

# Exploring the Flavor of the TeV

XXXX.XXXXXX in collaboration with A. Glioti, R. Rattazzi, L. Ricci

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Beyond BSM 14/8/2023

# Exploring the Flavor

## A summary and update

XXXX

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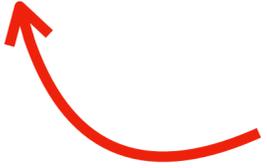
# The Flavor Problem #1

Of the SM. **Where does the fermion mass hierarchy arise from?**

- All flavor is encoded in Yukawa couplings (dim-4 operators)
- May well be explained in the far UV

$$\mathcal{L} \supset Y^{ij} \bar{\psi}_i \psi'_j H + \mathcal{O} \left( \frac{1}{\Lambda^\#} \right)$$

No obvious  
connection with the  
TeV scale

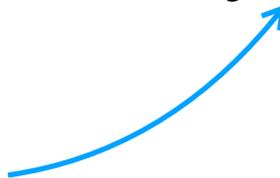


# The Flavor Problem #2

## Of the New Physics.

New particles should interact with the SM via sizable couplings in order to address the hierarchy problem. No evidence yet:

Defining connection to TeV



**WHY?!**

What is the flavor of the new physics?

How robust and generic is its flavor structure?

What kind of new physics is probed at colliders?

## In SUSY:

In the symmetric limit, flavor-violation analogous to the SM.

As an extreme and safest option one could assume the Yukawas are the only flavor-violating parameters.

MFV is plausible and effective (e.g. Gauge Med., Gaugino Med.)

## In models with strongly-coupled Higgs sectors:

No UV-complete (natural) description of flavor violation (only effective 4D or 5D)

Are there plausible options?

$$\mathcal{L} \supset c |\mathcal{O}_H|^2 + y_H^{ij} \bar{\psi}_i \psi'_j \mathcal{O}_H$$

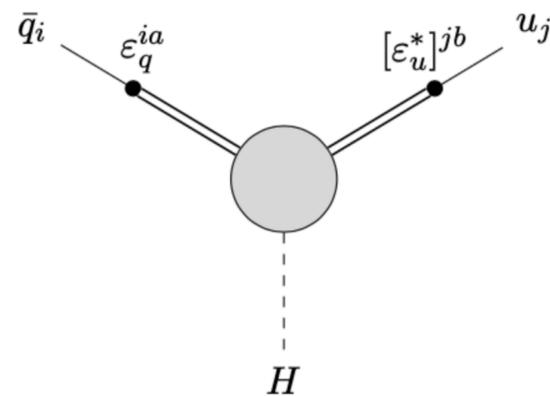
Irrelevant!

# Best Flavor picture for Strong Higgs: **Partial Compositeness**

Fundamental (SM) fermions  $\rightarrow$  Operators of the Strong Higgs Sector  $\rightarrow$  Interpolate resonances mixing with SM fermions (=partially composite)

$$\mathcal{L} \supset \lambda^{ia} \bar{\psi}_i \mathcal{O}_a + c |\mathcal{O}_H|^2 + \cancel{y_H^{ij} \bar{\psi}_i \psi'_j \mathcal{O}_H}$$

Definitely not a bilinear...



$$\rightarrow Y_u^{ij} = c_{ab} \frac{\lambda_q^{ia} [\lambda_u^*]^{jb}}{g_*} \rightarrow$$

In Anarchic scenarios  
Flavor hierarchy from renormalization  
(wavefunction in extra-dimension)

# Let's quantify the "problem": Generic New Physics

$d_n$	$ \bar{\theta}  \lesssim 10^{-10}$
p decay	$\Lambda_B \gtrsim 10^{12}$ TeV
$\nu$ masses	$\Lambda_L \gtrsim 10^{11}$ TeV
$K\bar{K}$	$\Lambda_q^{F,CP} \gtrsim 10^5$ TeV
$\Delta F = 2$	$\Lambda_q^{F,CP} \gtrsim 10^4$ TeV
$d_n \sim \frac{m_u}{\Lambda^2} e, \frac{\Lambda_{\text{QCD}}}{\Lambda^2} e$	$\Lambda_q^{F,CP} \gtrsim (50 - 100)$ TeV
$d_{\mu \rightarrow e \gamma} \sim \frac{m_\mu}{\Lambda^2} e$	$\Lambda_\ell^{F,CP} \gtrsim 10^3$ TeV
$d_e \sim \frac{m_e}{\Lambda^2} e$	$\Lambda_\ell^{F,CP} \gtrsim 10^3$ TeV
T parameter	$\Lambda_{\text{EW}} \gtrsim 10$ TeV
S parameter	$\Lambda_{\text{EW}} \gtrsim (2 - 3)$ TeV

**Most serious problems from Flavor and CP violation**

$d_n$	$ \bar{\theta}  \lesssim 10^{-10}$	
p decay	<del><math>\Lambda_B \gtrsim 10^{12}</math> TeV</del>	<b>B &amp; L</b>
$\nu$ masses	<del><math>\Lambda_L \gtrsim 10^{11}</math> TeV</del>	
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T parameter	<del><math>\Lambda_{\text{EW}} \gtrsim 10</math> TeV</del>	<b>Custodial O(4)</b>
S parameter	$\Lambda_{\text{EW}} \gtrsim (2 - 3)$ TeV	

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**Flavor-invariant  
CPV not observed**

Either QCD axion (no connection with flavor violation) or  
Small Flavor-invariant CP-odd phases  $\leftrightarrow$  Nelson-Barr, Parity, etc

$d_n$	<del><math> \bar{\theta}  \lesssim 10^{-10}</math></del>
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**Flavor and (flavourful) CP violation represent the main hurdles**

**(1) What Flavor Hypothesis can allow New Physics at the TeV?**  
**(2) How robust and generic are those?**  
**Model-dependent questions.**

- Flavor violation may come from bilinears (SUSY) or mixings (Strong Higgs)
- Model-dependent correlation between F-conserving & F-violating observables
- Model-dependent correlation between Indirect & Direct searches
- The correlation between tree-level & loop effects is model-dependent
- ...

We have to choose a concrete setup  
with concrete hypothesis on the new physics

## **We choose Partial Compositeness:**

- 1) Best flavor scenario for strongly-coupled Higgs sectors  
→ Less studied than SUSY
- 2) Concrete example where Flavor-violation does not come from bilinears  
→ Is MFV an option?
- 3) Offers a potential solution of Flavor Problem #1: it is a Theory of Flavor  
→ tension between “Explaining Flavor” & “Being Clever”

# Hypothesis

1)  $\mathcal{L}_{\cancel{F}} = \lambda^{ia} \bar{\psi}_i \mathcal{O}_a$

2) Resonances  $\Phi$  characterized by one mass scale  $m_*$  and one coupling  $g_{\text{SM}} \lesssim g_* \lesssim 4\pi$ .

Integrating out the resonances we get the EFT (F-violating, F-conserving)

$$\mathcal{L}_{\text{EFT}} = \mathcal{L}_{\text{SM}-H} + \frac{m_*^4}{g_*^2} \hat{\mathcal{L}}_{\text{EFT}} \left( \frac{g_* H}{m_*}, \frac{D_\mu}{m_*}, \frac{\lambda_\psi^{ia} \bar{\psi}^i}{m_*^{3/2}}, \frac{g_*^2}{16\pi^2}, \frac{g^2}{16\pi^2}, \frac{[\lambda_\psi^*]^{ia} \lambda_\psi^{ib}}{16\pi^2} \right)$$

Direct Vs  
Indirect

Loops (if needed)

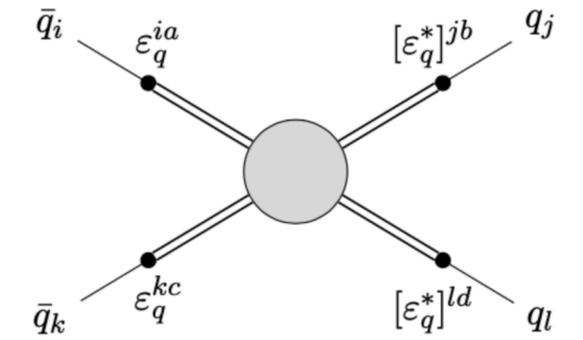
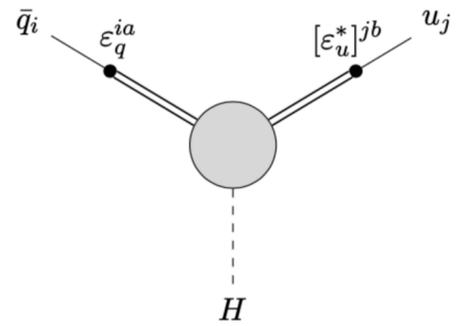
With coefficients that may or may not respect some symmetry...

3) Symmetries: B & L, O(4) Custodial

**Flavor parameters are either generic (Flavor Anarchy) or have some structure**

$\varepsilon_\psi = \lambda_\psi / g_*$  fermion compositeness

$Y_u^{ij} = c_{ab} \frac{\lambda_q^{ia} [\lambda_u^*]^{jb}}{g_*}$  Flavor hierarchy from renormalization (wavefunction in extra-dimension)



$$\frac{g_*^2}{m_*^2} c_{abcd} \varepsilon_q^{ia} [\varepsilon_q^*]^{jb} \varepsilon_q^{kc} [\varepsilon_q^*]^{ld} \bar{q}^i \gamma_\mu q^j \bar{q}^k \gamma^\mu q^l$$

4-fermion operators

# Hypothesis

Direct resonance searches controlled by the same  $g_*, m_*, \varepsilon_\psi$

$\Delta F=1$  arise dominantly from  $\left( H^\dagger i \overleftrightarrow{D}_\mu H \right) \bar{\psi}^i \gamma^\mu \psi^j$

# An actual Theory of Flavor: Anarchic Partial Compositeness

(Structureless O(1) flavor-violating coefficients)

$K\bar{K}$	$\Lambda_q^{F,CP} \gtrsim 10^5 \text{ TeV}$	$m_* \gtrsim (20 - 30) \text{ TeV}$	
$\Delta F = 2$	$\Lambda_q^{F,CP} \gtrsim 10^4 \text{ TeV}$	$m_* \gtrsim (10 - 20) \text{ TeV}$	
$d_n \sim \frac{m_u}{\Lambda^2} e$	$\Lambda_q^{F,CP} \gtrsim (50 - 100) \text{ TeV}$	$m_* \gtrsim (50 - 100) \frac{g_*}{4\pi} \text{ TeV}$	
$d_{\mu \rightarrow e \gamma} \sim \frac{m_\mu}{\Lambda^2} e$	$\Lambda_\ell^{F,CP} \gtrsim 10^3 \text{ TeV}$	$m_* \gtrsim 250 \frac{g_*}{4\pi} \text{ TeV}$	
$d_e \sim \frac{m_e}{\Lambda^2} e$	$\Lambda_\ell^{F,CP} \gtrsim 10^3 \text{ TeV}$	$m_* \gtrsim 10^3 \frac{g_*}{4\pi} \text{ TeV}$	
T parameter	$\Lambda_{EW} \gtrsim 10 \text{ TeV}$	<del><math>m_* \gtrsim 10 g_* \text{ TeV}</math></del>	
S parameter	$\Lambda_{EW} \gtrsim (2 - 3) \text{ TeV}$	$m_* \gtrsim (2 - 3) \text{ TeV}$	

Setting aside leptons...

$$\begin{aligned} m_*/g_* &\gtrsim (4 - 6) \text{ TeV} \\ m_* &\gtrsim (20 - 30) \text{ TeV} \end{aligned} \implies \frac{g_*^2 v^2}{m_*^2} \lesssim 10^{-3}$$

**Theories of Flavor  
are Unnatural  
(=The Flavor Problem)**

## Anarchy

Flavor explained  
 $m > 20\text{-}30$  TeV  
1/1000 tuning



## Naturalness

Flavor un-explained  
Collider-accessible  
Small tuning

**How close to the TeV can we go with reasonable hypothesis on the flavor structure?**

# MFV via Left-Universality (Left-Compositeness)

$$\mathcal{L}_{\text{mix}} = \lambda_q^{ia} \bar{q}_L^i \mathcal{O}_q^a + \lambda_u^{ia} \bar{u}_R^i \mathcal{O}_u^a + \lambda_d^{ia} \bar{d}_R^i \mathcal{O}_d^a,$$

Strong sector has  
U(3) Flavor symmetry  
& qL is “composite”

$$\lambda_q = \begin{pmatrix} \varepsilon_q & 0 & 0 \\ 0 & \varepsilon_q & 0 \\ 0 & 0 & \varepsilon_q \end{pmatrix} g_*$$

$$\frac{y_t}{g_*} \lesssim \varepsilon_q \lesssim 1.$$

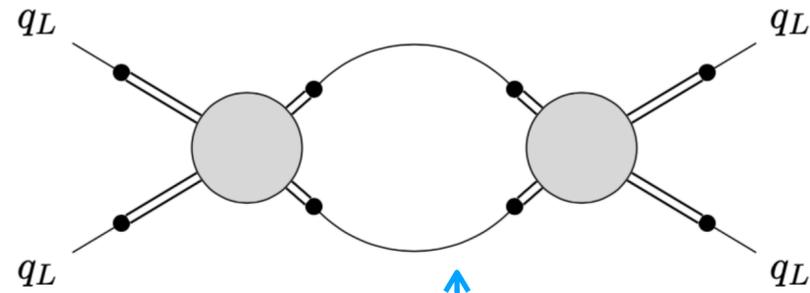
(qL is a resonance if  $\varepsilon \approx 1$ )

$$\Rightarrow \left\{ \begin{array}{l} \lambda_u = \frac{1}{\varepsilon_q} \begin{pmatrix} y_u & 0 & 0 \\ 0 & y_c & 0 \\ 0 & 0 & y_t \end{pmatrix} \\ \lambda_d = \frac{1}{\varepsilon_q} \begin{pmatrix} y_d & 0 & 0 \\ 0 & y_s & 0 \\ 0 & 0 & y_b \end{pmatrix} \end{array} \right. V_{\text{CKM}}^\dagger,$$

Minimal Flavor Violation

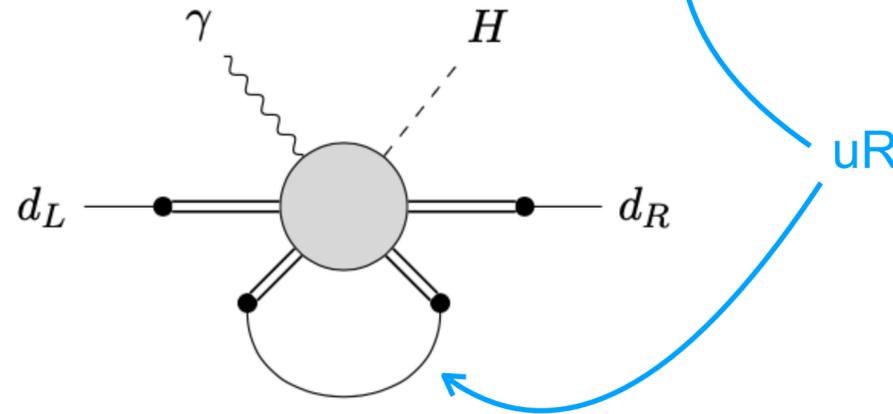
$$U(3)_q \times U(3)_{U+u} \times U(3)_{D+d}$$

$\Delta F=2$ : safe (mediated at 1-loop)



$$m_* \gtrsim 0.53 \text{ TeV}$$

$\Delta F=1$ : dominated by  $B \rightarrow XY$



$$m_* \gtrsim \frac{0.69}{\varepsilon_q} \text{ TeV}$$

Neutron EDM: suppressed by MFV (2-loops)

Universal correction to Z and W couplings

$$m_* \gtrsim 9.3 \varepsilon_q g_* \text{ TeV}$$

$$\frac{y_t}{g_*} \lesssim \varepsilon_q \lesssim 1.$$

$$m_* \gtrsim 7.5 \text{ TeV}$$

**Universality (MFV) severely constrained by  $\Delta F=0$  data!**

# Partial Left Universality: $U(2)$

$$\mathcal{L}_{\text{mix}} = \lambda_q^{ia} \bar{q}_L^i \mathcal{O}_q^a + \lambda_u^{ia} \bar{u}_R^i \mathcal{O}_u^a + \lambda_d^{ia} \bar{d}_R^i \mathcal{O}_d^a,$$

Strong sector has  
 $U(2)$  Flavor symmetry  
& qL "composite"

$$\lambda_q \sim \begin{pmatrix} \varepsilon_q & 0 \\ 0 & \varepsilon_q \\ 0 & 0 \end{pmatrix} g_* \oplus \begin{pmatrix} 0 \\ 0 \\ \varepsilon_{q3} \end{pmatrix} g_* \Rightarrow$$

$$\frac{y_c}{g_*} \lesssim \varepsilon_q \lesssim 1 \quad \frac{y_t}{g_*} \lesssim \varepsilon_{q3} \lesssim 1$$

$$\left\{ \begin{array}{l} \lambda_u \sim \frac{1}{\varepsilon_q} \begin{pmatrix} y_u & 0 \\ 0 & y_c \\ ay_c & by_c \end{pmatrix} \oplus \frac{1}{\varepsilon_{q3}} \begin{pmatrix} 0 \\ 0 \\ y_t \end{pmatrix} \\ \lambda_d \sim \frac{1}{\varepsilon_q} \begin{pmatrix} y_d & 0 \\ 0 & y_s \\ a'y_s & b'y_s \end{pmatrix} \tilde{\mathcal{O}}_d \oplus \frac{1}{\varepsilon_{q3}} \begin{pmatrix} 0 \\ 0 \\ y_b \end{pmatrix} \end{array} \right.$$

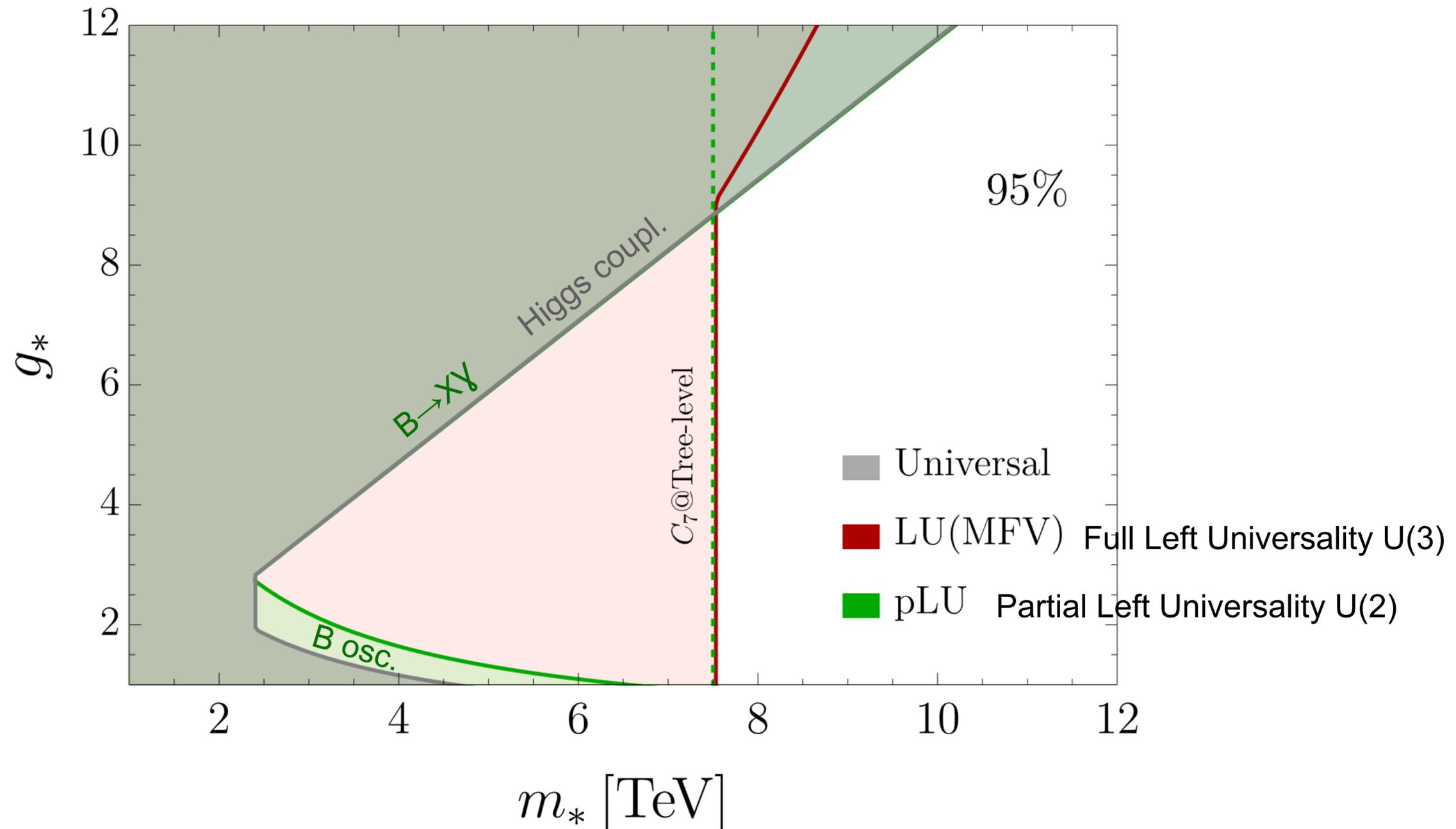
$O(\lambda)$  to reproduce CKM

$$\rightarrow U(\mathbf{2})_{Q+q} \times U(\mathbf{1})_{Q+q} \times U(\mathbf{3})_u \times U(\mathbf{3})_d$$

Best case scenario for Partial Left Universality:

$$0.02 \lesssim \varepsilon_q \lesssim 0.1 \quad \varepsilon_q \lesssim \varepsilon_{q3} \sim y_t/g_*$$

**A bit too small to interpret qL as composite...**  
 Is there a robust alternative?



# MFV with two doublets... (generic in O(5)/O(4))

$$\mathcal{L}_{\text{mix}} = \lambda_{q_u}^{ia} \bar{q}_L^i \mathcal{O}_{q_u}^a + \lambda_{q_d}^{ia} \bar{q}_L^i \mathcal{O}_{q_d}^a + \lambda_u^{ia} \bar{u}_R^i \mathcal{O}_u^a + \lambda_d^{ia} \bar{d}_R^i \mathcal{O}_d^a,$$

Name	$G_{\text{strong}}$	Universal $\lambda_\psi$	$G_F$	Non-universal $\lambda_\psi$
Right Univ.	$U(3)_U \times U(3)_D$	$\lambda_u \propto \mathbf{1}, \lambda_d \propto \mathbf{1}$	$U(3)_q \times U(3)_{U+u} \times U(3)_{D+d}$	$\lambda_{q_u} \propto Y_u, \lambda_{q_d} \propto Y_d$
Left Univ.1	$U(3)_U \times U(3)_D$	$\lambda_{q_u} \propto \mathbf{1}, \lambda_{q_d} \propto \mathbf{1}$	$U(3)_{q+U+D} \times U(3)_u \times U(3)_d$	$\lambda_u \propto Y_u^\dagger, \lambda_d \propto Y_d^\dagger$
Left Univ.2	$U(3)_{U+D}$	$\lambda_{q_u} \propto \mathbf{1}, \lambda_{q_d} \propto \mathbf{1}$	$U(3)_{q+U+D} \times U(3)_u \times U(3)_d$	$\lambda_u \propto Y_u^\dagger, \lambda_d \propto Y_d^\dagger$
Mixed Univ.1	$U(3)_U \times U(3)_D$	$\lambda_{q_u} \propto \mathbf{1}, \lambda_d \propto \mathbf{1}$	$U(3)_{q+U} \times U(3)_u \times U(3)_{D+d}$	$\lambda_u \propto Y_u^\dagger, \lambda_{q_d} \propto Y_d$
Mixed Univ.2	$U(3)_U \times U(3)_D$	$\lambda_u \propto \mathbf{1}, \lambda_{q_d} \propto \mathbf{1}$	$U(3)_{q+D} \times U(3)_{U+u} \times U(3)_d$	$\lambda_{q_u} \propto Y_u, \lambda_d \propto Y_d^\dagger$


**Symmetry of Strong Sector + (SM) Fermion Compositeness → MFV & Universality**

# MFV via Right-Universality (Right-Compositeness)

$$\mathcal{L}_{\text{mix}} = \lambda_{q_u}^{ia} \bar{q}_L^i \mathcal{O}_{q_u}^a + \lambda_{q_d}^{ia} \bar{q}_L^i \mathcal{O}_{q_d}^a + \lambda_u^{ia} \bar{u}_R^i \mathcal{O}_u^a + \lambda_d^{ia} \bar{d}_R^i \mathcal{O}_d^a,$$

UV hypothesis:  
U(3)xU(3) Flavor

$$\left\{ \begin{array}{l} \lambda_u \sim \begin{pmatrix} \varepsilon_u & 0 & 0 \\ 0 & \varepsilon_u & 0 \\ 0 & 0 & \varepsilon_u \end{pmatrix} g_* \\ \lambda_d \sim \begin{pmatrix} \varepsilon_d & 0 & 0 \\ 0 & \varepsilon_d & 0 \\ 0 & 0 & \varepsilon_d \end{pmatrix} g_* \end{array} \right. \Rightarrow \left\{ \begin{array}{l} \lambda_{q_u} \sim \frac{1}{\varepsilon_u} \begin{pmatrix} y_u & 0 & 0 \\ 0 & y_c & 0 \\ 0 & 0 & y_t \end{pmatrix} \\ \lambda_{q_d} \sim \frac{1}{\varepsilon_d} V_{\text{CKM}} \begin{pmatrix} y_d & 0 & 0 \\ 0 & y_s & 0 \\ 0 & 0 & y_b \end{pmatrix} \end{array} \right.$$

Minimal Flavor Violation

$$\frac{y_t}{g_*} \lesssim \varepsilon_u \lesssim 1 \quad \frac{y_b}{g_*} \lesssim \varepsilon_d \lesssim 1$$

$$U(3)_U \times U(3)_D \times U(3)_q \times U(3)_u \times U(3)_d \rightarrow U(3)_q \times U(3)_{U+u} \times U(3)_{D+d}$$

**Compositeness (LHC)**  $m_* \gtrsim 7.8 g_* \varepsilon_u^2 \text{ TeV}$

**$\Delta F=2$ : safe (B meson)**  $m_* \gtrsim \frac{6.6}{g_* \varepsilon_u^2} \text{ TeV}$

**$\Delta F=1$ : dominated by  $B \rightarrow XY$**   $m_* \gtrsim \frac{0.69}{\varepsilon_u} \text{ TeV}$

Agashe et al (2006)

Semi-leptonic B decays suppressed by LR protection of O(4) (crucial for Ebb!)

**Anomalous top couplings: LHC**  $m_* \gtrsim \frac{0.9}{\varepsilon_u} \text{ TeV}$

**Neutron EDM:** suppressed by MFV (2-loops)

**Universality (MFV) severely  
constrained by  $\Delta F=0$  data!**

$$m_* \gtrsim 7.2 \text{ TeV}$$

$$\varepsilon_u \sim 1/\sqrt{g_*} \gtrsim 0.3$$

**Tension!**

# Partial Up-Right-Universality

UV hypothesis:  
U(2)xU(3) Flavor

$$\left\{ \begin{array}{l} \lambda_u \sim \begin{pmatrix} \varepsilon_u & 0 \\ 0 & \varepsilon_u \\ 0 & 0 \end{pmatrix} g_* \oplus \begin{pmatrix} 0 \\ 0 \\ \varepsilon_{u_3} \end{pmatrix} g_* \\ \lambda_d \sim \begin{pmatrix} \varepsilon_d & 0 & 0 \\ 0 & \varepsilon_d & 0 \\ 0 & 0 & \varepsilon_d \end{pmatrix} g_* \end{array} \right. \Rightarrow \left\{ \begin{array}{l} \lambda_{qu} \sim \frac{1}{\varepsilon_u} \begin{pmatrix} y_u & 0 \\ 0 & y_c \\ ay_c & by_c \end{pmatrix} \oplus \frac{1}{\varepsilon_{u_3}} \begin{pmatrix} 0 \\ 0 \\ y_t \end{pmatrix} \\ \lambda_{qd} \sim U_d \frac{1}{\varepsilon_d} \begin{pmatrix} y_d & 0 & 0 \\ 0 & y_s & 0 \\ 0 & 0 & y_b \end{pmatrix} \end{array} \right.$$

$$\frac{y_c}{g_*} \lesssim \varepsilon_u \lesssim 1, \quad \frac{y_t}{g_*} \lesssim \varepsilon_{u_3} \lesssim 1, \quad \frac{y_b}{g_*} \lesssim \varepsilon_d \lesssim 1, \quad |a| \sim 1, \quad |b| \sim 1$$

$$U(\mathbf{2})_U \times U(\mathbf{1})_U \times U(\mathbf{3})_D \times U(\mathbf{3})_q \times U(\mathbf{3})_u \times U(\mathbf{3})_d \\ \rightarrow U(\mathbf{3})_q \times U(\mathbf{2})_{U+u} \times U(\mathbf{1})_{U+u} \times U(\mathbf{3})_{D+d}$$

**Compositeness (LHC)**  $m_* \gtrsim 7.8 g_* \varepsilon_u^2 \text{ TeV}$

**$\Delta F=2$ : safe (B meson)**  $m_* \gtrsim \frac{6.6}{g_* \varepsilon_{u_3}^2} \text{ TeV}$

**$\Delta F=1$ : dominated by  $B \rightarrow XY$**   $m_* \gtrsim \frac{0.69}{\varepsilon_q} \text{ TeV}$

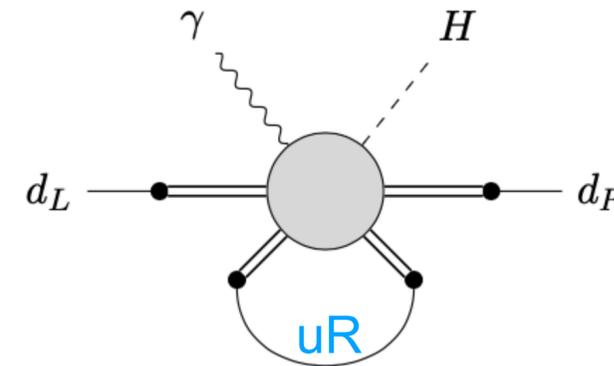
Agashe et al (2006)

Semi-leptonic B decays suppressed by LR protection of O(4) (crucial for Ebb!)

**Tension relaxed!**

**Anomalous top couplings: LHC**  $m_* \gtrsim \frac{0.9}{\varepsilon_u} \text{ TeV}$

**Neutron EDM: new contribution from d-quark dipole**



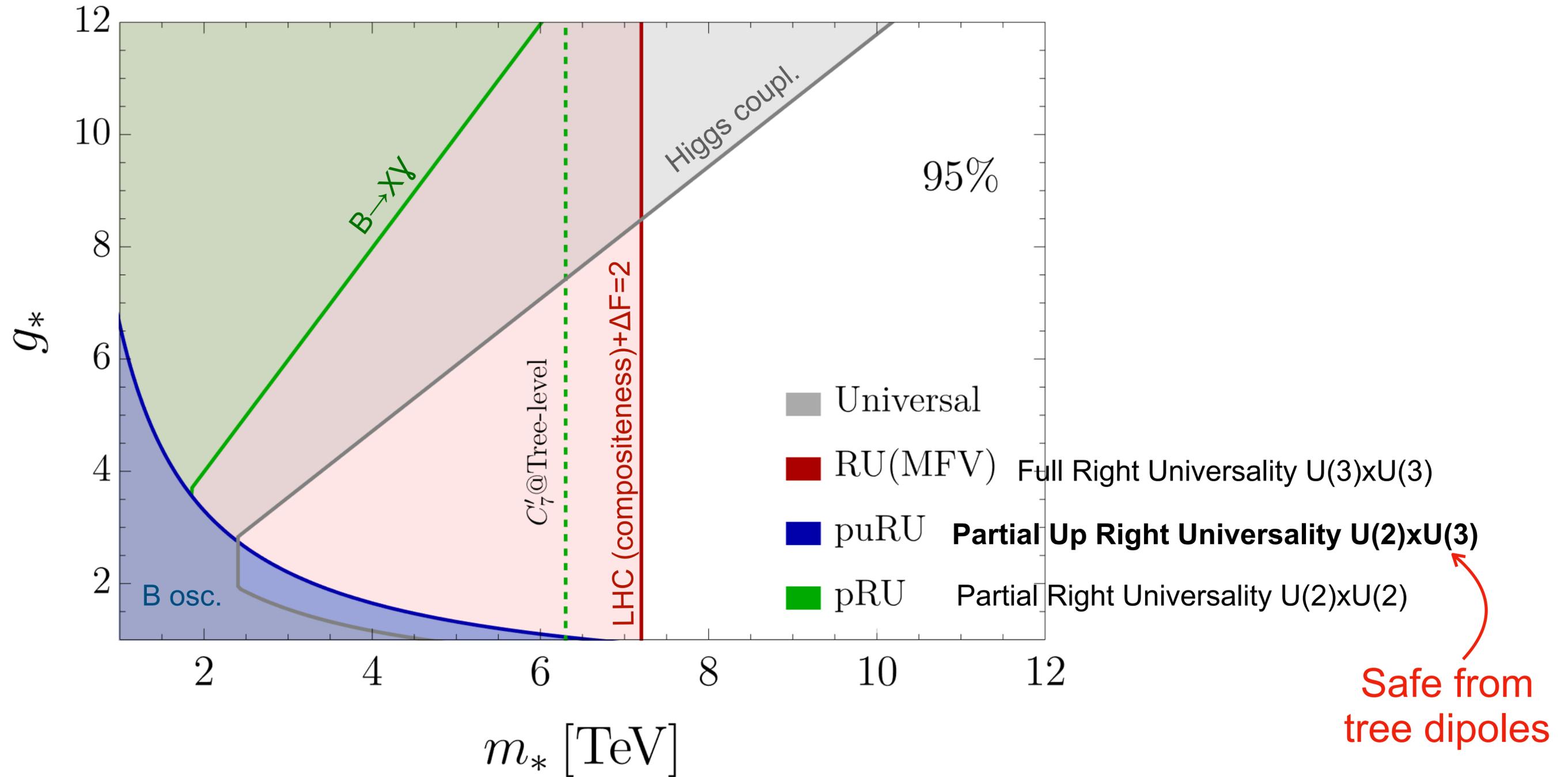
$m_* \gtrsim \frac{0.06}{\varepsilon_d} \text{ TeV}$

**Physics at the TeV is allowed**

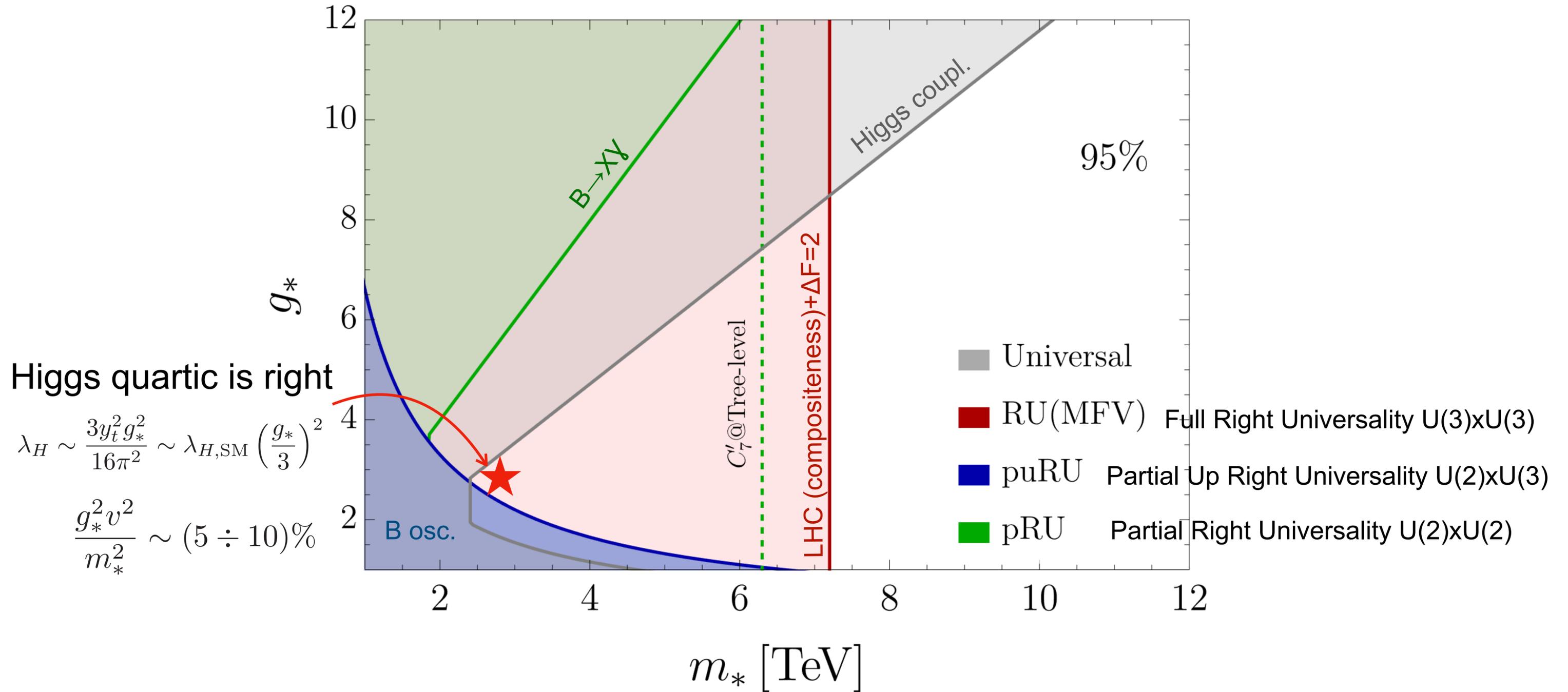
**by reasonable hypothesis:**  $\varepsilon_u \sim 0.3$   $\varepsilon_{u_3} \sim 1$  ( $\varepsilon_d \sim 0.5$ )

# We can realize MFV even with composite right-handed quarks

Best case scenario is Partial Up-Right Universality: tR separated from uR, cR  $\epsilon_u \sim 0.3, \epsilon_{u_3} \sim 1, \epsilon_d \sim 0.5$



- New physics directly accessible at colliders (competitive spin 1/2 & 1 searches)
- Modest tuning (only from Higgs vev)
- **Compositeness reasonably large ( $0.3 < \epsilon < 1$ ) to justify our hypothesis**



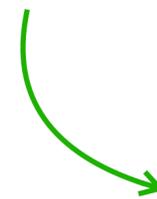
# General lessons

## Moving from Full (or U(3)) to Partial Universality (or U(2))

- Relaxes the most stringent  $\Delta F=0$  constraints, which kill Full Universality
- Still secludes CP-violation (both up & down needed in EDMs: enough to avoid constraints)
- $\Delta F=2$  transitions do not worsen significantly (basic MFV mechanism is still at work)
- Flavor-violating Higgs couplings never important
- Tree-level dipoles for  $B \rightarrow X\gamma$  are dangerous, except in Partial Up-Universality (MFV in down)
- The lepton sector is a different story...

# Partial Universality in the Lepton Sector?

UV hypothesis: Partial Right-Universality


$$\lambda_e \sim \begin{pmatrix} \varepsilon_e & 0 \\ 0 & \varepsilon_e \\ 0 & 0 \end{pmatrix} g_* \oplus \begin{pmatrix} 0 \\ 0 \\ \varepsilon_{e3} \end{pmatrix} g_* \Rightarrow \left\{ \lambda_\ell \sim \frac{1}{\varepsilon_e} \begin{pmatrix} y_e & 0 \\ 0 & y_\mu \\ a_\ell y_\mu & b_\ell y_\mu \end{pmatrix} \oplus \frac{1}{\varepsilon_{e3}} \begin{pmatrix} 0 \\ 0 \\ y_\tau \end{pmatrix} \right.$$

$$C_{e\gamma}^{21} \sim ec(a_\ell b_\ell) \frac{m_\tau}{m_*^2} (y_\mu/y_\tau)^3$$

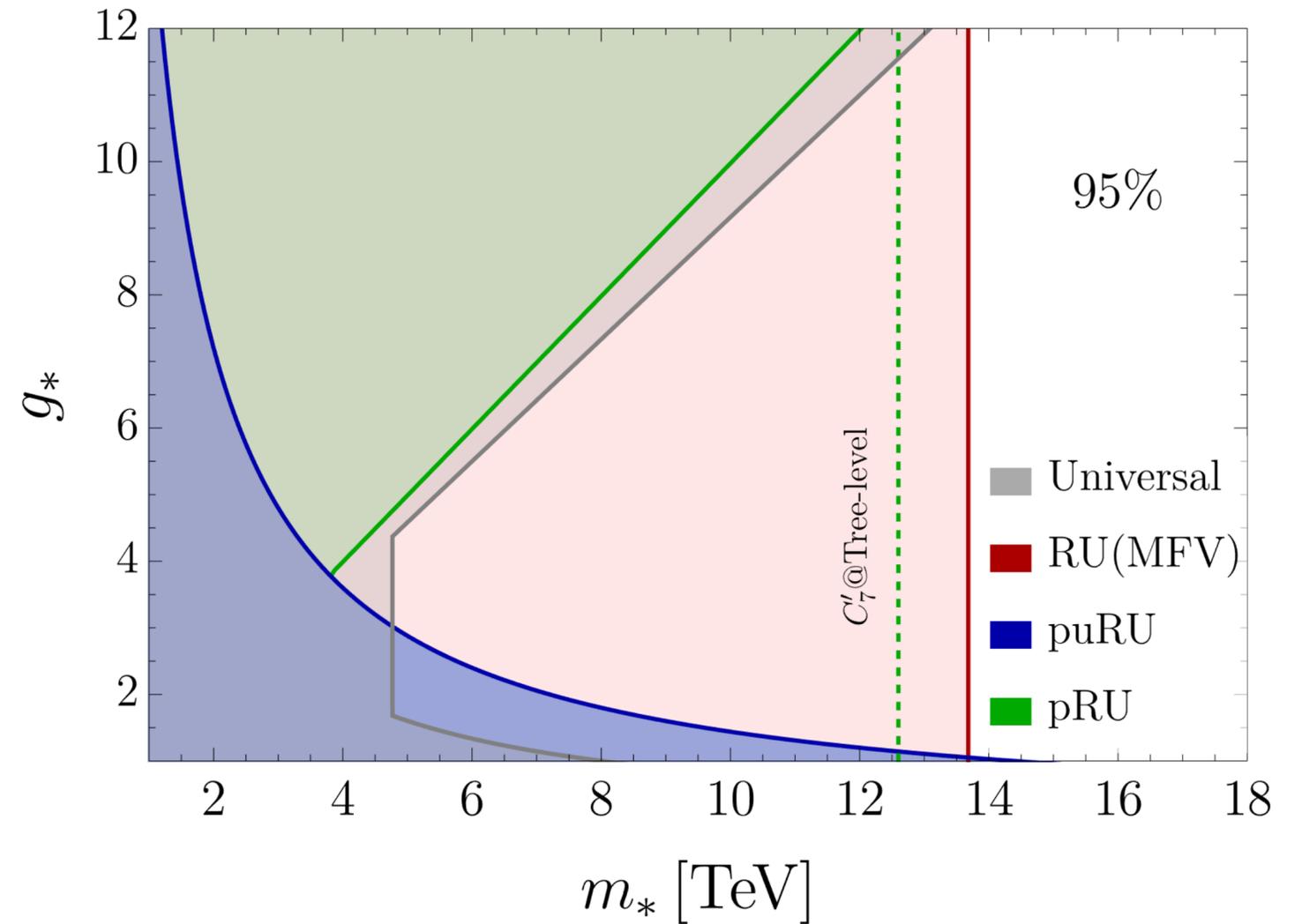
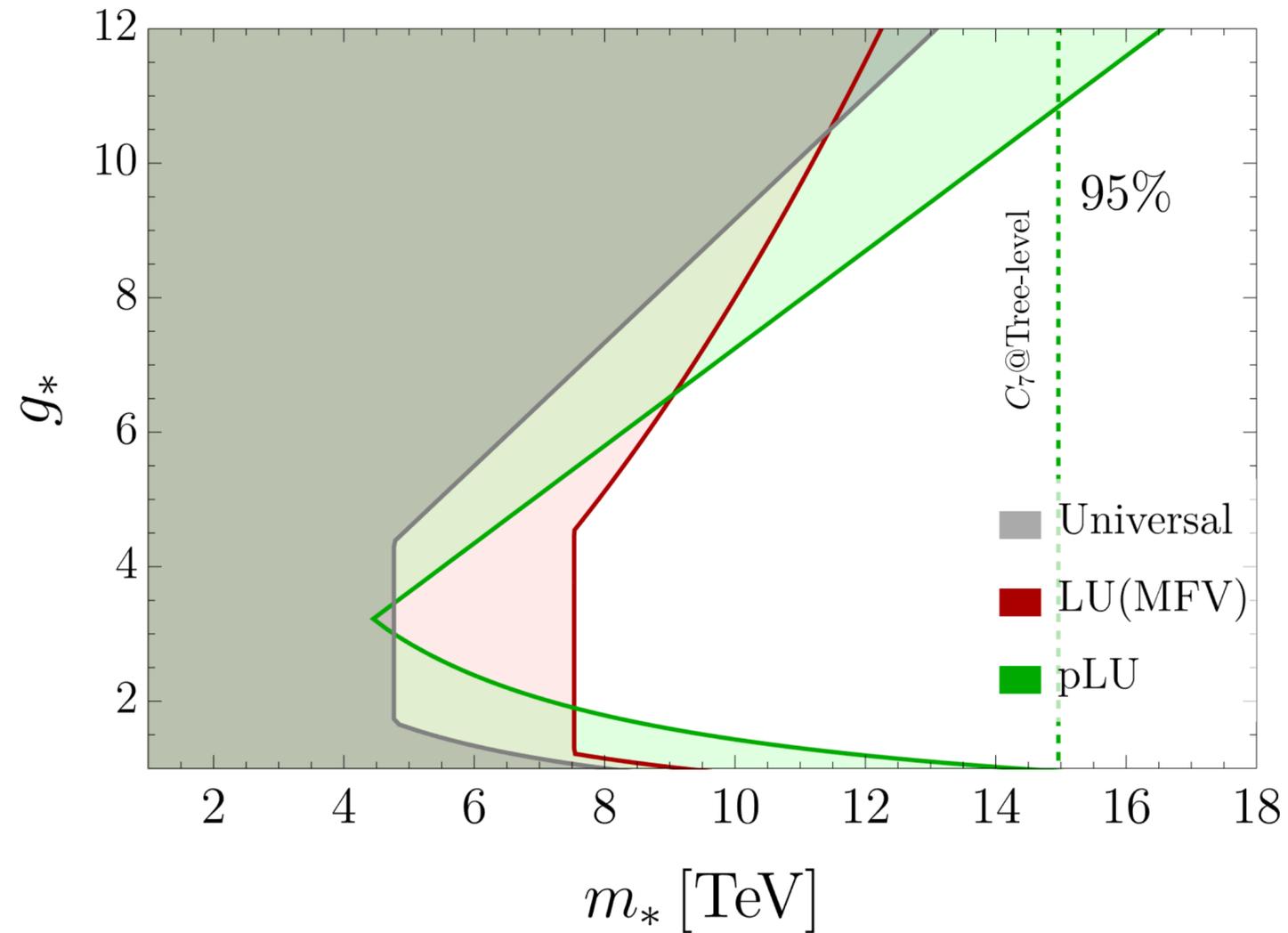
**$\mu \rightarrow e\gamma$  too large unless**  
—  $c$  is 1-loop  
—  $ab = \text{few}\%$

## Rough projections:

$\Delta F=2$  ( $\sim x4$  from HL-LHC),

$\Delta F=1$  ( $\sim x4$  from LHCb and Belle II),

$\Delta F=0$  ( $\sim x2-4$  from HL-LHC)



# Conclusions

- \* **Flavor is (and has been) one of the major “problems” for naturalness:**  
A concrete picture is required to guide our expectations and plan future
- \* **To explore options and consequences: have to make hypothesis on UV**  
We assumed flavor symmetries:
  - No explanation of structure (originated from higher scales)
  - But can identify viable patterns and correlations to be tested at colliders
- \* **Plausible scenario with “composite uR” and approximate  $U(2) \times U(3)$  exist**
- \* **“Composite qL” is perhaps less justifiable: any compelling picture?**
- \* **MFV is NOT the best option for strong Higgs (and hence SMEFT)**
- \* **We reach 10% tuning with physics directly accessible at LHC**  
To be compared with 0.1% of a theory of flavor: which is more *natural*?



**Anarchy**

**Cleverness**