The COHERENT Experiment

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for the COHERENT Collaboration

DPF 2019, Northeastern University, Boston
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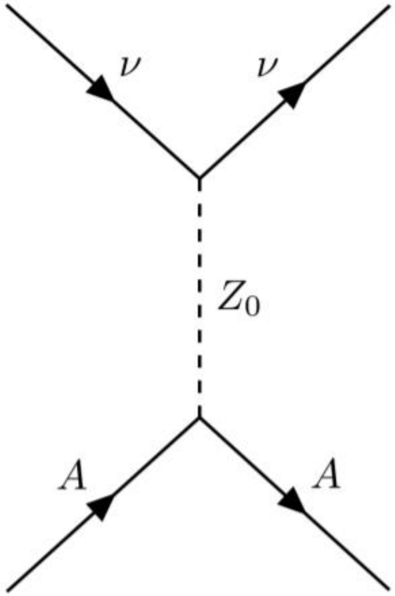
Coherent, Elastic ν-Nucleus Scattering (CEvNS)

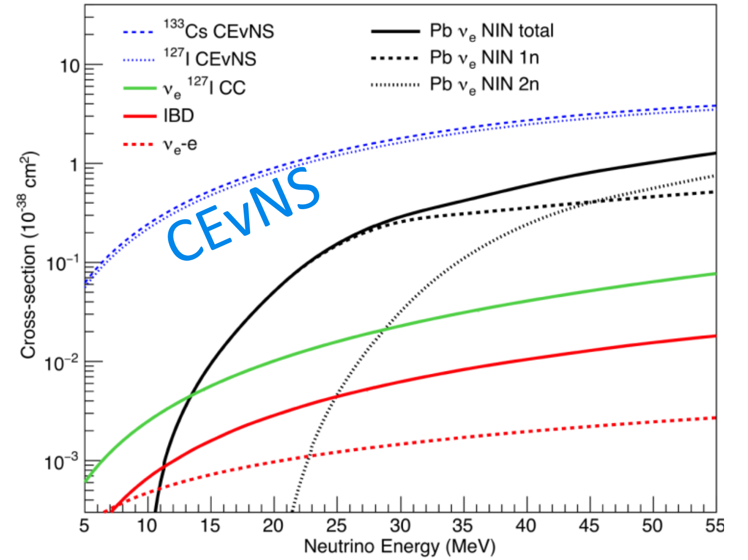


- A CEvNS interaction is a NC scatter off a nucleus where all target nucleons recoil in phase
  - The coherence criterion is only valid at low enough momentum transfers that the de Broglie wavelength is larger than the target nucleus: $Q^2 < (50\text{ MeV})^2$
  - Coherence also enhances the cross section

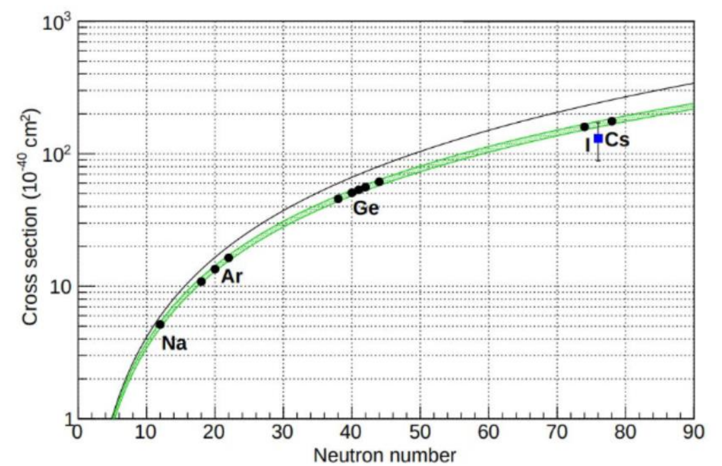
$$\sigma \approx \frac{G_F^2 N^2}{4\pi} E_\nu^2$$

CEvNS Cross Section

- The CEvNS cross section is very large compared to other neutrino process below E_ν=50 MeV
  - Three orders of magnitude larger than inverse beta decay for CsI



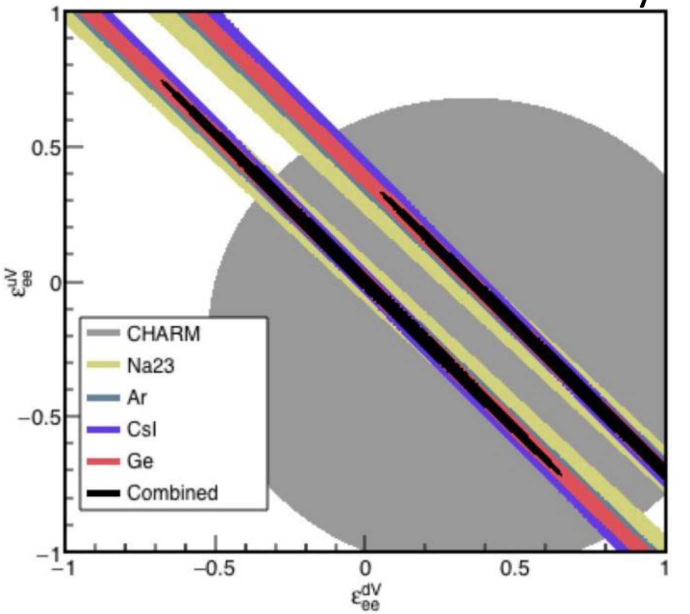
- The N^2 dependence is testable using a variety of detector materials
  - Each measurement carries its own challenges
  - Higher nuclei have larger cross section, but less energetic recoils
  - First measured by COHERENT in 2017!



CEvNS as a Probe of BSM Physics

- Neutrino-quark non-standard interactions
  - May explain tension in solar and reactor neutrino oscillation data

COHERENT Preliminary



For more information, see: Phys. Rev. D96 115007

- Dark photon search
  - Could explain g-2 anomaly
  - Would distort CEvNS recoil distribution in characteristic way
- Dark matter search
  - Sub-GeV dark matter accessible with accelerators and nicely complements direct detection efforts
  - More in R. Tayloe's talk this session

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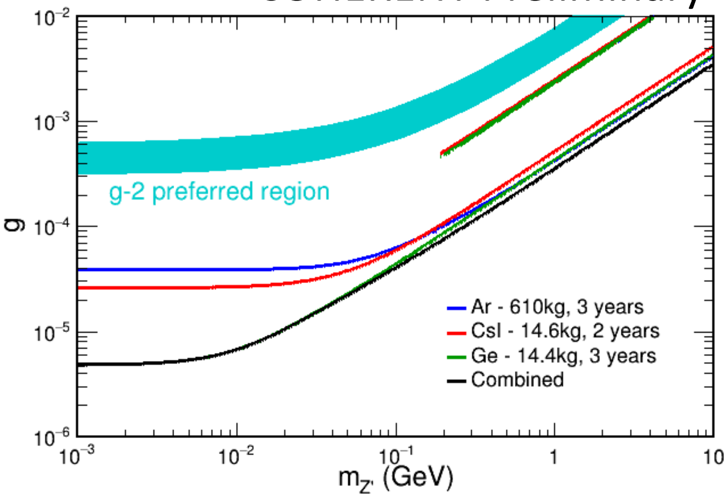

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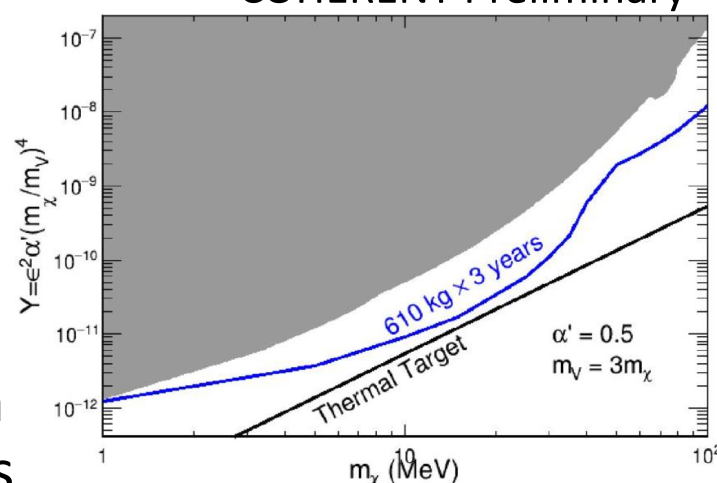


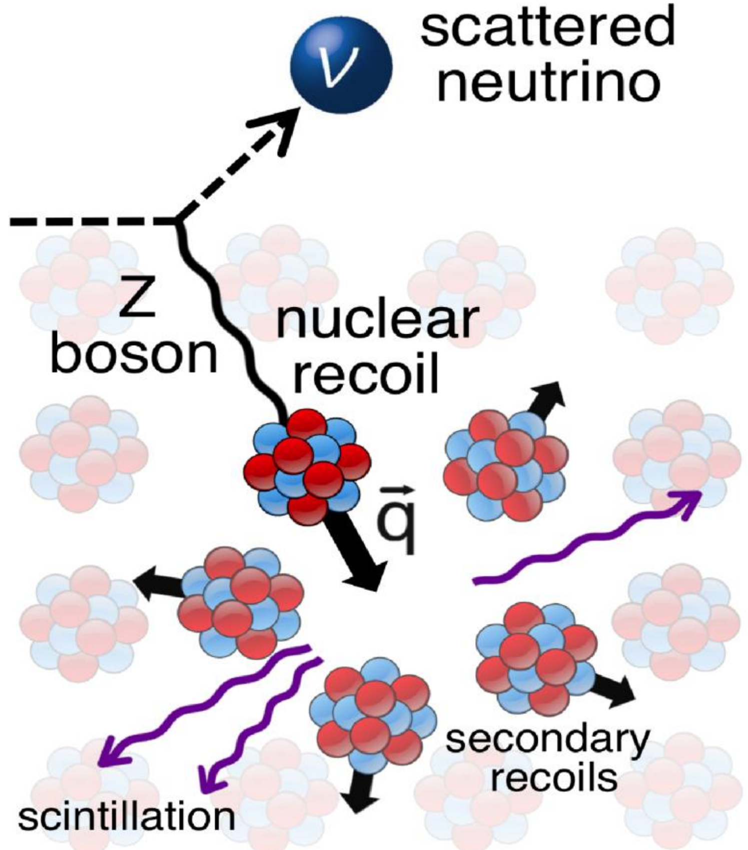
For more information, see:
JHEP 11 066
Phys. Rev. D92 095005

Nuclear Recoil Signature

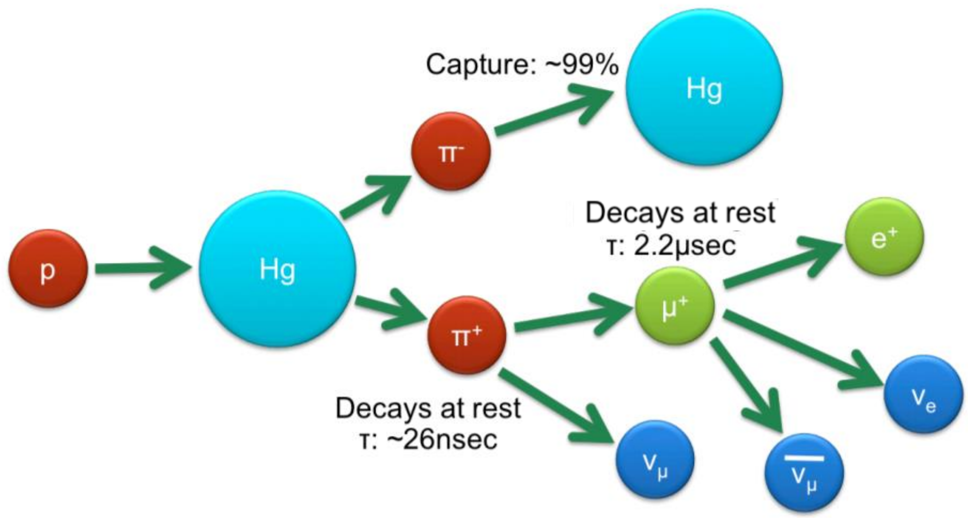
- The struck nucleus acquires a small recoil energy
  - Max recoil energy is $2E_\nu^2/M$
  - Only 10-80 keV for typical nuclei at 30 MeV

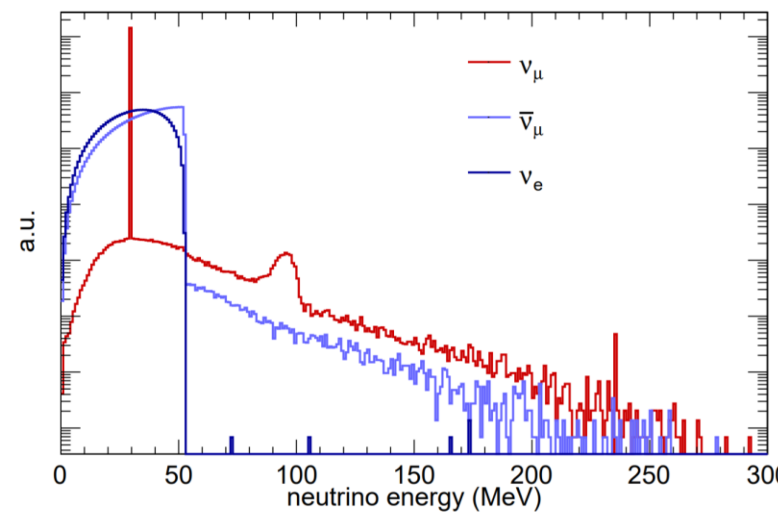
1: Need a detector with very low threshold
  - Recent advances in dark matter detection has made keV-scale thresholds possible

2: Will need to place detector in a large neutrino flux



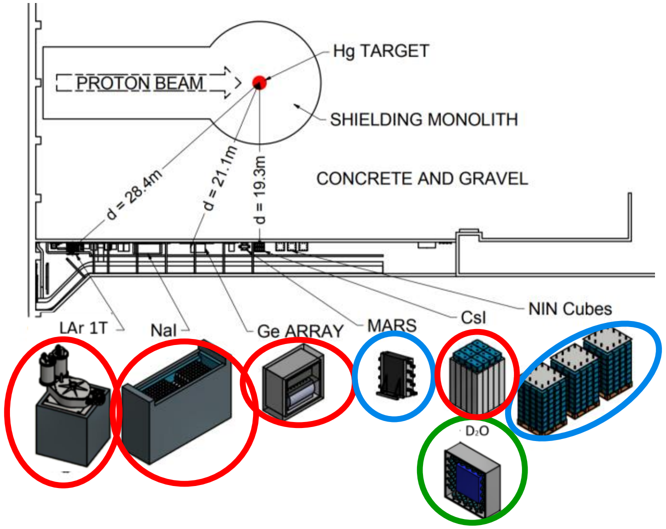
CEvNS at the Spallation Neutron Source





- Low energy pions are a natural by-product of the SNS
  - π^+ will stop and decay at rest with a well-known spectrum
  - Very small contamination of neutrinos from other modes
- Beam is pulsed, which reduces steady-state background and allows for in-situ background measurement
- The SNS is an ideal location for COHERENT detectors

The COHERENT Detectors



- A hallway near the target hall was found to have a low neutron background, dubbed "neutrino alley"
- Four detectors will measure CEvNS on different nuclei, testing the N^2 cross section dependence
- Two detectors study neutron backgrounds in neutrino alley
- One future detector will constrain the neutrino flux to improve precision of other cross section results

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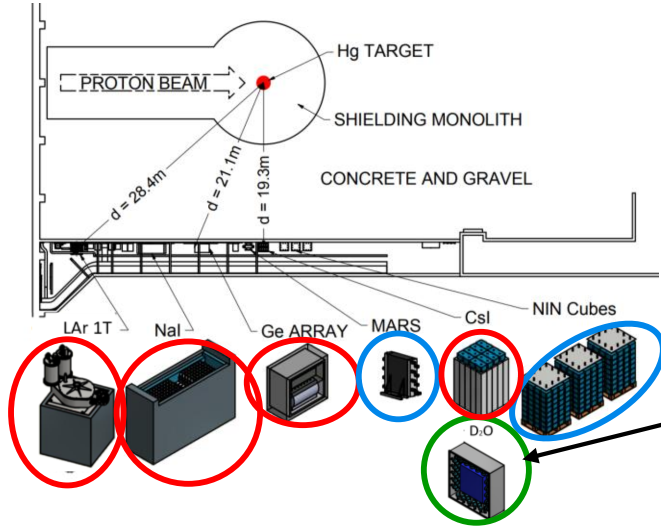

Will notably reduce our systematic errors – covered by R. Rapp this session

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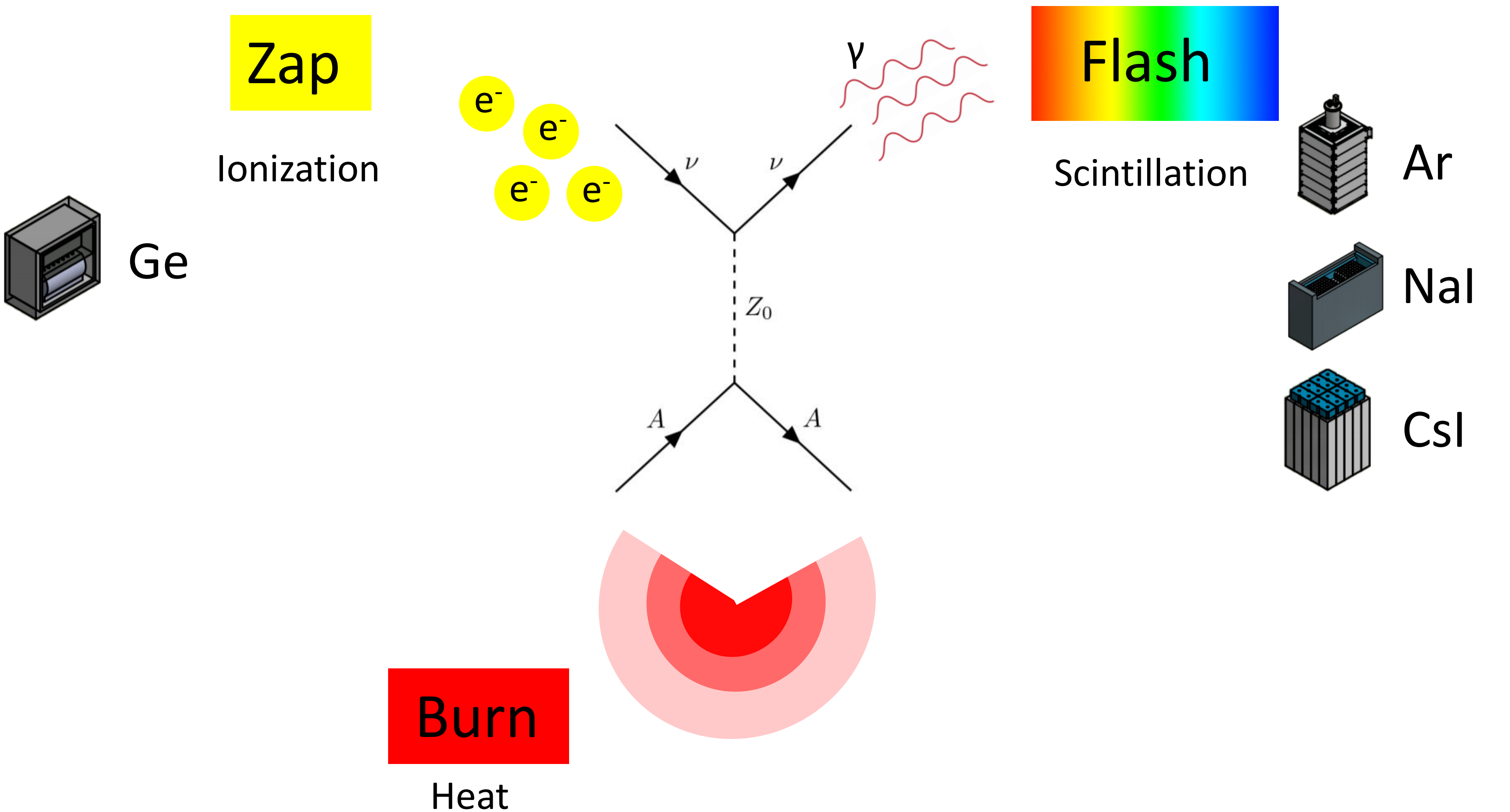
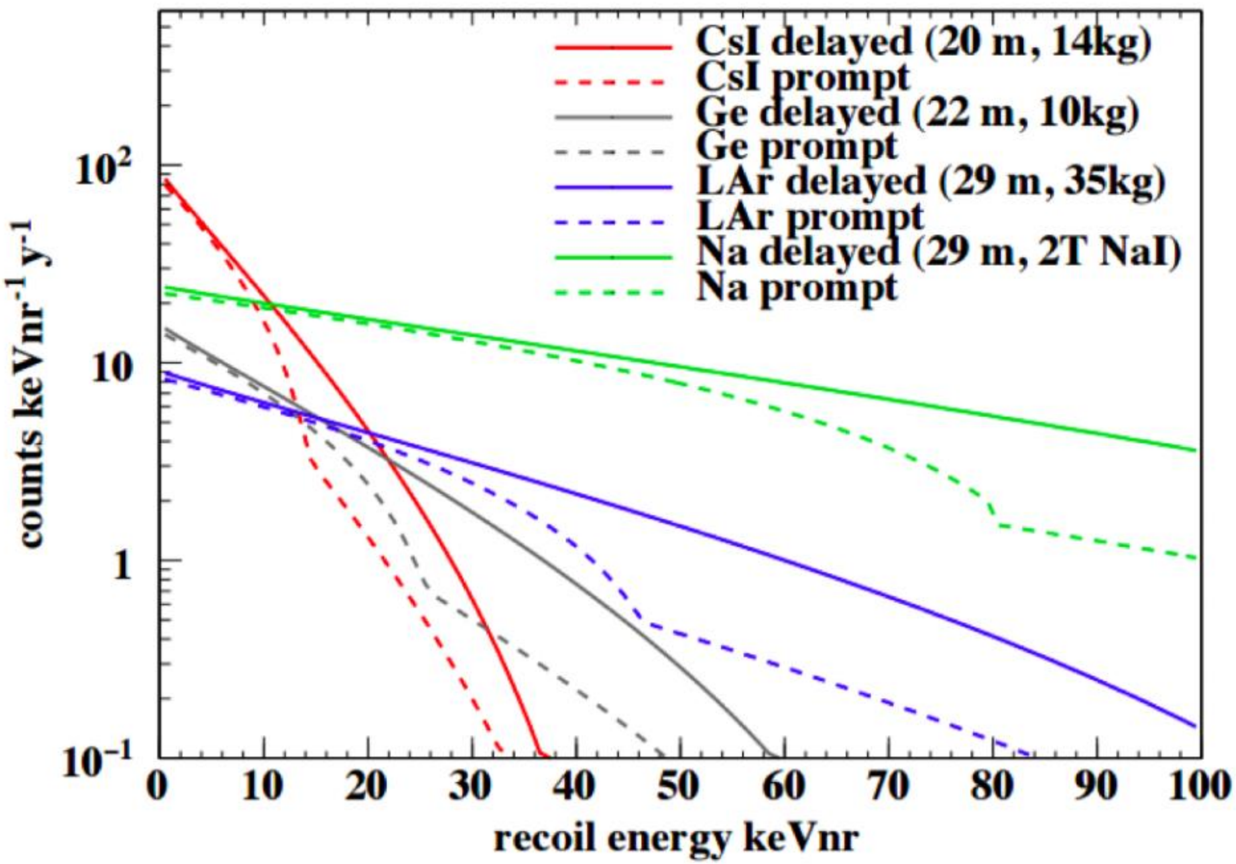
COHERENT Detection Strategies

WIMP experiments pioneered three detection principles

COHERENT looks for zaps and flashes



Expected CEvNS Rates



- CEvNS nuclear recoil energies without detector effects
- Higher mass nuclei see more CEvNS

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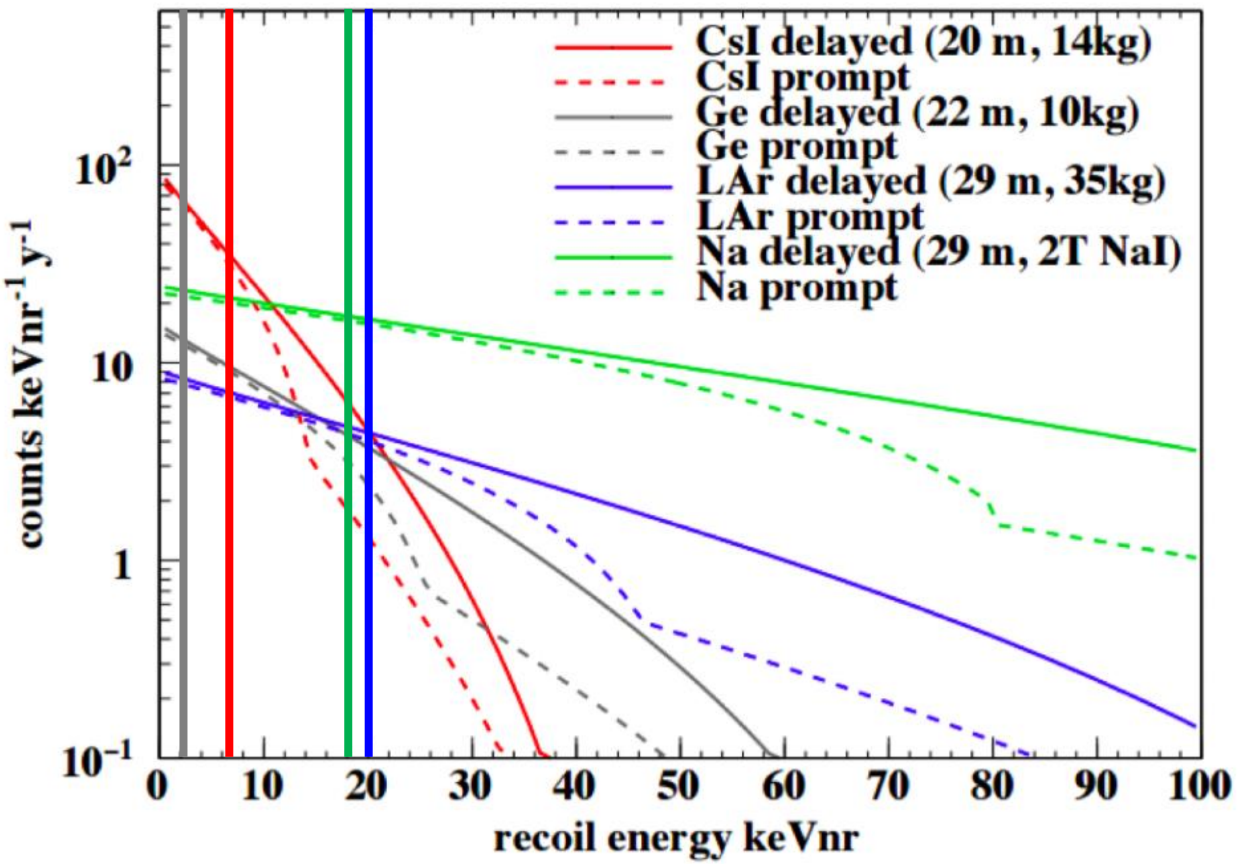
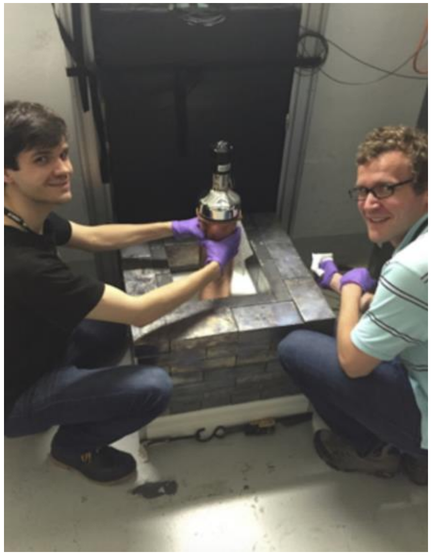
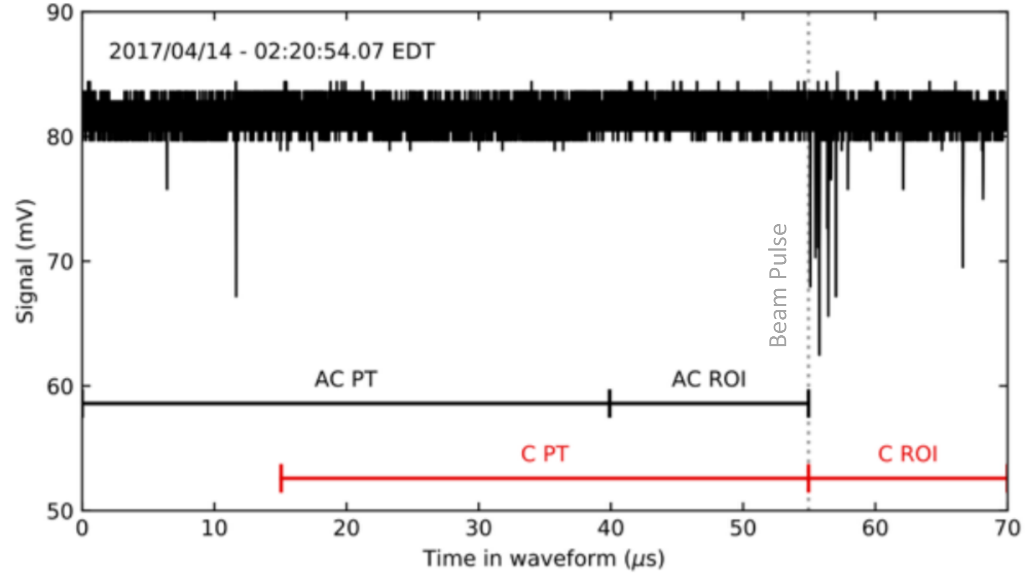


- ❑ CEvNS nuclear recoil energies without detector effects
- ❑ Higher mass nuclei see more CEvNS – but need lower thresholds!

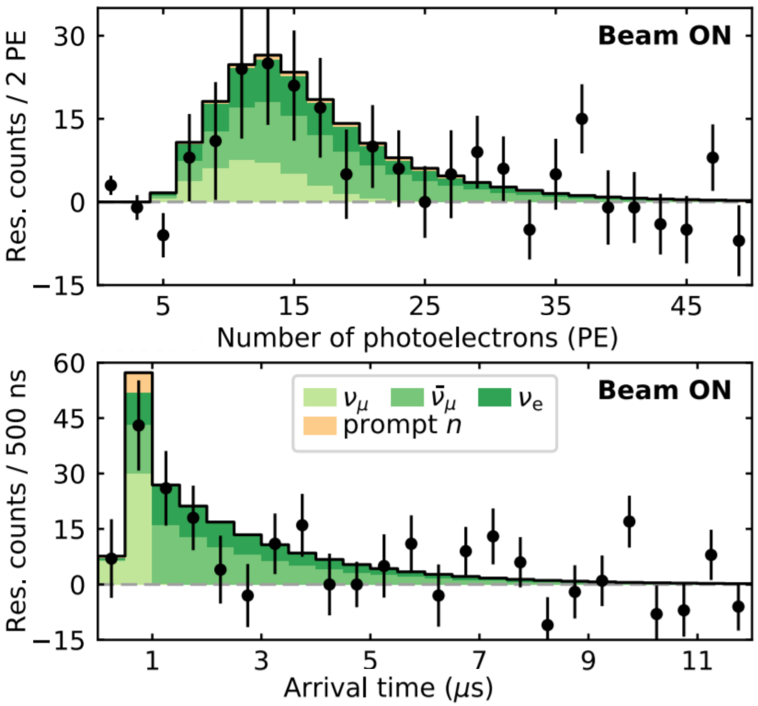
Measuring CEvNS with CsI





- 14.6 kg low-background CsI crystal was deployed
- It is shielded from neutron and gamma backgrounds with low-activity lead
- Detector activity is recorded by single PMT with uniform light yield across detector
- Deployed June 2015 and decommissioned June 2019

CsI – First Observation of CEvNS

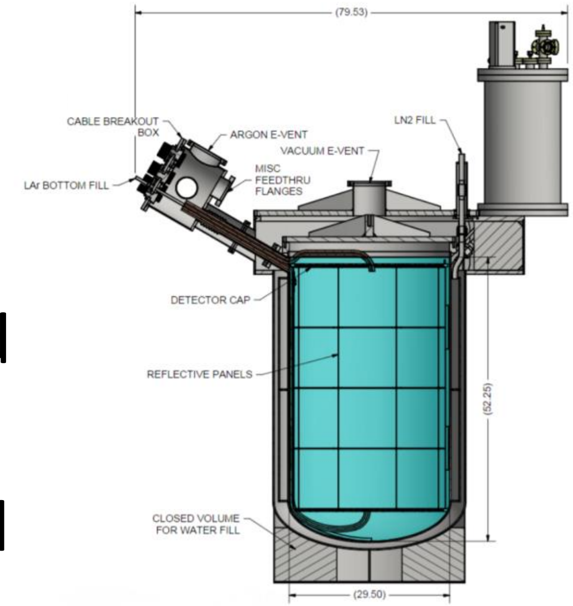


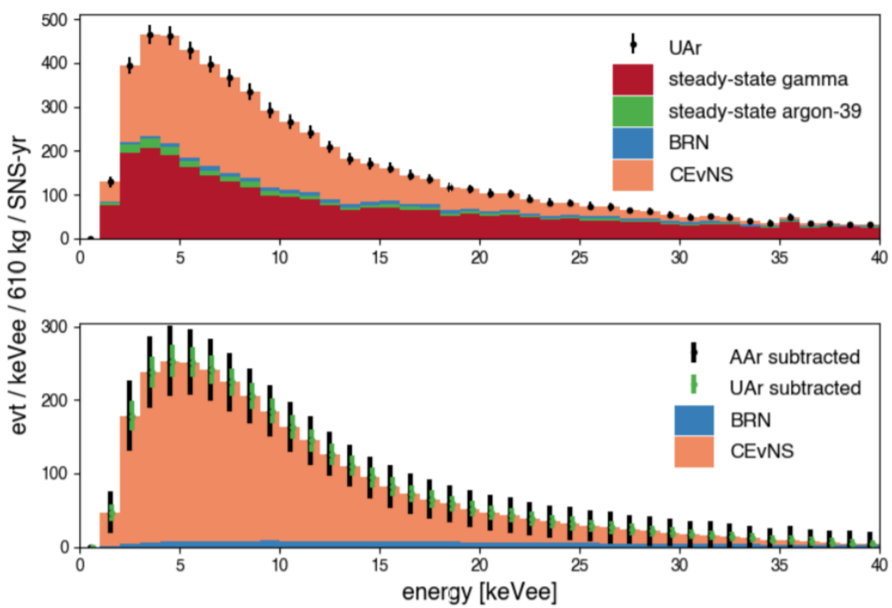
- A likelihood fit in recoil energy and arrival time gives an excess of 134 ± 22 counts
- Data is consistent with the standard model prediction of 173 ± 48 to within 1σ
- Background-only hypothesis rejected at 6.7σ

CsI dataset has since doubled and we are working on releasing data

Measuring CEvNS with Liquid Argon (LAr)

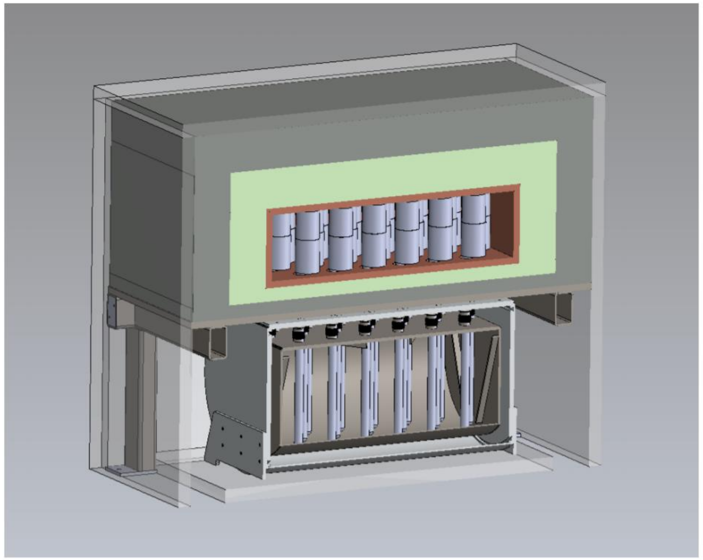
- A LAr detector with 610 kg of fiducial volume will be developed soon
- Simulations predict a 4.3 PE/keV$_{ee}$ light yield allowing a 20 keV$_{nr}$ threshold
- Plan to fill with underground-source argon to reduce ^{39}Ar decay background

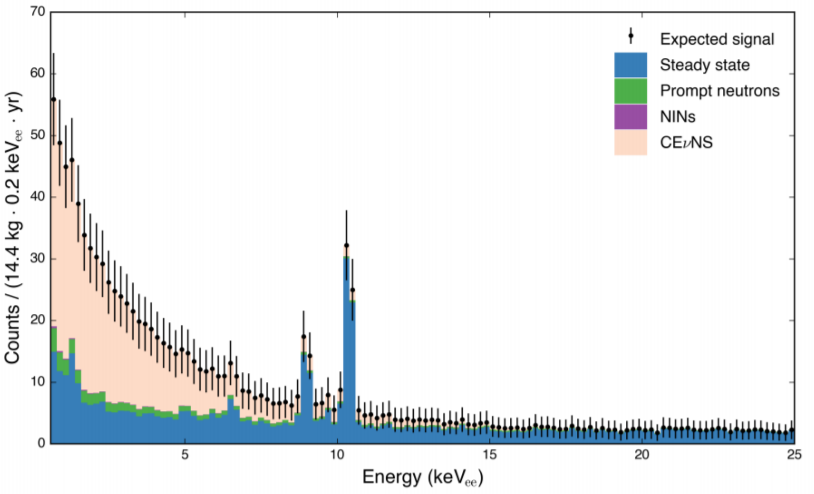




- Large mass allows for several thousand CEvNS collected per year!

Measuring CEvNS with Ge

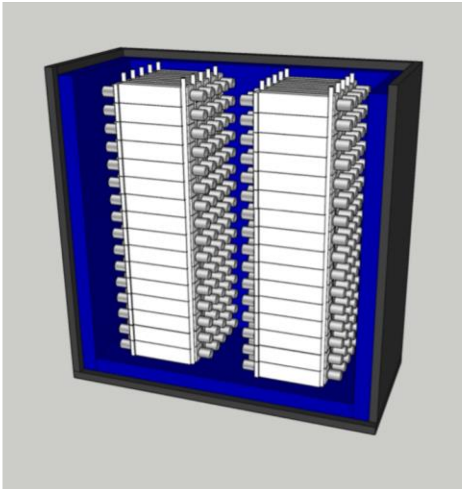


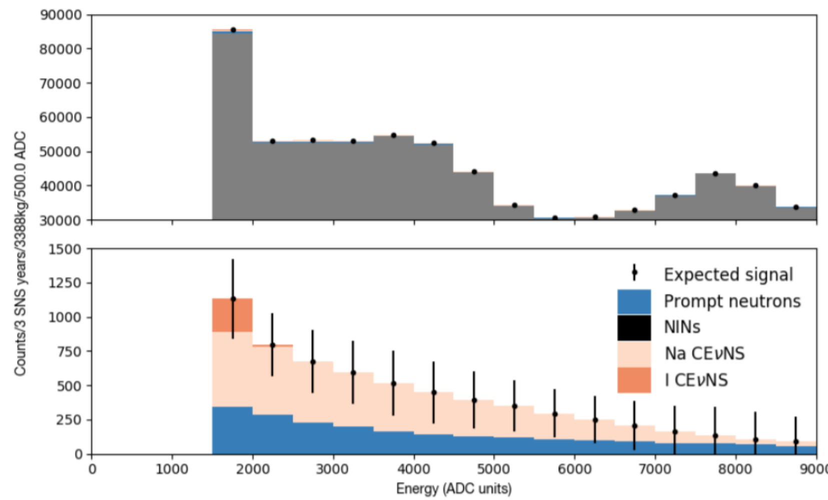


- We will implement 16 kg of high-purity Ge PPC detectors
  - Mass-produced and purchased from Canberra Industries
  - Will be placed in a radiological shield in neutrino alley

- Array of detectors will record ≈570 CEvNS events per year
- Technology will push the threshold to ≈2.5 keV$_{nr}$

Measuring CEvNS with Na





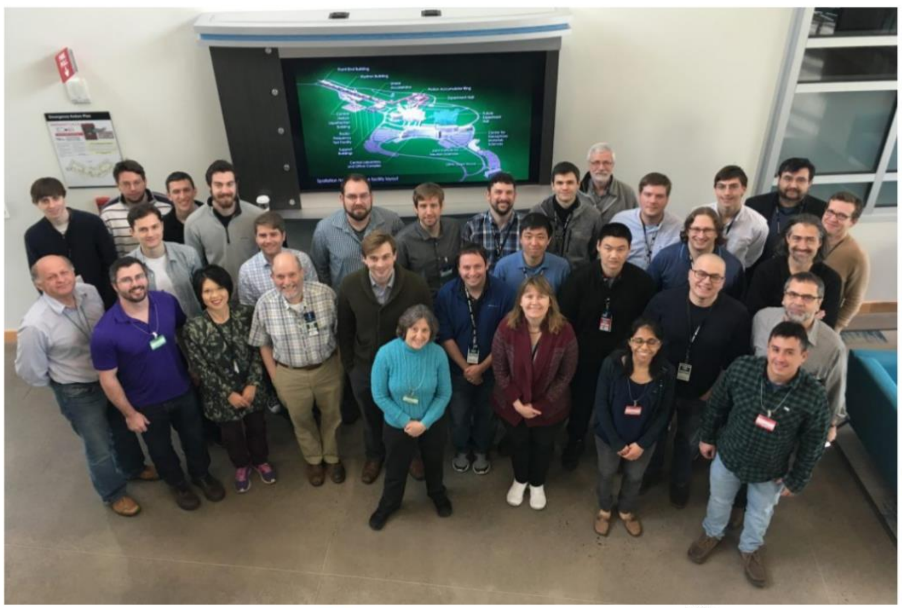
- We are repurposing hundreds of NaI crystals for a CEvNS measurement
  - A 185 kg prototype is running with plans to implement 3.3 t
- CEvNS signal clearly visible despite large steady-state backgrounds
- Na is the lightest CEvNS target COHERENT will probe
  - Great handle for studying N^2 cross section dependence

Summary

- The business of measuring CEvNS has just started
  - Gives us a new handle to probe fundamental physics beyond the standard model

- CEvNS was first observed by COHERENT with our CsI detector
- We’re not stopping there
  - CsI dataset has since doubled
  - Implement detectors with different targets and larger masses

Thank You from the COHERENT Collaboration!

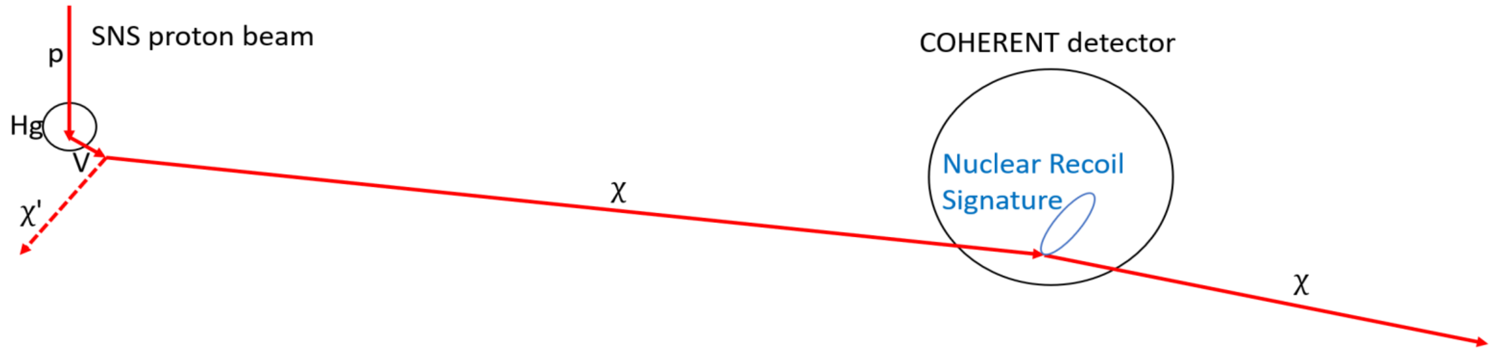


~80 members
~20 institutions
4 countries

Backup

Sub-GeV Dark Matter Searches with COHERENT

- The Lee-Weinberg bound[1] requires mass of a simple WIMP dark matter particle is greater than 1 GeV
- A Lower-mass DM may explain galactic rotation curves
  - However, an additional portal particle mediating interactions between DM and standard model particles is needed
  - Such a sub-GeV portal is easily accessible with accelerators



- CEvNS-like cross section enhancement make COHERENT detectors uniquely sensitive to 1-100 MeV dark matter particles

[1]Lee and Weinberg, PRL 39 165

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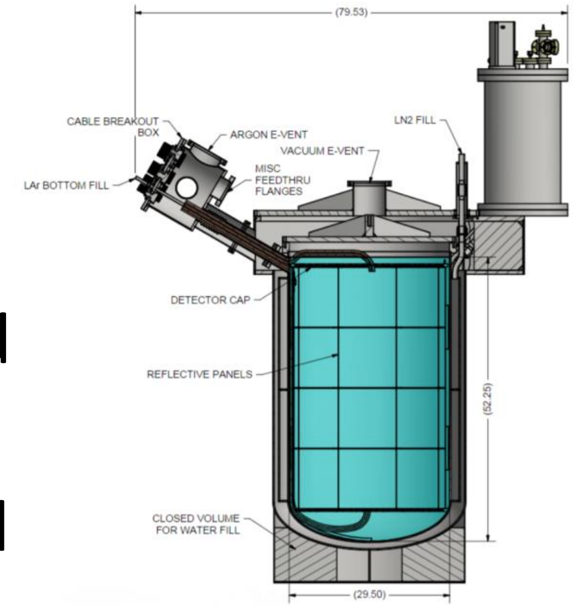
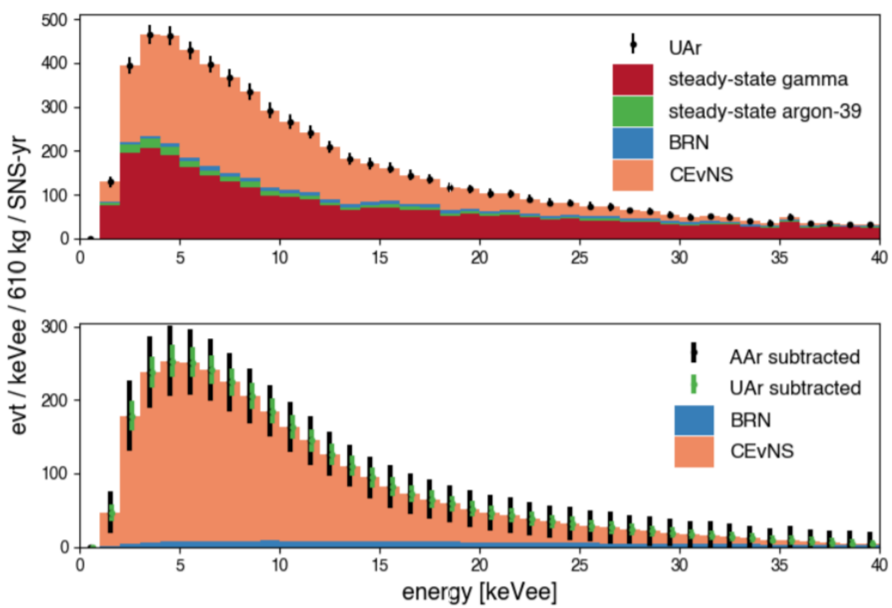
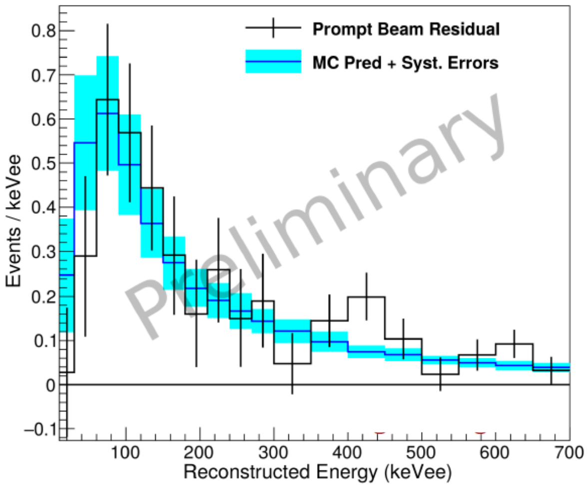




- Large mass allows for several thousand CEvNS collected per year!

Physics With a LAr Prototype Detector

- A LAr prototype has collected production data since 2017
  - 29 kg of LAr with a threshold near 20 keV_{nr}



- Run with partial shielding to study neutron interactions in detector
- Observed data is consistent with simulated neutron prediction

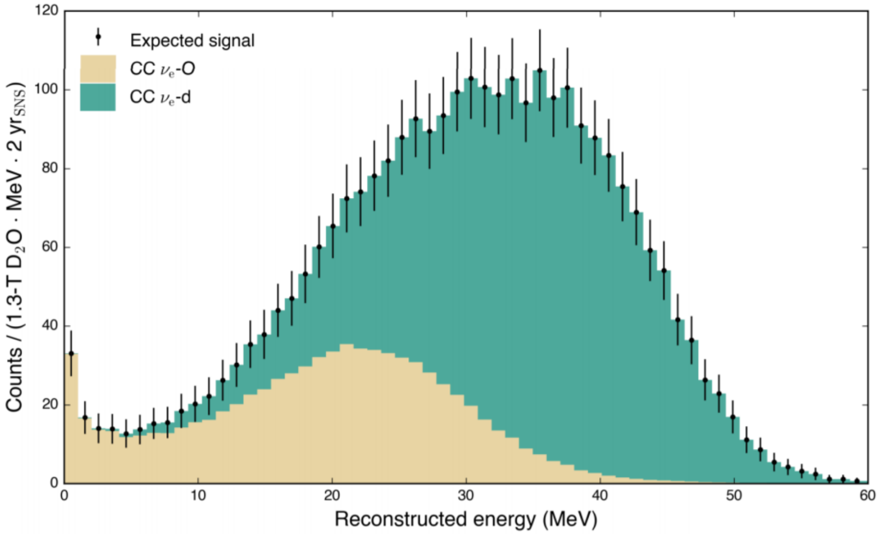
- Detector was later upgraded with a lower threshold
- A CEvNS analysis is underway
  - Expect to see 120 CEvNS on a large background

	Steady-State Background	Beam-Related Neutrons	CEvNS
Prompt	264	298	53
Delayed	924	< 1	67

Production Run Event Predictions

Reducing Flux Uncertainty with D_2O Detector

- For most CEvNS detectors, the flux uncertainty dominates the error budget for determining the CEvNS cross section
- The theoretical uncertainty on $\nu_e + d \rightarrow e + p + p$ is known precisely, to 2-3%
  - Measuring the rate in a detector with a large mass fraction of deuterium could would determine the flux to similar precision
  - Use heavy water Cherenkov!
- Will achieve reasonable statistics within two years
- $\nu_e + {}^{16}O$ background is manageable and low energy

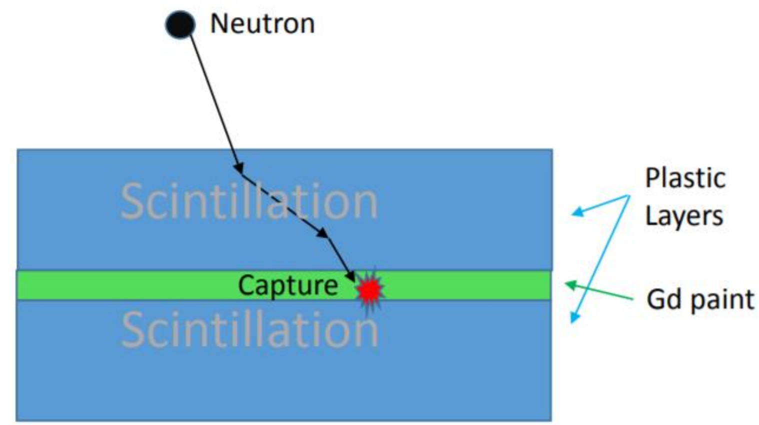


The NIN-Cubes Background Detectors

- CEvNS detectors are shielded with lead to reduce environmental gamma and neutron backgrounds
- Unfortunately, lead is a neutron-rich nucleus with a (relatively) large neutrino cross section
  - $\nu + {}^{208}\text{Pb} \rightarrow \nu + {}^{208\text{-}a}\text{Pb} + an + b\gamma$
  - $\nu + {}^{208}\text{Pb} \rightarrow e + {}^{208\text{-}a}\text{Bi} + an + b\gamma$
  - The Neutrino-Induced Neutron (NIN) processes
- NIN-Cubes in neutrino alley currently working to measure the NIN cross section
- Also interesting for the HALO experiment, which uses NIN interactions to detect bursts of neutrinos from supernovae

Background Detectors – MARS

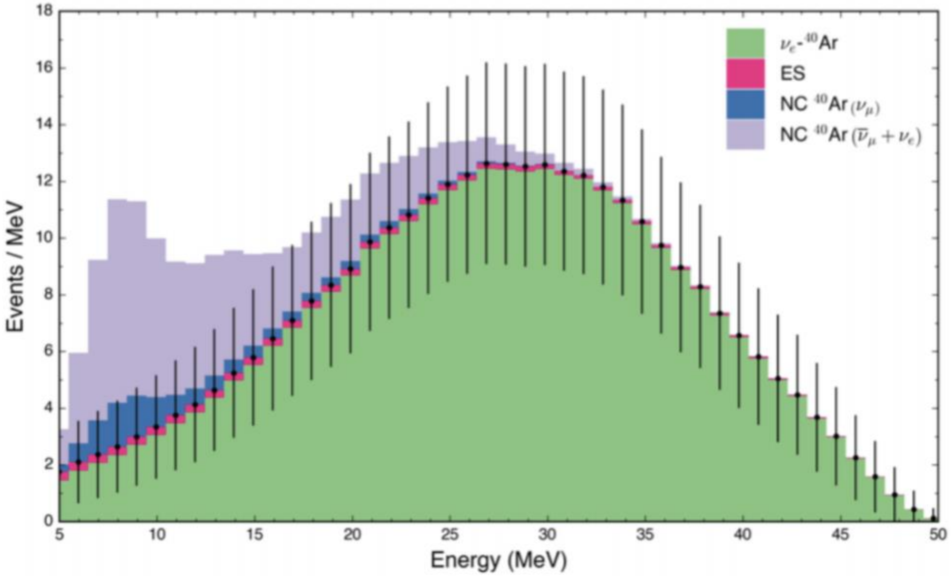
- We implemented the MARS detector to study the ambient neutron flux and spectrum throughout the hall
  - Important background for CEvNS searches



$n + {}^{157}Gd \rightarrow {}^{158}Gd + \sim 8MeV(gammas)$

- Uses plastic scintillator separated by layers of Gd paint
- Searches for prompt neutron recoil energy coincident with a neutron capture
- MARS designed to be semi-portable, to measure the neutron flux at multiple position

Physics Bonus Round: ν_e CC on ^{40}Ar



- LAr detector will see about 340 ν_e CC events / year
- XSec measurement piggybacks on CEvNS physics goals
- Very interesting for DUNE!
- π-DAR beam profile is very similar to supernova flux shape