Flavour physics 1

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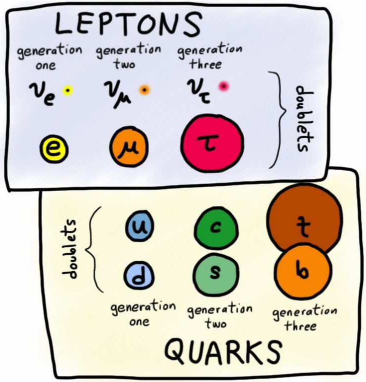
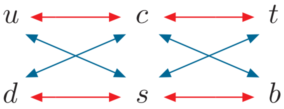
What is flavour physics?

- Three generations of matter

- flavour physics:
  physics of transistions between fermions of different generations

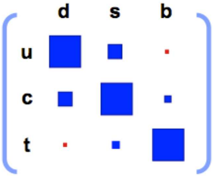




flavour-changing
charged/neutral currents

Why is flavour physics interesting?

- SM metrology:
  many of the free SM parameters related to flavour

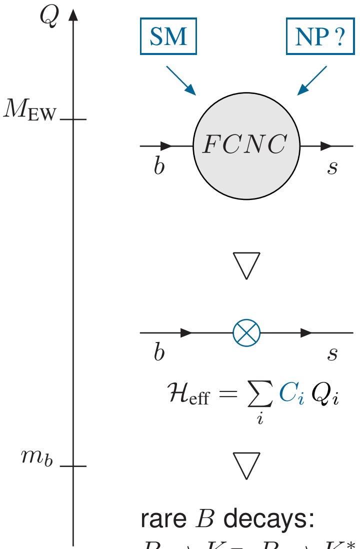


- SM flavour puzzle:
  hierarchy of fermion masses and mixing parameters not understood

- CP violation:
  in the SM related to flavour violation
  needed to explain matter anti-matter asymmetry in the universe

- indirect searches for new physics (NP):
  SM suppression renders flavour-changing neutral currents (FCNCs) sensitive to NP

Exploring New Physics in FCNCs



rare B decays:
$B \to K\pi$, $B \to K^* \mu\mu$,
$B \to X_s \gamma$, $B_s \to \mu\mu$, ...

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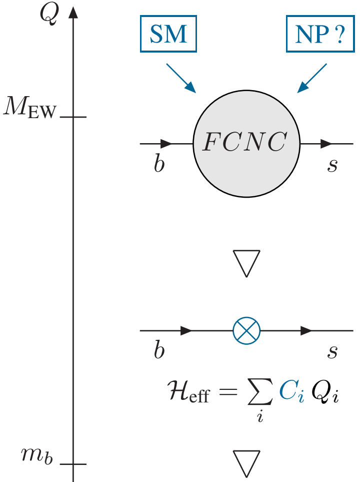

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1

Specific NP model
e.g. MSSM, Z', etc.

↓

additional contributions to
effective coefficients C_i

↓

predict impact on
rare B decays

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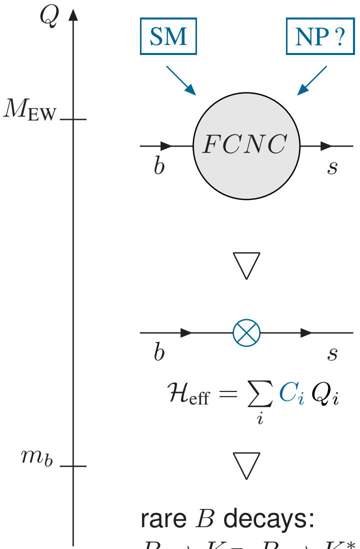

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2

Which NP model
can account for this pattern?

↑

fit effective coefficients
NP in certain C_i

↑

tensions in
rare B decay data

Outline

1. The spurion method in flavour physics
2. Effective theories in flavour physics
3. New physics in electroweak penguins?

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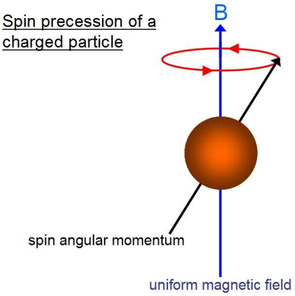
e^- in external $\vec{B}$ field

$$\mathcal{H} = \underbrace{\mathcal{H}_{\text{free } e^-}}_{SO(3)} + \underbrace{\mathcal{H}_{\vec{B}}}_{SO(2)}$$

external $\vec{B}$ field induces symmetry breaking

$$SO(3) \to SO(2)$$



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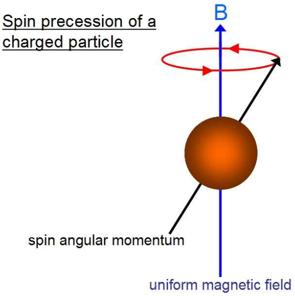

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consider $\vec{B}$ field as internal part of system
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$\Rightarrow$ total system invariant under $SO(3)$ symmetry

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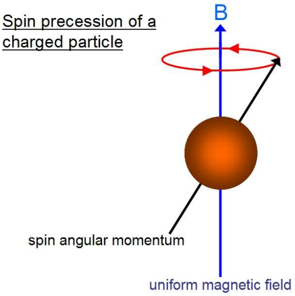

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$\vec{B}$ field $\quad \rightarrow \quad$ spurion:

non-dynamical (=constant) field which has been promoted to an object transforming under a symmetry

Applications

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- $\mathcal{H}_{\vec{B}}$ built from $\vec{S} = (\sigma_x, \sigma_y, \sigma_z)$ and $\vec{B} = (B_x, B_y, B_z)$
- $SO(3)$ invariance $\Rightarrow$ $\mathcal{H}_{\vec{B}}$ built from $\vec{S} \cdot \vec{B}$
  ($\vec{S}^2 = 3/2$ and $\vec{B}^2$ are constants)

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- $SO(3)$ invariance $\Rightarrow$ $\mathcal{H}_{\vec{B}}$ built from $\vec{S} \cdot \vec{B}$ ($\vec{S}^2 = 3/2$ and $\vec{B}^2$ are constants)
- $\mathcal{H}_{\vec{B}}$ linear in $\vec{S} \cdot \vec{B}$ because $(\vec{B} \cdot \vec{S})^2 = \vec{B}^2/4 =$ const.

$$\Rightarrow \quad \boxed{\mathcal{H}_{\vec{B}} = \mu \, \vec{S} \cdot \vec{B}}$$

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- naively: 3 $\rightarrow$ $\vec{B} = (B_x, B_y, B_z)$
- but: broken symmetry reduces number of physical parameters:

$$\# \text{ generators} \quad \begin{pmatrix} SO(3) \\ 3 \end{pmatrix} \longrightarrow \begin{pmatrix} SO(2) \\ 1 \end{pmatrix}$$

broken generators (rotations about x- and y-axis) can be used to rotate z-axis such that $\vec{B}||\hat{z}$

$\Rightarrow$ only one physical parameter $\rightarrow$ $\boxed{\vec{B} = (0, 0, |\vec{B}|)}$

Gauge interactions

$$\mathcal{L}^q_{\text{gauge}} = \bar{Q}_L i \not{D} Q_L + \bar{d}_R i \not{D} d_R + \bar{u}_R i \not{D} u_R$$

- D^μ contains photons, gluons and weak gauge bosons
- $Q_L : SU(2)_L$ doublet, $d_R, u_R : SU(2)_L$ singlet
- three generations in
  $Q_L = (Q_L^1, Q_L^2, Q_L^3), \quad d_R = (d_R^1, d_R^2, d_R^3), \quad u_R = (u_R^1, u_R^2, u_R^3)$

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$\mathcal{L}^q_{\text{gauge}}$ invariant under rotations

$$Q_L \to R^Q Q_L, \quad d_R \to R^d d_R, \quad u_R \to R^u u_R$$

$\Rightarrow$ gauge interactions cannot distinguish generations

Global flavour symmetry:

$$\boxed{[U(3)]^3 = U(3)_Q \times U(3)_u \times U(3)_d}$$

Yukawa interactions

$$\mathcal{L}_y^q = -\bar{Q}_L \Phi y^d d_R - \bar{Q}_L \Phi^c y^u u_R + h.c.$$

Φ : Higgs field ($SU(2)_L$ doublet), $\Phi^c = \sigma_2 \Phi^\dagger$

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$\mathcal{L}_y^q$ invariant under common phase transformation

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$\mathcal{L}_y$ breaks symmetry of $\mathcal{L}^q_{\text{gauge}}$:

$[U(3)]^3$ flavour $\longrightarrow$ $U(1)$ baryon number

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spurion method:
promote y^d, y^u to spurions transforming as

$$y^d \to R^Q y^d R^{d\dagger}, \quad y^u \to R^Q y^u R^{u\dagger}$$

$\Rightarrow$ $[U(3)]^3$ flavour symmetry restored

Choice of basis

y^d, y^u : generic complex 3×3 matrices
$\Rightarrow$ can be diagonalized by biunitary transformations

$$\hat{y}^d = S_1^\dagger y^d S_2, \qquad \hat{y}^u = S_3^\dagger y^u S_4$$

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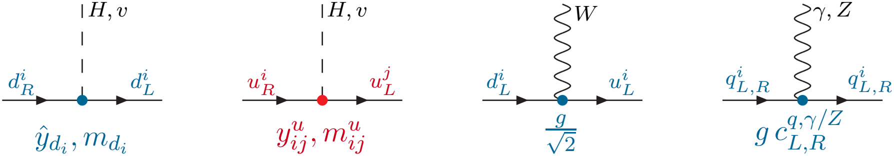
still: weak eigenbasis ($\mathcal{L}^q_{\text{gauge}}$ unchanged)
Q_L, d_R, u_R eigenstates of $\mathcal{L}^q_{\text{gauge}}$
$y^u = V^\dagger \hat{y}_u$ $\Rightarrow$ up-quark mass-terms non-diagonal

Weak vs. mass eigenbasis

weak eigenbasis:



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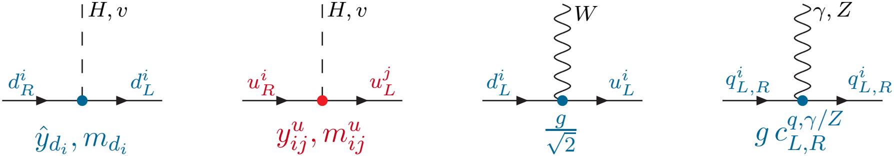

mass eigenbasis:

$$\bar{u}^i_L\, m^u_{ij}\, u^j_R \;=\; \bar{u}^i_L\, V^\dagger_{ij}\, m_{u_j}\, u^j_R \;=\; \bar{u}'^j_L\, m_{u_j}\, u^j_R \qquad \text{with } m_{u_j} = y_{u_j} v$$

perform rotation: $\quad u^i_L \;\to\; u'^i_L \;=\; V_{ij}\, u^j_L$

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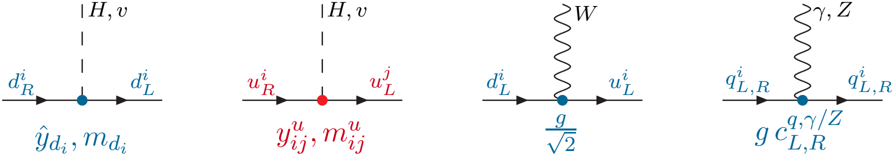

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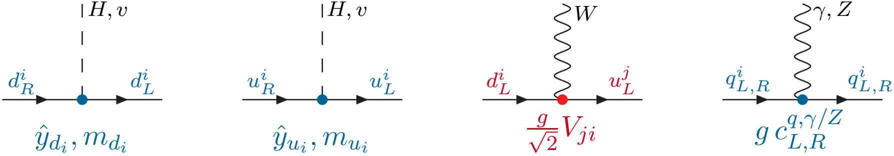

physical parameters in $\mathcal{L}_y^q$?

Yukawa matrices

y^d, y^u

36 parameters

(18 real, 18 phases)

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flavour symmetry

$[U(3)]^3$

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baryon symmetry

$U(1)$

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physical parameters

m_d, m_u, V_{CKM}

10 parameters

(9 real, 1 phase)

Yukawa-couplings and CKM matrix

9 real parameters

- 6 quark masses ($\hat{=}$ diagonal Yukawa couplings $\hat{y}_{d_i}, \hat{y}_{u_i}$)
- 3 mixing angles in CKM matrix

1 phase

- phase in CKM matrix $\rightarrow$ source of CP-violation in SM

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$$\hat{y}^d = \begin{pmatrix} y_d & 0 & 0 \\ 0 & y_s & 0 \\ 0 & 0 & y_b \end{pmatrix} \sim 0, \qquad \hat{y}^u = \begin{pmatrix} y_u & 0 & 0 \\ 0 & y_c & 0 \\ 0 & 0 & y_t \end{pmatrix} \sim \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

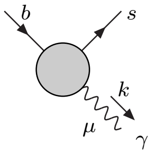
$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \sim \mathcal{O}(\begin{pmatrix} 1 & \lambda & \lambda^3 \\ \lambda & 1 & \lambda^2 \\ \lambda^3 & \lambda^2 & 1 \end{pmatrix}), \qquad \lambda \approx 0.22$$

$\rightarrow$ peculiar structure of measured quark masses and CKM matrix leads to strong suppression of FCNCs (flavour-changing neutral currents) in the SM

FCNCs

example:

exclusive decay $\overline{B} \to X_s\gamma$ (quark-level: $b \to s\gamma$)



gauge invariance implies:

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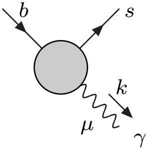

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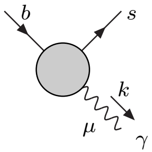

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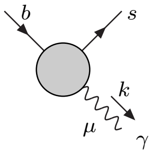

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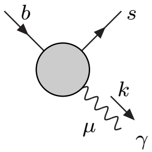

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$$\approx y_b y_t^2 V^*_{ts} V_{tb}[\bar{s}_L\sigma^{\mu\nu}k_\nu b_R]$$

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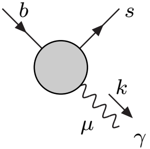

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$$y^d \to R^Q y^d R^{d\dagger}, \qquad y^u \to R^Q y^u R^{u\dagger}$$

$[U(3)]^3$ invariance implies: $\quad (y_d = \hat{y}_d,\ y_u = V^\dagger \hat{y}^u)$

$$\begin{aligned}
\mathcal{M}^{\mu}_L &\propto \bar{Q}^2_L \left(y^u y^{u\dagger} y^d\right)_{23} \sigma^{\mu\nu} k_\nu d^3_R = \sum_i \bar{Q}^2_L\, V^*_{i2}\, \hat{y}^u_i\, \hat{y}^u_i\, V_{i3}\, \hat{y}^d_3\, \sigma^{\mu\nu}\, k_\nu\, d^3_R \\
&\approx y_b y_t^2 V^*_{ts} V_{tb} [\bar{s}_L \sigma^{\mu\nu} k_\nu b_R] \\
\mathcal{M}^{\mu}_R &\propto \bar{d}^2_R \left(y^{d\dagger} y^u y^{u\dagger}\right)_{23} \sigma^{\mu\nu} k_\nu Q^3_L = \sum_i \bar{d}^2_R\, \hat{y}^d_2\, V^*_{i2}\, \hat{y}^u_i\, \hat{y}^u_i\, V_{i3}\, \sigma^{\mu\nu}\, k_\nu\, d^3_R \\
&\approx y_s y_t^2 V^*_{ts} V_{tb} [\bar{s}_R \sigma^{\mu\nu} k_\nu b_L]
\end{aligned}$$

FCNCs

$$\mathcal{M}^{\mu}_{b\to s\gamma} = a_L \left(m_b m_t^2 V_{ts}^* V_{tb}\right) \left[\bar{s}_L \sigma^{\mu\nu} k_\nu b_R\right] + a_R \left(m_s m_t^2 V_{ts}^* V_{tb}\right) \left[\bar{s}_R \sigma^{\mu\nu} k_\nu b_L\right]$$

Suppression of FCNCs in SM:

- loop-induced
- small CKM elements: $V_{ts}^* V_{tb} \sim \lambda^2$
- GIM-suppression:
  mass-independent terms cancel because of unitarity of CKM matrix
- here in addition: helicity suppression m_b/v
  (suppression of right-handed current by m_s/m_b)

Unitarity triangle

Unitarity of CKM matrix:

$$\sum_u V_{ud} V^*_{ud'} = 0 \quad \text{for} \quad d \neq d', \qquad \sum_d V_{ud} V^*_{u'} = 0 \quad \text{for} \quad u \neq u'$$

- 6 different relations: 3 for up-, 3 for down-quarks
- each relation defines triangle in complex plane (unitarity triangles)

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$$\begin{array}{ccccccc} V_{ud}V^*_{us} & + & V_{cd}V^*_{cs} & + & V_{td}V^*_{ts} & = & 0 \\ \mathcal{O}(\lambda) & & \mathcal{O}(\lambda) & & \mathcal{O}(\lambda^5) & & \end{array}$$

$\rightarrow$ distorted triangle!

Unitarity triangle

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$\rightarrow$ THE unitarity triangle!

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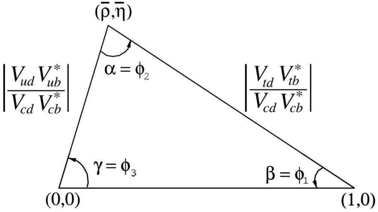
$$\frac{V_{ud} V^*_{ub}}{V_{cd} V^*_{cb}} + 1 + \frac{V_{td} V^*_{tb}}{V_{cd} V^*_{cb}} = 0$$

$\rightarrow$ THE unitarity triangle!



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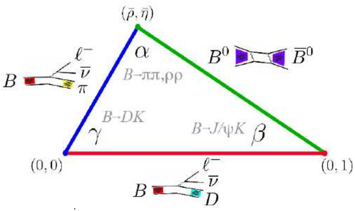
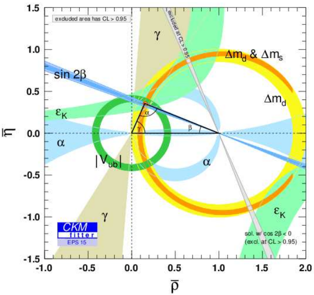
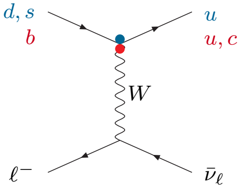
Overconstraining measurements:





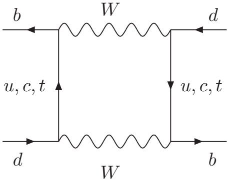
- $|V_{ud}|$, $|V_{us}|$, $|V_{ub}|$, $|V_{cb}|$ at tree-level from semi-leptonic decays
- $|V_{td}|$, $|V_{ts}|$ only at loop-level via FCNCs
  Δm_d from $B - \overline{B}$ mixing $\rightarrow$ $|V_{td}|$



$B^0 - \overline{B}^0$ mixing

box diagrams mediate $B^0 - \overline{B}^0$ transitions:

$i\mathcal{M}_{12} \quad =$



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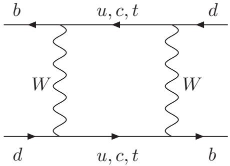

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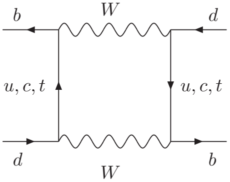
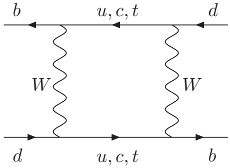
$i\mathcal{M}_{12}$ =  + 

time evolution:

$$i\frac{d}{dt}\begin{pmatrix} B^0(t) \\ \overline{B}^0(t) \end{pmatrix} = \mathcal{H}\begin{pmatrix} B^0(t) \\ \overline{B}^0(t) \end{pmatrix}, \qquad \mathcal{H} = \mathcal{M} + i\Gamma$$

- $\mathcal{M}, \Gamma$ hermitian 2×2 matrices:
  $\mathcal{M}$: transition within B^0-$\overline{B}^0$ system, Γ : decay of $B^0, \overline{B}^0$

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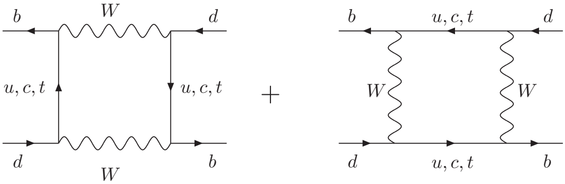

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  $\mathcal{M}$: transition within B^0-$\overline{B}^0$ system, $\quad \Gamma$: decay of $B^0, \overline{B}^0$
- empirically: $\Gamma_{ij} \ll \mathcal{M}_{ij}$, $\quad$ CPT-invariance: $\mathcal{M}_{11} = \mathcal{M}_{22}$

$$\Rightarrow \mathcal{H} \approx \begin{pmatrix} \mathcal{M}_{11} & \mathcal{M}_{12} \\ \mathcal{M}_{12}^* & \mathcal{M}_{11} \end{pmatrix} \qquad \rightarrow \text{eigenvalues: } \mathcal{M}_{11} \pm |\mathcal{M}_{12}|$$

$\Rightarrow$ mass difference $\Delta m_d = 2|\mathcal{M}_{12}|$

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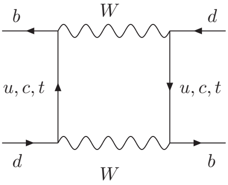

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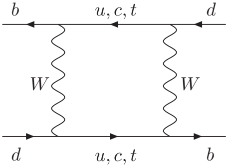

$$\mathcal{M}_{12} = \sum_{ij} (V_{id} V_{ib}^*)(V_{jd} V_{jb}^*)\ f(x_i, x_j), \qquad x_i = m_{u_i}^2 / M_W^2$$

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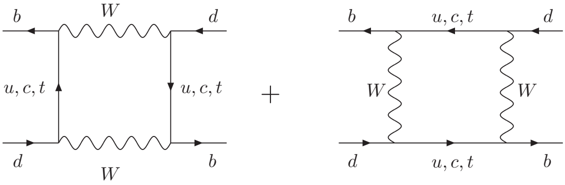

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GIM mechanism ($x_u \approx x_c \approx 0$):

$$\underbrace{V_{ud} V_{ub}^* \, g(x_u) + V_{cd} V_{cb}^* \, g(x_c)} + V_{td} V_{tb}^* \, g(x_t)$$

$$\approx \underbrace{(V_{ud} V_{ub}^* + V_{cd} V_{cb}^*)}_{-V_{td} V_{tb}^*} \, g(0)$$

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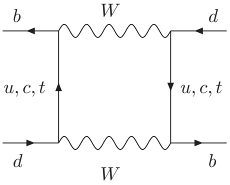

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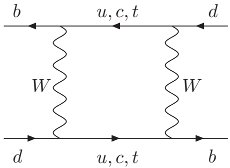

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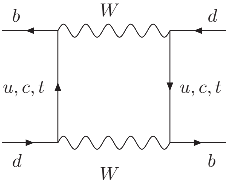
$B^0 - \overline{B}^0$ mixing

$i\mathcal{M}_{12}$ $=$



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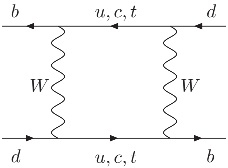

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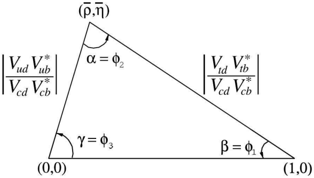
$$\Rightarrow \quad \mathcal{M}_{12} \approx (V_{td}V_{tb}^*)^2\, [f(x_t, x_t) - 2f(x_t, 0) + f(0,0)]$$

$V_{td}V_{tb}^* = V_{td} + \mathcal{O}(\lambda^4) \quad \Rightarrow \quad \Delta m_d = 2|\mathcal{M}_{12}|$ measures $|V_{td}|$

Δm_d and Δm_s

with $|V_{cd}|$ and $|V_{cb}|$ from semi-leptonic decays:

Δm_d measures side $\left|\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*}\right| \propto \frac{\Delta m_d}{|V_{cd}||V_{cb}|}$ of unitarity triangle



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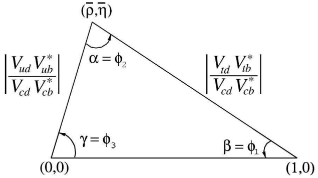

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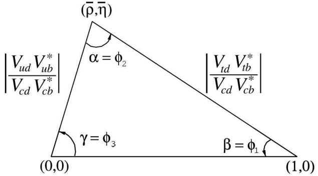

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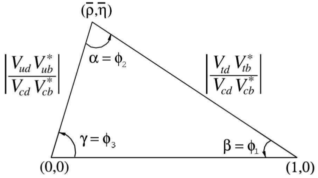
- ratio of hadronic matrix elements can be calculated to higher precision than individual hadronic matrix elements



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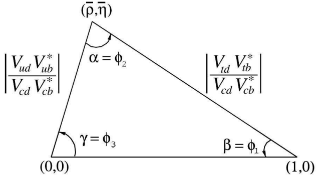
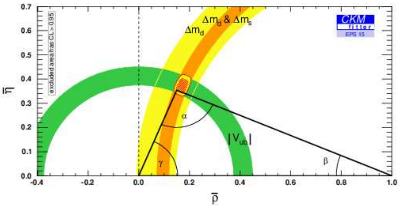
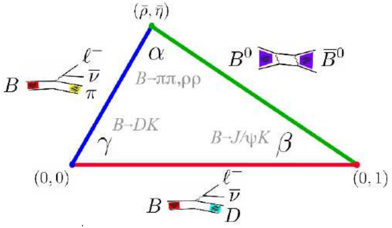
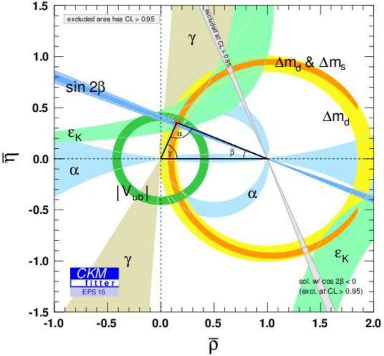




CKM metrology

Overconstraining measurements:





angles of unitarity triangle related to CP violation, e.g.

- mixing-induced CP asymmetry in $B \to J/\psi K_s \quad \to \quad \beta$
- direct CP asymmetry in $B \to DK \quad \to \quad \gamma$

Flavour beyond the SM

generic extension of SM
$\rightarrow$ new sources of flavour ($= [U(3)]^3$) violation

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example: MSSM $\rightarrow$ soft SUSY-breaking terms

$$-\mathcal{L}_{\text{soft}}^{\text{SUSY}} \supset \widetilde{Q}_L^* \widetilde{m}_Q^2 \widetilde{Q}_L + \widetilde{u}_R^* \widetilde{m}_u^2 \widetilde{u}_R + \widetilde{d}_R^* \widetilde{m}_d^2 \widetilde{d}_R + \widetilde{u}_R^* H_u a^u \widetilde{Q}_L + \widetilde{d}_R^* H_d a^d \widetilde{Q}_L + h.c.$$

$\widetilde{m}_Q^2, \widetilde{m}_u^2, \widetilde{m}_d^2$: 3×3 hermitian mass matrices

a^u, a^d : 3×3 trilinear coupling matrices

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$\widetilde{m}_Q^2, \widetilde{m}_u^2, \widetilde{m}_d^2$: 3×3 hermitian mass matrices
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need further spurions to restore flavour symmetry:

$$\widetilde{m}_Q^2 \rightarrow R^Q \widetilde{m}_Q^2 R^{Q\dagger}, \quad \widetilde{m}_u^2 \rightarrow R^u \widetilde{m}_u^2 R^{u\dagger}, \quad \widetilde{m}_d^2 \rightarrow R^d \widetilde{m}_d^2 R^{d\dagger}$$

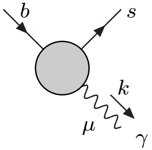
$$a^u \rightarrow R^u a^u R^{Q\dagger}, \quad a^d \rightarrow R^d a^d R^{Q\dagger}$$

$\Rightarrow$ new contributions to FCNCs

FCNCs beyond the SM

example:

exclusive decay $\overline{B} \to X_s\gamma$ (quark-level: $b \to s\gamma$)



$$\mathcal{M}_L^\mu \propto \bar{Q}_L^2 a_{23}^{d\dagger} \sigma^{\mu\nu} k_\nu d_R^3 = a_{32}^{d*}\, \bar{s}_L \sigma^{\mu\nu} k_\nu b_R$$

$$\mathcal{M}_R^\mu \propto \bar{d}_R^2 a_{23}^{d} \sigma^{\mu\nu} k_\nu Q_L^3 = a_{23}^{d}\, \bar{s}_R \sigma^{\mu\nu} k_\nu b_L$$

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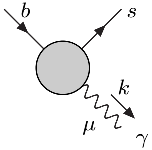

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$\Rightarrow$ strong constraints on new flavour structures

$\Rightarrow$ flavour problem of new physics

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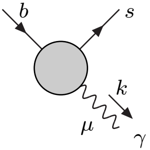

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MFV hypothesis: (Minimal Flavour Violation)

y^u, y^d are the only spurions of the $[U(3)]^3$ flavour symmetry

flavour problem of new physics reduces to SM flavour problem

Minimal Flavour Violation

MFV hypothesis: (Minimal Flavour Violation)
y^u, y^d are the only spurions of the $[U(3)]^3$ flavour symmetry

parametrisation of flavoured NP parameters in terms of y^d, y^u

e.g. SUSY-breacking terms:

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$$a^d = A_0 y^d \left[a_2 + b_4 y^u y^{u\dagger} + ...\right]$$

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MFV hypothesis: (Minimal Flavour Violation)
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"more minimal" definition $b_i \equiv 0$?
not RGE invariant: if imposed at one scale, $b_i \neq 0$ induced at others

CMSSM (constrained MSSM): $b_i \equiv 0$ at Planck scale

Radiative flavour violation

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- assume exact flavour symmetry in Yukawa sector
  use flavour structure of NP model to generate small quark masses and $V \neq 1$ radiatively

  Radiative Flavour Violation (RFV) [Weinberg'72]

  from soft-susy breaking terms
  [Buchmüller,Wyler'83, Banks'88, Borzumati,Farrar,Polonsky'98'99, Ferrandis,Haba'04]

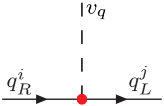
  today: strong constraints from FCNCs
  but: RFV from trilinear A-terms still viable
  [Crivellin,LH,Nierste,Scherer'11]

MFV vs. RFV

	gauge sector		Yukawa sector	SUSY breaking
MFV	$U(3)^3$	$\longrightarrow$	$U(1)_B$	

$$Y^{q(0)} = \begin{pmatrix} y^q_{11} & y^q_{12} & y^q_{13} \\ y^q_{21} & y^q_{22} & y^q_{23} \\ y^q_{31} & y^q_{32} & y^q_{33} \end{pmatrix}$$

m_{u_i}, m_{d_i}, V_{ij}



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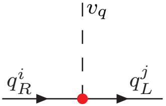

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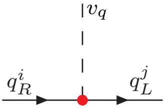
RFV

$$U(3)^3 \longrightarrow U(2)^3$$

$$Y^{q(0)} = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & y^q \end{pmatrix}$$

$$m_t, m_b, V = 1$$



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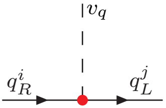
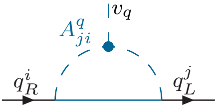
$$m_u, m_d, m_s, m_c, V_{ij}(i \neq j)$$





Radiative Flavour Violation

$U(2)^3$ symmetry of Yukawa sector

- obeyed by bilinear squark mass terms $\widetilde{M}^2_{Q_L,u_R,d_R}$
- broken by trilinear $A^{u,d}$-terms

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This scenario of RFV

- links the breaking of flavour-symmetries to SUSY-breaking
- explains overall smallness of quark-masses m_u, m_d, m_s, m_c and CKM-elements V_{ti}, V_{ib} $(i = 1, 2)$ by loop suppression
- softens the SUSY flavour problem by linking most of the flavour off-diagonal SUSY-breaking terms to measured CKM elements
- allows to split the third squark generation from the first two in order have
  - light stops as favoured by the hierarchy problem
  - heavy squarks of first two generations avoiding bounds from direct searches

A-terms

perform $U(2)$-rotations on left- and righthanded superfields such that

$$A^{q=u,d} = \begin{pmatrix} A^q_{11} & 0 & A^q_{13} \\ 0 & A^q_{22} & A^q_{23} \\ A^q_{31} & A^q_{32} & A^q_{33} \end{pmatrix}, \qquad V^{(0)} = \begin{pmatrix} \cos\theta_C & \sin\theta_C & 0 \\ -\sin\theta_C & \cos\theta_C & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

θ_C =exp. measured Cabbibo-angle

- minimal flavour violation with respect to the first two generations
- avoid tight contraints from Kaon physics

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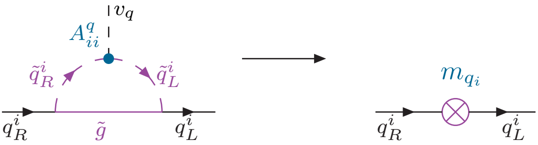
radiative mass generation ($q = u, d$, $i = 1, 2$):



$$m_{q_i} = a_q \, A^q_{ii} \, v_q$$

smallness of light quark masses $\longleftrightarrow$ $a_q \sim \dfrac{\alpha_s}{4\pi}$

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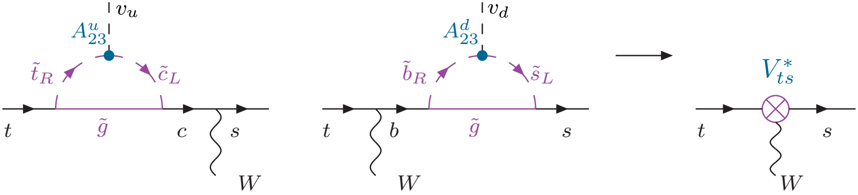
radiative CKM generation (example: V_{ts}):



$$V^*_{ts} = b_u\, A^u_{23}\, \frac{v_u}{m_t} - b_d\, A^d_{23}\, \frac{v_d}{m_b}$$

smallness of CKM elements V_{ti}, V_{ib} $(i = 1, 2)$ $\longleftrightarrow$ $b_q \sim \frac{\alpha_s}{4\pi}$

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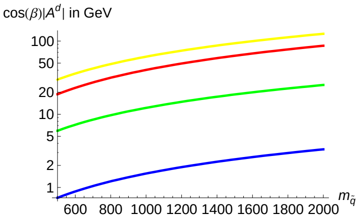

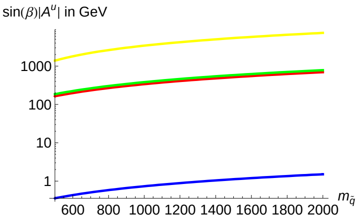

loop-functions in radiative mass and CKM generation do not decouple for $M_{\mathrm{SUSY}} \to \infty$

$\Rightarrow$ RFV works also for high SUSY mass scale

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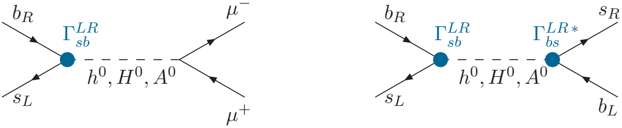
contribution of A^q_{31}, A^q_{32} to CKM elements helicity-suppressed

(small quark mass ratios m_s/m_b, m_c/m_t,...)

- A^q_{31}, A^q_{32} not constrained from measured CKM elements
- A^q_{31}, A^q_{32} act as sources of non-minimal flavour violation
  $\Rightarrow$ different phenomenology than MFV scenarios

Higgs (double) penguins



- MFV:

$$\Gamma_{sb}^{LR} \propto y_b\, y_t^2\, V_{ts}^* V_{tb}\,, \qquad \Gamma_{bs}^{LR*} \propto y_s\, y_t^2\, V_{ts}^* V_{tb}$$

$\Rightarrow$ Experimental bounds on $B_s \to \mu^+\mu^-$ render Higgs double penguin effects in $B_s - \bar{B}_s$ mixing negligible because of $\Gamma_{bs}^{LR*}/\Gamma_{sb}^{LR} \propto m_s/m_b$

- RFV:

$$\Gamma_{sb}^{LR} \propto A_{23}^d \propto V_{ts}^*\,, \qquad \Gamma_{bs}^{LR*} \propto A_{32}^{d*}$$

$\Rightarrow$ Γ_{bs}^{LR*} not suppressed with respect to Γ_{sb}^{LR}