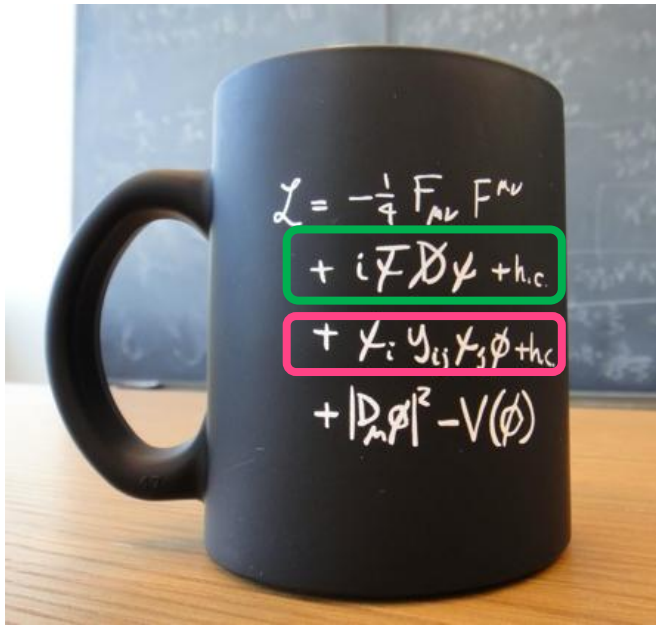
Low Scale Models for Higgs and Flavour

Joe Davighi, CERN

Higgs @ Capri, October 6th -10th 2025

Our Guide to New Physics



1. Fermion interactions with SM gauge bosons are flavour universal
2. Fermion interactions with Higgs highly non-universal

Masses: $1 \approx y_t \gg y_c \gg y_u \sim 10^{-5}, y_e \sim 10^{-6}$
Mixings: $V_{us} \gg V_{cb} \gg V_{ub}$

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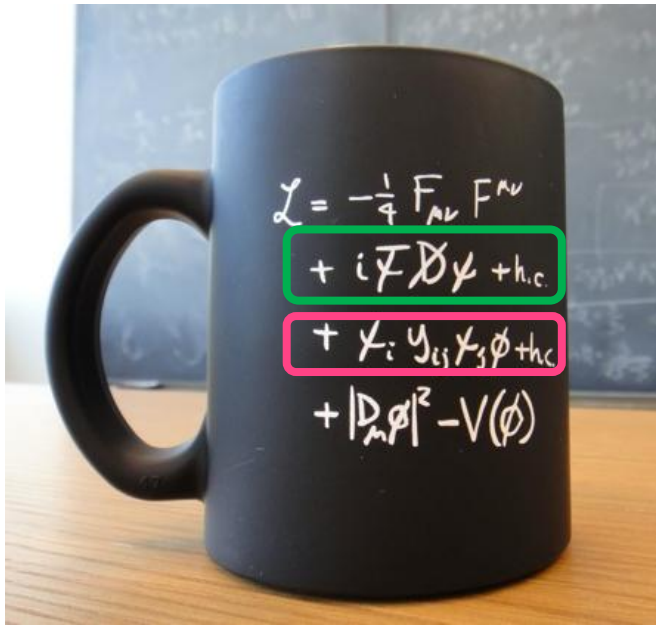

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$\Longrightarrow$ New physics at *some* heavy scale

[y_{ij} have logarithmic running]

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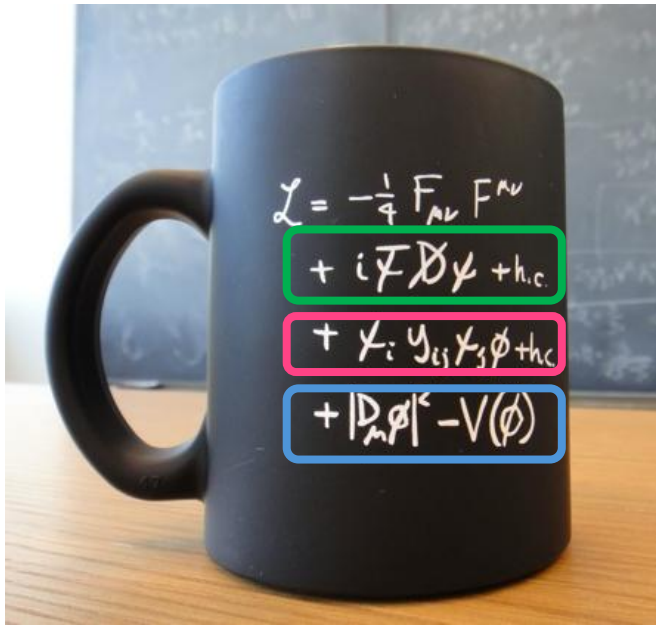
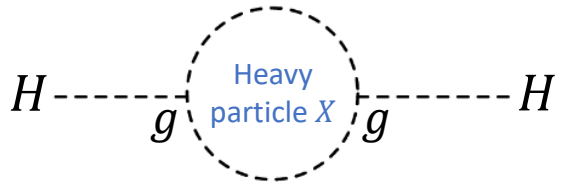


1. Fermion interactions with SM gauge bosons are flavour universal
2. Fermion interactions with Higgs highly non-universal $y_{ij} \ll y_t$

   $\Longrightarrow$ New physics at *some* heavy scale
3. Hierarchy problem: $m_h^2 \ll M_{\rm NP}^2$



$\Longrightarrow \delta M_h^2\big|_{\text{from } X} \sim \left(\frac{g^2}{16\pi^2}\right)^n M_{\rm NP}^2$

# of loops

E.g. for flavour, neutrino masses, unification

$\Longrightarrow$ BSM particles **near TeV**

E.g. SUSY, compositeness

See S. Pokorski's talk

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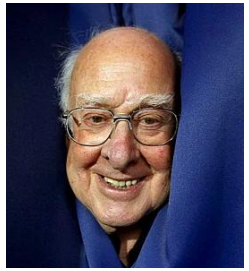

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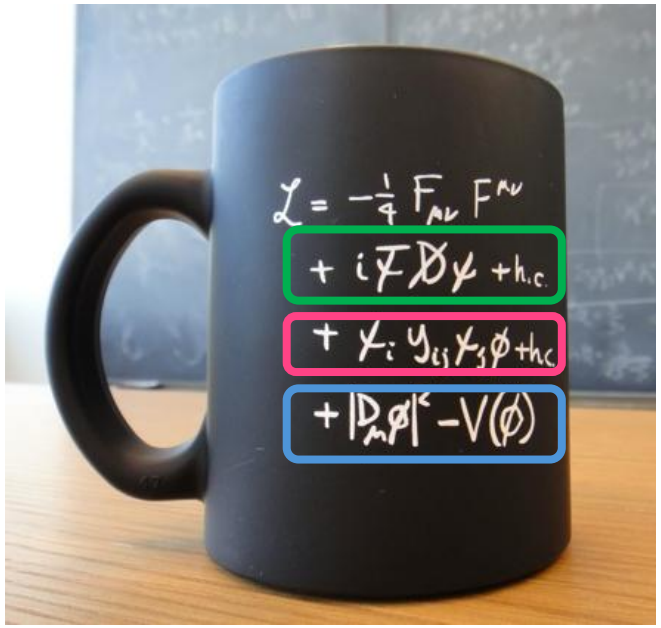

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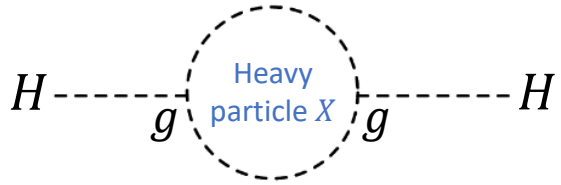

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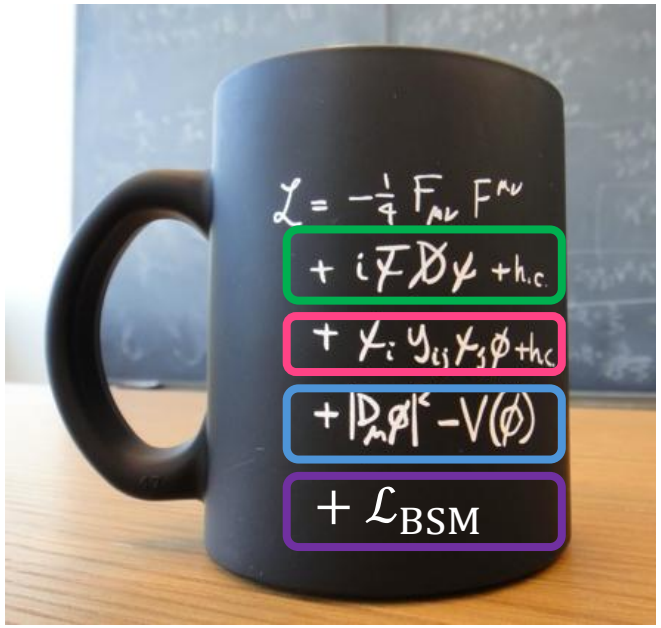

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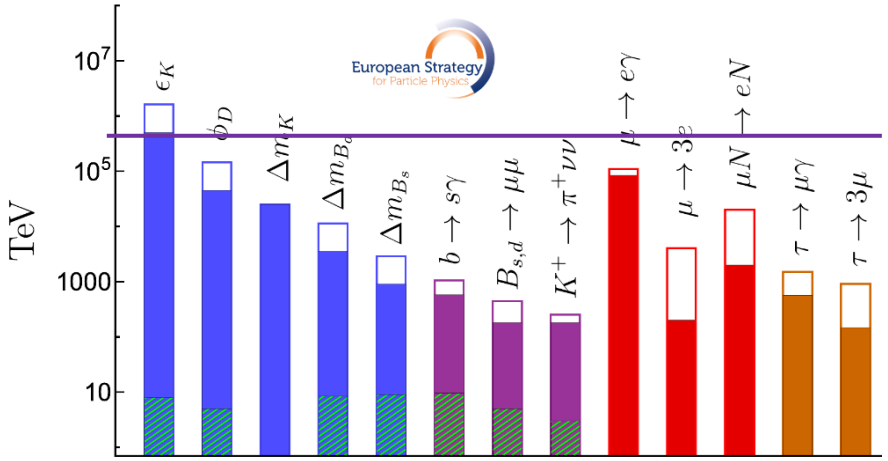
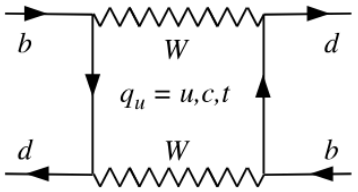
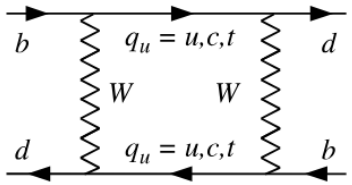


FCNCs very suppressed in SM





2025 ESPPU

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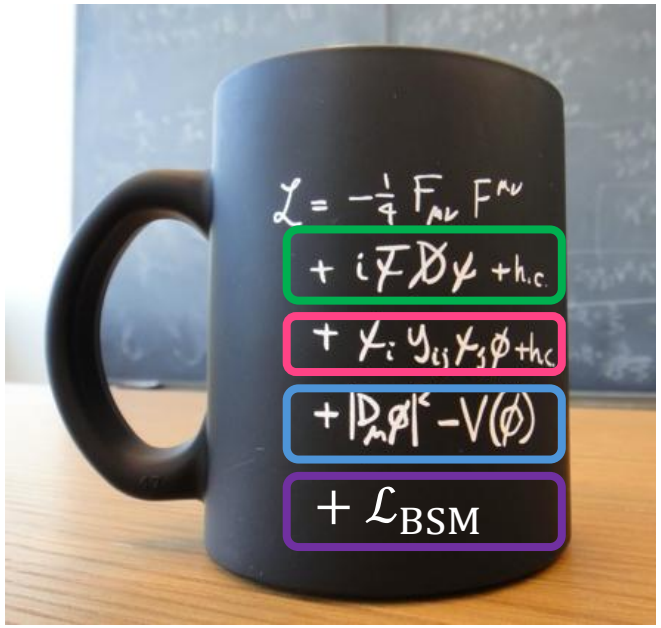

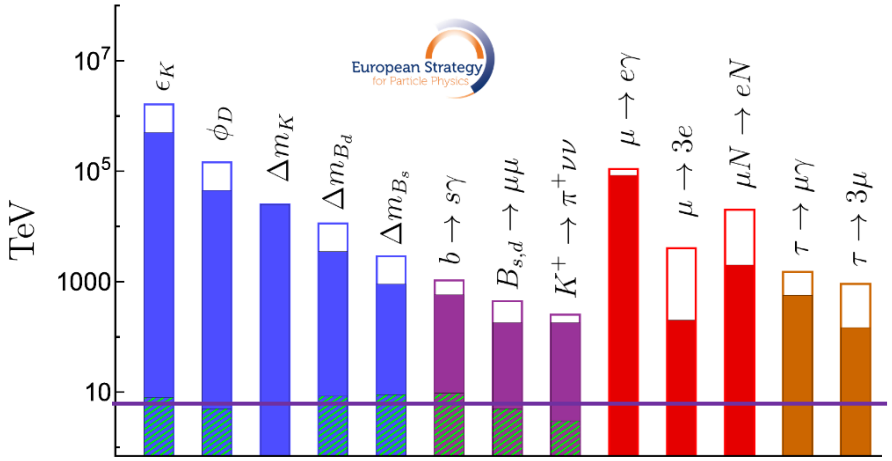

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A solution: Minimal Flavour Violation

D'Ambrosio, Giudice, Isidori, Strumia, hep-ph/0207036 …

$y_{ij} \bar{\psi}_i H \psi_j$ are *only* couplings that distinguish flavour

E.g. kaon mixing with MFV: $\frac{1}{\Lambda_{sd}^2} \sim y_t^4 (V_{31} V_{32}^*)^2 \frac{1}{\Lambda_{\rm NP}^2} \sim \left(\frac{10^{-4 \div 5}}{\Lambda_{\rm NP}} \right)^2$

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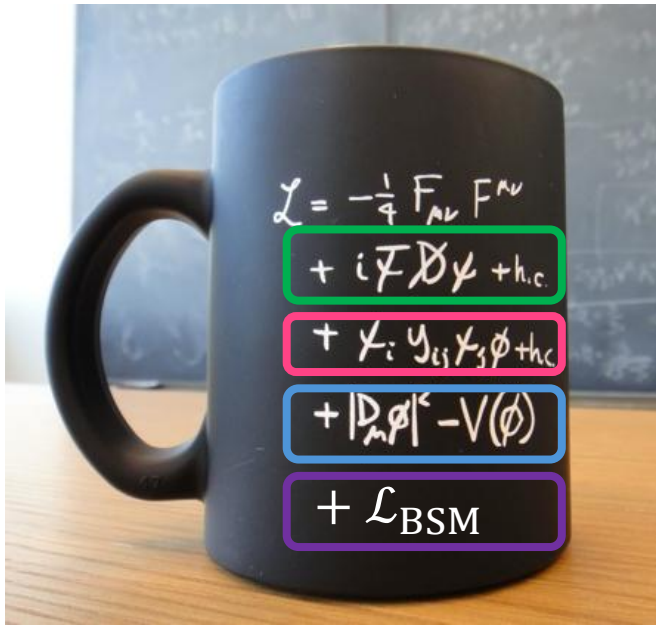

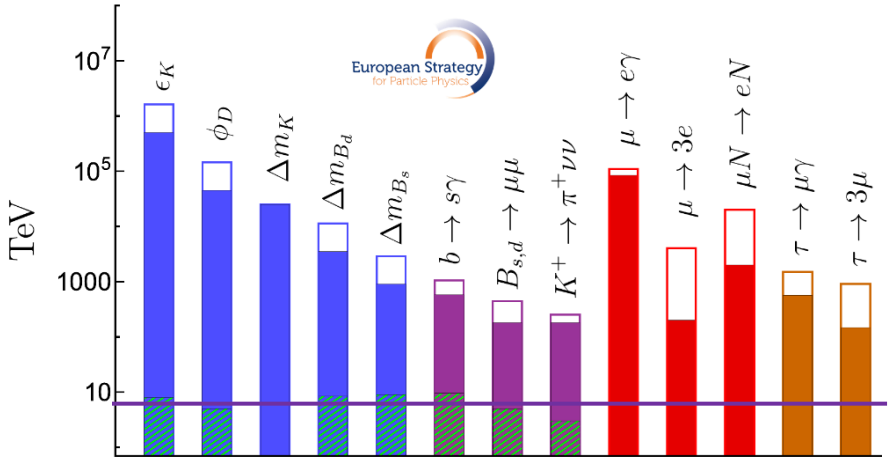

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… But hard to square this with solving **2** at low scale

+ LHC $\Rightarrow \Lambda_{\rm MFV} \approx 5 \div 10$ TeV: worse explanation of **3**

For composite Higgs $M_*^{\rm MFV} \approx 7 \div 8$ TeV

Glioti, Rattazzi, Ricci, Vecchi, 2402.09503

This talk:

Flavour Deconstruction = a class of TeV scale, non-universal models that provides a natural explanation of:

1. Flavour universal ψ int. with A_μ
2. Flavour non-universal ψ int. with H
3. Hierarchy problem — Embed Higgs as composite pNGB (wip)
4. Flavour conserving ψ int. with TeV BSM
   ≠ flavour universal! (as assumed in MFV)

The models have **rich phenomenology** across high pT, flavour, and EW precision observables

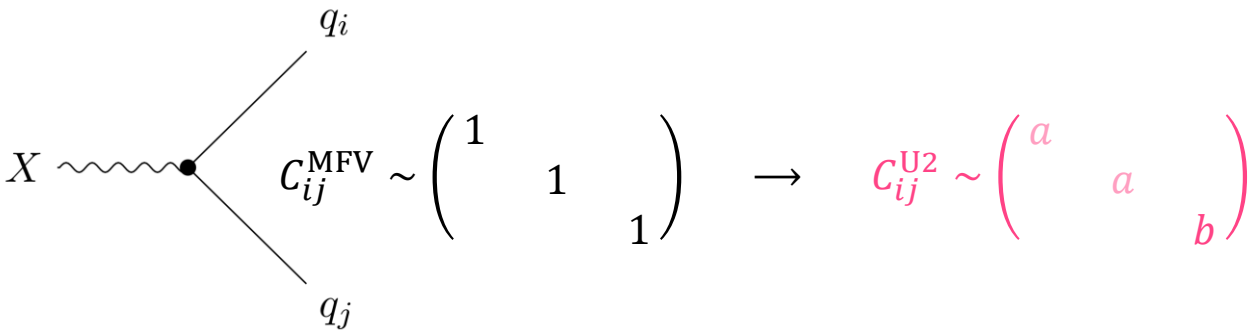
2. Flavour Deconstruction

Li, Ma, 1981, …
Arkani-Hamed, Cohen, Georgi hep-th/0104005 …
Craig, Green, Katz 1103.3708 …
Bordone, Cornella, Fuentes-Martin, Isidori, 1712.01368 …

Davighi, Isidori, 2303.01520…
Davighi, 2501.16064

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

From MFV to U2: Flavour Non-Universal New Physics



$$C_{ij}^{\mathrm{MFV}} \sim \begin{pmatrix} 1 & & \\ & 1 & \\ & & 1 \end{pmatrix} \rightarrow C_{ij}^{\mathrm{U2}} \sim \begin{pmatrix} a & & \\ & a & \\ & & b \end{pmatrix}$$

$(q_1, q_2) \sim \mathbf{2}$, $q_3 \sim \mathbf{1}$ of $U(2)_q$ etc

Barbieri et al 1105.2296
Isidori, Straub 1202.0464
Fuentes-Martin et al, 1909.02519

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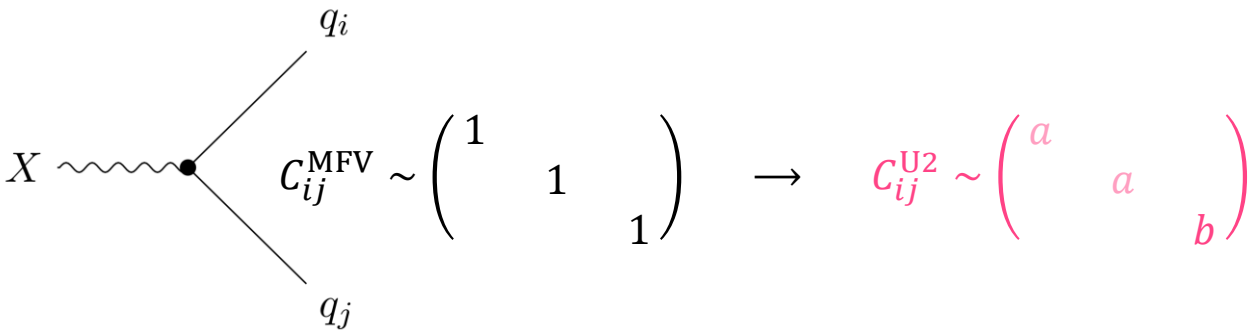

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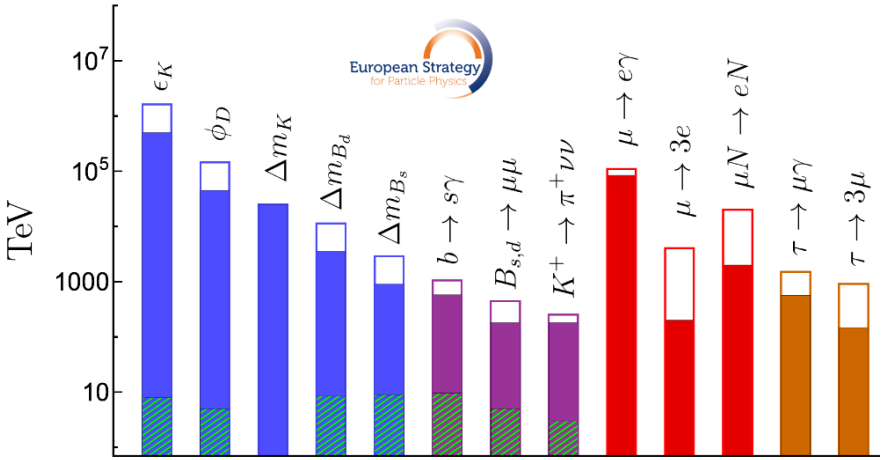
Just as good flavour protection as MFV ☑

Example: Kaon mixing with ~~MFV~~ U2

$$\frac{1}{\Lambda_{sd}^2} \sim y_t^4 (V_{31} V_{32}^*)^2 \frac{1}{\Lambda_{\text{NP}}^2} \sim \left(\frac{10^{-5}}{\Lambda_{\text{NP}}}\right)^2$$



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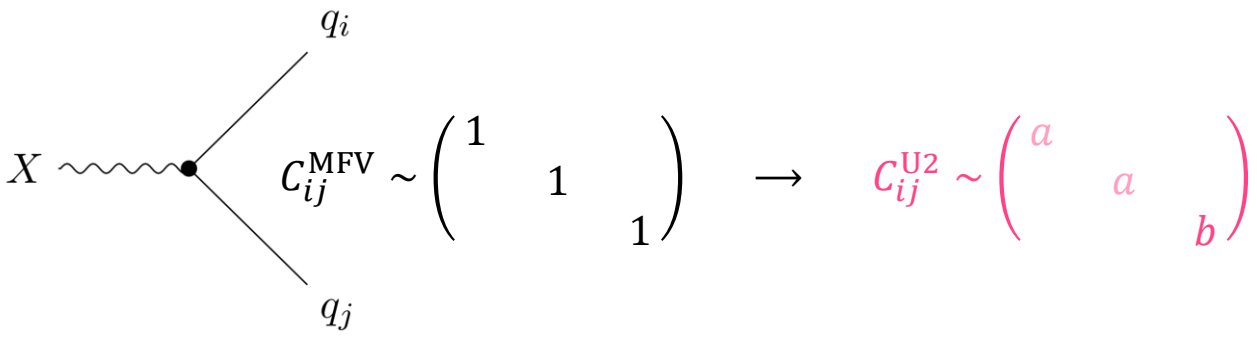

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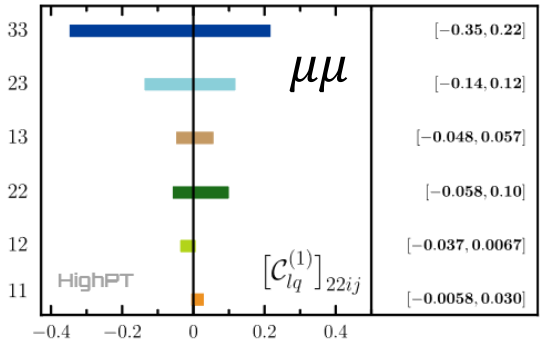

Allwicher et al, 2207.10714; 2207.10756

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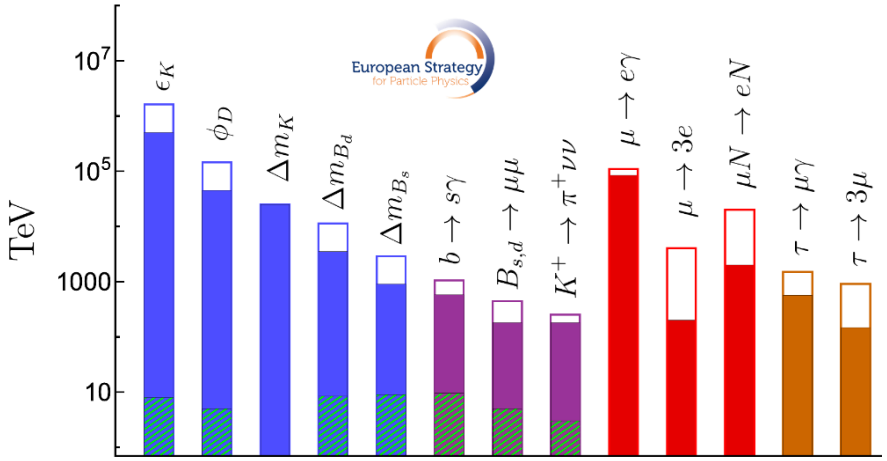


Two reasons to prefer U2 over MFV:

1. Lowering Λ

Limit $a \ll b$ can **reduce little hierarchy** by a factor a few → $\Lambda_{\text{U}(2)} \approx 1 \div 2$ TeV

2. Solving the SM flavour puzzle!

The *same* $U(2)$-like non-universal BSM could explain SM *and* BSM flavour puzzles

$$y_{ij}^u \approx \begin{pmatrix} & < 0.01 & 0.04 \\ & & 1 \end{pmatrix} \leftarrow y_t$$

For composite Higgs

$M_*^{\text{U}(2)} \approx 1 \div 2$ TeV

Glioti, Rattazzi, Ricci, Vecchi, 2402.09503

U2 decouples strong bounds:

- $pp \to jj$
- Modified W-couplings

Whence U2?

- Horizontal: $G_{\mathrm{SM}} \times G_{\mathrm{hor}} \to G_{\mathrm{SM}}$ Froggatt, Nielsen, Nucl Phys B (1979)
- Deconstruction: $G_{12} \times G_3 \to G_{\mathrm{SM}}$

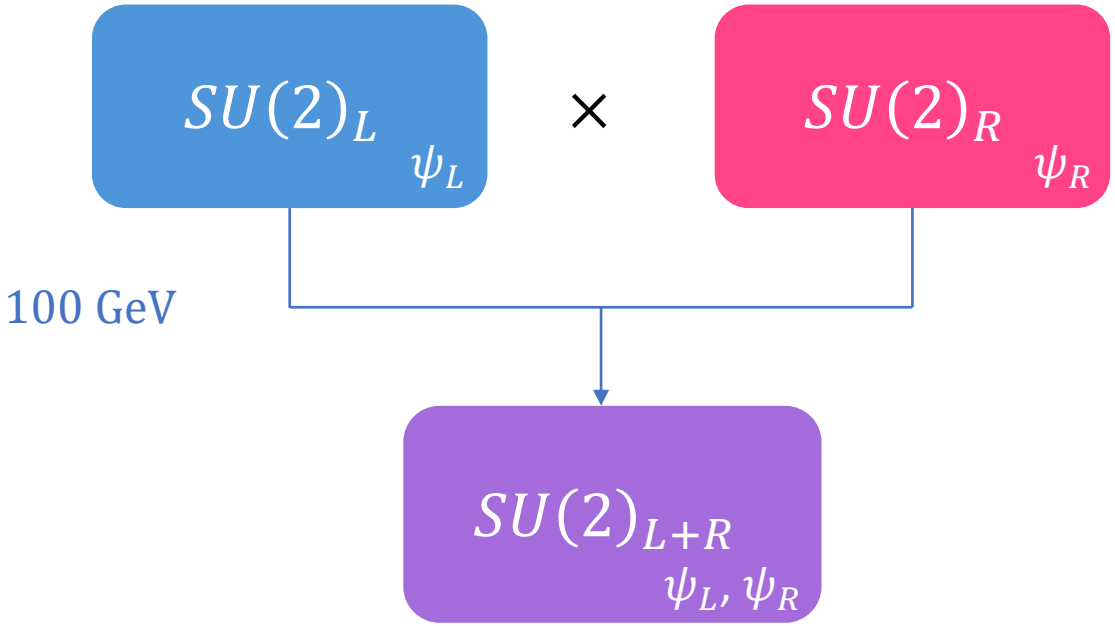
This talk

Universality as a likely accident

An analogy for flavour deconstruction:

Standard Model

Fundamentally *chiral*, ψ_L and ψ_R charged under different gauge interactions



Chiral

$\langle H \rangle$ OR $\langle \bar{q} q \rangle$

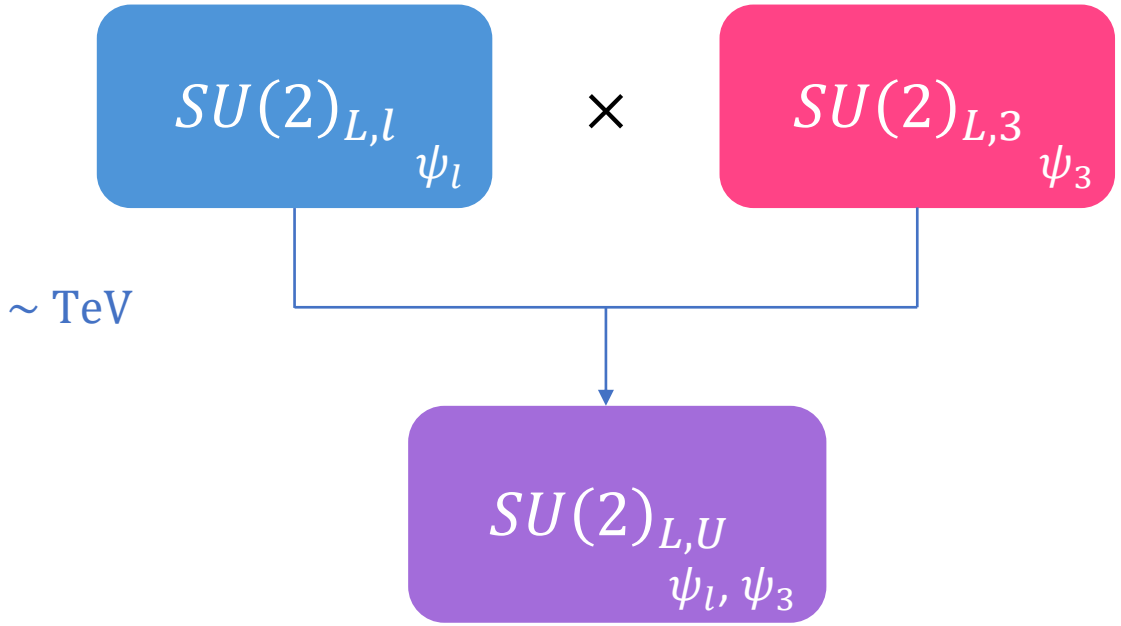
Quigg, Shrock, 0901.3958

Vector-like in IR

Universality as a likely accident

A Theory of Flavour?

Fundamentally *non-universal*, ψ_l and ψ_3 charged under different gauge interactions



Non-universal

$\langle\phi\rangle$ OR $\langle\bar{\Psi}\Psi\rangle$

Flavon Hyper-quark

Flavour Universal in IR

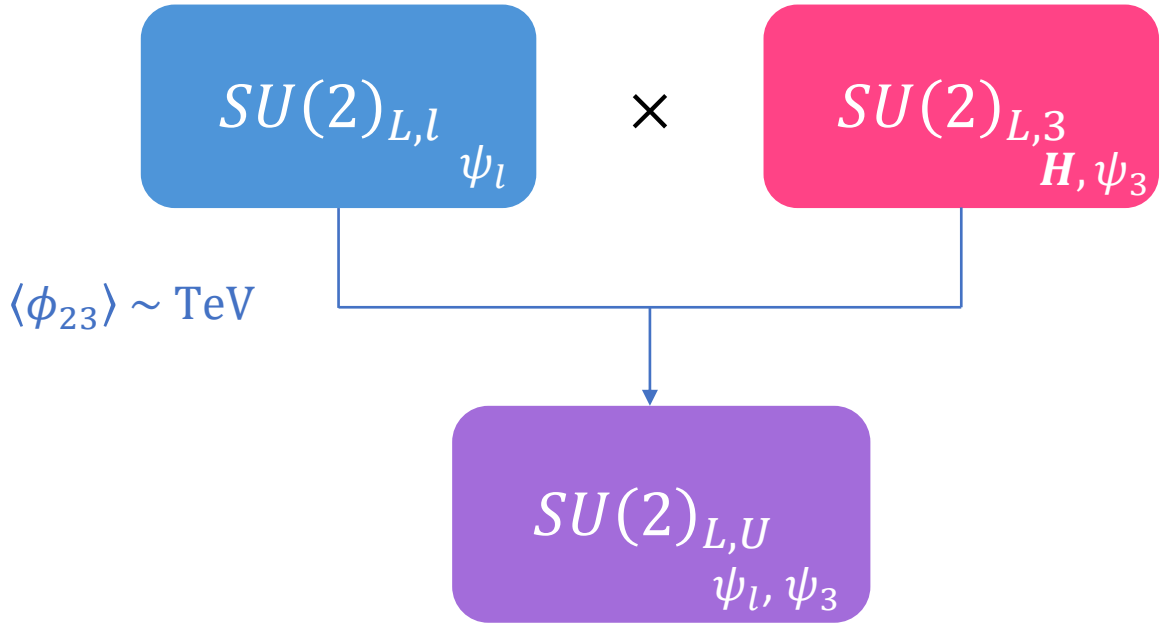
In both cases, this symmetry breaking pattern is generic (ind. of gauge couplings, ϕ rep, ...)

[*Goursat (1889):* The only non-trivial subgroup embedding of $G \hookrightarrow G \times G$ is the **diagonal** one]

Deconstruction: SM flavour puzzle ☑

A Theory of Flavour? Yes! [Iff you deconstruct an EW force]

Fundamentally *non-universal*, ψ_l and ψ_3 charged under different gauge interactions



Flavour non-universal ψ int. with H ☑

$\psi_{3,L} H \psi_{3,R} \quad \rightarrow y_t \sim 1$

$\psi_{2,L} H \psi_{3,R} \frac{\phi_{23}}{\Lambda_{23}} \quad \rightarrow V_{cb} \ll 1$ etc

$$y^u_{ij} \approx \begin{pmatrix} & & \\ & & \\ & < 0.01 & \boxed{0.04} \\ & & 1 \end{pmatrix}$$

Deconstruction: BSM flavour puzzle ☑

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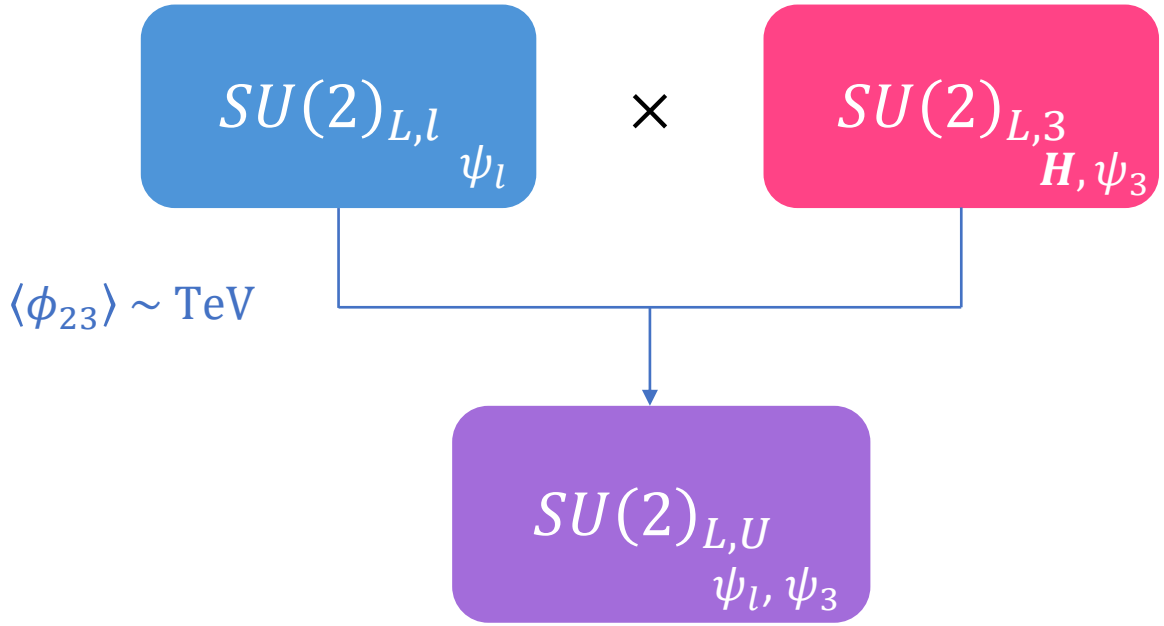


Flavour conserving ψ int. with BSM ☑

Vector bosons in adj G; flavour structure:

$$C_{ij} \sim g_{\text{SM}} \begin{pmatrix} g_{12}/g_3 & & \\ & g_{12}/g_3 & \\ & & g_3/g_{12} \end{pmatrix}$$

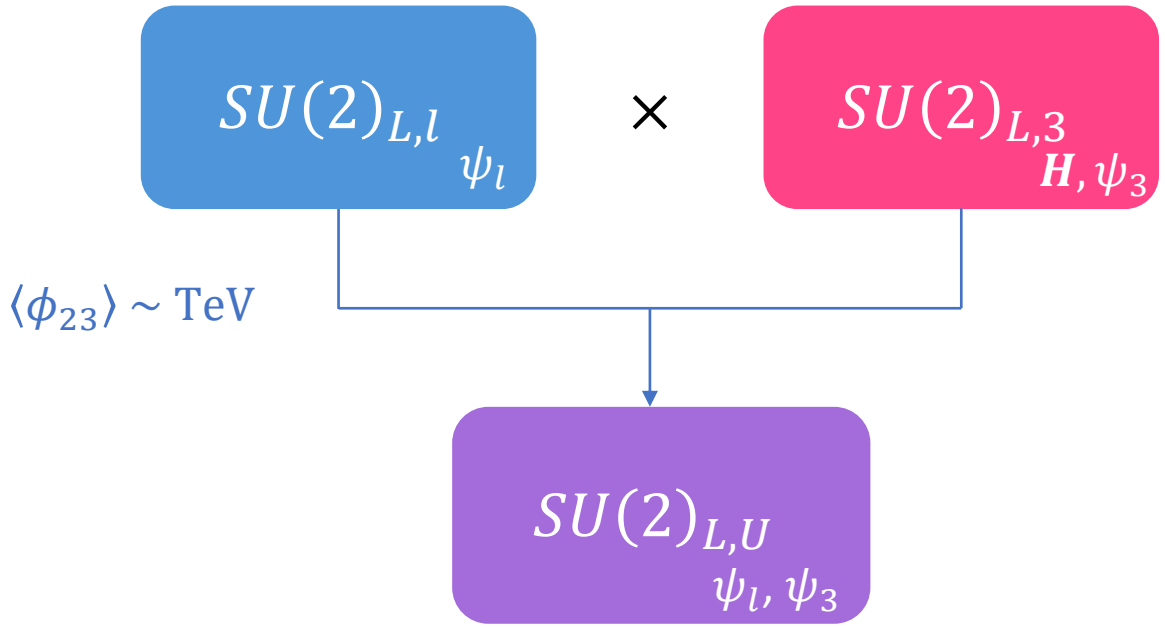
$G_{12} \times G_{3+H} \to G_{\text{SM}}$ **can** occur near TeV b/c

- No 1-2 flavour violation
- $g_3 \gg g_{1,2}$ limit possible

Deconstruction: Hierarchy Problem?

A Theory of Flavour? Yes! [Iff you deconstruct an **EW force**]

Fundamentally *non-universal*, ψ_l and ψ_3 charged under different gauge interactions



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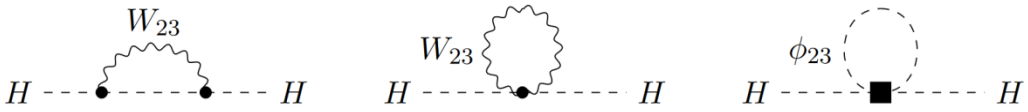
Should occur near TeV to not destabilize Higgs



$$\delta m_h^2 \sim g_3^2 M^2 / 16\pi^2$$

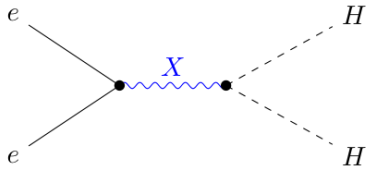
Davighi, Isidori, 2303.01520

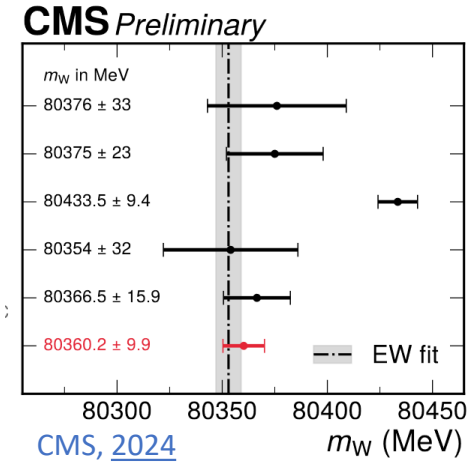
Phenomenology of Electroweak Deconstruction

$DU(1)_Y$: **Davighi**, Stefanek 2305.16280; Fernández Navarro, King 2305.07690
$DSU(2)_L$: **Davighi**, Gosnay, Miller, Renner 2312.13346; Capdevila, Crivellin, Lizana, Pokorski 2401.00848

EWPOs: tree-level shifts in Z/W-pole means EW constraints often strongest!

- A key observable is m_W: $\mathrm{D}SU(2)_L \Rightarrow \delta m_W < 0$; $\mathrm{D}U(1)_Y \Rightarrow \delta m_W > 0$

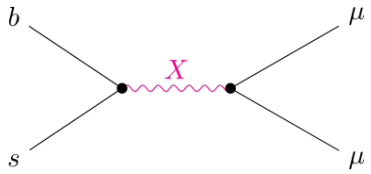




CMS, 2024

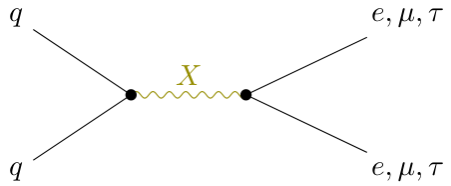
Flavour: key observable is $BR(B_s \to \mu^+\mu^-)$, measured precisely at LHC

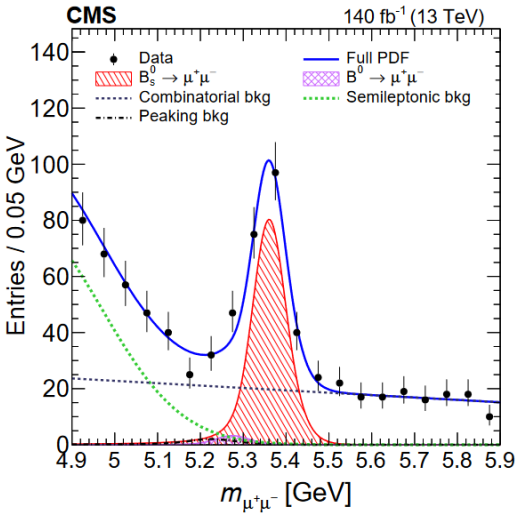
- B_s mixing strictly subleading in these models
- Power-suppressed by $y_Q = 1/6$ for $\mathrm{D}U(1)_Y$



LHC high p_T: driven by valence-quark couplings

- Favours $g_3 \gg g_{12}$ region i.e. $\theta \to \pi/2$





CMS, 2212.10311

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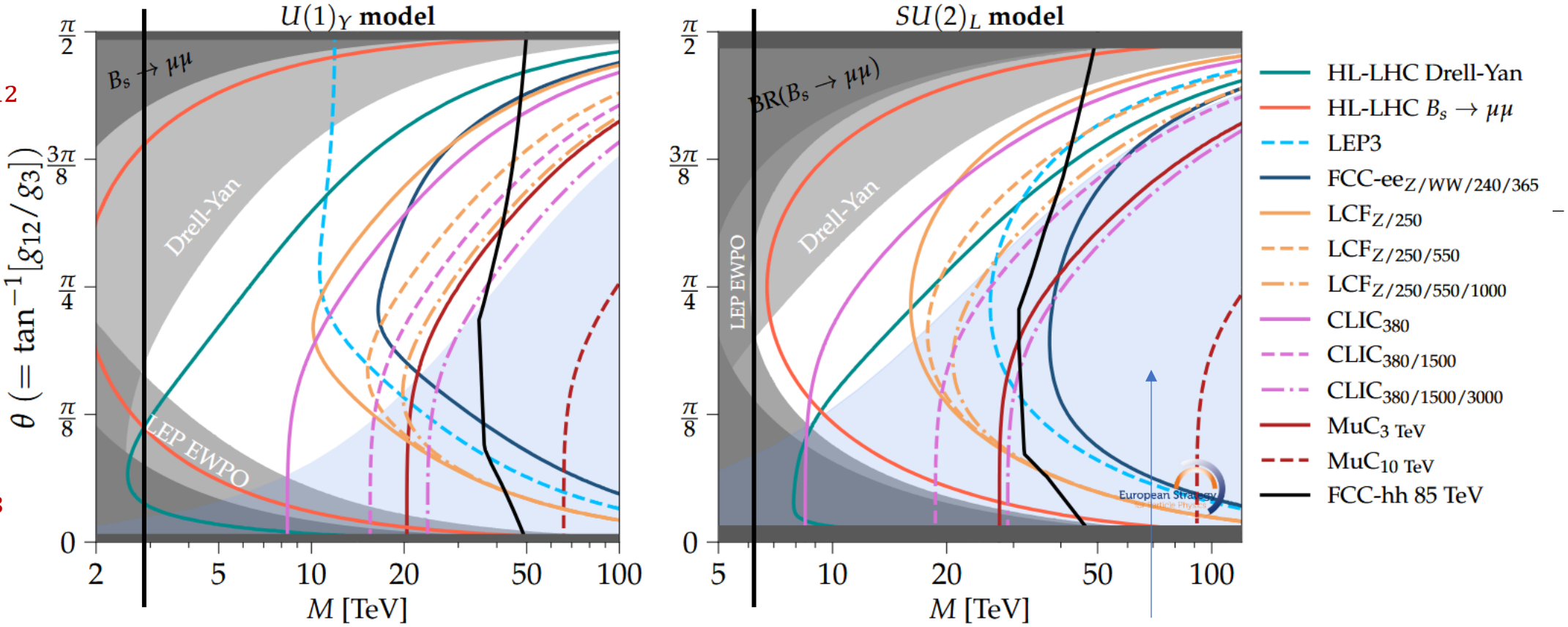
$DU(1)_Y$: **Davighi**, Stefanek 2305.16280; Fernández Navarro, King 2305.07690
$DSU(2)_L$: **Davighi**, Gosnay, Miller, Renner 2312.13346; Capdevila, Crivellin, Lizana, Pokorski 2401.00848

*Credit **Sophie Renner** for ESPPU versions*

Large g_{12}

Large g_3

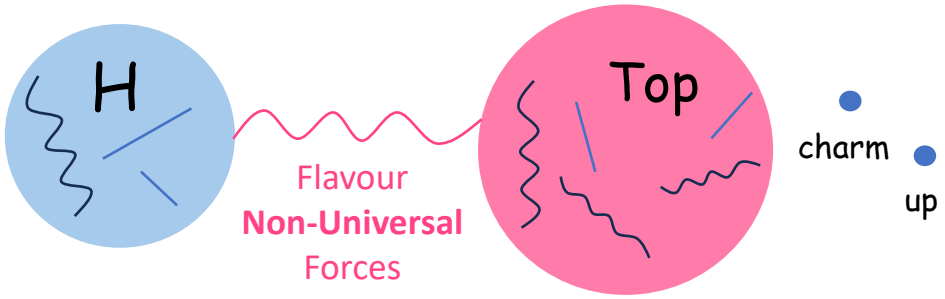


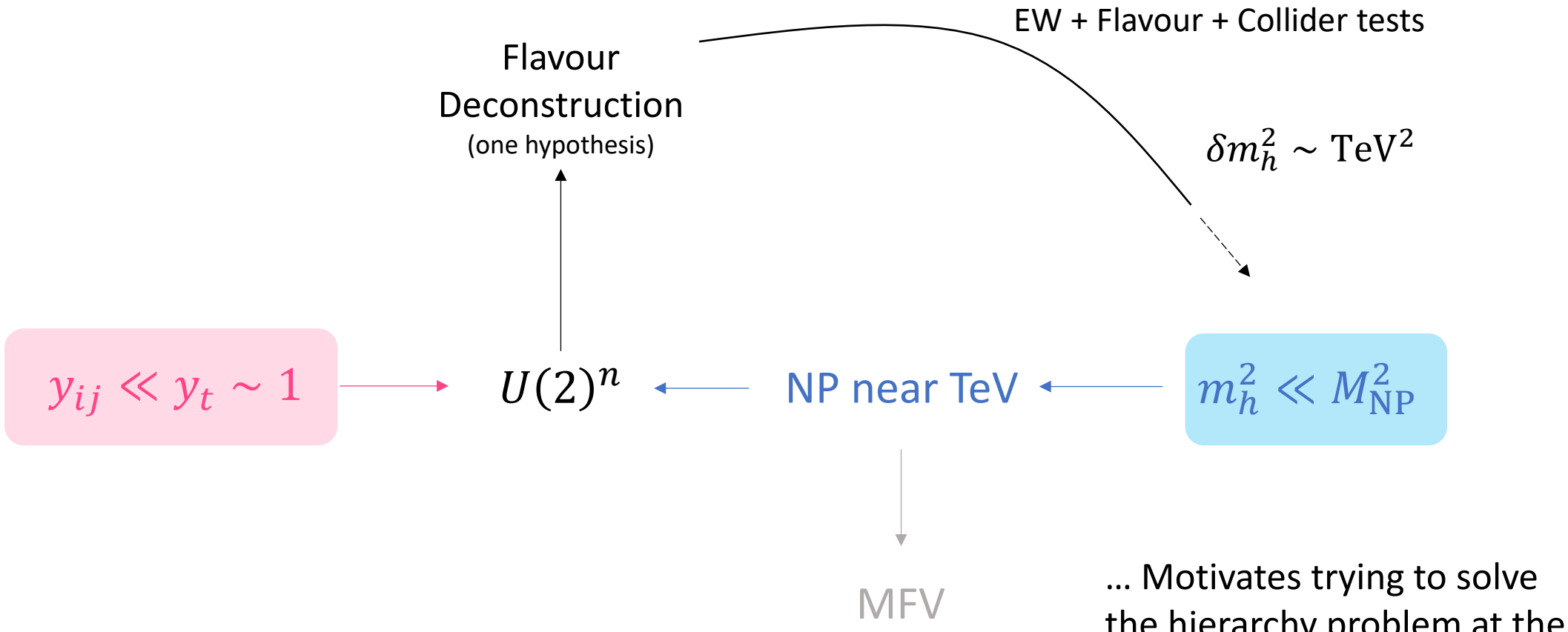
Currently, $M \gtrsim 3$ TeV

$M \gtrsim 6$ TeV

$\delta m_h^2 > \text{TeV}^2$
Region disfavoured by naturalness

3. Higgs and Flavour – Together





… Motivates trying to solve the hierarchy problem at the same time

Flavour Deconstructing the Composite Higgs

Covone, **Davighi**, Isidori, Pesut, 2407.10950; see also Lizana, 2412.14243

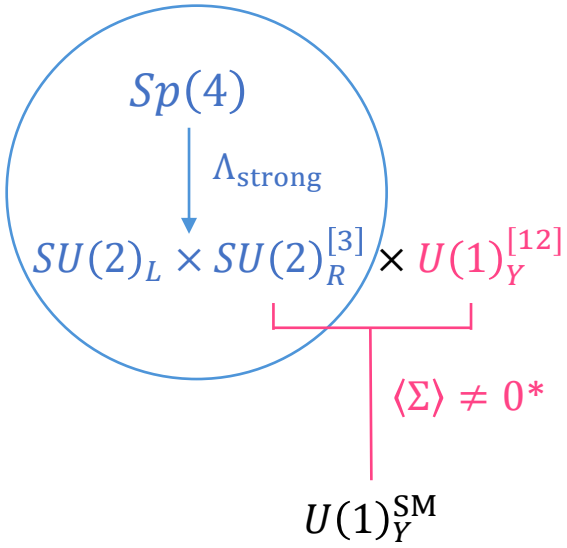
Flavour deconstruction can be combined with Composite Higgs at ~ 2 TeV:

⟶ Solves flavour puzzle

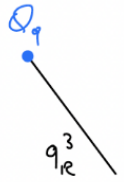
⟶ Gauge protected $M_*^{\mathrm{U}(2)} \approx 1 \div 2$ TeV

⟶ Cures large hierarchy problem

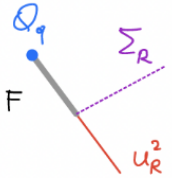
⇒ Higgs as pNGB



*Σ is for now elementary…



3rd gen ~ partial composite



1st /2nd gens ~ elementary

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Covone, **Davighi**, Isidori, Pesut, 2407.10950

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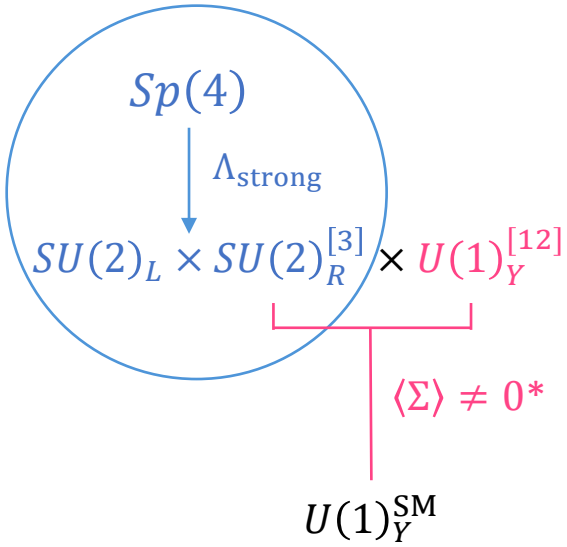

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$V(h)$ generated by explicit $Sp(4)$ breaking: y_t and $g_{L,R}$

$$\Longrightarrow m_h^2 = \frac{1}{16\pi^2}\left[4n_c y_t^2 M_T^2 - \frac{9}{2} g_{R,3}^2 M_\rho^2 \left(1 - \frac{2M_{W_R}^2}{M_\rho^2}\right)\right]$$

Realising the Higgs mass
- $g_{R,3}^2 \sim 1$ can better cancel y_t contribution
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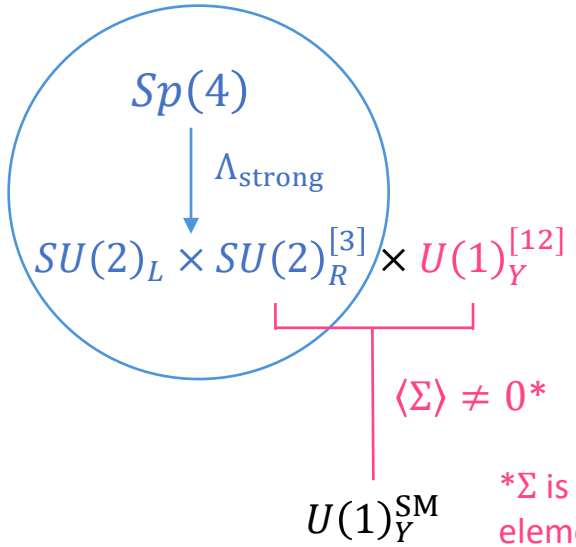

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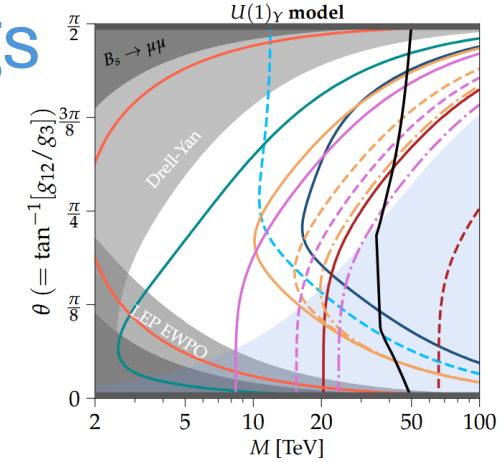
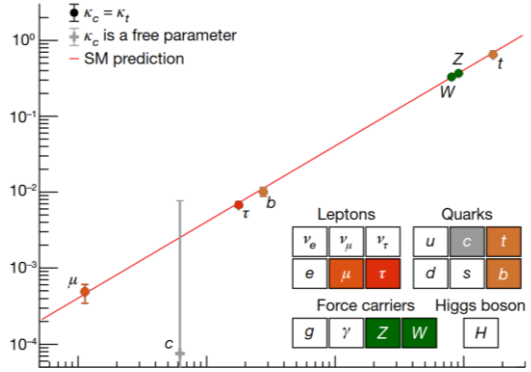
*Signatures of heavy gauge bosons →



*Signatures of composite dynamics: →

- Modified HWW and HZZ
- Searches for top partners et al
- Universal shifts in EWPOs



Phenomenologically viable benchmark:

- Large $g_{R,3} \sim 1$
- Light top partner $M_T \approx 2$ TeV; spin-1 resonance $M_\rho \approx 10$ TeV
- Deconstruction scale $v_\Sigma \approx 3$ TeV
- Order 5% tuning in Higgs mass

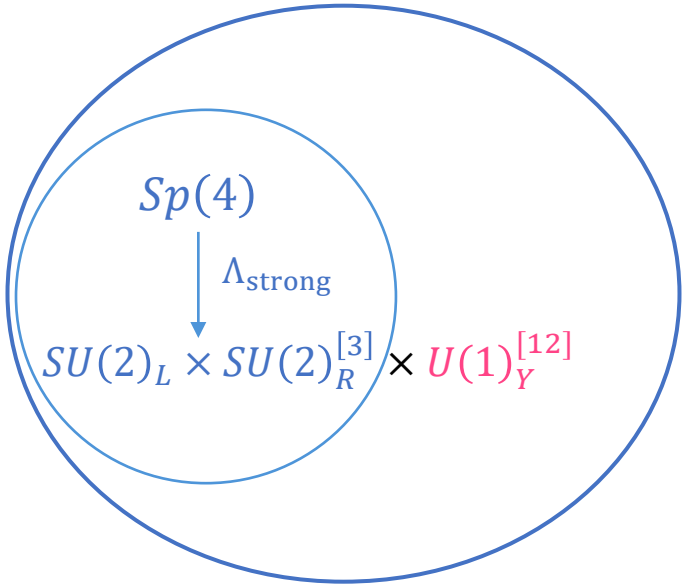
Phenomenology needs to be explored in more detail…

Deconstruction without hierarchy problems

Davighi, Isidori, *work in progress*

An elementary scalar Σ introduces a second hierarchy problem.

To also embed Σ as a pNGB, need to enlarge strong sector to include the full deconstructed gauge group



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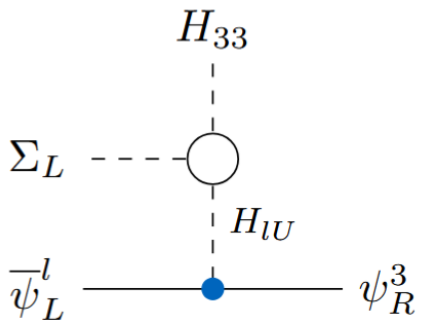
Sketched example:

Global breaking $Sp(6)_{\text{global}} \to SU(2)_L^{12} \times SU(2)_L^{3} \times SU(2)_R^{U}$

Delivers x12 pNGBs:

$$(\quad , \mathbf{2} , \mathbf{2} \quad) \oplus (\mathbf{2} , \quad \mathbf{2} \quad) \oplus (\mathbf{2} \quad \mathbf{2} , \quad)$$



$$V^{\text{cubic}} \supset -\frac{N_c}{2\pi^2}\frac{M_{\mathcal{O}_T}^2}{f} y_t \hat{y}_{cb} \text{Tr}[H_{3U}\Sigma_L H_{lU}^\dagger]$$

$$\epsilon_L = \frac{v_L h_{H\Sigma H}}{M_{lU}^2} \sim \sqrt{\frac{N_c}{8\pi^2}}\frac{1}{(4\pi f)}\frac{M_{\mathcal{O}_T}^2}{f} \sim \sqrt{\frac{N_c}{8\pi^2}}\frac{1}{4\pi} \approx 0.03\,,$$

SM Higgs (tuned mass)

H_{12} → light Yukawas*

Link field Σ (natural mass)

The **same assumption** (light top partner) is needed for light pNGB Higgs **and** flavour hierarchies

* No vector-like fermions needed!

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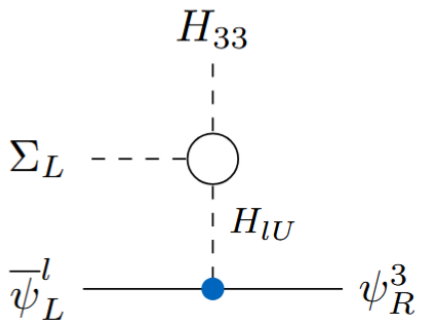

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The **same assumption** (light top partner) is needed for light pNGB Higgs **and** flavour hierarchies

Challenges: UV model? Origin of top partners?

* No vector-like fermions needed!

Conclusions

Higgs remains a central motivation for TeV BSM

Flavour cannot be overlooked when trying to understand the light Higgs

Pre-LHC: postpone flavour and solve the hierarchy problem with MFV

Alternatively, an intrinsically flavour non-universal approach can

1. Render m_h more natural e.g. in composite Higgs framework
2. Simultaneously unlock the flavour puzzle e.g. by flavour deconstruction
3. … and has rich phenomenology: great potential at HL-LHC and future experiments is just beginning to be explored

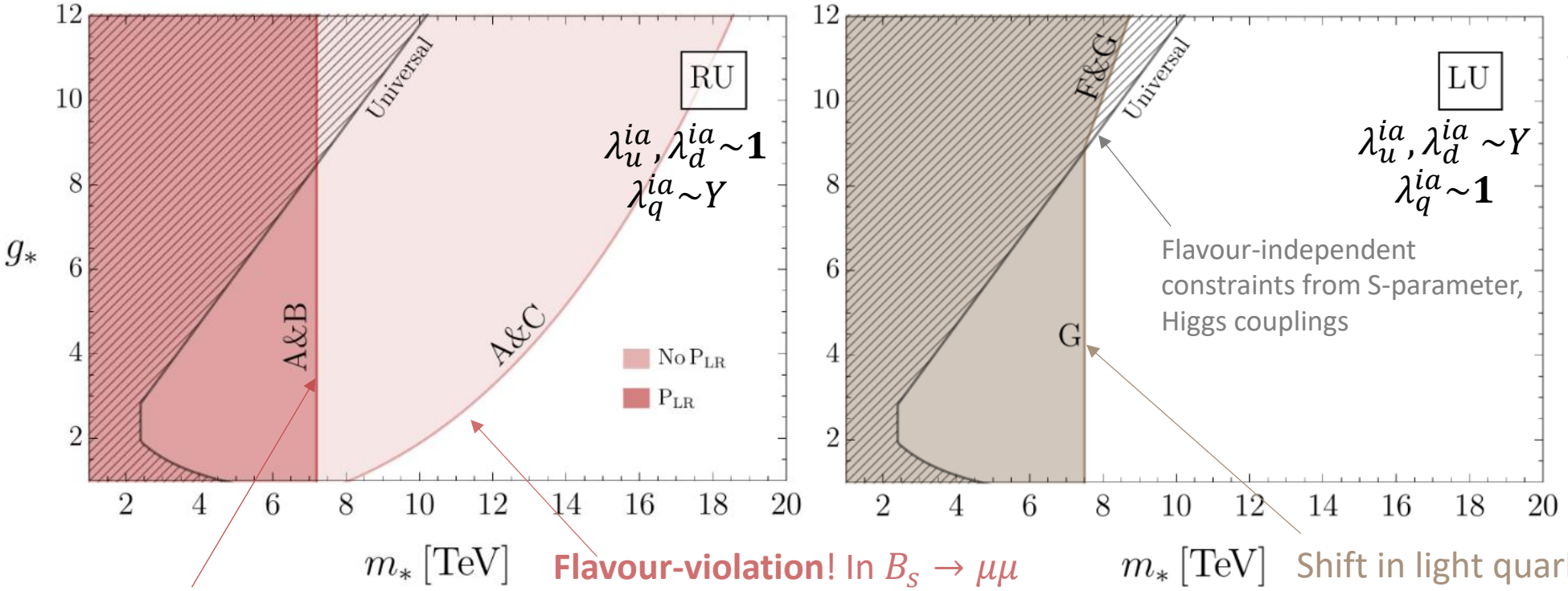
Thank you!

Backup

Lowering $\Lambda_{\rm NP}$ with U2

Composite Higgs with MFV: $M_* \gtrsim 7 \div 8$ TeV

Glioti, Rattazzi, Ricci, Vecchi, 2402.09503



Label	Observable
A	$pp \to jj$
B	$\Delta F = 2\,(B_d)$
C	$B_s \to \mu^+\mu^-$
D	nEDM
E	$B^0 \to K^{*0} e^+ e^-$ (C_7')
F	$B \to X_s \gamma$ (C_7)
G	W-coupling

Flavour-violation! In $B_s \to \mu\mu$

Shift in light quark **couplings to W boson**

Di-jet constraints from **LHC**, driven by light quark couplings

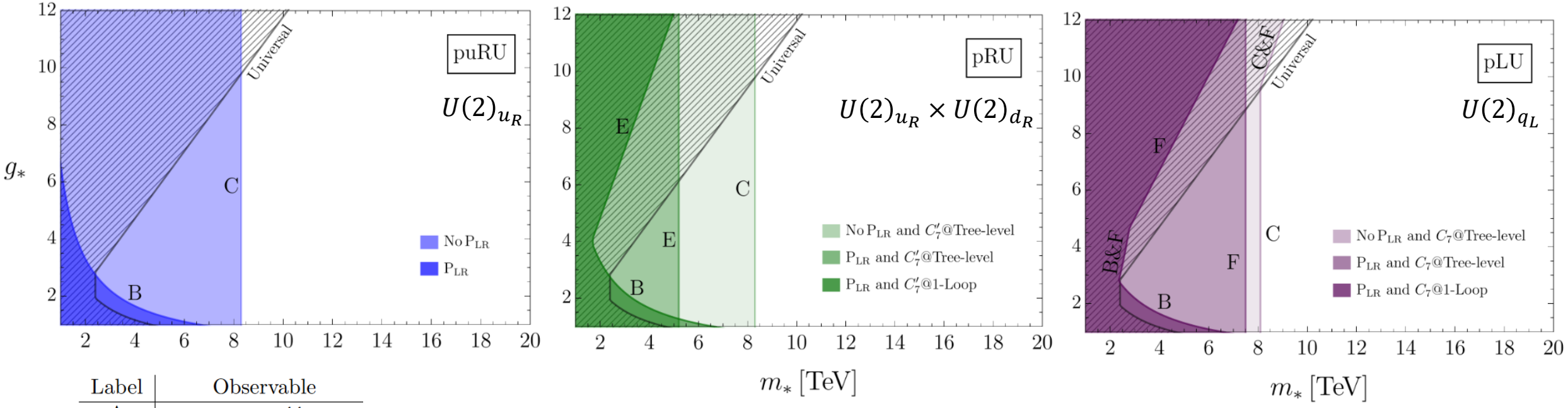
$P_{\rm LR}$ is an extension of custodial by a `left-right' exchange symmetry [kills Zb_Lb_L correction]

Strongest current bounds are driven by couplings to **light generation fermions** OR **flavour violation**, not EW constraints

Lowering $\Lambda_{\rm NP}$ with U2

Composite Higgs with U2 + P_{LR}: $M_* \gtrsim 1 \div 2$ TeV

Glioti, Rattazzi, Ricci, Vecchi, 2402.09503



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~~G~~	~~W-coupling~~

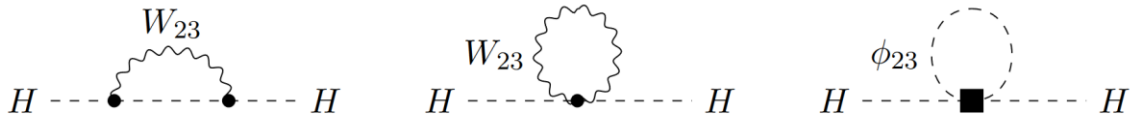
Going from MFV to U(2), we decouple the strong LHC constraints: dominant bounds now heavy-to-light quark flavour-violation + universal EW constraints

What to Deconstruct?

Davighi, Isidori [2303.01520](2303.01520)

	Deconstructed force	$SU(3)$	$SU(2)_L$	$SU(2)_R$	$U(1)_Y$	$U(1)_{B-L}$
Flavour	$\lvert V_{cb}\rvert \ll 1$	✓	✓	×	✓	✓
	$y_i \ll y_3$	×	✓	✓	✓	×
EW	Natural upper limit of $\lvert\tan\theta\rvert M$	90 TeV	20 TeV	40 TeV	40 TeV	500 TeV
	EWPOs order	1-loop	Tree	Tree	Tree	1-loop
		$Y \sim \begin{pmatrix} \times & \times & \\ \times & \times & \\ & & \times \end{pmatrix}$	$\begin{pmatrix} & & \\ \times & \times & \times \end{pmatrix}$	$\begin{pmatrix} & & \times \\ & & \times \\ & & \times \end{pmatrix}$	$\begin{pmatrix} & & \\ & & \times \end{pmatrix}$	$\begin{pmatrix} \times & \times & \\ \times & \times & \\ & & \times \end{pmatrix}$

"Finite naturalness" limits on M_X from requiring the finite part of $\delta m_h^2 \lesssim 1\ \mathrm{TeV}^2$



General Lesson

- Need to deconstruct part of the EW symmetry to explain the flavour puzzle
- Unavoidable tree-level δ EWPOs
- Unavoidable 1-loop δm_h^2

Non-Universality from Flavour Deconstruction

Davighi, Isidori 2303.01520

	Deconstructed force	$SU(3)$	$SU(2)_L$	$SU(2)_R$	$U(1)_Y$	$U(1)_{B-L}$
Flavour	$\lvert V_{cb}\rvert \ll 1$	✓	✓	×	✓	✓
	$y_i \ll y_3$	×	✓	✓	✓	×
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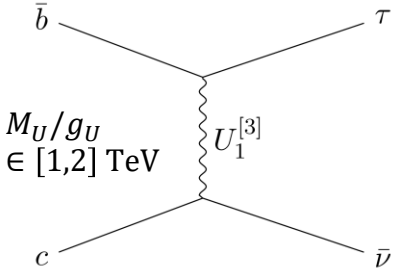
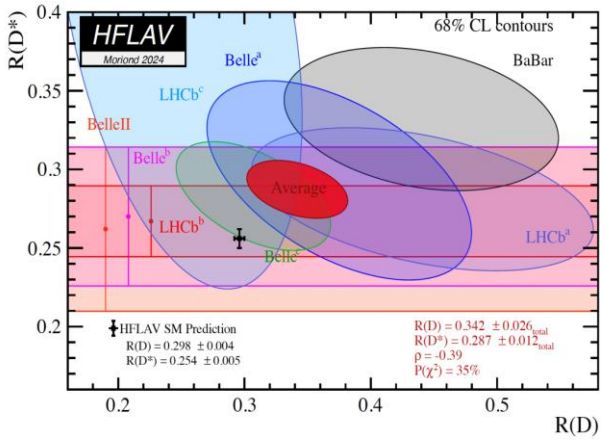
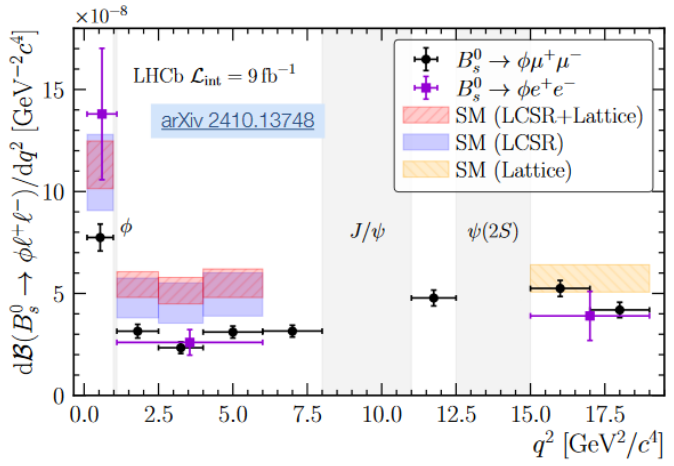
	EWPOs order	1-loop	Tree	Tree	Tree	1-loop

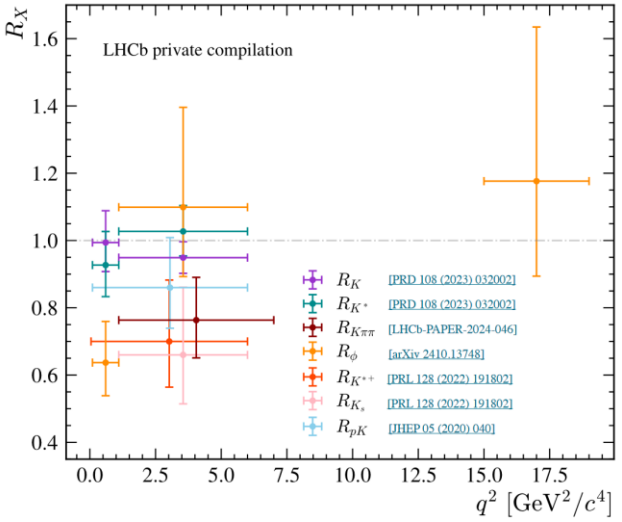
Aside: If enlarge $SU(3)^{[3]} \to SU(4)^{[3]}$, can also explain $b \to c\tau\nu$ anomalies in $R_{D^{(*)}}$ & $bs\mu\mu$ via '4-3-2-1' models



Buttazzo, Greljo, Isidori, Marzocca, 1706.07808; Di Luzio, Greljo, Nardecchia, 1708.08450; Bordone, Cornella, Fuentes-Martin, Isidori, 1712.01368; Greljo, Stefanek, 1802.04274; Di Luzio, Fuentes-Martin, Greljo, Nardecchia, Renner, 1808.00942; Fuentes-Martin, Stangl, 2004.11376 …







Experimental hints for deconstruction near TeV?

LHCb Implications 2024

A UV scenario: from Deconstruction to Unification

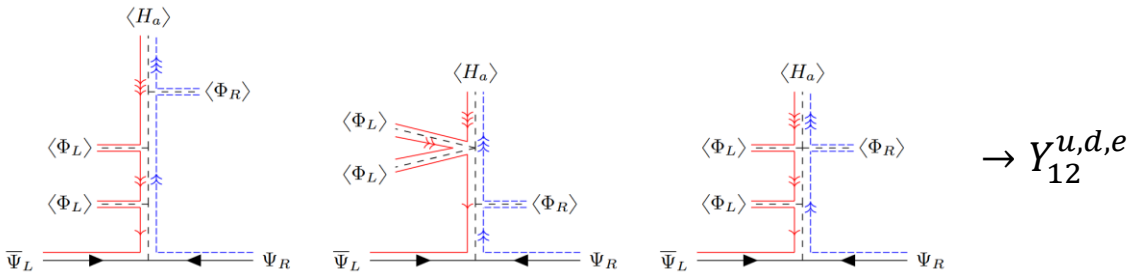
Davighi, Tooby-Smith, 2201.07245, Davighi, 2206.04482

Whence $G_1 \times G_2 \times G_{3+\mathrm{H}}$? One path is to **reunify** in the UV! Using e.g. $SU(2)^{n_f} \cong Sp(2)^{n_f} \hookrightarrow Sp(2n_f)$

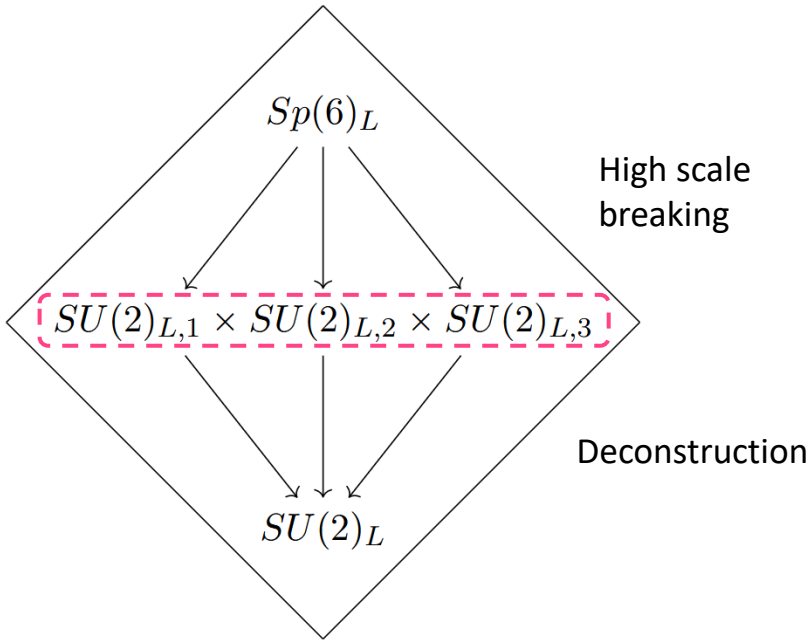
Electroweak flavour unification: $\mathrm{G_{UV}} = SU(4) \times Sp(6)_L \times Sp(6)_R$

- **All SM matter unified*** into $\Psi_L \sim (\mathbf{4}, \mathbf{6}, \mathbf{1})$ + $\Psi_R \sim (\mathbf{4}, \mathbf{1}, \mathbf{6})$
- Offers a "gauge answer" to "why 3 generations?"
- Solves flavour puzzle with the minimal ingredients

E.g.



$\rightarrow Y_{12}^{u,d,e}$



- Low-energy pheno matches that of deconstructed $SU(2)_L \times U(1)_Y$

*Very few anomaly-free options that do this!
See the classification of all embeddings of 3-flavour SM gauge algebra: Allanach, Gripaios, Tooby-Smith, 2104.14555

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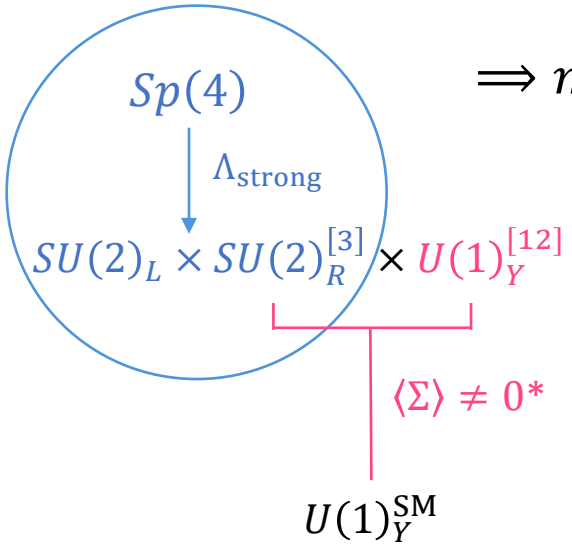
$M_\Psi \sim 100$ TeV

$\langle \phi_{23} \rangle \sim 1$ TeV

EW

⇒ Higgs as pNGB



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Enhanced predictivity
- Require $\boldsymbol{2M_{W_R}^2 < M_\rho^2}$ to avoid sign flip in m_h^2

- $y_2 \ll y_3 \Rightarrow M_\Psi >$ few 100 TeV
  Now this gives **no radiative** $\boldsymbol{\delta m_h^2}$ contribution thanks to compositeness at lower scale ☺