Flavor without symmetries

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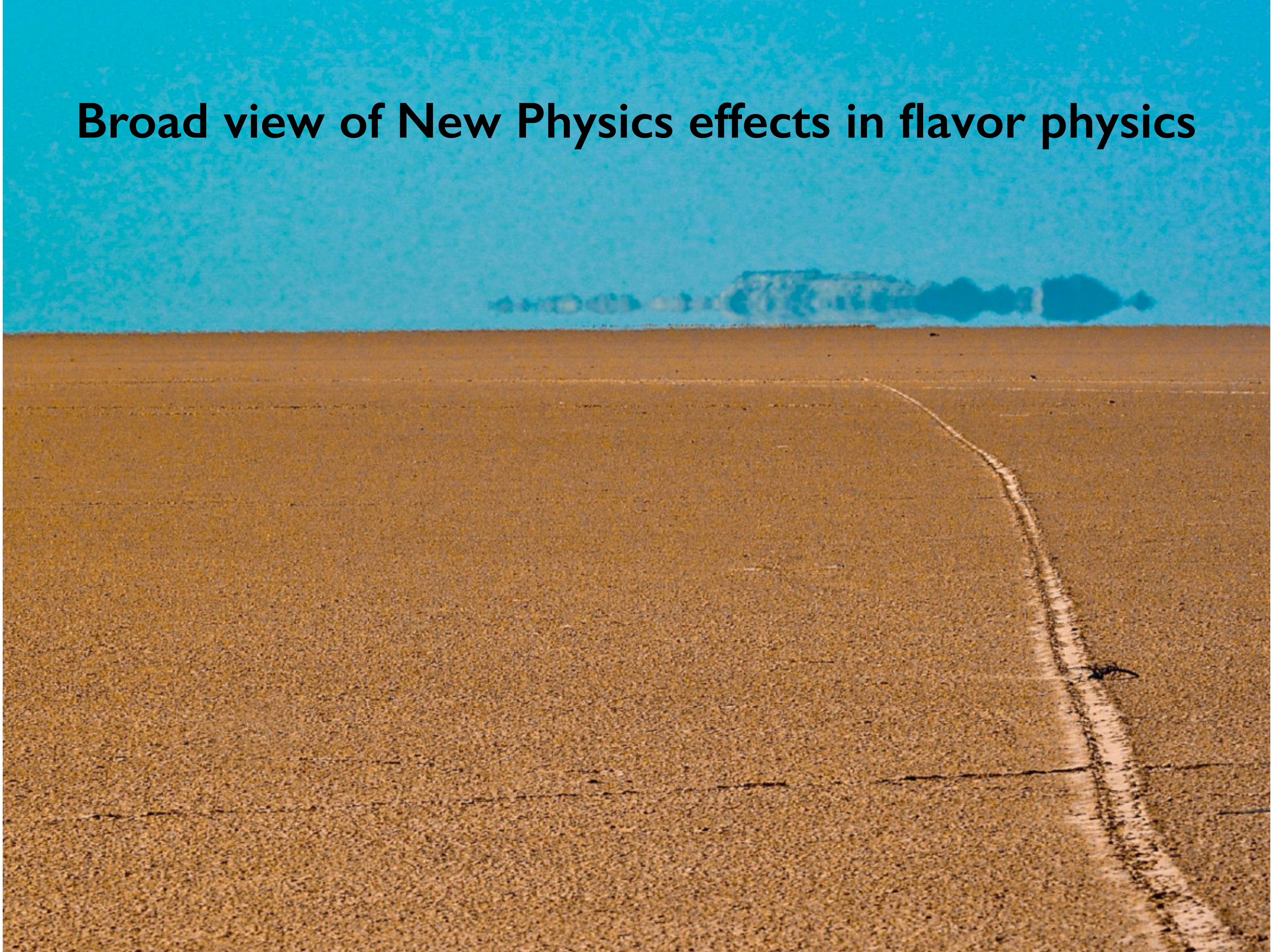
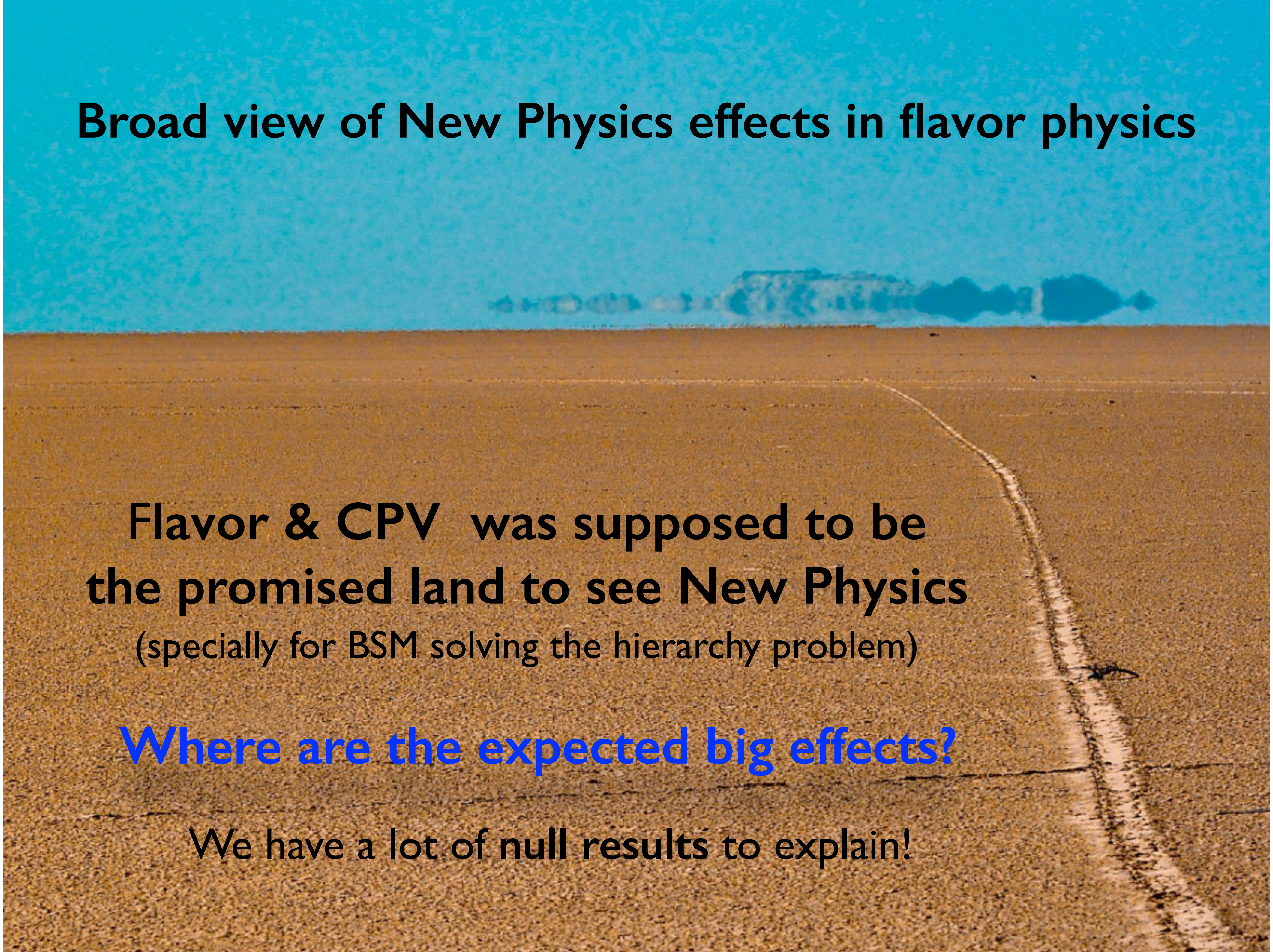
Broad view of New Physics effects in flavor physics




Broad view of New Physics effects in flavor physics
Flavor & CPV was supposed to be
the promised land to see New Physics
(specially for BSM solving the hierarchy problem)
Where are the expected big effects?
We have a lot of **null results** to explain!

“Cheap” ways to explain it:

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☛ Demand similar BSM flavor-structure as in the SM:

Imposed CP & Flavor Symmetries in the BSM

“Cheap” ways to explain it:

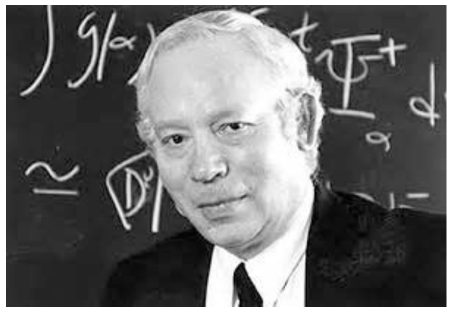
- ☛ Demand BSM is very heavy ~10^3 TeV *but… hierarchy problem?*
- ☛ Demand similar BSM flavor-structure as in the SM:

Imposed CP & Flavor Symmetries in the BSM

Nevertheless…

“…symmetry and its generalizations are not fundamental at all, but just accidents, approximate consequences of deeper principles. To the extent that these symmetries were our spies in the high command of nature, we were exaggerating their importance, as also often happens with real spies”

Steven Weinberg



This is also the **lesson from the SM:**

Not based on symmetries!

(gauge symmetries ☛ redundancies of the theory
arise as a consequence of Lorentz symmetry
Weinberg's Book I, page 246)

CP & flavor symmetries in the BSM should arise from dynamics!

Symmetries from dynamics

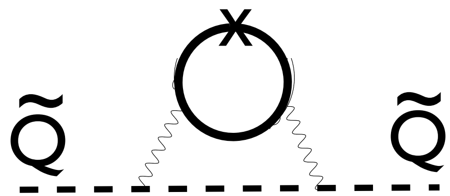
Only few examples known:

Symmetries from dynamics

Only few examples known:

SUSY: **Gauge Mediated Susy Breaking (GMSB)**

soft-masses through gauge interactions (flavor blind)



but today minimal **GMSB** highly tuned to reproduce M_H~125 GeV

Beyond minimal models… **EDMs** are sizable!

$$d_e \sim 10^{-28} \mathrm{cm\,e} \left(\frac{M_S}{10\ \mathrm{TeV}} \right)^2 \tan\beta$$

Symmetries from dynamics

Only few examples known:

Composite Higgs:

Yukawas from linear mixing to operators of the strong sector:

$$\mathcal{L}_{\rm lin} = \epsilon_{f_i}\, \bar{f}_i\, \mathcal{O}_{f_i}$$

partial-compositeness

↳ portal to the strong sector

Explicit example (for the top):

arXiv:1502.00390

SU(4) strong sector

Fermions:

a) three $\Psi_{L,R} \in$ **4** (fundamental)

b) five $\Upsilon \in$ **6** (antisym. matrix)

$$\Psi\Upsilon\Psi = \mathcal{O}_{\rm top}$$

Operator that can be coupled to the top

Global sym.

$$G = SU(5) \times SU(3) \times SU(3)' \times U(1)_X \times U(1)'$$

$$\downarrow$$

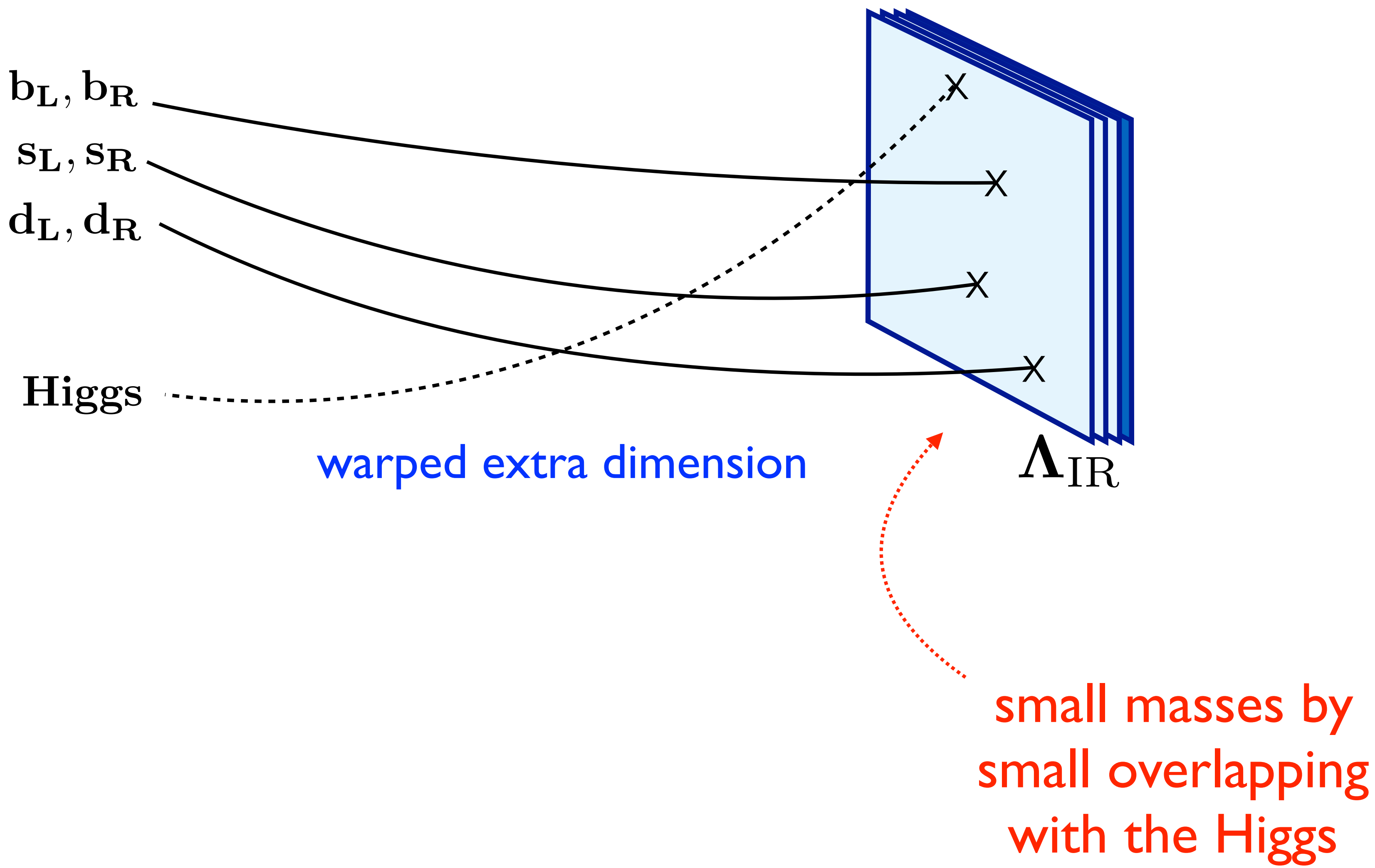
$$H = SO(5) \times SU(3)_{\rm color} \times U(1)_X$$

dimension at weak coupling: 9/2

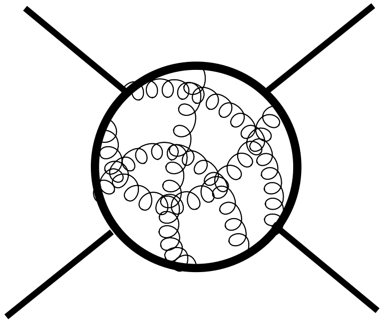
dimension needed at strong coupling: 5/2 ($\gamma = 2$)

Possible? lattice could tell us!

Geometric perspective



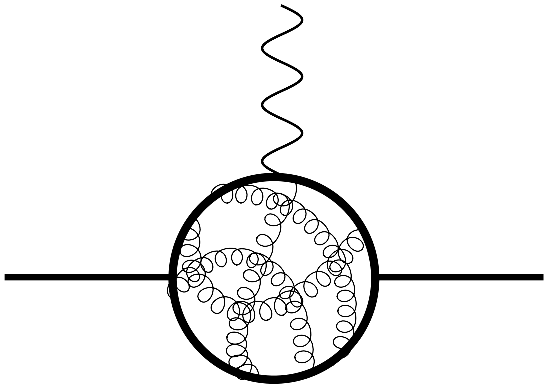
Flavor & CP-violation constraints



$$\frac{g_*^2}{\Lambda_{\rm IR}^2}\epsilon_{f_i}\epsilon_{f_j}\epsilon_{f_k}\epsilon_{f_l}\,\bar f_i\gamma^\mu f_j\bar f_k\gamma_\mu f_l$$

↳ scale of the strong sector: expected ~TeV

ϵ_K bound: $\mathbf{\Lambda_{\rm IR} > 10}$ TeV



$$\frac{g_*^2}{16\pi^2}\frac{g_* v}{\Lambda_{\rm IR}^2}\epsilon_{f_i}\epsilon_{f_j}\,\bar f_i\sigma_{\mu\nu}f_j\,gF^{\mu\nu}$$

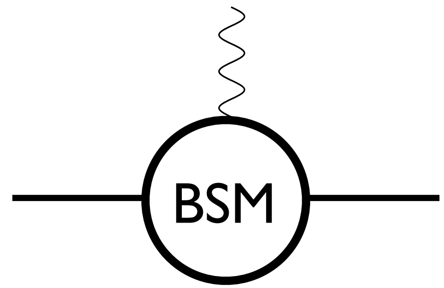
EDM bound: $\mathbf{\Lambda_{\rm IR} > 100}\ \text{TeV}\left(\frac{\mathbf{g_*}}{\mathbf{3}}\right)$

$\mu\to e\gamma$ bound: $\mathbf{\Lambda_{\rm IR} > 60}\ \text{TeV}\left(\frac{\mathbf{g_*}}{\mathbf{3}}\right)$

Towards suppressing EDMs

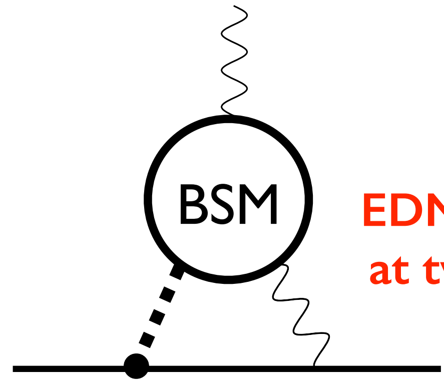
Avoid linear mixing of light fermions to BSM:

$$\mathcal{L}_{\rm lin} = \epsilon_{f_i}\, \bar{f}_i\, \mathcal{O}_{f_i}$$



Bilinear mixing: $\mathcal{L}_{\rm bil} \sim \bar{f}_i \mathcal{O}_H f_j$

↳ portal to the BSM: the Higgs



EDM at most
at two-loop!

Not possible in the MSSM,
but possible in composite Higgs models

Possibility considered here:

G.Panico, AP 1603.06609

(also related work by Matsedonskyi 15, Cacciapaglia etal 15)

$$\mathcal{L}_{\rm lin} = \epsilon_{f_i}\, \bar{f}_i\, \mathcal{O}_{f_i}$$

↳ portal decouples at higher energies:

e.g. if a constituent get a mass ~Λ_f

↓

$$\mathcal{L}_{\rm bil} \sim \bar{f}_i \mathcal{O}_H f_j$$

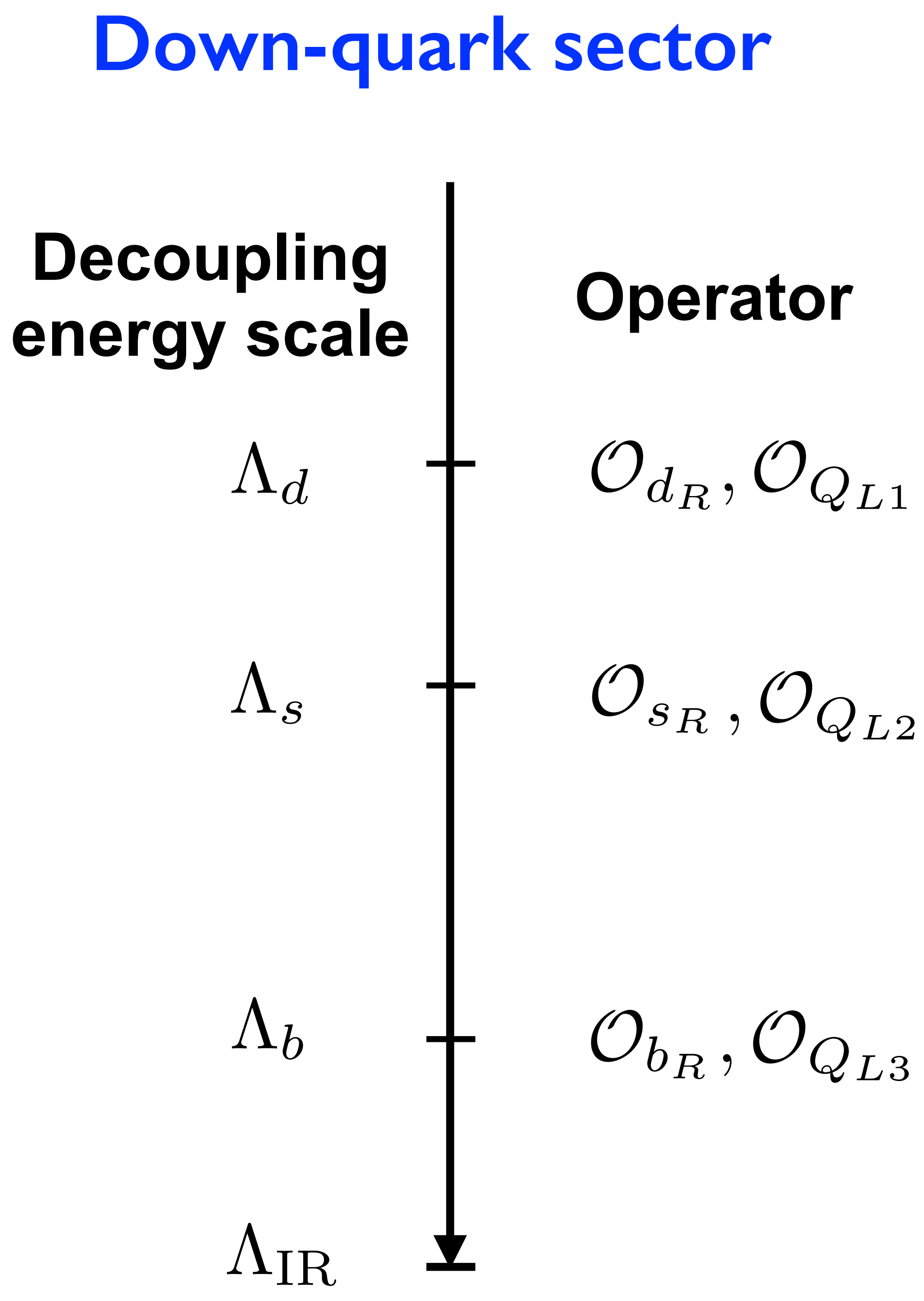
bilinear mixing generated at Λ_f

↳ Operator of the strong sector that at $\Lambda_{\rm IR}$ projects into the Higgs:

$$\langle 0|\mathcal{O}_H|H\rangle \neq 0$$

e.g. $\mathcal{O}_H \sim \bar{\psi}\psi$

The larger the scale of decoupling, the smaller the fermion mass!


Down-quark sector
Decoupling energy scale
Operator
Λ_d
$\mathcal{O}_{d_R}, \mathcal{O}_{Q_{L1}}$
Λ_s
$\mathcal{O}_{s_R}, \mathcal{O}_{Q_{L2}}$
Λ_b
$\mathcal{O}_{b_R}, \mathcal{O}_{Q_{L3}}$
Λ_{IR}

Envisaging from explicit examples:

SU(4) strong sector

Fermions:

a) three $\Psi_{L,R} \in \mathbf{4}$ (fundamental)

b) five $\Upsilon \in \mathbf{6}$ (antisym. matrix)

$$\Psi \Upsilon \Psi = \mathcal{O}_{\rm top}$$

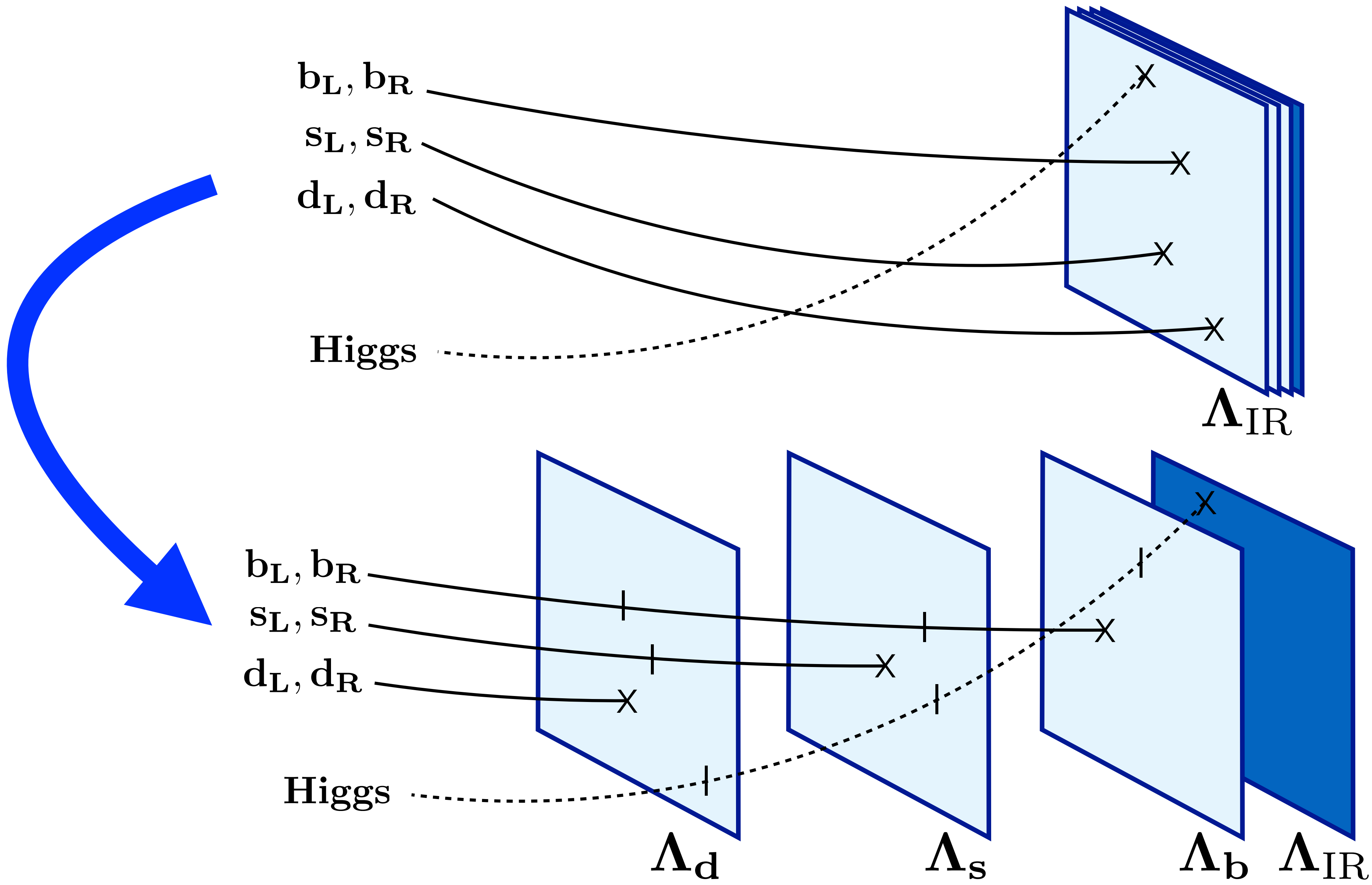
add more elementary fermions Ψ
with explicit masses

M_{Ψ_d} — $\Psi_d \Upsilon \Psi_d$

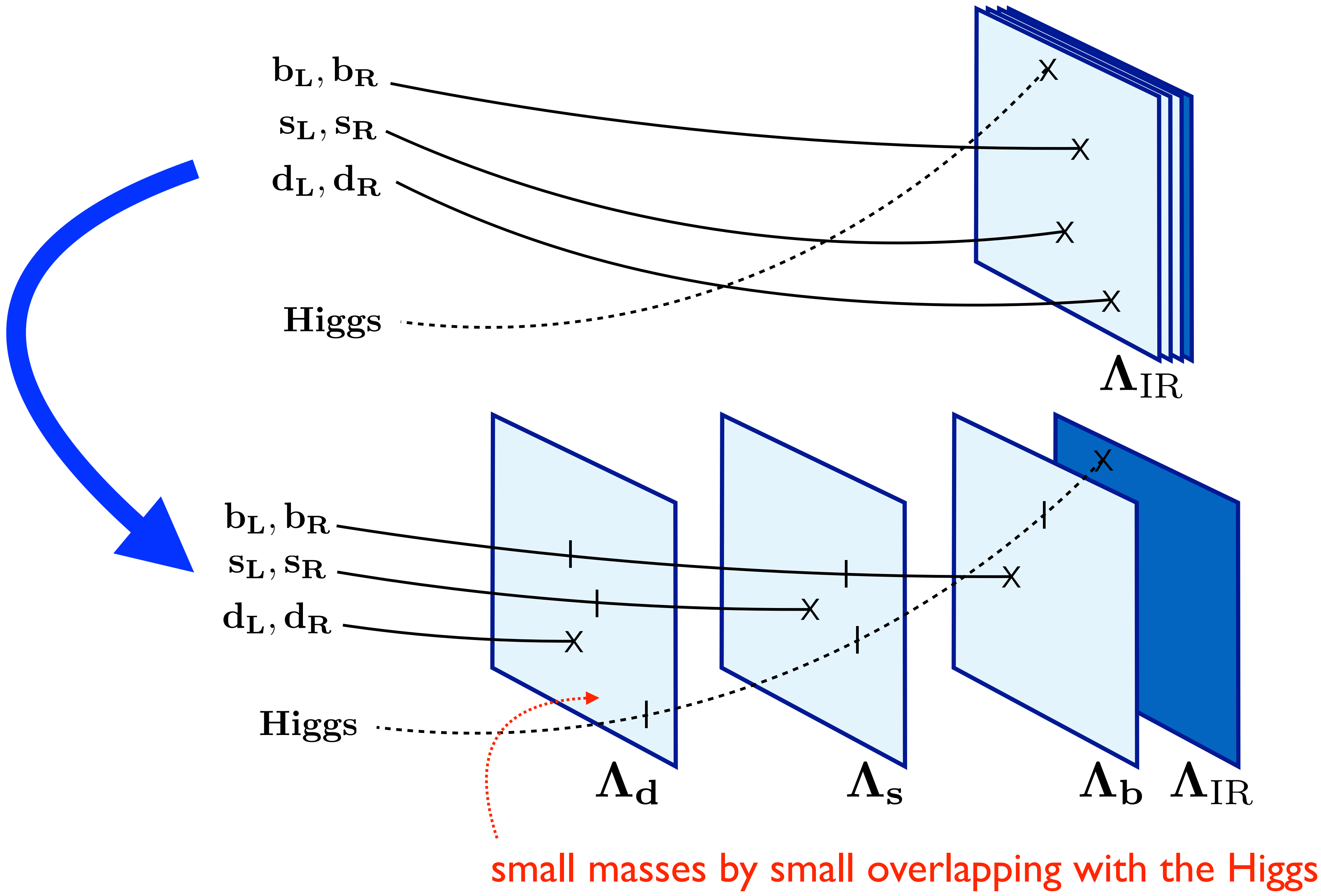
M_{Ψ_s} — $\Psi_s \Upsilon \Psi_s$

M_{Ψ_b} — $\Psi_b \Upsilon \Psi_b$

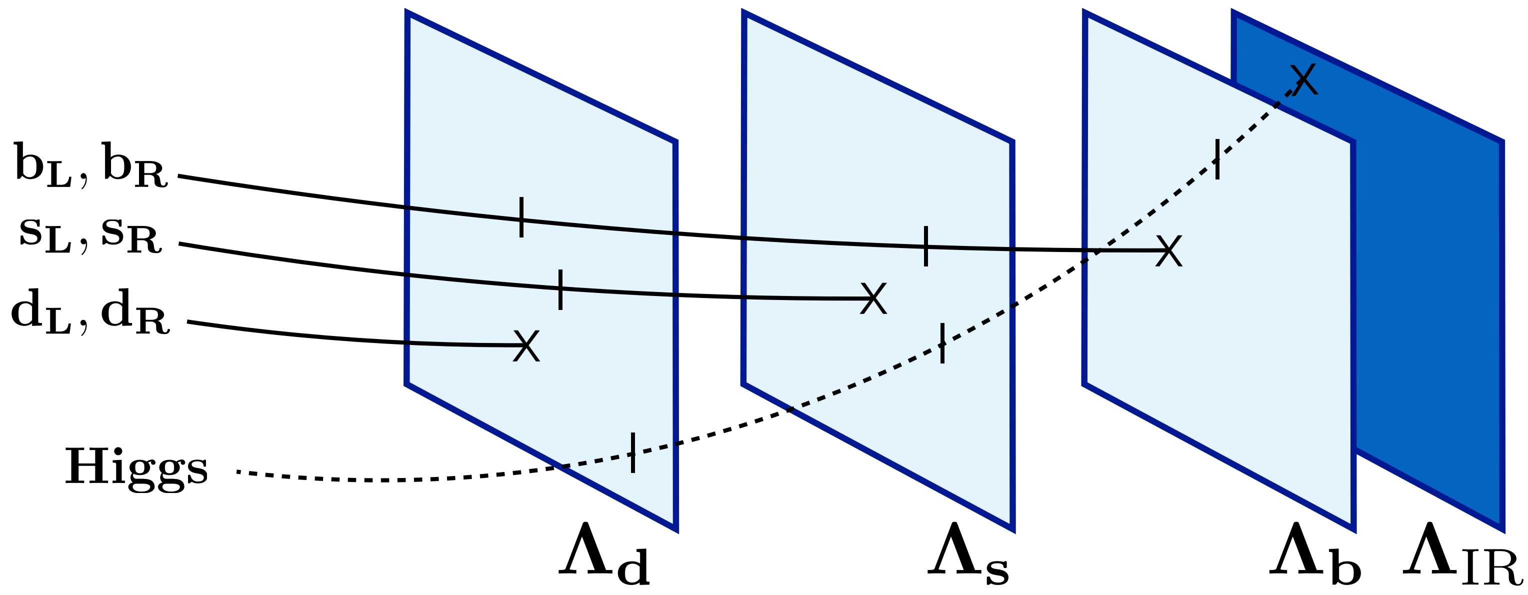
Geometric perspective



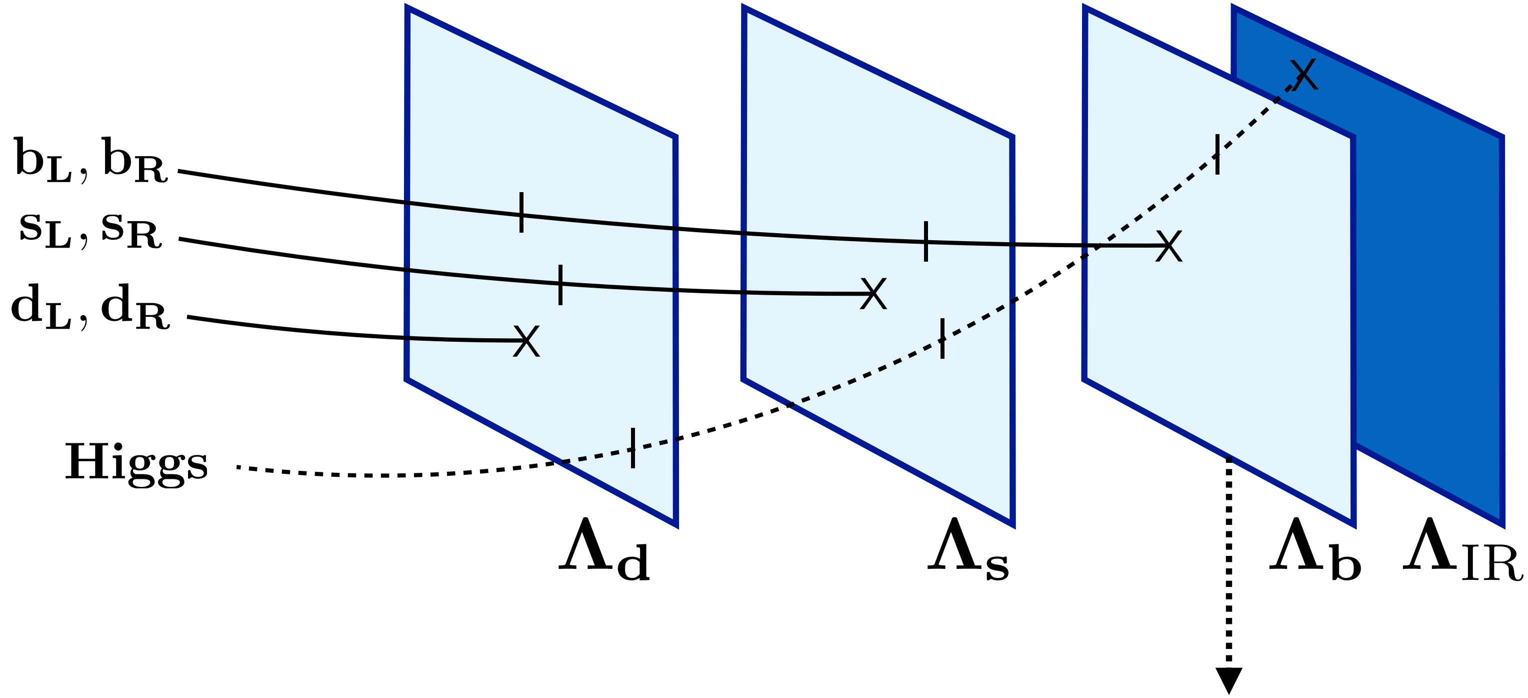
Geometric perspective



Emergent flavor structure

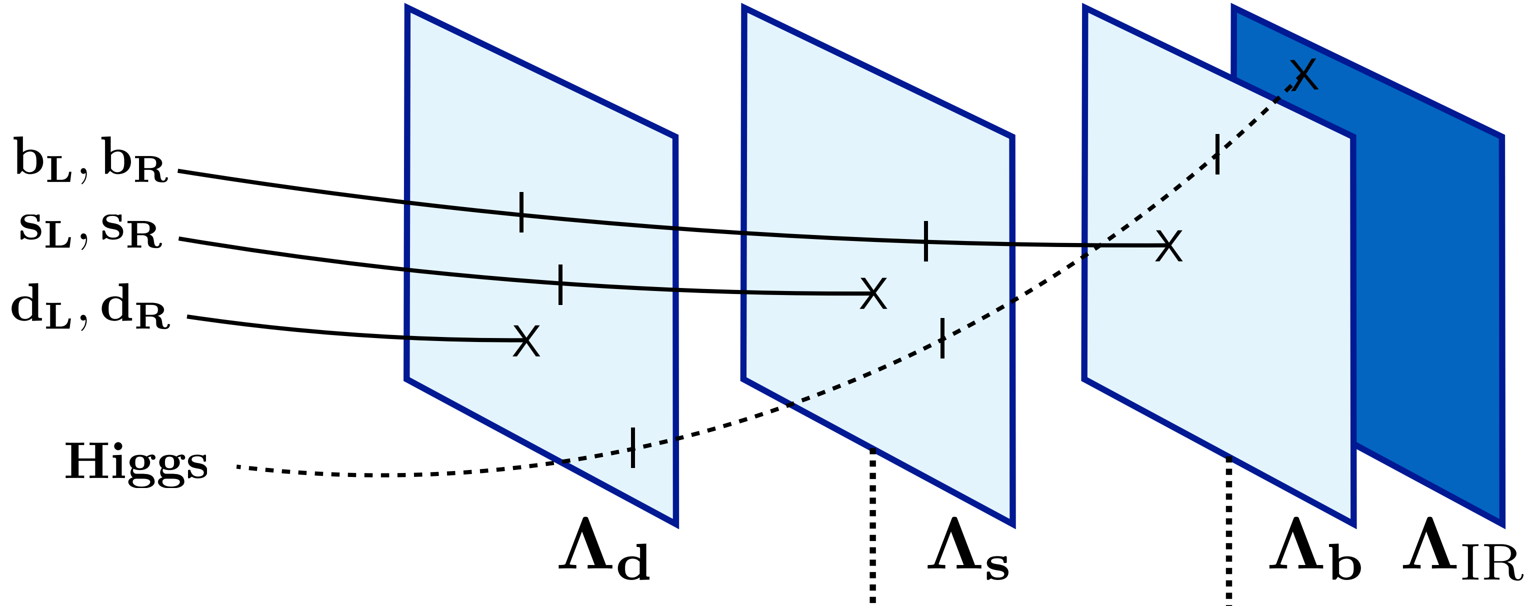


Emergent flavor structure



$$\cdot\, g_* \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \epsilon_{b_L}^{(3)} \epsilon_{b_R}^{(3)} \end{pmatrix} \left(\frac{\Lambda_{\mathrm{IR}}}{\Lambda_b} \right)^{d_H - 1}$$

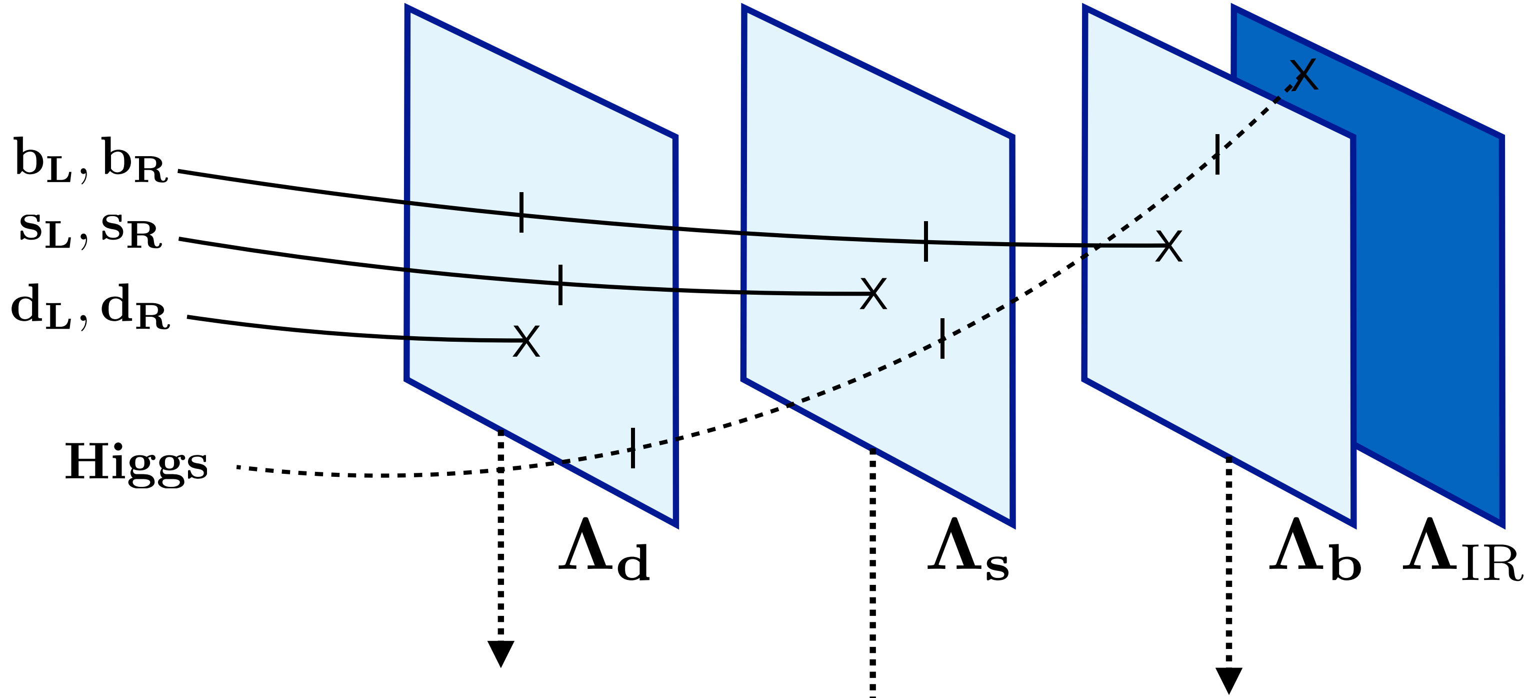
Emergent flavor structure



$$g_* \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \epsilon_{b_L}^{(3)} \epsilon_{b_R}^{(3)} \end{pmatrix} \left(\frac{\Lambda_{\rm IR}}{\Lambda_b}\right)^{d_H-1}$$

$$g_* \begin{pmatrix} 0 & 0 & 0 \\ 0 & \epsilon_{s_L}^{(2)} \epsilon_{s_R}^{(2)} & \epsilon_{s_L}^{(2)} \epsilon_{b_R}^{(2)} \\ 0 & \epsilon_{b_L}^{(2)} \epsilon_{s_R}^{(2)} & \end{pmatrix} \left(\frac{\Lambda_{\rm IR}}{\Lambda_s}\right)^{d_H-1}$$

Emergent flavor structure



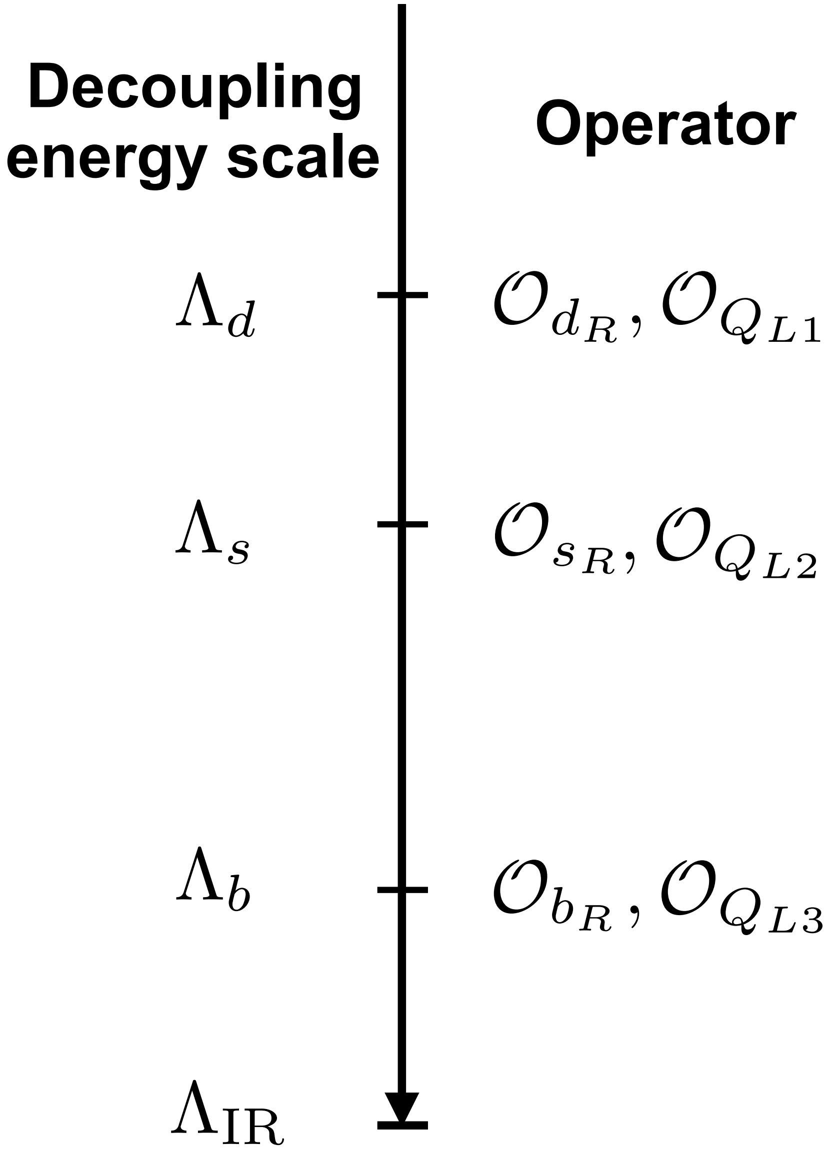
$$g_* \begin{pmatrix} \epsilon^{(1)}_{d_L}\epsilon^{(1)}_{d_R} & \epsilon^{(1)}_{d_L}\epsilon^{(1)}_{s_R} & \epsilon^{(1)}_{d_L}\epsilon^{(1)}_{b_R} \\ \epsilon^{(1)}_{s_L}\epsilon^{(1)}_{d_R} & & \\ \epsilon^{(1)}_{b_L}\epsilon^{(1)}_{d_R} & & \end{pmatrix} \left(\frac{\Lambda_{\rm IR}}{\Lambda_d}\right)^{d_H-1}$$

$$g_* \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \epsilon^{(3)}_{b_L}\epsilon^{(3)}_{b_R} \end{pmatrix} \left(\frac{\Lambda_{\rm IR}}{\Lambda_b}\right)^{d_H-1}$$

$$g_* \begin{pmatrix} 0 & 0 & 0 \\ 0 & \epsilon^{(2)}_{s_L}\epsilon^{(2)}_{s_R} & \epsilon^{(2)}_{s_L}\epsilon^{(2)}_{b_R} \\ 0 & \epsilon^{(2)}_{b_L}\epsilon^{(2)}_{s_R} & \end{pmatrix} \left(\frac{\Lambda_{\rm IR}}{\Lambda_s}\right)^{d_H-1}$$

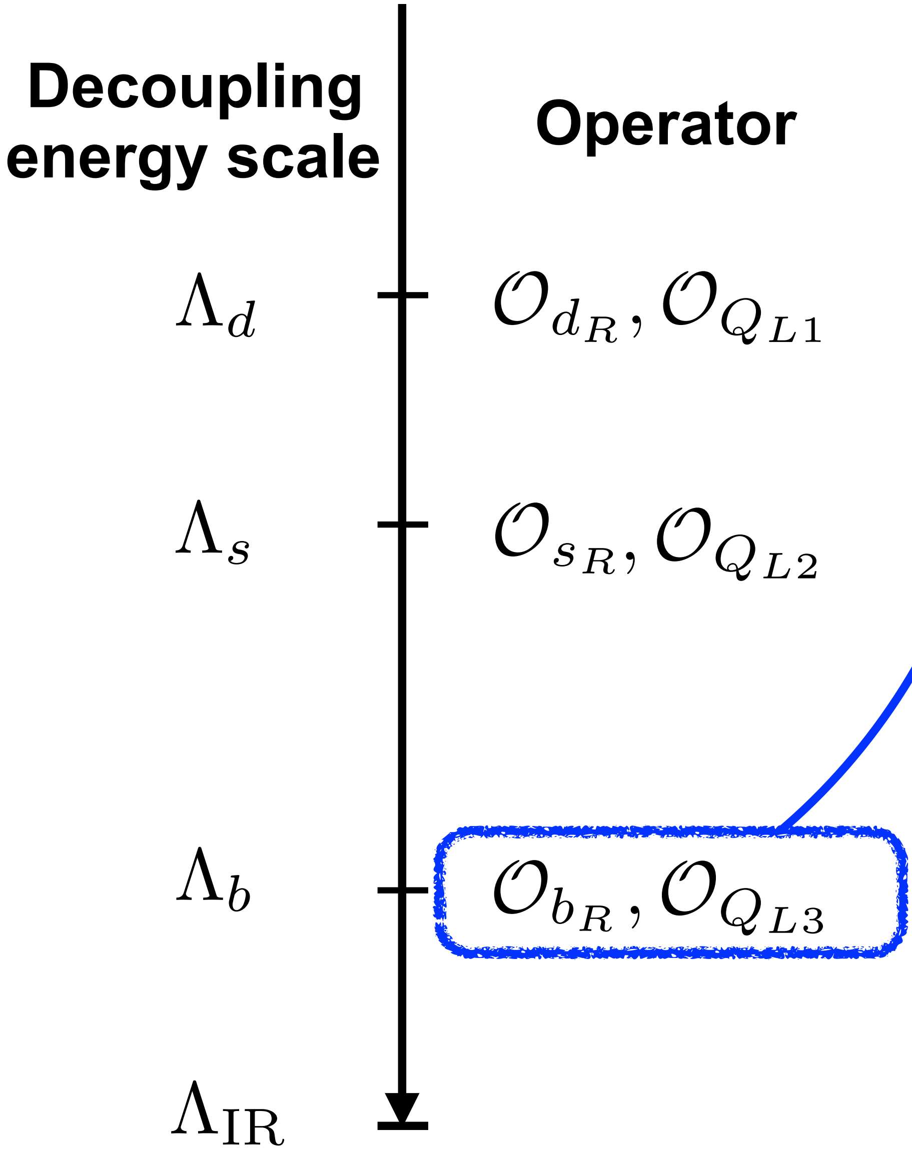
Emergent flavor structure

Down-quark sector



Emergent flavor structure

Down-quark sector



$$\mathcal{L}^{(3)}_{\rm lin} = \epsilon^{(3)}_{b_L} \bar{Q}_{L3}\, \mathcal{O}_{Q_{L3}} + \epsilon^{(3)}_{b_R} \bar{b}_R\, \mathcal{O}_{b_R}$$

below Λ_b:

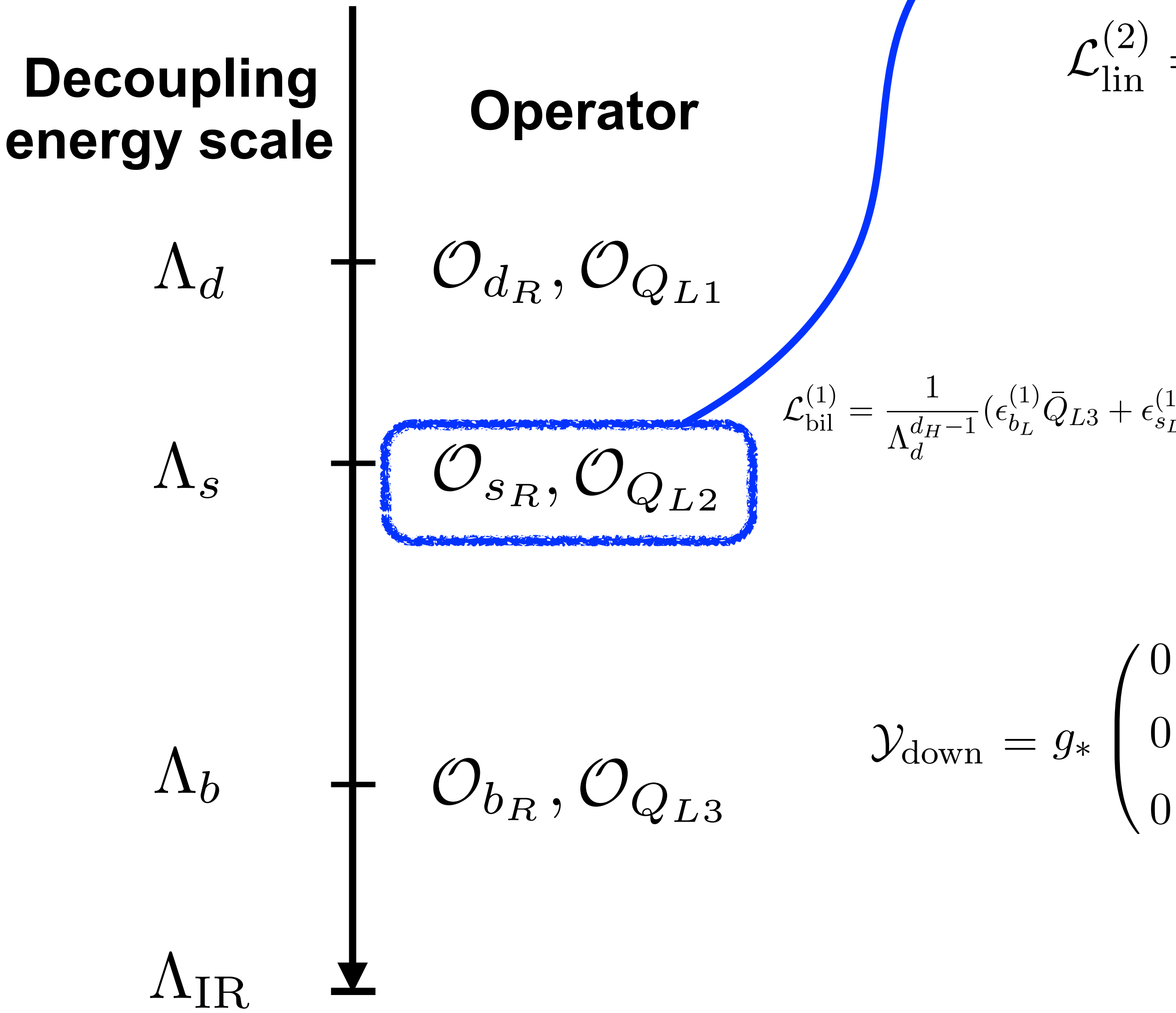
$$\mathcal{L}^{(3)}_{\rm bil} = \frac{1}{\Lambda_b^{d_H-1}} (\epsilon^{(3)}_{b_L} \bar{Q}_{L3}) \mathcal{O}_H (\epsilon^{(3)}_{b_R} b_R)$$

below $\Lambda_{\rm IR}$:

$$\mathcal{Y}_{\rm down} = g_* \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \epsilon^{(3)}_{b_L}\epsilon^{(3)}_{b_R} \end{pmatrix} \left(\frac{\Lambda_{\rm IR}}{\Lambda_b}\right)^{d_H-1}$$

Emergent flavor structure

Down-quark sector



$$\mathcal{L}_{\rm lin}^{(2)} = (\epsilon_{b_L}^{(2)} \bar{Q}_{L3} + \epsilon_{s_L}^{(2)} \bar{Q}_{L2})\, \mathcal{O}_{Q_{L2}} + (\epsilon_{b_R}^{(2)} b_R + \epsilon_{s_R}^{(2)} s_R)\, \mathcal{O}_{s_R}$$

below Λ_s:

$$\mathcal{L}_{\rm bil}^{(1)} = \frac{1}{\Lambda_d^{d_H-1}} (\epsilon_{b_L}^{(1)} \bar{Q}_{L3} + \epsilon_{s_L}^{(1)} \bar{Q}_{L2} + \epsilon_{d_L}^{(1)} \bar{Q}_{L1}) \mathcal{O}_H (\epsilon_{b_R}^{(1)} b_R + \epsilon_{s_R}^{(1)} s_R + \epsilon_{d_R}^{(1)} d_R)$$

below $\Lambda_{\rm IR}$:

$$\mathcal{Y}_{\rm down} = g_* \begin{pmatrix} 0 & 0 & 0 \\ 0 & \epsilon_{s_L}^{(2)} \epsilon_{s_R}^{(2)} & \epsilon_{s_L}^{(2)} \epsilon_{b_R}^{(2)} \\ 0 & \epsilon_{b_L}^{(2)} \epsilon_{s_R}^{(2)} & \end{pmatrix} \left(\frac{\Lambda_{\rm IR}}{\Lambda_s} \right)^{d_H - 1}$$

Emergent flavor structure

Down-quark sector

Decoupling energy scale	Operator
Λ_d	$\mathcal{O}_{d_R}, \mathcal{O}_{Q_{L1}}$
Λ_s	$\mathcal{O}_{s_R}, \mathcal{O}_{Q_{L2}}$
Λ_b	$\mathcal{O}_{b_R}, \mathcal{O}_{Q_{L3}}$
$\Lambda_{\rm IR}$	

below $\Lambda_{\rm IR}$:

$$\mathcal{Y}_{\rm down} = g_* \begin{pmatrix} \epsilon^{(1)}_{d_L}\epsilon^{(1)}_{d_R} & \epsilon^{(1)}_{d_L}\epsilon^{(1)}_{s_R} & \epsilon^{(1)}_{d_L}\epsilon^{(1)}_{b_R} \\ \epsilon^{(1)}_{s_L}\epsilon^{(1)}_{d_R} & & \\ \epsilon^{(1)}_{b_L}\epsilon^{(1)}_{d_R} & & \end{pmatrix} \left(\frac{\Lambda_{\rm IR}}{\Lambda_d}\right)^{d_H - 1}$$

Emergent flavor structure

"Onion" structure:

$$\mathcal{Y}_{\rm down} \simeq \begin{pmatrix} Y_d & \alpha_R^{ds} Y_d & \alpha_R^{db} Y_d \\ \alpha_L^{ds} Y_d & Y_s & \alpha_R^{sb} Y_s \\ \alpha_L^{db} Y_d & \alpha_L^{sb} Y_s & Y_b \end{pmatrix}$$

$$Y_f \equiv g_* \epsilon_{f_{Li}}^{(i)} \epsilon_{f_{Ri}}^{(i)} \left(\frac{\Lambda_{\rm IR}}{\Lambda_f} \right)^{d_H - 1} \simeq m_f / v$$

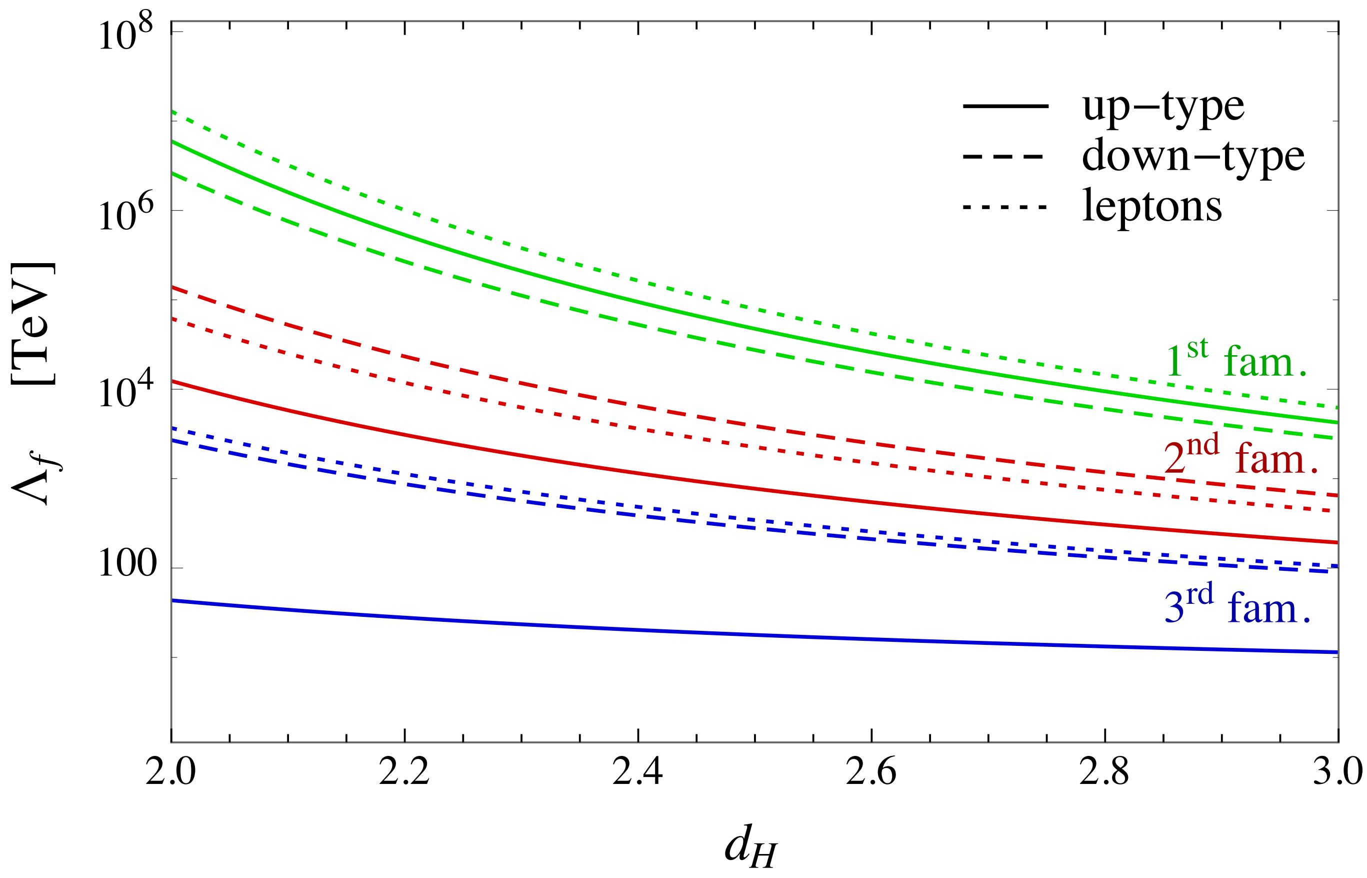
- Smaller Yukawas for large decoupling scale!
- Mixing angles suppressed by Yukawas: $\theta_{ij} \sim Y_i / Y_j$

CKM mostly the rotation in the down-quark sector!

Similarly for the up-quark sector (and lepton sector)

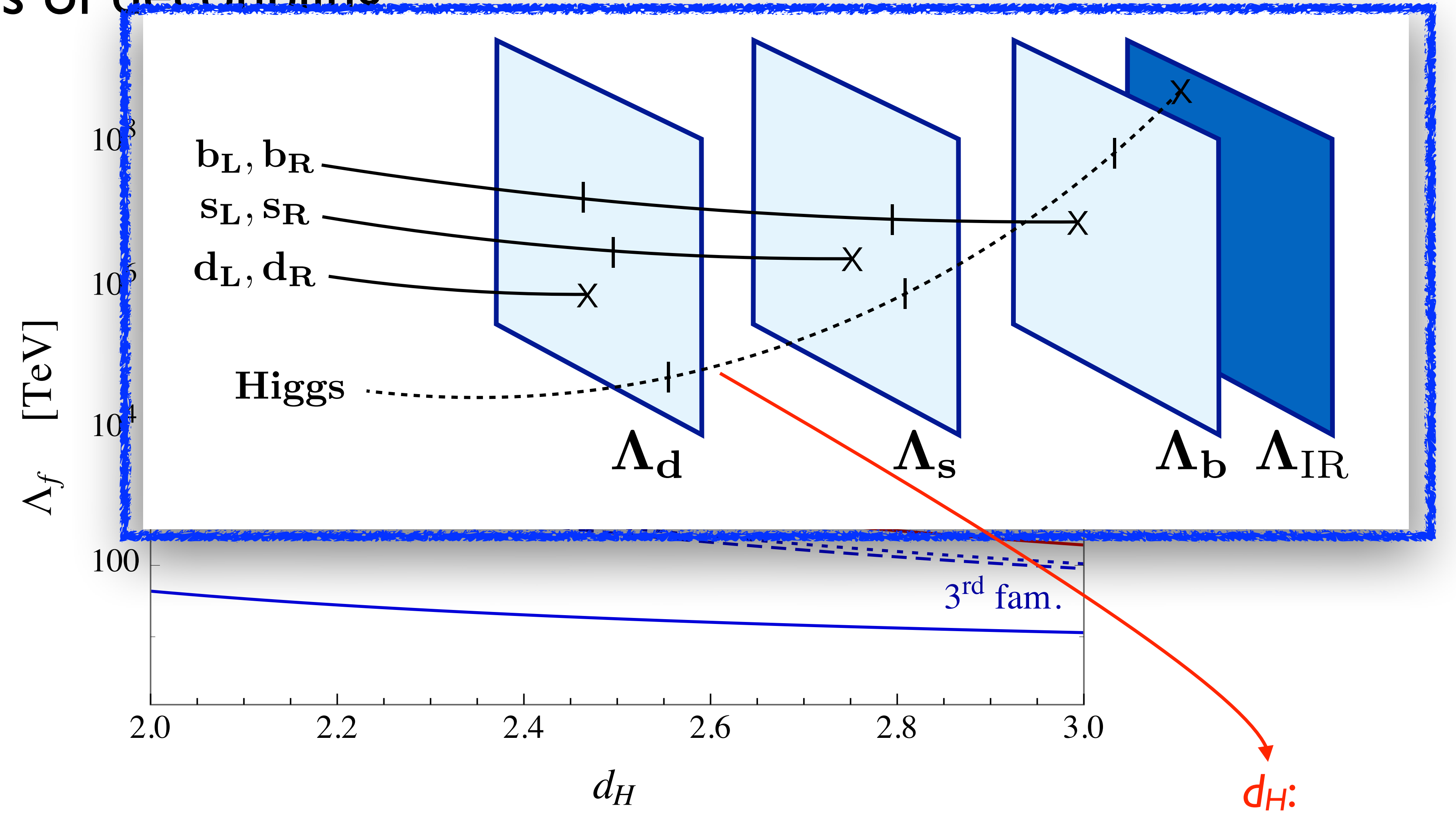
Decoupling scale	Operator
Λ_u	$\mathcal{O}_{u_R}$
Λ_d	$\mathcal{O}_{d_R}, \mathcal{O}_{Q_{L1}}$
Λ_s	$\mathcal{O}_{s_R}$
Λ_c	$\mathcal{O}_{c_R}, \mathcal{O}_{Q_{L2}}$
Λ_b	$\mathcal{O}_{b_R}$
$\Lambda_t \sim \Lambda_{\rm IR}$	$\mathcal{O}_{t_R}, \mathcal{O}_{Q_{L3}}$

Scales of decoupling:



dimension of the Higgs operator

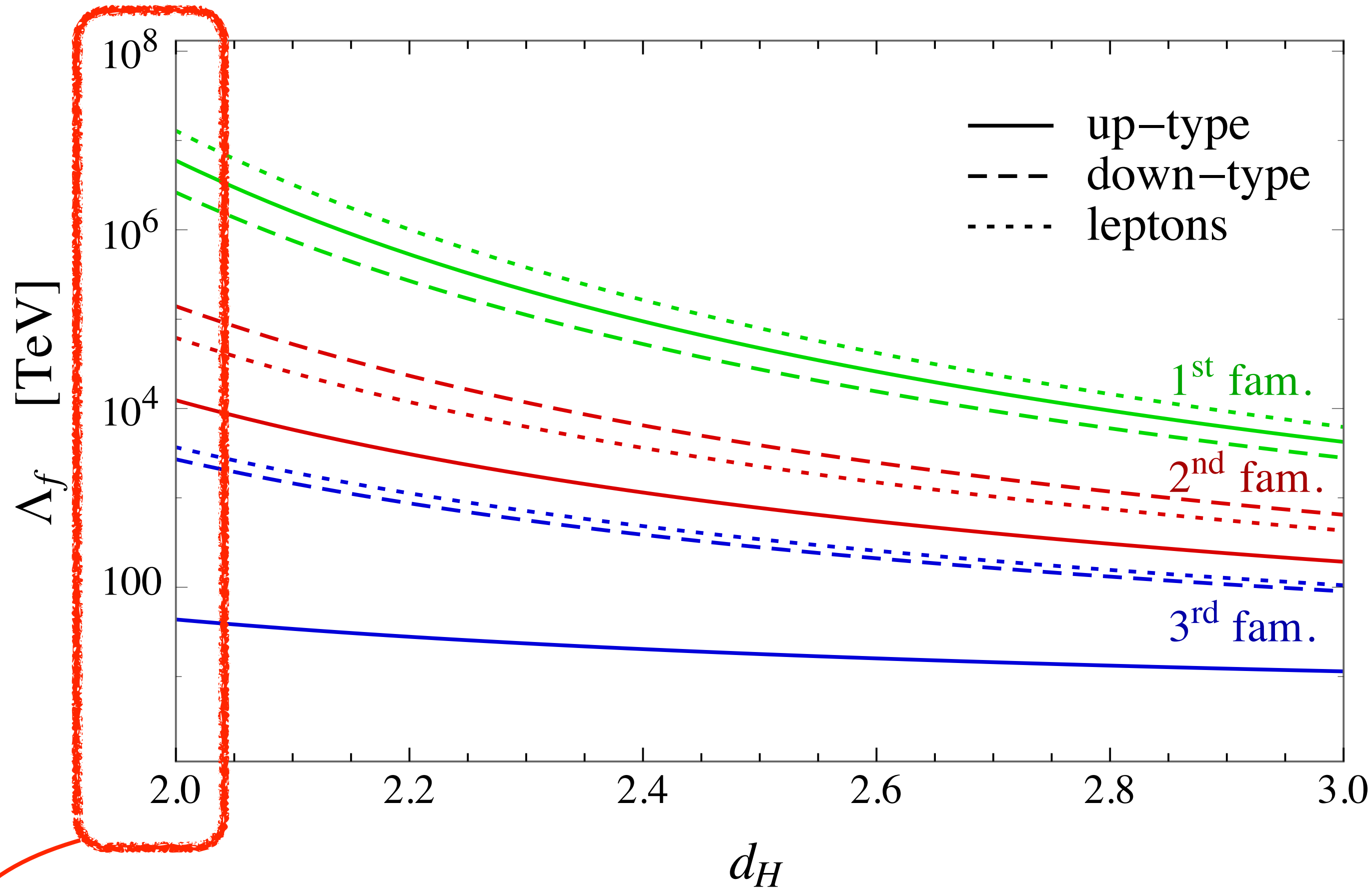
Scales of decoupling:



dimension of the Higgs operator

d_H: determines the profile of the 5D Higgs field

Scales of decoupling:



d_H~2 needed to pass FCNC

("walking TC": d_H~2 instead of ~3)

dimension of the Higgs operator

Flavor and CP-violating effects

$\Delta F = 2$	t partly-comp.	s partly-comp.	bilin. mixing (2nd fam.)	bilin. mixing (1st fam.)	Anarchic
Q_1^{sd}	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 5x_t}$	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 4x_t}$	$\Lambda_{\rm IR} \gtrsim 1.8 x_c \sqrt{\alpha_L^{ct}}$	$\Lambda_{\rm IR} \gtrsim 0.2 x_d$	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 4x_t}$
Q_2^{sd}	–	$\Lambda_{\rm IR} \gtrsim 1\sqrt{g_*}$	·	·	$\Lambda_{\rm IR} \gtrsim 1\sqrt{g_*}$
$\tilde{Q}_2^{sd}$	–	$\Lambda_{\rm IR} \gtrsim 0.5\sqrt{g_* \alpha_L^{ds}}$	·	·	$\Lambda_{\rm IR} \gtrsim 1\sqrt{g_*}$
Q_4^{sd}	–	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 5\sqrt{\alpha_L^{ds}}}$	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 5\sqrt{\alpha_L^{ds}}}$	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 5\sqrt{\alpha_L^{ds}}}$	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 10}$
Q_1^{bd}	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 5x_t}$	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 6x_t}$	·	·	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 6x_t}$
$\tilde{Q}_2^{bd}$	–	$\Lambda_{\rm IR} \gtrsim 0.3\sqrt{g_* \alpha_L^{ds}}$	·	·	$\Lambda_{\rm IR} \gtrsim 0.6\sqrt{g_*}$
Q_4^{bd}	–	$\Lambda_{\rm IR} \gtrsim 0.4\sqrt{\alpha_L^{sd}}$	$\Lambda_{\rm IR} \gtrsim 0.3\sqrt{\alpha_L^{db}}$	·	$\Lambda_{\rm IR} \gtrsim 0.8$
Q_1^{bs}	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 5x_t}$	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 7x_t}$	$\Lambda_{\rm IR} \gtrsim 0.6 \alpha_R^{cb} x_c$	·	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 7x_t}$
$\tilde{Q}_2^{bs}$	–	$\Lambda_{\rm IR} \gtrsim 0.4\sqrt{g_*}$	·	·	$\Lambda_{\rm IR} \gtrsim 0.4\sqrt{g_*}$
Q_4^{bs}	–	$\Lambda_{\rm IR} \gtrsim 1$	$\Lambda_{\rm IR} \gtrsim 0.1\sqrt{\alpha_L^{sb}}$	·	$\Lambda_{\rm IR} \gtrsim 1$
Q_1^{cu}	·	·	·	·	$\Lambda_{\rm IR} \gtrsim 1x_t$
Q_2^{cu}	·	·	·	·	$\Lambda_{\rm IR} \gtrsim 0.7\sqrt{g_*}$
Q_4^{cu}	·	·	·	·	$\Lambda_{\rm IR} \gtrsim 1.1$

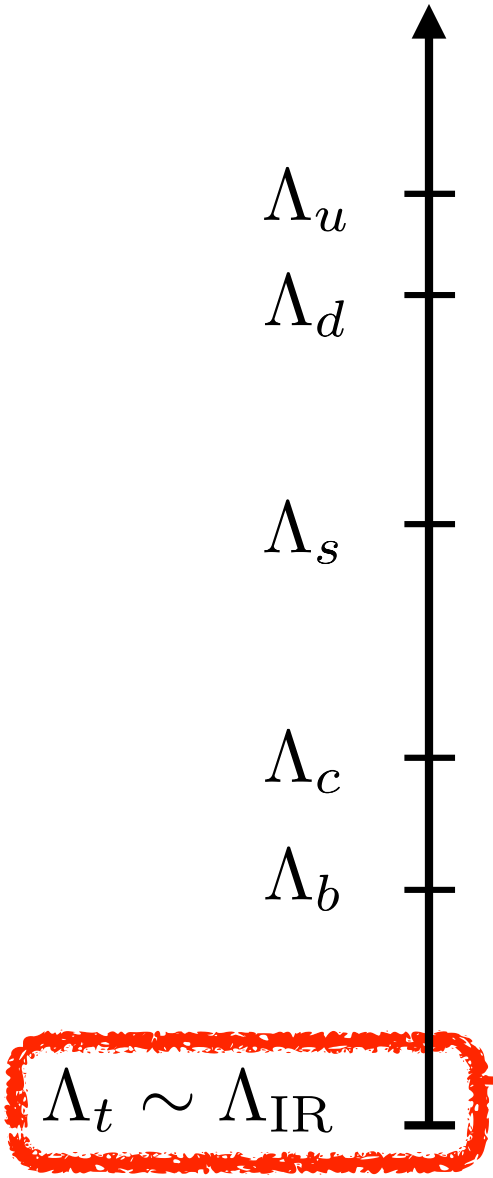
Table 2: *Bounds on $\Lambda_{\rm IR}$ for the different scenarios considered in the text. The effects are separated according to their origin: from the top (or strange) partial compositeness at $\Lambda_{\rm IR}$, or from the UV scale Λ_f at which the second and first families get bilinear mixings to the Higgs. The results are given in TeV. Entries with a "·" correspond to negligible bounds, while "–" means that the corresponding operator is not generated. The most relevant constraints are highlighted in boldface.*

$$x_t = \epsilon_{t_L}^{(3)}/\epsilon_{t_R}^{(3)}$$

$\Delta F = 1$	t partly comp.	b partly comp.	s partly comp.	Anarchic
$\bar{s}_L \sigma^{\mu\nu} e F_{\mu\nu} b_R$	–	$\Lambda_{\rm IR} \gtrsim 0.12 g_*$	$\Lambda_{\rm IR} \gtrsim 0.12 g_*$	$\Lambda_{\rm IR} \gtrsim 0.12 g_*$
$\bar{s}_R \sigma^{\mu\nu} e F_{\mu\nu} b_L$	–	·	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 0.8 g_*}$	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 0.8 g_*}$
$\bar{s}_L \sigma^{\mu\nu} g_s G_{\mu\nu} d_R$	–	·	$\Lambda_{\rm IR} \gtrsim 0.5 g_*$	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 1.1 g_*}$
$\bar{s}_R \sigma^{\mu\nu} g_s G_{\mu\nu} d_L$	–	·	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 1.1 g_*}$	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 1.1 g_*}$
$\bar{s}_L \gamma^\mu b_L H^\dagger i \overleftrightarrow{D}_\mu H$	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 3\sqrt{g_* x_t}}$ (*)	$\Lambda_{\rm IR} \gtrsim 0.4\sqrt{g_* x_b}$	$\Lambda_{\rm IR} \gtrsim 0.4\sqrt{g_* x_b}$	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 3\sqrt{g_* x_t}}$
$\bar{s}_L \gamma^\mu d_L H^\dagger i \overleftrightarrow{D}_\mu H$	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 4\sqrt{g_* x_t}}$ (*)	$\Lambda_{\rm IR} \gtrsim 0.50\sqrt{g_* x_b}$	$\Lambda_{\rm IR} \gtrsim 0.5\sqrt{g_* x_b}$	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 4\sqrt{g_* x_t}}$
$\Delta F = 0$	t partly-comp.	b partly-comp.	s partly-comp.	Anarchic
$\bar{b}_L \gamma^\mu b_L H^\dagger i \overleftrightarrow{D}_\mu H$	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 5\sqrt{g_* x_t}}$ (*)	$\Lambda_{\rm IR} \gtrsim 0.6\sqrt{g_* x_b}$	$\Lambda_{\rm IR} \gtrsim 0.6\sqrt{g_* x_b}$	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 5\sqrt{g_* x_t}}$
Neutron EDM	t partly-comp.	b partly-comp.	s partly-comp.	Anarchic
$\bar{d}_L \sigma^{\mu\nu} e F_{\mu\nu} d_R$	–	$\Lambda_{\rm IR} \gtrsim 0.24 g_* \sqrt{\alpha_L^{db}}$	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 1.2 g_* \sqrt{\alpha_L^{ds}}}$	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 2.5 g_*}$
$\bar{u}_L \sigma^{\mu\nu} e F_{\mu\nu} u_R$	·	·	·	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 0.9 g_*}$
$\bar{d}_L \sigma^{\mu\nu} g_s G_{\mu\nu} d_R$	–	$\Lambda_{\rm IR} \gtrsim 0.3 g_* \sqrt{\alpha_L^{db}}$	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 1.5 g_* \sqrt{\alpha_L^{ds}}}$	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 3.2 g_*}$
$\bar{u}_L \sigma^{\mu\nu} g_s G_{\mu\nu} u_R$	·	·	·	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 1.2 g_*}$
$\bar{c}_L \sigma^{\mu\nu} g_s G_{\mu\nu} c_R$	·	·	·	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 1 g_*}$
$\bar{b}_L \sigma^{\mu\nu} g_s G_{\mu\nu} b_R$	–	$\Lambda_{\rm IR} \gtrsim 0.6 g_*$	·	$\Lambda_{\rm IR} \gtrsim 0.6 g_*$
$\bar{t}_L \sigma^{\mu\nu} g_s G_{\mu\nu} t_R$	$\Lambda_{\rm IR} \gtrsim 0.24 g_*$	·	·	$\Lambda_{\rm IR} \gtrsim 0.24 g_*$
Leptons	t party comp.	τ partly-comp.	μ partly-comp.	Anarchic
$\bar{e}_L \sigma^{\mu\nu} e F_{\mu\nu} e_R$	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 1.6\sqrt{g_* x_t}}$	$\Lambda_{\rm IR} \gtrsim 0.5 g_* \sqrt{\alpha_L^{e\tau} \alpha_R^{e\tau}}$	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 2 g_* \sqrt{\alpha_L^{e\mu} \alpha_R^{e\mu}}}$	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 32 g_*}$
$\bar{\mu} \sigma^{\mu\nu} e F_{\mu\nu} e_{L,R}$	·	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 1.2 g_* \sqrt{\alpha_{L,R}^{e\tau} \alpha_{R,L}^{\mu\tau}}}$	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 5 g_* \sqrt{\alpha_{L,R}^{e\mu}}}$	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 19 g_*}$
$\bar{\tau} \sigma^{\mu\nu} e F_{\mu\nu} \mu_{L,R}$	·	$\Lambda_{\rm IR} \gtrsim 0.7 g_* \sqrt{\alpha_{L,R}^{\mu\tau}}$	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 1.3 g_*}$	$\boldsymbol{\Lambda_{\rm IR} \gtrsim 1.3 g_*}$
$\bar{\tau} \sigma^{\mu\nu} e F_{\mu\nu} e_{L,R}$	·	·	$\Lambda_{\rm IR} \gtrsim 0.1 g_* \sqrt{\alpha_{L,R}^{e\mu}}$	$\Lambda_{\rm IR} \gtrsim 0.4 g_*$

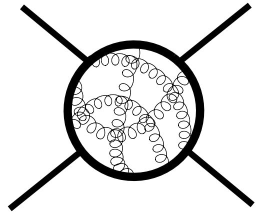
Table 3: *Bounds on $\Lambda_{\rm IR}$ from assuming that the top, bottom, etc. are partly composite at $\Lambda_{\rm IR}$. The results are given in TeV. Entries with a "·" correspond to negligible bounds, while "–" means that the corresponding operator is not generated. The most relevant constraints are highlighted in boldface. If a custodial P_{LR} symmetry [31] is present in the top mixings, the bounds denoted by (*) are absent.*

Different effects at different scales:



Effects from the top

$\Delta F = 2$ **transitions**



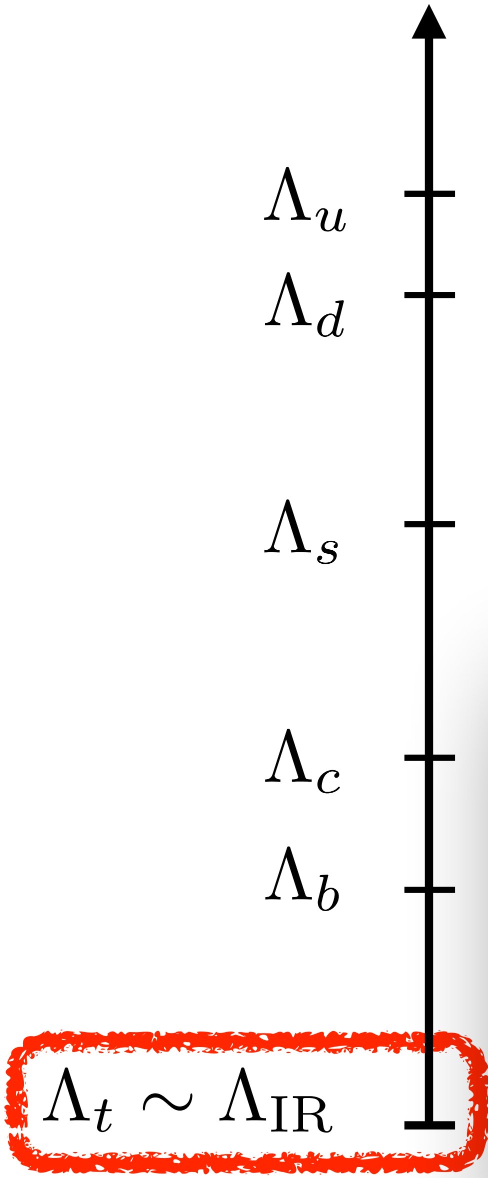
$$\sim \frac{Y_t^2}{\Lambda_{\mathrm{IR}}^2} \left(\overline{Q}_{L3}\gamma^\mu Q_{L3}\right)^2$$

physical basis rotation ~V_{CKM}

ϵ_K, ΔM_{Bd}, ΔM_{Bs}

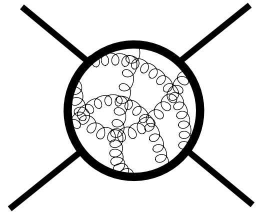
correlated and all close to the experimental value for Λ_{IR}~2-3 TeV

Different effects at different scales:



Effects from the top

$\Delta F = 2$ transitions

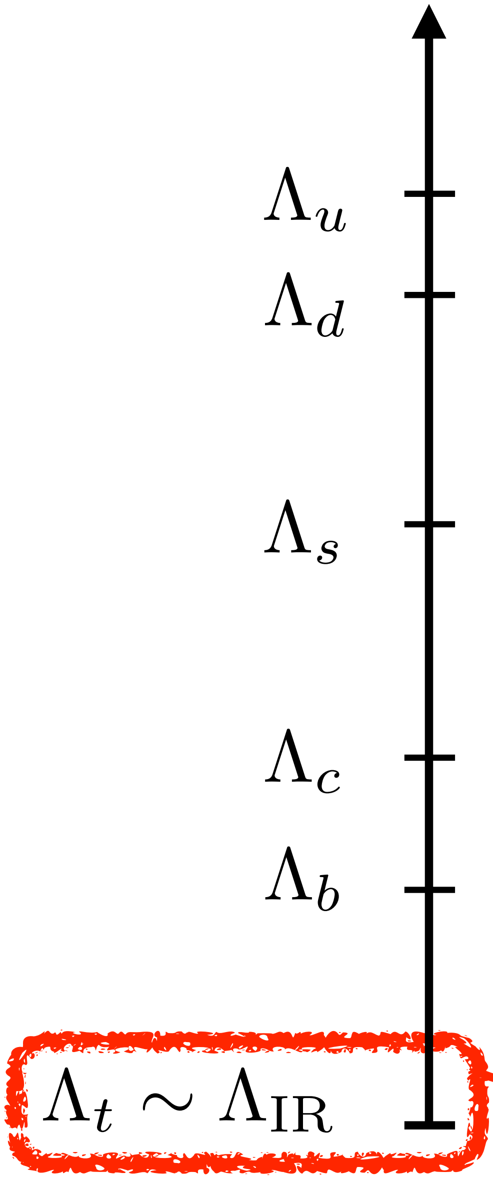


$$\sim \frac{Y_t^2}{\Lambda_{\rm IR}^2} \; (\overline{Q}_{L3}\gamma^\mu Q_{L3})^2$$

Predictions:

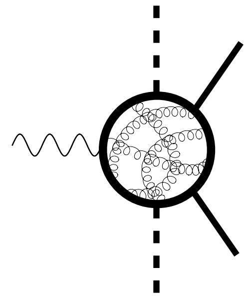
- Only CKM phase
- $\dfrac{\Delta M_{B_d}}{\Delta M_{B_s}} \simeq \left.\dfrac{\Delta M_{B_d}}{\Delta M_{B_s}}\right|_{\rm SM}$

Different effects at different scales:



Effects from the top

$\Delta F = 1$ transitions



$$\sim \frac{g_* Y_t}{\Lambda_{\rm IR}^2}\, \bar{Q}_{L3}\gamma^\mu Q_{L3} i H^\dagger \overleftrightarrow{D}_\mu H$$

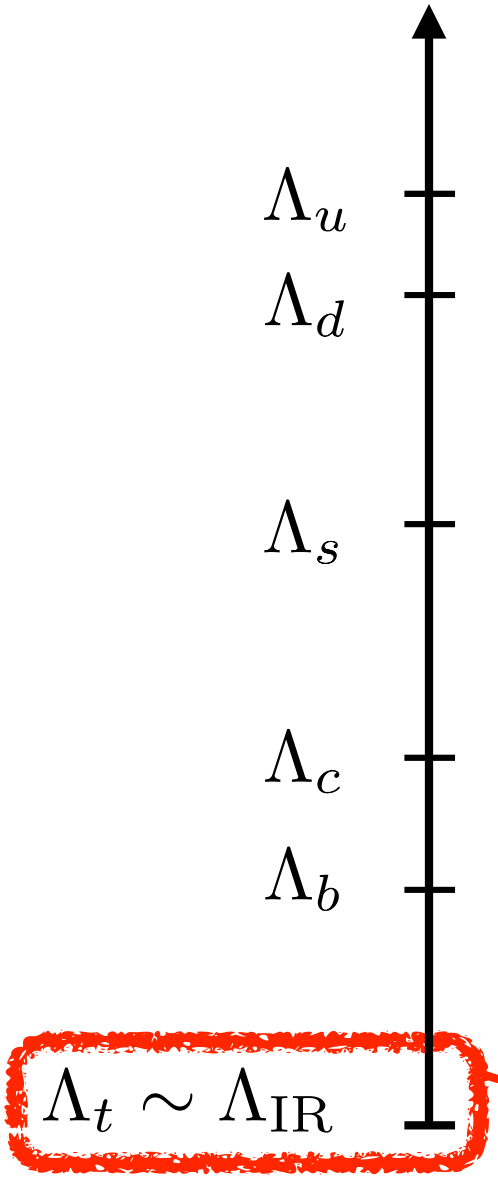
physical basis
rotation ~ $V_{\rm CKM}$

$$\left(V^\dagger_{\rm CKM})_{33}\bar{b}_L + (V^\dagger_{\rm CKM})_{23}\bar{s}_L + (V^\dagger_{\rm CKM})_{13}\bar{d}_L\right)\gamma^\mu\left((V_{\rm CKM})_{33}b_L + (V_{\rm CKM})_{32}s_L + (V_{\rm CKM})_{31}d_L\right)Z_\mu$$

correlated prediction for K→μμ, ϵ'/ϵ, B→Xll, Z→bb

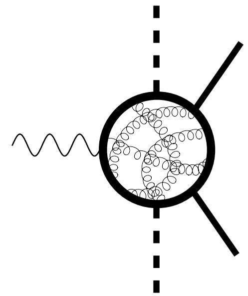
all close to the experimental value for $\Lambda_{\rm IR}$~4-5 TeV

Different effects at different scales:



Effects from the top

$\Delta F = 1$ transitions



$$\sim \frac{g_* Y_t}{\Lambda_{\rm IR}^2}\, \bar{Q}_{L3}\gamma^\mu Q_{L3} i H^\dagger \overleftrightarrow{D}_\mu H$$

$\left(V^\dagger_{\rm CKM})_{33}\bar{b}_L + (V^\dagger_{\rm CK\cdots}\right.$ … $\left.(V_{\rm CKM})_{33}b_L + (V_{\rm CKM})_{32}s_L + (V_{\rm CKM})_{31}d_L\right) Z_\mu$

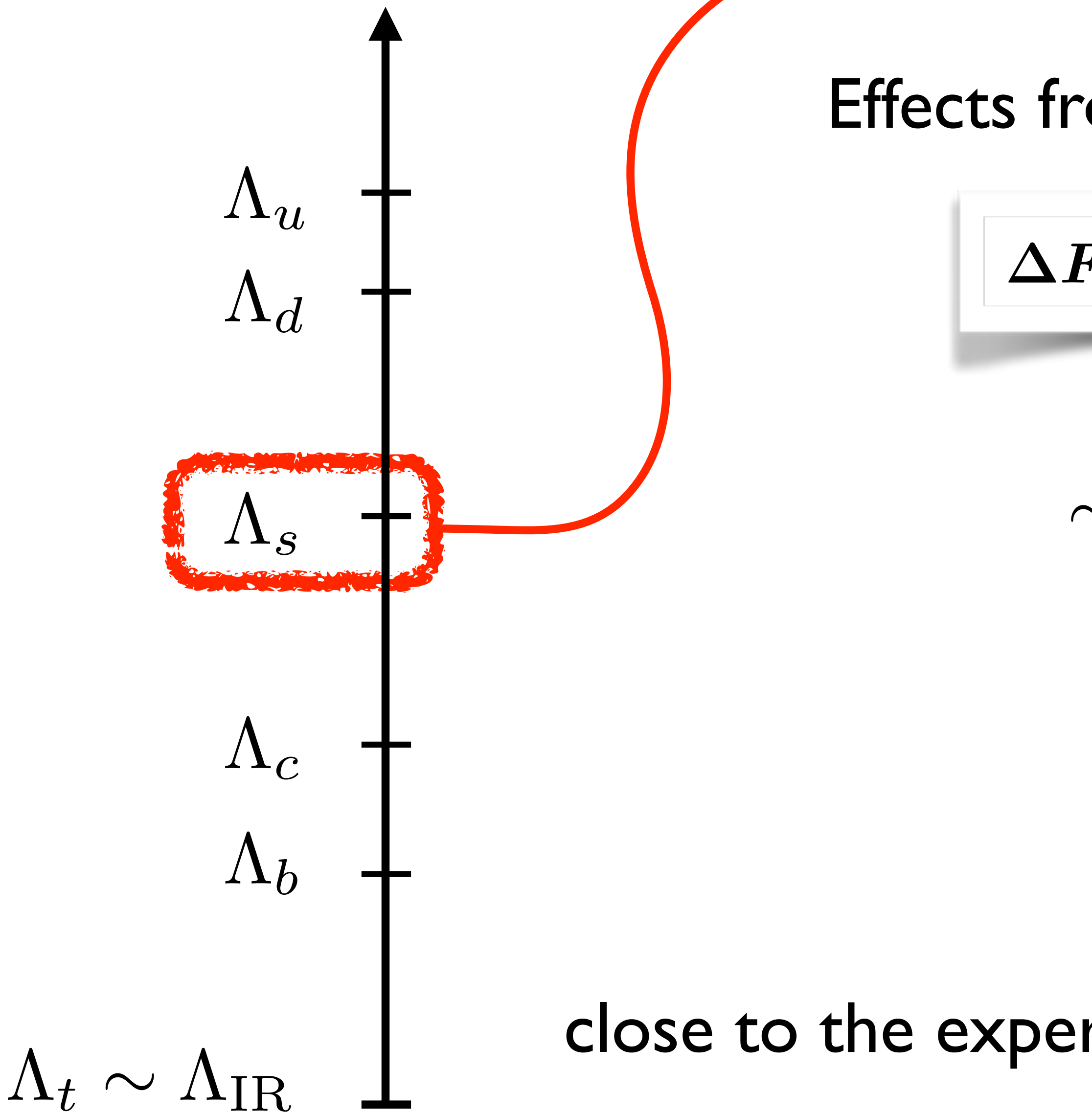
$V_{\rm CKM}$

Suppressed if left↔right symmetry

cor… prediction for K→μμ, ϵ'/ϵ, B→Xll, Z→bb

all close to the experimental value for $\Lambda_{\rm IR}$~4-5 TeV

Different effects at different scales:



Effects from the strange scale

$\Delta F = 2$ transitions

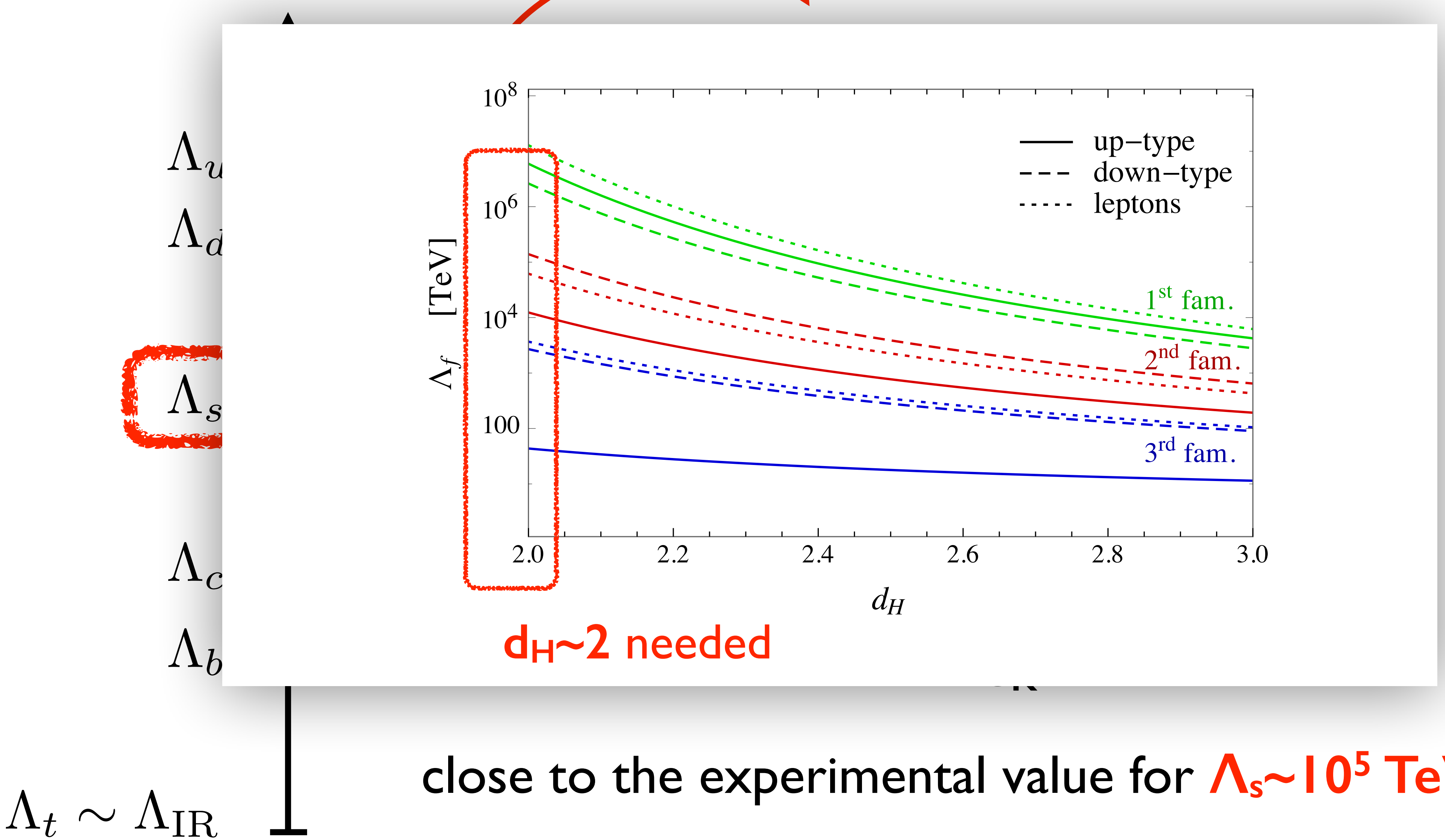
$$\sim \frac{g_*^2}{\Lambda_s^2} (\overline{Q}_{L2} s_R)(\overline{s}_R Q_{L2})$$

↓ physical basis rotation ~V_{CKM}

ϵ_K

close to the experimental value for $\Lambda_s \sim 10^5$ TeV

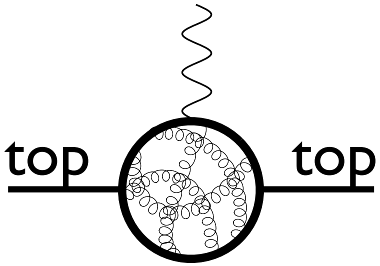
Different effects at different scales:



close to the experimental value for $\Lambda_s \sim 10^5$ TeV

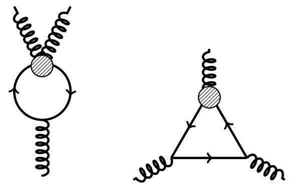
EDMs

- EDM of u,d,e suppressed by $\Lambda_{d,u,e} > 10^9$ GeV
- Largest constraint from the top EDM:



$$c^t_{\rm edm} \simeq \frac{g_*^2}{16\pi^2}\frac{m_t}{\Lambda_{\rm IR}^2}$$

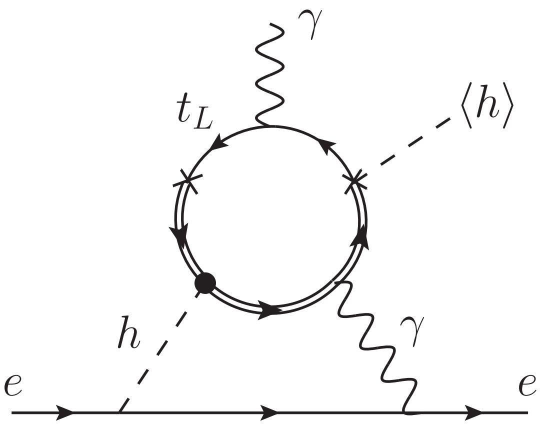
→



Weinberg operator

→ d_N

- Two-loop Barr-Zee-like diagrams to d_e:



☛ d_N & d_e around the present bound for $\Lambda_{IR} \sim$ TeV

Always EDM!

If only one scale for each family:

Decoupling scale	Operator
$\Lambda_u \sim \Lambda_d \sim \Lambda_e$	$\mathcal{O}_{d_R}, \mathcal{O}_{Q_{L1}}\ \mathcal{O}_{u_R}$
$\Lambda_c \sim \Lambda_s \sim \Lambda_\mu$	$\mathcal{O}_{s_R}\ \mathcal{O}_{c_R}, \mathcal{O}_{Q_{L2}}$
$\Lambda_t \sim \Lambda_b \sim \Lambda_\tau$	$\mathcal{O}_{t_R}, \mathcal{O}_{Q_{L3}}\ \mathcal{O}_{b_R}$

Splittings within a given family must be explained by different mixings (ϵ_{f_i}) at the respective scales

Only main difference: **$\mu \to e\gamma$ gets close to the exp. bound**

Other issues:

- Modifications to Higgs couplings:

  Similar effects as with linear mixing

- Neutrino masses:

Majorana: $$\frac{1}{\Lambda_\nu^{2d_H-1}}\bar{L}^c\mathcal{O}_H\mathcal{O}_H L \longrightarrow m_\nu \simeq \frac{g_*^2 v^2}{\Lambda_{\rm IR}}\left(\frac{\Lambda_{\rm IR}}{\Lambda_\nu}\right)^{2d_H-1}$$

for d_H~2, dimension-7 operator

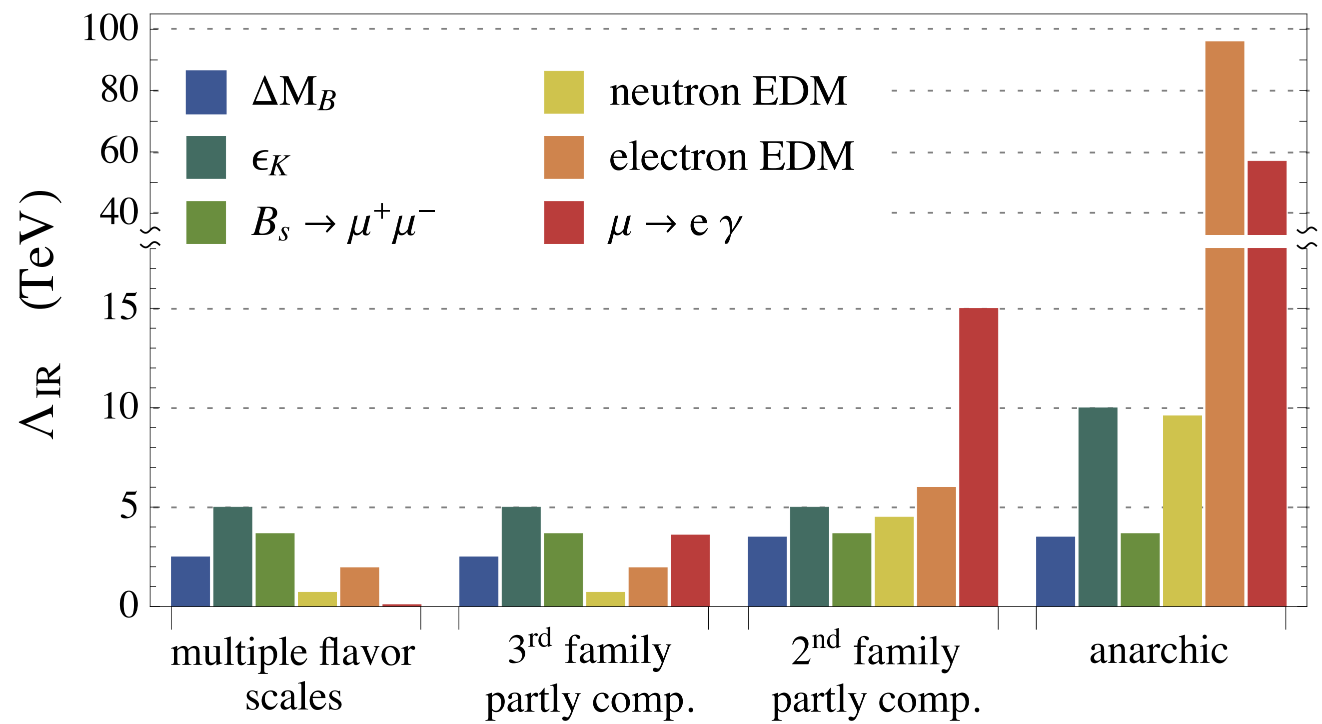
$$m_\nu \sim 0.1 - 0.01 \text{ eV} \quad \text{for} \quad \Lambda_\nu \sim 0.8 - 1.5\times 10^8 \text{ GeV}$$

Dirac: $$\frac{1}{\Lambda_\nu^{d_H-1}}\mathcal{O}_H\bar{L}\nu_R$$

for d_H~2, dimension-5 operator as in the SM

Summary

- Flavor symmetries must be an **emergent** phenomena
- A **working example**: Flavor from mixing to the BSM at different dynamical scales (different branes)
- **Consistent** with all experiments for TeV new-physics scale:



$$\frac{1}{\Lambda_{IR}^2}\left(g_{ij}\,\bar{d}_{Li}\gamma^\mu d_{Lj}\right)^2 \;, \quad \frac{g_* v^2}{\Lambda_{IR}^2} g_{ij}\left(\bar{d}_{Li}\gamma^\mu d_{Lj}\right)\frac{g Z_\mu}{\cos\theta_W}\,,$$

$$g_{ij} \equiv Y_t x_t (V^\dagger_{CKM})_{i3}(V_{CKM})_{3j}\,,$$

many observables around the corner!