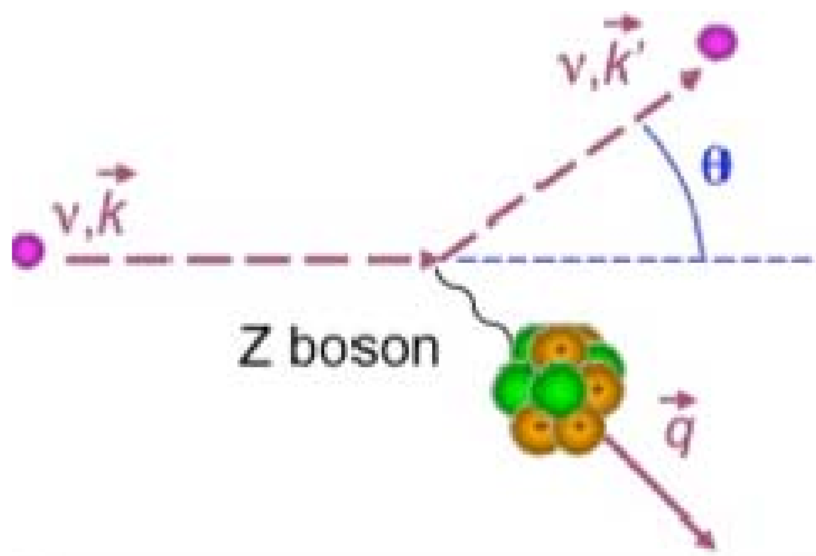
COHERENT SNS ν Scattering

Phil Barbeau, Duke University
Matthew Green, NC State

Coherent **ν**-Nucleus Scattering

- Predicted in 1974 with the realization of the weak neutral current: as yet unobserved
- Neutrino scatters coherently off all Nucleons → cross section enhancement: $\sigma \propto \mathbf{N^2}$
- Initial and final states must be identical: Neutral Current elastic scattering
- Nucleons must recoil in phase →low momentum transfer qR <1 → *very* low energy nuclear recoil



D. Z. Freedman, PRD 9 (5) 1974

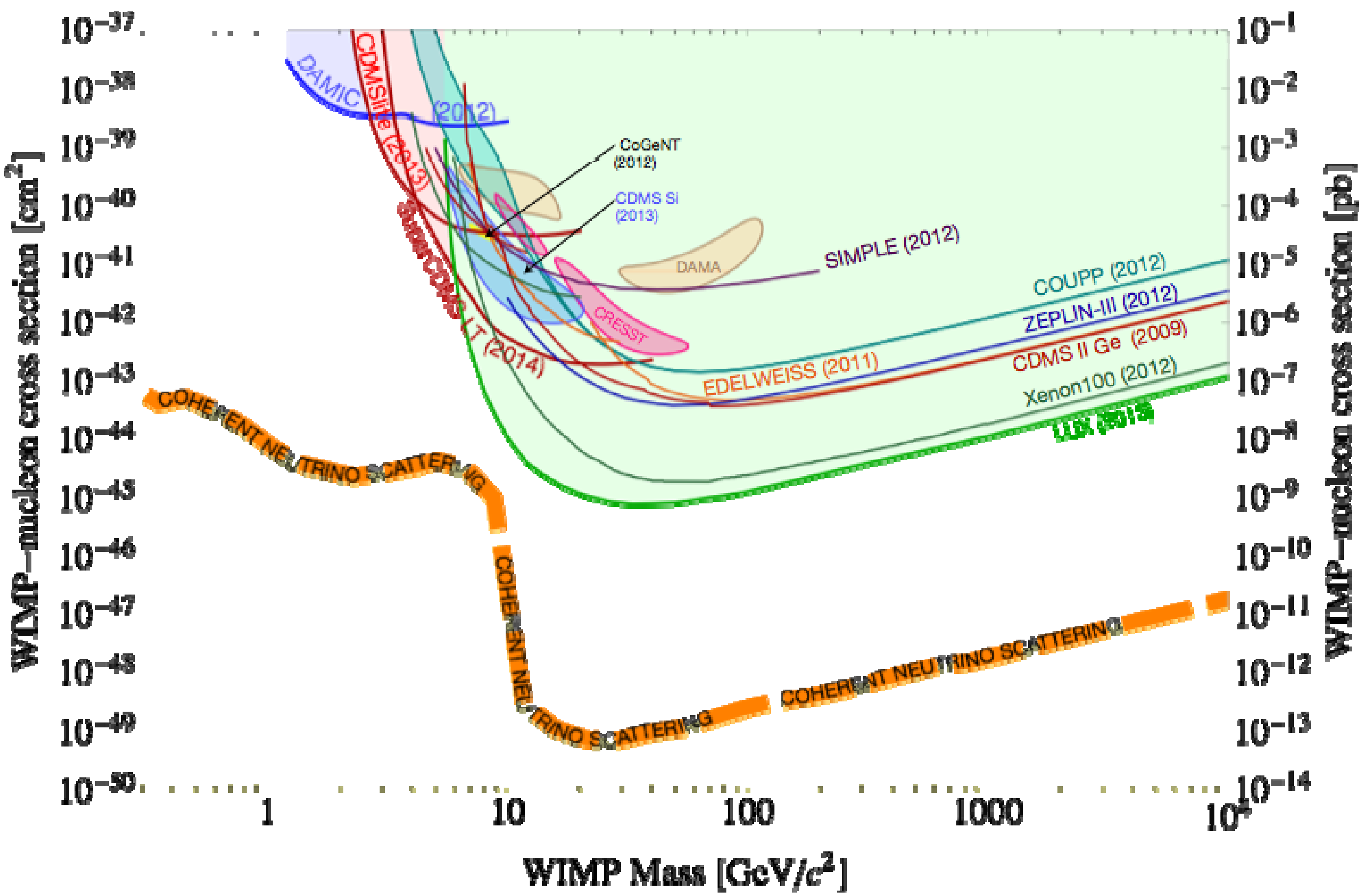
Why Measure Coherent ν-Nucleus Scattering?

- Largest σ in Supernovae dynamics. We should measure it to validate the models

J.R. Wilson, PRL 32 (74) 849

Why Measure Coherent ν-Nucleus Scattering?

- CEvNS is an irreducible background from WIMP searches, and should be measured in order to validate background models and detector responses.

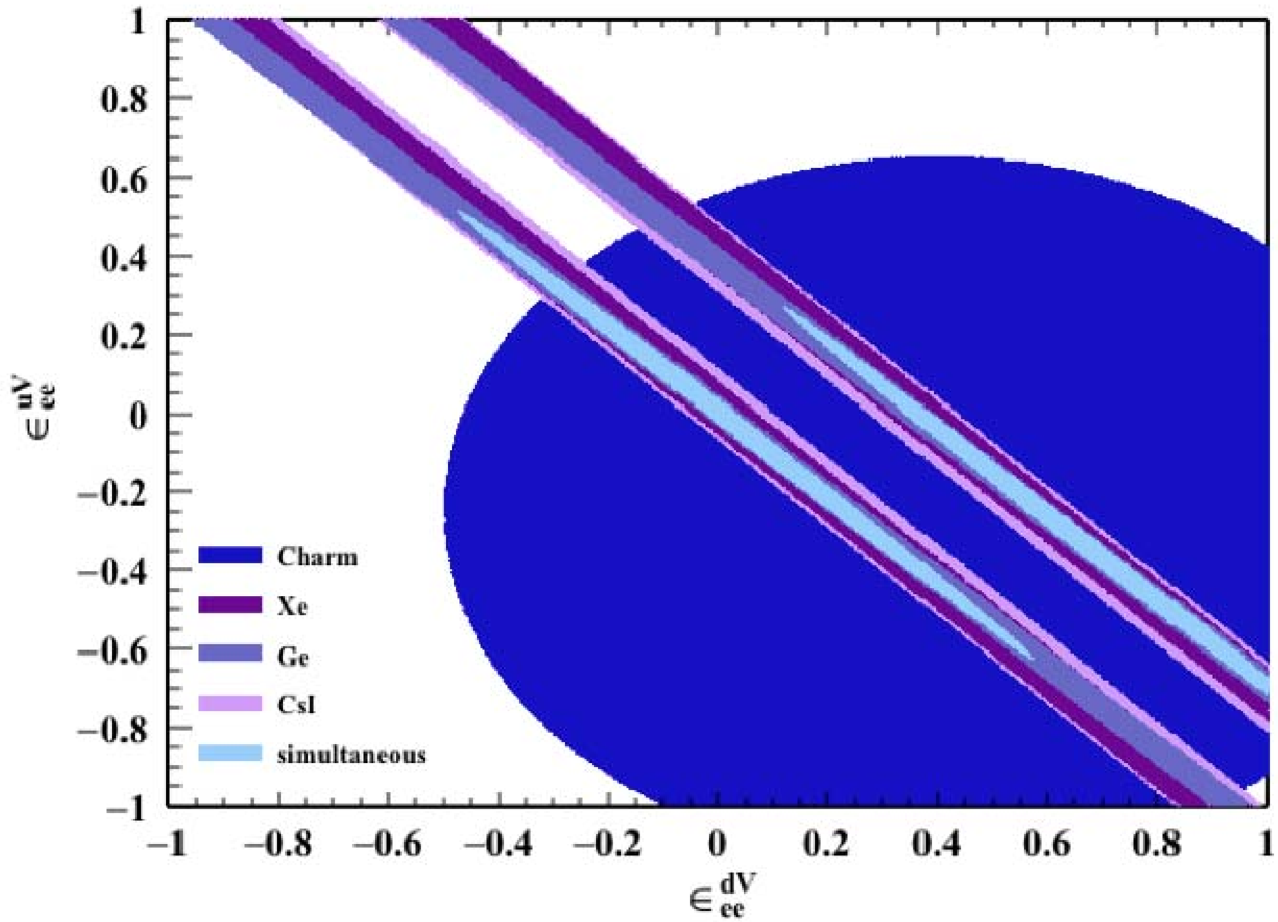


Why Measure Coherent ν-Nucleus Scattering?

- By measuring the relative rates on several nuclear targets we dramatically extend the sensitivity of searches for Non-Standard ν Interactions

K. Scholberg, Phys.Rev.D73:033005,2006

J. Barranco et al., JHEP0512:021,2005



Why Measure Coherent ν-Nucleus Scattering?

- A high-σ, neutral current detector would be a clean way to search for sterile ν's

  A. Drukier & L. Stodolsky, PRD 30 (84) 2295

- The development of a coherent neutrino scattering detection capability provides perhaps the best way to explore any sterile neutrino sector that could be uncovered with ongoing experiments.

  A. J. Anderson et al., PRD 86 013004 (2012)

- Coherent σ proportional to Q_W^2. A precision test of σ is a sensitive test of new physics above the weak scale. M_{top} and M_{higgs} are known → Remaining theoretical uncertainties ~0.2%

  L. M. Krauss, PLB 269, 407

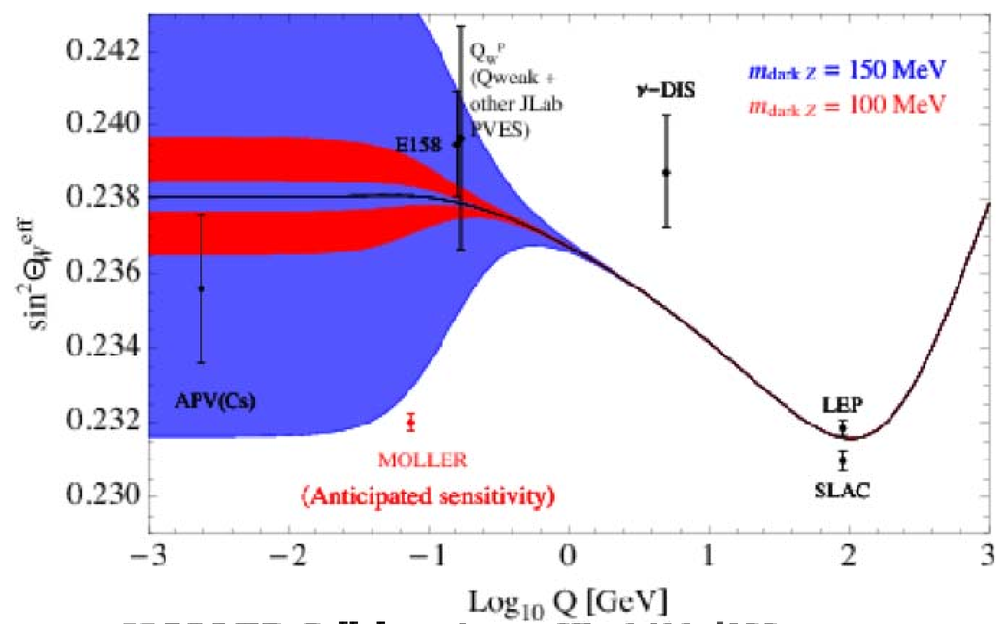
$$\sigma_{coh} \sim \frac{G_f^2 E^2}{4\pi}(Z(4\ sin^2\theta_w - 1) + N)^2$$

- Neutrino Magnetic Moments

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

- Measuring the neutron distribution functions (Form Factors)

  K. Patton, et al., PRC 86, 024216



MOLLER Collaboration, arXiv:1411.4088

COHERENT SNS

Duke University
Indiana University
ITEP
LANL
LBNL
MEPhI

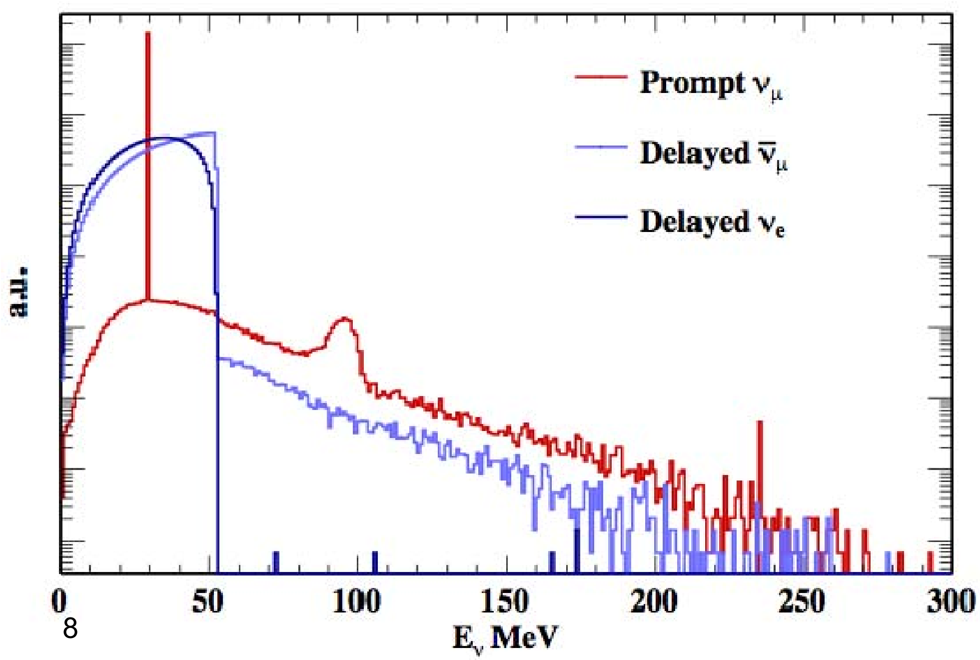
NC Central University
NC State University
New Mexico State University
ORNL
SNL

TUNL
UC Berkeley
University of Chicago
University of Florida
University of Tennessee
University of Washington

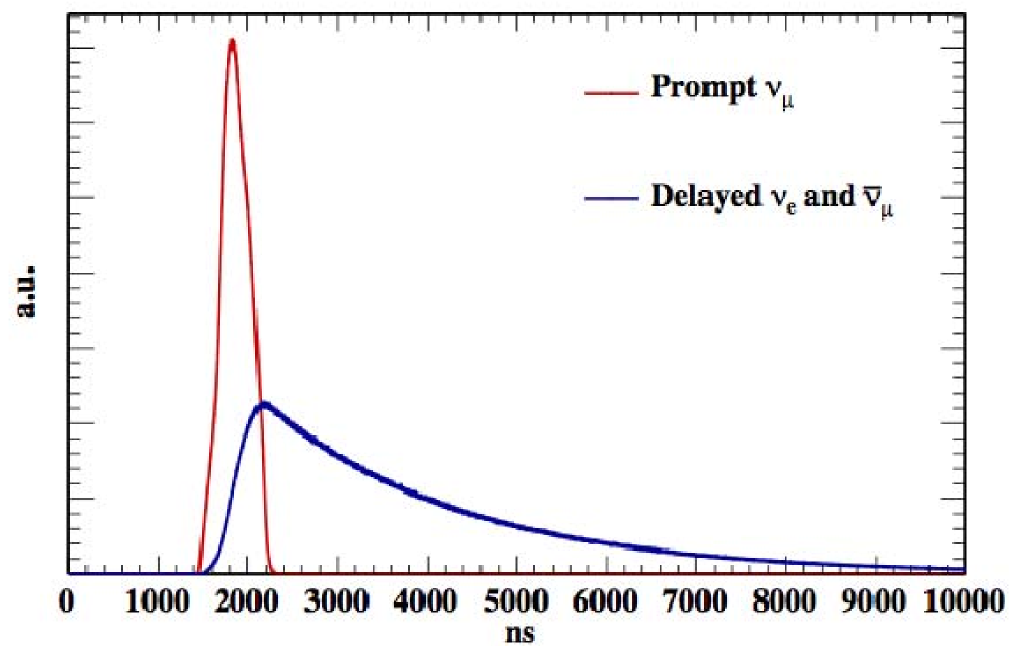
The Spallation Neutron Source

- Pion Decay-at-Rest Neutrino Source
- ν flux 4.3×10^{7} ν cm^{-1} s^{-1} at 20 m
- Pulsed: 800 ns full-width at 60 Hz

<1% contamination from non-CEvNS scatters

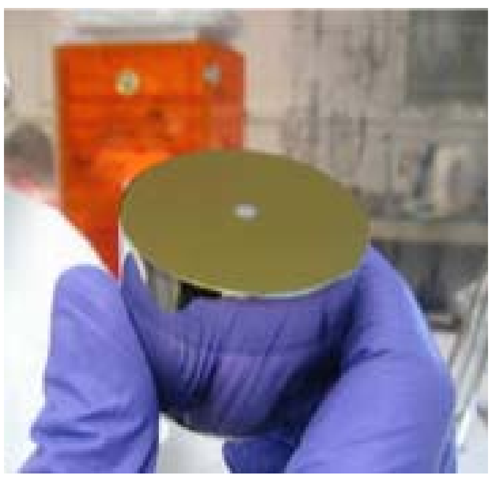


~4x10^-5 background reduction



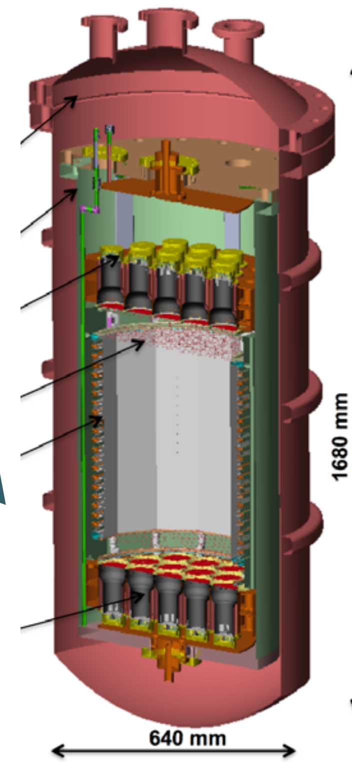
Making an Unambiguous Measurement

- Observe the pulsed ν time-structure
- Observe the 2.2 μs characteristic decay of muon decay ν's
- Observe the N^2 cross section behavior between targets



P-Type Point Contact HPGe

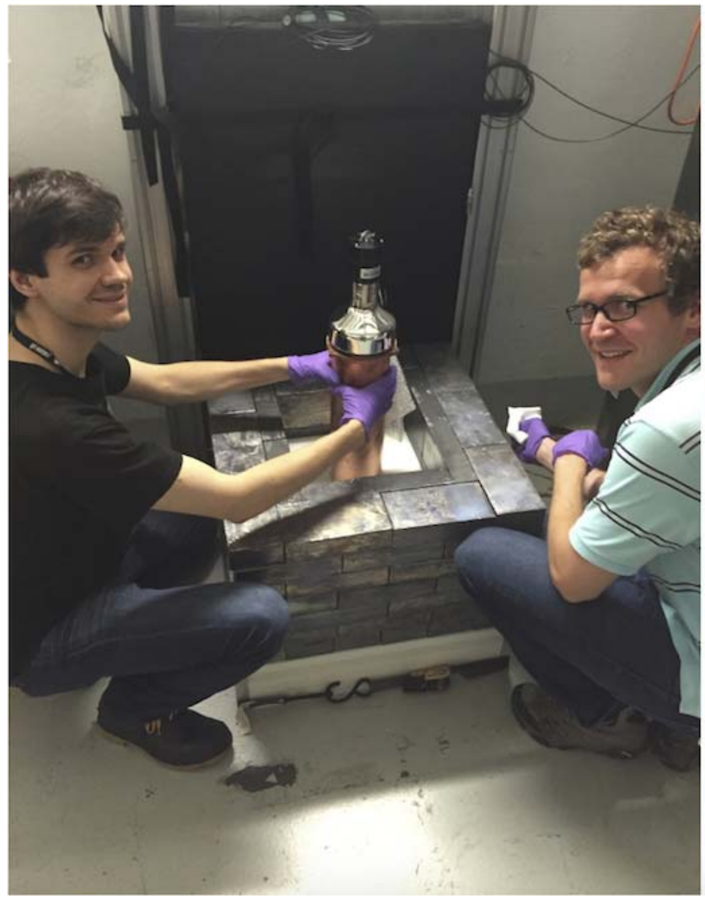
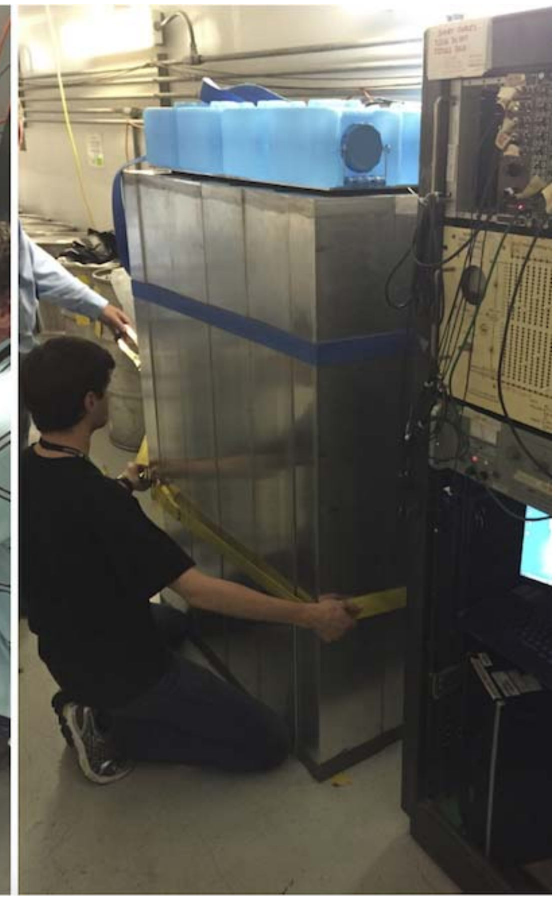
Low-Background CsI[Na]



Xe

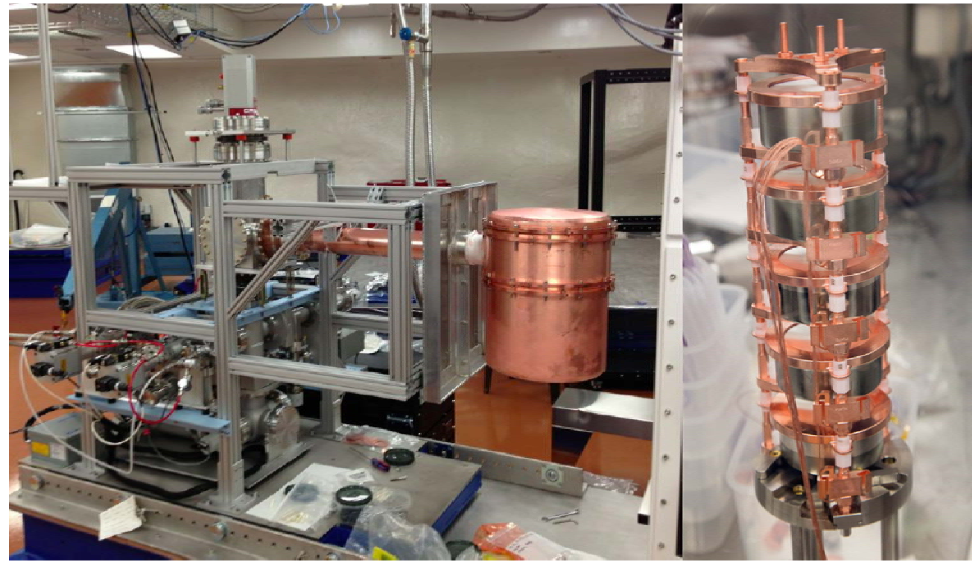
Detector Subsystems: CsI[Na]

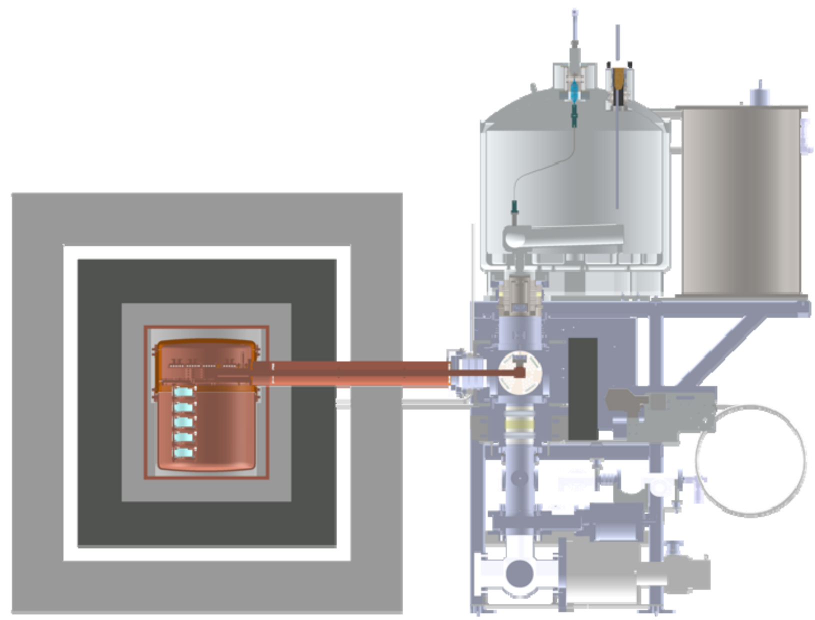
- 14 kg low-background CsI[Na] crystal
- Large N: 74, 78
- Already installed at SNS

Detector Subsystems: HPGe PPCs

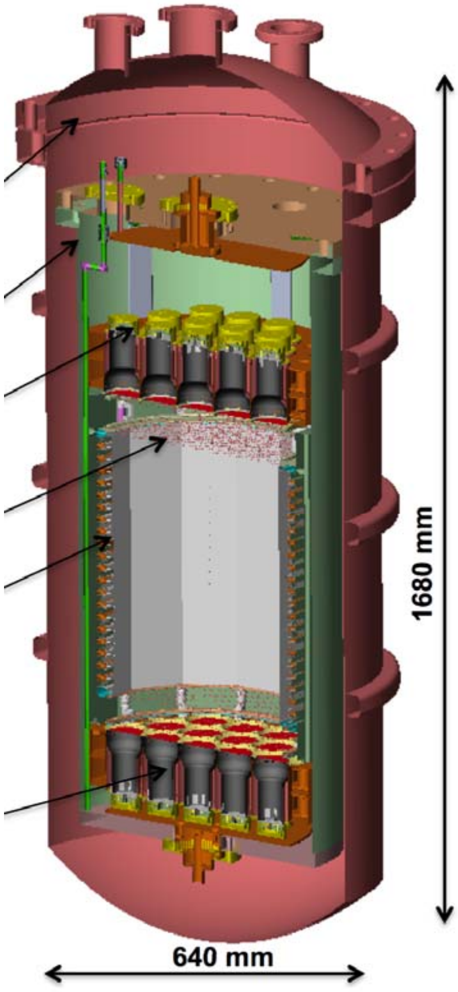
- Repurposed Majorana Demonstrator Prototype Module
- 15kg PPC detector mass
- Smaller N: 38-44
- Excellent resolution at low energy
- Well-measured quenching factor





Detector Subsystems: 2-Phase Xe

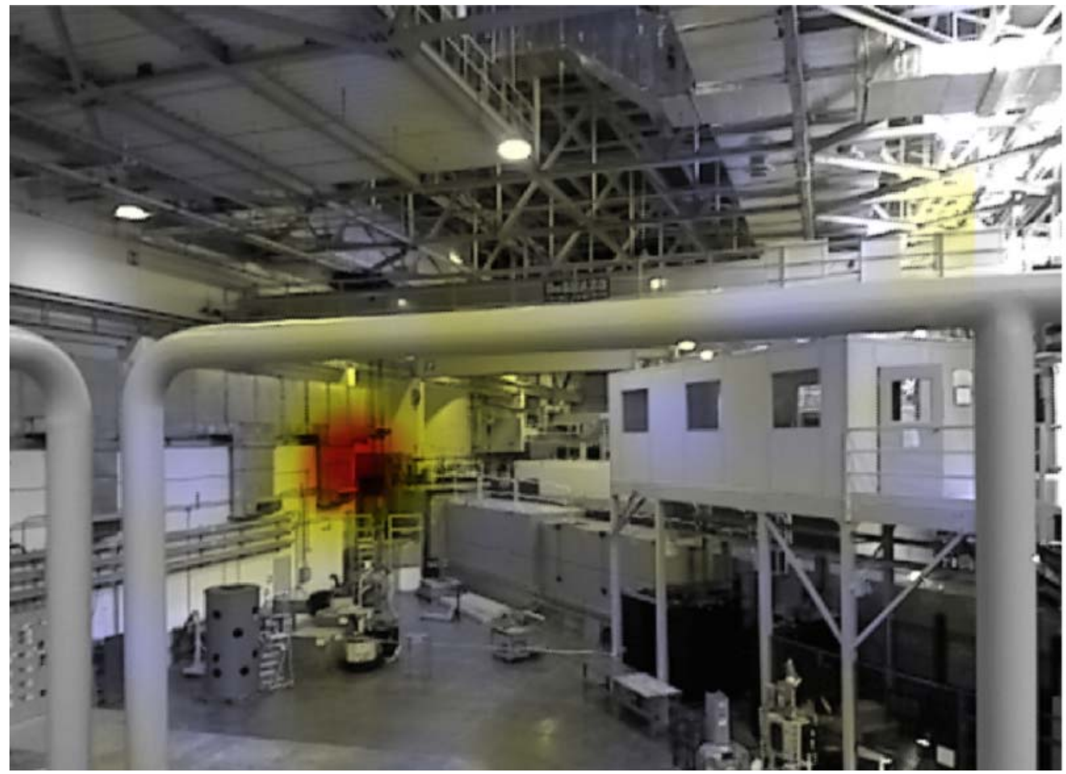
- 100kg fiducial mass
- Large N: 74-82*
- Assembled at MEPhI
- Preparations being made for shipment to ORNL



***N = 82 conspicuously depleted in this sample.**

Backgrounds

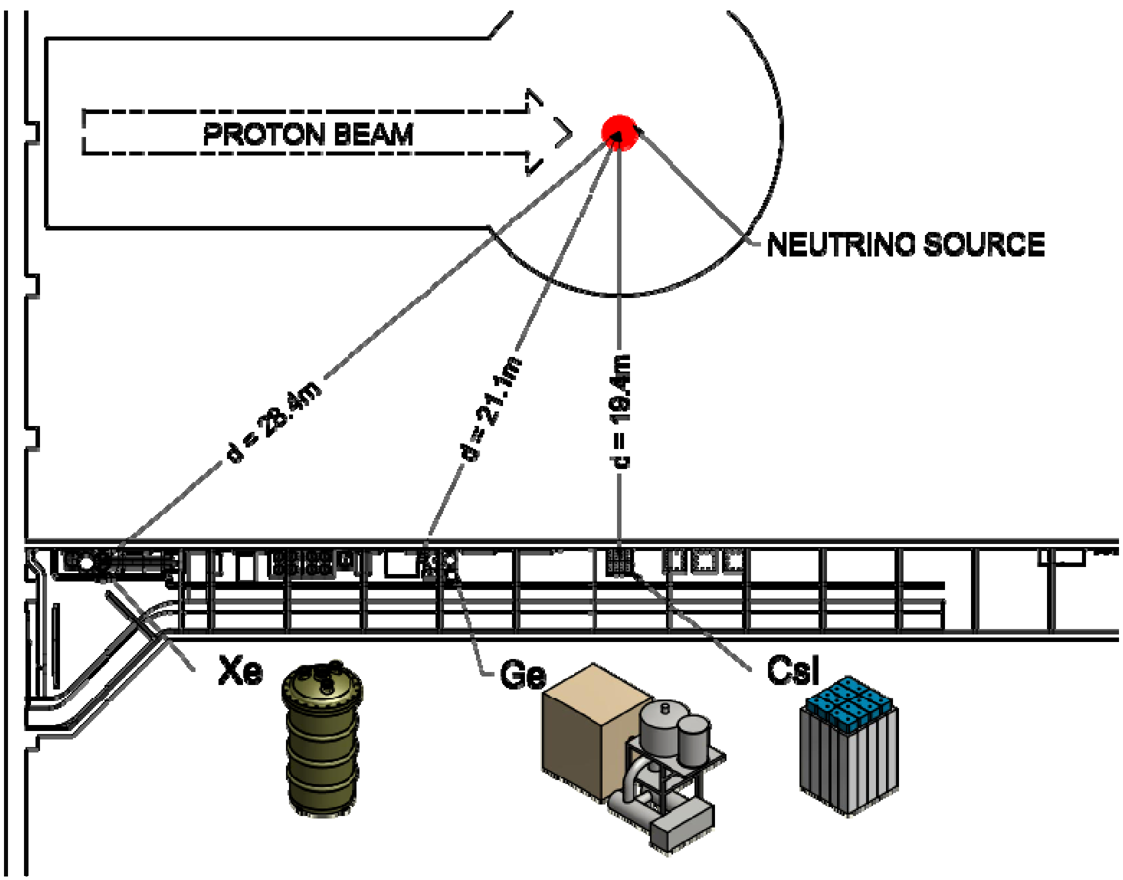
The SNS is a facility designed to produce neutrons (> 100 MeV), and that those neutrons are pulsed with the same time structure of the neutrinos (**with the exception of the characteristic decay time of the muon**).

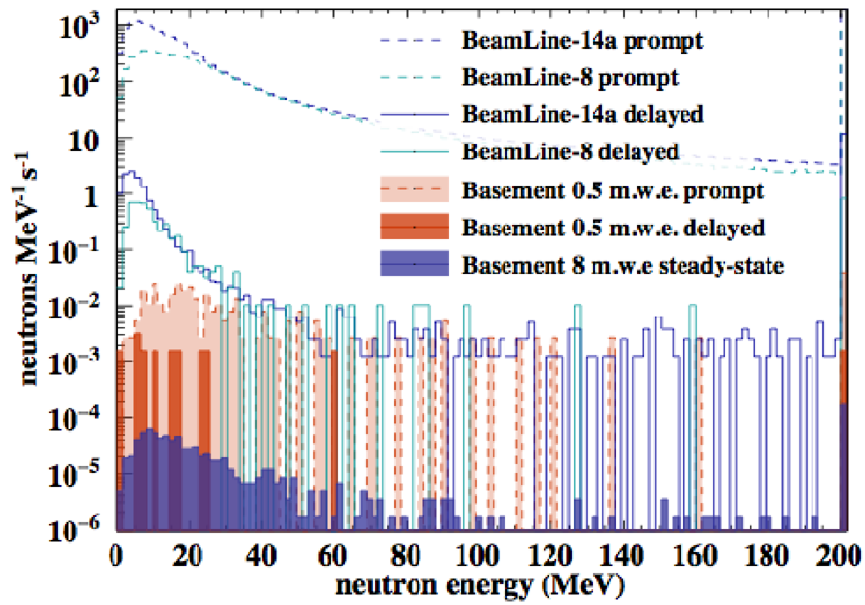


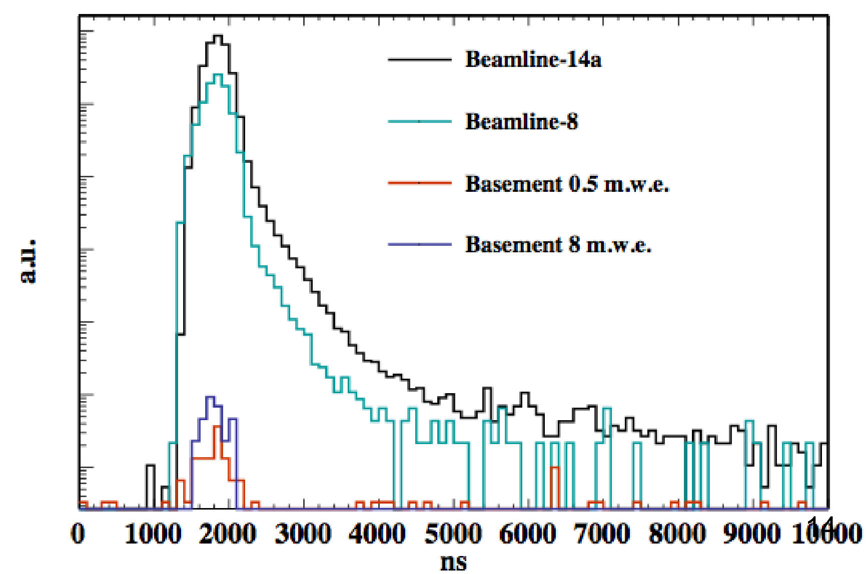
Neutron image of the SNS target, through shielding

Hunting for a Background-Free Location

- Extensive background measurement campaign since 2013 points to the SNS basement as the optimal location (>10^4 reduction)







New Background: $\boldsymbol{\nu}$-induced neutrons (NINs)

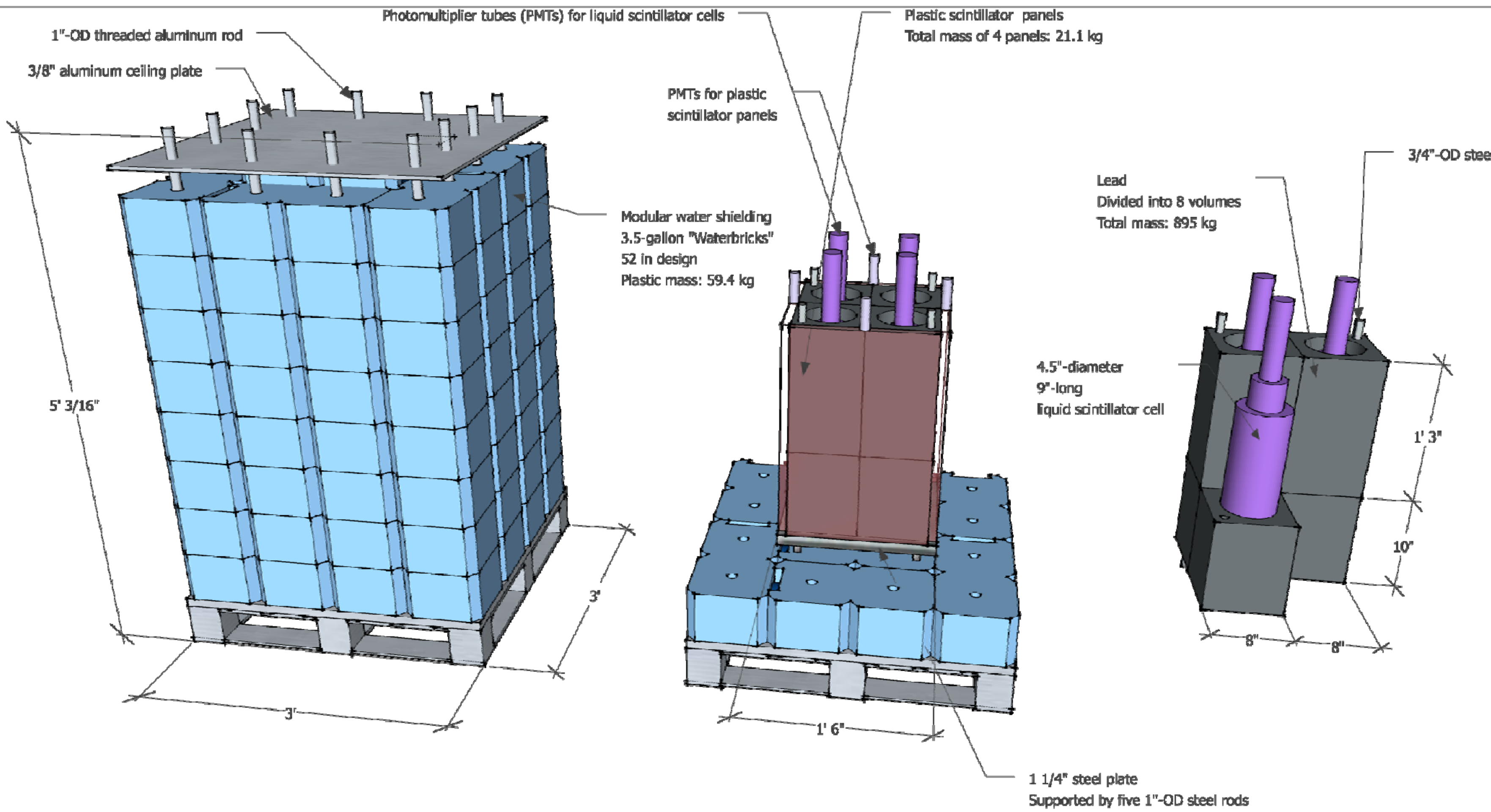
- The detector shields use several tons of lead
- Neutrons can be produced near the detectors. They will be pulsed, and share the 2.2 μs decay time of the ν's
- Need to measure this $\boldsymbol{\sigma}$ and optimize the shields
- Important for HALO

CsI(Na) detector and shield

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

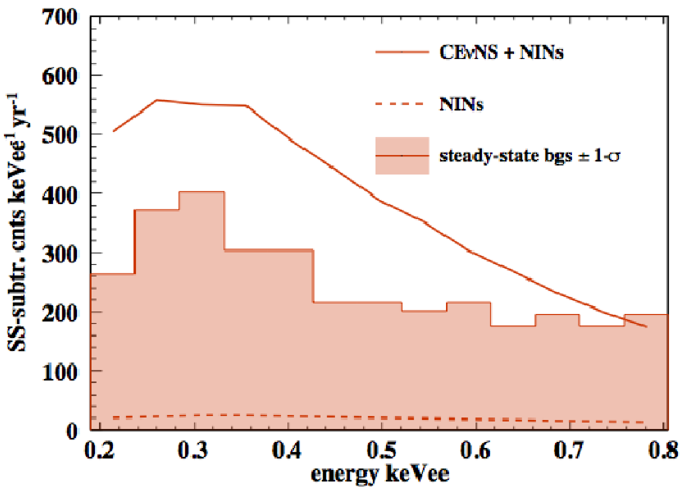
$$\nu_x +^{208} Pb \Rightarrow {}^{208}Pb^* + \nu_x' \qquad (NC)$$
$$\Downarrow$$
$$^{208-y}Pb + x\gamma + yn.$$

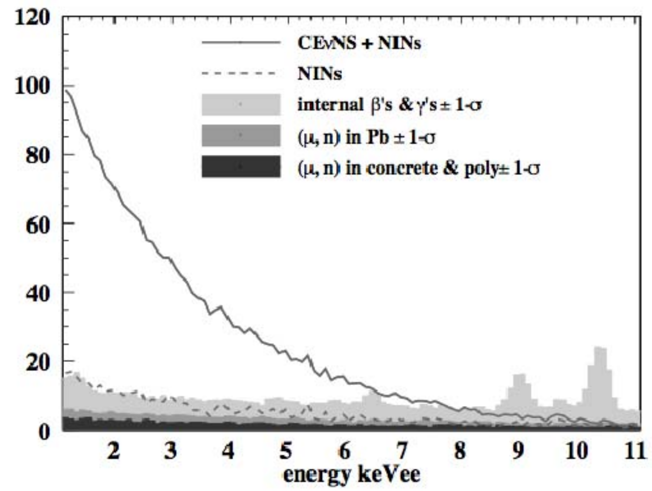
Measuring the ν-induced Neutrons

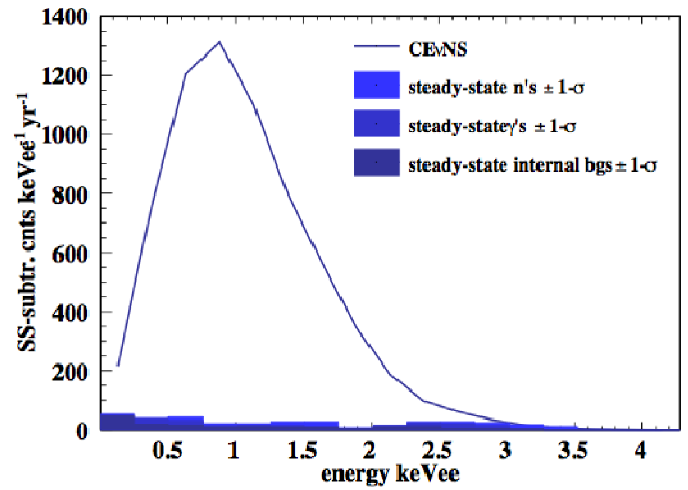


- Several palletized (mobile) targets with LS detectors delivered to the SNS
- Will measure neutrino-induced-neutrons on Pb, Fe and Cu

Expected Signals

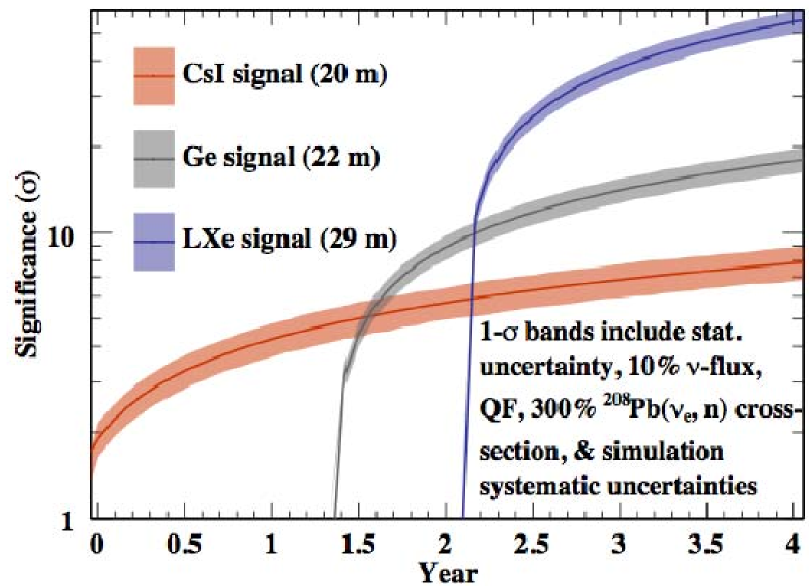




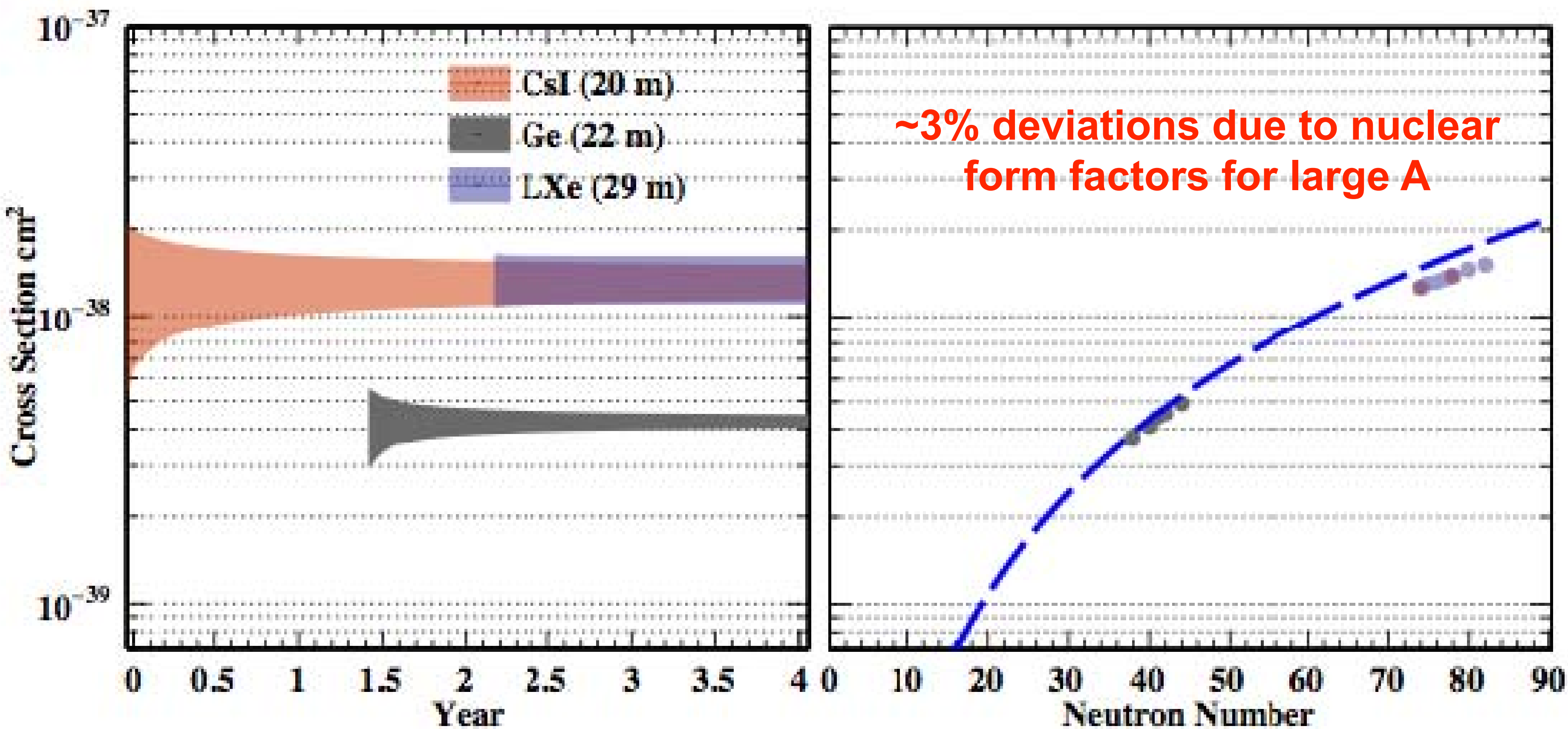


Steady-state background measured with anti-coincident triggers

NIN production rates inform the optimal shielding designs



Three Detectors in Concert

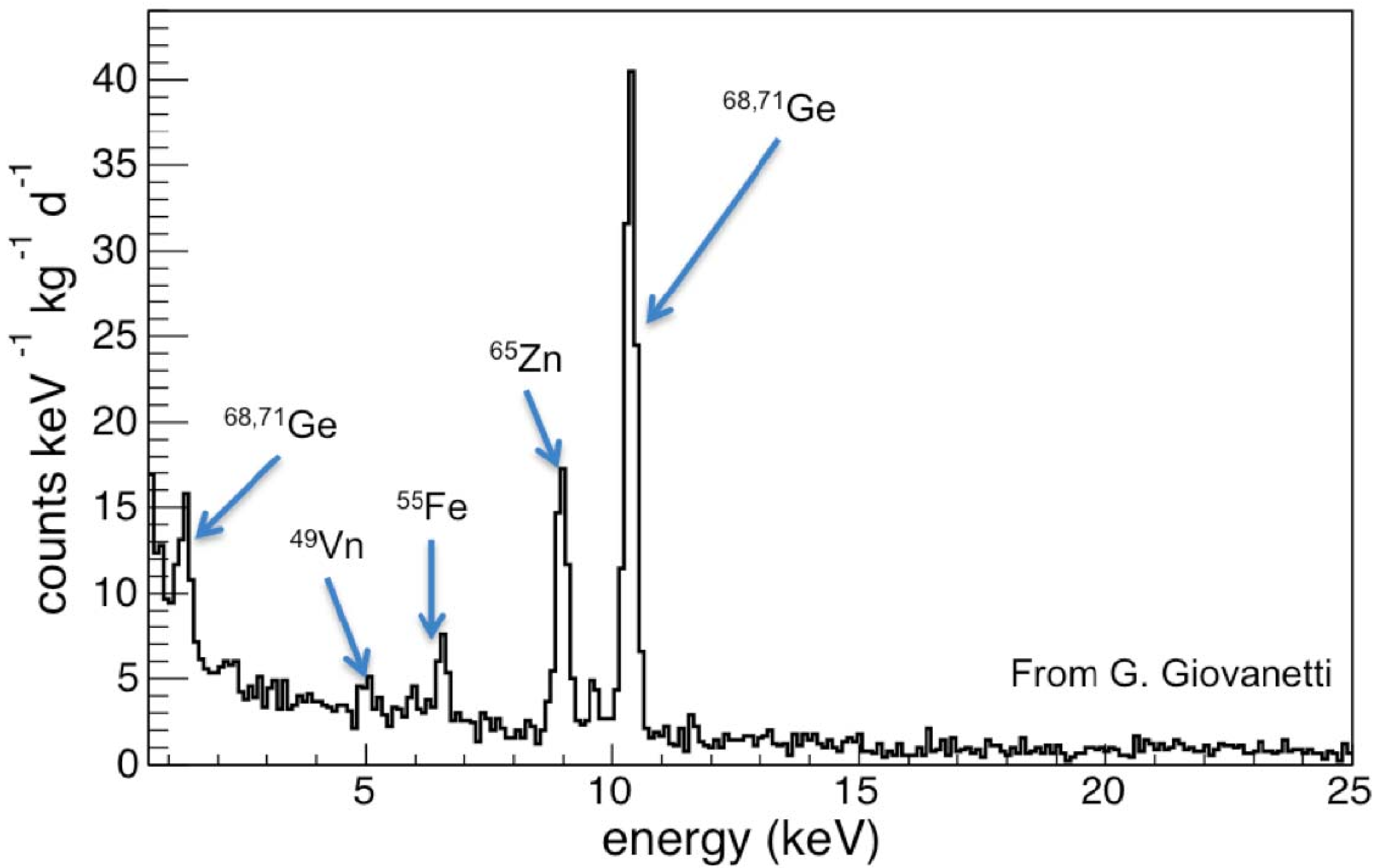


- Statistics and systematics limited.
- 10% beam flux uncertainty not included

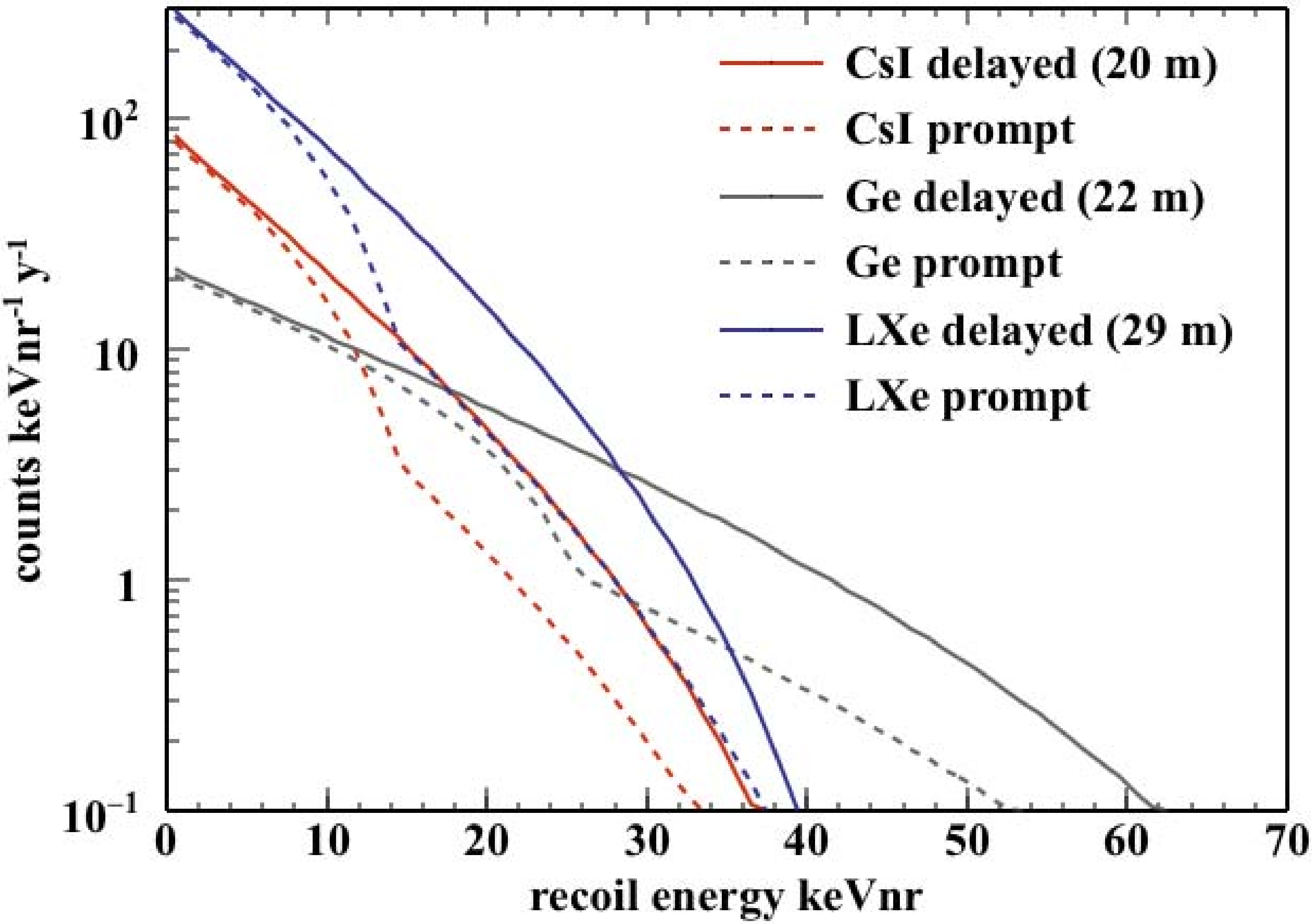
Summary

- A new collaboration has formed, combining the efforts of several groups that have been aiming towards a coherent neutrino-nucleus scattering measurement.
- Background studies indicate the basement as the optimal location
- CsI[Na] has already been delivered and installed
- Several detectors to measure the **ν**-induced induced neutron emission cross-sections on Pb, Fe and Cu installed an on their way
- We expect each detector sub-system to reach ~ 5σ significance for an excess, pulsed with the beam around year 2-2.5
- This will allow us to confirm that the signal is beam-related **(pulsed nature)**, a result of ν's **(2.2 μs decay)** and due to CEνNS **(σ~N^2)**

Backup Slides: Ge Intrinsic BG: MALBEK



Backup Slides: Recoil Spectra



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)