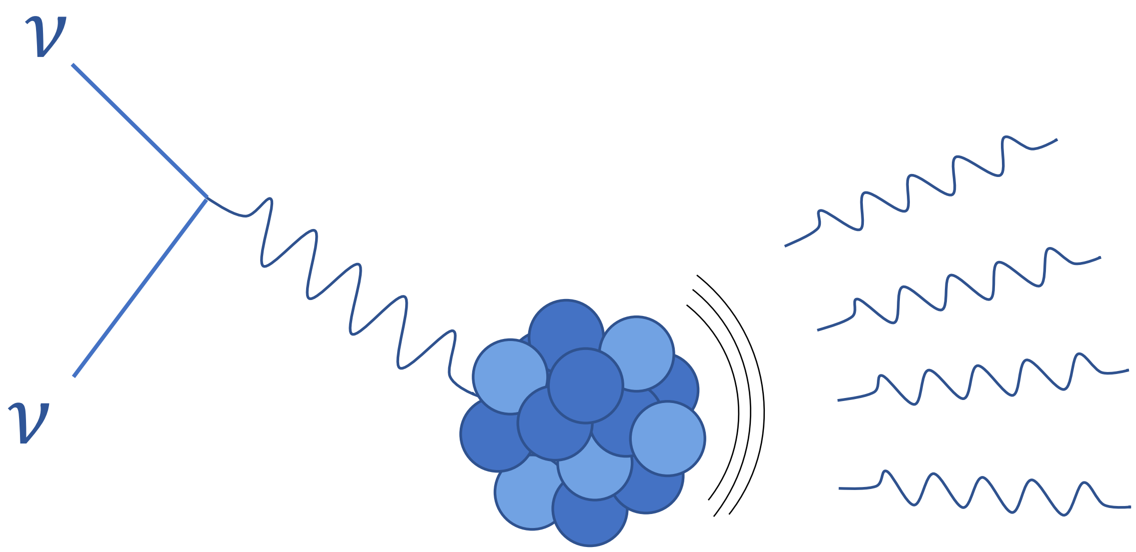
Constraining new physics with Coherent Elastic Neutrino-Nucleus Scattering



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ICHEP 2024, Prague

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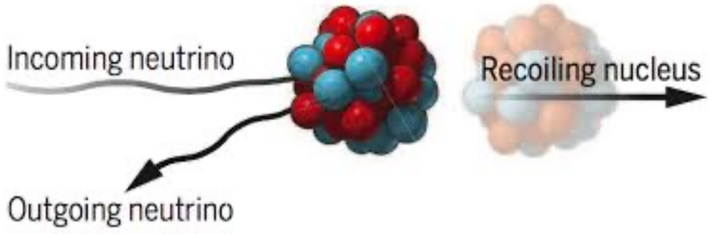
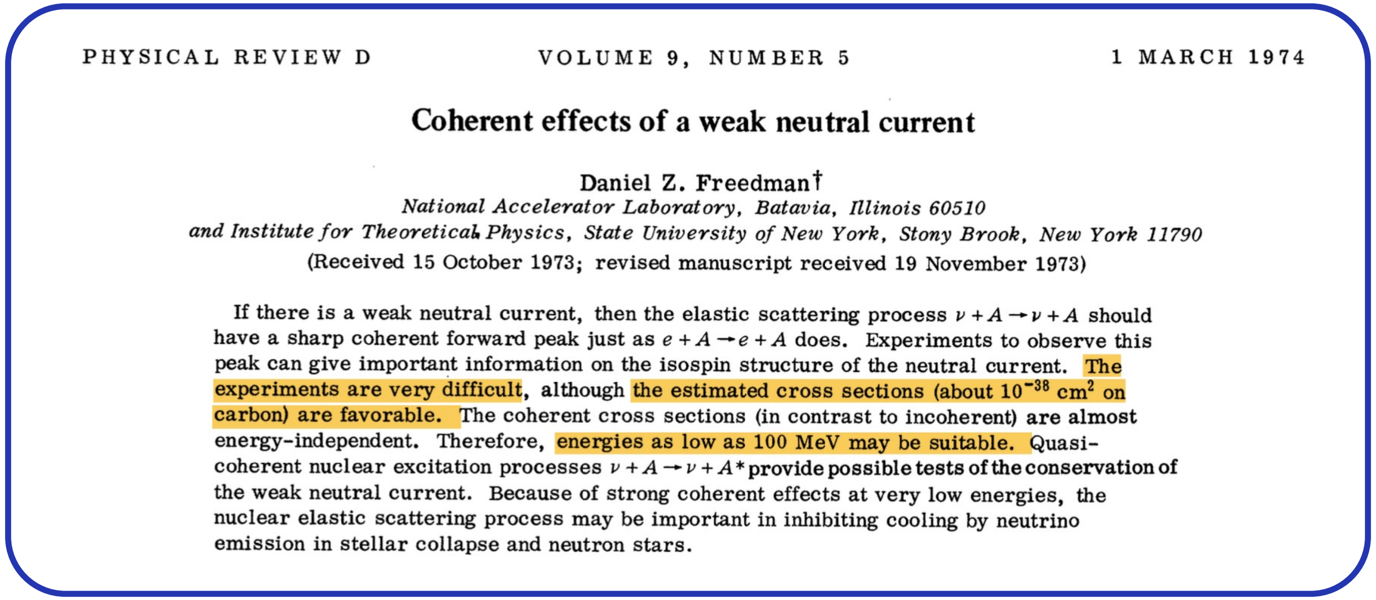
Outline

- Coherent Elastic Neutrino Nucleus Scattering.
- The COHERENT Experiment.
- Future experimental prospects.
- Phenomenolgy of CEνNS.
- Conclusions.

Coherent
Elastic
Neutrino
Nucleus
Scattering



D. Z. Freedman, Phys. Rev. D 9 (1974)
COHERENT Collaboration, Science 357 (2017) 6356



PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

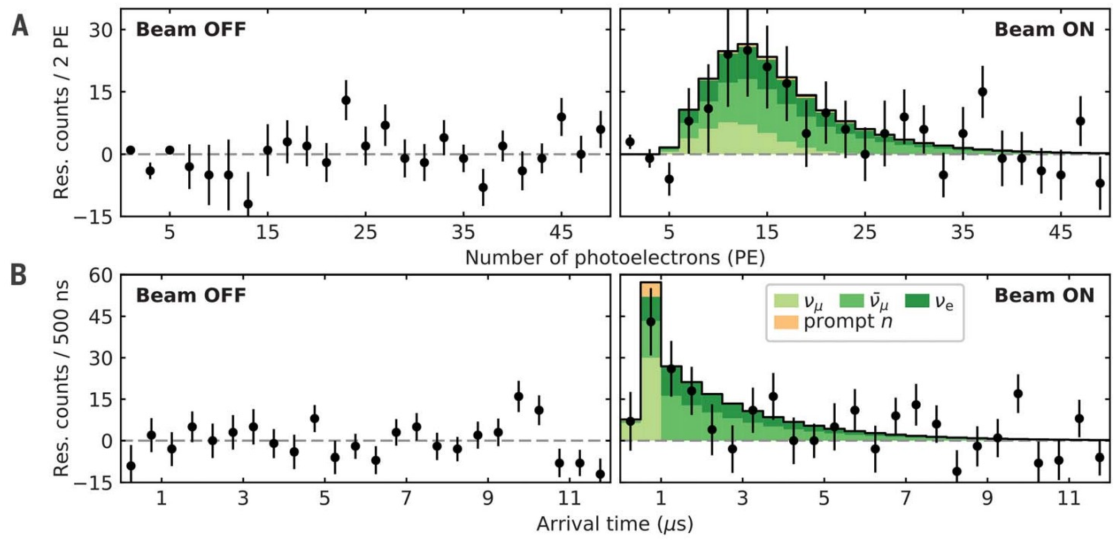
Coherent effects of a weak neutral current

Daniel Z. Freedman†
National Accelerator Laboratory, Batavia, Illinois 60510
and Institute for Theoretical Physics, State University of New York, Stony Brook, New York 11790

(Received 15 October 1973; revised manuscript received 19 November 1973)

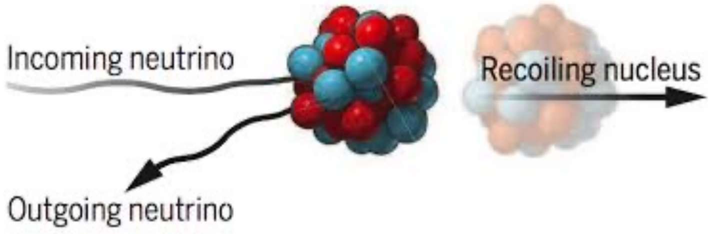
If there is a weak neutral current, then the elastic scattering process $\nu + A \to \nu + A$ should have a sharp coherent forward peak just as $e + A \to e + A$ does. Experiments to observe this peak can give important information on the isospin structure of the neutral current. The experiments are 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.

50 years since first proposal by Freedman!



7 years since first detection by COHERENT!

Coherent **E**lastic **ν**eutrino **N**ucleus **S**cattering



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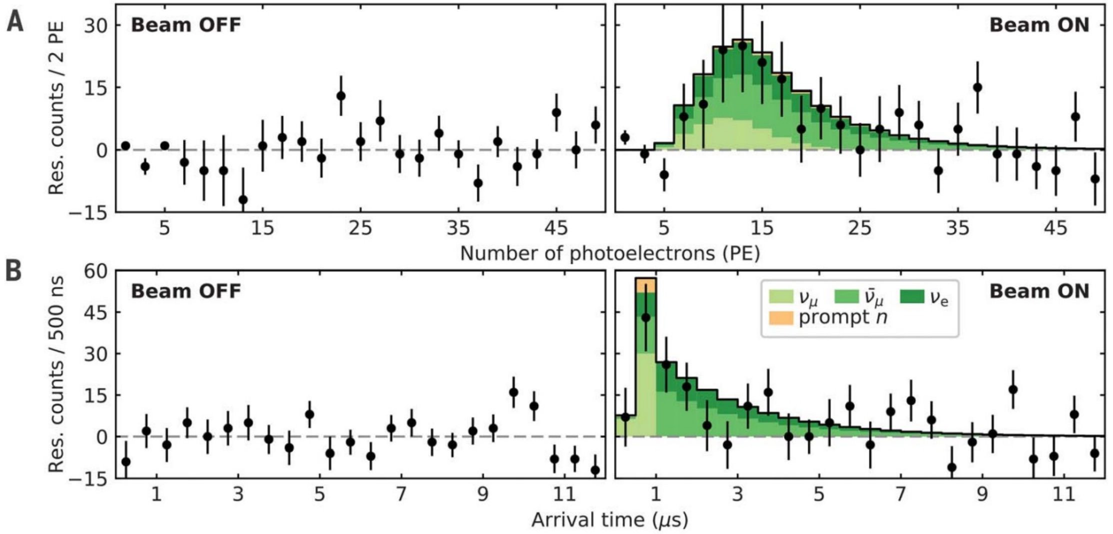

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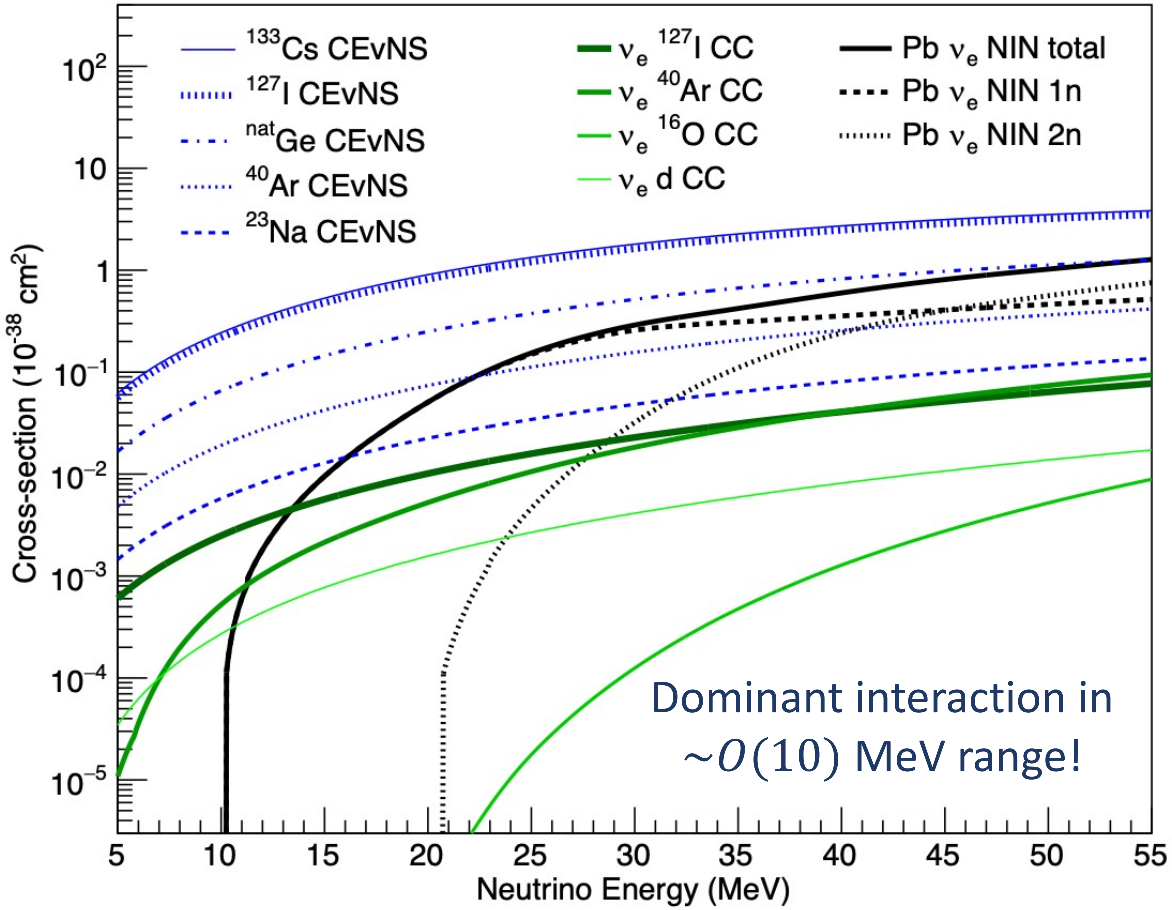
CEνNS as a Standard Model prediction

A neutral current process



Diana Parno's Talk at Magnificent CEvNS 2024

The good news

- Large cross section.
- Small detectors needed.

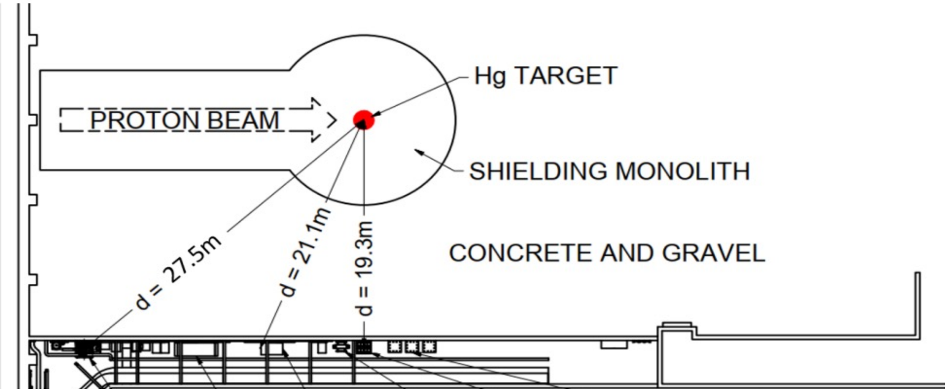
$$\left.\frac{d\sigma_{\nu\mathcal{N}}}{dE_{\mathrm{nr}}}\right|^{\mathrm{SM}}_{\mathrm{CE}\nu\mathrm{NS}} = \frac{G_F^2 m_N}{\pi} F_W^2(|\vec{q}|^2)\left(Q_V^{\mathrm{SM}}\right)^2\left(1 - \frac{m_N E_{\mathrm{nr}}}{2E_\nu^2}\right)$$

The not so good news

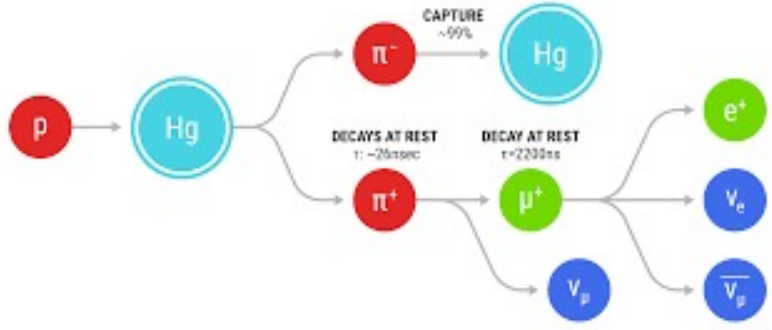
- Very low energy thresholds needed.

Measuring CEνNS at the Spallation Neutron Source

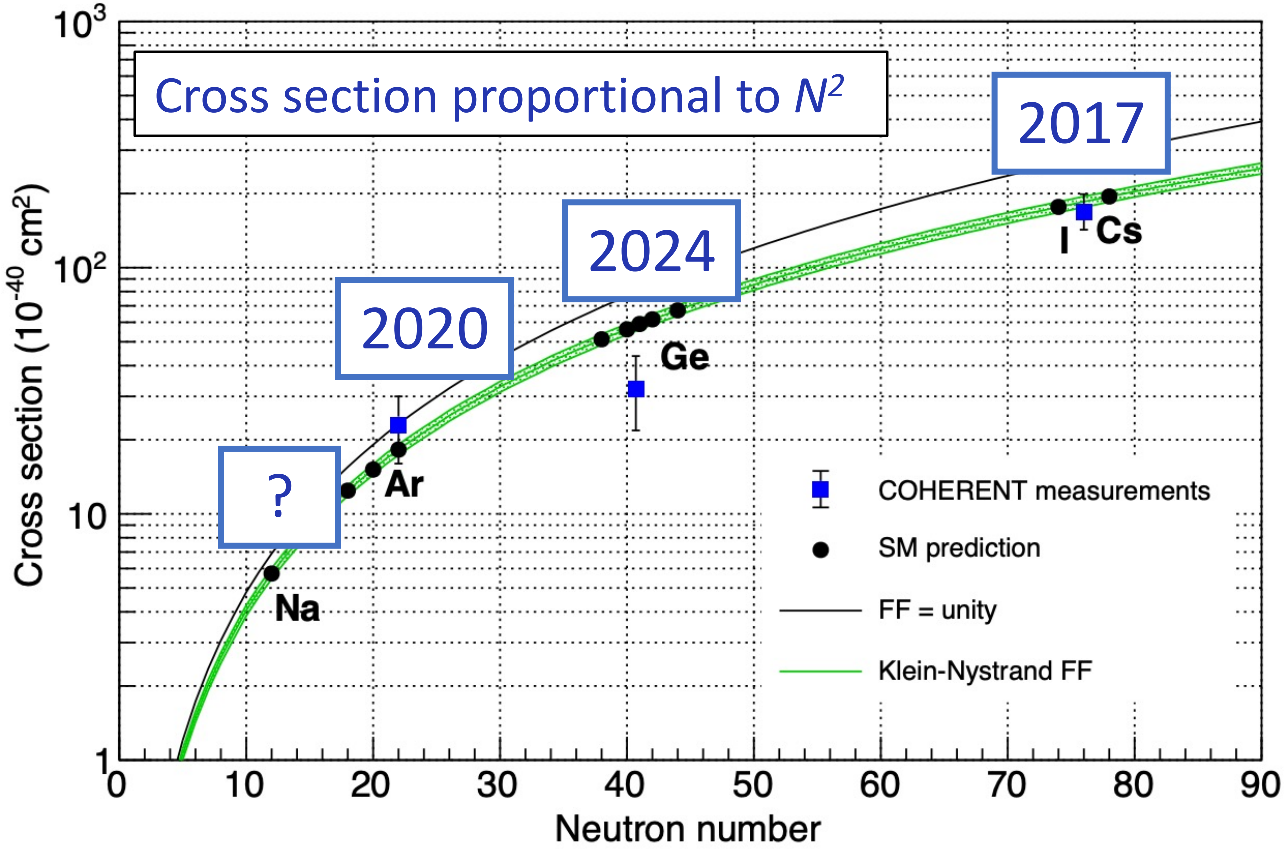
The COHERENT experiment



COHERENT Collaboration, Science 357 (2017) 6356



Production of neutrinos from pion and muon decay at rest.



Matthew Green's Talk Neutrino 2024

$$\left(Q_V^{SM}\right)^2 = \left(g_V^p Z + g_V^n N\right)^2 \sim N^2$$

$$g_V^p = \frac{1}{2} - \sin^2\theta \qquad g_V^n = -\frac{1}{2}$$

Different sources for CEνNS measurements

Current experiments and future prospects.

Source	Characteristics	Collaborations
Spallation Sources	• Decay of pions at rest. • Up to 52 MeV. • Detected!	COHERENT (SNS), ESS (European Spallation Source)
Reactor Experiments	• Nuclear reactions. • Up to ≈ 8 MeV range. • Very low thresholds.	CONUS, CONNIE, TEXONO, NUCLEUS
Solar Neutrinos	• Reactions within the sun. • ^{8}B contribution. • Up to ≈ 15 MeV.	XENON, PANDA X

Phenomenology of CEvNS

A variety of models can be tested

θ_W Weak Mixing Angle

M. Cadeddu et al Phys.Rev. C 104 (2021)
D. Aristizabal et al JHEP 09 (2022) 076
V. De Romeri et al JHEP 04 (2023) 035
B. C. Canas et al Phys. Lett. B 784 (2018)

Neutron rms radius

M. Cadeddu et al Rev. Lett. 120 (2018)
O. Miranda et al JHEP 2005 (2020) 130
R. R. Rossi et al Phys. Rev. D 109 (2024)

SM

ε Non-Standard Interactions

P. B. Denton et al JHEP 04 (2021) 266
O. Miranda et al New J.Phys. 17 (2015)

μ Magnetic Moments

T. Kosmas et al Phys.Rev. D92 (2015)
M. Atzori Corona et al JHEP 09 (2022) 164

ν_s Sterile neutrinos

O. G. Miranda et al JHEP 12 (2021) 191
V. De Romeri et al JHEP 04 (2023) 035

S_1 Leptoquark Models

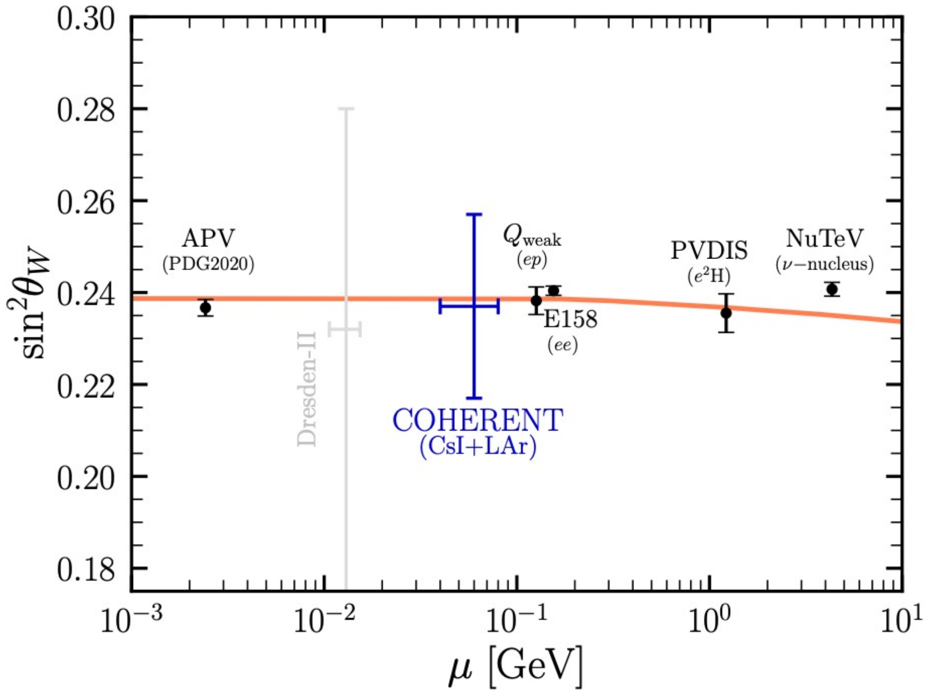
R. Calabrese et al Phys. Rev. D 107 (2023)
V. De Romeri et al Phys.Rev.D 109 (2024)

New Physics

Standard Model tests at low energies

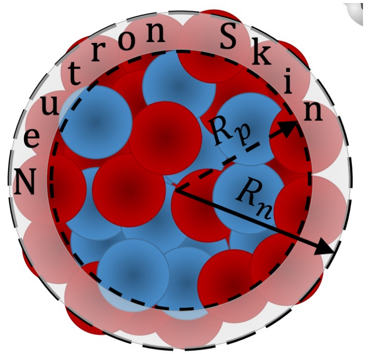
Weak mixing angle and neutron rms radius – Current COHERENT

- Present in CEνNS cross section within the weak charge Q_W.

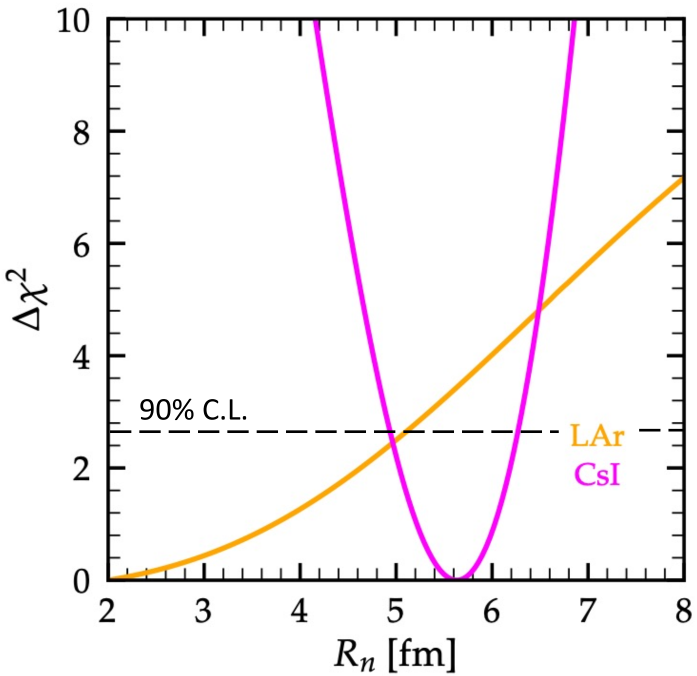


De Romeri, Miranda, Papoulias, **GSG**, Tórtola, and Valle, JHEP 04 (2023) 035

- Present in CEνNS cross section within $F(q^2)$.
- $F(q^2)$ parametrizes the distribution of neutrons.



Cadeddu's Talk at NuFact 2018

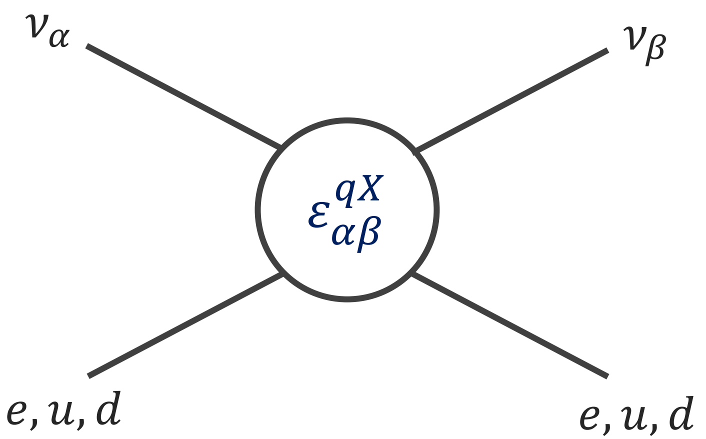


Beyond the Standard Model physics

Non-Standard Interactions – Current COHERENT

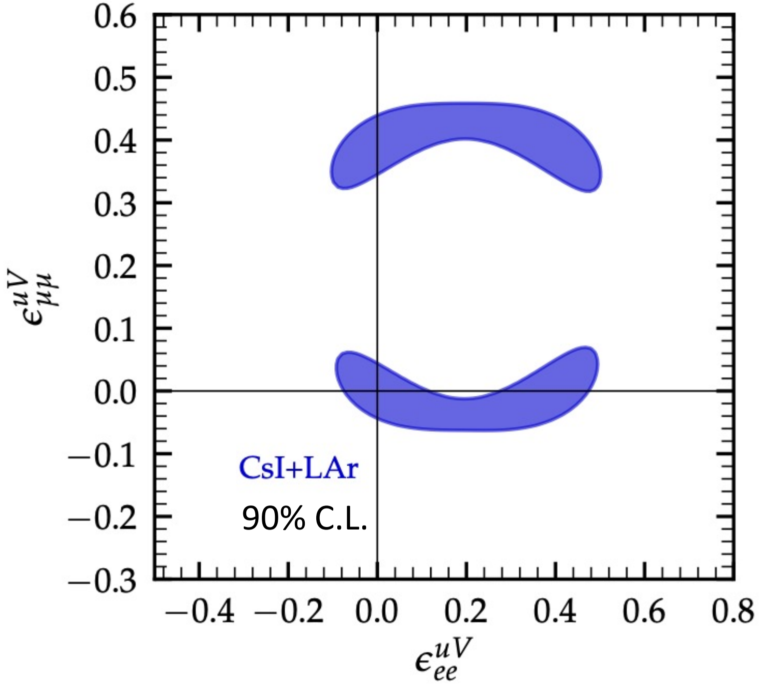
The Model

Neutral current Lagrangian introduced to allow for non-universal and flavor changing interactions.



$$\mathcal{L}_{\rm NC}^{\rm NSI} = -2\sqrt{2}G_F \sum_{q,\ell,\ell'} \varepsilon_{\ell\ell'}^{qX} (\bar{\nu}_\ell \gamma^\mu P_L \nu_{\ell'})(\bar{f}\gamma_\mu P_X f)\,,$$

Non-Universal NSI



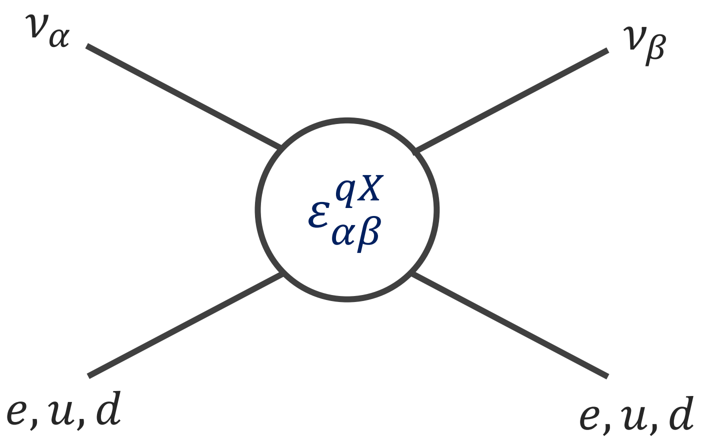
De Romeri, Miranda, Papoulias, **GSG**, Tórtola, and Valle, JHEP 04 (2023) 035

Beyond the Standard Model physics

Non-Standard Interactions – Future ESS

The Model

Neutral current Lagrangian introduced to allow for non-universal and flavor changing interactions.



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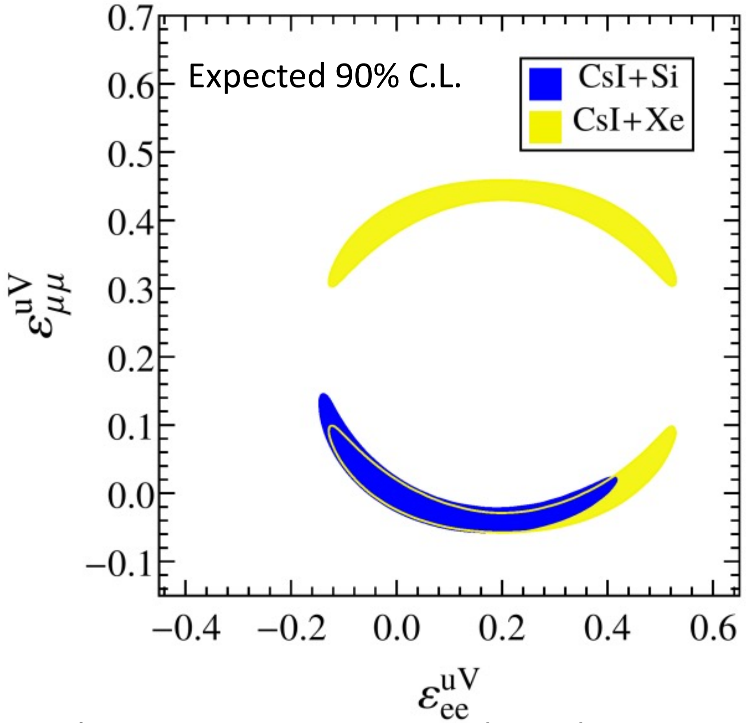
Non-Universal NSI

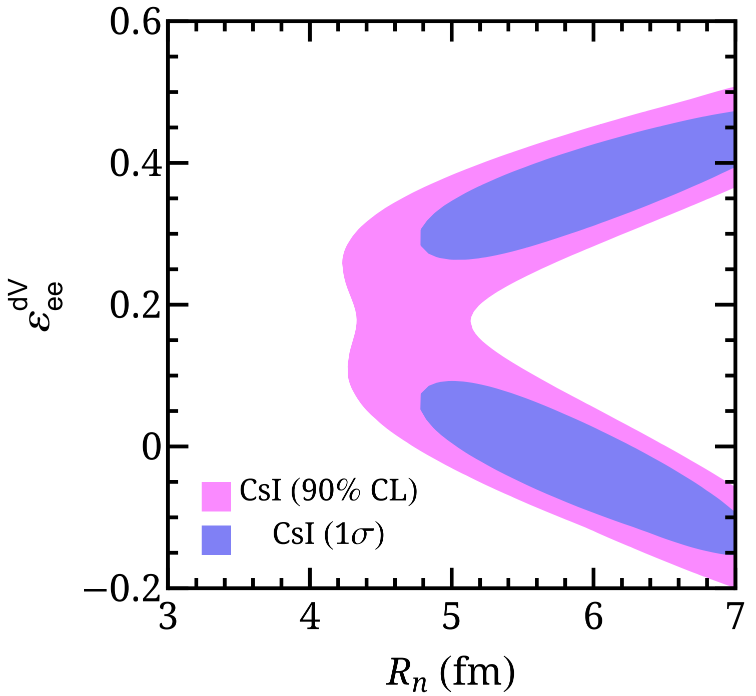


Chatterjee, Lavignac, Miranda, and **GSG**, Phys.Rev.D 107 (2023)

Interplay between SM and new physics

NSI and neutron rms radius – Current COHERENT

- We either do not know the nuclear structure or indeed have the presence of NSI.



Rossi, **GSG**, and Tórtola Phys. Rev. D 109 (2024)

Interplay between SM and new physics

NSI and neutron rms radius – Current COHERENT – Future reactor

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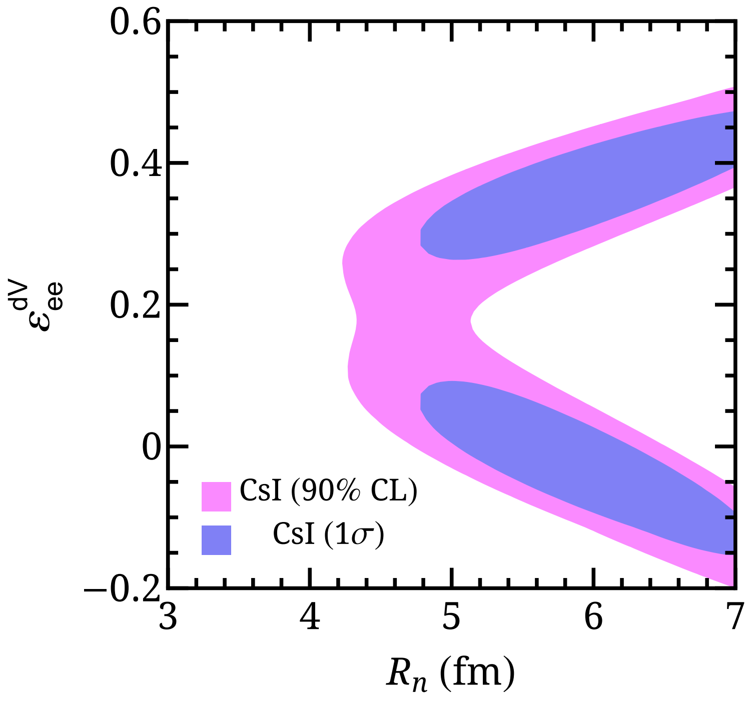
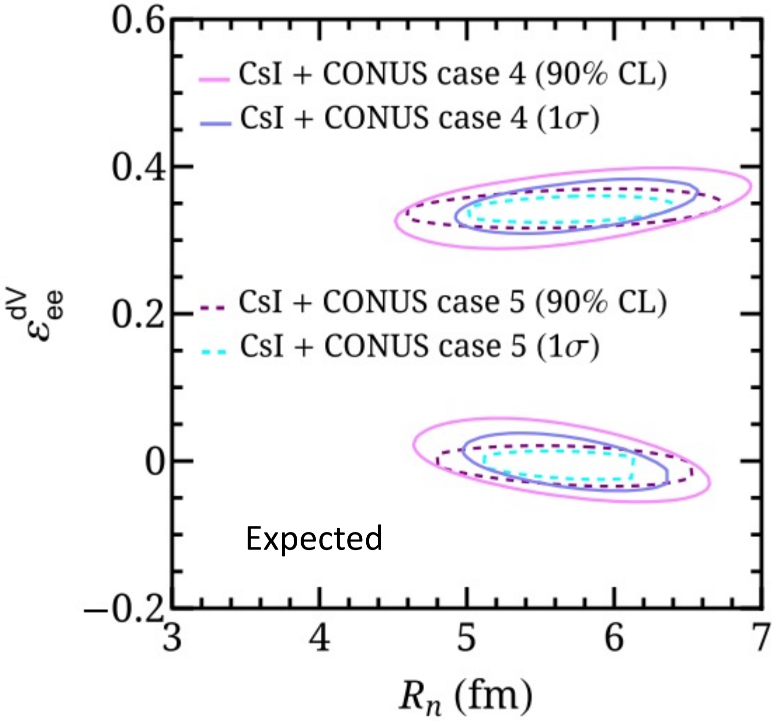


Rossi, **GSG**, and Tórtola Phys. Rev. D 109 (2024)

- Reactor neutrinos are not sensitive to the nuclear structure.

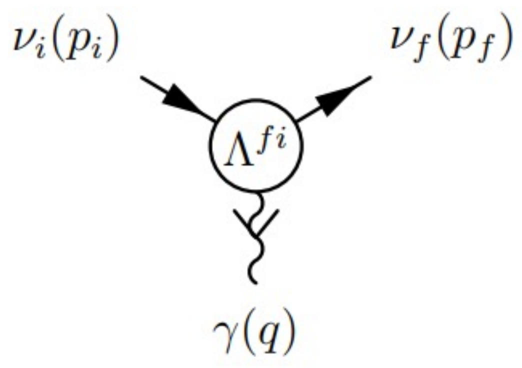


Beyond the Standard Model physics

Electromagnetic properties of neutrinos – Current COHERENT

The Model

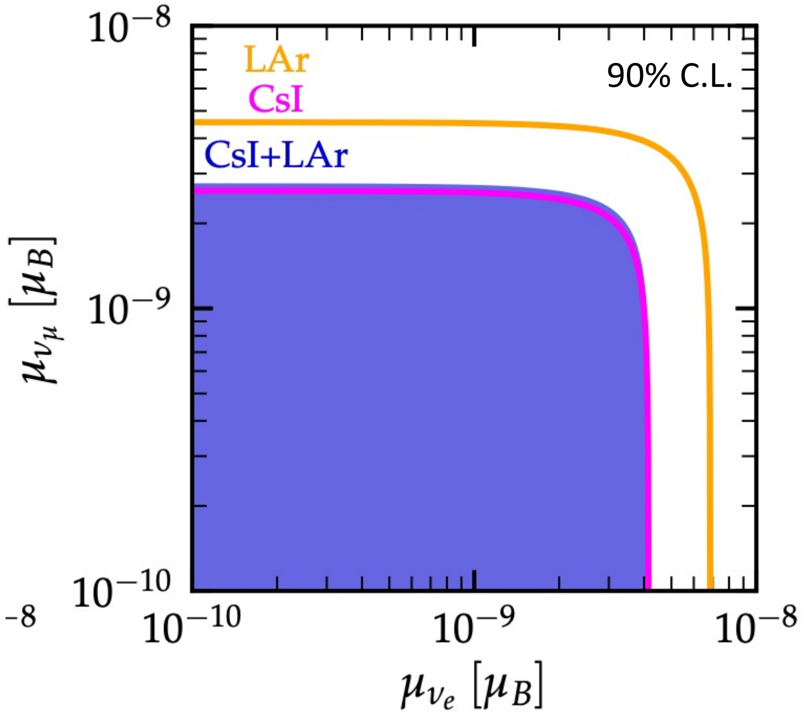
Massive neutrinos can induce a neutrino coupling to the photon at loop level



$$\Lambda_\mu^{fi}(q) = \left(\gamma_\mu - q_\mu \not{q}/q^2\right)\left[\mathfrak{f}_Q^{fi}(q^2) + \mathfrak{f}_A^{fi}(q^2) q^2 \gamma_5\right] - i\sigma_{\mu\nu}q^\nu \left[\mathfrak{f}_M^{fi}(q^2) + i\mathfrak{f}_E^{fi}(q^2)\gamma_5\right]$$

Neutrino Magnetic Moment

No Interference with SM cross section.



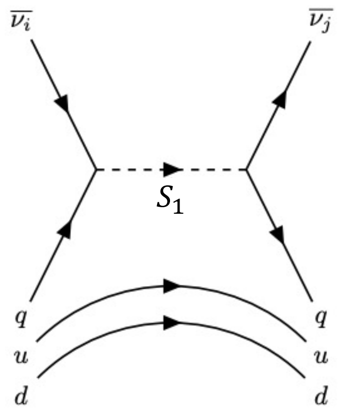
De Romeri, Miranda, Papoulias, **GSG**, Tórtola, and Valle, JHEP 04 (2023) 035

Beyond the Standard Model physics

Leptoquark scenarios – Future COHERENT

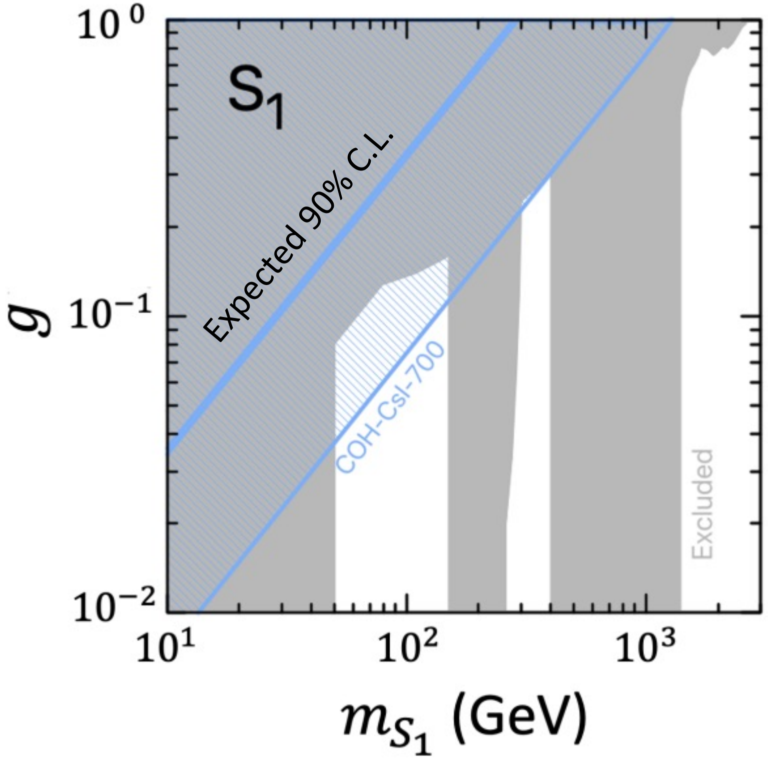
The Model

Hypothetical particles that couple to both leptons and quarks in many extensions to the SM.



$$\mathcal{L} \subset (\lambda_{1j}\bar{u}^c P_L \ell_j - \lambda_{1j}\bar{d}^c P_L \nu_j) S_1^{-1/3} + \text{h.c.}$$

Singlet under SU(2)$_L$

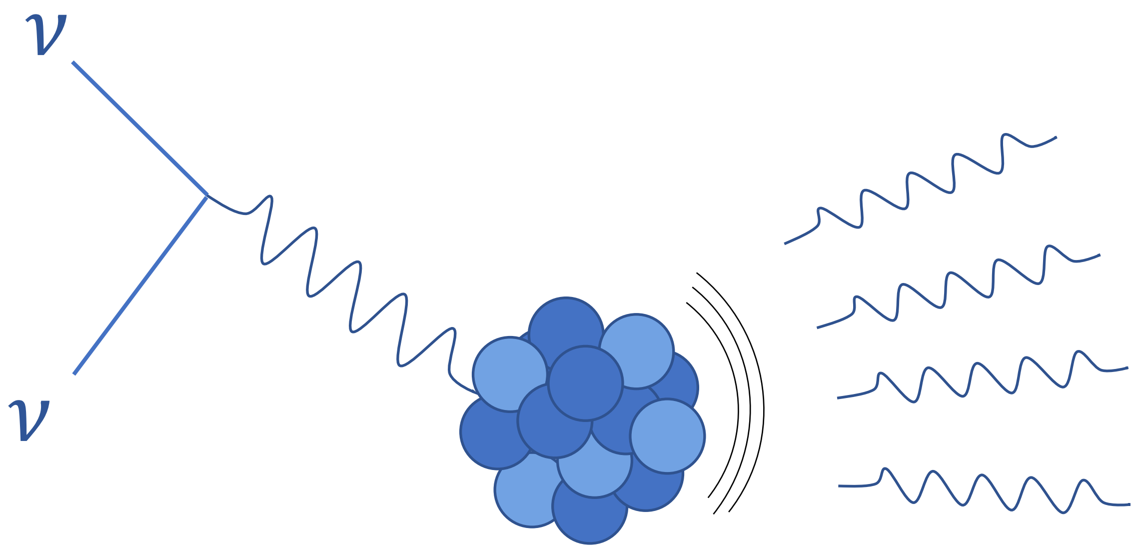


De Romeri, Lozano, and **GSG,** Phys.Rev.D 109 (2024)

Conclusions

- CEνNS is a powerful tool to perform tests of the SM.
- We can also use CEνNS to constrain new physics scenarios such as NSI, magnetic moments and leptoquark parameters.
- Combination of detectors can help to reduce degeneracies in the parameter space.
- Many different experiments are on their way to take more data.

Thank you!



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