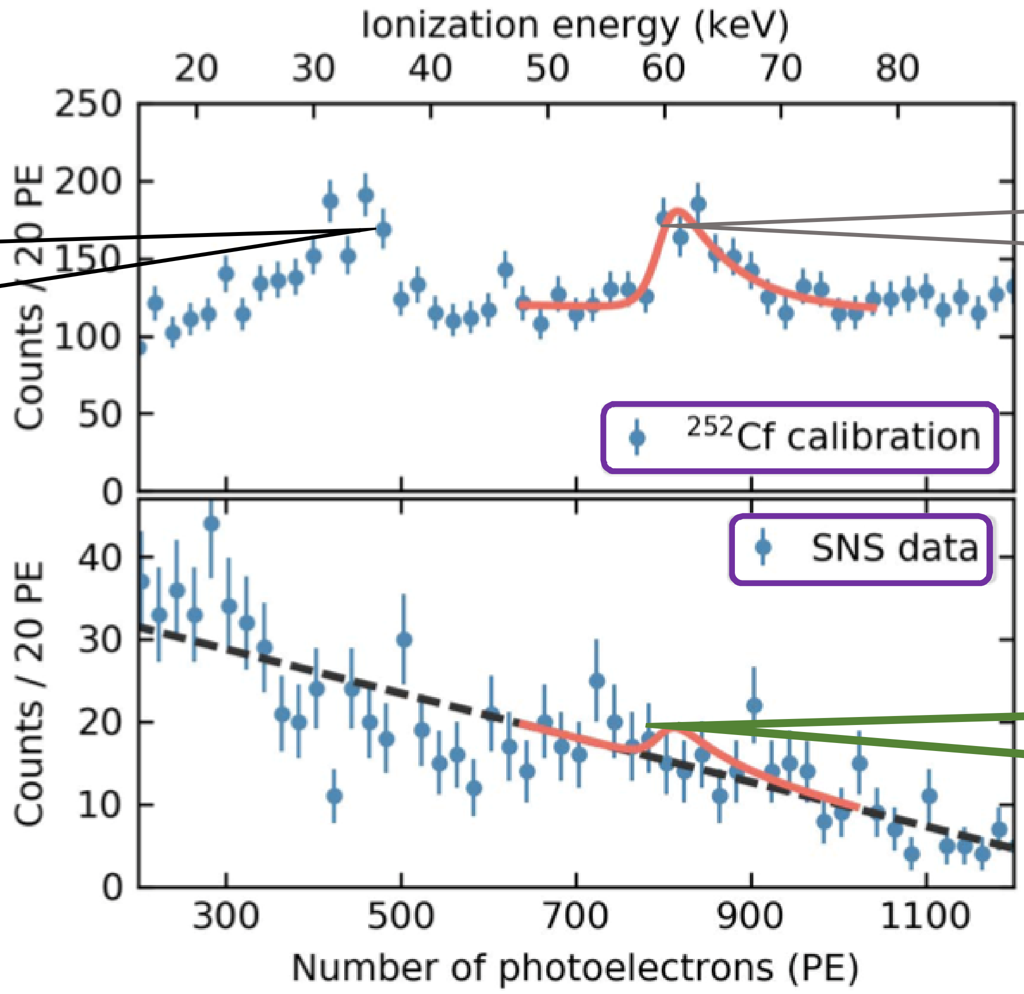


Neutron background data-taking for ~2 years before first CEvNS detectors

CsI data-taking starting summer 2015

Further in-situ limits on in-beam neutrons

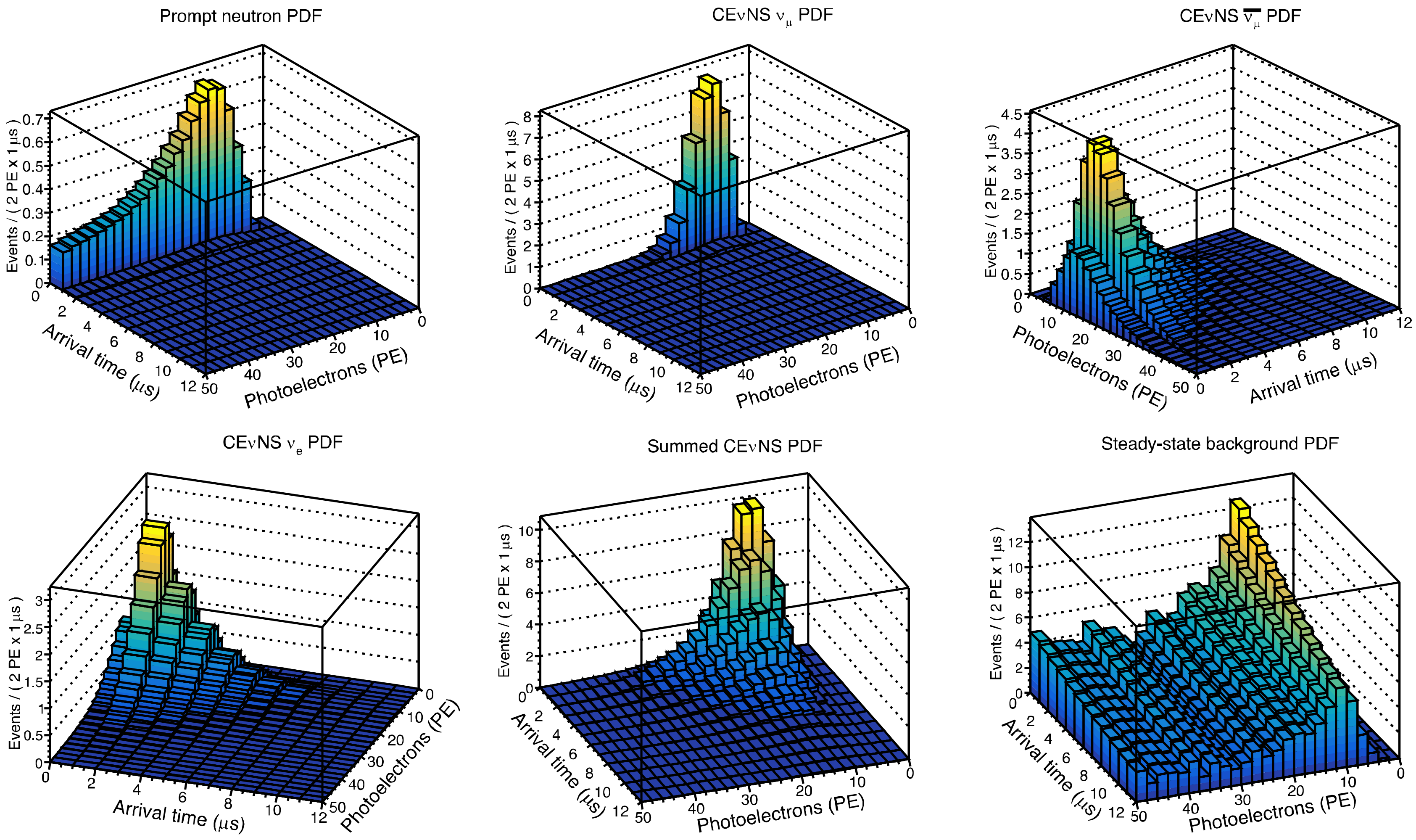
Electron capture decay of ^{128}I at 31.8 keV



^{127}I(n,n'γ) inelastic scattering recoil and γ peak at 57.6 keV

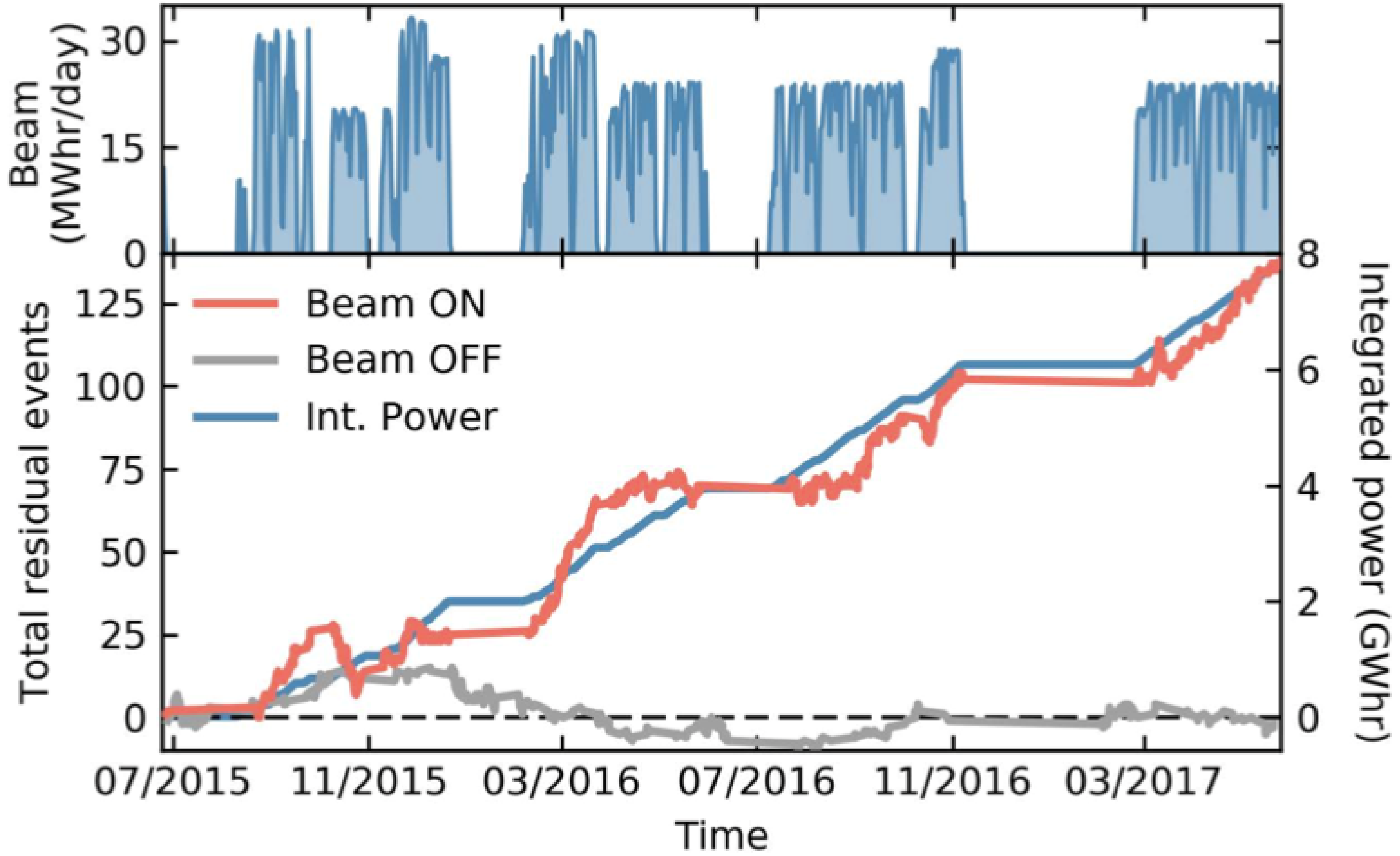
90% CL maximum allowed neutron counts for Beam-ON data

2D Likelihood Analysis Probability Distribution Functions
(move to extra slides)



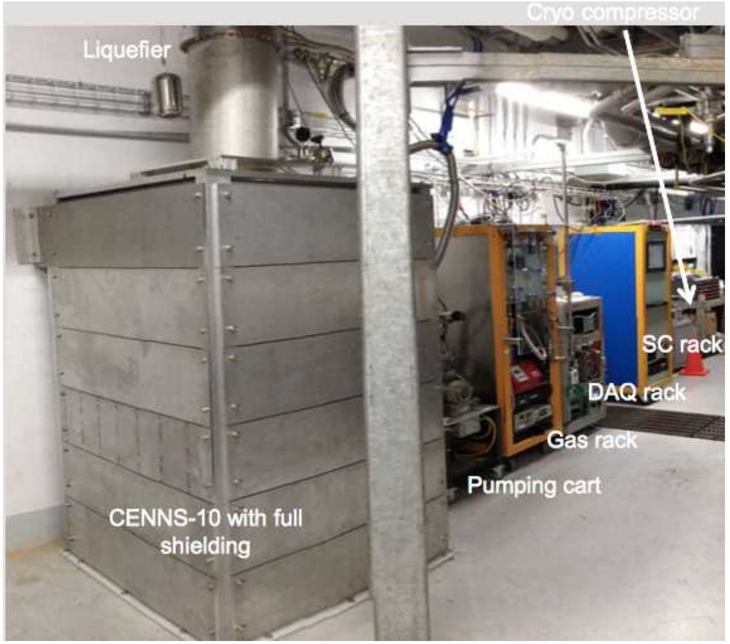
Time evolution of residual counts in C-AC spectra

Total residual counts vs. time consistent with entirely beam-induced events.

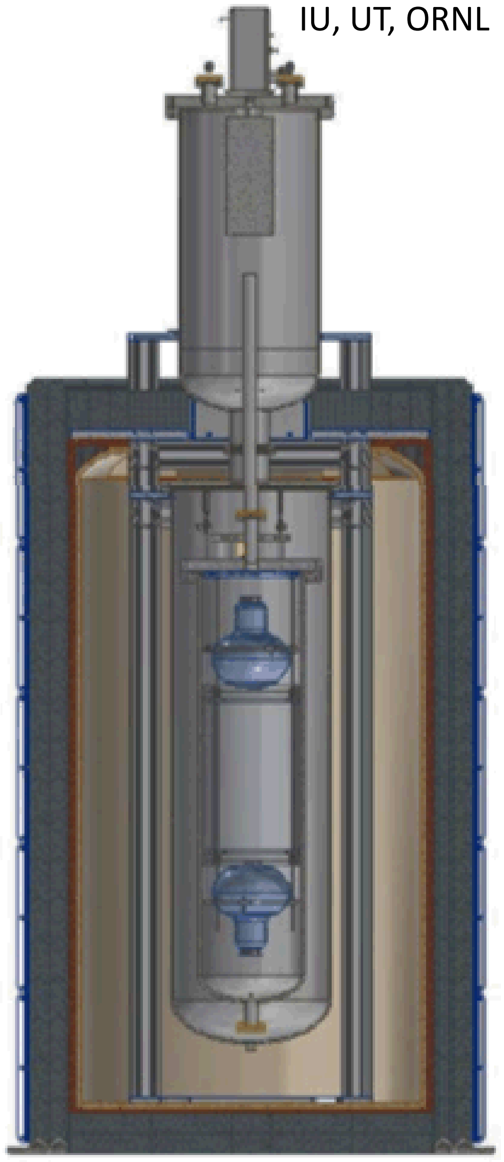


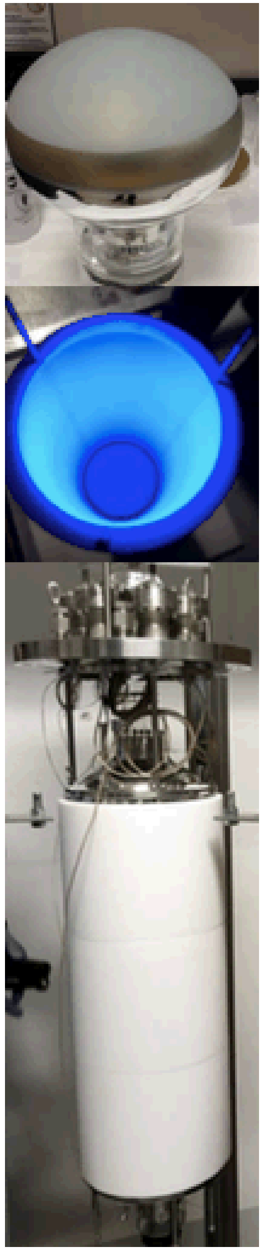
Single-Phase Liquid Argon

- 22 kg fiducial mass
- 2 x Hamamatsu 5912-02-MOD 8” PMTs
  - 8” borosilicate glass window
  - 14 dynodes
  - QE: 18%@ 400 nm
- Wavelength shifter: TB-coated Teflon walls and PMTs
- Cryomech cryocooler – 90 Wt
  - PT90 single-state pulse-tube cold head



IU, UT, ORNL

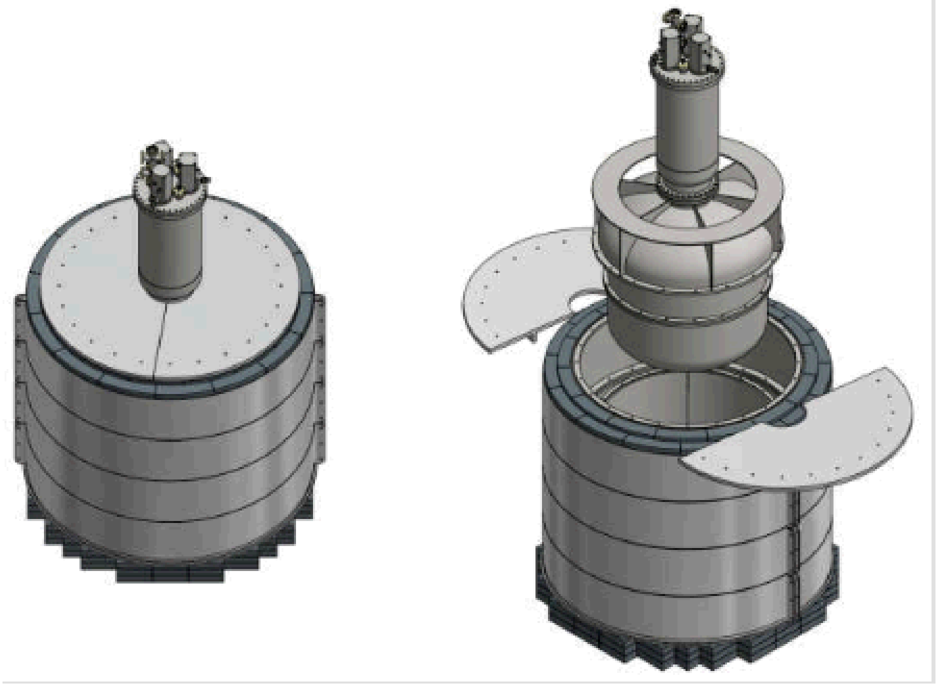


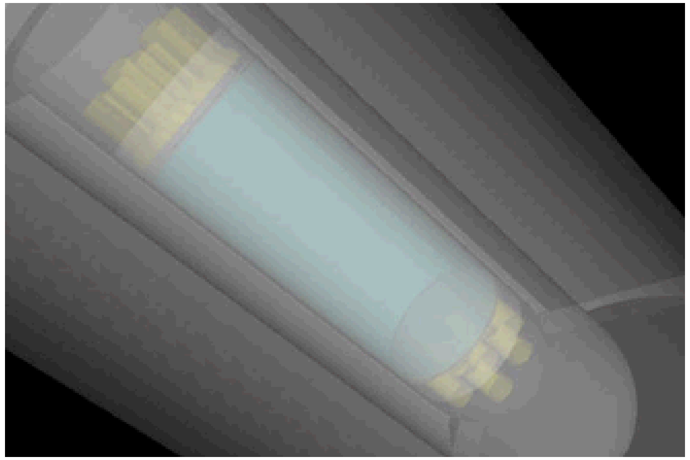


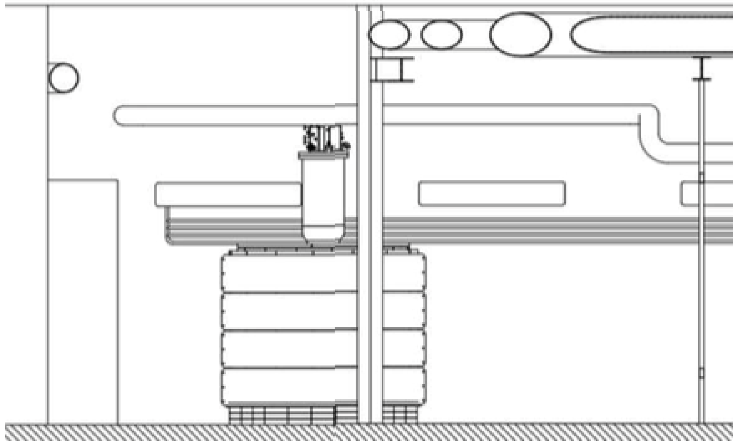
Detector from FNAL, previously built (J. Yoo et al.) for CENNS@BNB
(S. Brice, Phys.Rev. D89 (2014) no.7, 072004)

Future LAr concepts

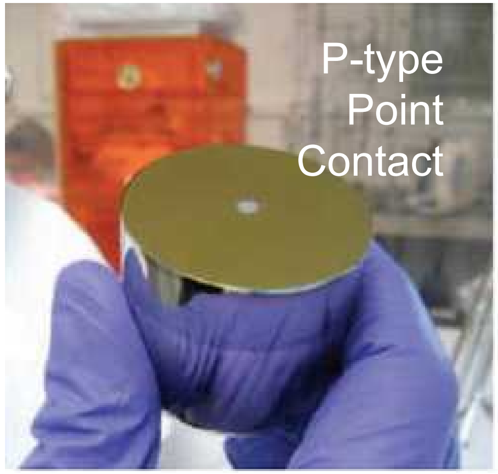
- 1-tonne scale feasible in Neutrino Alley
- Considering depleted argon to reduce ^{39}Ar background
- Considering SiPMs



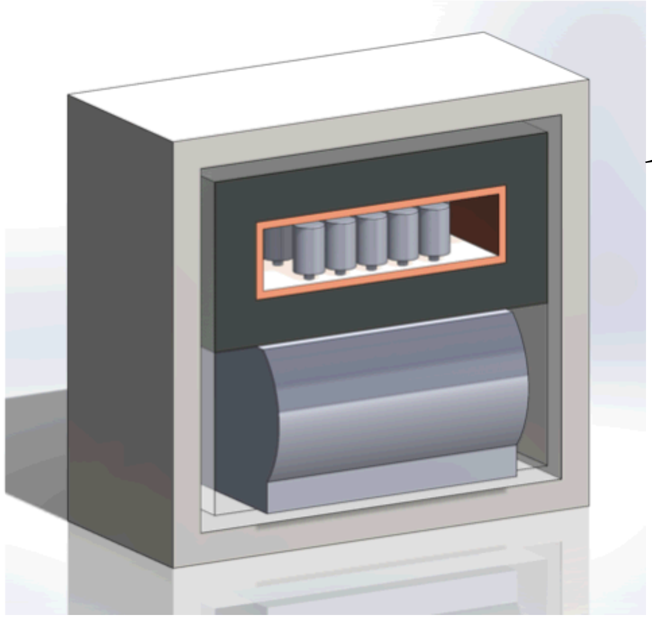




High-Purity Germanium Detectors



- Excellent low-energy resolution & threshold
- Well-measured quenching factor
- Reasonable timing: 1 μs e^-/h drift time



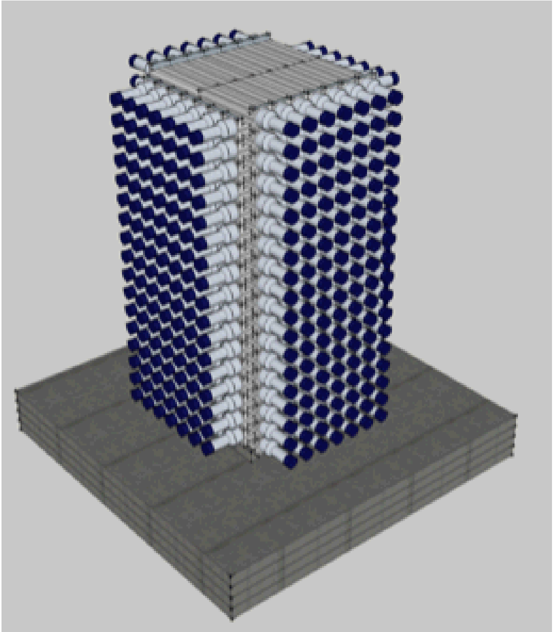
- Canberra cryostats in multi-port dewar
- Compact 4” poly+ 1” Cu+ 6” Pb shield
- 2” muon veto
- Designed to enable additional detectors

- 10 kg of detectors available (MAJORANA unenriched prototypes)
- Under refurbishment/test at NCSU, Duke and LANL
- Dewar fabrication nearly complete
- Future: additional 2.5 kg detectors (UChicago, NCSU)

Sodium Iodide (NaI[Tl]) Detectors (NaIvE)

- 2 tons in hand, up to 9 tons available
- QF measured at TUNL ~ 15%
- require PMT base refurbishment (dual gain) to enable low threshold for CEνNS on Na measurement
- development and instrumentation tests underway at UW, Duke

Multi-ton concept



In the meantime: 185 kg deployed at SNS to measure ν_eCC on ^{127}I.

Isotope	Reaction Channel	Source	Experiment	Measurement (10^{-42} cm^2)	Theory (10^{-42} cm^2)
^{127}I	^{127}I$(\nu_e, e^-)^{127}$Xe	Stopped π/μ	LSND	284 ± 91(stat) ± 25(sys)	210–310 [Quasiparticle] (Engel, Pittel, and Vogel, 1994)

J.A. Formaggio and G. Zeller, RMP 84 (2012) 1307-1341