Uplifted Supersymmetry

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with Bogdan Dobrescu
(arXiv:1001.3147)

Plan

A new phase of an old model?

- MSSM review
- The MSSM at and near $\tan\beta = \infty$
- Loop generated masses
- Phenomenology
- Conclusions

MSSM

- The "minimal" supersymmetric version of the SM
- Partners of opposite spin
- Anomalies require two Higgs (Higgsino) doublets
- Holomorphy forces a Type-II 2HDM i.e. one Higgs (H_u) couples only to up-type quarks and one (H_d) only couples to down-type quarks and leptons

$$W = y_u\, \hat{u}^c \hat{H}_u \hat{Q} - y_d\, \hat{d}^c \hat{H}_d \hat{Q} - y_\ell\, \hat{e}^c \hat{H}_d \hat{L} + \mu\, \hat{H}_u \hat{H}_d$$

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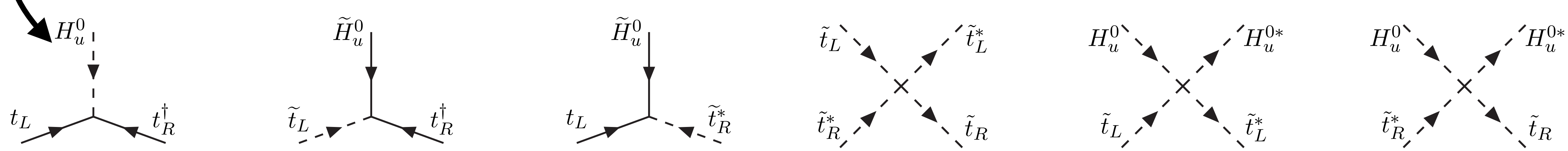


2HDM

At tree level can define $\tan\beta \equiv \frac{v_u}{v_d}$

The MSSM Yukawa couplings

$$y_u^{MSSM} = \frac{y_u^{SM}}{\sin\beta} \qquad y_d^{MSSM} = \frac{y_d^{SM}}{\cos\beta}$$

Ratios of Yukawas in MSSM same as in SM

Usually perturbativity [$y_b \leq \mathcal{O}(1)$] places a constraint on yb:

$$\tan\beta \lesssim 50 - 60$$

I wish to consider the case of $\tan\beta \approx \infty$

2HDM in MSSM

Assign R-charges

$$R[\hat{H}_d, \hat{Q}, \hat{u}^c, \hat{e}^c] = 0 \text{ and } R[\hat{H}_u, \hat{d}^c, \hat{L}] = 2$$

Tree-level Higgs potential is (no B_μ term)

$$\underbrace{\left(|\mu|^2 + m_{H_u}^2\right)}_{<0} |H_u|^2 + \underbrace{\left(|\mu|^2 + m_{H_d}^2\right)}_{>0} |H_d|^2 + \frac{g'^2}{8}\left(|H_u|^2 - |H_d|^2\right)^2 + \frac{g^2}{2}\left|H_u^\dagger T^a H_u + H_d^\dagger T^a H_d\right|^2$$

$$M_{h^0}^2 = -2\left(|\mu|^2 + m_{H_u}^2\right) = M_Z^2$$

$$M_{H^0}^2 = M_{A^0}^2 = 2|\mu|^2 + m_{H_u}^2 + m_{H_d}^2$$

$$M_{H^\pm}^2 = M_{A^0}^2 + M_W^2$$

Only H_u gets a vev: $\tan\beta = \infty$

Only u,c,t massive?

Down-type fermion masses

$$W = y_u\,\hat{u}^c \hat{H}_u \hat{Q} - y_d\,\hat{d}^c \hat{H}_d \hat{Q} - y_\ell\,\hat{e}^c \hat{H}_d \hat{L} + \mu\,\hat{H}_u \hat{H}_d$$

All chiral symmetries explicitly broken by superpotential

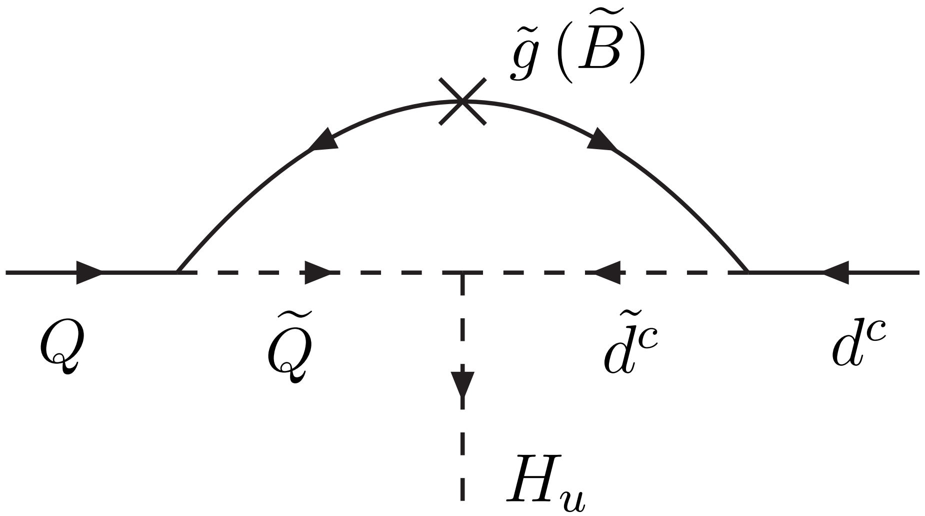
$$U(3)^5 \to U(1)_B \times U(1)_L$$

Once SUSY is broken can generate new "wrong-type" Yukawas

$$-y'_d\,d^c H_u^\dagger Q - y'_\ell\,e^c H_u^\dagger L + \mathrm{H.c.}$$

Loop generation of masses (a short domino) [Dobrescu and PJF]

Uplifted Higgs couplings

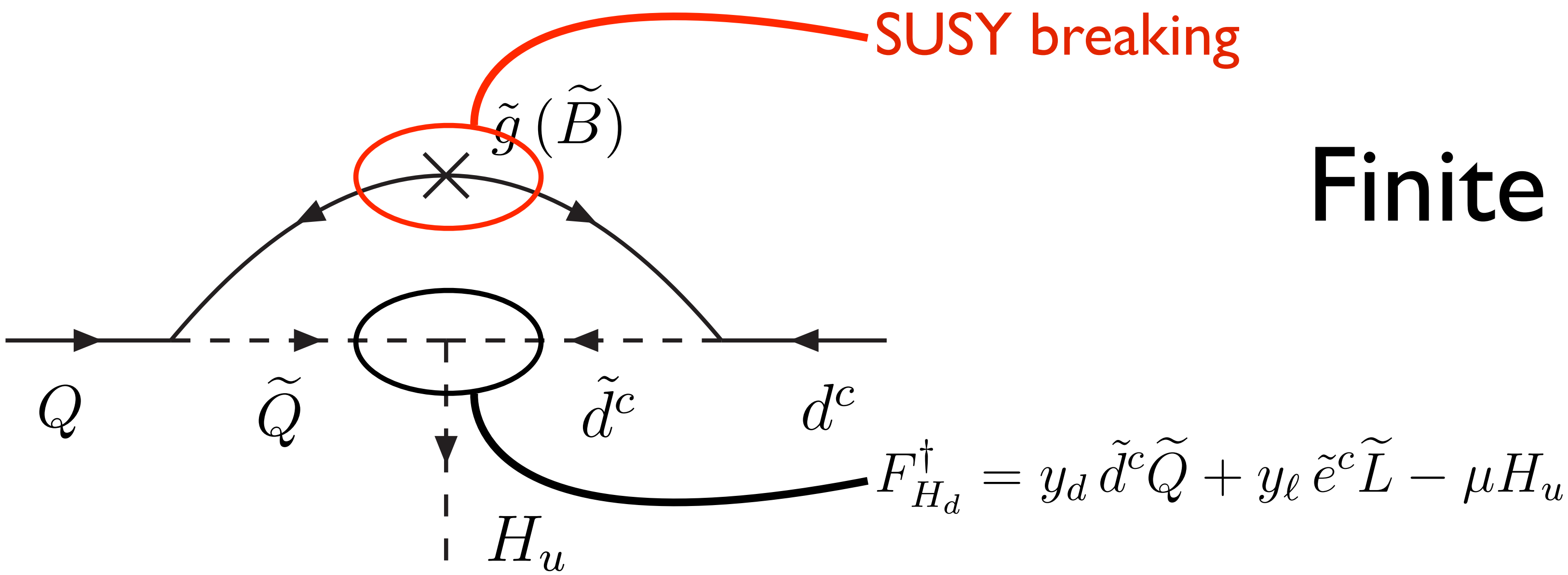


Finite loop

$$y'_d = -y_d \frac{2\alpha_s}{3\pi} \frac{|\mu|}{M_{\tilde{d}}} F\left(\frac{M_{\tilde{g}}}{M_{\tilde{Q}}}, \frac{M_{\tilde{d}}}{M_{\tilde{Q}}} \right)$$

$$F(x,y) = \frac{2xy}{x^2 - y^2} \left(\frac{y^2 \ln y}{1 - y^2} - \frac{x^2 \ln x}{1 - x^2} \right)$$

Uplifted Higgs couplings



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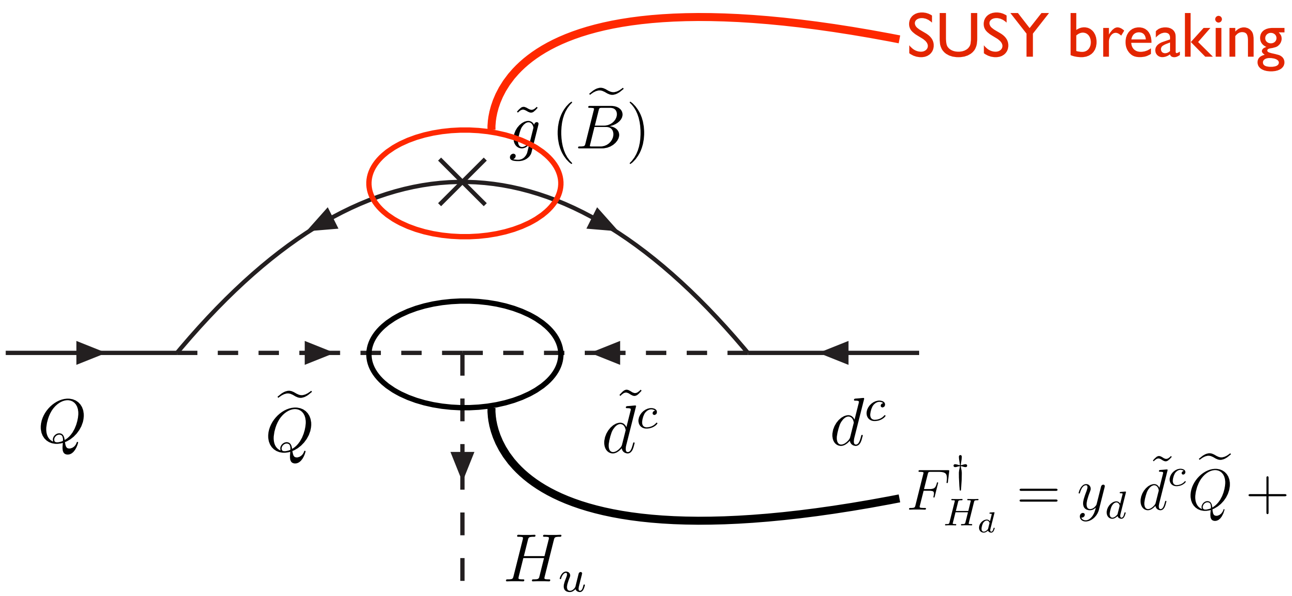

$$F^\dagger_{H_d} = y_d\,\tilde{d}^c\widetilde{Q} + y_\ell\,\tilde{e}^c\widetilde{L} - \mu H_u$$

Finite loop

Lagrangian parameter

Effective Yukawa

$$y'_d = -y_d \frac{2\alpha_s}{3\pi}\frac{|\mu|}{M_{\tilde{d}}} F\left(\frac{M_{\tilde{g}}}{M_{\tilde{Q}}}, \frac{M_{\tilde{d}}}{M_{\tilde{Q}}}\right)$$

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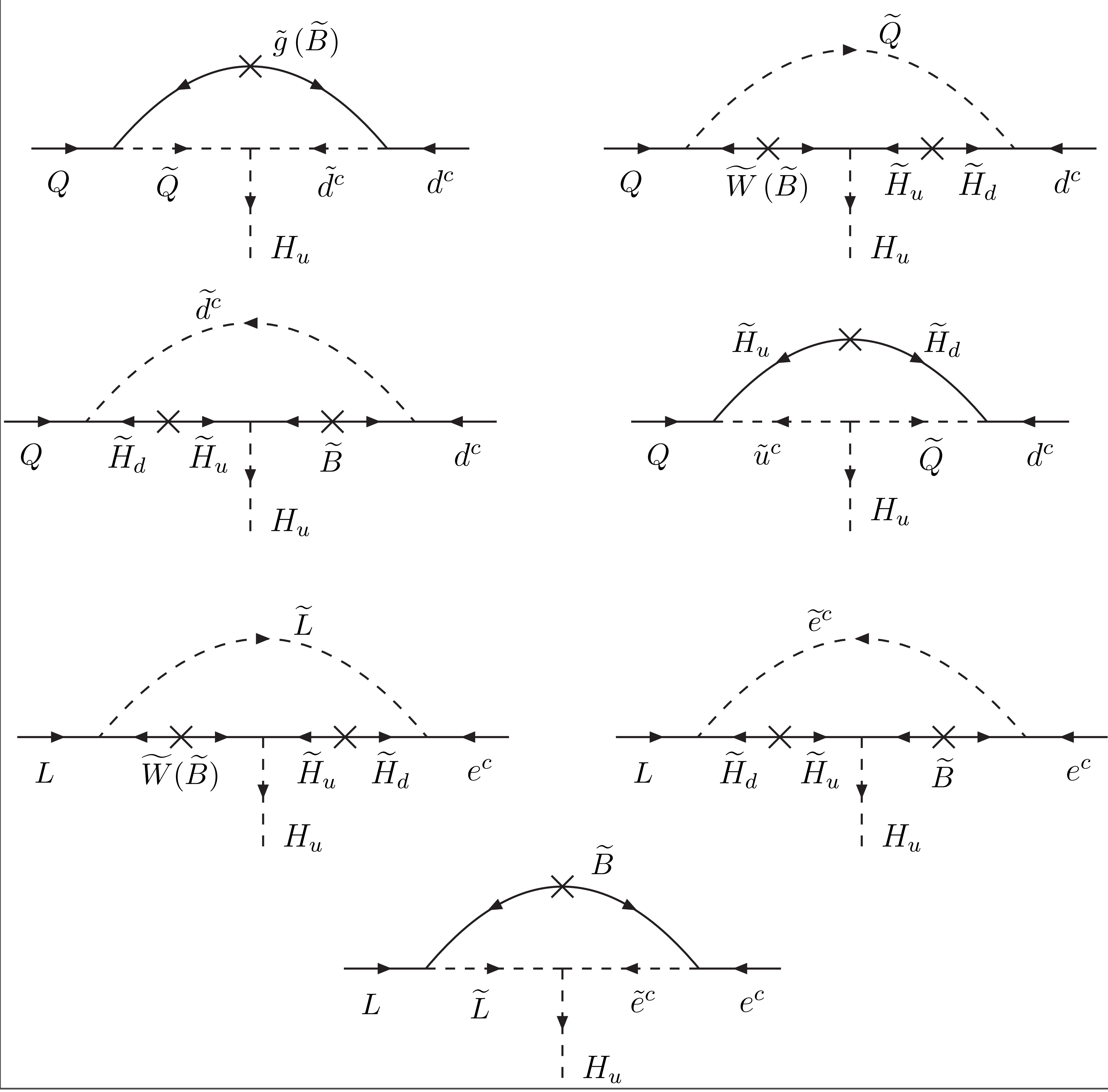
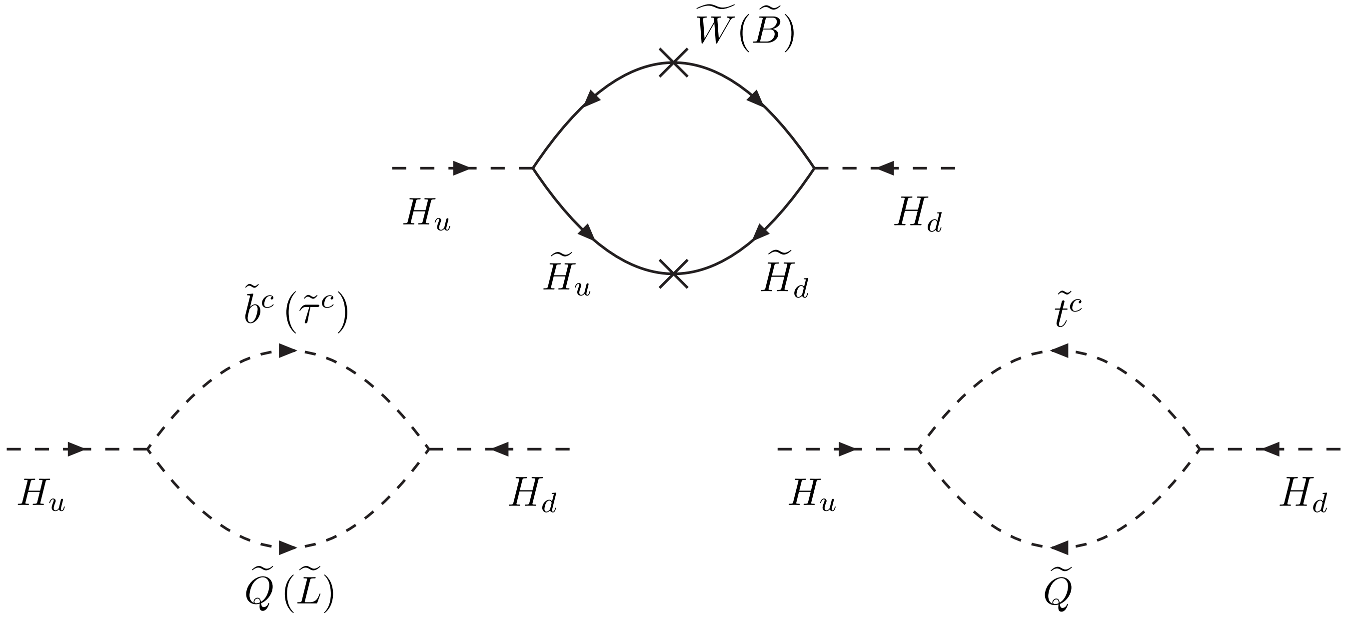


Down-type quarks

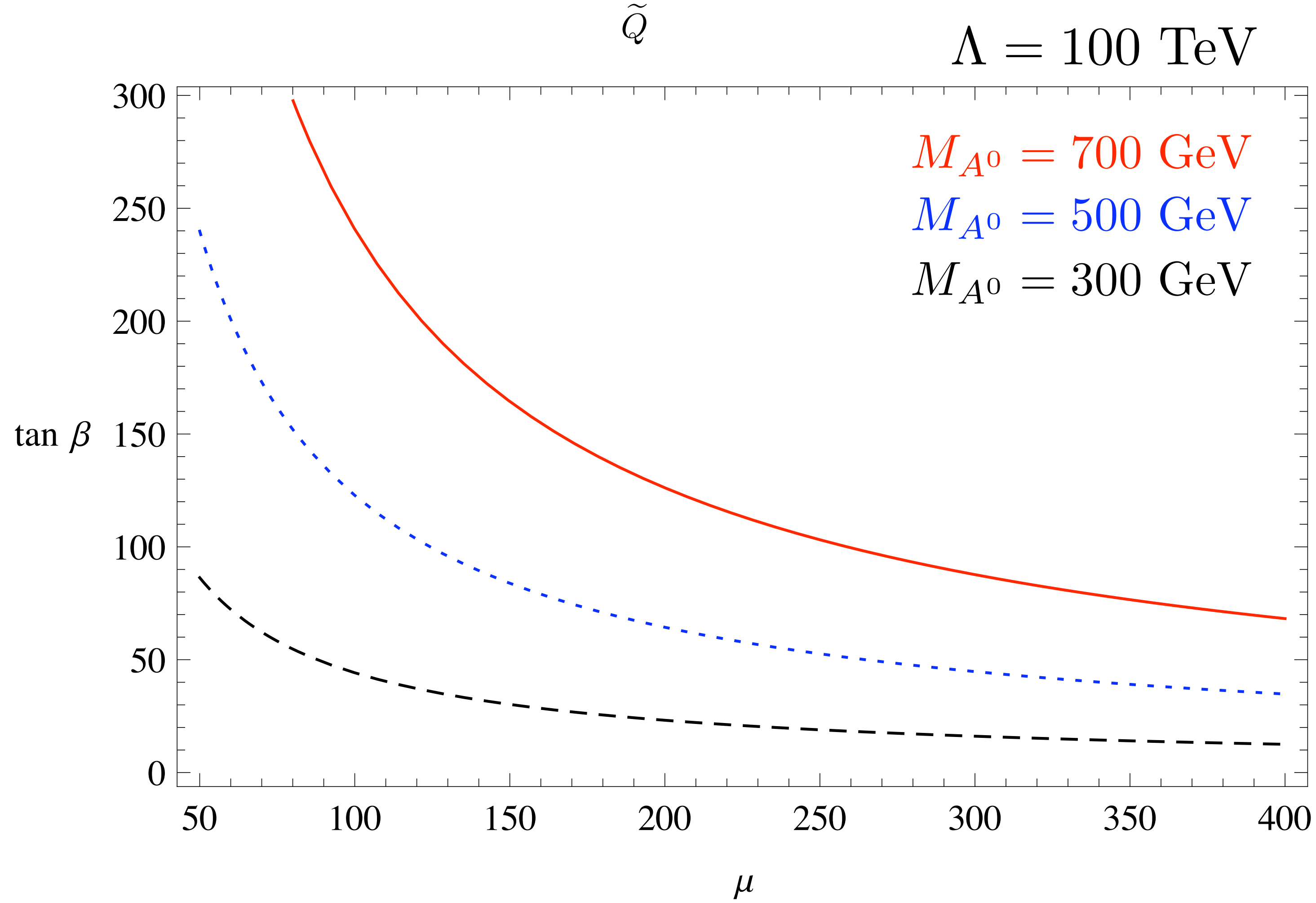
Leptons

Loop corrections to $\tan\beta$

Once SUSY is broken B_μ generated at one loop



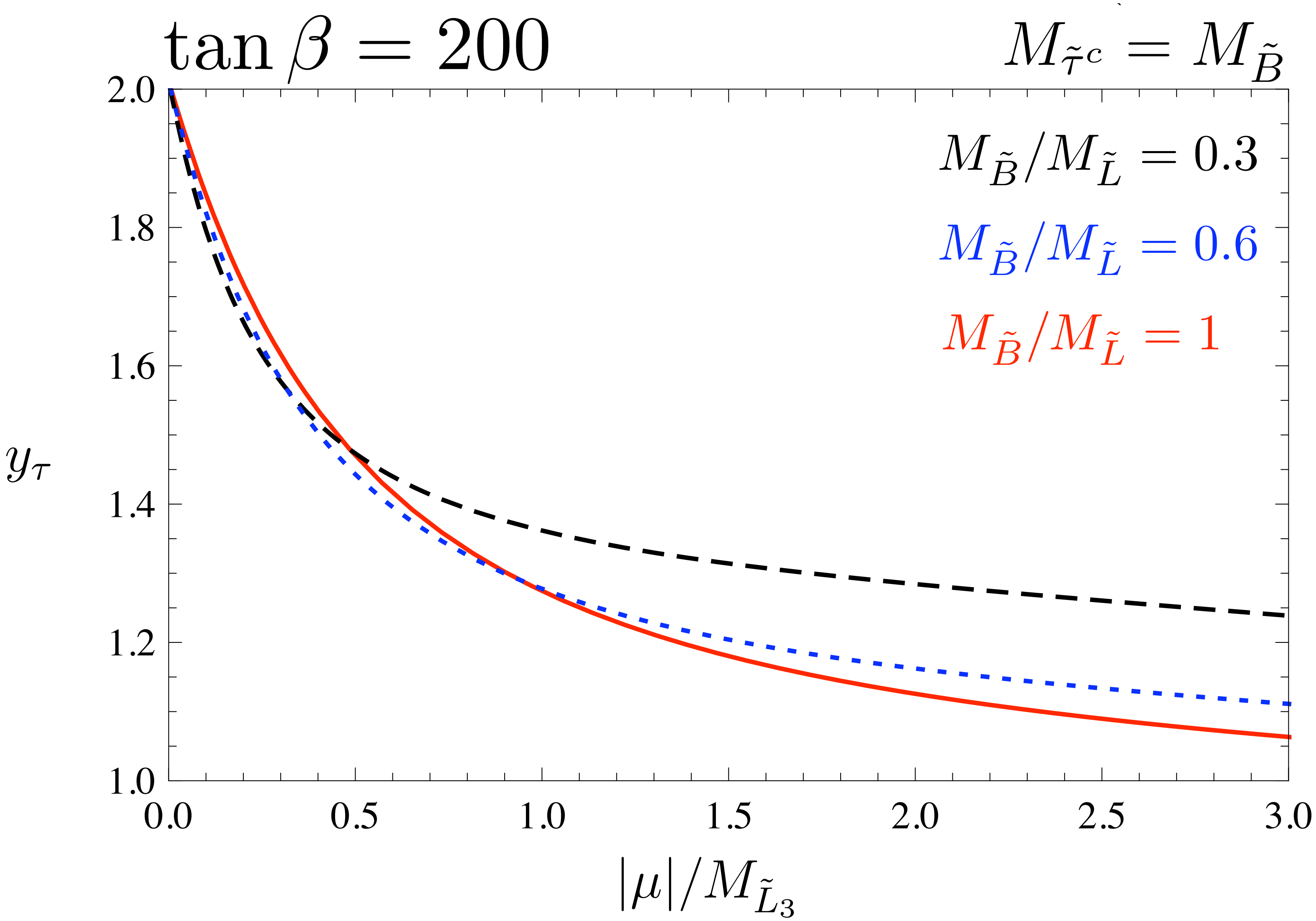
Log divergent



Loop induced masses

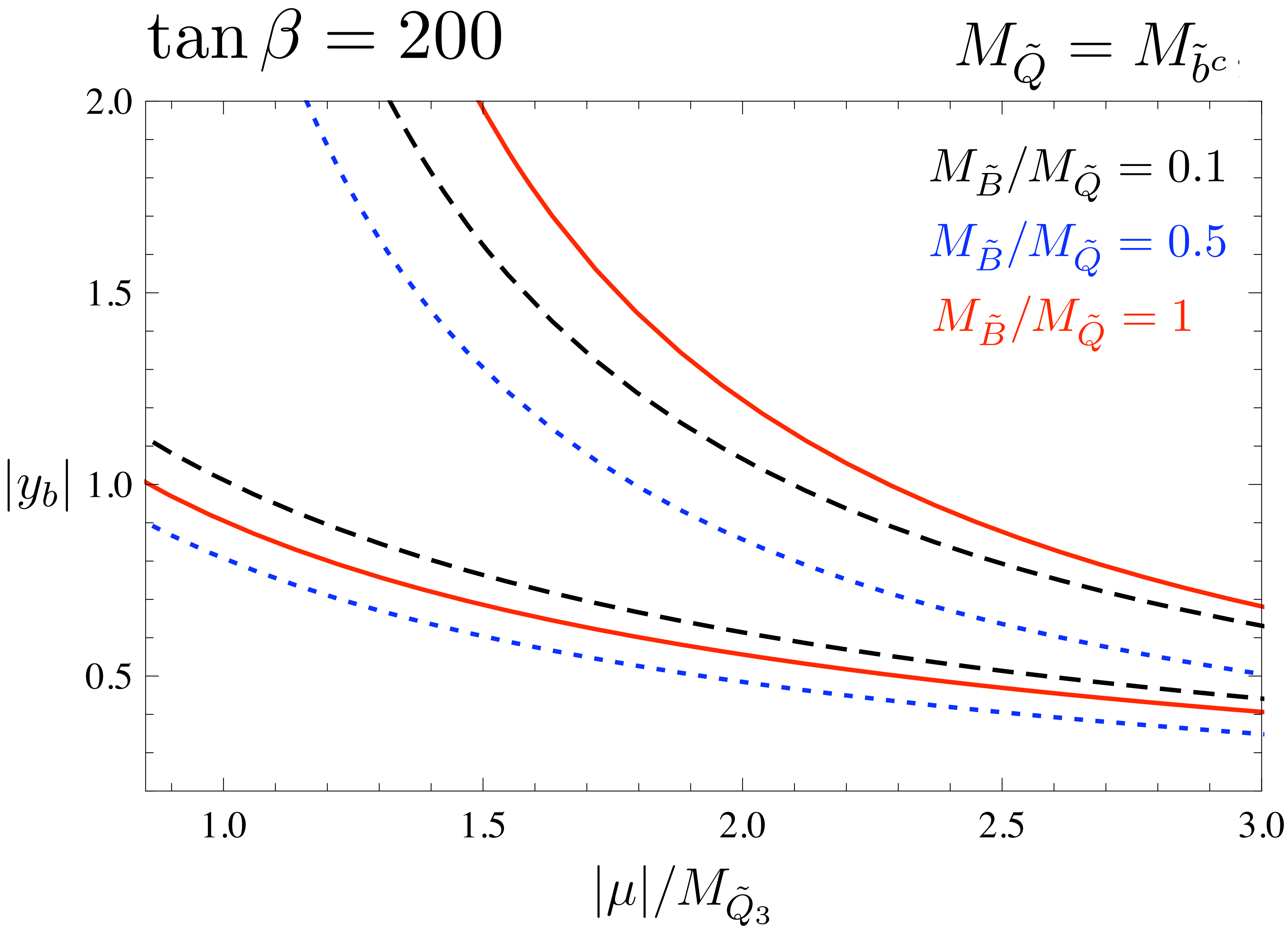
With $\tan\beta \neq \infty$

$$m_\ell = y_\ell\, v_d + y'_\ell v_u$$



$$\left(\frac{M_1}{g_1^2} = \frac{M_2}{g_2^2} = \frac{M_3}{g_3^2} \right)$$

Loop induced masses



Uplifted Higgses

Higgs (h^0) that couples to WW mainly in H_u

Heavy Higgses (A^0, H^0, $H^\pm$) in H_d

- Couplings of heavy Higgses larger than in MSSM
- Width of heavy Higgses go up
- Branching ratios and production altered

$$y^b_{H^0} = -\frac{1}{\sqrt{2}}\left(y_b \cos\alpha + y'_b \sin\alpha\right) \approx -\frac{y_b}{\sqrt{2}} \quad ,$$

$$y^b_{A^0} = y^b_{H^-} = \frac{1}{\sqrt{2}}\left(y_b \sin\beta - y'_b \cos\beta\right) \approx \frac{y_b}{\sqrt{2}}$$

$$y^b_{h^0} = \frac{1}{\sqrt{2}}\left(y_b \sin\alpha - y'_b \cos\alpha\right) \approx -\frac{1}{\sqrt{2}}\left[\frac{y_b}{\tan\beta}\left(\frac{M^2_{A^0} + M^2_Z}{M^2_{A^0} - M^2_Z}\right) + y'_b\right]\left[1 + O(1/\tan^2\beta)\right]$$

Uplifted Higgses at hadronic machines

- Production of heavy Higgses through gluon fusion with b loops and in association with b's increases.
- Decays to taus can dominate

$$B(H^0, A^0 \to \tau^+\tau^-) \approx \frac{y_\tau^2}{y_\tau^2 + 3y_b^2}$$

Could be as large as 80%
cf. usual MSSM/2HDM ~10%

Look for H^0, A^0 in $b\,\bar{b}\,\tau^+\tau^-$ or $\tau^+\tau^-$

Look for $H^\pm$ in $\bar{b}\,t\tau\,\nu$

Conclusions

$\tan\beta$

$1 \qquad\qquad \sim 50 \qquad\qquad \longrightarrow \qquad\qquad \infty$

Usual MSSM — Uplifted MSSM

- Down-type fermion masses generated at one loop by fields of MSSM
- Ratios of Yukawas not as in MSSM
- $\tan\beta$ a potentially confusing variable
- Higgs production at hadronic machines increased
- Decays to taus dominate
- Easier to find the heavy Higgses

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The MSSM is revolting!

The revolution in particle physics is here

Formulae

Uplifted lepton coupling

$$y'_\ell = \frac{y_\ell\,\alpha}{8\pi} e^{i(\theta_W-\theta_\mu)} \left\{ \frac{3}{s_W^2} F\left(\frac{M_{\tilde{W}}}{M_{\tilde{L}}}, \frac{|\mu|}{M_{\tilde{L}}}\right) + \frac{e^{i(\theta_B-\theta_W)}}{c_W^2} \left[-F\left(\frac{M_{\tilde{B}}}{M_{\tilde{L}}}, \frac{|\mu|}{M_{\tilde{L}}}\right) \right.\right.$$

$$\left.\left. + 2F\left(\frac{M_{\tilde{B}}}{M_{\tilde{e}}}, \frac{|\mu|}{M_{\tilde{e}}}\right) + \frac{2|\mu|}{M_{\tilde{e}}} F\left(\frac{M_{\tilde{B}}}{M_{\tilde{L}}}, \frac{M_{\tilde{e}}}{M_{\tilde{L}}}\right) \right] \right\}$$

Uplifted down-quark coupling

$$(y'_d)_F = -\frac{y_d}{3\pi} e^{i(\theta_g-\theta_\mu)} \frac{2|\mu|}{M_{\tilde{d}}} \left[\alpha_s F\left(\frac{M_{\tilde{g}}}{M_{\tilde{Q}}}, \frac{M_{\tilde{d}}}{M_{\tilde{Q}}}\right) + \frac{\alpha e^{i(\theta_B-\theta_g)}}{24 c_W^2} F\left(\frac{M_{\tilde{B}}}{M_{\tilde{Q}}}, \frac{M_{\tilde{d}}}{M_{\tilde{Q}}}\right) \right]$$

$$(y'_d)_{\tilde{H}} = \frac{y_d\alpha}{8\pi} e^{i(\theta_W-\theta_\mu)} \left\{ \frac{3}{s_W^2} F\left(\frac{M_{\tilde{W}}}{M_{\tilde{Q}}}, \frac{|\mu|}{M_{\tilde{Q}}}\right) + \frac{e^{i(\theta_B-\theta_W)}}{3c_W^2} \left[F\left(\frac{M_{\tilde{B}}}{M_{\tilde{Q}}}, \frac{|\mu|}{M_{\tilde{Q}}}\right) + 2F\left(\frac{M_{\tilde{B}}}{M_{\tilde{d}}}, \frac{|\mu|}{M_{\tilde{d}}}\right) \right] \right\}$$

$$(y'_d)_A = \frac{y_u y_d}{16\pi^2} e^{-i\theta_\mu} \frac{A_u^*}{M_{\tilde{u}}} F\left(\frac{M_{\tilde{u}}}{M_{\tilde{Q}}}, \frac{|\mu|}{M_{\tilde{Q}}}\right)$$

$$y'_d = (y'_d)_F + (y'_d)_{\tilde{H}} + (y'_d)_A$$