DECONSTRUCTING FLAVOUR

REVIVAL OF OLD IDEAS   BUT NEW INCARNATIONS

FOR DECADES, TWO DRIVING FORCES IN SEARCH FOR BSM PHYSICS (IN PARTICLE PHYSICS ITSELF)

1. STABILIZATION OF THE HIGGS MASS IN THE PRESENCE OF THE BSM PHYSICS

A PROBLEM OF THE SM (SU(3)xSU(2)xU(1) RENORMALISABLE GAUGE THEORY)

2. FLAVOUR HIERARCHIES (INCLUDING NEUTRINO MASSES AND MIXINGS)

IN A CERTAIN SENSE, FLAVOUR ITSELF IS A BEYOND THE SM CONCEPT- THE FIRST EVIDENCE FOR BSM PHYSICS

VERY LIKELY, THE TWO PROBLEMS ARE INTERCONNECTED…

FLAVOUR AND THE SM

- Flavor symmetry $U(3)^5$, only broken by Yukawas:

$$\mathscr{L} = -\frac{1}{4}F^a_{\mu\nu}F^{a\,\mu\nu} + \bar{\psi}_a \not{D} \psi_a + |D_\mu H|^2 - V(H) + (Y_{ab}\,\bar{\psi}^a_L\,H\,\psi^b_R + \mathrm{h.c.})$$

$$U(3)^5 = U(3)_q \times U(3)_u \times U(3)_d \times U(3)_\ell \times U(3)_e$$

Largest breaking

PHENOMENOLOGY OF FLAVOUR PHYSICS: **pattern of quark masses and mixing,taken from experiment**

$$U(3)^5 \xrightarrow[\text{Top Yuk.}]{} U(2)_q \times U(2)_u \times U(3)_d \times U(3)_\ell \times U(3)_e$$

$$U(3)^5 \xrightarrow[\text{3rd fam. Yuk.}]{} U(2)^5$$

APPROXIMATE SYMMETRIES

IN THE LIMIT OF MASSLESS NEUTRINOS AND EXACT U(2) GLOBAL SYMMETRIES FOR THE FIRST TWO GENERATIONS

NO FCNC PROCESSES
LEPTON NUMBER CONSERVATION
LEPTON FLAVOUR CONSERVATION

BOTH ARE WEAKLY VIOLATED BUT CONTROL FCNC , LNV AND LFV AND GIVE MANY MORE PREDICTIONS

PHENOMENOLOGY IN THE SM OF APPROXIMATE U(2) FLAVOUR SYMMETRIES

R. Barbieri, G. R. Dvali, and L. J. Hall, Predictions
from a U (2) flavor symmetry in supersymmetric
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R. Barbieri, G. Isidori, J. Jones-Perez, P. Lodone, and
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A. Crivellin, L. Hofer, and U. Nierste, The MSSM with
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R. Barbieri, D. Buttazzo, F. Sala, and D. M. Straub,
Flavour physics from an approximate U (2)3 symmetry,
JHEP 07 (2012) 181, [arXiv:1203.4218].

A. J. Buras and J. Girrbach, On the Correlations
between Flavour Observables in Minimal U (2)3 Models,
JHEP 01 (2013) 007, [arXiv:1206.3878].

SM AS AN EFFECTIVE THEORY (SMEFT)

L_{SM} + $SU(2)$ x U(1) invariant higher dim operators

e.g. dim 6 four fermion operators contributing to

$M - \bar{M}$ Mixing, FCNC decays

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \frac{C_{ijkl}}{\Lambda^2}(\bar{Q}_i Q_j \bar{Q}_k Q_l) + \ldots .$$

$l_j \to l_i \gamma$ decays

$$\mathcal{L}_{eff} = \frac{C_{ij}}{\Lambda^2}(\bar{L}_j \sigma^{\mu\nu} E_i) H B^{\mu\nu}$$

FLAVOUR PRECISION DATA -→

FLAVOUR BLIND SMEFT WOULD REQUIRE

$$\Lambda \propto \mathcal{O}(10^4) TeV$$

TASKS FOR BSM: EXPLAIN THE PHENOMENOLOGICAL APPROXIMATE SYMMETRIES OF FERMION MASSES AND MIXING,

CONTROL BSM PHYSICS
(IN PARTICULAR, CONTROL SMEFT)

THEORY OF FLAVOUR AND BSM PHYSICS

SU(2)xU(1)xG_F

E.G. FROGGATT-NIELSEN $U(1)_F$

CONTINOUS INTEREST IN EXPERIMENTAL SIGNATURES OF HORIZONTAL SYMMETRIES CAPABLE TO "EXPLAIN" THE PATTERN OF FERMION MASSES AND MIXING, BY IMPOSING THEM ON SMEFT

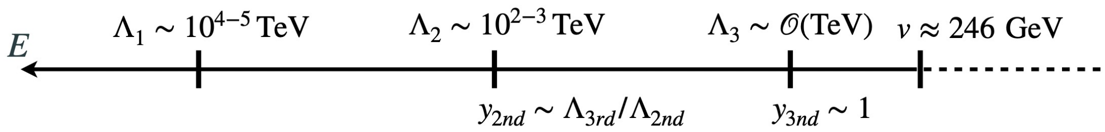
FOR INSTANCE:
SEARCHING FOR BSM PHYSICS IN YUKAWA COUPLINGS AND FLAVOUR SYMMETRIES,
J. ALONSO-GONZALEZ, A. de GIORGI, L. MERLO, SP: 2109.07490

MAPPING AND PROBING FROGGATT-NIELSEN SOLUTIONS TO THE QUARK FLAVOR PUZZLE,
C. CORNELLA, D. CURTIN, E.T. NEIL, J.G. THOMPSON, 2306.08026

TESTING THE FROGGATT-NIELSEN MECHANISM WITH LEPTON VIOLATION,
C. CORNELLA, D. CURTIN, G. KRNJAIC, M. MELLORS

ANOTHER IDEA:
MULITI-SCALE APPROACH TO FERMION MASSES
(INVERSE HIERACHY)

- Multiscale picture for flavor:



A DYNAMICAL EXPLANATION OF FLAVOUR HIERARCHIES AS A CONSEQUENCE OF THE EXISTENCE OF SEVERAL NEW SCALES.

THE APPROXIMATE U(2) GLOBAL SYMMETRY WOULD EMERGE **AT TeV** SCALE AS AN ACCIDENTAL SYMMETRY OF A BSM STRUCTURE, WITH THE SM EMBEDDED IN IT.

INVERSE HIERARCHY MODELS: HIGH NEW SCALES RESPONSIBLE FOR LIGHT FERMION MASSES, LOW SCALE PHYSICS RESPONSIBLE FOR THE THIRD GENERATION MASSES.

Z. G. Berezhiani, The Weak Mixing Angles in Gauge Models with Horizontal Symmetry: A New Approach to Quark and Lepton Masses, Phys. Lett. B 129 (1983) 99–102.

Z. G. Berezhiani and R. Rattazzi, Inverse hierarchy approach to fermion masses, Nucl.Phys. B 407 (1993) 249–270, [hep-ph/9212245].

R. Barbieri, G. R. Dvali, and A. Strumia, Fermion masses and mixings in a flavor symmetric GUT, Nucl. Phys. B 435 (1995) 102–114, [hep-ph/9407239].

MOST RECENT IMPLEMENTATION: A REVIVAL OF MODELS BASED

ON THE (OLD) IDEA OF DECONSTRUCTION OF A GAUGE GROUP INTO

A PRODUCT (MULTI-GAUGE) OF GAUGE GROUPS

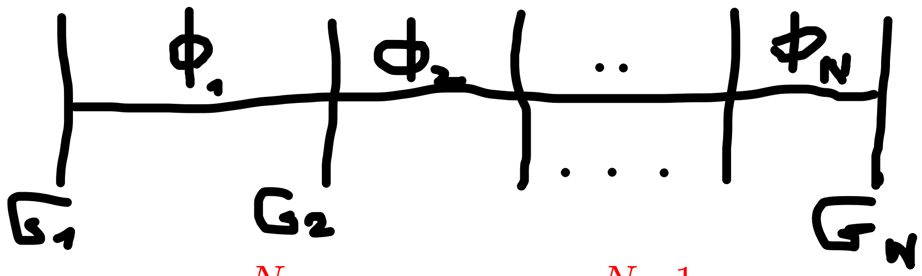
$U(2)^N$ GLOBAL SYMMETRIES EMERGE AS ACCIDENTAL SYMMETRIES DUE TO NON-UNIVERSAL FLAVOUR ASSIGNMENT TO THE GAUGE GROUPS IN THE PRODUCT

COMMON FUTURE OF THOSE FLAVOUR MODELS: NEW MASSIVE VECTOR BOSONS AND VERY RICH INTERESTING PHENOMENOLOGY

RENORMALISABLE!

DECONSTRUCTION OF A 4-dim GAUGE THEORY WITH SYMMMETRY G INTO MULTI-GAUGE, G^N
WITH BI-FUNDAMENTAL SCALARS Φ_N AS LINKS -→ IN THE IR, AFTER SPONTANEOUS BREAKING
BY THE vevs OF Φ_N ONE OBTAINS THE DYNAMICS OF G in 5 dim! WITH ZERO MODES (G) AND
"KALUZA- KLEIN" MODES IN ADJONT REP

EXTRA DIMENSION MAY INSPIRE 4-dim MODEL BUILDING



C. T. Hill, S. P, J. Wang, [hep-th/0104035].
N. Arkani-Hamed, A. G. Cohen, H. Georgi, [hep-th/0104005].

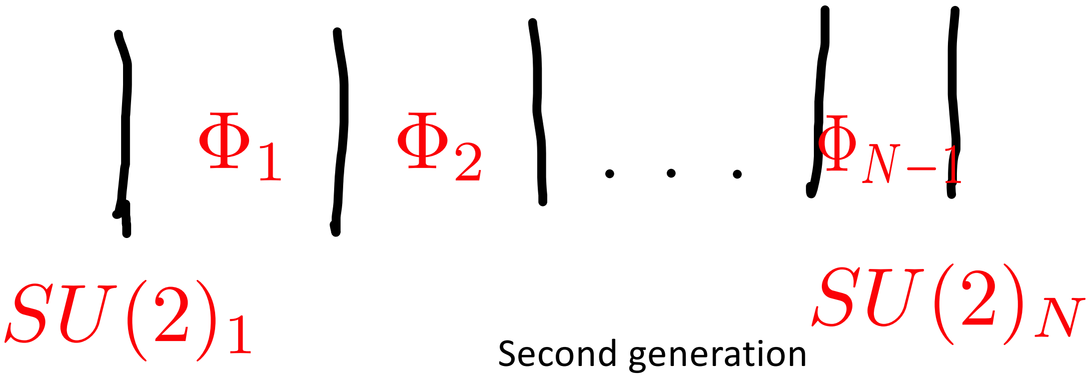
$$\mathcal{L} = -\frac{1}{4}\sum_{i=0}^{N} F_{\mu\nu,i}F_i^{\mu\nu} - \sum_{k=0}^{N-1} |D_\mu\phi_k|^2 + m_k^2|\phi_k|^2) - \sum_{k,l=0}^{N} \lambda_{kl}|\phi_k|^2|\phi_l|^2$$

$$\Phi_i \to v_i e^{(i\phi^a T^a/v_i)}$$

$$D_\mu\phi_k = [\partial_\mu + ig(\frac{A_{\mu,k}}{2} - q\frac{A_{\mu,k+1}}{2})]\phi_k$$

DECONSTRUCTING FLAVOUR (MORE PRECISELY: DECONSTRUCTING ELECTROWEAK SU(2)xU(1))

H.-C. Cheng, C. T. Hill, S. P., J. Wang, The Standard Model in the Latticized Bulk, [hep-th/0104179]; see also MOOSE STRUCTURES: H. Georgi, A Tool Kit for Builders of Composite Models, Nucl. Phys. B 266 (1986) 274–284.



Second generation

First generation

Third generation

Higgs with non-zero vev

EXTENDED ELECTROWEAK GAUGE GROUPS

X. Li and E. Ma, Gauge Model of Generation Nonuniversality, Phys. Rev. Lett. 47 (1981) 1788.
D. J. Muller and S. Nandi, Top flavor:
A Separate SU (2) for the third family, [hep-ph/9602390].
G. R. Dvali and M. A. Shifman, Families as neighbors in extra dimension, [hep-ph/0001072].
………………

GENERAL FRAMEWORK, NOT JUST ONE CONCRETE MODEL; A STIMULATION FOR EXPERIMENTAL SEARCHES

RENEWED INTEREST

A. Greljo and B. A. Stefanek, Third family quark–lepton unification at the TeV scale, Phys. Lett. B 782 (2018) 131–138, [arXiv:1802.04274].

O. L. Crosas, G. Isidori, J. M. Lizana, N. Selimovic, and B. A. Stefanek, Flavor non-universal vector leptoquark imprints in K → πν ¯ν and ΔF = 2 transitions, Phys. Lett. B 835 (2022) 137525, [arXiv:2207.00018].

L. Allwicher, G. Isidori, J. M. Lizana, N. Selimovic, and B. A. Stefanek, Third-family quark-lepton Unification and electroweak precision tests, JHEP 05 (2023) 179, [arXiv:2302.11584].

M. Bordone, C. Cornella, J. Fuentes-Martin, and G. Isidori, A three-site gauge model for flavor hierarchies and flavor anomalies, Phys. Lett. B 779 (2018) 317–323, [arXiv:1712.01368].

M. Blanke and A. Crivellin, B Meson Anomalies in a Pati-Salam Model within the Randall-Sundrum Background, Phys. Rev. Lett. 121 (2018), no. 1011801, [arXiv:1801.07256].

J. Davighi and G. Isidori, Non-universal gauge interactions addressing the inescapable link between Higgs and flavour, JHEP 07 (2023) 147,[arXiv:2303.01520].

M. Fern´andez Navarro and S. F. King, Tri-hypercharge: a separate gauged weak hypercharge for each fermion family as the origin of flavour, JHEP 08 (2023) 020, [arXiv:2305.07690].

J. Davighi and B. A. Stefanek, Deconstructed Hypercharge: A Natural Model of Flavour, arXiv:2305.16280.

M. Fern´andez Navarro, S. F. King, and A. Vicente, Tri-unification: a separate SU (5) for each fermion family, arXiv:2311.05683.

R. Barbieri and G. Isidori, Minimal flavour deconstruction, arXiv:2312.14004.

A. Greljo and A. E. Thomsen, Rising Through the Ranks: Flavor Hierarchies from a Gauged SU (2) Symmetry, arXiv:2309.11547.

M. Bordone, C. Cornella, J. Fuentes-Martin, G. Isidori, A three-site gauge model for flavor hierarchies and flavor anomalies, Phys. Lett. B 779 (2018) 317–323, arXiv:1712.01368.
J. Davighi, A. Gosnay, D. J. Miller, S. Renner, Phenomenology of a Deconstructed Electroweak Force, JHEP 05 (2024)085, arXiv:2312.13346.
B. Capdevila, A. Crivellin, J. M. Lizana, S. Pokorski, SU(2)L deconstruction and flavour (non)-universality, JHEP 08 (2024) 031, arXiv:2401.00848.
J. Fuentes-Mart´ın, J. M. Lizana, Deconstructing flavor anomalously, JHEP 07 (2024) 117, arXiv:2402.09507.
M. Fern ´andez Navarro, S. F. King, A. Vicente, Minimal complete tri-hypercharge theories of flavour, JHEP 07 (2024) 147, arXiv:2404.12442.
J. M. Lizana, A common origin of the Higgs boson and the flavour hierarchies, JHEP, arXiv:2412.14243
M. Fernandez Navarro . S.F. King and A. Vincente, Natural neutrino mass hierarchy in a theory of gauge flavour deconstruction 2506.21687 [hep-ph]
R. Barbieri, Phenomenology of Minimal Flavour Deconstruction at the lowest new scale, 2409.08657 [hep-ph]

START WITH A 3-SITE MODEL $SU(2)_1 \times SU(2)_2 \times SU(2)_3$

ONE LEFT-HANDED SU(2), FOR EACH FAMILY SEPARATELY

$\Lambda_1 \propto 10^{3-4} TeV$ ↓ BY THE VEV OF Φ_1

$SU(2)_{12} \times SU(2)_3$

$\Lambda_2 \propto \mathcal{O}(10) TeV$ ↓ BY THE VEV OF Φ_2

$SU(2)_{SM}$

ONE GETS APPROXIMATE U(2) GLOBAL SYMMETRY FOR THE FIRST TWO FAMILIES (APPROXIMATELY UNIVERSAL SU(2) GAUGE INTERACTIONS) IF, IN ADDITION THE HIGGS CARRIES ONLY $SU(2)_3$ CHARGES

HEAVY VECTOR BOSONS FROM THE FIRST $M_{W''} = \mathcal{O}(\Lambda_1)$

AND SECOND BREAKING $M_{W'} = \mathcal{O}(\Lambda_2)$

INTERESTING QUESTIONS:

WHAT TO DECONSTRUCT? WHICH PART OF THE SM?

UV COMPLETIONS (MULTI-HIGGS, VECTOR LIKE FERMIONS) FOR
BREAKING (SLIGHTLY) U(2)'s

LOCALISATION OF LEPTONS, CHIRAL ANOMALY CANCELATION (NEW FERMIONS –CHIRAL WITH
RESPECT TO THE ORIGINAL GAUGE GROUPS BUT VECTOR LIKE IN THE SM
(PMNS PATTERN)

UV COMPLETIONS FOR GETTING THE VEV's OF BI-DOUBLET SCALARS
FROM RENORMALISABLE THEORIES (ELEMENTARY OR COMPOSITE (JAVIER LIZANA))

LINK TO THE HIERARCHY PROBLEM (THE HIGGS AS A PSEUDO-GOLDSTONE)-LITTLE
HIGGS MODELS OR TECHNICOLOUR LIKE MODELS.

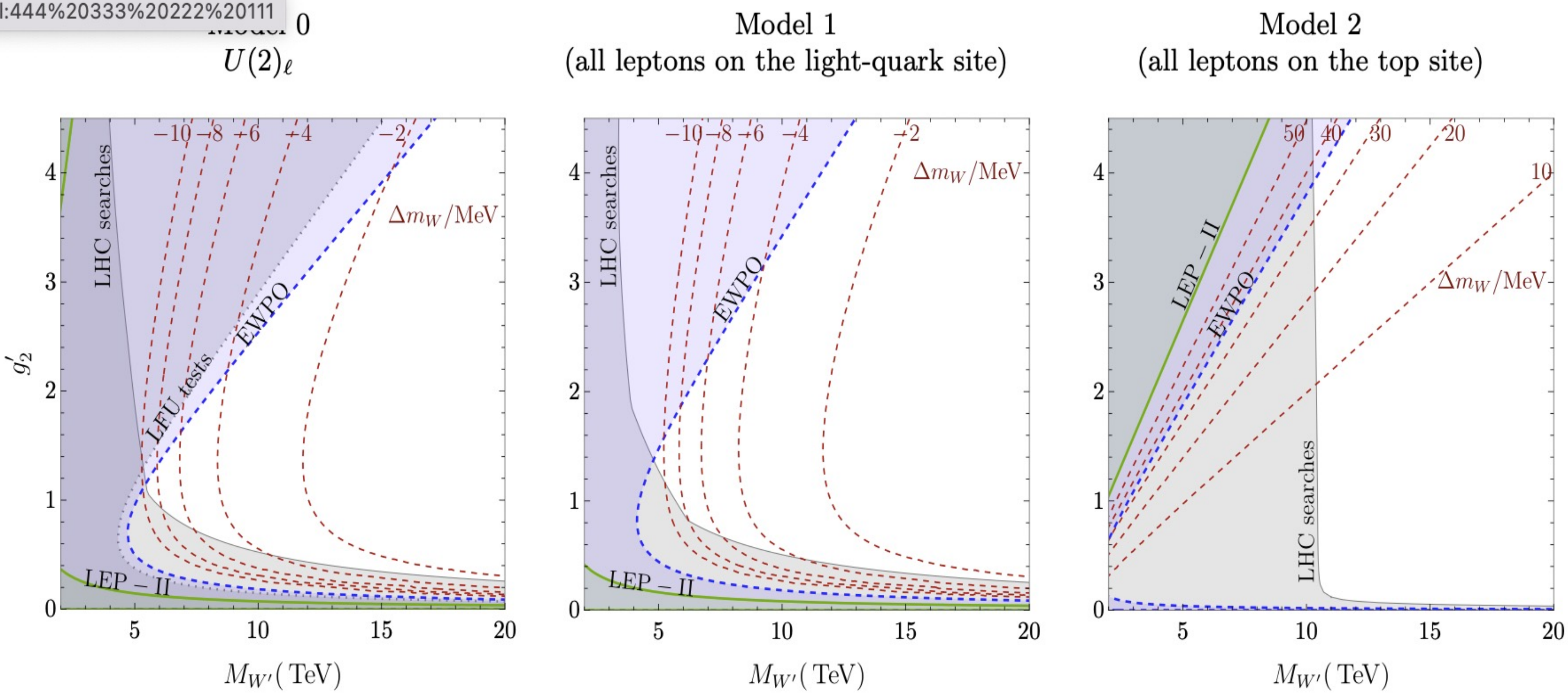
A VARIETY OF PHENOMENOLOGICAL PREDICTIONS FOLLOWING FROM

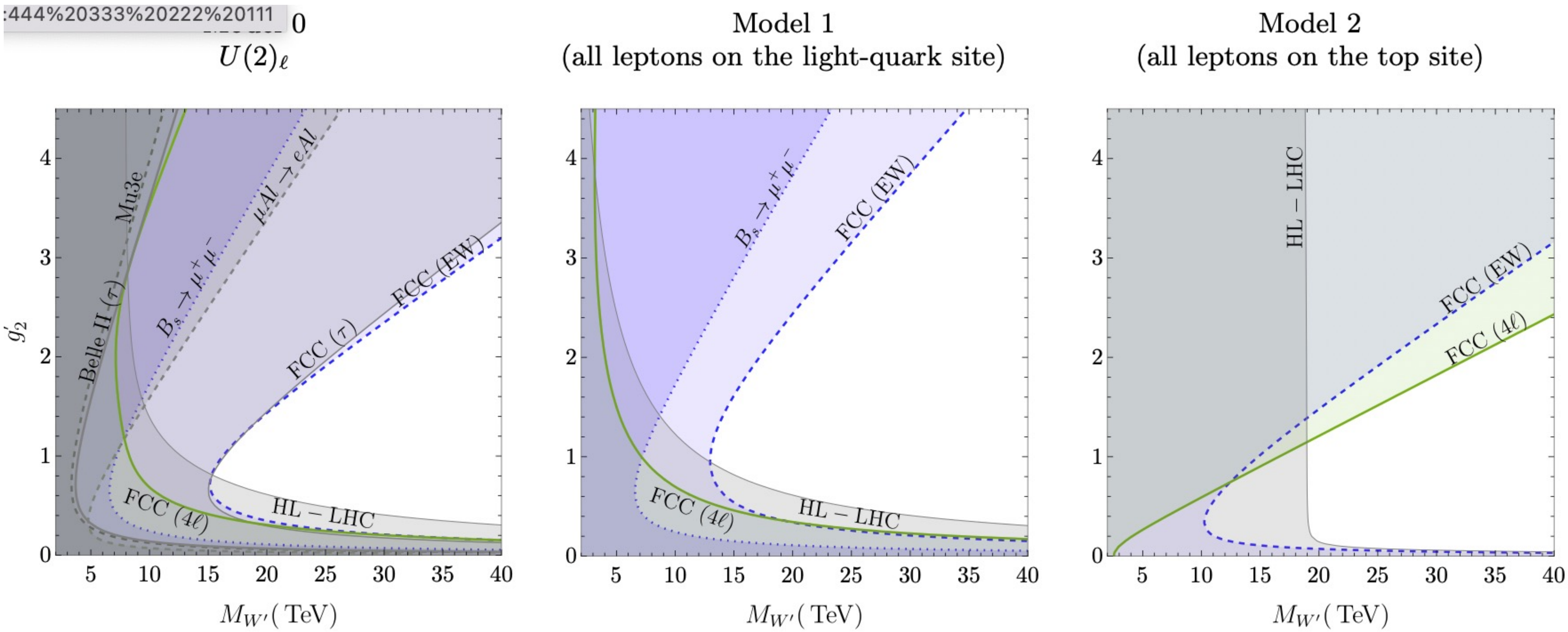
a) POSSIBLE DIRECT PRODUCTION OF VECTOR TRIPLETS IN pp COLLISIONS

b) TREE-LEVEL EXCHANGE OF THE VECTOR TRIPLET IN FOUR-FERMION PROCESSES

c) MODIFICATION OF THE W,Z COUPLINGS TO FERMIONS DUE TO THEIR MIXING WITH THE TRIPLET AFTER ELECTROWEAK SYMMETRY BREAKING

MANY CORRECTIONS TO THE EWPO OF ORDER $\mathcal{O}(\frac{M_W^2}{M_{W'}^2})$, DEPENDING ON THE LOCALISATION OF LEPTONS


Model 0
U(2)ℓ
Model 1
(all leptons on the light-quark site)
Model 2
(all leptons on the top site)
LHC searches
LFU tests
EWPO
LEP − II
Δm_W/MeV
−10
−8
−6
−4
−2
50
40
30
20
10
g'_2
M_W' (TeV)
0
1
2
3
4
5
10
15
20



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0
$U(2)_\ell$
Model 1
(all leptons on the light-quark site)
Model 2
(all leptons on the top site)
g_2'
$M_{W'}$(TeV)
Belle II (τ)
Mu3e
$B_s \to \mu^+\mu^-$
$\mu Al \to eAl$
FCC (τ)
FCC (EW)
FCC (4ℓ)
HL − LHC

SUMMARY

"NEARBY" NEW SCALES STILL POSSIBLE IN THE CONTEXT OF FLAVOUR
(BTW, FROGGATT-NIELSEN MODELS MUCH MORE CONSTRAINING FOR A NEW SCALE)

GOOD NEWS FOR NEW ACCELERATORS; RICH PHENO CALLS FOR MORE DATA

A FRAMEWORK to LINK FLAVOUR HIERARCHIES TO THE HIGGS NATURALNESS
(see e.g. Javier Lizana)

BACK UP

$\Phi_{ij} = \Lambda\delta_{ij}$, it generates a gauge boson mass matrix, which in the (W_μ^1, W_μ^2) basis is given by

$$\mathbb{M}_W^2 = \frac{\Lambda^2}{4}\begin{pmatrix} g_1^2 & -g_1 g_2 \\ -g_1 g_2 & g_2^2 \end{pmatrix}. \quad (1)$$

The massless eigenstate corresponds to the SM gauge boson $W_\mu^{(0)}$, with a universal coupling

$$g_L = \frac{g_1 g_2}{\sqrt{g_1^2 + g_2^2}}, \quad (2)$$

to SM $SU(2)_L$ doublets, independently if they are doublets of $SU(2)_1$ or $SU(2)_2$ prior to the breaking.[1] In addition there is a massive $SU(2)_L$ triplet $W_\mu'^{(0)} \sim (\mathbf{1}, \mathbf{3})_0$, with squared mass $M_{W'}^2 = \frac{\Lambda^2}{4}(g_1^2 + g_2^2)$ and couplings

$$g_1' = -\sqrt{g_1^2 - g_L^2}, \qquad g_2' = \frac{g_L^2}{\sqrt{g_1^2 - g_L^2}}, \quad (3)$$

where $g'_{1(2)}$ is the coupling to fields located in the first (second) site prior to the breaking. As a convention, we

The interactions between the massive vector triplet and the SM fields can be parametrised by the Lagrangian

$$\mathcal{L} \supset -\frac{1}{2}\Bigg[g^q \sum_{i=1,2} \bar{q}_L^i \gamma^\mu \sigma_a q_L^i + g_{33}^q \bar{q}_L^3 \gamma^\mu \sigma_a q_L^3 + \sum_{i=1.2.3} g_{ii}^\ell \bar{\ell}_L^i \gamma^\mu \sigma_a \ell_L^i + g^H H^\dagger \sigma_a i \overleftrightarrow{D}^\mu H\Bigg] W_\mu^{\prime(0)a},$$

$$g^q = -\frac{g_L^2}{g_2'}, \qquad g_{33}^q = g^H = g_2'.$$

- Model 0:

$$g^{\ell}_{11} = g^{\ell}_{22} = -\frac{g_L^2}{g_2'}, \qquad g^{\ell}_{33} = g_2'. \tag{20}$$

- Model 1:

$$g^{\ell}_{11} = g^{\ell}_{22} = g^{\ell}_{33} = -\frac{g_L^2}{g_2'}, \tag{21}$$

- Model 2:

$$g^{\ell}_{11} = g^{\ell}_{22} = g^{\ell}_{33} = g_2'. \tag{22}$$

Integrating out the vector triplet at tree level generates the Wilson coefficients in the SM effective field theory (SMEFT) written in Appendix A.

C. $Z - Z'$ and $W - W'$ mixing

Once the SM Higgs acquires a VEV, the EW symmetry is broken. The coupling between the massive-vector triplet and the Higgs current in Eq. (4) generates a mass mixing between the SM gauge bosons and the W' and Z' bosons. The mass eigenstates are thus given by

$$\begin{aligned} W^{\pm} &= \cos\alpha_{WW'} W^{(0)\pm} + \sin\alpha_{WW'} W'^{(0)\pm}, \\ W'^{\pm} &= \cos\alpha_{WW'} W'^{(0)\pm} - \sin\alpha_{WW'} W^{(0)\pm}, \end{aligned} \tag{23}$$

$$\begin{aligned} Z &= \cos\alpha_{ZZ'} Z^{(0)} + \sin\alpha_{ZZ'} W_3'^{(0)}, \\ Z' &= \cos\alpha_{ZZ'} W_3'^{(0)} - \sin\alpha_{ZZ'} Z^{(0)}, \end{aligned} \tag{24}$$

where $Z^{(0)} = c_W W_3^{(0)} + s_W B$ and the mixing angles are

$$\sin\alpha_{WW'} = -\frac{g^H}{g_L}\frac{m_W^2}{M_{W'}^2}, \tag{25}$$

$$\sin\alpha_{ZZ'} = \frac{\sin\alpha_{WW'}}{c_W}, \tag{26}$$

where $m_W = g_L v/2$. These mixings will lead to corrections of the couplings of the SM Z and W to fermions, affecting the EWPO. When the triplet is integrated out, these corrections are described in the SMEFT by the Wilson coefficients $C_{Hq}^{(3)}$ and $C_{H\ell}^{(3)}$ (see Appendix A).

YUKAWA COUPLINGS

$U(2)_q \times U(3)_u \times U(3)_d$ accidental symmetry. If we charge the Higgs doublet under $SU(2)_2$ one can only write third generation Yukawa couplings[2]

$$-\mathcal{L} \supset y_i^{(t)} \bar{q}_L^3 H^c u_R^i + y_i^{(b)} \bar{q}_L^3 H d_R^i. \tag{5}$$

Here we can use the freedom to perform rotations between the right-handed (RH) quarks, i.e. redefining $y_i^{(t)} u_R^i \to y_t t_R$, and $y_i^{(b)} d_R^i \to y_b b_R$. We will thus work in the interaction basis where $u_R^3 = t_R$ and $d_R^3 = b_R$. Note that these Yukawa couplings have further broken the $U(3)_{u,d}$ flavour symmetries to $U(2)_{u,d}$. This fixes the quark and Higgs couplings of the vector triplet in Eq. (4) to be

$$g^q = -\frac{g_L^2}{g_2'}, \qquad g_{33}^q = g^H = g_2'. \tag{6}$$

$$-\mathcal{L} \supset \frac{1}{\Lambda'} \sum_{\substack{i=1,2\\ j=1,2,3}} \left(y_{ij}^{(u)} \bar{q}_L^i \Phi H^c u_R^j + y_{ij}^{(d)} \bar{q}_L^i \Phi H d_R^j \right), \tag{7}$$

where Λ' is some NP scale above Λ. After breaking

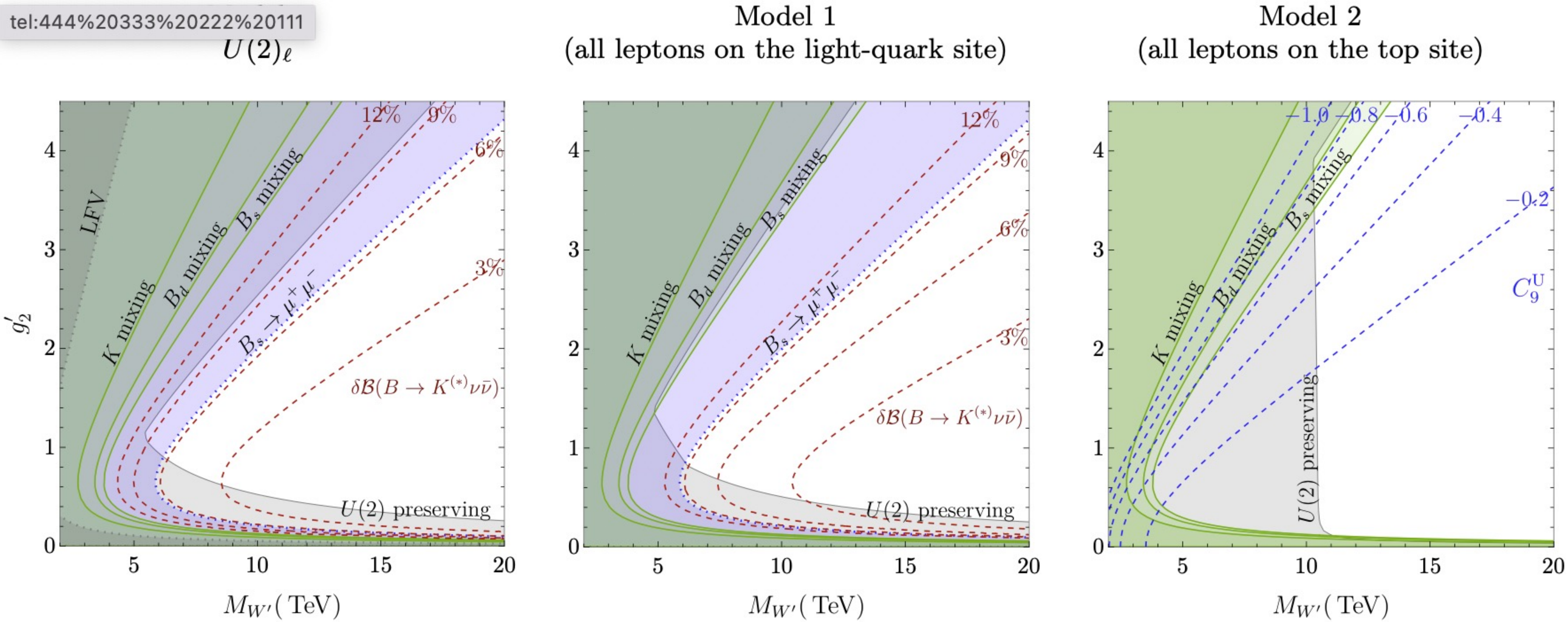
****

Several UV completions could generate these effective operators:

(1) **Extra Higgses:** We may add a scalar doublet of $SU(2)_1$, with hypercharge $1/2$, H_1. We can write in the Lagrangian terms like,

$$\begin{aligned} -\mathcal{L} \supset\; & m_{H_1}^2 |H_1^2| + \mu H_1^\dagger \Phi H_2 \\ & + \sum_{\substack{i=1,2\\ j=1,2,3}} \left(y_{ij}^{(u)} \bar{q}_L^i H_1^c u_R^j + y_{ij}^{(d)} \bar{q}_L^i H_1 d_R^j \right), \end{aligned} \tag{8}$$

where now $H_2 \equiv H$ is the Higgs located in the top-site used before. When H_1 is integrated out, the effective Yukawa couplings of Eq. (7) with $\Lambda' \sim m_{H_1}^2/\mu$ are generated.[3]



$U(2)_\ell$
Model 1
(all leptons on the light-quark site)
Model 2
(all leptons on the top site)
LFV
K mixing
B_d mixing
B_s mixing
$B_s \to \mu^+\mu^-$
12%
9%
6%
3%
$\delta\mathcal{B}(B \to K^{(*)}\nu\bar{\nu})$
$U(2)$ preserving
-1.0
-0.8
-0.6
-0.4
-0.2
C_9^{U}
g_2'
$M_{W'}$ (TeV)

Non-Universality from Flavour Deconstruction

$$G_1 \times G_2 \times G_{3+\mathrm{H}} \xrightarrow{\langle \phi_{12} \rangle \sim 10^{2\div 3}\ \mathrm{TeV}} G_{12} \times G_{3+\mathrm{Higgs}} \xrightarrow{\langle \phi_{23} \rangle \sim 1\ \mathrm{TeV}} G_{123}$$

$U(2)$ violation

Delivers $U(2)$ flavour symmetry

$$\psi_1 H \psi_3 \frac{\phi_{23}\phi_{12}}{\Lambda_{23}\Lambda_{12}} \to V_{ub} \ll V_{cb} \ll 1$$

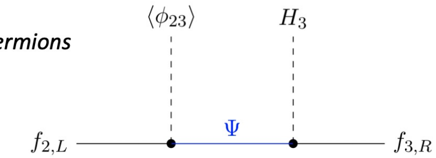
etc

$$\psi_2 H \psi_3 \frac{\phi_{23}}{\Lambda_{23}} \to V_{cb} \ll 1$$

etc

SM Flavour Puzzle ☑

Example UV:
Vector-like fermions



$$\Lambda_{23} \sim M_\Psi / g$$