Neutrinoless Double Beta Decay With Large N EFT

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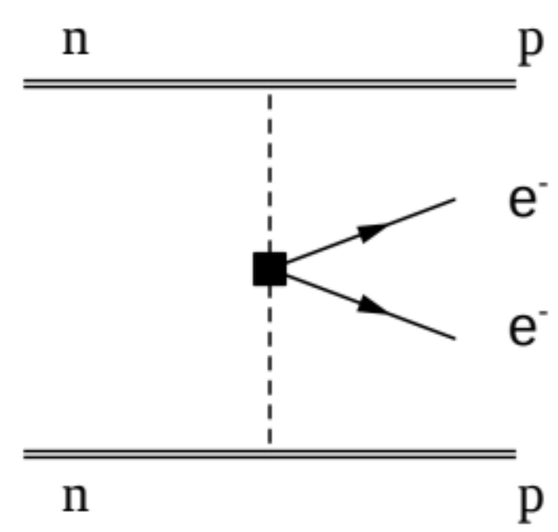
Physics Background

Neutrinoless double beta decay is a hypothetical nuclear transition that has not been discovered yet. Successful observation of this would be a clear indication of BSM.



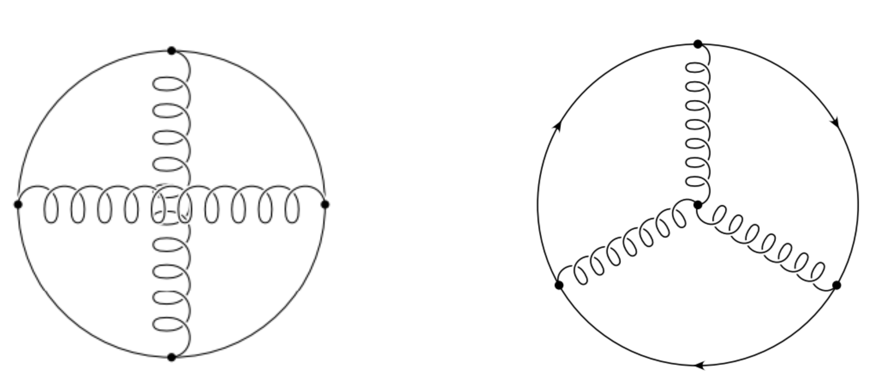
Tools Being Used

EFTs

- encode the relevant low-energy interactions through operators, which are used in many-body nuclear calculations.
- Each operator has an undetermined coefficient, known as the low-energy constants (g LECs), which must be fixed to make accurate predictions.

By extending QCD to a hypothetical limit of many colors, the **large-N** framework imposes a natural hierarchy on the nuclear interactions and decay operators:

- The leading "planar" contributions dominate



vDoBe is a open source code for neutrinoless double β-decay calculations in bounds of couplings and scale of new physics in the SMEFT framework up to dimension 9.

Our Part of The Problem - LECs from Large N

- Four-quark Operators

$$
\begin{aligned}
O_1 &= \bar{q}_L^\alpha \gamma_\mu \tau^+ q_L^\alpha \, \bar{q}_L^\beta \gamma^\mu \tau^+ q_L^\beta \,, \\
O_2 &= \bar{q}_R^\alpha \tau^+ q_L^\alpha \, \bar{q}_R^\beta \tau^+ q_L^\beta \,, \\
O_3 &= \bar{q}_R^\alpha \tau^+ q_L^\beta \, \bar{q}_R^\beta \tau^+ q_L^\alpha \,, \\
O_4 &= \bar{q}_L^\alpha \gamma_\mu \tau^+ q_L^\alpha \, \bar{q}_R^\beta \gamma^\mu \tau^+ q_R^\beta \,, \\
O_5 &= \bar{q}_L^\alpha \gamma_\mu \tau^+ q_L^\beta \, \bar{q}_R^\beta \gamma^\mu \tau^+ q_R^\alpha \,,
\end{aligned}
$$

Use Fiertz Identity for the rest from O_2

$$(1 \pm \gamma^5)_{ij}(1 \pm \gamma^5)_{kl} = \frac{1}{2}\Big[(1 \pm \gamma^5)_{il}(1 \pm \gamma^5)_{kj} - \tfrac{1}{2}\big[(1 \pm \gamma^5)\sigma^{\mu\nu}\big]_{il}\big[(1 \pm \gamma^5)\sigma_{\mu\nu}\big]_{kj}\Big]$$

$$\Rightarrow O_3 = -\frac{1}{2} O_2 + \ldots$$

$$[(1 \pm \gamma^5)\gamma^\mu]_{ij}[(1 \mp \gamma^5)\gamma_\mu]_{kl} = 2\,(1 \pm \gamma^5)_{il}(1 \mp \gamma^5)_{kj}$$

$$\Rightarrow O_5 \underset{\smile}{=} -2 O_2$$

After large N factorization

- 0νββ Langrangian

$$\mathcal{L}^{(9)}_{\Delta L=2} = \frac{1}{v^5} \sum_i \Big[\Big(C^{(9)}_{i\,\mathrm{R}}\, \bar{e}_R C \bar{e}_R^T + C^{(9)}_{i\,\mathrm{L}}\, \bar{e}_L C \bar{e}_L^T \Big)\, O_i + C^{(9)}_i \bar{e}\gamma_\mu \gamma_5 C \bar{e}^T\, O_i^\mu \Big]$$

- Chiral Langrangian

$$
\begin{aligned}
\mathcal{L}_\pi^{\text{scalar}} = \frac{F_0^4}{4} \Big[& \frac{5}{3} g_1^{\pi\pi} C^{(9)}_{1\mathrm{L}} L^\mu_{21} L_{21\,\mu} + \Big(g_2^{\pi\pi} C^{(9)}_{2\mathrm{L}} + g_3^{\pi\pi} C^{(9)}_{3\mathrm{L}} \Big) \operatorname{Tr}\left(U\tau^+ U\tau^+\right) \\
& + \Big(g_4^{\pi\pi} C^{(9)}_{4\mathrm{L}} + g_5^{\pi\pi} C^{(9)}_{5\mathrm{L}} \Big) \operatorname{Tr}\left(U\tau^+ U^\dagger \tau^+\right) \Big] \frac{\bar{e}_L C \bar{e}_L^T}{v^5} + (L \leftrightarrow R)
\end{aligned}
$$

Using large N Factorization for $O_2/O_1/O_4$

$$< J_1 J_2 > = < J_1 > < J_2 > + < J_1 J_2 >_c$$

$$= < J_1 > < J_2 > [1 + \frac{< J_1 J_2 >_c}{< J_1 > < J_2 >}] \quad \sim \frac{1}{N_c}$$

$$< J_i > \sim N_c$$

$$< J_1 J_2 >_c \sim N_c$$

QCD & ChiPT Correlation function matching

$$\frac{1}{Z_{QCD}[0]} \frac{\delta Z_{QCD}}{\delta \chi_{ab}}\Bigg|_{\chi_{ab}=0} = \frac{1}{Z_{Chi}[0]} \frac{\delta Z_{Chi}}{\delta \chi_{ab}}\Bigg|_{\chi_{ab}=0}$$

$$< \bar{q}_L^a q_R^b > \to -\frac{B_0 F_0^2}{2} U^+_{ba}$$

Left-handed Lepton Bilinear $\bar{e}_L C \bar{e}_L^T$

$$O_2 : \quad \mathcal{L}_{0\nu\beta\beta} \supset \frac{1}{v^5} C^{(9)}_{2L}\, \widetilde{(l)}\, (\bar{u}_R d_L)[\bar{u}_R d_L]$$

$$\Rightarrow \frac{1}{v^5} C^{(9)}_{2L} < (\bar{u}_R d_L)_x > < [\bar{u}_R d_L]_x >$$

$$\to \frac{1}{v^5} C^{(9)}_{2L} \frac{F_0^4}{4} \underbrace{(B_0^2)}_{g_2^{\pi\pi}}\ Tr(\tau^+ U^+ \tau^+ U^+)$$

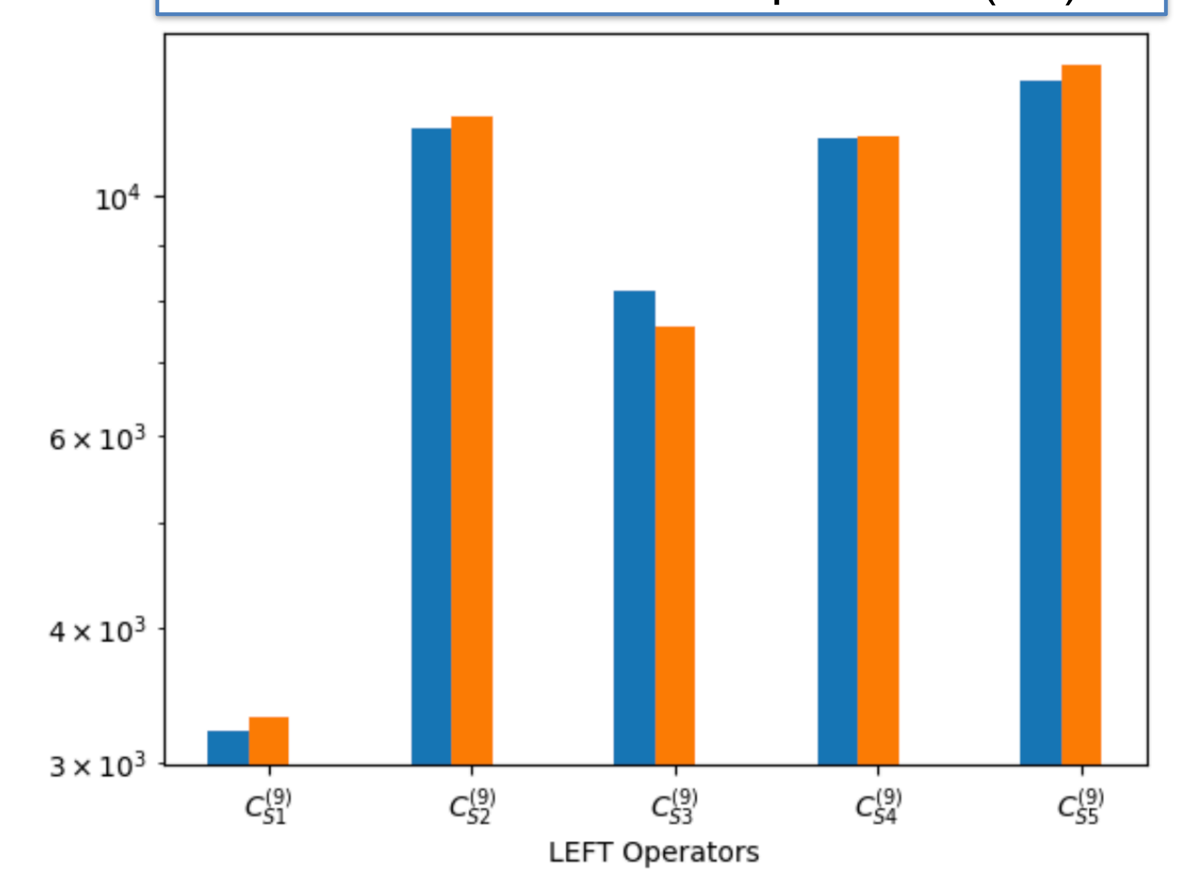
Results From Large N & SM

- Blue: Lattice QCD Result
- Orange: Large N EFT Result

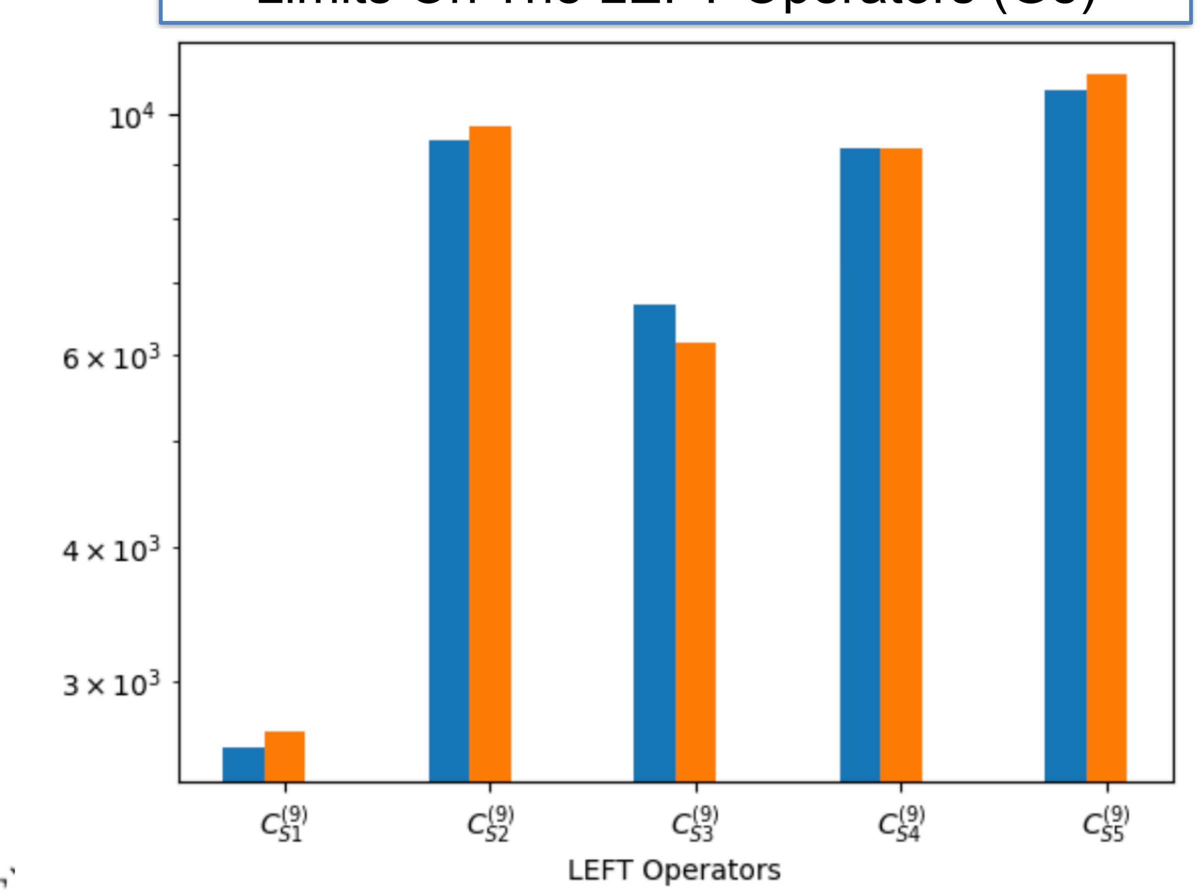
Table of LECs

$g_1^{\pi\pi}$	$g_2^{\pi\pi}$	$g_3^{\pi\pi}$	$g_4^{\pi\pi}$	$g_5^{\pi\pi}$
0.36	2.00	-0.62	-1.90	-8.00
0.60	7.80	-4.00	-1.88	-15.5

Limits On The LEFT Operators (Xe)



Limits On The LEFT Operators (Ge)



Final Remarks / Reference

- Large N factorization works better for vector-vector operators
- Consideration of coulomb for future work

- *V. Cirigliano, W. Dekens, J. de Vries, M. L. Graesser & E. Mereghetti, "A neutrinoless double beta decay master formula from effective field theory," JHEP 12 (2018) 097. / O. Scholer, J. de Vries & L. Gráf, "νDoBe — A Python tool for neutrinoless double beta decay," JHEP 08 (2023) 043. / V. I. Borodulin, R. N. Rogalyov & S. R. Slabospitskii, "CORE 3.2 (Compendium of Relations, Version 3.2)," arXiv:1702.08246 [hep-ph].*