Trilinear SUSY-breaking terms as the origin of flavour?

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Andreas Crivellin and UN, arXiv:0810.1613 [hep-ph]

Outline

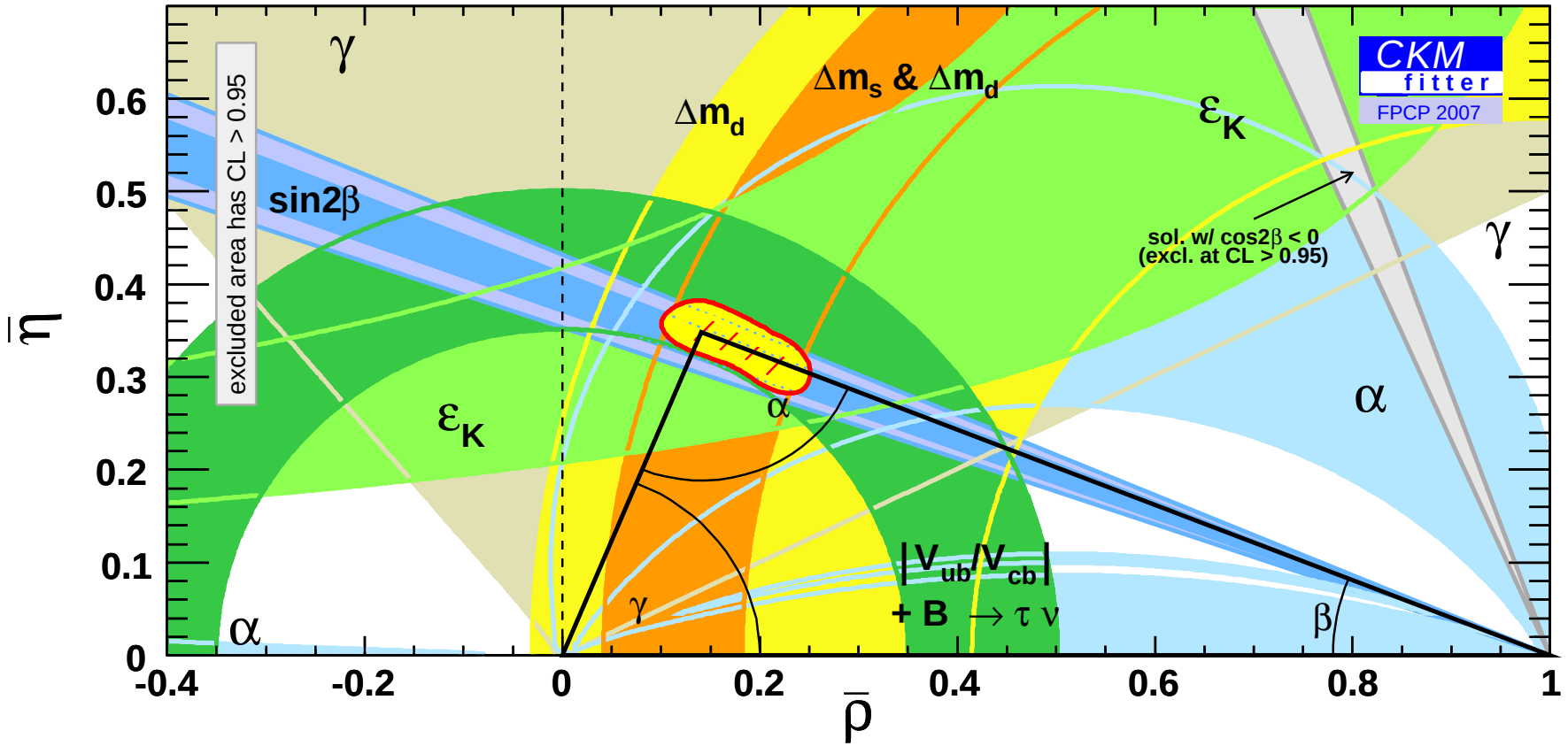
1. New constraints on the squark mass matrices
2. Flavour violation from trilinear terms
3. Summary

1. New constraints on the squark mass matrices

In a weak basis with a diagonal up–type Yukawa matrix Y^u the off–diagonal elements of the down–type Yukawa matrix Y^d range from $|Y^d_{31}| \sim 10^{-7}$ to $|Y^d_{23}| \sim 6 \cdot 10^{-4}$ at the scale $M_{\rm SUSY} = \mathcal{O}(500\ \text{GeV})$.

$\Rightarrow$ FCNC processes are highly sensitive to new physics at the TeV scale.

Experimental status of the unitarity triangle



consistent with the Standard Model

$\Rightarrow$ CKM mechanism is the dominant source of flavour violation.

The Standard Model works too well:

Flavour problem of TeV scale physics

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In the Minimal Supersymmetric Standard Model (MSSM) all potential new sources of flavour violation come from the SUSY breaking sector. The success of the flavour physics programs at the B factories and the Tevatron severely constrains the associated parameters in the squark mass matrices.

SUSY flavour problem

Down squark mass matrix in the super-CKM basis

In the convention of: F. Gabbiani, E. Gabrielli, A. Masiero and L. Silvestrini, Nucl. Phys. B 477 (1996) 321 [arXiv:hep-ph/9604387].

$$
M^2_{\tilde{q}} = \begin{pmatrix}
\left(M^{\tilde{q}}_{1L}\right)^2 & \Delta^{\tilde{q}LL}_{12} & \Delta^{\tilde{q}LL}_{13} & \Delta^{\tilde{q}LR}_{11} & \Delta^{\tilde{q}LR}_{12} & \Delta^{\tilde{q}LR}_{13} \\
\Delta^{\tilde{q}LL*}_{12} & \left(M^{\tilde{q}}_{2L}\right)^2 & \Delta^{\tilde{q}LL}_{23} & \Delta^{\tilde{q}RL*}_{12} & \Delta^{\tilde{q}LR}_{22} & \Delta^{\tilde{q}LR}_{23} \\
\Delta^{\tilde{q}LL*}_{13} & \Delta^{\tilde{q}LL*}_{23} & \left(M^{\tilde{q}}_{3L}\right)^2 & \Delta^{\tilde{q}RL*}_{13} & \Delta^{\tilde{q}RL*}_{23} & \Delta^{\tilde{q}LR}_{33} \\
\Delta^{\tilde{q}LR*}_{11} & \Delta^{\tilde{q}RL}_{12} & \Delta^{\tilde{q}RL}_{13} & \left(M^{\tilde{q}}_{1R}\right)^2 & \Delta^{\tilde{q}RR}_{12} & \Delta^{\tilde{q}RR}_{13} \\
\Delta^{\tilde{q}LR*}_{12} & \Delta^{\tilde{q}LR*}_{22} & \Delta^{\tilde{q}RL}_{23} & \Delta^{\tilde{q}RR*}_{12} & \left(M^{\tilde{q}}_{2R}\right)^2 & \Delta^{\tilde{q}RR}_{23} \\
\Delta^{\tilde{q}LR*}_{13} & \Delta^{\tilde{q}LR*}_{23} & \Delta^{\tilde{q}LR*}_{33} & \Delta^{\tilde{q}RR*}_{13} & \Delta^{\tilde{q}RR*}_{23} & \left(M^{\tilde{q}}_{3R}\right)^2
\end{pmatrix}
$$

Dimensionless quantity: $\delta_{ij}^{q\,XY} = \dfrac{\Delta_{ij}^{\tilde{q}\,XY}}{\frac{1}{6}\sum_s \left[M_{\tilde{q}}^2\right]_{ss}}$ with $X, Y = L, R$.

FCNC constraints:

F. Gabbiani, E. Gabrielli, A. Masiero and L. Silvestrini 1996,
M. Ciuchini *et al.* 1998,
F. Borzumati, C. Greub, T. Hurth and D. Wyler 2000,
D. Becirevic *et al.* 2001,
M. Ciuchini *et al.* 2007.

Vacuum stability bounds:

J. A. Casas, A. Lleyda and C. Munoz 1995,
J. A. Casas and S. Dimopoulos 1996.

New: Bounds from a fine-tuning argument...

Recall:

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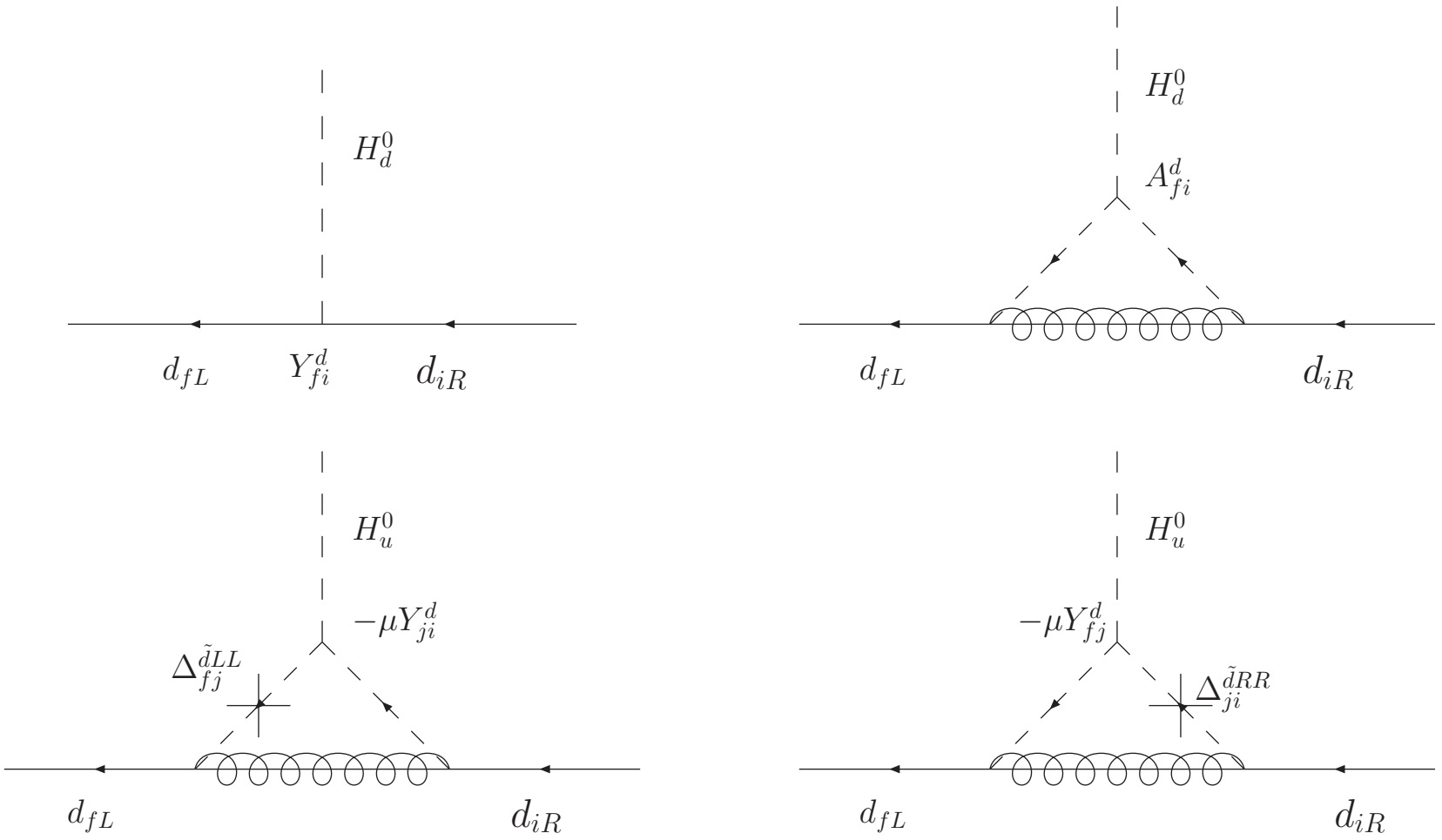
To avoid fine-tuning we demand that the finite loop corrections to the CKM matrix do not exceed the measured values.

Corrections to Y^d_{ij}



Lower row: relevant for large $\tan\beta$,

Hall, Rattazzi, Sarid 1993; Hamzaoui, Pospelov, Toharia 1998; Babu, Kolda 1999.

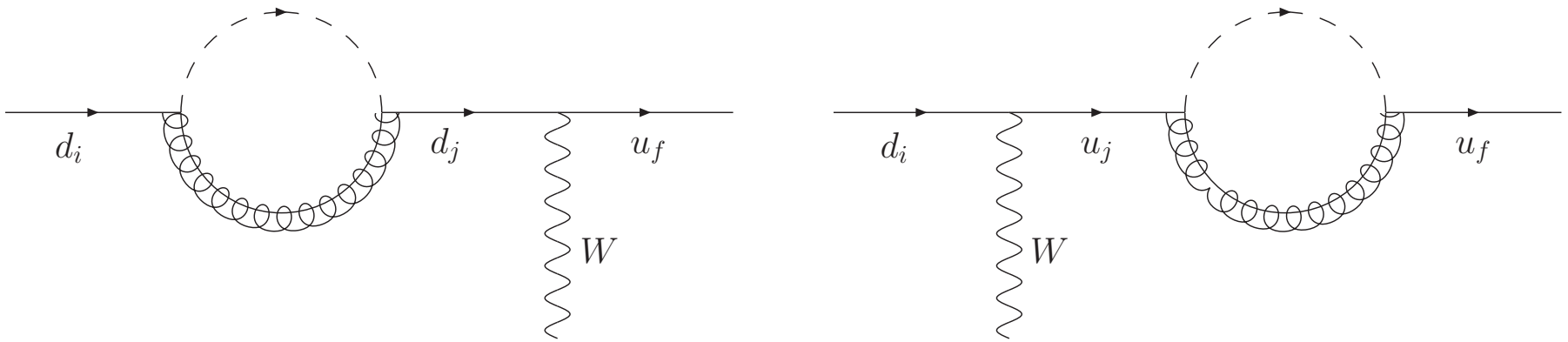
Best method: Work in the super-CKM basis with physical fields (i.e. after electroweak symmetry breaking) and calculate the finite counterterms to the CKM elements from squark-gluino loops.

Advantages:

- works for any hierarchy between M_{SUSY} and the electroweak vev $v = 174$ GeV, left-right mixing of squarks is easily included,
- directly gives constraints on $\delta_{ij}^{q\,XY}$,
- multi-purpose result: CKM counterterms are also useful for charged-Higgs and chargino couplings and top decays.

CKM renormalisation for minimal flavour violation: Blazek, Raby, Pokorski 1995

The large effects appear through chirally enhanced self-energies:



Effect:

$$V^{(0)} \to V = \left(1 + \Delta U_L^{u\dagger}\right) V^{(0)} \left(1 + \Delta U_L^{d}\right)$$

with unitary rotations $(1 + \Delta U_L^{u,d})$ computed from the self-energies.
$V^{(0)}$ is the bare CKM matrix and V is the physical CKM matrix.

The fine-tuning bounds are obtained by setting $V^{(0)} = 1$.

Qualitative result: We find new bounds for $|\delta_{ij}^{q\,LR}|$ with $j > i$.

Results and comparison

quantity	our bound	bound from FCNC	bound from vacuum stability
$\delta_{12}^{d\,LR}$	0.0011	0.006, K mixing	0.00015
$\delta_{13}^{d\,LR}$	0.001	0.15, B_d mixing	0.005
$\delta_{23}^{d\,LR}$	0.01	0.06, $b\to s\gamma$	0.05
$\delta_{13}^{d\,LL}$	0.032	0.5, B_d mixing	--
$\delta_{12}^{u\,LR}$	0.0047	0.016, D mixing	0.0012
$\delta_{13}^{u\,LR}$	0.027	--	0.22
$\delta_{23}^{u\,LR}$	0.27	--	0.22

Bounds calculated with $m_{squark}=m_{gluino}=1000$GeV

The quoted bound on $|\delta_{13}^{d\,LL}|$ further assumes $\mu \tan\beta \sim 20$ TeV.

2. Flavour violation from trilinear terms

All FCNC bounds on $|\delta^{d\,LR}_{ij}|$, $j > i$, are weaker than the bounds from CKM renormalisation, if $M_{\rm SUSY} > 500$ GeV.

$\Rightarrow$ We can set $V^{(0)} = 1$ and generate V solely from $\delta^{d\,LR}_{ij}$

Radiative flavour violation: S. Weinberg 1972

flavour from soft SUSY terms:

W. Buchmüller, D. Wyler 1983,

F. Borzumati, G.R. Farrar, N. Polonsky, S.D. Thomas 1998, 1999

J. Ferrandis, N. Haba 2004

This idea is still viable, albeit only with A^d_{ij} and A^u_{ij} entering

$$\Delta^{\tilde{d}\,LR}_{ij} = A^d_{ij} v_d, \qquad \Delta^{\tilde{u}\,LR}_{ij} = A^u_{ij} v_u \qquad \text{for } j > i.$$

Flavour symmetries

Gauge sector: $[U(3)]^3$

Yukawa sector: Keep Yukawa couplings for the third generation, because $y_t \sim 1$ and y_b and y_τ successfully unify.

$$[U(2)]^3 \times U(1)$$

$$\Rightarrow \quad Y^d = \text{diag}(0, 0, y_b) \quad \text{and} \quad Y^u = \text{diag}(0, 0, y_t).$$

Ferrandis, Haba 2004

$\Delta^{\tilde{u}\,LL}_{ij}$, $\Delta^{\tilde{u}\,RR}_{ij}$: same $[U(2)]^3 \times U(1)$ symmetry as Yukawa sector (e.g. through universality at a high scale)

$A^{\tilde{u}\,LR}_{ij}$, $A^{\tilde{d}\,LR}_{ij}$: spurion fields breaking $[U(2)]^3 \times U(1)$ to $U(1)_B$ also destroy the symmetry of $\Delta^{\tilde{u}\,LL}_{ij}$, $\Delta^{\tilde{u}\,RR}_{ij}$ through renormalisation, but do not generate dangerous flavour violation.

Electric dipole moments

Darkest corner of the MSSM: The phases of A^q_{ii} and μ generate too large EDMs. If light quark masses are generated radiatively through soft SUSY-breaking terms, this "supersymmetric CP problem" is substantially alleviated:

- The phases of A^q_{ii} and m_q are aligned, i.e. zero.
- The phase of μ does not enter the EDMs at the one-loop level, because the Yukawa couplings of the first two generations are zero.

Borzumati, Farrar, Polonsky, Thomas 1998, 1999

3. Summary

- We have worked out the one-loop renormalisation of the CKM matrix in the generic MSSM.
- We have derived powerful constraints on the elements $\delta^{q\,LR}_{ij}$ with $j > i$ from the requirement that the radiative corrections to the CKM matrix should not exceed the measured value. For example: $|\delta^{u,LR}_{13}| \leq 0.062$.
- The old idea of flavour violation from soft SUSY breaking terms has been challenged by the B factories and the Tevatron but is still alive: If $M_{\rm SUSY} \geq 500$ GeV all quark flavour can be generated from A^q_{ij}.
- The model is economical: Flavour violation and SUSY breaking have the same origin and small quark masses and small off-diagonal CKM elements are explained by a loop suppression.
- The EDM problem is substantially alleviated.
- The one-loop renormalisation of the CKM matrix has phenomenological applications in charged-Higgs and chargino physics.