

# Exploring the Flavor Symmetry Landscape of Composite Higgs models

Lorenzo Ricci



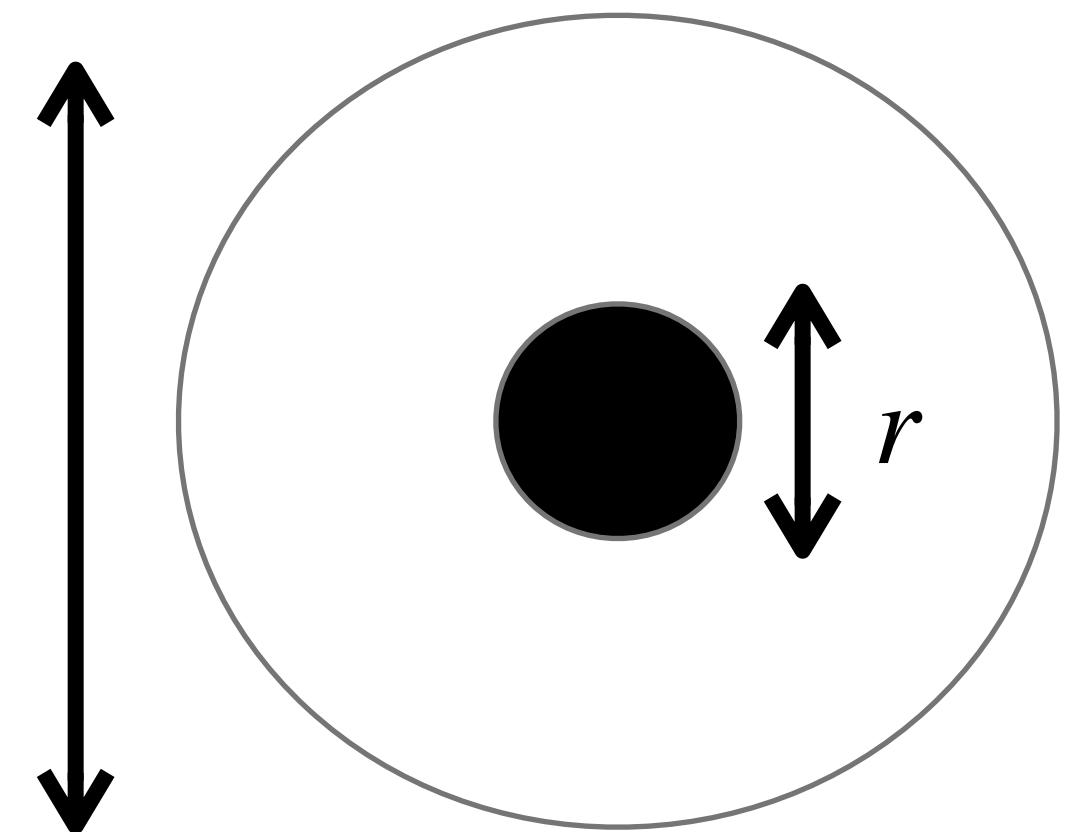
UNIVERSITY OF  
MARYLAND

*Based on [Glioti, Rattazzi, LR, Vecchi (to appear)]*

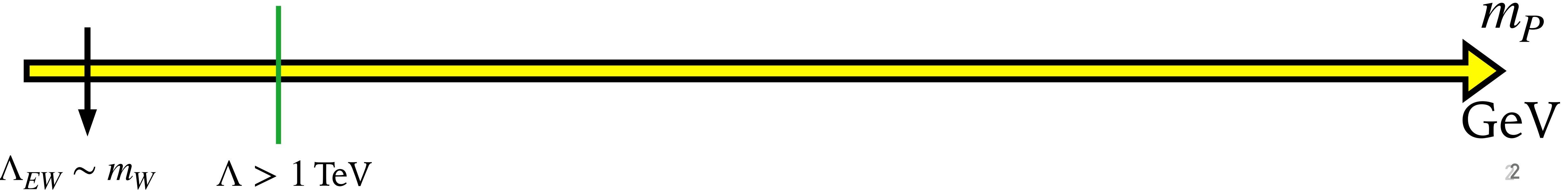
*PHENO 2023*

# The Higgs: composite or elementary?

$$\lambda_c \sim \frac{1}{\Lambda_{EW}}$$

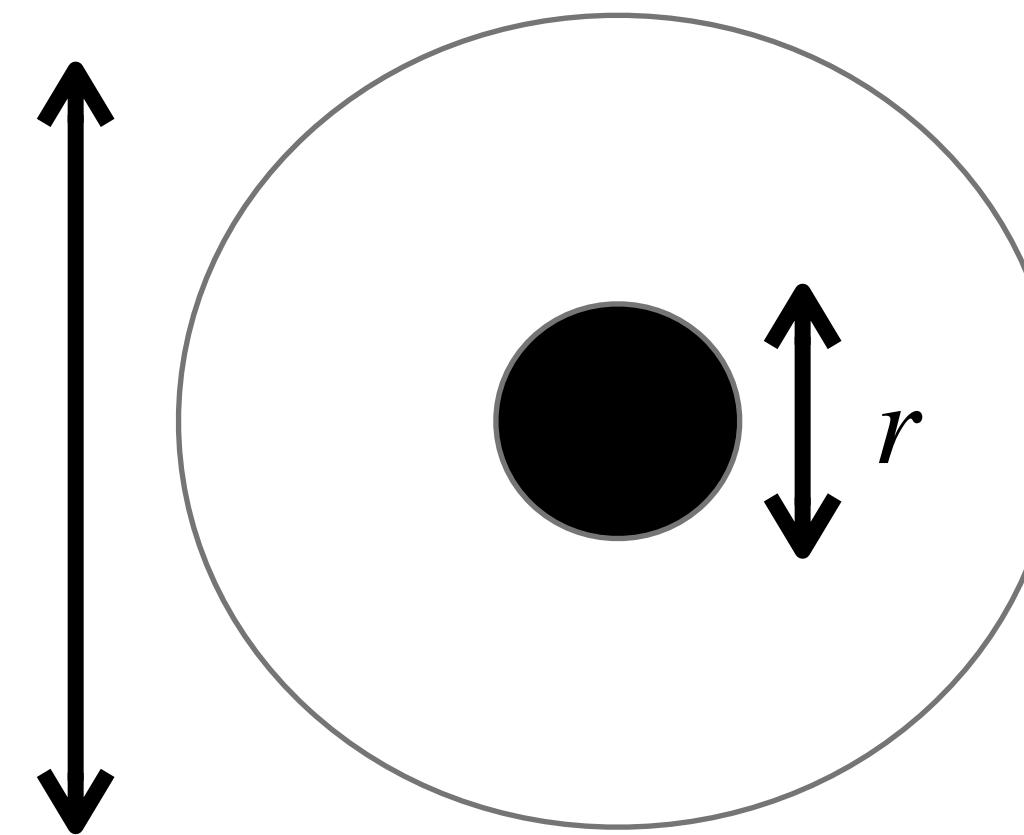


$$r \sim \frac{1}{\Lambda}$$



# The Higgs: composite or elementary?

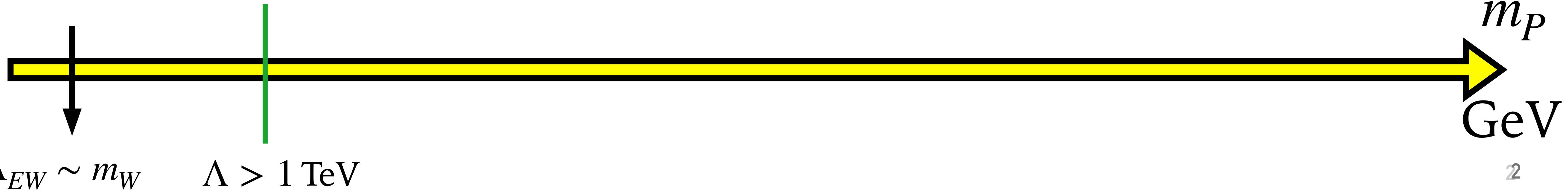
$$\lambda_c \sim \frac{1}{\Lambda_{EW}}$$



$$r \sim \frac{1}{\Lambda}$$

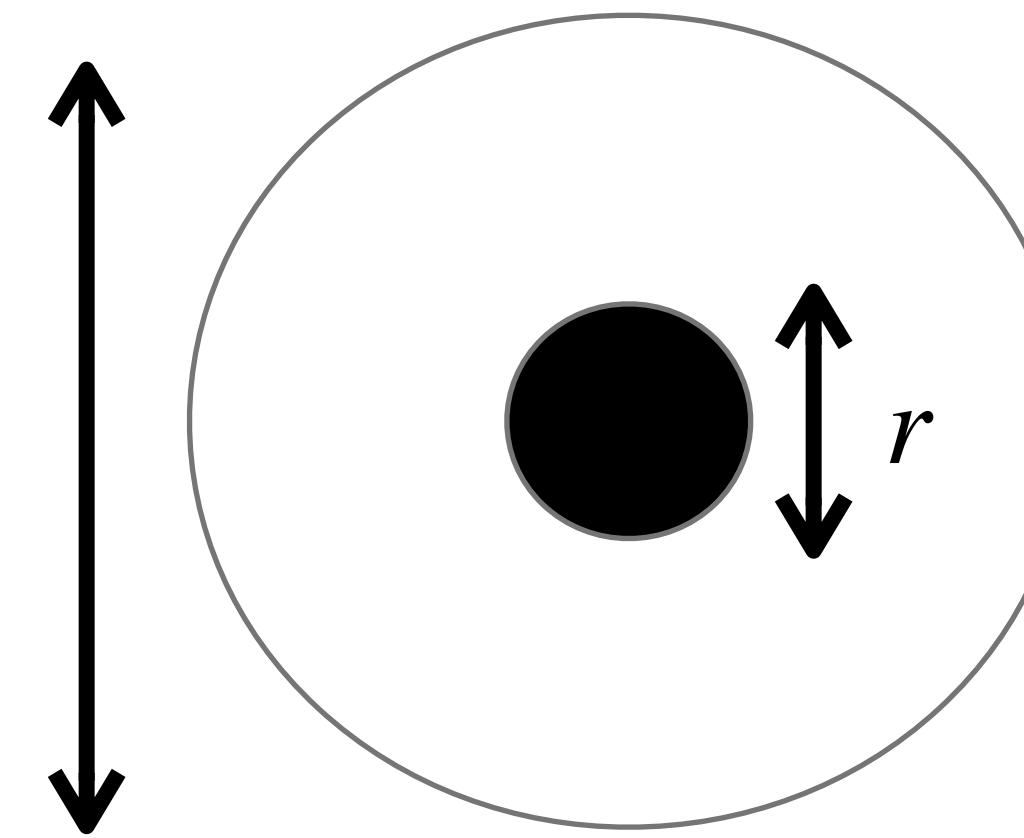
$$r \ll \lambda_c$$

- As simple as the SM
- Fine-tuned
- We cannot test it



# The Higgs: composite or elementary?

$$\lambda_c \sim \frac{1}{\Lambda_{EW}}$$



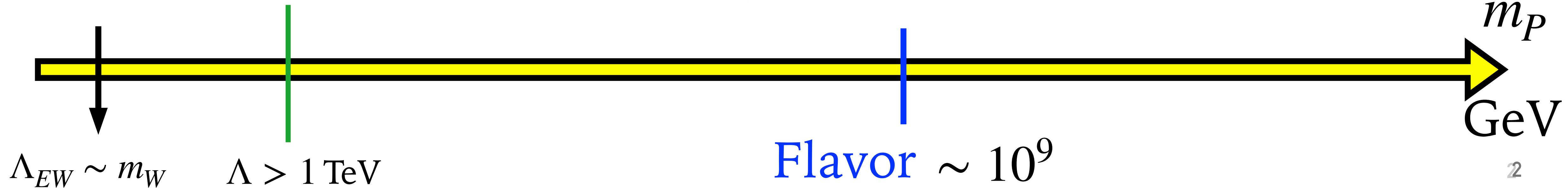
$$r \sim \frac{1}{\Lambda}$$

$$r \sim (\text{few TeV})^{-1} < \lambda_c$$

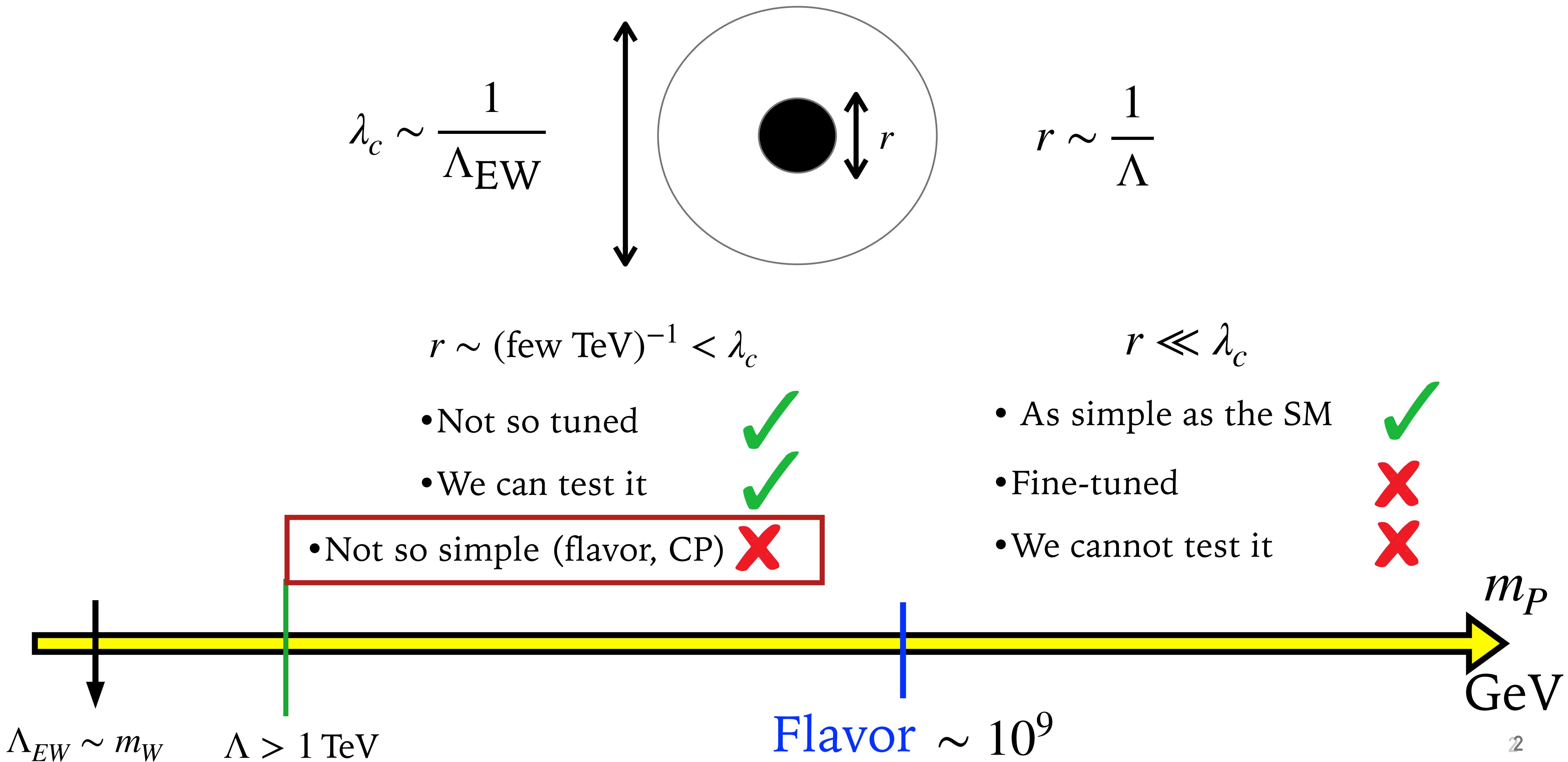
- Not so tuned ✓
- We can test it ✓
- Not so simple (flavor, CP) ✗

$$r \ll \lambda_c$$

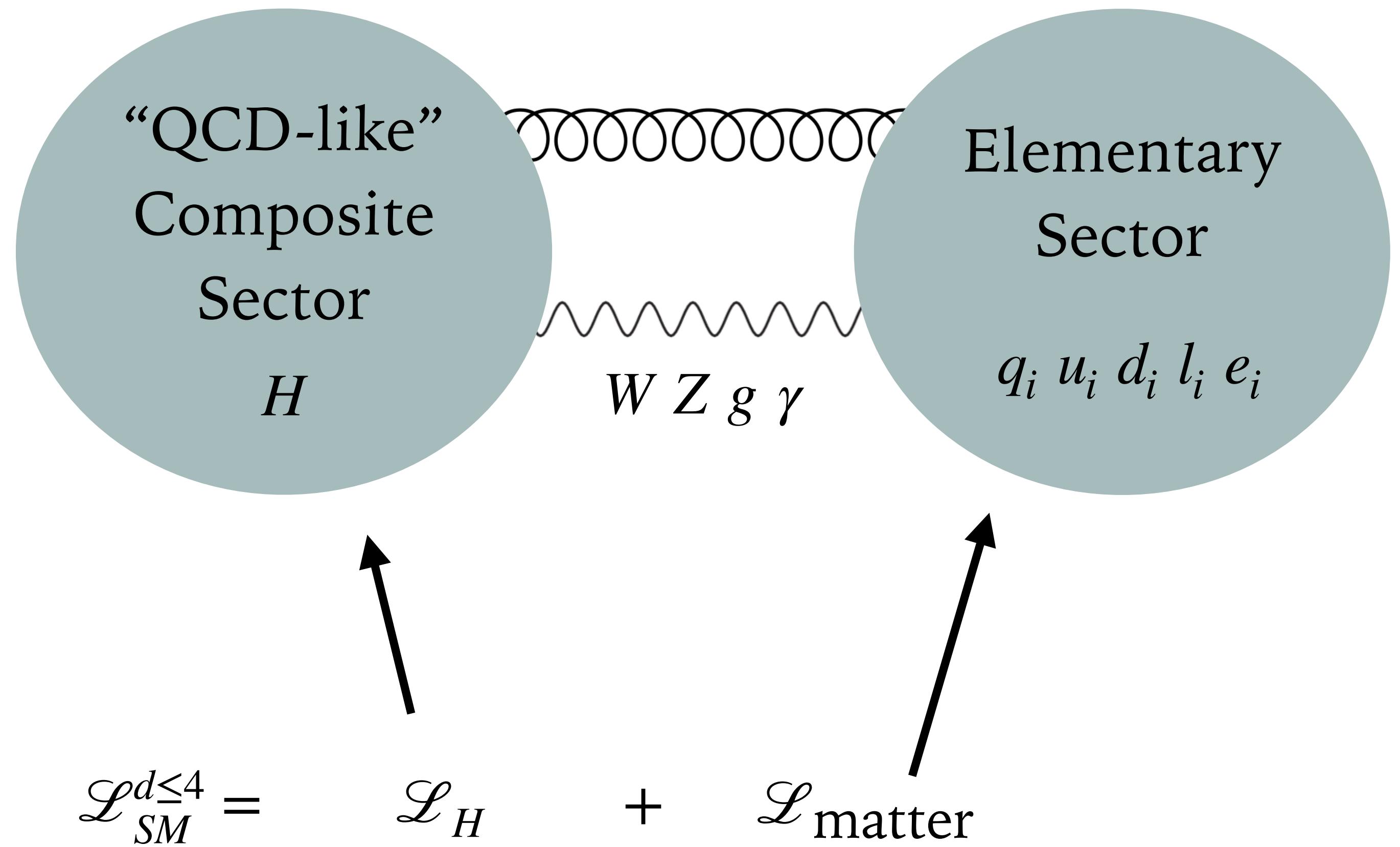
- As simple as the SM ✓
- Fine-tuned ✗
- We cannot test it ✗



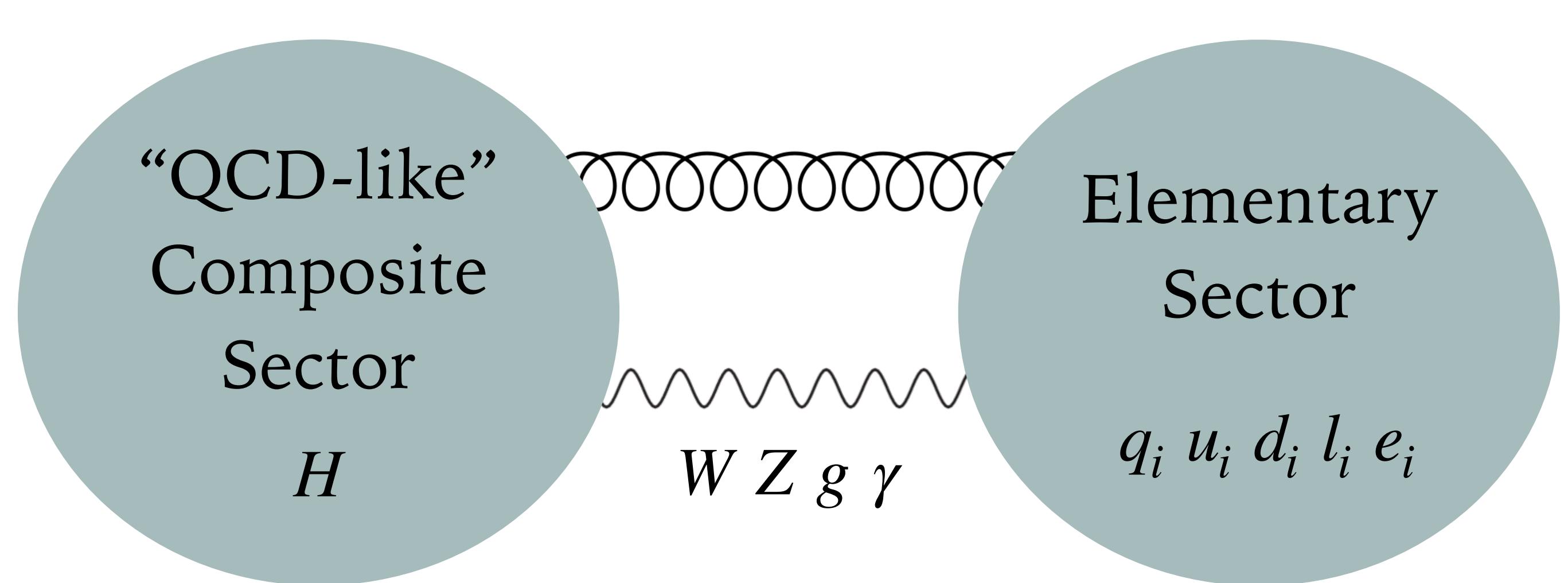
# The Higgs: composite or elementary?



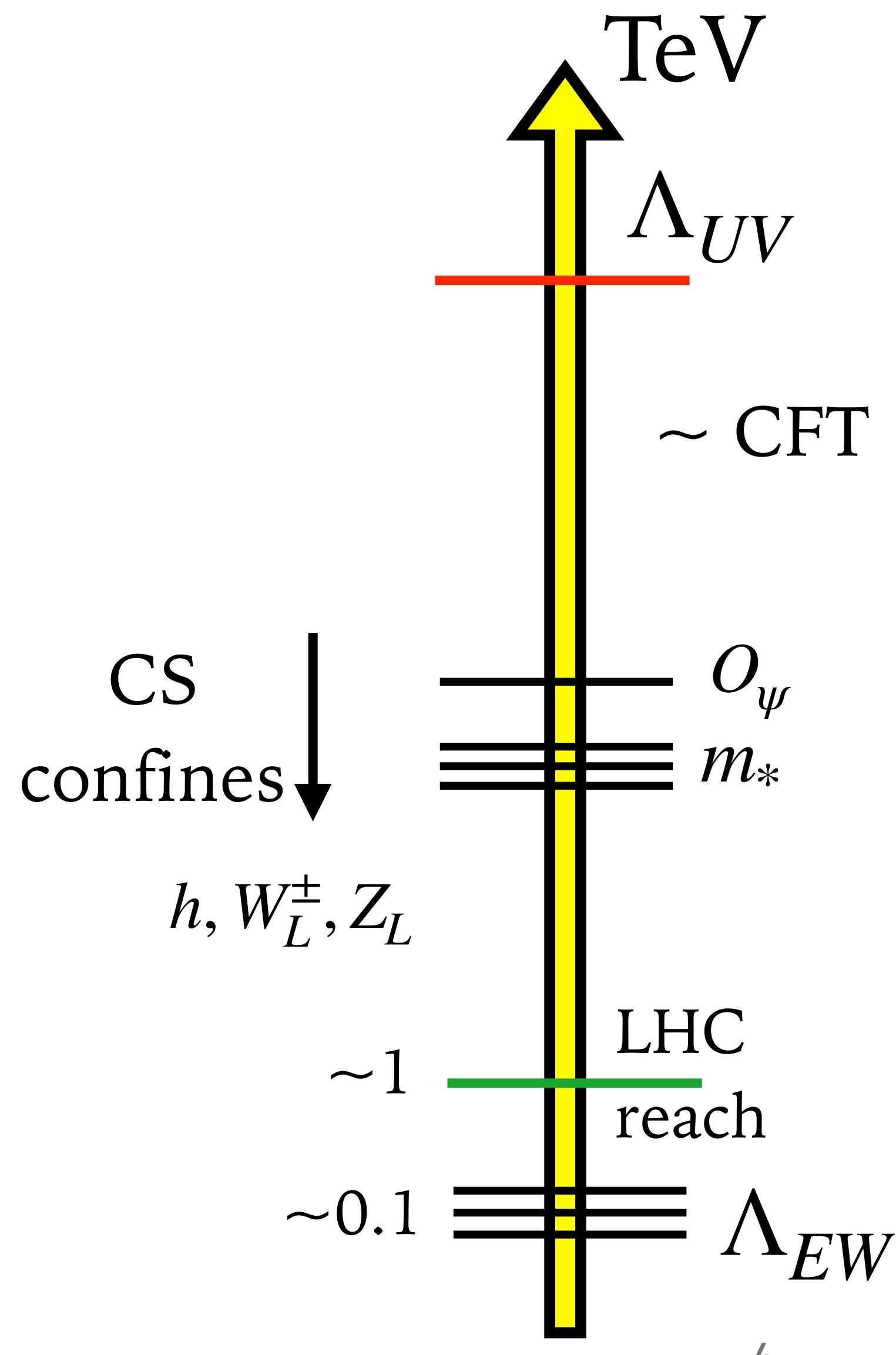
# Composite Higgs 101



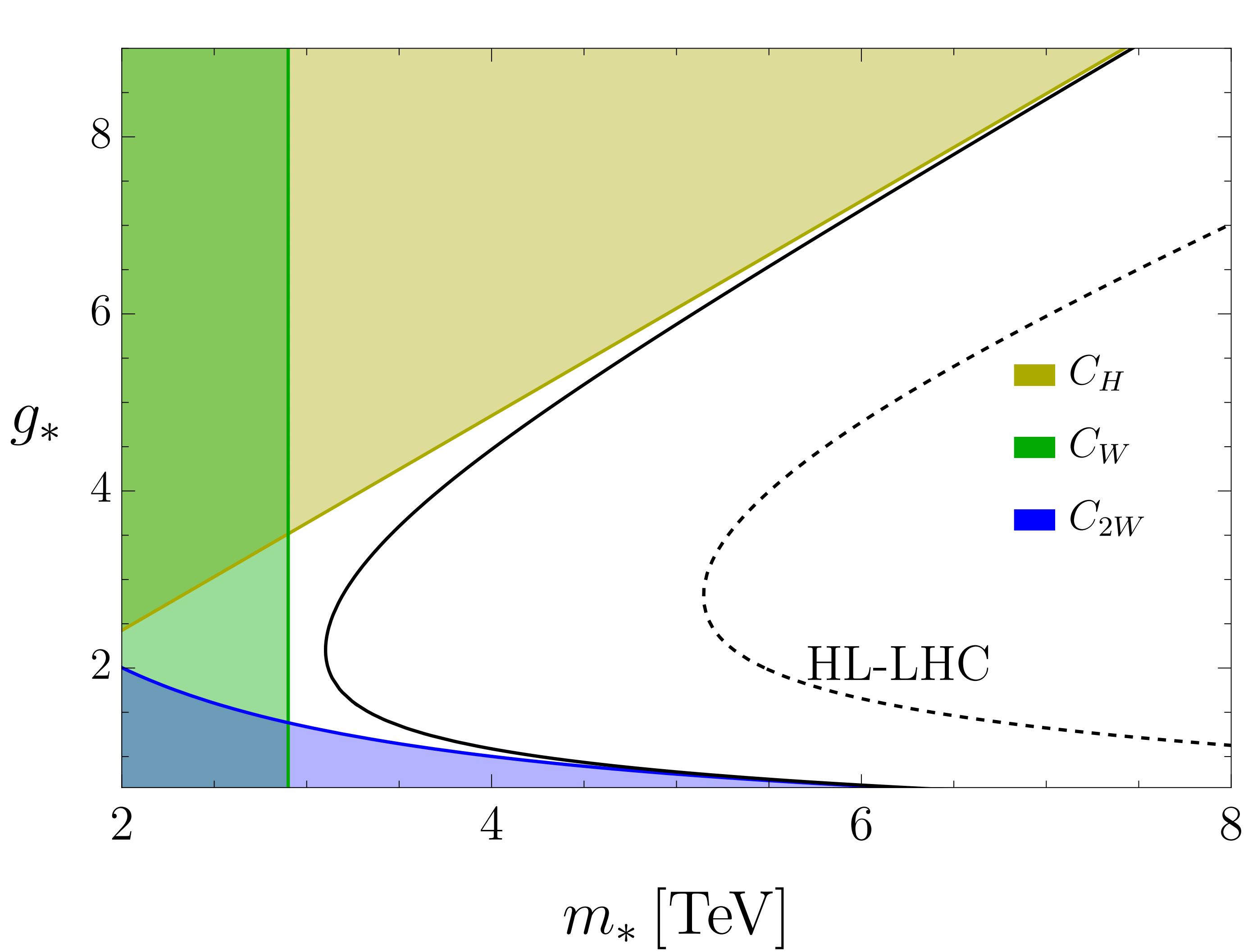
# Composite Higgs 101



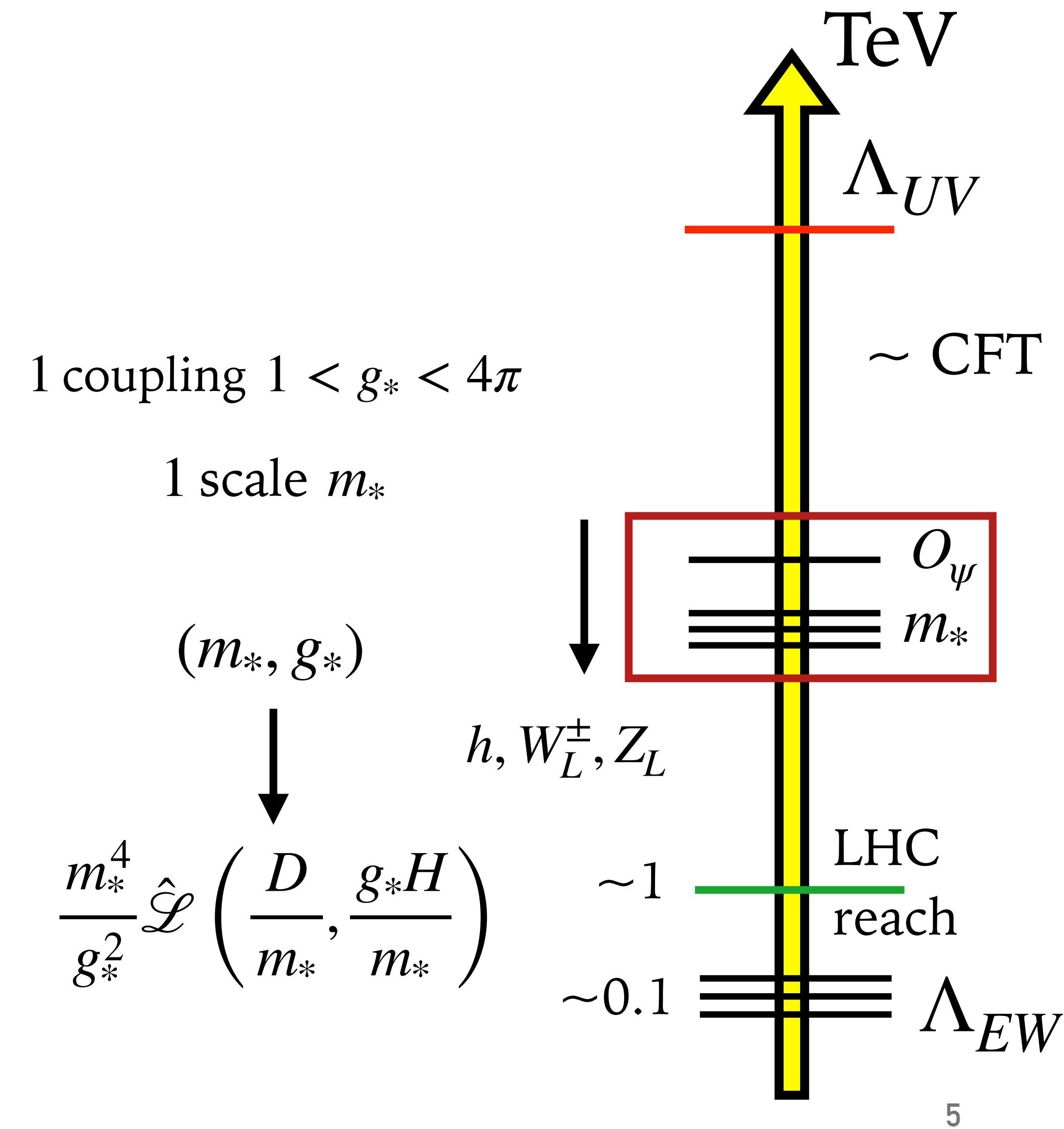
- The Composite Sector confines and delivers a bunch of resonances at  $m_*$
- The Composite Sector “naturally” explains  $\Lambda_{UV} \gg m_*$
- The Higgs emerges as a pseudo-goldstone boson and it is lighter than the other resonances



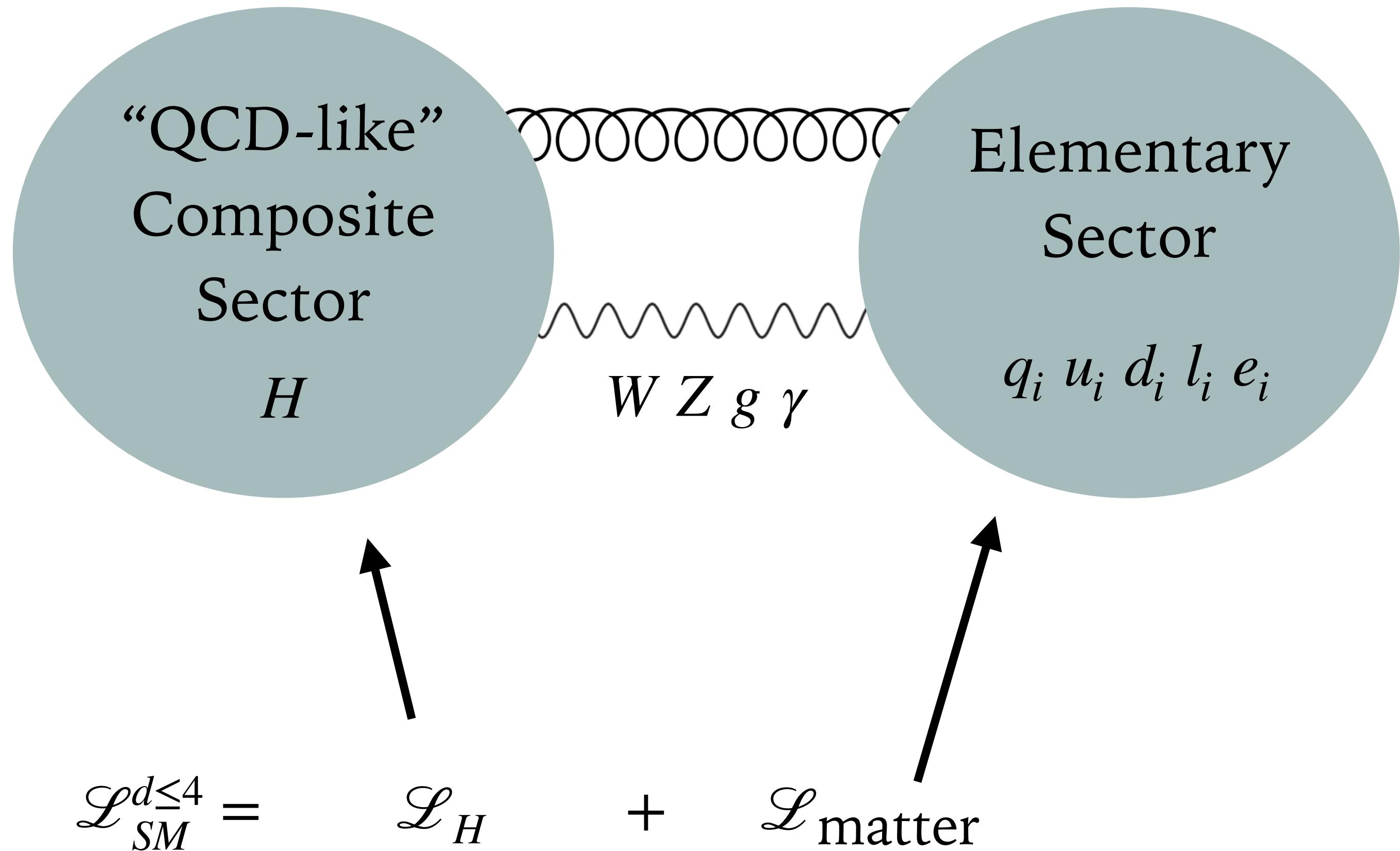
# Composite Higgs 101



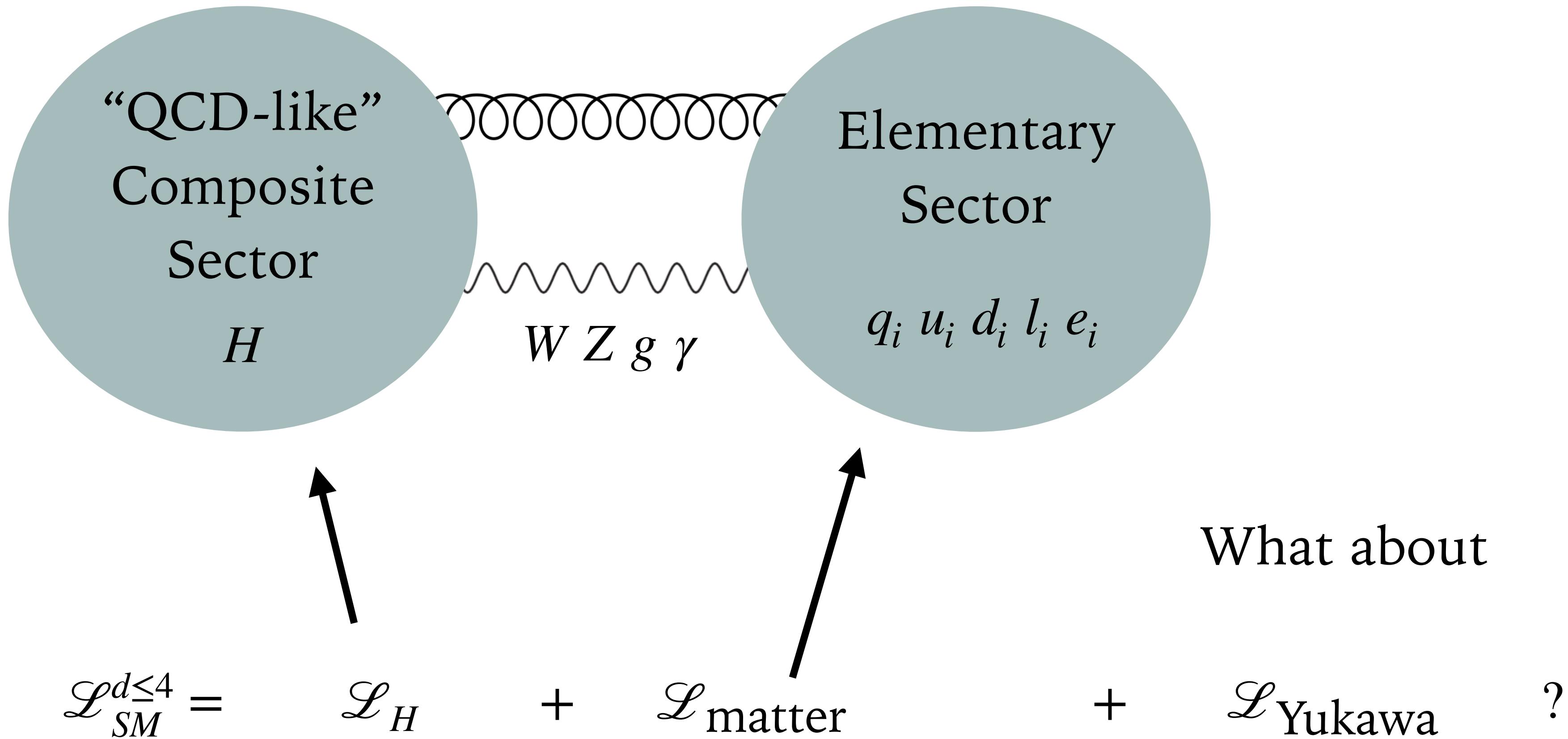
[CMS (22)][Panico, LR, Wulzer (22)][European strategy (20)]



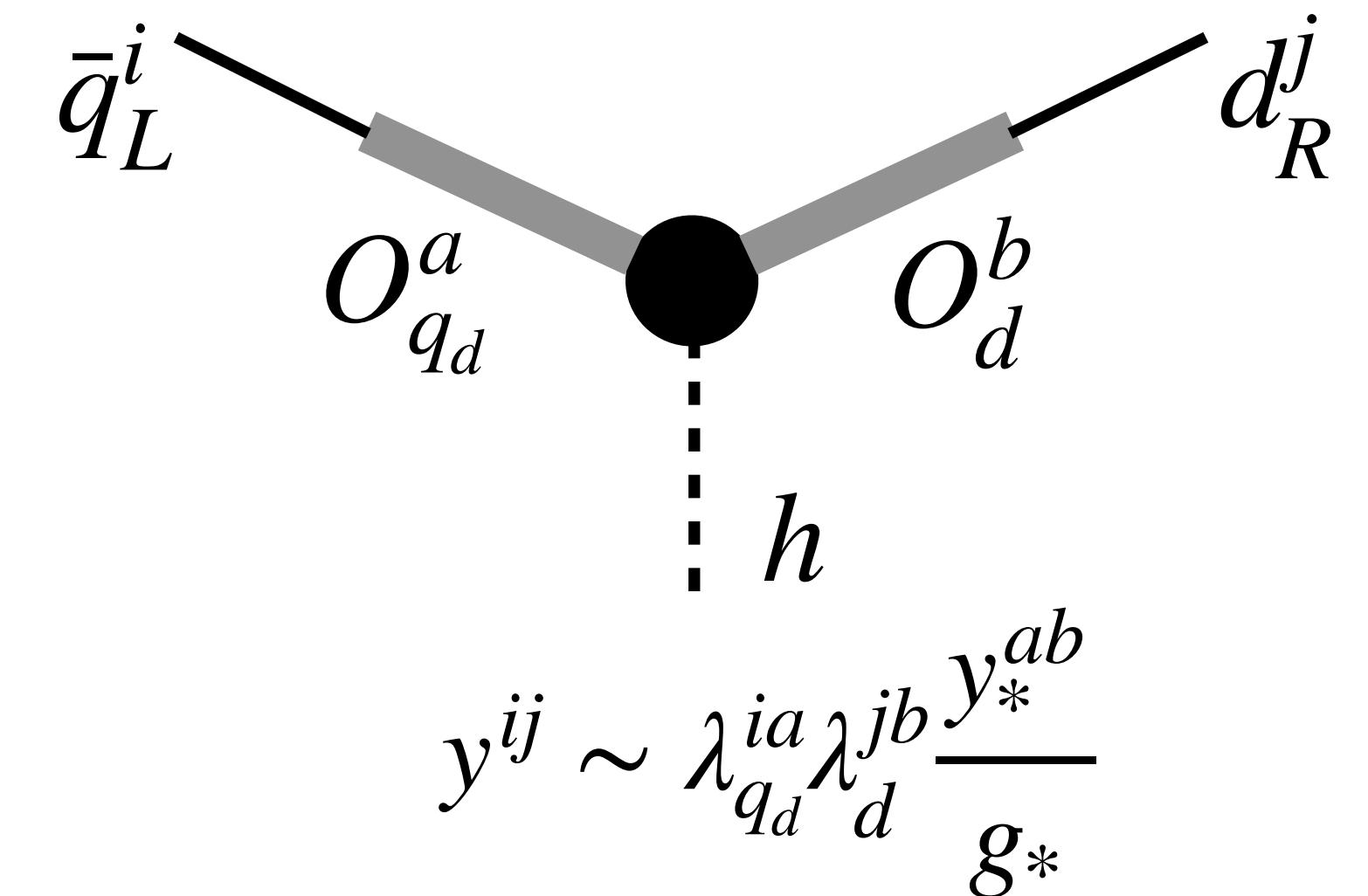
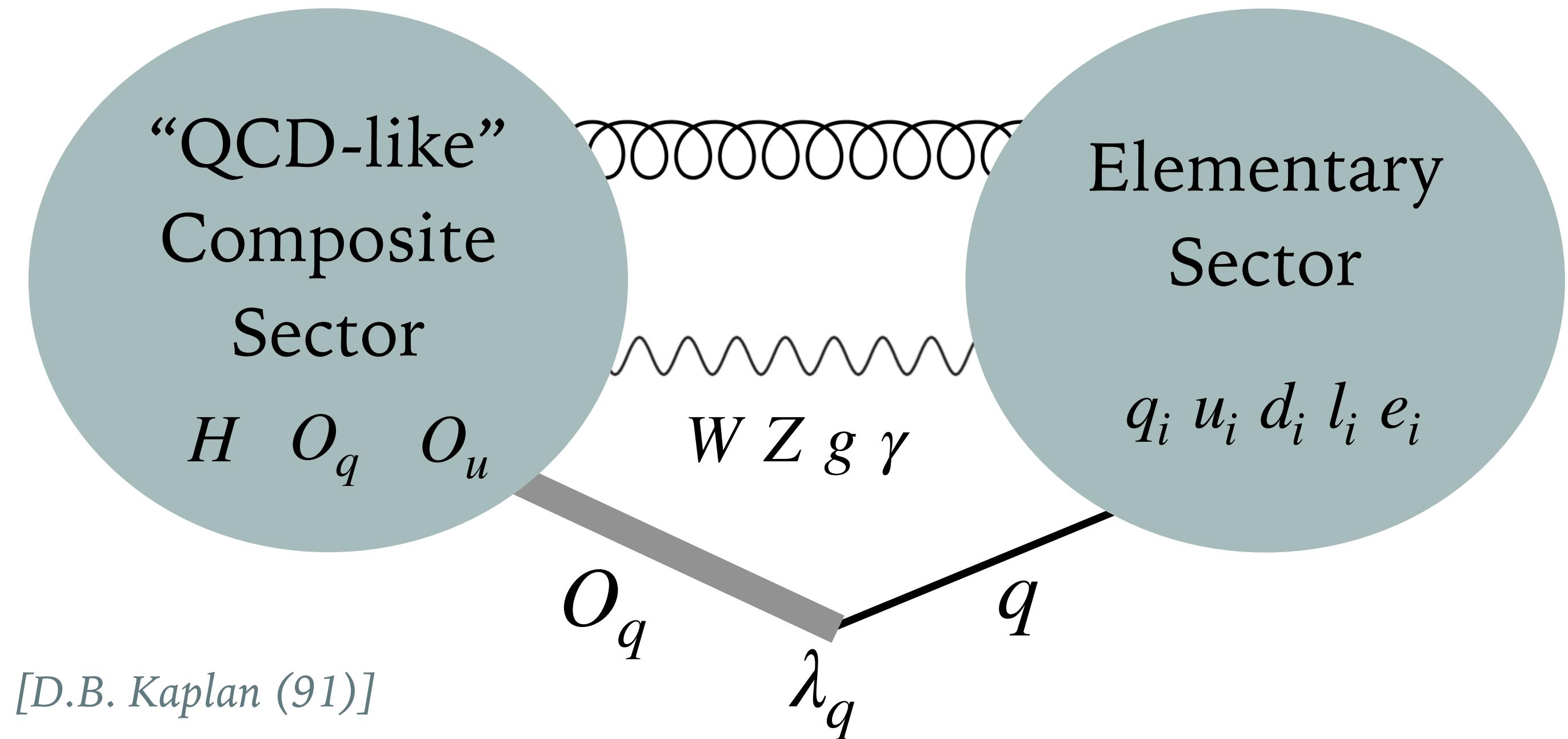
# Composite Higgs 101



# Composite Higgs 101



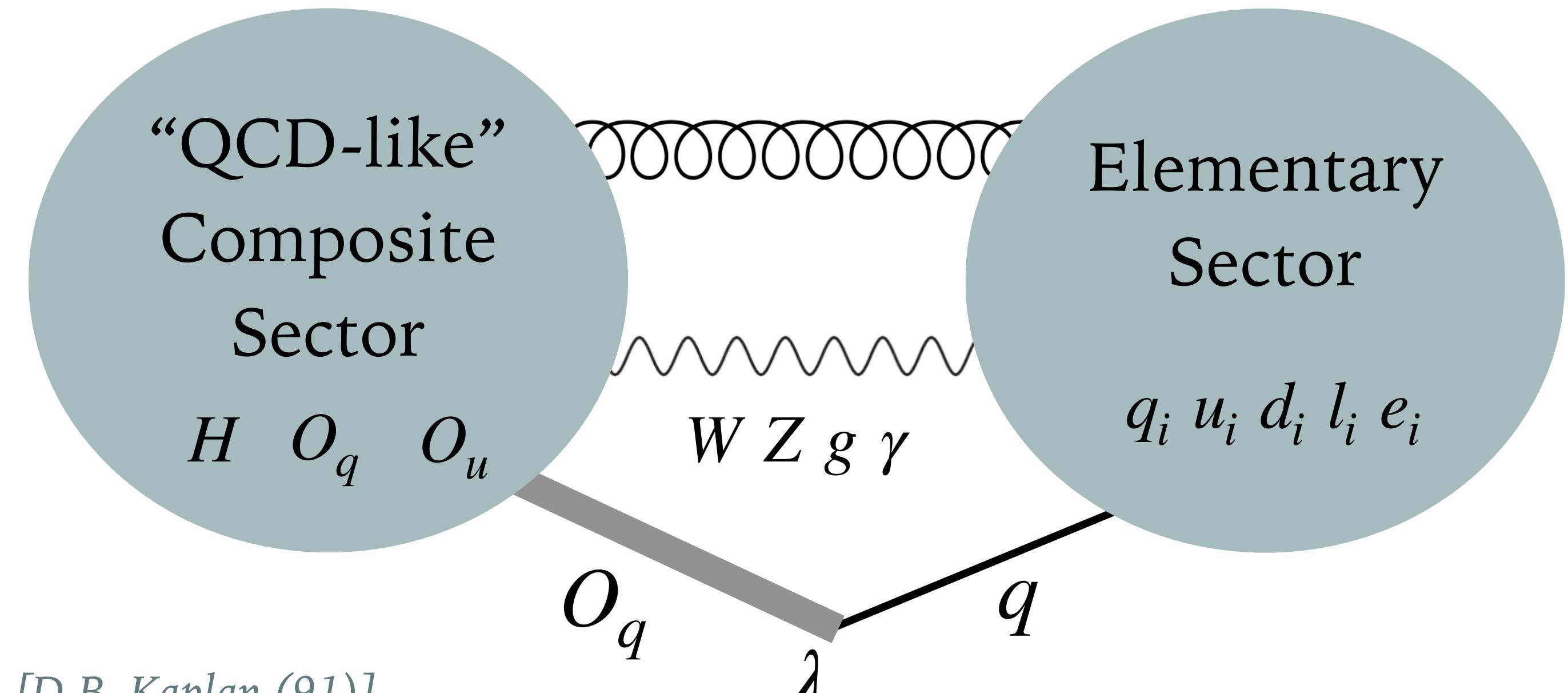
# Partial compositeness



$$\mathcal{L}_{\text{mix}} = \lambda_{q_u}^{ia} \bar{q}_L^i O_q^a + \lambda_{q_d}^{ia} \bar{q}_L^i O_q^a + \lambda_u^{ai} \bar{O}_u^a u_R^i + \lambda_d^{ai} \bar{O}_d^a d_R^i$$

The mixings  $\lambda$  control all the flavor transitions and CP violations in the SM

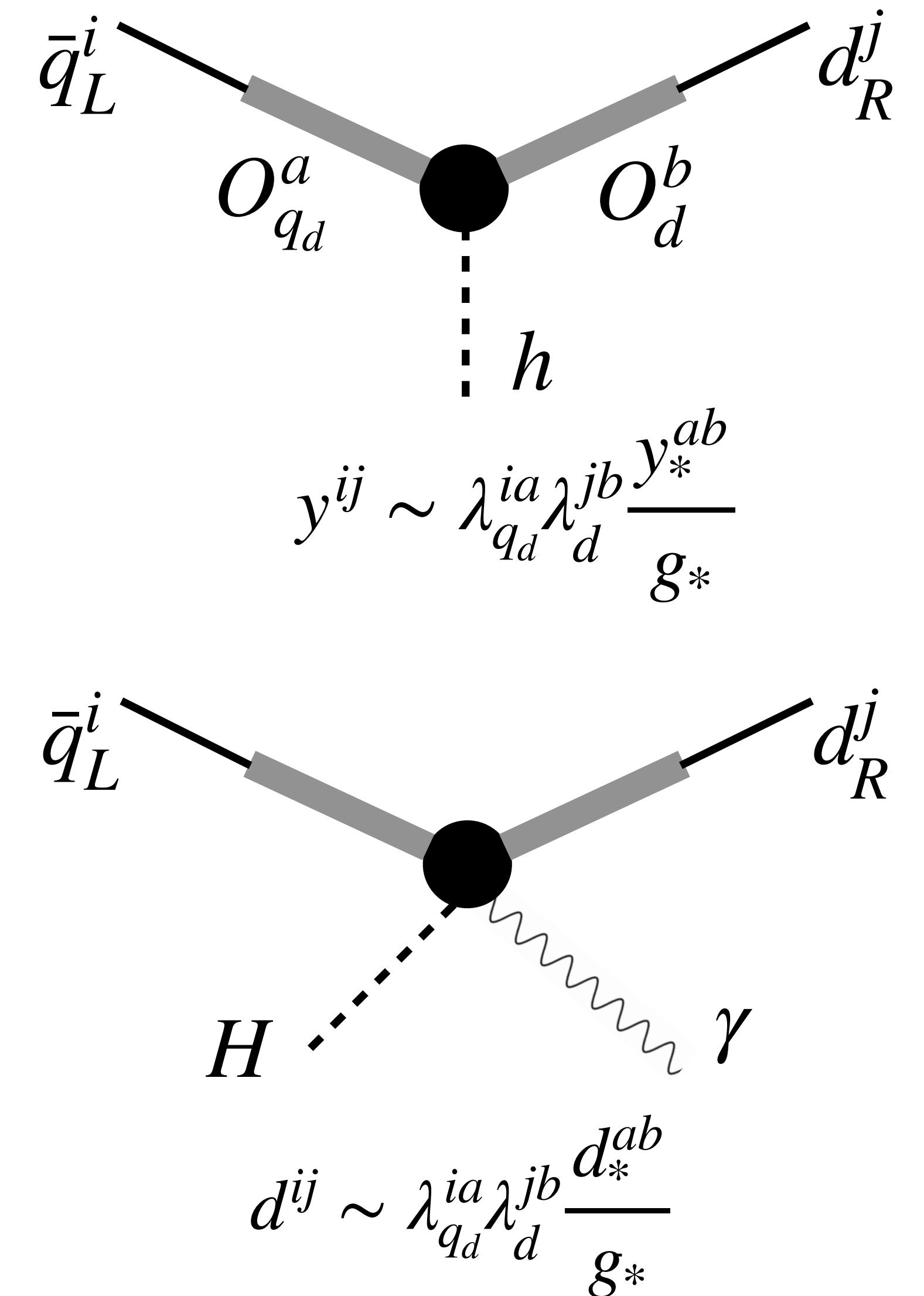
# Partial compositeness



[D.B. Kaplan (91)]

$$\mathcal{L}_{\text{mix}} = \lambda_{q_u}^{ia} \bar{q}_L^i O_q^a + \lambda_{q_d}^{ia} \bar{q}_L^i O_q^a + \lambda_u^{ai} \bar{O}_u^a u_R^i + \lambda_d^{ai} \bar{O}_d^a d_R^i$$

The mixings  $\lambda$  control all the flavor transitions and CP violations in the SM



# A landscape of Flavor symmetries

The mixings  $\lambda$  break the flavor group  $\mathcal{F}_c \times U(3)^3$  (CS x SM) up to  $U(1)_B$ . We can systematically classify the different options in terms  $\mathcal{F}_c$  and the pattern of flavor symmetry breaking.

$$O_{q_{u/d}}^a, O_u^a, O_d^a \in \mathcal{F}_c$$
$$\mathcal{F}_c \times U(3)^3 \xrightarrow{\lambda} U(1)_B$$

# A landscape of Flavor symmetries

The mixings  $\lambda$  break the flavor group  $\mathcal{F}_c \times U(3)^3$  (CS x SM) up to  $U(1)_B$ . We can systematically classify the different options in terms  $\mathcal{F}_c$  and the pattern of flavor symmetry breaking.

$$\mathcal{F}_c \times U(3)^3 \xrightarrow{\lambda} U(1)_B$$

$O_{q_{u/d}}^a, O_u^a, O_d^a \in \mathcal{F}_c$

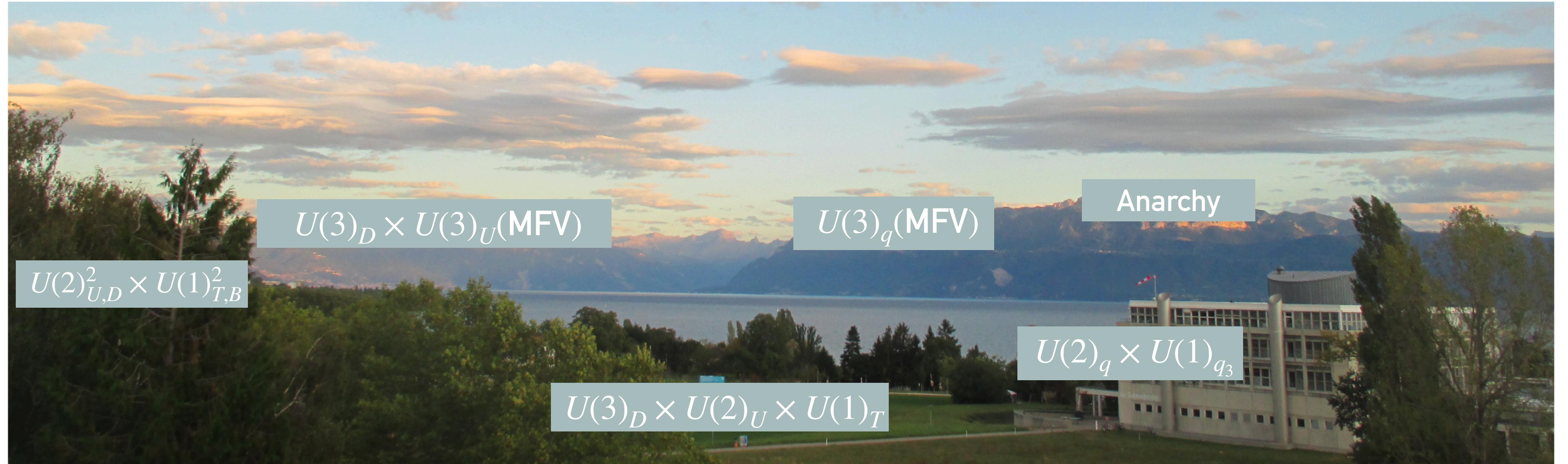


# A landscape of Flavor symmetries

The mixings  $\lambda$  break the flavor group  $\mathcal{F}_c \times U(3)^3$  (CS x SM) up to  $U(1)_B$ . We can systematically classify the different options in terms  $\mathcal{F}_c$  and the pattern of flavor symmetry breaking.

$$\mathcal{F}_c \times U(3)^3 \xrightarrow{\lambda} U(1)_B$$

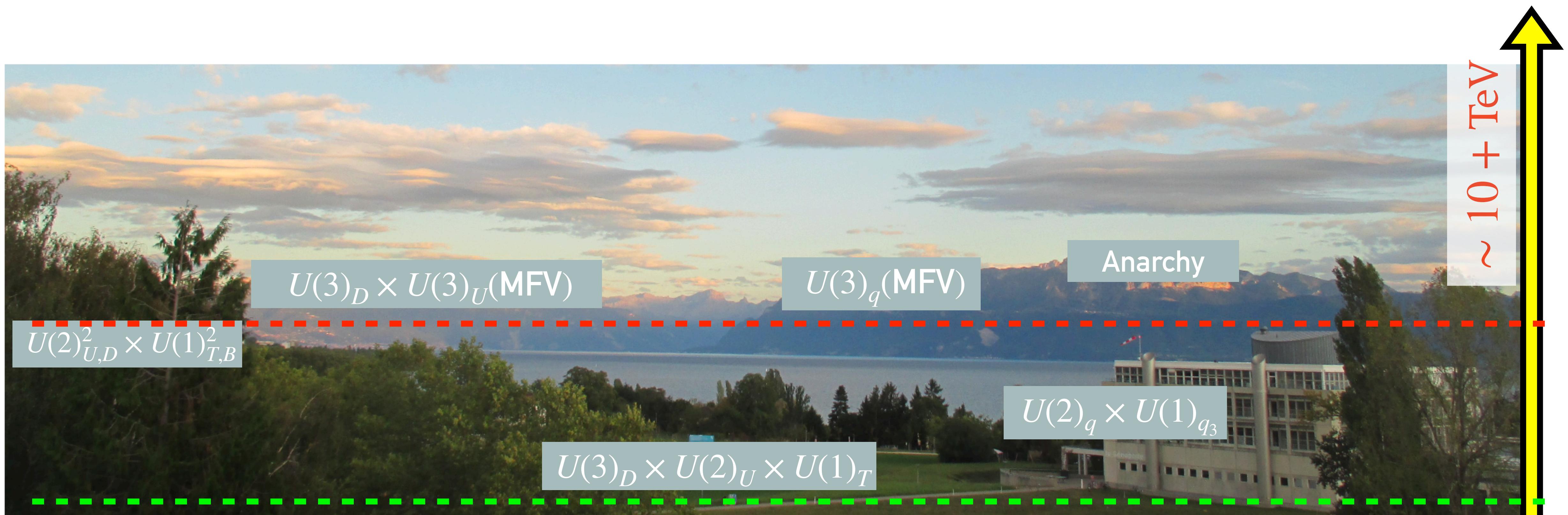
$O_{q_{u/d}}^a, O_u^a, O_d^a \in \mathcal{F}_c$



# A landscape of Flavor symmetries

The mixings  $\lambda$  break the flavor group  $\mathcal{F}_c \times U(3)^3$  (CS x SM) up to  $U(1)_B$ . We can systematically classify the different options in terms  $\mathcal{F}_c$  and the pattern of flavor symmetry breaking.

$$\mathcal{F}_c \times U(3)^3 \xrightarrow{\lambda} U(1)_B$$
$$O_{q_{u/d}}^a, O_u^a, O_d^a \in \mathcal{F}_c$$



# Exploring the Landscape of flavor symmetries

No symmetries

“anarchy”

✗ Large Electric dipoles

$$\text{nEDM} \quad m_* \gtrsim \frac{g^*}{4\pi} 75 \text{ TeV}$$

✗ Large Flavor transitions

$$\varepsilon_K, \Delta m_K \quad m_* \gtrsim 20 \text{ TeV}$$

[Gherghetta, Pomarol (00)][Agashe, Perez, Soni (05)]

[Keren-Zur et al. (12)]

For leptons see: [Redi (13)] [Frigerio, Serra, Vecchi (18)]

# Exploring the Landscape of flavor symmetries

No symmetries

“anarchy”

✗ Large Electric dipoles

$$\text{nEDM} \quad m_* \gtrsim \frac{g_*}{4\pi} 75 \text{ TeV}$$

✗ Large Flavor transitions

$$\varepsilon_K, \Delta m_K \quad m_* \gtrsim 20 \text{ TeV}$$

[Gherghetta, Pomarol (00)][Agashe, Perez, Soni (05)]  
[Keren-Zur et al. (12)]

All of the symmetries  
(of the SM)  
“MFV”

✗  $\Delta m_{B_d}, S_{\psi K_s} \quad m_* \gtrsim \frac{6.5}{g_* \varepsilon_u^2}$

✗  $pp \rightarrow uu \quad m_* \gtrsim g_* \varepsilon_u^2 13 \text{ TeV}$

$$m_* \gtrsim 9 \text{ TeV}$$

[Barbieri, et al. (12)][Redi, Weiler (11)]

For leptons see: [Redi (13)] [Frigerio, Serra, Vecchi (18)]

# Exploring the Landscape of flavor symmetries

No symmetries

“anarchy”

✗ Large Electric dipoles

$$\text{nEDM} \quad m_* \gtrsim \frac{g_*}{4\pi} 75 \text{ TeV}$$

✗ Large Flavor transitions

$$\varepsilon_K, \Delta m_K \quad m_* \gtrsim 20 \text{ TeV}$$

[Gherghetta, Pomarol (00)][Agashe, Perez, Soni (05)]  
[Keren-Zur et al. (12)]

All of the symmetries  
(of the SM)  
“MFV”

✗  $\Delta m_{B_d}, S_{\psi K_s}$   $m_* \gtrsim \frac{6.5}{g_* \varepsilon_u^2}$

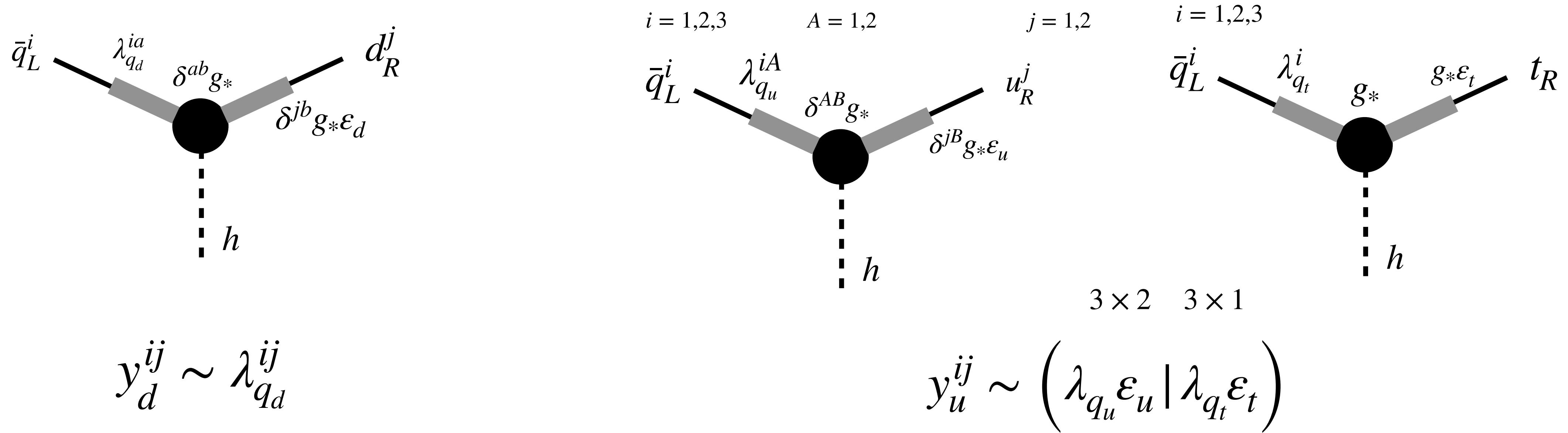
✗  $pp \rightarrow uu \quad m_* \gtrsim g_* \varepsilon_u^2 13 \text{ TeV}$

$$m_* \gtrsim 9 \text{ TeV}$$

[Barbieri, et al. (12)][Redi, Weiler (11)]

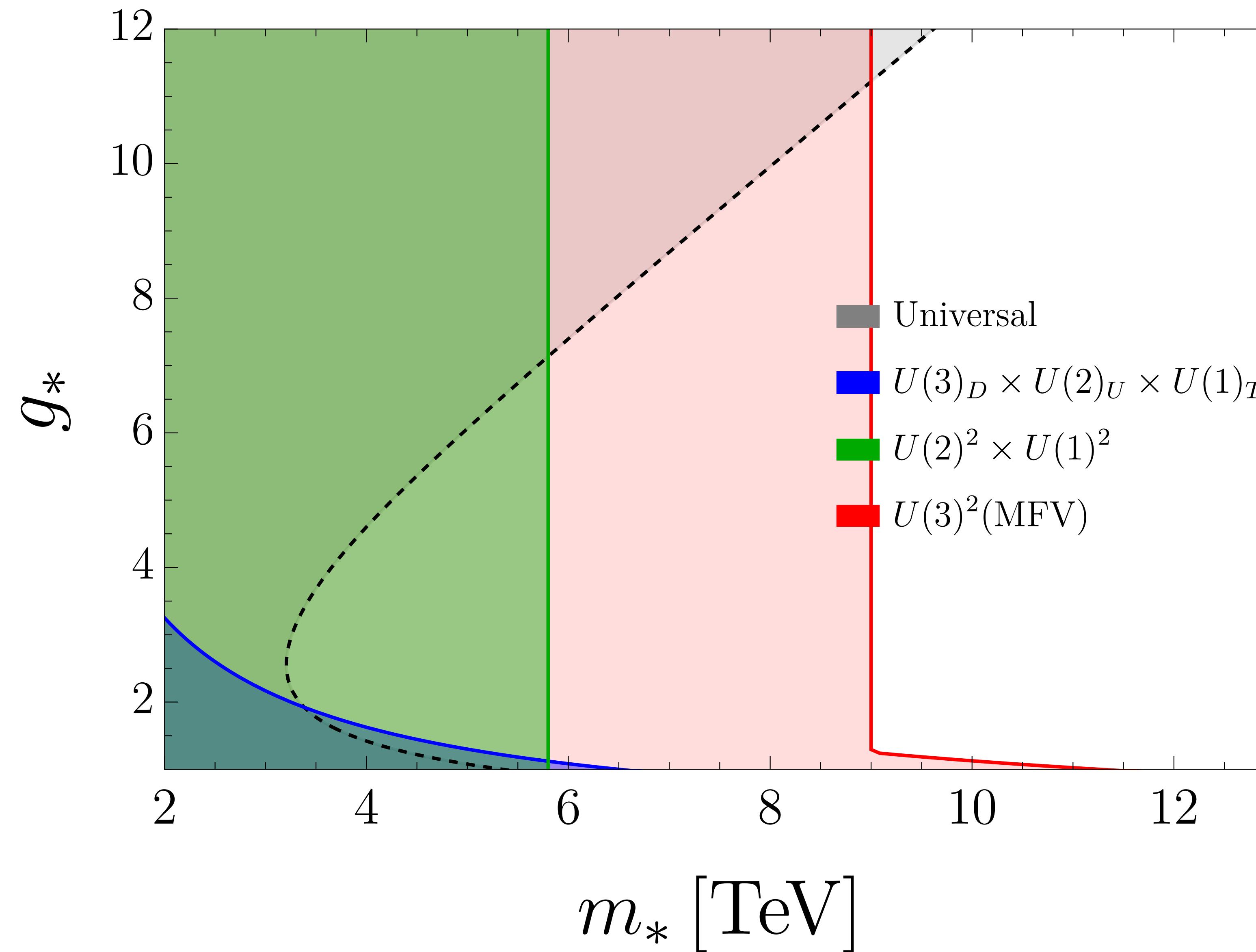
Flavor strongly constraints the  
“standard” setups

# The most clever setup: $U(3)_D \times U(2)_U \times U(1)_T$



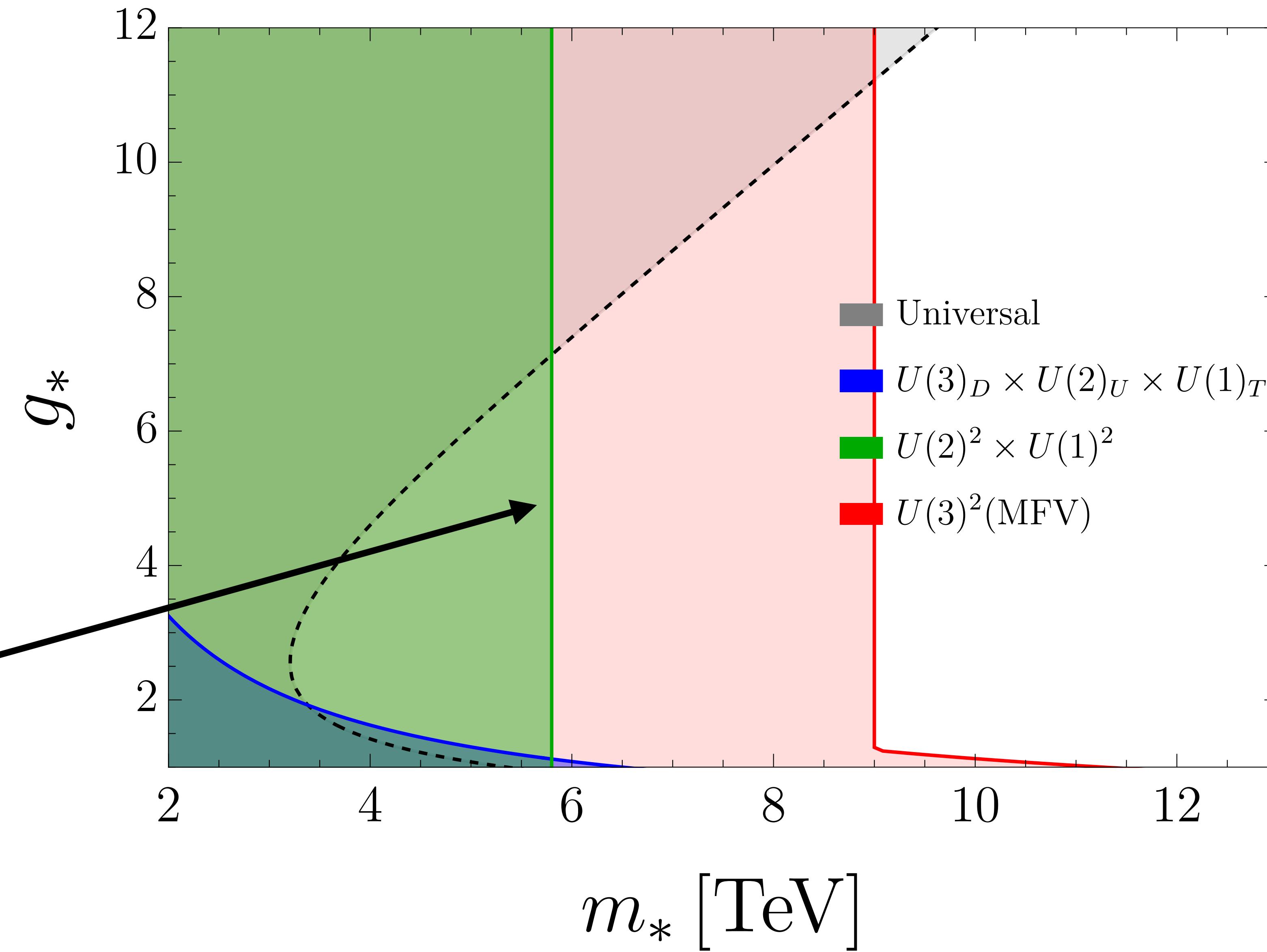
- $\epsilon_u$  sufficiently small to evade  $pp \rightarrow uu$  ( $m_* \gtrsim g_* \epsilon_u^2$  13 TeV)
- $\epsilon_t$  sufficiently large to suppress  $\Delta F = 2$  transitions ( $m_* \gtrsim \frac{6.5}{g_* \epsilon_t^2}$  TeV)
- Enough symmetries not to generate dangerous CP odd effects (no eDMs)

# The most clever setup: $U(3)_D \times U(2)_U \times U(1)_T$



# The most clever setup: $U(3)_D \times U(2)_U \times U(1)_T$

New effects from  
 $b \rightarrow s\gamma$   
No advantages in  
less symmetric  
models



# Conclusion & Outlook

- Flavor and CP-odd observables strongly constrain New Physics at the TeV
- CH models w/ suitable flavor symmetries are still compatible with New Physics near the (HL-)LHC reach
- The most clever setup:  $U(3)_D \times U(2)_U \times U(1)_T$
- B-physics plays a crucial role ( $\Delta m_{B_d}$ ,  $S_{\psi K_s}$ ,  $b \rightarrow s\gamma$ , ...)

# Conclusion & Outlook

- Flavor and CP-odd observables strongly constrain New Physics at the TeV
- CH models w/ suitable flavor symmetries are still compatible with New Physics near the (HL-)LHC reach
- The most clever setup:  $U(3)_D \times U(2)_U \times U(1)_T$
- B-physics plays a crucial role ( $\Delta m_{B_d}$ ,  $S_{\psi K_s}$ ,  $b \rightarrow s\gamma$ , ...)
- Many more experimental updates in the near future (HL-LHC, Belle II, Mu3e, Mu2e,...) will better capture this landscape of flavor symmetries.

*Thank you!*