Future physics opportunities with COHERENT

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for the COHERENT Collaboration

Magnificent CEvNS

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Beam upgrades at the SNS

- COHERENT status is always changing
  - Continuing deployment of new detectors with significant improvement in sensitivity
  - ORNL currently investing in SNS upgrades: proton power upgrade and construction of second target station
- COHERENT sensitivity can be separated into approximately three phases

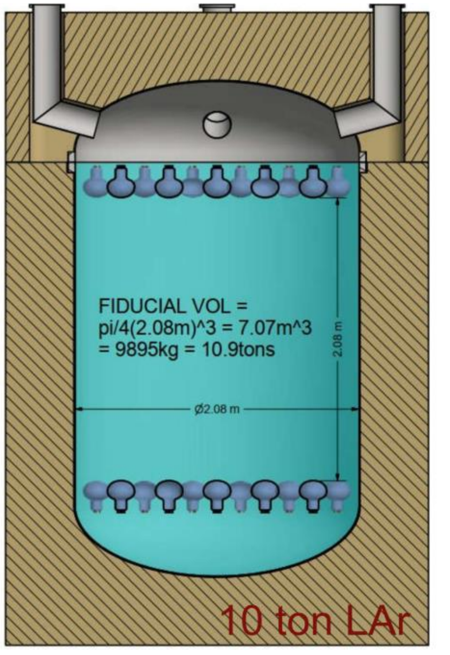
2015 2023 2032

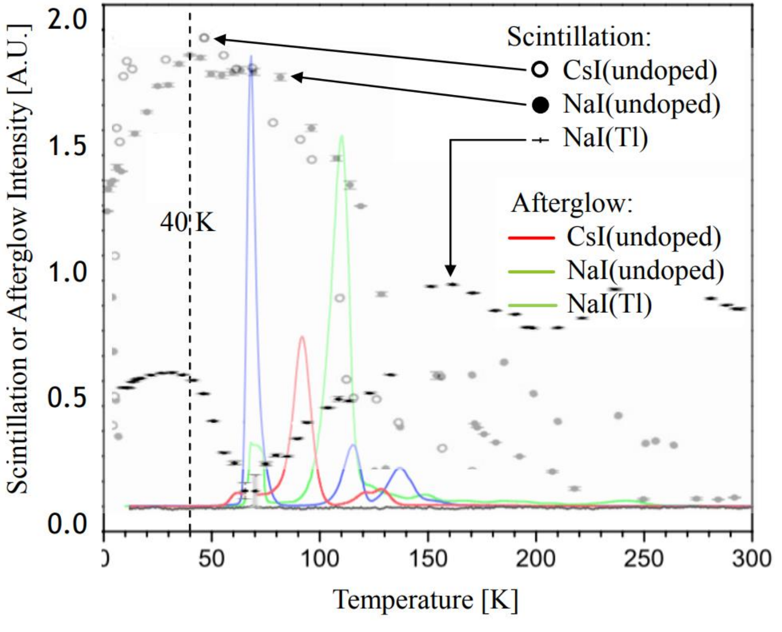
	First light	Precision at Neutrino Alley	STS
Ar	24 kg	610 kg	10000 kg
Ge		18 kg	
CsI	14 kg	10 kg*	700 kg*

*Cryogenic scintillator with sub-keV threshold

New CEvNS detectors to be deployed

- COHERENT already successful with CEvNS detection with argon using a 24kg single-phase, scintillating calorimeter
- Upgrade to 610 kg in Neutrino Alley and 10t at the STS at a baseline of 20m
- Threshold and dynamic range designed to allow simultaneous measurement of 10 keV to 50 MeV to measure both CEvNS

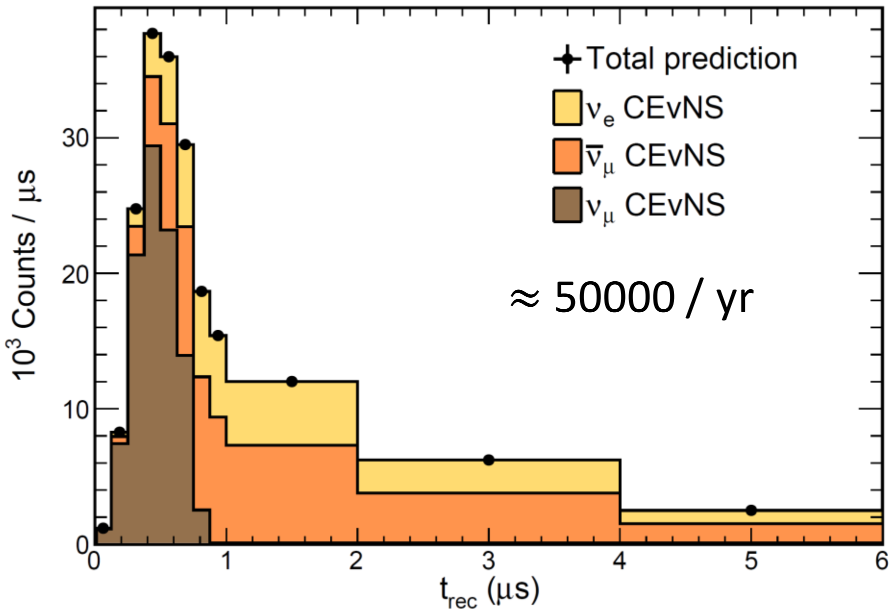


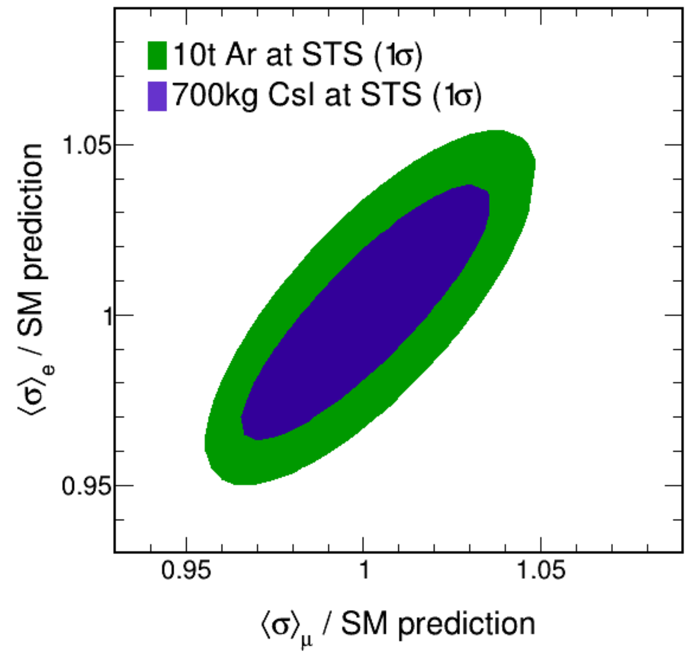


- We also plan for an array of cryogenic, undoped CsI scintillating detectors
  - Cooling undoped CsI to 40 K increases the crystal light yield while also eliminating background scintillation within the crystal (afterglow light)
- Can deploy 700 kg of crystal with a threshold of $\approx 0.1\ \mathrm{keV_{ee}}$ due to the favorable light yield

Ultimate scale of CEvNS samples

CEvNS event rate in 10t argon detector after 5 years

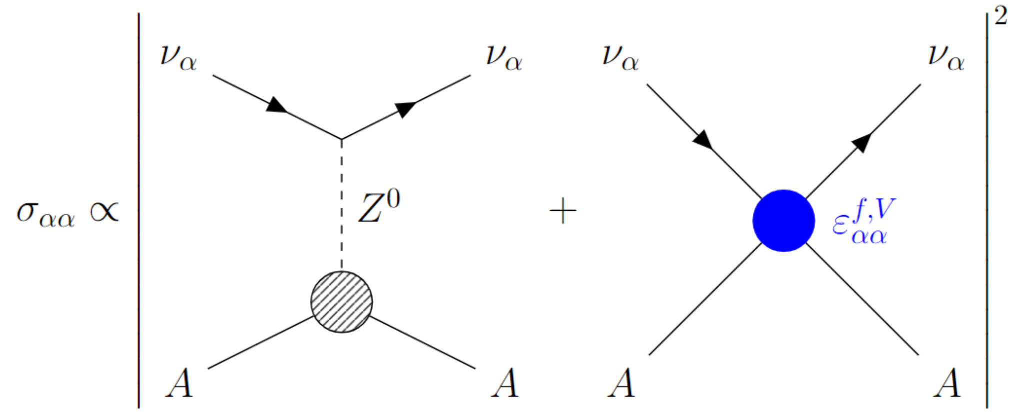




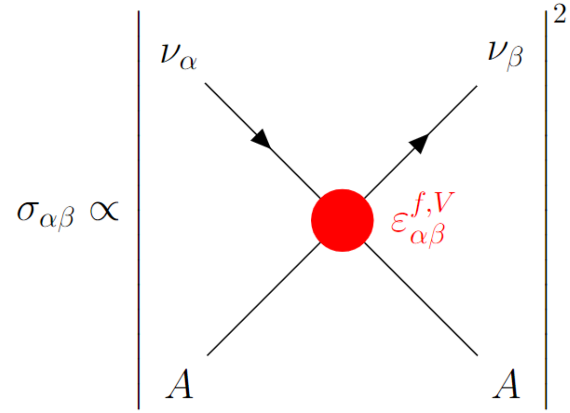
- In the future, total cross section measurements will be limited by flux uncertainty, but a we will precisely compare the cross section for different flavors
- Sensitive to 1% differences in μ- and e-flavor cross sections testing lepton universality of CEvNS (at tree level)

Searching for BSM interactions with CEvNS

Flavor conserving interactions – Interference between new mediator and Z which breaks lepton universality



Flavor changing interactions – Would add new scattering processes not allowed by the standard model



Scattering model parameterized by effective couplings, $\varepsilon_{\alpha\alpha}^{f,V}$ and $\varepsilon_{\alpha\beta}^{f,V}$, x G_F

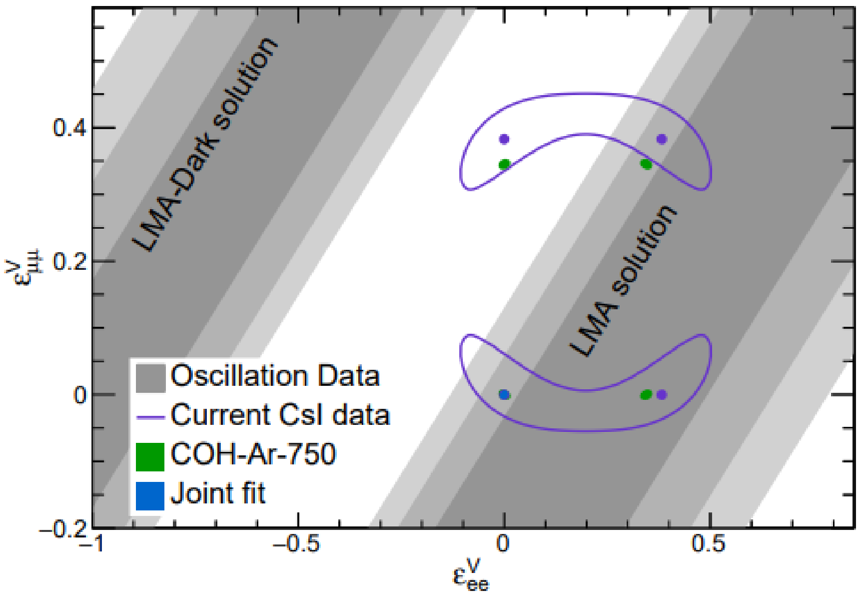
Adjusts weak charge in CEvNS cross section:

$$Q_{W,\alpha} = (2\varepsilon_{\alpha\alpha}^{u,V} + \varepsilon_{\alpha\alpha}^{d,V} + g_p^V)Z + (\varepsilon_{\alpha\alpha}^{u,V} + 2\varepsilon_{\alpha\alpha}^{d,V} + g_n^V)N + \sum_{\alpha\neq\beta}\left[(2\varepsilon_{\alpha\beta}^{u,V} + \varepsilon_{\alpha\beta}^{d,V})Z + (\varepsilon_{\alpha\beta}^{u,V} + 2\varepsilon_{\alpha\beta}^{d,V})N\right]$$

STS data disambiguates neutrino oscillation data

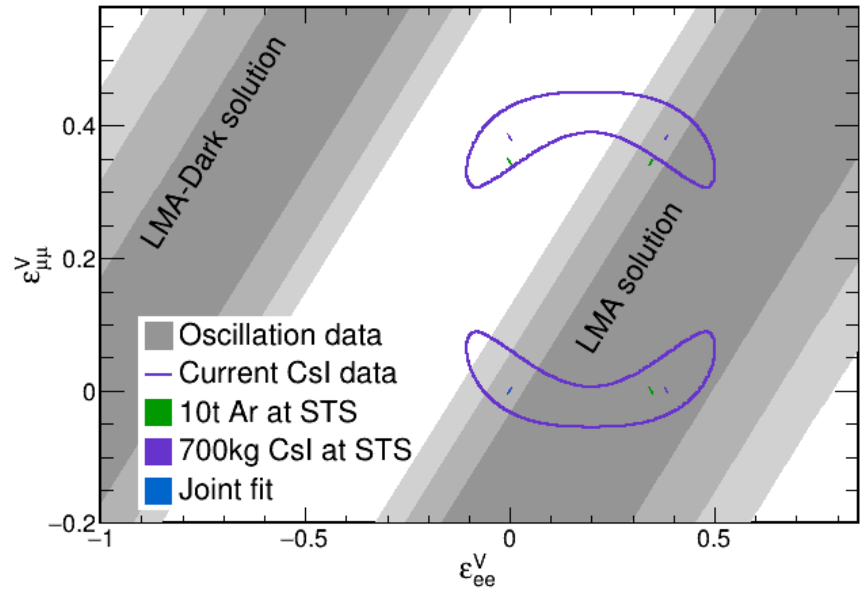
Neutrino Alley reach

3 years of argon + 3 years of CsI



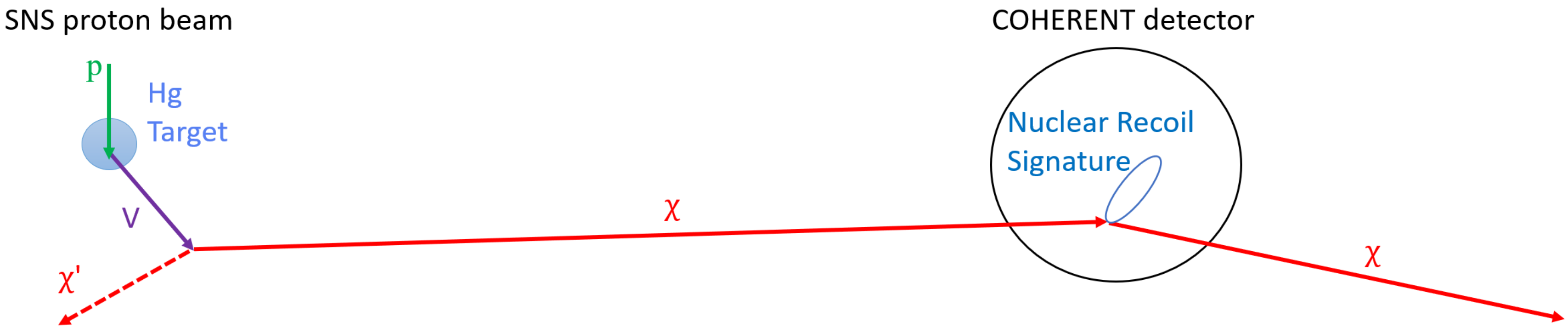
STS reach

5 years of argon + 5 years of CsI



- Same degeneracy condition causes confusion for the θ_{12} octant
- The $\boldsymbol{\theta_{12} > \pi/4}$ "LMA-Dark" solution is well motivated – interesting tension between solar and reactor measurements of Δm^2_{21} are slightly discrepant
  - Could be cause by NSI scattering in solar interior
- But, LMA-D is disfavored by initial CsI data with additional data from the STS capable of completely resolving this ambiguity

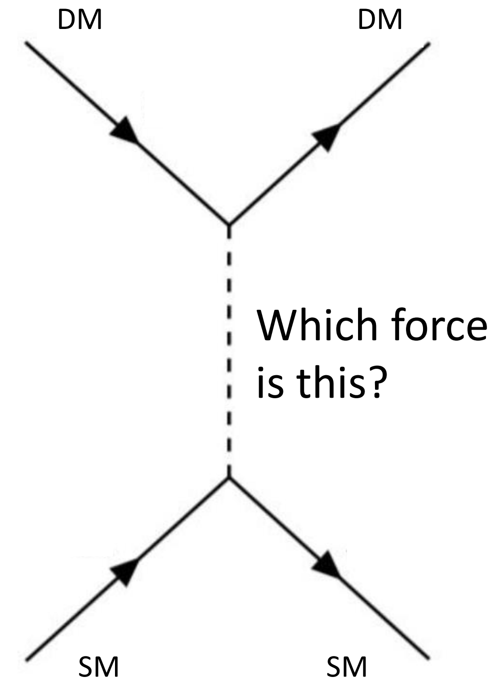
Searching for dark matter with CEvNS detectors at the SNS



- A CEvNS detector at the SNS operates like a standard beam dump experiment
- Any hidden sector particles with masses below ≈ 220 MeV/c^2 could be produced in the many proton-Hg interactions within the SNS target
- This may include mediator particles between SM and dark matter particles!

Low-mass DM phenomenology

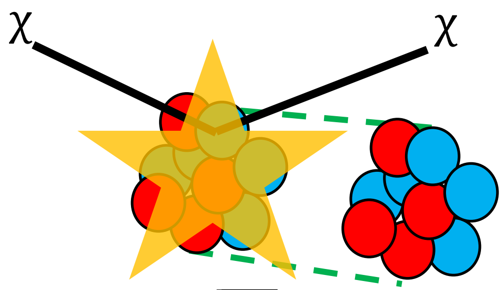
- For decades, experiments have focused on classic WIMP searches assumed to interact with the weak force
- The DM scattering cross section is $\sigma \sim m_\chi^2/m_Z^4$
  - Lower DM mass → lower cross section → higher DM abundance
  - If $m_\chi < 2$ GeV/c^2, predicted relic abundance would be so large it would close the universe, preventing the modern universe



- No longer assume DM interacts with SM particles via the weak force, but some yet unknown hidden sector particle, V
- In this scenario, $\sigma \sim m_\chi^2/m_V^4$ which is consistent with modern cosmology even at low mass scales
- Simplest scenario postulates a vector mediator that kinetically mixes with SM photon: $\mathcal{L} \sim \frac{1}{2}\varepsilon^2 F_{\mu\upsilon}V^{\mu\upsilon}$
- Model parameters
  - DM and mediator masses: m_χ and m_V
  - SM-mediator and DM-mediator couplings: ε and α_D
- Relic abundance given in terms of $Y = \varepsilon^2\alpha_D\left(m_\chi/m_V\right)^4$

Classical WIMP mass regime:
  Lee and Weinberg, Phys. Rev. Lett. **39** 165 (1977)
Early sub-GeV DM phenomenology:
  Fayet, Phys. Rev. **D70**, 023514 (2004)
  Boehm and Fayet, Nuc. Phys. **B683**, 219 (2004)
  Pospelov et al., Phys. Lett. **B662**, 53 (2008)
Coherent DM scattering / DM at the SNS:
  deNiverville et al., Phys. Rev. **D84**, 075020 (2015)
  Dutta et al., Phys. Rev. Lett. **123**, 061801 (2019)

Advantages of low-recoil detectors: cross section



$$\lambda = h/\sqrt{Q^2} \gg R_p$$

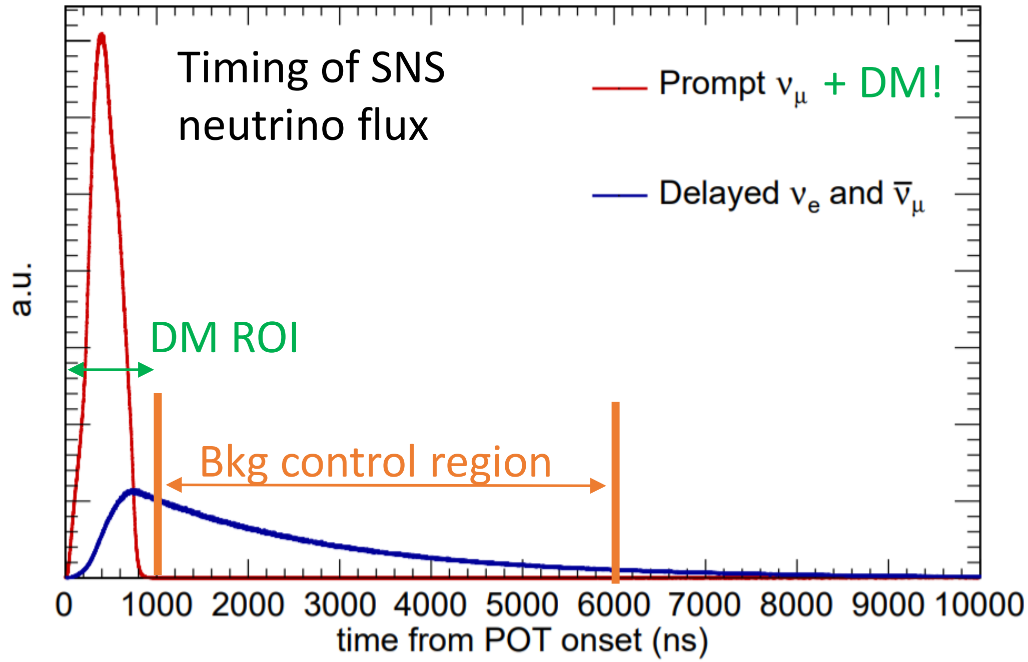
- We're dealing with low enough Q^2 that the deBroglie wavelength is large compared to nuclear radius
- All nucleons within nucleus recoil coherently from neutrino or DM scattering
- Astroparticle direct-detection experiments have exploited this for years – now accelerator experiments can too with CEvNS detectors

- This coherency gives a Z^2 enhancement in the cross section → big effect for CsI (Z of 53/55)
- Game-changing – a small 14-kg detector produced strongest constraint on light dark matter yet with impressive potential in the future

Direct-detection experiments searching for light dark matter

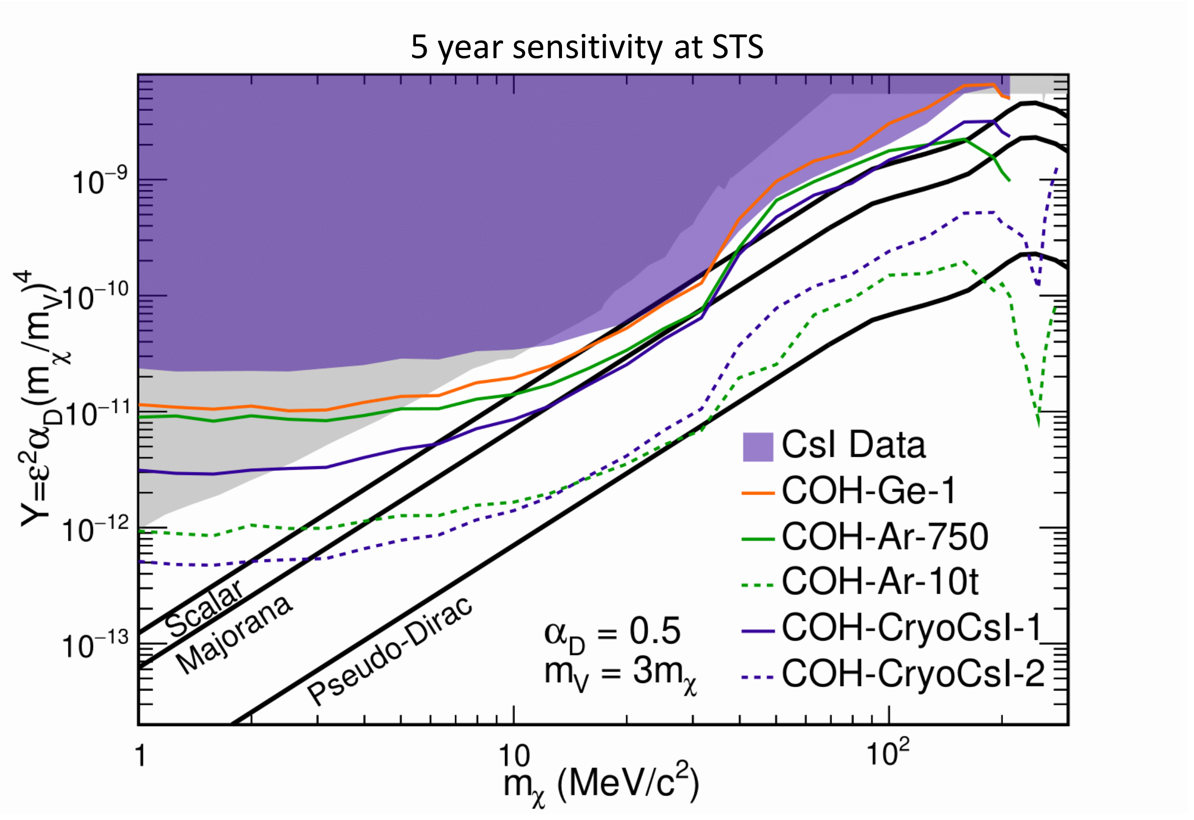
		Mass (t)
	LSND	167
	MiniBooNE	450
First CEvNS detector	COHERENT CsI	0.0146
Future program at STS	10t Ar detector	10

Advantages of spallation sources: constraining uncertainties



- CEvNS is the principal beam-related background for DM search
  - SM cross section precisely known, but uncertainties in detector response that are unique to each detector
- Since DM is relativistic, it is expected coincident with protons on target
  - No DM coincident with delayed CEvNS from $\upsilon_e/\bar{\upsilon}_\mu$ flux
- The delayed time window gives us a control sample – can constrain systematic uncertainties in situ and use to refine background estimates in the DM timing ROI
- Ensures DM search never systematics limited – syst uncertainty shrinks as fast as stat

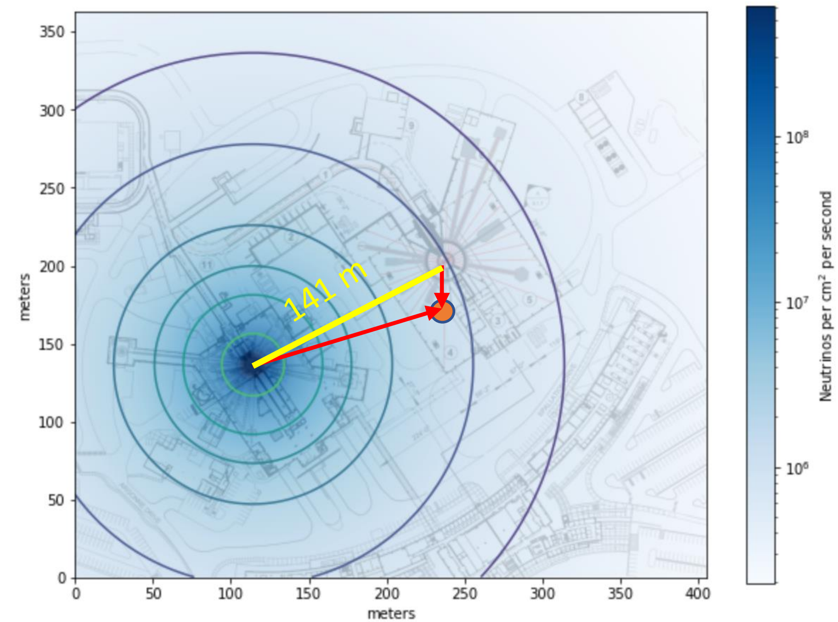
Future COHERENT sensitivity to dark matter



- Immediate future: germanium detector currently being commissioned – will fully explore scalar target at lower masses
- In coming years: future argon and cryogenic CsI detector from COHERENT – will be sensitive to a lower DM flux and probe the Majorana fermion target
- In next decade: large detectors placed forward at the STS (dashed lines) will begin to ambitiously test even the most pessimistic spin scenarios

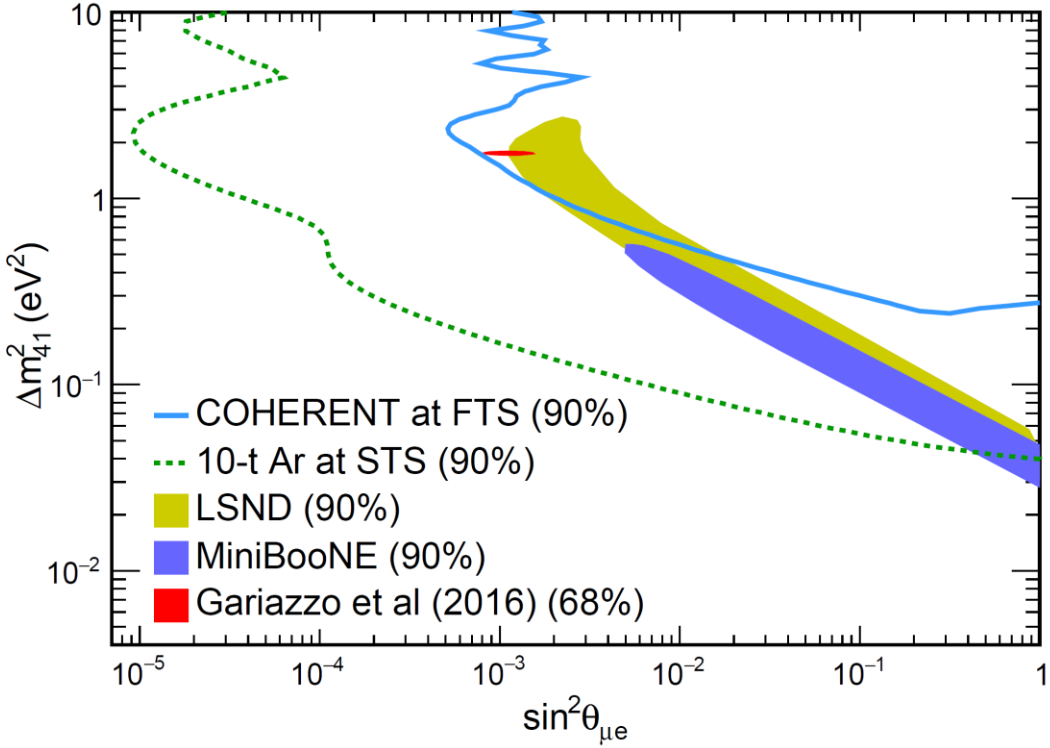
The SNS: perfectly designed to test sterile neutrinos

- Having two operating neutrino flux sources so near each other gives the SNS a unique opportunity
- As soon as the STS begins delivering beam, any detector at either target will receive beam from both targets
  - Analyze neutrino disappearance on two different baselines using the well-understood CEvNS channel within the same detector – correlated systematics



- A 10-t argon CEvNS detector which will be large enough to see CEvNS from each target so that we sample oscillation effects from both baselines
  - Assume L_{STS} = 20 m and L_{FTS} = 121 m
  - Uncertainties on detector response and interaction model are eliminated, similar to two-detector long-baseline oscillation experiments (DUNE, NOvA, T2K, etc.)

STS sensitivity to sterile oscillation parameters



- After five years of data at the STS, a 10t argon single-phase scintillation detector would eliminate the global best fit oscillation parameters to a high degree of certainty and test nearly the entire parameter space allowed by LSND/MiniBooNE
  - Will implement an additional detection strategy with different and well-controlled systematic uncertainties to understand the LSND anomaly

- A large detector at the STS would significantly improve on the reach of future CEvNS data accessible at the FTS collected due to simultaneous measurement on two baselines

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NRF National Research Foundation of Korea
NNSA National Nuclear Security Administration
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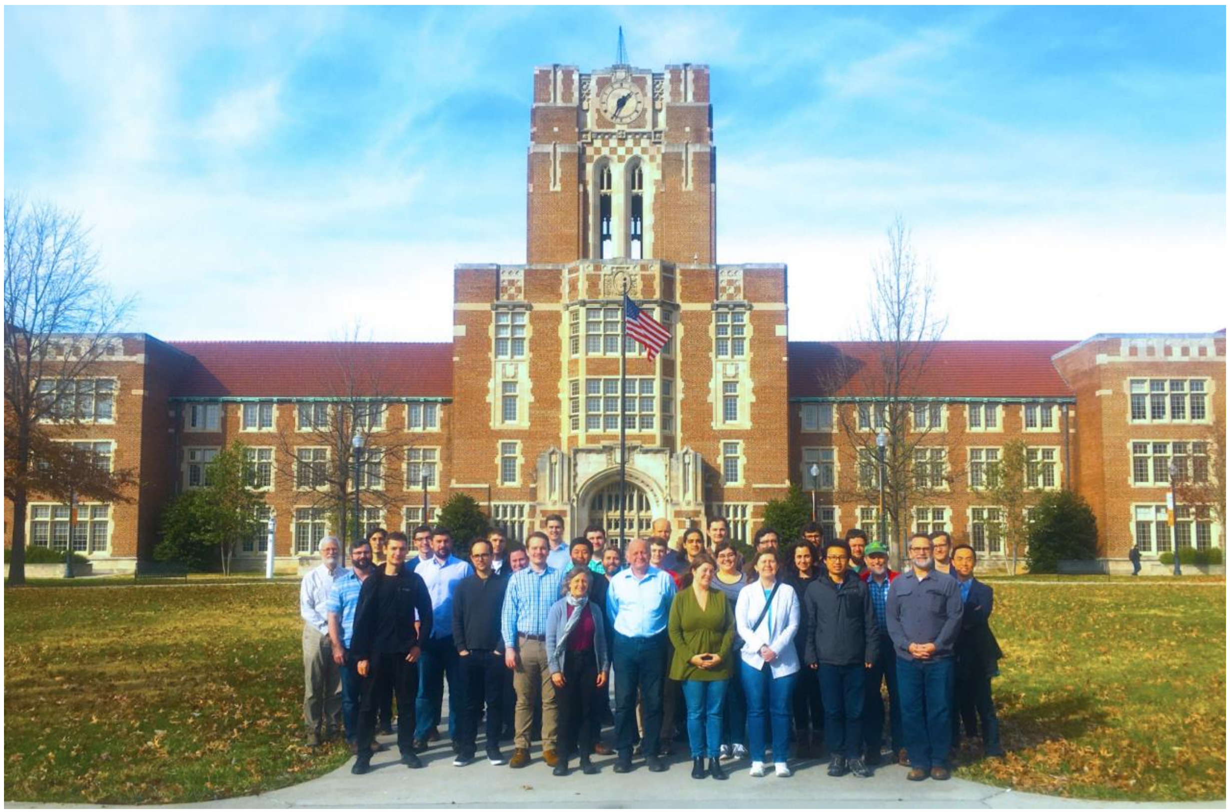

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