The COHERENT *neutrino-nucleus scattering research program at the* ORNL *Spallation* N*eutron* S*ource*

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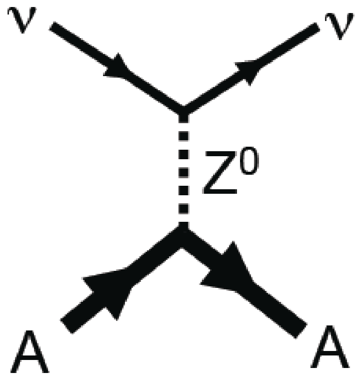
For the COHERENT Collaboration



Coherent Elastic Neutrino-Nucleus Scattering - CEvNS

A neutrino scatters off a nucleus via exchange of a Z, and the nucleus recoils as a whole; coherent up to E_ν ~ 50 MeV

$$\nu + A \rightarrow \nu + A$$

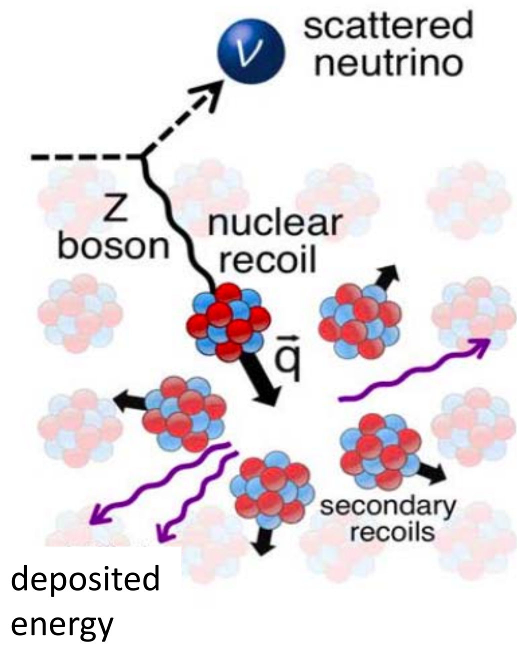
Well understood Standard Model calculation
- differential cross section with respect to T, the nuclear recoil energy,
- dependence on neutron number

$$\frac{d\sigma}{dT} \propto N^2$$

Experimental signature - nuclear recoil
less than about 50 keV of energy deposited from nuclear recoil

➔ WIMP dark matter detectors developed over the last ~decade are sensitive to ~ keV to 10's of keV recoils

➔ Strong, pulsed neutrino source - SNS



Physics of CEvNS

- Supernovae: Expected to be important in core-collapse SN processes and possible SN detection channel.

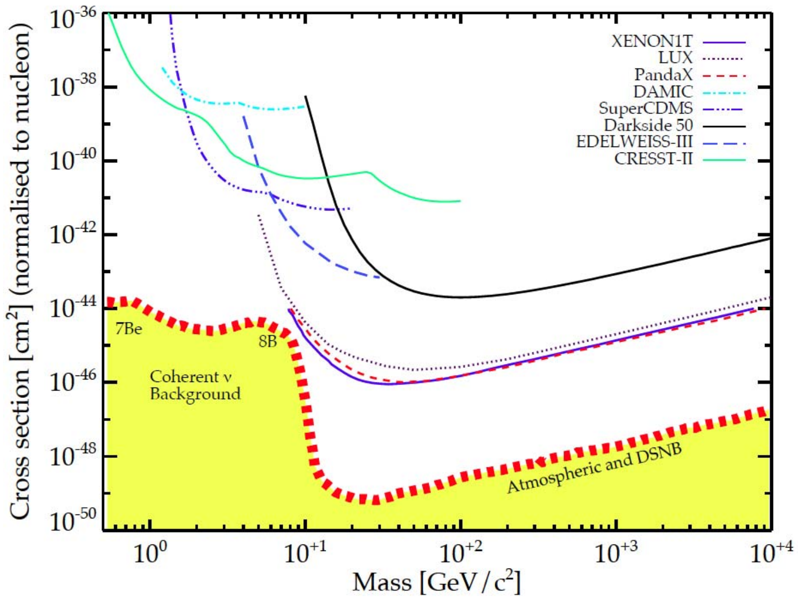
- Nuclear Physics: nuclear form factors
  g_A quenching

- Astrophysical Signals: Solar and SN

- ν oscillations: A possible ν_s detection channel

- Standard Model tests, eg: $\sin^2 \theta_{Weff}$ for low Q
  non-standard interactions of neutrinos
  neutrino magnetic moment

- Dark Matter: Important background for 10-ton direct searches



L. Strigari Private Communication October 2017
J. Billard, E. Figueroa-Feliciano, L. Strigari arXiv:1307.5458v2 (2013)

COHERENT Program

Neutrino source

pulsed proton beam on a mercury target

at the Spallation Neutron Source (SNS) at ORNL

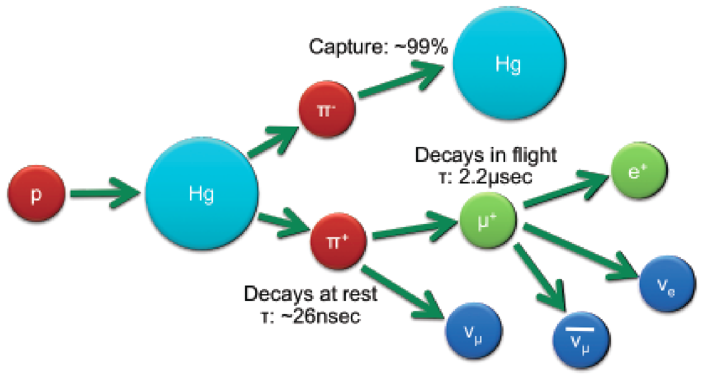
Suite of detector systems for N^2 dependence

well characterized, want low thresholds

Reduce, characterize and control backgrounds

especially 10 - 100 MeV neutrons

SNS Neutrino Beam Timing Profile



$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

2-body decay: monochromatic 29.9 MeV ν_μ
PROMPT

$$\downarrow$$

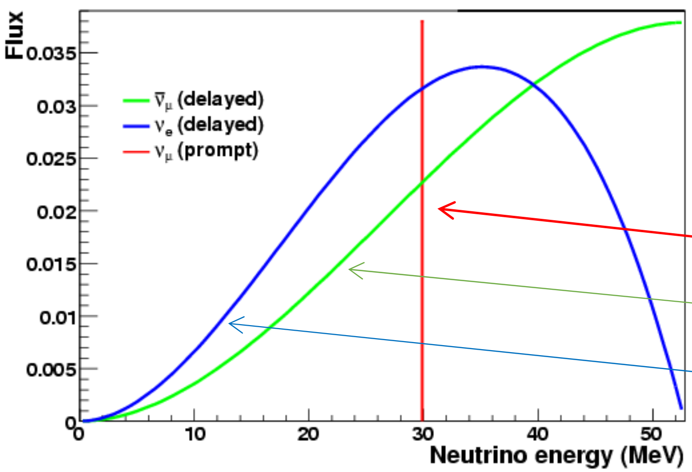
$$\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e$$

3-body decay: range of energies between 0 and $m_\mu/2$
DELAYED (2.2 μs)

1 MW power for high ν flux

60 Hz timing protons on target (POT)

Produces sharply pulsed time structure for background rejection factor ~ 10^{-4}

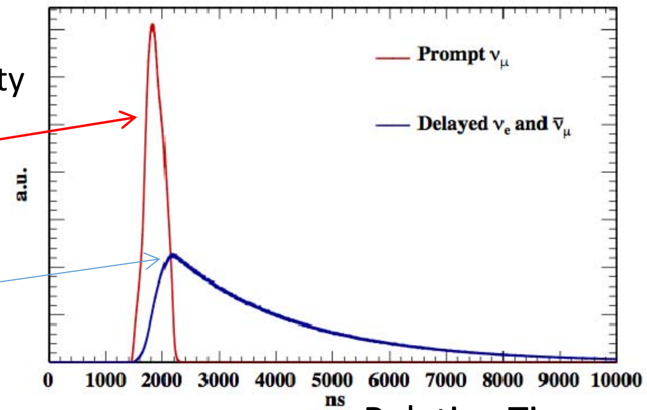


Prompt ν_μ

delayed ν_μ–bar

delayed ν_e

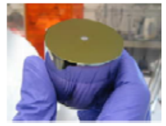
Intensity



Relative Time

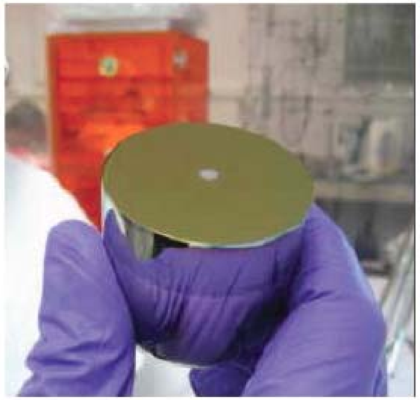
COHERENT CEvNS Detector Status and Future

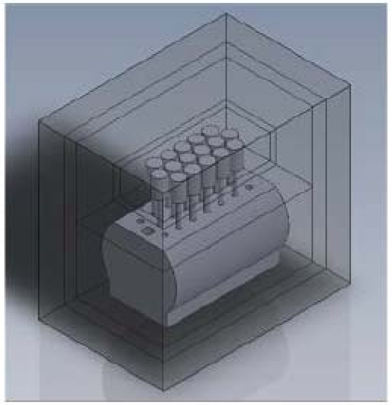
DNP Talk	Nuclear Target	Technology	Mass (kg)	Distance from source (m)	Recoil threshold (keVr)	Data-taking start date	Possible Future
JG - 2	**CsI[Na]**	Scintillating crystal	14.6	20	6.5	9/2015	Continue data accumulation
	Ge	HPGe PPC	10	22	5	2018	Additional detectors, 2.5-kg detectors
JG - 3	**LAr**	Single-phase	22	29	20	12/2016, upgraded summer 2017	Expansion to ~1 tonne scale
JG - 4	**NaI[Tl]**	Scintillating crystal	185* /2000	28	13	*high-threshold deployment summer 2016	Expansion to 2 tonne, up to 9 tonnes

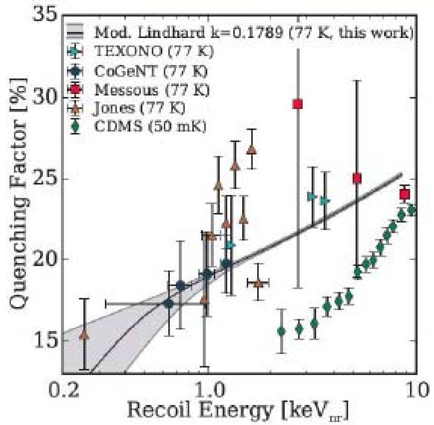




Detector Subsystem - Array of PPC HP Ge

- Smaller N: 38-44
- Excellent resolution at low energies
- Well-measured quenching factor
- Phase I: 5-10kg PPC Ge detector array:
  - **Repurposing on-hand Majorana Demonstrator/LANL ^{nat}Ge detectors.**
  - **Copper/Lead/Poly shield with Plastic scintillator μ-veto.**
  - **Installation**
- **Potential Phase II: Expansion of target with larger-mass (C4-style) point contact detectors.**







Backgrounds

NEUTRONS

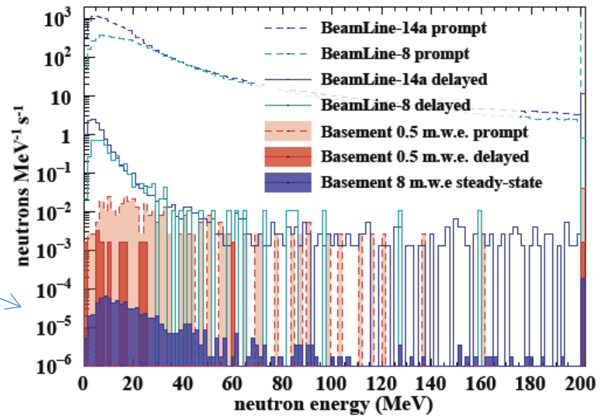
100 keV – 1 MeV neutrons in the detector can produce similar recoil spectra as our neutrino scattering signal

Multiple technologies, complementary analysis to determine background neutrons

Prompt neutron flux ~ 1×10^{-7} neutrons/cm^2/s

Expected rates in detectors - below CEvNS signal

Low neutron background in basement area



NEUTRINO INDUCED NEUTRONS (NINs)

Neutrons can be produced near the detectors. They will be pulsed, and share the 2.2 μs decay time of the neutrinos

$$\nu_e + {}^{208}Pb \Rightarrow {}^{208}Bi^* + e^- \quad (CC)$$
$$\Downarrow$$
$$ {}^{208-y}Bi + x\gamma + yn$$

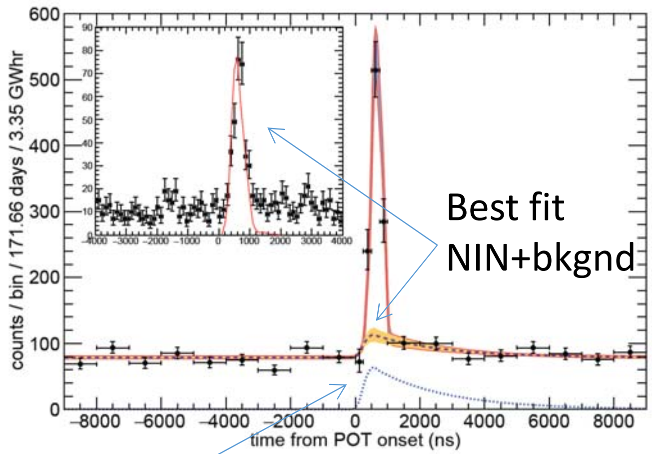
$$\nu_x + {}^{208}Pb \Rightarrow {}^{208}Pb^* + \nu_x' \quad (NC)$$
$$\Downarrow$$
$$ {}^{208-y}Pb + x\gamma + yn.$$

In-situ measurements using EJ - 301 cells inside CsI detector region - measured flux lower than expected

Analysis of NIN data in dedicated neutrino-cube underway

Process important in its own right

Arrival Time of n-like events
EJ301 Data



Best fit NIN+bkgnd

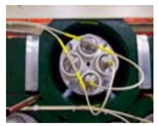
Predicted NIN

COHERENT Non-CEvNS Detectors ("In-COHERENT")

Sandia Neutron Scatter Camera	Multiplane liquid scintillator	Neutron background	Deployed 2014-2016
LS in CoSI Shield	liquid scintillator	NINs background	Deployed 2014-2015
SciBath	WLS fiber + liquid scintillator	Neutron background	Deployed 2015
NaI[TI]	Scintillating crystal	ν_eCC	High-threshold deployment 2016
Lead Nube	Pb + liquid scintillator	NINs in lead	Deployed 2016
Iron Nube	Fe + liquid scintillator	NINs in iron	Deployed 2017
MARS	Plastic scintillator and Gd sandwich	Neutron background	Deployed 2017
Mini-HALO	Pb + NCDs	NINs in lead	In design





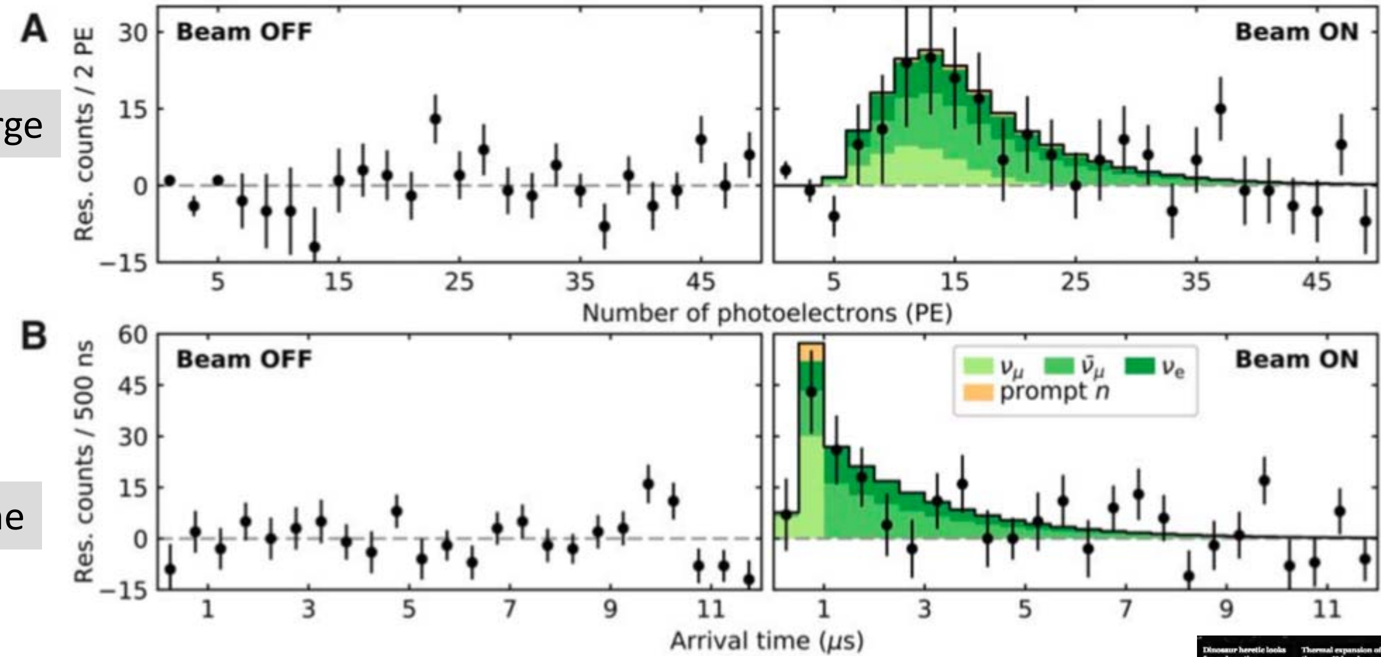
And many more ideas and activities for Neutrino Alley and beyond...

- Inelastic CC and NC in Ar, Pb, ...
- Other crystal or scint deployments in CsI shield
- Study of NIN with liquid scintillator in CsI shield
- Flux normalization using D_2O (well known xscn)
- Ancillary measurements: Quenching Factors

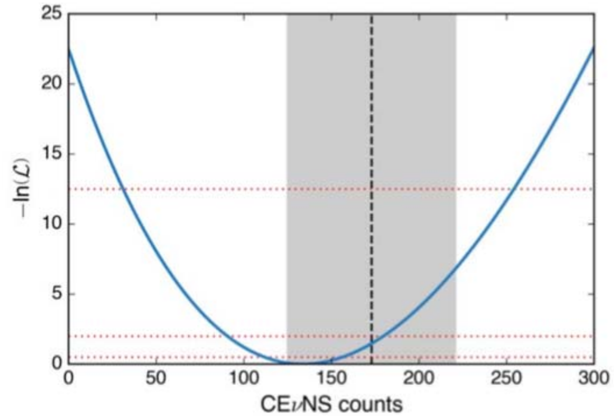
First Observation of CEvNS - at the SNS with 14.6-kg CsI[Na] detector

Charge

Time



SM prediction, 173 events



Best fit: 134 ± 22 observed events

Observation of coherent elastic neutrino-nucleus scattering

D. Akimov[1,2], J. B. Albert[3], P. An[4], C. Awe[4,5], P. S. Barbeau[4,5], B. Becker[6], V. Belov[1,2], A. Brown[4,7], A. Bolozdy...

+ See all authors and affiliations

Science 03 Aug 2017:
eaao0990
DOI: 10.1126/science.aao0990

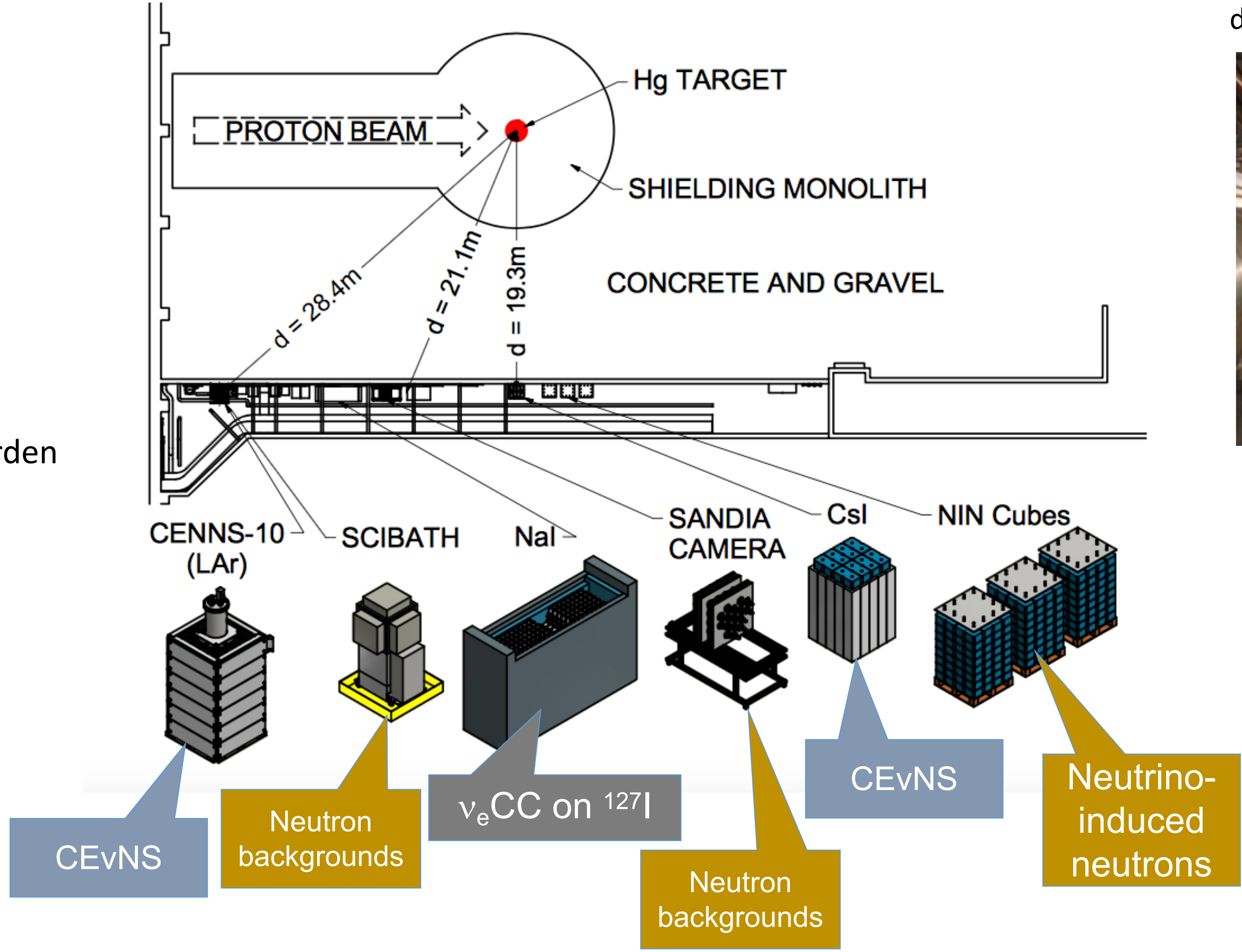
Peer Reviewed
← see details

No CEvNS rejected at 6.7σ, consistent w/SM within 1σ

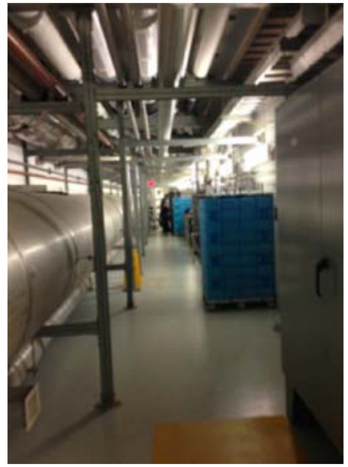
D. Akimov et al., *Science*, 2017
http://science.sciencemag.org/content/early/2017/08/02/science.aao0990

Deployments so far in Neutrino Alley

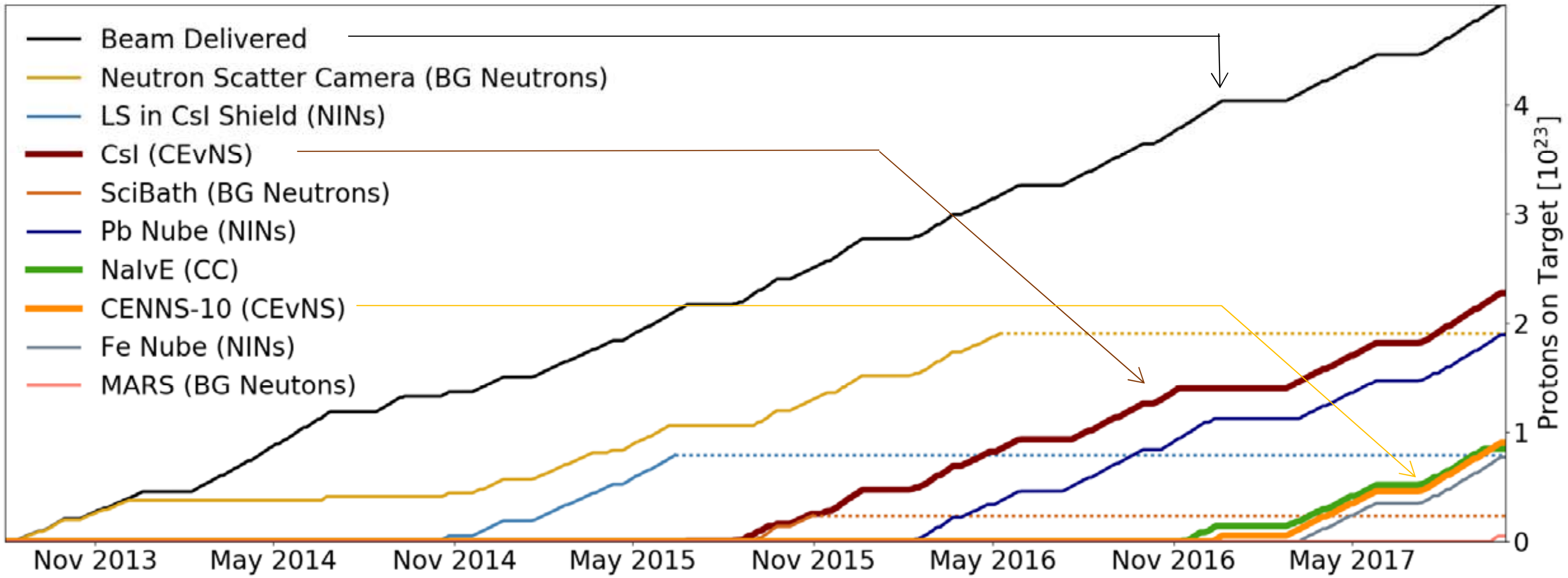
Basement siting
low neutron flux
~ 8 mwe overburden



View looking down "Neutrino Alley"

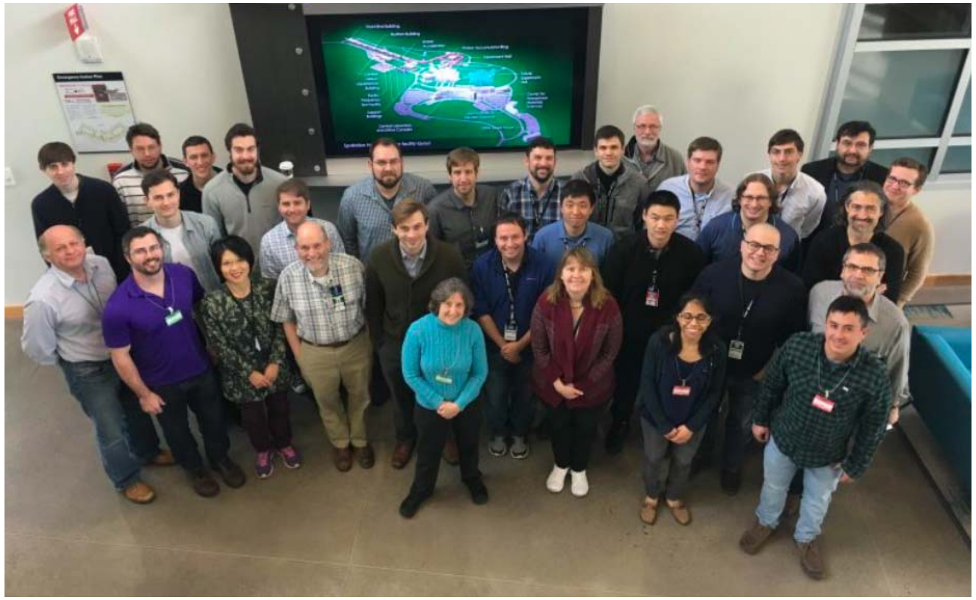


Cummulative Protons on Target
Monitoring of Accumulated Statistics in Each Subsystem



The COHERENT collaboration

http://sites.duke.edu/coherent



~80 members, 19 institutions, 4 countries

DMM supported by NSF-HRD-1601174

The COHERENT Experimental Program

To unambiguously measure the coherent neutrino-nucleus cross section in multiple nuclei.

The COHERENT Collaboration has observed CEvNS in CsI

Mulitple target materials in development and acquiring data
CsI, LAr, NaI[Tl], Ge (show N^2 dependence)
Other target materials under consideration for feasibility

Supports other activities: quenching factor measurements, charged current cross sections, NINs measurements, ...

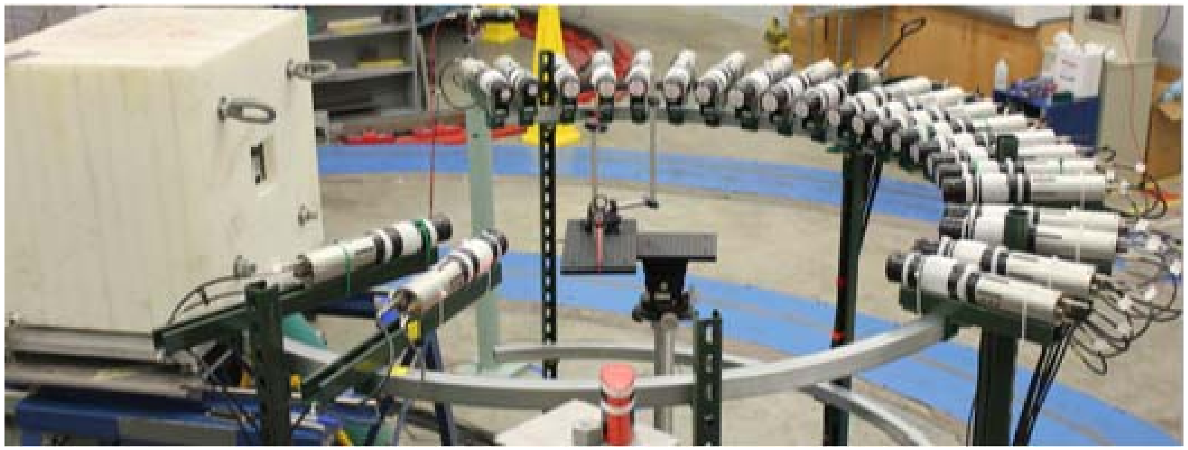
Work toward target sensitivity for nuclear physics, NSI measurements,...

Extra Slides -
Cool Pictures for Just in Case

Backup Slides: Quenching Factor Measurements

- A facility has been developed at Duke/TUNL to enable the precision calibration of all of these detectors. *CsI(Na) and NaI(Tl) data in the can. Quenching factor uncertainties are the dominant uncertainty on the cross-sections, after the beam flux.*

- The neutron beam is tunable (20 keV - 3 MeV), Monochromatic (3 keV width), collimated (1.5 cm) and pulsed (2 ns)



Neutron Background Studies at the SNS Basement

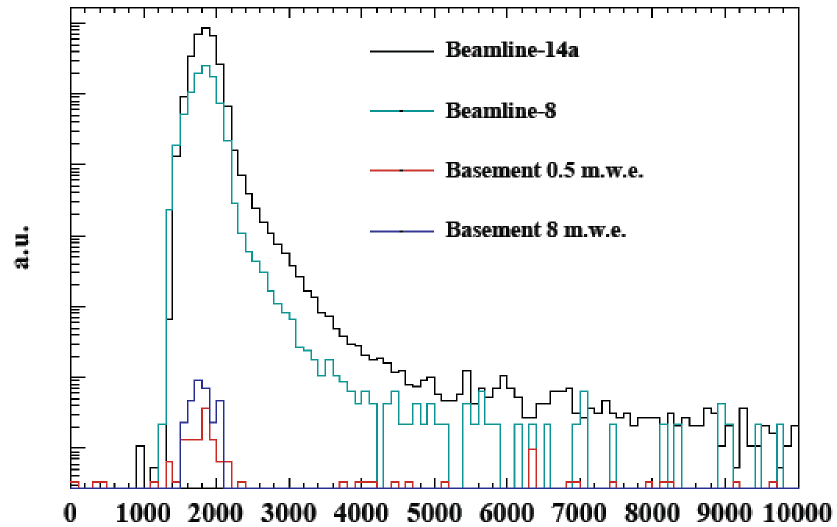
Fast neutron backgrounds in the basement are clearly associated with 800 ns protons on target

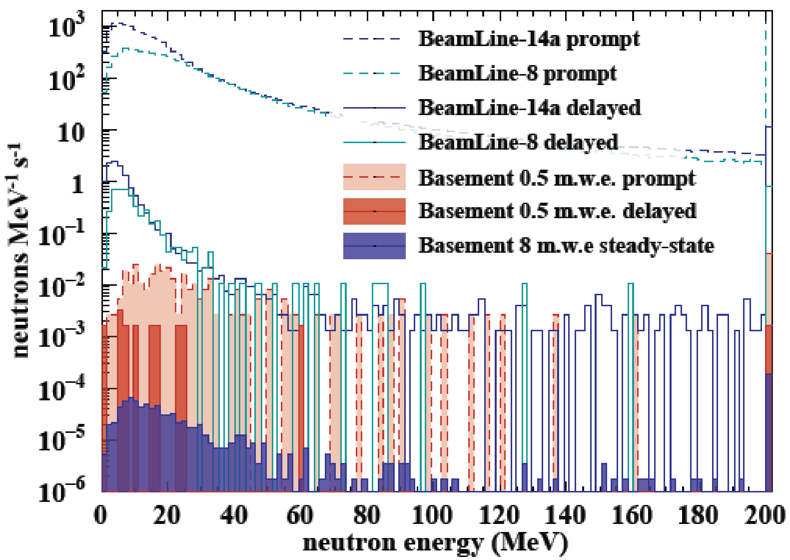
A 2.2 μs window after the beam would highlight muon decay neutrinos (ν_μ-bar, ν_e)

Neutron backgrounds reduced by at least an order of magnitude in the delayed window compared to prompt

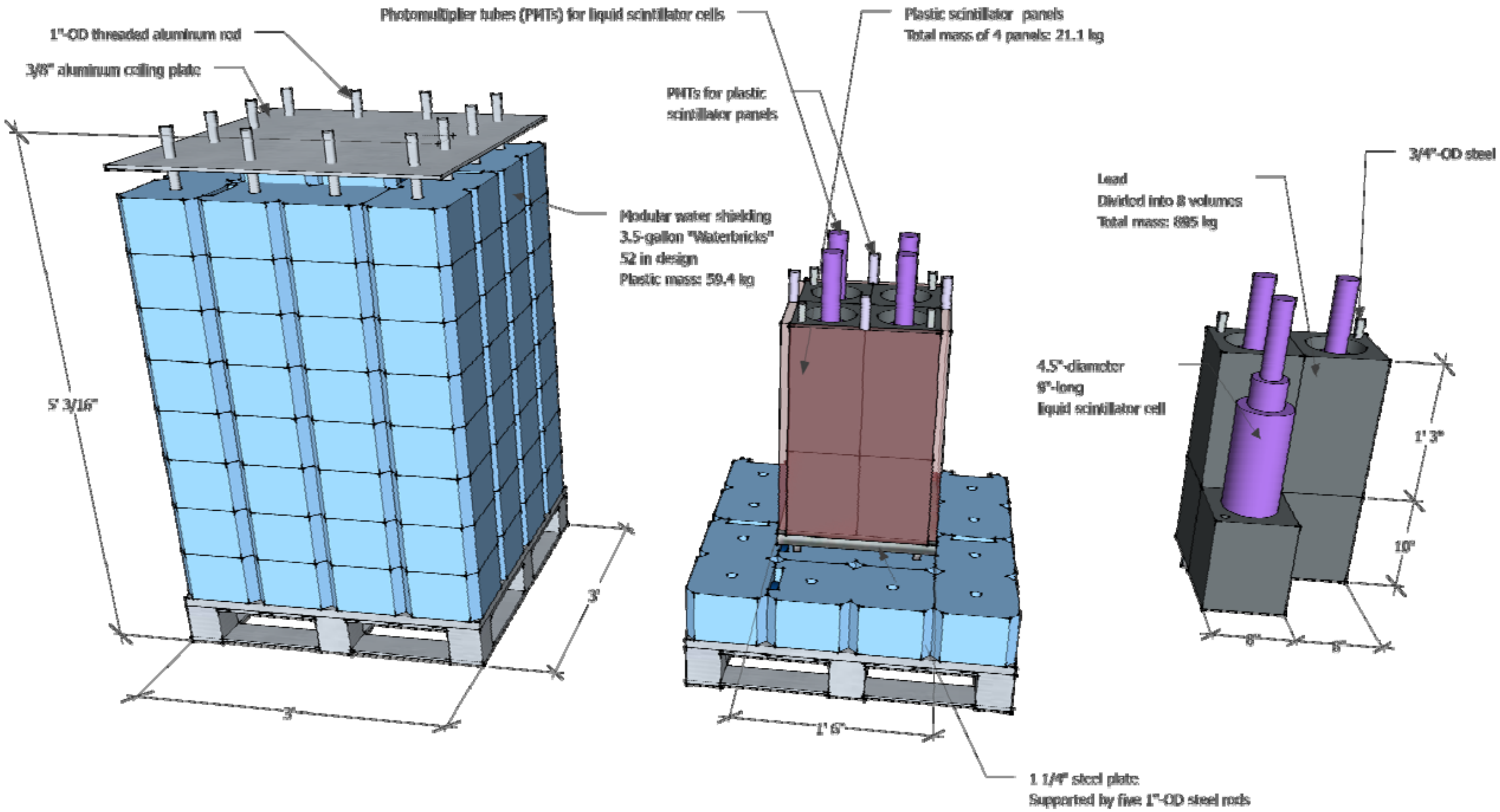
Neutrons in the delayed window are significantly lower in energy and therefore relatively easier to shield.

Scatter-camera data (SNL)
Consistent with earlier Portable LS Cells data (ORNL)
Confirmation with initial data from SciBath imager (IU)





Measuring the ν-induced Neutrons



- Several palletized (mobile) targets with LS detectors delivered to the SNS
- Will measure neutrino-induced-neutrons on Pb, Fe and Cu