# Non-Standard Neutrino Interactions with Coherent Elastic Neutrino-Nucleus Scattering at TEXONO

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TAUP2025 - 19th International Conference on Topics in Astroparticle and Underground Physics, Xichang/China, Aug 24-30

# Constraints on New Physics with Light Mediators and Generalized Neutrino Interactions via Coherent Elastic Neutrino Nucleus Scattering

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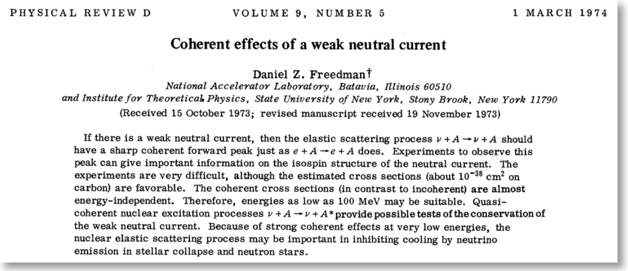
(Dated: July 16, 2025)

We investigate new physics effects on Coherent Elastic Neutrino Nucleus Scattering (CE$\nu$NS) within the framework of Non-Standard Interactions (NSI) and generalized neutrino interactions (GNI). Additionally, we examine the possibility of light mediators from a simplified model that includes all possible Lorentz-invariant interactions of vector (V), axialvector (A), scalar (S), pseudoscalar (P), and tensor (T) types. Constraints and allowed regions at the 90% C. L. for masses and couplings in each new physics scenario have been obtained through the analysis of TEXONO data, which includes two datasets from a high-purity $n-$type point contact germanium (nPCGe) detector in 2016 and an advanced $p-$type point contact Ge (pPCGe) detector in 2025. The results are presented in comparison with other reactor and accelerator-based neutrino experiments for complementarity.

***<u>Accepted in Phys. Rev. D (31 July)</u>***

# Introduction : CEvNS prediction to observation

- First proposed in 1974. D. Freedman, Phys. Rev. D 9, 1389
- Coherence requires **small momentum transfer**, leading to **sub-keV** nuclear recoils.
- Active experimental programs to observe and measure the CEvNS processes with,
  - **reactor neutrinos ($\bar{\nu}_e$): TEXONO, CONUS+(at 3.7σ),** Nature 643,1229 (2025)
    CONNIE, Dresden-II,…
  - **accelerator neutrinos (from SNS): COHERENT(at 6.7σ)** Science 357, 1123 (2017) -> PRL 126, 012002 (2021) PRL 129, 081801 (2022) PRL 134, 231801 (2025)
    - a stopped-pion beam **(DAR-π process)** – $\nu_e, \nu_\mu$, and $\bar{\nu}_\mu$ fluxes.
  - **solar neutrinos (from $^8$B): XENONnT,** PRL 133, 191002 (2024) **PandaX-4T** PRL 133, 191001 (2024)
    (at 2.7σ and 2.6σ as 'neutrino fog' in DM experiments).


PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

**Coherent effects of a weak neutral current**

Daniel Z. Freedman†
*National Accelerator Laboratory, Batavia, Illinois 60510*
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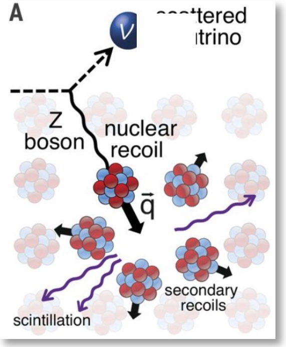
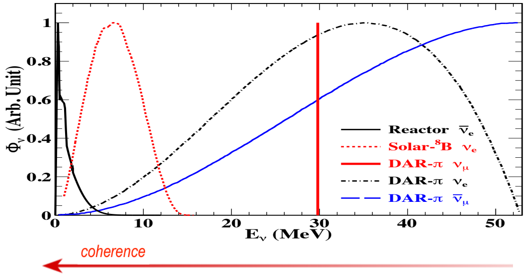
(Received 15 October 1973; revised manuscript received 19 November 1973)

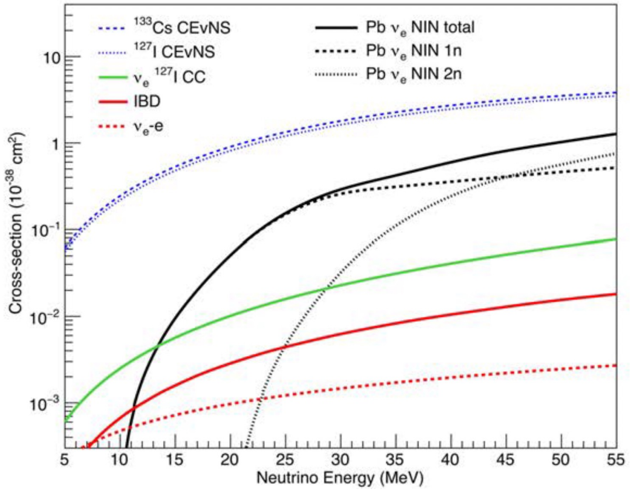
If there is a weak neutral current, then the elastic scattering process $\nu + A \to \nu + A$ should have a sharp coherent forward peak just as $e + A \to e + A$ does. Experiments to observe this peak can give important information on the isospin structure of the neutral current. The experiments are very difficult, although the estimated cross sections (about $10^{-38}$ cm$^2$ on carbon) are favorable. The coherent cross sections (in contrast to incoherent) are almost energy-independent. Therefore, energies as low as 100 MeV may be suitable. Quasi-coherent nuclear excitation processes $\nu + A \to \nu + A^*$ provide possible tests of the conservation of the weak neutral current. Because of strong coherent effects at very low energies, the nuclear elastic scattering process may be important in inhibiting cooling by neutrino emission in stellar collapse and neutron stars.



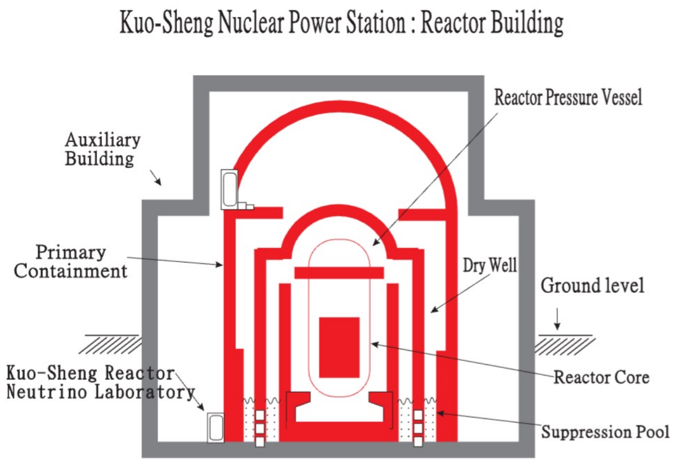

*Well understood SM calculation!*

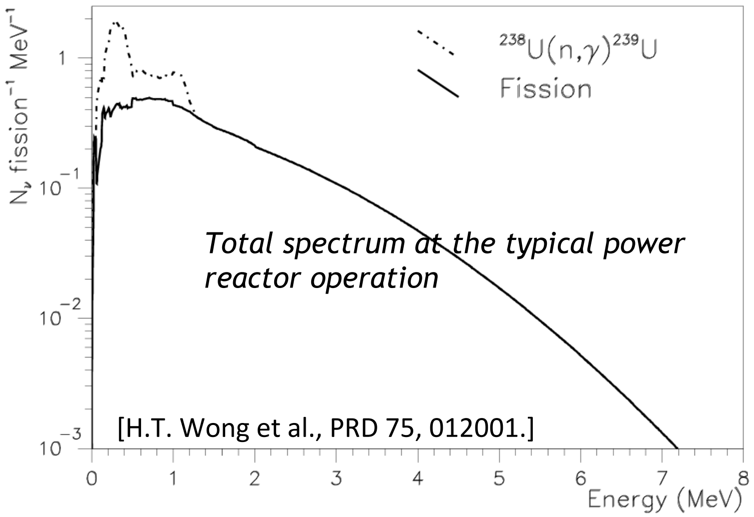
$$\frac{d\sigma}{dT} \propto N^2$$



# Introduction : TEXONO [Taiwan EXperiment On NeutrinO] Reactor Neutrino Experiment

- **Detector Site** → located at Kuo-Sheng Nuclear Power Plant, Taiwan
- **Program** → Low-Energy Neutrino Physics & Dark Matter Searches
- **Flux** → $\sim 6.35\times10^{12}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}\ \bar{\nu}_e$ at **2.9 GW** thermal power (**28 m** from reactor core)
- **Detectors** → HPGe point-contact (nPCGe 2016 – 300 eV; pPCGe 2025 – 200 eV)
- **Future** → KSNL reactors shut down (2023). TEXONO CEvNS program moving to **Sanmen Reactor Laboratory (China).**

# Coherent Elastic Neutrino-Nucleus Scattering (CEvNS)

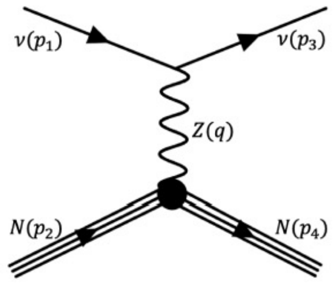
- SM amplitude and differential cross-section for CEvNS,

$$\mathscr{M} = \frac{G_F}{\sqrt{2}} \bar{\nu}(p_3)\gamma^\mu(1-\gamma^5)\nu(p_1) \times \overline{N}(p_4)\gamma_\mu \left(Q_{\mathrm{SM}_V} - \gamma^5 Q_{\mathrm{SM}_A}\right) N(p_2)$$

$$\left[\frac{d\sigma}{dT_N}\right]_{\mathrm{SM}} = \frac{G_F^2 m_N}{4\pi}\left(Q^2_{\mathrm{SM}_V}\mathcal{K}_V + Q^2_{\mathrm{SM}_A}\mathcal{K}_A\right)$$

$$\mathcal{K}_V = 1 - \frac{m_N T_N}{2E_\nu^2} - \frac{T_N}{E_\nu} + \frac{T_N^2}{2E_\nu^2}$$
$$\mathcal{K}_A = 1 + \frac{m_N T_N}{2E_\nu^2} - \frac{T_N}{E_\nu} + \frac{T_N^2}{2E_\nu^2}$$

- $\boldsymbol{Q_{SM_V}}$ (vector) and $\boldsymbol{Q_{SM_A}}$ (axialvector) are the weak charges,




$$\nu_\alpha(\bar{\nu}_\alpha) + N(\mathcal{Z},\mathcal{N}) \longrightarrow \nu_\alpha(\bar{\nu}_\alpha) + N(\mathcal{Z},\mathcal{N})$$

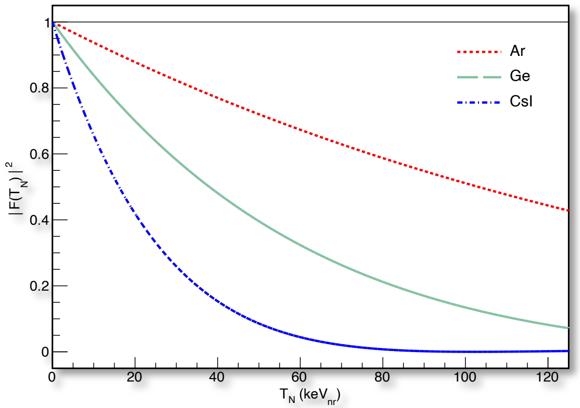
$$Q_{\mathrm{SM}_V} = g_p^V \mathcal{Z} F_{\mathcal{Z}}(q^2) + g_n^V \mathcal{N} F_{\mathcal{N}}(q^2) = \left[\mathcal{Z}\left(1-4\sin^2\theta_W\right) - \mathcal{N}\right] F_V(q^2)$$

$$Q^2_{SM_A} = \frac{8\pi}{2J+1}(\Delta_u^p - \Delta_d^p)^2 \; S_{11}^{\mathcal{T}}(q^2)$$

$g_V^p = 1 - 4\sin^2\theta_W \approx 0.0453$   $g_V^n = -1$   *w/ rad. corr* →   $g_V^n \approx -1.0234$   $g_V^p \approx 0.0762$

Nuclear coherence described by **Helm form factor**,

$$F(q^2) = \left[\frac{3}{qR_0}\right] j_1(qR_0)\, exp\left[-\frac{1}{2}q^2 s^2\right]$$

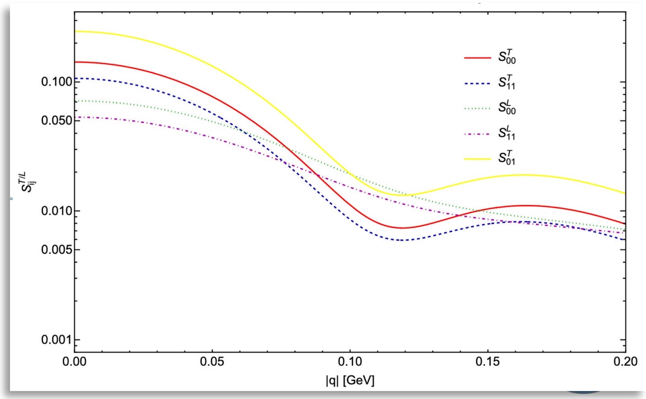



For non-zero nuclear spin, **spin structure functions** are,

$$F_A(q^2) = \frac{8\pi}{2J+1}\left[(g_A^0)^2\; S_{00}^{\mathcal{T}}(q^2) + g_A^0 g_A^1\; S_{01}^{\mathcal{T}}(q^2) + (g_A^1)^2\; S_{11}^{\mathcal{T}}(q^2)\right],$$

$$g_A^p = -g_A^n$$

PRD 102, 074018



# Light mediators in a simplified model

- New mediators **(vector, axialvector, scalar, pseudoscalar,** and **tensor)** , each assumed to have light mass, extend CEvNS beyond the SM.

$$\mathcal{L}_S \supset [(g_{\nu S}\bar{\nu}_R \nu_L + h.c.) + g_{qS}\bar{q}q]S$$

$$\mathcal{L}_P \supset [(g_{\nu P}\bar{\nu}_R \nu_L + h.c.) - i g_{qP}\gamma^5 \bar{q}q]P$$

$$\mathcal{L}_V \supset [g_{\nu V}\bar{\nu}_L \gamma^\mu \nu_L + g_{qV}\bar{q}\gamma^\mu q]V_\mu$$

$$\mathcal{L}_A \supset [g_{\nu A}\bar{\nu}_L \gamma^\mu \nu_L - g_{qA}\bar{q}\gamma^\mu \gamma^5 q]A_\mu$$

$$\mathcal{L}_T \supset [g_{\nu T}\bar{\nu}_R \sigma^{\mu\nu} \nu_L - g_{qT}\bar{q}\sigma^{\mu\nu} q]T_{\mu\nu}$$

$$g_{VN} = \Big[\mathcal{Z}\sum_q Q'^p_q g_{Vq} + \mathcal{N}\sum_q Q'^n_q g_{Vq}\Big] F_V(q^2),$$

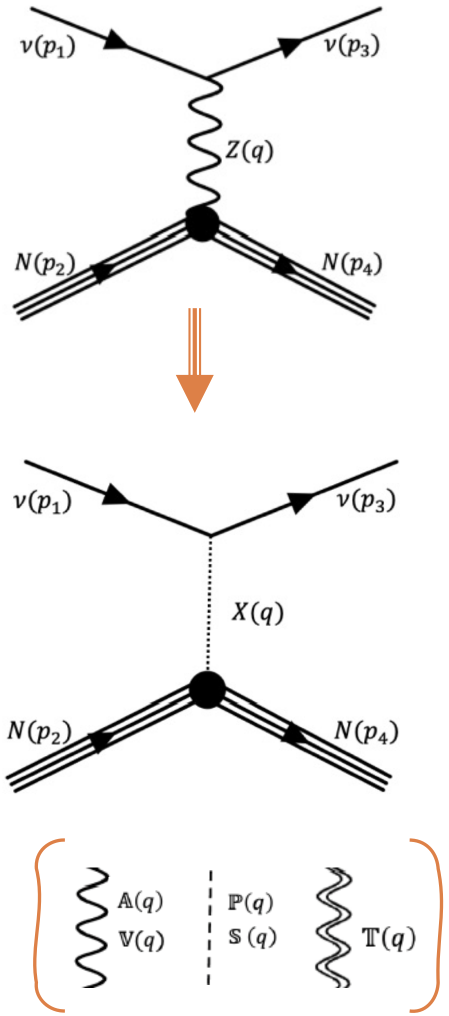
$$g_{SN} = \Big[\mathcal{Z}\sum_q g_{Sq}\frac{m_p}{m_q} f^p_{Tq} + \mathcal{N}\sum_q g_{Sq}\frac{m_n}{m_q} f^n_{Tq}\Big] F_S(q^2),$$

$$g_{PN} = \Big[\mathcal{Z}\sum_q g_{Pq}\frac{m_p}{m_q}\Delta^p_q + \mathcal{N}\sum_q g_{Pq}\frac{m_n}{m_q}\Delta^n_q\Big] \times \Big(1 - \sum_{q'}\frac{\bar{m}}{m_{q'}}\Big) F_P(q^2),$$

$$g_{AN} = \sqrt{\frac{8\pi}{2J+1}}\big[g_{Aq}(\Delta^p_u + \Delta^p_d)\big],$$

$$g_{TN} = \sqrt{\frac{8\pi}{2J+1}}\big[g_{Tq}(\delta^p_u + \delta^p_d)\big].$$

| Parameter | Value |
|---|---|
| $m_u$ | 2.16 |
| $m_d$ | 4.67 |
| $m_s$ | 93.4 |
| $m_n$ | 939.6 |
| $m_p$ | 938.3 |
| $Q'^p_u = Q'^n_d$ | 2 |
| $Q'^n_u = Q'^p_d$ | 1 |
| $f^p_{T_u}$ | 0.0208 |
| $f^n_{T_u}$ | 0.0411 |
| $f^p_{T_d}$ | 0.0189 |
| $f^n_{T_d}$ | 0.0451 |
| $\Delta^p_u = \Delta^n_d$ | 0.842 |
| $\Delta^n_u = \Delta^p_d$ | -0.427 |
| $\delta^p_u = \delta^n_d$ | 0.784 |
| $\delta^n_u = \delta^p_d$ | -0.204 |



# Light mediators in a simplified model

❖**differential cross-sections** for **SPVAT** interactions,

$$\left[\frac{d\sigma}{dT_N}\right]_V = \frac{G_F^2 m_N}{4\pi}\frac{2Q_V^2}{(m_V^2+2m_N T_N)^2}\mathcal{K}_V \quad \textbf{V}$$

$$\left[\frac{d\sigma}{dT_N}\right]_{V_{INT}} = \frac{G_F^2 m_N}{4\pi}\frac{2\sqrt{2}Q_V Q_{SM_V}}{m_V^2+2m_N T_N}\mathcal{K}_V \quad \textbf{V}_{INT}$$

$$\left[\frac{d\sigma}{dT_N}\right]_A = \frac{G_F^2 m_N}{4\pi}\frac{2Q_A^2}{(m_A^2+2m_N T_N)^2}S_{00}^{\mathcal{T}}(q^2)\,\mathcal{K}_A \quad \textbf{A}$$

$$\left[\frac{d\sigma}{dT_N}\right]_S = \frac{G_F^2 m_N}{4\pi}\frac{Q_S^2}{(m_S^2+2m_N T_N)^2}\mathcal{K}_S \quad \textbf{S}$$

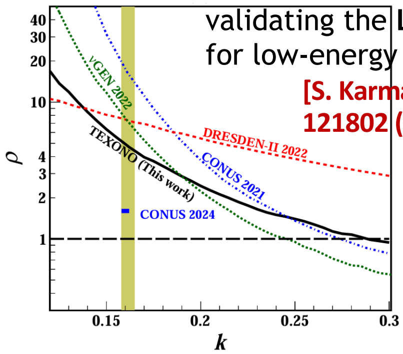
$$\left[\frac{d\sigma}{dT_N}\right]_P = \frac{G_F^2 m_N}{4\pi}\frac{Q_P^2}{(m_P^2+2m_N T_N)^2}\mathcal{K}_P \quad \textbf{P}$$

$$\left[\frac{d\sigma}{dT_N}\right]_T = \frac{G_F^2 m_N}{4\pi}\frac{Q_T^2}{(m_T^2+2m_N T_N)^2} \times\left[8S_{00}^{\mathcal{T}}(q^2)\,\mathcal{K}_V + 16S_{00}^{\mathcal{L}}(q^2)\left(1-\frac{T_N}{E_\nu}\right)\right] \quad \textbf{T}$$

$$\mathcal{K}_S = \frac{m_N T_N}{E_\nu^2} + \frac{T_N^2}{2E_\nu^2}$$

$$\mathcal{K}_P = \frac{T_N^2}{2E_\nu^2}$$

$$Q_X = \frac{g_{X\nu}g_{XN}}{G_F}$$




✓ Recent pPCGe results are **consistent with SM expectations** validating the **Lindhard model** for low-energy quenching factors.

**[S. Karmakar et. al, PRL 134, 121802 (2025)]**

## *Detector responses*

**Linhard QF (k=0.162):**

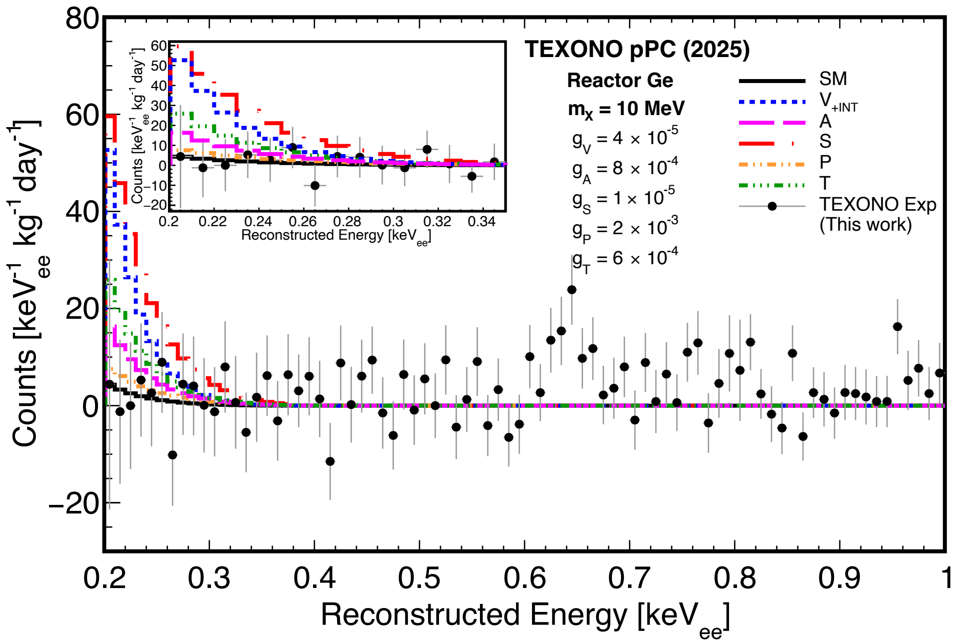
$$Q_F = \frac{k\ g(\epsilon)}{1+k\ g(\epsilon)}$$

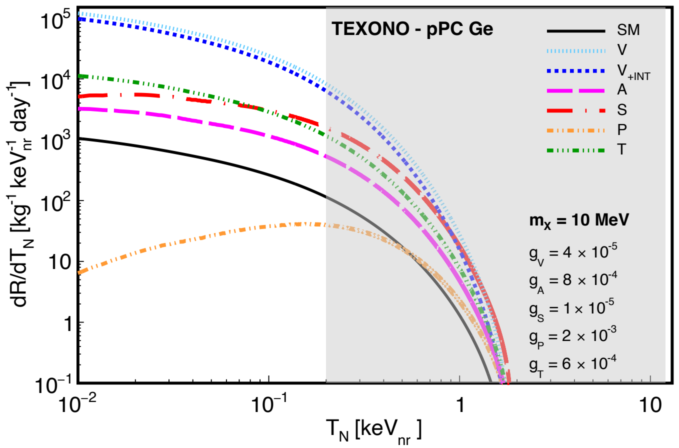
$$g(\epsilon) = 3\epsilon^{0.15} + 0.7\epsilon^{0.6} + \epsilon$$

$$\epsilon = 11.5\ Z^{-7/3}\ T_N$$

**Energy Res:** $\sigma^2 = \sigma_o^2 + E_{ee}\eta F$

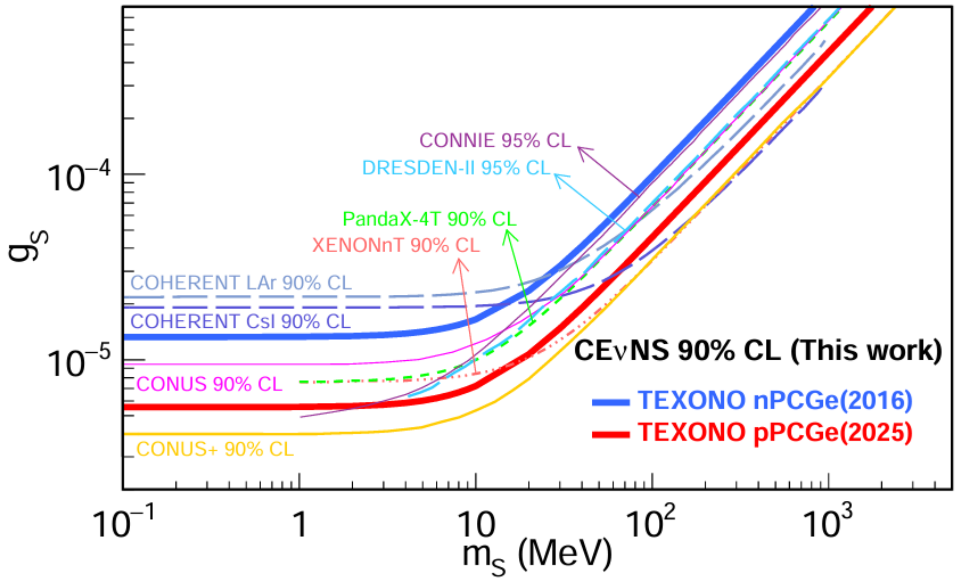
$$R_X = N_{tar}\int_{T_{N_{th}}}^{T_{N_{max}}} dT \int_{E_{\nu_{min}}}^{E_{\nu_{max}}} dE_\nu \frac{d\Phi}{dE_\nu}\left[\frac{d\sigma}{dT_N}\right]_X$$

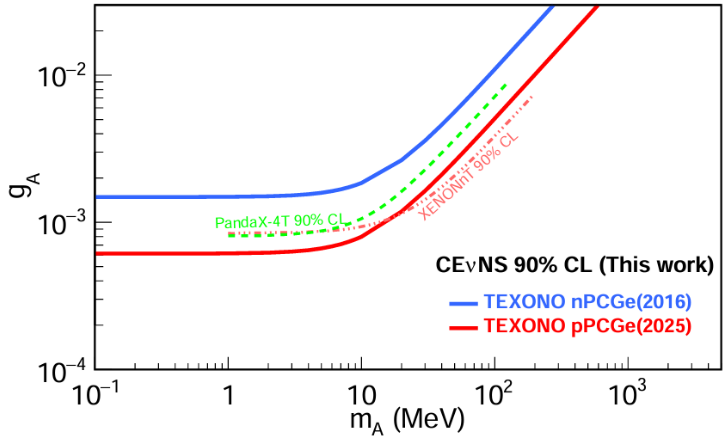


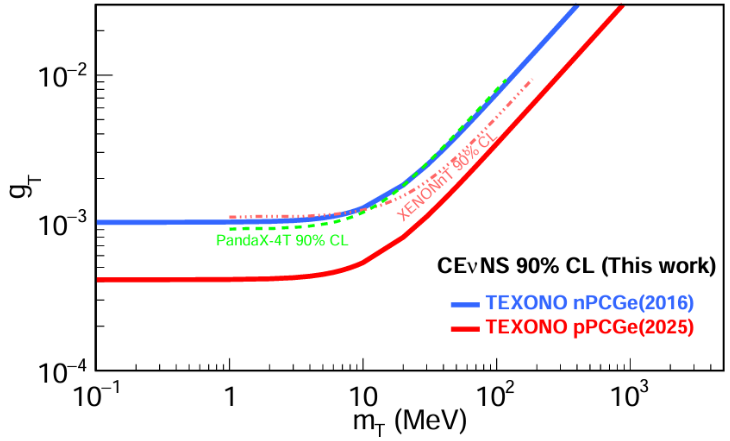



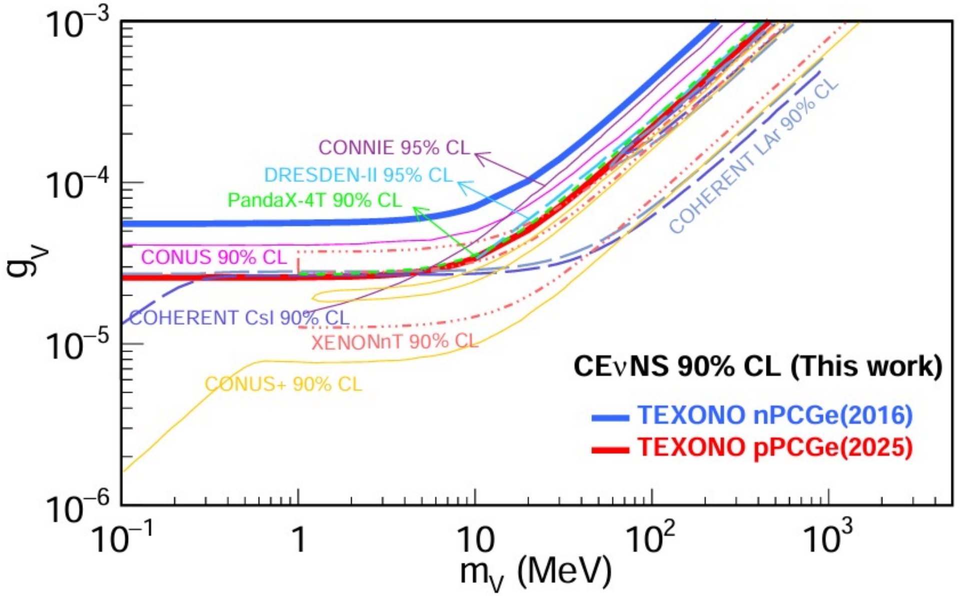
# TEXONO limits on light mediators (S,P,V,A,T)
## (vs. Global bounds)

$$\chi^2 = \sum_i \left[ \frac{R_{\rm expt}(i) - R_{\rm SM}(i) - R_X(i)}{\Delta(i)} \right]^2$$



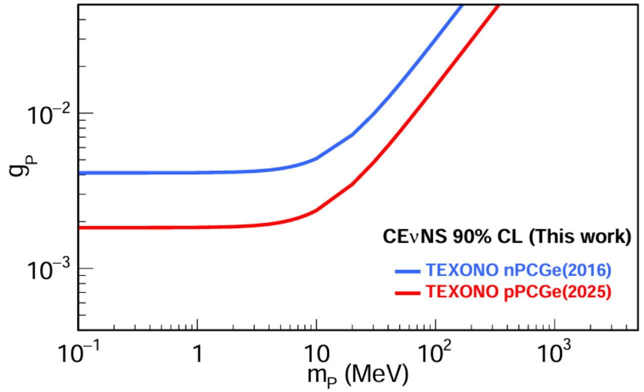




- TEXONO pPCGe (2025) improves over nPCGe (2016),
- and provides competitive bounds worldwide.

- A and T → spin-dependent.
- P → also spin-dependent but suppressed by recoil energy, so spin effects not included here.



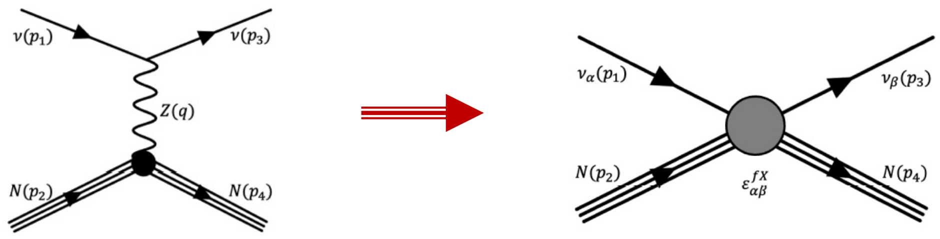


DRESDEN-II : PRD 106,L031702(2022)
CONNIE : JHEP 04(2020)054
CONUS : JHEP 05(2022)085
XENONnT
PandaX-4T : JCAP05(2025)012
CONUS+ : Phys. Lett. B 864 (2025) 139438
Phys. Rev. D 112, 015007
COHERENT : JHEP 2023, 35 (2023)

# Model-independent NSI framework

- NSI described as **four-Fermi point-like** interaction.
  - valid in the heavy mediator limit ($M_X^2 \gg q^2$).
- acts in quark level ⟶ interacting as a non-universal flavor-conserving **(FC)** or flavor-violating **(FV)** process.
- NSI encoded in $\boldsymbol{\varepsilon_{\alpha\beta}^{fX}}$ coupling parameters ⟶ reflects modifications of the SM weak charge.
- determined by **ratio of mediator coupling to mediator mass** (in light mediator models).

$$-\mathscr{L}_{NSI}^{eff} = \frac{G_F}{\sqrt{2}}[\bar{\nu}_\alpha \gamma_\mu (1-\gamma^5)\nu_\beta][\bar{f}\gamma^\mu(\varepsilon_{\alpha\beta}^{fV} - \varepsilon_{\alpha\beta}^{fA}\gamma^5)f]$$




$$Q_{\mathrm{SM}_V} = g_p^V \mathcal{Z} F_{\mathcal{Z}}(q^2) + g_n^V \mathcal{N} F_{\mathcal{N}}(q^2)$$

| SM | SM+NSI(Vectorial) |
|---|---|
| $(g_V^p)^2$ | $(\tilde{g}_V^p)^2 + \sum_{\ell' \neq e}(2\varepsilon_{\alpha e}^{uV} + \varepsilon_{\alpha e}^{dV})^2$ |
| $(g_V^n)^2$ | $(\tilde{g}_V^n)^2 + \sum_{\ell' \neq e}(\varepsilon_{\alpha e}^{uV} + 2\varepsilon_{\alpha e}^{dV})^2$ |
| $g_V^p g_V^n$ | $\tilde{g}_V^p \tilde{g}_V^n + \sum_{\ell' \neq e}(2\varepsilon_{\alpha e}^{uV} + \varepsilon_{\alpha e}^{dV})(\varepsilon_{\alpha e}^{uV} + 2\varepsilon_{\alpha e}^{dV})$ |

$$\varepsilon_{\alpha\beta}^{fX} \simeq \frac{g_{X\nu} g_{XN}}{\sqrt{2} G_F M_X^2}$$

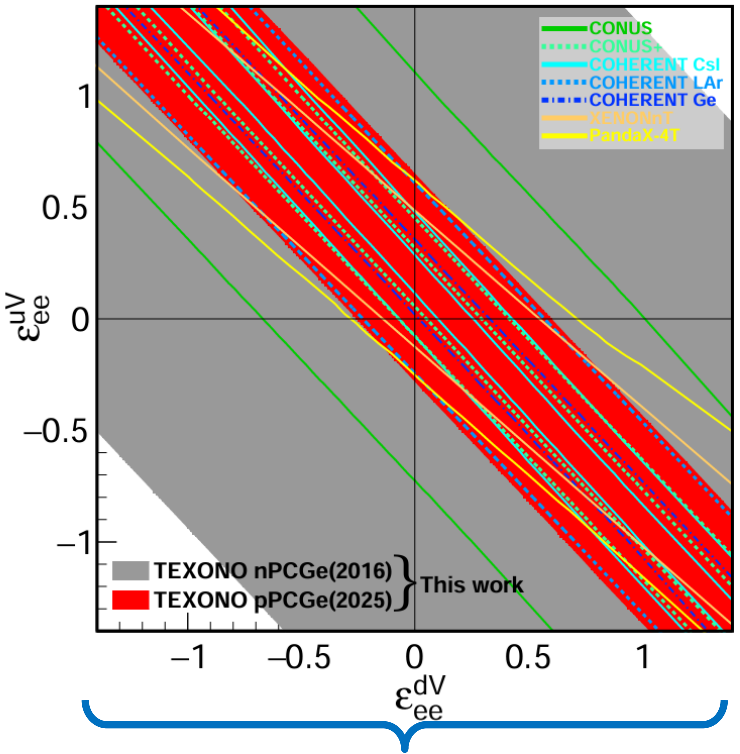
# TEXONO limits from model-independent NSI(Vector-type)

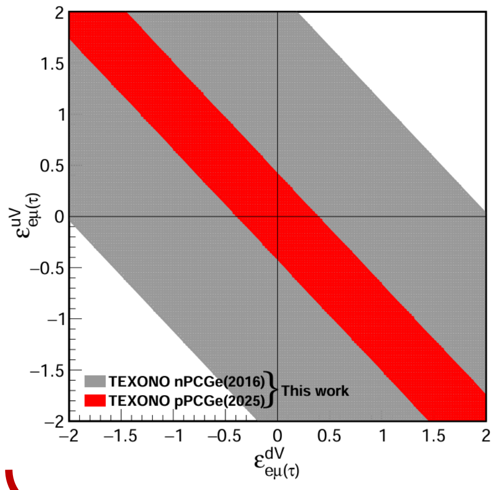
## (vs. Global bounds)

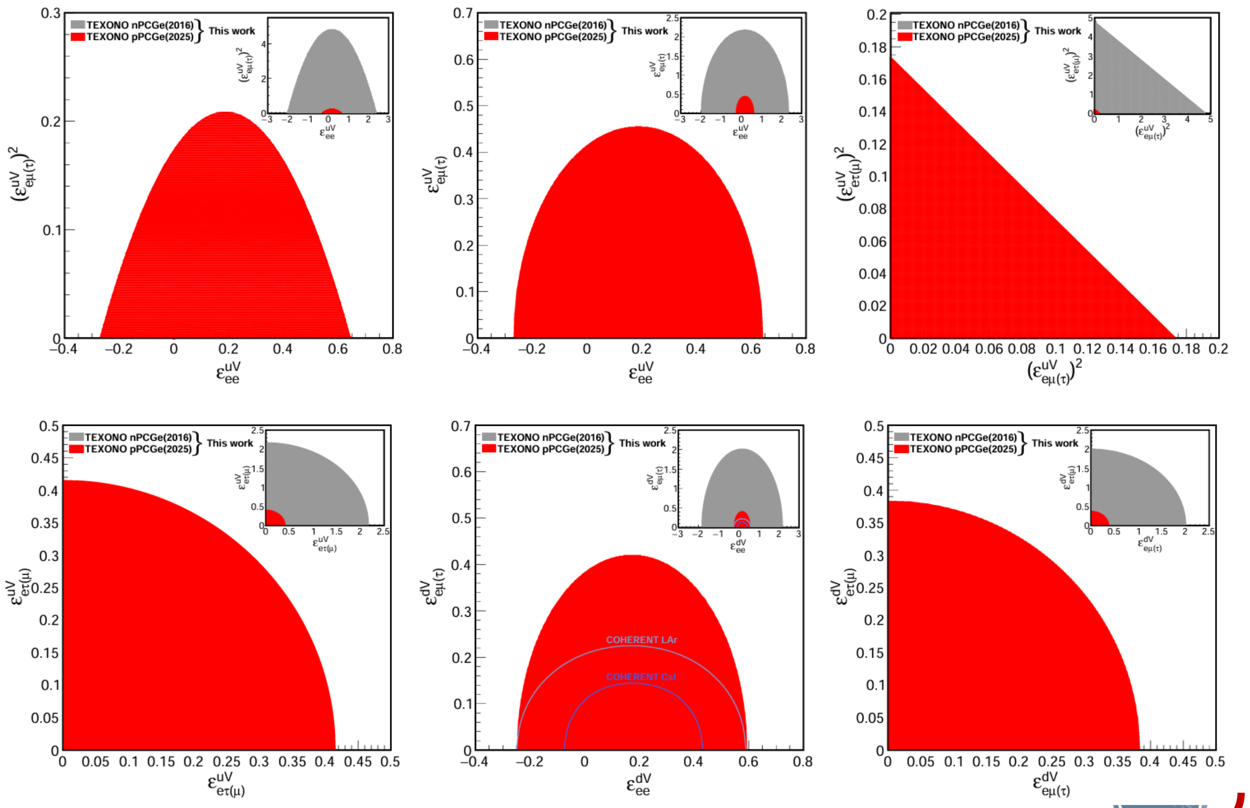
$$\left[\frac{d\sigma}{dT_N}\right]_V^{NSI} = \frac{G_F^2 m_N}{\pi} |F_V(q^2)|^2 \left[\varepsilon_{\alpha\beta}^{uV}(\mathcal{N}+2\mathcal{Z}) + \varepsilon_{\alpha\beta}^{dV}(2\mathcal{N}+\mathcal{Z})\right]^2 \mathcal{K}_V,$$

$$\left[\frac{d\sigma}{dT_N}\right]_{V_{INT}}^{FC} = \frac{G_F^2 m_N}{\pi}|F_V(q^2)|^2 \times \left[\varepsilon_{\alpha\alpha}^{uV}(\mathcal{N}+2\mathcal{Z}) + \varepsilon_{\alpha\alpha}^{dV}(2\mathcal{N}+\mathcal{Z})\right] \times \left[\left(1-4\sin^2\theta_W\right)\mathcal{Z}-\mathcal{N}\right]\mathcal{K}_V,$$

| | Flavor Conserving (FC) | Flavor Violating (FV) |
|---|---|---|
| Vector : $\varepsilon^{qV}$ (q=u,d) | $\varepsilon^{uV}_{ee}$ - $\varepsilon^{dV}_{ee}$ | $\varepsilon^{uV}_{e\mu(\tau)}$ - $\varepsilon^{dV}_{e\mu(\tau)}$ |
| | | $\varepsilon^{qV}_{ee}$ – $\varepsilon^{qV}_{e\mu(\tau)}$ |
| | | $\varepsilon^{qV}_{e\mu(\tau)}$ - $\varepsilon^{qV}_{e\tau(\mu)}$ |



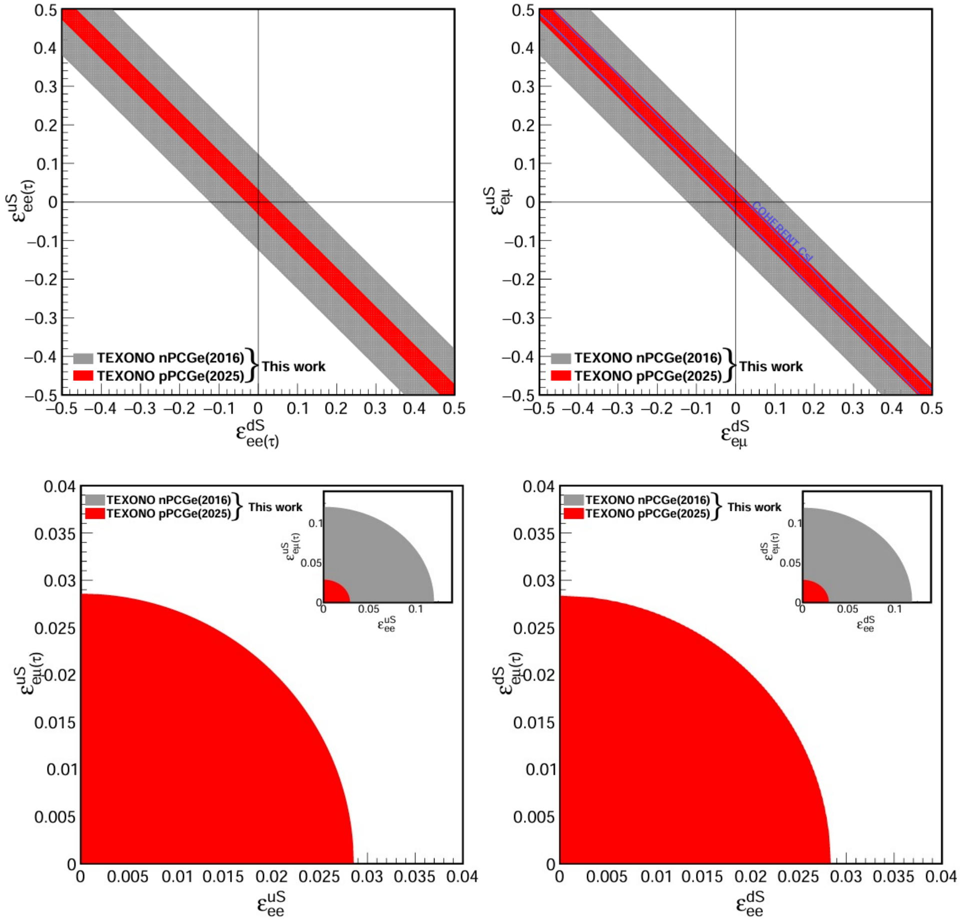



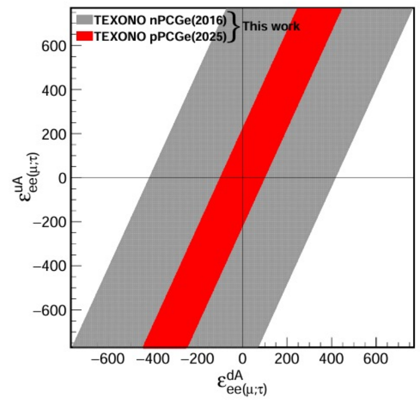
# TEXONO limits from model-independent NSI(SPAT-type)

- a general extension of NSI beyond vector case.

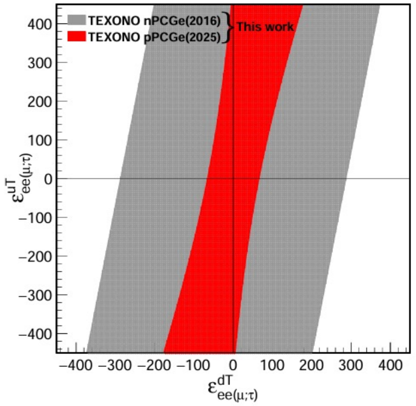
| | FC-FC (or FV-FV) | FC-FV |
|---|---|---|
| SPAT : $\varepsilon^{qX}$ (q=u,d) | $\varepsilon^{uX}_{ee(\mu;\tau)}$ - $\varepsilon^{dX}_{ee(\mu;\tau)}$ | $\varepsilon^{qS}_{ee}$ - $\varepsilon^{qS}_{e\mu(\tau)}$ |



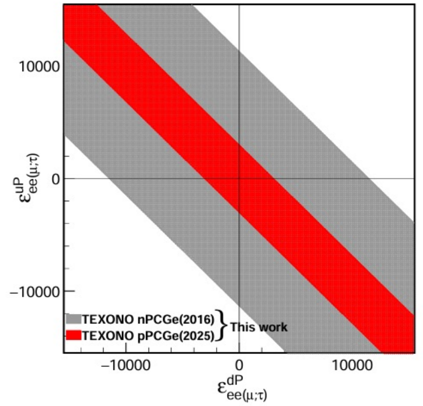

$$\left[\frac{d\sigma}{dT_N}\right]^{NSI}_S = \frac{G_F^2 m_N}{2\pi}|F_S(q^2)|^2 \times \left[\varepsilon^{uS}_{\alpha\beta}\left(\mathcal{N}\frac{m_n}{m_u}f^n_{Tu} + \mathcal{Z}\frac{m_p}{m_u}f^p_{Tu}\right) + \varepsilon^{dS}_{\alpha\beta}\left(\mathcal{N}\frac{m_n}{m_d}f^n_{Td} + \mathcal{Z}\frac{m_p}{m_d}f^p_{Td}\right)\right]^2 \mathcal{K}_S$$




$$\left[\frac{d\sigma}{dT_N}\right]^{NSI}_A = \frac{G_F^2 m_N}{\pi}\left(\frac{8\pi}{2J+1}\right) \times \frac{1}{4}\left[\varepsilon^{uA}_{\alpha\beta}\left(\Delta^p_u\sqrt{S^{\mathcal{T}}_p(q^2)} + \Delta^n_u\sqrt{S^{\mathcal{T}}_n(q^2)}\right) + \varepsilon^{dA}_{\alpha\beta}\left(\Delta^p_d\sqrt{S^{\mathcal{T}}_p(q^2)} + \Delta^n_d\sqrt{S^{\mathcal{T}}_n(q^2)}\right)\right]^2 \mathcal{K}_A$$




$$\left[\frac{d\sigma}{dT_N}\right]^{NSI}_T = \frac{G_F^2 m_N}{\pi}\left(\frac{8\pi}{2J+1}\right) \times \left\{\left[\varepsilon^{uT}_{\alpha\beta}\left(\delta^p_u\sqrt{S^{\mathcal{T}}_p(q^2)} + \delta^n_u\sqrt{S^{\mathcal{T}}_n(q^2)}\right) + \varepsilon^{dT}_{\alpha\beta}\left(\delta^p_d\sqrt{S^{\mathcal{T}}_p(q^2)} + \delta^n_d\sqrt{S^{\mathcal{T}}_n(q^2)}\right)\right]^2 \mathcal{K}_V + \left[\varepsilon^{uT}_{\alpha\beta}\left(\delta^p_u\sqrt{S^{\mathcal{L}}_p(q^2)} + \delta^n_u\sqrt{S^{\mathcal{L}}_n(q^2)}\right) + \varepsilon^{dT}_{\alpha\beta}\left(\delta^p_d\sqrt{S^{\mathcal{L}}_p(q^2)} + \delta^n_d\sqrt{S^{\mathcal{L}}_n(q^2)}\right)\right]^2\left(2 - \frac{2T_N}{E_\nu}\right)\right\}$$




$$\left[\frac{d\sigma}{dT_N}\right]^{NSI}_P = \frac{G_F^2 m_N}{2\pi}|F_P(q^2)|^2 \times \left[\varepsilon^{uP}_{\alpha\beta}\left(\mathcal{N}\frac{m_n}{m_u}\Delta^n_u + \mathcal{Z}\frac{m_p}{m_u}\Delta^p_u\right) + \varepsilon^{dP}_{\alpha\beta}\left(\mathcal{N}\frac{m_n}{m_d}\Delta^n_d + \mathcal{Z}\frac{m_p}{m_d}\Delta^p_d\right)\right]^2 \times \left(1 - \sum_{q'}\frac{\bar{m}}{m_{q'}}\right)^2 \mathcal{K}_P.$$

# Summary & outlook

❖ **CEvNS has evolved** from a theoretical prediction to an observable phenomenon → enabling a **rich research program** across neutrino properties, DM detection, BSM physics…

➢ **Non-Standard Interactions (NSI):**
- Provide a powerful framework to explore **new physics BSM and constrain NSI parameters** (SPVAT).
- Our analysis

  → **light mediator models** and **model-independent NSI generalized to all Lorentz-invariant picture.**

  → **TEXONO pPCGe (2025) and nPCGe (2016)** data.

❑ **TEXONO:**
- ❑ capable of **probing NSI effects with competitive sensitivity, with** improved low thresholds and exposure.
- ❑ TEXONO complements other CEvNS efforts and is emerging as a **competitive player** in the global research landscape—alongside CONUS+,COHERENT, CONNIE, and Dresden-II.
- ❑ **Next** → $\nu - e$ scattering channel with combined TEXONO CsI(Tl) + Ge data.

# *Thank you*
# *for your attention...*

***References:***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