COHERENT: CEvNS and More at the SNS

Matthew Green for the COHERENT Collaboration

NEUTRINO 2024 - June 21, 2024

NC STATE UNIVERSITY

OAK RIDGE National Laboratory

TUNL Triangle Universities Nuclear Laboratory

NSF

U.S. DEPARTMENT OF ENERGY | Office of Science

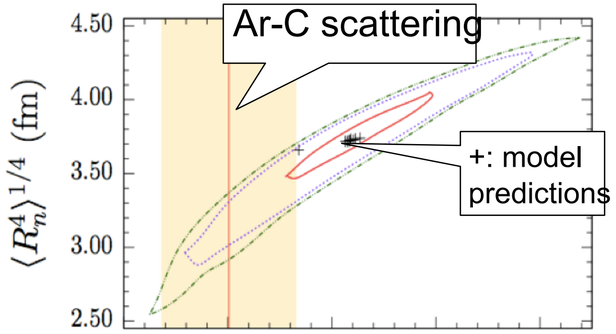
Broad Impact of CEvNS Studies

CEvNS measurements are relevant for a wide array of physics.

Largest σ in Supernova Dynamics

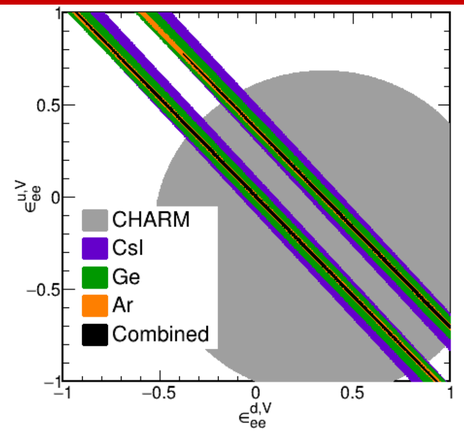
J.R. Wilson, PRL 32, 849 (1974)
C. Horowitz et al., PRD 68, 02005 (2003)

Nuclear Form Factors

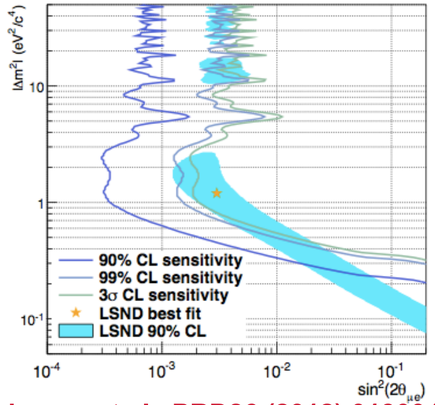


P. S. Amanik and G. C. McLaughlin, J. Phys. G 36:015105
K. Patton et al., PRC86 (2012) 024612

Non-Standard Interactions

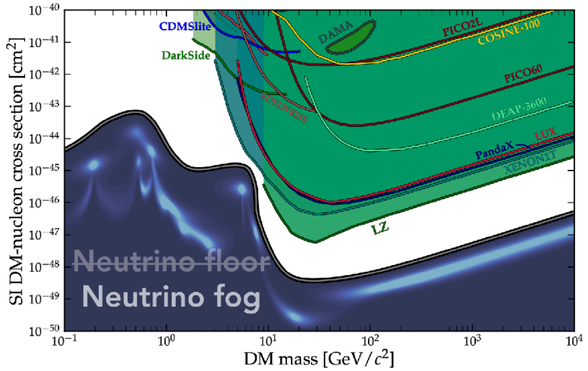


Sterile Searches



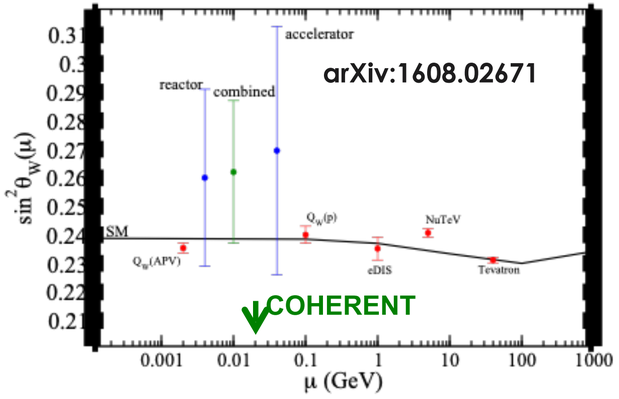
A. Anderson et al., PRD86 (2012) 013004

Background for Dark Matter Searches

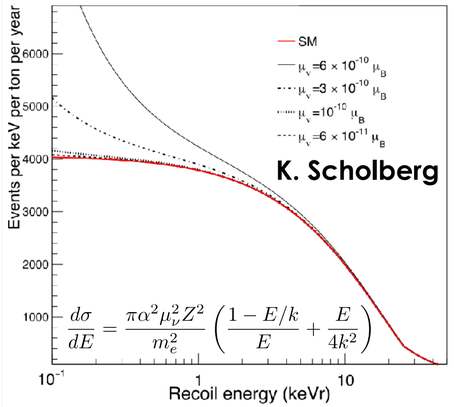


C. O'Hare, Magnificent CEvNS 2024

Weak Mixing Angle

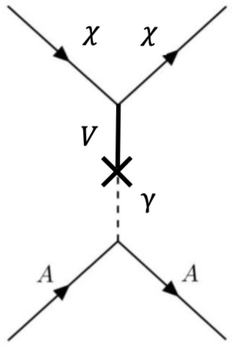


Neutrino Magnetic Moments



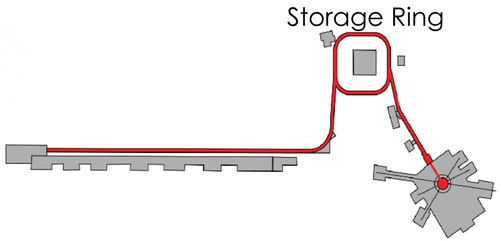
See Kosmas et al., arXiv:1505.03202

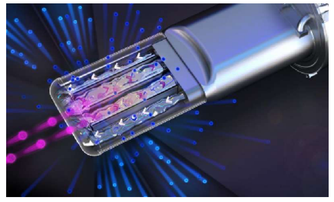
Accelerator Dark Matter Searches

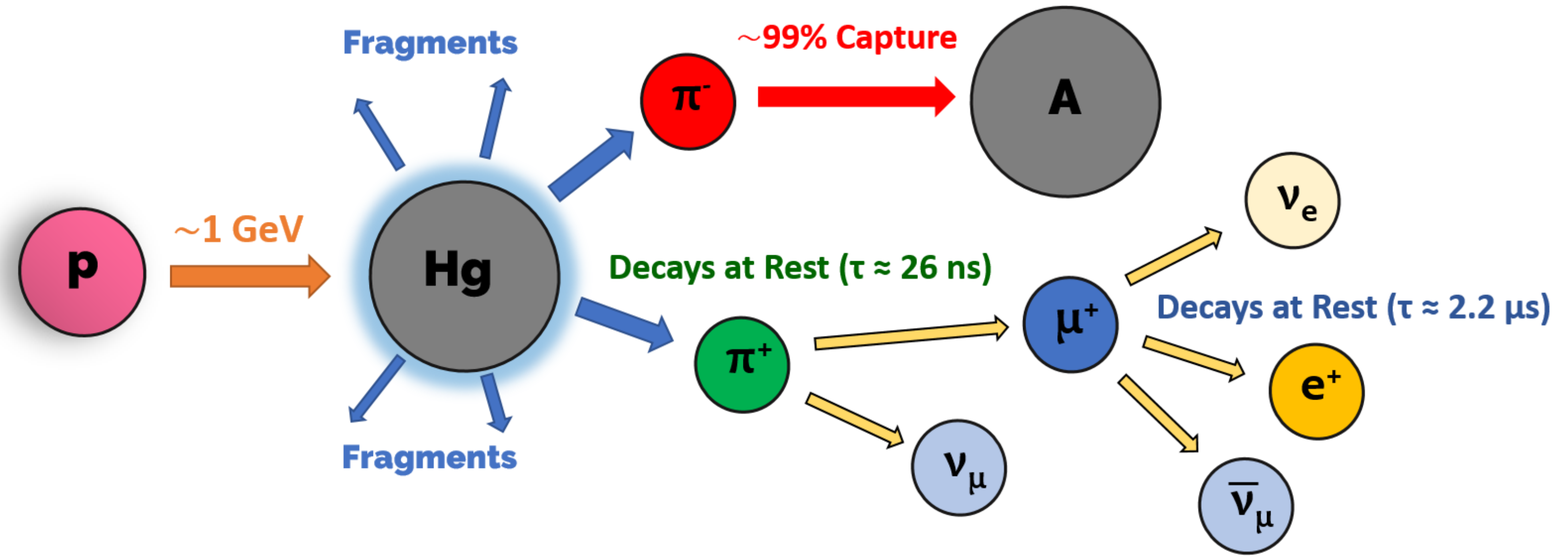


deNiverville et al., PRD92 (2015) 095005

Neutrino Production at the SNS







- Proton Beam:
  - 0.9-1.3GeV
  - 0.9-1.7MW, **soon 2MW (PPU)**.
- Total ν flux: ~4.3 x 10^7 cm^{-2} s^{-1} at 20m
- Beam timing & duty cycle (60Hz, 380ns FWHM) allow for powerful reduction of steady-state backgrounds (~10^{-4})

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

2-body π⁺-decay: Prompt (26nsec)
Monochromatic: 29.9MeV ν_μ

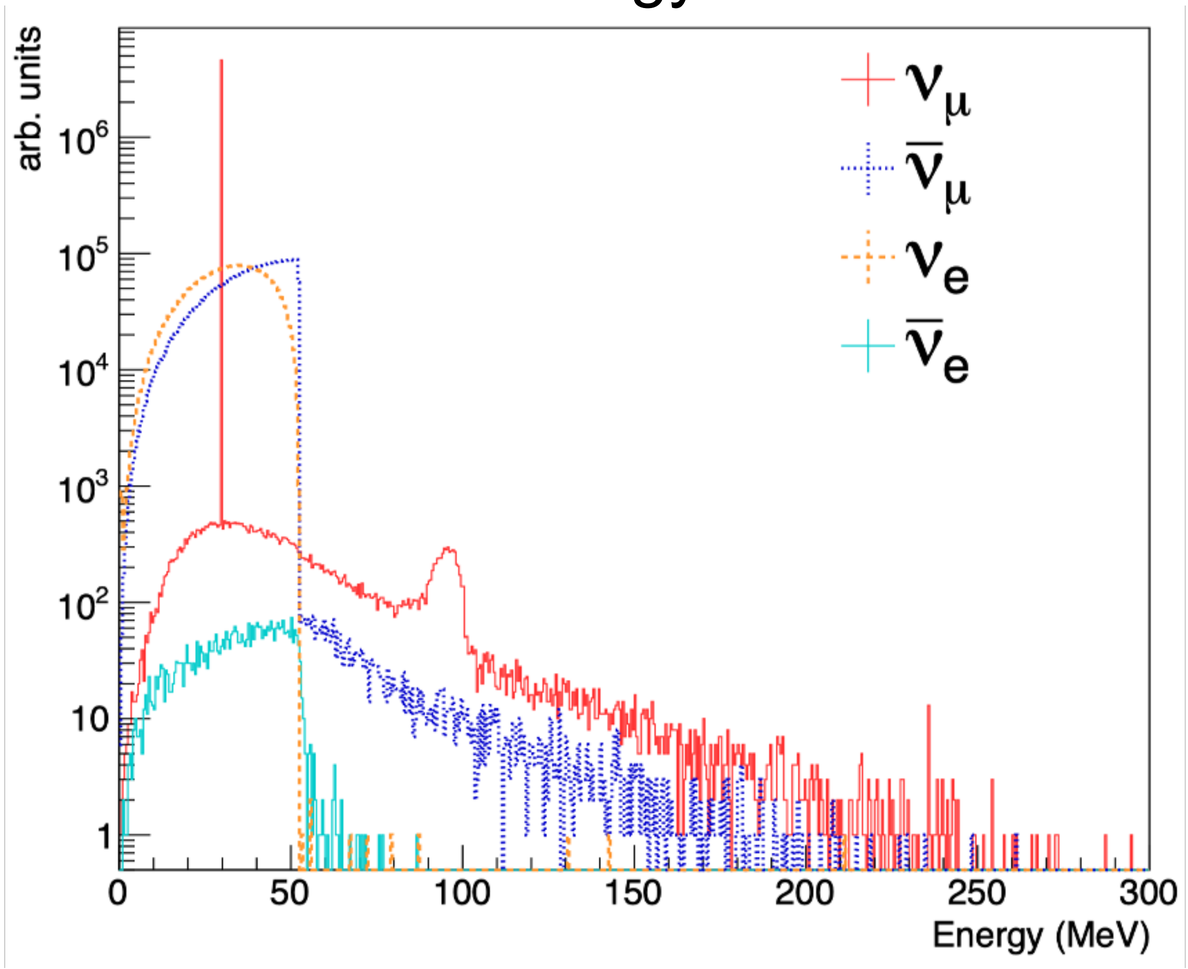
$$\downarrow$$

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

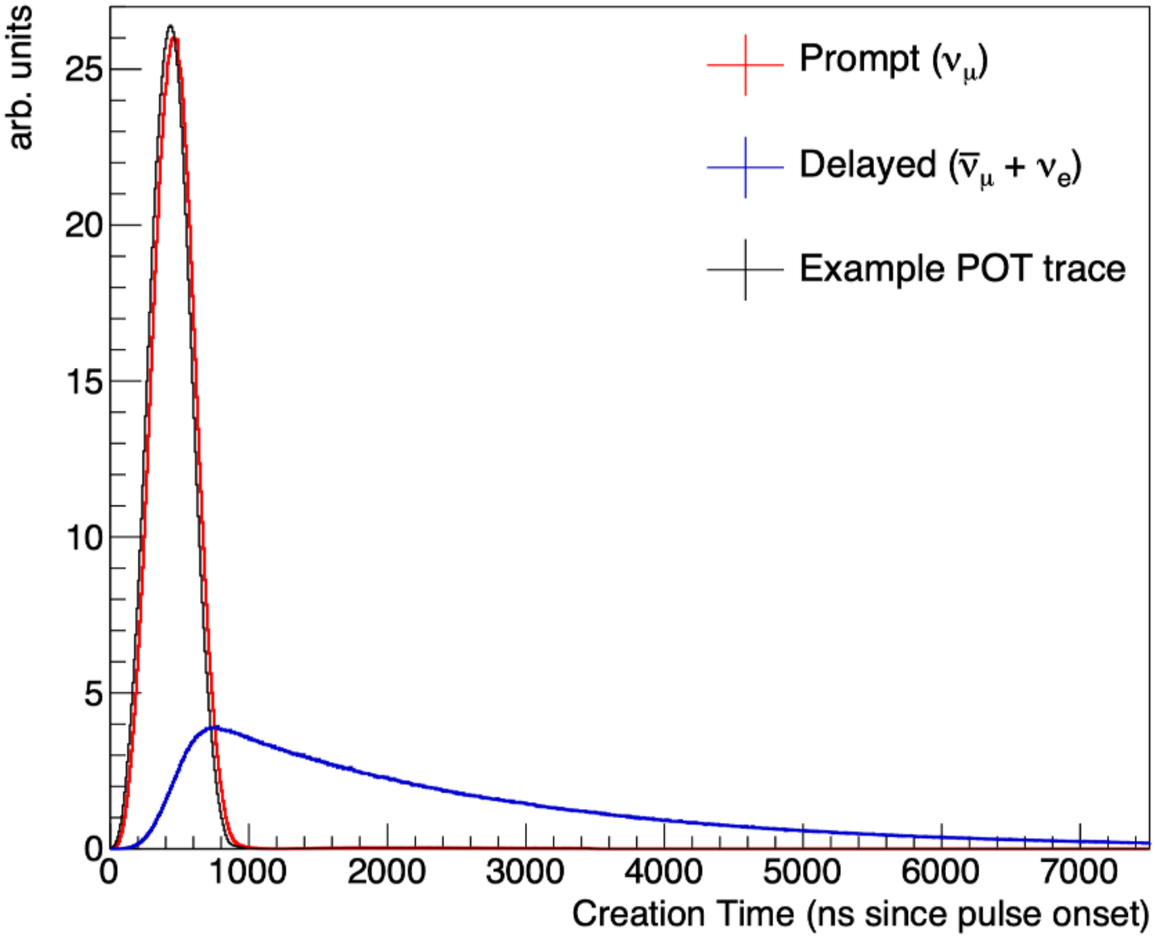
3-body μ⁻-decay:
Delayed (2.2μsec)
0-53MeV $\bar{\nu}_\mu$, ν_e

Neutrino Production at the SNS

Energy

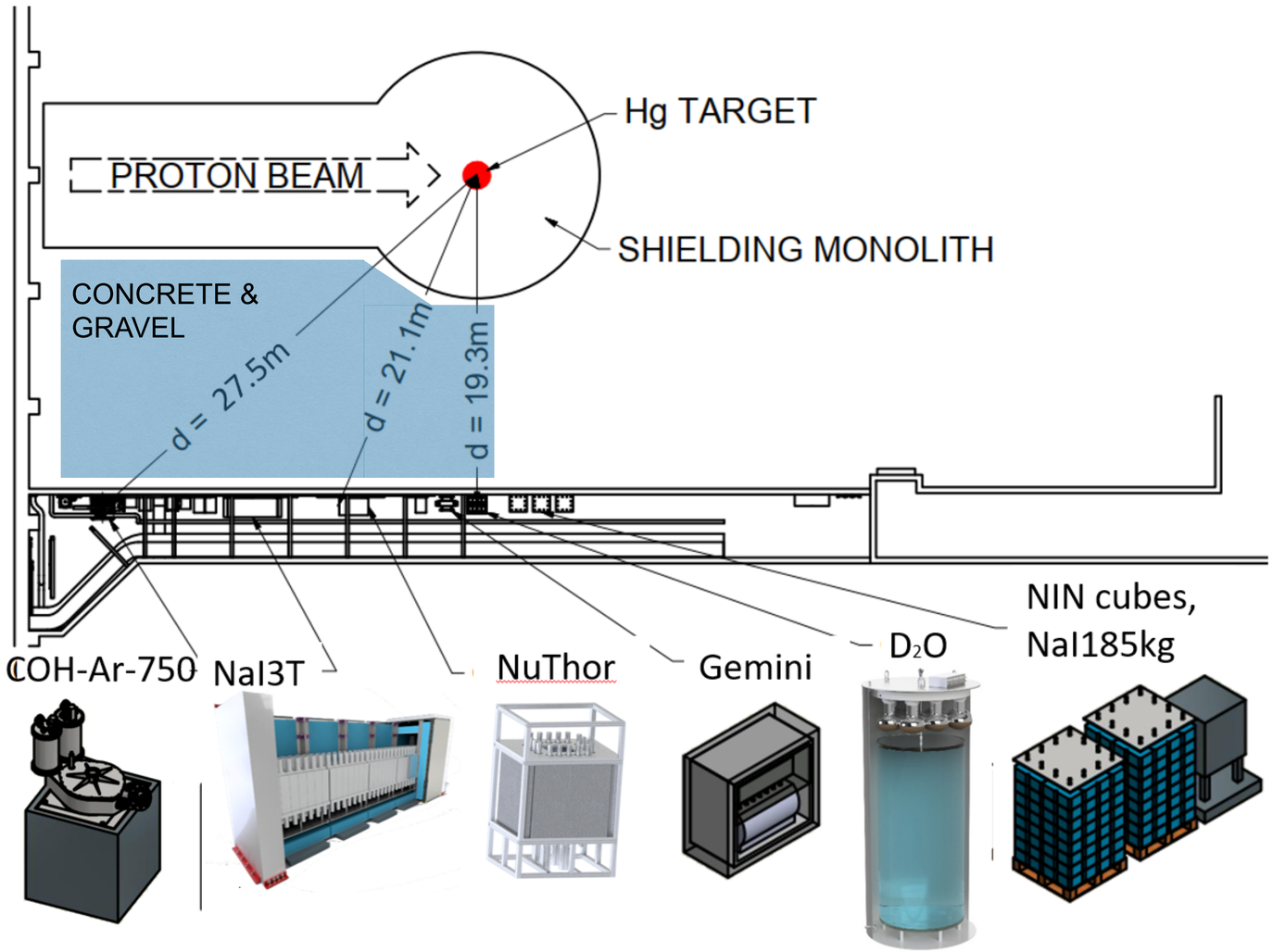


Time



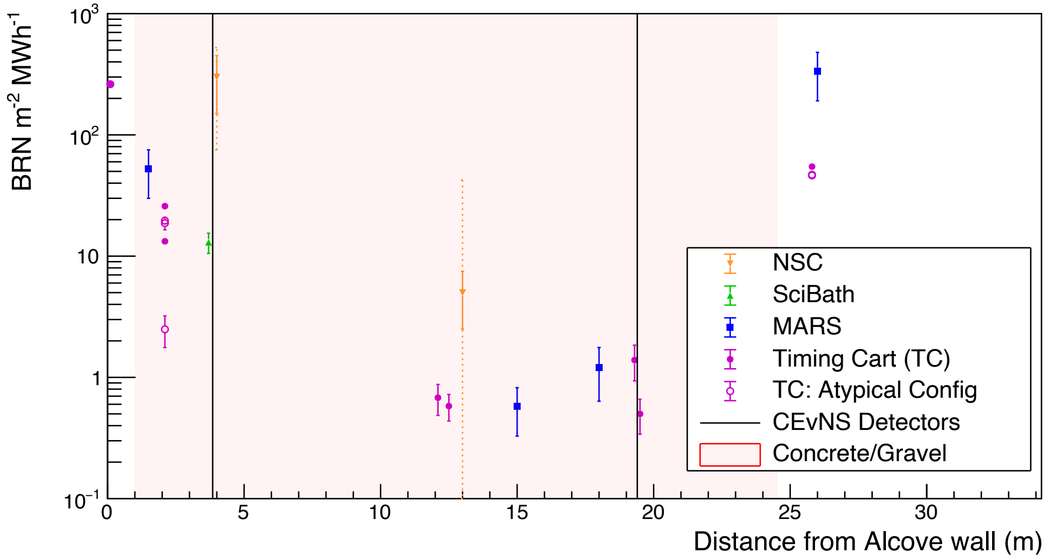
COHERENT, Phys. Rev. D 106 032003 (2022)

COHERENT's Home: Neutrino Alley



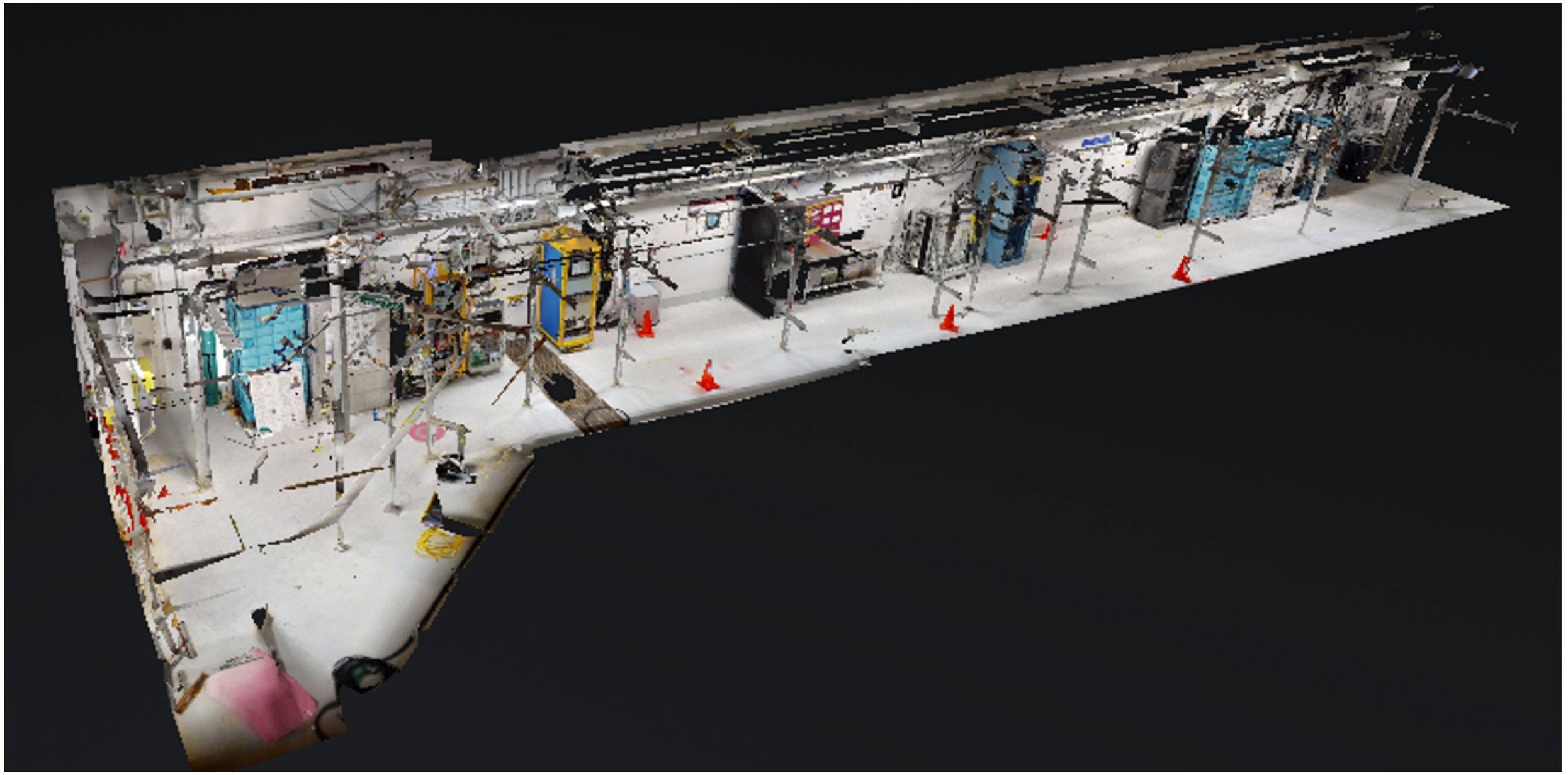
Neutrino Alley

- Steady-state backgrounds:
  - Cosmic Rays (8 m.w.e. overburden)
  - 511keV γ-rays (SNS infrastructure)
  - Environmental γ-rays
- Beam-related backgrounds:
  - Fast neutrons
  - Neutrino-Induced Neutrons (NINs)



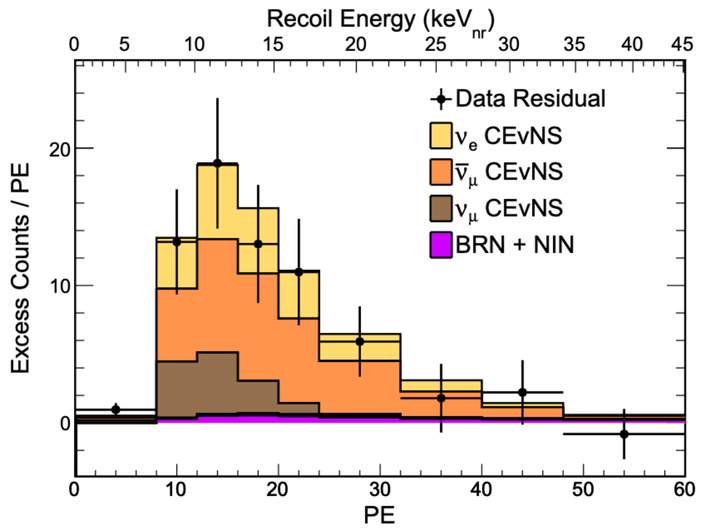
R. Rapp, PhD Dissertation (2022)

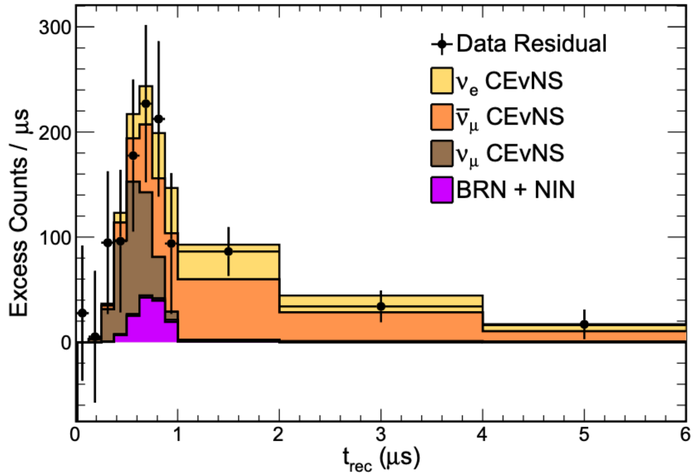
COHERENT's Home: Neutrino Alley



COHERENT's First 2 CEvNS Measurements

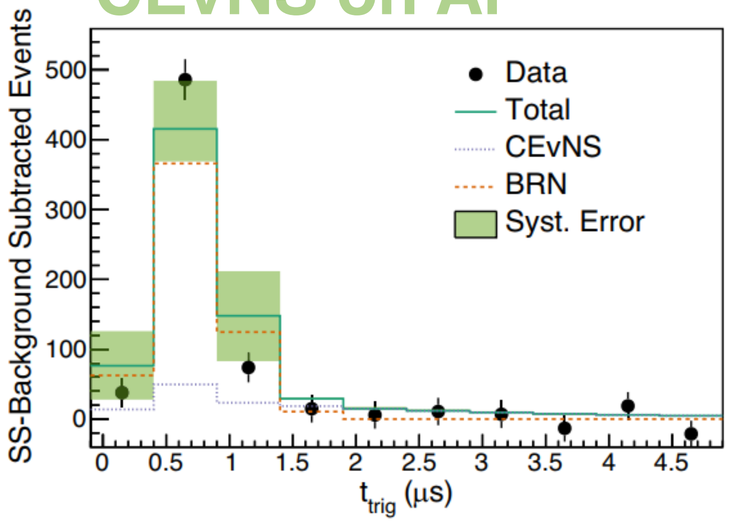
CEvNS on CsI

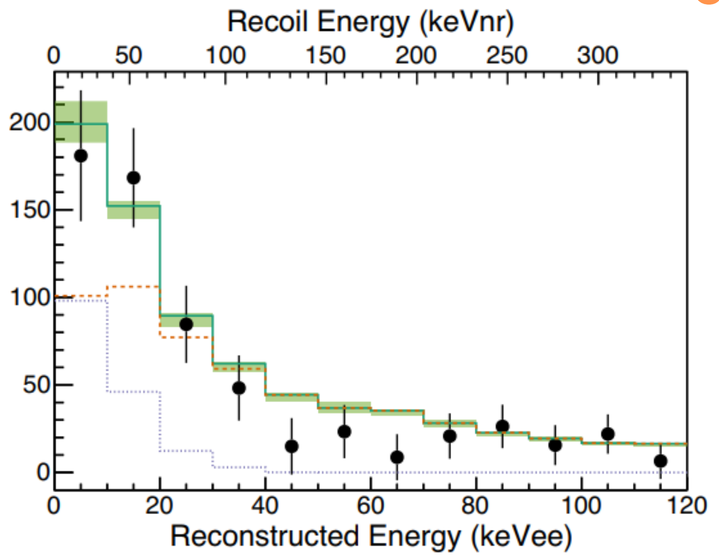


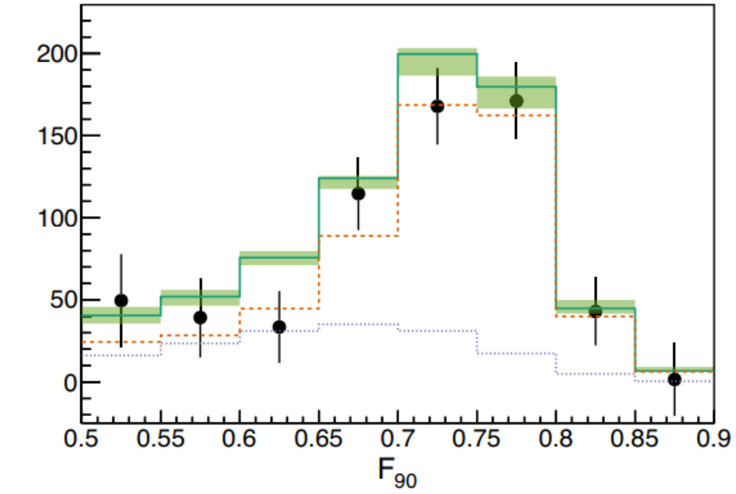


COHERENT, PRL 129 081801 (2022)

CEvNS on Ar

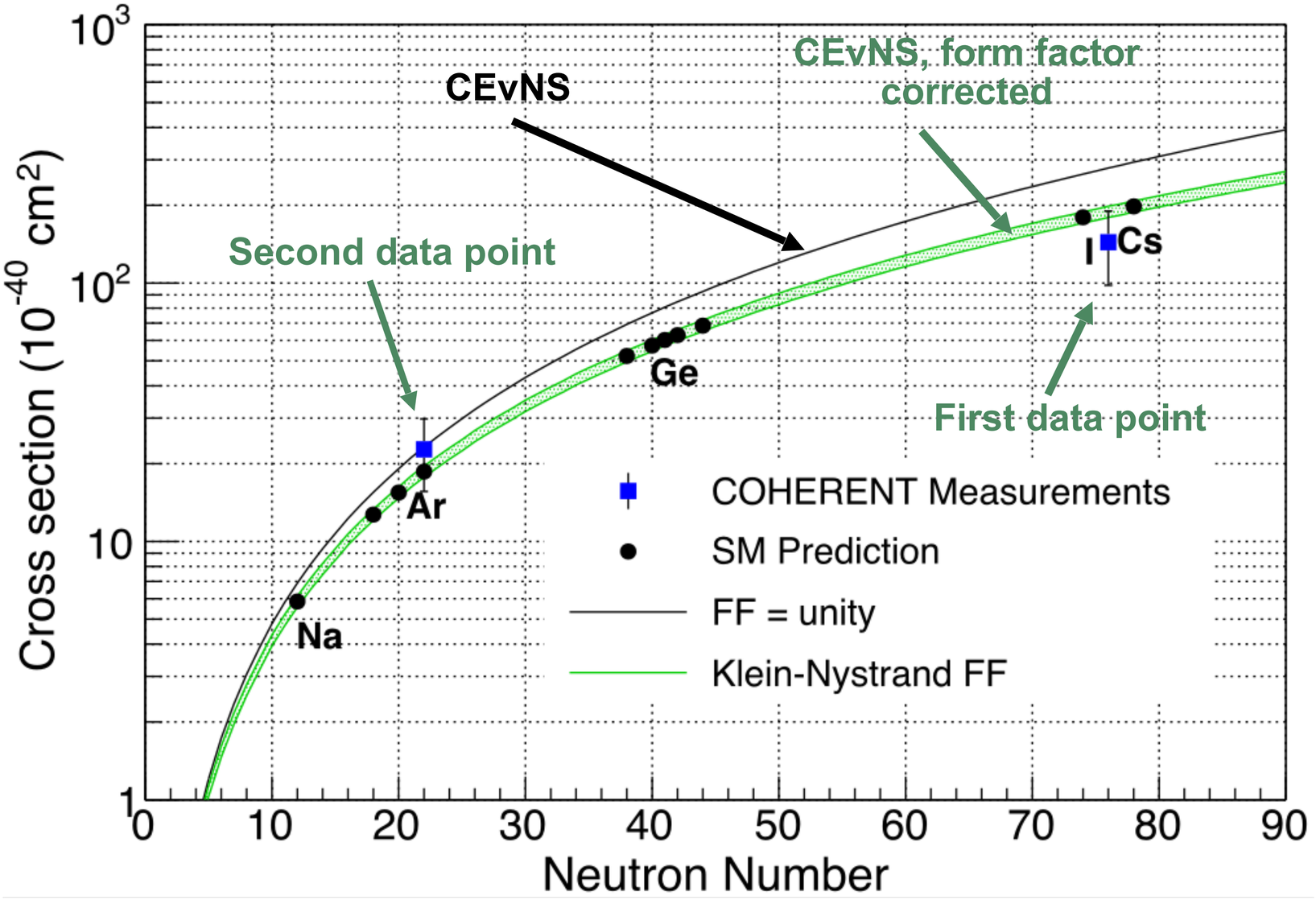






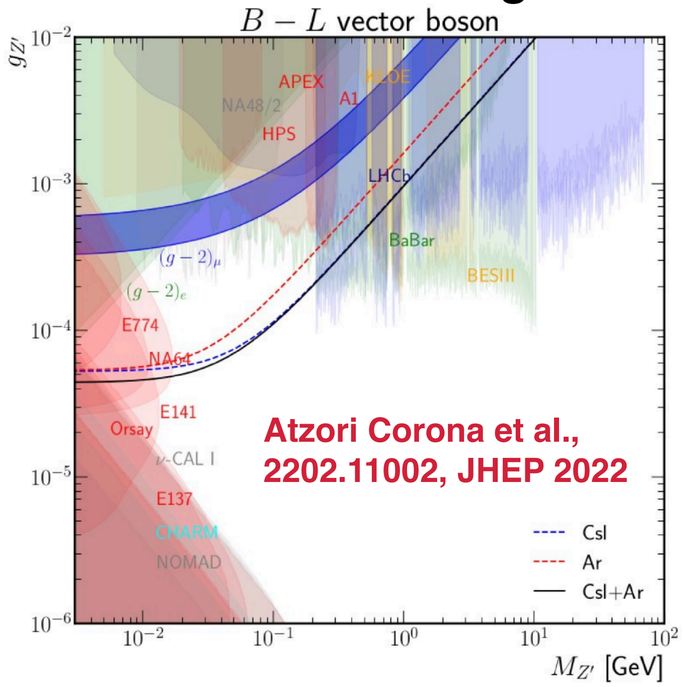
COHERENT, PRL 126 012002 (2021)

COHERENT's First 2 CEvNS Measurements

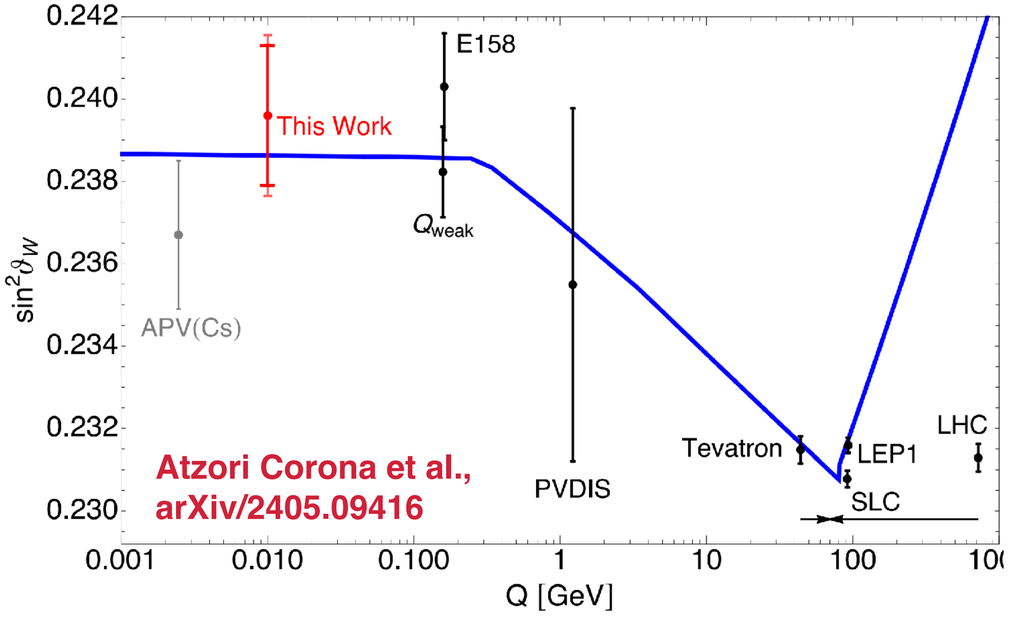


COHERENT's Physics Impact

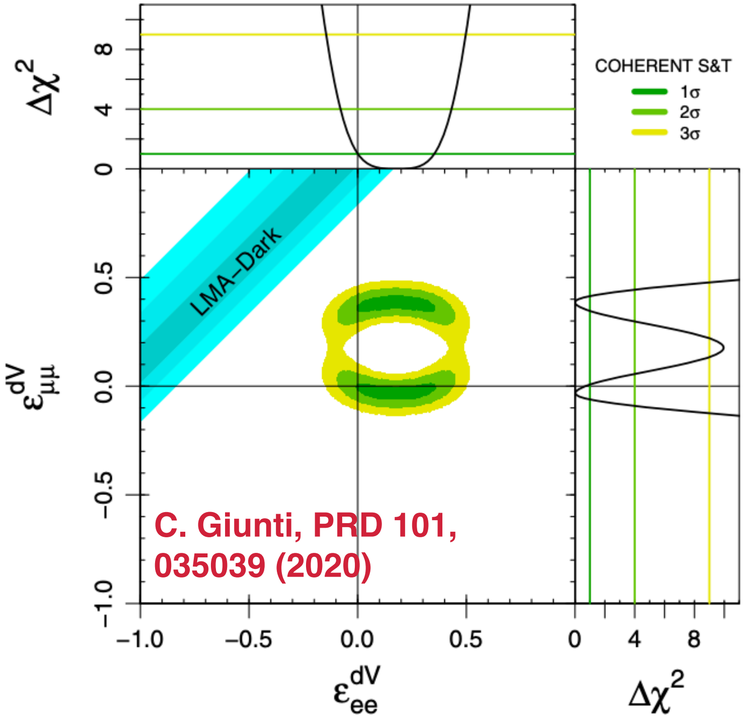
Constraints on Light Z'



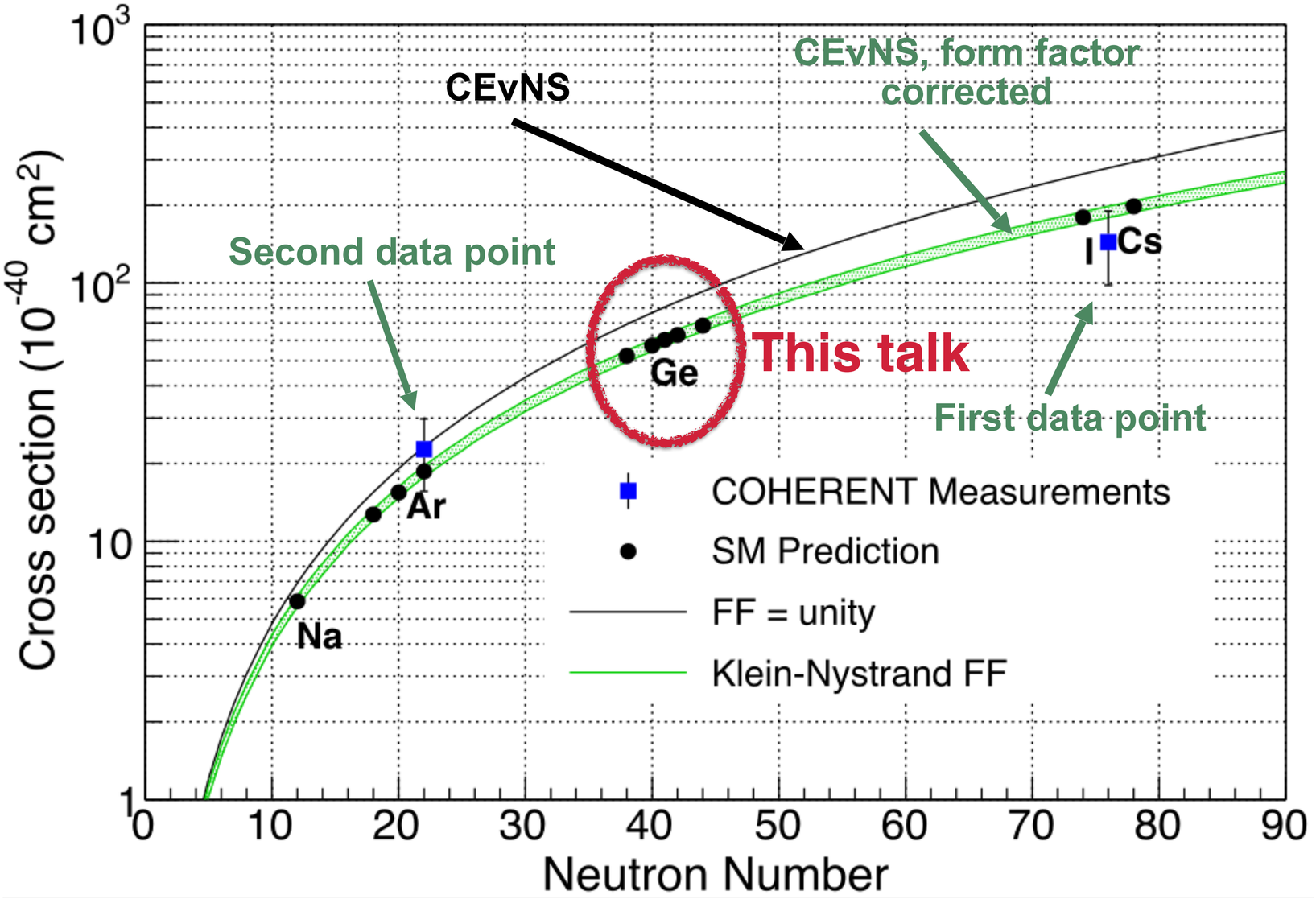
CEvNS & APV combined fit of θ_W



Limits on Non-Standard Neutrino Interactions

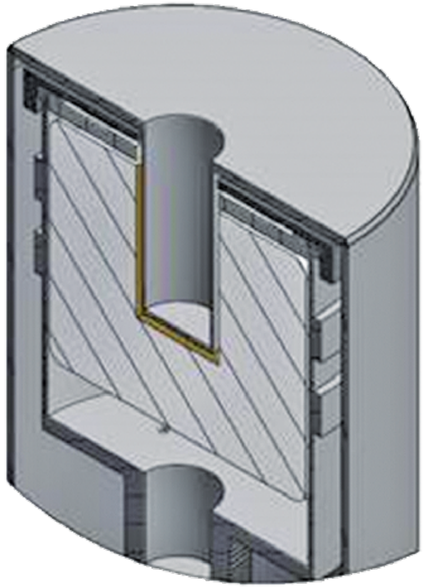


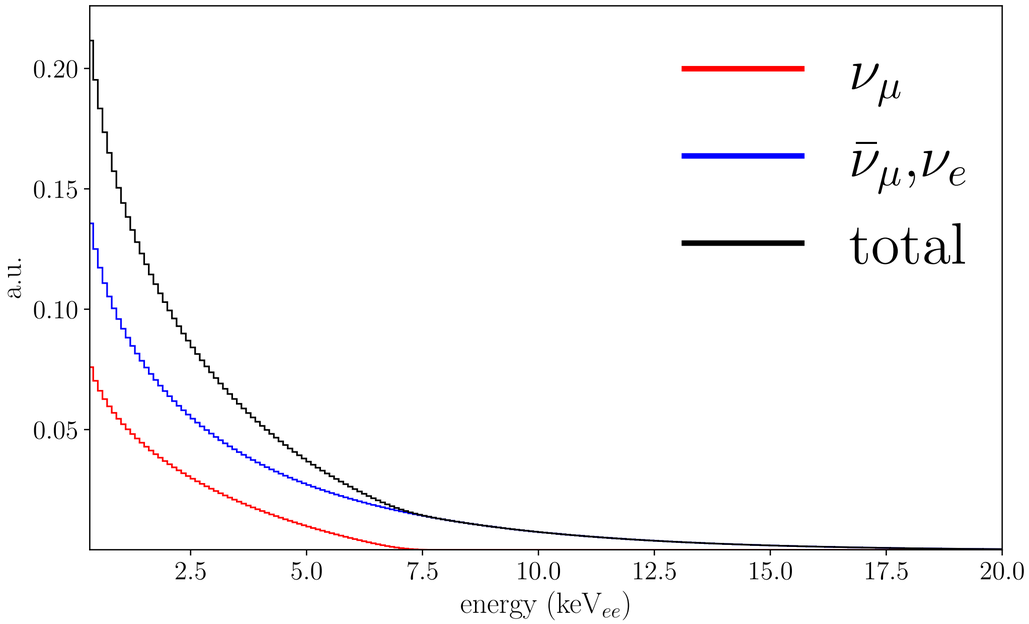
COHERENT's Next CEvNS Measurement: Ge



HPGe Detectors for CEvNS

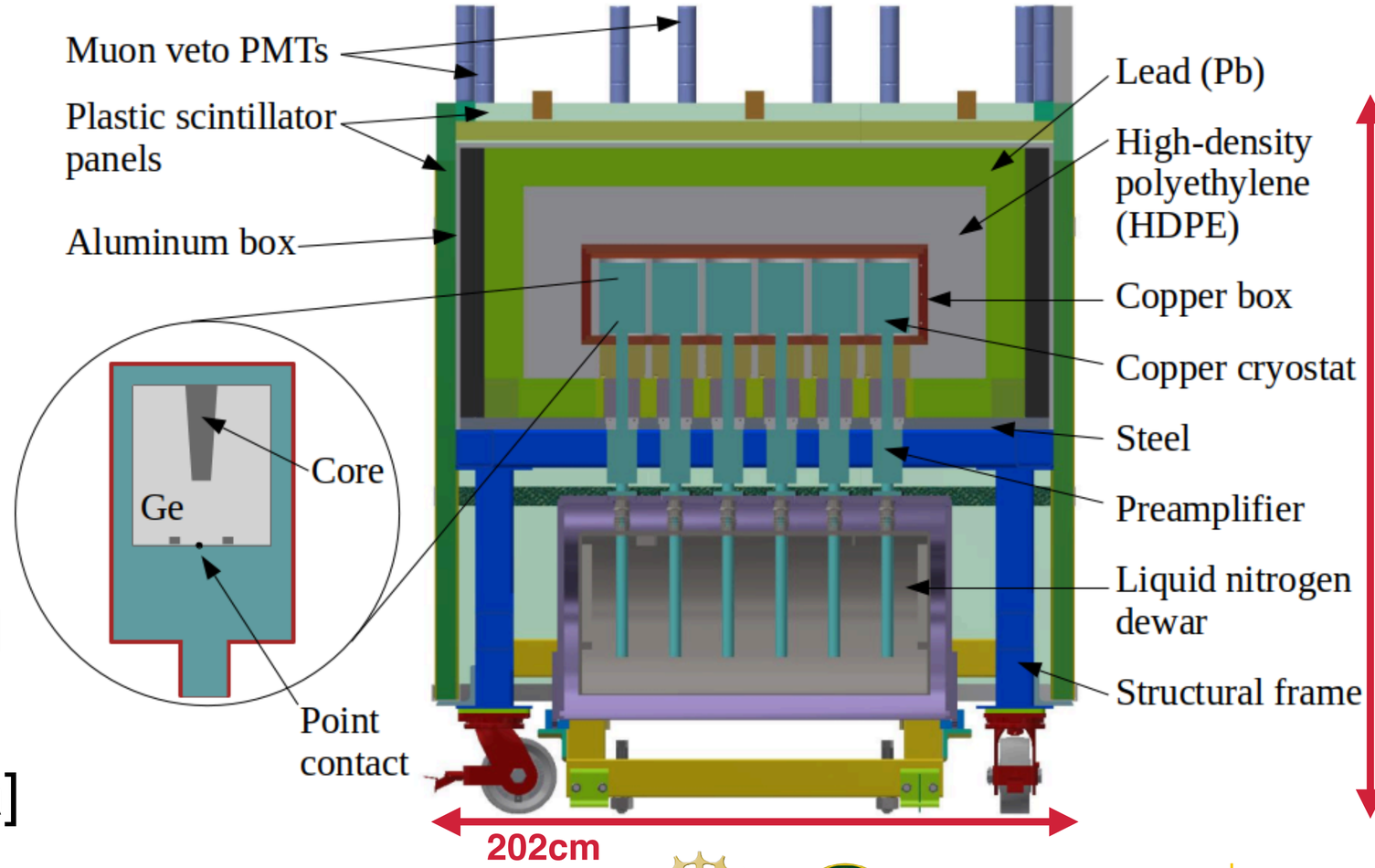
- P-Type Point Contact (PPC) Ge detectors well-suited to precision CEvNS measurements:
  - Excellent energy resolution
  - Low thresholds
  - Well-understood systematics.
- Inverted Coaxial form factor (ICPC) allows for large detector masses (>2 kg) with superior noise characteristics.



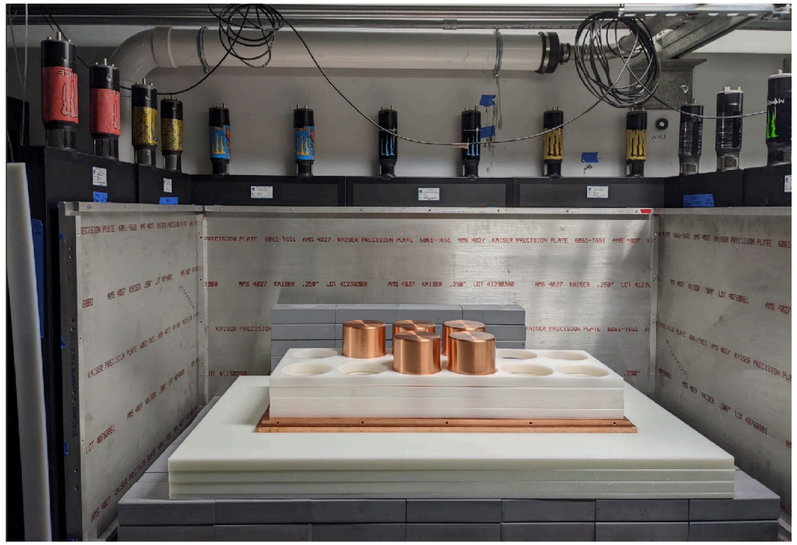


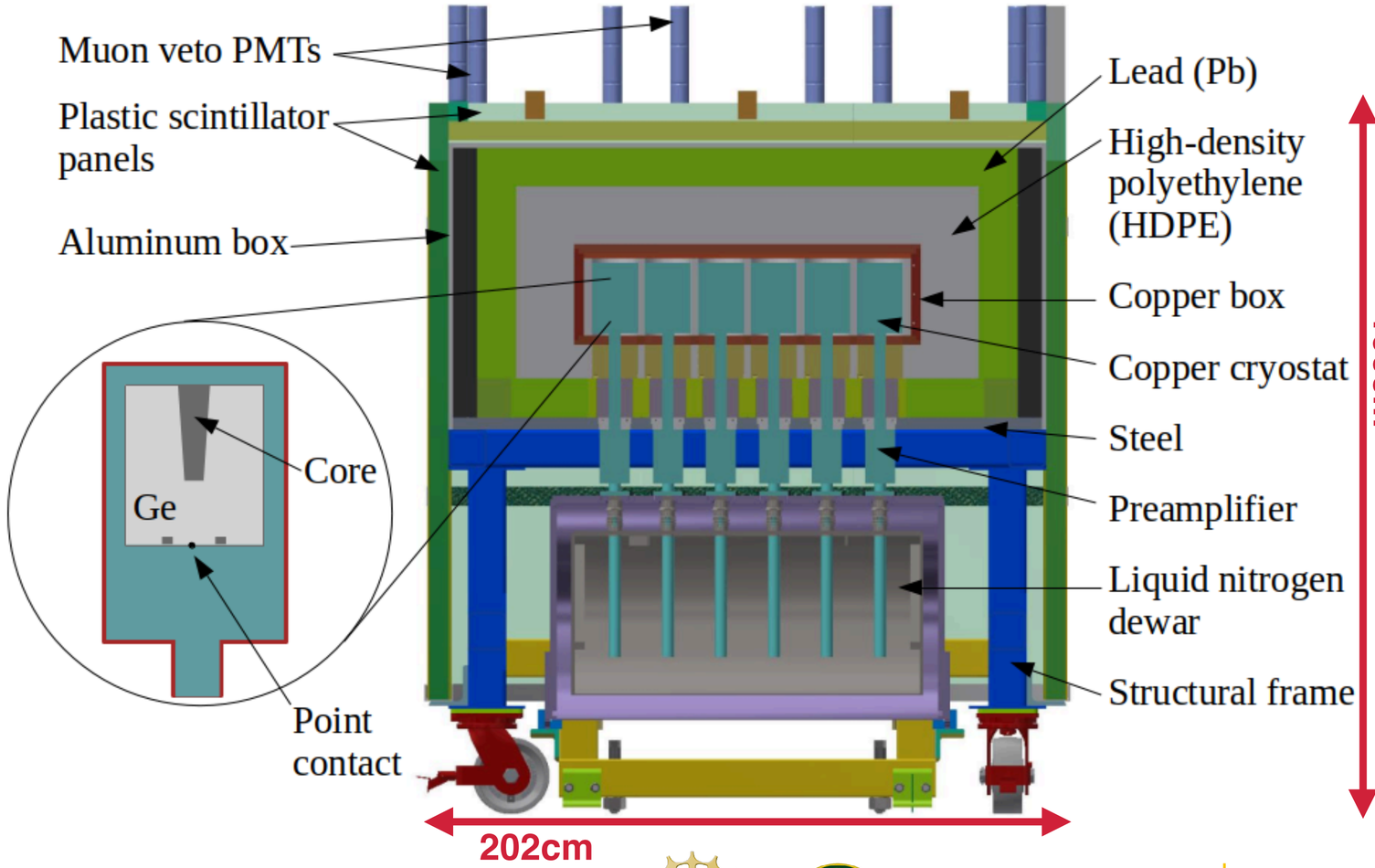
COHERENT's Ge Array: **Ge-Mini**

- 18-kg array of ICPC Ge detectors at the SNS.
- NSF MRI Award 1920001
- Detectors:
  - 8 detectors ~ 2.2 kg each
  - Mirion Tech., Meriden, CT USA
  - < 150 eV FWHM pulser resolution
  - < ~500 eV noise threshold
  - < ~3 keV_{nr} CEvNS threshold
- Compact Cu, Poly, Pb shield
- PI-scintillator muon veto
- Site: 19.2m baseline; CsI[Na] location

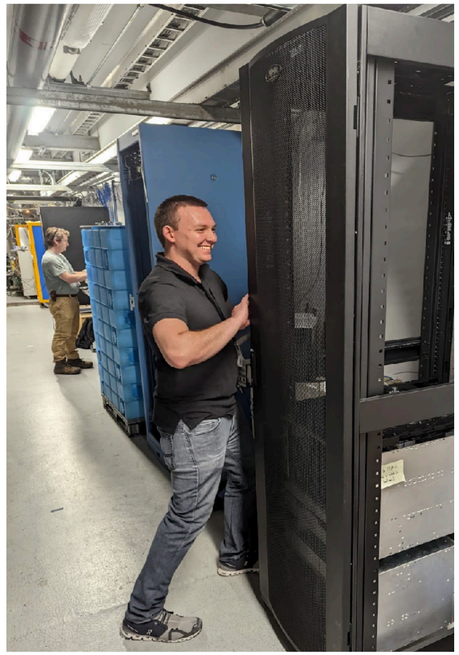


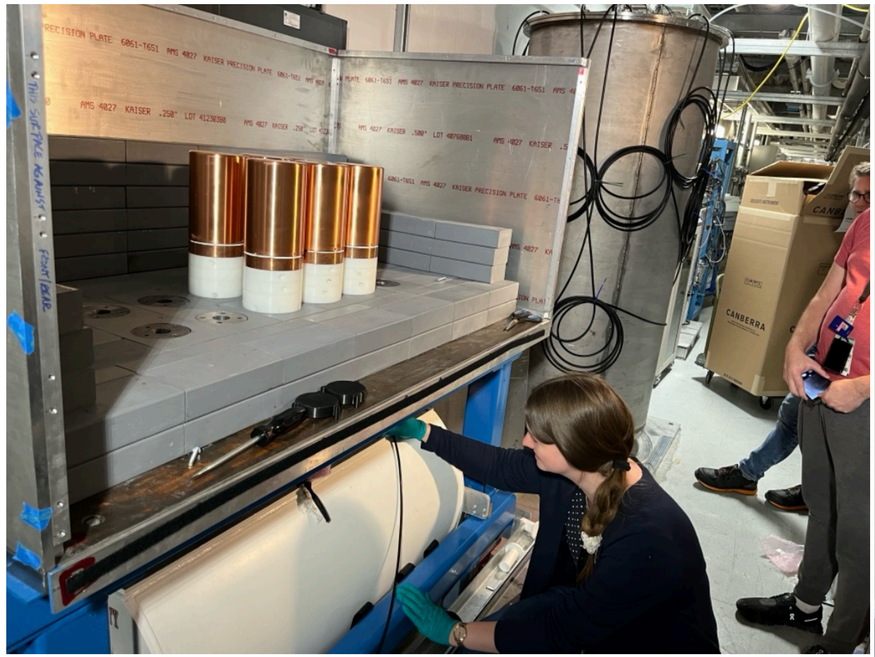
COHERENT's HPGe Array: **Ge-Mini**

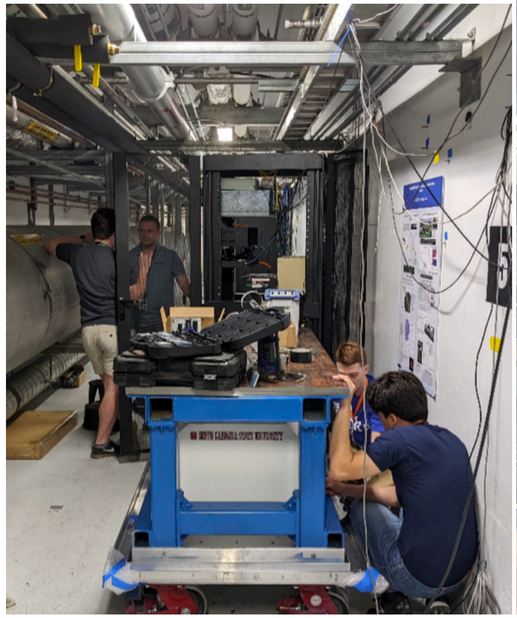




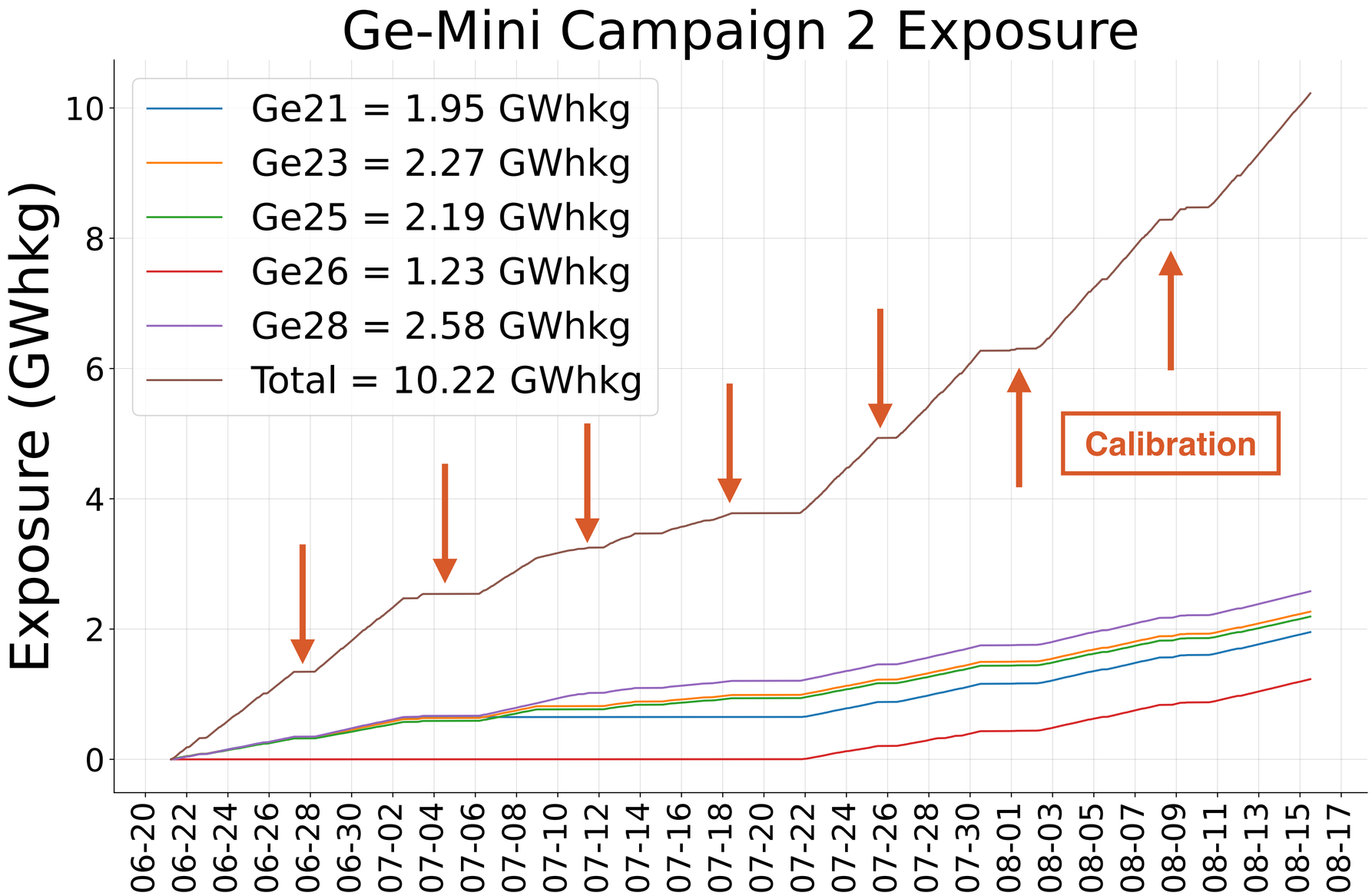
Ge-Mini Assembly & Commissioning





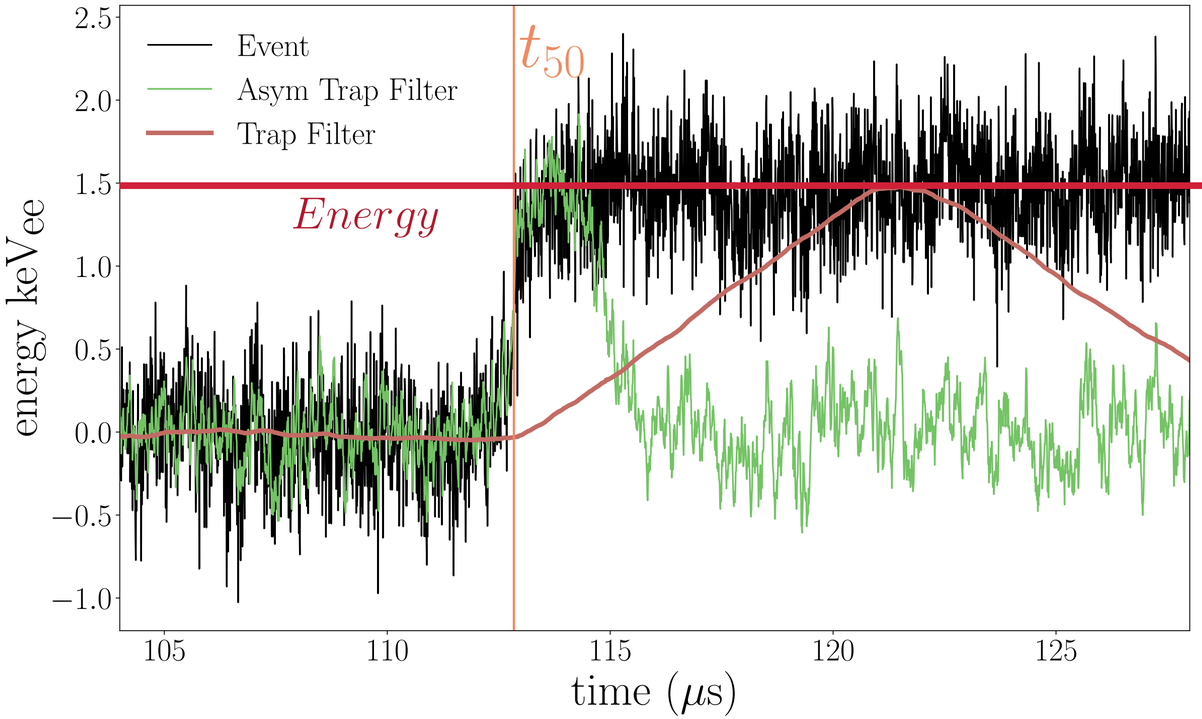


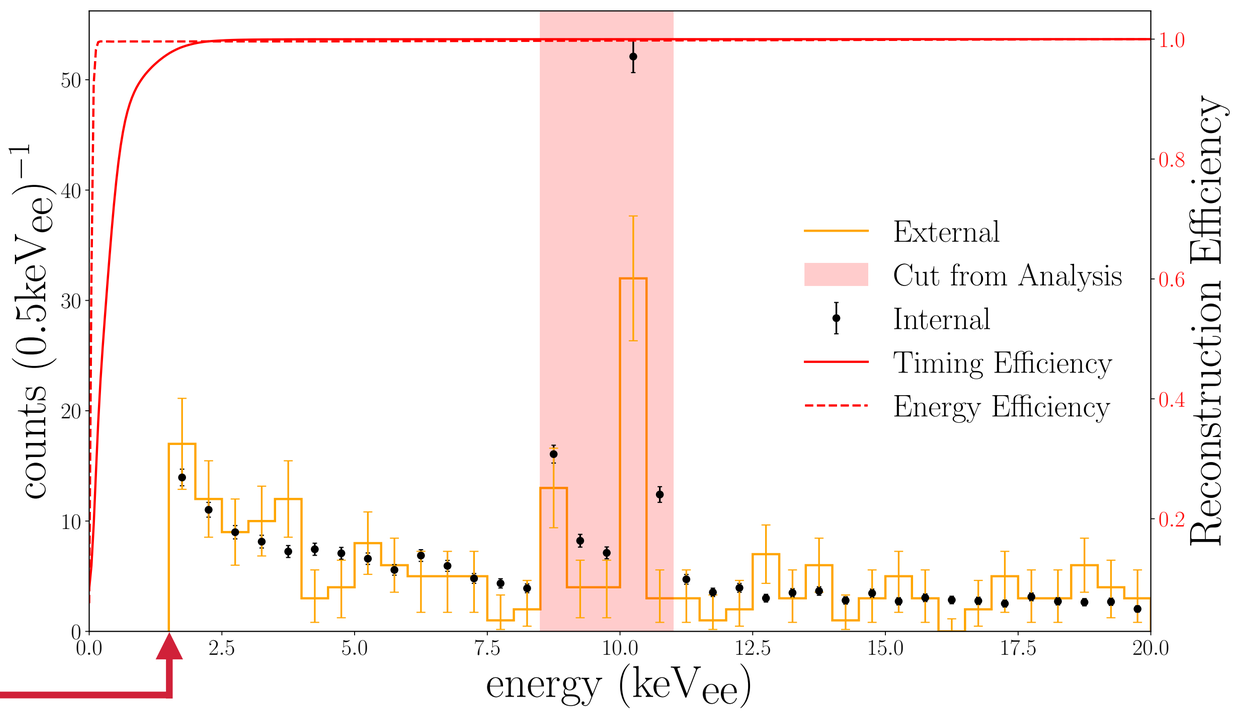
Ge-Mini Campaign 2



Energy & Time Reconstruction

arXiv:2406.13806

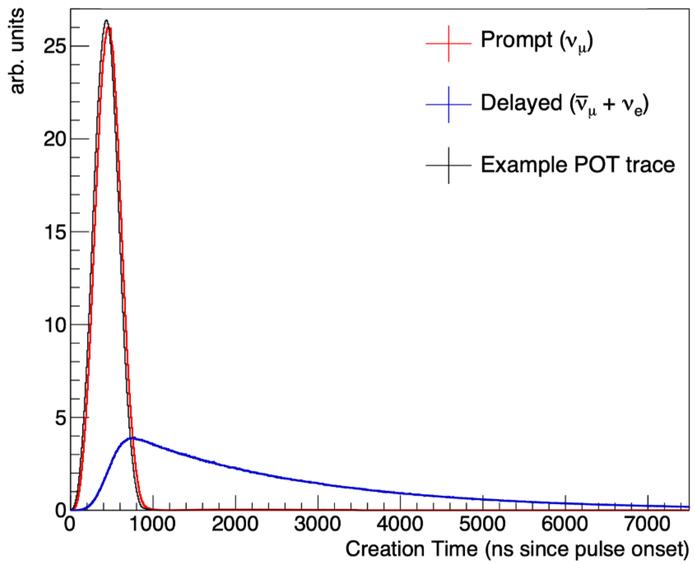




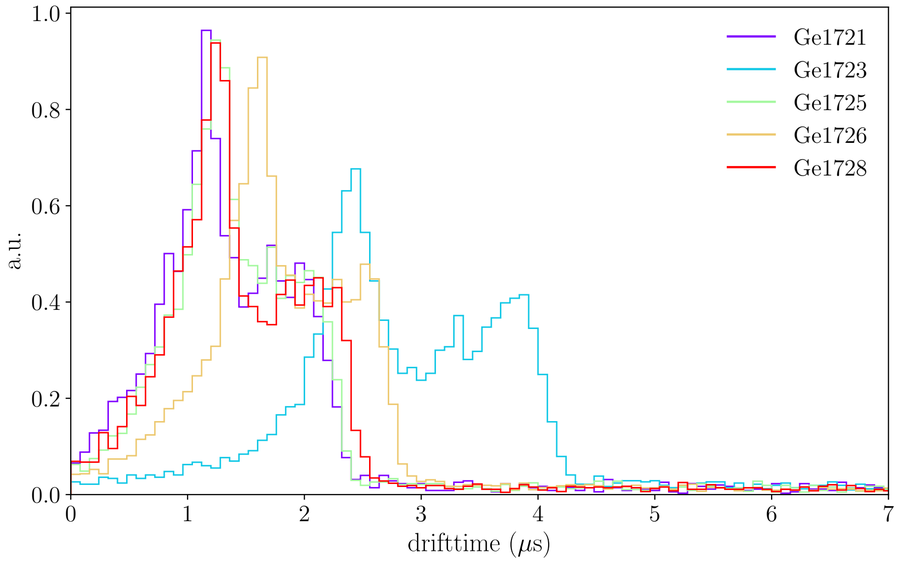
Current Analysis Threshold = 1.5 keV_{ee}.
Limited by timing reconstruction in this analysis

CEvNS Timing Distribution

SNS ν Time Distribution

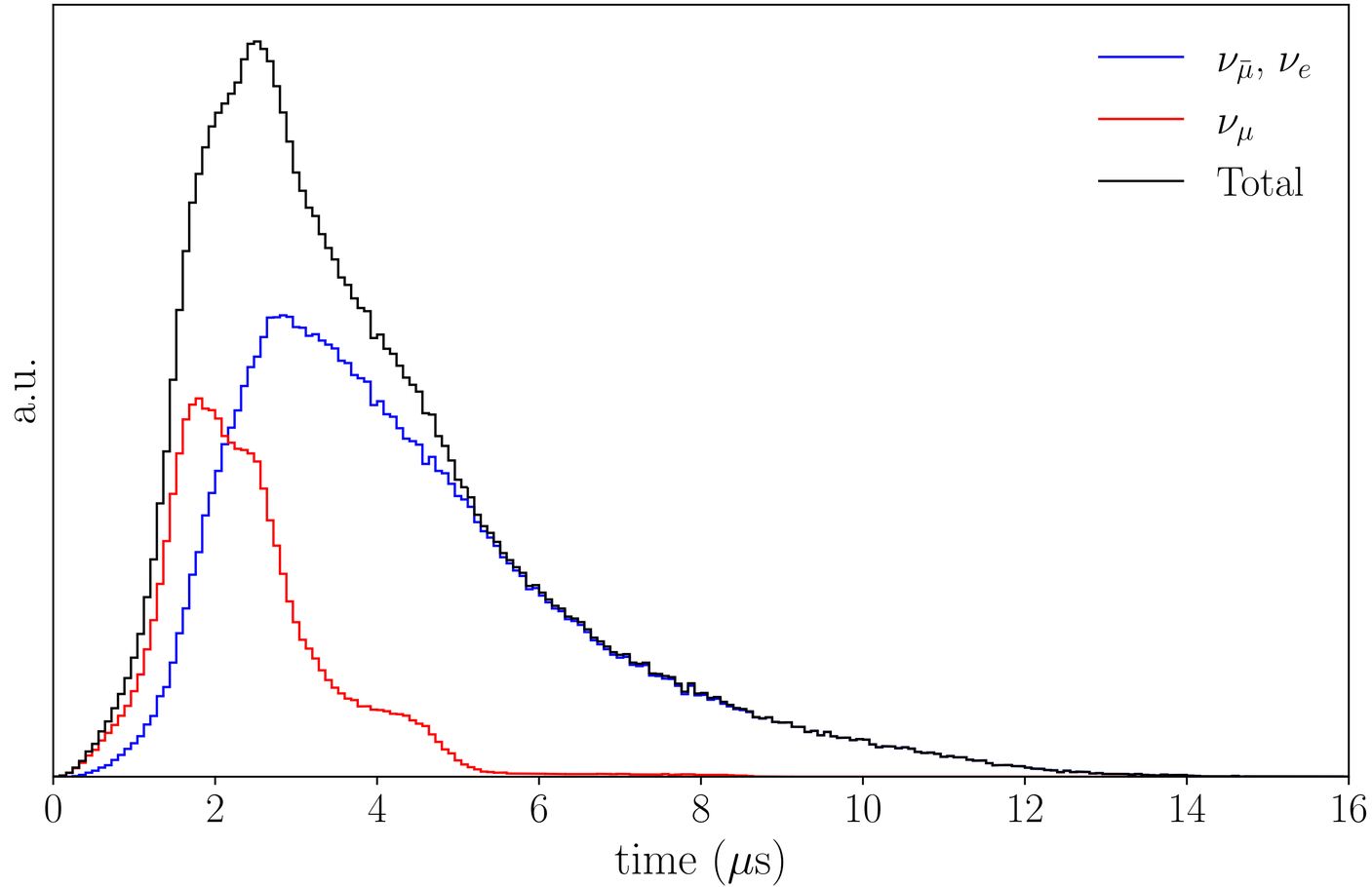


Measured Drift Time



- Neutrino signal timing distribution convolution of:
  - Neutrino production (prompt: ~0-0.8 μsec; delayed: ~0-8 μsec)
  - Detector drift-times (~0-3 μsec)
  - Waveform time reconstruction resolution (<0.5 μsec)

Signal Time Distribution (Time since POT signal)



Ge-Mini Campaign 2 Results

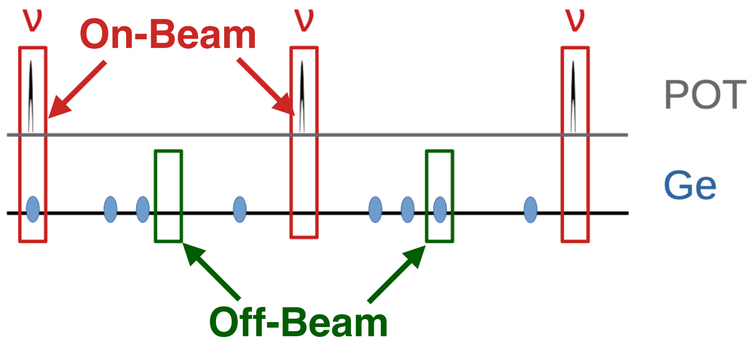
Counting analysis:

- E,t : [1.5, 8.5 keV$_{ee}$], [0, 8 μs]
- CEvNS-like events: **21.0 ± 7.8**

2D, unbinned extended-likelihood fit:

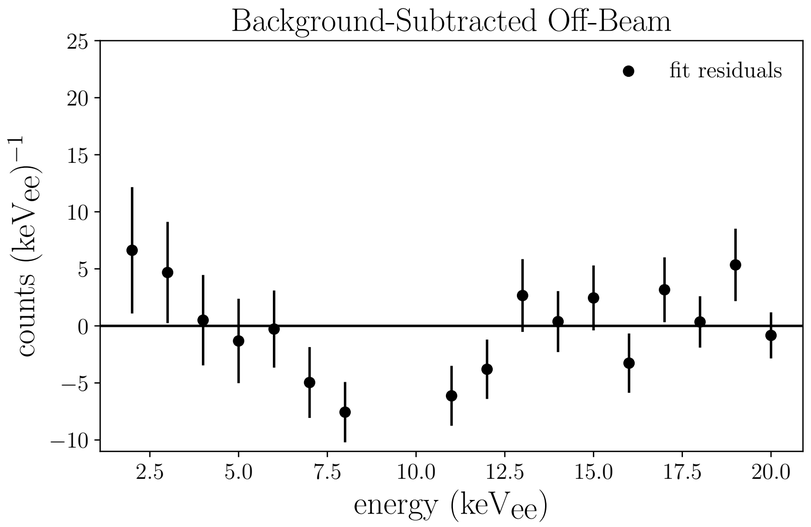
- CEvNS signal
- Steady-state background
- Prompt n expected: 0.67±0.34

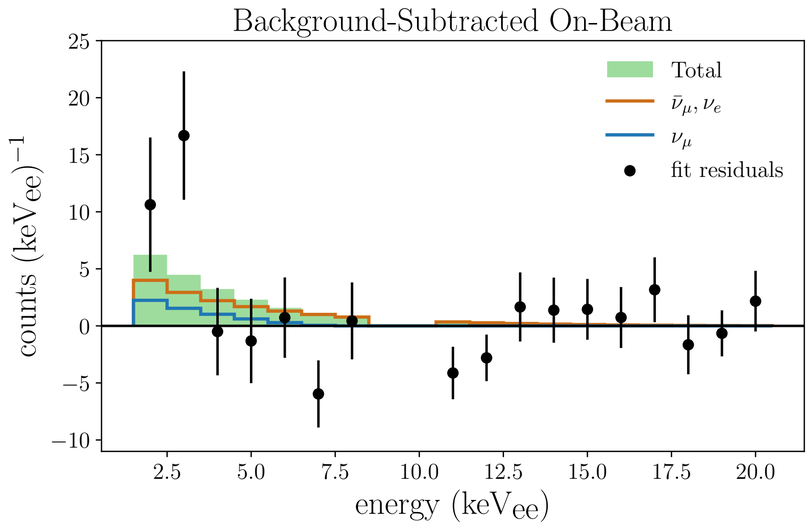
externally triggered 120 Hz

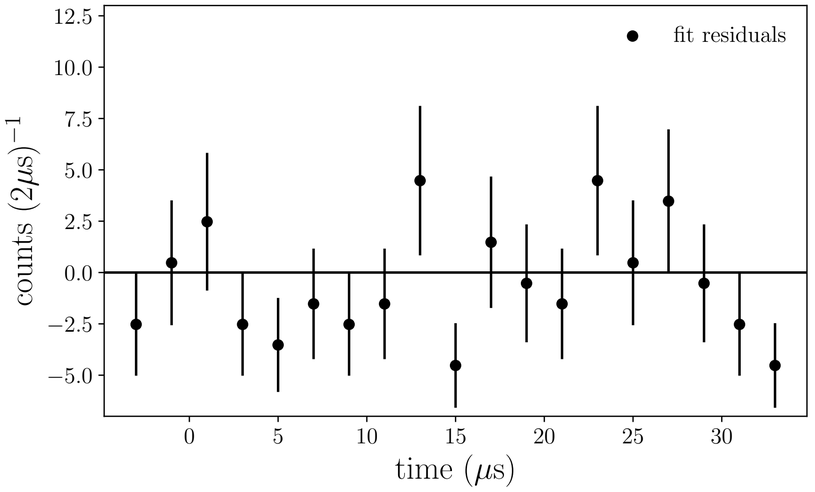


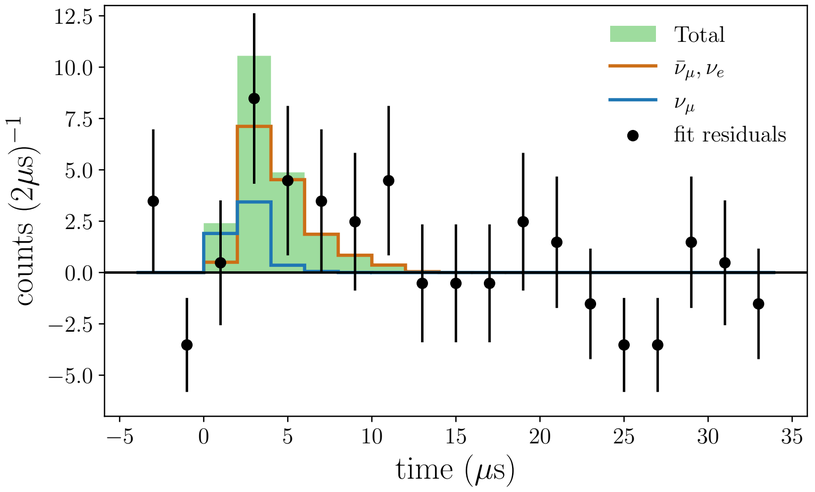
Off-Beam

On-Beam



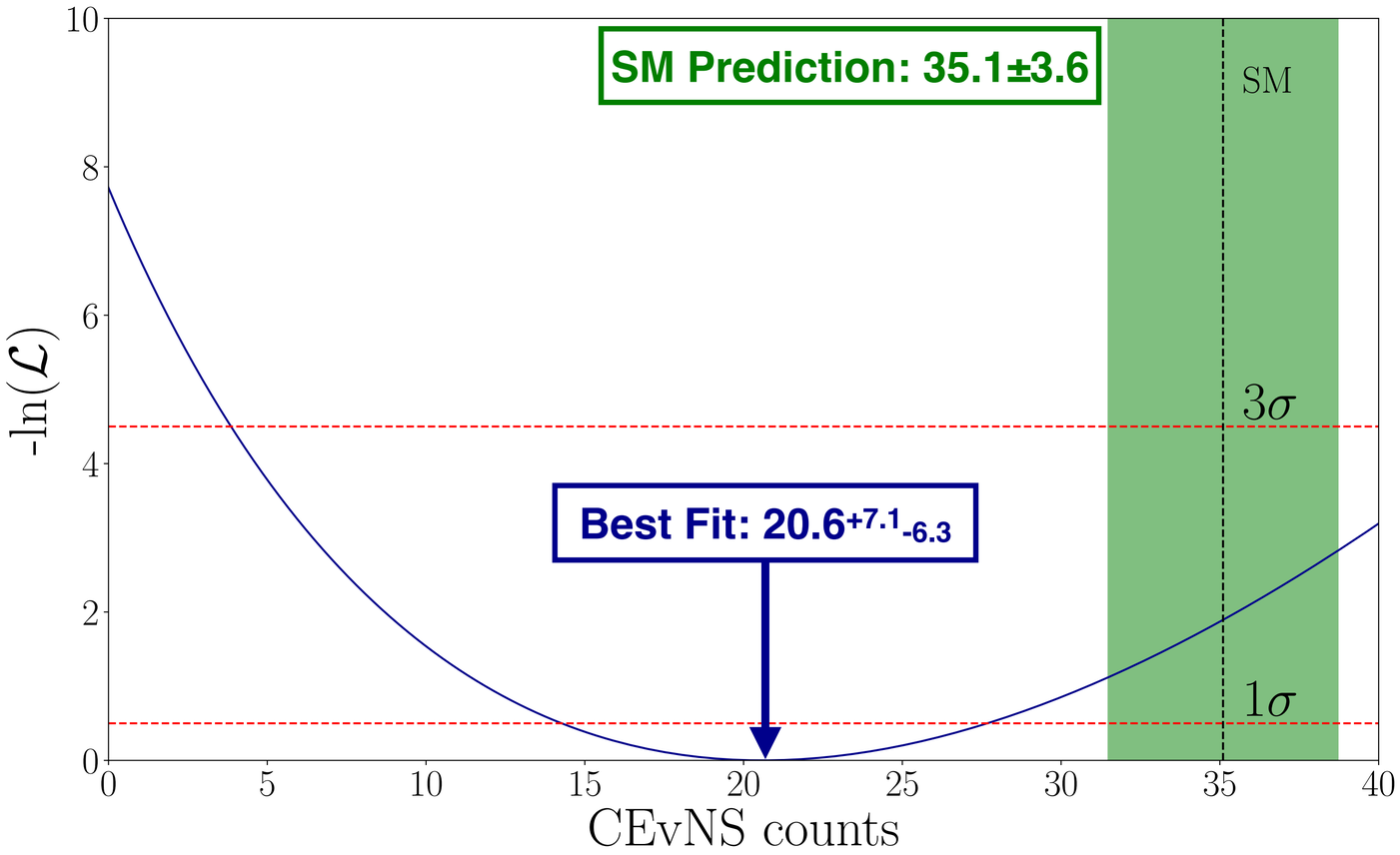






arXiv:2406.13806

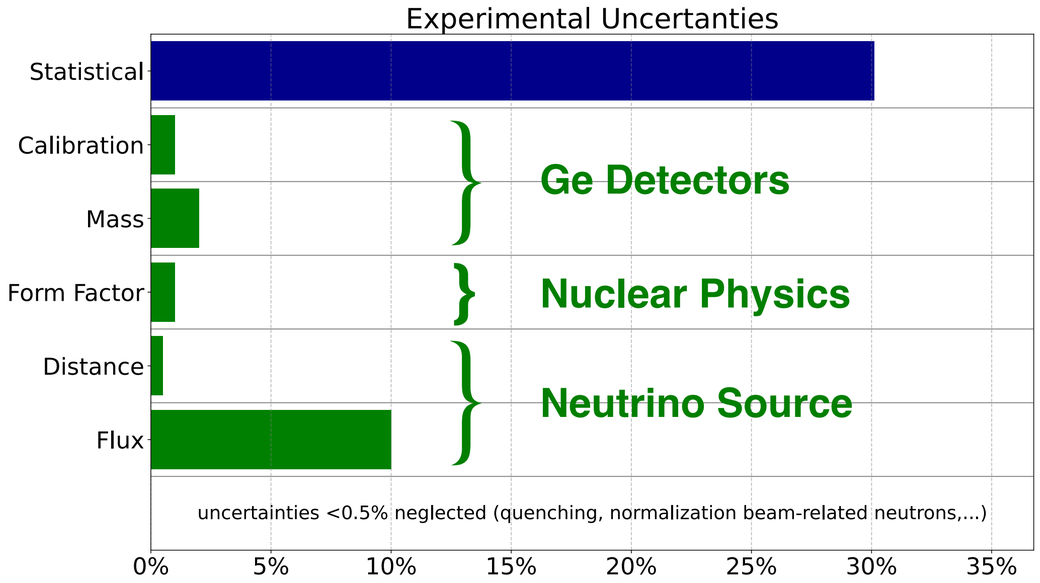
Ge-Mini Campaign 2 Results



2D Unbinned Extended Likelihood Fit:

- Null Hypothesis rejected at 3.9σ
- Reduced χ^2: 1.84 (p=0.40)
- 1.8σ separation from SM prediction

arXiv:2406.13806

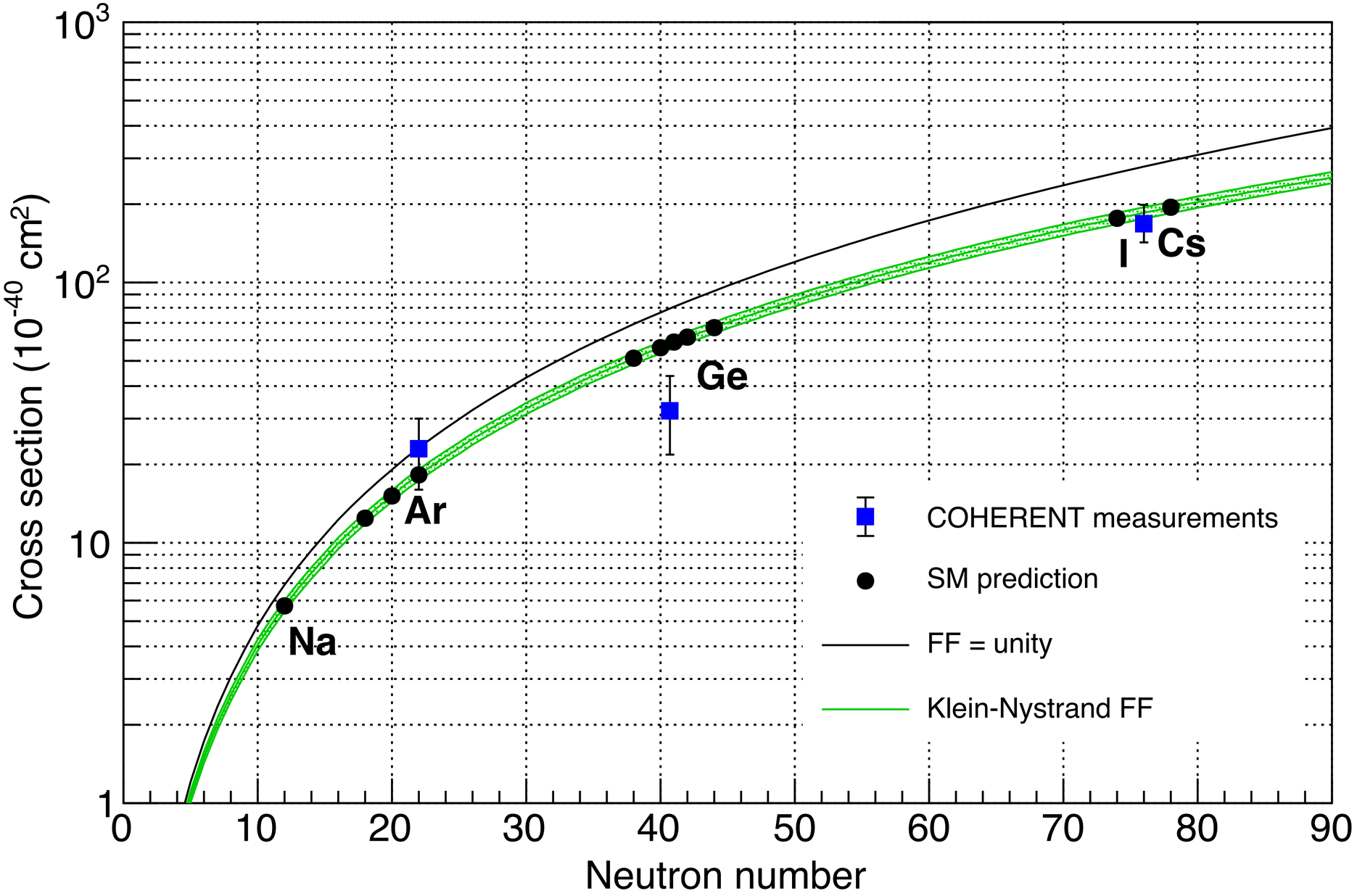


Systematic Uncertainties:

- SNS ν flux: 10%
- Active detector mass: 2%
- Total: 10.3%

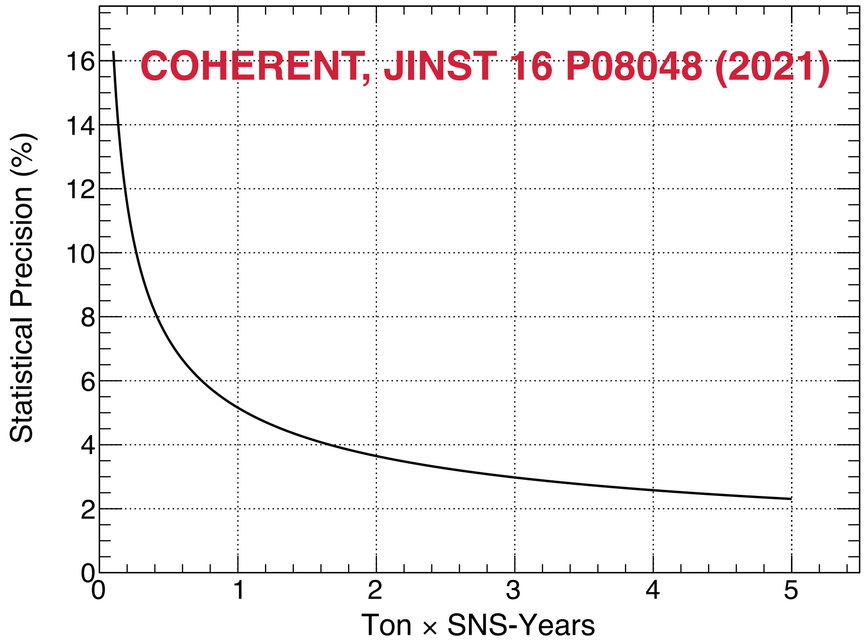
See Poster 55: Janina Hakenmüller

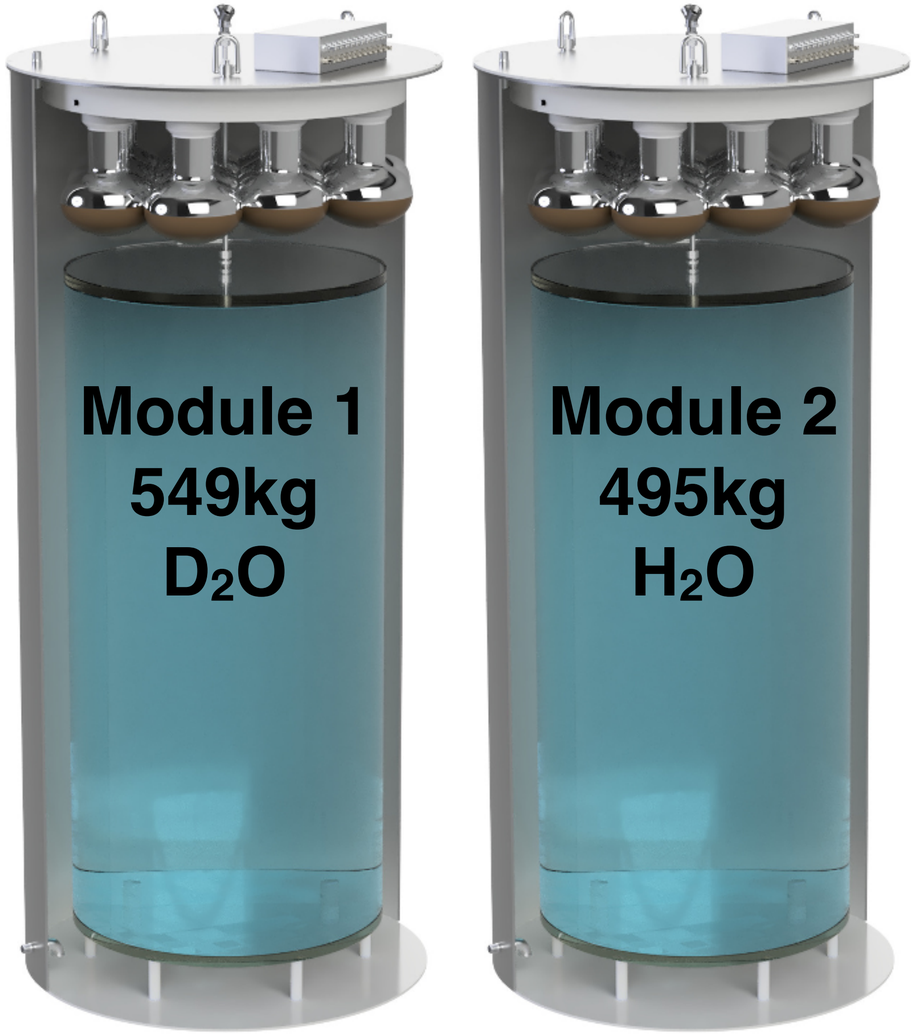
Ge-Mini Campaign 2 Results



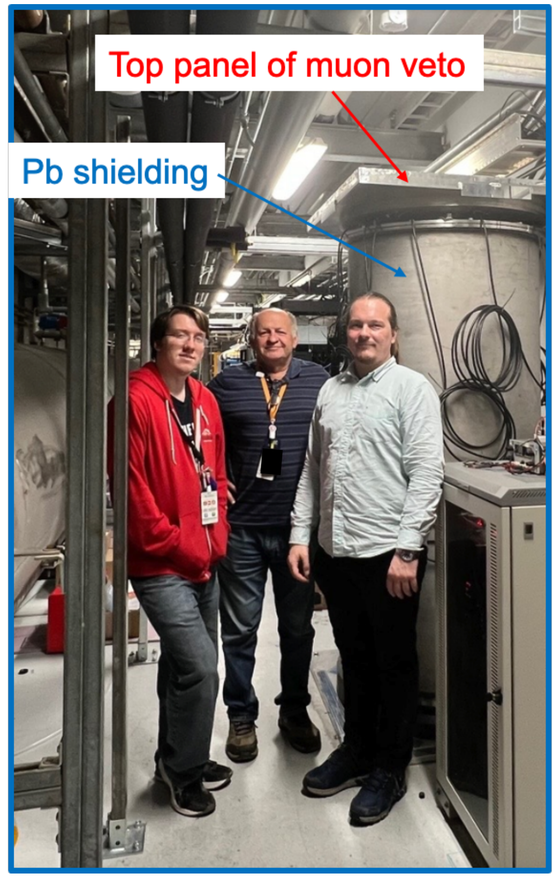
Improving Neutrino Flux Precision: D_2O

- SNS π-DAR ν flux unmeasured.
- Disagreement between theoretical models.
- ν_e + d xsec well-understood.
- Ultimate ~3% precision.
- D_2O data-taking currently underway.
- Bonus: ν_e + O xsec at SN energies.



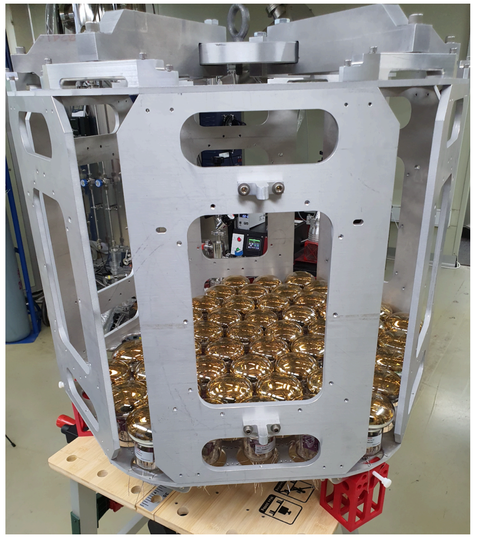


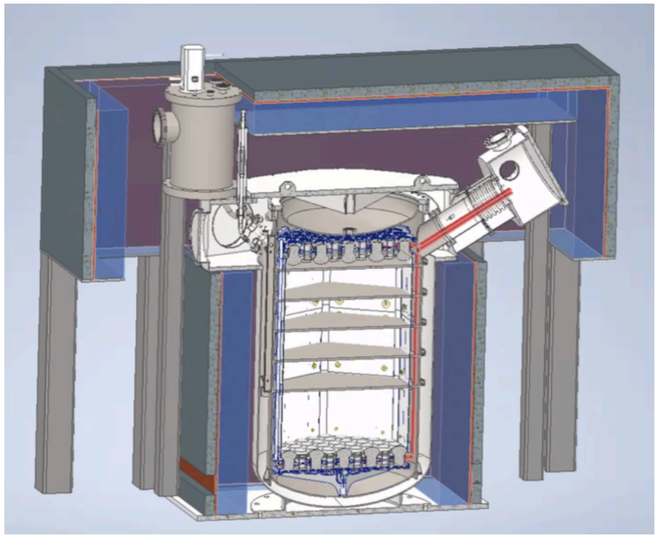
See Poster 444: Gen Li



Precision CEvNS: COH-Ar-750

- Single-phase LAr calorimeter
- 3000 CEvNS events/yr;
  500 inelastic events/yr
- Phase I detector funded
- R&D for Phase II upgrades:
  - SiPMs
  - Xe-doping
- Commissioning late 2024
- First data: 2025

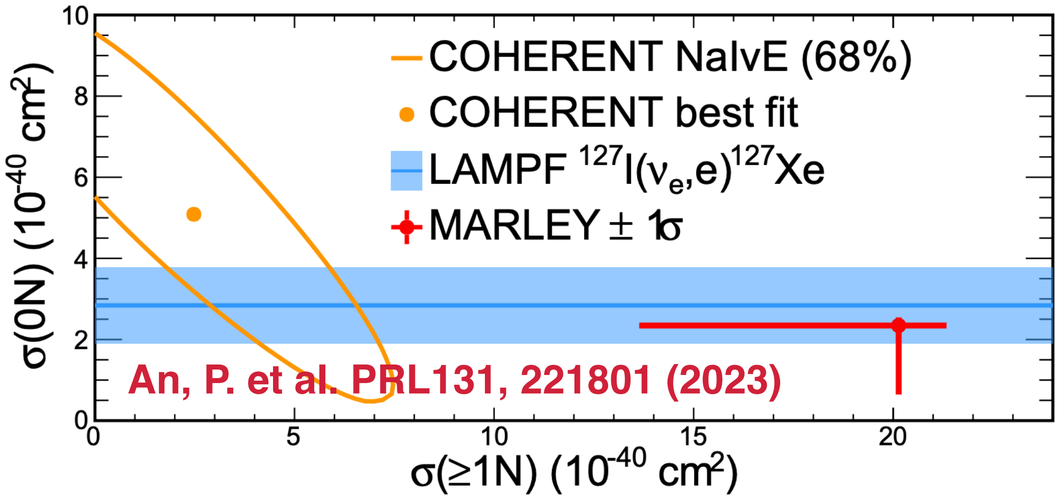




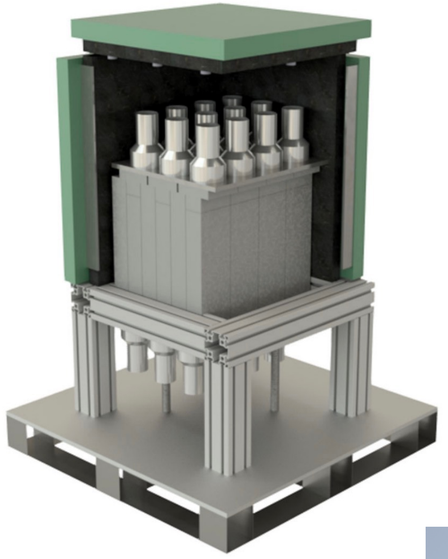
See Poster 453: Vinicius Da Silva

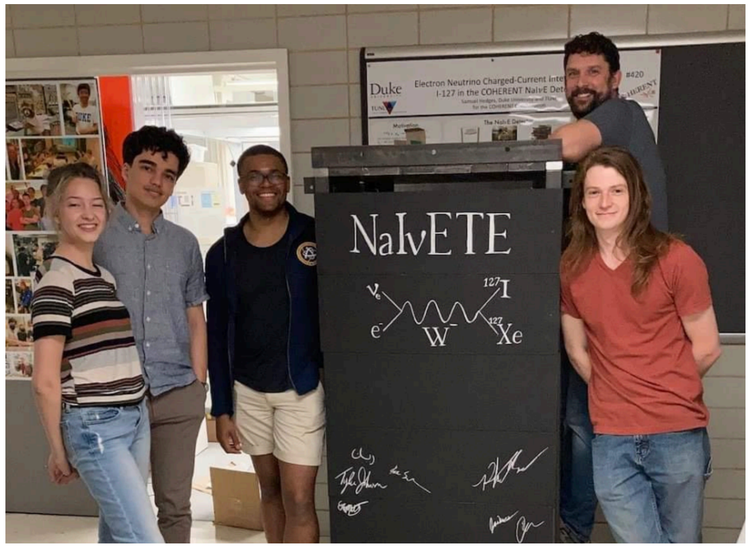
Lightest Target: NaI

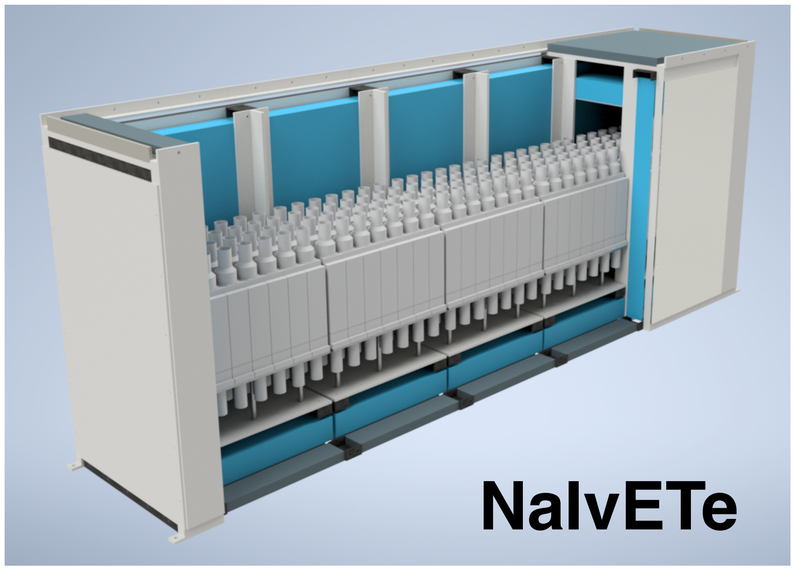
- Repurposed Advanced Spectroscopic Portal program NaI detectors; 7.7 kg ea.
- NaIvE: 185 kg
  - ^{127}I CC measurement
  - CEvNS background measurement at the SNS: ~200-400 ckkd before timing suppression.
- NaIvETe: 2.4 tonnes
  - Nominal threshold of 3 keV$_{ee}$
  - More crystals on hand for possible expansion
  - Detector designed with dual gain bases to allow measurement of CEvNS and higher-energy CC events



NaIvE



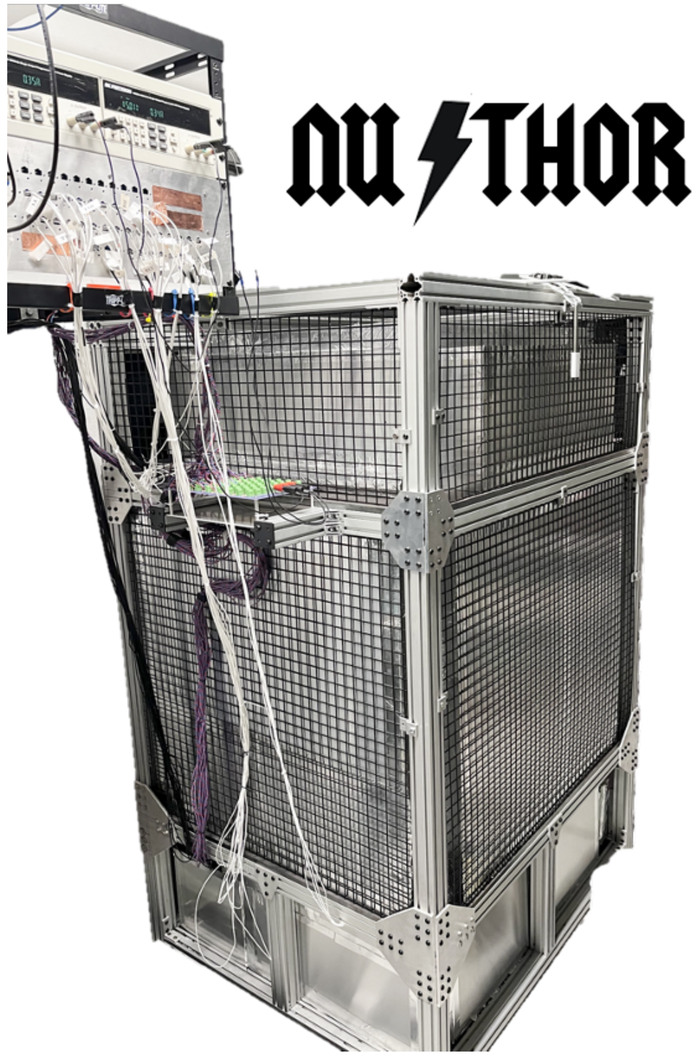


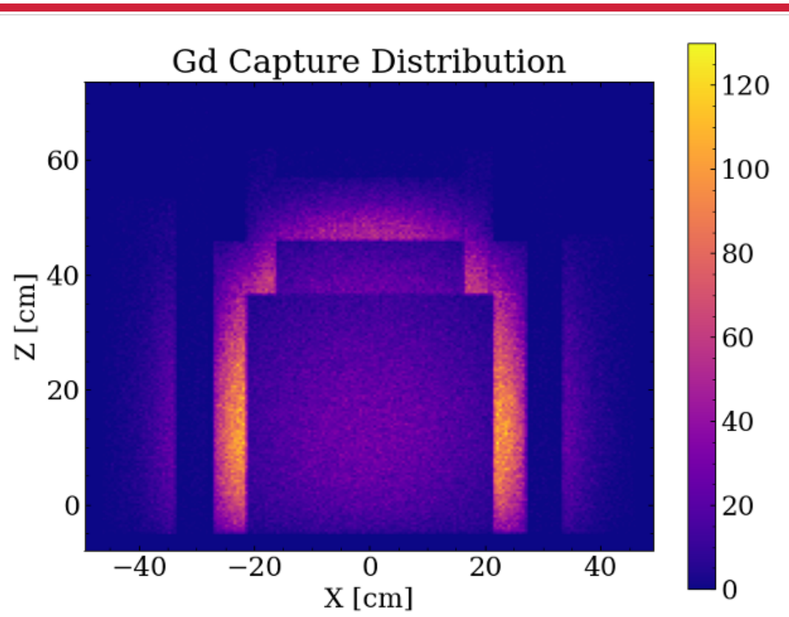


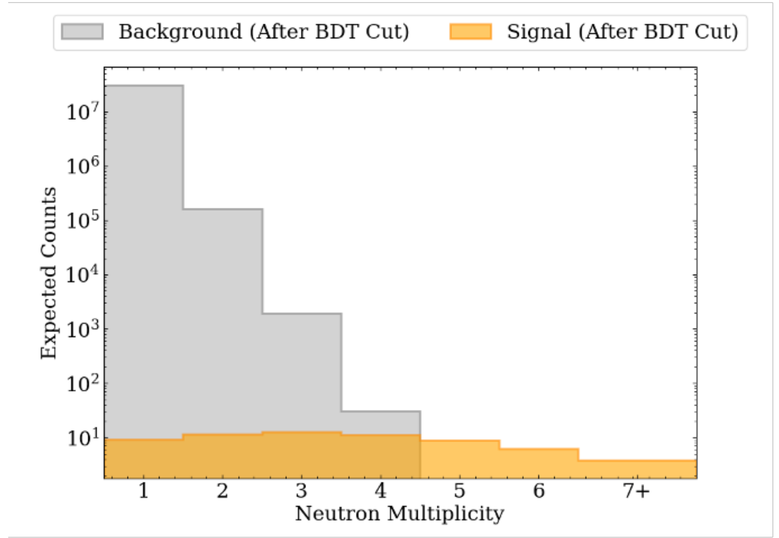
See Poster 96: Sam Hedges

COHERENT Inelastics: NuThor

- Neutrino-induced fission of Th
- 3000 SNS-hrs of data collected
- Higher power data this summer
- Neutrino-induced Fission & Neutron Emission analyses on-going and reaching maturity







See Poster 200: Tyler Johnson

New Initiatives!

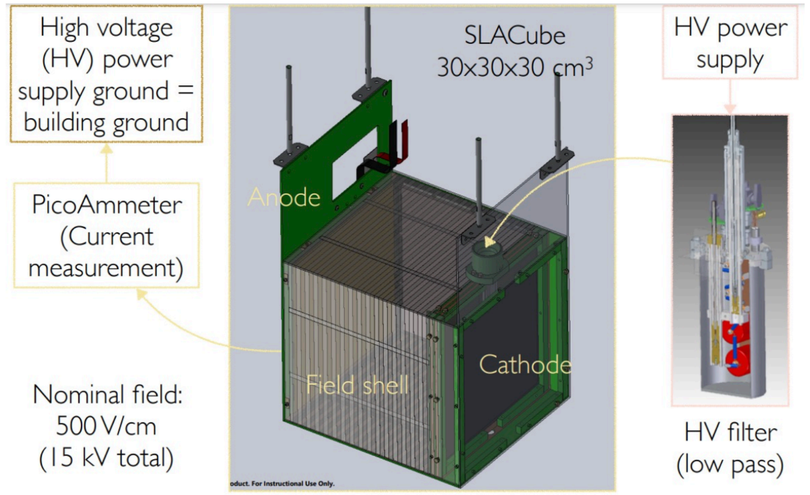
See Poster 265: Dmitry Rudik

LAr TPC

Proposal:

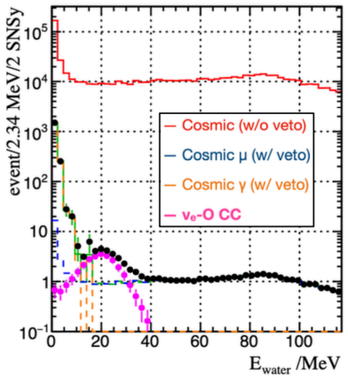
250 kg LAr TPC for DUNE-like CC detection

Main background cosmic muons



H_2O

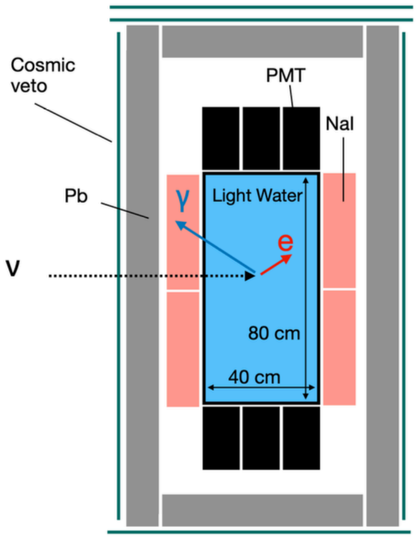
$$\nu_e + {}^{16}\mathrm{O} \rightarrow e^- + \mathrm{F}^*$$



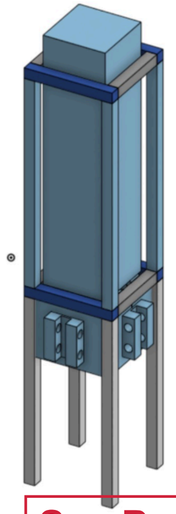
100 L water to measure ν_e-O CC

10 cm lead shielding

Few tens of events in two SNS-years



Lead Glass

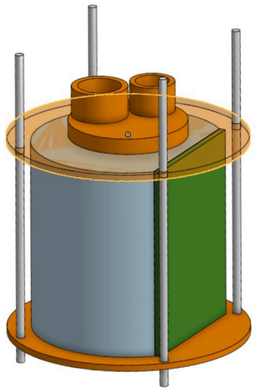


Measuring inelastic neutrino scattering on lead

Prototype
40 kg lead glass
2 PMTs
No shielding

See Poster 568: Nixon Ogoi

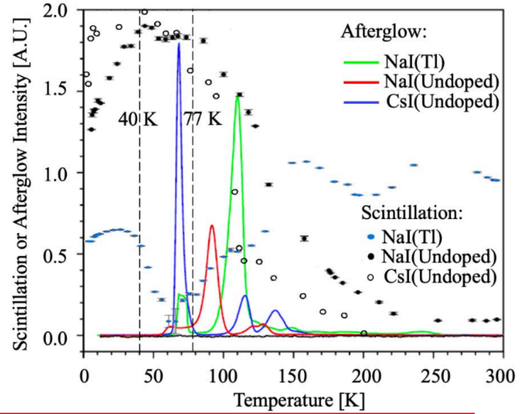
Cryogenic Undoped CsI



Like CsI[Na], but better

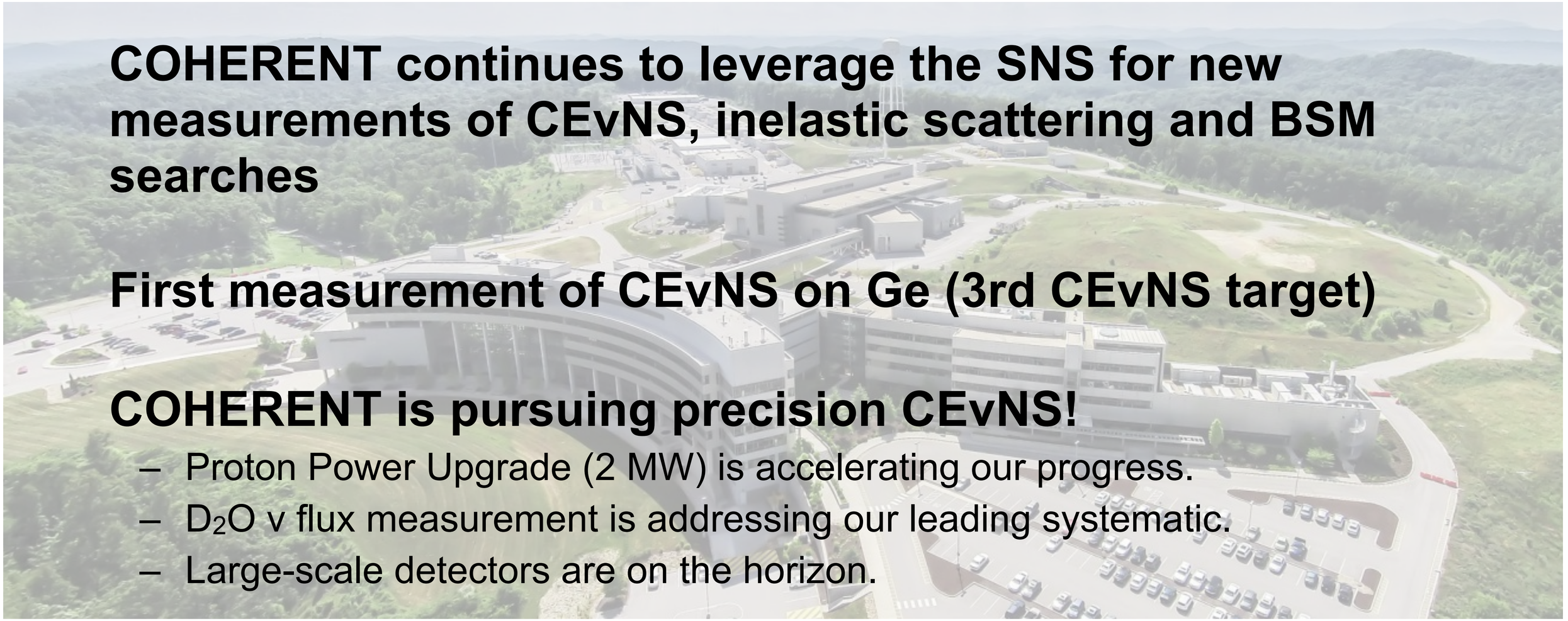
Higher light yield at or below 77 K

SiPMs: high QE, no Cherenkov radiation low dark count rate (at low T)



See Poster 442: Charles Prior
See Poster 495: Chenguang Su

Summary



COHERENT continues to leverage the SNS for new measurements of CEvNS, inelastic scattering and BSM searches

First measurement of CEvNS on Ge (3rd CEvNS target)

COHERENT is pursuing precision CEvNS!

- Proton Power Upgrade (2 MW) is accelerating our progress.
- D_2O ν flux measurement is addressing our leading systematic.
- Large-scale detectors are on the horizon.

COHERENT Collaboration

@NEUTRINO2024:

96: S. Hedges, *Measurement of the electron-neutrino charged-current cross section on iodine-127 with the COHERENT NaIvE detector*

155: J. Hakenmüller, *CEvNS detection with Ge-Mini*

200: T. Johnson, *The First Search for Neutrino-Induced Nuclear Fission*

265: D. Rudik, *The COHERENT experiment*

442: C. Prior, *Exploring the Advantages of an Undoped, Cryogenic CsI Detector for CEvNS Experiments at the SNS with COHERENT*

444: G. Li, *Status of the D_2O Detector for the COHERENT Experiment*

453: V. Da Silva, *Measuring Electron Neutrino Charged-Current interactions on Argon at 10-50 MeV with the COHERENT 750 kg Detector*

495: C. Su: *Characterization and Optimization of Cryogenic Pure CsI Detector for CLOVERS Experiment*

568: N. Ogoi, *Measuring Inelastic-Neutrino Scattering on Lead Using a Cherenkov Detector at the Spallation Neutron Source at ORNL*