

Phenomenological implications of the high-precision COHERENT germanium CE ν NS data

M. Atzori Corona ^{1,*} M. Cadeddu ^{2,†} N. Cargioli ^{2,‡}
G. Co' ^{3,§} F. Dordei ^{2,¶} C. Giunti ^{4,**} and R. Pavarani ^{2,5,††}

¹*Istituto Nazionale di Fisica Nucleare (INFN), Sezione di Roma Tor Vergata,
Via della Ricerca Scientifica, I-00133 Rome, Italy*

²*Istituto Nazionale di Fisica Nucleare (INFN), Sezione di Cagliari,
Complesso Universitario di Monserrato - S.P. per Sestu Km 0.700, 09042 Monserrato (Cagliari), Italy*

³*Dipartimento di Matematica e Fisica “E. De Giorgi” Università del Salento.
Istituto Nazionale di Fisica Nucleare (INFN), Sezione di Lecce
via Arnesano, 73100 Lecce, Italy*

⁴*Istituto Nazionale di Fisica Nucleare (INFN),
Sezione di Torino, Via P. Giuria 1, I-10125 Torino, Italy*

⁵*Università degli Studi di Padova, Dipartimento di Fisica e Astronomia “Galileo Galilei”,
Via Francesco Marzolo 8, 35131 Padova, Italy*

(Dated: Monday 11/05/26, 01:31)

This work presents the first comprehensive phenomenological analysis of the newly released Coherent Elastic Neutrino-Nucleus Scattering (CE ν NS) data on germanium, measured by the COHERENT collaboration at the Spallation Neutron Source. Leveraging the unprecedented precision of this dataset, we provide state-of-the-art determinations of key Standard Model and nuclear physics parameters. Specifically, we extract updated constraints on the weak mixing angle, the neutrino charge radii, and we perform a detailed extraction of the neutron root-mean-square radius of germanium nuclei. Additionally, we use these results to evaluate scenarios beyond the Standard Model, placing robust bounds on neutrino non-standard interactions. To maximize the statistical power and robustness of our findings, whenever possible, we perform a global combined analysis incorporating previous COHERENT measurements along with reactor antineutrino data from the CONUS+, TEXONO, and ν GeN experiments as well as dark-matter experiments.

I. INTRODUCTION

The transition from a statistics-dominated to a systematics-dominated measurement marks an important threshold in any experimental program. It signals that the dataset has matured to the point where further progress requires not only more data, but deeper control over the underlying physics. The COHERENT collaboration has recently crossed this threshold in the coherent elastic neutrino-nucleus scattering (CE ν NS) program on germanium [1]. With roughly three times the neutrino exposure of their previous result [2], an active mass of (8.53 ± 0.08) kg, a lowered analysis threshold of 0.5 keV, made possible by improved pulse onset reconstruction, and a substantial suppression of back-

grounds through pulse shape discrimination, the new Ge-Mini measurement achieves a total uncertainty of approximately 10%, with the neutrino flux normalization now constituting the dominant source of systematic uncertainty. This is the most precise CE ν NS measurement to date.

From a phenomenological standpoint, this development calls for a thorough reanalysis. The first COHERENT germanium dataset [2], which has been studied in Refs. [3–5], was limited by statistics at the 30% level, and exhibited a mild deficit with respect to the Standard Model (SM) prediction whose interpretation remained ambiguous. The new measurement resolves this tension: the observed signal yield is fully consistent with the SM within 1σ , both in the new dataset alone and in the combination with the earlier result.

CE ν NS [6] is a low-energy weak neutral-current process whose cross section scales with the square of the nuclear weak charge, making it simultaneously sensitive to the electroweak sector of the SM, to the internal structure of nuclei, and to new physics modifying neutrino couplings [7–12]. At the Spallation Neutron Source (SNS), the well-determined timing structure of the neutrino flux further separates the

* mcorona@roma2.infn.it

† matteo.cadeddu@ca.infn.it

‡ nicola.cargioli@ca.infn.it

§ giampaolo.co@le.infn.it

¶ francesca.dordei@cern.ch

** carlo.giunti@to.infn.it

†† riccardo.pavarani@ca.infn.it

prompt ν_μ component from the delayed $\bar{\nu}_\mu$ and ν_e contributions, enabling independent constraints on flavor-dependent interactions. All of these handles become sharper as the statistical uncertainty shrinks, motivating a new round of precision extractions of the weak mixing angle $\sin^2 \vartheta_W$, the neutron root-mean-square (rms) radius of germanium, neutrino charge radii, and bounds on non-standard neutrino interactions (NSI).

The phenomenological reach of the new dataset is further amplified by the availability of complementary CE ν NS measurements on the same nuclear target from reactor antineutrino experiments, such as CONUS+ [13]. At reactor sites, the neutrino energies are limited to a few MeV, keeping the momentum transfer small enough that nuclear form factor effects are negligible, thereby providing a cleaner window onto fundamental SM parameters and neutrino properties. This complementarity between accelerator and reactor sources on a common germanium target, first exploited in a previous analysis [3], is now considerably more powerful given the improved precision of the SNS measurement. Moreover, we incorporate data from COHERENT CsI [14] and Ar [15, 16], TEXONO [17], and ν GeN [18] as well as dark-matter experiments [19–21] into global combined analyses wherever the combination adds discriminating power. These results demonstrate once again the power of CE ν NS as a fundamental probe of the SM, which is expected to further improve in the near future thanks to new detectors and facilities under development [22–26].

II. CE ν NS CROSS SECTION AND NUCLEAR INPUTS

The differential cross section for CE ν NS of a neutrino ν_ℓ ($\ell = e, \mu, \tau$) off a nucleus $\mathcal{N}$ with Z protons and N neutrons, as a function of the nuclear recoil energy T_{nr} , reads [27]

$$\frac{d\sigma_{\nu_\ell\mathcal{N}}}{dT_{\text{nr}}} = \frac{G_F^2 M}{\pi} \left(1 - \frac{MT_{\text{nr}}}{2E^2}\right) (Q_{\ell,\text{SM}}^V)^2, \quad (1)$$

where G_F is the Fermi constant, E the neutrino energy, and M the nuclear mass.¹ The weak nuclear

charge is

$$Q_{\ell,\text{SM}}^V = g_V^p(\nu_\ell) Z F_Z(|\vec{q}|^2) + g_V^n N F_N(|\vec{q}|^2), \quad (2)$$

where $g_V^p(\nu_\ell)$ and g_V^n are the weak neutral-current vector couplings of protons and neutrons, and F_Z , F_N are the corresponding nuclear form factors evaluated at momentum transfer $|\vec{q}| \simeq \sqrt{2MT_{\text{nr}}}$. Including radiative corrections in the $\overline{\text{MS}}$ scheme [31–33], the SM values of these couplings are [34]

$$g_V^p(\nu_e) = 0.0379, \quad g_V^p(\nu_\mu) = 0.0297, \quad (3)$$

$$g_V^p(\nu_\tau) = 0.0253, \quad g_V^n = -0.5117, \quad (4)$$

obtained fixing $\sin^2 \vartheta_W$ to its SM value at low momentum transfer, $\sin^2 \vartheta_W(Q \rightarrow 0) = 0.23873(5)$ [33]. The flavor dependence of $g_V^p(\nu_\ell)$ originates from the neutrino charge radii, which represent the only non-vanishing electromagnetic properties of neutrinos in the SM [35].

The nuclear form factors in Eq. (2) encode the spatial distribution of protons and neutrons inside the nucleus via the Fourier transform of the corresponding nucleon density $\rho_{Z(N)}$. Their departure from unity grows with increasing momentum transfer and produces a progressive suppression of full coherence [36], that is central to the interpretation of COHERENT data. To describe the form factors, the Helm parameterisation [37] could be adopted for both F_Z and F_N , which has been shown to be practically equivalent to the symmetrised Fermi [38] and Klein-Nystrand [39] parameterisations. The Helm form factor depends on the proton and neutron rms radii of the nucleus, and we fix the surface thickness to $s = 0.9$ fm [40]. Proton rms radii are derived from charge radii obtained via muonic atom spectroscopy and electron scattering [41–44], whose average value for the isotopic composition of germanium is equal to $R_p(\text{Ge}) = 4.078(1)$ fm. For the neutron rms radii, which lack precise direct measurements for the germanium isotopes, one could use the values obtained from the recent nuclear shell model (NSM) estimate of the corresponding neutron skins ΔR_{np} (i.e. the differences between the neutron and the proton rms radii) in Ref. [45]. Here, however, as our baseline, we adopt the predictions from Hartree-Fock plus Bardeen-Cooper-Schrieffer (HF+BCS) calculations [46] using the D1S Gogny effective interaction [47]. To quantify the sensitivity to nuclear modelling, we assess the spread between this baseline and two alternative predictions: the aforementioned NSM estimate, which tends to yield larger neutron radii, and the HF+BCS calculation with the D1M Gogny interaction [48], which

¹ We use natural units $\hbar = c = 1$ throughout. For the isotopic composition of germanium we use the values from Ref. [28]. Here, we neglect the very small axial-vector contribution to the interaction [29, 30].

gives the smallest values. The proton and neutron rms radii for all models and germanium isotopes are summarised in Tab. I of Ref. [3].

III. ANALYSIS OF CE ν NS DATA

Existing datasets

For the reactor-based experiments, we analyse CONUS+ [13] and TEXONO [17] data following Ref. [34], and ν GeN data [18] following Ref. [3]. We refer to their combination hereafter as **Reactors**. The COHERENT CsI [14] and Ar [15, 16] datasets are analysed according to Refs. [31, 49], and the first 2025 COHERENT germanium dataset [2] according to Ref. [3].

COHERENT germanium 2026

The neutrino flux at the SNS consists of a prompt ν_μ component and a delayed ν_e and $\bar{\nu}_\mu$ component with well-determined energy spectra [1]. The flux is characterised by $N_{\text{POT}} = 4.68 \times 10^{22}$ protons on target, a yield of (0.37 ± 0.04) neutrinos per proton, and a source-to-detector baseline of $L = 19.2$ m [1].

In each nuclear-recoil energy-bin i , the expected CE ν NS event number $N_i^{\text{CE}\nu\text{NS}}$ on a germanium target is given by

$$N_i^{\text{CE}\nu\text{NS}} = N_T \int_{T_{\text{nr}}^i}^{T_{\text{nr}}^{i+1}} dT_{\text{nr}} \int_0^{T_{\text{nr}}^{\prime\text{max}}} dT_{\text{nr}}' R(T_{\text{nr}}, T_{\text{nr}}') \times \int_{E_{\text{min}}(T_{\text{nr}}')}^{E_{\text{max}}} dE \sum_{\nu_\ell = \nu_e, \nu_\mu, \bar{\nu}_\mu} \frac{dN_{\nu_\ell}}{dE} \frac{d\sigma_{\nu_\ell - \mathcal{N}}}{dT_{\text{nr}}'}, \quad (5)$$

with the sum running over $\nu_\ell \in \{\nu_e, \nu_\mu, \bar{\nu}_\mu\}$. Here dN_{ν_ℓ}/dE is the neutrino flux [50], $R(T_{\text{nr}}, T_{\text{nr}}')$ is the energy resolution function [2], $T_{\text{nr}}^{\prime\text{max}} \simeq 2E_{\text{max}}^2/M$, $E_{\text{max}} = m_\mu/2 \simeq 52.8$ MeV, $E_{\text{min}}(T_{\text{nr}}') \simeq \sqrt{MT_{\text{nr}}'/2}$, and N_T is the total number of target atoms in the detector volume.

The relation between the observed ionization energy T_e and the true nuclear recoil energy T_{nr} is given by $T_e = f_Q(T_{\text{nr}}) T_{\text{nr}}$, where f_Q is the quenching factor, whose energy dependence has important consequences for the extraction of SM and beyond-SM parameters [4, 51, 52]. In this work we adopt the Lindhard model with $k = 0.157$ [53]. The timing structure of the data is incorporated by extracting the arrival-time distributions of the individual neutrino components from Ref. [54] and distributing the

predicted CE ν NS events into time bins of $2 \mu\text{s}$, yielding $N_j^{\text{CE}\nu\text{NS}}$ where j labels the time bins.

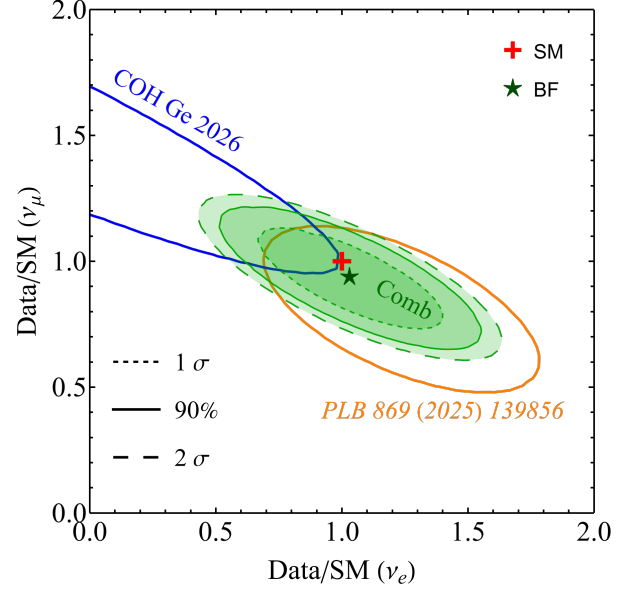


FIG. 1. Agreement between CE ν NS data and SM predictions for COHERENT germanium 2026 data (blue contour), the combination [3] of CsI+Ar, **Reactors**, and COHERENT germanium 2025 data (orange contour) and the full combination (green regions), displayed separately for electron and muon neutrinos. Contours are at 1σ (dotted), 90% (solid) and 2σ (dashed) CL. The dark green star marks the best fit, and the red cross indicates the SM expectation.

The statistical analysis is performed via a simultaneous least-squares fit to the beam-on (ON) and beam-off (OFF) data in both energy (E) and time (T), treating the four one-dimensional distributions independently:

$$\chi^2 = \chi_{\text{E,ON}}^2(\eta, \beta) + \chi_{\text{E,OFF}}^2(\beta) + \chi_{\text{T,ON}}^2(\eta, \beta) + \chi_{\text{T,OFF}}^2(\beta) + \left(\frac{\eta - 1}{\sigma_\eta}\right)^2, \quad (6)$$

where each term is a Gaussian least-squares function. For example,

$$\chi_{\text{E,ON}}^2 = \sum_i \frac{(N_i^{\text{exp}} - \eta N_i^{\text{CE}\nu\text{NS}} - \beta N_i^{\text{SSB}})^2}{\sigma_i^2}, \quad (7)$$

with N_i^{exp} the observed counts and σ_i the corresponding uncertainty as read from Ref. [1], and N_i^{SSB} the steady-state background prediction in bin i . The nuisance parameter η rescales the signal and is shared across all four datasets, while β

accounts for the background normalization. The signal systematic uncertainty is $\sigma_\eta = 10.3\%$, dominated by the neutrino flux normalization (10%), with subdominant contributions from the detector baseline (0.5%), energy calibration (0.8%), active mass (2.0%), form factors (0.8%) and quenching factor (0.7%) [1].

Our fit to the total CE ν NS normalization yields 126 ± 11 events, in good agreement with the COHERENT result of 124^{+14}_{-12} [1] and with our theoretical prediction of 129 events under the D1S model.

To probe potential flavor-dependent effects and exploit the discriminating power of the timing information, we split the signal normalization $\eta = \text{Data}/\text{SM}$ into independent electron- and muon-neutrino components following the strategy introduced in Ref. [34]. This decomposition also enables a direct comparison with **Reactor** data, which are sensitive exclusively to the ν_e flavor. Putting together COHERENT Ge 2026 with COHERENT CsI, Ar and **Reactors**, the results of this combined analysis are shown in Fig. 1 and yield

$$\begin{aligned} \eta(\nu_e) &= 1.03^{+0.25}_{-0.24} (1\sigma), \quad ^{+0.40}_{-0.40} (90\%), \quad ^{+0.48}_{-0.48} (2\sigma), \\ \eta(\nu_\mu) &= 0.94^{+0.12}_{-0.14} (1\sigma), \quad ^{+0.21}_{-0.22} (90\%), \quad ^{+0.26}_{-0.27} (2\sigma). \end{aligned} \quad (8)$$

Both values are consistent with the SM prediction within 1σ , resolving the mild tension observed in the earlier COHERENT germanium data [2, 3]. A general agreement among all CE ν NS datasets and probes is observed across the full combination. A closer inspection of the COHERENT Ge 2026 contour alone reveals that, despite the good agreement of the total event yield discussed above, the data are only marginally consistent with the SM prediction when the two flavor components are treated independently, lying approximately at the boundary of the 90% CL region. This feature originates from a mild excess of events in the prompt timing window, which is populated predominantly by ν_μ neutrinos, driving a preference for an enhanced muon-neutrino cross section. This effect is absorbed into the combined analysis and is consistent with a statistical fluctuation, but it is worth noting that it will persist in all analyses that allow for flavor-dependent signal normalizations.

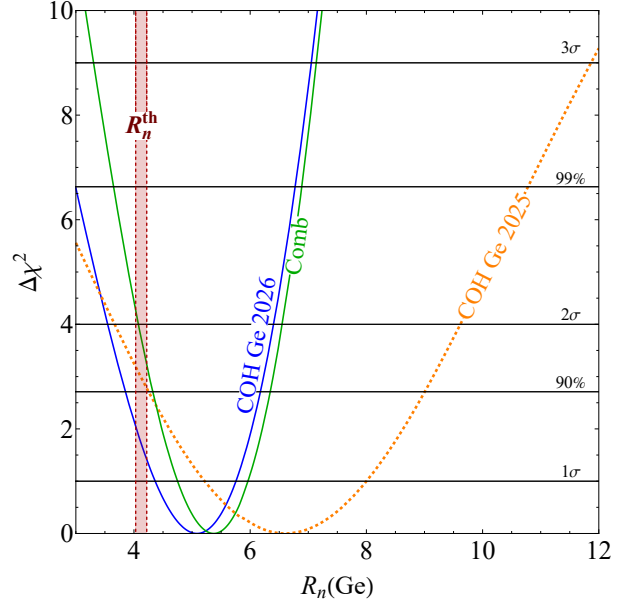


FIG. 2. $\Delta\chi^2$ profile as a function of $R_n(\text{GeV})$ for COHERENT Ge 2026 (blue solid line) and, for comparison, for the first COHERENT Ge 2025 (orange dotted line) [3]. The combined analysis is shown in green, while the red vertical band represents the range of the average germanium neutron radius predicted by nuclear models, spanning from the D1M interaction [48] to the NSM model [45].

IV. IMPLICATIONS FOR ELECTROWEAK AND NUCLEAR PHYSICS

A. Neutron rms radius of germanium

We extract the neutron rms radius of germanium $R_n(\text{GeV})$, averaged over the isotopic composition, by treating it as a free parameter in the fit while fixing $\sin^2 \vartheta_W$ to its SM value at low momentum transfer. The proton rms radii are held fixed to the values derived from the measured charge radii, as described in Sec. II.

The resulting $\Delta\chi^2$ profile as a function of $R_n(\text{GeV})$ is shown in Fig. 2 for COHERENT Ge 2026 and, for comparison, the first COHERENT 2025 germanium [2, 3] datasets. The theoretical R_n^{th} prediction is indicated by the red vertical band, following the prescription described in Sec. II.

The improvement brought by the new data is immediately apparent: the 2026 profile is substantially narrower, with the 1σ uncertainty reduced by roughly a factor of two with respect to the earlier result. The best-fit value and associated 1σ uncer-

tainties read

$$\text{COH Ge 2026: } R_n(\text{Ge}) = 5.08^{+0.67}_{-0.72} \text{ fm}, \quad (9)$$

consistent with the D1S theoretical prediction at the 1.4σ level. We also show the combined result obtained by summing the profile likelihoods of both germanium datasets, which further tightens the constraint to

$$\text{Comb: } R_n(\text{Ge}) = 5.37^{+0.59}_{-0.62} \text{ fm}, \quad (10)$$

lying about 2σ away from the theoretical prediction, indicated as the spread between the average NSM estimate ($R_n = 4.22$ fm) and the HF+BCS calculation with the D1M Gogny interaction ($R_n = 4.03$ fm). This result can be directly translated into a measurement of the average neutron skin of germanium

$$\Delta R_{\text{np}}(\text{Ge}) = 1.29^{+0.59}_{-0.62} \text{ fm}. \quad (11)$$

While the uncertainty remains large, the central value significantly exceeds the nuclear model predictions of $\Delta R_{\text{np}} \sim 0.1$ fm [3]. This trend is not unique to germanium: similarly large neutron skin values have been extracted from $\text{CE}\nu\text{NS}$ measurements on CsI and Ar targets [31, 44], and are also observed in electroweak probes of heavy nuclei such as PREX-II [55]. Whether this pattern reflects a genuine systematic effect in the $\text{CE}\nu\text{NS}$ analyses, a common bias in nuclear form factor modelling, or simply the limited statistical power of current datasets remains an open question that future high-precision measurements will be able to address.

B. Weak mixing angle

To place our results in the broader context of electroweak precision measurements, we also perform a one-dimensional extraction of $\sin^2 \vartheta_W$ with $R_n(\text{Ge})$ fixed to the D1S prediction, corresponding to an average radius of $R_n(\text{Ge}) = 4.09$ fm [3]. The outcome is displayed in Fig. 3 together with the SM running prediction as a function of the characteristic momentum transfer Q . The new COHERENT germanium determination at $Q \sim 40$ MeV

$$\text{COH Ge 2026: } \sin^2 \vartheta_W = 0.235^{+0.021}_{-0.020}, \quad (12)$$

represents the most precise single-experiment extraction of the weak mixing angle from $\text{CE}\nu\text{NS}$ data to date. The improvement over the previous germanium result [2] reflects directly the reduction of the statistical uncertainty from 30% to below 10%

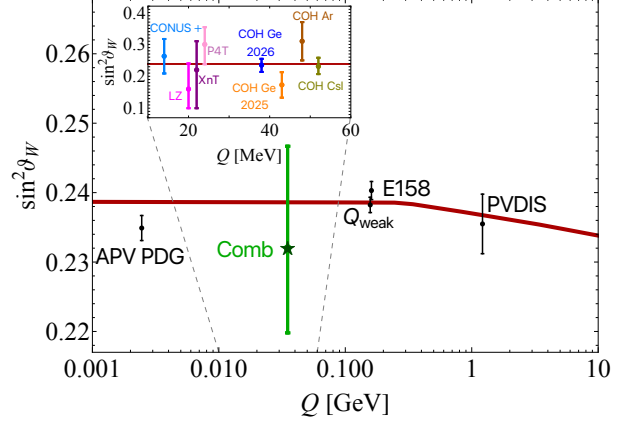


FIG. 3. Variation of the value of $\sin^2 \vartheta_W$ with Q in the low-energy range. The SM prediction is shown as the dark red solid curve, together with experimental determinations in black from Möller scattering (E158) [56], deep inelastic scattering of polarized electrons on deuterons (PVDIS) [57], and the result from the proton weak charge (Q_{weak}) [58] and atomic parity violation [33]. The result derived in this paper for COHERENT Germanium 2026 data is shown in blue in the inset, together with the COHERENT $\text{CE}\nu\text{NS}$ measurements from CsI [31], Ar [44], and Germanium 2025 [3] datasets, CONUS+ [34], PandaX [59], XENONnT [59], and LZ [21]. The combined analysis of all $\text{CE}\nu\text{NS}$ data is reported in green.

in the new dataset. We perform a combined analysis including COHERENT CsI [14], Ar [15, 16], and the previous COHERENT 2025 germanium result [2], together with reactor $\text{CE}\nu\text{NS}$ data from CONUS+ [13], TEXONO [17], and νGeN [18] as well as $\text{CE}\nu\text{NS}$ results from XENONnT [19] and PandaX [20], analyzed as detailed in Ref. [59]. For the LZ [21] dataset, we adopt a conservative approach by using a Gaussian prior on $\sin^2 \vartheta_W$, centered on the collaboration best-fit value and with a standard deviation $\sigma = 0.08$ [21]. This global analysis yields

$$\text{Comb: } \sin^2 \vartheta_W = 0.234^{+0.015}_{-0.012}, \quad (13)$$

representing the current state of the art in low-energy determinations of the weak mixing angle based on $\text{CE}\nu\text{NS}$ probes. It is shown in Fig. 3 alongside determinations from other low-energy probes including APV [33], E158 [56], Q_{weak} [58], and PVDIS [57]. All $\text{CE}\nu\text{NS}$ -based determinations shown in the figure inset are mutually consistent and in good agreement with the SM prediction, painting a coherent picture of the electroweak sector across a wide range of momentum transfers.

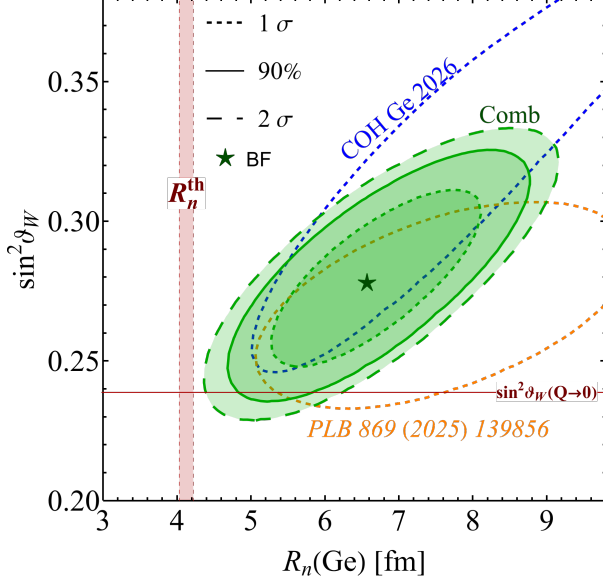


FIG. 4. Constraints obtained by fitting simultaneously the weak mixing angle and the average rms Ge neutron radius on COHERENT Ge 2026 data (blue contour), the combination [3] of *Reactors*, $\nu - e^-$ scattering data and the COHERENT germanium 2025 result (orange contour) and the full combination (green regions). Contours are at 1σ (dotted), 90% (solid) and 2σ (dashed) CL. The theoretical predictions are shown by the red bands.

C. Joint fit of $R_n(\text{Ge})$ and $\sin^2 \vartheta_W$

We next consider the simultaneous determination of $R_n(\text{Ge})$ and $\sin^2 \vartheta_W$, treating both as free parameters in the fit. The resulting confidence regions in the $(R_n(\text{Ge}), \sin^2 \vartheta_W)$ plane are shown in Fig. 4 at 1σ , 90% and 2σ CL, for the analysis of COHERENT Ge 2026 alone and for the combination with the previous COHERENT germanium dataset, *Reactors* [3] and $\nu - e^-$ scattering data from TEXONO [60], LSND [61], LAMPF [62], LZ [63], PandaX [64] and XENONnT [65]. For reference, the SM value $\sin^2 \vartheta_W(Q \rightarrow 0)$ is indicated by the horizontal red line, and the theoretical prediction for $R_n(\text{Ge})$ is shown as a vertical shaded band.

The two-dimensional fit confirms the picture emerging from the one-dimensional analysis: the new COHERENT germanium data alone already yield a competitive determination of both parameters. The combination with *Reactor* data, which provides a tight, largely R_n -independent constraint on $\sin^2 \vartheta_W$, breaks the degeneracy between the two parameters that is intrinsic to the accelerator-only fit, resulting in a significant reduction of the allowed

region. The combined two-dimensional best-fit values are

$$2\text{D Comb: } \sin^2 \vartheta_W = 0.278^{+0.023}_{-0.019}, \quad (14)$$

$$2\text{D Comb: } R_n(\text{Ge}) = 6.6^{+1.0}_{-0.8} \text{ fm}. \quad (15)$$

Driven by the positive correlation between $R_n(\text{Ge})$ and $\sin^2 \vartheta_W$ inherent to the COHERENT data, the extracted neutron rms radius takes on an unexpectedly large value. Consequently, our result systematically exceeds HF+BCS calculations and lies more than 2σ away from the theoretical prediction [3, 45]. The combined result supersedes the previous determination of Ref. [3], yielding a markedly reduced uncertainty driven by the improved statistical precision of the 2026 dataset.

D. Neutrino charge radii

We extract the neutrino charge radii $\langle r_{\nu_e}^2 \rangle$ and $\langle r_{\nu_\mu}^2 \rangle$ by treating them as free parameters in the fit and considering a momentum-dependence in the neutrino charge radii radiative corrections as detailed in Ref. [66]. The corresponding 90% confidence regions in the $(\langle r_{\nu_e}^2 \rangle, \langle r_{\nu_\mu}^2 \rangle)$ plane are shown in Fig. 5 for COHERENT Ge 2026, together with the previous CE ν NS result reported in Ref. [3], and their combination. For each neutrino flavor, there exist two values of the charge radius that produce the same observed rate: one close to the SM prediction and one substantially shifted. As expected, this fourfold degeneracy structure characteristic of neutrino charge radii measurements [67] also appears here, with two/four allowed regions symmetric under swap of both charge radii. The combination selects the physically preferred solution in agreement with the SM expectation [68, 69]

$$\langle r_{\nu_e}^2 \rangle_{\text{SM}} \simeq -0.83 \times 10^{-32} \text{ cm}^2, \quad (16)$$

$$\langle r_{\nu_\mu}^2 \rangle_{\text{SM}} \simeq -0.48 \times 10^{-32} \text{ cm}^2. \quad (17)$$

Here, we report the combined best-fit values in the region around the SM, as the degenerate regions are excluded by a global fit of neutrino data [70], namely

$$\langle r_{\nu_e}^2 \rangle = -0.3^{+4.4}_{-4.3}(1\sigma),^{+6.9}_{-7.4}(90\%) \times 10^{-32} \text{ cm}^2, \quad (18)$$

$$\langle r_{\nu_\mu}^2 \rangle = -1.6^{+3.8}_{-1.9}(1\sigma),^{+5.0}_{-3.3}(90\%) \times 10^{-32} \text{ cm}^2. \quad (19)$$

V. IMPLICATIONS FOR PHYSICS BEYOND THE STANDARD MODEL

We interpret the data in terms of non-standard neutrino interactions mediated by heavy parti-

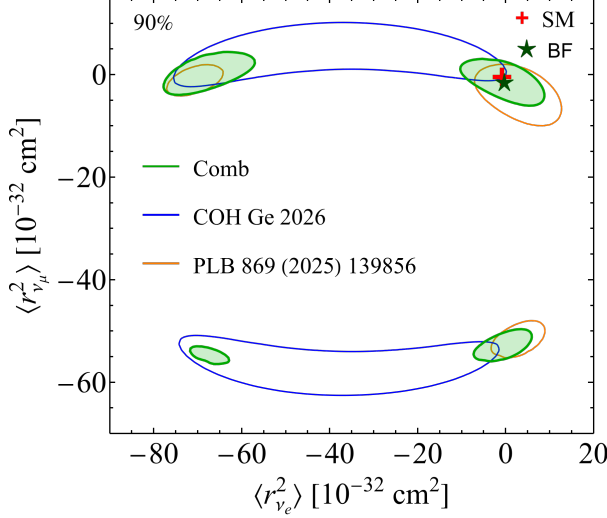


FIG. 5. Allowed regions at 90% CL on the electronic and muonic neutrino charge radii, from the analysis of COHERENT 2026 germanium (blue contour), the combination [3] of COHERENT CsI, Ar, and 2025 Ge as well as **Reactor** CE ν NS data (orange contour), together with their combined analysis (green shaded area). The red cross indicates the SM values reported in Eqs. (16) and (17), while the green star represents the best-fit of the combined analysis.

cles [71–73], parameterised through generic vector couplings $\epsilon_q^{\alpha\beta}$ affecting the scattering of an α -flavor neutrino off a q -type quark. For simplicity, we consider a flavor-diagonal scenario ($\alpha = \beta$) involving only the neutrino-up-quark scattering by performing a two-dimensional fit in the $(\epsilon_u^{ee}, \epsilon_u^{\mu\mu})$ plane. The resulting 90% confidence regions are shown in Fig. 6 for COHERENT Ge 2026 alone, COHERENT CsI+Ar+Ge 2025 and **Reactors**, and the full combination. The COHERENT Ge 2026 contour exhibits the characteristic two/four-lobe structure that arises from the quadratic dependence of the CE ν NS cross section on the effective neutrino-quark couplings: a flip in both ϵ_u^{ee} and $\epsilon_u^{\mu\mu}$ can leave the total rate approximately invariant, generating two pairs of degenerate solutions symmetric under $\epsilon_u^{ee} \rightarrow \bar{\epsilon} - \epsilon_u^{ee}$, where $\bar{\epsilon}$ is determined by the SM weak charge. The **Reactors** constraint, being sensitive exclusively to the ν_e flavor, appears as two vertical bands that restrict the allowed values of ϵ_u^{ee} independently of $\epsilon_u^{\mu\mu}$. The combination of all datasets retains four compact regions, one of which centred on the SM point $(\epsilon_u^{ee}, \epsilon_u^{\mu\mu}) = (0, 0)$. While the constraints derived using solely the COHERENT Ge 2026 data are fully consistent with the official bounds reported by

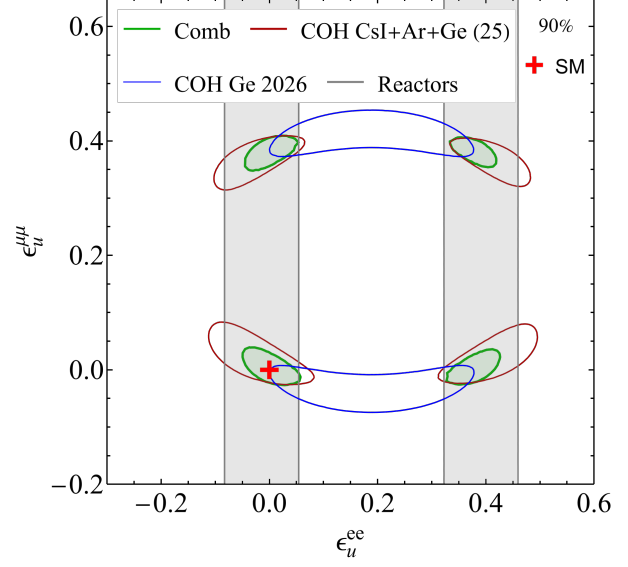


FIG. 6. Allowed 90% CL regions in the $(\epsilon_u^{ee}, \epsilon_u^{\mu\mu})$ parameter space. The blue contour represents the constraints from the new COHERENT Ge 2026 dataset. The dark red contour shows the combination involving COHERENT CsI, Ar, and the 2025 Ge data, while the grey vertical bands denote the constraints from **Reactor** experiments, which are sensitive only to the ν_e flavor. The green filled contours show the full combination, also consistent with the SM expectation (indicated by the red cross).

the collaboration [1], our global combination with all other available CE ν NS datasets significantly tightens these limits.

Following the same strategy of Ref. [34], in addition to flavor-diagonal NSI couplings to a specific quark, we also investigate the interplay between NSI couplings to up and down quarks for a given neutrino flavor. Focusing on the electron-neutrino sector, we perform a two-dimensional fit in the $(\epsilon_d^{ee}, \epsilon_u^{ee})$ plane. The resulting 90% CL constraints are illustrated in Fig. 7. Because the CE ν NS cross section probes a coherent superposition of neutrino-nucleon scatterings, it is essentially sensitive to a linear combination of the up and down quark couplings weighted by the proton and neutron numbers of the target nucleus. This physical dependence manifests as a strong anti-correlation in the parameter space, generating the observed diagonal bands whose slope is strictly dictated by the Z/N ratio of the target.

As shown in the figure, the latest COHERENT Ge 2026 dataset significantly narrows the allowed parameter space compared to the older COHERENT Ge 2025 measurement, demonstrating the re-

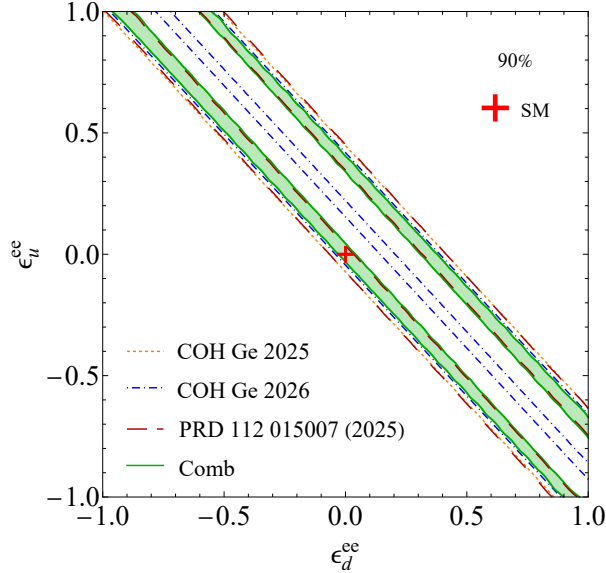


FIG. 7. Allowed 90% CL regions in the $(\epsilon_d^{ee}, \epsilon_u^{ee})$ parameter space for vector NSI couplings. The plot illustrates the constraints from the previous COHERENT Ge 2025 data (orange dotted lines), the newly updated COHERENT Ge 2026 data (blue dot-dashed lines), and a previous phenomenological fit [34] including TEXONO, CONUS+, and COHERENT CsI+Ar (red dashed lines). The solid green shaded region corresponds to the updated global combination. The SM prediction (red cross) lies perfectly within the newly combined allowed region.

markable impact of the increased exposure and lowered analysis threshold. The inclusion of all available datasets [34] (TEXONO, CONUS+, and COHERENT CsI+Ar) into a global combined fit provides the most stringent constraints to date along this degenerate direction. Once again, the SM prediction $(\epsilon_d^{ee}, \epsilon_u^{ee}) = (0, 0)$ is thoroughly embedded within the combined 90% CL allowed region, further reinforcing the robustness of the SM against the presence of non-standard vector interactions in the low-energy regime.

VI. CONCLUSIONS

We have presented the first comprehensive phenomenological analysis of the new COHERENT germanium CE ν NS dataset, which represents the most precise measurement of this process to date. With roughly three times the neutrino exposure of the earlier result, a lowered analysis threshold, and improved background rejection, the new data cross the threshold from a statistics-dominated to a systematics-dominated regime, opening new opportunities for precision CE ν NS phenomenology.

Our simultaneous fit to the energy and timing distributions yields 126 ± 11 CE ν NS events, in good agreement with both the COHERENT collaboration result and our theoretical prediction. The combined flavor-separated normalization analysis confirms full consistency with the SM within 1σ for both neutrino components, resolving the mild tension observed in the analysis of the first germanium dataset [3]. We note that when considering the COHERENT Ge 2026 dataset in isolation, the muonic channel exhibits an intriguing excess that warrants further investigation.

From this improved dataset we have extracted updated determinations of several SM and nuclear physics parameters. The neutron rms radius of germanium is measured as $R_n(\text{Ge}) = 5.08^{+0.67}_{-0.72}$ fm from COHERENT Ge 2026 alone, while the global CE ν NS combination yields $\sin^2 \vartheta_W = 0.234^{+0.015}_{-0.012}$, the most precise low-energy determination of the weak mixing angle from CE ν NS to date. Constraints on neutrino charge radii and on non-standard neutrino interactions in both the $(\epsilon_u^{ee}, \epsilon_u^{\mu\mu})$ and $(\epsilon_d^{ee}, \epsilon_u^{ee})$ planes have also been significantly improved with respect to previous analyses, with the SM prediction consistently falling within all combined allowed regions.

These results demonstrate that CE ν NS has entered a precision era. Future improvements in the SNS neutrino flux normalization will further reduce the dominant systematic uncertainty, making CE ν NS an increasingly powerful probe of the electroweak sector, nuclear structure, and physics beyond the Standard Model.

-
- [1] M. Adhikari *et al.* (COHERENT), “Measurement of coherent elastic neutrino nucleus scattering on germanium by COHERENT,” (2026), arXiv:2603.17951 [hep-ex].
[2] S. Adamski *et al.* (COHERENT), Phys. Rev. Lett.

- 134**, 231801 (2025).
[3] M. Atzori Corona, M. Cadeddu, N. Cargioli, G. Co’, F. Dordei, and C. Giunti, Phys. Lett. B **869**, 139856 (2025), arXiv:2506.13555 [hep-ph].
[4] Y. Li, G. Herrera, and P. Huber, “New Physics ver-

- sus Quenching Factors in Coherent Neutrino Scattering,” (2025), arXiv:2502.12308 [hep-ph].
- [5] J. Liao, D. Marfatia, and J. Zhang, *Phys. Rev. D* **110**, 055040 (2024), arXiv:2408.06255 [hep-ph].
 - [6] D. Z. Freedman, *Phys. Rev. D* **9**, 1389 (1974).
 - [7] V. De Romeri, D. K. Papoulias, F. Pompa, G. Sanchez Garcia, and C. A. Ternes, (2026), arXiv:2603.00554 [hep-ph].
 - [8] V. De Romeri, D. K. Papoulias, G. Sanchez Garcia, C. A. Ternes, and M. Tórtola, “Neutrino electromagnetic properties and sterile dipole portal in light of the first solar CE ν NS data,” (2024), arXiv:2412.14991 [hep-ph].
 - [9] P. Coloma, I. Esteban, M. C. Gonzalez-Garcia, L. Larizgoitia, F. Monrabal, and S. Palomares-Ruiz, *JHEP* **05**, 037 (2022), arXiv:2202.10829 [hep-ph].
 - [10] M. Demirci and M. F. Mustamin, *Phys. Rev. D* **109**, 015021 (2024), arXiv:2312.17502 [hep-ph].
 - [11] M. Demirci and M. F. Mustamin, *Eur. Phys. J. C* **85**, 1 (2025), arXiv:2412.03140 [hep-ph].
 - [12] V. De Romeri, O. G. Miranda, D. K. Papoulias, G. Sanchez Garcia, M. Tórtola, and J. W. F. Valle, *JHEP* **04**, 035 (2023), arXiv:2211.11905 [hep-ph].
 - [13] N. Ackermann et al., “First observation of reactor antineutrinos by coherent scattering,” (2025), arXiv:2501.05206 [hep-ex].
 - [14] D. Akimov et al., “Measurement of the Coherent Elastic Neutrino-Nucleus Scattering Cross Section on CsI by COHERENT,” (2021), arXiv:2110.07730 [hep-ex].
 - [15] D. Akimov et al. (COHERENT), *Phys. Rev. Lett.* **126**, 012002 (2021), arXiv:2003.10630 [nucl-ex].
 - [16] D. Akimov et al. (COHERENT), “COHERENT Collaboration data release from the first detection of coherent elastic neutrino-nucleus scattering on argon,” (2020), arXiv:2006.12659 [nucl-ex].
 - [17] S. Karmakar et al. (TEXONO), *Phys. Rev. Lett.* **134**, 121802 (2025), arXiv:2411.18812 [nucl-ex].
 - [18] V. Belov et al. (nuGeN), (2025), 10.1088/1674-1137/adb9c8, arXiv:2502.18502 [hep-ex].
 - [19] E. Aprile et al. (XENON), *Phys. Rev. Lett.* **133**, 191002 (2024), arXiv:2408.02877 [nucl-ex].
 - [20] Z. Bo et al. (PandaX), *Phys. Rev. Lett.* **133**, 191001 (2024), arXiv:2407.10892 [hep-ex].
 - [21] D. S. Akerib et al. (LZ), “Searches for Light Dark Matter and Evidence of Coherent Elastic Neutrino-Nucleus Scattering of Solar Neutrinos with the LUX-ZEPLIN (LZ) Experiment,” (2025), arXiv:2512.08065 [hep-ex].
 - [22] S. S. Chatterjee, S. Lavignac, O. G. Miranda, and G. Sanchez Garcia, *Phys. Rev. D* **107**, 055019 (2023), arXiv:2208.11771 [hep-ph].
 - [23] J. I. Collar et al., (2025), arXiv:2512.19788 [hep-ph].
 - [24] A. Chattaraj, A. Majumdar, D. K. Papoulias, and R. Srivastava, *JHEP* **05**, 064 (2025), arXiv:2501.12443 [hep-ph].
 - [25] M. Cappelli et al. (NUCLEUS), (2026), arXiv:2603.28276 [physics.ins-det].
 - [26] M. Atzori Corona, M. Cadeddu, N. Cargioli, F. Dordei, C. Giunti, and R. Pavarani, *Universe* **11**, 416 (2025), arXiv:2509.04205 [physics.ins-det].
 - [27] M. Cadeddu, F. Dordei, and C. Giunti, *EPL* **143**, 34001 (2023), arXiv:2307.08842 [hep-ph].
 - [28] M. Berglund and M. E. Wieser, *Pure and Applied Chemistry* **83**, 397 (2011).
 - [29] R. Abdel Khaleq, J. L. Newstead, C. Simenel, and A. E. Stuchbery, *Phys. Rev. D* **111**, 033003 (2025), arXiv:2405.20060 [hep-ph].
 - [30] D. Aristizabal Sierra, P. M. Candela, V. De Romeri, D. K. Papoulias, and L. T. S., (2026), arXiv:2603.05281 [hep-ph].
 - [31] M. Atzori Corona, M. Cadeddu, N. Cargioli, F. Dordei, C. Giunti, and G. Masia, *Eur. Phys. J. C* **83**, 683 (2023), arXiv:2303.09360 [nucl-ex].
 - [32] J. Erler and S. Su, *Prog. Part. Nucl. Phys.* **71**, 119 (2013), arXiv:1303.5522 [hep-ph].
 - [33] S. Navas et al. (Particle Data Group), *Phys. Rev. D* **110**, 030001 (2024).
 - [34] M. A. Corona, M. Cadeddu, N. Cargioli, F. Dordei, and C. Giunti, *Phys. Rev. D* **112**, 015007 (2025).
 - [35] C. Giunti, K. Kouzakov, Y.-F. Li, and A. Studenikin, “Neutrino Electromagnetic Properties,” (2024), arXiv:2411.03122 [hep-ph].
 - [36] M. Cadeddu, C. Giunti, Y. F. Li, and Y. Y. Zhang, *Phys. Rev. Lett.* **120**, 072501 (2018), arXiv:1710.02730 [hep-ph].
 - [37] R. H. Helm, *Phys. Rev.* **104**, 1466 (1956).
 - [38] J. Piekarewicz, A. R. Linero, P. Giuliani, and E. Chicken, *Phys. Rev. C* **94**, 034316 (2016), arXiv:1604.07799 [nucl-th].
 - [39] S. Klein and J. Nystrand, *Phys. Rev. C* **60**, 014903 (1999), arXiv:hep-ph/9902259.
 - [40] J. Friedrich and N. Voegler, *Nucl. Phys. A* **373**, 192 (1982).
 - [41] G. Fricke, C. Bernhardt, K. Heilig, L. A. Schaller, L. Schellenberg, E. B. Shera, and C. W. de Jager, *Atom. Data Nucl. Data Tabl.* **60**, 177 (1995).
 - [42] G. Fricke and K. Heilig, “Nuclear charge radii ^{32}Ge germanium: Datasheet from landolt-bornstein - group i elementary particles, nuclei and atoms, volume 20,” (2004), copyright 2004 Springer-Verlag Berlin Heidelberg.
 - [43] I. Angeli and K. P. Marinova, *Atom. Data Nucl. Data Tabl.* **99**, 69 (2013).
 - [44] M. Cadeddu, F. Dordei, C. Giunti, Y. F. Li, E. Picciau, and Y. Y. Zhang, *Phys. Rev. D* **102**, 015030 (2020), arXiv:2005.01645 [hep-ph].
 - [45] M. Hoferichter, J. Menéndez, and A. Schwenk, *Phys. Rev. D* **102**, 074018 (2020), arXiv:2007.08529 [hep-ph].
 - [46] G. Co, M. Anguiano, and A. M. Lallena, *Phys. Rev. C* **104**, 014313 (2021), arXiv:2107.09938 [nucl-th].
 - [47] J. F. Berger, M. Girod, and D. Gogny, *Comput. Phys. Commun.* **63**, 365 (1991).
 - [48] E. Chabanat, P. Bonche, P. Haensel, J. Meyer, and R. Schaeffer, *Nucl. Phys. A* **635**, 231 (1998), [Erra-

- tum: Nucl.Phys.A 643, 441–441 (1998)].
- [49] M. Atzori Corona, M. Cadeddu, N. Cargioli, F. Dordei, C. Giunti, Y. F. Li, E. Picciau, C. A. Ternes, and Y. Y. Zhang, JHEP **05**, 109 (2022), arXiv:2202.11002 [hep-ph].
 - [50] D. Akimov et al. (COHERENT), Phys. Rev. D **106**, 032003 (2022), arXiv:2109.11049 [hep-ex].
 - [51] J. Colaresi, J. I. Collar, T. W. Hossbach, C. M. Lewis, and K. M. Yocum, Phys. Rev. Lett. **129**, 211802 (2022), arXiv:2202.09672 [hep-ex].
 - [52] M. Atzori Corona, M. Cadeddu, N. Cargioli, F. Dordei, and C. Giunti, Phys. Lett. B **852**, 138627 (2024), arXiv:2307.12911 [hep-ph].
 - [53] J. Lindhard, V. Nielsen, M. Scharff, and P. V. Thomsen, Kgl. Danske Videnskab., Selskab. Mat. Fys. Medd. **33**, 10 (1963).
 - [54] R. Bouabid (COHERENT), “Latest Germanium Results From the COHERENT Collaboration,” (2026), presentation at the wine and cheese seminar.
 - [55] D. Adhikari et al. (PREX), Phys. Rev. Lett. **126**, 172502 (2021), arXiv:2102.10767 [nucl-ex].
 - [56] P. L. Anthony et al. (SLAC E158), Phys. Rev. Lett. **95**, 081601 (2005), hep-ex/0504049 [hep-ex].
 - [57] D. Wang et al. (PVDIS), Nature **506**, 67 (2014).
 - [58] D. Androic et al. (Qweak), Nature **557**, 207 (2018).
 - [59] M. Atzori Corona, M. Cadeddu, N. Cargioli, F. Dordei, and M. Sestu, “When backgrounds become signals: neutrino interactions in xenon-based dark matter detectors,” (2025), arXiv:2509.22178 [hep-ph].
 - [60] M. Deniz et al. (TEXONO), Phys. Rev. D **81**, 072001 (2010), arXiv:0911.1597 [hep-ex].
 - [61] L. B. Auerbach et al. (LSND), Phys. Rev. D **63**, 112001 (2001), arXiv:hep-ex/0101039.
 - [62] R. C. Allen, H. H. Chen, P. J. Doe, R. Hausmann, W. P. Lee, X. Q. Lu, H. J. Mahler, M. E. Potter, K. C. Wang, T. J. Bowles, R. L. Burman, R. D. Carlini, D. R. F. Cochran, J. S. Frank, E. Pisasetzky, V. D. Sandberg, D. A. Krakauer, and R. L. Talaga, Phys. Rev. D **47**, 11 (1993).
 - [63] J. Aalbers et al. (LZ), Phys. Rev. Lett. **131**, 041002 (2023), arXiv:2207.03764 [hep-ex].
 - [64] D. Zhang et al. (PandaX), Phys. Rev. Lett. **129**, 161804 (2022), arXiv:2206.02339 [hep-ex].
 - [65] E. Aprile et al. (XENON), Phys. Rev. Lett. **129**, 161805 (2022), arXiv:2207.11330 [hep-ex].
 - [66] M. Atzori Corona, M. Cadeddu, N. Cargioli, F. Dordei, and C. Giunti, JHEP **05**, 271 (2024), arXiv:2402.16709 [hep-ph].
 - [67] M. Cadeddu, C. Giunti, K. A. Kouzakov, Y.-F. Li, Y.-Y. Zhang, and A. I. Studenikin, Phys. Rev. D **98**, 113010 (2018), [Erratum: Phys.Rev.D 101, 059902 (2020)], arXiv:1810.05606 [hep-ph].
 - [68] J. Bernabeu, L. G. Cabral-Rosetti, J. Papavassiliou, and J. Vidal, Phys. Rev. D **62**, 113012 (2000), arXiv:hep-ph/0008114.
 - [69] J. Bernabeu, J. Papavassiliou, and J. Vidal, Phys. Rev. Lett. **89**, 101802 (2002), [Erratum: Phys.Rev.Lett. 89, 229902 (2002)], arXiv:hep-ph/0206015.
 - [70] M. Atzori Corona, M. Cadeddu, N. Cargioli, F. Dordei, C. Giunti, and C. A. Ternes, Phys. Rev. Lett. **135**, 231803 (2025), arXiv:2504.05272 [hep-ph].
 - [71] P. Coloma, M. C. Gonzalez-Garcia, M. Maltoni, and T. Schwetz, Phys. Rev. D **96**, 115007 (2017), arXiv:1708.02899 [hep-ph].
 - [72] P. Coloma, M. C. Gonzalez-Garcia, M. Maltoni, J. a. P. Pinheiro, and S. Urrea, JHEP **08**, 032 (2023), arXiv:2305.07698 [hep-ph].
 - [73] A. M. Suliga and I. Tamborra, Phys. Rev. D **103**, 083002 (2021), arXiv:2010.14545 [hep-ph].