RADPyC2026

Coherent Elastic Neutrino-Nucleus Scattering in Germanium detectors

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Extending the Standard Model

While the Standard Model successfully describes most visible matter, the discovery of neutrino oscillations proves they have mass. Pointing directly to physics beyond this framework.

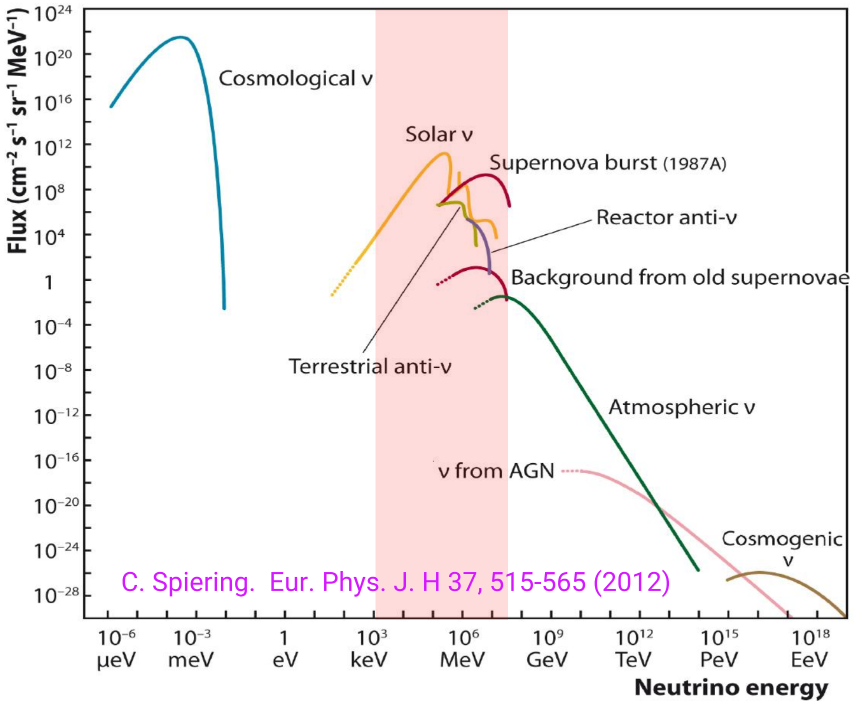
Dirac or Majorana?
Are neutrinos their own antiparticles?

Mass ordering?
What is the ordering of ther masses (Normal or Inverted)?

Sterile neutrinos?
Are there unseen, additional neutrino species?

Absolute mass scale?
What is their true mass?

Neutrino fluxes



C. Spiering. Eur. Phys. J. H 37, 515-565 (2012)

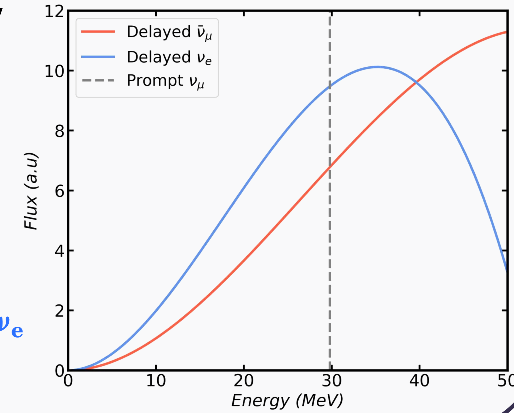
Spallation Neutron Source (SNS)

π-DAR Neutrinos (Pion Decay At Rest)

- Pulsed beam
- **~ 4.3x10⁷ cm⁻²s⁻¹ at 20 m**

$$\pi^+ \longrightarrow \mu^+ + \nu_\mu$$

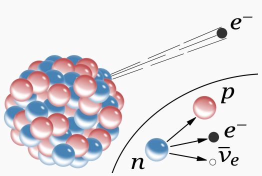
$$\mu^+ \longrightarrow e^+ + \bar{\nu}_\mu + \nu_e$$

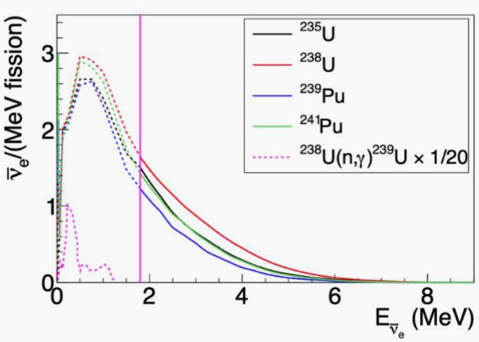


Antineutrinos from reactors

- High flux

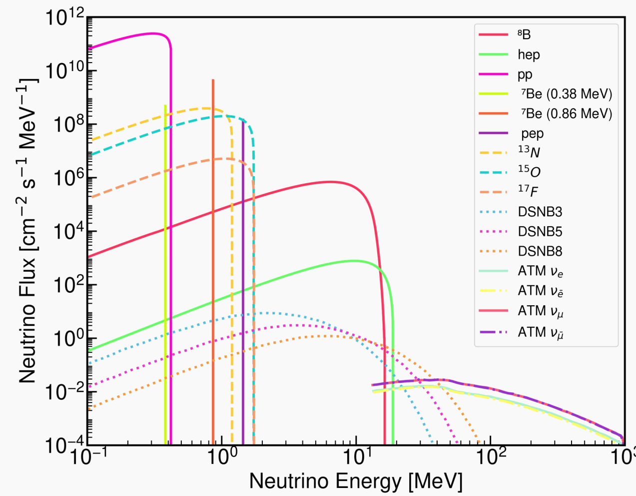
  10^{12} - 10^{13} cm^{-2}s^{-1} at 15 m
- Low energy, up to **8/10 MeV**





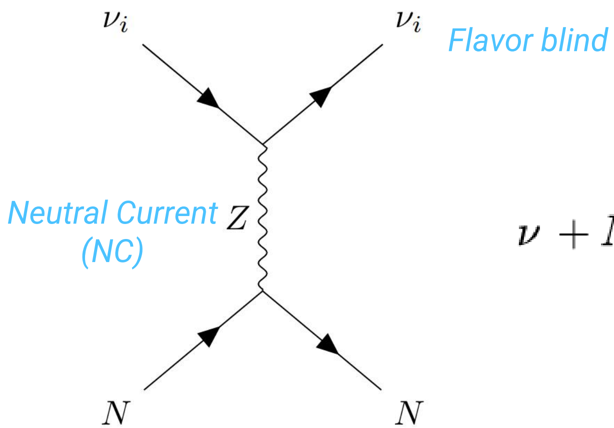
$$\mathbf{n} \rightarrow \mathbf{p} + \mathbf{e}^- + \bar{\nu}_e$$

Solar, atmospheric and DSNB neutrinos

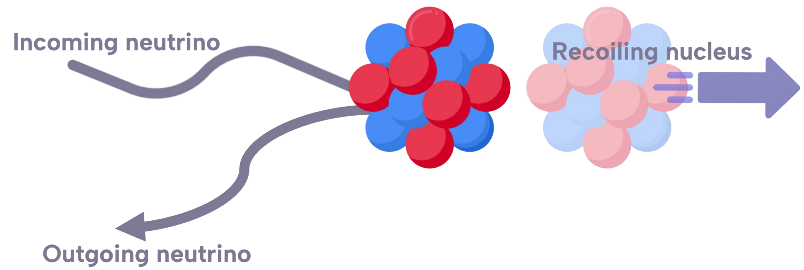


LDH, J. M Lamprea, O.G. Miranda arXiv:2512.19784

Coherent Elastic Neutrino-Nucleus Scattering (CEvNS)



$$\nu + N \longrightarrow \nu + N$$



Neutrino wavelength > Nucleus size

$$Q \ll 1/R$$

The neutrino 'sees' the entire nucleus, not individual nucleons.

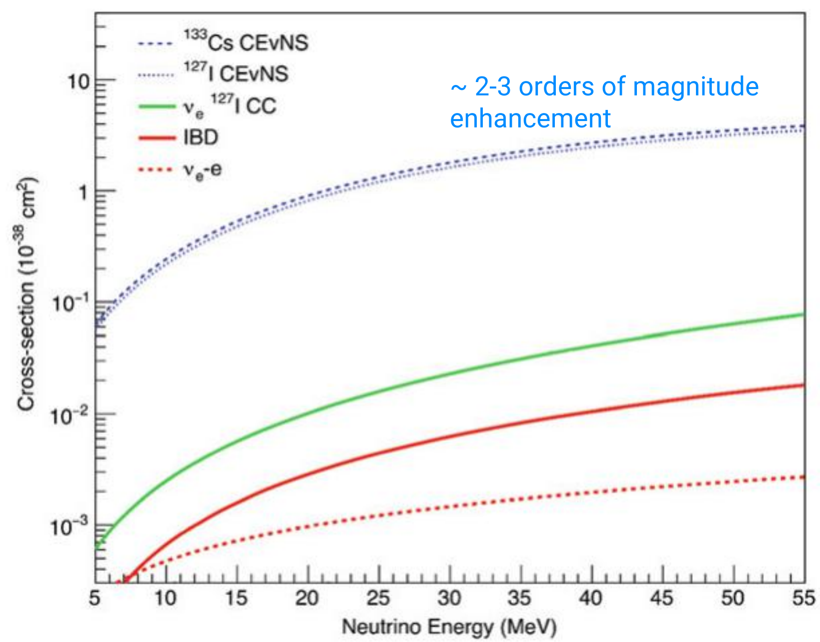
The cross-section for this process is given by:

$$\frac{d\sigma}{dT} = \frac{G_f^2}{2\pi} \underbrace{Q_W^2}\, \underbrace{F^2(Q^2)} \left(2 - \frac{MT}{E_\nu^2}\right)$$

$Q_W^2 = (Z\, g_p^V + N\, g_n^V)^2 \propto N^2$
(Coherent Enhancement)

Form Factor
(Loss of Coherence)

- Proposed in 1974 by Daniel Z. Freedman.
- Observed by the COHERENT collaboration.
  - In 2017 with CsI detector.
  - In 2020 with Liquid Argon detector.
  - In 2025 with Ge detector.
- Observed by CONUS+ in **2025**

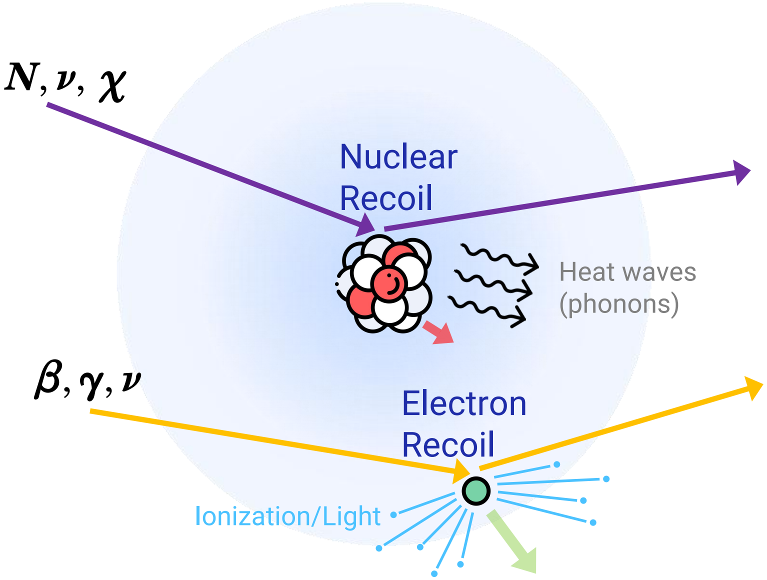


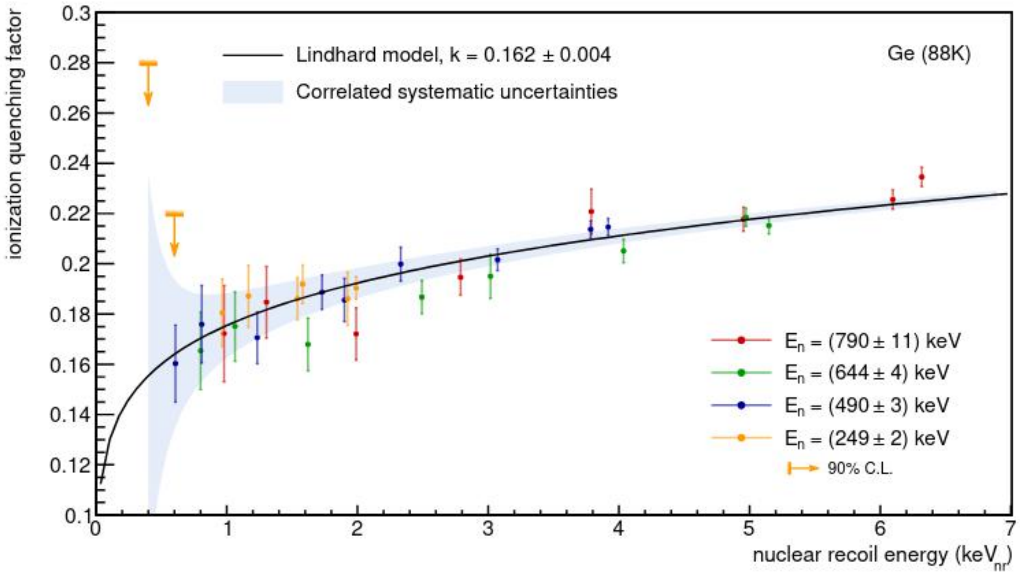
D. Akimov et al. Science 357,1123-1126 (2017)

From the interaction to the signal...

Nuclear recoil: Signal for CEvNS and Dark Matter

Heavy nucleus → Slow movement → Energy lost to heat





A. Bonhomme et al. Eur. Phys. J. C 82, 815 (2022)

Electron recoil: Typical background

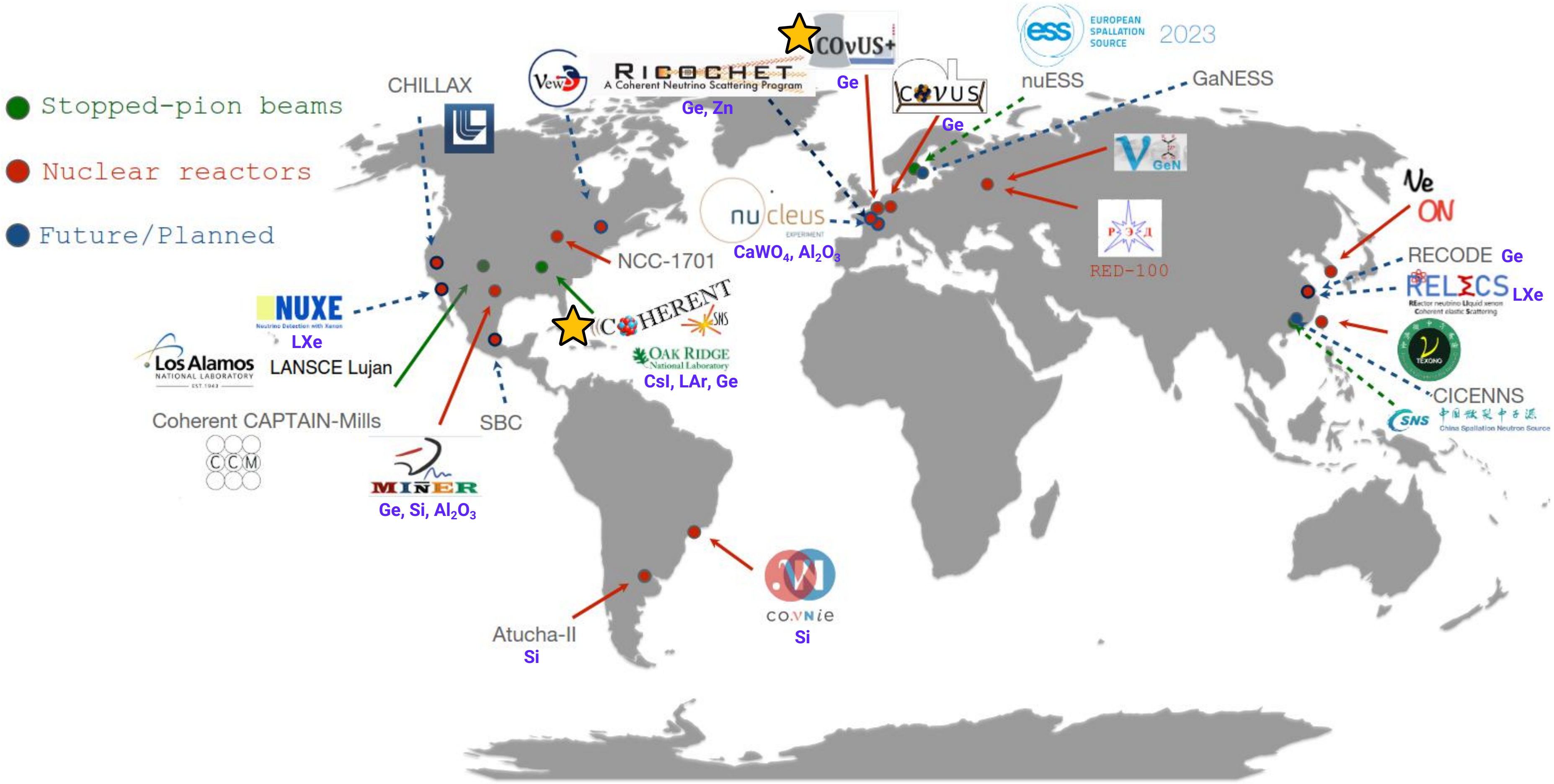
Light electron → Fast movement → High Ionization/Light yield

Quenching Factor (QF)

$$E_{\text{measured}}(\text{keV}_{ee}) = QF \times E_{\text{NRecoil}}(\text{keV}_{nr})$$

QF describes the signal suppression of Nuclear Recoils relative to Electron Recoils.

Status of CEvNS experiments



Multi-target → From light to heavy nuclei to test N^2

↓ Si ↓ CsI

Complementarity → Combining π-DAR and reactor sources

- High energy
- Pulsed

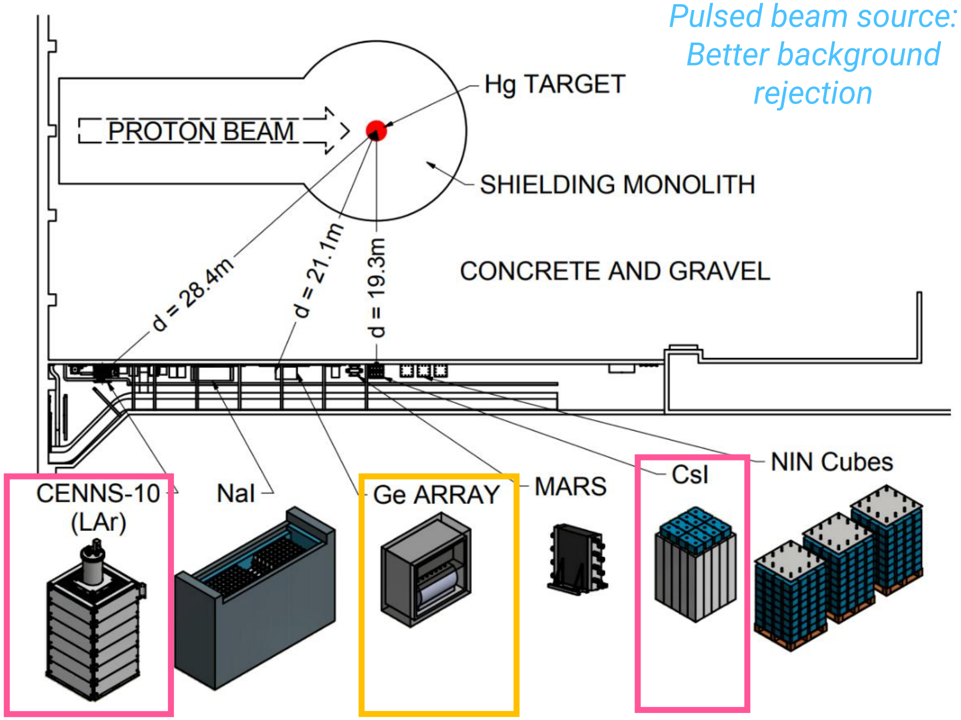
- Low energy
- Continuous

Observations at COHERENT

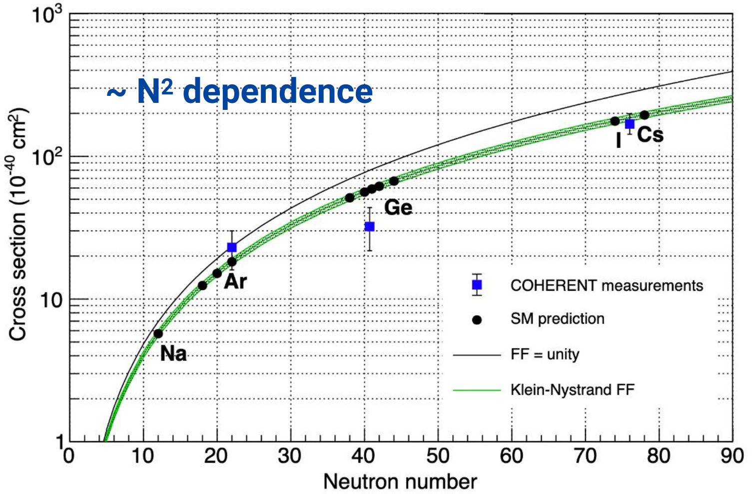
Spallation Neutron Source (SNS)

The SNS's pulsed beam structure allows for a timing-based analysis.

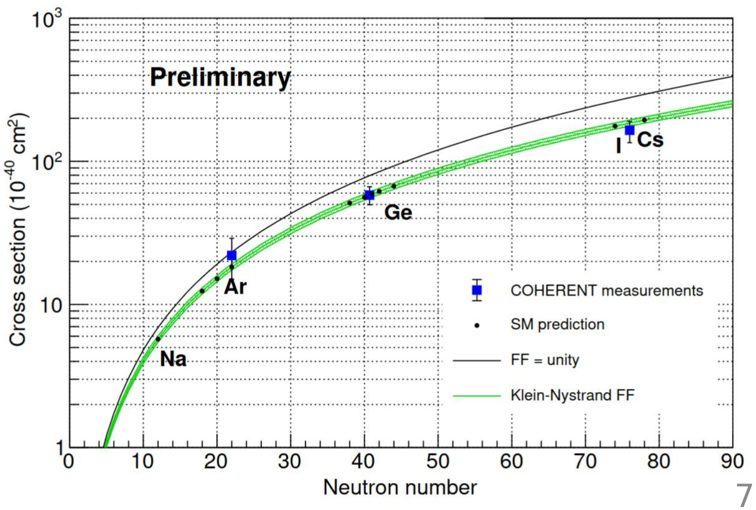
Pulsed beam source: Better background rejection



24 kg (2020) | **10 kg** (2025) | **14 kg** (2017)



R. Bouabid @Magnificent CEvNS 2024



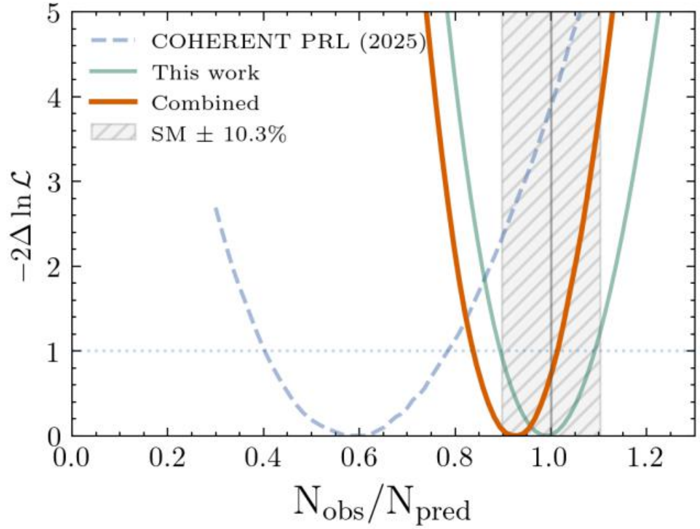
COHERENT collab. arXiv:2602.15652

From Evidence to Precision (COHERENT Ge-Mini)

In under a year, the COHERENT Ge-Mini campaign moved from the first statistical evidence of CEvNS on natural germanium to a high-precision measurement.

	First evidence Campaign (2025)	Precision Campaign (2026)
Exposure	1.96 x 10^{22} POT	4.68 x 10^{22} POT
Threshold	1.5 keV_{ee} (~ 6.7 keV_{nr})	0.5 keV_{ee} (~ 2.5 keV_{nr})
Observed CEvNS Signal	20.6 counts	123 counts
Expected CEvNS events	35.1 events	124 events

- Reaching the ~ 2.5 keV_{nr} threshold allow to reach a low-energy sensitivity.
- The increased exposure and lower analysis threshold led to a significant reduction of the statistical uncertainty from 30% to less than 10%.
- The extracted cross-section perfectly matches theoretical predictions, showing agreement with the Standard Model to within 1σ.



COHERENT collab. arXiv:2603.17951

CEvNS phenomenology

The expected recoil spectrum is calculated by convolving the neutrino flux with the cross-section and detector response.

$$\frac{dR}{dE_r} = N_T \times \int \frac{d\Phi}{dE_\nu} \times \frac{d\sigma}{dE_r} \times \epsilon(E_r)\, dE_\nu$$

Detector (N_T) — Flux (Source) ($\frac{d\Phi}{dE_\nu}$) — Theory (Interaction) ($\frac{d\sigma}{dE_r}$) — Experiment ($\epsilon(E_r)$)

A parameter space scan determines if the Experimental Data is consistent with the **Standard Model prediction** or if a **new physics hypothesis** is preferred.

Standard Model & Nuclear

- **Weak Mixing Angle ($sin^2\theta_W$)**
- Neutron Radius (R_n)

Neutrino EM properties

- Neutrino Charge Radius ($\langle r_\nu^2 \rangle$)
- Neutrino Magnetic Moment (μ_ν)
- Neutrino electric millicharge (q_ν)

Beyond the Standard Model

- **New neutrino interactions (NSI, NGI)**
- **Light Mediators (Z', Dark photons)**
- Sterile Neutrinos (ν_s)
- New particles
- Dark Matter (CEvNS as background)

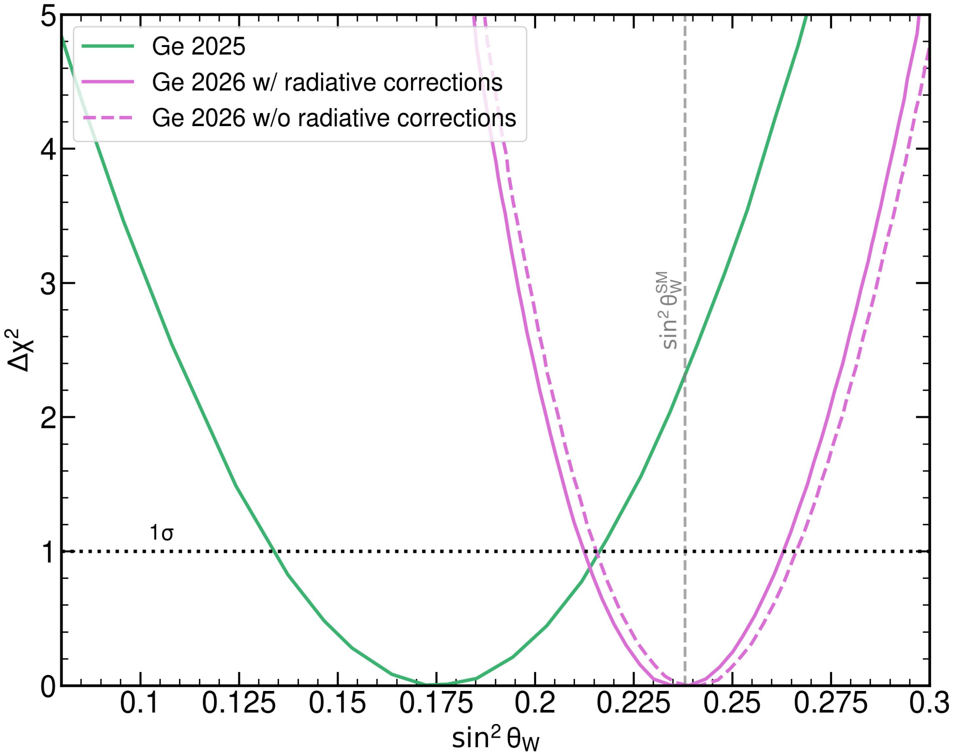
Weak Mixing Angle

The CEvNS cross-section scales with the square of the weak nuclear charge (Q_W). In the Standard Model, this is directly tied to the weak mixing angle:

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

$sin^2\theta_W \approx 0.238$
The proton contribution to Q_W is suppressed, making CEvNS primarily sensitive to the neutron distribution.

- CEvNS provides a purely weak-interaction measurement of $\sin^2\theta_W$ at very low momentum transfer ($q \approx 0$).
- This allows to test the theoretical "running" (energy dependence) of the weak mixing angle, complementing high-energy measurements from colliders (like LEP and the LHC).

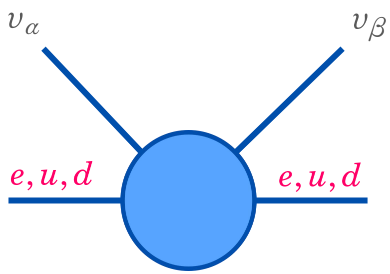


V. De Romeri, **LDH**, et al. arXiv:2605.27121 (accepted in JHEP)

Non-Standard Interactions (NSI)

NSIs provide a general framework to quantify new physics in the neutrino sector. For neutral currents, this can be described with the following effective four-fermion Lagrangian

$$\mathscr{L}^{\mathrm{NSI-NC}} = -2\sqrt{2}G_F \sum_{f,P,\alpha,\beta} \varepsilon^{fP}_{\beta\alpha} \left(\bar{\nu}_\alpha \gamma^\mu P_L \nu_\beta\right)\left(\bar{f}\gamma_\mu P f\right)$$



$\varepsilon^{fP}_{\alpha\alpha}$ → Non-universal parameter

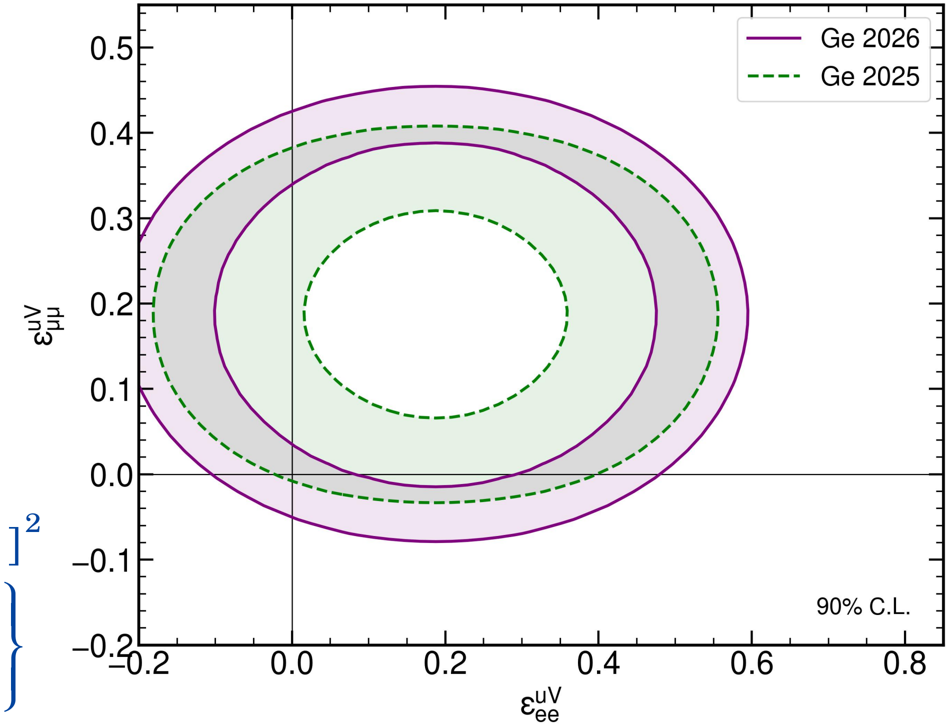
$\varepsilon^{fP}_{\beta\alpha}$ → Flavor-changing parameter

$$\varepsilon^{qV}_{\beta\alpha} = \varepsilon^{qL}_{\beta\alpha} + \varepsilon^{qR}_{\beta\alpha}$$

In the presence of NSI, the Standard Model CEvNS cross-section is modified by these parameters:

$$\frac{d\sigma}{dT} \simeq \frac{G_F^2 M}{\pi}\left(1 - \frac{MT}{2E_\nu^2}\right) F^2(q^2) \times$$

$$\left\{\left[Z\left(g_V^p + 2\varepsilon^{uV}_{\alpha\alpha} + \varepsilon^{dV}_{\alpha\alpha}\right) + N\left(g_V^n + \varepsilon^{uV}_{\alpha\alpha} + 2\varepsilon^{dV}_{\alpha\alpha}\right)\right]^2 + \sum_{\beta\neq\alpha}\left[Z\left(2\varepsilon^{uV}_{\beta\alpha} + \varepsilon^{dV}_{\beta\alpha}\right) + N\left(\varepsilon^{uV}_{\beta\alpha} + 2\varepsilon^{dV}_{\beta\alpha}\right)\right]^2\right\}$$

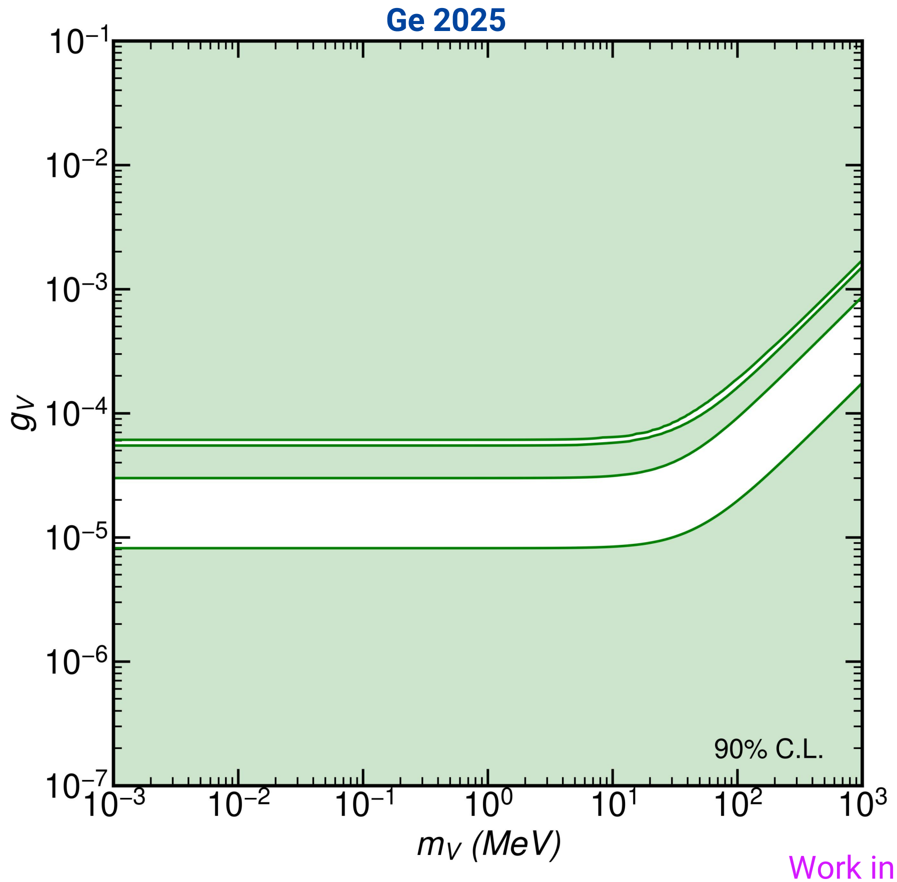


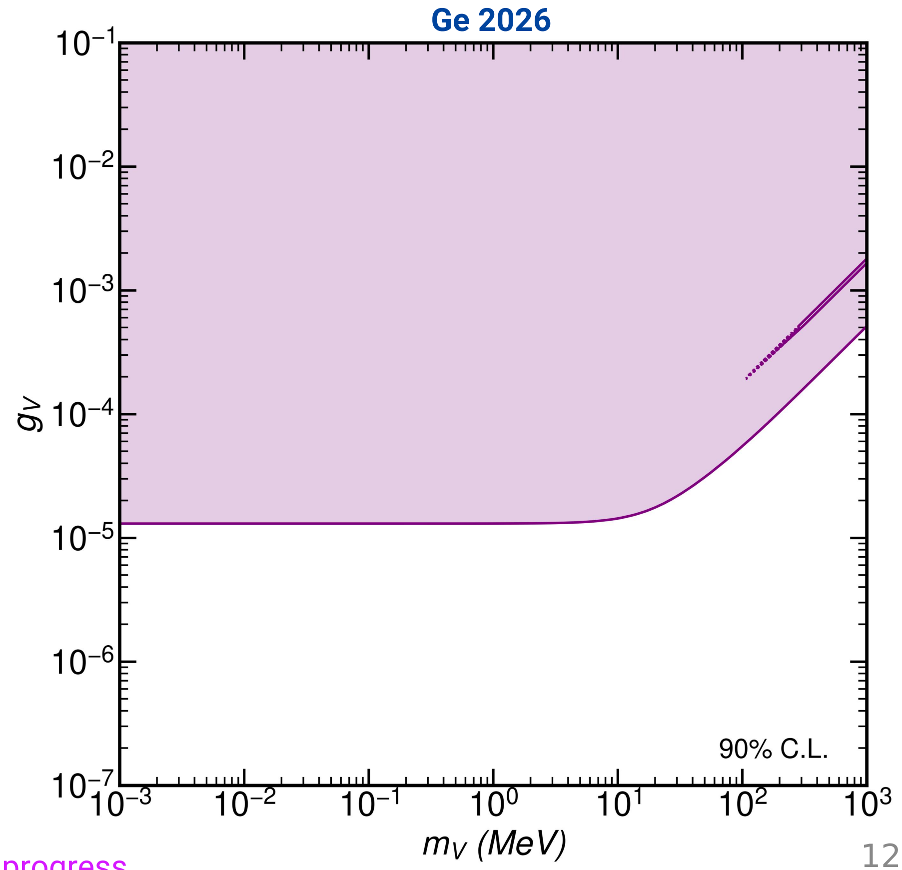
Light mediators

The cross section for a light vector type new mediator is

$$\left.\frac{d\sigma}{dT}\right|_{LM} = \left(1 + \kappa\,\frac{3\,(Z+N)\,g_V^2}{\sqrt{2}\,G_F\,Q_V^{SM}\,(2\,m_N T + m_V^2)}\right)^2 \left.\frac{d\sigma}{dT}\right|_{SM}$$

Universal couplings κ =1



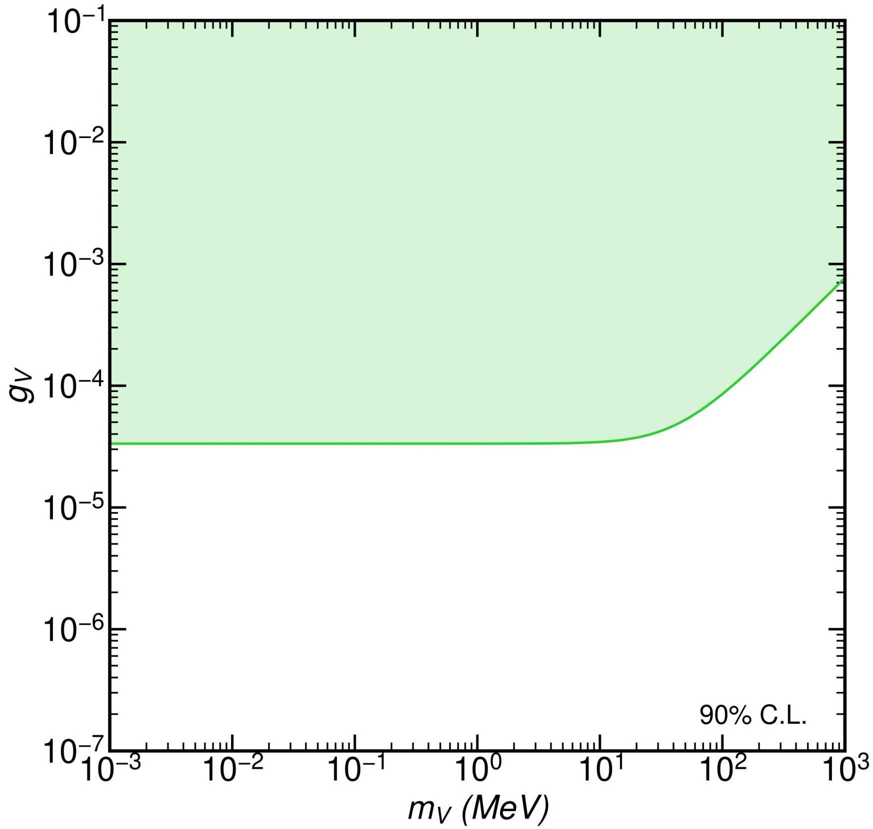


Work in progress

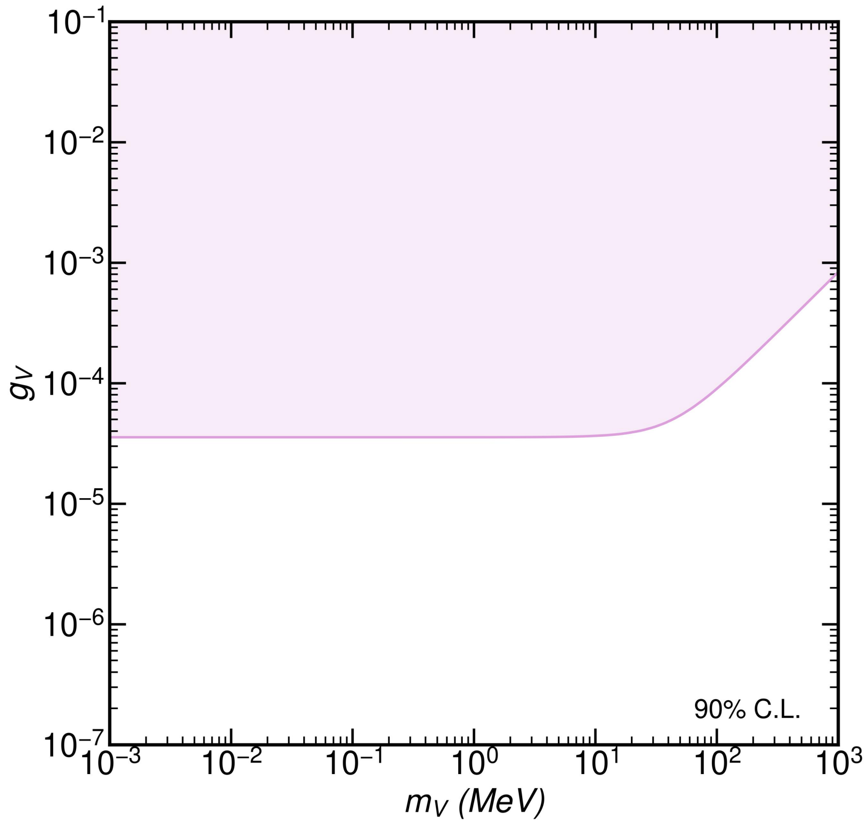
Light mediators

B-L model κ =-1/3

Ge 2025



Ge 2026



Work in progress

Lindhard parameter k

The Lindhard Ionization Yield Model: $E_{\text{measured}}(\text{keV}_{ee}) = QF \times E_{\text{NRecoil}}(\text{keV}_{nr})$

The quenching factor is given by

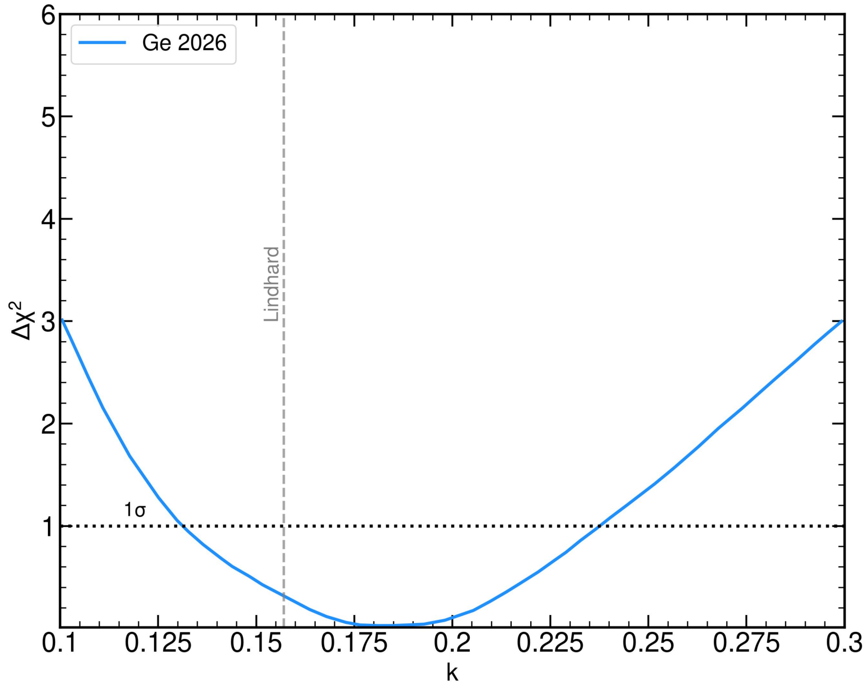
$$QF = \frac{k\, g(\epsilon)}{1 + k\, g(\epsilon)}$$

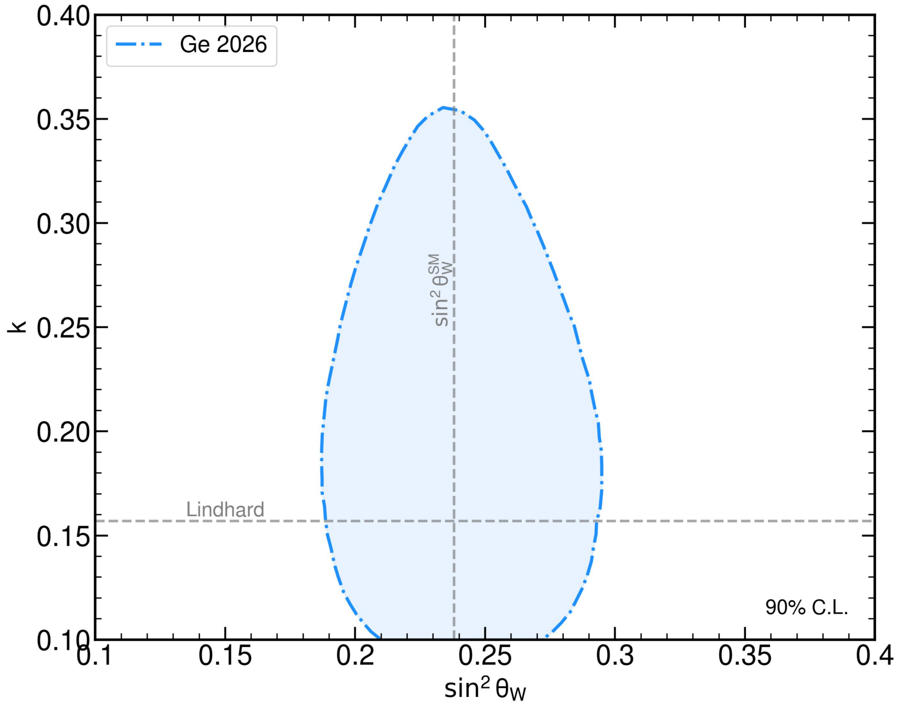
where

$$g(\epsilon) = 3\,\epsilon^{0.15} + 0.7\,\epsilon^{0.6} + \epsilon$$

Dimensionless reduced energy

$$\epsilon = 11.5\, Z^{-\frac{7}{3}} \left(\frac{E_R}{keV_{nr}} \right)$$





Combined COHERENT & CONUS+ Analysis: V. De Romeri, **LDH**, *et al.*,
arXiv:2605.27121 (accepted in JHEP).

Conclusions

1. The COHERENT Ge-Mini campaign successfully lowered its analysis threshold to 0.5 keVee and increased its total exposure. This resulted in the observation of 123 CEvNS counts and reduced the statistical uncertainty to less than 10%.

2. The 2025 statistical deficit yielded tighter and artificiall limits for universal light mediators, but both datasets provide comparable constraints for models like the B−L mediator.

3. This new data can be directly combined with reactor measurements from CONUS+ for a more powerful global analysis.

Thank you!

Back Up

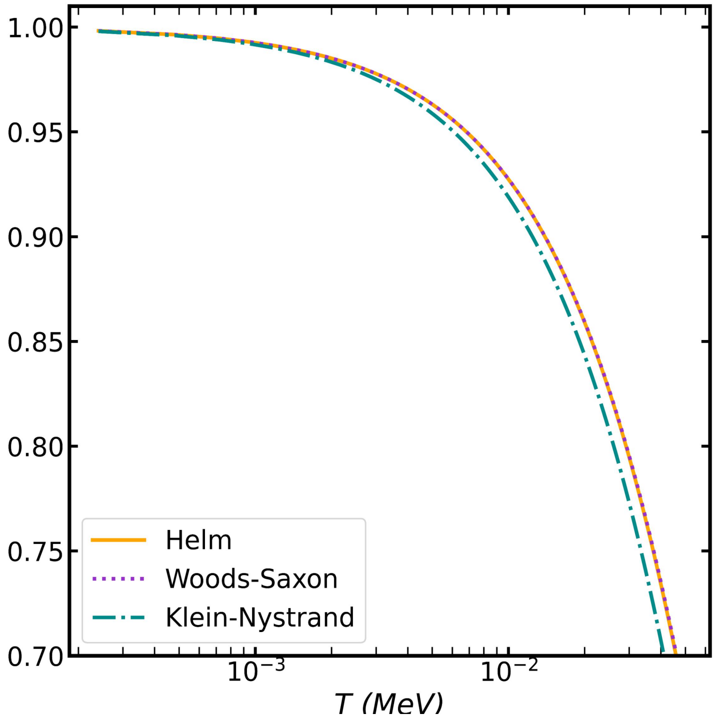
Nuclear Form Factor

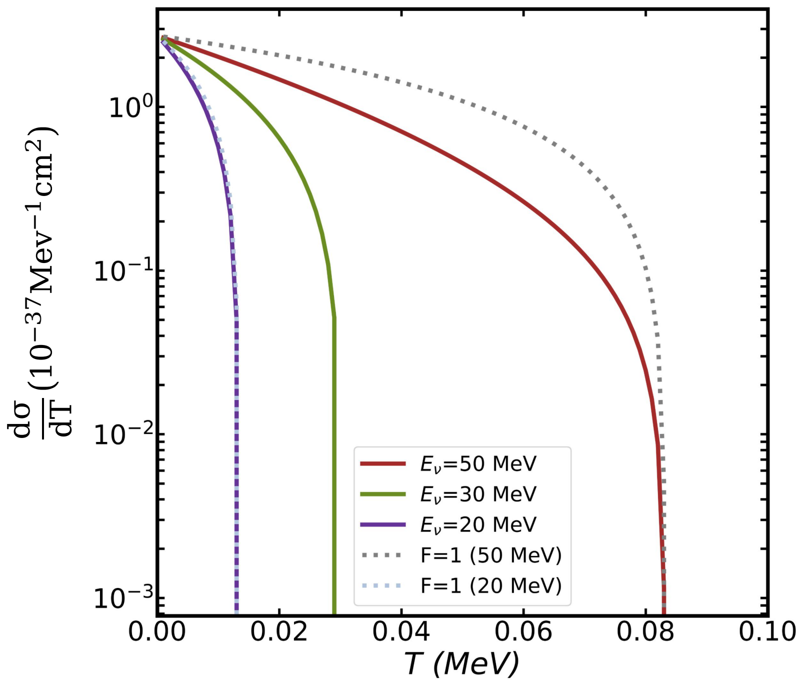
Form factor evaluated at
$Q^2 = 2MT$ → Momentum transfer

- Symmetrized Fermi
- Helm
- Klein-Nystrand

$$F_{KN} = 3\,\frac{j_1(qR_A)}{qR_A}\left[1 + (q\,a_k)^2\right]^{-1}$$

$$j_1 = \frac{sen(x)}{x^2} - \frac{cos(x)}{x}$$





Neutrino generalized interactions (NGI)

$$\mathcal{L}^{NGI} = \frac{G_F}{\sqrt{2}} \sum_X \overline{\nu} \Gamma^X \nu \overline{q} \Gamma_X (C_X^q + i\gamma_5 D_X^q) q$$

$$X = \quad S, \quad P, \quad V, \quad A, \quad T$$

Scalar | Pseudo-scalar | Vectorial | Axial | Tensorial

$$\Gamma^X = \left\{ \mathbb{I}, i\gamma^5, \gamma^\mu, \gamma^\mu \gamma^5, \sigma^{\mu\nu} \equiv \frac{i}{2}[\gamma^\mu, \gamma^\nu] \right\}$$

D. Aristizabal Sierra, Valentina De Romeri, and N. Rojas
Phys. Rev. D 98, 075018 (2018)

Radiative corrections

Considering electroweak radiative corrections (wich indice flavor and momentum dependence) the effective couplings become:

$$g_V^p(\nu_l) = \frac{\rho}{2}\left(1 - 4\sin^2\theta_W\right) + C_{rad}^p - 2\phi_{\nu_l W}$$

$$g_V^n = -\frac{\rho}{2} + C_{rad}^n$$

The C_{rad} terms contains the universal WW and ZZ bos corrections

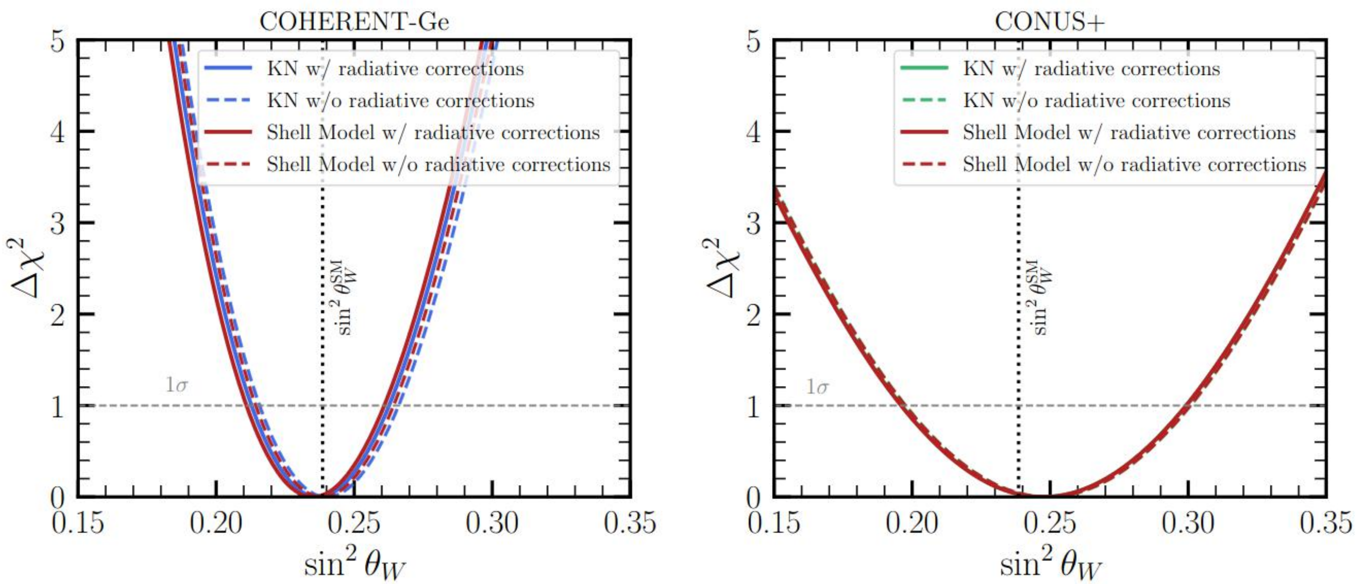
$$C_{rad}^p = 2\,\delta_{WW}^{\text{cross}} + \delta_{\,WW}^{\,\text{box}} + \rho\left(2\delta_{ZZ}^{uL} + \delta_{ZZ}^{dL} - 2\delta_{ZZ}^{uR} - \delta_{ZZ}^{dR}\right)$$

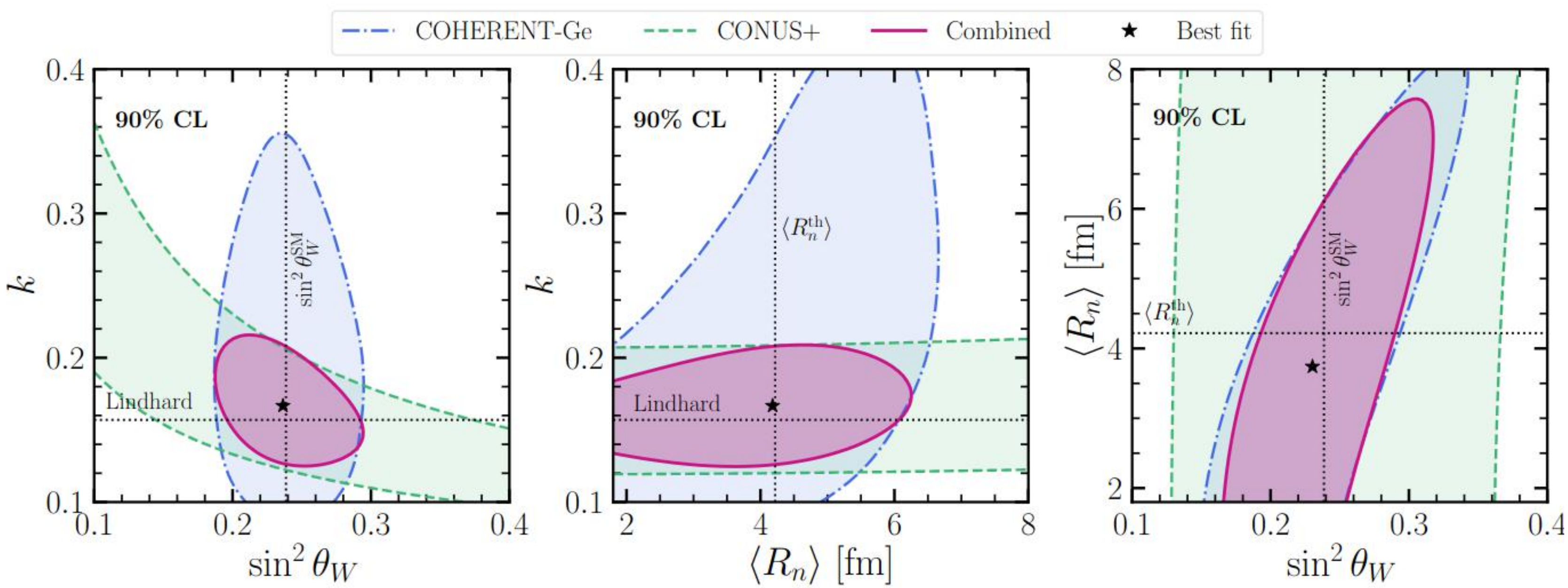
$$C_{rad}^n = 2\,\delta_{WW}^{\text{box}} + \delta_{\,WW}^{\,\text{cross}} + \rho\left(2\delta_{ZZ}^{dL} + \delta_{ZZ}^{uL} - 2\delta_{ZZ}^{dR} - \delta_{ZZ}^{uR}\right)$$

The individual box and crossed-box contributions are defined as

$$\delta_{WW}^{\text{box}} = -\frac{\hat{\alpha}_Z}{2\pi\hat{s}_Z^2}\left[1 - \frac{\hat{\alpha}_s(M_W)}{2\pi}\right] \qquad \delta_{WW}^{\text{cross}} = \frac{\hat{\alpha}_Z}{8\pi\hat{s}_Z^2}\left[1 + \frac{\hat{\alpha}_s(M_W)}{\pi}\right]$$

$$\delta_{ZZ}^{fX} = -\frac{3\hat{\alpha}_Z}{8\pi\hat{s}_Z^2\hat{c}_Z^2}\left(g_{LX}^{\nu_l f}\right)^2\left[1 - \frac{\hat{\alpha}_s(M_Z)}{\pi}\right]$$





V. De Romeri, **LDH**, et al. arXiv:2605.27121 (accepted in JHEP)