Flavor Physics and Dark Matter in SUSY GUT Models

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Based on works with

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Supersymmetry

Why SUSY?

- It provides solution to hierarchy problem,
- improves gauge coupling unification,
- provides dark matter particle.

Unsolved problem:

How do we understand flavor structure within SUSY?

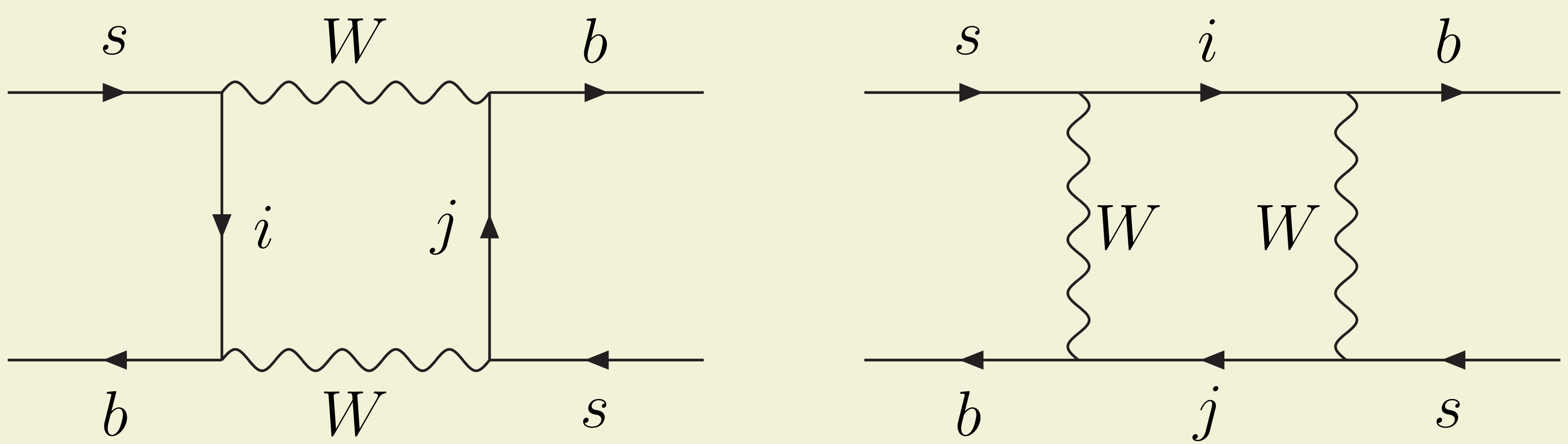
(How SUSY is broken?)

Flavor & SUSY

- Flavor puzzle of SUSY: (without restriction by hand) soft breaking terms allow large flavor changing processes.
- FCNC can be suppressed by flavor universal SUSY breaking:
  - Universal squarks and sleptons masses $m_{\tilde{U}}, m_{\tilde{D}}, m_{\tilde{Q}}, m_{\tilde{L}}, m_{\tilde{E}} = I m_0$.
  - Universal trilinear coupling coefficents $A = Y A_0$ ($Y =$ Yukawa).
- Nevertheless, nonuniversality still arises through RGE, $\Rightarrow$ FCNC through radiative correction.
- Within SUSY GUT - How the quark sector is related to the lepton sector?

$B_s - \bar{B}_s$ mixing

- Large phase is measured:
  CDF: $\phi_s \in [0.28, 1.29]$
  (PRL100 (2008) 161802)
  D0 : $\phi_s = 0.57^{+0.30}_{-0.24}(\mathrm{stat})^{+0.02}_{-0.07}(\mathrm{syst})$
  (PRL101 (2008) 241801)
- Standard Model:
  $\phi_s = 2\beta_s \equiv 2\arg\left(-V_{ts}V_{tb}^*/V_{cs}V_{cb}^*\right) \simeq 0.04$



$B_s - \bar{B}_s$ mixing - SUSY

- Chargino box diagrams.
- Double penguin diagrams through heavy Higgs.
  This is $\propto \tan^4\beta$ and $\propto 1/m_A^4$
  (Recall also that BR$(B_s \to \mu\mu) \propto \tan^6\beta$)

Define

$$C_{B_s} e^{2i\phi_{B_s}} = \frac{M_{12}^{\rm SM} + M_{12}^{\rm NP}}{M_{12}^{\rm SM}}$$

then

$$\phi_s = 2(\beta_s - \phi_{B_s})$$

Neutrino in the GUT-shell

- Observation:
  θ_{12} (solar) - large, θ_{23} (atmospheric) - large, θ_{13} (reactor) - small, and small neutrino masses.
- Light neutrinos through seesaw:

$$\mathcal{M}_\nu^{\mathrm{light}} = f\langle\Delta_L\rangle - Y_\nu M_R^{-1} Y_\nu^{\mathrm{T}} \langle H_u^0\rangle^2$$

  Seesaw type II I

  Δ_L is an SU(2)$_L$ triplet, and f is a Majorana coupling $\frac{1}{2}LL\Delta_L$.
- Large mixing through Majorana coupling (type II) or Dirac coupling (type I).

GUT boundary condition

Squark and slepton mass matrices:

$$M_{\tilde{F}}^2 = m_0^2[\mathbf{1} - \kappa_F U_F \mathrm{diag}(k_1, k_2, 1) U_F^\dagger]$$

- Minimal type SU(5) :

$$\kappa_L = \kappa_{D^c}, \quad U_L = U_{D^c}, \quad \kappa_Q = \kappa_{U^c} = \kappa_{E^c} = 0$$

- Minimal type SO(10) :

$$\kappa_Q = \kappa_{U^c} = \kappa_{D^c}, \quad U_Q = U_{U^c} = U_{D^c}, \quad \kappa_L = \kappa_{E^c}$$

(To obey proton decay constraint. Dutta, Mimura and Mohapatra, PRL**94** (2005) 091804, PRD**72** (2005) 075009)

Neutralino Dark Matter

Direct detection cross section

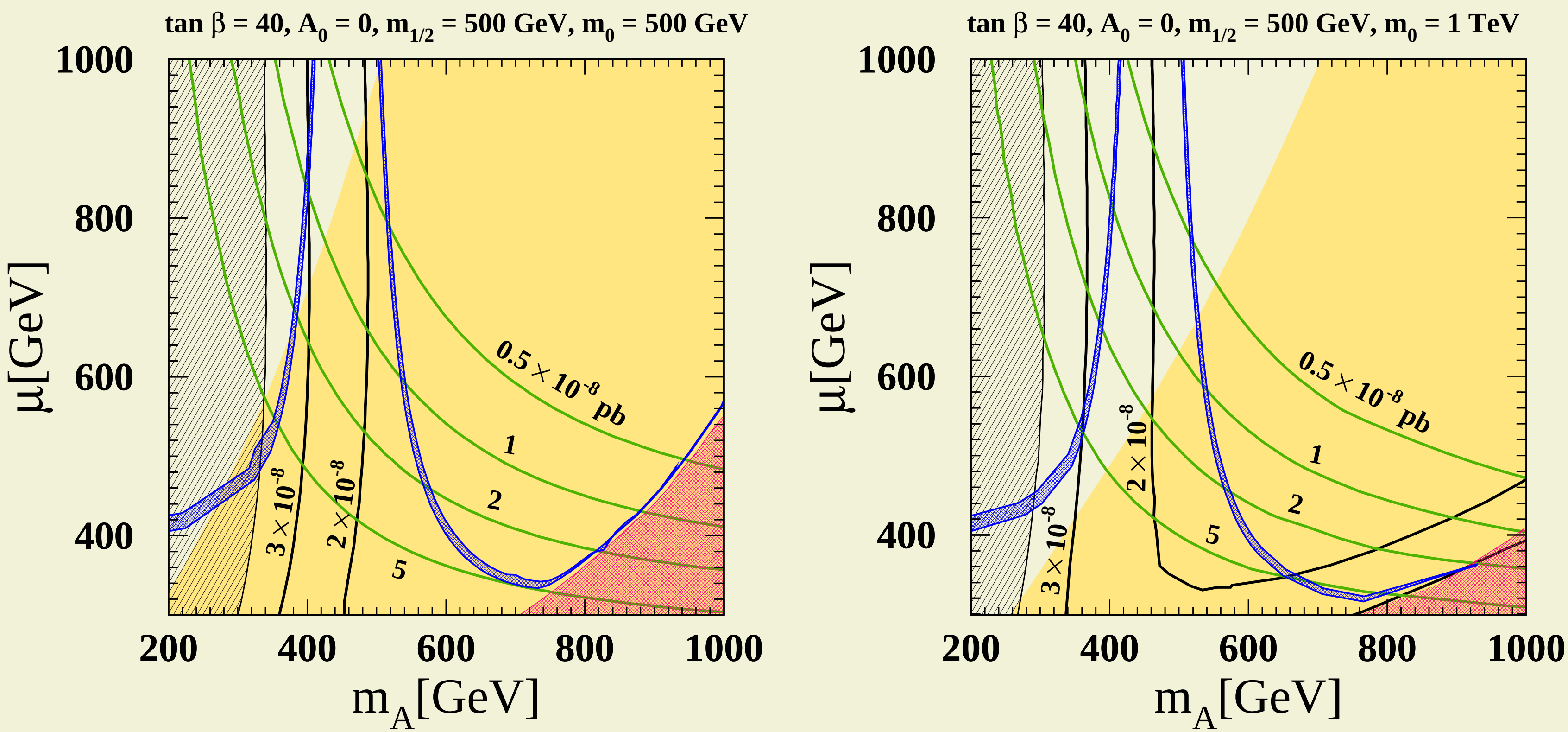
$$\sigma_{\tilde{\chi}_1^0 - p} \simeq \frac{4}{\pi} m_p^4 |(A^u f_u/m_u + A^c f_c/m_c + A^t f_t/m_t) + (A^d f_d/m_d + A^s f_s/m_s + A^b f_b/m_b)|^2$$

where, $f_q \equiv \langle p | m_q \bar{q} q | p \rangle / m_p$, and $f_u \simeq 0.027$; $f_d \simeq 0.039$; $f_s \simeq 0.36$; $f_c = f_b = f_t \simeq 0.043$

$$A^{d,s,b} = \frac{g_2^2 m_{d,s,b}}{4 M_W} \left(-\frac{\sin\alpha}{\cos\beta} \frac{F_h}{m_h^2} + \frac{\cos\alpha}{\cos\beta} \frac{F_H}{m_H^2} \right)$$

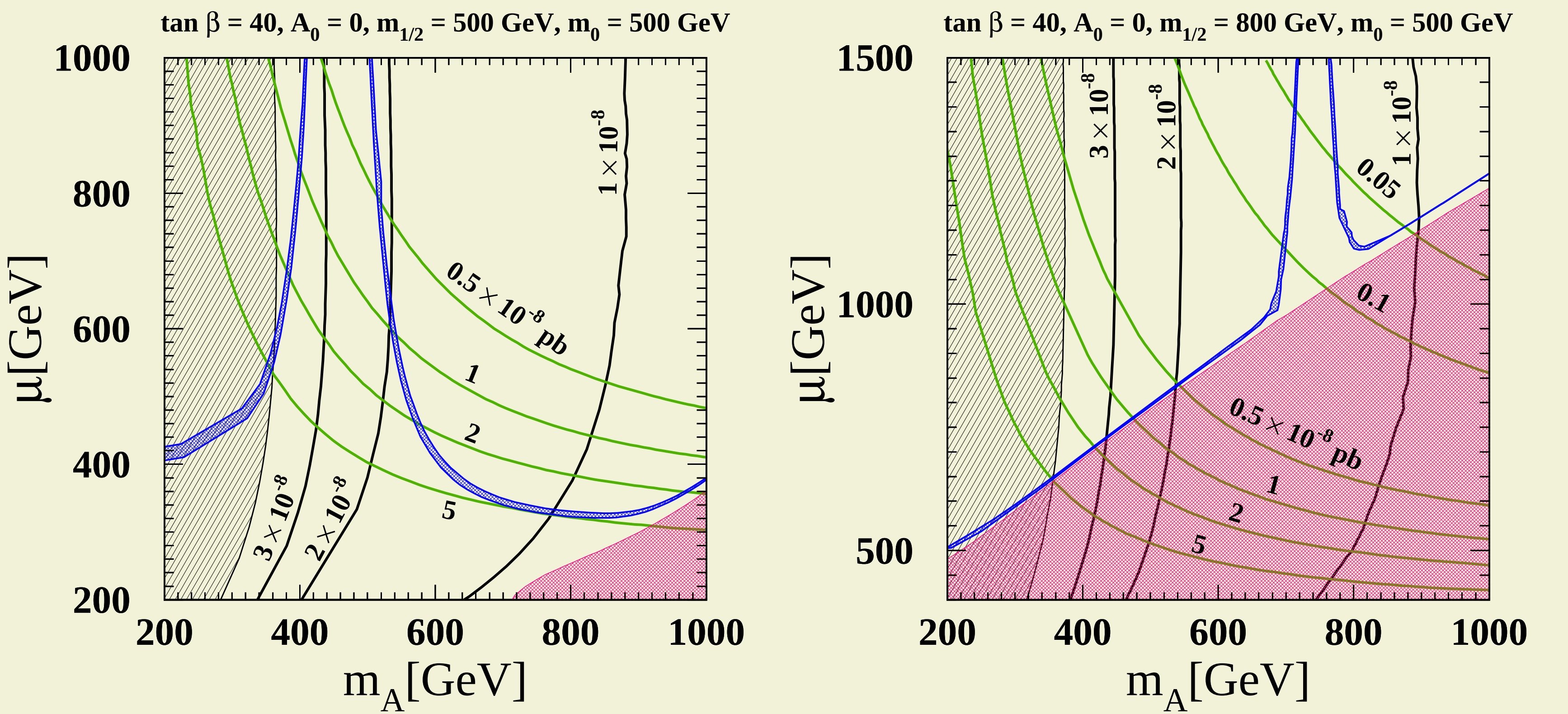
$$A^{u,c,t} = \frac{g_2^2 m_{u,c,t}}{4 M_W} \left(\frac{\cos\alpha}{\sin\beta} \frac{F_h}{m_h^2} + \frac{\sin\alpha}{\sin\beta} \frac{F_H}{m_H^2} \right)$$

SU(5) $m_A - \mu$ plane

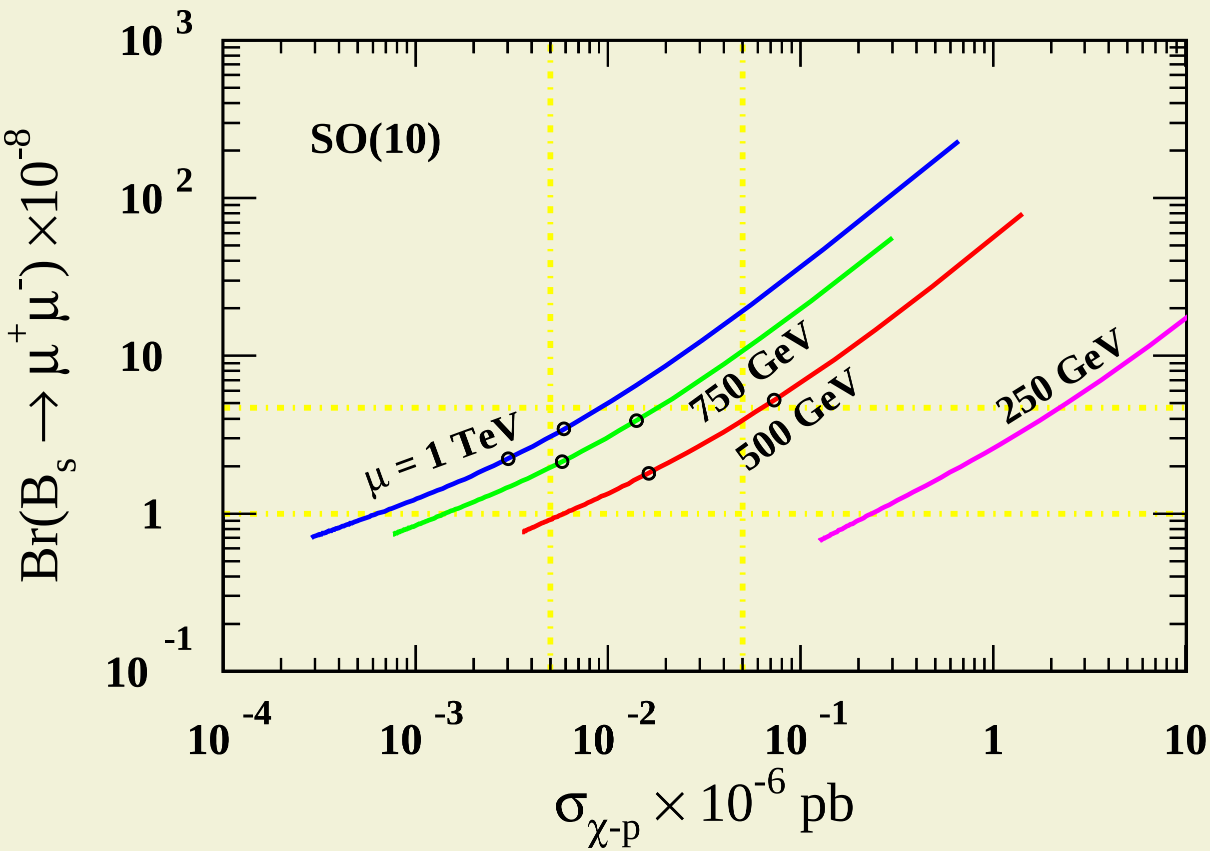


$|2\phi_{B_s}| = 0.5$ rad.

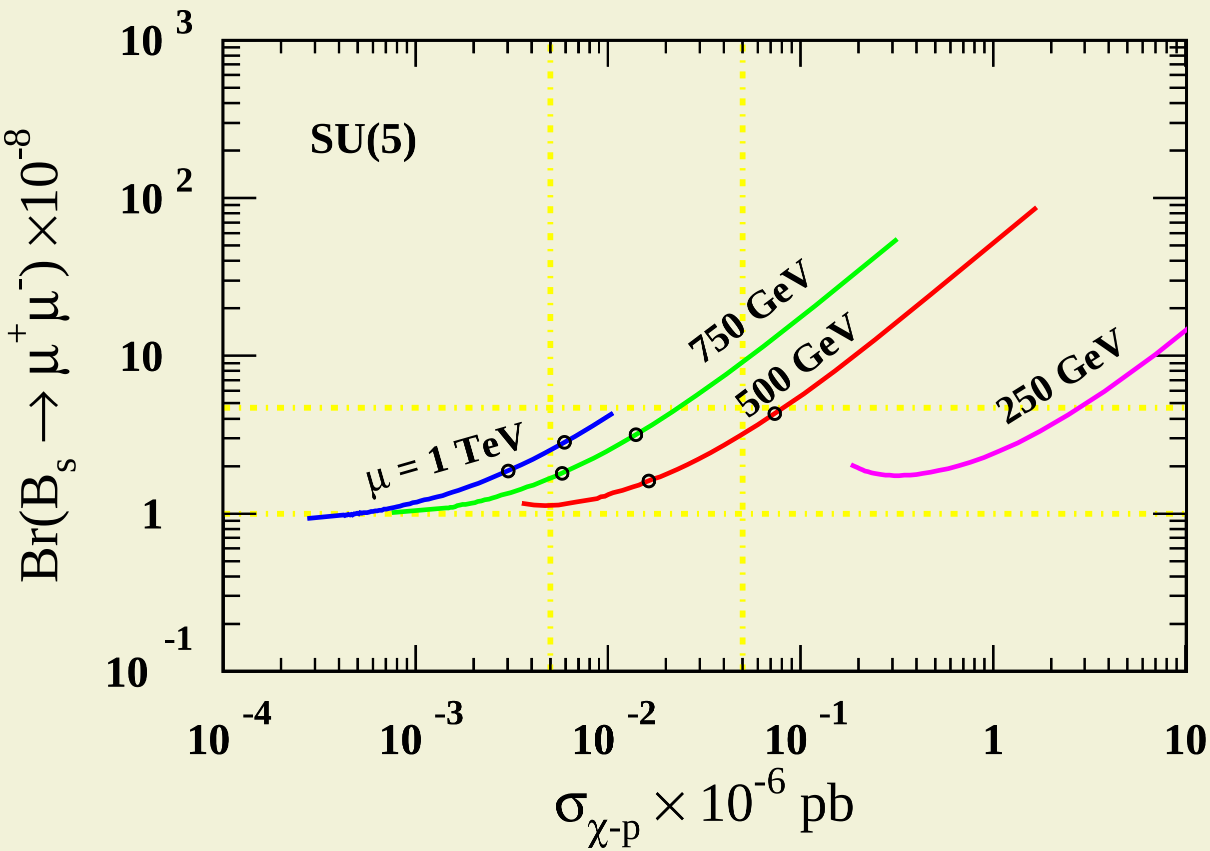
SO(10) $m_A - \mu$ plane



$|2\phi_{B_s}| = 0.5$ rad.



$\tan\beta = 40$, $A_0 = 0$, $m_0 = 500$ GeV, $m_{1/2} = 500$ GeV



$\tan\beta = 40$, $A_0 = 0$, $m_0 = 500$ GeV, $m_{1/2} = 500$ GeV

Conclusion

- We have looked at models of SUSY GUT in which $B_s - \bar{B}_s$ mixing phase can be large and with large neutrino mixing.
- Combined with other flavor changing constraints and dark matter constraints we found that the funnel region is still allowed by both SU(5) and SO(10), and favored by SU(5).
- Stronger constraints from upcoming experimental results can provide further hints on the SUSY GUT model.