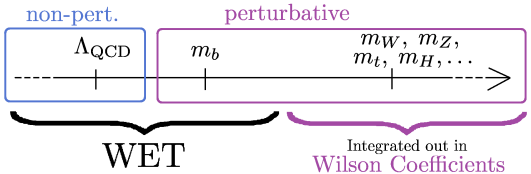
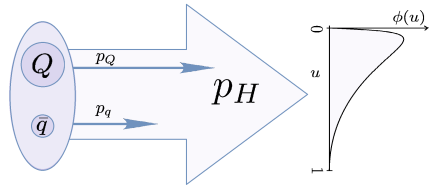
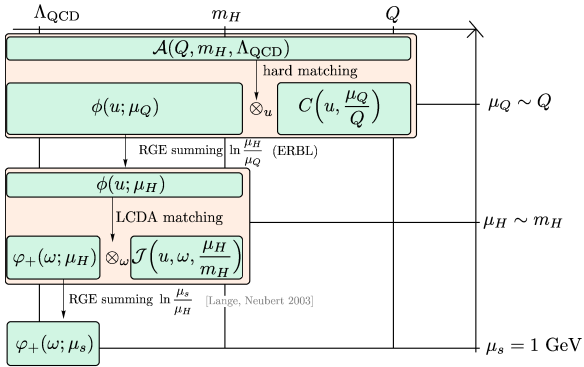
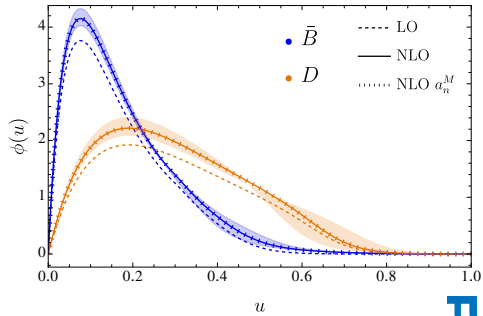
We employ **Effective Field Theories** (HQET, SCET, ...) to separate perturbative physics from universal non-perturbative inputs:



LCDAs appear in factorization theorems







based on M. Beneke, GF, K. K. Vos, Y. Wei 2305.06401

NEUTRINO MASSES AND UNITARITY VIOLATION FROM HIGHER SU(2) REPRESENTATIONS

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New Frontiers in Theoretical Physics 2023

CONVEGNO NAZIONALE DI FISICA TEORICA

INFN Istituto Nazionale di Fisica Nucleare

SCUOLA NORMALE SUPERIORE

ROMA TRE UNIVERSITÀ DEGLI STUDI

S. Marciano, A. Giarnetti, D. Meloni, J. H. Garcia, D. Vatsyayan
arxiv: 23XX.XXXXX]

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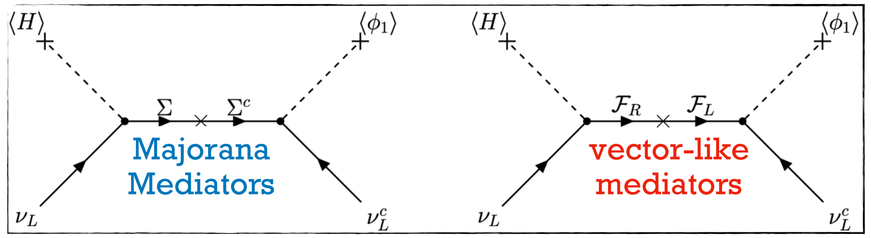
Extra scalars ϕ_i

$$\frac{c_5^{(0)}}{\Lambda} LLHH + \frac{c_5^{(1)}}{\Lambda} LLH\phi_i + \frac{c_5^{(2)}}{\Lambda} LL\phi_i\phi_i + \frac{c_5^{(3)}}{\Lambda} LL\phi_i\phi_j$$



no 2HDM

(SU(2),Y)

List of *genuine* models

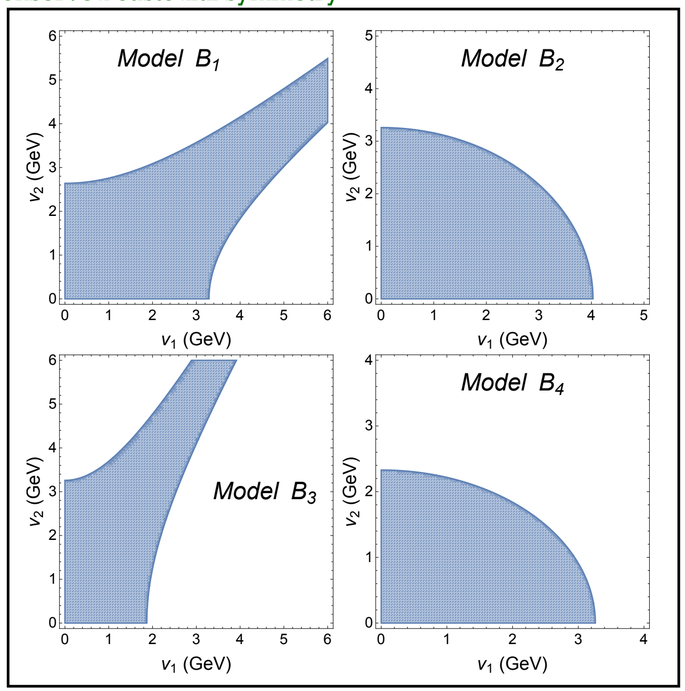
see also McDonald JHEP 07 (2013) 020

Model	New Scalar Multiplets	Fermion Mediator	Operator
$\mathbf{A_1}$	$\phi_1 = (4,-1/2)$	$\Sigma = (5,0) \geq 2$	$\mathcal{O}_5^{(2)}$
$\mathbf{A_2}$	$\phi_1 = (4,-3/2)$	$\mathcal{F} = (3,-1)$	$\mathcal{O}_5^{(1)}$
$\mathbf{B_1}$	$\phi_1 = (4,1/2),\ \ \phi_2 = (4,-3/2)$	$\mathcal{F} = (5,-1)$	$\mathcal{O}_5^{(3)}$
$\mathbf{B_2}$	$\phi_1 = (3,0),\ \ \phi_2 = (5,-1)$	$\mathcal{F} = (4,-1/2)$	$\mathcal{O}_5^{(3)}$
$\mathbf{B_3}$	$\phi_1 = (5,-2),\ \ \phi_2 = (5,1)$	$\mathcal{F} = (4,3/2)$	$\mathcal{O}_5^{(3)}$
$\mathbf{B_4}$	$\phi_1 = (5,-1),\ \ \phi_2 = (5,0)$	$\mathcal{F} = (4,1/2)$	$\mathcal{O}_5^{(3)}$

genuiness

Naturally-small induced VEVs v_i

Conserved custodial symmetry

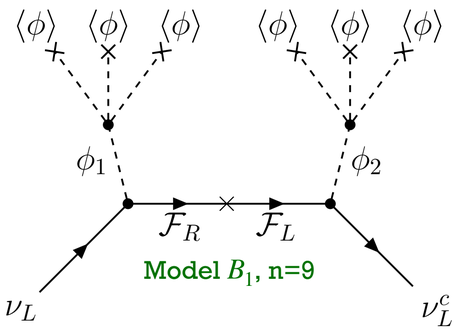


$v_i < \mathcal{O}(\text{GeV}) \ll v$ so $\Lambda \Downarrow$

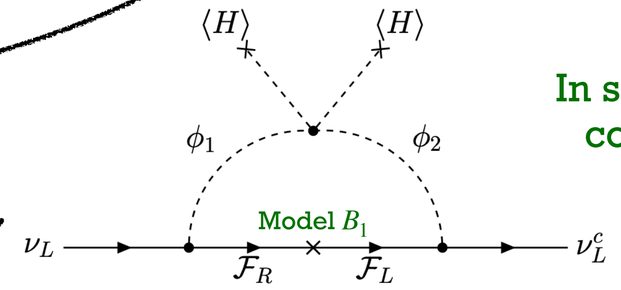
For example for A_1

$V \supset \lambda_1(\phi_1 H)(H^\dagger H) \Rightarrow v_1 \simeq \lambda_1 \frac{v^3}{m_\phi^2}$

$v_1 \ll v$ for $v \ll m_\phi$ and/or $\lambda_1 \ll 1$



$D > 5$ Weinberg operators $\frac{c_n^{(0)}}{\Lambda^{n-4}} LLHH(H^\dagger H)^{\frac{n-5}{2}}$ Anamiati et al 2018



In some cases, loop contribution may dominate

Deviation from unitarity of PMNS from D=6 operators

$$\mathscr{L}_{eft} \supset c_6^{(i)} \left(\bar{L}\,\phi_i\right) iD^\mu \gamma_\mu \left(\phi_i^\dagger L\right) \qquad c_6^{(i)} = \frac{Y_i\, Y_i^\dagger}{\Lambda^2}$$

$$U_{PMNS} \to U \equiv (\mathbb{1} - \epsilon)\, U_L^\nu$$

$$v_{\phi_i}^2\, c_6^{(i)} = \epsilon \propto v_{\phi_i}^2 c_5^{(i)}/\Lambda \quad \Rightarrow$$

Deviation from unitarity is suppressed by smallness of neutrino masses