EFT analysis of the COHERENT experiment with right-handed Dirac neutrinos

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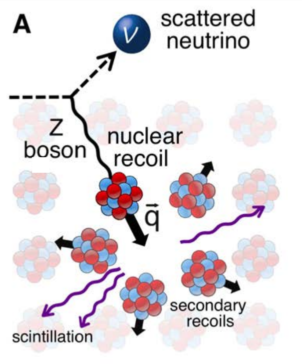
CEνNS and the COHERENT experiment

CEνNS



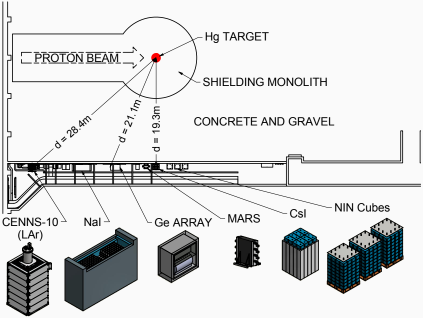
[from COHERENT coll.]

The Coherent Elastic ν-Nucleus Scattering (CEνNS):
In the elastic region, the vectorial part of the weak charge sees the nucleus as a whole, instead of the constituents.

$$|\bar{\mathcal{M}}|^2 \propto N^2$$

Scattering with nucleus gets enhanced by the number of neutrons squared.

The COHERENT experiment



Using a Hg target for a proton beam allows us to produce pions (almost) at rest. These pions decay into muons, which later decay to electrons. A concrete wall will shield the detector for most of the particles emitted, leaving only the neutrinos.

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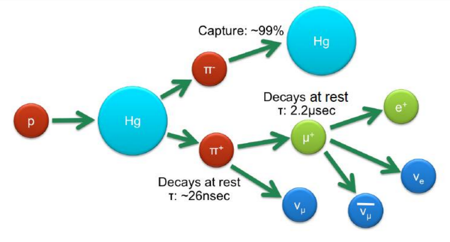

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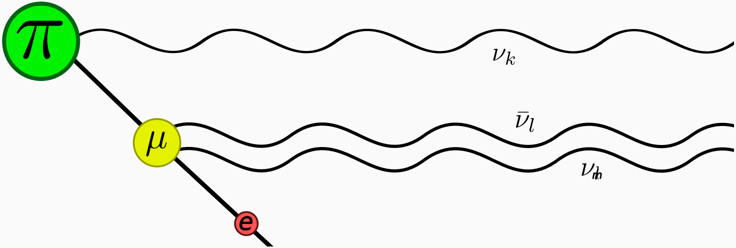
The COHERENT experiment

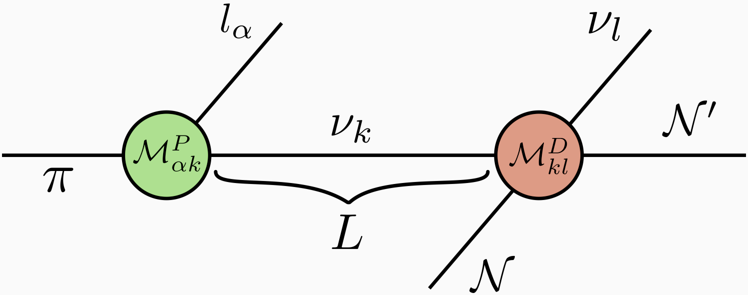
We will have 3 neutrino sources



EFT formalism and QFT description of ν-oscillations

Oscillations in QFT

The first element we need is a QFT framework to study ν-oscillations



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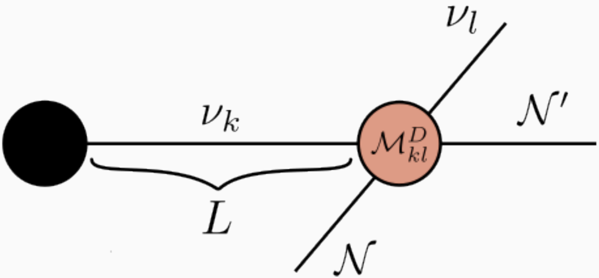

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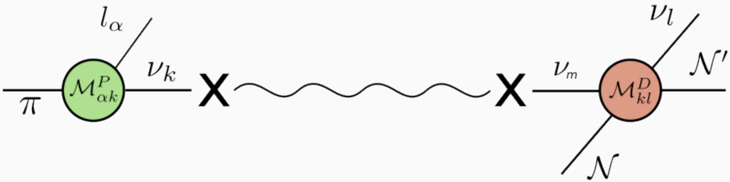
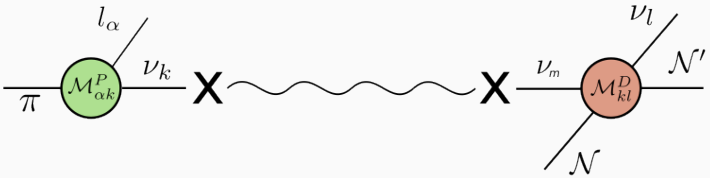


Rate in QFT

The rate in this formalism can be expressed as[1−2]:

$$R_\alpha^S = \frac{N_S(t)}{32\pi L^2 m_S m_{\mathcal{N}} E_\nu} \sum_{j,k,l} e^{-i\frac{L\Delta m_{kl}^2}{2E_\nu}} \int d\Pi_{P'} \mathcal{M}_{\alpha k}^P \bar{\mathcal{M}}_{\alpha l}^P \int d\Pi_{D'} \mathcal{M}_{jk}^D \bar{\mathcal{M}}_{jl}^D \tag{1}$$



[1] Bresó-Pla, V.; Falkowski, A.; González-Alonso, M.; Monsálvez-Pozo, K. J. High Energ. Phys. 2023, 2023, 74.

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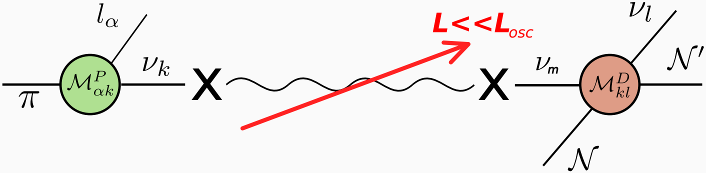

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νWEFT

We consider the weak effective field theory extended with 3 families of right-handed neutrino (νWEFT)

$$\delta\mathcal{L}^{NC} \supset \frac{-1}{v^2}\cdot\left\{\sum_{X,X'}[\epsilon^{qq}_{XX'}]_{\alpha\beta}\left(\bar{\nu}_\alpha\Gamma_X\nu_\beta\right)\left(\bar{q}\Gamma_{X'}q\right)+ + \frac{1}{2}[\epsilon_F]_{\alpha\beta}\,\bar{\nu}_\alpha\sigma_{\mu\nu}P_L\nu_\beta F^{\mu\nu}+\text{h.c.}\right\} \tag{3}$$

$$\delta\mathcal{L}^{\pi} \supset -\frac{2V_{ud}}{v^2}\cdot\sum_{XX'}\left[\epsilon^{ud}_{XX'}\right]_{\alpha\beta}\left(\bar{\nu}_\alpha\Gamma_X l_\beta\right)\left(\bar{d}\Gamma_{X'}u\right) \tag{4}$$

$$\delta\mathcal{L}^{\mu} \supset -\frac{2}{v^2}\cdot\sum_{X,X'}[\rho_{XX'}]^{ab}_{\alpha\beta}\left(\bar{l}_\alpha\Gamma_X\nu_\beta\right)\cdot\left(\bar{\nu}_\alpha\Gamma_{X'}l_\beta\right). \tag{5}$$

The Wilson coefficients $\epsilon^{qq}_{XX'}$, $\epsilon^{ud}_{XX'}$ and $\rho_{XX'}$ encapsulate the NP dependence and can be matched to specific NP models.

From quarks to nucleons and nucleus

The nucleus can be considered a non-relativistic particle. For this reason, we will perform a matching between the quark level Lagrangian and the non-relativistic nucleon fields ψ_N, where $N = (p, n)$.

In the zero-recoil limit, we find two kinds of interactions:

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Our findings about the lack of enhancement for the tensor operator differ from previous works (see Ref.[$3-4$] as an example), but are consistent with, e.g., the recent analysis of Ref.[5] in the context of dark-matter searches.

[3] J. Barranco, A. Bolanos, E.A. Garces, O.G. Miranda and T.I. Rashba, Tensorial NSI and Unparticle physics in neutrino scattering, Int. J. Mod. Phys. A 27 (2012) 1250147 [1108.1220]
[4] D. Aristizabal Sierra, V. De Romeri and N. Rojas, COHERENT analysis of neutrino generalized interactions, Phys. Rev. D 98 (2018) 075018 [1806.07424].

[5] A. Glick-Magid, Nonrelativistic nuclear reduction for tensor couplings in dark matter direct detection and

$\mu \to e$ conversion, Phys. Rev. D 110 (2024) L051701 [2312.08339].

Rate

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The resulting rate is of the form

$$\frac{dN}{dtdT} = g_\pi(t)\frac{dN^{prompt}}{dT} + g_\mu(t)\frac{dN^{delayed}}{dT} \tag{6}$$

where *prompt* and *delayed* refer to the pion and muon decay processes, respectively, and $g_S(t)$ encode the time dependence of the events.

Rate

The rate can be conveniently written as SM fluxes times effective cross-sections:

$$\frac{dN^{prompt}}{dT} = N_T \int dE_\nu \frac{d\Phi^{\rm SM}_{\nu_\mu}}{dE_\nu} \frac{d\tilde{\sigma}_{\nu_\mu}}{dT} \tag{7}$$

$$\frac{dN^{delayed}}{dT} = N_T \int dE_\nu \left(\frac{d\Phi^{\rm SM}_{\nu_e}}{dE_\nu} \frac{d\tilde{\sigma}_{\nu_e}}{dT} + \frac{d\Phi_{\bar{\nu}_\mu}}{dE_\nu} \frac{d\tilde{\sigma}_{\bar{\nu}_\mu}}{dT} \right) \tag{8}$$

where the differential cross-sections are given by

$$\begin{aligned} \frac{d\tilde{\sigma}_f}{dT} = (m_\mathcal{N} + T)\frac{\mathcal{F}^2(q^2)}{8\pi v^4} \Bigg\{ & (\tilde{Q}^f_V)^2 \cdot \left(1 - \frac{m_\mathcal{N} T}{2E_\nu^2} - \frac{T}{E_\nu}\right) + (\tilde{Q}^f_S)^2 \cdot \frac{m_\mathcal{N} T}{2E_\nu^2} \\ & + (\tilde{Q}^f_F)^2 \cdot \frac{v^2}{2m_\mathcal{N} T} \left(1 - \frac{T}{E_\nu}\right) + (\tilde{Q}^f_{SF})^2 \cdot \frac{v}{2E_\nu} \left(1 - \frac{T}{2E_\nu}\right) \Bigg\}, \end{aligned} \tag{9}$$

where $f = (\mu,\ \bar{\mu},\ e)$ and $\tilde{Q}^f_V = \tilde{Q}^f_V(\mathrm{SM} + \mathrm{NP\ parameters})$.

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- **NP only in detection + flavor universality.** We find disagreement with previous works.
- **NP only in production.** We become sensitive to NP involving RH-ν in production.
- **Linear NP terms.** There is no linear interference between the operators with RH-neutrinos and the ones present in the SM.
- **Second order NP terms.** We become sensible to RH-ν operators.

THANK YOU