FLAVOR PHYSICS BEYOND THE STANDARD MODEL

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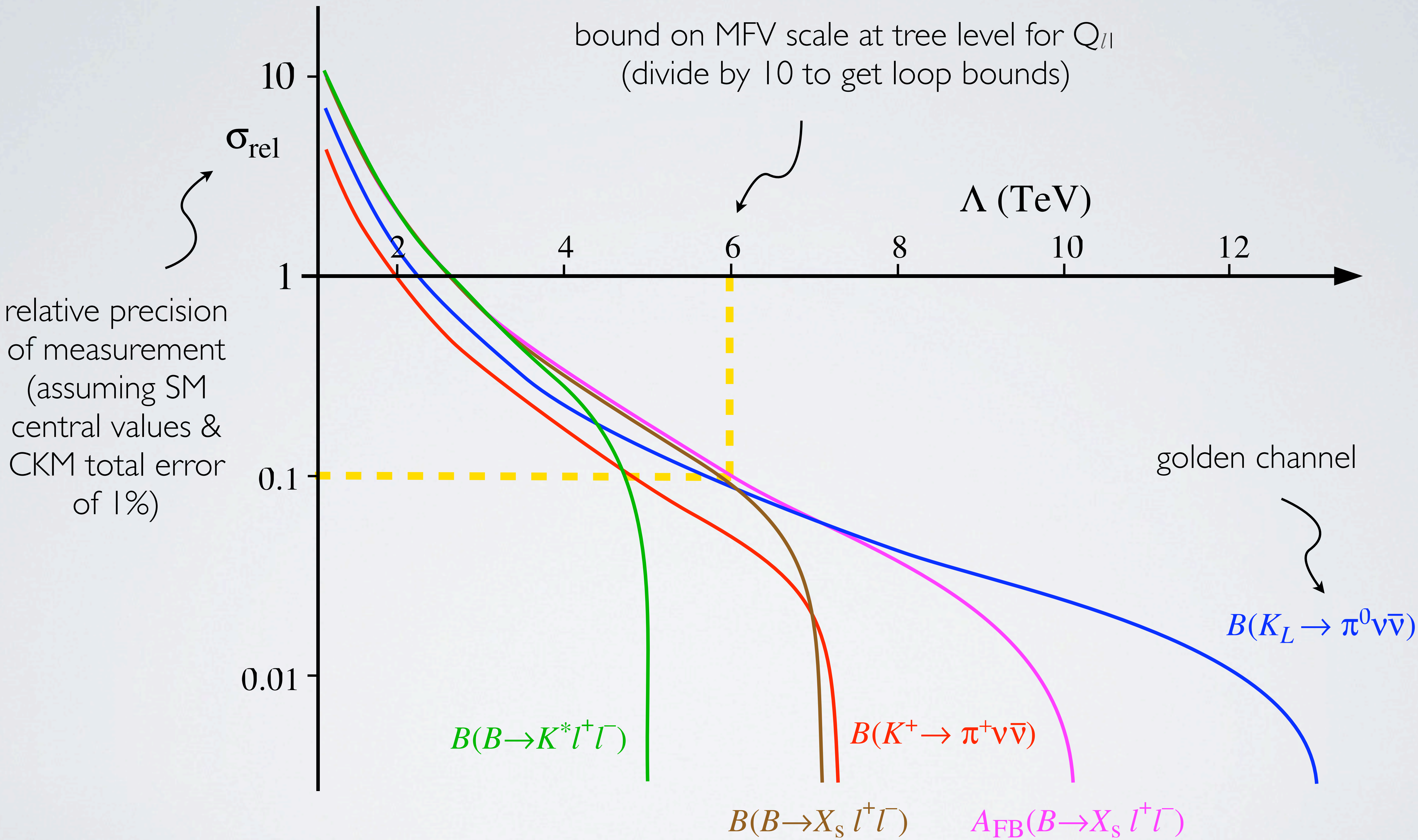
University of Mainz (THEP)

School on Flavor Physics (Flavianet)
University of Bern, June 21 – July 2, 2010

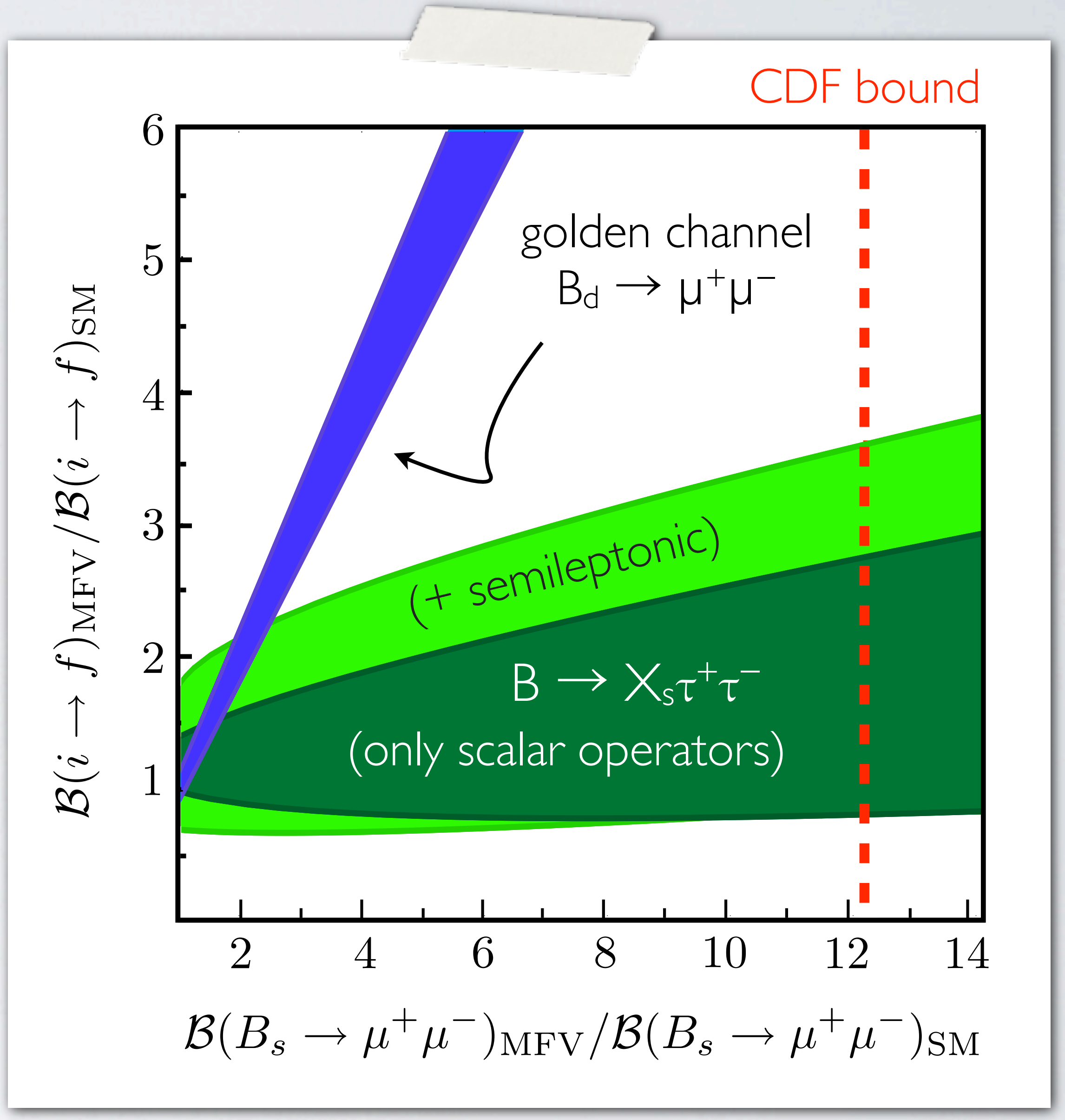
DISTINGUISHING MFV FROM SM IS HARD



[Bryman *et al.*,hep-ph/0505171; D'Ambrosio *et al.*,hep-ph/0207036]

ONCE SM IS DEAD, FALSIFYING MFV IS EASY

- MFV hypothesis can be refuted by
  - violation of correlations (MFV sum rules)



[Hurth *et al.*, arXiv:0807.5039; Bobeth *et al.*, hep-ph/0505110; UH & Weiler, arXiv:0706.2054]

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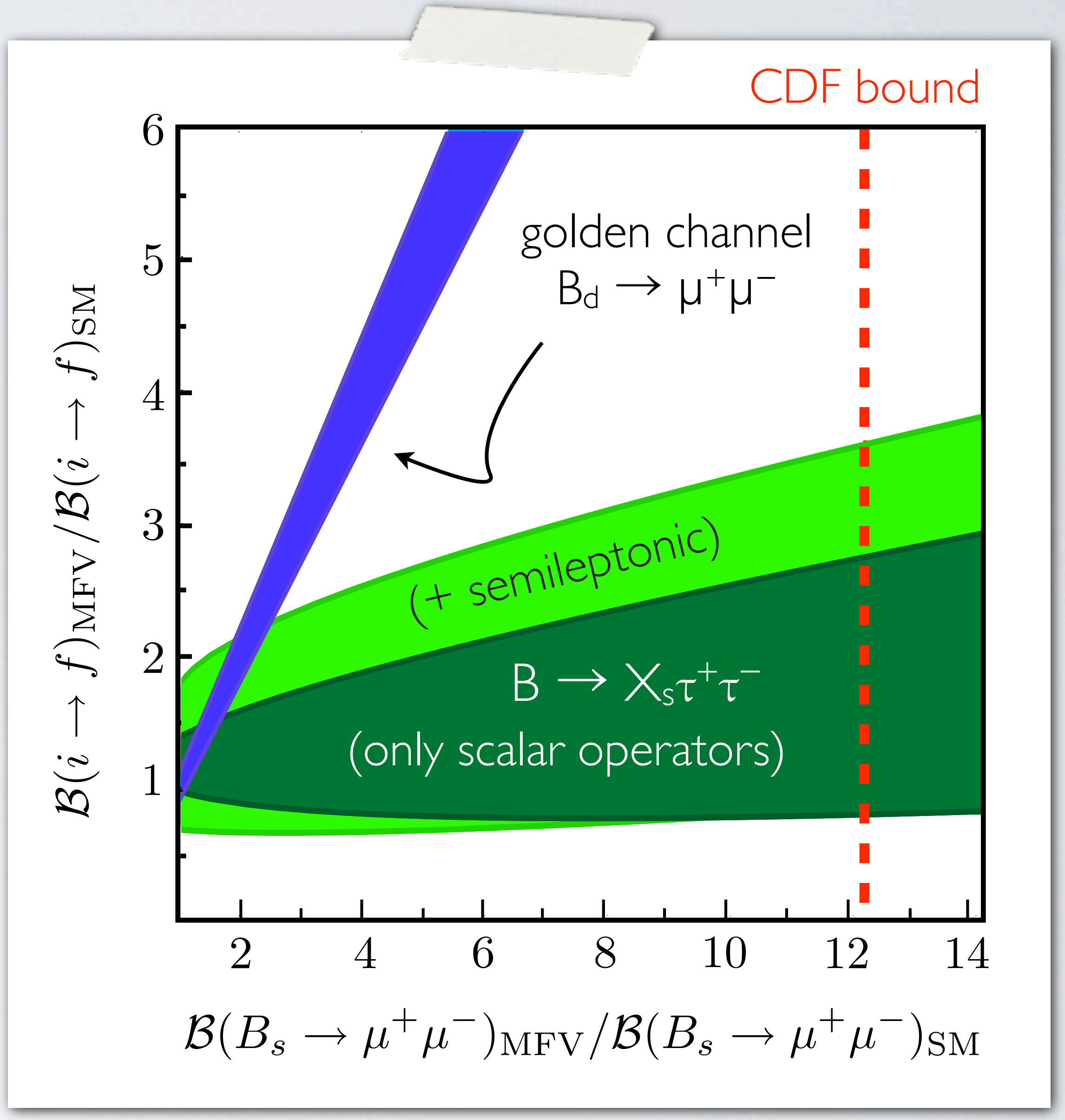

Exercise 5: Which parameter determine the slope of the blue line in MFV models?

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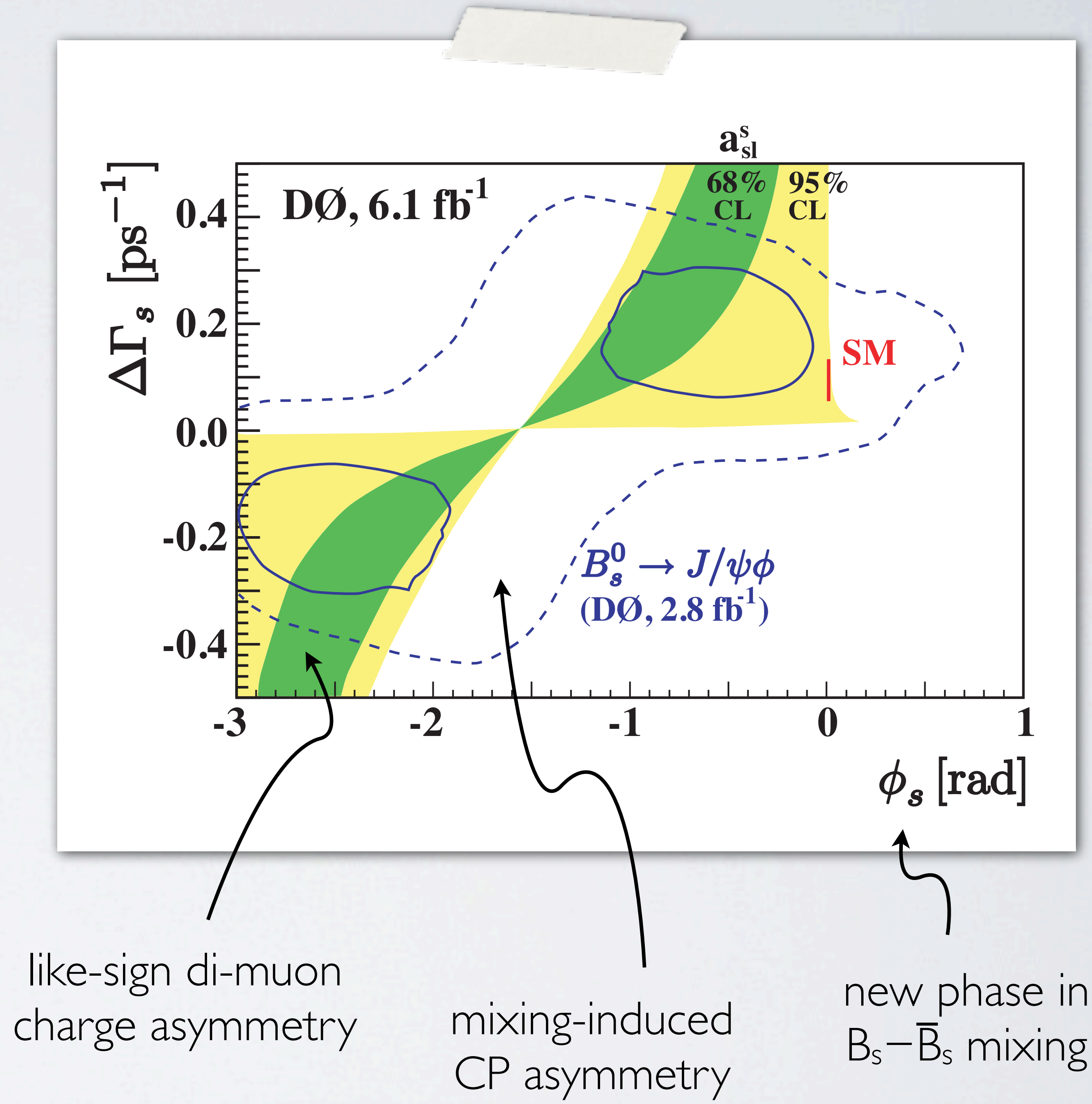
  - observation of new CP phases (flavor non-diagonal ones)



[DØ Collaboration, arXiv:1005.2757; Tevatron B Working Group note 9787; Oakes, talk at FPCP 2010]

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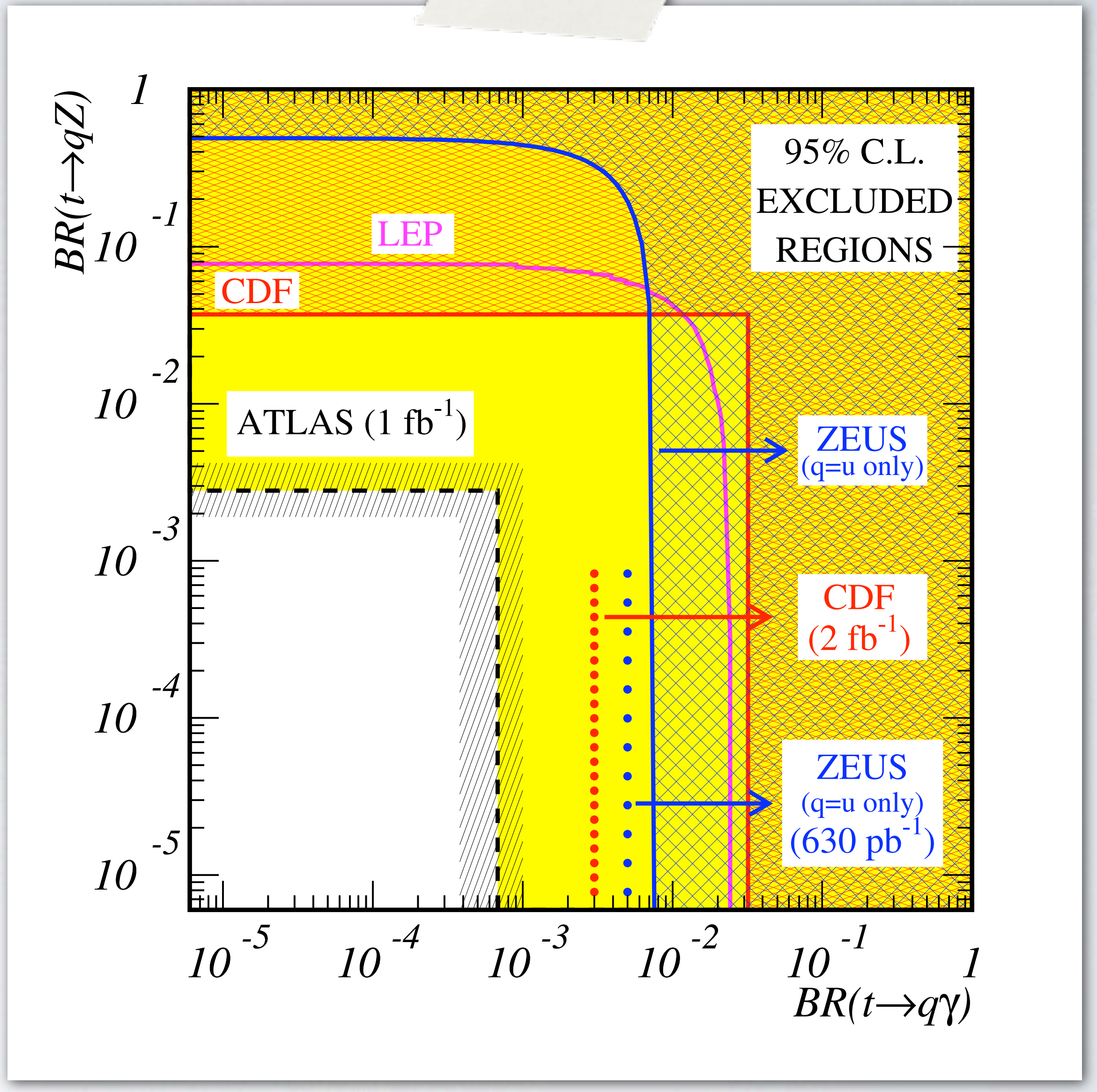
  - measurements of top-quark FCNCs ($t \to q\gamma$, $t \to qZ$, ...)



[ATLAS Collaboration, arXiv:0901.0512; arXiv:0712.1127; CMS Collaboration, J. Phys. G34, 995 (2007)]

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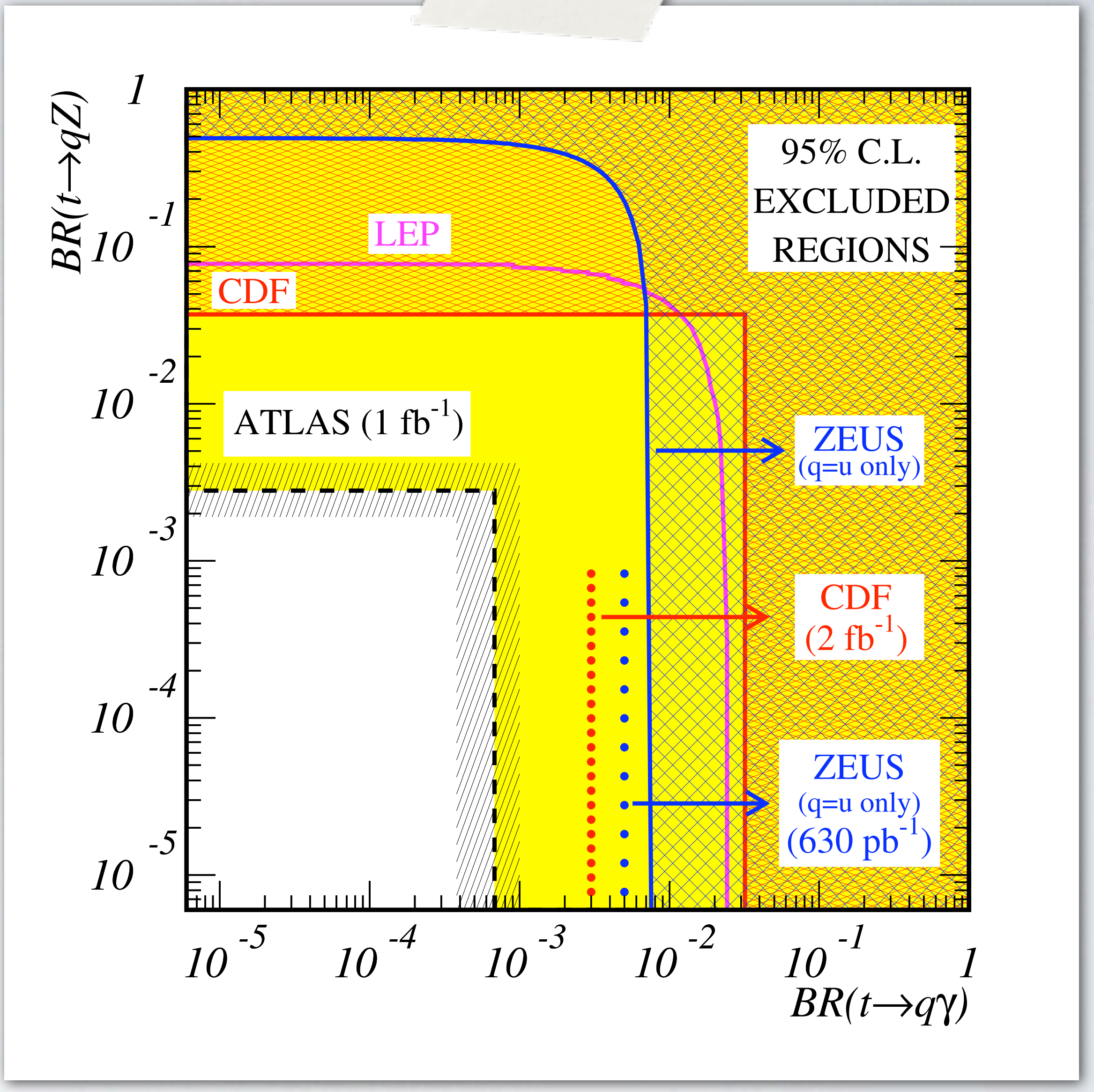

Exercise 6: Estimate the size of the branching fractions for FCNC top-quark decays in the SM

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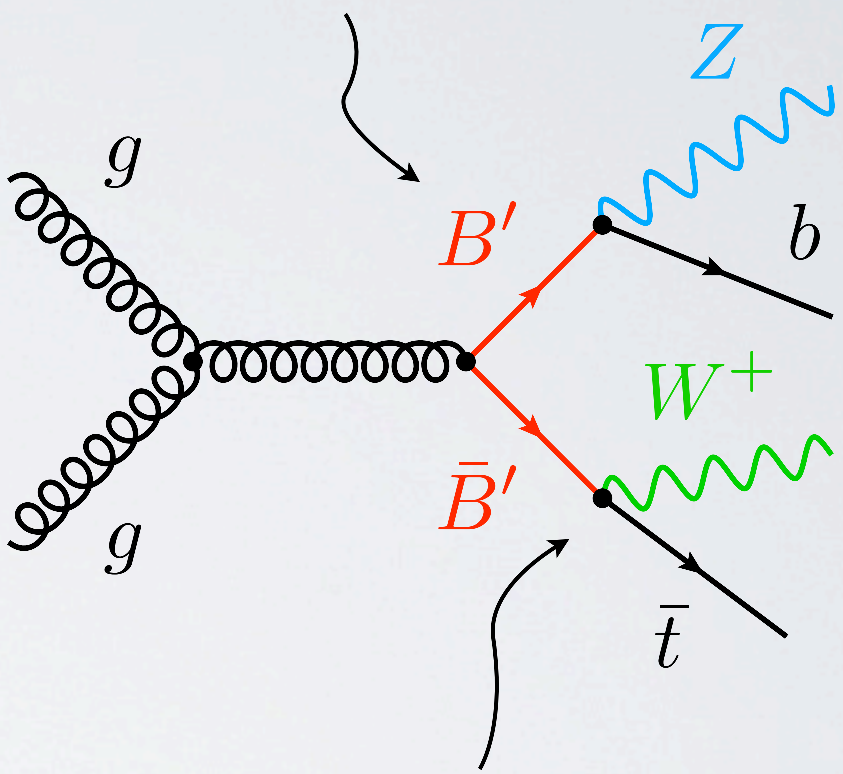
  - observation of new CP phases (flavor non-diagonal ones)
  - measurements of top-quark FCNCs ($t \to q\gamma$, $t \to qZ$, ...)
  - finding that vector-like matter decays undemocratically
  - ...

MFV predicts that there at least 3 vector-like down-type quarks



mass eigenstates decay predominantly to SM quarks of same generation (mixing of 3rd to 1st, 2nd family suppressed by at least $|V_{cb}|$ in MFV)

[Grossman *et al.*, arXiv:0706.1845; Arnold, Fornal & Trott, arXiv:1005.2185]

EXTENDED HIGGS SECTORS

- The main problem in extending the Higgs sector is how to get rid of excessive FCNCs. The generic Yukawa Lagrangian for 2HDM reads:

$$\mathcal{L}_{\text{Yukawa}} = \bar{Q}_L^i \,(X_{d1})_{ij}\, d_R^j \phi_d + \bar{Q}_L^i \,(X_{u2})_{ij}\, u_R^j \phi_u$$
$$+ \bar{Q}_L^i \,(X_{d2})_{ij}\, d_R^j \tilde{\phi}_u + \bar{Q}_L^i \,(X_{u1})_{ij}\, u_R^j \tilde{\phi}_d + \text{h.c.}$$

couplings to the "wrong" Higgs doublet
will generically induce tree-level FCNCs

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- There are two main strategies to get rid of this harmful effects

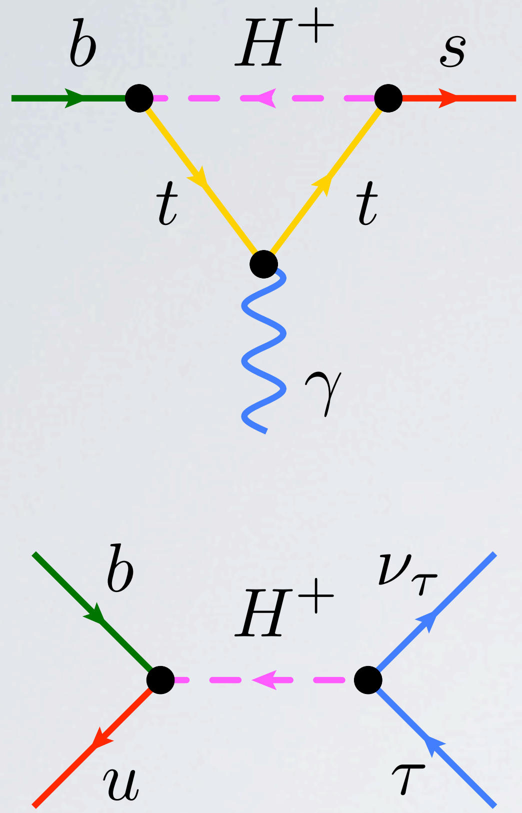
  i) By flavor-blind symmetries ("natural flavor conservation"): in case of 2HDM-II one uses a $U(1)_{PQ}/Z_2$ symmetry such that $X_{d2} = X_{u1} = 0$,

$$\phi_d \to -\phi_d \qquad d_R \to -d_R$$

remaining fields even under Z_2

[Glashow & Weinberg, Phys. Rev. D15, 1958 (1977); Paschos, Phys. Rev. D15, 1966 (1977)]

FCNC CONSTRAINTS ON 2HDM-II

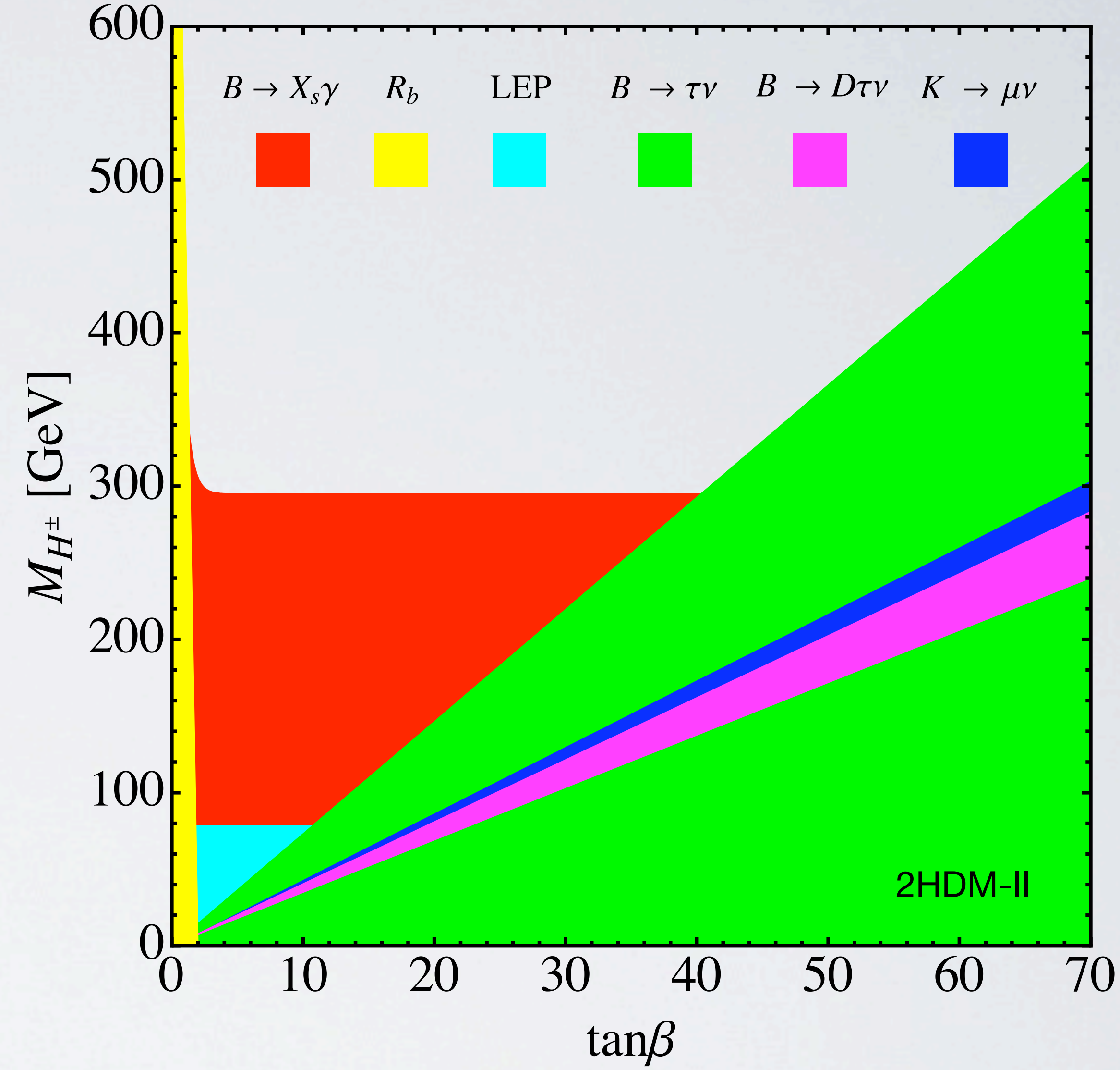


2HDM-II diagrams

$$\frac{m_t^2}{M_{H^\pm}^2} \ln \frac{m_t^2}{M_{H^\pm}^2}$$

$$\tan^2\beta \, \frac{m_B^2}{M_{H^\pm}^2}$$

$M_{H^\pm}$ dependence of amplitude



- Even though the effects of charged Higgs-boson loops in the 2HDM-II are necessarily constructive, the $\tan\beta$-independent bound following from $B \to X_s\gamma$ remains with $M_{H^\pm} > 295$ GeV at 95% CL very strong

[Misiak *et al.*, hep-ph/0609232; UH, arXiv:0805.2141]

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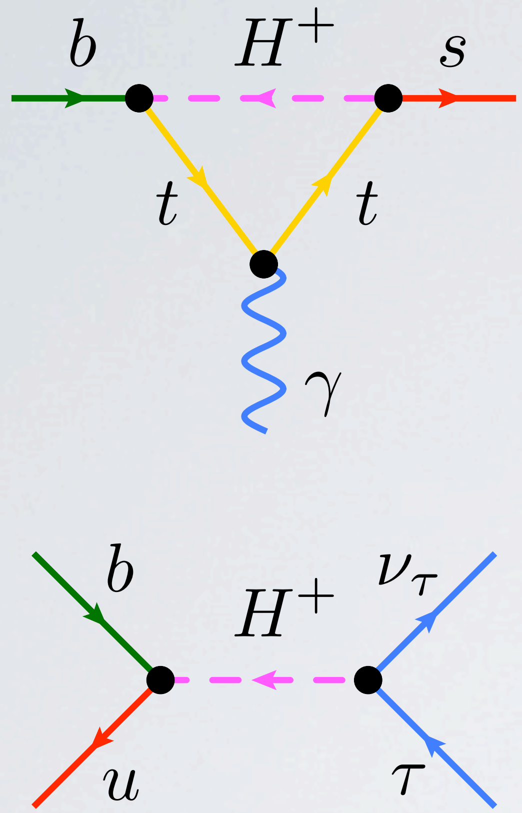

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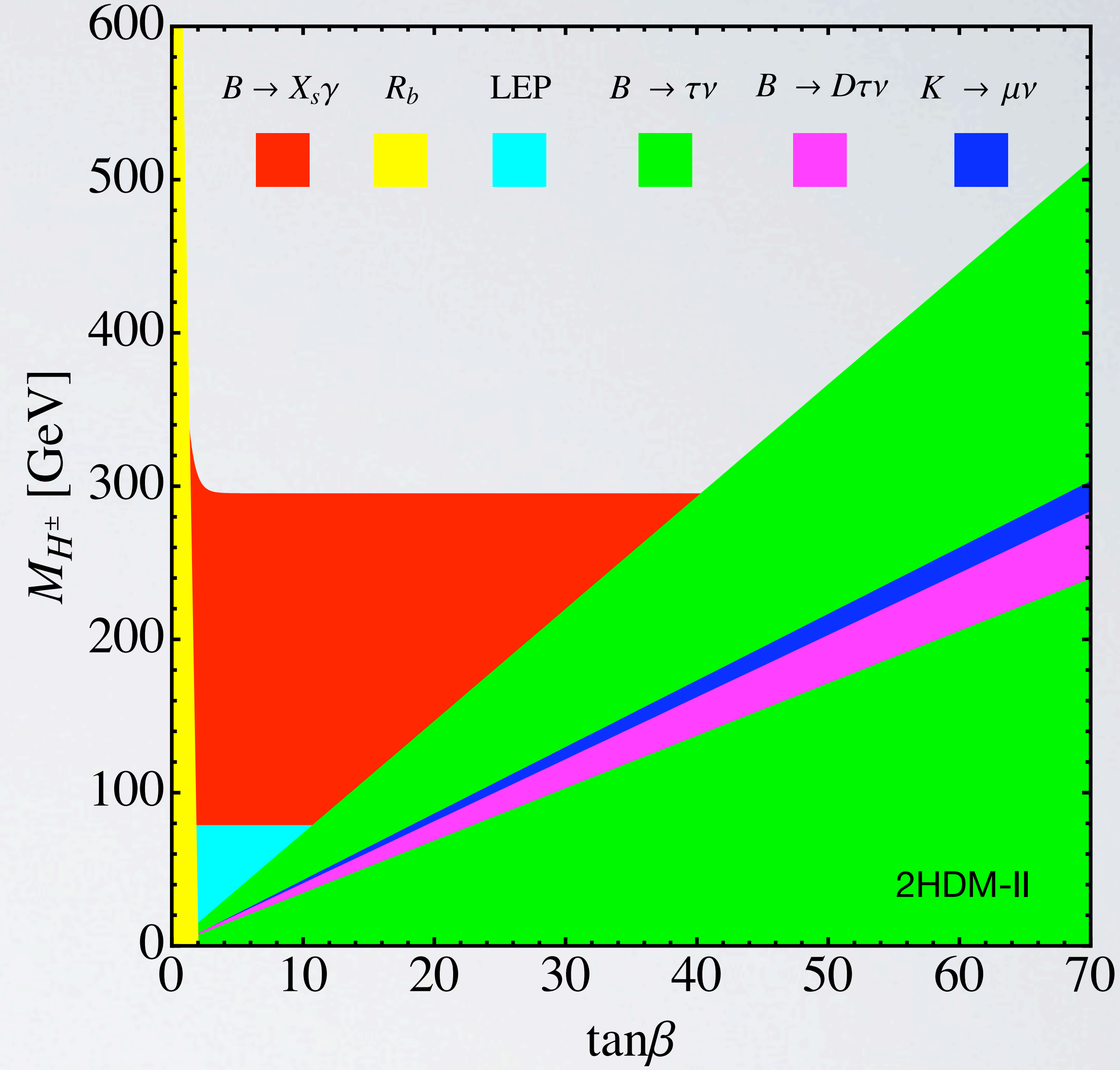

- In particular, B → $X_s\gamma$ still prevails over the large-tanβ enhanced decays B → τν, B → Dτν & K → μν for all values of tanβ below 40. Including all available flavor data disfavors a large portion of the parameter space

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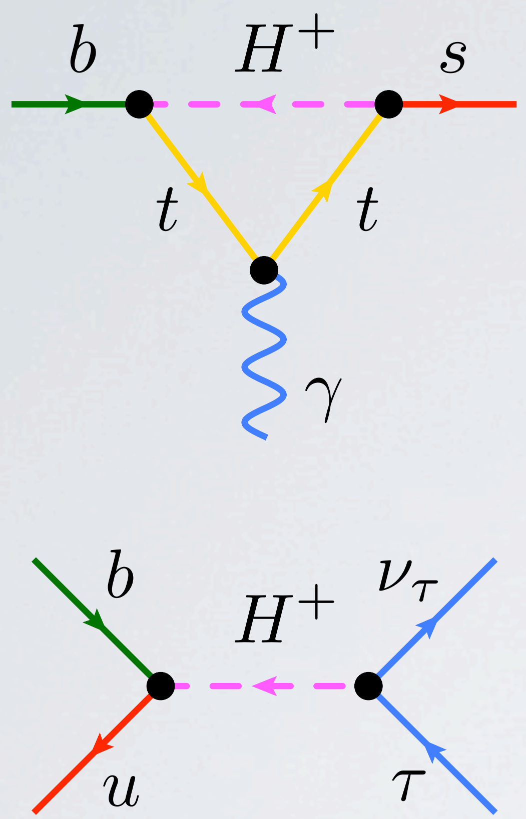

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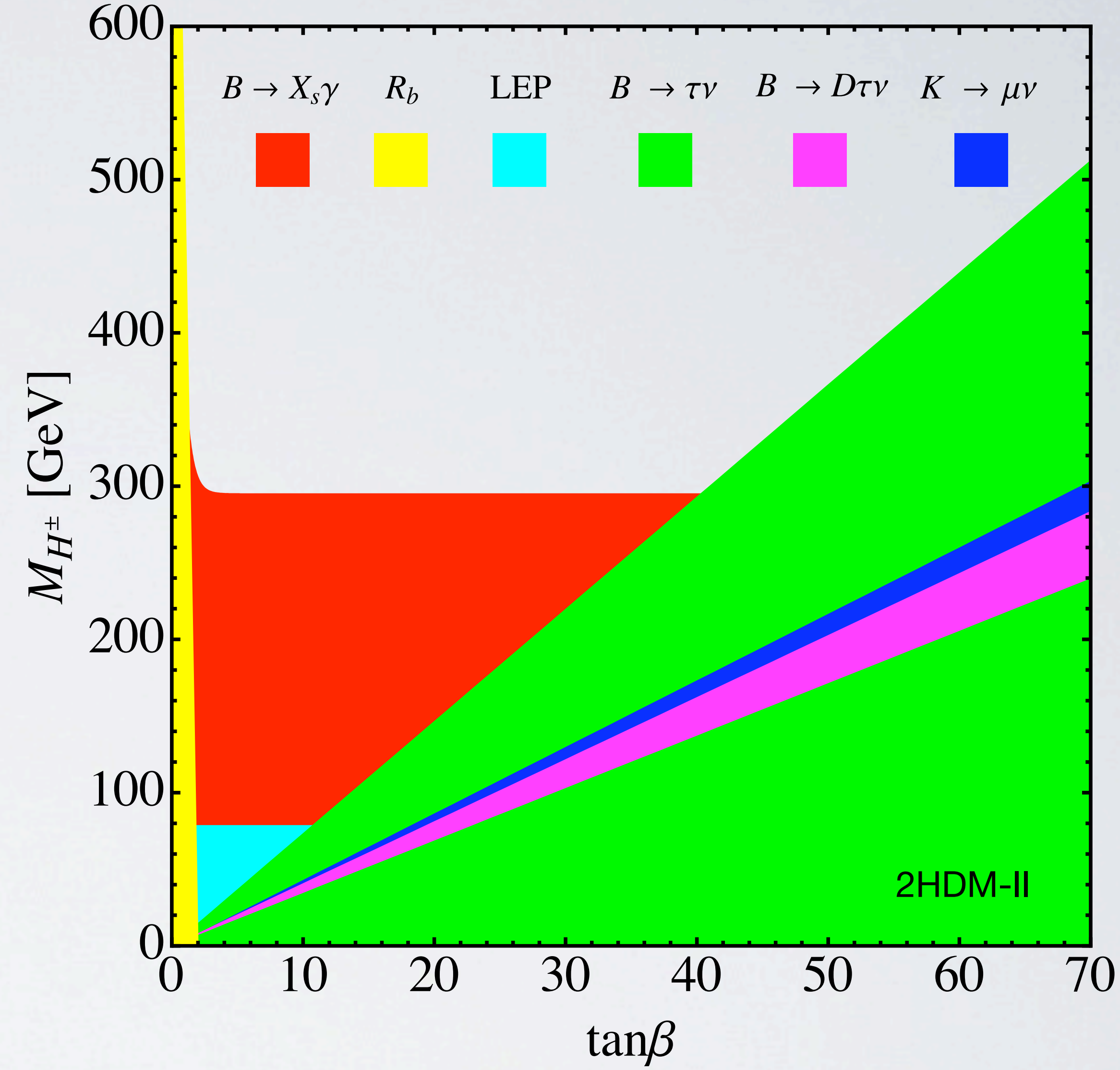
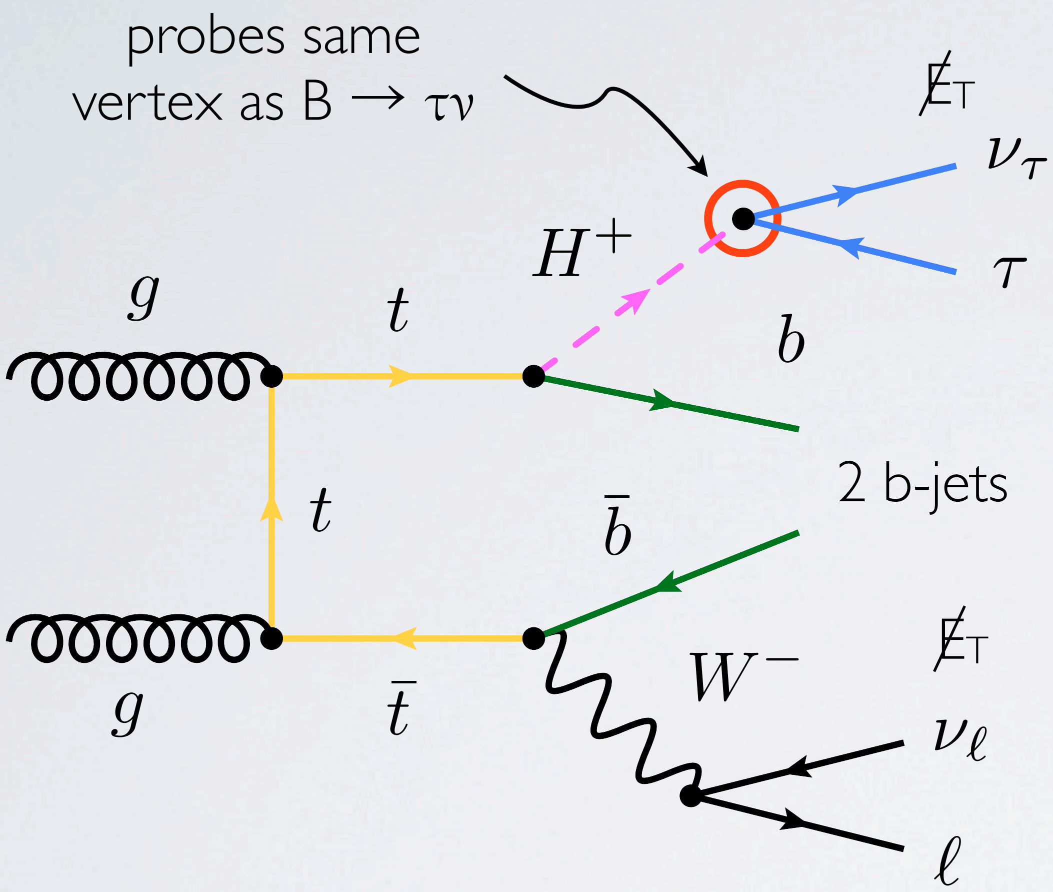
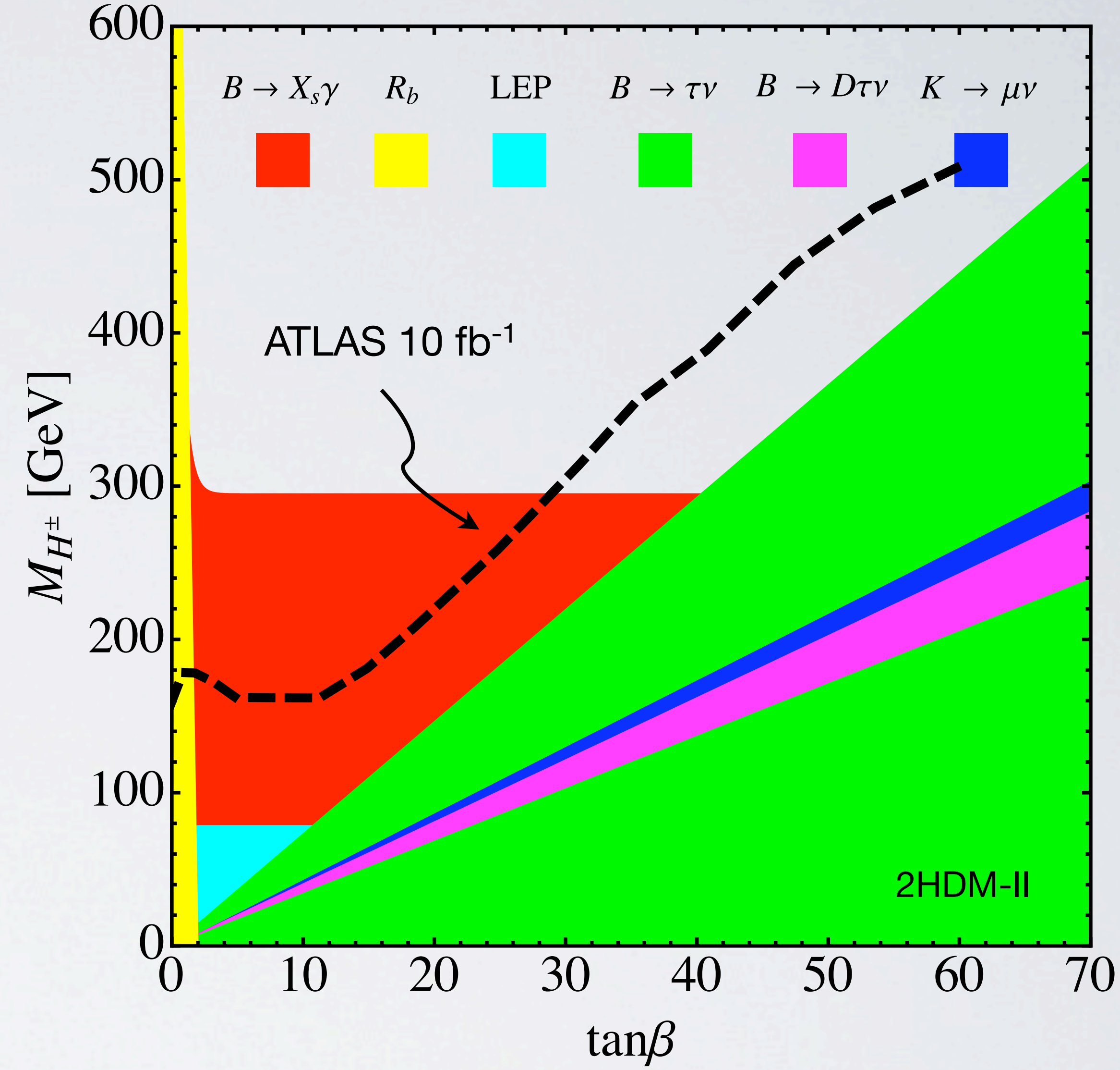


- In particular, $B \to X_s\gamma$ still prevails over the large-tanβ enhanced decays $B \to \tau\nu$, $B \to D\tau\nu$ & $K \to \mu\nu$ for all values of tanβ below 40. Including all available flavor data disfavors a large portion of the parameter space

<u>Exercise 7:</u> In which way does $R_b = \Gamma(Z \to b\bar{b})/\Gamma(Z \to \text{hadrons})$ depend on charged Higgs-boson mass?

HEAVY HIGGSES: FLAVOR & LHC INTERPLAY





- The current constraints on the 2HDM-II parameters that follow from flavor physics are comparable & thus complementary to the expected 95% CL exclusion limits of the LHC from gg/gb → t(b)H^+, $H^+ \to \tau\nu$/tb

[Robertson, talk SuperB Physics Workshop, Warwick; ATLAS Collaboration, arXiv:0901.0512]

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- There are two main strategies to get rid of this harmful effects

  ii) By flavor symmetries (& symmetry breaking): for example one can use MFV hypothesis, which guarantees that

$$X_{d1} \propto X_{d2} \qquad X_{u1} \propto X_{u2}$$

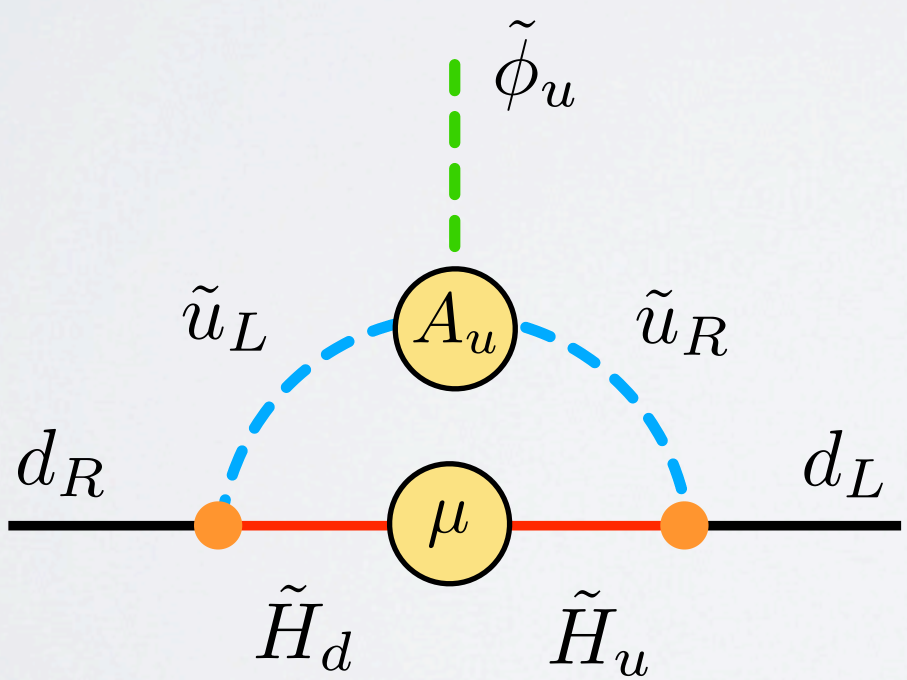
[see for example Babu & Nandi, hep-ph/9907213; Giudice & Lebedev, arXiv:0804.1753; Buras *et al.*, arXiv:1005.5310]

EXTENDED HIGGS SECTORS

- But both mechanism are not radiatively stable (problem is particularly severe if the theory contains additional dofs at the TeV scale):

  i) To avoid a massless pseudo-scalar field, the $U(1)_{PQ}$ Peccei-Quinn symmetry must be necessarily broken in the Higgs potential

MSSM diagram



Tree level:

$$X_{d2} = 0 \qquad X_{d1} = Y_d$$

One loop:

$$X_{d2} = \epsilon \Delta_d \qquad X_{d1} = Y_d + \ldots$$

even if $\varepsilon \approx 10^{-2}$ (typical loop suppression), FCNCs are too large unless Δ_d is very small or aligned with Y_d

[see for example Hall, Rattazzi & Sadrid, hep-ph/9306309]

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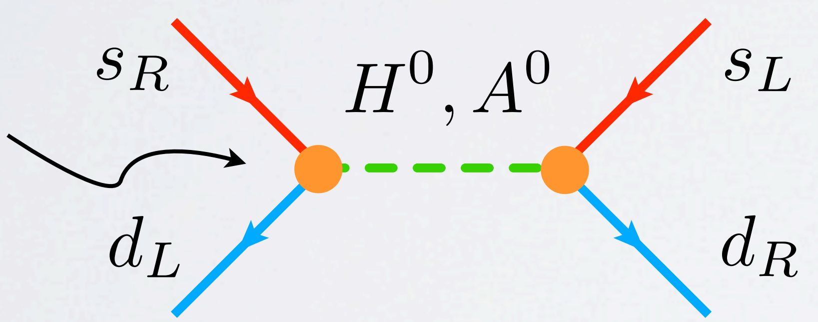
strongest constraint arises from CP violation in neutral kaon system

vertex containing SUSY effects



$$|\epsilon|\ \left|\mathrm{Im}\left[(\Delta_d^*)_{21}(\Delta_d)_{12}\right]\right|^{1/2} \lesssim 3\cdot 10^{-7}\,\frac{M_A}{100\,\mathrm{GeV}}\,\cos\beta$$

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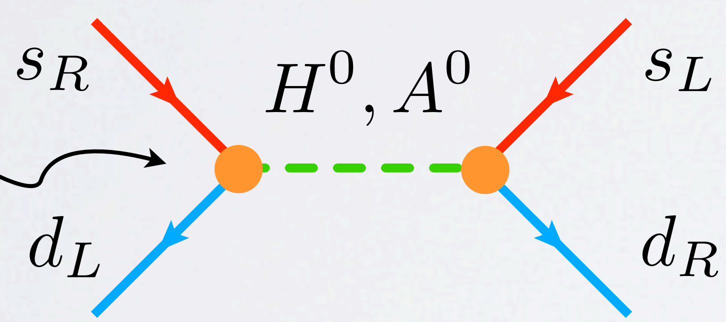

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Exercise 8: Give arguments why the shown diagram is particularly dangerous

EXTENDED HIGGS SECTORS

- But both mechanism are not radiatively stable (problem is particularly severe if the theory contains additional dofs at the TeV scale):

ii) Even if exact (discrete case), symmetries do not protect FCNCs when higher-dimensional operators are taken into account

$$\Delta\mathcal{L}_{\mathrm{Yukawa}} = \frac{c_D}{\Lambda^2}\,\bar{Q}_L i\not{D} Q_L(\phi^\dagger\phi) + \frac{c_\phi}{\Lambda^2}\,\bar{Q}_L\phi d_R(\phi^\dagger\phi) + \ldots$$

[Giudice & Lebedev, arXiv:0804.1753; Agashe & Contino, arXiv:0906.1542; Azatov, Toharia & Zhu, arXiv:0906.1542]

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EWSB: ϕ = v + h

chirally suppressed

unsuppressed

$$\Delta M_d = -v\,(\underbrace{c_D Y_d}_{\text{chirally suppressed}} + \underbrace{c_\phi}_{\text{unsuppressed}})\,\frac{v^2}{\Lambda^2} + \ldots$$

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mismatch leads to Higgs-boson FCNCs (already for one Higgs doublet)

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Exercise 9: Can you think of a symmetry that forbids the chirally unsuppressed operator?

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  ii) Even if exact (discrete case), symmetries do not protect FCNCs when higher-dimensional operators are taken into account

$$\Downarrow$$

To reach a sufficient protection of Higgs FCNCs one needs to protect the flavor-symmetry breaking . Possible ways to achieve such a protection is provided by Froggatt-Nielsen mechanism, partial compositeness (hierarchical fermion profiles), MFV, ...

WHEN IS NEW PHYSICS MFV?

The origin of the flavor structure has to be decoupled from new-physics scale:

$$\Lambda_\mathrm{F} \gg \Lambda$$

Below the flavor scale, the new interactions have to be flavor blind (or their flavor structure has to resemble the one in the SM)

It follows that little can be learned about the origin of flavor at the LHC, ...

MFV MSSM

- The MSSM with unbroken supersymmetry (SUSY) is MFV. So if the SUSY breaking (SB) is flavor blind the MSSM will be MFV

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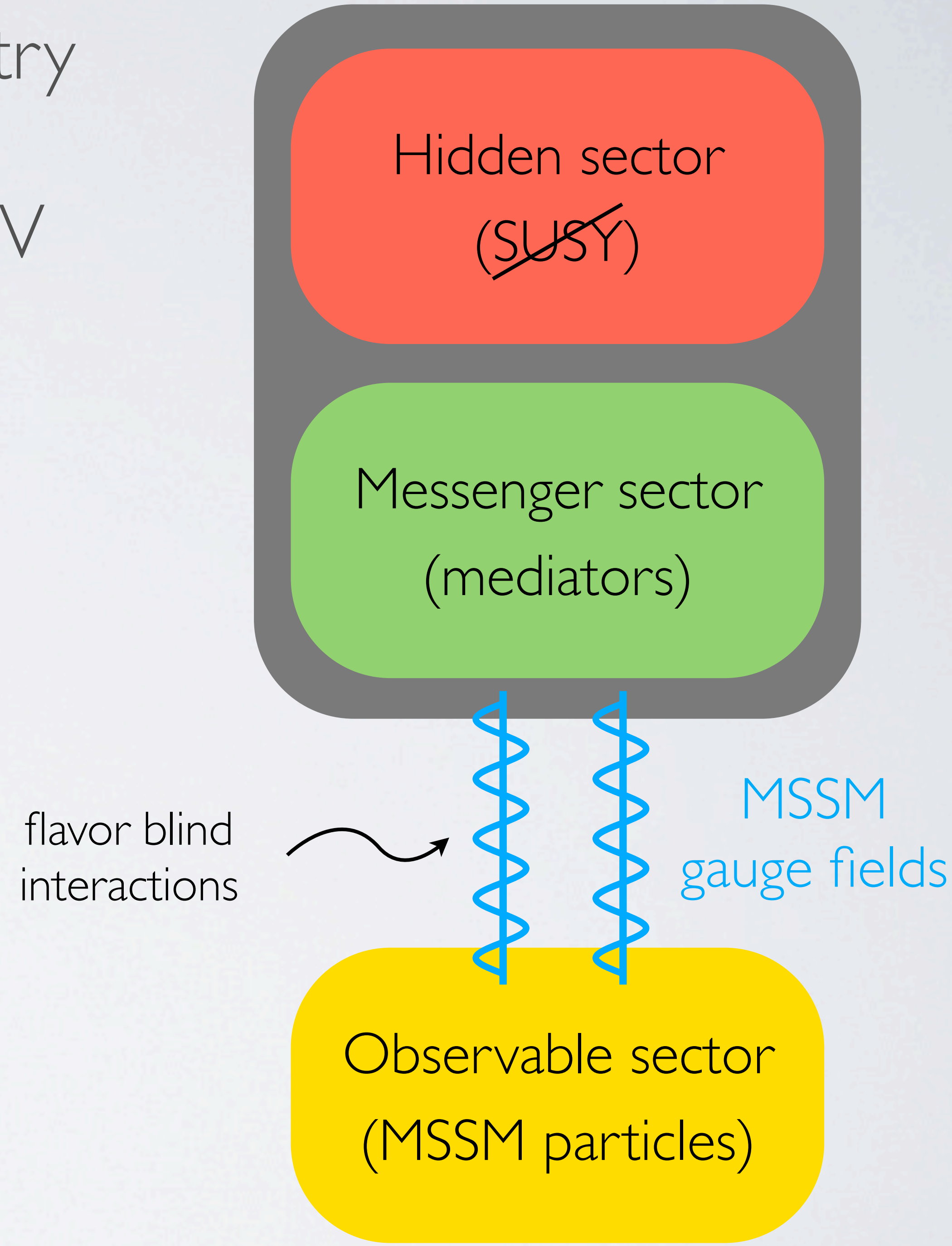
- In models with gauge-mediated SB (GMSB), soft terms are generated at the messenger scale Λ_M. If $\Lambda_M << \Lambda_F$, soft terms feel flavor breaking only through Yukawa interactions. The flavor-violating effects in soft terms then correspond to operators $d \geq 5$, suppressed by powers of Λ_M/Λ_F (GMSB = MFV with super-GIM)



[for a review see Giudice & Rattazzi, hep-ph/9801271]

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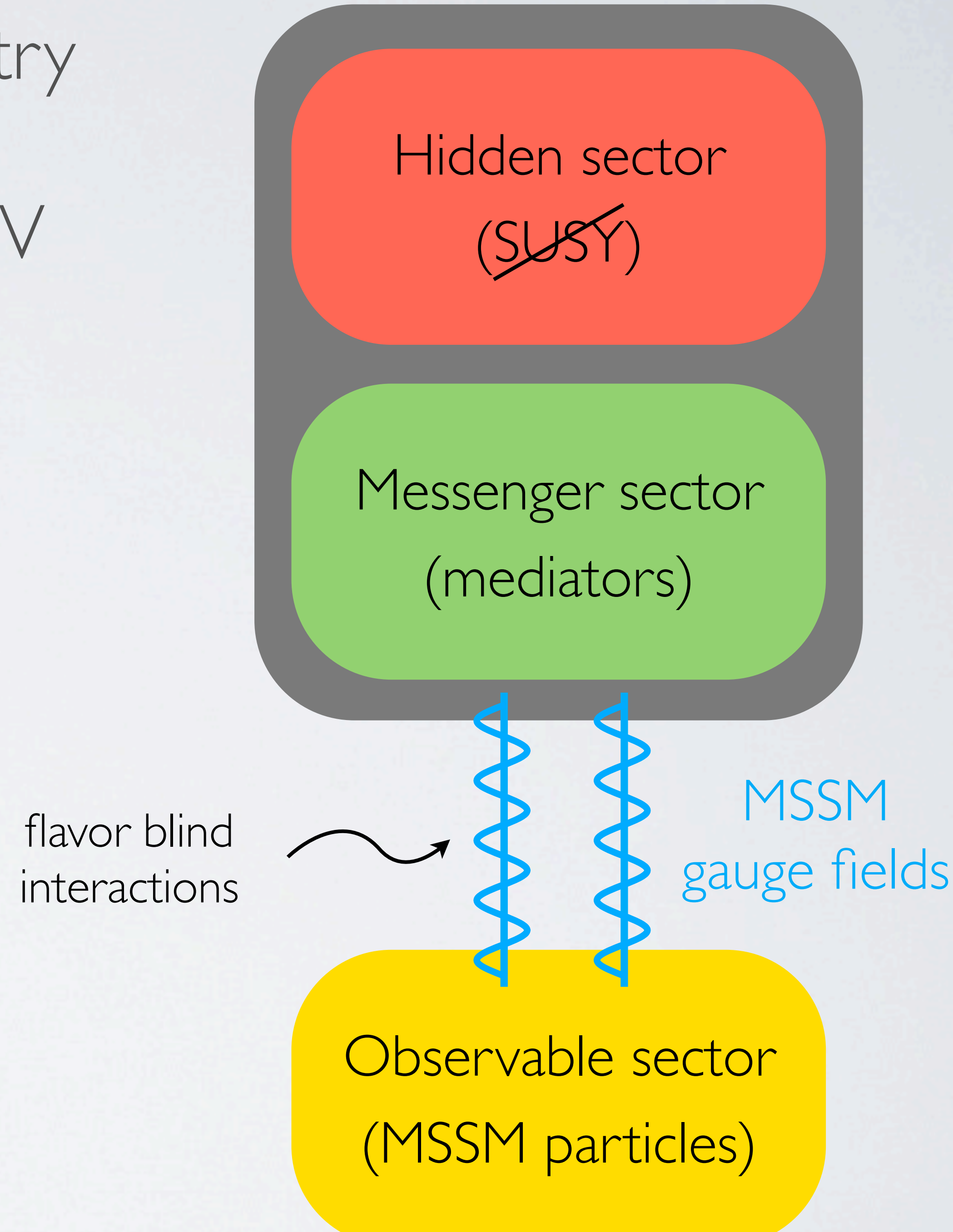
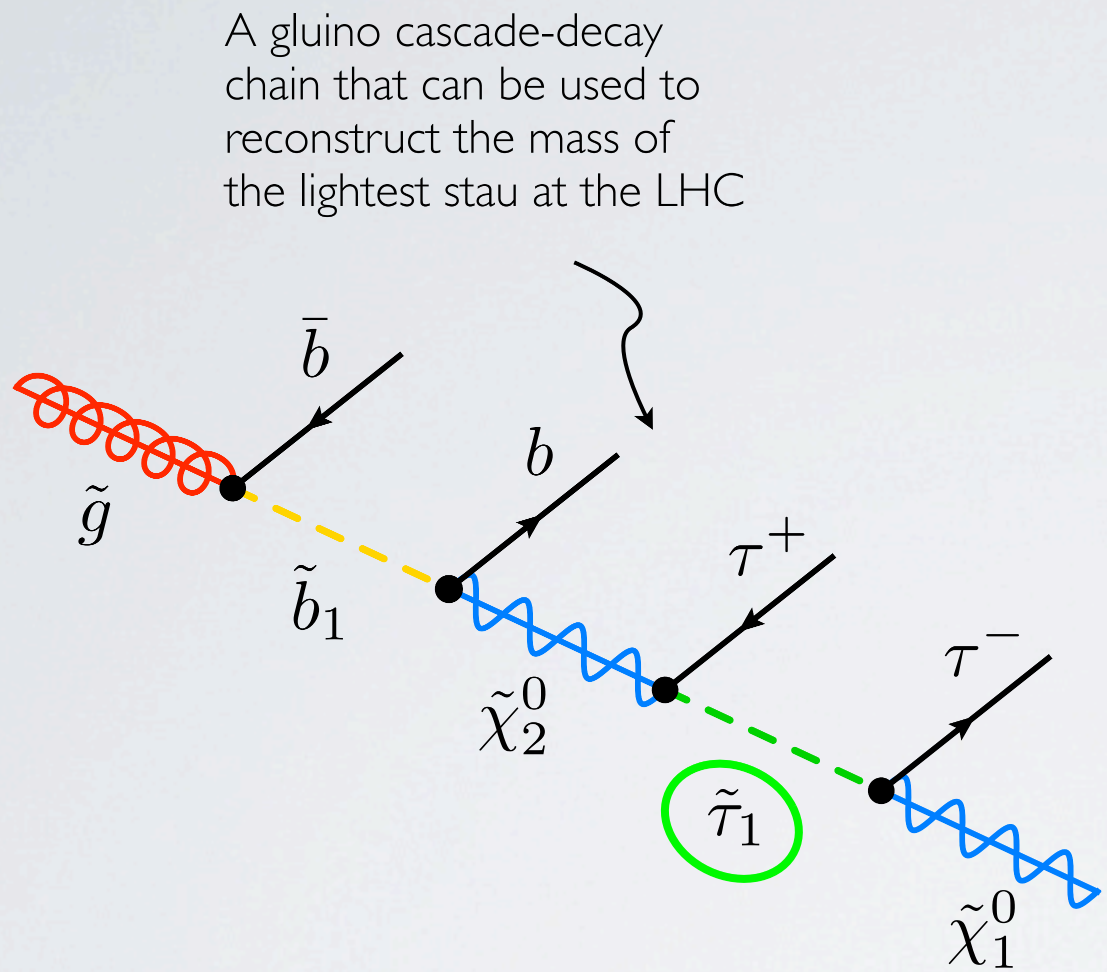
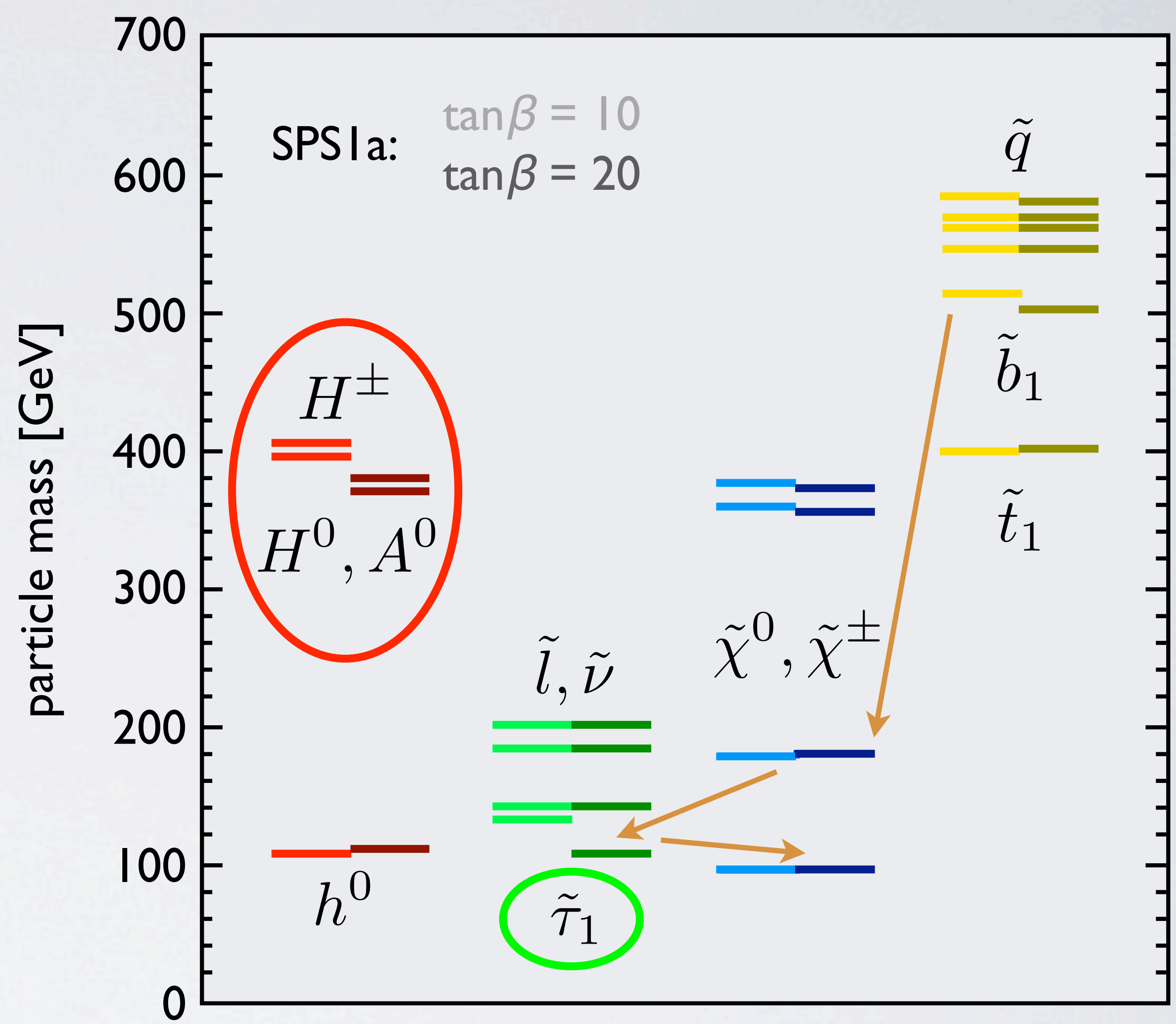
- If gravity mediates SB, soft terms arise at the Planck scale, $M_{Pl} > \Lambda_F$. There is hence no obvious reason why SB masses for squarks should be flavor-invariant. Minimal supergravity (mSUGRA), which solves SUSY flavor problem by assuming universality of scalar masses (an assumption without strong justification) is thus very special



[for a review see Martin, hep-ph/9709356]

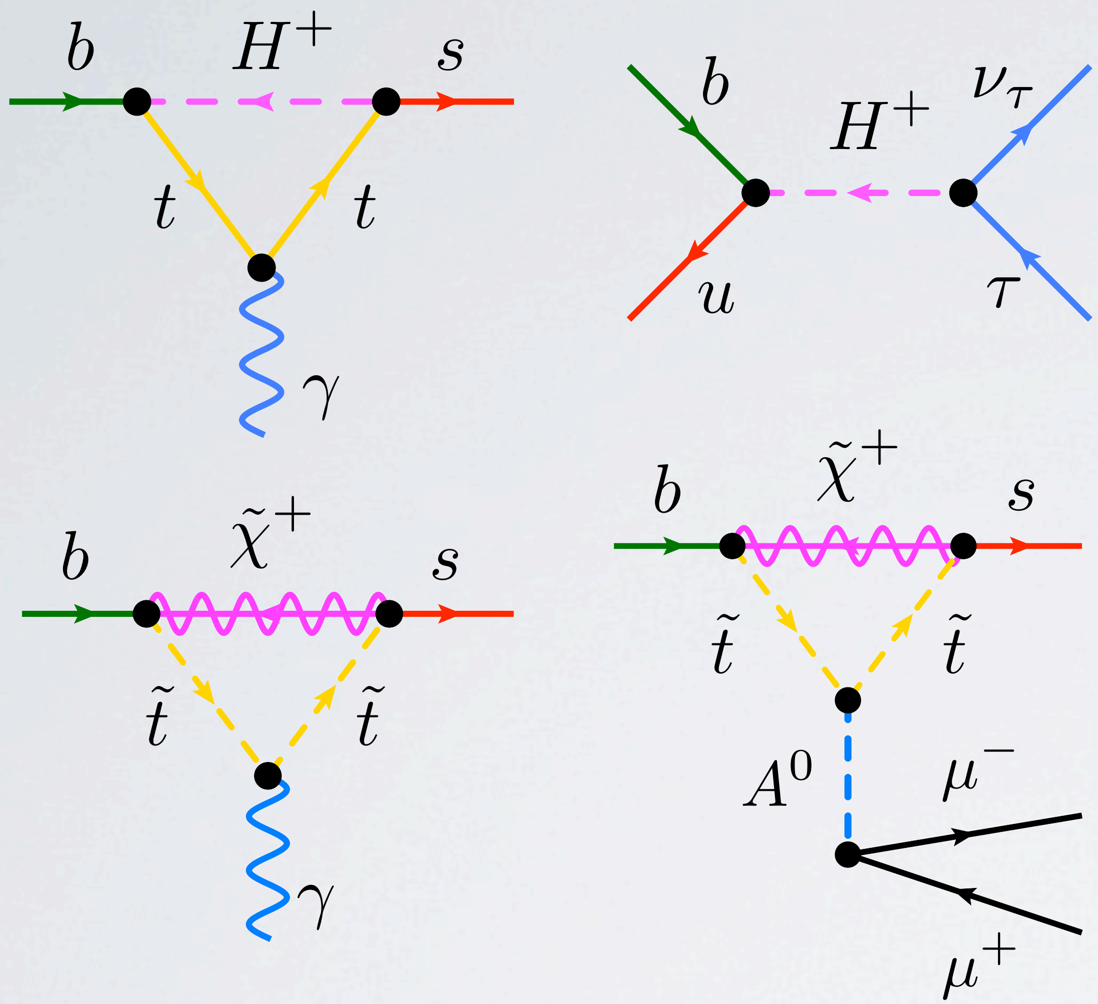
MSUGRA: FLAVOR & LHC INTERPLAY



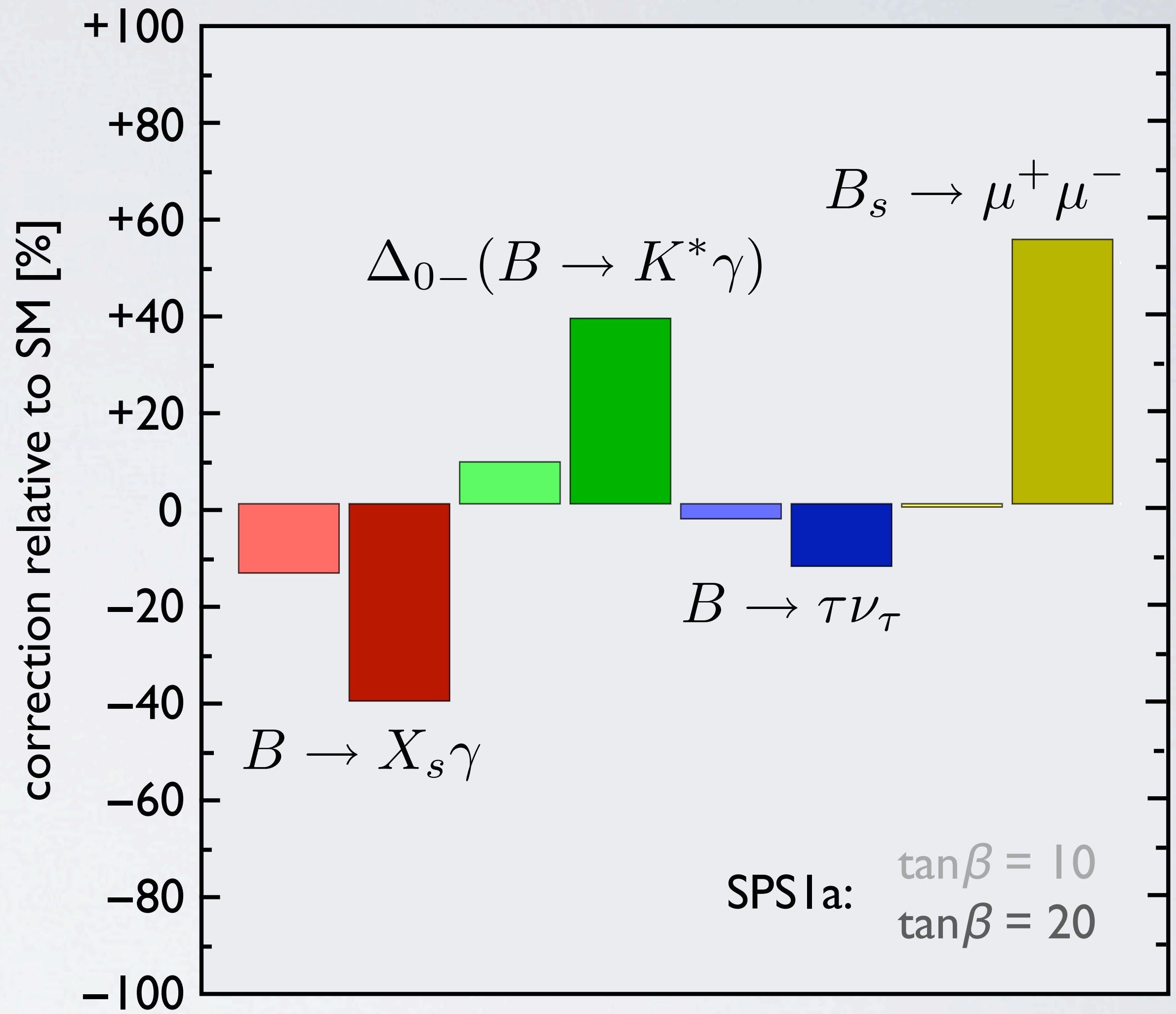


- Apart from masses of heavy Higgses and lightest stau, mSUGRA spectrum does not change much with tanβ. For SPS1a, SM decay modes of Higgses hard to detect at the LHC and stau mass can be measured with precision of 20% at best. As a result, the LHC sensitivity to tanβ is rather restricted

MSUGRA: FLAVOR & LHC INTERPLAY



mSUGRA diagrams



- Rare and radiative B decays are quite sensitive to tanβ (both branching fractions & isospin asymmetries). By measuring correlated shifts in the observables one can determine tanβ with 10% accuracy. This exceeds by far LHC sensitivity based on the discovery of the stop, A^0 & the light Higgs

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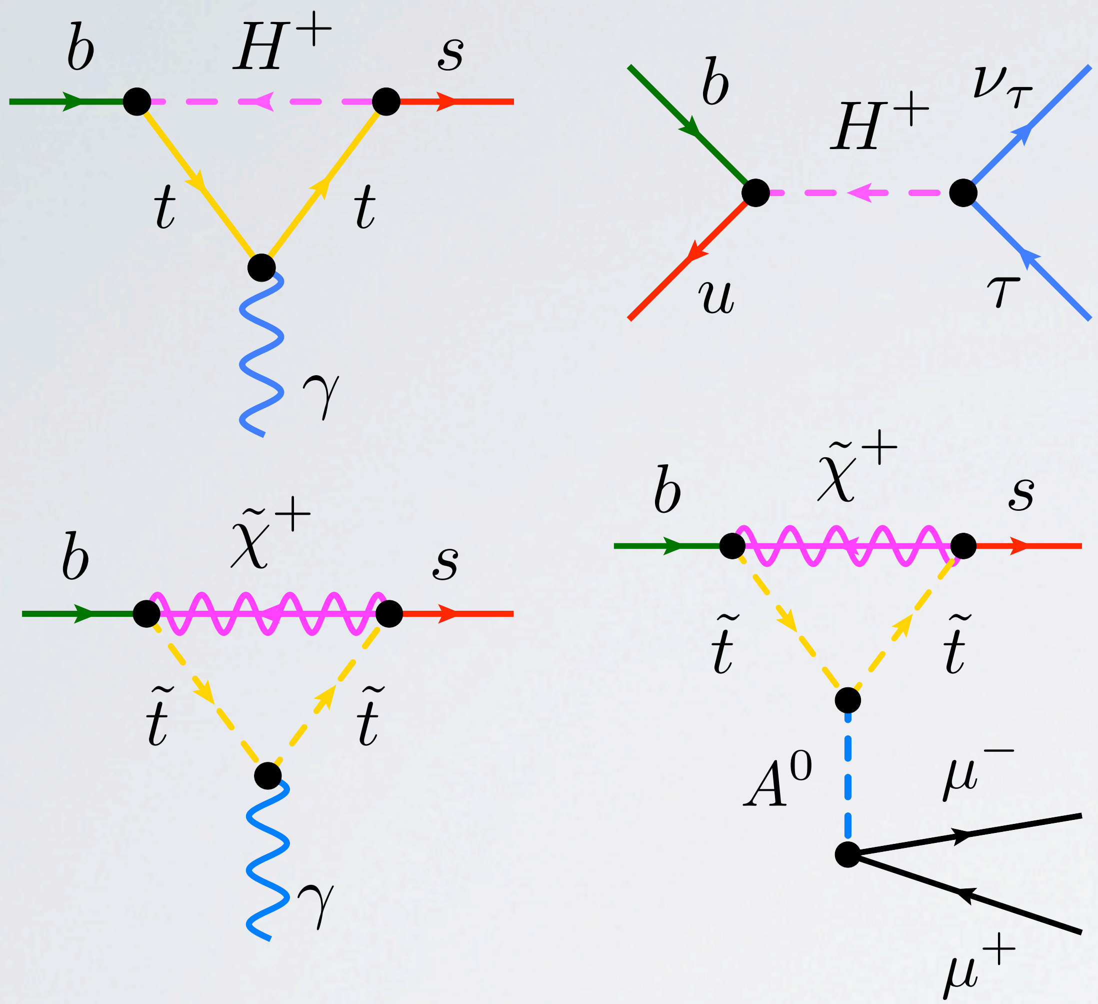

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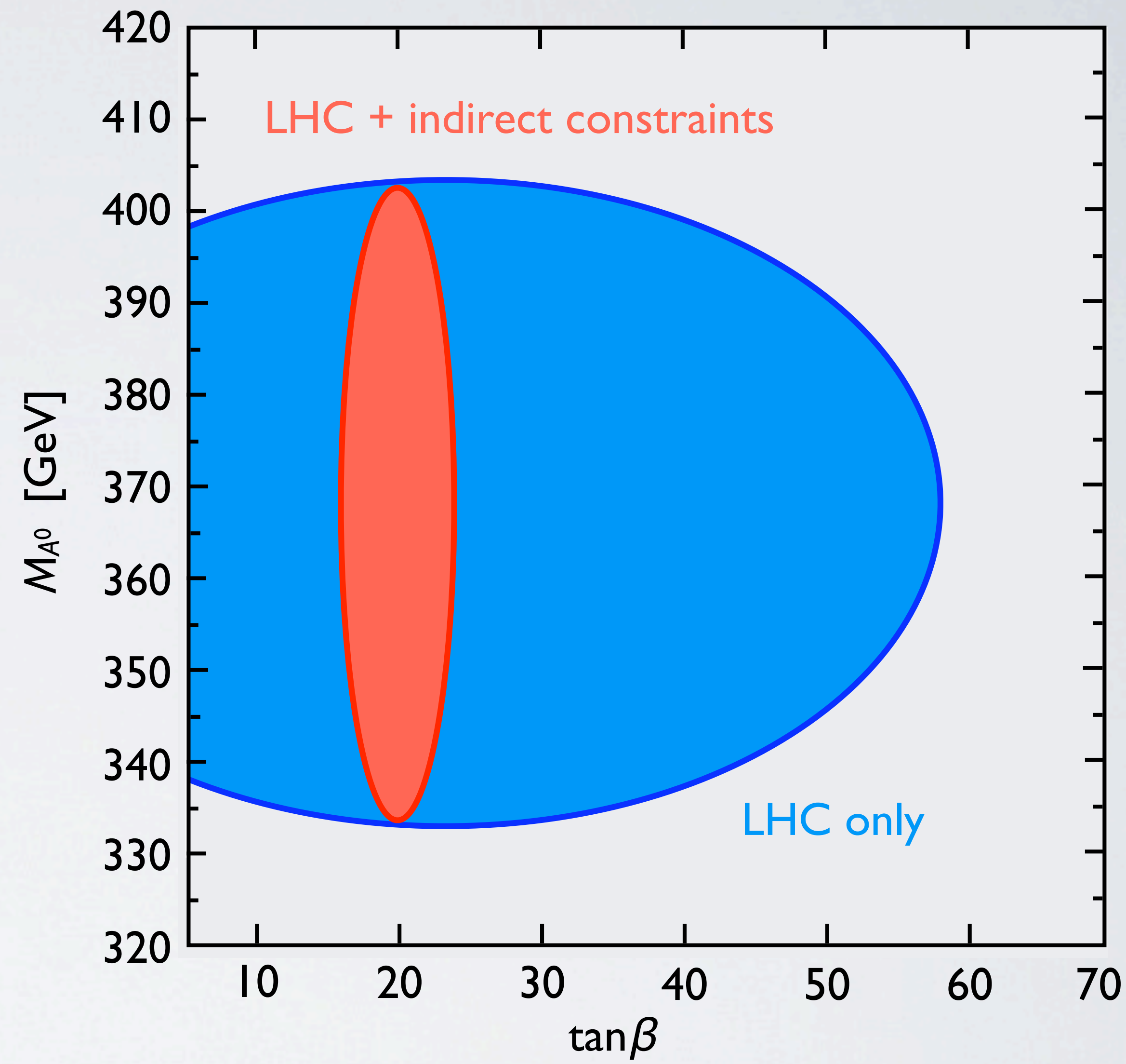

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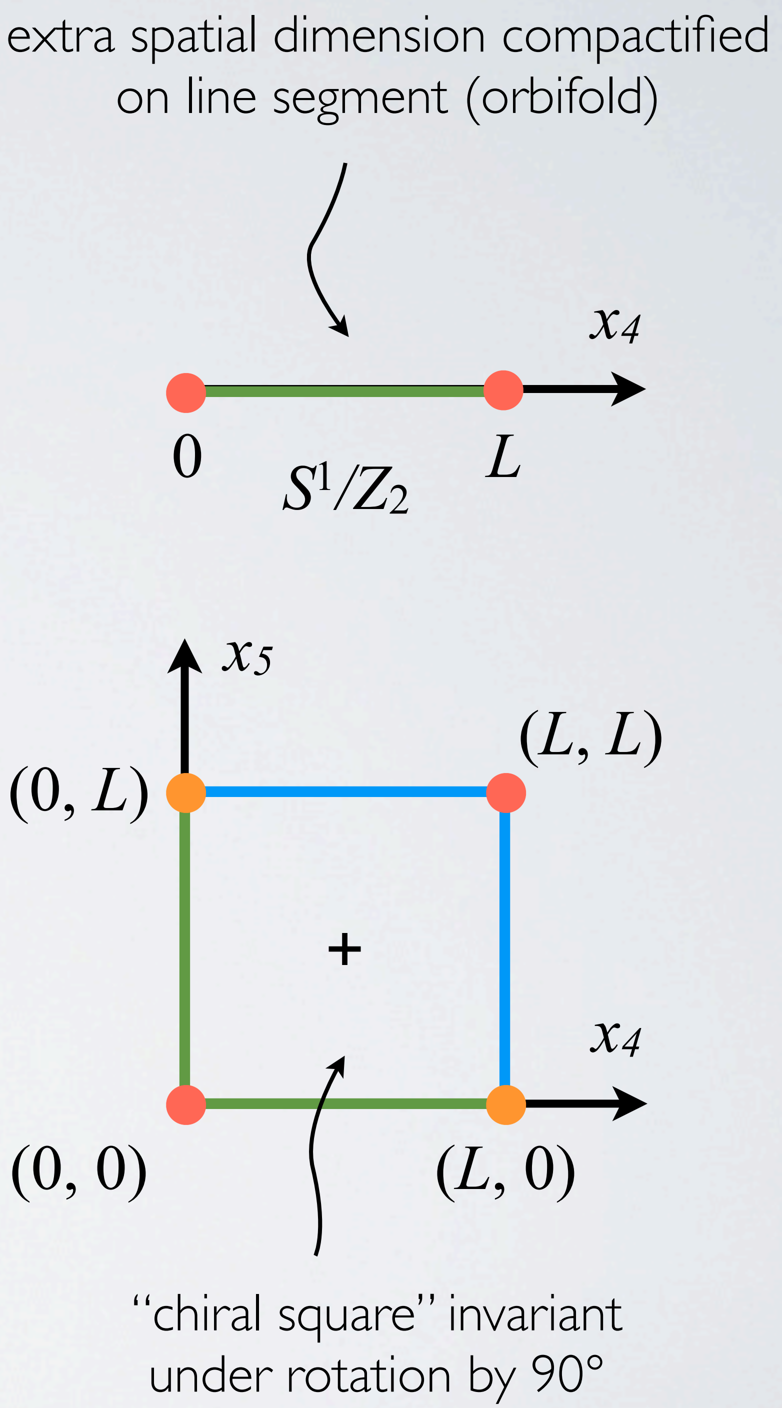
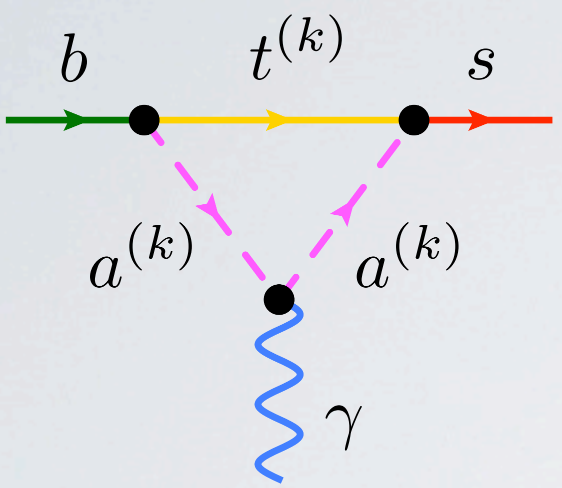
OTHER MFV MODELS

- Alternatives to MFV SUSY typically require an appropriate UV completion. Possible (*ad hoc*) constructions are:
  - mUED models in 5D & 6D

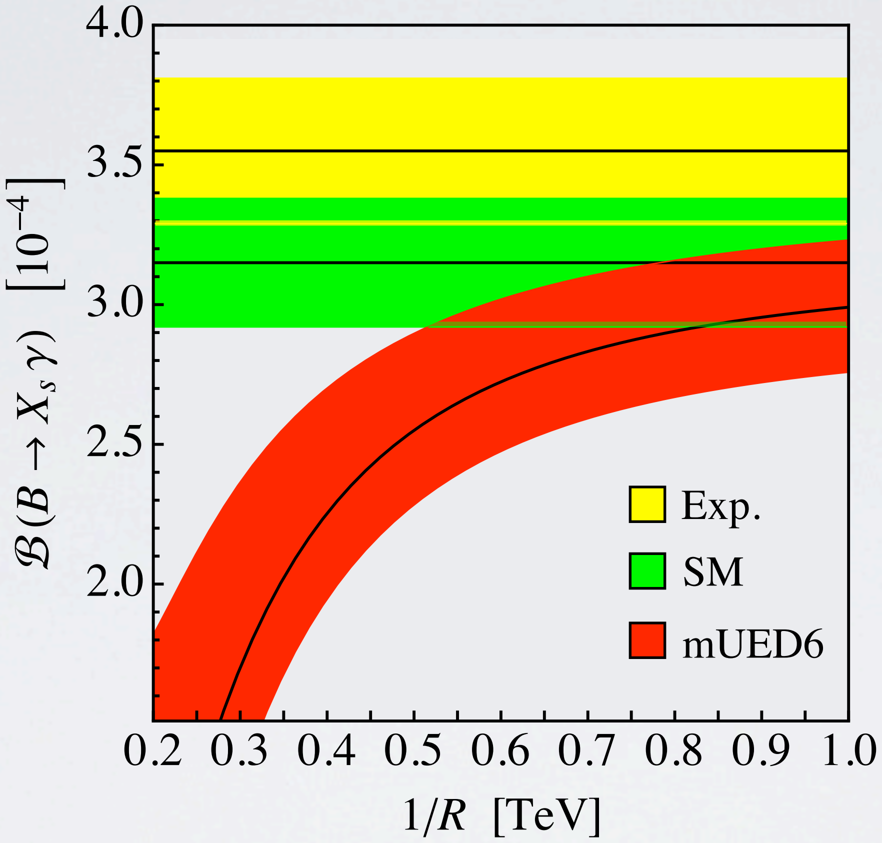


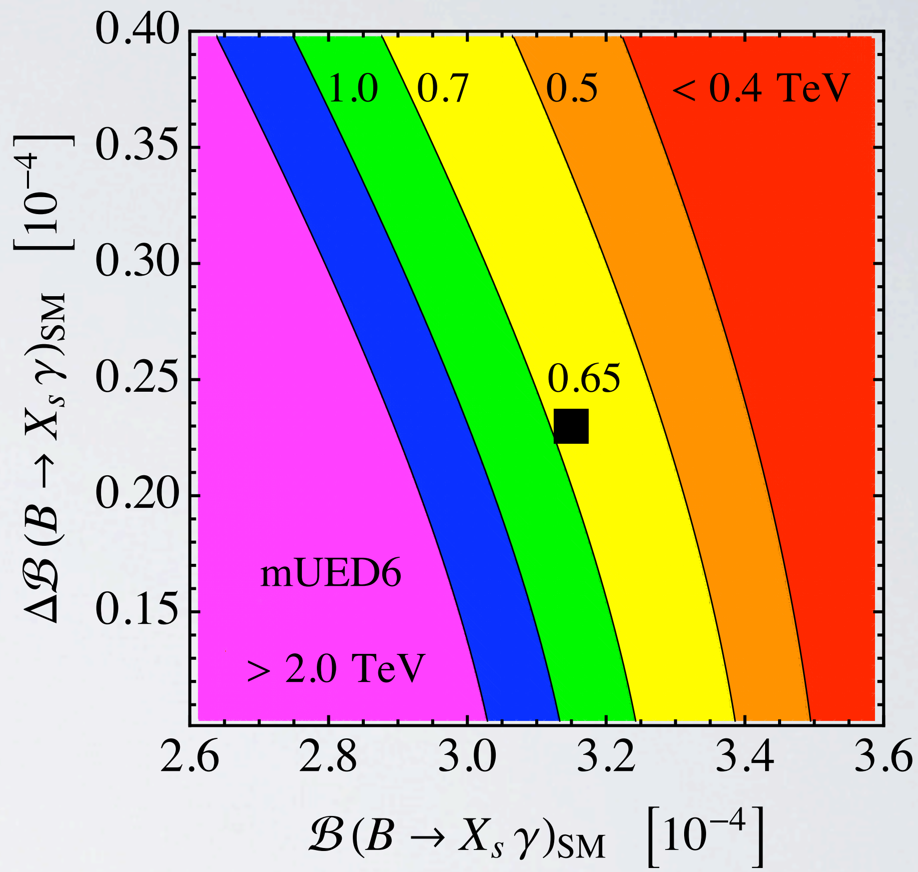
[Buras *et al.*, hep-ph/0212143, hep-ph/0306158; UH & Weiler, hep-ph/0703064; Freitas & UH, arXiv:0801.4346]

MAIN FLAVORFUL FINDING IN MUED MODELS



mUED photon pinguin



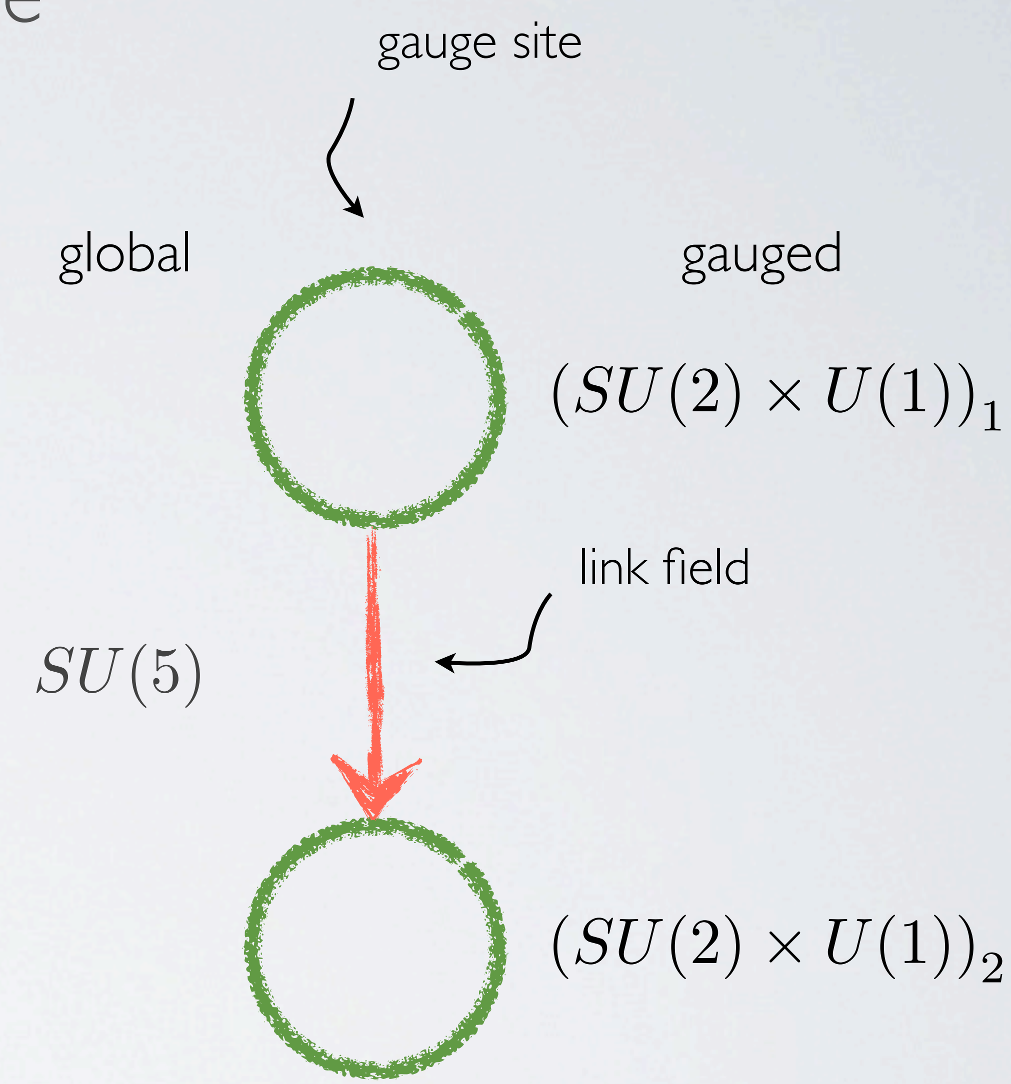


- In mUED scenarios, Kaluza-Klein (KK) contributions always reduce $B \to X_s\gamma$ rate relative to SM. This allows to derive most stringent limits on KK scale 1/R > 600, 650 GeV in 5D & 6D mUED. In case of 6D mUED, obtained limit is at variance with the bound from dark matter, 1/R < 500 GeV

[UH & Weiler, hep-ph/0703064; Freitas & UH, arXiv:0801.4346]

OTHER MFV MODELS

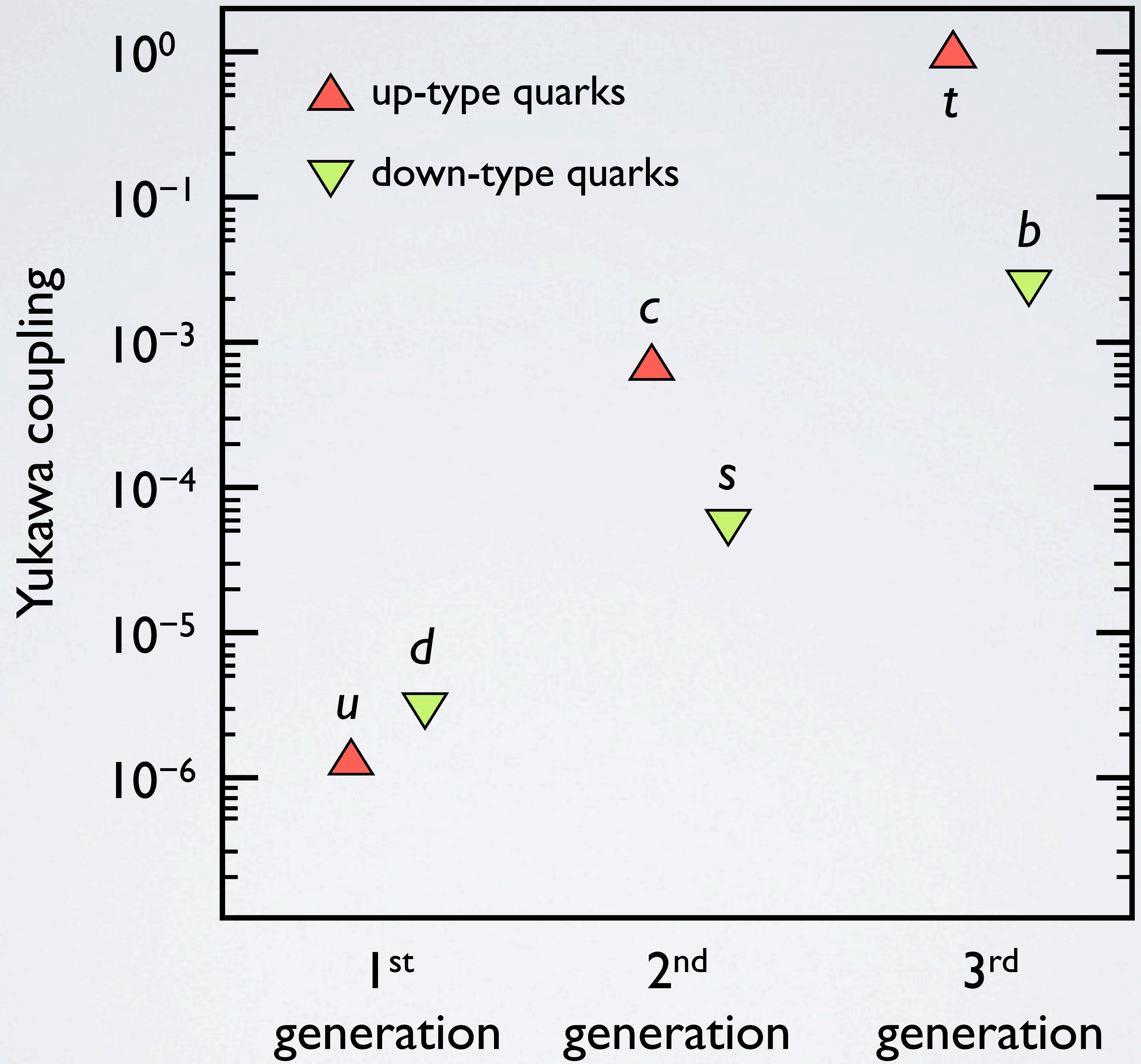
- Alternatives to MFV SUSY typically require an appropriate UV completion. Possible (*ad hoc*) constructions are:
  - mUED models in 5D & 6D
  - littlest Higgs model without T-parity
  - ...



"moose diagram" of littlest Higgs model based on SU(5)/SO(5)

[Buras, Poschenrieder & Uhlig, hep-ph/0410309, hep-ph/0501230; Bardeen *et al.*, hep-ph/0607189]

WHO ORDERED THIS?

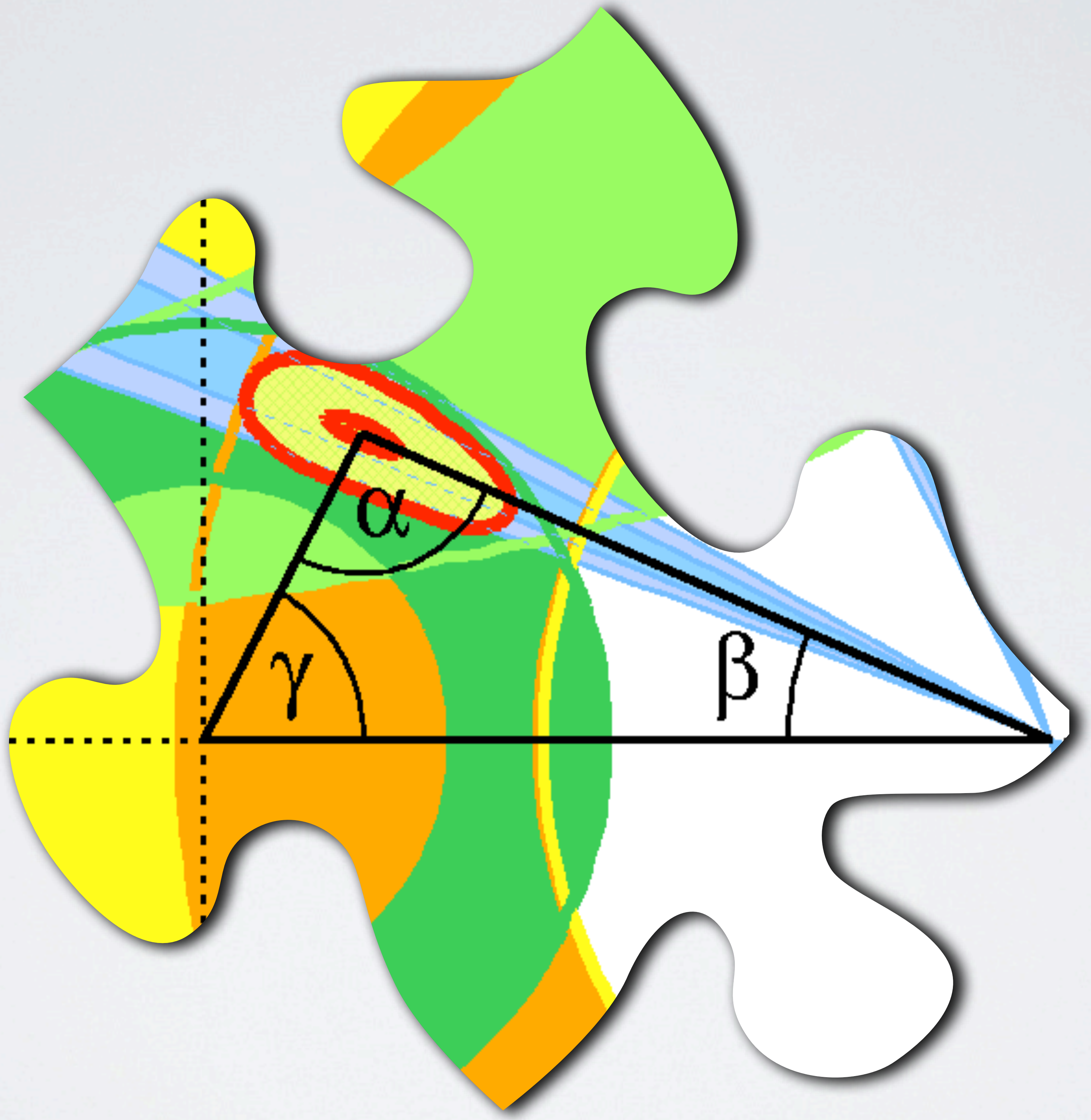


WHO ORDERED THIS?

$$\boldsymbol{V}_{\mathrm{CKM}} \approx \begin{array}{cc} \begin{array}{ccc} d & s & b \end{array} & \\ \begin{pmatrix} 1 & \lambda & \lambda^3 \\ -\lambda & 1 & \lambda^2 \\ -\lambda^3 & -\lambda^2 & 1 \end{pmatrix} & \begin{array}{c} u \\ c \\ t \end{array} \end{array}$$

$\lambda \approx 0.23$, Cabibbo angle

WHO ORDERED THIS?



UNDERLYING PRINCIPLE?

$$Y_d \approx \mathrm{diag}\left(10^{-5}, 0.0005, 0.026\right)$$

$$Y_u \approx \begin{pmatrix} 10^{-5} & -0.002 & 0.007 + 0.004i \\ 10^{-6} & 0.007 & -0.04 + 0.0008i \\ 10^{-8} + 10^{-7}i & 0.0003 & 0.96 \end{pmatrix}$$

- The feature that all the SM flavor parameters are small & hierarchical (compared to $g_1 \approx 0.3$, $g_2 \approx 0.6$, $g_3 \approx 1$ & $\lambda_{\mathrm{Higgs}} \approx 1$) begs for a new-physics explanation. The same new dynamics should (in the best of all worlds) simultaneously solve the flavor problem in a natural way

HIERARCHIES FROM SYMMETRIES

- To explain the hierarchies in the quark sector, the Froggatt-Nielsen (FN) mechanism employs a global $U(1)_F$ flavor (horizontal) symmetry:

$$(\widetilde{Y}_d)_{ij} \left(\frac{\Phi_F}{\Lambda_F} \right)^{-Q_i + d_j} \bar{Q}_L^i d_R^j \phi$$

$U(1)_F$ spontaneously broken by vacuum expectation value (VEV) of flavon field Φ_F (gauge singlet with $m_F \approx \Lambda_F$, $q_F = -1$)

$$\langle \Phi_F \rangle = F$$

$$(Y_d^{\rm eff})_{ij} = (\widetilde{Y}_d)_{ij}\, \epsilon^{-Q_i + d_j} \qquad \epsilon = \frac{F}{\Lambda_F} \ll 1$$

effective down-type Yukawa coupling = Y_d

$U(1)_F$ charges of Q_L^i, d_R^j

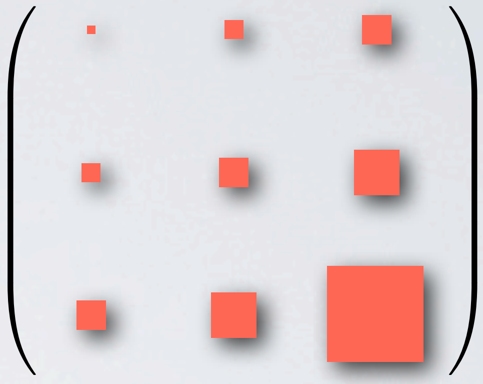
small parameter needed to explain hierarchies

[Froggatt & Nielsen, Nucl. Phys. B147, 277 (1979)]

QUARK MASSES & MIXINGS

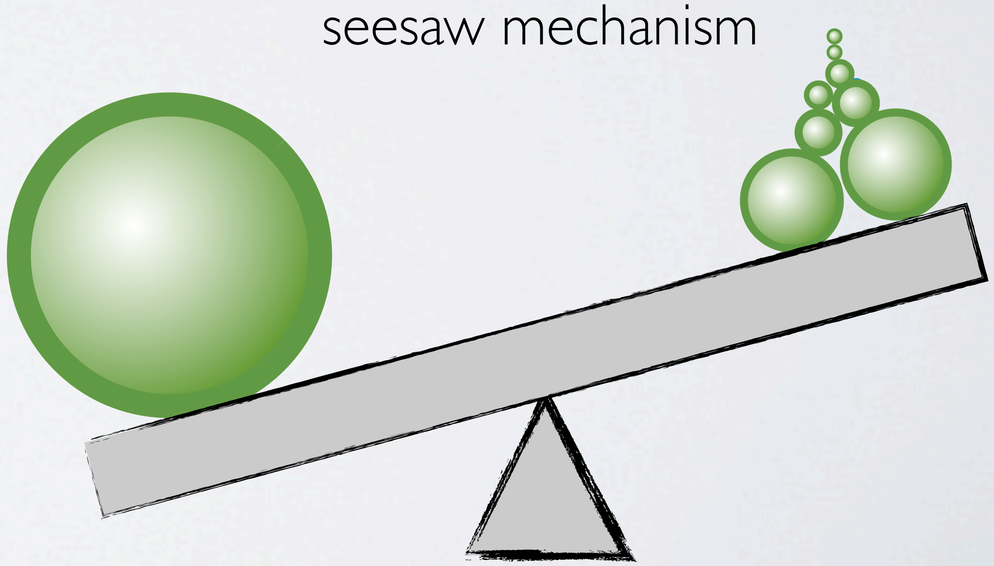
- The SM quark mass matrices are then given by

$$M_{d,u} = \frac{v}{\sqrt{2}}\,\mathrm{diag}\left(\epsilon^{Q_i}\right)\widetilde{Y}_{d,u}\,\mathrm{diag}\left(\epsilon^{d_i,u_i}\right) =$$



where $\widetilde{Y}_{d,u}$ are structureless, complex matrices (not SM Yukawas) with elements of O(1), called anarchic & $\varepsilon_{Q_i} < \varepsilon_{Q_j}$, $\varepsilon_{d_i,u_i} < \varepsilon_{d_j,u_j}$ for $i < j$

- In mathematical analogy, to the seesaw mechanism of neutrinos, matrices of this form give rise to hierarchical mass eigenvalues & mixing matrices



[Froggatt & Nielsen, Nucl. Phys. B147, 277 (1979)]

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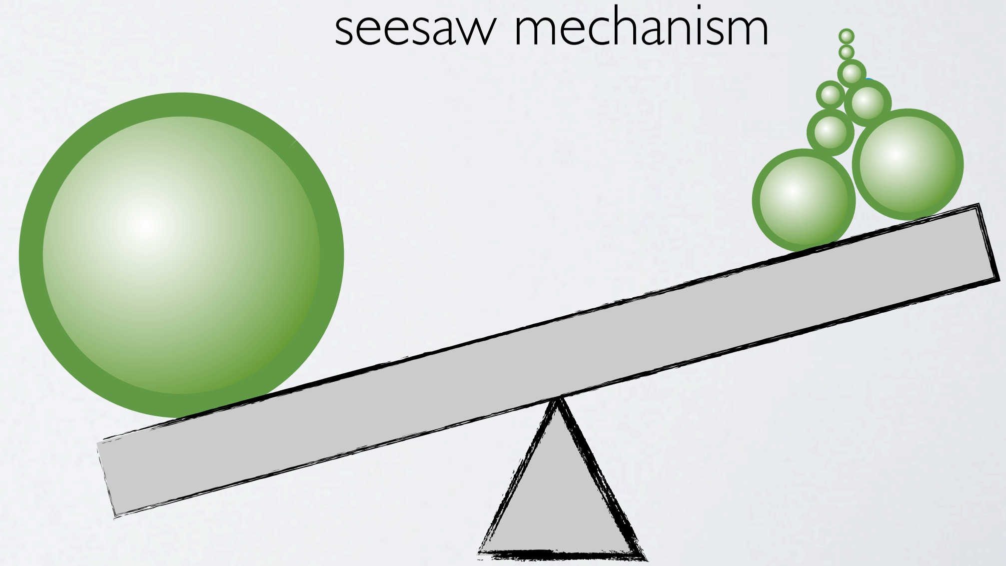


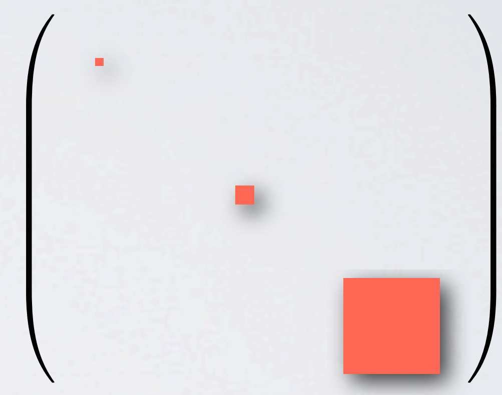
[for the seesaw mechanism see Minkowski, Phys. Lett. B67, 421 (1977)]

QUARK MASSES & MIXINGS

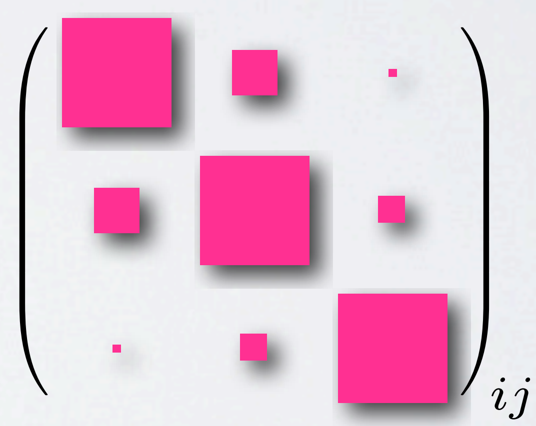
- In consequence, after diagonalizing the mass matrices take the form:

certain combination of entries of $\widetilde{Y}_{d,u}$

$$m_{d,u} = \frac{v}{\sqrt{2}} \bar{Y}_{d,u} \, \mathrm{diag}\left(\epsilon^{Q_i + d_i, u_i}\right) =$$



$$(V_{\mathrm{CKM}})_{ij} \sim \begin{cases} \epsilon^{Q_i - Q_j}\,, & i \leq j \\ \epsilon^{Q_j - Q_i}\,, & i > j \end{cases} =$$



up to an O(1) factor (a function of entries of $\widetilde{Y}_{d,u}$)

"ratios" of left-handed rotations

[Froggatt & Nielsen, Nucl. Phys. B147, 277 (1979)]

QUARK MASSES & MIXINGS

- The desired hierarchies are now obtained by choosing the 9 $U(1)_F$ charges appropriately (in fact one charge remains undetermined because there are only $6_{\text{masses}} + 2_{\text{angles}} = 8$ conditions):

$$m_d \sim \frac{v}{\sqrt{2}}\epsilon^{Q_1+d_1} \qquad m_u \sim \frac{v}{\sqrt{2}}\epsilon^{Q_1+u_1}$$

$$m_s \sim \frac{v}{\sqrt{2}}\epsilon^{Q_2+d_2} \qquad m_c \sim \frac{v}{\sqrt{2}}\epsilon^{Q_2+u_2}$$

$$m_b \sim \frac{v}{\sqrt{2}}\epsilon^{Q_3+d_3} \qquad m_t \sim \frac{v}{\sqrt{2}}\epsilon^{Q_3+u_3}$$

explaining exact amount of CP violation needs tuning in $\widetilde{Y}_{d,u}$

$$\lambda \sim \epsilon^{Q_1-Q_2} \qquad A \sim \epsilon^{3Q_2-2Q_1-Q_3} \qquad \bar{\rho} + i\bar{\eta} \sim 1$$

[Froggatt & Nielsen, Nucl. Phys. B147, 277 (1979)]

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Exercise 10: If you really want to understand the FN mechanism, derive this relations including all O(1) factors

SO FAR SO GOOD

- We have learnt (so far), that the FN mechanism provides us with an explanation of the quark mass & mixing, provided we have a small effective flavor-violating parameter at our disposal

$$\epsilon = \frac{F}{\Lambda_F} \ll 1$$

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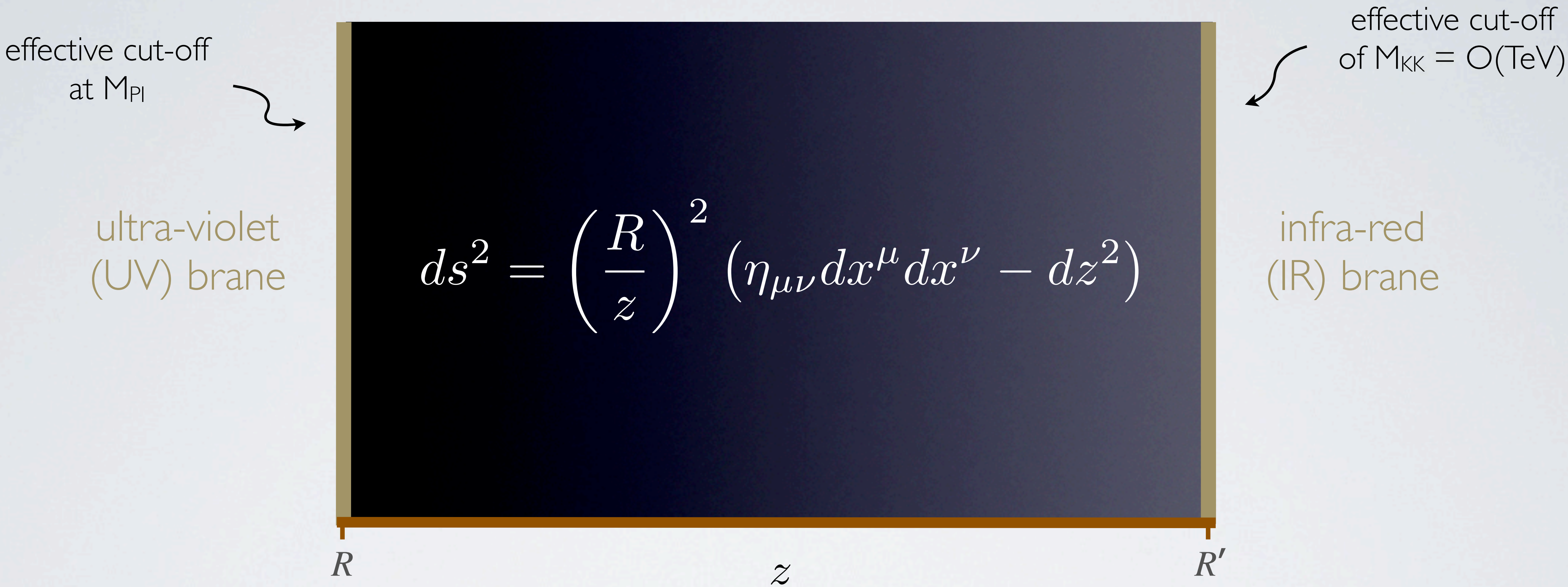
  i) A: By harnessing the idea of split fermions, which consists in placing the left- & right-handed quark wave functions at different points (geometrical sequestering) in a warped extra dimension (WED)

[see for example Arkani-Hamed & Schmaltz, hep-ph/9903417]

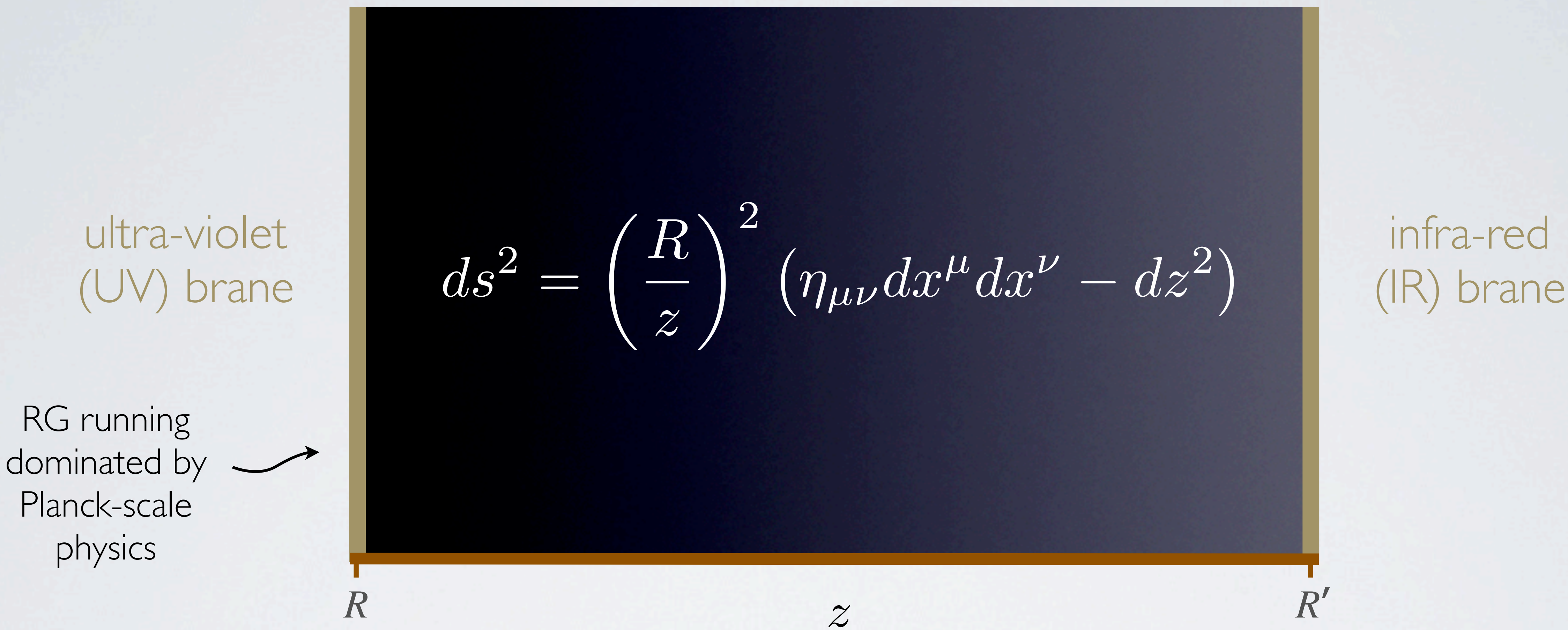
VIRTUES OF WARPED MODELS



- Solution to gauge-hierarchy problem via gravitational red-shifting

[Randall & Sundrum, hep-ph/9905221]

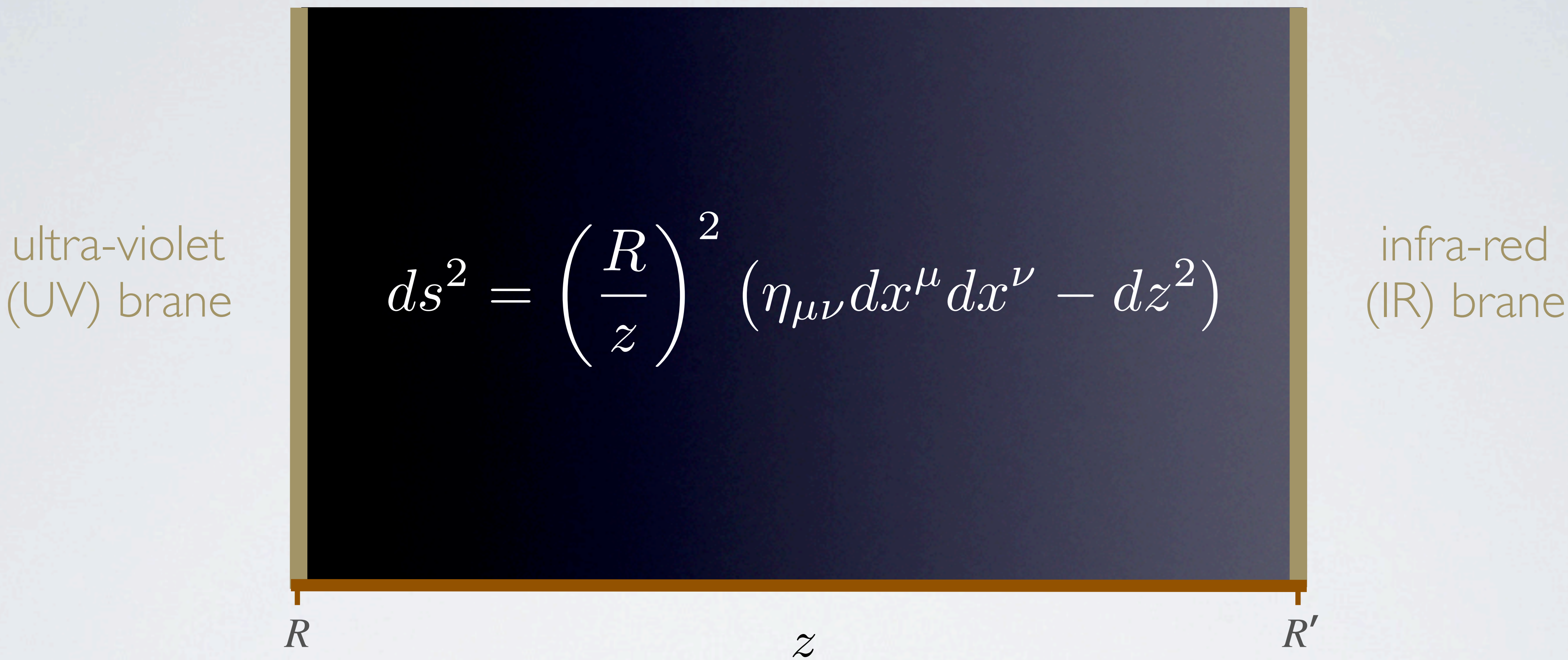
VIRTUES OF WARPED MODELS



- Solution to gauge-hierarchy problem via gravitational red-shifting
- Unlike in flat extra dimensions, logarithmic running of gauge couplings

[see for example Pomarol, hep-ph/0005293; Randall & Schwartz,hep-th/0108144]

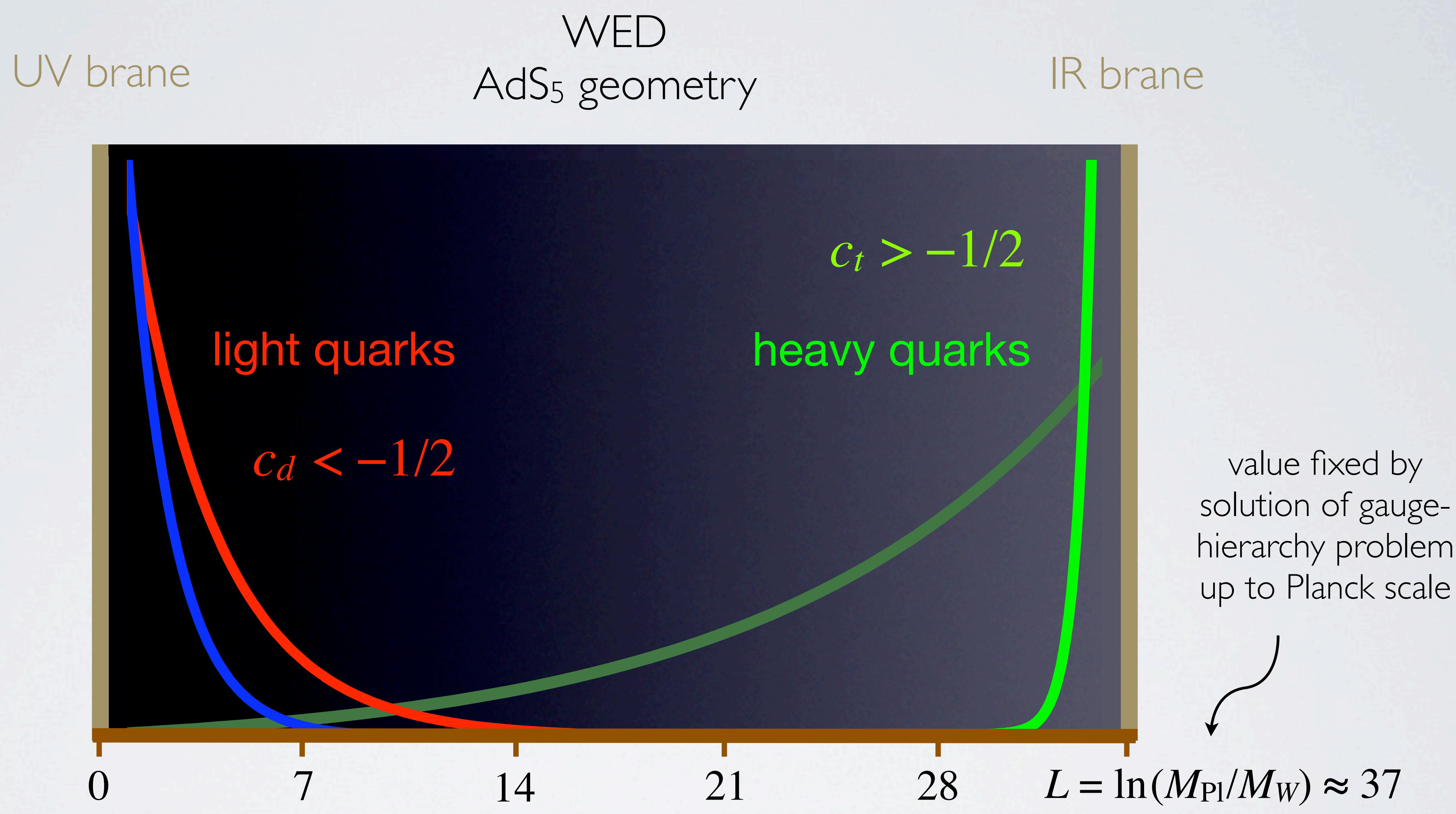
VIRTUES OF WARPED MODELS



- Solution to gauge-hierarchy problem via gravitational red-shifting
- Unlike in flat extra dimensions, logarithmic running of gauge couplings
- AdS/CFT calculable models of strong EWSB: holographic technicolor, composite Higgs, pseudo Nambu-Goldstone-boson Higgs, ...

[see for example Agashe, Contino & Pomarol, hep-ph/0412089]

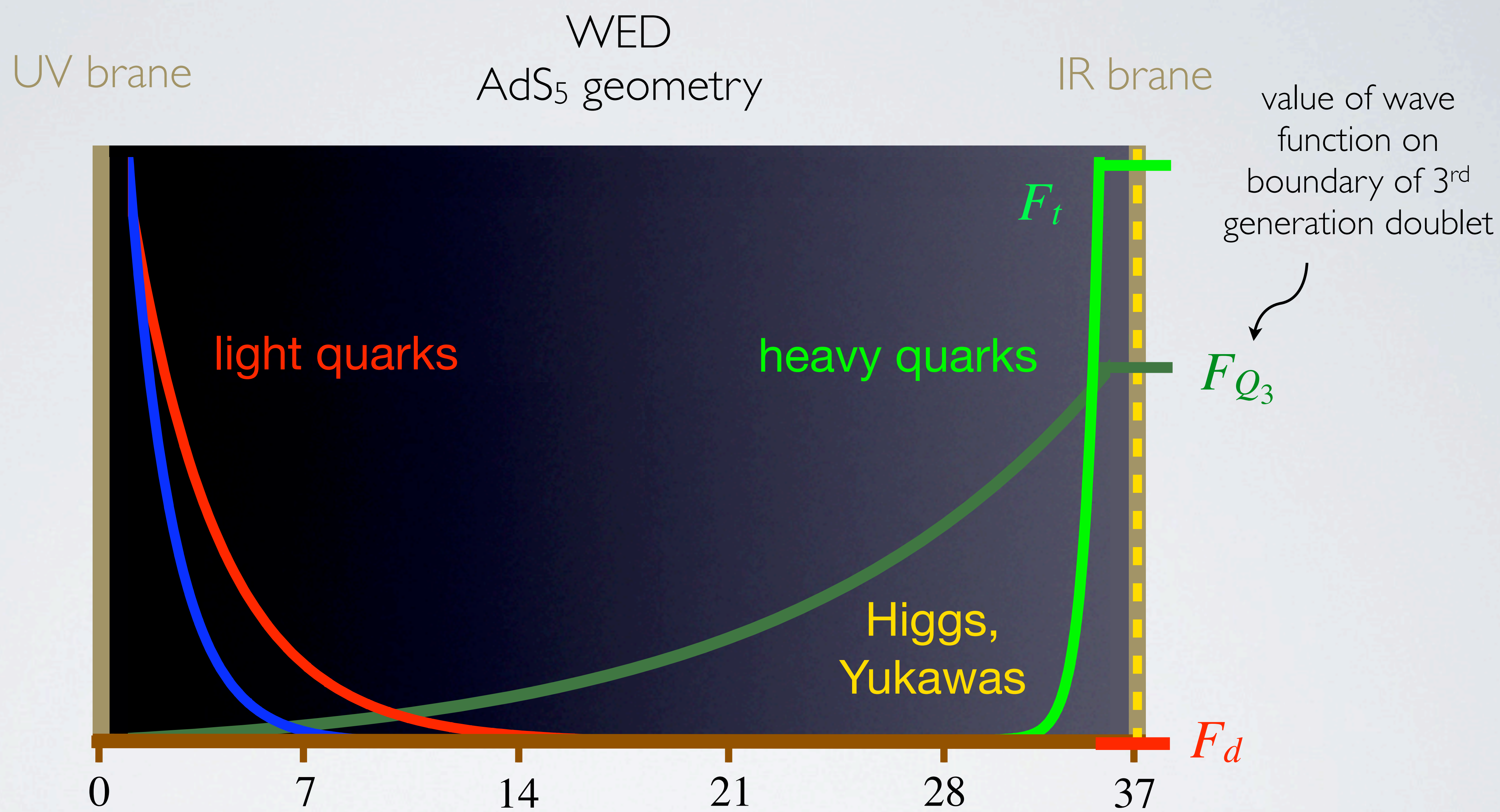
SEQUESTERING FLAVOR IN A WED



- The localization of the quarks in the extra dimension depends exponentially on parameters of O(1), the 5D bulk mass parameters c_{Q_i}, c_{d_i,u_i}

[Grossman & Neubert, hep-ph/9912408; Gherghetta & Pomarol, hep-ph/0003129]

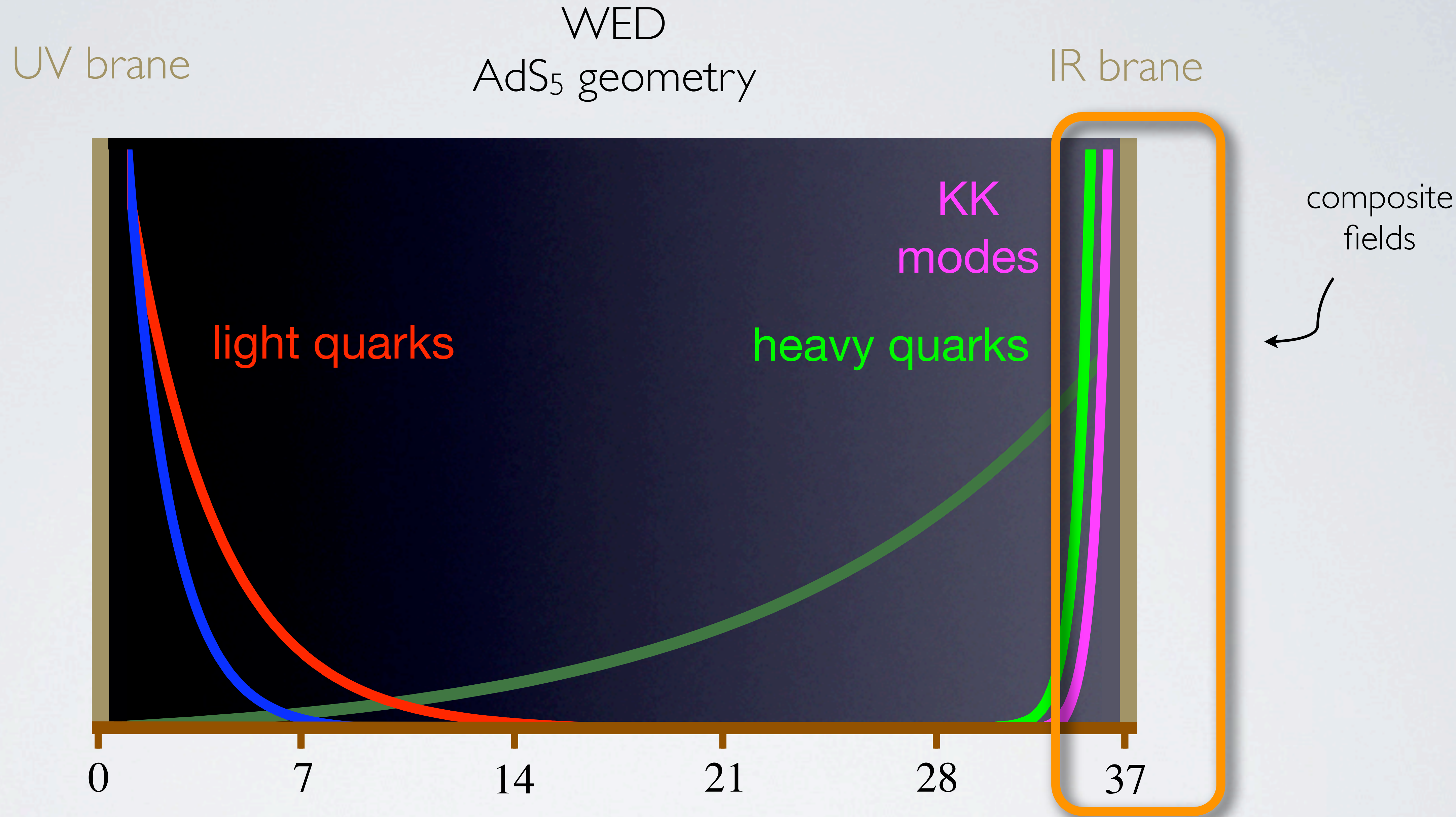
SEQUESTERING FLAVOR IN A WED



- The overlaps F_{Qi}, $F_{di,ui}$ with the IR-localized Higgs sector are exponentially small for the light quarks, while they are of O(1) for the top quark

[Gherghetta & Pomarol, hep-ph/0003129]

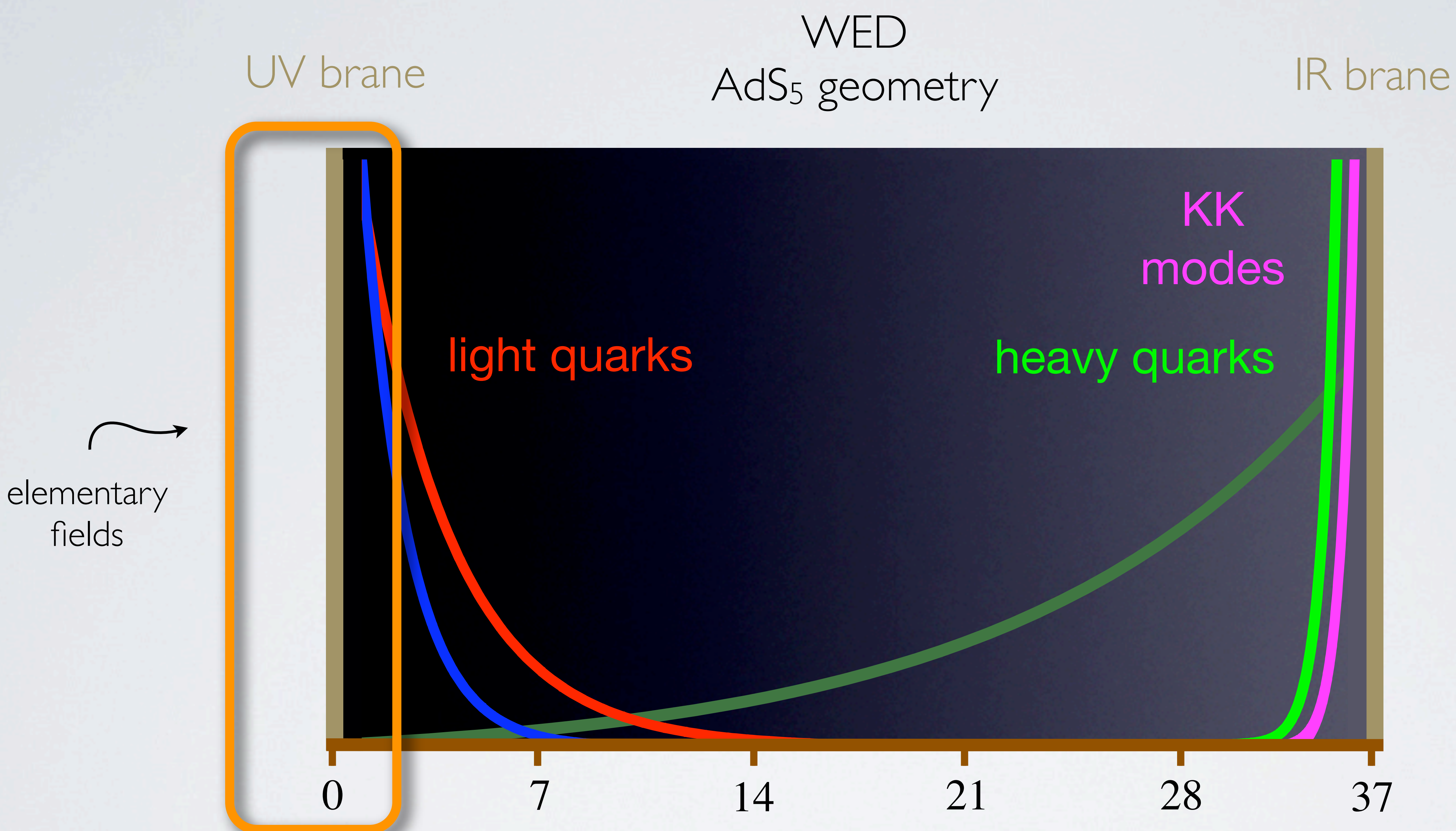
SEQUESTERING FLAVOR IN A WED



- All KK excitations live close to IR brane. In case of gluon this leads to an enhancement of the coupling by $\sqrt{L}$ relative to the zero mode (SM gluon)

[Davoudiasl *et al.*, hep-ph/9911262; Pomarol, hep-ph/9911294; Chang *et al.*, hep-ph/9912498]

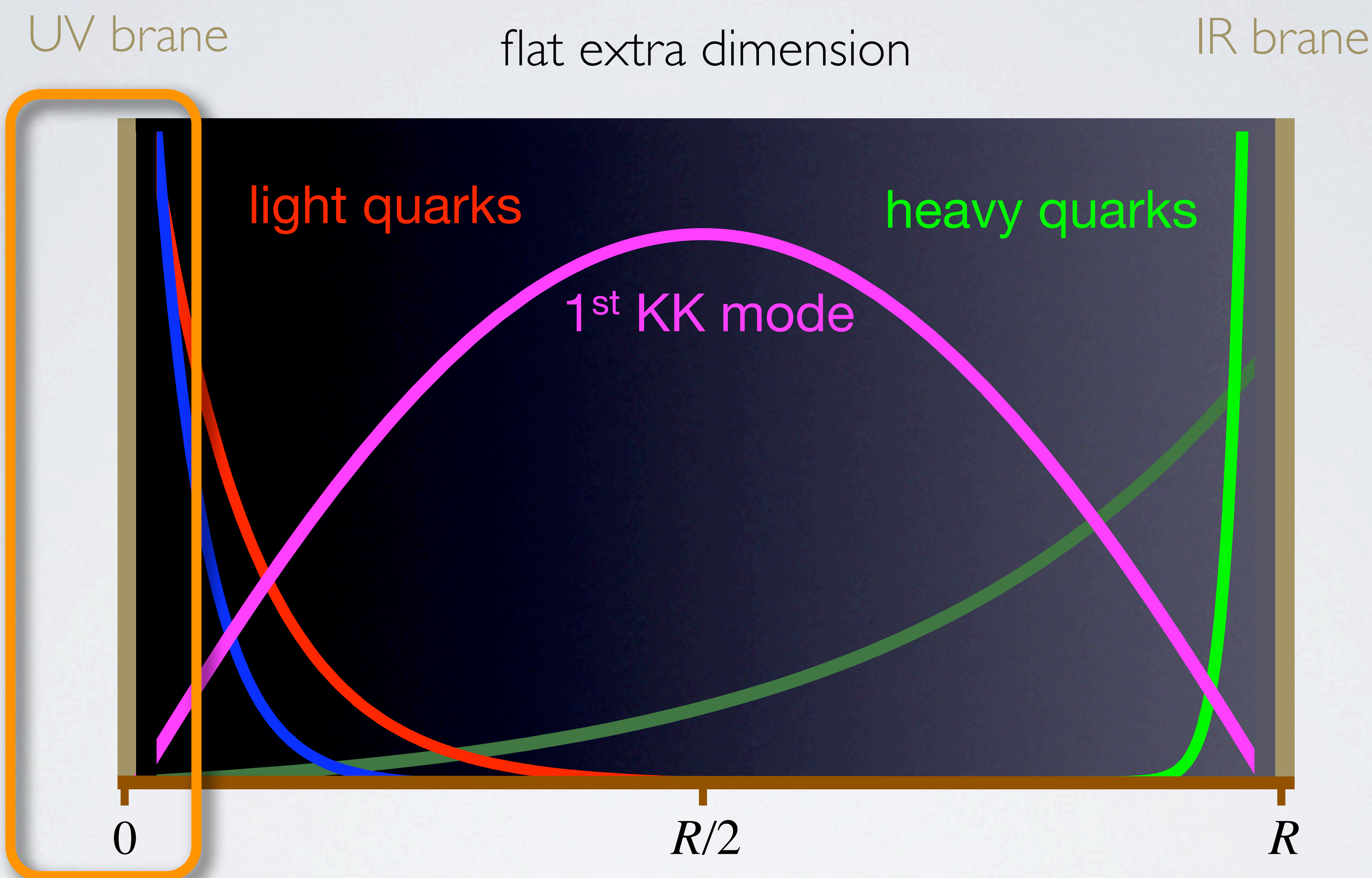
SEQUESTERING FLAVOR IN A WED



- As all light quark generations live in the UV, their couplings to W, Z bosons (located in IR) & KK gluons are almost independent of specific flavor

[Gherghetta & Pomarol, hep-ph/0003129]

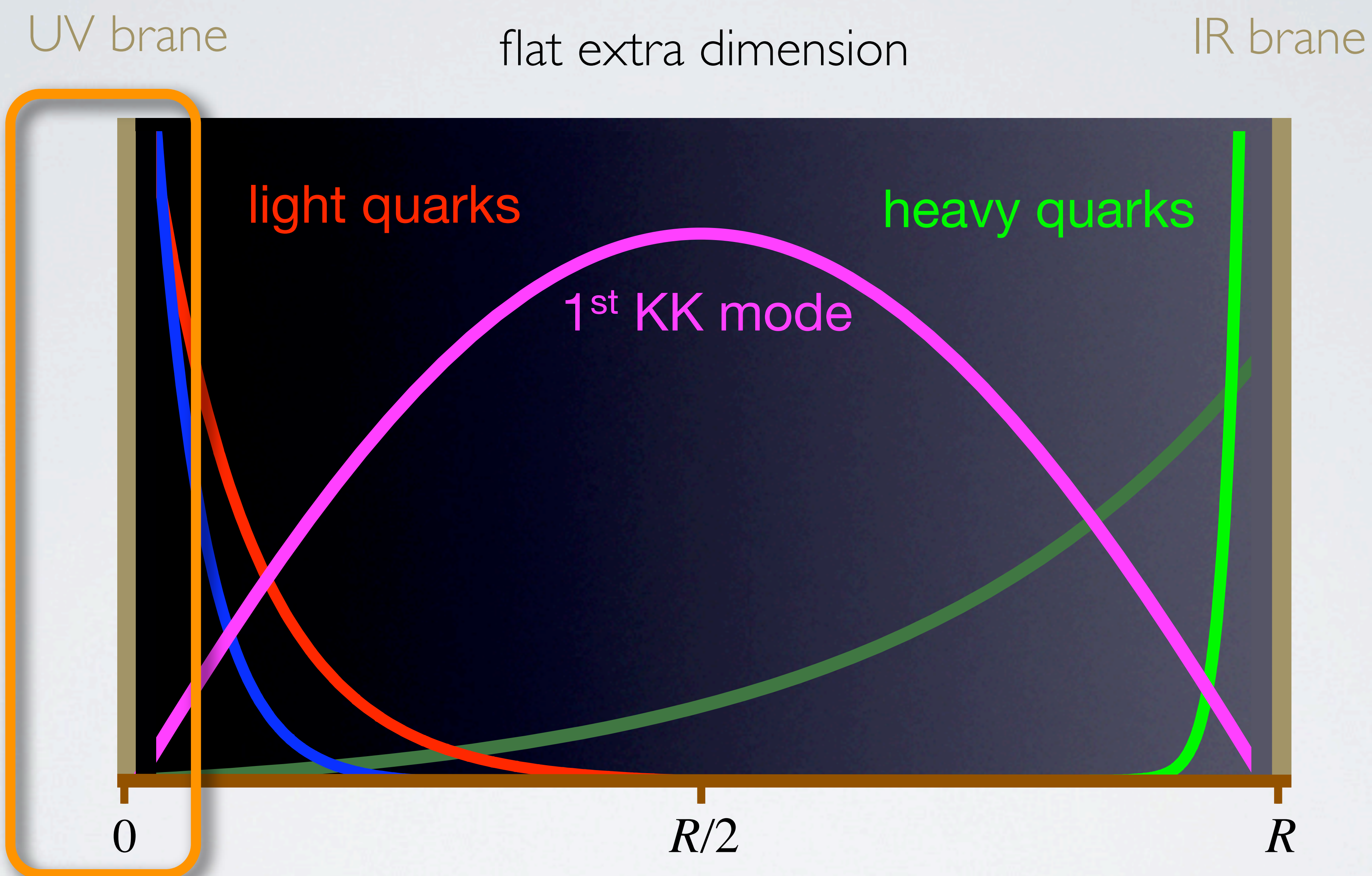
FLAVOR IN FLAT EXTRA DIMENSIONS



- Due to different overlaps, light quarks couple generation-dependent to KK modes, which leads to large FCNCs unless KK scale $M_{KK} = 1/R > 5000$ TeV

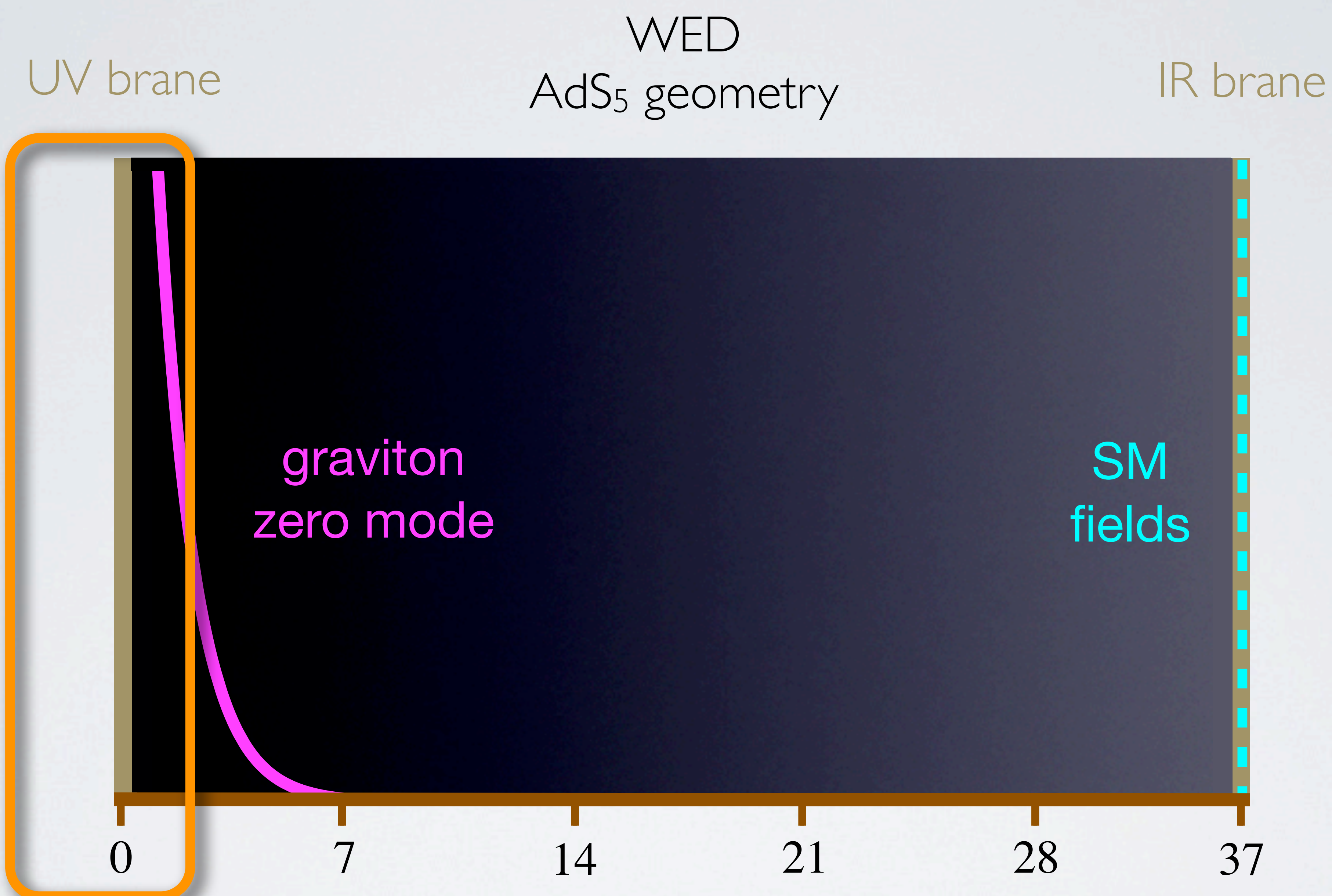
[Delgado, Pomarol & Quiros, hep-ph/9911252]

FLAVOR IN FLAT EXTRA DIMENSIONS



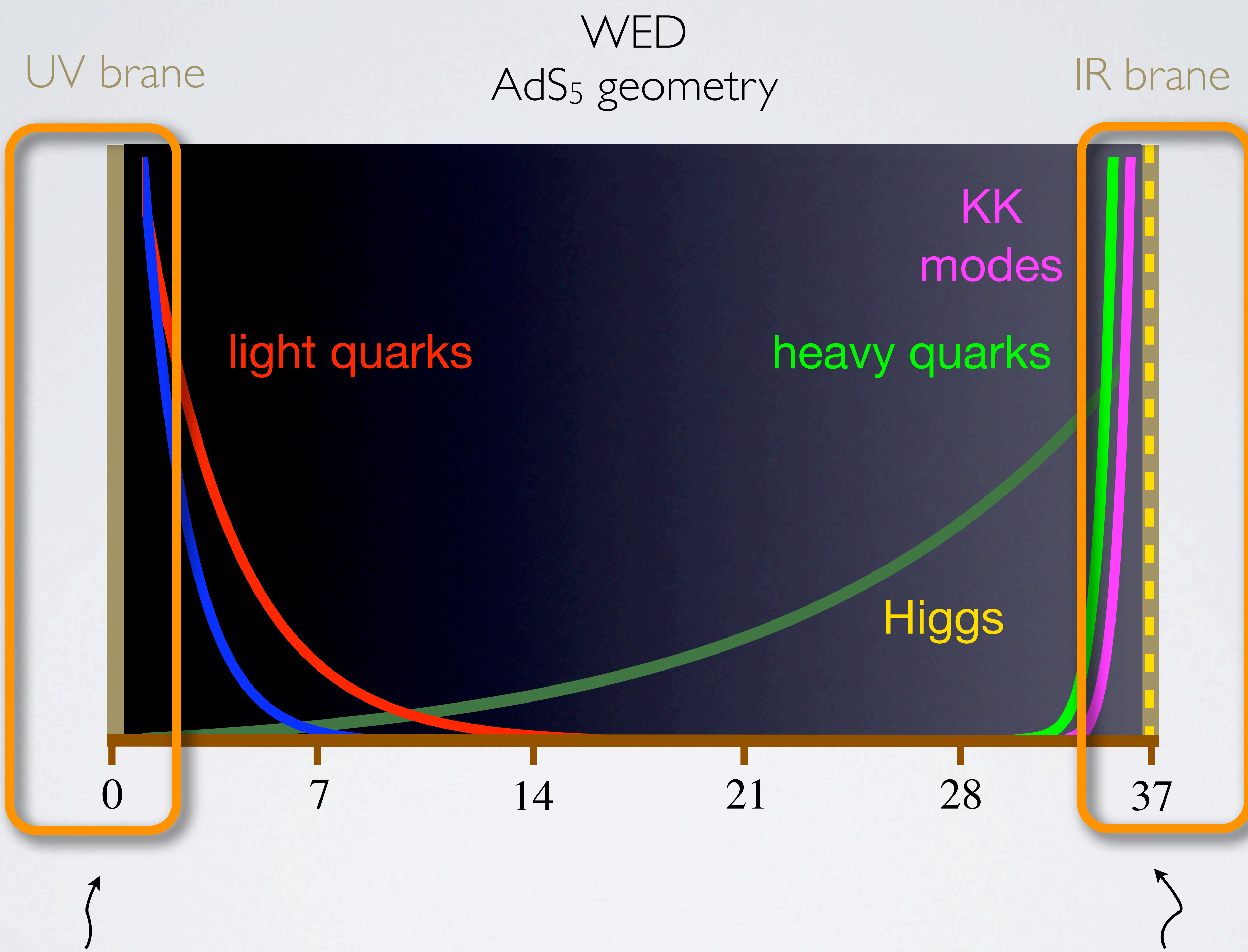
- Even if the KK modes couple flavor-independent (mUEDs), d ≥ 5 operators not strongly suppressed, as the cut-off scale $\Lambda = O(10/R)$ in flat models

FLAVOR IN A WED WITH SM ON IR BRANE



- The fields on the IR brane feel a cut-off of a few TeV. The contributions of $d \geq 5$ operators to FCNCs & S, T, U are then generically too large

SEQUESTERING FLAVOR IN A WED



Flavor physics: distinct pattern of deviation from SM in FCNCs (K, B, ...)

LHC physics: altered production and decay of composites (top, Higgs, ...)

FIRST STRIKE

- Two immediate questions arise:

  i) Q: How can we generate such a small parameter naturally?

  i) A: By harnessing the idea of split fermions, which consists in placing the left- & right-handed quark wave functions at different points (geometrical sequestering) in a warped extra dimension (WED)

$$\epsilon = \frac{F}{\Lambda_F} \ll 1 \quad \Longleftrightarrow \quad e^{-L} \approx \frac{M_W}{M_{\rm Pl}} \ll 1$$

effective flavor-violating parameter in FN mechanism

warp factor in models with AdS_5 geometry

ANALOGY IN ITS FULL BEAUTY

- FN mechanism:

$$(Y_d^{\mathrm{eff,FN}})_{ij} = (\widetilde{Y}_d)_{ij}\, \epsilon^{-Q_i+d_j}$$

  - parameter ε = F/Λ
  - $U(1)_F$ symmetry
  - $U(1)_F$ charges Q_i, d_j, u_j
  - VEV of flavon field Φ_F

- Bulk fermions in WED:

$$(Y_d^{\mathrm{eff,WED}})_{ij} = (\widetilde{Y}_d)_{ij}\, e^{-L(c_{Q_i}+c_{d_j})}$$

  - warp factor e^{-L}
  - self-similarity along φ
  - bulk mass parameters c_{Q_i}, c_{d_j,u_j}
  - IR brane at $\varphi = \pi$

[Casagrande *et al.*, arXiv:0807.4537; Blanke *et al.*, arXiv:0809.1073]

SO FAR SO GOOD (NOT REALLY)

- We still have to address the 2^{nd} question:

  ii) Q: How can such a small parameter give us a (partial) protection (a GIM mechanism) of unwanted FCNCs?

SECOND STRIKE

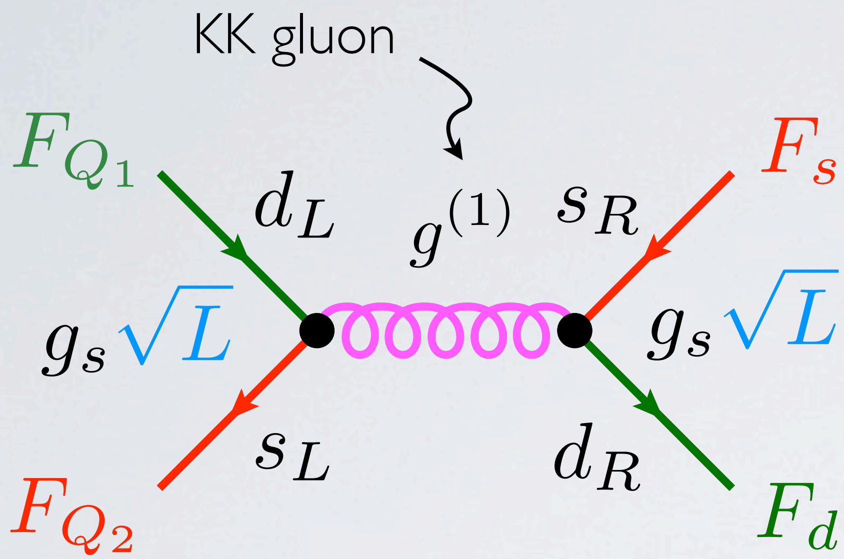
- We still have to address the 2nd question:

  ii) Q: How can such a small parameter give us a (partial) protection (a GIM mechanism) of unwanted FCNCs?

  ii) A: In a model with AdS_5 background this is a immediate consequence of the so-called Randall-Sundrum (RS) GIM ...

[Gherghetta & Pomarol, hep-ph/0003129; Agashe, Perez & Soni, hep-ph/0406101, hep-ph/0408134]

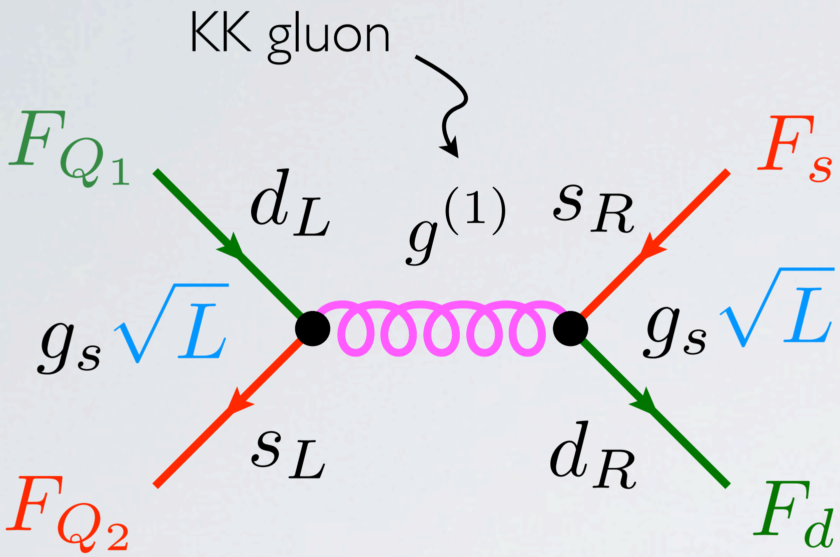
RS-GIM MECHANISM



$$\sim \frac{g_s^2}{M_{\rm KK}^2}\, L\, F_{Q_1} F_{Q_2} F_d F_s$$

- In WED models, quark FCNCs are already induced at the tree-level via the virtual exchange of, for example, KK gluons ($g^{(1)}$, ...), which at first sight looks woorisome

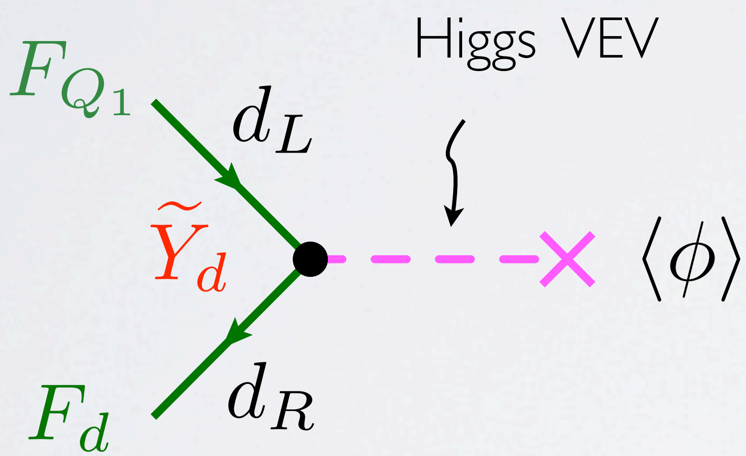
RS-GIM MECHANISM



$$\sim \frac{g_s^2}{M_{\mathrm{KK}}^2}\, L\, F_{Q_1} F_{Q_2} F_d F_s$$

$$\sim \frac{g_s^2}{M_{\mathrm{KK}}^2}\, L\, \frac{m_d m_s}{(v\bar{Y}_d)^2}$$

certain combination of fundamental Yukawas $\widetilde{Y}_d$

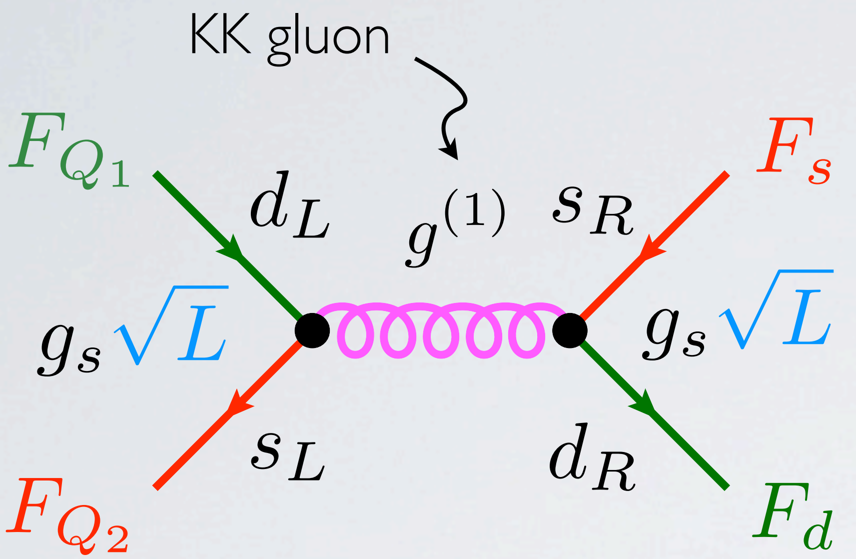


$$m_d \sim v\, F_{Q_1} \widetilde{Y}_d F_d$$

- Since the flavor-changing vertices depend on the same exponentially small overlaps F_{Q_i}, F_{d_i,u_i} that generate the light masses, FCNCs involving quarks of 1st & 2nd family are partially protected (RS-GIM mechanism)

[Agashe, Perez & Soni, hep-ph/0406101, hep-ph/0408134]

RS-GIM MECHANISM



$$\sim \frac{g_s^2}{M_{\mathrm{KK}}^2}\, L\, F_{Q_1} F_{Q_2} F_d F_s$$

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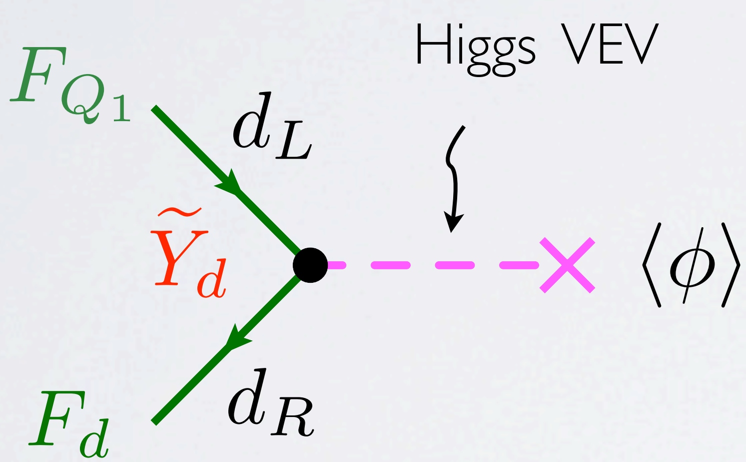
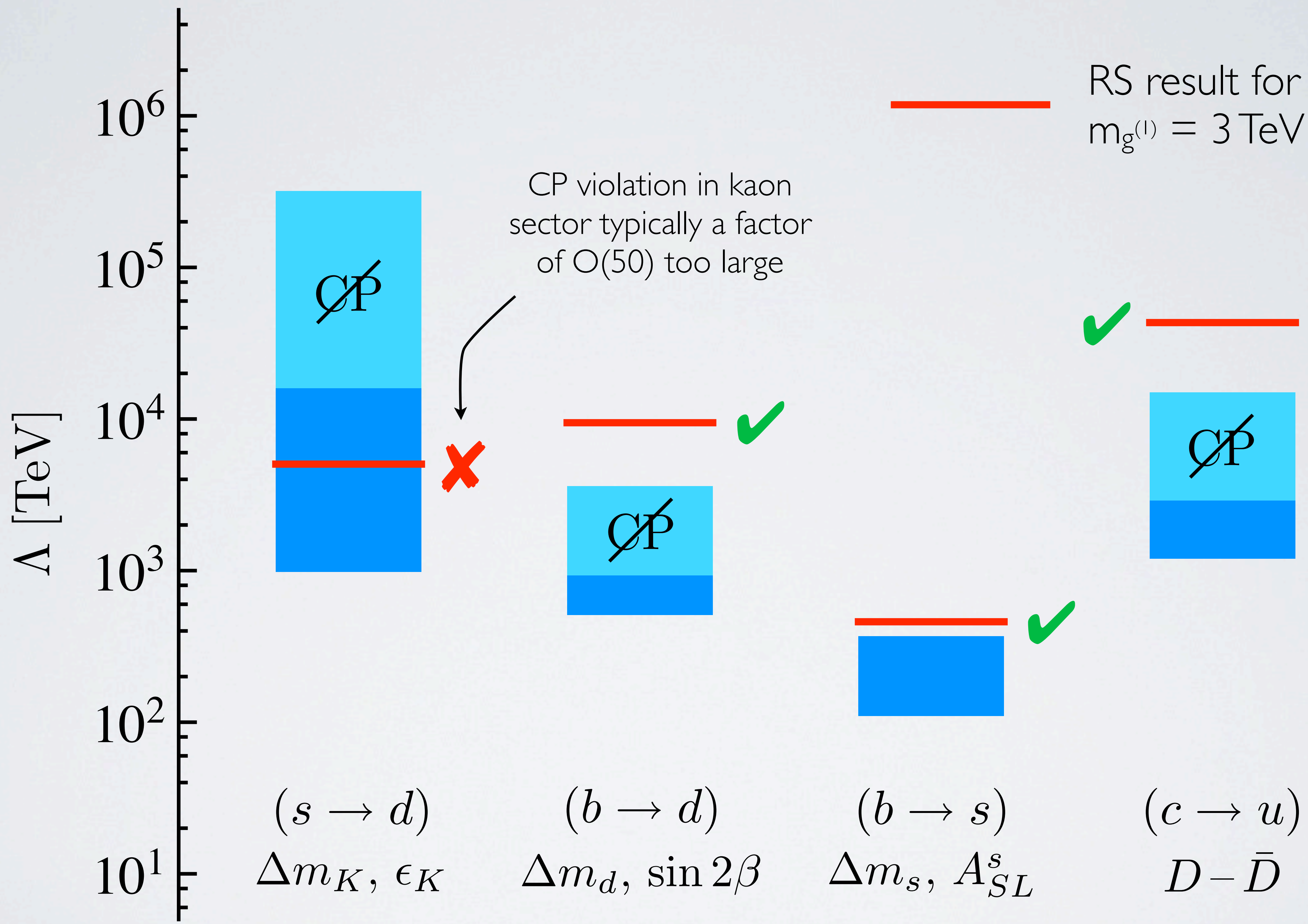


$$m_d \sim v\, F_{Q_1} \widetilde{Y}_d F_d$$

- Unfortunately, the KK-gluon contribution does not match onto the left-handed operator we know from the SM, but on the left-right operator which is most severely constrained. Is the RS-GIM powerful enough?

RS-GIM MECHANISM ALMOST WORKS



[Csaki, Falkowski & Weiler, arXiv:0804.1954, Blanke *et al.*, arXiv:0809.1073; Bauer *et al.*, arXiv:0912.1625]

RS-GIM MECHANISM ALMOST WORKS

- For KK scales in the reach of LHC (a few TeV), it seems that a solution of the little CP problem in kaon sector requires an additional flavor alignment some kind of MFV (or an tuning at the percent level)

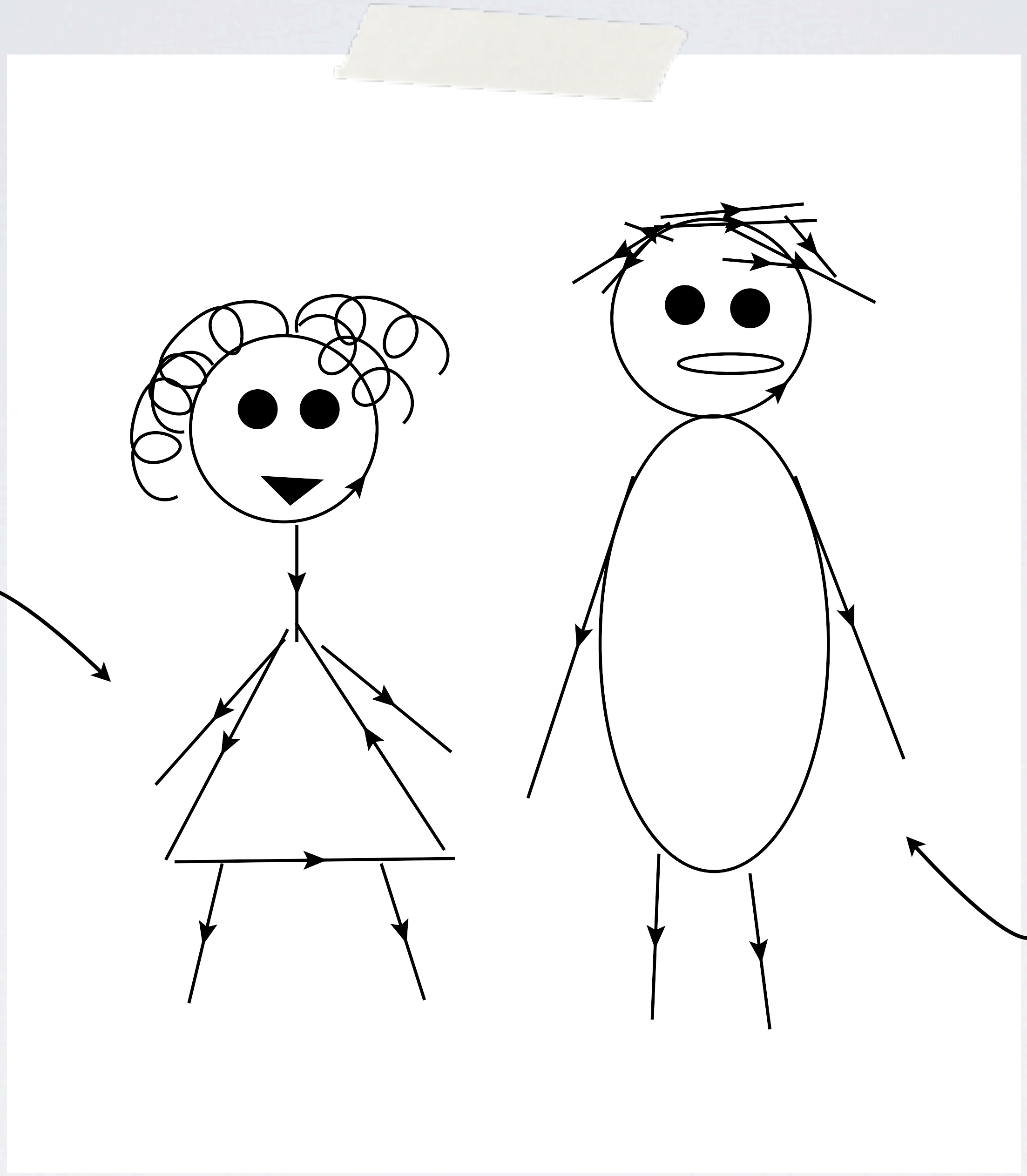
[see for example Santiago, arXiv:0806.1230; Csaki *et al.*, arXiv:0709.1714, arXiv:0806.3757; arXiv:0907.0474]

RS-GIM MECHANISM ALMOST WORKS

- For KK scales in the reach of LHC (a few TeV), it seems that a solution of the little CP problem in kaon sector requires an additional flavor alignment some kind of MFV (or an tuning at the percent level)
- To discuss how such an alignment can be achieved would probably be worthwhile, but I am already over time, so let me conclude with ...

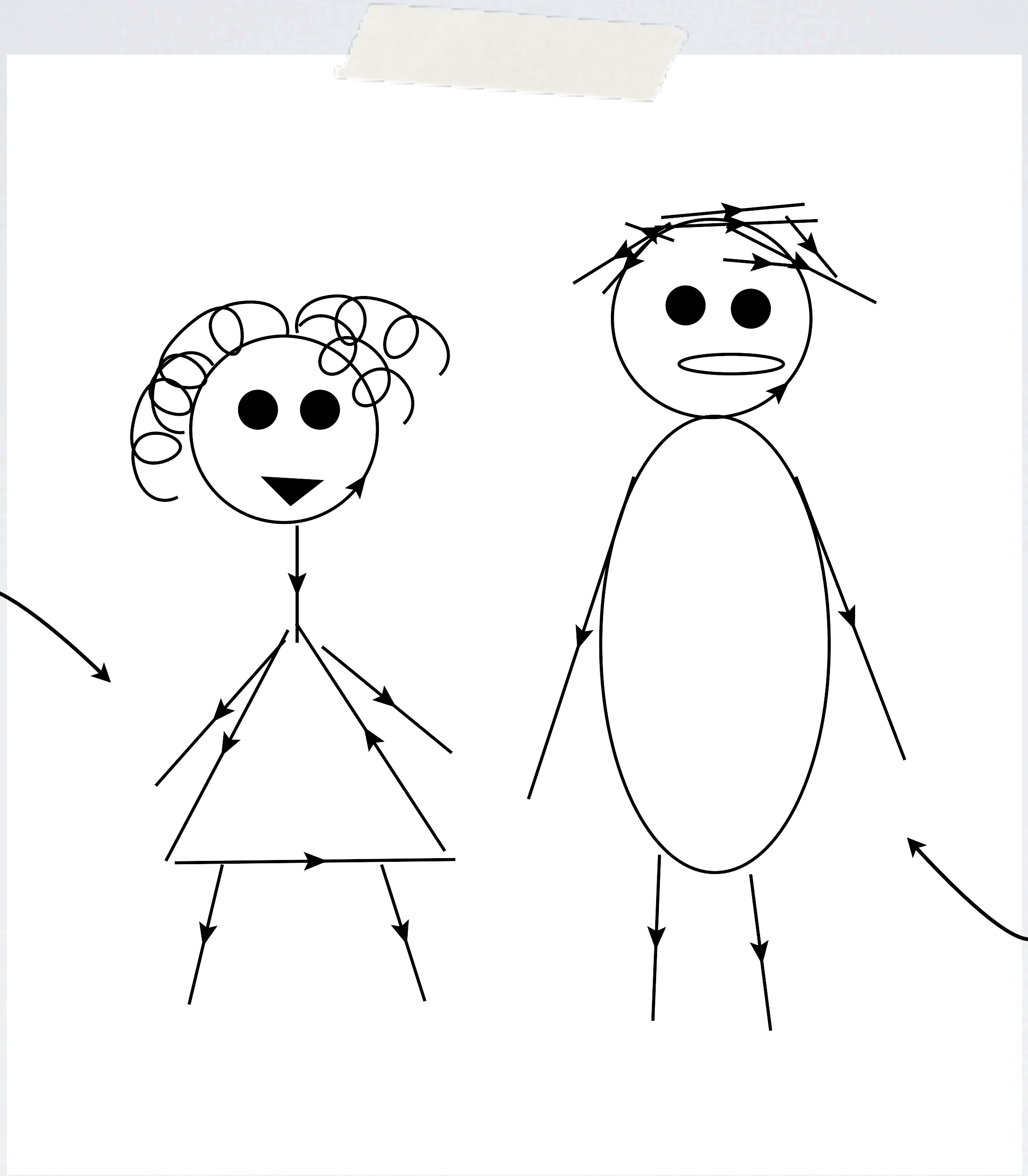
TO GET THE FLAVOR RIGHT IS EASY

Prof. L. Randall



Prof. R. Sundrum

TO GET FLAVOR RIGHT IS DIFFICULT



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