CENNS

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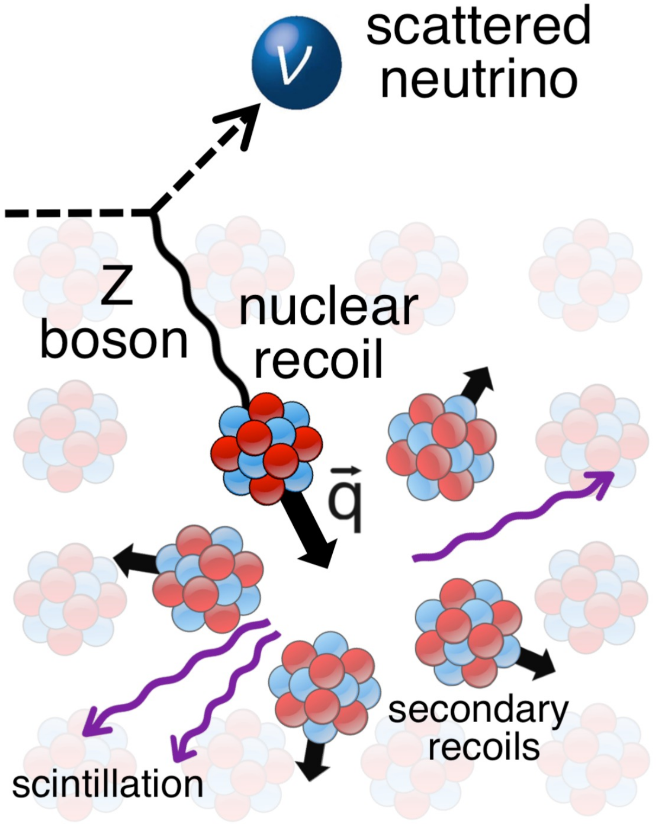
K-Neutrino Symposium 2024 – July 25, 2024

1. CEvNS (Coherent Elastic ν-Nucleus Scattering)
2. Neutrino Source: Spallation Neutron Source
3. CENNS-10: First LAr CEvNS Detector
4. CENNS-1ton: Ton-Scale LAr CEvNS Detector
5. CEvNS related physics

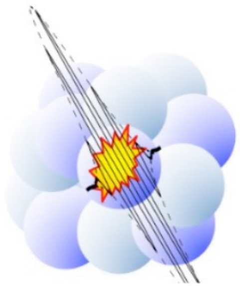


- Neutral weak-current theorized in 1974
- Neutrino interacts with a whole nucleus when qR < 1
- Precise cross section within the Standard Model

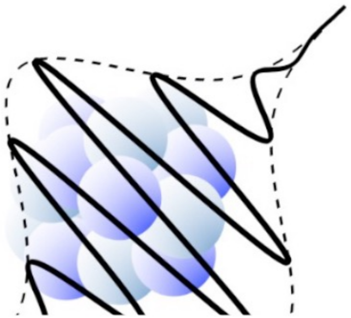
$$\frac{d\sigma}{dT} = \frac{G_F^2 M}{2\pi} Q_W^2 \left(2 - \frac{2T}{E_\nu} - \frac{MT}{E_\nu^2}\right)$$

M: Nucleus mass
T: recoil energy
Q_W: weak charge

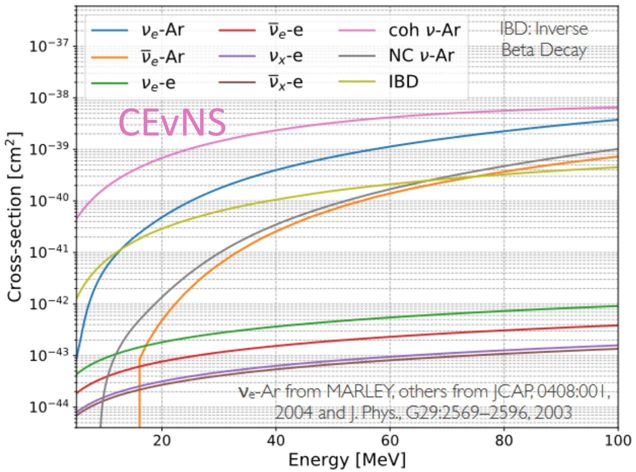
- N^2 dependent cross section ($Q_W = N - 0.076Z \cong N$)
- Dominant process in low energy (< 100 MeV)
- Max recoil energy $\cong 2E_\nu^2/M$ < 100 keV (by kinematics)
- Need a low threshold detector and intense neutrino source



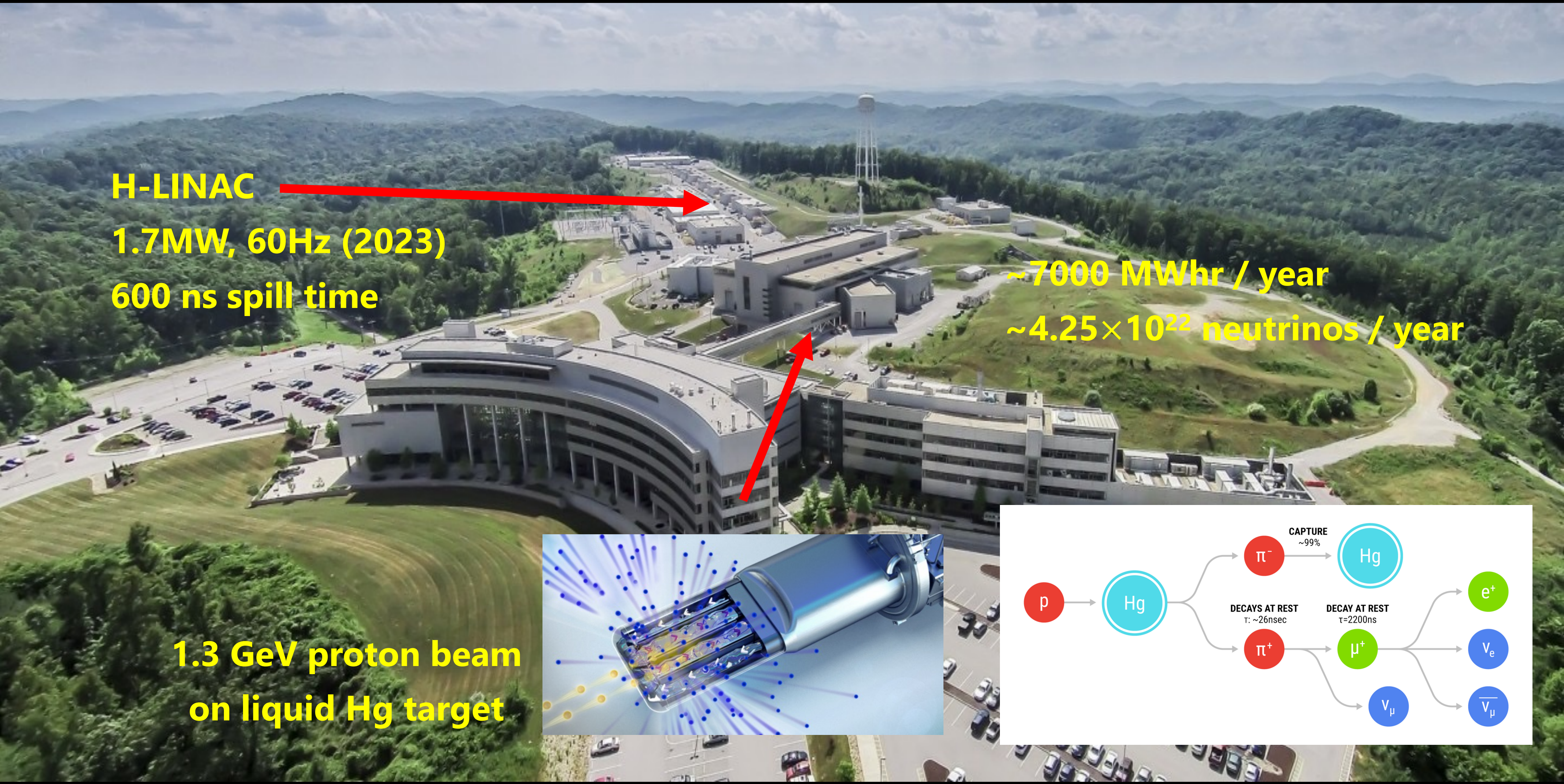
High Q = short de Broglie wavelength



Low Q = long de Broglie wavelength



Spallation Neutron Source (SNS)



- Mesons are created by p-Hg collision
- π^- captured by Hg (> 99%)
- π^+ decay at rest (DAR) (> 99%): **monochromatic**

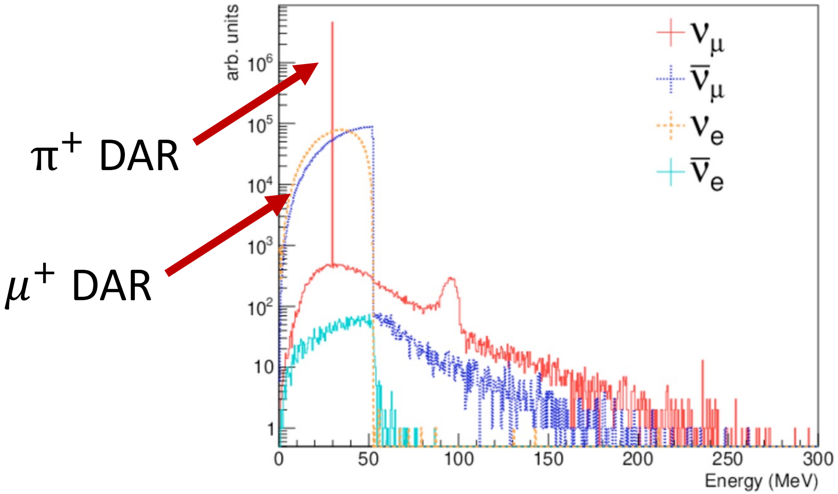
$$E_{\nu_\mu} = \frac{m_\pi^2 - m_\mu^2}{2m_\pi} \cong 29.8\ \mathrm{MeV}$$

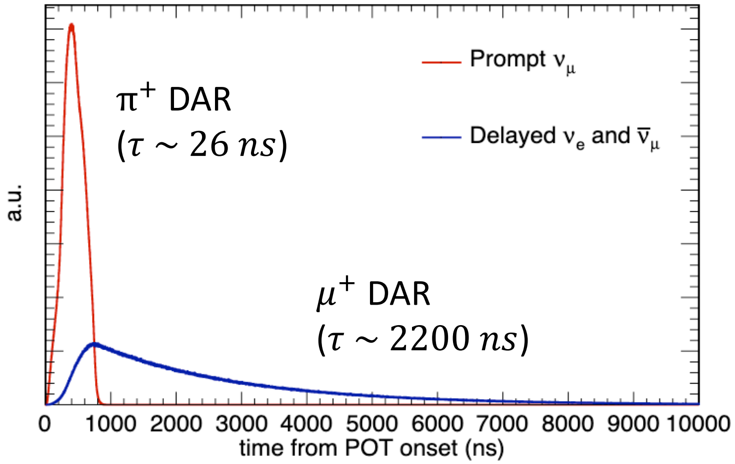
- μ^+ decay at rest (> 99%): follow **Michel spectrum**

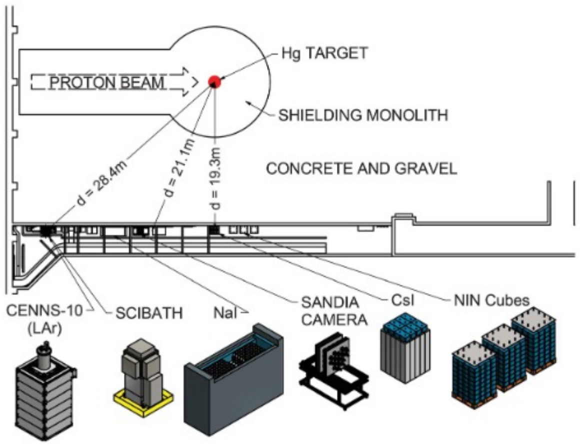
$$\frac{dN_{\bar{\nu}_\mu}}{dE_\nu} = \eta \frac{64E_\nu^2}{m_\mu^3}\left(\frac{3}{4} - \frac{E_\nu}{m_\mu}\right), \qquad \frac{dN_{\nu_e}}{dE_\nu} = \eta \frac{192E_\nu^2}{m_\mu^3}\left(\frac{1}{2} - \frac{E_\nu}{m_\mu}\right)$$

η: *normalization constant*

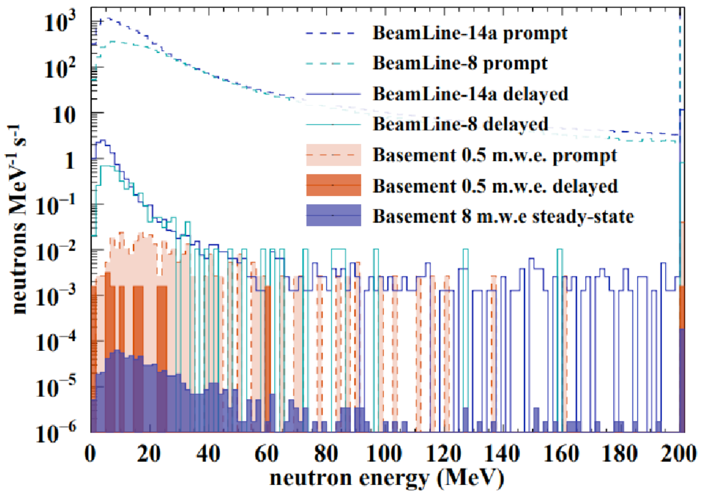
- Accurate energy and timing spectra due to pion DAR





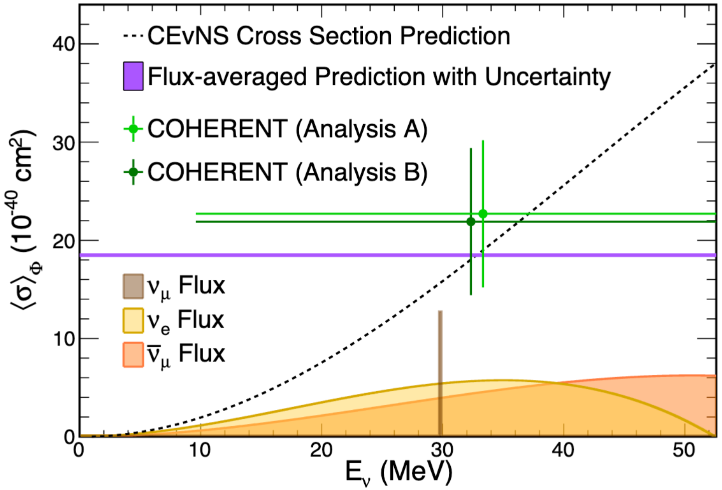


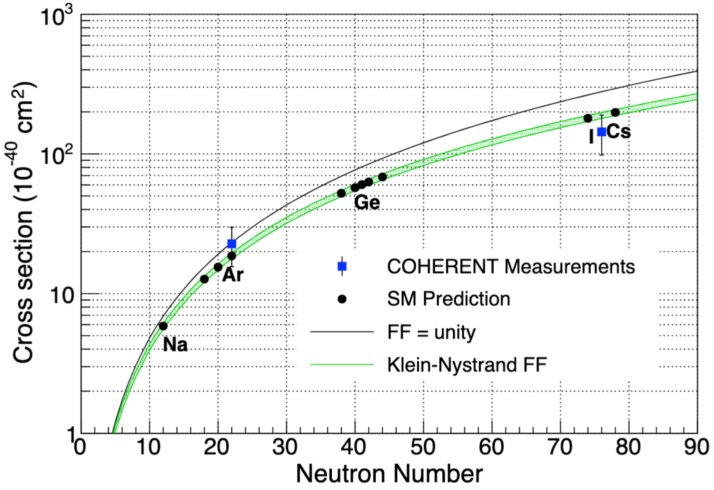
COHERENT detectors (2020)

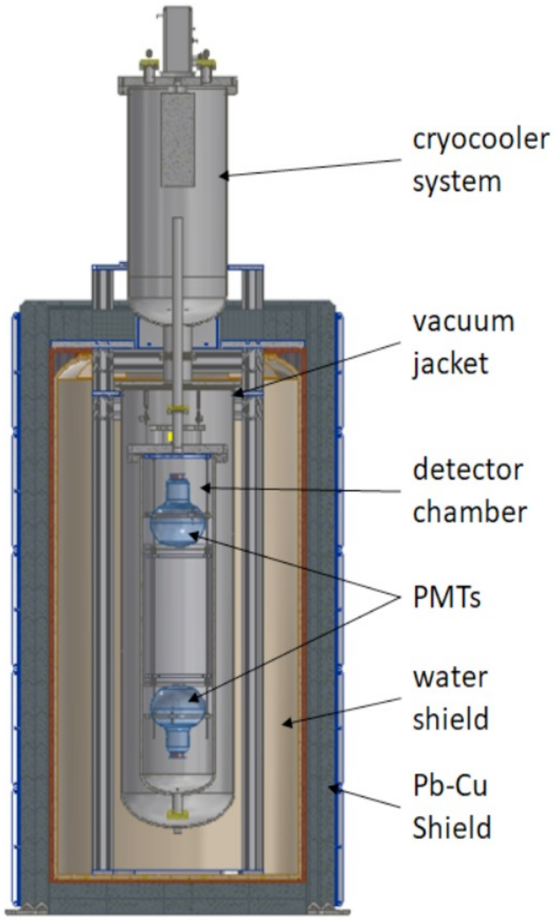


- 8 m.w.e. overburden can reduce cosmic muon
- Steel + Concrete shielding for beam produced neutron
- CEvNS detectors with Background detectors
  - CEvNS: CENNS (LAr), CsI, NaI, Gemini (HPGe)
  - Neutron Background: SciBath, Sandia Camera

- 24-kg single phase Liquid Argon detector with 2 PMT
- Measured CEvNS cross section in 2020 (within 1σ of SM)
- Verified N^2 dependence of CEvNS cross section
- Measured 159 ± 43 CEvNS events (SM predicted: 128 ± 17)
- ~30% statistical uncertainty on CEvNS event -> CENNS-1ton

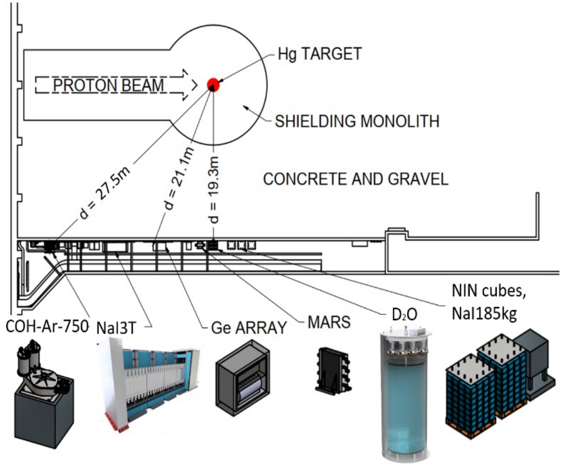




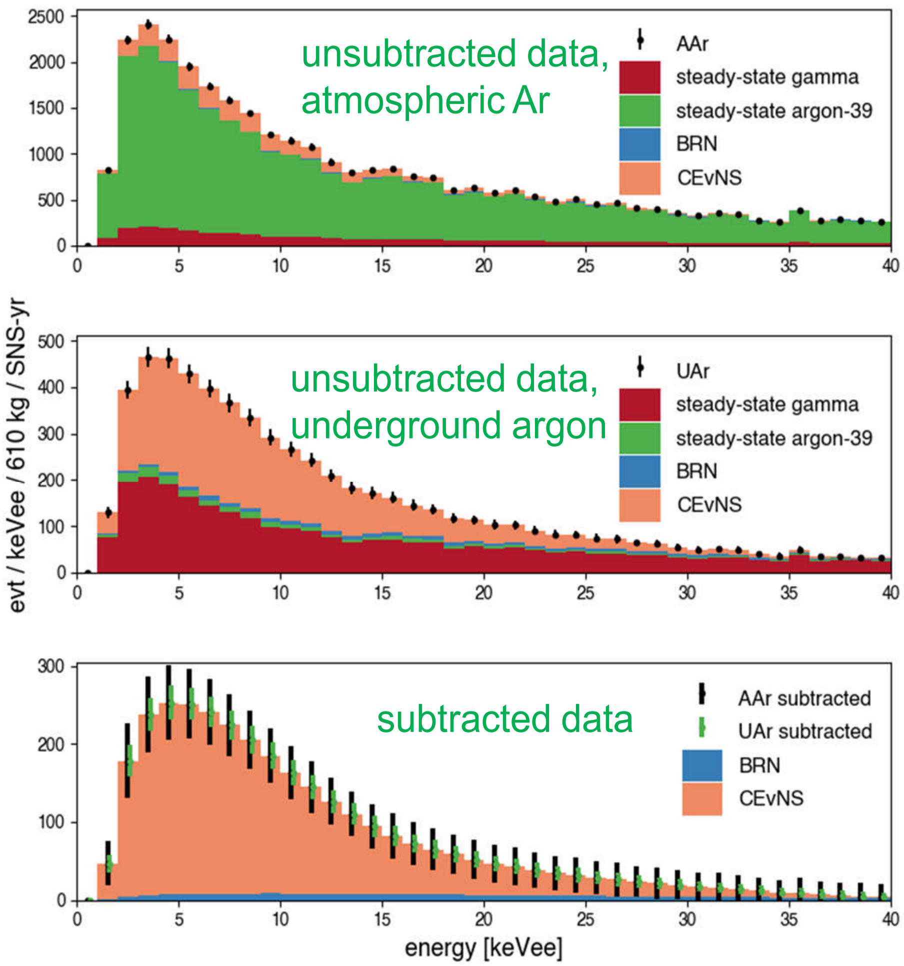


- 610-kg Liquid Argon detector with 122 PMTs
- Replacing CENNS-10 at the same location
- Expect ~3000 CEvNS / ~400 inelastic for a year
- Reduce uncertainty to 5% within 3 years
- Allow precision physics study

CENNS-1ton



Future COHERENT detectors

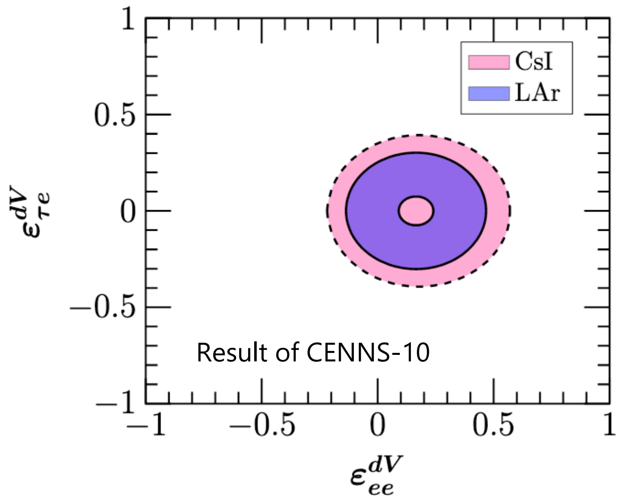


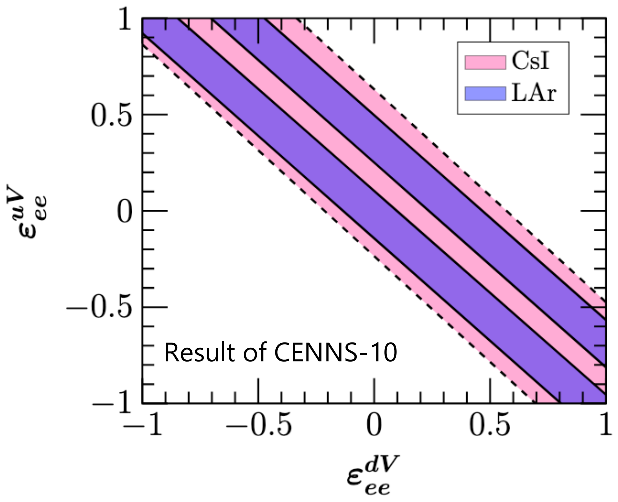
- CEvNS spectrum is distorted by NSI

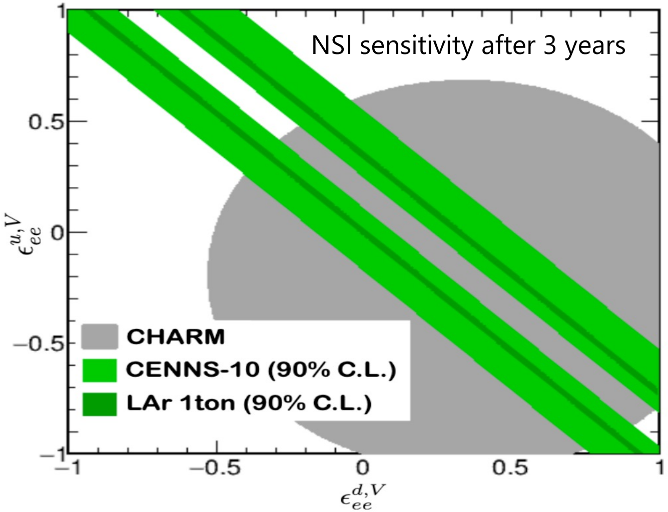
$$\frac{d\sigma}{dT} = \frac{G_F^2 M}{2\pi} Q_W^2 \left(2 - \frac{2T}{E_\nu} - \frac{MT}{E_\nu^2}\right)$$

$$Q_W^V \rightarrow Q_{NSI}^V = \left[\left(g_V^p + 2\epsilon_{ee}^{uV} + \epsilon_{ee}^{dV}\right)Z + \left(g_V^n + \epsilon_{ee}^{uV} + 2\epsilon_{ee}^{dV}\right)N\right]F_n(Q^2)$$

- Expect 10 times higher sensitivity than CENNS-10





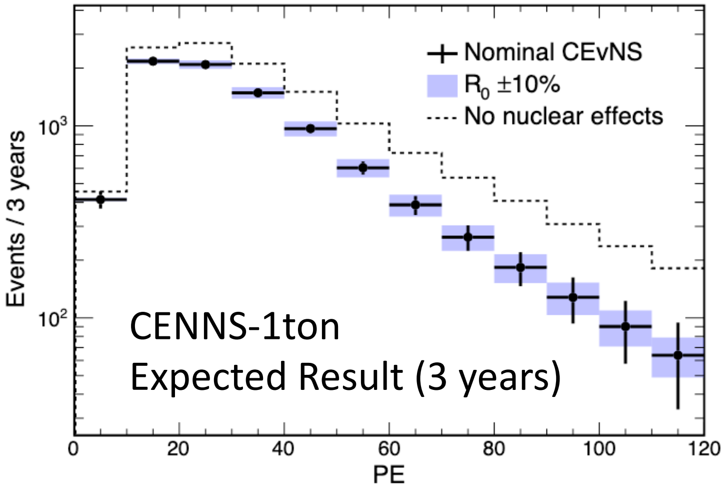


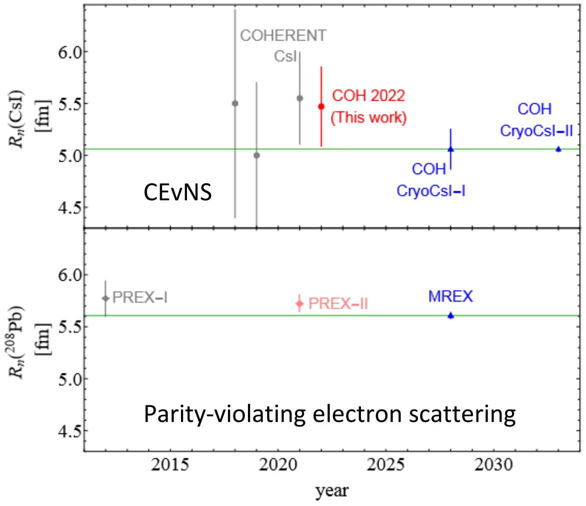
Neutron radius

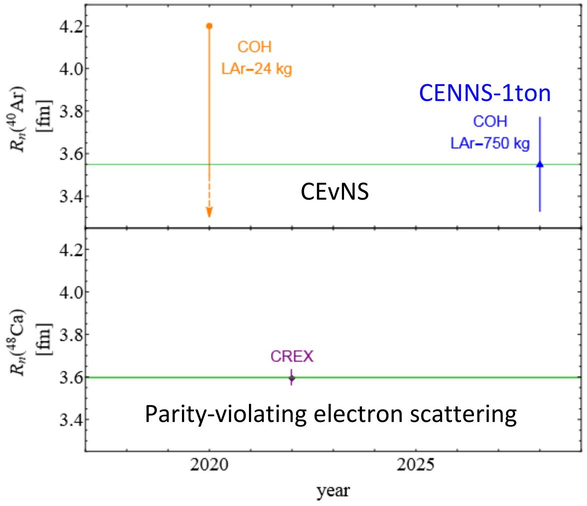
- Neutron radius can improve understanding of neutron star, supernova, etc.
- Neutron radius is encoded by nuclear form factor in weak charge

$$\frac{d\sigma}{dT} = \frac{G_F^2 M}{2\pi}\left[g_V^p Z F_p(Q^2) + g_V^n N \boldsymbol{F_n(Q^2)}\right]\left(2 - \frac{2T}{E_\nu} - \frac{MT}{E_\nu^2}\right)$$

- CENNS-10 first experimentally determined neutron radius in Argon





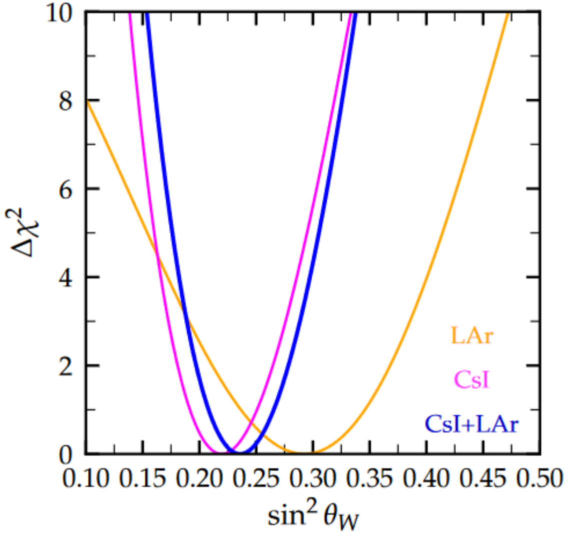


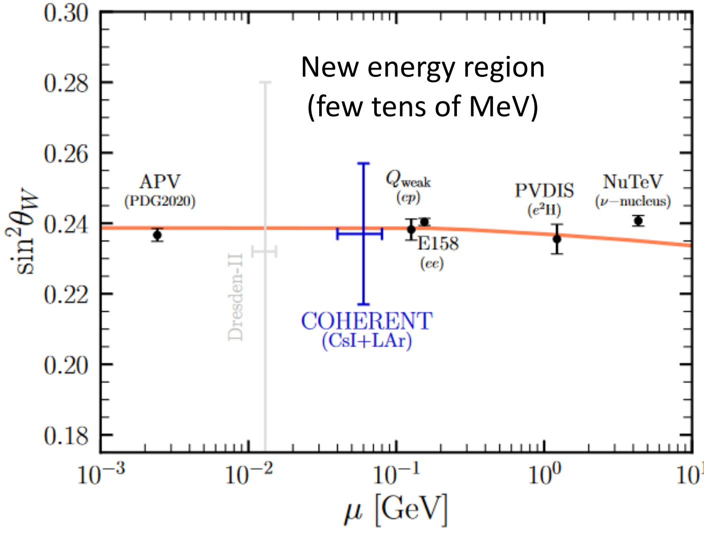
- CEvNS can test fundamental parameters in the electroweak sector at low energies

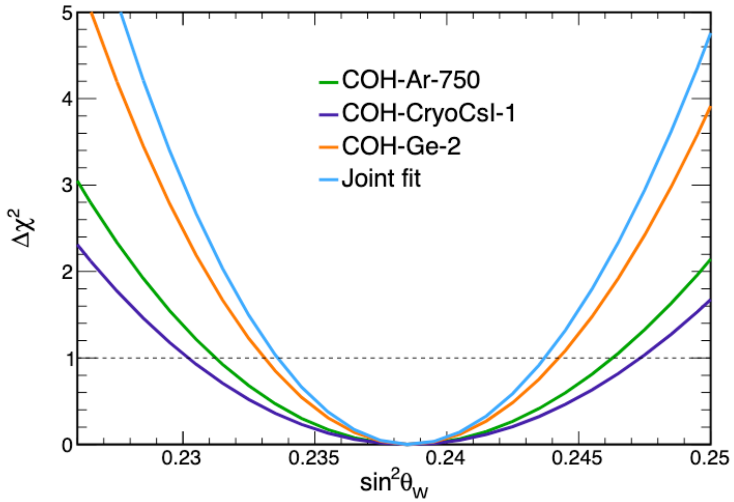
$$\frac{d\sigma}{dT} = \frac{G_F^2 M}{2\pi} Q_W^2 \left(2 - \frac{2T}{E_\nu} - \frac{MT}{E_\nu^2}\right)$$

$$Q_W^V = N - (1 - 4\sin^2\theta_W)Z, \qquad Q_W^A = [g_p^A(Z_+ - Z_-) + g_n^A(N_+ - N_-)]$$

Result of CENNS-10







Using 3 years data (68% CL)

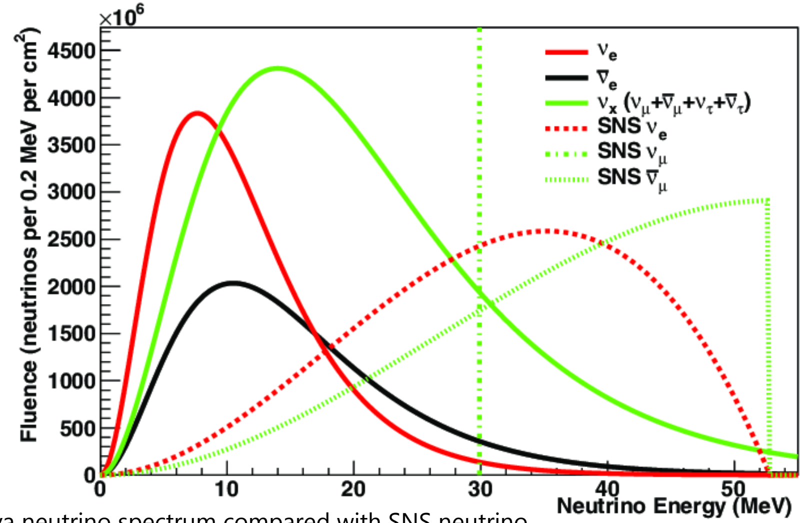
Inelastic ν-Argon Scattering

- Detect ~340 CC and ~100 NC per year without background events

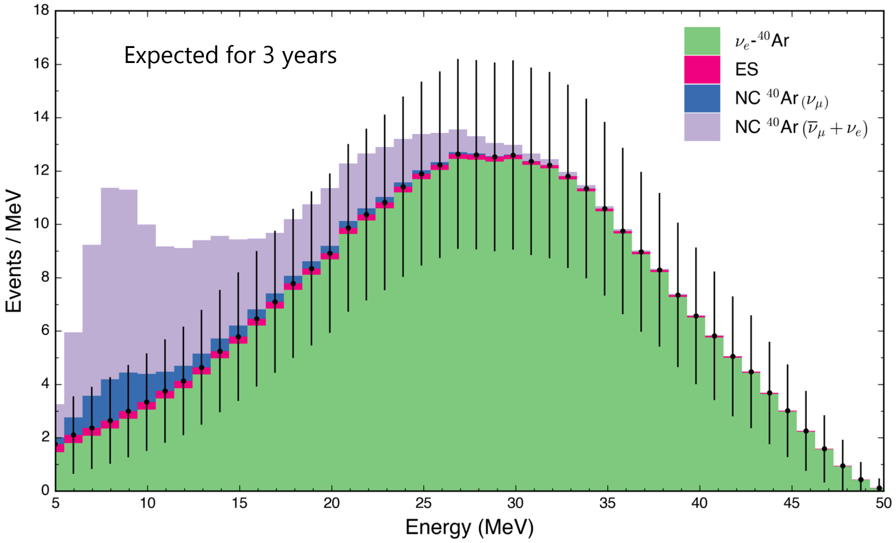
$$CC: \quad \nu_e + 40Ar \rightarrow e^+ + 40K^*$$

$$NC: \; \nu_x + 40Ar \rightarrow \nu_x + 40Ar^*$$

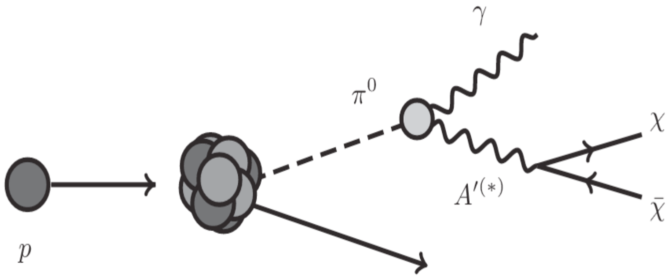
- Expect to measure cross section to ~5% precision after 3 years
- Support experiments utilizing the inelastic channel (ex: DUNE)



supernova neutrino spectrum compared with SNS neutrino

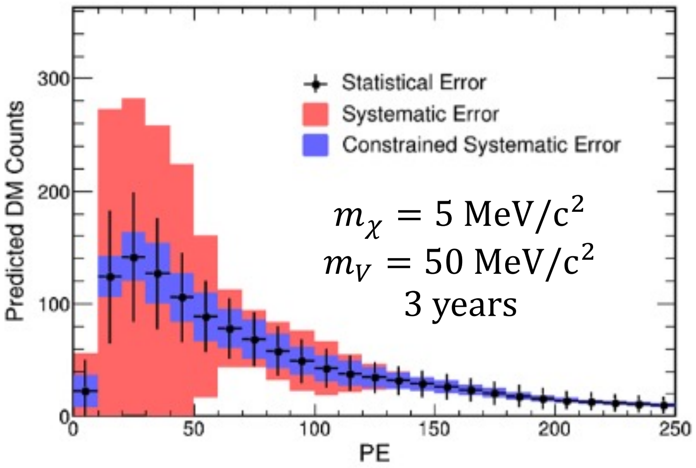


Beam



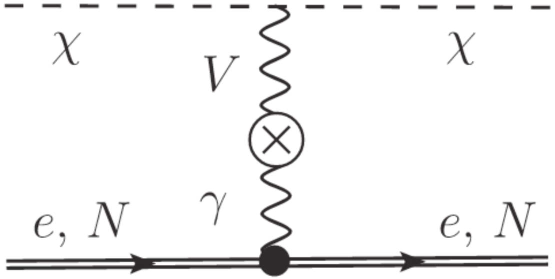
Sub-GeV DM can be generated at SNS beam

Dominant channel for Vector portal DM: $\pi^0 \rightarrow V\gamma \rightarrow \chi\chi$



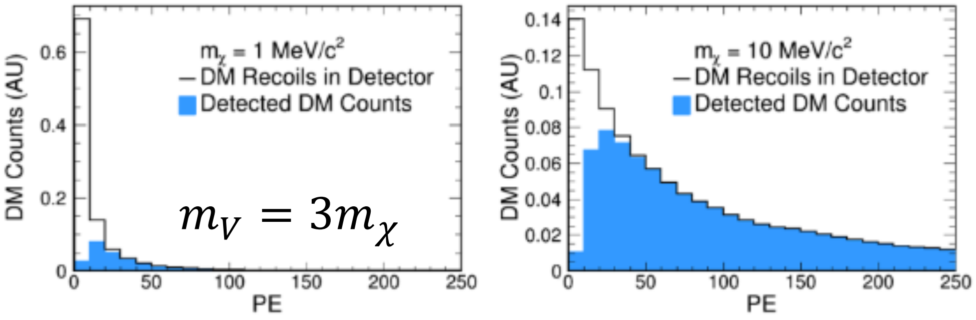
Error can be reduced by delayed time range

Detector



Coherent DM-nucleus scattering

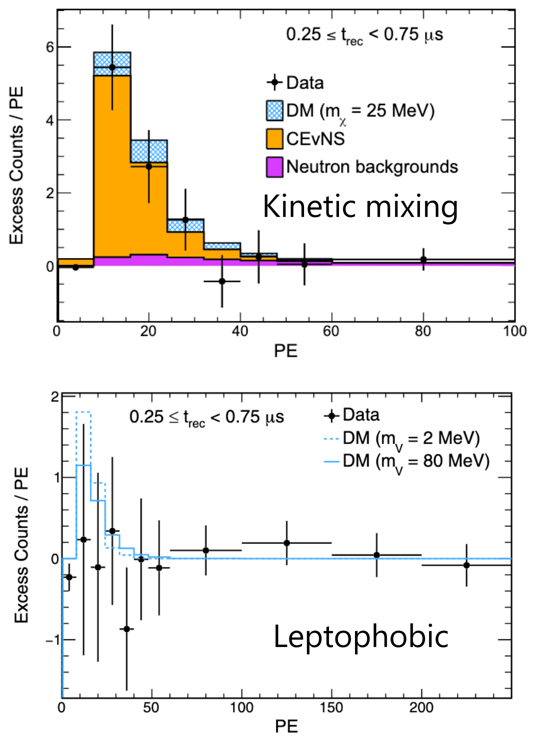
DM make nuclear recoil signal as same as CEvNS



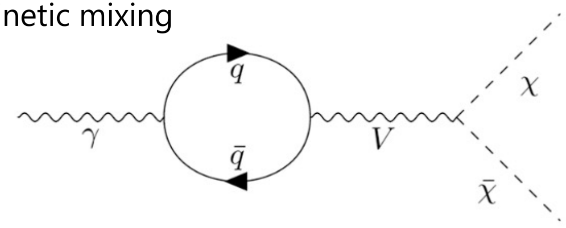
Simulation using same efficiency of CENNS-10

- CsI detector searched DM beyond the cosmological expectation
- Future COHERENT detectors can improve sensitivity

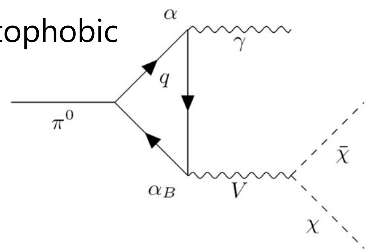
Results of CsI detector

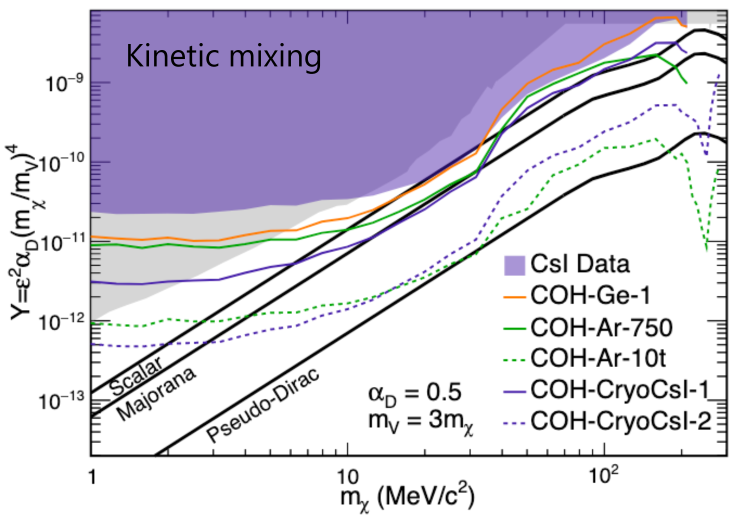


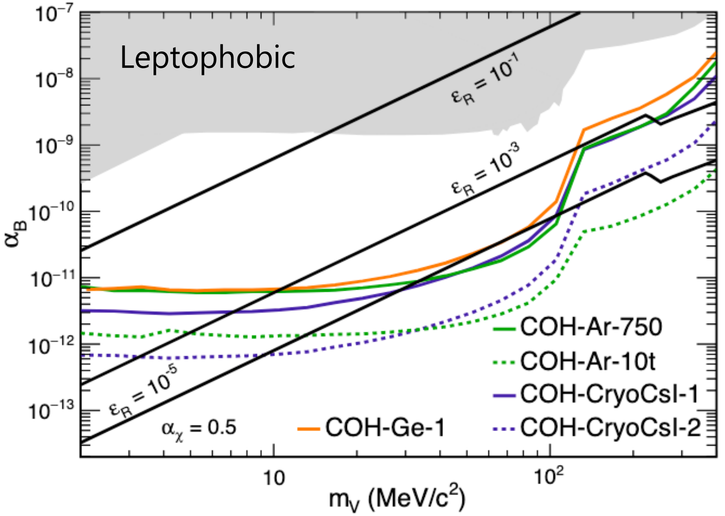
Kinetic mixing



Leptophobic

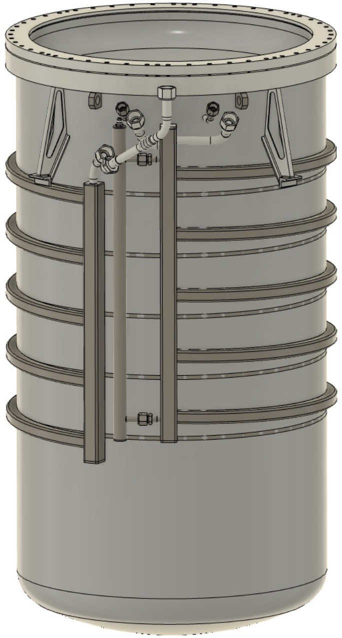




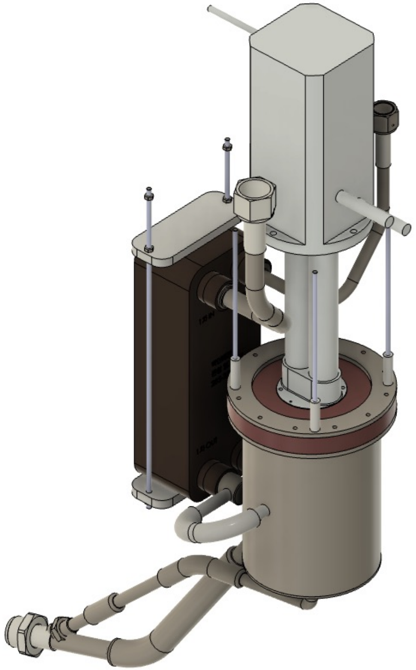


- CENNS-1ton has 2 cryocoolers with LN2 circulation line
- Since ~1ton Liquid Argon needs to be filled, it is crucial to know the liquefying rate
- Testing that the cryocoolers have sufficient cooling power to liquefy vaporized argon

Argon Circulation System



LN2 line for precooling

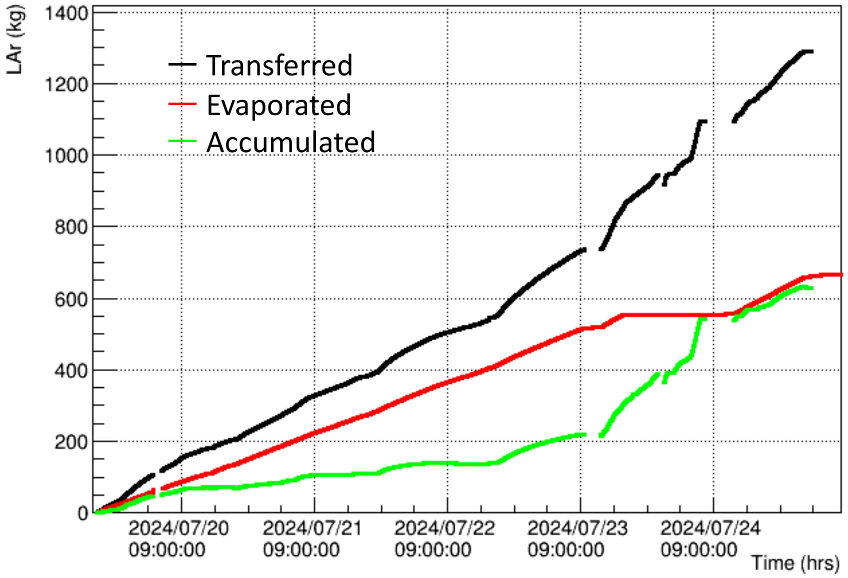


Argon condensing cup with cryocooler

- After turning on cryocooler, the system spent about 3 hours entering the condensing state
- Cooling power is not high enough to initially cool down the chamber without LN2
- With LN2 cooling, ~ 50% Liquid argon is accumulated in chamber

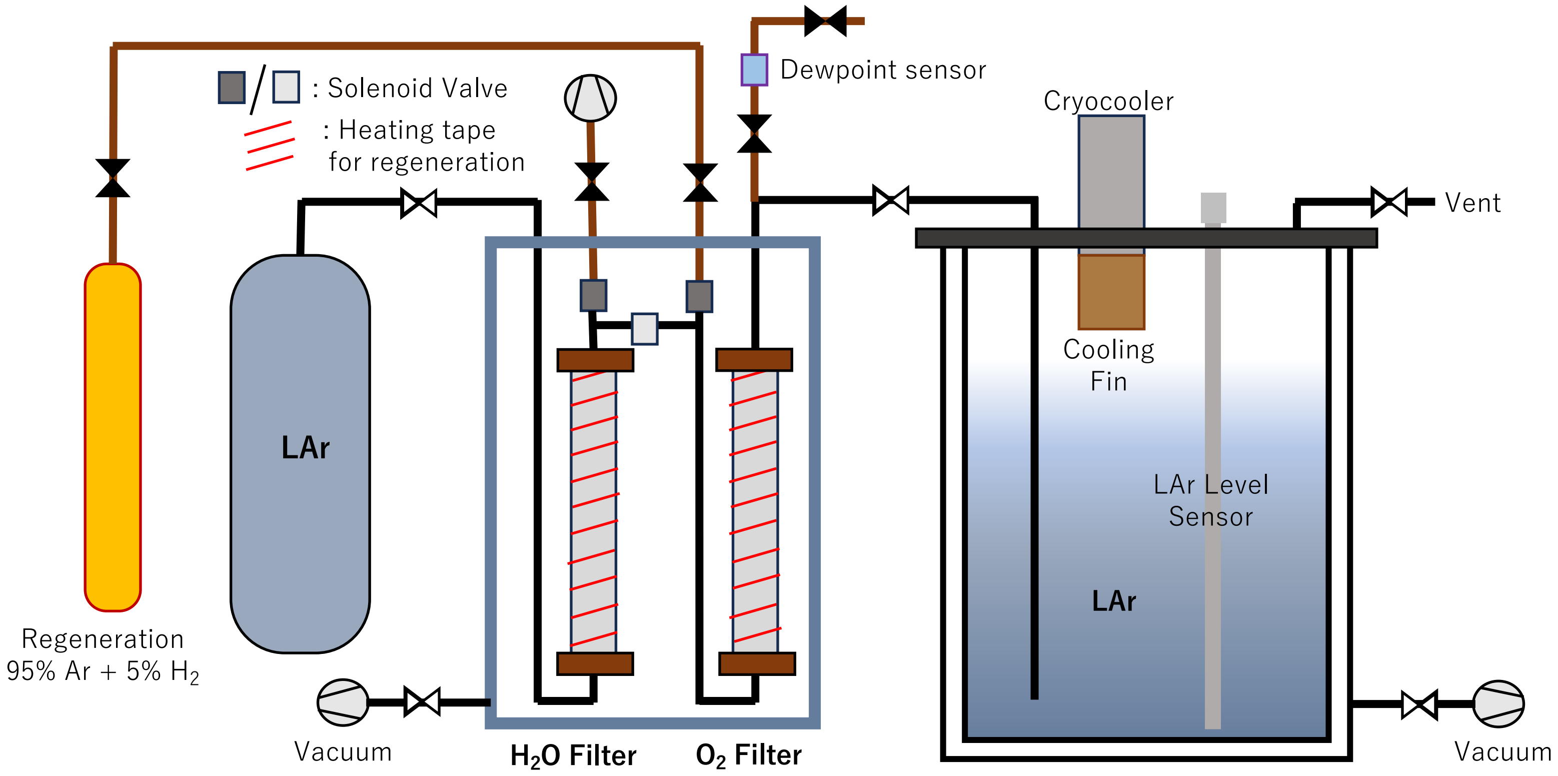
Filling LN2

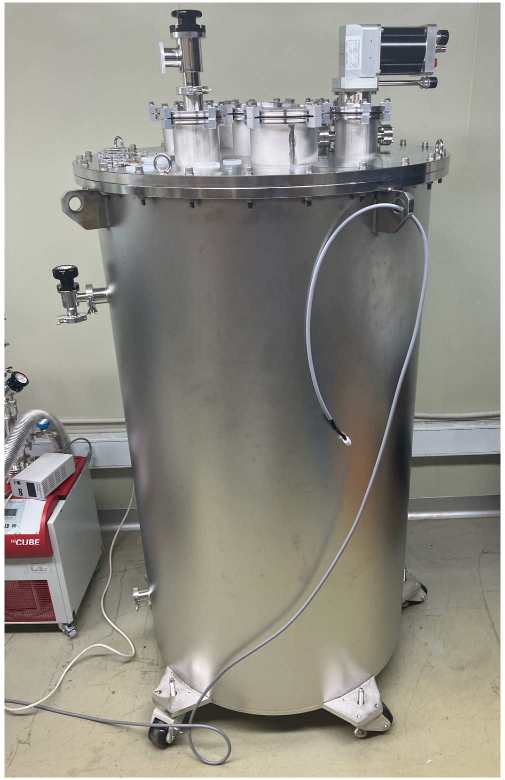
Filling LAr



LAr Accumulation

- Purifying Liquid Argon is much faster than purifying argon gas
- Conducting GM cooler and heating tests





Summary

- COHERENT first observed CEvNS with SNS beam
  - CsI (2017), CENNS-10 (2020), Ge-Mini (2024)
- CENNS-1ton can measure CEvNS precisely and study several physics cases
  - Non-Standard Interaction
  - Neutron Radius
  - Weinberg angle
  - Inelastic neutrino-Argon Scattering
  - Beam Produced Dark Matter
- Tests are ongoing at SNU
  - Argon condensing test, Liquid argon purification test, etc…

Thank you