New constraints on the flavour structure of left-handed squarks

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„Do squarks have to be degenerate? Constraining the mass splitting with $K-\bar{K}$ and $D-\bar{D}$ mixing.“

[Phys. Rev. D81: 095004, 2010, arXiv: 1002.2653 [hep-ph]]

Outline

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2. Meson mixing in the MSSM
3. Electroweak contributions
4. Constraining the mass splitting of the first two generations of left-handed squarks
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1. Introduction

The squark mass mixing matrix:

$$M_{\tilde{q}}^2 = \begin{pmatrix} M_{\tilde{q}LL}^2 & M_{\tilde{q}LR}^2 \\ M_{\tilde{q}RL}^2 & M_{\tilde{q}RR}^2 \end{pmatrix}$$

$SU(2)_L$ gauge invariance:

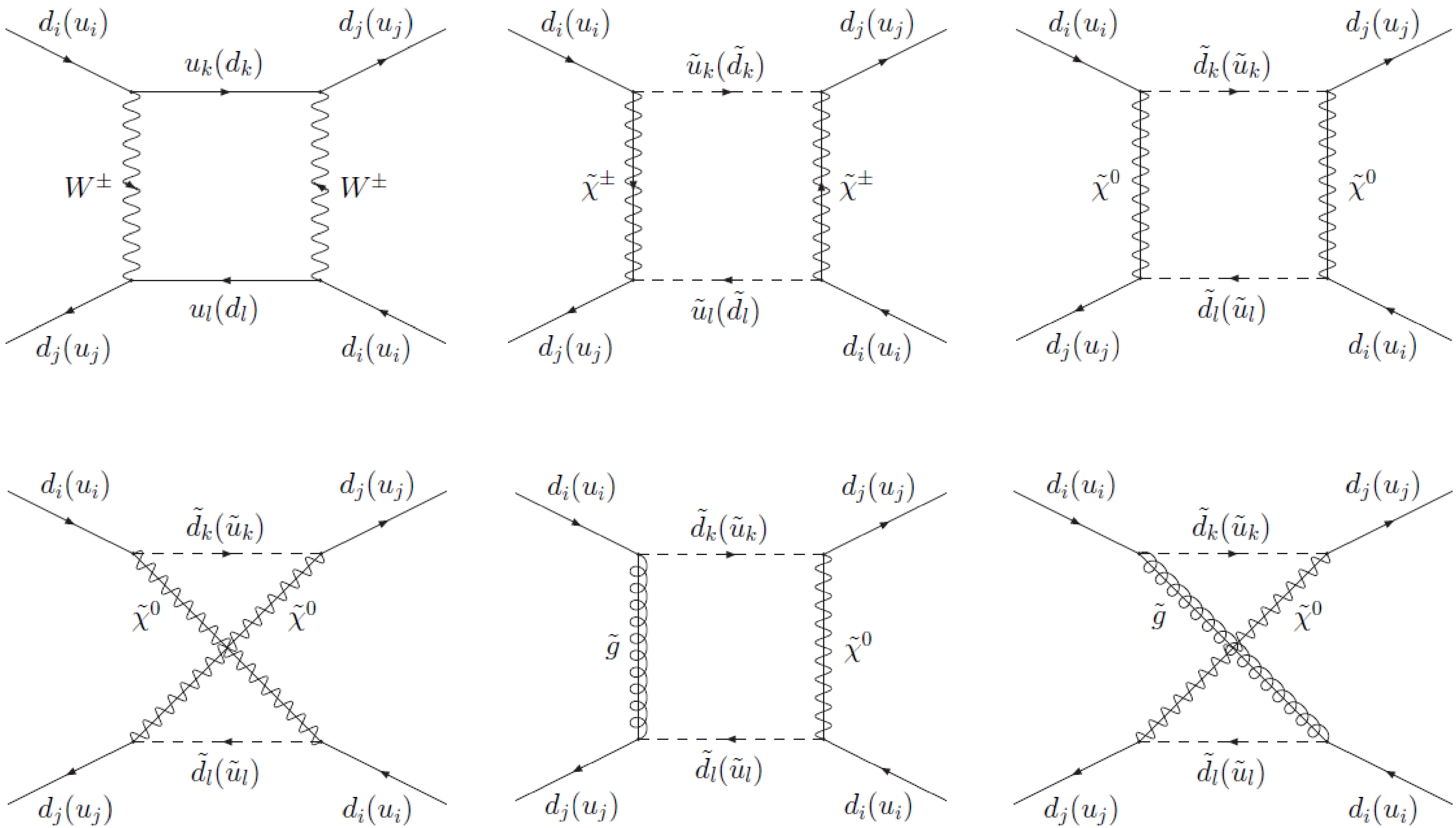
$$M_{\tilde{u}LL}^2 = K M_{\tilde{d}LL}^2 K^\dagger$$

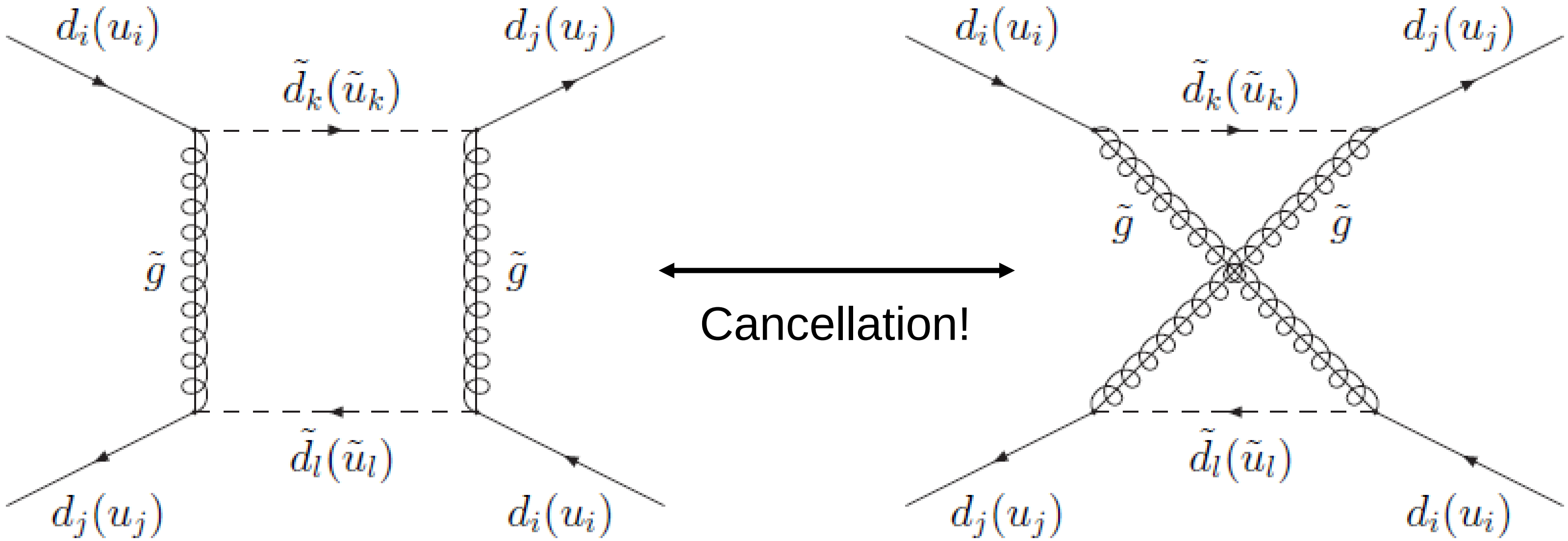
K: CKM matrix

Mass insertion parametrisation:

$$\delta_{ij}^{\tilde{q}XY} = \frac{\left(M_{\tilde{q}XY}^2\right)_{ij}}{\tilde{M}^2} \qquad \tilde{M}^2 = \frac{1}{6}\sum_k \left(M_{\tilde{q}}^2\right)_{kk}$$

2. Meson mixing in the MSSM





$$m_{\tilde{g}} \approx 1.5 m_{\tilde{q}}$$

Meson-antimeson mixing: FCNC process, suppressed

in the SM, because:

- loop induced.
- of smallness of the CKM elements.
- of GIM suppression.

Operator product expansion:

$$\langle M | H_{full} | \bar{M} \rangle \overset{!}{=} \sum_i C_i(\mu) \langle M | Q_i(\mu) | \bar{M} \rangle$$

Most important contribution from

$$Q_1 = \bar{q}_1^\alpha \gamma_\mu P_L q_2^\alpha \bar{q}_1^\beta \gamma^\mu P_L q_2^\beta$$

⟶ Wilson coefficient

$$C_1 = C_1^{SM} + C_1^{\tilde{\chi}^\pm \tilde{\chi}^\pm} + C_1^{\tilde{\chi}^0 \tilde{\chi}^0} + C_1^{\tilde{g}\tilde{g}} + C_1^{\tilde{g}\tilde{\chi}^0}$$

3. Electroweak contributions

Electroweak contribution suppressed by a factor g_2^4 / g_s^4 in comparison to the gluino contribution.

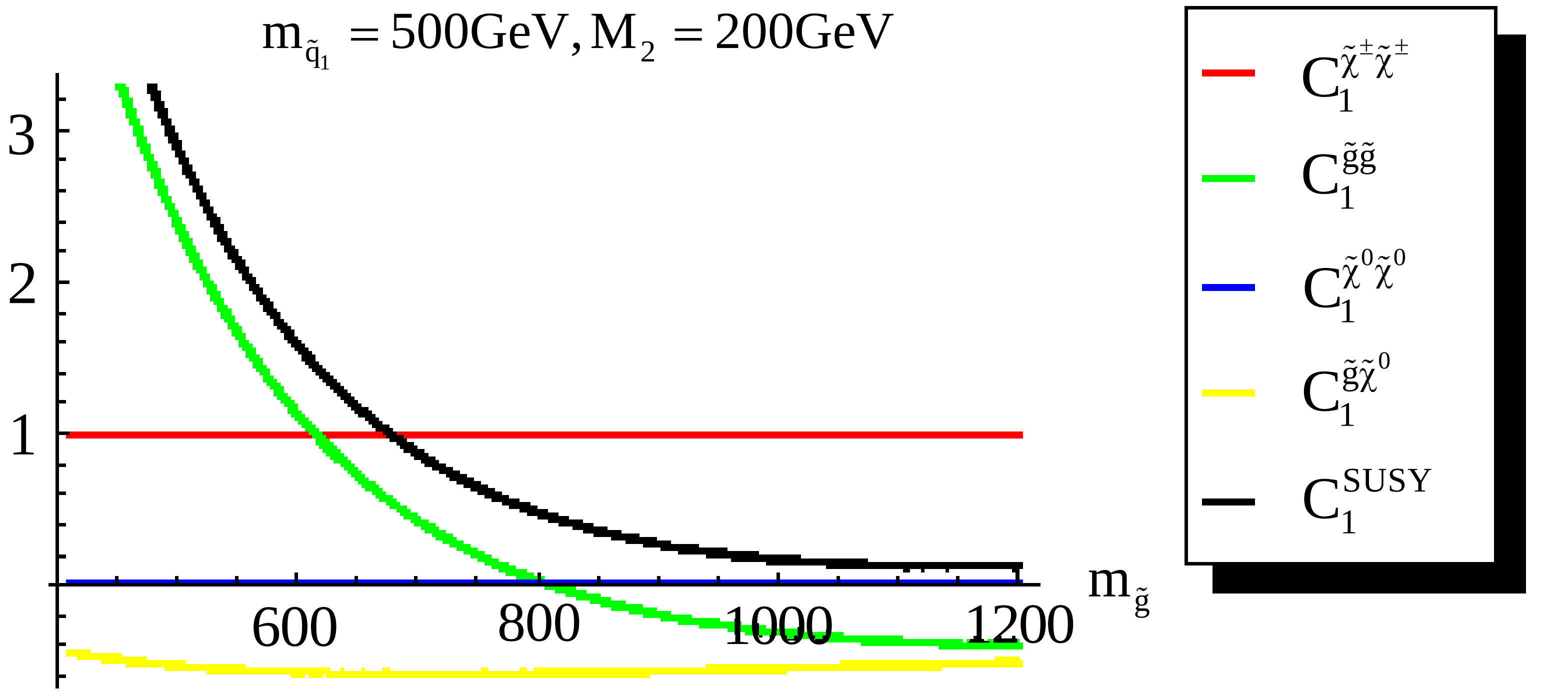
→ **Neglected in most analyses.**

However:

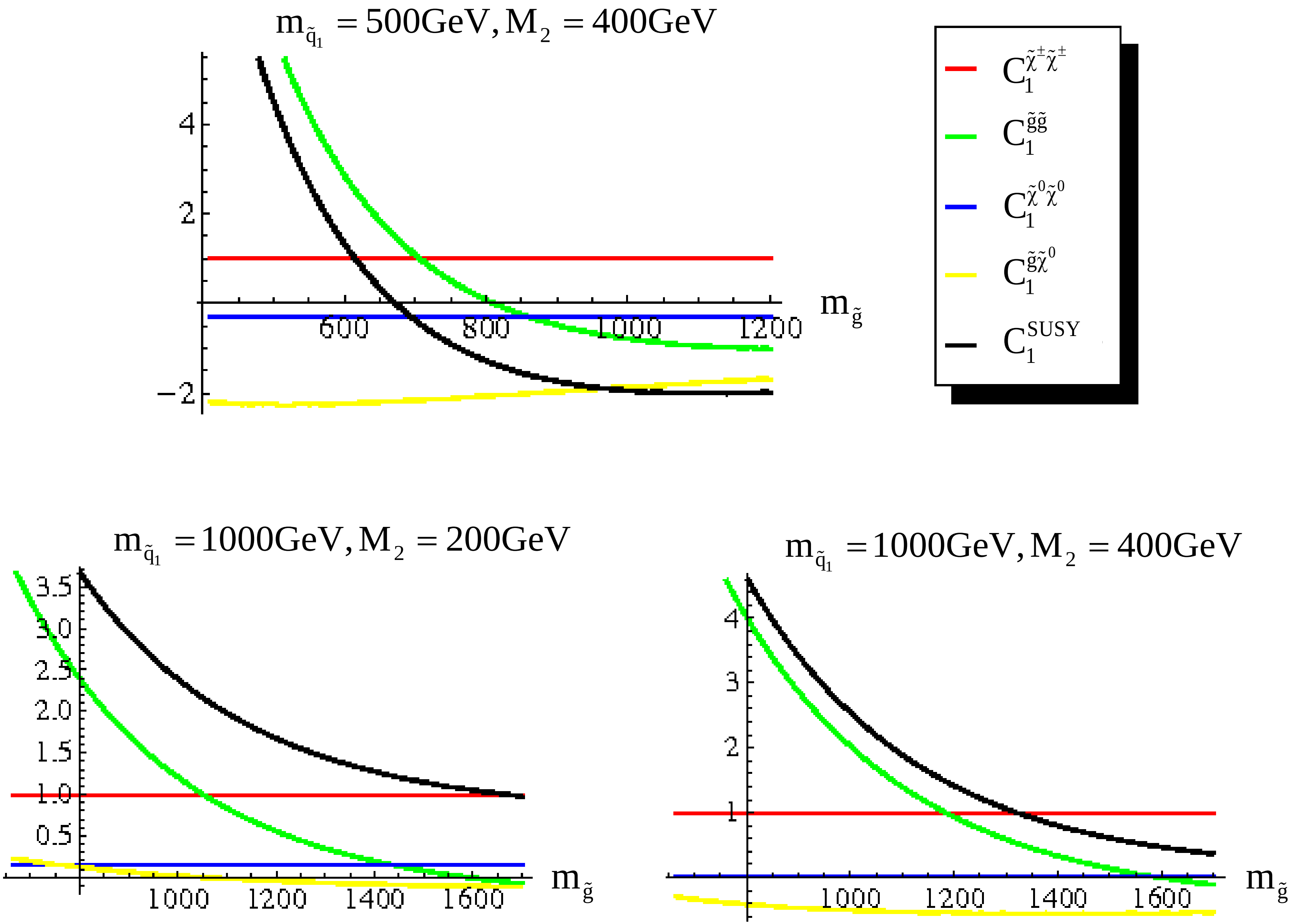
- Winos couple to $\tilde{q}_L$ with g_2.
- Cancellation between the crossed and uncrossed gluino boxes for $m_{\tilde{g}} \approx 1.5 m_{\tilde{q}}$.
- No such cancellation in the chargino box diagrams.

$$\Downarrow$$

If $\delta_{ij}^{\tilde{q}LL} \neq 0 \quad \Longrightarrow$ **Neglecting the gaugino contribution in not justified.**



Size of the real part of Wilson coefficient C_1 normalised to the chargino contribution.


$m_{\tilde{q}_1} = 500\text{GeV}, M_2 = 400\text{GeV}$
$C_1^{\tilde{\chi}^\pm\tilde{\chi}^\pm}$
$C_1^{\tilde{g}\tilde{g}}$
$C_1^{\tilde{\chi}^0\tilde{\chi}^0}$
$C_1^{\tilde{g}\tilde{\chi}^0}$
C_1^{SUSY}
$m_{\tilde{g}}$
4
2
−2
600
800
1000
1200
$m_{\tilde{q}_1} = 1000\text{GeV}, M_2 = 200\text{GeV}$
3.5
3.0
2.5
2.0
1.5
1.0
0.5
1000
1200
1400
1600
$m_{\tilde{g}}$
$m_{\tilde{q}_1} = 1000\text{GeV}, M_2 = 400\text{GeV}$
4
3
2
1
1000
1200
1400
1600
$m_{\tilde{g}}$

4. Constraining the mass splitting of the first two generations of left-handed squarks

Experimental bounds from FCNCs

$\Longrightarrow$
- Super GIM mechanism neccessary.
- Bounds on the mass insertions $\delta_{ij}^{\tilde{q}XY}$.

Question: Which regions in the MSSM parameter space with non-degenerate squarks are compatible with $K-\bar{K}$ and $D-\bar{D}$ mixing?

Constraints from $\Delta m_{K,D}^{NP} \leq \Delta m_{K,D}^{exp}$ and $\left|\varepsilon_K^{NP}\right| \leq 0.6\left|\varepsilon_K^{exp}\right|$.

(Blum et al., PRL 102 (2009) 211802; Agashe at al. hep-ph/0509117); see analyses from UTfit and CKMfitter collaborations.

Four scenarios:

1. Complete alignment in the up sector:

$$M^2_{\tilde{u}LL} = \mathrm{diag}\left(m^2_{\tilde{q}_1}, m^2_{\tilde{q}_2}, m^2_{\tilde{q}_2}\right) \xrightarrow{SU(2)} \delta^{\tilde{d}LL}_{12} = \lambda\left(1-\frac{\lambda^2}{2}\right)\left(\frac{m^2_{\tilde{q}_1}-m^2_{\tilde{q}_2}}{\tilde{M}^2}\right)+O\left(\lambda^5\right)$$

⟶ **Constraints from Kaon mixing.**

Wolfenstein parameter $\lambda = 0.23$.

2. Complete alignment in the down sector:

$$M^2_{\tilde{d}LL} = \mathrm{diag}\left(m^2_{\tilde{q}_1}, m^2_{\tilde{q}_2}, m^2_{\tilde{q}_2}\right) \xrightarrow{SU(2)} \delta^{\tilde{u}LL}_{12} = \lambda\left(1-\frac{\lambda^2}{2}\right)\left(\frac{m^2_{\tilde{q}_2}-m^2_{\tilde{q}_1}}{\tilde{M}^2}\right)+O\left(\lambda^5\right)$$

⟶ **Constraints from D-$\bar{D}$ mixing**

3. Intermediate alignment:

(Blum et al., PRL 102 (2009) 211802, arXiv: 0903.2118v1 [hep-ph].)

$$M^2_{\tilde{u}LL} = V_d^\dagger \cdot \mathrm{diag}\left(m^2_{\tilde{q}1}, m^2_{\tilde{q}2}, m^2_{\tilde{q}2}\right) \cdot V_d \quad \text{where} \quad V_d = \begin{pmatrix} \cos\theta_d & \sin\theta_d & 0 \\ -\sin\theta_d & \cos\theta_d & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$\theta_d = f\left(\left|C_1^K\right|, \left|C_1^D\right|, \theta_c\right) = 6.9^\circ$$

4. Off-diagonal element with maximal phase:

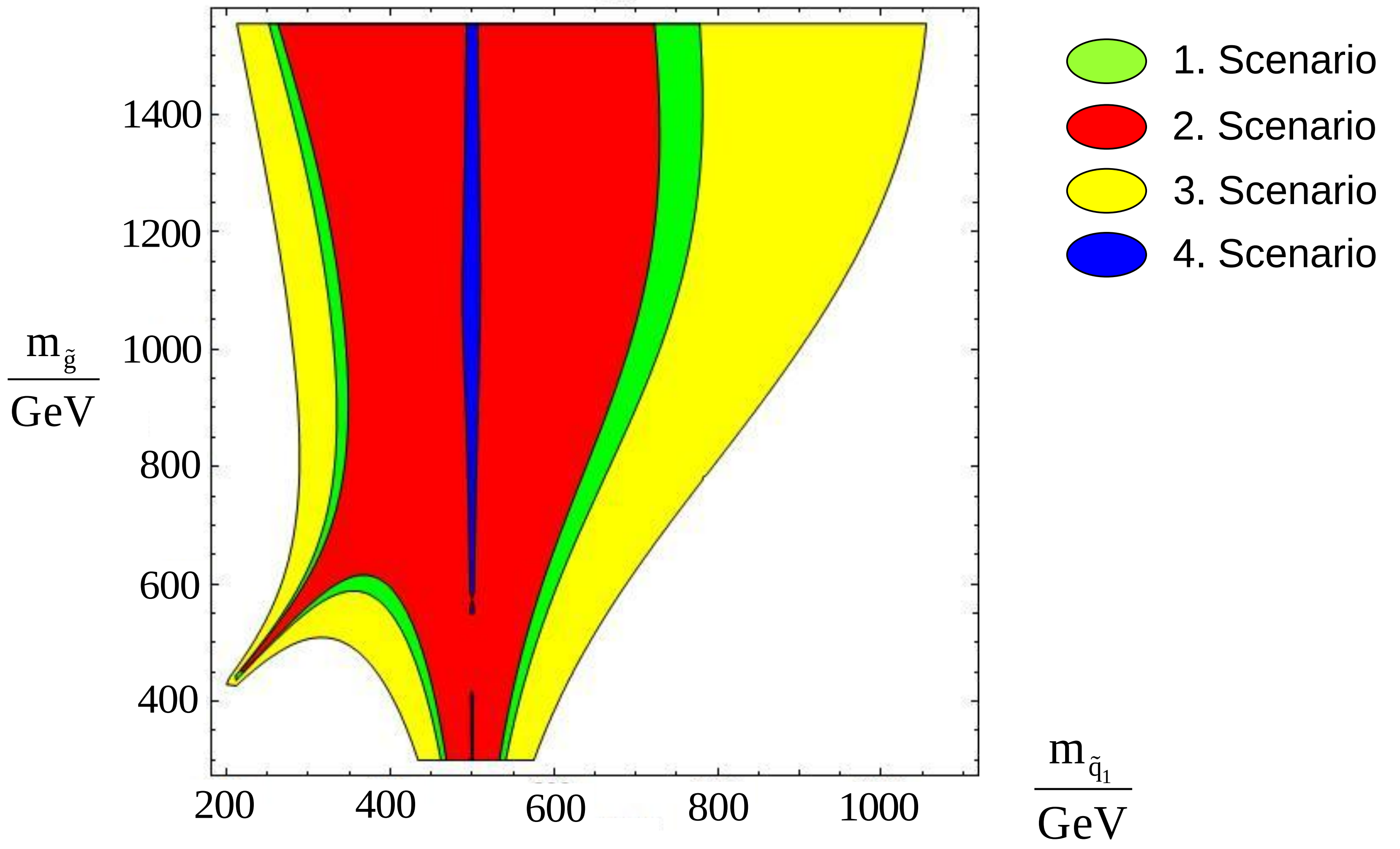
$$M^2_{\tilde{d}LL} = \begin{pmatrix} m^2_{\tilde{q}} & \tilde{M}^2 \left|\delta_{12}^{\tilde{d}LL}\right| e^{i\frac{\pi}{4}} & 0 \\ \tilde{M}^2 \left|\delta_{12}^{\tilde{d}LL}\right| e^{-i\frac{\pi}{4}} & m^2_{\tilde{q}} & 0 \\ 0 & 0 & m^2_{\tilde{q}} \end{pmatrix}$$

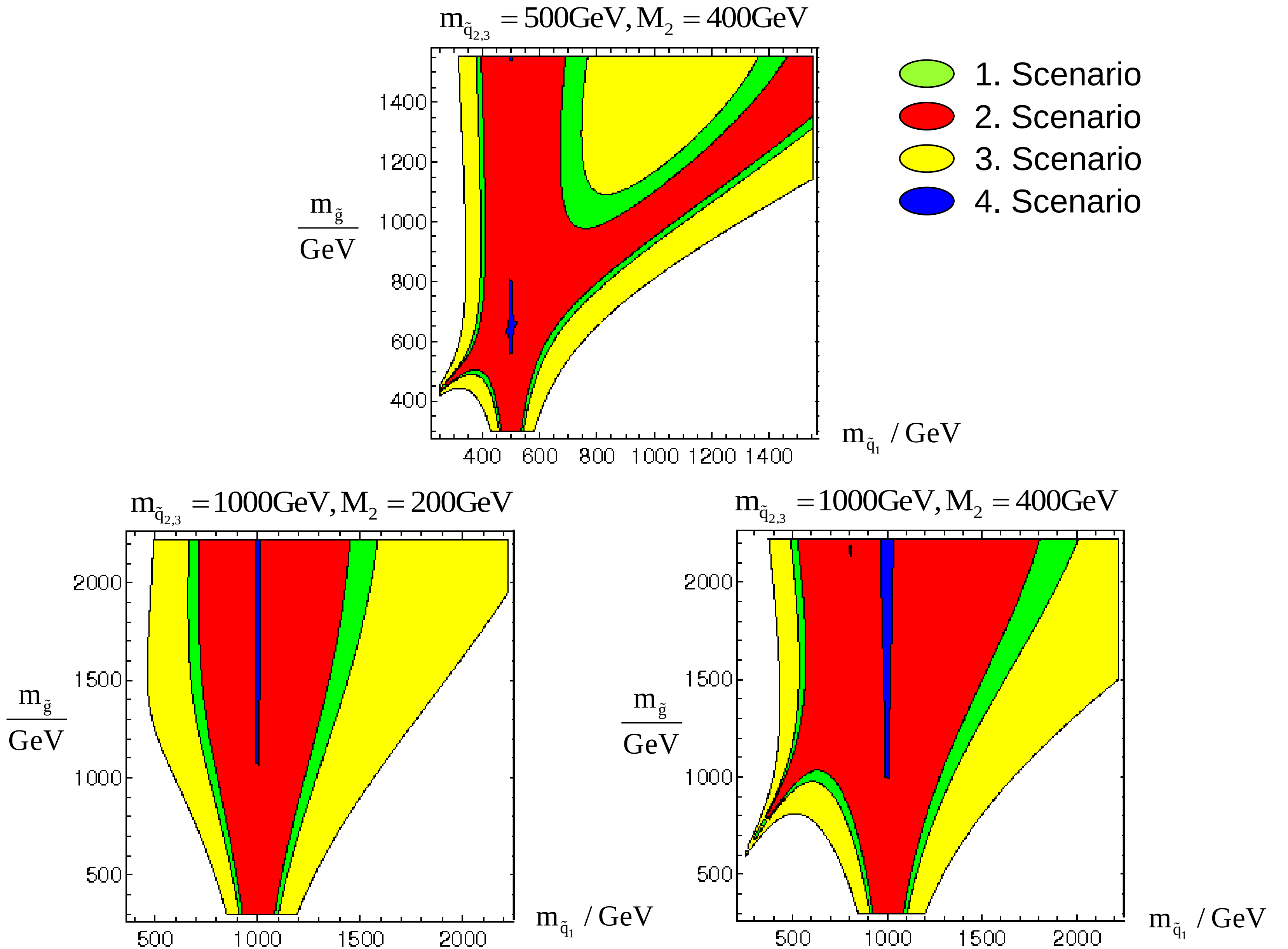
$\Longrightarrow$ Maximal imaginary part of C_1^K.

$\Downarrow$

Maximal constraint on the mass splitting from $|\varepsilon_K|$.

$$m_{\tilde{q}_{2,3}} = 500\text{GeV}, M_2 = 200\text{GeV}$$




$m_{\tilde{q}_{2,3}} = 500GeV, M_2 = 400GeV$
1. Scenario
2. Scenario
3. Scenario
4. Scenario
$\frac{m_{\tilde{g}}}{GeV}$
1400
1200
1000
800
600
400
400 600 800 1000 1200 1400
$m_{\tilde{q}_1}$ / GeV
$m_{\tilde{q}_{2,3}} = 1000GeV, M_2 = 200GeV$
$\frac{m_{\tilde{g}}}{GeV}$
2000
1500
1000
500
500 1000 1500 2000
$m_{\tilde{q}_1}$ / GeV
$m_{\tilde{q}_{2,3}} = 1000GeV, M_2 = 400GeV$
$\frac{m_{\tilde{g}}}{GeV}$
2000
1500
1000
500
500 1000 1500 2000
$m_{\tilde{q}_1}$ / GeV

5. Summary and Conclusions

- We examined the constraints on the mass splitting between the first two generations of left-handed squarks from $K-\bar{K}$ and $D-\bar{D}$ mixing.
- We considered the gluino as well as the electroweak contributions and examined their size.
- The gluino contribution suffers from the cancellation between the crossed and uncrossed boxes for $m_{\tilde{g}} \approx 1.5 m_{\tilde{q}}$.

  $\Longrightarrow$ In the presence of $\delta_{ij}^{\tilde{q}LL}$ the electroweak contribution can be of the same order as the gluino contribution, especially if $m_{\tilde{q}} < m_{\tilde{g}}$ and $M_2 = (\alpha_2 / \alpha_3) m_{\tilde{g}}$.

- There are strong constraints on the mass splitting of the first two generations of left-handed squarks for light gluino masses.
- For $m_{\tilde{g}} \approx m_{\tilde{q}}$ there are large regions allowed with highly non-degenerate squark masses.

  $\Longrightarrow$ Interesting for LHC benchmark scenarios and models with Abelian flavour symmetries.