Flavour Physics in Randall-Sundrum Models

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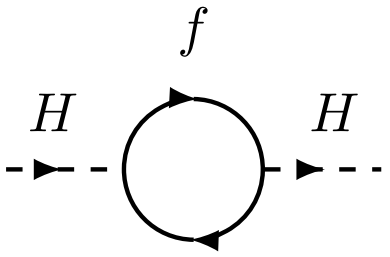
based on arxiv:0807.4537

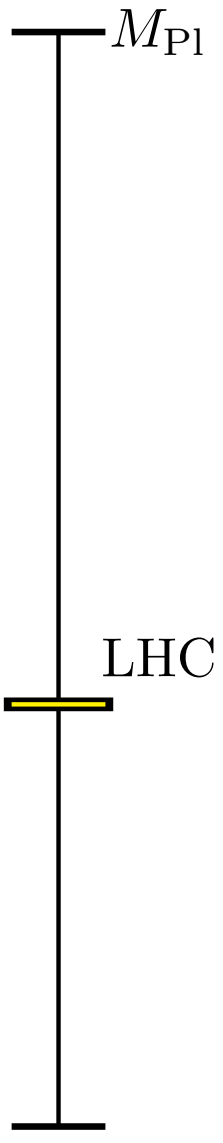
1. Motivation
2. The minimal Randall-Sundrum (RS) model
3. Flavour Observables
4. Summary & Conclusion

Motivation

- The Hierarchy problem
  Why is the Higgs mass so much lighter than the Planck scale?



$$\Rightarrow \Delta m_H^2 = -\frac{|\lambda_f|^2}{8\pi^2}\left[m_f^2 + \ldots\right]$$



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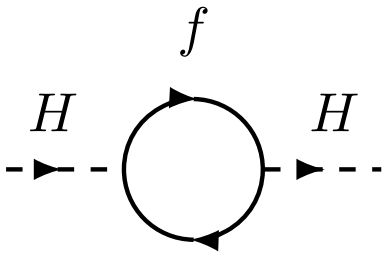

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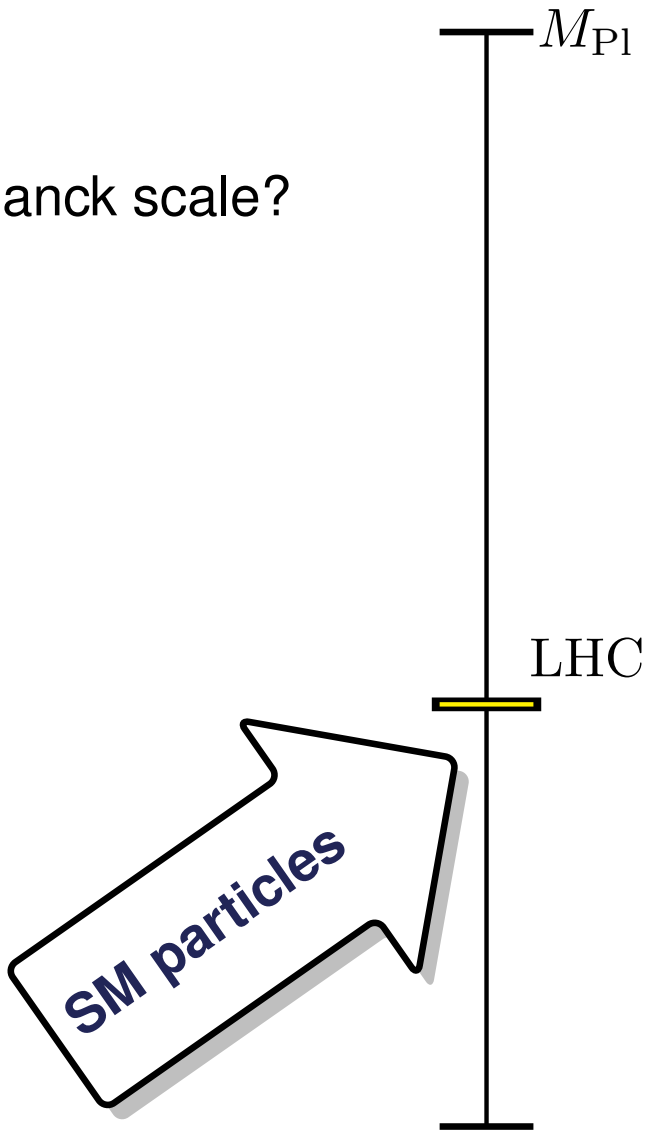

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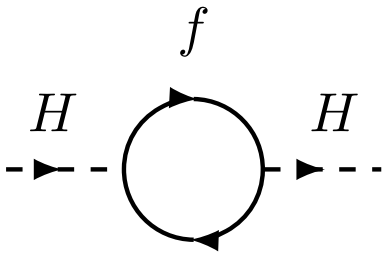

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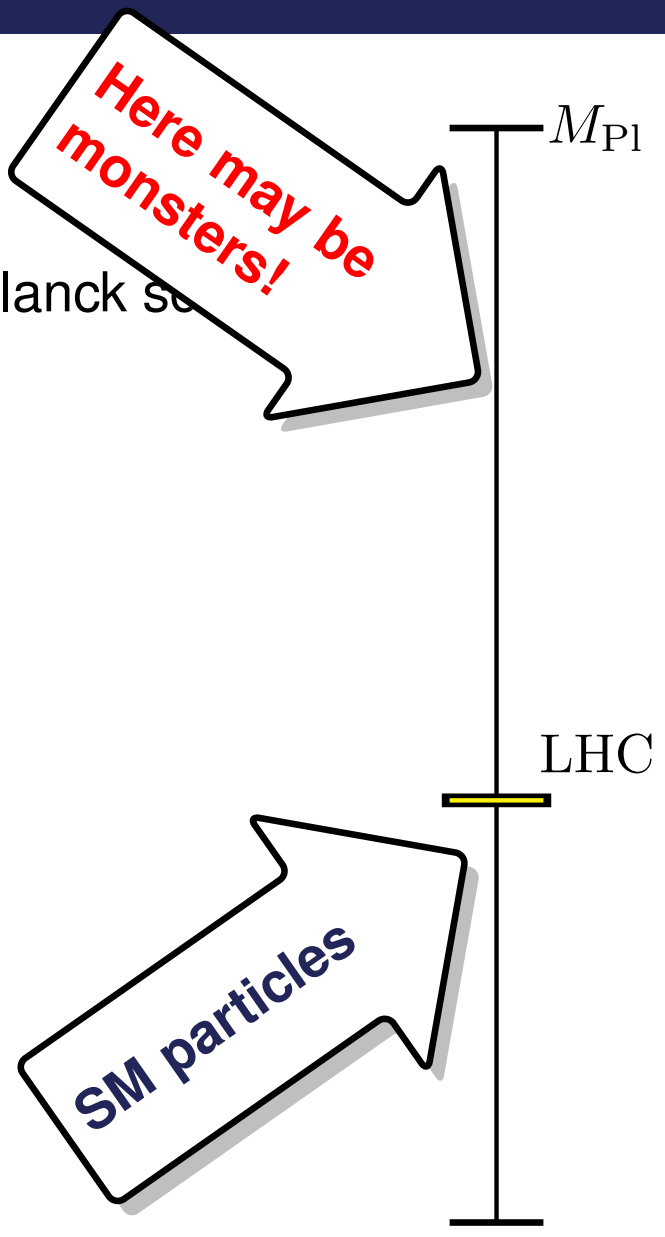

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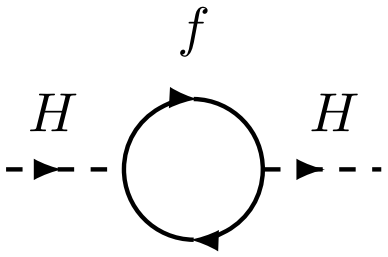
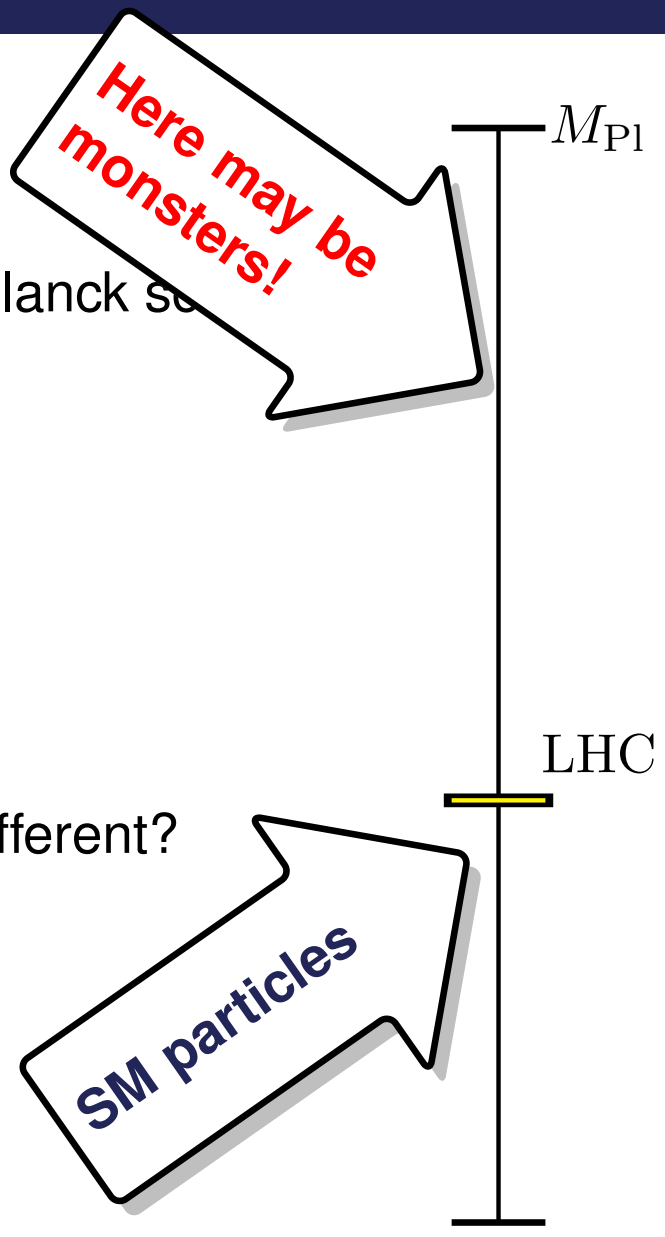


$$\Rightarrow \Delta m_H^2 = -\frac{|\lambda_f|^2}{8\pi^2}\left[m_f^2 + \ldots\right]$$

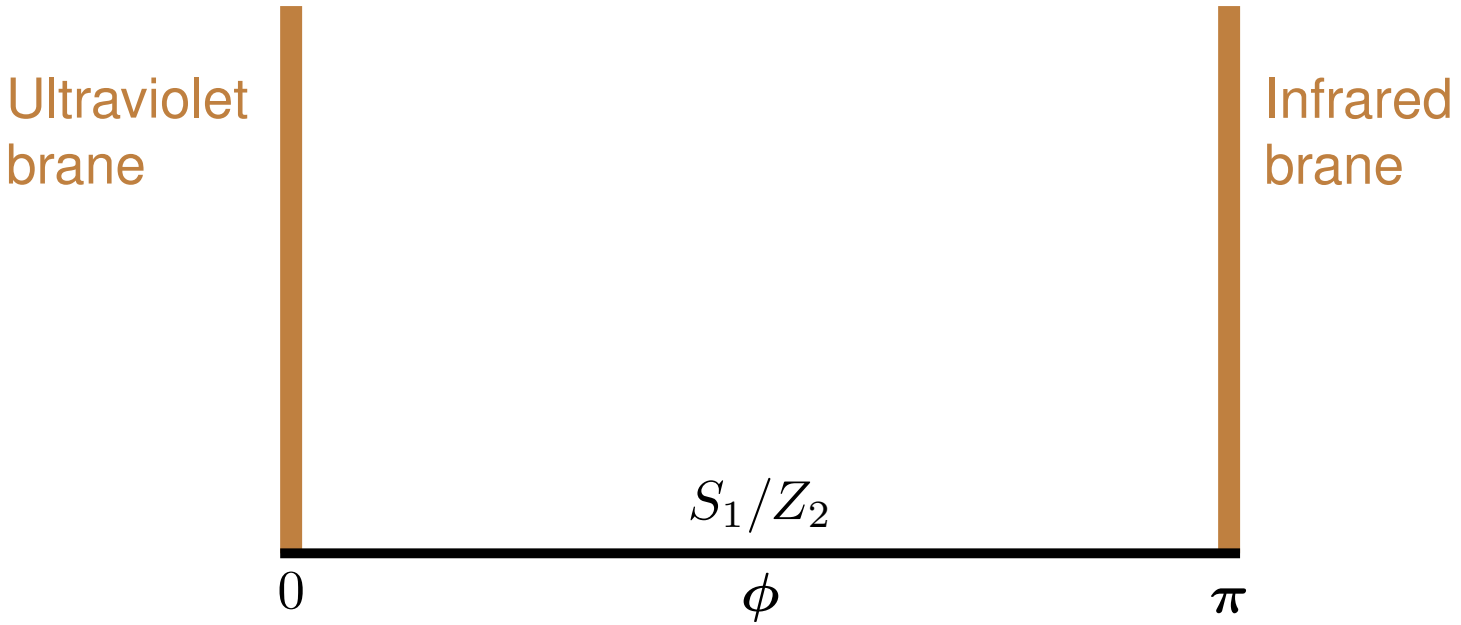
- The flavour puzzle
  Why are the masses of elementary particles so different?

Hamburger fisher boat $\longleftrightarrow$ Queen Mary II

up quark $\longleftrightarrow$ top quark

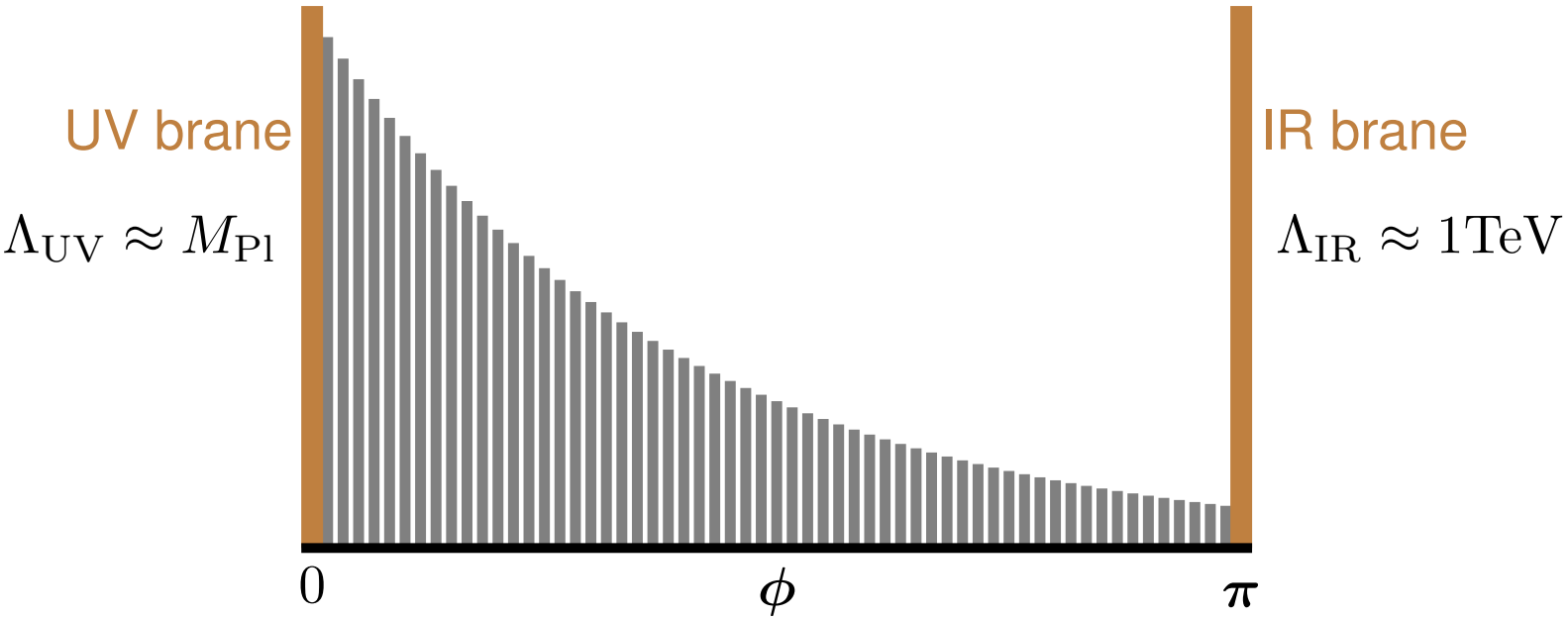


Geometry



$$\mathrm{d}s^2 = e^{-2\sigma}\eta_{\mu\nu}\mathrm{d}x^\nu \mathrm{d}x^\mu - r^2\mathrm{d}\phi^2 \qquad , \sigma = kr|\phi|$$

Geometry



$$\mathrm{d}s^2 = e^{-2\sigma}\eta_{\mu\nu}\mathrm{d}x^\nu \mathrm{d}x^\mu - r^2\mathrm{d}\phi^2 \quad \Rightarrow \quad \Lambda_{\rm IR} = e^{-kr\pi}\Lambda_{\rm UV}$$

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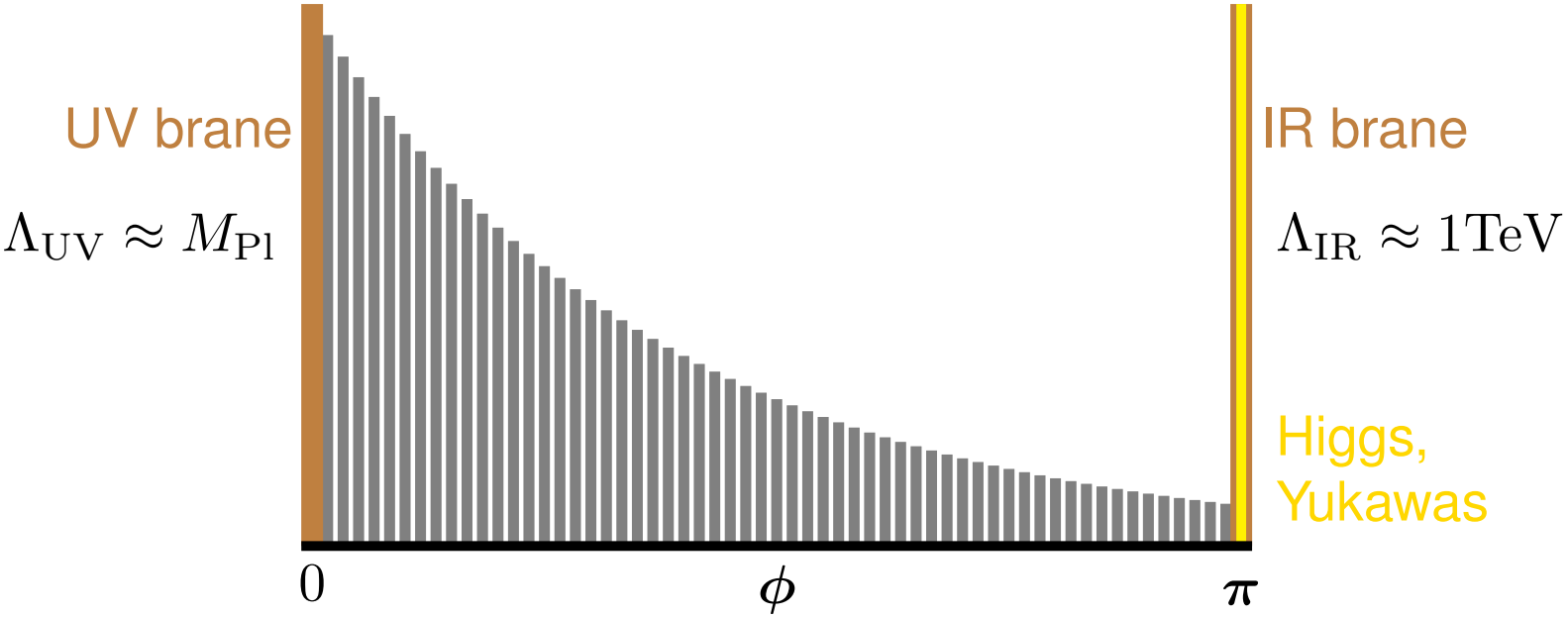
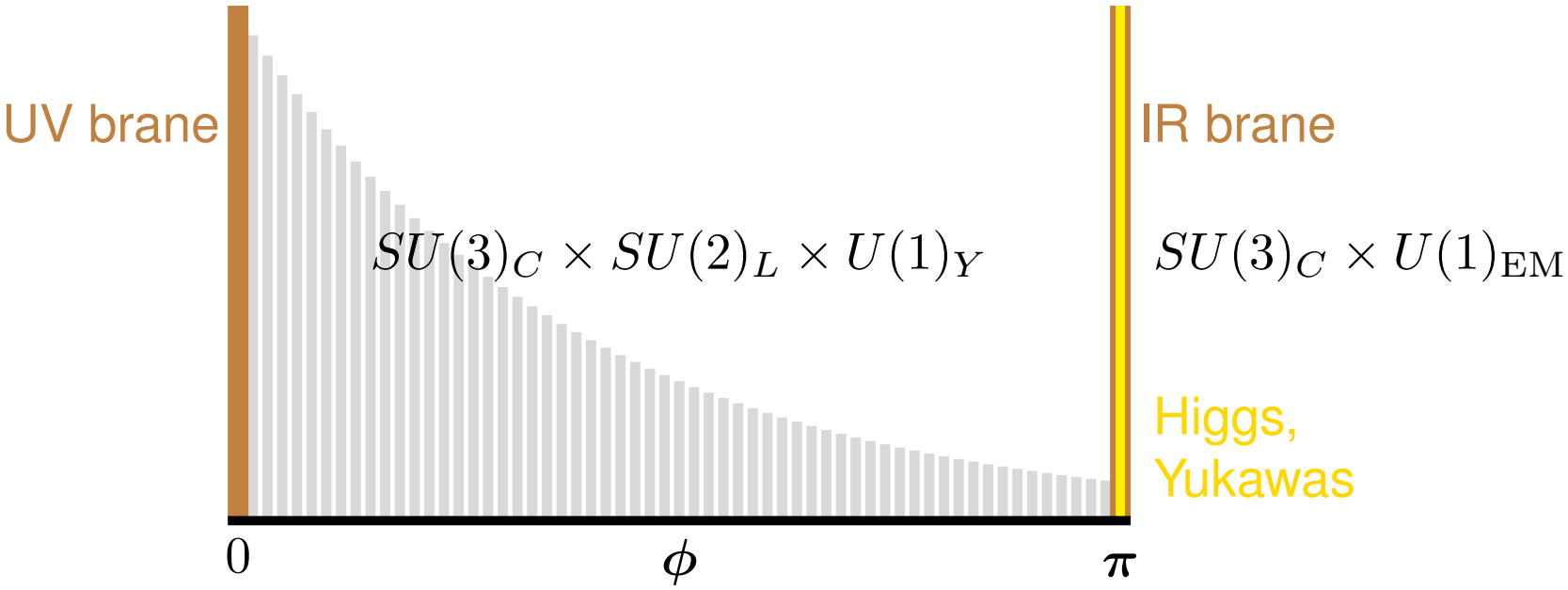


$$ds^2 = e^{-2\sigma}\eta_{\mu\nu}dx^\nu dx^\mu - r^2 d\phi^2 \quad \Rightarrow \quad \Lambda_{\rm IR} = e^{-kr\pi}\Lambda_{\rm UV}$$

$$\epsilon = \frac{\Lambda_{\rm IR}}{\Lambda_{\rm UV}} \equiv e^{-kr\pi} = \frac{M_W}{M_{\rm Pl}} \approx 10^{-16}, \qquad L = -\ln\epsilon \approx 37$$

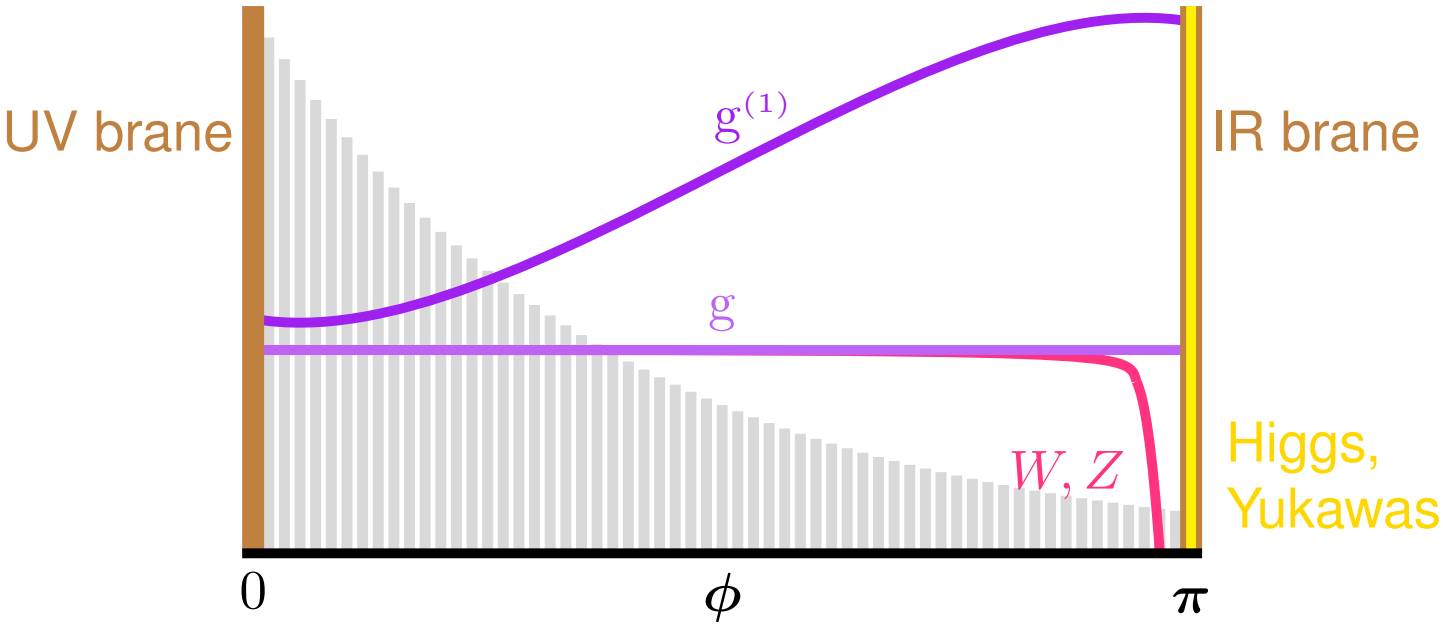
✓ Solves Hierarchy problem due to redshifted Planck mass

Gauge sector

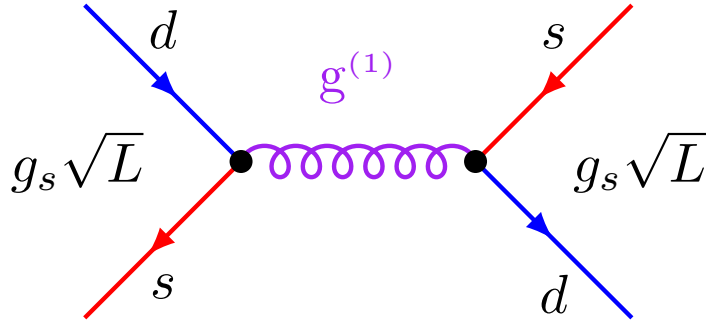


Gauge fields are 5D fields (so-called “bulk fields”)
Since the extra dimension is compact they are decomposed into 4D Kaluza-Klein (KK) modes, analogue to QM fields in a potential well

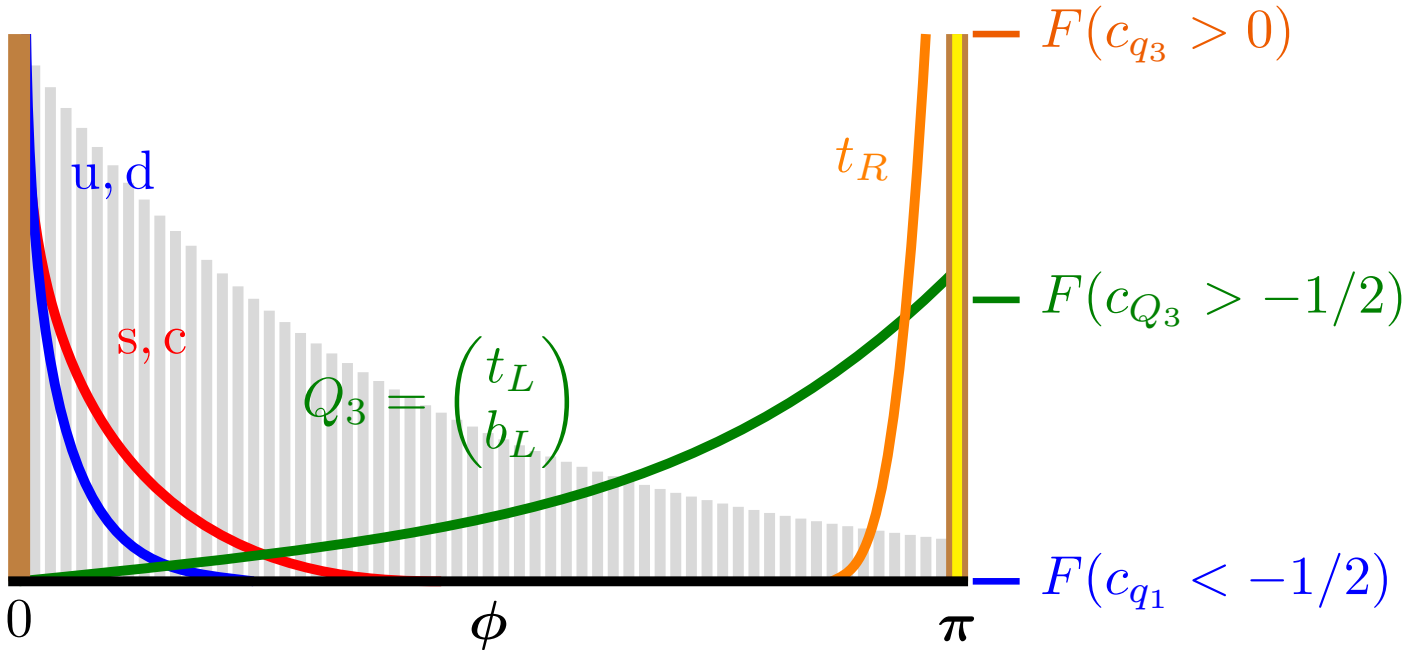
Gauge sector



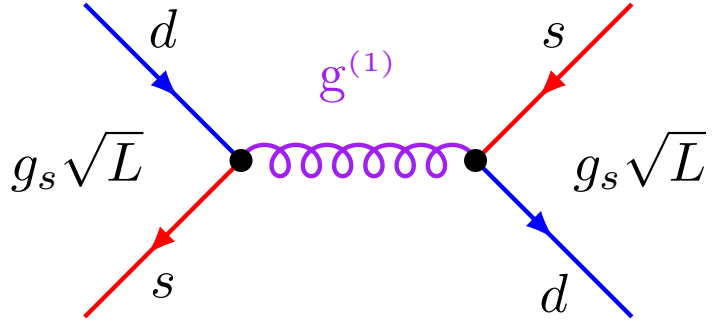
Non flat profiles of KK modes lead to non-diagonal overlap integrals with fermions and potentially large flavour changing neutral currents (FCNC's).



Fermion sector



Order one parameters c_{q_i} control localization of fermions in the bulk.



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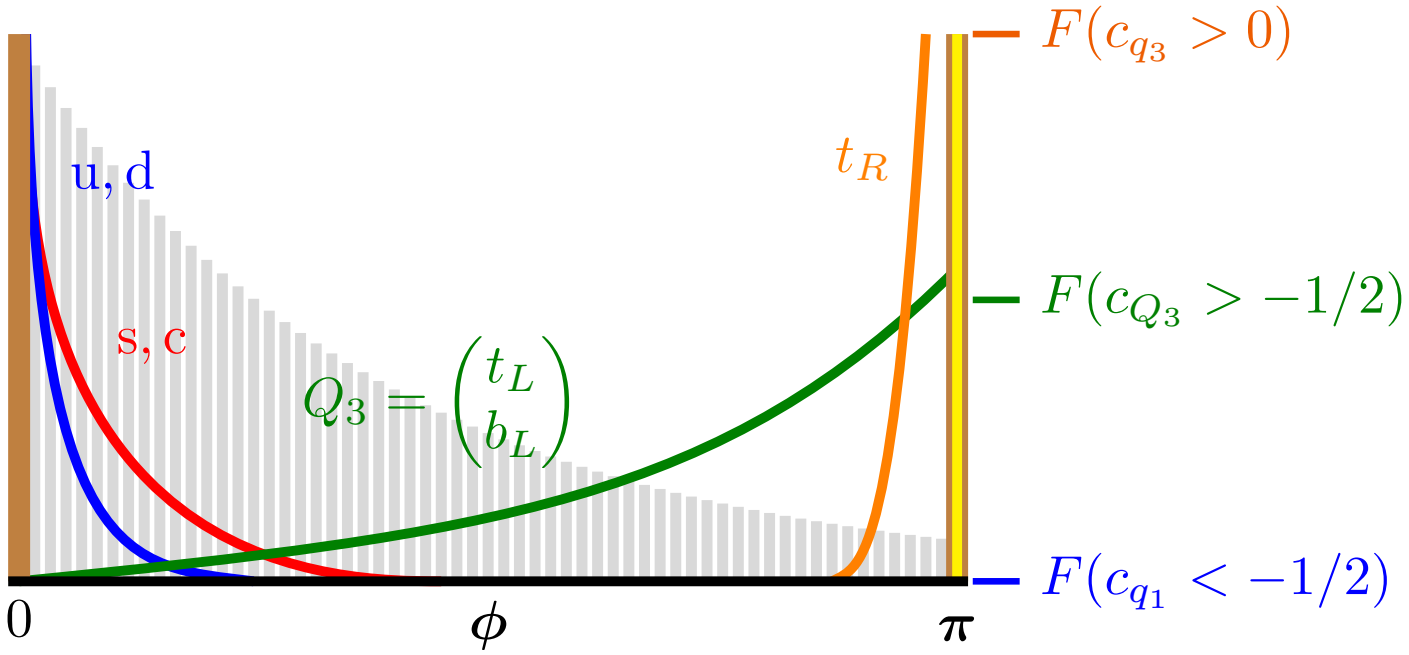
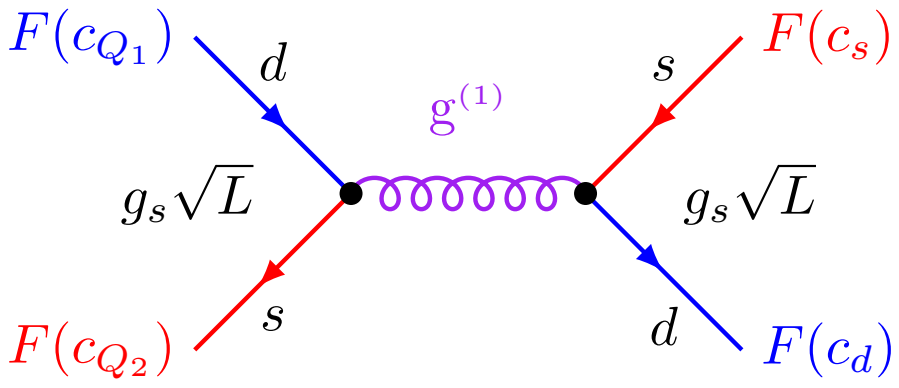


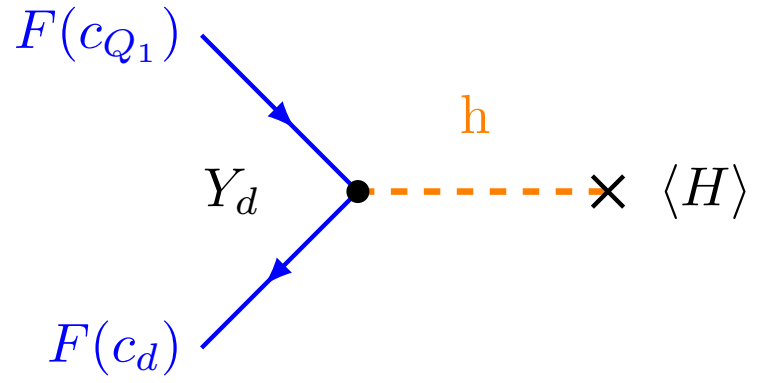
9 parameters c_{q_i} chosen in a way to satisfy 8 conditions $\{m_{q_i}, V_{us}, V_{cs}\}$.



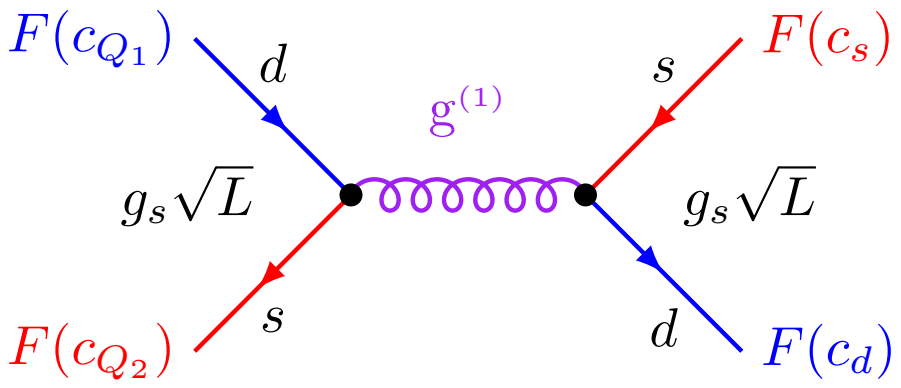
Fermion sector - RS GIM

The parameters which control the masses of the light quarks suppress potentially dangerous FCNC's : RS-GIM.

$$m_d \sim \frac{v}{\sqrt{2}} F(c_{Q_1})\, Y_d^{(5D)}\, F(c_d)$$
$$\sim \frac{v}{\sqrt{2}} Y_d^{\text{eff}}$$



$$\frac{g_s^2\, L}{M_{\text{KK}}^2} F(c_{Q_1}) F(c_d) F(c_{Q_2}) F(c_s)$$
$$\sim \frac{g_s^2}{M_{\text{KK}}^2} L \frac{2 m_d m_s}{\left(v Y_d^{(5D)}\right)^2}$$



Flavour Structure

- Yukawa matrices $(Y_d)_{ij}$ can be chosen to be anarchic and of order one:

$$(Y_d^{\rm eff})_{ij} \equiv F(c_{Q_i})(Y_d)_{ij}^{(5D)} F(c_{d_j})$$

- Hierarchical masses and mixings can be generated by relying on order one parameters only:

$$m_{q_i} = \mathcal{O}(1)\frac{v}{\sqrt{2}} F(c_{Q_i})F(c_{q_i})$$

$$\bar{\rho}, \bar{\eta} = \mathcal{O}(1)\,, \qquad \lambda = \mathcal{O}(1)\frac{F(c_{Q_1})}{F(c_{Q_2})}\,, \qquad A = \mathcal{O}(1)\frac{F^3(c_{Q_2})}{F^2(c_{Q_2})F(c_{Q_3})}$$

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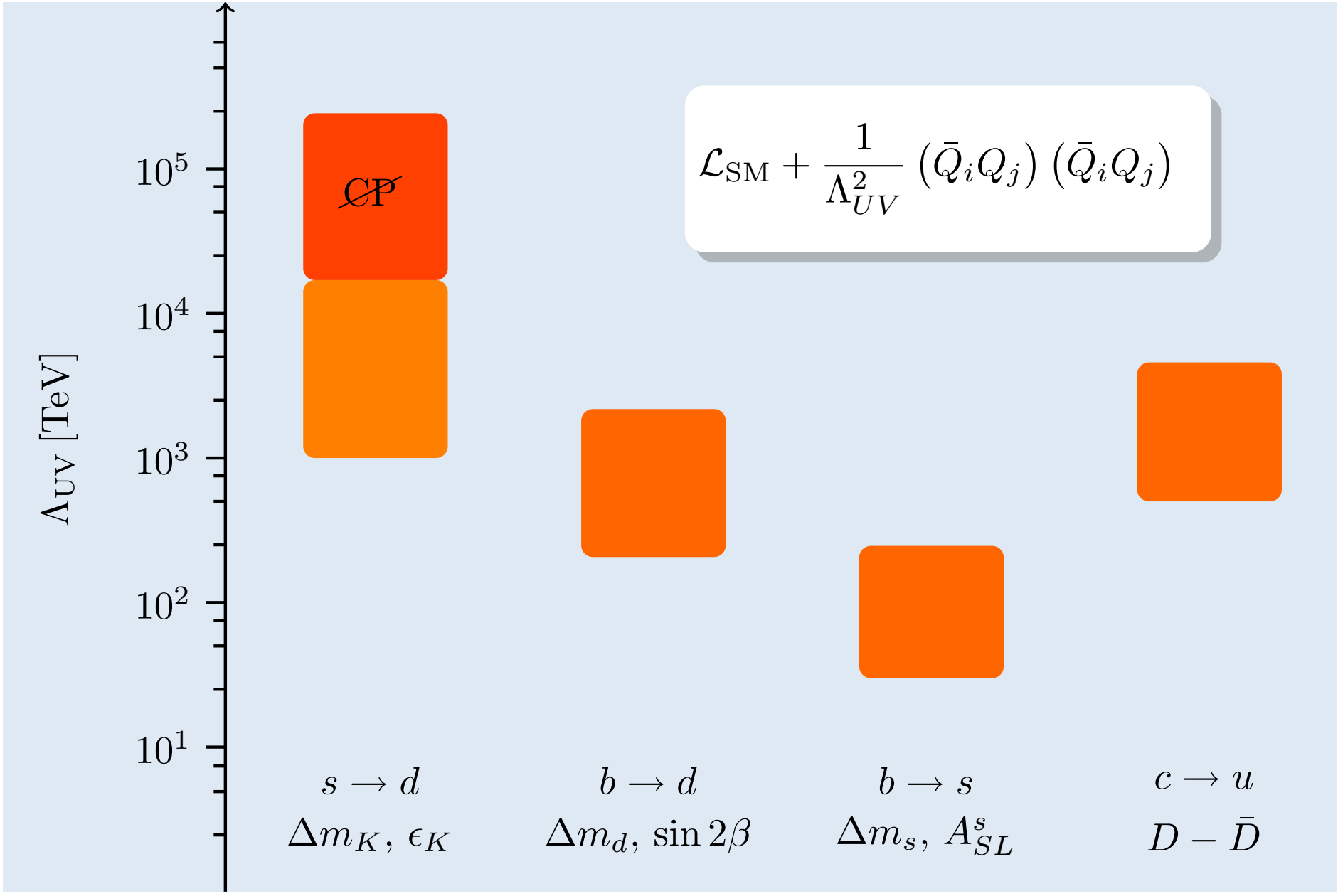
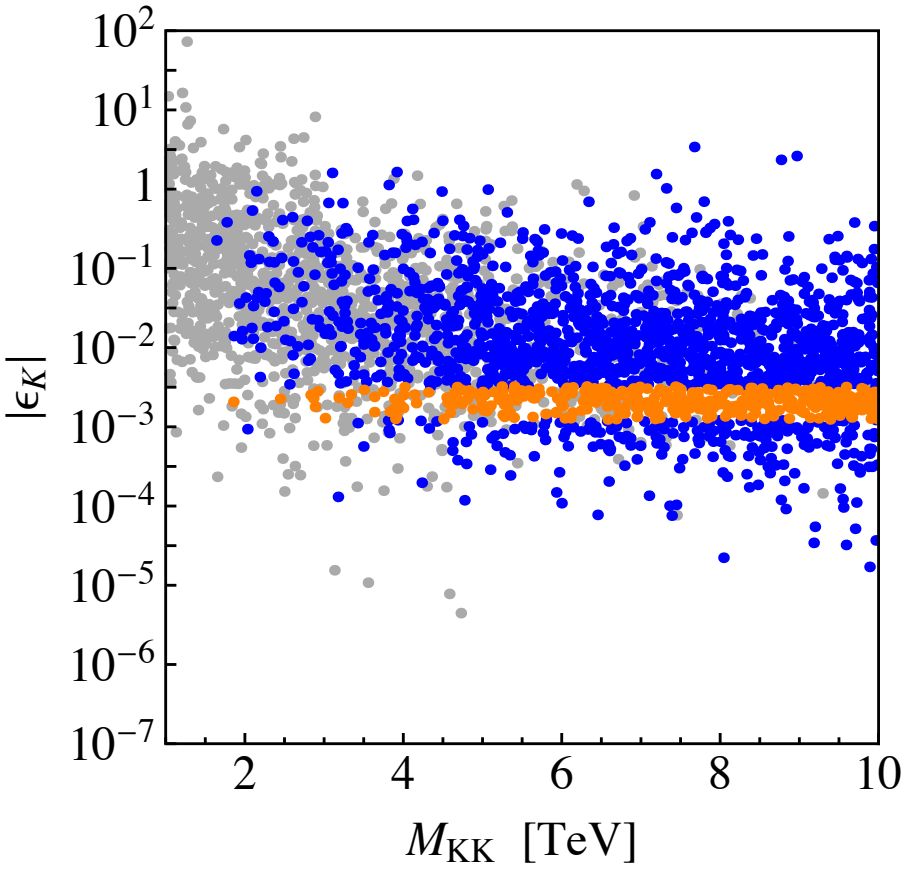
✓ Provides explanation for flavour puzzle!

Flavour in RS



Meson Mixing: Neutral Kaons

Generically $|\epsilon_K|$ by a factor $\mathcal{O}(50)$ enhanced with respect to $|\epsilon_K|_{\rm exp} = (2.23 \pm 0.01) \times 10^{-3}$.



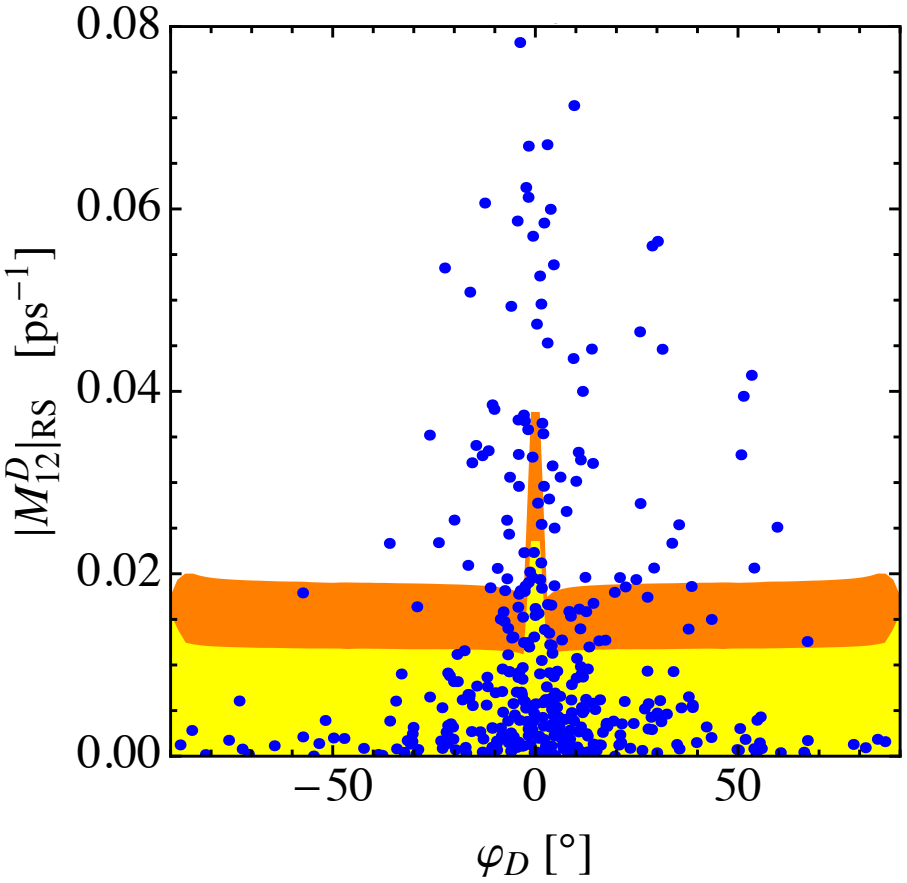
3000 randomly chosen RS points with $|Y_q| < 3$ reproducing quark masses and CKM parameters with $\chi^2/dof < 11.5/10$ corresponding to 68% CL

- Without $Z \to b\bar{b}$ constraint
- With $Z \to b\bar{b}$ constraint at 95% CL
- Satisfying 95% CL $|\epsilon_K| \in [1.3, 3.3] \cdot 10^{-3}$

Meson Mixing: Neutral D Mesons

Very large effects possible in $D - \bar{D}$ mixing, including large CP violation. Prediction might be testable at LHCb

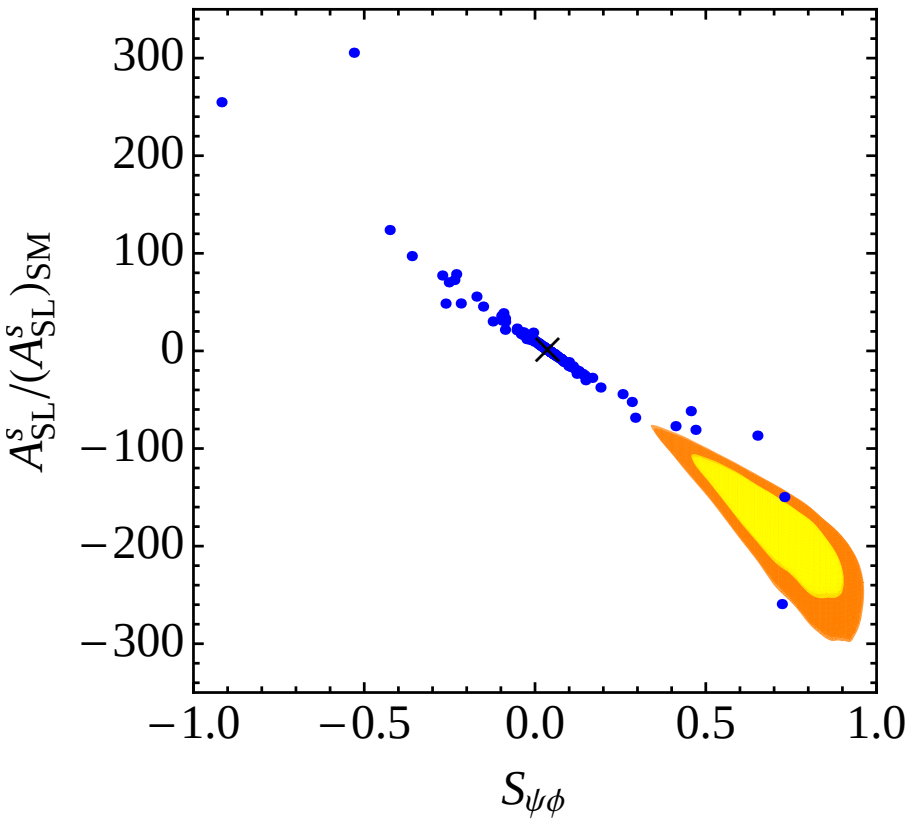
$$(M_{12}^D)^* = \langle \bar{D} | \mathcal{H}_{\text{eff,RS}}^{\Delta C=2} | D \rangle$$
$$= |M_{12}^D| e^{2i\phi_D}$$



- Experimentally favoured region at 68% CL
- Experimentally favoured region at 95% CL
- consistent with quark masses, CKM parameters, and 95% CL limit $|\epsilon_K| \in [1.3, 3.3] \cdot 10^3$

Meson Mixing: B_s Sector

In RS model significant corrections to semileptonic CP asymmetry A^s_{SL} and $S_{\Psi\Phi} = \sin(2|\beta_s| - 2\phi_{B_s})$ consistent with $|\epsilon_K|$ can arise



$$A^s_{SL} = \frac{\Gamma(\bar{B}_s \to \ell^+ X) - \Gamma(\bar{B}_s \to \ell^- X)}{\Gamma(\bar{B}_s \to \ell^+ X) + \Gamma(\bar{B}_s \to \ell^+ X)} = \mathrm{Im}\frac{\Gamma^s_{12}}{M_{12}}$$

- SM: $A^s_{SL} = 2 \cdot 10^{-5}$, $S_{\Psi\phi} = 0.04$
- Experimentally favoured region at 68% CL
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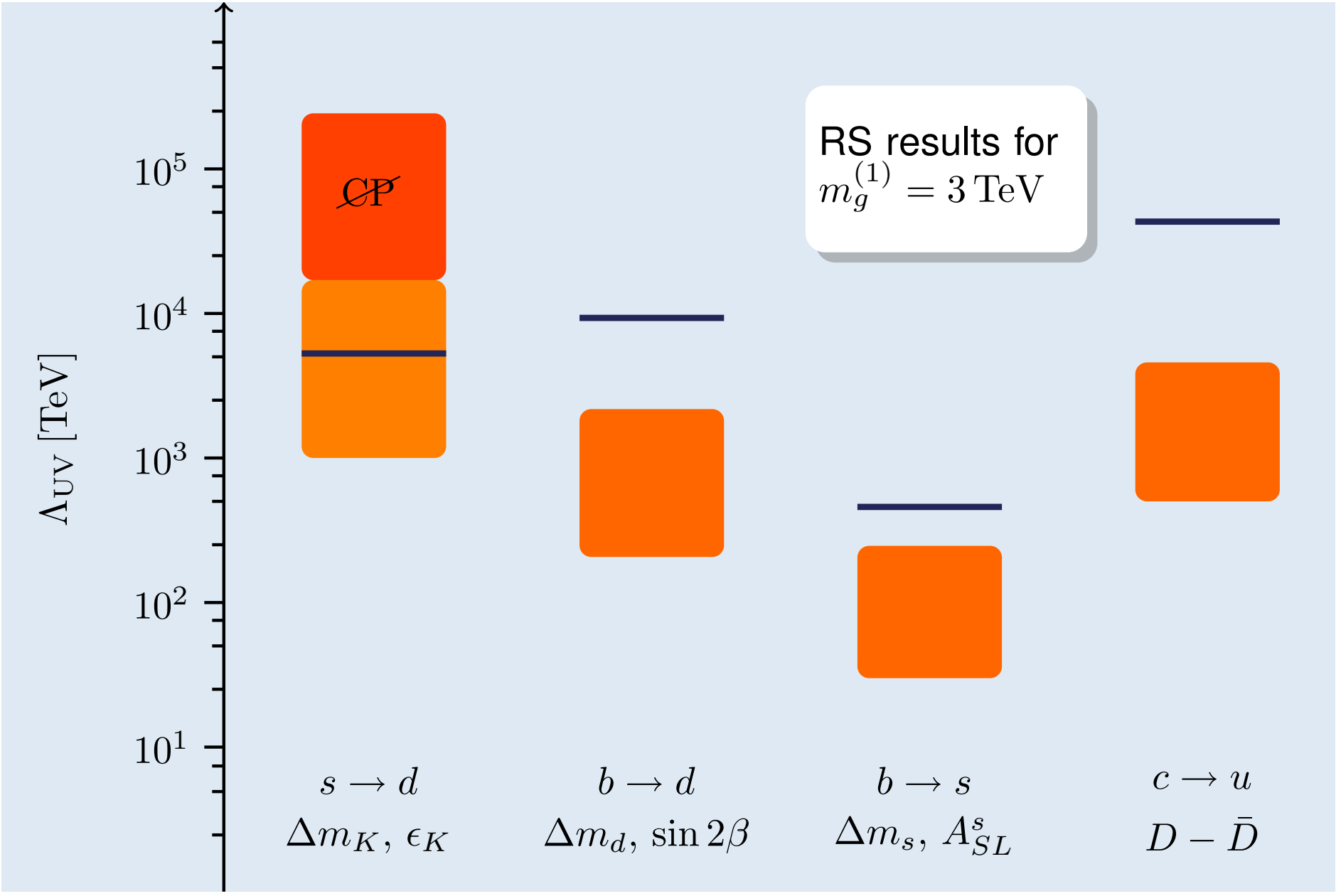

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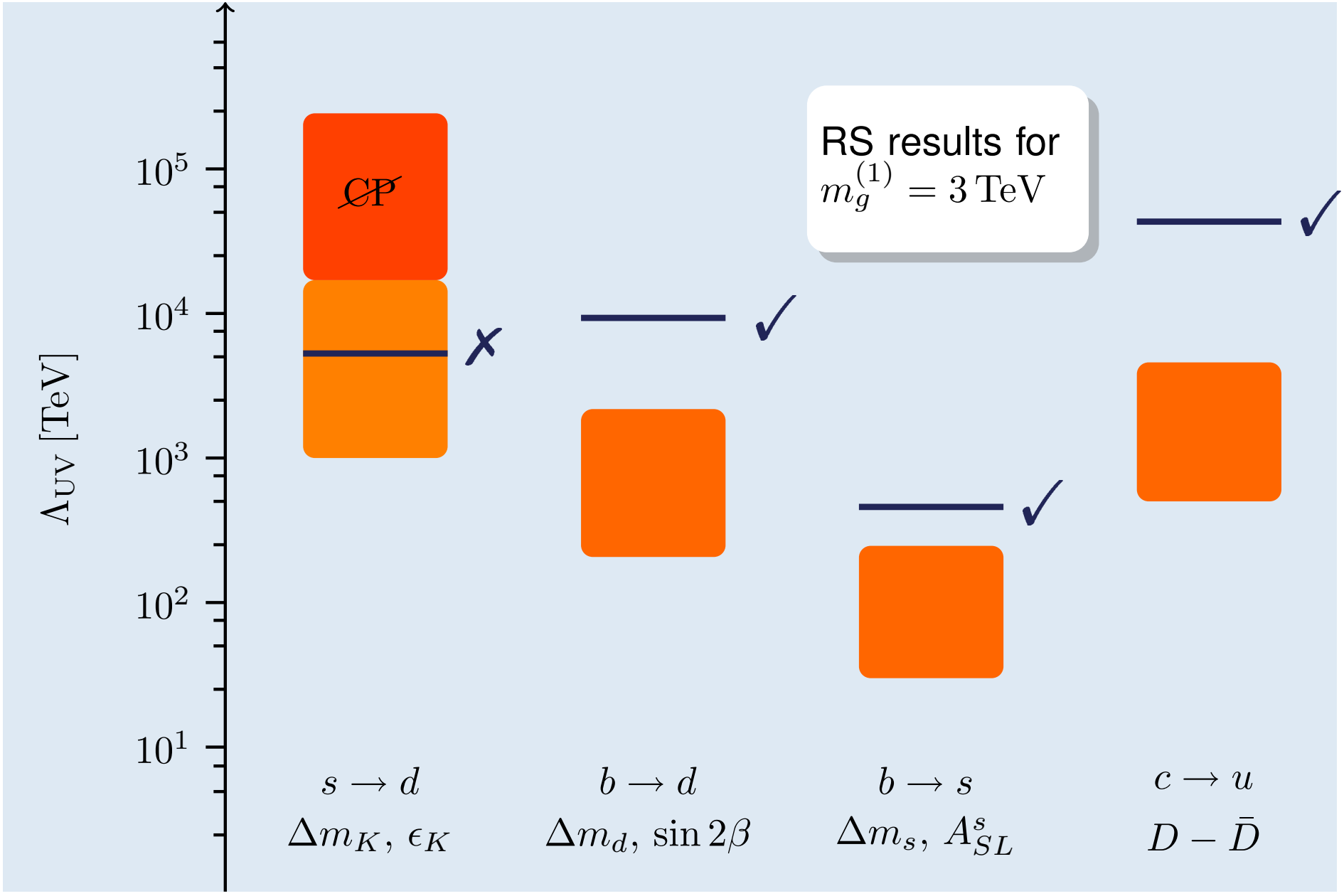

Summary and Conclusion

- Warped extra dimensions offer compelling geometrical explanation of gauge and fermion hierarchy problem, mysteries left unexplained in SM
- Flavour-changing tree-level transitions of K and B_s mesons particularly interesting as their sensitivity to KK scale extends beyond LHC reach.
- Flavour-anarchy models need tuning to survive constraints from CP- violation in kaon sector, which calls for additional flavour structure