GLOBAL FITS AT THE PRECISION FRONTIER: TESTING THE STANDARD MODEL WITH NEUTRINOS

Francesca Dordei et al. | francesca.dordei@cern.ch

PRL 135, 231803 (2025)

SCAN ME

*M. Atzori Corona, M. Cadeddu, N. Cargioli, **F. Dordei**, C. Giunti, C. A. Ternes*

NEUTRINO '26
International Conference on Neutrino Physics and Astrophysics
June 22nd - 26th, 2026

INFN CAGLIARI

SCAN ME

The Low-Energy Neutrino Scattering fit
LEνS-fit

Introduction

The **Standard Model** (SM) of particle physics is our best description of particles and their interactions.

- Highly predictive, but with many free parameters.
- Clearly not the ultimate theory of particle physics.

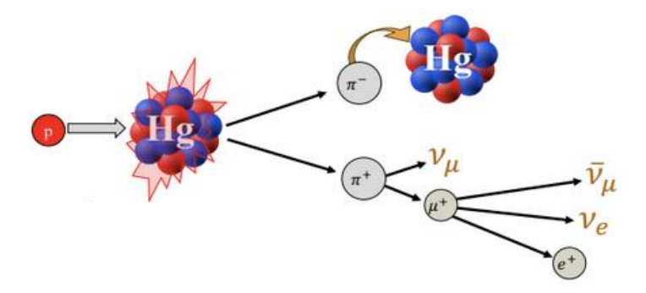
Neutrinos are special players to test the SM

- Interact only weakly;
- Beyond the SM "by nature";
- A sector with several anomalous results.

See **M. Cadeddu's poster**: "*Resolving the gallium anomaly: sterile neutrinos and the breakdown of the factorization of leptonic wavefunctions*"

The low-energy sector, in particular, is not well explored. Possible **neutrino sources** for these studies are:

Accelerators

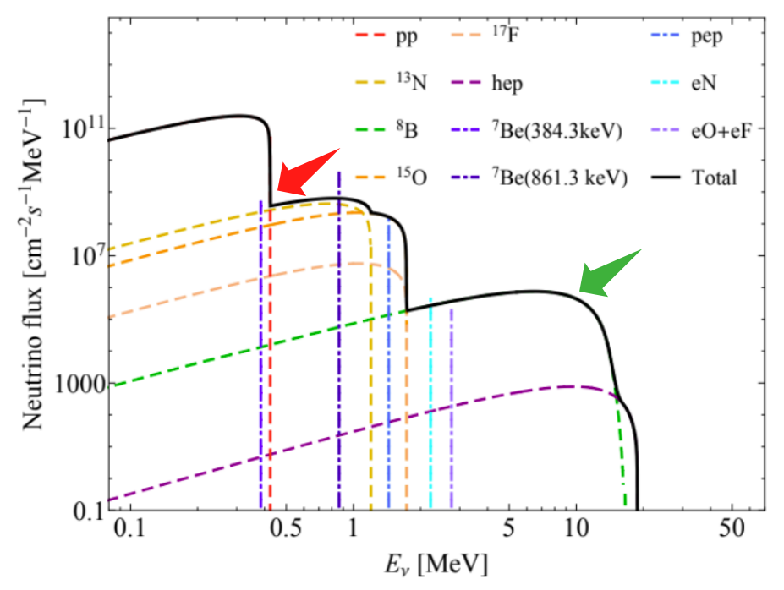


Both muon and electron flavors
$E_\nu \sim 30$ MeV (up to 50 MeV)

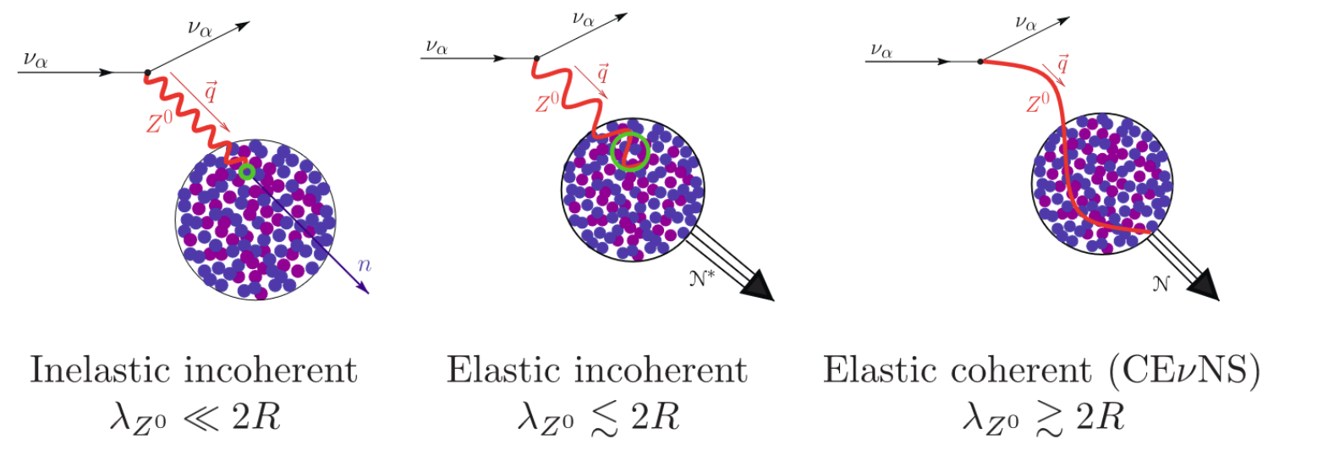
Reactors

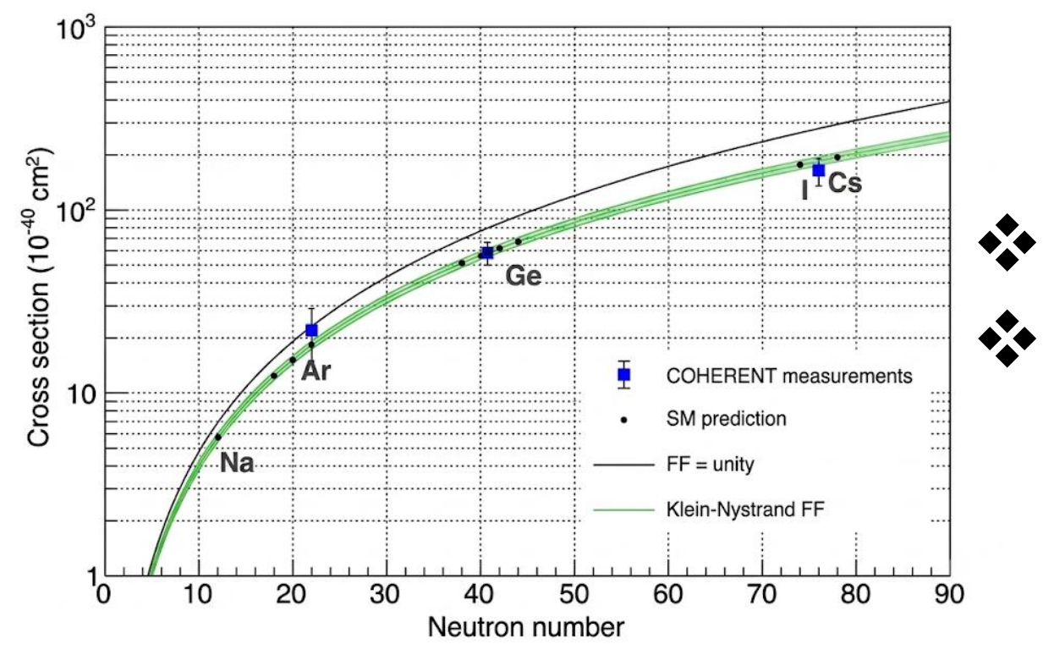
Only $\bar{\nu}_e$
$E_\nu \sim 1$-10 MeV

All active flavors at detection
$E_\nu \lesssim 16$ MeV



At low energies we can consider mainly **two processes**:





- ❖ **νES**: neutrino-Electron Elastic Scattering
- ❖ **CEνNS**: Coherent Elastic neutrino-Nucleus Scattering

Observed in 2017 for the first time by COHERENT!
[M. Cadeddu et al., EPL, 143 3 (2023) 34001]

Recipe for a global fit

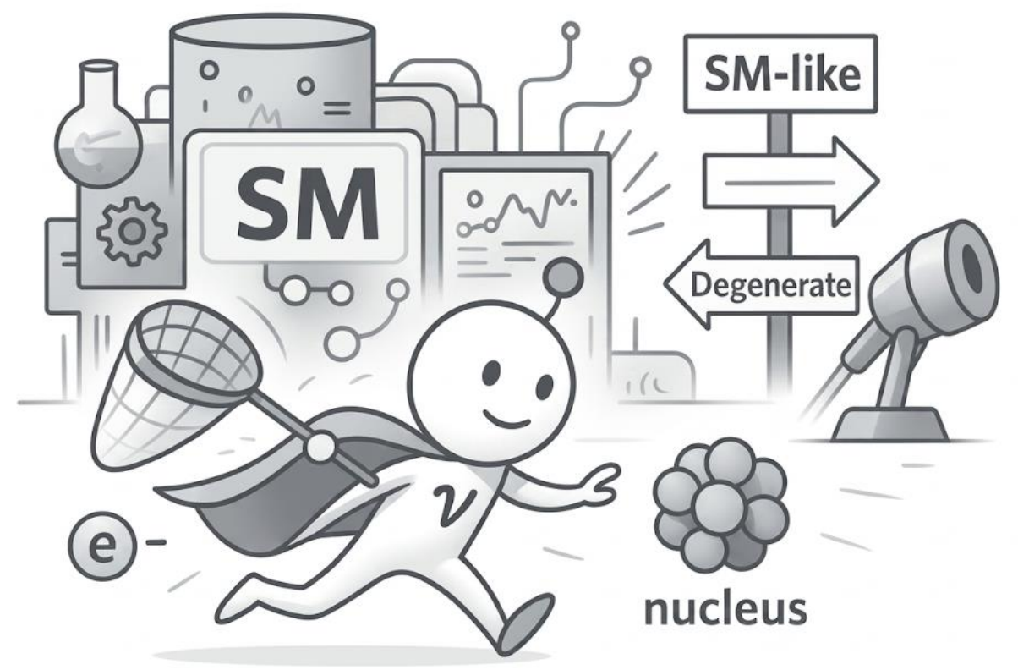
Accelerator Neutrinos
- ❑ COHERENT CsI
- ❑ COHERENT LAr
- ❑ COHERENT Ge
- ❑ LSND
- ❑ LAMPF
- ❑ BNL-E734
- ❑ CHARM-II
- ❑ CCFR

Solar Neutrinos
- ❑ Lux-Zeplin
- ❑ PandaX-4T
- ❑ XENONnT

Reactor (anti-)Neutrinos
- ❑ TEXONO Ge
- ❑ νGEN
- ❑ CONUS+
- ❑ TEXONO CsI

We **combine for the first time** all available measurements of the processes:

■ CEνNS ■ νES ■ CEνNS and νES



Key ingredients:

- ✓ Same theoretical framework;
- ✓ Consistent assumptions;
- ✓ Correct for the differences in energies among experiments;
- ✓ Account for the different ν flavors.

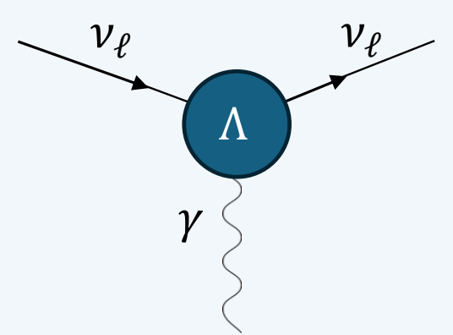
Neutrino charge radius

[Phys. Rev. Lett. 135, 231803 (2025), arXiv:2504.05272]

SCAN ME

The **neutrino charge radius** (NCR):

- ❑ Exists even if the neutrino is neutral and nearly massless;
- ❑ The **only non-zero electromagnetic neutrino property** predicted by the SM;
- ❑ The only flavor-dependent contribution to CEνNS;
- ❑ Treated as a **radiative correction** in the cross-section definition;
- ❑ Defined at zero momentum transfer.



Higher order interaction with photons!

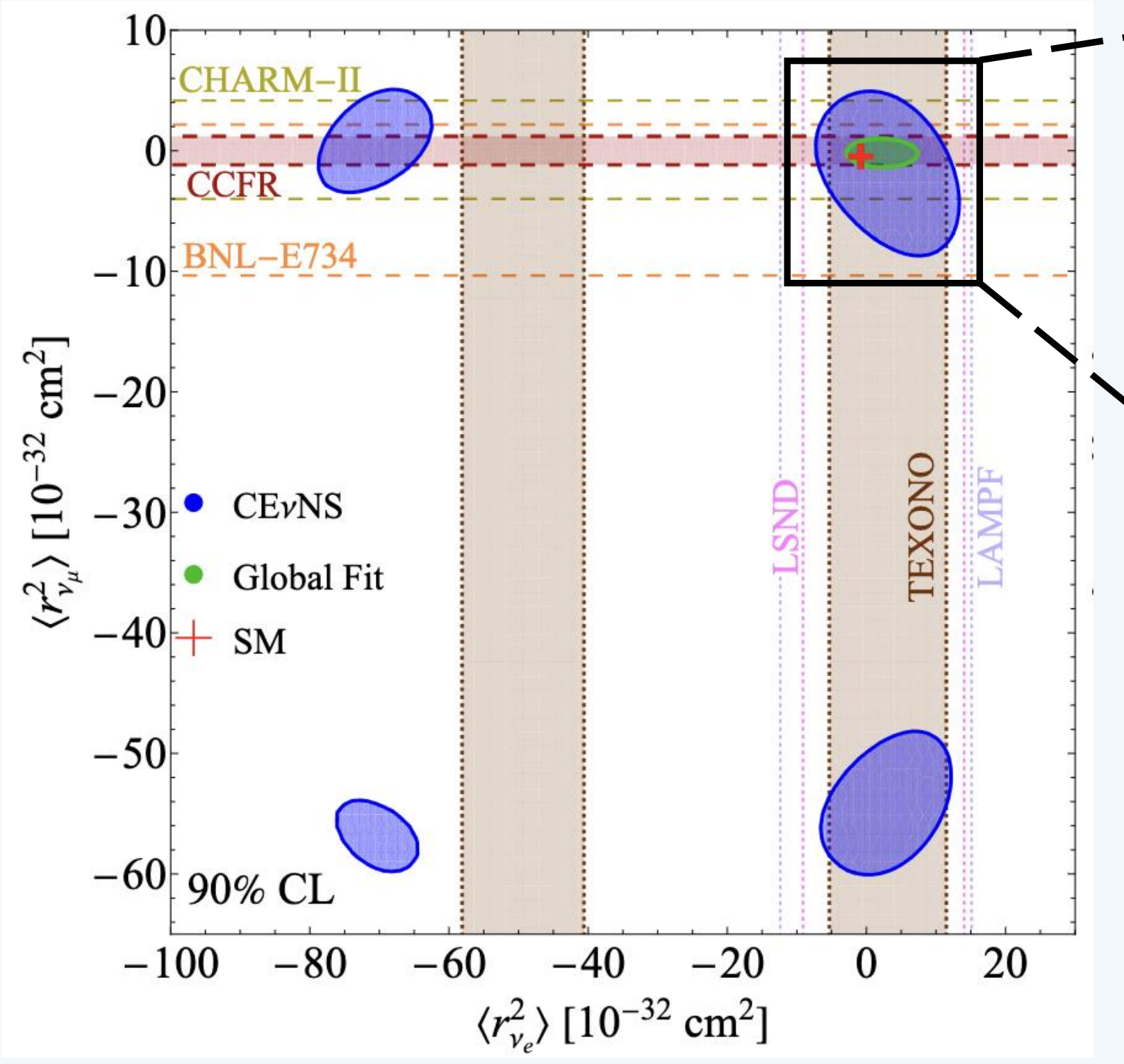
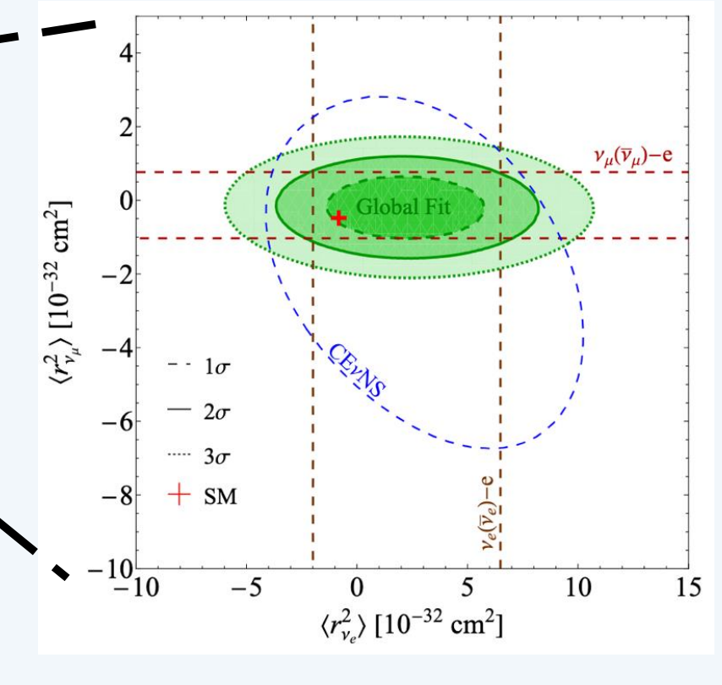
$$\langle r^2_{\nu_\ell}\rangle_{\rm SM} = -\frac{G_F}{2\sqrt{2}\pi^2}\left[3 - 2\ln\left(\frac{m_\ell^2}{m_W^2}\right)\right]$$

We account for the fact that **none of the experiments is performed at zero momentum transfer**.

$$\boxed{\langle r^2_{\nu_\ell}\rangle^{\rm eff} = \frac{6G_F}{\sqrt{2}\pi\alpha}\,\phi^{\rm eff}_{\nu_\ell W}(q^2) = -\frac{G_F}{2\sqrt{2}\pi^2}\left[3 - 12R_\ell(q^2)\right]}$$

[M. Atzori Corona et al., JHEP05 (2024) 271]

SCAN ME

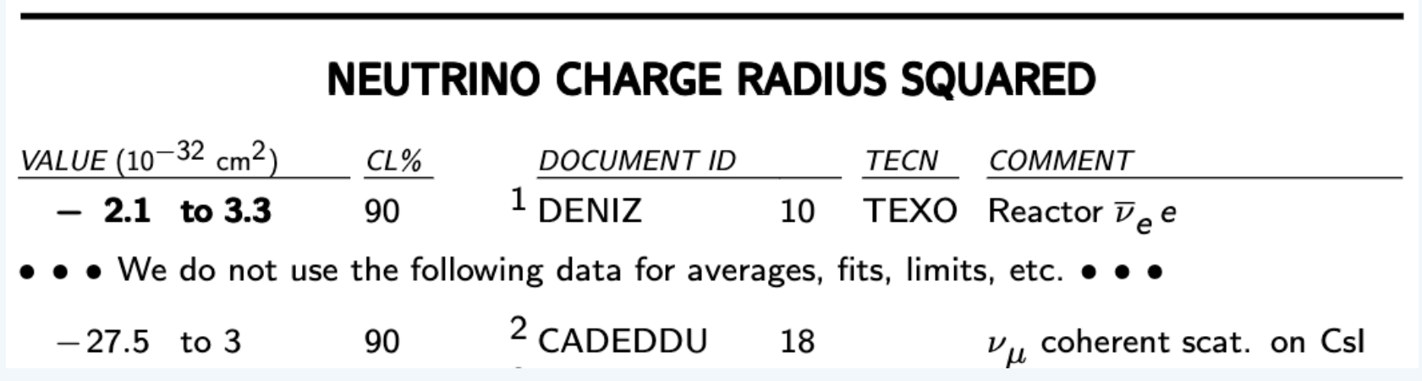
Combining all data, we are able to select one single allowed region!

Global fit results:

$$\langle r^2_{\nu_e}\rangle = 2.2^{+2.4}_{-2.3}\text{x}10^{-32}\text{cm}^2$$
$$\langle r^2_{\nu_\mu}\rangle = -0.19^{+0.55}_{-0.56}\text{x}10^{-32}\text{cm}^2$$
$$\langle r^2_{\nu_\tau}\rangle = 7.5^{+8.9}_{-12}\text{x}10^{-32}\text{cm}^2$$

SM predictions:

$$\langle r^2_{\nu_e}\rangle_{\rm SM} \cong -0.83\text{x}10^{-32}\text{cm}^2$$
$$\langle r^2_{\nu_\mu}\rangle_{\rm SM} = -0.48\text{x}10^{-32}\text{cm}^2$$
$$\langle r^2_{\nu_\tau}\rangle_{\rm SM} = -0.30\text{x}10^{-32}\text{cm}^2$$



NEUTRINO CHARGE RADIUS SQUARED

VALUE (10^{-32} cm^2)	CL%	DOCUMENT ID		TECN	COMMENT
− **2.1 to 3.3**	90	[1] DENIZ	10	TEXO	Reactor $\bar{\nu}_e e$
• • • We do not use the following data for averages, fits, limits, etc. • • •					
−27.5 to 3	90	[2] CADEDDU	18		ν_μ coherent scat. on CsI

Our limits in the latest version of the PDG!

Future CEνNS detectors will reach a precision level similar to that of the current global fit! [M. Atzori Corona et al., Universe 2025, 11(12), 416]

Neutral current couplings

[Phys. Rev. Lett. 135, 231803 (2025), arXiv:2504.05272]

SCAN ME

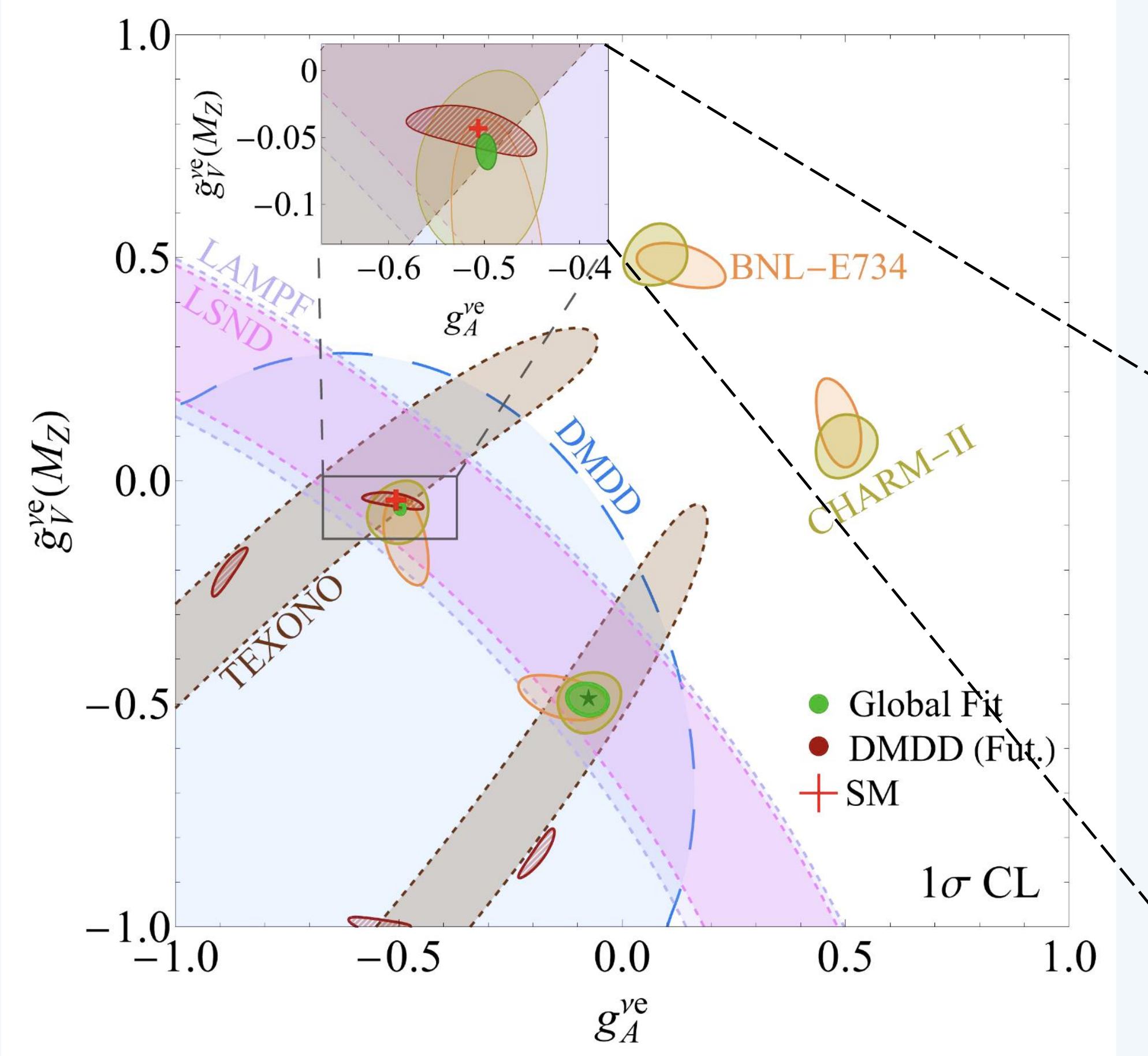
Looking at the basis of the EW theory, we can constrain the **neutral current couplings**:

$$\frac{d\sigma^{\rm free}_{\nu_\ell e}(E_\nu,T_e)}{dT_e} \cong \frac{G_F^2\, m_e}{2\pi}\left[\left(g_V^{\nu_\ell} + g_A^{\nu_\ell}\right)^2 + \left(g_V^{\nu_\ell} - g_A^{\nu_\ell}\right)^2\left(1 - \frac{T_e}{E_\nu}\right)^2 - \left(g_V^{\nu_\ell\,2} - g_A^{\nu_\ell\,2}\right)\frac{m_e T_e}{E_\nu^2}\right]$$

Differences from the PDG approach:

- ❑ Includes more experimental data;
- ❑ Correct for the flavor-dependent contribution;
- ❑ Correct for the different energy scales.

- Global fit of νES scattering data from **Reactors**, **Accelerators** and **Solar neutrinos**.
- Combining all data we select two allowed regions.



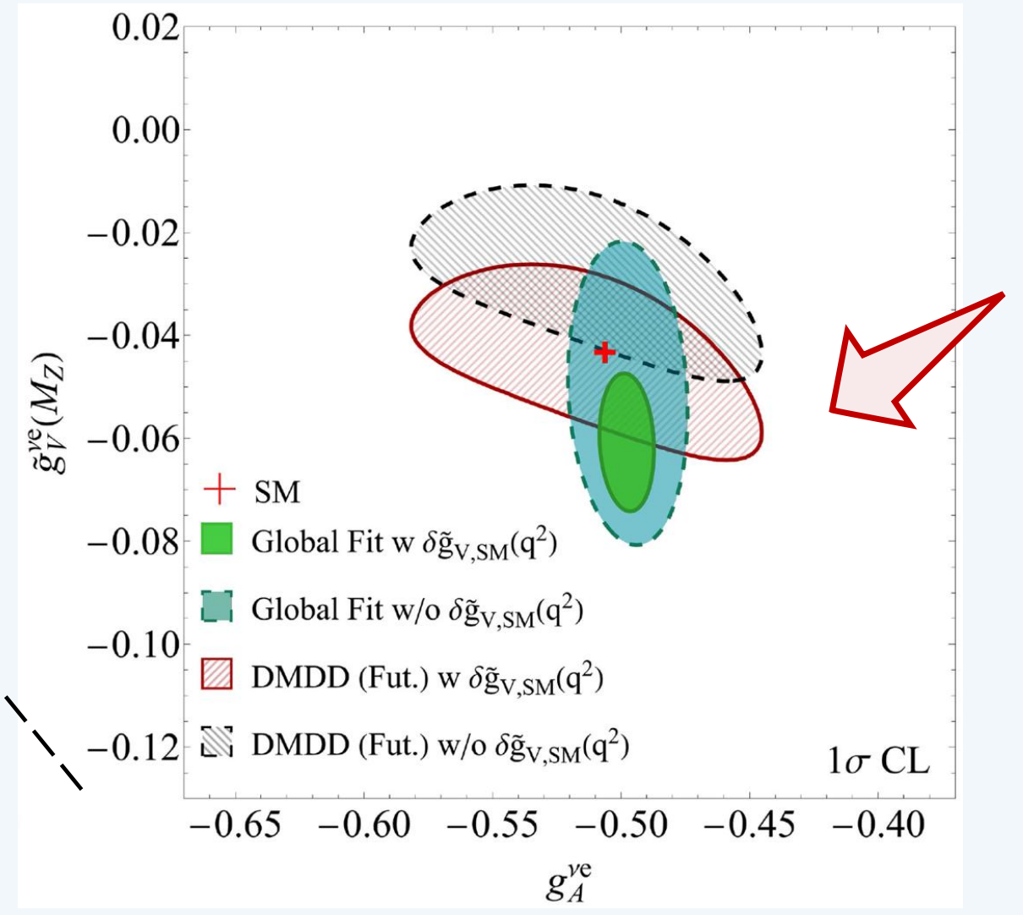
The Global fit mildly prefers the degenerate solution ($\Delta\chi^2 \approx 2.1$ for 2 d.o.f.):

$$\boxed{\begin{aligned}\tilde{g}_V^{\nu_e}(M_Z) &= [-0.53,-0.45] \cup [-0.08,-0.03]\\ g_A^{\nu_e} &= [-0.52,-0.48] \cup [-0.13,-0.03]\end{aligned}}$$

@90% C.L.

To be compared to the SM calculation:

$$\boxed{\begin{aligned}\tilde{g}_{V,\,\rm SM}^{\nu_e}(M_Z) &= -0.0433\\ g_{A,\rm SM}^{\nu_e} &= -0.5062\end{aligned}}$$



- ✓ **Future DM detectors** could break the degeneracy!
- ✓ The momentum dependent correction will be fundamental to interpret future data.

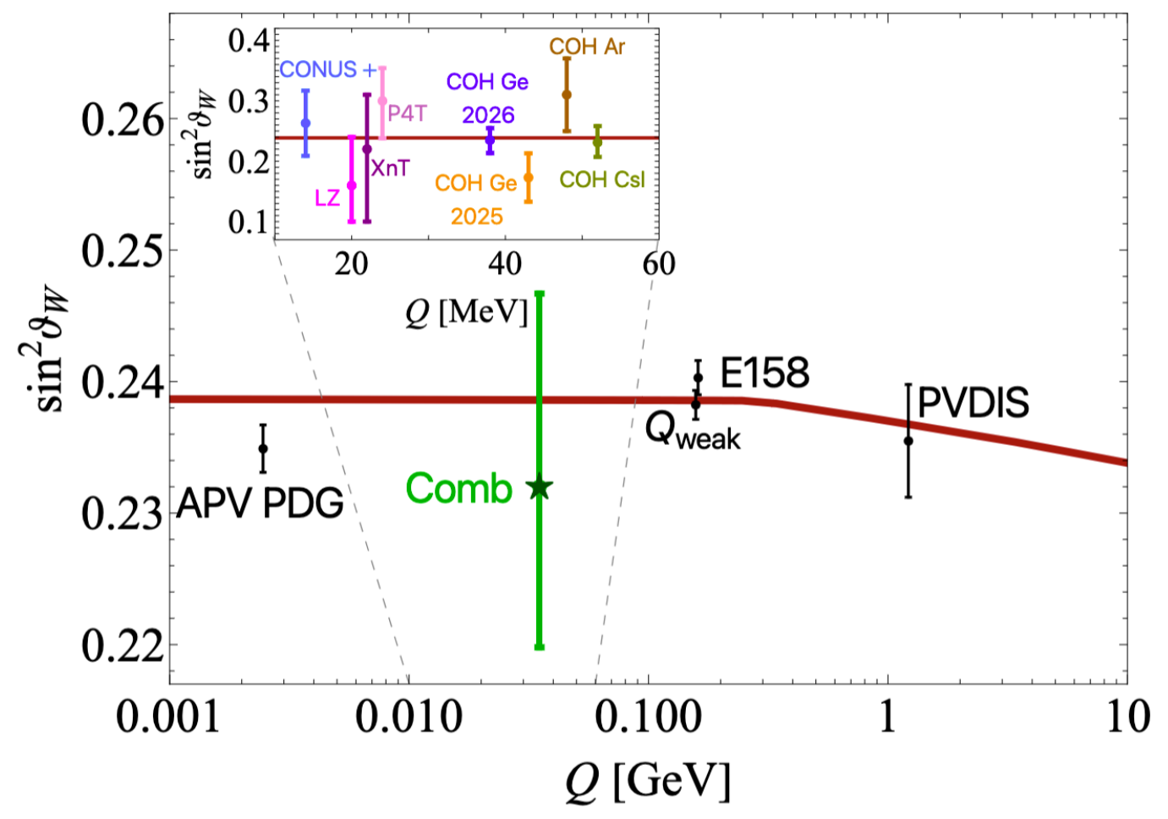
New COHERENT Ge results

NEW

First phenomenological analysis of the newly released CEνNS data on germanium by COHERENT.
[COHERENT, arXiv:2603.17951]

$$\frac{d\sigma^{\rm CE\nu NS}(E_\nu,E_r)}{dE_r} \cong \frac{G_F^2\, m_N}{4\pi}\left(1 - \frac{m_N E_r}{2E_\nu^2}\right)\left[g_V^p\left(\sin^2(\vartheta_W)\right) Z F_Z\left(|\vec{q}|^2\right) + g_V^n N F_N\left(|\vec{q}|^2\right)\right]^2 + \dots$$

Neutrino energy
Mass of the nucleus
SM vector proton coupling
SM vector neutron coupling
NSI, new ν properties
Nuclear recoil energy
Weak mixing angle
Proton Form Factor
Neutron Form Factor



$g_V^p = 1 - 4\sin^2(\vartheta_W) \sim 0.05$. Moreover Z<N, so the contribution of the proton form factor is negligible, but still allows measuring the **weak mixing angle at low energies**:

$$\boxed{\sin^2(\vartheta_W) = 0.234^{+0.015}_{-0.012}}$$

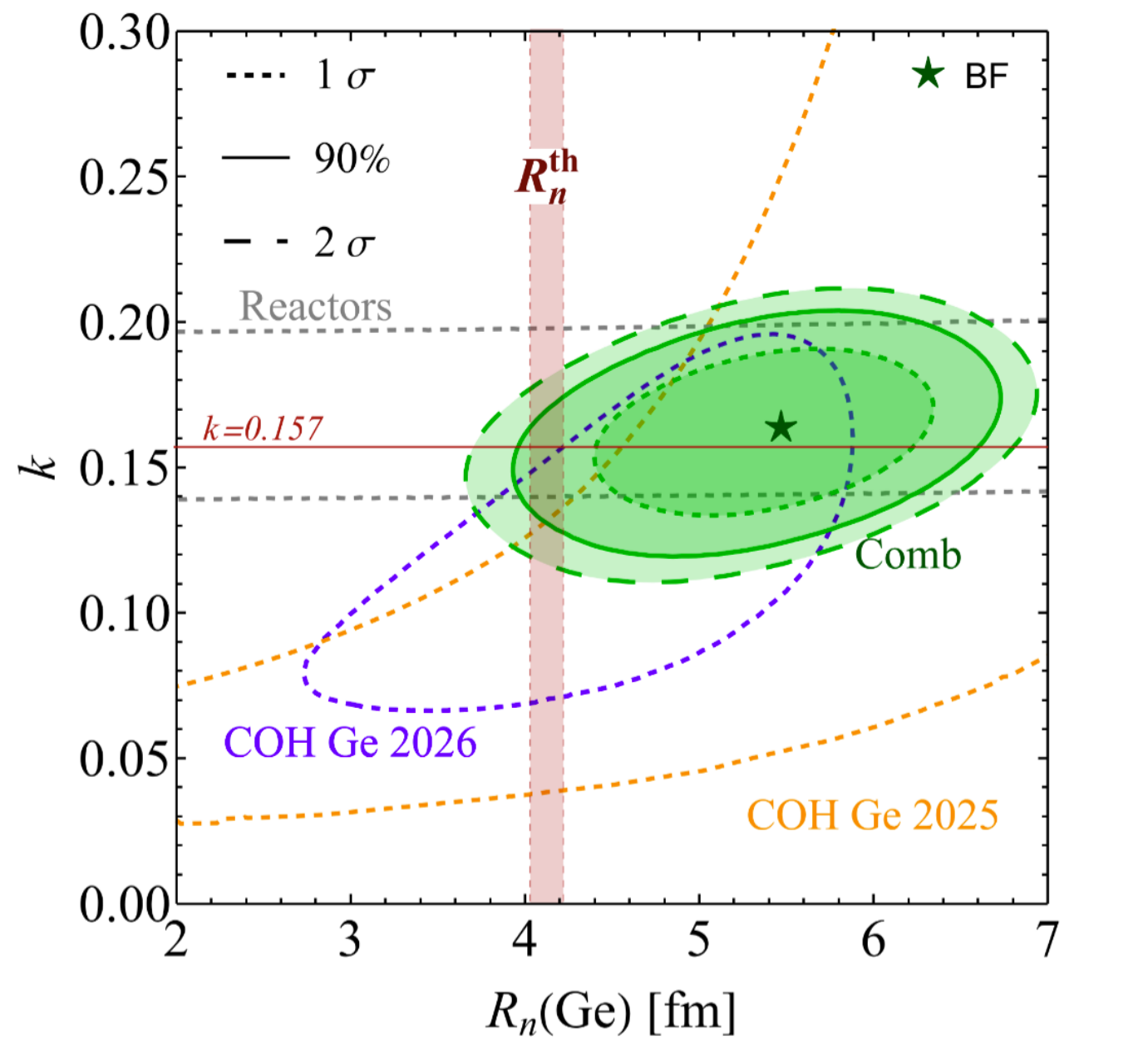
representing the current state of the art based on all CEνNS probes.

Combining both 2024 and 2026 Ge datasets, the **neutron rms radius of germanium** is

$$\boxed{R_n({\rm Ge}) = 5.37^{+0.59}_{-0.62}\ {\rm fm}}$$

We tested its dependence on the standard **Lindhard quenching factor** framework, described by the $\mathcal{K}$ parameter, which encapsulates the response to nuclear recoils relative to the electron ones.

- Our fit clearly reveals a **correlation in the $\mathcal{K} - R_n(\text{Ge})$ plane**!



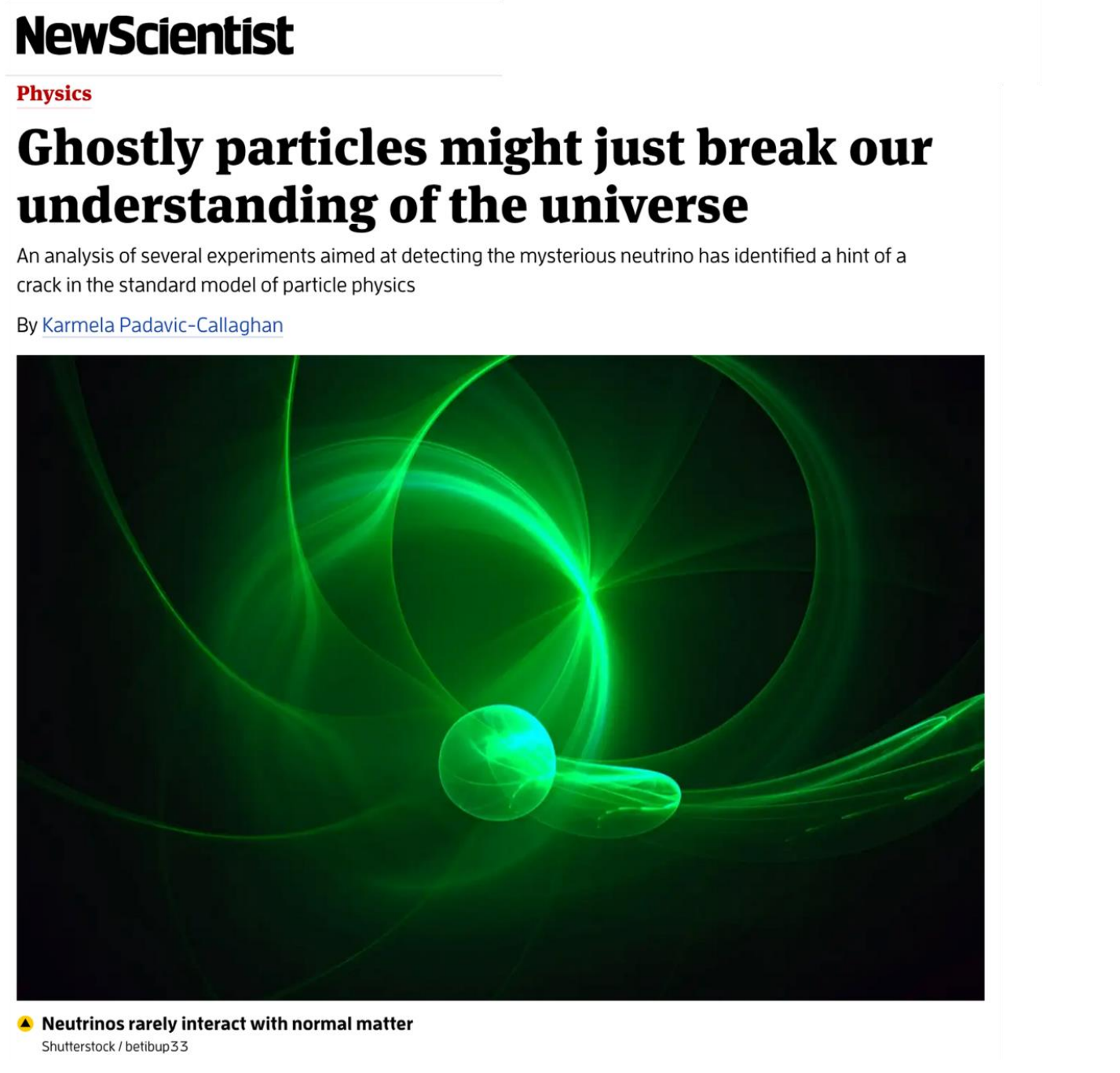
SCAN ME

Read our latest work to see more measurements and constraints on SM and beyond the SM quantities!
[M. Atzori Corona et al., arXiv:2605.07975]

Conclusions

Low energy **neutrinos provide a powerful tool for testing the SM**, especially when combining data into a **global fit**.

- CEνNS and νES data provide **complementary info**! We can break degeneracies if we properly account for:
  - ❑ Radiative corrections;
  - ❑ Flavor-dependent contributions;
  - ❑ Energy-scale dependences.
- (Un)fortunately SM looks pretty well so far!



NewScientist

Physics

Ghostly particles might just break our understanding of the universe

An analysis of several experiments aimed at detecting the mysterious neutrino has identified a hint of a crack in the standard model of particle physics

By Karmela Padavic-Callaghan

Neutrinos rarely interact with normal matter

Shutterstock / betibup33