CEvNS and MeV-scale Cross-Section Measurements for Supernova Neutrinos

Yun-Tse Tsai (SLAC)

NNN Workshop

October 30th, 2026

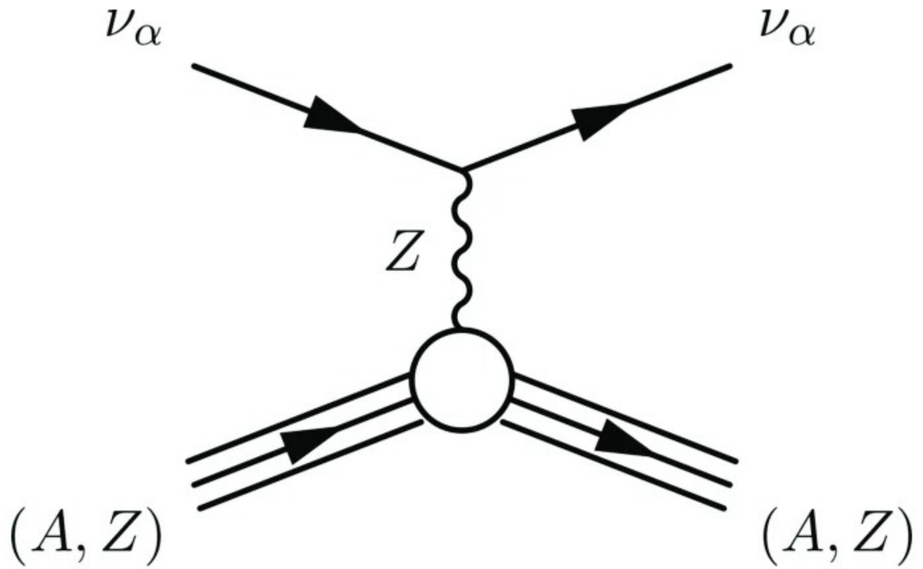
SLAC NATIONAL ACCELERATOR LABORATORY

Coherent Elastic ν-Nucleus Scattering (CEvNS)

- Standard Model weak interaction
- Neutral-current, no interaction threshold
- $QR_{nucl} \ll 1$, Q: momentum transfer, R_{nucl}: nucleus size
  - Interact coherently with entire nucleus
  - Large σ at $E_\nu \lesssim 50$MeV
  - $\sigma \propto N^2$, N: neutrons
- Small uncertainties in the SM prediction
- Predicted in 1974 by D.Z. Freedman

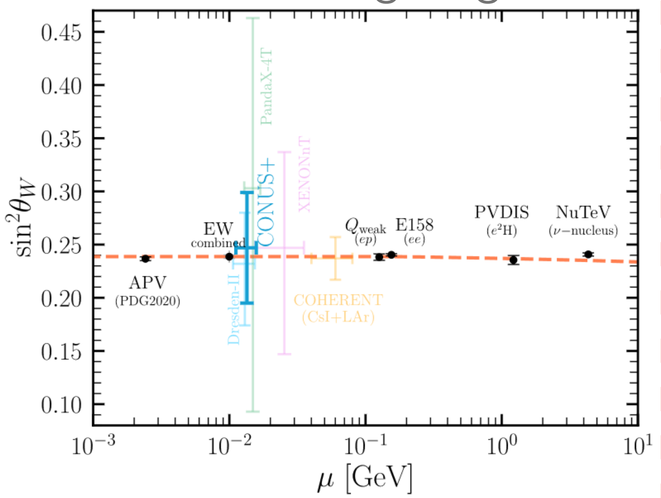
$$\frac{d\sigma}{dT} \approx \frac{G_F^2 M}{4\pi}\left(1 - \frac{MT}{2E_\nu^2}\right)[N - (1 - 4\sin^2\theta_W)Z]^2 F^2(Q^2)$$

$$T \leq \frac{2E_\nu^2}{M} \qquad F(Q^2) \to 1 \text{ at } Q^2 \to 0$$



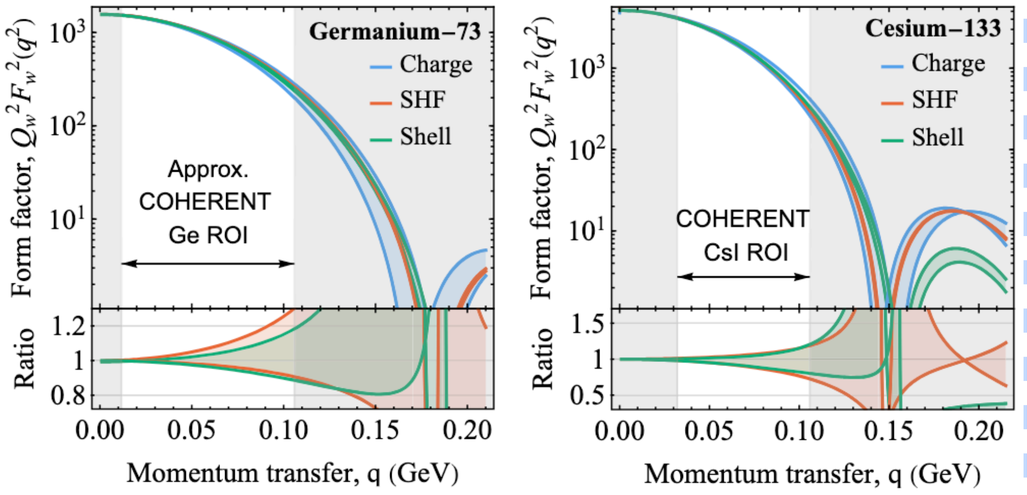
Measuring CEvNS: Precision Test of the SM

Weak mixing angle



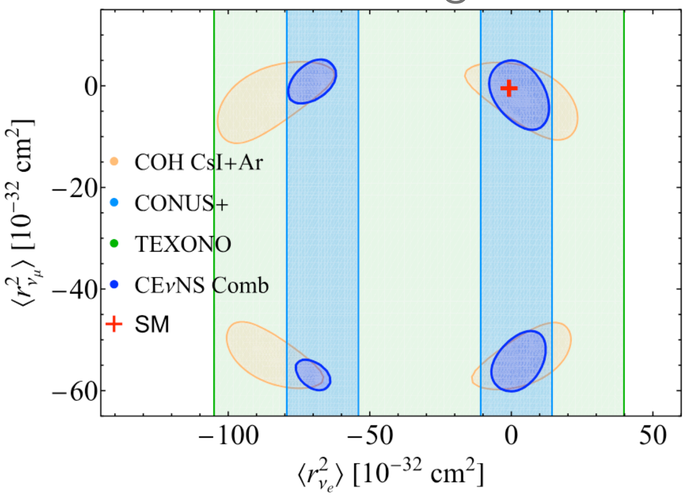
PRD 111, 075025 (2025)

Neutron form factor



PRD 111, 033003 (2025)

Neutrino charge radius



PRD 112, 015007 (2025)

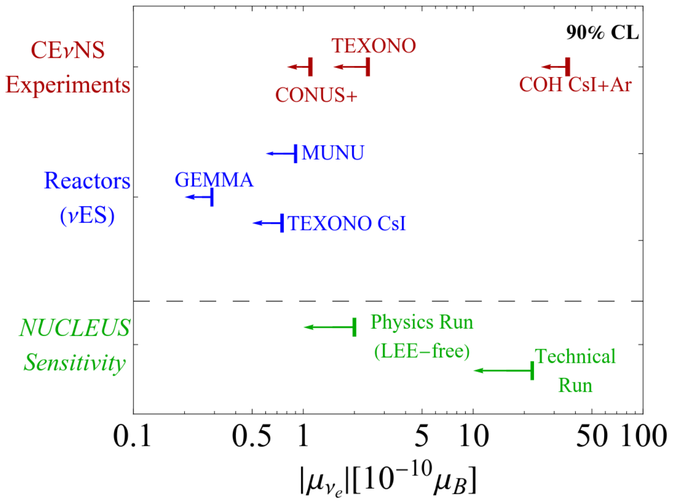
$$\frac{d\sigma}{dT} \approx \frac{G_F^2 M}{4\pi}\left(1 - \frac{MT}{2E_\nu^2}\right) Q_W^2 F^2(Q^2)$$

$$Q_W = N - (1 - 4\sin^2\theta_W)Z$$

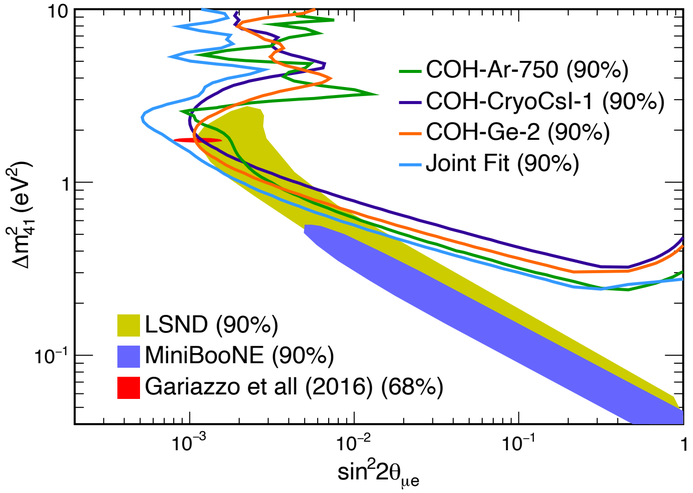
Q_W depends on neutrino charge radii, which is O(-10^{-33}cm^2) in the SM

Measuring CEvNS: Probing BSM

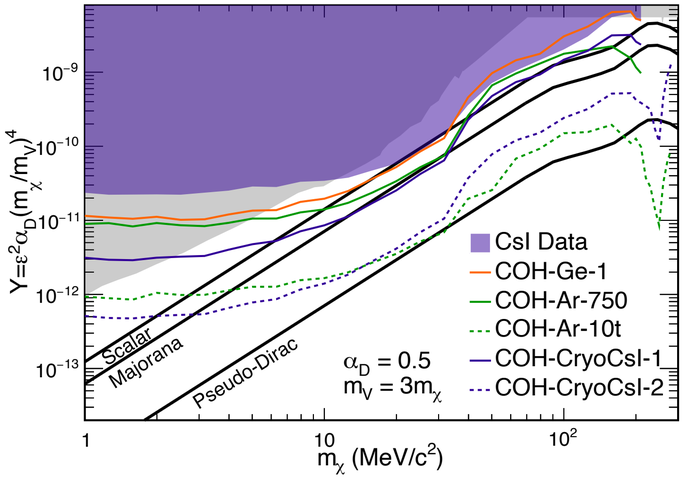
Neutrino magnet moment



Sterile neutrino search

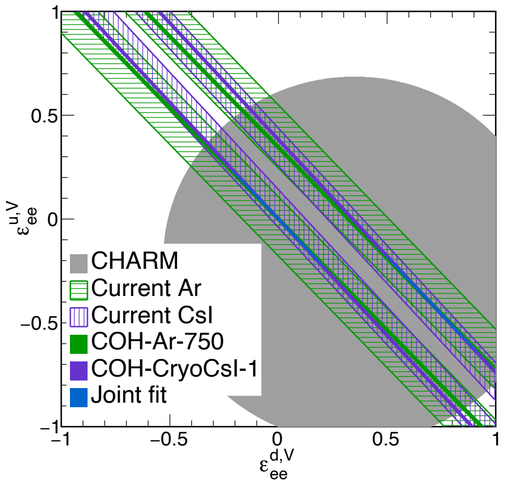


Accelerator-produced dark matter



CEvNS cross section and recoil spectrum is sensitive to neutrino magnet moment

Active ν disappearance analysis



Non-standard interaction (NSI): NSI couplings can modify Q_W

PRD 114, 012016 (2026)
Snowmass 2022, arXiv: 2204.04575

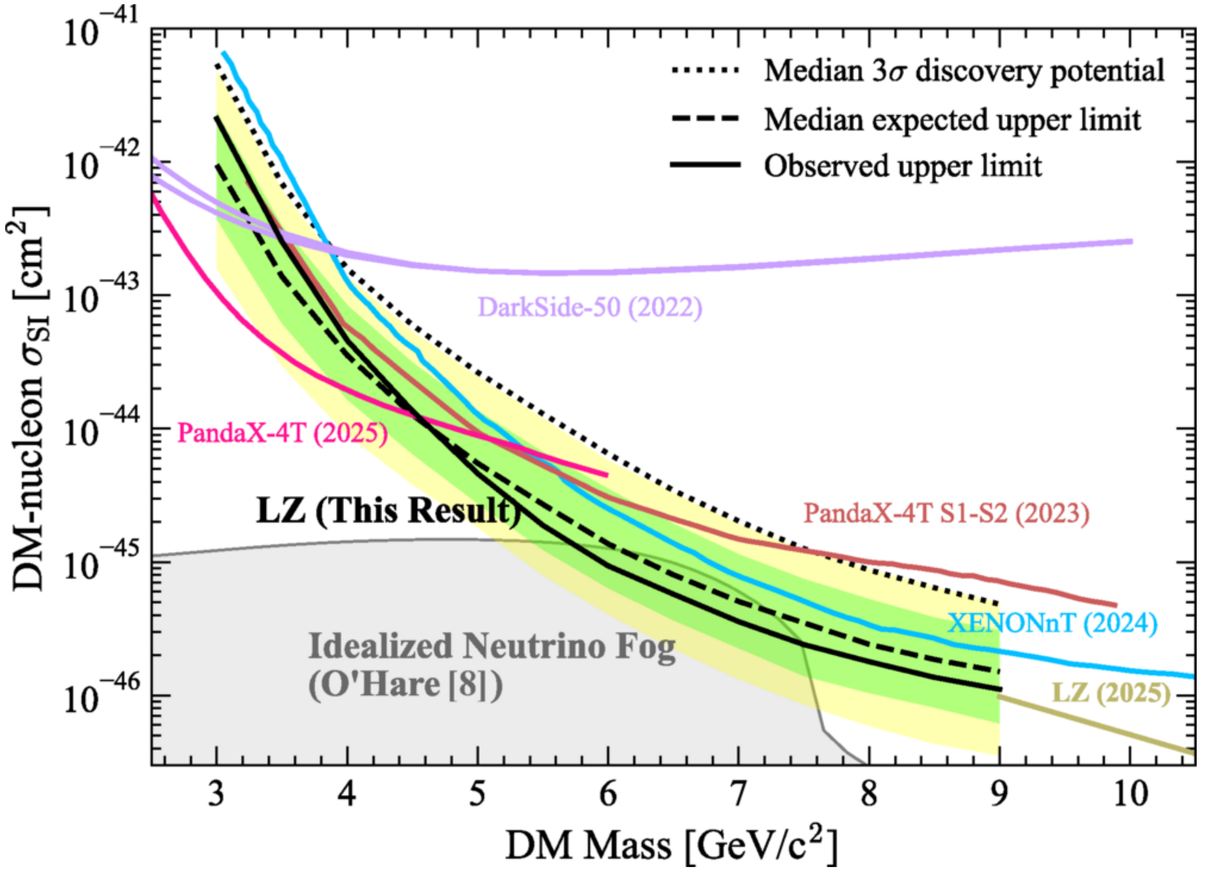
Astrophysical Neutrinos and Others

Understand astrophysics: supernova, sun, etc.

- Core-collapse supernova: 99% of its gravitational binding energy releases in neutrinos with tens-of-MeV
- Diffuse supernova neutrino background (DSNB)
- Solar neutrinos

Background “neutrino fog” of direct detection of dark matter search

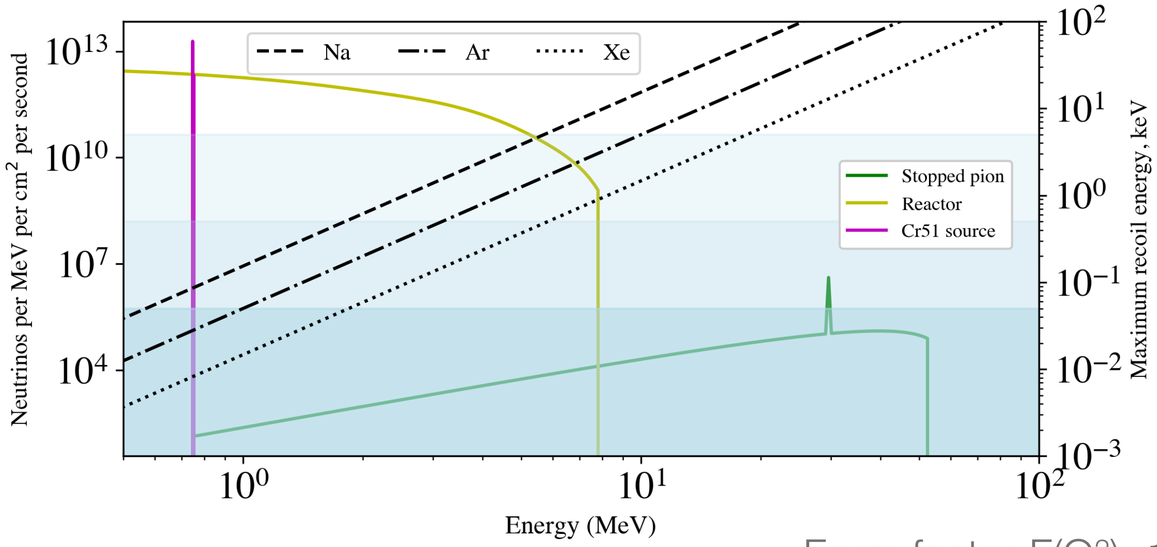
Reactor monitoring



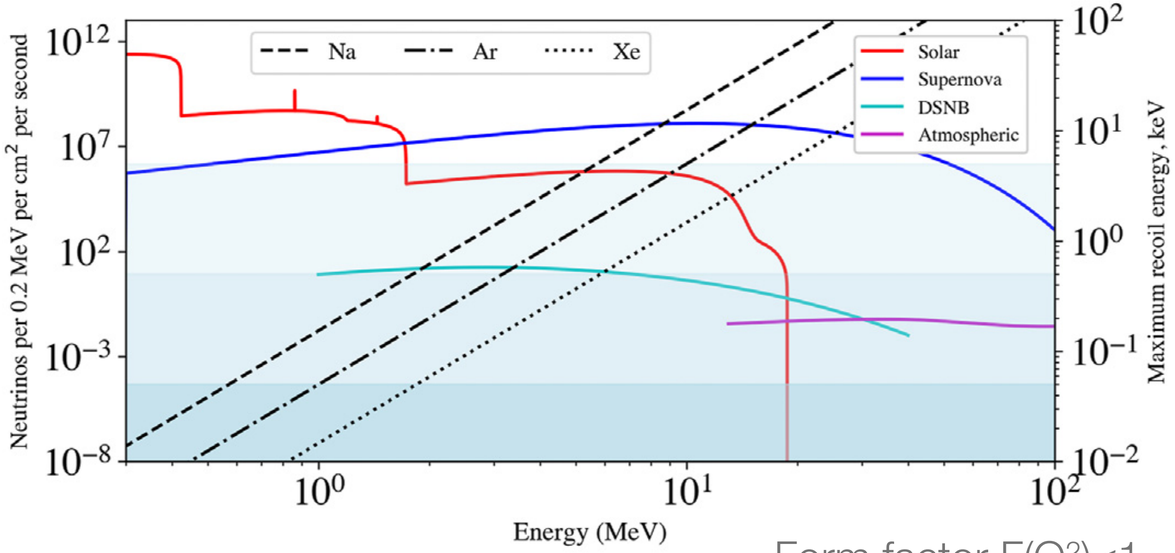
PRL 137, 091806 (2026)

Neutrino Sources for CEvNS Measurements

Artificial ν sources:
stopped π, reactor



Natural ν sources:
solar, supernova, atmospheric



Form factor $F(Q^2)<1$

keV — 100 MeV

Recoil energy < detector threshold

Form factor $F(Q^2)<1$

keV — 100 MeV

Too high energy for coherence

Scholberg, K., Hakenmüller, J., & Pershey, D. (2026). Coherent elastic neutrino-nucleus scattering. In C. S. Fischer (Ed.), Encyclopedia of Particle Physics, Vol 4, 570-588

CEvNS Detection

Recoil nucleus energy: O(10eV$_{NR}$)-O(10keV$_{NR}$)

Background and noise dominated, requires

- Radiopure materials, shielding
- Low noise level

Quenching factor = detected/deposited energy

Similar consideration to the direct-detection dark matter detectors

Typical detector technologies: ionization, light, heat

- scintillating crystals: CsI, NaI
- semiconductor ionization detectors: high-purity Ge (HPGe), Si CCDs
- noble liquids: LAr, LXe
- cryogenic bolometers: Al_2O_3, $CaWO_4$, Ge, Zi, etc.



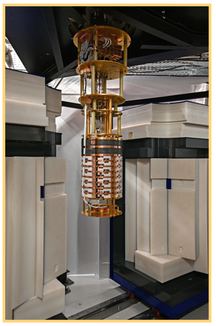
NaI @ COHERENT



HPGe @ COHERENT



LAr @ COHERENT



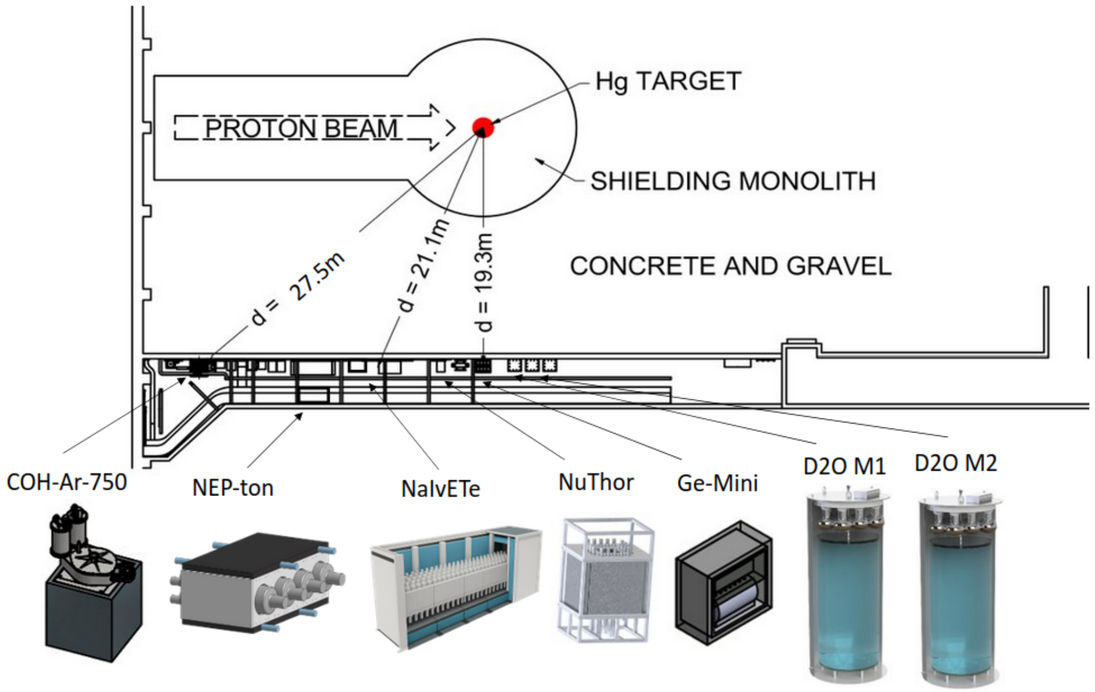
Cryo bolometer @RICOCHET

Stopped π: COHERENT

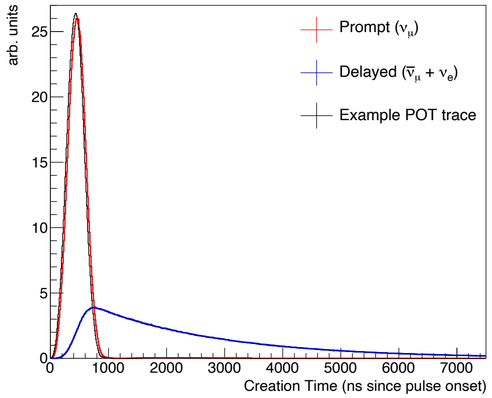
Spallation neutron source (SNS) at ORNL, US:
1.3 GeV proton beam striking Hg at 60Hz, 2MW

$\pi^+ \rightarrow \mu^+ + \nu_\mu$ (prompt)

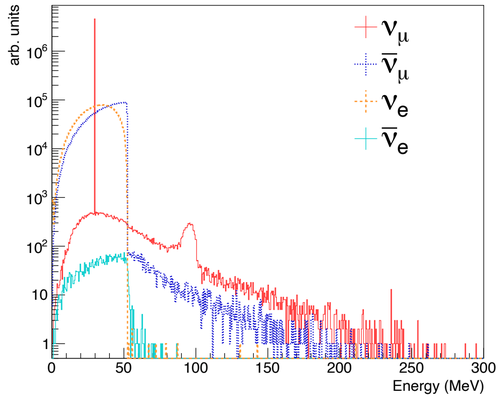
$\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$ (delayed)



Simulated neutrino timing



Simulated neutrino energy



Well-understood neutrino energy spectrum, 10% uncertainty on the scale

Pulsed beam, good for background rejection

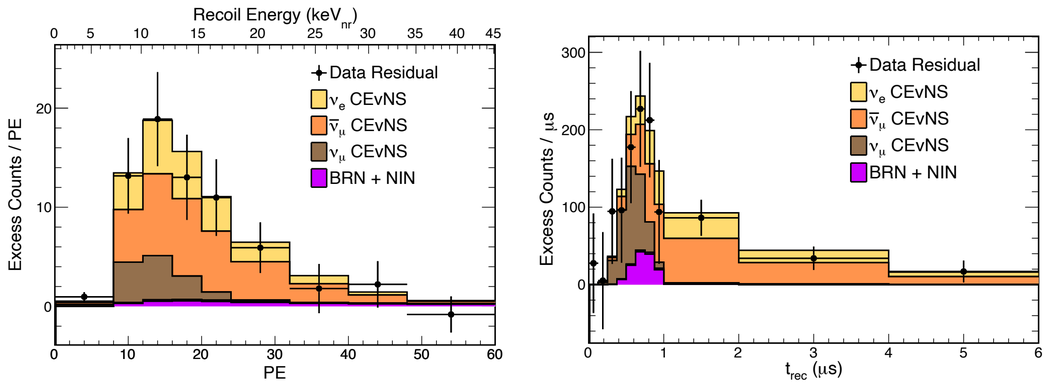
Shielding for cosmic rays and beam neutrons

Multiple detector targets: CsI, Ar, Ge, NaI, D_2O

First CEvNS observation: CsI scintillating crystal at room temperature by COHERENT (2017)

COHERENT Results: CsI and Ar

CsI full data analysis: PRL 129, 081801 (2022)



14.6kg active mass, 3.2×10^{23} POT

Improved analysis:

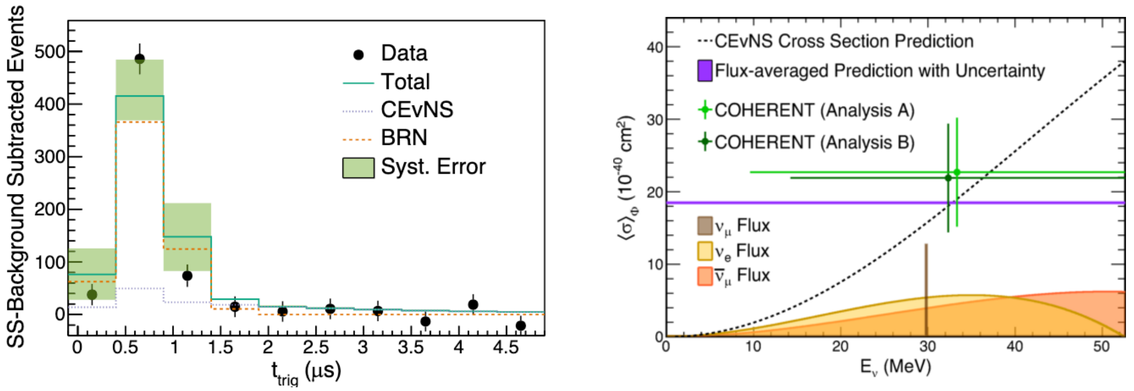
- Lowered threshold
- Afterglow corrected

Preliminary results (final result to come):

Cross section: $(1.87\pm0.27)\times10^{-38}$cm^2

Weak mixing angle: 0.238±0.025

First Ar result: PRL 126, 012002 (2021)

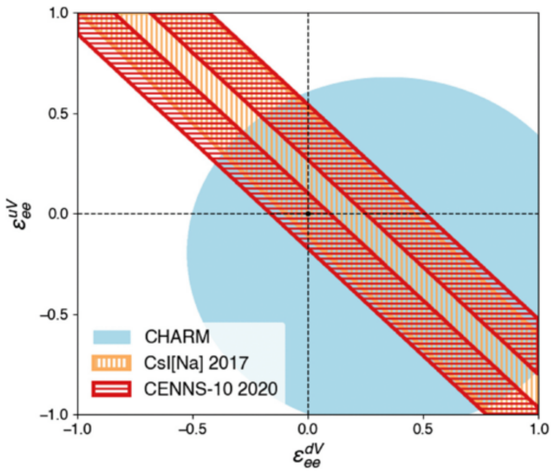


24 kg active mass, 13.7×10^{22} POT

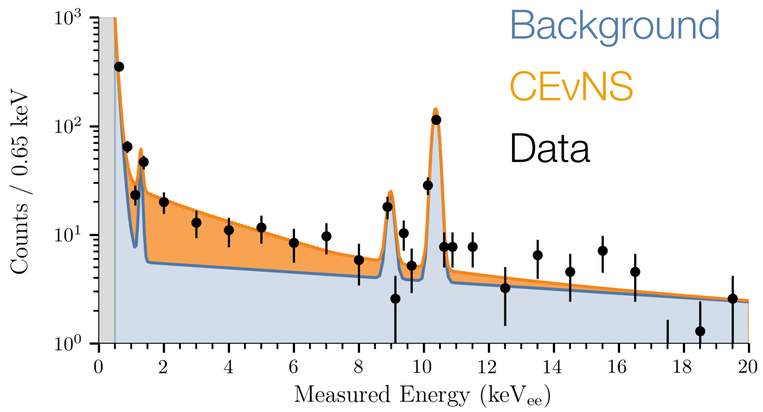
Flux-averaged σ, significance>3 S.D.: $(2.2\pm0.7)\times10^{-39}$cm^2

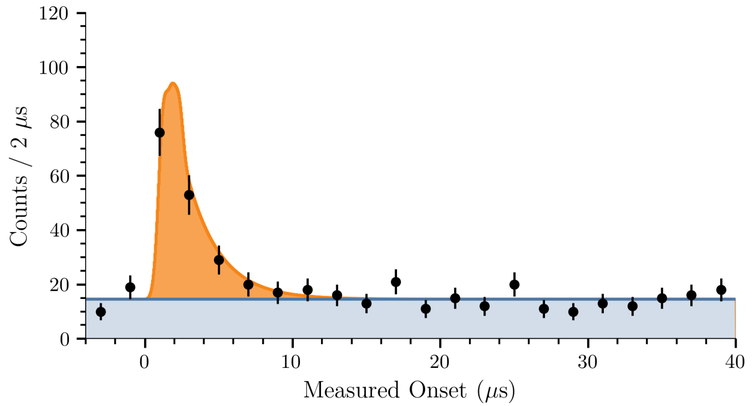
Consistent with the SM

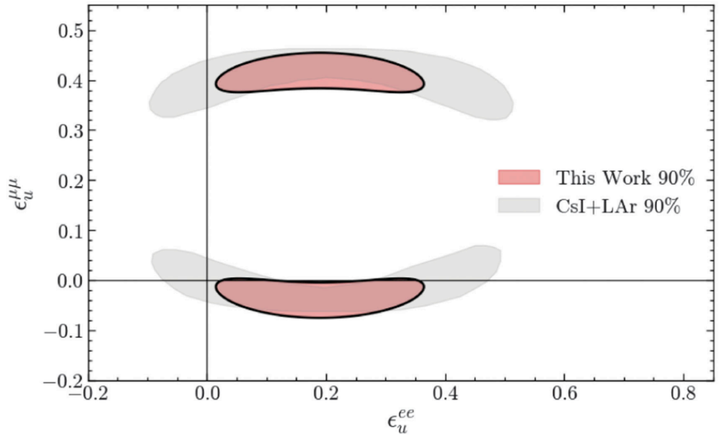
Constrained NSI



COHERENT Results: Ge







New result, second Ge measurement with active mass 8.53±0.08kg: PRL 137, 171801 (2026)

- Increased exposure: 3 → 4 months (4.69×10^{22}POT)
- Lowered threshold: 1.5 keV$_{ee}$→0.5 keVee
- ML to identify cross-talks

First systematics-limited data sample

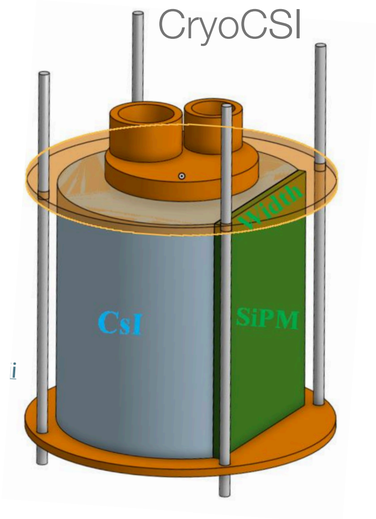
Flux-averaged cross section/SM prediction: 0.98±0.1(stat.)±0.1(syst.)

Neutrino time structure (prompt ν_μ vs delayed $\nu_e, \bar{\nu}_\mu$) allows flavor-dependent CEvNS

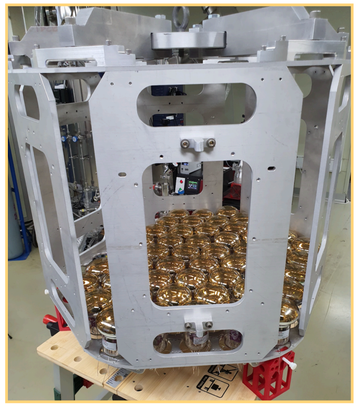
Result interpreted in terms of NSI

COHERENT Ongoing Efforts

CryoCSI



COH-Ar-750



CryoCsI: to be deployed in late 2026/2027

- Threshold: 5 keV_{NR}→0.5 keV_{NR}

COH-Ar-750: 750-kg LAr scintillation detector being commissioned

- Expect ~5000 CEvNS events per year

NaIvETE: 1.4/2.4 tons NaI deployed

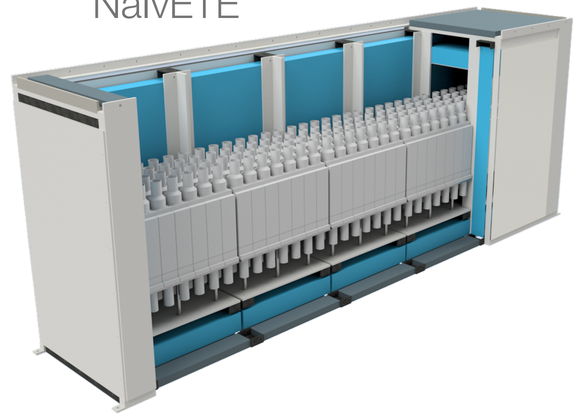
- Light target: ^{23}Na, upgrading with low-noise high-gain PMTs

D_2O: 549kg deployed, analysis underway

- Expected to constrain ν flux scale to 3-5%
- The 2nd module with H_2O

Liquid Neon: lightest target under consideration

NaIvETE



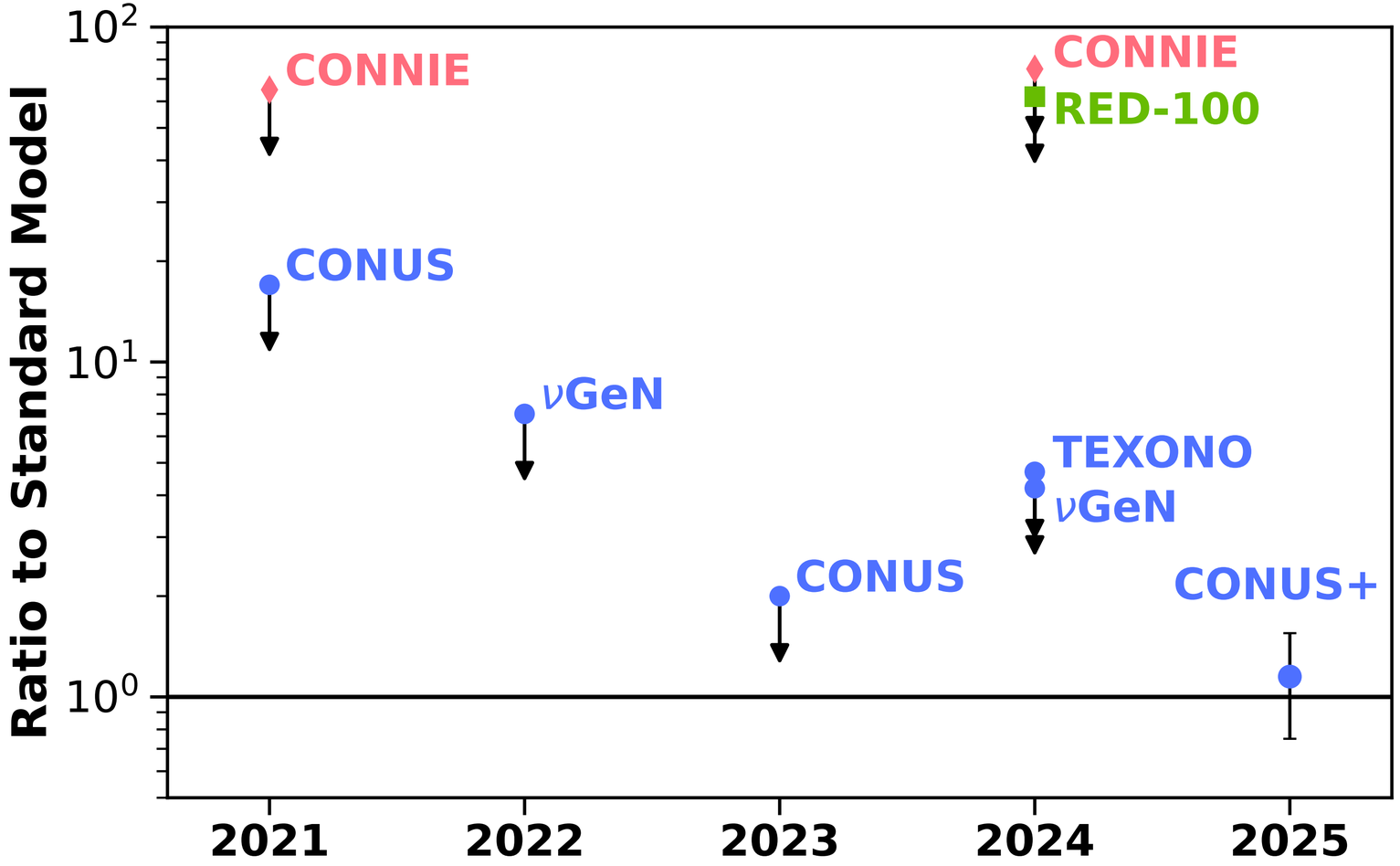
D_2O



Stopped-π Facilities and their Future CEvNS Plans

	Spallation Neutron Source	LANSCE	European Spallation Source	China Spallation Neutron Source	JSNS^2
Location	Oak Ridge, US	Los Alamos, US	Lund, Sweden	Dongguan, China	Tokai, Japan
Status	Operating	Operating	1st n production planned in 2027	Upgrade to be complete this year	Operating
Proton Energy	1.3 GeV	0.8 GeV	2 GeV	1.6 GeV	3 GeV
Power	2MW @ 60Hz	<1 MW @ 20Hz	5 MW @ 14Hz	0.5 MW @ 25Hz	1MW @ 25Hz
Beam Width	< 1μs	~280 ns	2.86ms	0.5ms	100ns
Target	Hg	W	W	W	Hg
CEvNS Program	COHERENT	CCM: LAr scintillator	CryoCsI, HPGe, high pressure TPC: Ar, Kr, Xe	CsI, commissioning this year	No explicit plan

Reactor CEvNS



- HPGe
- Si CCDs
- Xe TPC

Lower E_ν than stopped π sources, more coherent

No ν timing information

Encyclopedia of Particle Physics, Vol 4, 570-588

CONUS+

First measurement of reactor CEvNS: Nature 643, 1229-1233 (2025), M. Meier's talk on Wednesday

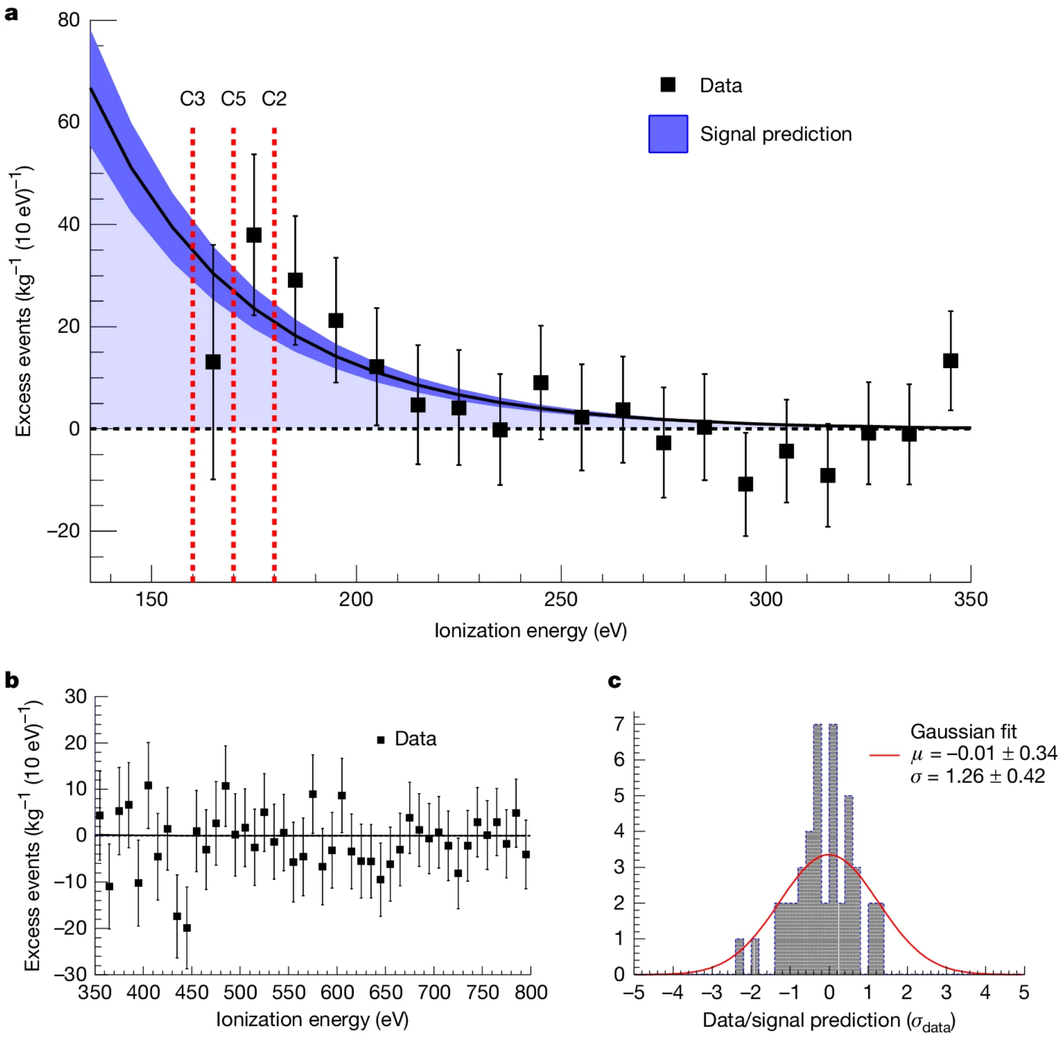
CONUS→CONUS+

- Threshold: 210→160-180 eV_{ee}
- Trigger efficiency at low energies improved to ~100%

2.83±0.02 kg active mass, 327 kg-days reactor on

CEvNS cross section measured/SM: 1.14±0.36, significance 3.7 S.D.

Upgrade: larger mass, lower threshold, longer data collection



Other Operating and Future Experiments for Reactor CEvNS

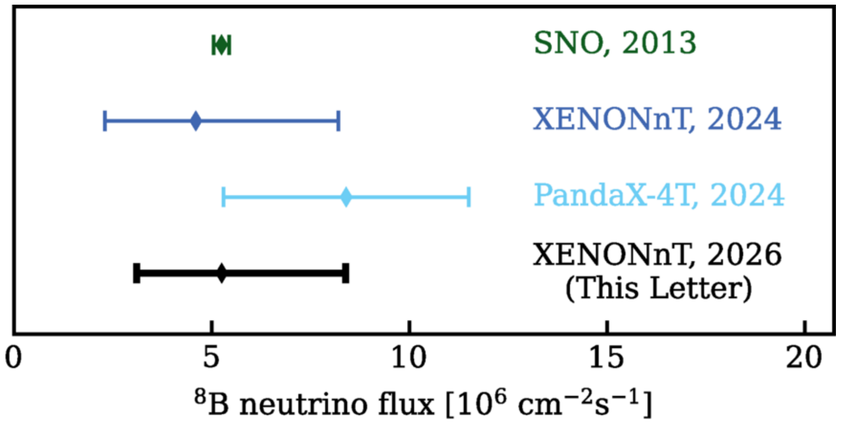
Experiment	Detector	Threshold	Status	Experiment	Detector	Threshold	Status
vGeN	HPGe, point contact Ge	290eV$_{ee}$	Being upgraded	RED-100	LXeTPC	2keV$_{NR}$	Upgrading to LAr
CONNIE	Si skipper CCDs	15eV$_{ee}$	Being upgraded	NUCLEUS	Cryogenic $CaWO_4$ bolometers	Goal: ~10-20eV$_{NR}$	Commissioning
NEON	NaI scintillator	O(100eV$_{ee}$)	Operating	RELICS	LXeTPC	O(100eV$_{NR}$)	Commissioning
RICOCHET	Cryogenic Ge & Zn bolometers	O(10eV$_{NR}$)	Operating	MINER	Cryogenic Ge/ Si bolometers	Goal: O(10eV$_{NR}$)	R&D/ development
RECODE	HPGe	210/220eV$_{ee}$	Operating	Atucha II	Si skipper CCDs	Goal: O(10eV$_{ee}$)	R&D/ development

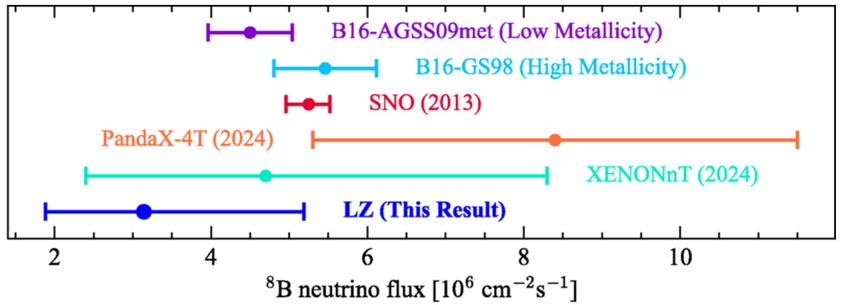
Solar CEvNS

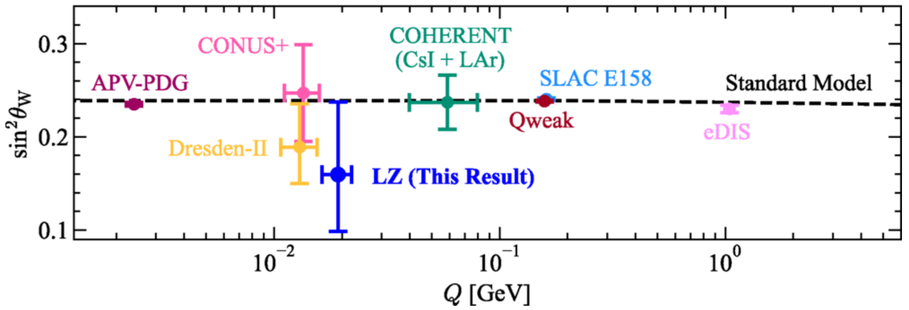
Underground, massive dual-phase LXeTPCs for direct dark-matter detection, threshold at ~1keV$_{NR}$

Understand more solar ν production and oscillation, ν_τ couplings, detector calibration

	PandaX-4T	LZ	XENONnT
Publication	PRL 133, 191001 (2024)	PRL 137, 091806 (2026)	PRL 137, 091807 (2026)
Exposure (Tonne×year)	1.2/1.04	5.7	6.77
^{8}B ν flux (10^6cm^{-2}s^{-1})	8.4±3.1	$3.1^{+2.1}_{-1.3}$	5^{+3}_{-2}
Significance (S.D.)	2.64	4.5	3.3







N^2-dependence

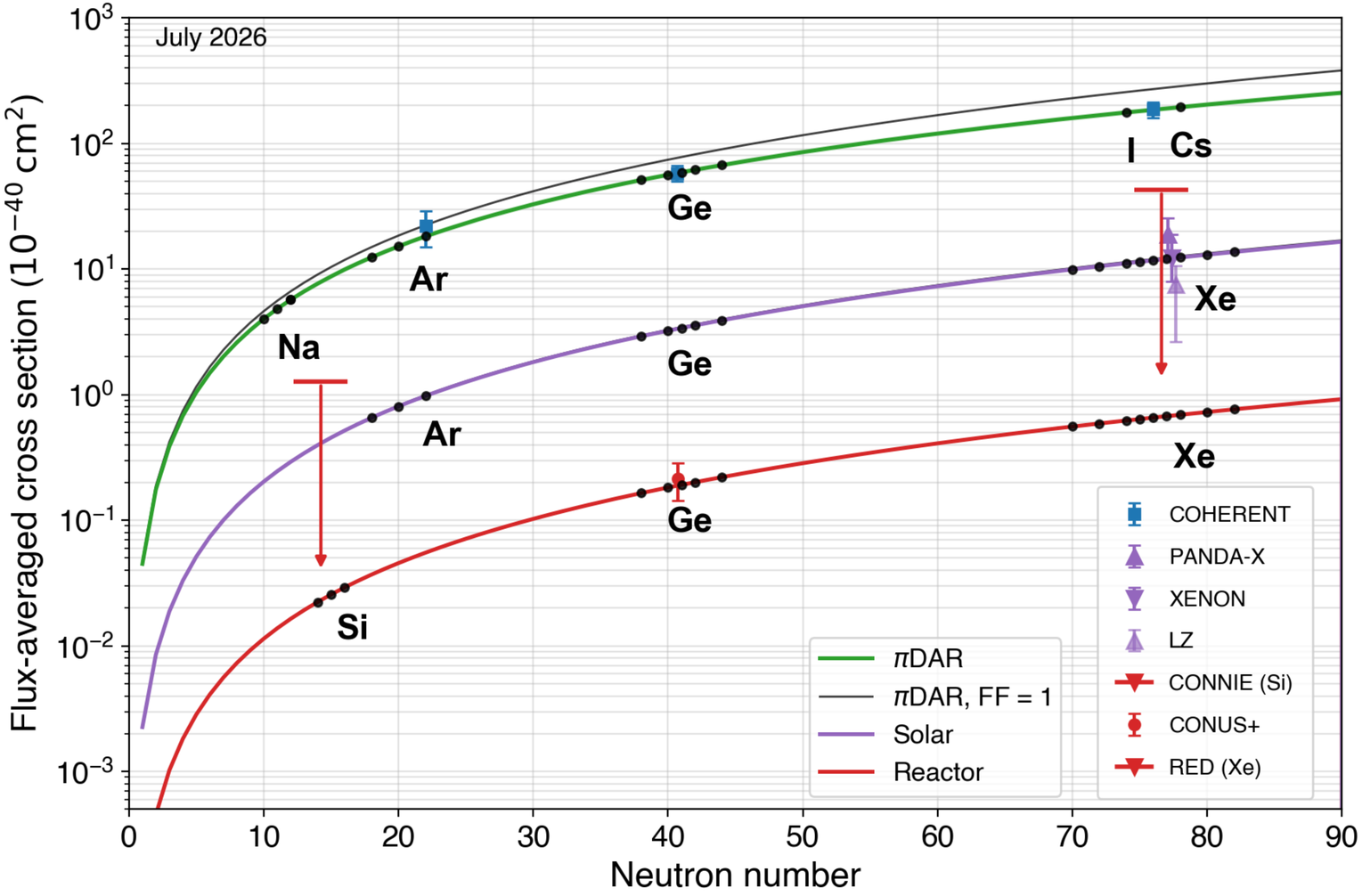


Figure courtesy of Kate Scholberg

Supernova Neutrino Measurements

99% of the binding energy of a core-collapse supernova is carried by neutrinos of all the flavors

Fit data spectra to the pinched-thermal form

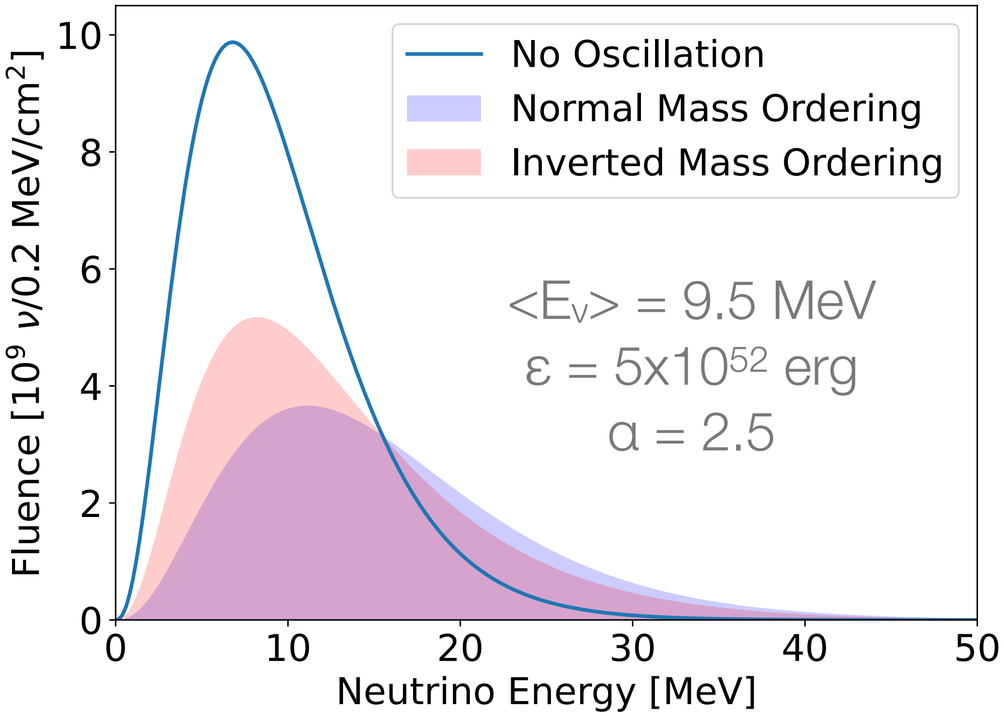
$$\phi(E_\nu) = \mathcal{N}\left(\frac{E_\nu}{< E_\nu >}\right)^{\alpha} \exp\left[-(\alpha+1)\frac{E_\nu}{< E_\nu >}\right]$$

E_ν: neutrino energy

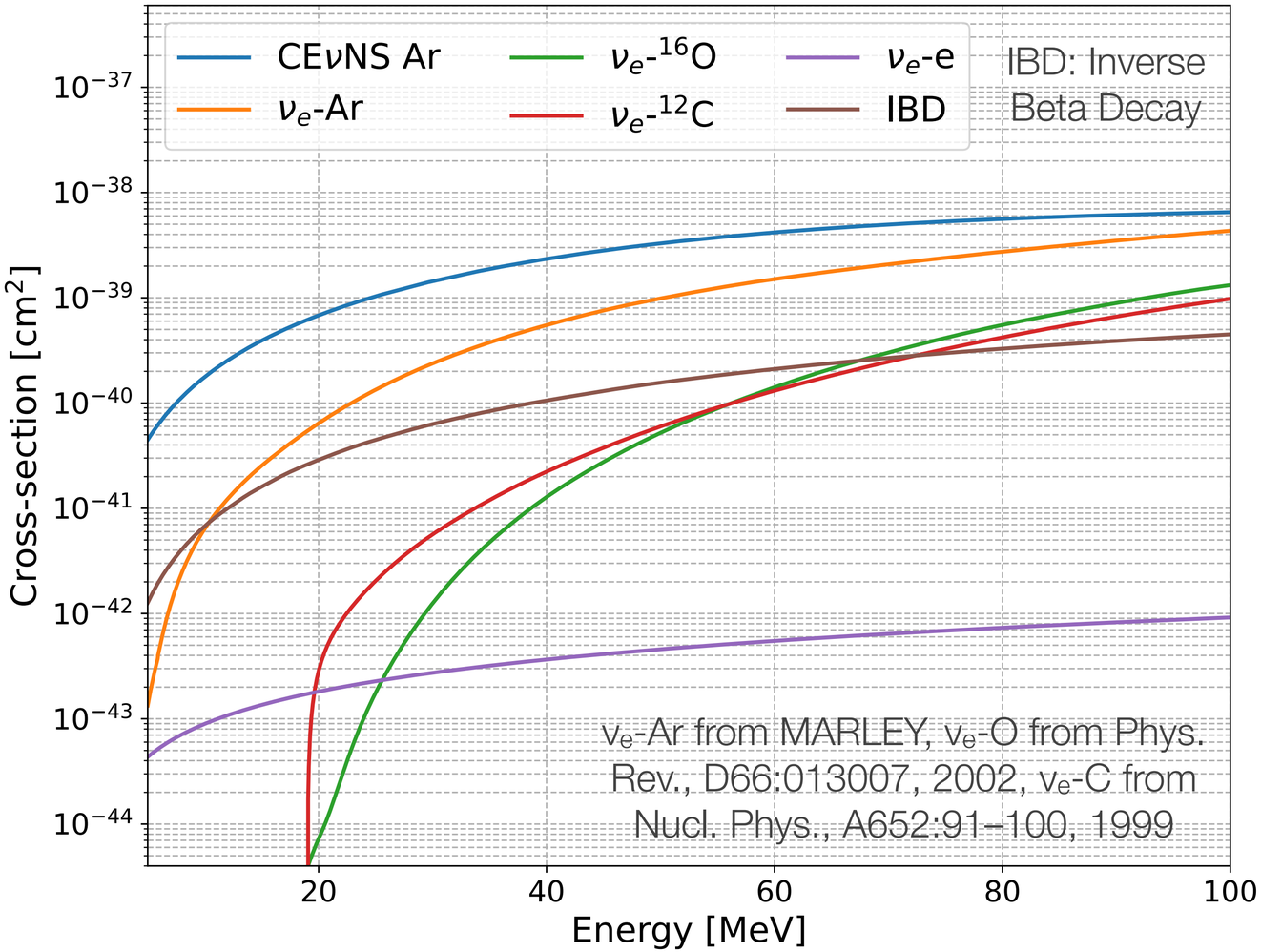
$<E_\nu>$: average E_ν

N ∝ ν luminosity, ε

α: pinching parameter



Supernova ν Cross Sections



Desire to know the spectra of all the ν flavors,
$\nu_e, \bar{\nu}_e, \nu_x\ (\nu_\mu, \nu_\tau), \bar{\nu}_x\ (\bar{\nu}_\mu, \bar{\nu}_\tau)$

Flavor-blind: CEvNS

$\bar{\nu}_e$: Inverse beta decay (IBD)

→Water/ice Cherenkov, liquid scintillation detectors

ν_e: ν_e-Ar CC interactions

→Ar detectors: DUNE

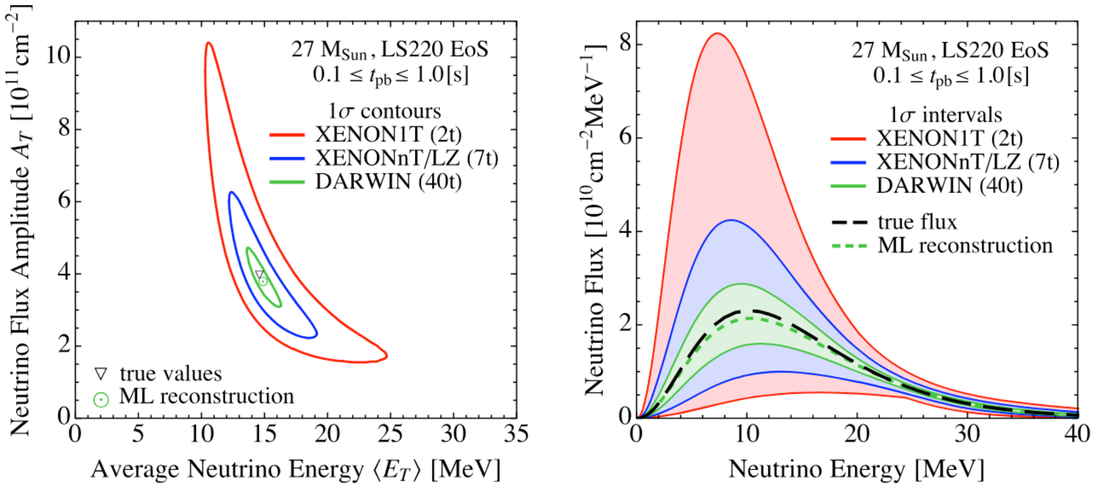
Supernova CEvNS Glow

Flavor-blind CEvNS to constrain and disentangle ν flavor transitions owing to matter effects and collective effects

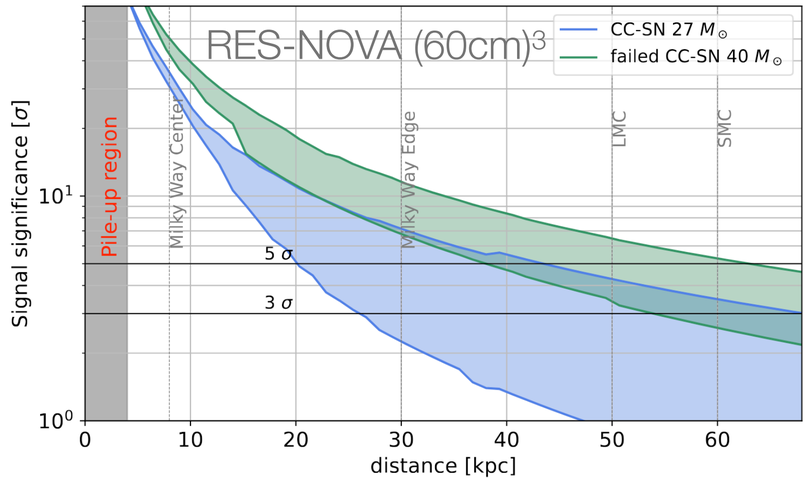
Xe TPCs for DM direct detection or 0νββ search: similar to solar CEvNS

RES-NOVA: cryogenic bolometers with ancient Pb, with threshold ~1keV$_{NR}$

- First prototype expected to operate at LNGS at the end of 2026



PRD 94, 103009 (2016)



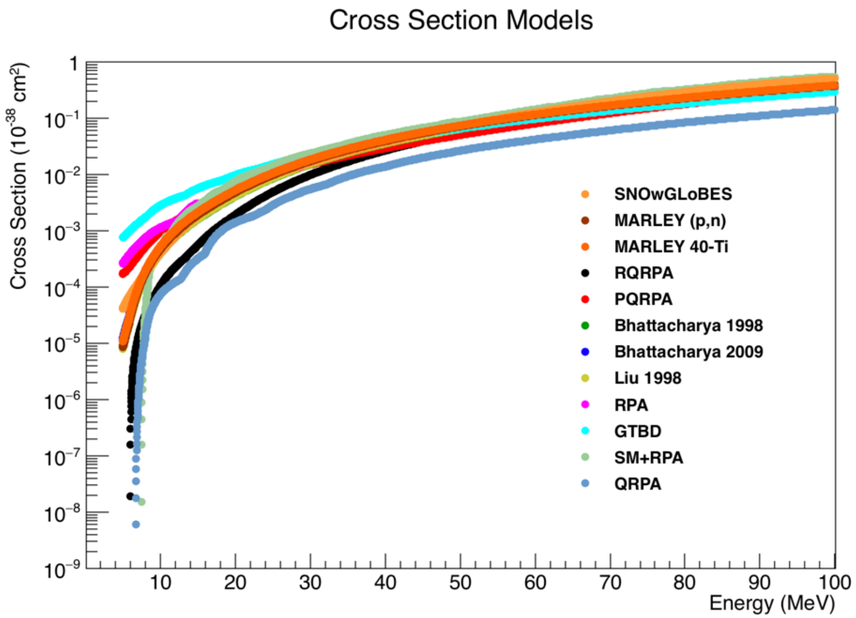
L. Pattavina et al JCAP10(2021)064

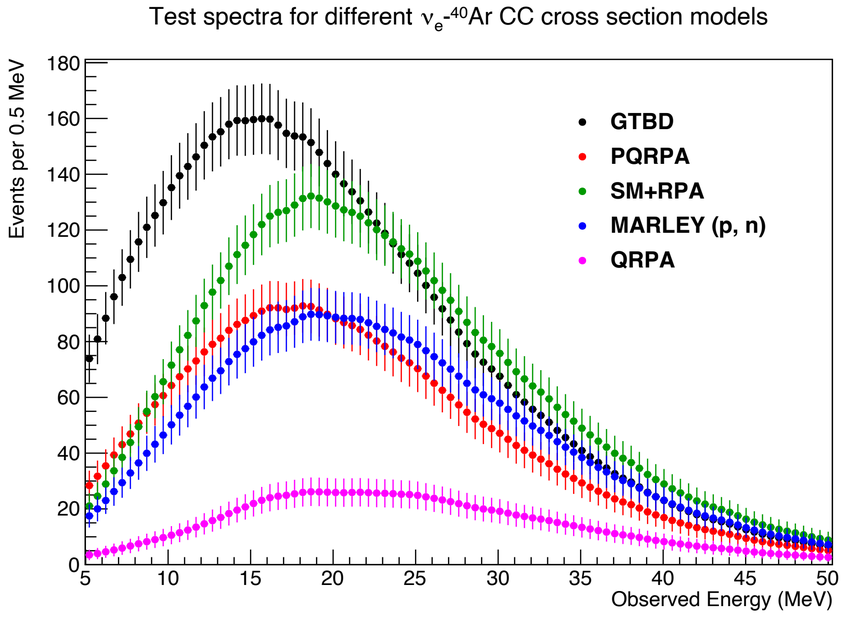
Impact from ν_e-Ar Charged-Current Cross Section

ν_e-Ar charged-current (CC) interaction cross section with E_ν<100 MeV has never been measured

- Theoretical models vary > O(10%)

Highly significant impacts on DUNE supernova ν measurements, particularly on ε, biased from -94% to 1400% in extreme scenarios (PRD 107, 112012 (2023))





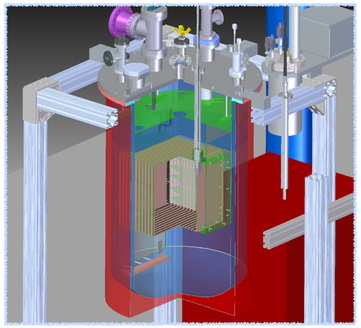
SNeND using Stopped-π Facility

SNeND: Supernova Neutrino constrained by Neutrino Data

Measure ν_e-Ar CC cross sections with well-understood ν flux and functional equivalent detector to DUNE far detector, LArTPCs

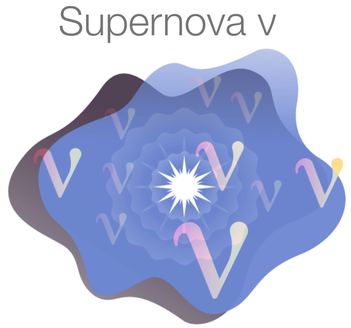
Example case: Propose to build a LArTPC at COHERENT, where SNS ν flux will be measured at (3-5)%



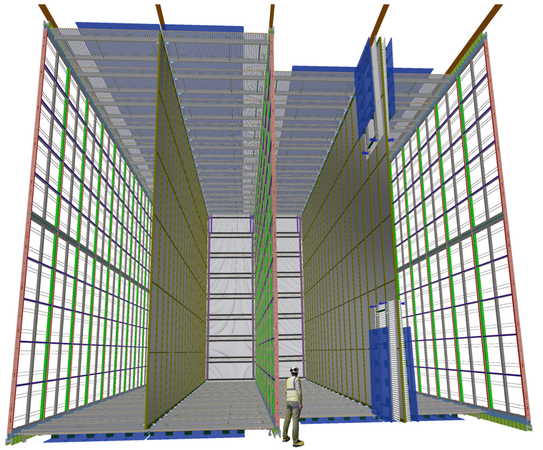


Artificial ν O(10m) SNeND detector

$$L = \frac{\#\text{Events in DUNE}}{\#\text{Events in SNeND}}$$

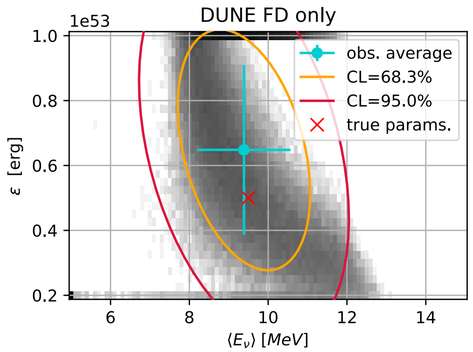


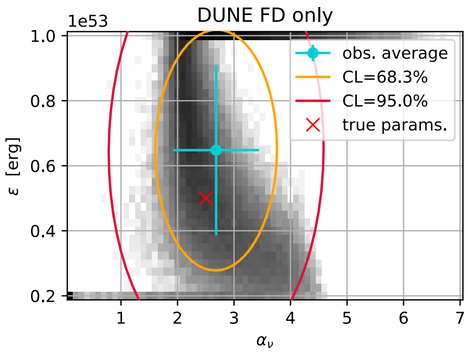
O(10kpc)

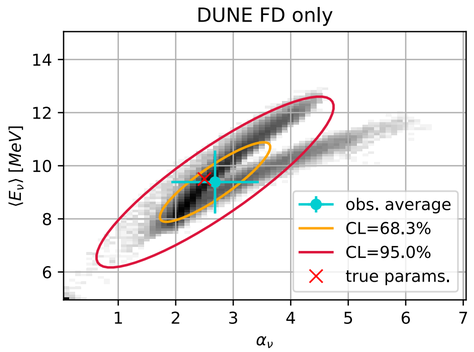


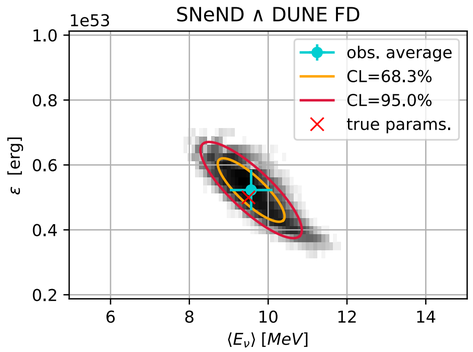
DUNE far detector

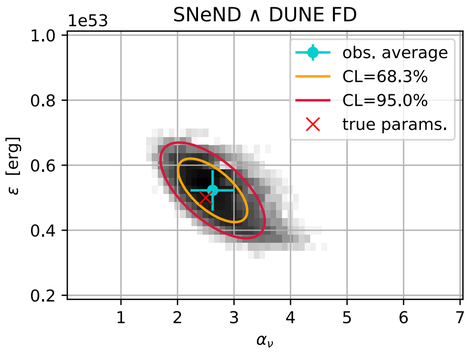
SNeND Constraints

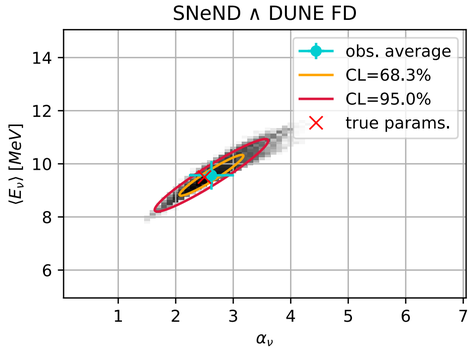


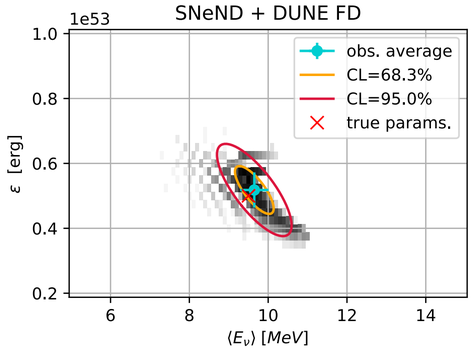


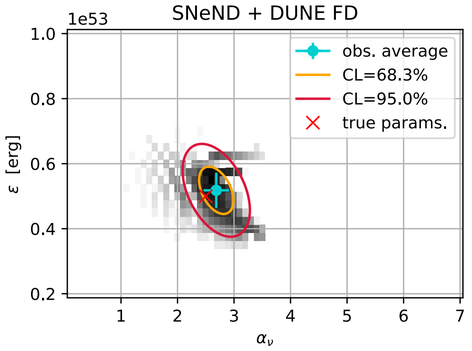


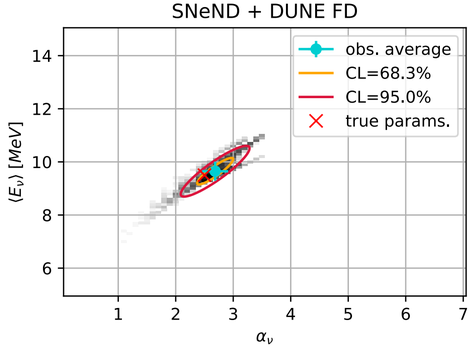












Measured ν_e-Ar CC cross section to 20%

ν_e-Ar CC cross section measured to the 20% precision in a LArTPC detector with the same resolution as DUNE FD; two slightly different statistic methods to constrain the DUNE measurements (preliminary results)

Summary

CEvNS - rapidly growing field since the first observation in 2017; currently statistically limited

SM precision testing and BSM probing with artificial neutrino sources: stopped π and reactor neutrinos

Astrophysical measurements with solar and supernova neutrinos

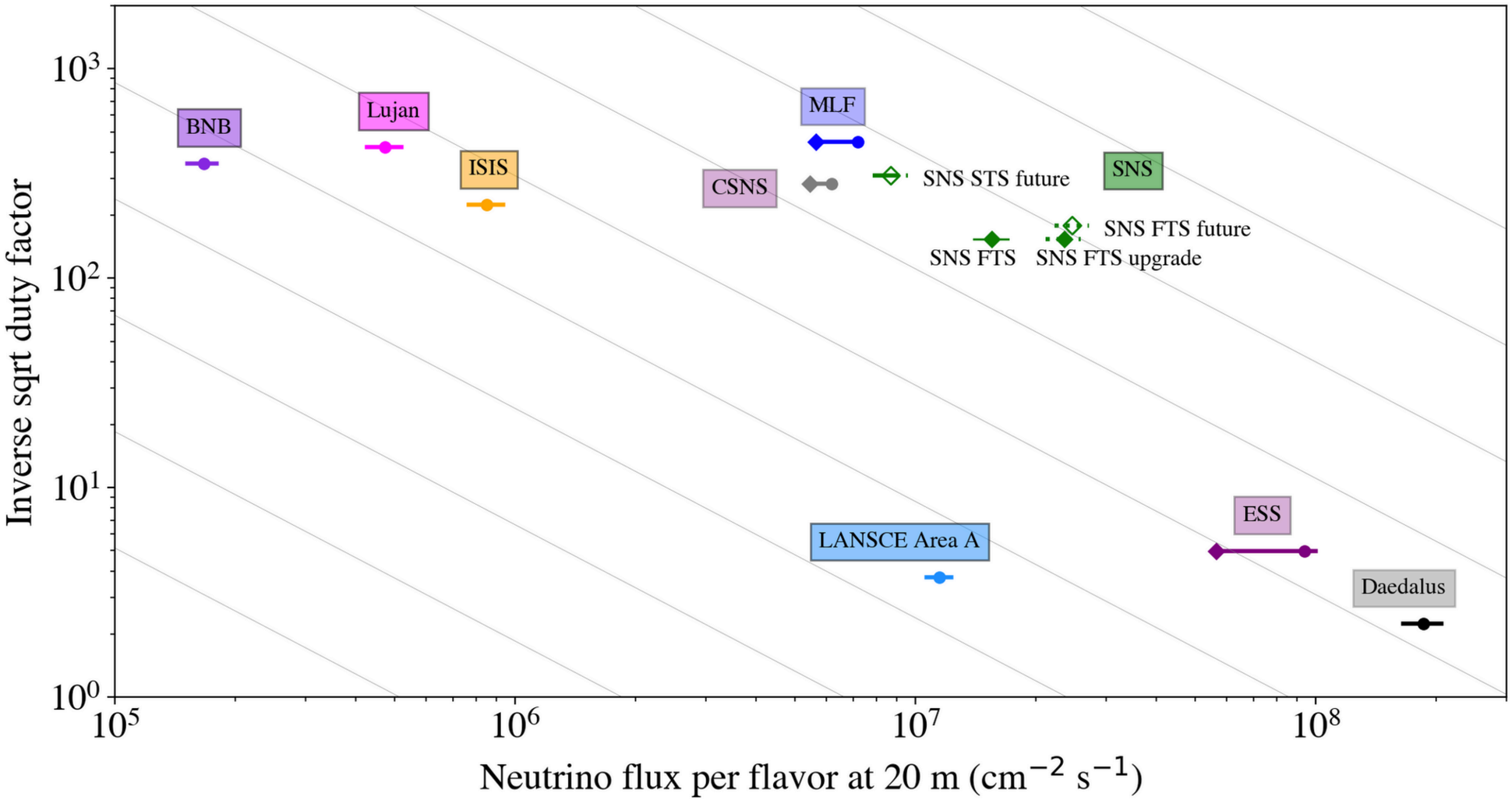
Expanding communities with facilities, experiments, detector R&D (common with direct DM search)

CEvNS facilities and experiments enable more MeV-scale neutrino cross section measurements for better constraining astrophysical studies

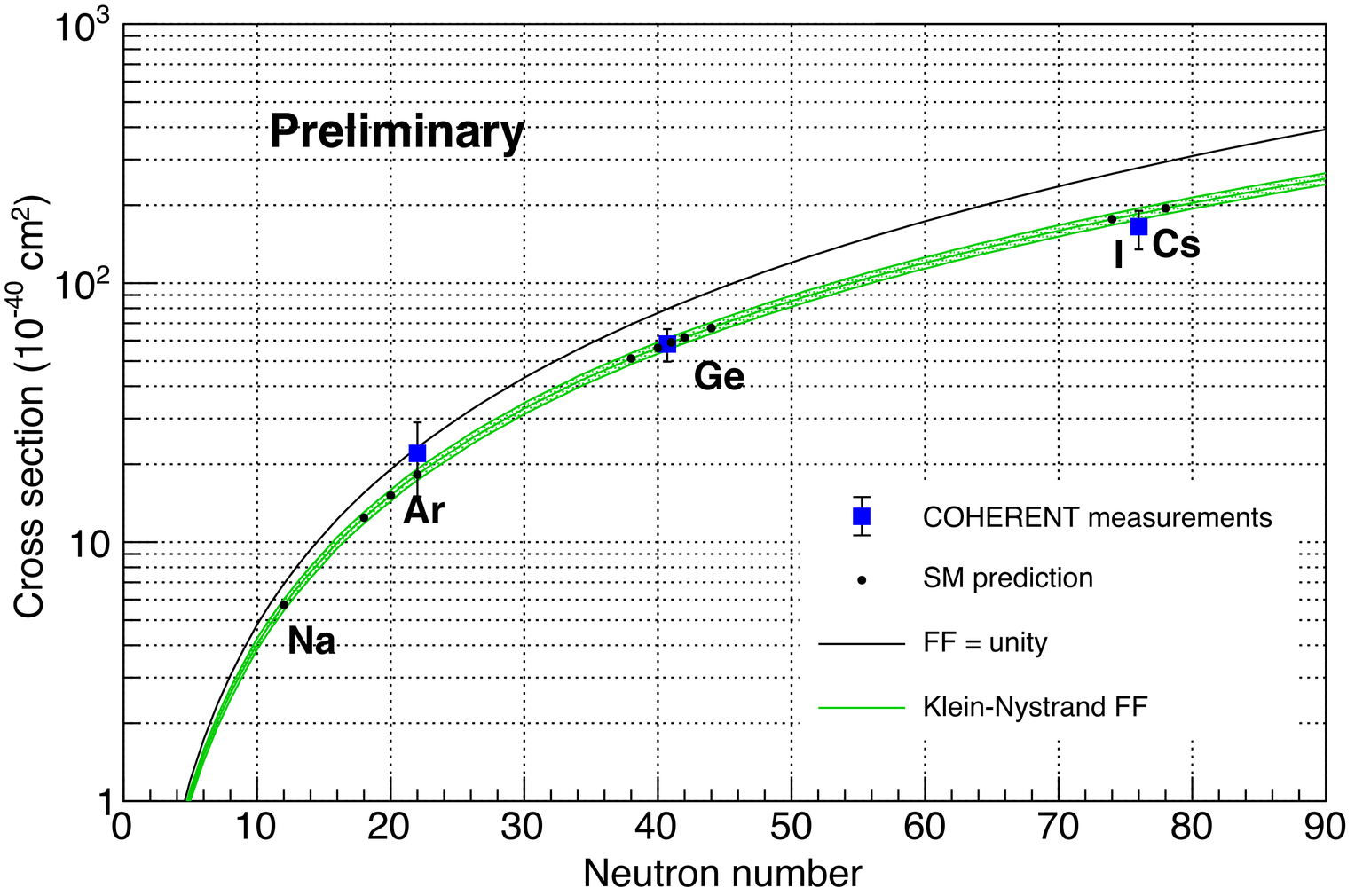


Backup

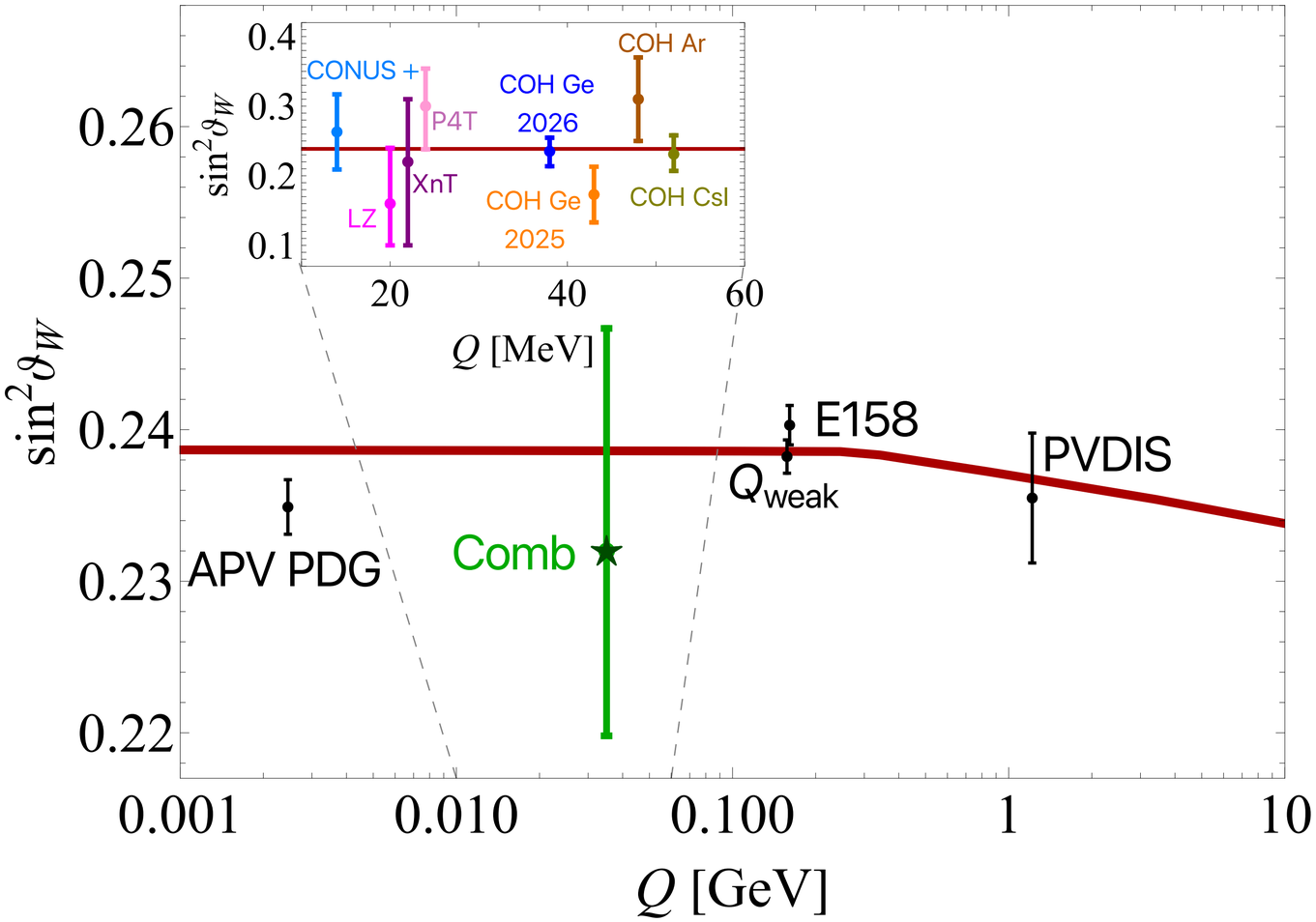
Comparison of Stopped Pion Sources



N^2-dependence at COHERENT



SM Case Study: Weak Mixing Angle



CEvNS around the World

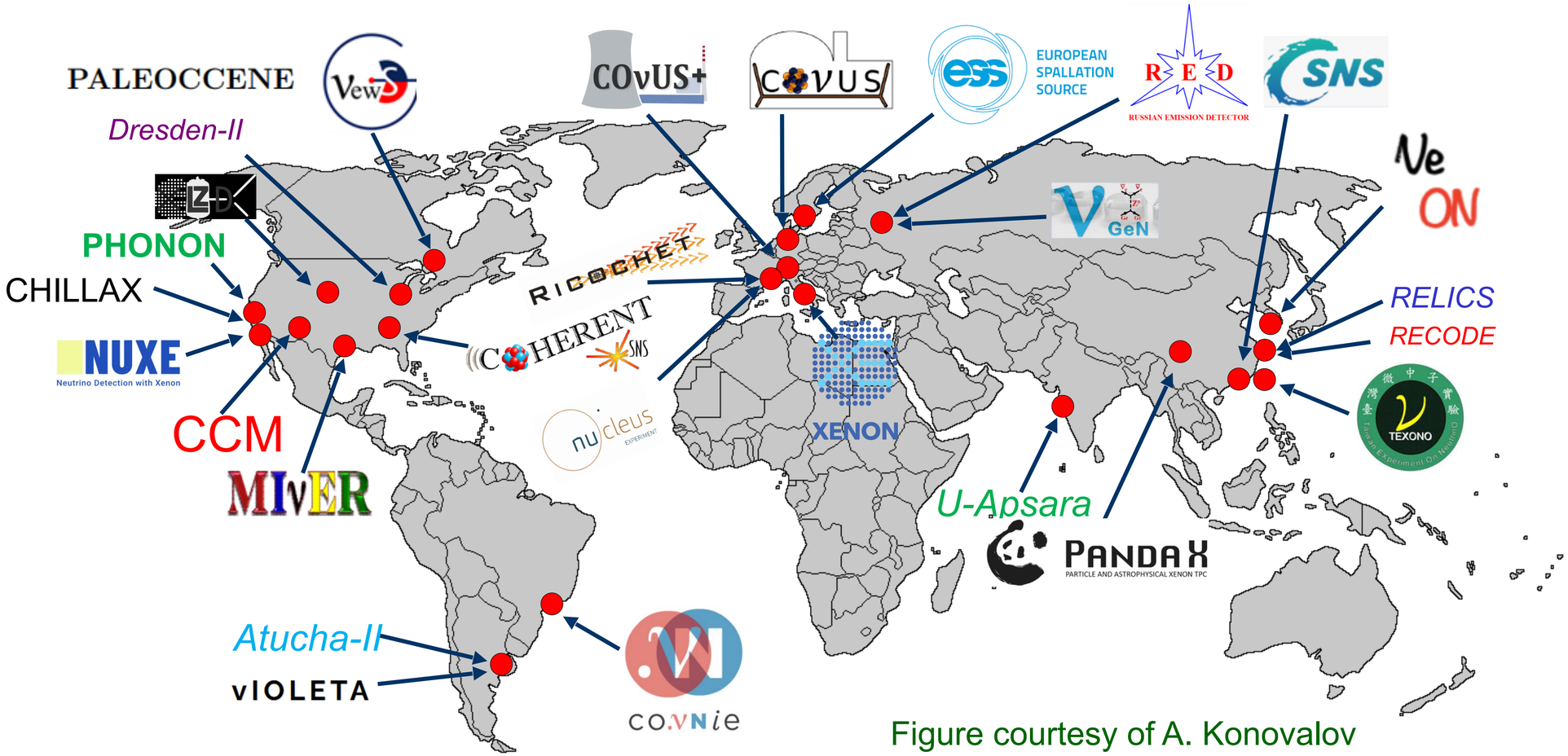
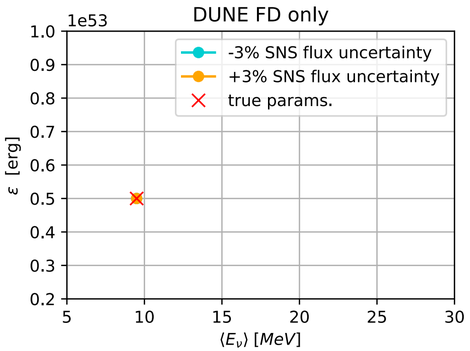
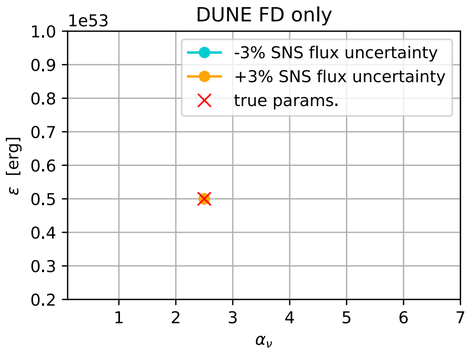
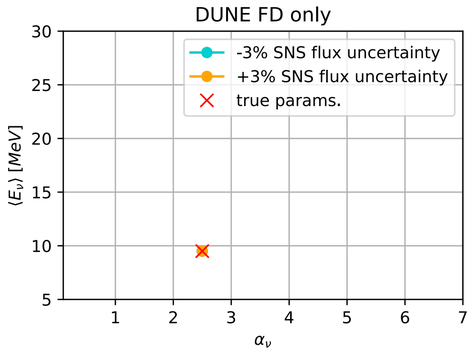


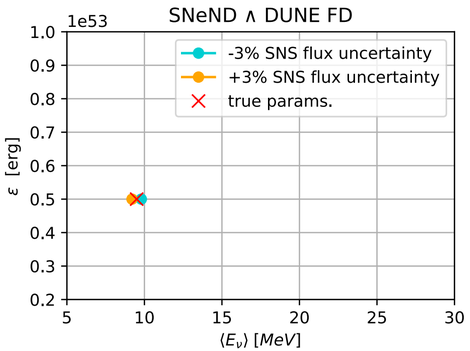
Figure courtesy of A. Konovalov

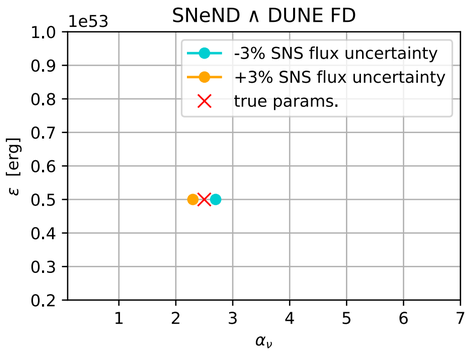
SNeND Constraints: SNeND Neutrino Flux

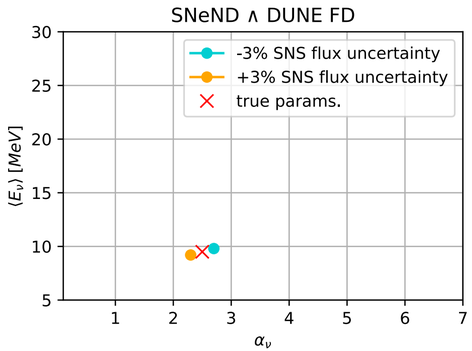


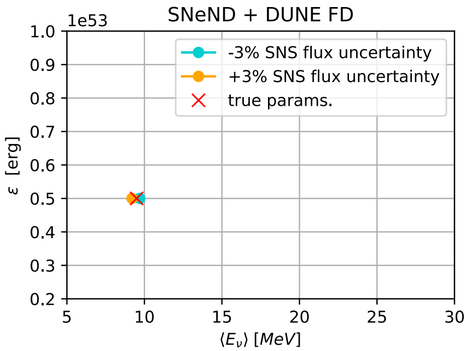


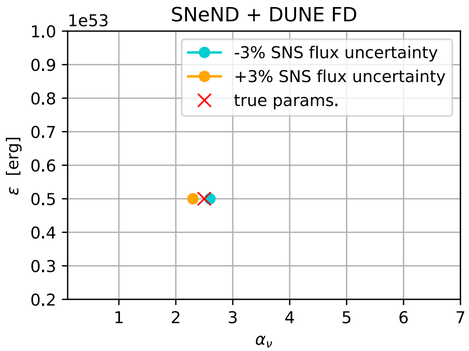


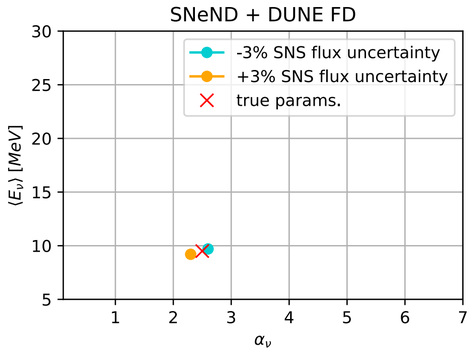












Measured ν_e flux scale to 3% in SNeND, no impact on the results using only DUNE FD data

ν_e flux scale measured to the 3% precision in a LArTPC detector with the same resolution as DUNE FD; two slightly different statistic methods but have no impact on ν_e flux scale