Probing the Flavour Structure of SUSY Breaking With Rare B–Processes

A Beyond Leading Order Analysis

John Foster

Università di Padova

Flavour in the Era of the LHC, November 2005

Based on K. Okumura, L. Roszkowski (hep-ph/0208101, hep-ph/0308102) and
JF, K. Okumura, L. Roszkowski (hep-ph/0410323, hep-ph/0506146, hep-ph/0510422)

Supersymmetry

- Currently one of the best candidates for new physics at the LHC.
- How SUSY is broken, particularly the flavour structure, is currently not known.
- Non–trivial flavour structure in the squark can give rise to large deviations from the minimal flavour violation (MFV) scenario.
- FCNC processes (*e.g.* $\bar{B} \longrightarrow X_s\gamma$, $\bar{B}_s \longrightarrow \mu^+\mu^-$, $\bar{B}_s - B_s$ mixing) particularly sensitive to the flavour structure of the squark sector.
- Provide a useful means of constraining SUSY flavour violation.

General Flavour Mixing

- Flavour violation in the soft terms measured by the dimensionless parameters δ^d_{XY}.

$$\left(\delta^d_{LL}\right)_{ij} = \frac{\left(m^2_{d,LL}\right)_{ij}}{\sqrt{\left(m^2_{d,LL}\right)_{ii}\left(m^2_{d,LL}\right)_{jj}}}, \qquad \left(\delta^d_{LR}\right)_{ij} = \frac{\left(m^2_{d,LR}\right)_{ij}}{\sqrt{\left(m^2_{d,LL}\right)_{ii}\left(m^2_{d,RR}\right)_{jj}}}.$$

- $m^2_{d,XY}$ related to SUSY soft terms (m^2_Q, $v_d A_d$, m^2_D) by unitary transformations.
- Similar definitions for δ^d_{RR} and δ^d_{RL}.

Beyond Leading Order Calculations

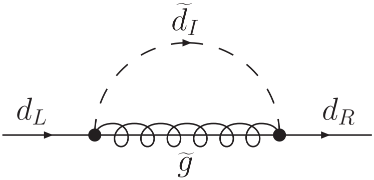
- The usefulness of the limits one can place on SUSY flavour violation is tied to the accuracy of the underlying calculation.
- NLO SUSY calculations for a variety of FCNC processes exist but often focus on a particular limit or are incomplete.
- Beyond Leading Order (BLO) calculations provide a means of including large corrections that might arise in a complete NLO calculation.
- Include the resummation of the large logarithms and **tan** β enhanced terms.
- Large logs **($\sim$ log m^2_{SUSY}/m^2_W)** corrections induced by running from the SUSY to the electroweak scale.

Beyond Leading Order Calculations

- **tan** β enhanced corrections manifest themselves as threshold corrections to the quark masses and Higgs vertices.
- The most well–known of these corrections are those to the bottom quark mass.

$$m_b^{(0)} = \frac{m_b}{1 + \epsilon_b \tan\beta}$$

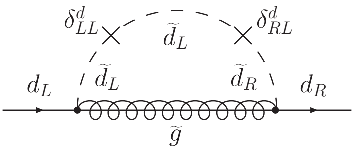
$$\epsilon_b \tan\beta \sim \mathcal{O}(0.1 - 1)$$

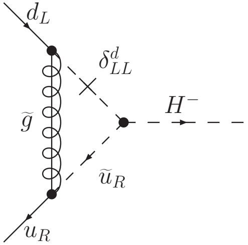


- Similar corrections arise for the charged and neutral Higgs vertices.

$\tan\beta$ Enhanced Effects
General Flavour Mixing

- GFM effects further modify the structure of the corrected vertices and masses present in the theory
- *e.g.* For flavour violation between left handed squarks...





- Similar corrections exist for the remaining three insertions

$\bar{B} \longrightarrow X_s\gamma$

- The good agreement between the experimental result:

$$\mathrm{BR}\left(\bar{B} \to X_s\gamma\right)_{exp.} = (3.39 \pm 0.30) \times 10^{-4}$$

  and the theoretical prediction

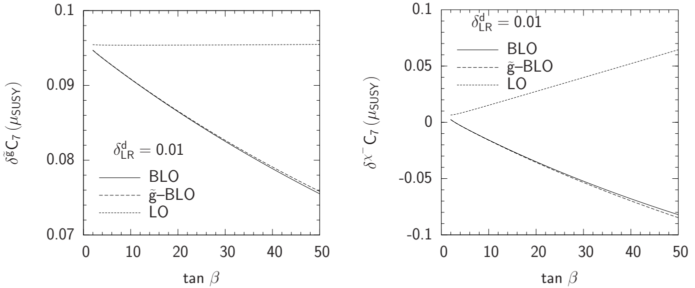
$$\mathrm{BR}\left(\bar{B} \to X_s\gamma\right)_{SM} = (3.70 \pm 0.30) \times 10^{-4}$$

  places a strong constraint on any model of new physics.
- BLO calculations exist for MFV (Degrassi *et al.* '00, Carena *et al.* '00) and GFM (OR '03, FOR '05).
- The difference between a BLO and LO calculation can be especially large in the GFM case.

Focusing Effects Beyond the Leading Order

$m_{\tilde{q}} = m_{\tilde{g}}/\sqrt{2} = 1$ TeV, $m_A = \mu = -A_u = 500$ GeV

- The large difference stems from cancellations between the gluino and chargino contributions to the decay.
- *e.g.* For the insertion δ^d_{LR}...

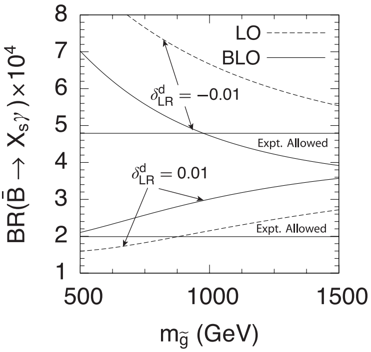


- Similar cancellations for δ^d_{RL} and δ^d_{RR} (not for δ^d_{LL} as a LO chargino contribution exists).

Focusing Effect Beyond the Leading Order

$\tan\beta = 40$, $m_{\tilde{q}} = 1$ TeV, $m_A = \mu = -A_u = 500$ GeV

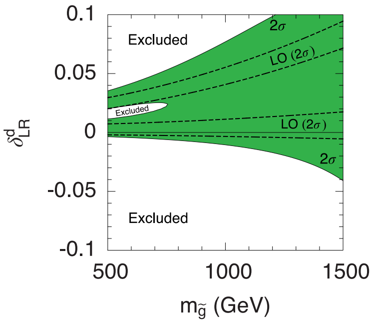
- Reduction of the gluino contribution and the partial cancellation with the chargino contribution leads to a focusing effect.



Focusing Effect Beyond the Leading Order

$\tan\beta = 40$, $m_{\tilde{q}} = 1$ TeV, $m_A = \mu = -A_u = 500$ GeV

- Such effects can significantly loosen the bounds placed on the mixing amongst squarks (left–right mixings in particular). *e.g.*



Focusing Effect Beyond the Leading Order

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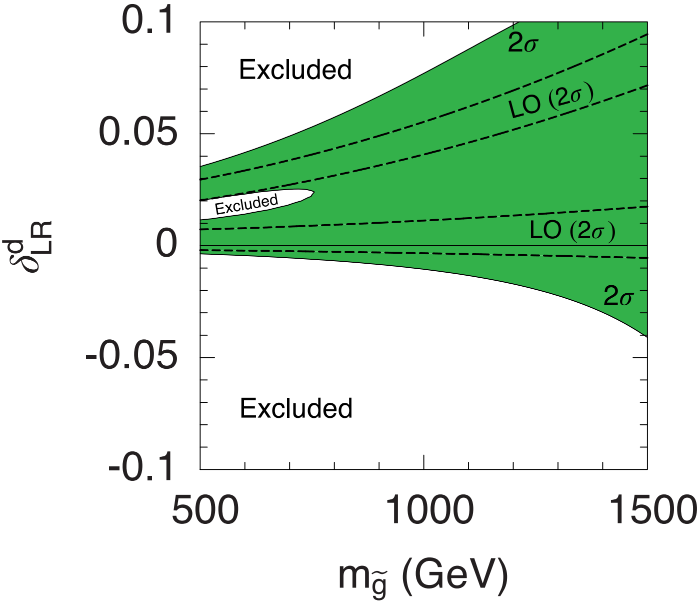
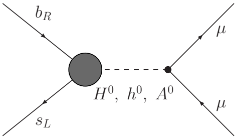
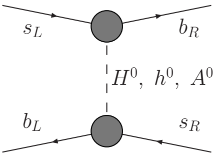


$\bar{B}_s \longrightarrow \mu^+\mu^-$ and $\bar{B}_s - B_s$ mixing



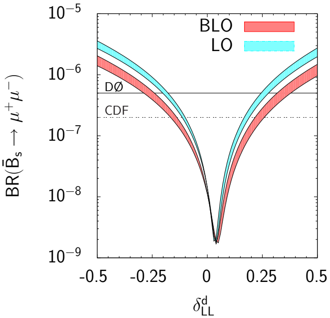
- SUSY corrections to the neutral Higgs vertex can lead to **BR** $(\bar{B}_s \rightarrow \mu^+\mu^-) \propto \mathbf{tan^6}\,\beta$.
- Models with large **tan** β lead to values for **BR** $(\bar{B}_s \rightarrow \mu^+\mu^-)$ in excess of the SM prediction of $\sim \mathbf{3 \times 10^{-9}}$.
- Double Higgs penguin diagrams can lead to $\Delta M_{B_s}^{DP} \propto \mathbf{tan^4}\,\beta$.
- MFV corrections : Deviations from the SM prediction of $\sim$ **18** ps^{-1} towards the experimental limit (95% C.L.) of **14.5** ps^{-1} (HFAG).
- Suppressed by factor of m_s. GFM effects can bypass this factor.

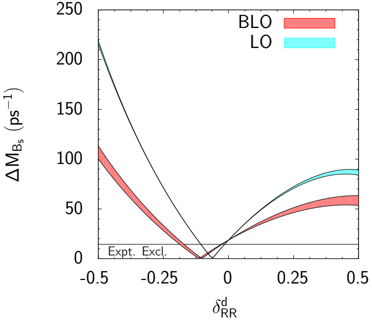


BLO effects – $\bar{B}_s \longrightarrow \mu^+\mu^-$ and ΔM_{B_s}

$m_{\tilde{q}} = 1$ TeV, $m_A = \mu = -A_u = 500$ GeV, $\tan\beta = 50$, $m_{\tilde{g}} = [m_{\tilde{q}}/\sqrt{2}, \sqrt{2}\, m_{\tilde{q}}]$

- BLO effects decrease the contributions arising from LL and RR insertions for both processes (for $\mu > 0$).
- Mixed double Higgs penguin diagrams – one mediated by chargino exchange, the other mediated by gluino exchange.

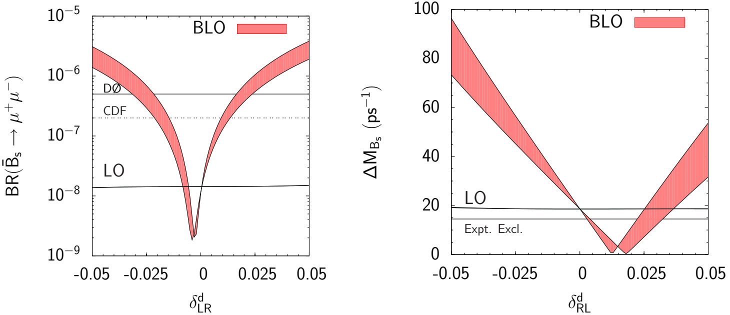




BLO effects – $\bar{B}_s \to \mu^+\mu^-$ and ΔM_{B_s}

$m_{\tilde{q}} = 1$ TeV, $m_A = \mu = -A_u = 500$ GeV, $\tan\beta = 50$, $m_{\tilde{g}} = [m_{\tilde{q}}/\sqrt{2}, \sqrt{2}\, m_{\tilde{q}}]$

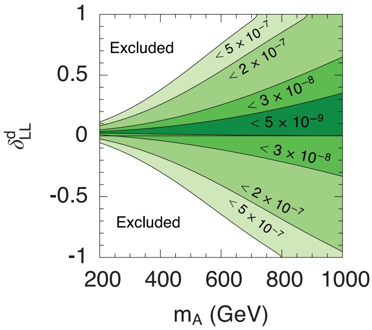
- At LO the contributions due to LR and RL insertions to the neutral Higgs penguin accidentally cancel.
- BLO effects reintroduce a dependence on these parameters.

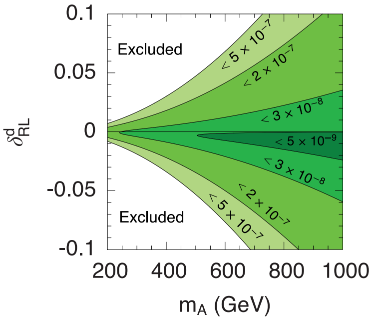


Constraints Imposed by $\bar{B}_s \to \mu^+\mu^-$

$m_{\tilde{q}} = m_{\tilde{g}} = 1$ TeV, $\mu = -A_u = 500$ GeV, $\tan\beta = 40$

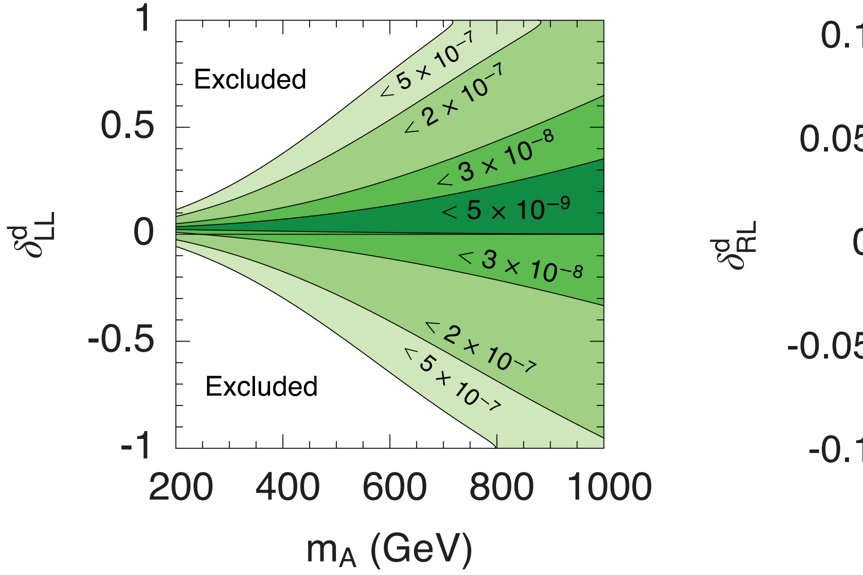
- The constraints imposed by $\bar{B}_s \to \mu^+\mu^-$ are already proving useful if m_A is small and $\tan\beta$ is large.





Constraints Imposed by $\bar{B}_s \to \mu^+\mu^-$

$m_{\tilde{q}} = m_{\tilde{g}} = 1$ TeV, $\mu = -A_u = 500$ GeV, $\tan\beta = 40$



Constraints Imposed by $\bar{B}_s \longrightarrow \mu^+\mu^-$

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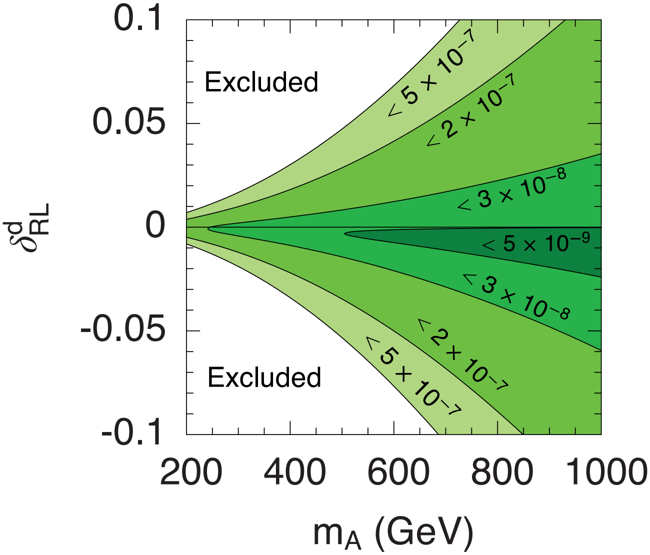
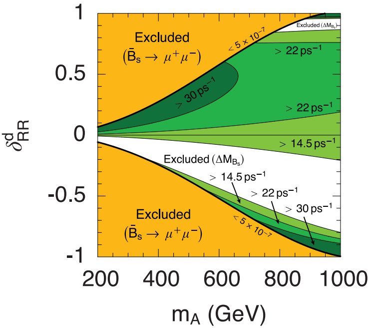
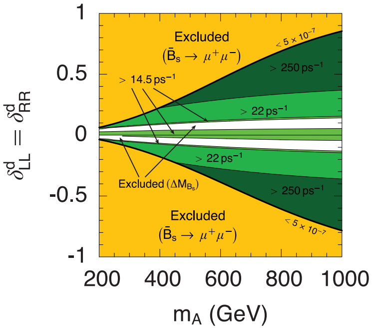


Constraints Imposed by $\bar{B}_s - B_s$ Mixing

$m_{\tilde{q}} = m_{\tilde{g}} = 1$ TeV, $\mu = -A_u = 500$ GeV, $\tan\beta = 40$

- The lower bound on ΔM_{B_s} also proves to be rather useful.





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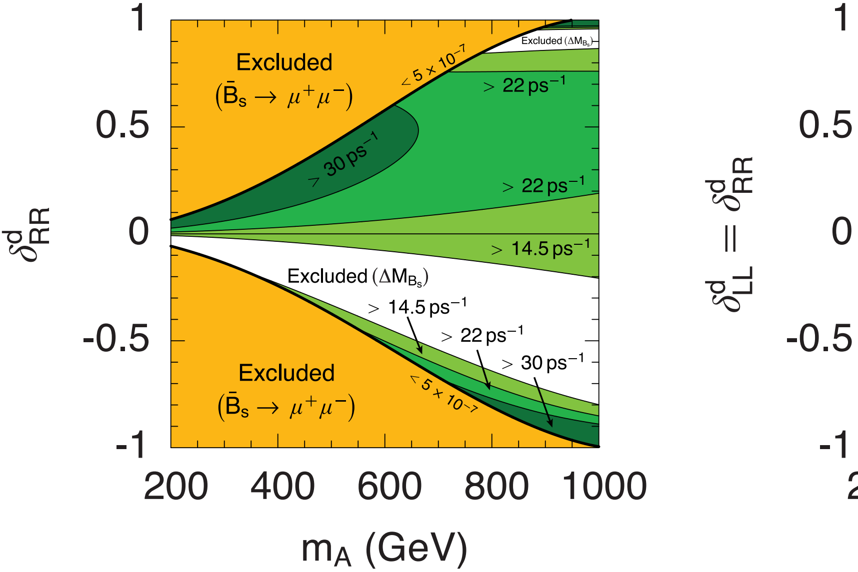

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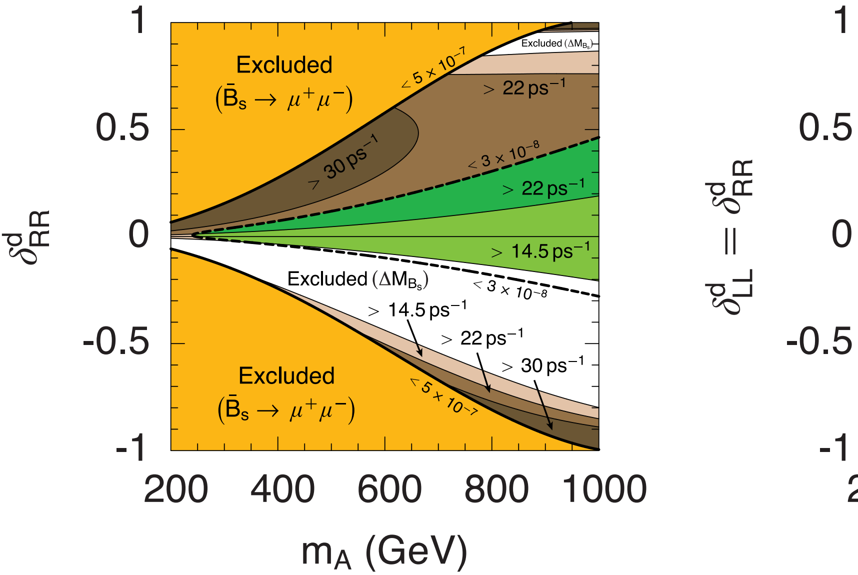

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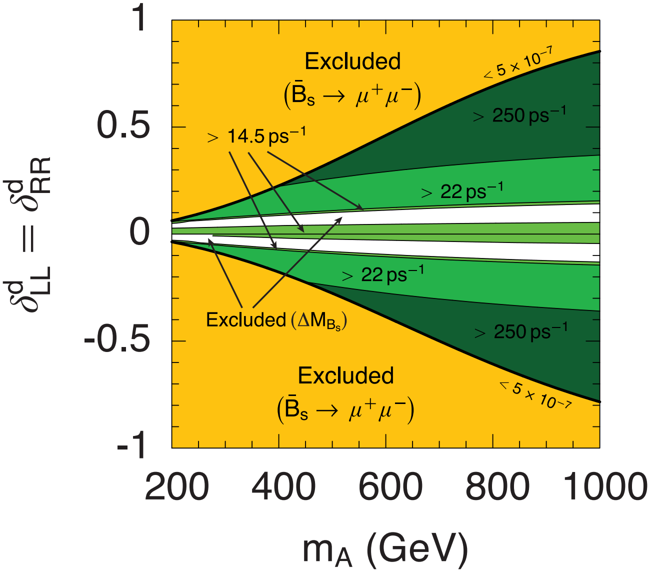

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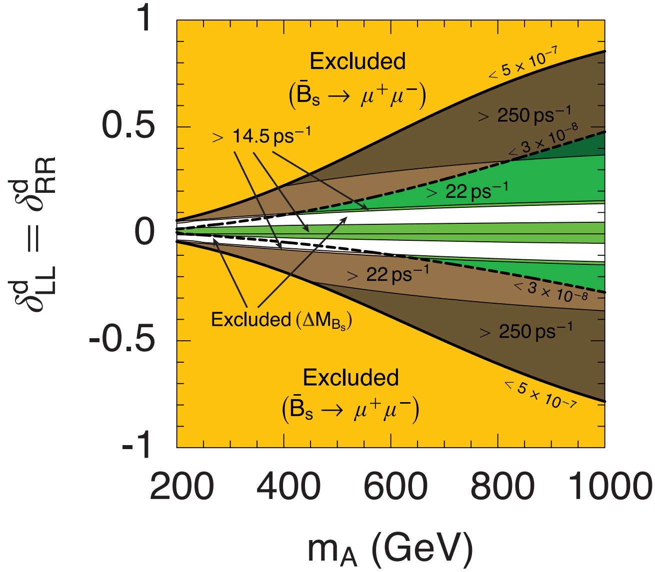
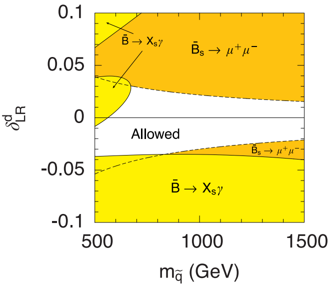
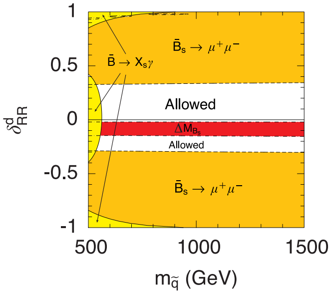


Limits on Flavour Violation

$\tan\beta = 40$, $m_{\tilde{g}} = \sqrt{2} m_{\tilde{q}}$, $A_u = -m_{\tilde{q}}$, $\mu = m_{\tilde{q}}/\sqrt{2}$, $m_A = 500$ GeV

- $\bar{B}_s \to \mu^+\mu^-$ and ΔM_{B_s} already provide useful constraints on a variety of insertions: δ^d_{RR} in particular.





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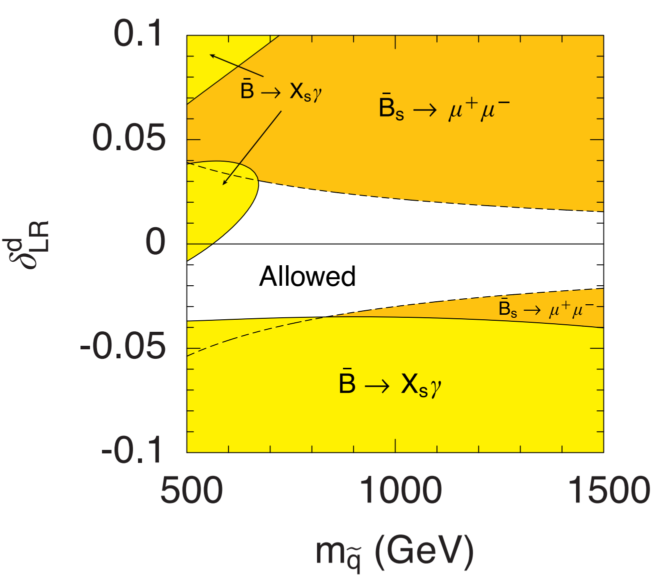

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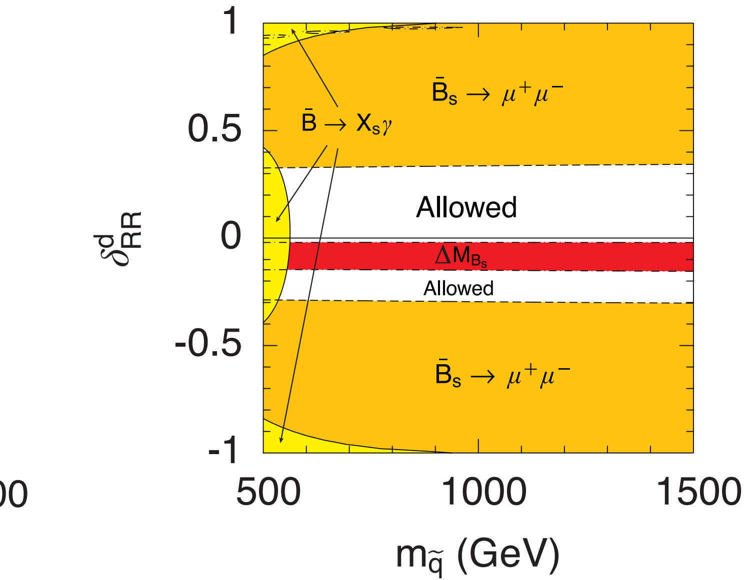
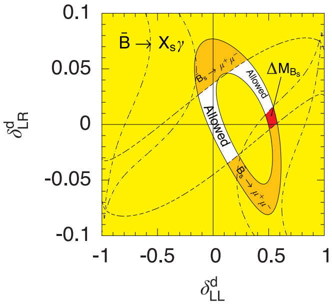


Limits on Flavour Violation

$m_{\tilde{q}} = m_{\tilde{g}} = 1$ TeV, $\mu = -A_u = 500$ GeV, $m_A = 500$ GeV, $\tan\beta = 40$

- The combination of the three decays can also play a role in constraining combinations of insertions.



Limits on Flavour Violation

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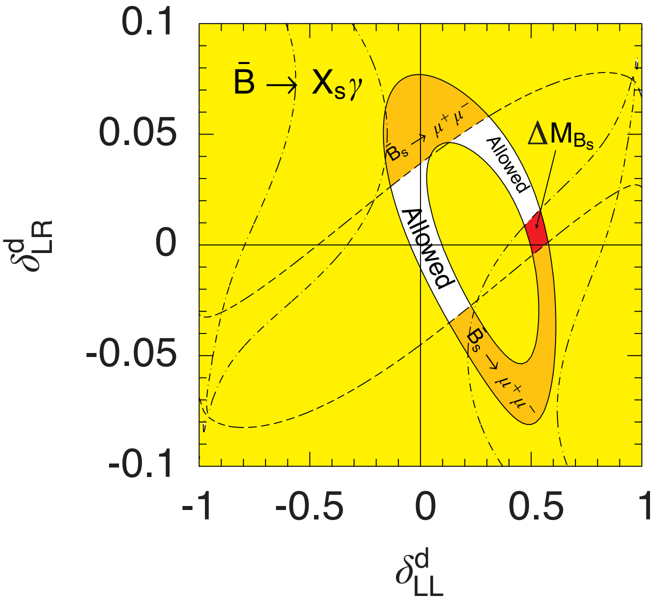
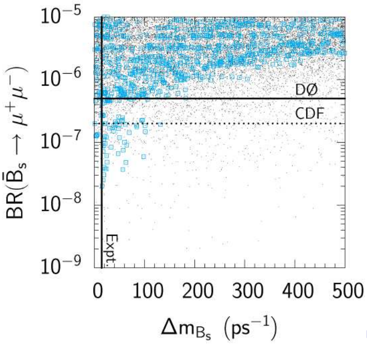


Limits on Flavour Violation

$\tan\beta = 40$, $m_{\tilde{g}} = m_{\tilde{q}} = 500$ GeV, $A_t = -0.5 m_{\tilde{q}}$, $\mu = 0.5 m_{\tilde{q}}$, $m_A = 250$ GeV

- Successful measurement of either BR $(\bar{B}_s \to \mu^+\mu^-)$ or ΔM_{B_s} will place an extremely useful constraint on general flavour mixing.
- $\delta^d_{LL}, \delta^d_{RR} = [-0.8, 0.8]$, $\delta^d_{LR}, \delta^d_{RL} = [-0.08, 0.08]$.



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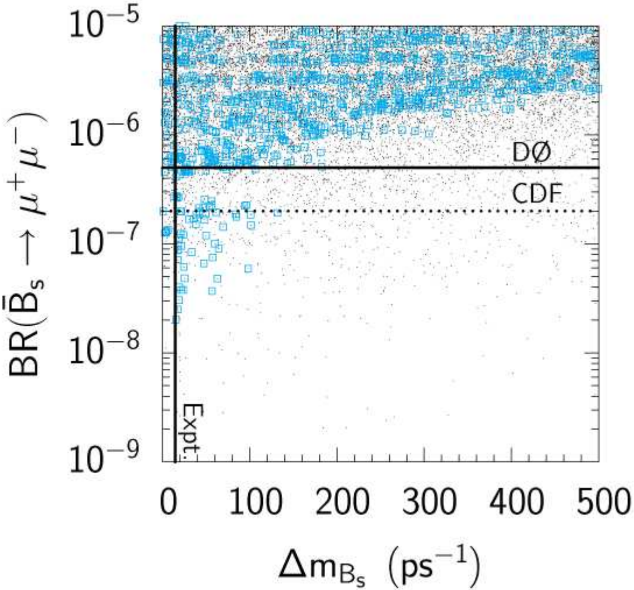

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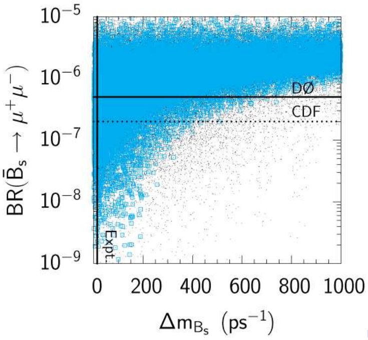

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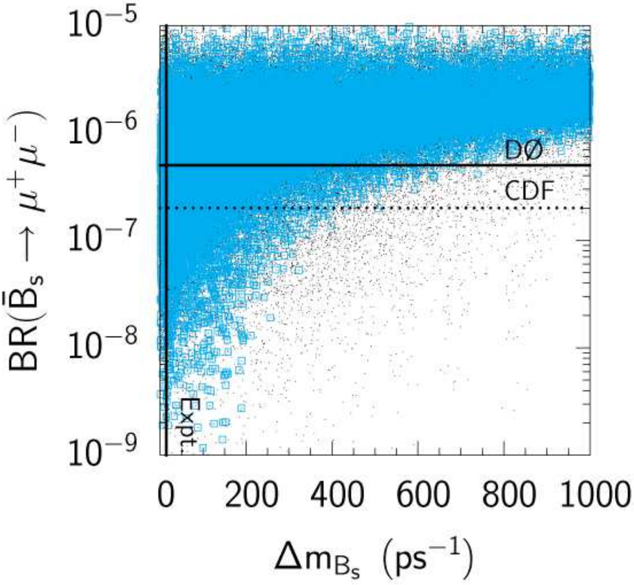

Summary

- Rare B–decays provide an ideal probe of the flavour structure of soft SUSY breaking.
- Beyond Leading Order corrections play an important role in MFV and GFM frameworks.
- The B physics programs at the Tevatron and the LHC will be able to probe a large range of allowed parameter space for GFM models with large **tan** β.