Flavour Models with Dirac Gauginos

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Based on work done with

E. Dudas, M. Goodsell and L. Hurtier
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M. Goodsell
hep-ph/1407.5076

MOTIVATION

- No (clear) signatures of supersymmetry at LHC8
- Constraints on the flavour structure of the superpartner spectrum are increasingly severe
    - This encourages non-minimal SUSY extensions of the Standard Model with suppressed collider bounds and flavour changing transitions

SUSY models with DIRAC GAUGINOS

fit this description

SUSY Models with Dirac Gauginos

talks by G. Kribs, T. Gregoire

Why yes

- Larger squark - gluino splitting
- Modified Higgs sector
- Preserves R-symmetry
- Finite correction to Higgs mass
- Suppressed squarks' production
- Detectable scalar superpartners
- Milder flavour constraints

Why not

- "Plurality is not to be posited without necessity"
  William of Ockham
- Lost gauge coupling unification
- Model building somewhat difficult

Kribs, Poppitz, Weiner `08; Blechman, Ng `08;
Kumar, Tucker-Smith, Weiner `10; Fok, Kribs `10;
Davies, McCullough `12; Fok `12; Morita, Nakano, Shimomura `13

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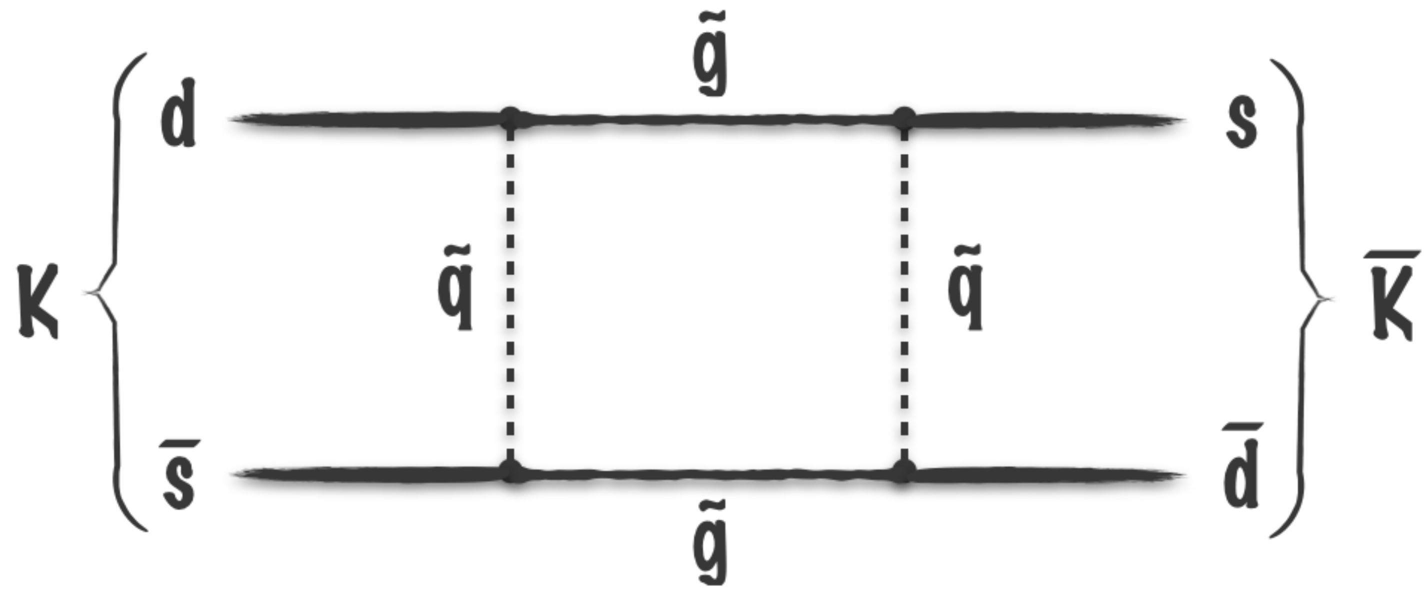
Outline of talk

- Overview of Neutral Meson Mixing in supersymmetry
- Flavour patterns for squarks (Degeneracy, Alignment, Hierarchy)
- Majorana vs Dirac contribution to FCNCs
- Majorana vs Dirac with nearly degenerate squarks
- Majorana vs Dirac with aligned or hierarchical squarks

Results

- For nearly degenerate squarks, Dirac flavour constraints are milder than Majorana (quantitative analysis)
- For aligned/hierarchical squarks it is model dependent but generally Dirac is less better (or even worse) than Majorana

Neutral Meson Mixing in SUSY



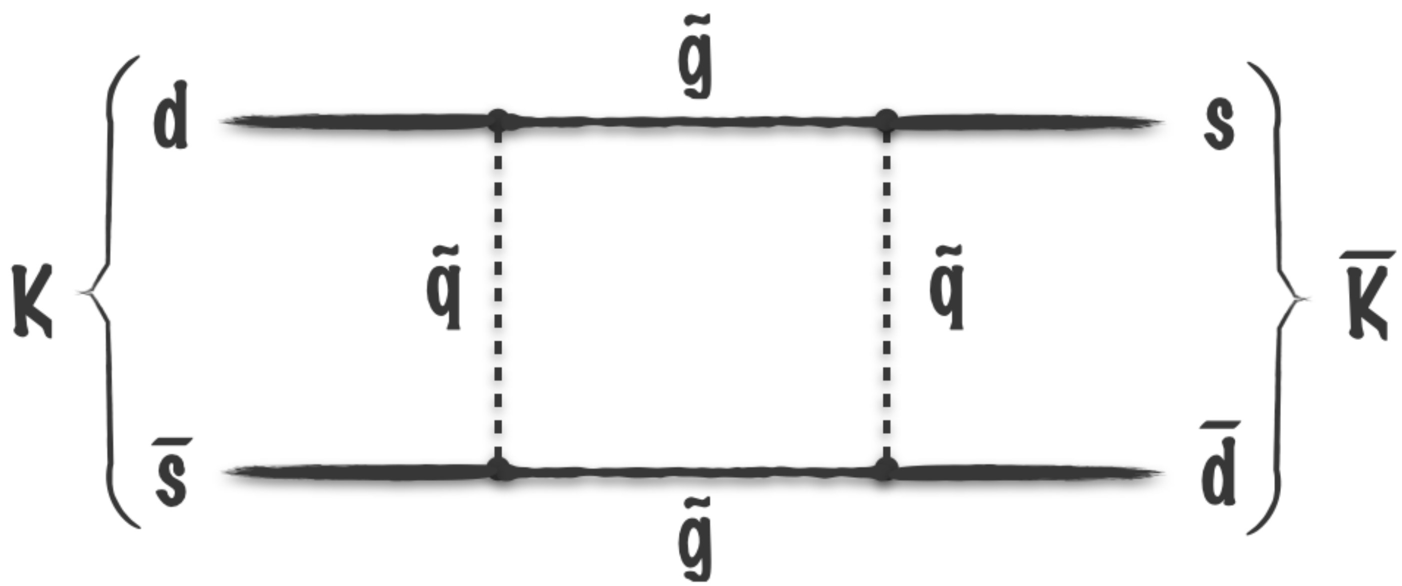
$$\mathcal{H}_K = \left(\text{Coefficients that depend on gluino couplings, masses etc} \right) \times \left(\text{dimension 6 4-fermion operators} \right)$$

$$\mathrm{Re}\langle K|\mathcal{H}_K|\overline{K}\rangle \longrightarrow \Delta M_K = M_{K_L} - M_{K_S} = 3.484 \times 10^{-15}\,\mathrm{GeV}$$

$$\mathrm{Im}\langle K|\mathcal{H}_K|\overline{K}\rangle \longrightarrow \epsilon_K = 2.228 \times 10^{-3}$$

Similarly for B_d-mesons, B_s-mesons and D-mesons

The squarks' diagonalizing matrix



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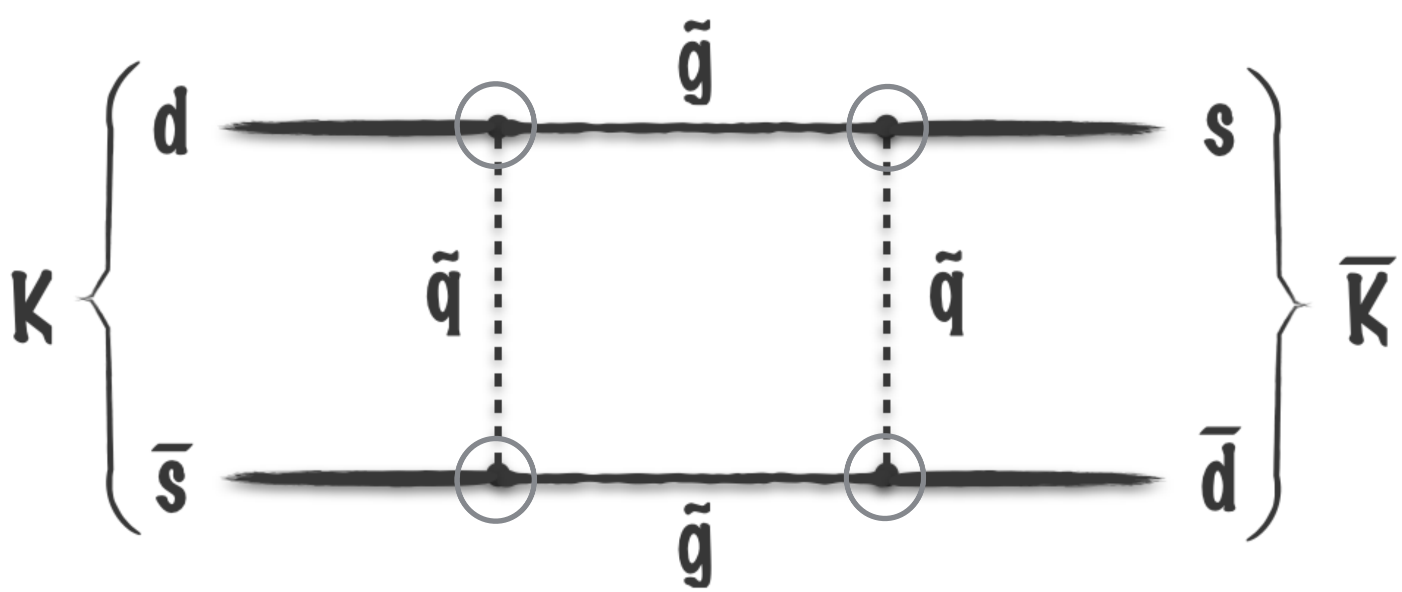
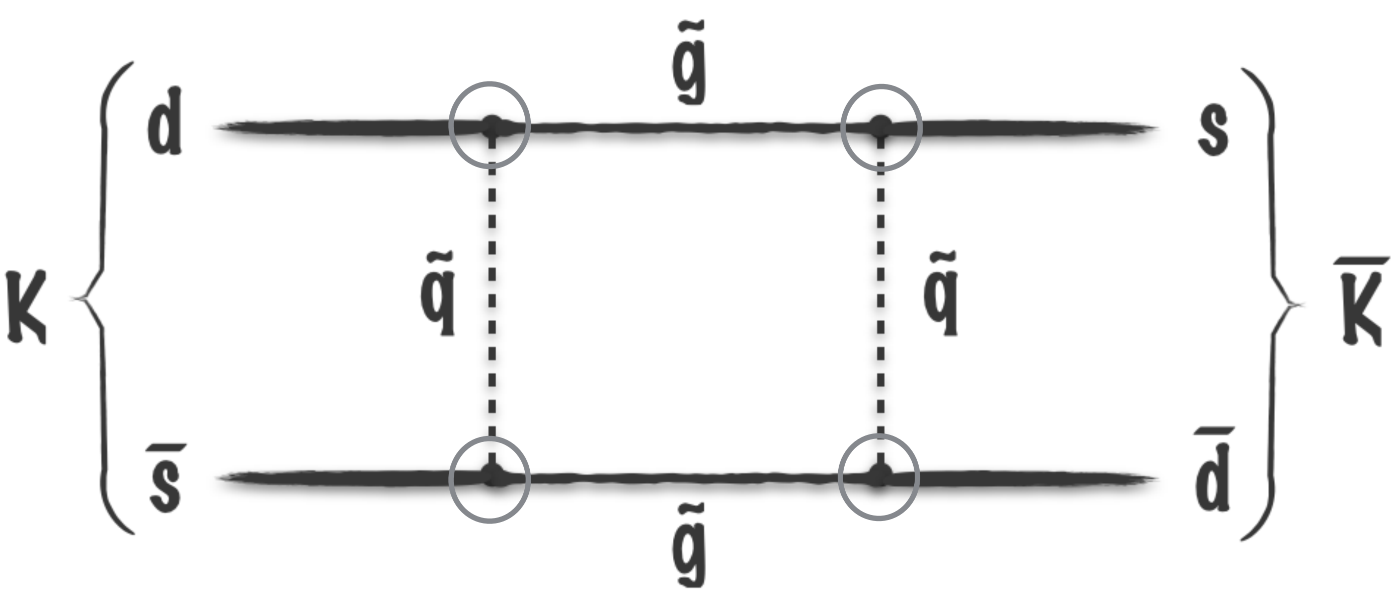


The squarks' diagonalizing matrix

$$g_s\, \tilde{q}_I^*\, \tilde{g}\, q_I$$



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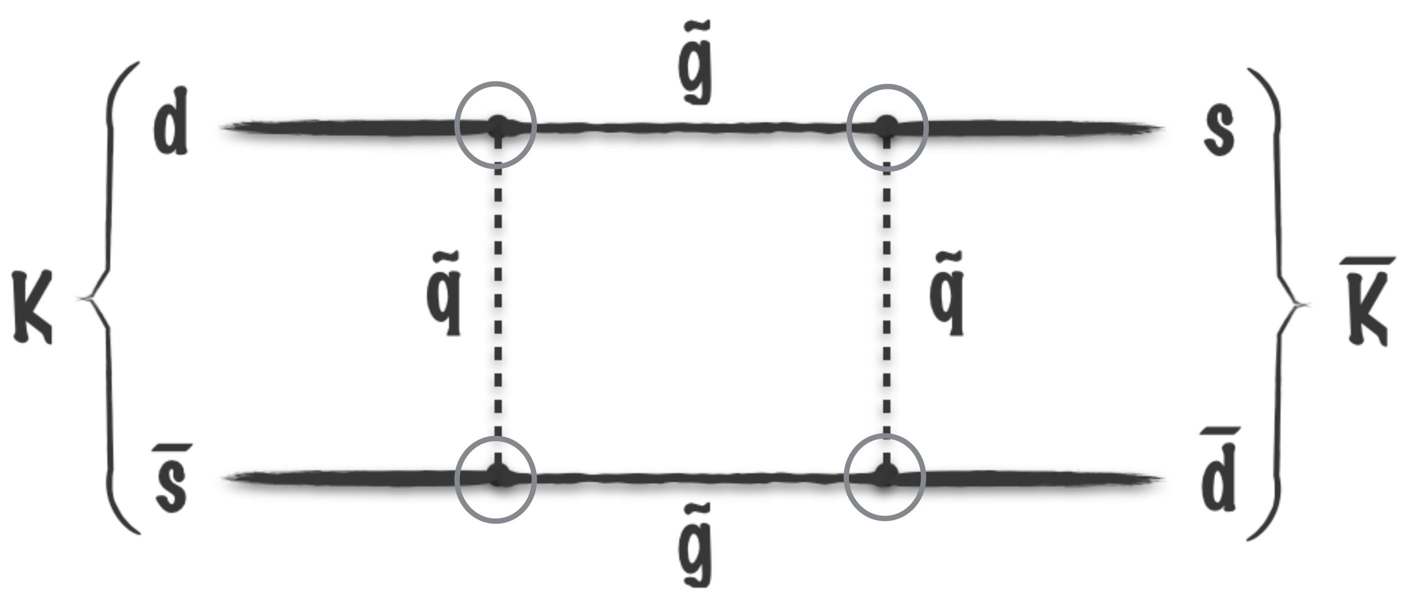
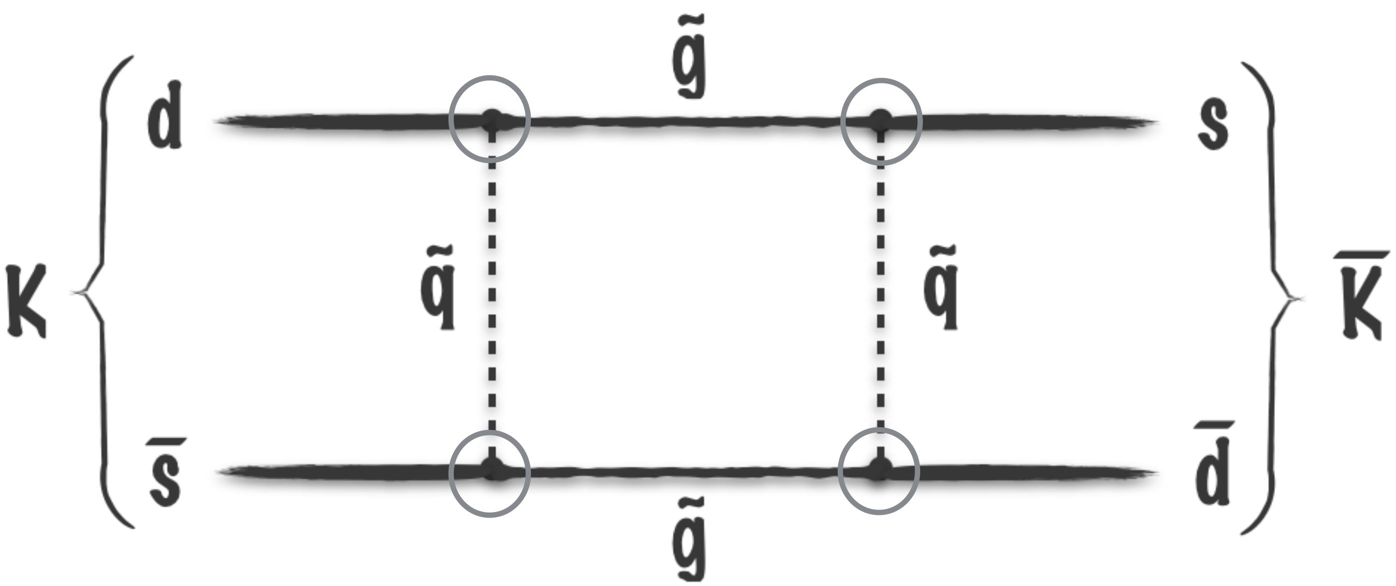


$$g_s\, \tilde{q}_I^*\, \tilde{g}\, q_I$$

diagonalization

$$g_s\, \tilde{q}_I^*\, (Z^\dagger_{IK} V_{KJ}) \tilde{g}\, q_J$$

The squarks' diagonalizing matrix



$$g_s\, \tilde{q}^*_I\, \tilde{g}\, q_I$$

diagonalization

$$g_s\, \tilde{q}^*_I\, (Z^\dagger_{IK} V_{KJ})\, \tilde{g}\, q_J$$

$W^\dagger_{IJ}$ squark diagonalizing matrix in the basis where quarks are diagonal

Flavour Patterns for squarks

$$\mathcal{H}_K = \left(\begin{array}{c} \text{Coefficients that} \\ \text{depend on gluino} \\ \text{couplings, masses etc} \end{array} \right) \times \left(\begin{array}{c} \text{dimension 6} \\ \text{4-fermion} \\ \text{operators} \end{array} \right)$$

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$\overline{d_L}\gamma^\mu s_L \, \overline{d_L}\gamma_\mu s_L$

$\overline{d_R} s_L \, \overline{d_L} s_R$

etc

Flavour Patterns for squarks

$$\mathcal{H}_K = \left(\begin{array}{c}\text{Coefficients that}\\ \text{depend on gluino}\\ \text{couplings, masses etc}\end{array}\right) \times \left(\begin{array}{c}\text{dimension 6}\\ \text{4-fermion}\\ \text{operators}\end{array}\right)$$

$$W_{IK} W_{LM} \, \mathrm{LOOP}(m^2_{\tilde{g}}, m^2_{\tilde{g}}, m^2_{\tilde{q}_K}, m^2_{\tilde{q}_M}) \, W^\dagger_{KJ} W^\dagger_{MN}$$

$\overline{d_L}\gamma^\mu s_L \, \overline{d_L}\gamma_\mu s_L$

$\overline{d_R} s_L \, \overline{d_L} s_R$

etc

- **Degenerate squarks**

  Suppression by the unitarity of W (à la GIM)

- **Aligned squark mass matrix**

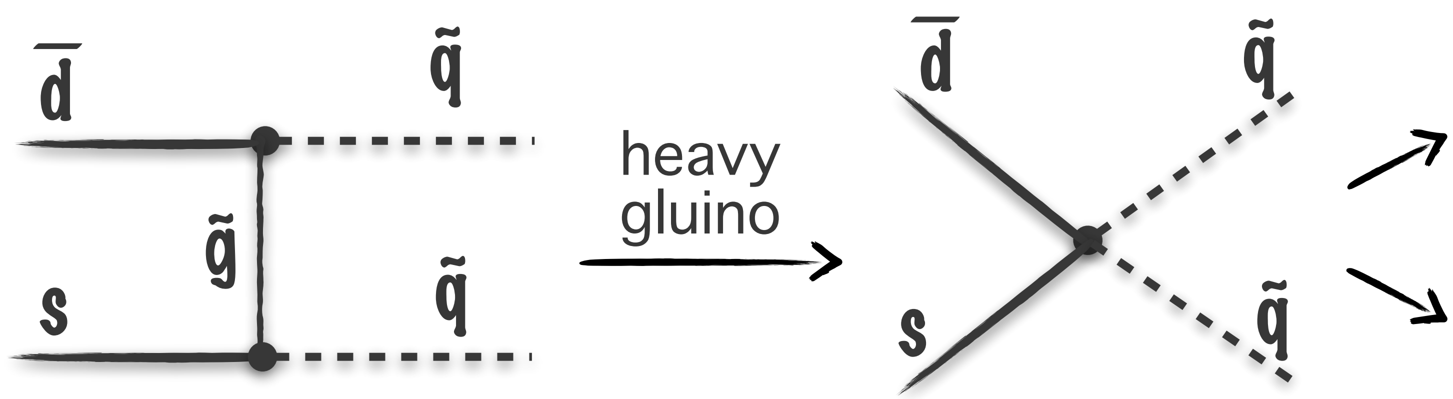
  Squark and quark mass matrices are nearly aligned

- **Hierarchical squarks**

  The contribution of the heavy squarks is negligible

Dirac vs Majorana contribution to FCNC

If gauginos have Dirac mass, chirality flip transitions are forbidden



$\sim \frac{1}{m_{\tilde{g}}} \tilde{d}_R \tilde{s}^*_L \overline{d}_R s_L$ for Majorana

$\sim \frac{1}{m^2_{\tilde{g}}} \tilde{d}_L \partial_\mu \tilde{s}^*_L \overline{d}_L \gamma^\mu s_L$ for Dirac

For nearly degenerate squarks, the contribution to FCNC from Dirac is suppressed with respect to Majorana

$$\frac{\Delta M_K|_{Majorana}}{\Delta M_K|_{Dirac}} \sim \frac{m^2_{\tilde{g}}}{m^2_{\tilde{q}}}$$

Kribs, Poppitz, Weiner `08

Dirac vs Majorana contribution to FCNC

- For nearly degenerate squarks: $\frac{\Delta M_K|_{Majorana}}{\Delta M_K|_{Dirac}} \sim \frac{m_{\tilde{g}}^2}{m_{\tilde{q}}^2}$

- For other flavour patterns it is model dependent but generally:

1) $\frac{\Delta M_K|_{Majorana}}{\Delta M_K|_{Dirac}} \sim \mathrm{Log}\left(\frac{m_{\tilde{g}}^2}{m_{\tilde{q}}^2}\right)$

2) Same-chirality and chirality-flip transitions can partially cancel

➡ Flavour constraints with Dirac gauginos are less better or even worse than with Majorana gauginos

Majorana with nearly degenerate squarks

- Bounds are not much stronger than earlier results because of higher squarks' and gluinos' masses
- Bounds from ϵ_K are around 25 times stronger than bounds from ΔM_K

$m_{\tilde{g}} = 1.5\,\mathrm{TeV}$

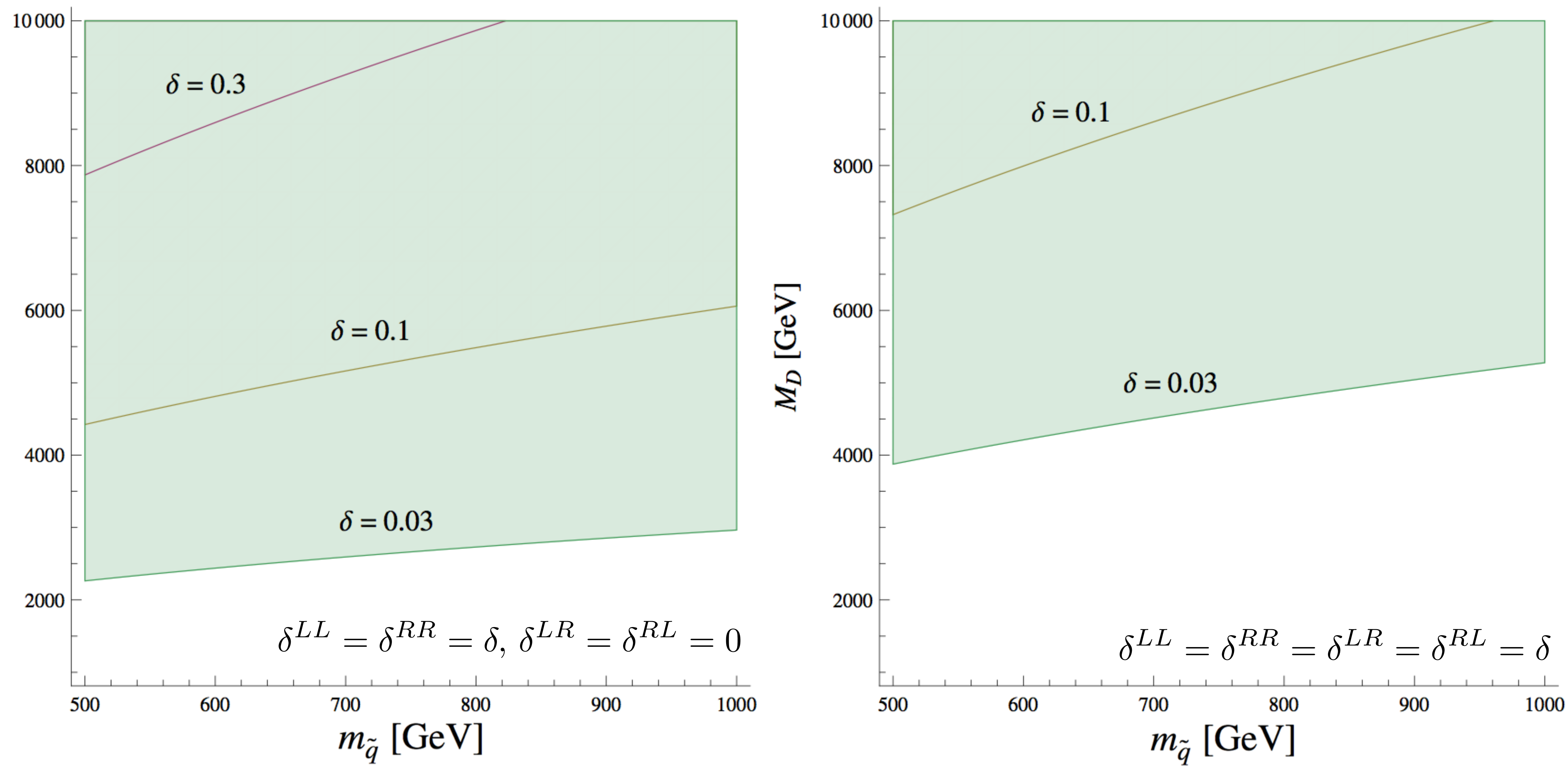
$m_{\tilde{q}}$ [GeV]	$\delta^{LL} \neq 0$	$\delta^{LL} = \delta^{RR} \neq 0$	$\delta^{LR} = \delta^{RL} \neq 0$
750	0.211	0.002	0.004
1500	0.180	0.002	0.014
2000	0.157	0.003	0.008

$m_{\tilde{g}} = 2\,\mathrm{TeV}$

$m_{\tilde{q}}$ [GeV]	$\delta^{LL} \neq 0$	$\delta^{LL} = \delta^{RR} \neq 0$	$\delta^{LR} = \delta^{RL} \neq 0$
750	0.192	0.002	0.005
1500	0.374	0.003	0.011
2000	0.240	0.003	0.019

$$\delta^{AB} = \sqrt{|\mathrm{Re}(\delta_{12}^{AB})^2|} \simeq 25\sqrt{|\mathrm{Im}(\delta_{12}^{AB})^2|}$$

Dirac with nearly degenerate squarks



- The mass split ΔM_K is accommodated but ϵ_K is still problematic

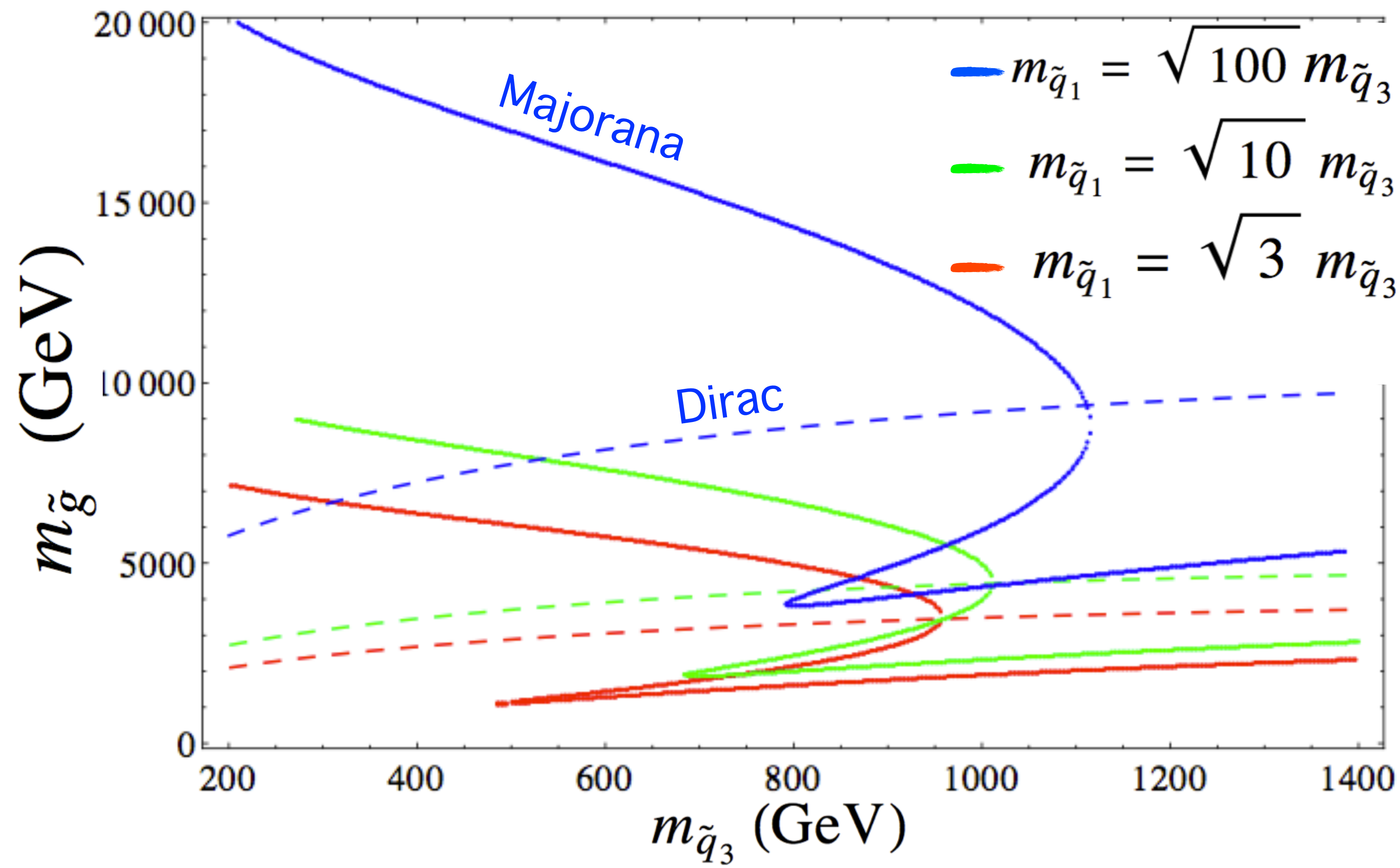
$$\delta^{AB} = \sqrt{|\mathrm{Re}(\delta_{12}^{AB})^2|} \simeq 25 \sqrt{|\mathrm{Im}(\delta_{12}^{AB})^2|}$$

Dirac vs Majorana with aligned squarks

- 2 U(1) symmetries

Charges		
Q	$\overline{D}$	$\overline{U}$
$(3,0)$	$(-1,2)$	$(-1,2)$
$(0,1)$	$(4,-1)$	$(1,0)$
$(0,0)$	$(0,1)$	$(0,0)$

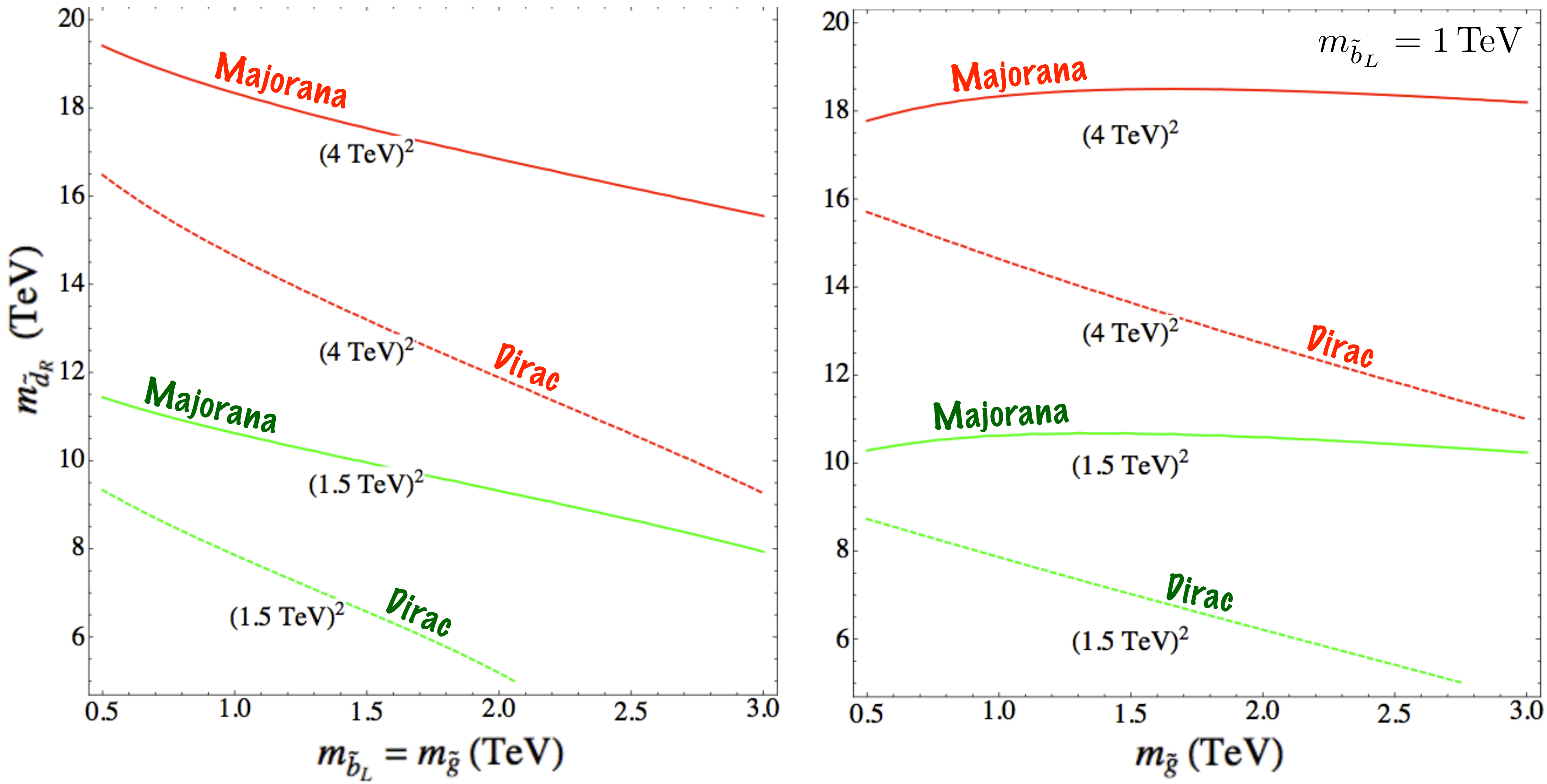
- More freedom in mass hierarchies



➡ Majorana better than Dirac

Dirac vs Majorana with hierarchical squarks

Contour plots from bound on ϵ_K



$$|m^2_{\tilde{d}_R} - m^2_{\tilde{b}_R}| = (1.5\,\mathrm{TeV})^2 \ , \ (4\,\mathrm{TeV})^2$$

On the explicit model of Dudas, Gersdorff, Pokorski, Ziegler `13

Conclusions

- Chirality flip transitions are forbidden in SUSY models with Dirac gauginos. This modifies flavour physics with respect to Majorana.

- For nearly degenerate squarks, flavour constraints on Dirac models are milder than those on Majorana.

- For aligned/hierarchical squarks this statement is model dependent but generally Dirac is less better (or worse) than Majorana

1) $$\frac{\Delta M_K|_{Majorana}}{\Delta M_K|_{Dirac}} \sim \mathrm{Log}\left(\frac{m_{\tilde{g}}^2}{m_{\tilde{q}}^2}\right)$$

2) Same-chirality and chirality-flip transitions can partially cancel

Other directions

- SUSY with a multiTeV breaking scale (favours Dirac gauginos)
  - Light gravitino phenomenology is modified
  - Light sgluon phenomenology is modified

Goodsell, PT, hep-ph/1407.5076

- Generalized gaugino masses (Dirac + Majorana + adjoint)
  - Gluinos with suppressed quark-squark couplings ("fake" gluinos)

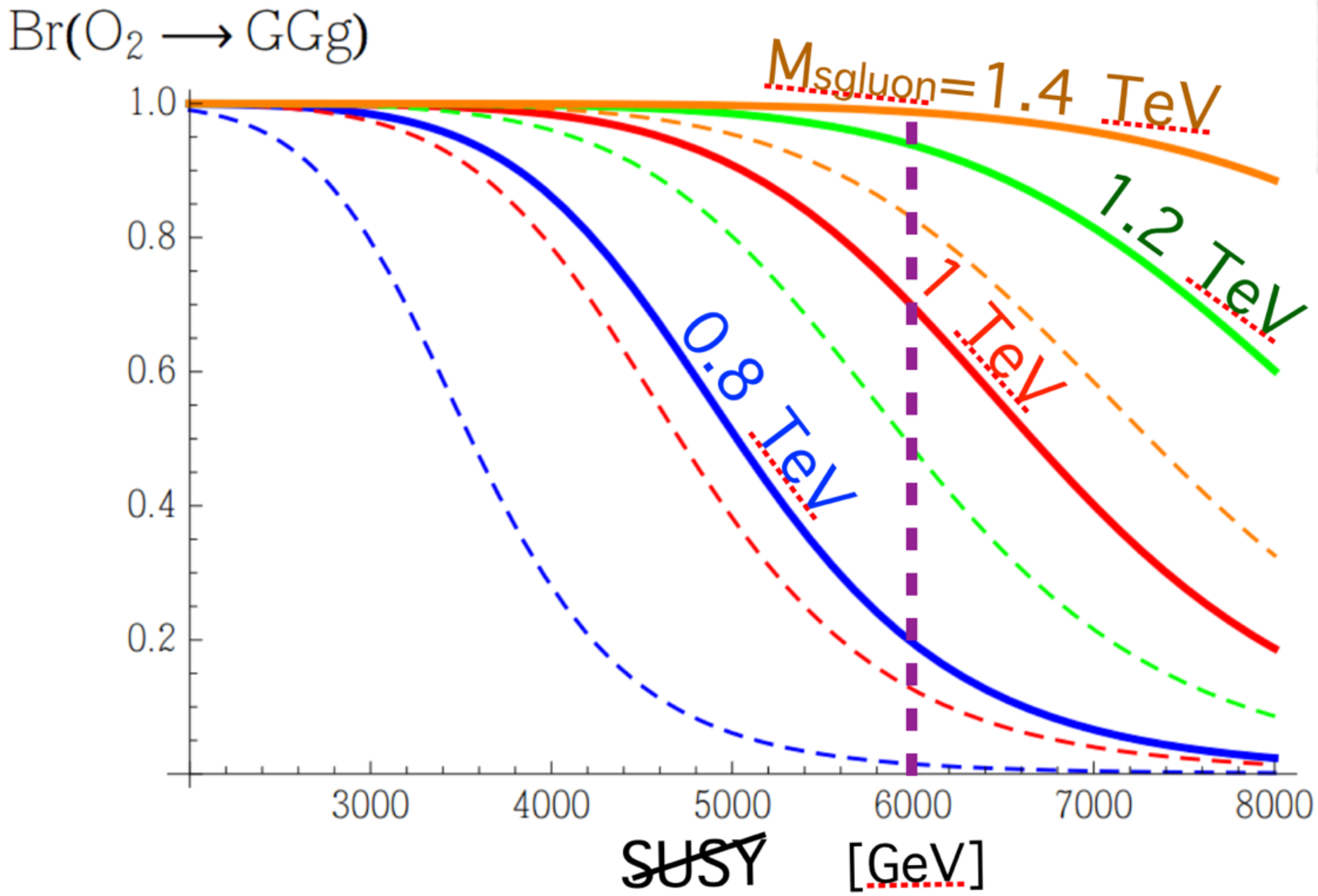
(Very) low scale SUSY breaking

- Non-minimal extension: A multiTeV SUSY breaking scale
  - Ultralight gravitino
  - Gaugino masses are expected to be Dirac
  - New adjoint scalars, including a colour octet ("sgluon")
  - ...

- Simplified scenario for light gravitino phenomenology:

Consider Dirac gluinos, gravitinos, sgluons (and possibly 3rd gen squarks)

M. Goodsell, PT 1407.5076



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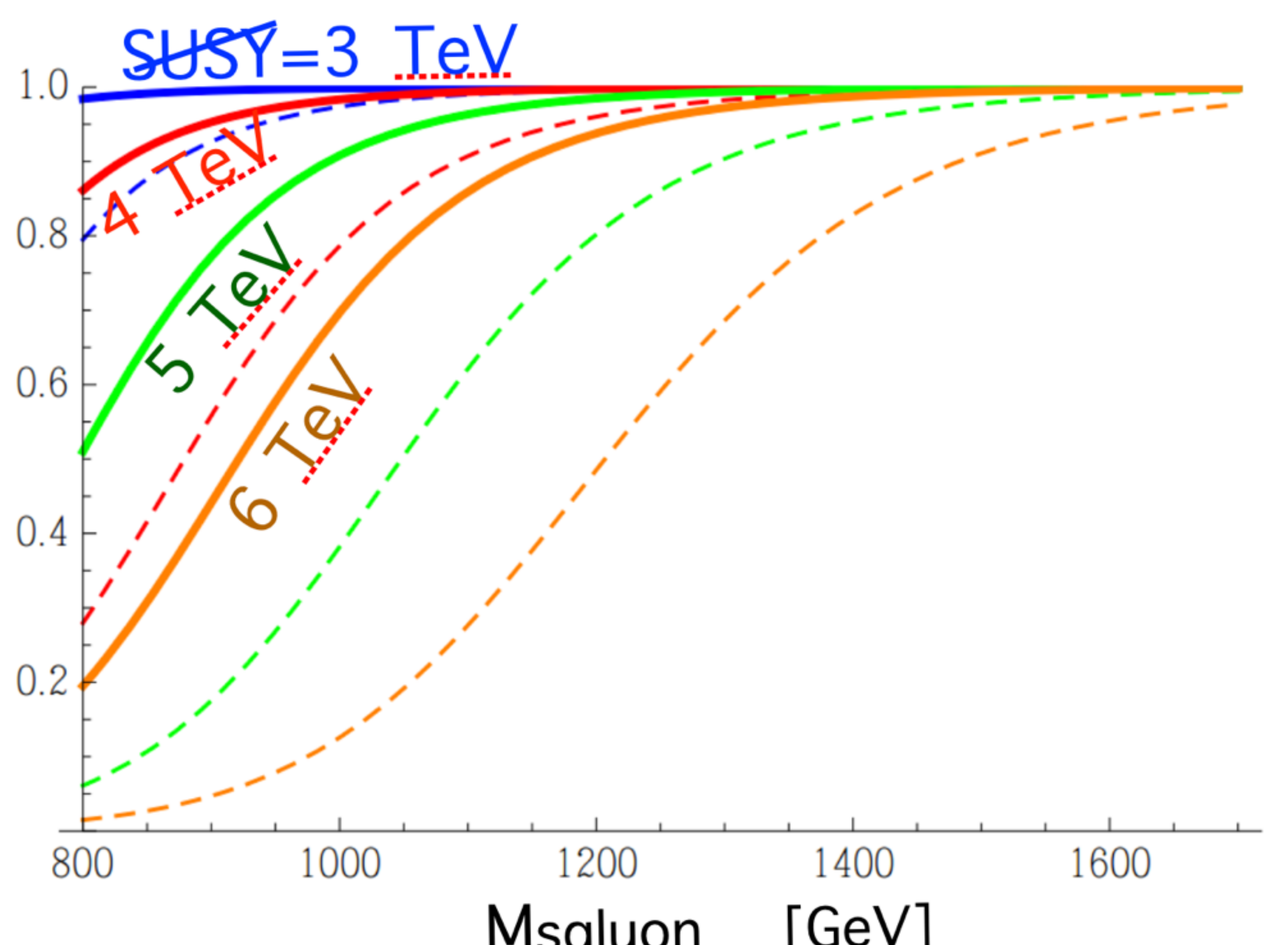
LHC bounds
Mgluino > 1.2 TeV
Msgluon > 0.8 TeV



If Mgluino > Msgluon, the sgluon has two main decay modes:

1) One-loop to $t\bar{t}$

2) Tree level to G+G+gluon

Light sgluon phenomenology is modified

Light gravitino phenomenology is modified

Thank you!