Rare Decays at LHC

(within SUSY)

((recent developments))

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Flavor Violation beyond the SM

∗ Data on FCNC suggest that – if $\Lambda_{NP} \sim \sqrt{s_{LHC}} \sim \Lambda_{EWKSB}$ – it is very natural that the suppression of flavor changing transitions is similar to the one in the SM

$$\mathcal{A}_{\rm SM}(b \to q) \sim V_{tb} V_{tq}^* \cdot (m_t^2 - m_c^2)/m_W^2$$

$$\mathcal{A}_{\rm NP}(b \to q) \sim f \cdot (m_{\tilde{t}}^2 - m_{\tilde{c}}^2)/\Lambda_{NP}^2 \qquad f = \tilde{V} \tilde{V}^\dagger\text{: NP flavor mixing}$$

$$f \sim f_{\rm SM} + \epsilon \text{ and } f_{\rm SM} = \lambda^n,\ \lambda \simeq \sin \Theta_C \simeq 0.2.$$

∗ Flavor suppression as in the SM ($\epsilon = 0$):

Minimal Flavor Violation (MFV)

Chivukula, Georgi ‘87; d‘Ambrosio et al ‘02 non-symmetry based definitions: Ali,London ’99; Buras^2 ’00

∗ Within MFV, the Yukawas are just parameters as in the SM.

$*$ The superpotential ($N = 1$, unbroken R-parity) is MFV !

$W_{MSSM} = QY_u H_u U + QY_d H_d D + LY_e H_d E + \mu H_d H_u$

$*$ Squark flavor-mixing within MFV expressed through quark-Yukawas

$$\tilde{m}_Q^2 \quad = \quad \tilde{m}^2(a_1 \mathbf{1} + b_1 Y_u Y_u^\dagger + b_2 Y_d Y_d^\dagger) \quad \text{etc.}$$

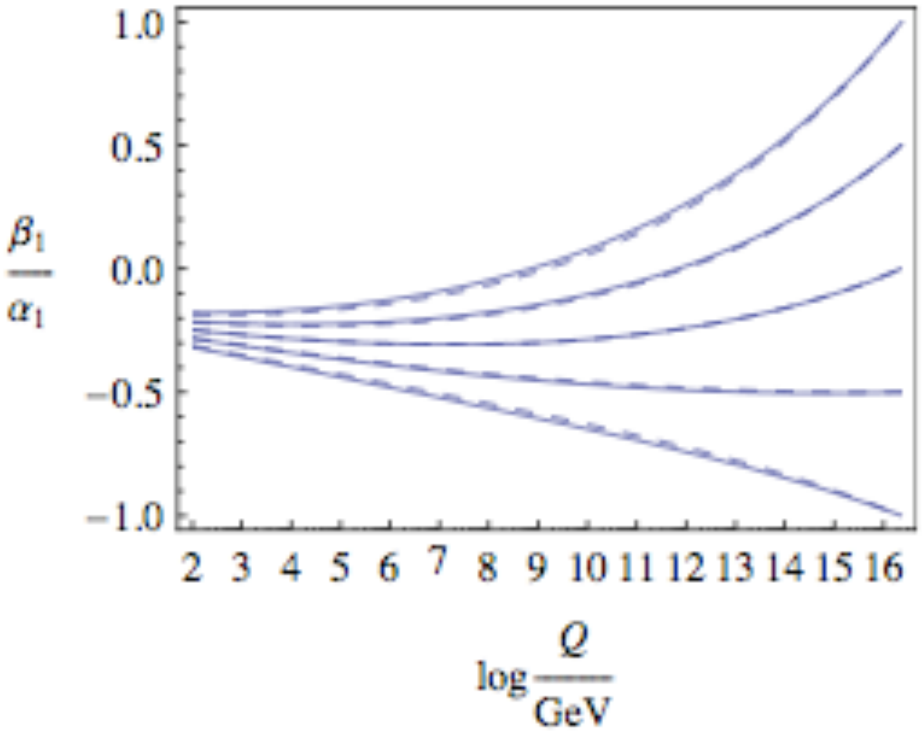
Controlled departure from flavor-blind SUSY breaking.

$*$ Anomaly mediation, gauge mediation and CMSSM/mSUGRA (by construction) are MFV.

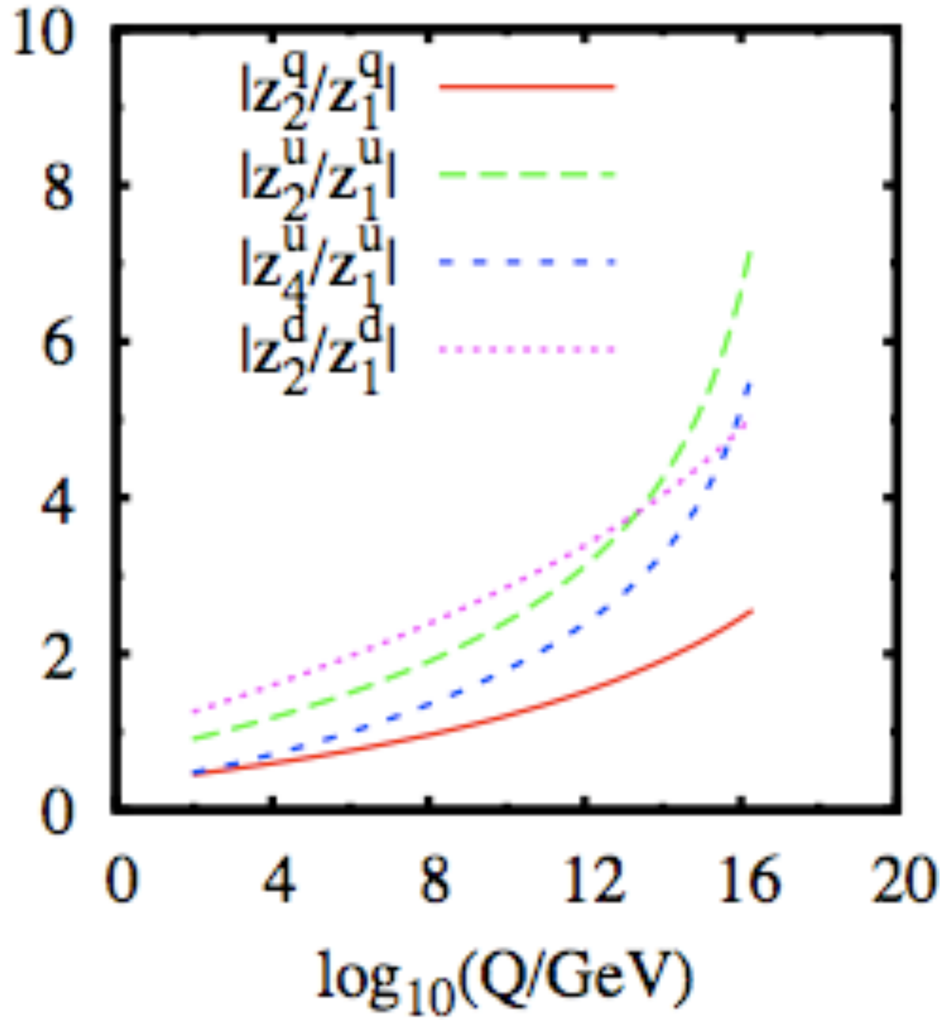
Running MFV Coefficients b_i/a_j

left: SPS2 - middle curve: $b_i(M_{GUT} = 0)$ Paradisi et al 0805.3989

right: AMSB Allanach et al 0902.4880



(e) SPS4

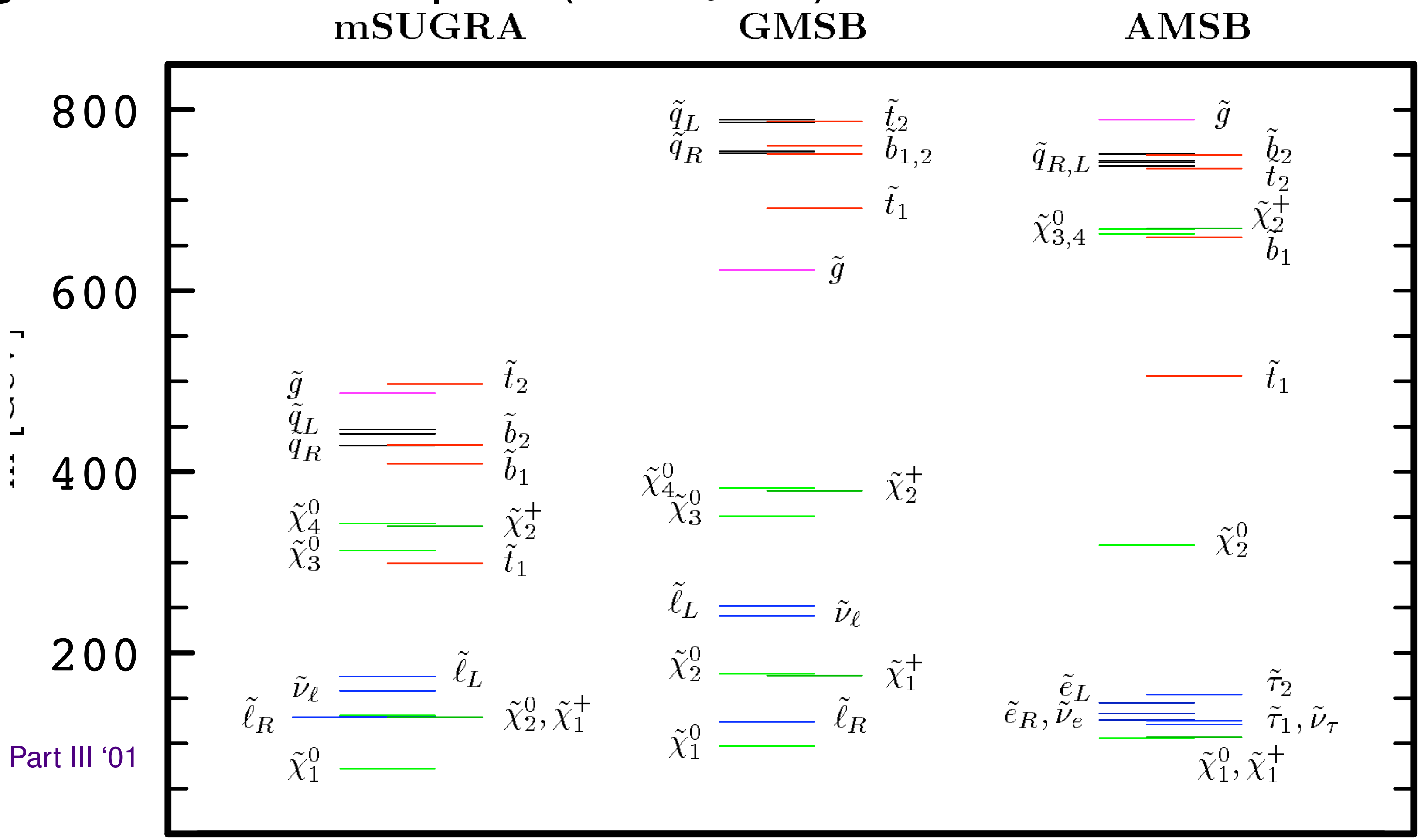


For low $\tan\beta$, mAMSB becomes exactly flavor blind in the QIR-fixed point limit of Y_t 0902.4880 .

- Highly degenerate squarks of 1st and 2nd generation:

$\Delta m/m_0 \sim \lambda_c^2/2; \qquad \Delta m < 1$ GeV

- 3rd generation decoupled (via V_{CKM}).

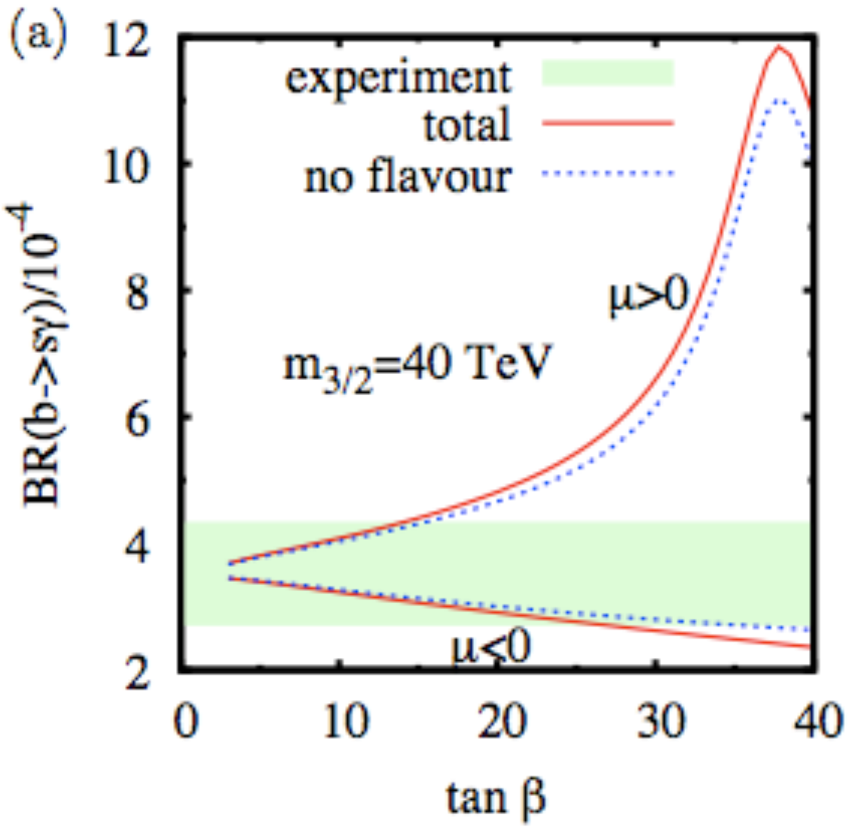


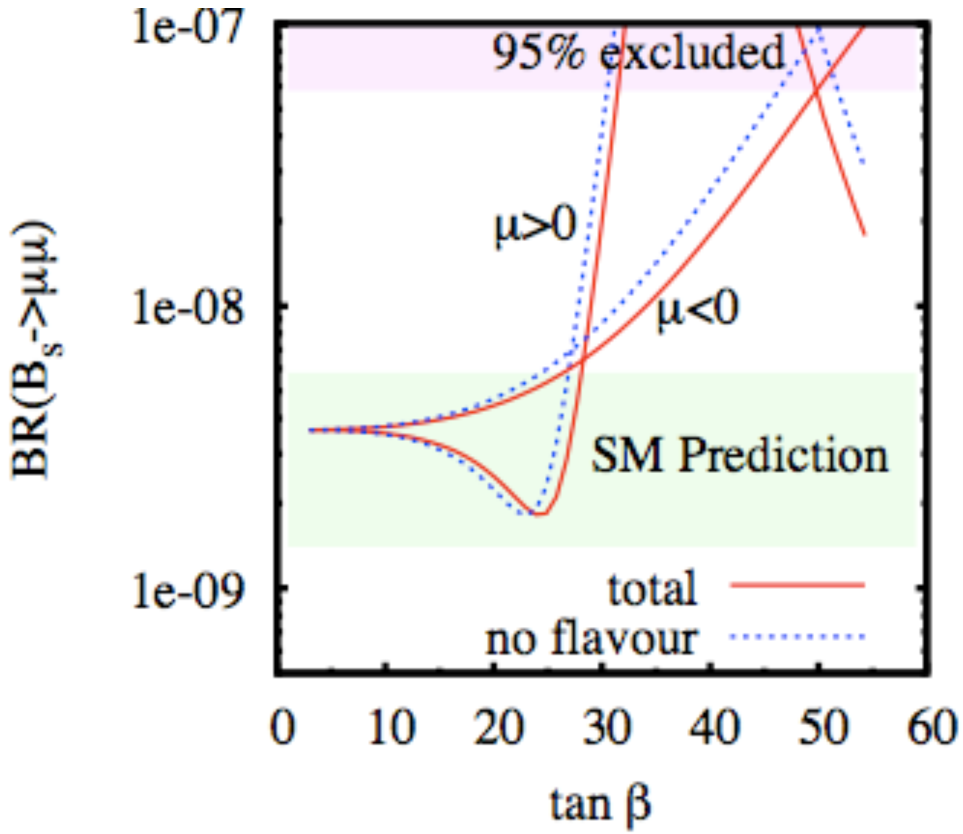
TESLA TDR Part III '01

Predictivity and large effects in FCNC loops

$*$ Predictive $\mathcal{O}(1)$ effects within MFV models if $\tan\beta$ largish. many works

Here, AMSB ($m_{3/2} = 40$ TeV) Figs from Allanach et al 0902.4880





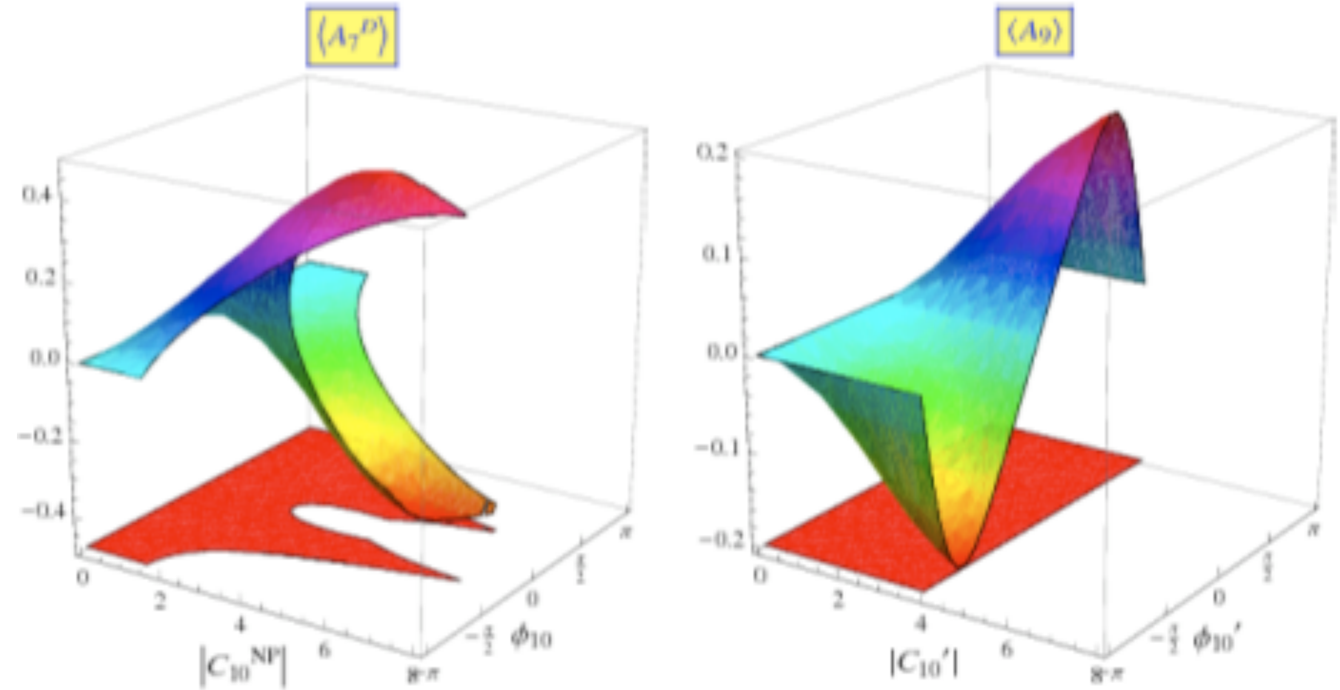
Analytical expressions for the full flavor structure, that is, a_i, b_j or $(\delta^q)_{ij}$, within mAMSB 0902.4880 .

Testing SUSY Flavor with FCNC-Loops: CP

$\ast$ Huge non-MFV effects thru non-CKM CP-phases: 8 asymmetries in angular distribution $\Gamma(q^2, \Theta_l, \Theta_K, \varphi)$ in $B \to (K^* \to K\pi)\mu^+\mu^-$

4 CP-asys CP-odd: untagged $\bar{B}_s, B_s \to (\Phi \to KK)\mu^+\mu^-$ Bobeth et al 0805.2525

$\ast$ Three CP-asy's are T_N-odd and can be $\mathcal{O}(1)$ with NP Figs. from 0805.2525



Other recent works on angular analyses [hep-ph]: Bobeth et al 0709.4174, Egede et al 0807.2589, Altmannshofer et al 0811.1214

A viable non-MFV model ?

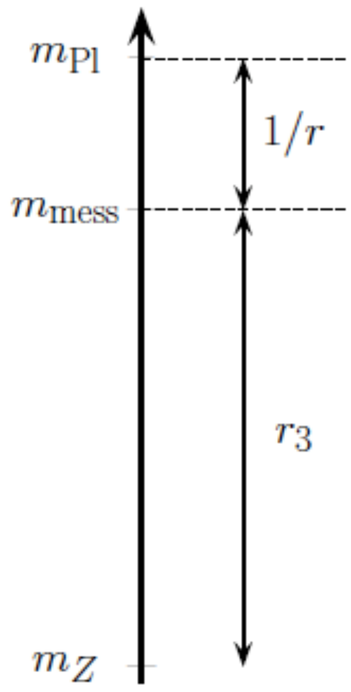
$*$ Can we probe the (always present) effects from gravity mediation with gauge mediation being the dominant effect of SUSY-breaking ?

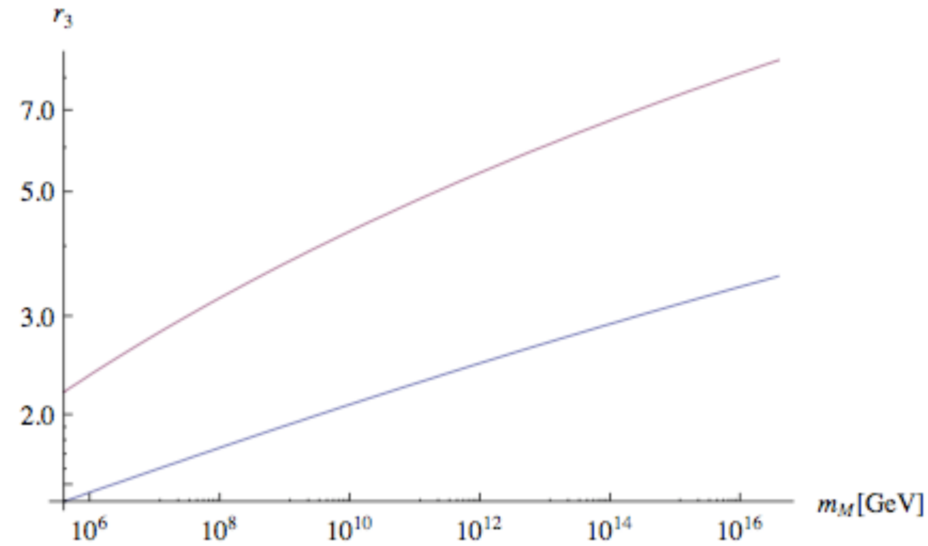
$*$ Is the model viable, or, what are the current constraints, arising from flavor physics, on hybrid gauge-gravity mediation ?

based on 0812.0511 [hep-ph] with Yonit Hochberg and Yossi Nir, to appear in JHEP.

related works (sleptons): Feng et al, 0712.0674; Nomura et al, 0712.2074, 0802.2582

Hybrid Gauge-Gravity Mediation





* MSSM-RGE-factor for soft squark masses $\tilde{m}^2(m_Z) = r_3 \tilde{m}^2(m_{mess})$

$$r_3 = r_3(m_M) = 1 + \frac{8}{3\pi}\left(\int_{\ln(m_Z)}^{\ln(m_M)} dt \frac{\alpha_3^3(t)}{\alpha_3^2(m_M)}\right)\frac{M_3^2(m_M)}{\tilde{m}^2(m_M)};$$

$$\frac{M_3^2(m_M)}{\tilde{m}_{12}^2(m_M)} = \frac{3}{8} N_M + \mathcal{O}\left[\left(\frac{\alpha_i}{\alpha_3}\right)^2\right], i = 1, 2, \quad \text{for } q = Q, U, D \qquad r_3 \gtrsim 1 \text{ (mGMSB)}$$

* Ratio of soft masses $r = \tilde{m}^2_{gravity}/\tilde{m}^2_{gauge}$

$$r \sim \left(\frac{m_M}{m_{Pl}}\right)^2 \left(\frac{4\pi}{\alpha_3(m_M)}\right)^2 \frac{3}{8}\frac{1}{N_M}$$ (mGMSB; highest F-term couples to gauge mediation)

Hybrid Gauge-Gravity Mediation, at m_{mess}

* At the messenger scale m_M:

$$
\begin{aligned}
M^2_{\tilde{Q}_L}(m_M) &= \tilde{m}^2_{Q_L}(\mathbf{1} + rX_{Q_L}), \\
M^2_{\tilde{D}_R}(m_M) &= \tilde{m}^2_{D_R}(\mathbf{1} + rX_{D_R}), \\
M^2_{\tilde{U}_R}(m_M) &= \tilde{m}^2_{U_R}(\mathbf{1} + rX_{U_R})
\end{aligned}
$$

* Froggatt-Nielson-terms with V_{ij}: CKM, m_{q_i}: quark masses

$$
(X_{q_{L,R}})_{ii} \sim 1, \quad (X_{q_L})_{ij} \sim |V_{ij}|, \quad (X_{q_R})_{ij} \sim \frac{m_{q_i}/m_{q_j}}{|V_{ij}|} \quad (i < j), \quad q = U, D.
$$

Hybrid Gauge-Gravity Mediation, at m_Z

(in flavor basis)

$$
\begin{aligned}
M^2_{\tilde{Q}_L}(m_Z) &\sim \tilde{m}^2_{Q_L}(r_3\mathbf{1} + c_u Y_u Y_u^\dagger + c_d Y_d Y_d^\dagger + r X_{Q_L}), \\
M^2_{\tilde{U}_R}(m_Z) &\sim \tilde{m}^2_{U_R}(r_3\mathbf{1} + c_{uR} Y_u^\dagger Y_u + r X_{U_R}), \\
M^2_{\tilde{D}_R}(m_Z) &\sim \tilde{m}^2_{D_R}(r_3\mathbf{1} + c_{dR} Y_d^\dagger Y_d + r X_{D_R})
\end{aligned}
$$

$*$ c_u, c_d, c_{uR}, c_{dR} are RGE-induced and of order $[5/(16\pi^2)] \ln(m_M/m_Z)$ and can be $\mathcal{O}(1)$ for $m_M \sim m_{\text{GUT}}$.

$*$ FN-terms are either RG-invariant to good approximation, or changed by $\mathcal{O}(1)$ factors, which is anyway the precision to which the X_{ij} are known.

Hybrid Gauge-Gravity Mediation, $(\delta^q_{ij})_{L,R}$

(in basis with diagonal quark mass matrices and gluino couplings)

$$
\begin{aligned}
(\delta^u_{12})_L &\sim \frac{|V_{12}|}{r_3}\max(r, c_d y_b^2 |V_{ub}V^*_{cb}/V_{12}|) \sim r\frac{|V_{12}|}{r_3}, \\
(\delta^d_{12})_L &\sim \frac{|V_{12}|}{r_3}\max(r, c_u y_t^2 |V_{ts}V^*_{td}/V_{12}|) \sim r\frac{|V_{12}|}{r_3}, \\
(\delta^u_{i3})_L &\sim \frac{|V_{i3}|}{r_3}\max(r, c_d y_b^2) \sim \hat{r}\frac{|V_{i3}|}{r_3}, \\
(\delta^d_{i3})_L &\sim \frac{|V_{i3}|}{r_3}\max(r, c_u y_t^2) \sim \frac{|V_{i3}|}{r_3}, \qquad \hat{r} \equiv \max\{r, y_b^2\}. \\
(\delta^q_{ij})_R &\sim \frac{r}{r_3}\frac{m_{q_i}}{m_{q_j}|V_{ij}|}, \qquad i \neq 3
\end{aligned}
$$

$\ast$ With $r > y_t^2 |V_{ts}|^2$ to have gravity contribution non-negligible.

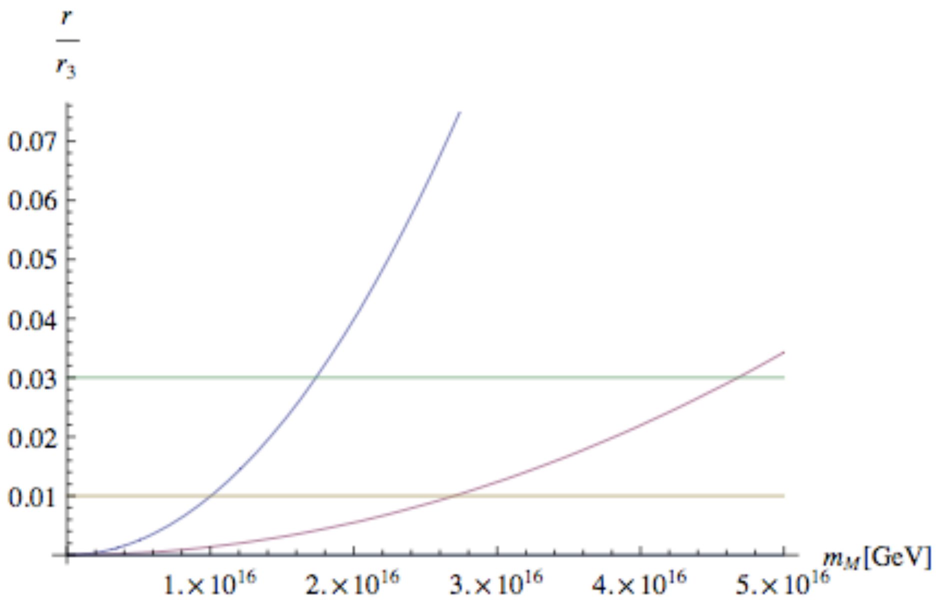
Hybrid Gauge-Gravity Mediation, δ^q_{ij} Predictions

* The RGE-factor r_3 suppresses flavor violation, i.e., the δ^q_{ij}.
* The $(\delta^d_{i3})_L$ is insensitive to gravity-mediation because of the dominant MFV-RGE contributions from gauge-mediation.
* $\langle \delta^q_{ij} \rangle = \sqrt{(\delta^q_{ij})_L (\delta^q_{ij})_R}$ are independent of the CKM matrix elements.
* The strongest bound on r is from $\langle \delta^d_{12} \rangle$

$$r/r_3 \lesssim 0.01 - 0.03$$

Hybrid Gauge-Gravity Mediation, δ^q_{ij} Predictions

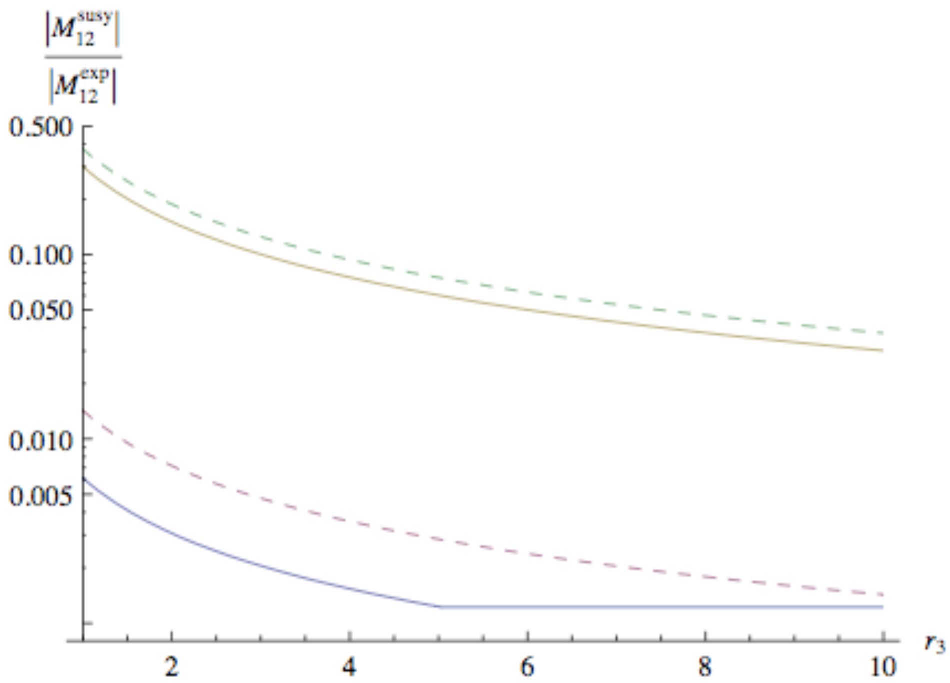
* The strongest bound on r is from $\langle \delta^d_{12} \rangle$: $r/r_3 \lesssim 0.01 - 0.03$.



For number of mesenger $N_M = 1$ (upper) and $N_M = 3$ (lower curve).

* $m_M \lesssim m_{Pl}/10^3$ for $N_M = 1$ (mGMSB; highest F-term couples to gauge mediation).

Hybrid Gauge-Gravity Mediation, B, D-mixing



Upper two curves for $\tan\beta = 30$ and $m_{A^0} = 200$ GeV.

$*$ B_d, B_s-mixing: Effects of order ten percent if $\tan\beta$ is large, otherwise one percent.

$*$ D-mixing: $|M_{12}^{\rm susy}/M_{12}^{\rm exp}| \lesssim 5\%$ (order 1 in different flavor model possible).

Hybrid Gauge-Gravity Mediation, $B \to \mu\mu$

$$R_{\mu\mu} = \frac{\mathcal{B}(B_s \to \mu^+\mu^-)}{\mathcal{B}(B_d \to \mu^+\mu^-)} \sim \frac{m_{B_s} f_{B_s}^2 \tau_{B_s}}{m_{B_d} f_{B_d}^2 \tau_{B_d}} \times r_{\rm ps} \times \begin{cases} \frac{|V_{ts}|^2}{|V_{td}|^2} & \text{for (MFV}, (\delta^d_{i3})_L), \\ \frac{|m_s V_{td}|^2}{|m_d V_{ts}|^2} & \text{for } ((\delta^d_{i3})_R), \\ \frac{m_s}{m_d} & \text{for } (\langle \delta^d_{i3} \rangle), \end{cases}$$

* From top to bottom: 25 (MFV),14,19 (this FN-model);

$R_{\mu\mu}$ suppressed w.r.t. MFV/SM. Both Br‘s can be enhanced.

* Since $(\delta^d_{i3})_R \gtrsim (\delta^d_{i3})_L \to$ look for RH-currents, possibly even with CP-violation.

Summary

- We considered the effects of gravity-induced SUSY-breaking within gauge mediation. The model is a viable non-MFV scenario if the separation between the Planck and the messenger scale is sufficiently large.
- Given a model of flavor at the Planck scale, the hybrid gauge-gravity model is predictive, and can be tested with precision flavor experiments.
- The analysis can be extended to general gauge mediation by using distinct $r_3(Q)$, $r_3(U)$, $r_3(D)$ and relaxing the mGMSB squark-gluino mass relation; Then, also $r_3(X) < 1$ becomes possible.