# $B_s \to \mu^+\mu^-$ and MSSM Searches

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# Outline

# Indirect Searches of New Physics

- Probe particles running inside a loop, even ones too heavy to be produced at colliders
- Can study the flavor stucture
- Complementary to the direct serch
- $B \to X_s\gamma$, $(g-2)_\mu$, $B \to X_s l^+ l^-$, $B_{(d,s)} - \overline{B}_{(d,s)}$ mixing, $B_s \to \mu^+\mu^-$
- $B_s \to \mu^+\mu^-$ is very sensitive to MSSM with large $\tan\beta$

# $B(B_s \to \mu^+\mu^-)$

- CDF saw excess with 7 fb$^{-1}$ CDF, arXiv:1107.2304

$$B(B_s \to \mu^+\mu^-)^{\mathrm{CDF}} = (1.8^{+1.1}_{-0.9}) \times 10^{-8}$$
$$4.6 \times 10^{-9} < B(B_s \to \mu^+\mu^-)^{\mathrm{CDF}} < 3.9 \times 10^{-8} \text{ @ 90\% CL}$$
$$B(B_s \to \mu^+\mu^-)^{\mathrm{CDF}} < 4.0 \times 10^{-8} \text{ @ 95\% CL} \quad (1)$$

- CMS measurement with 1.14 fb$^{-1}$ CMS, arXiv:1107.5834

$$B(B_s \to \mu^+\mu^-)^{\mathrm{CMS}} < 1.9(1.6) \times 10^{-8} \text{ @ 95 (90)\% CL} \quad (2)$$

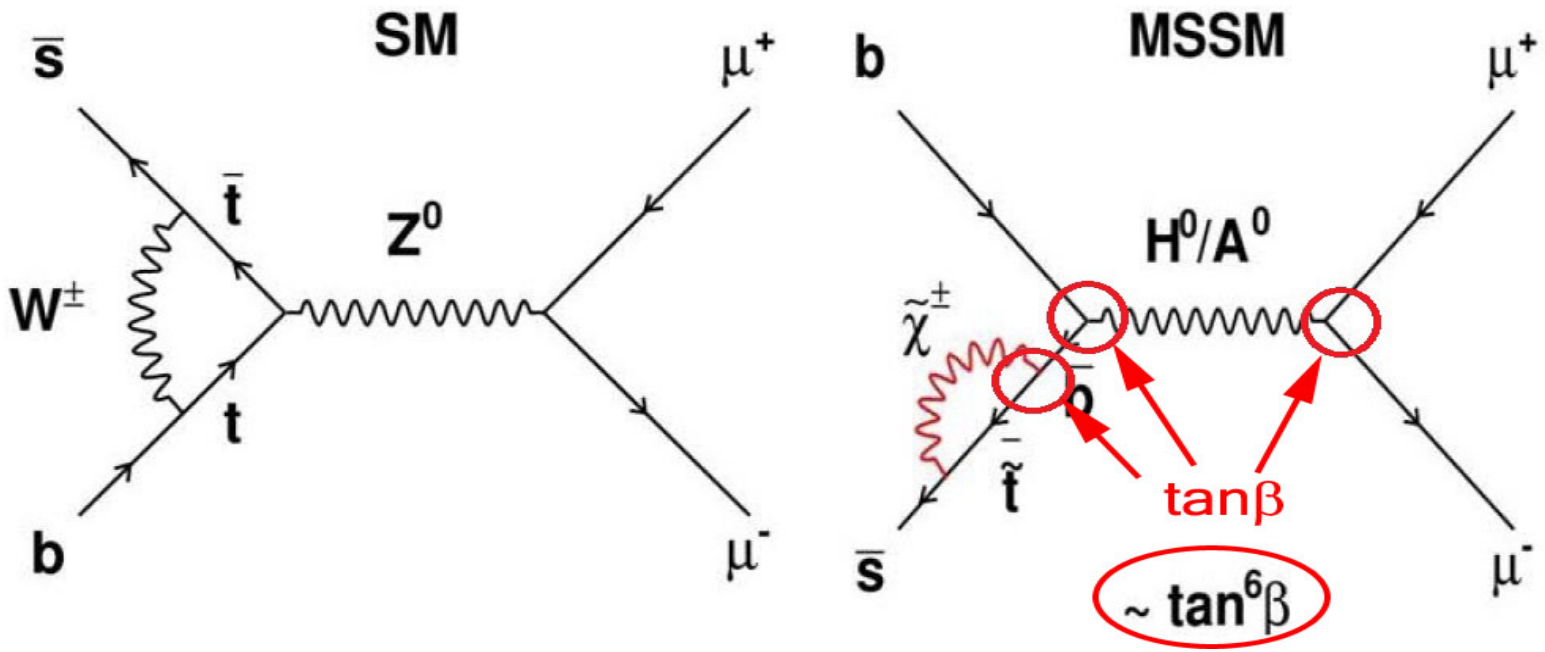
- SM prediction

$$B(B_s \to \mu^+\mu^-)^{\mathrm{SM}} = (3.2 \pm 0.2) \times 10^{-9} \quad (3)$$

# Implications of CDF measurement on MSSM

$B(B_s \to \mu^+\mu^-)$

- $\propto A_t^2 \mu^2 \tan^6\beta m_A^{-4} \mathrm{Max}(\mu, m_{\mathrm{stop}})^{-4}$ (D. Hooper & C. Kelso, arXiv:1107.3858)




$B_s \to \mu^+\mu^-$ diagrams

# Implications of CDF measurement on MSSM

(D. Hooper & C. Kelso, arXiv:1107.3858)

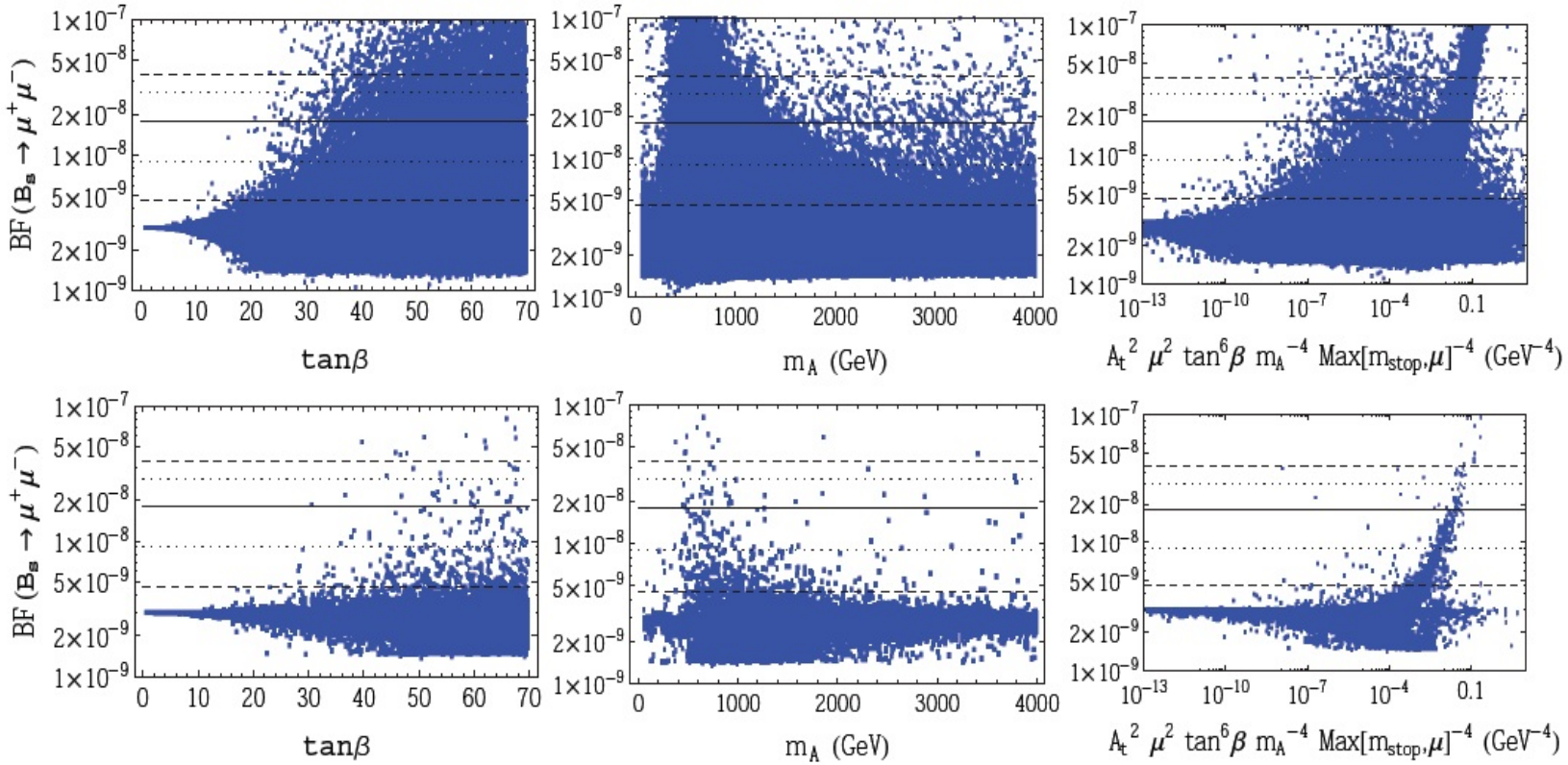



Figure: Upper (Lower) panel: without (with) relic density constraint

# Implications of CDF measurement on MSSM

(D. Hooper & C. Kelso, arXiv:1107.3858)

Regions consistent with thermal relic density

- $\widetilde{\chi}$ coannihilates with $\widetilde{\tau}_1$
- $A$-resonance region $(2m_{\widetilde{\chi}_0} \approx m_A)$
- $A(\widetilde{\chi}\widetilde{\chi} \to A \to b\bar{b}, \tau\bar{\tau}) \propto \tan^2\beta / m_A^2$

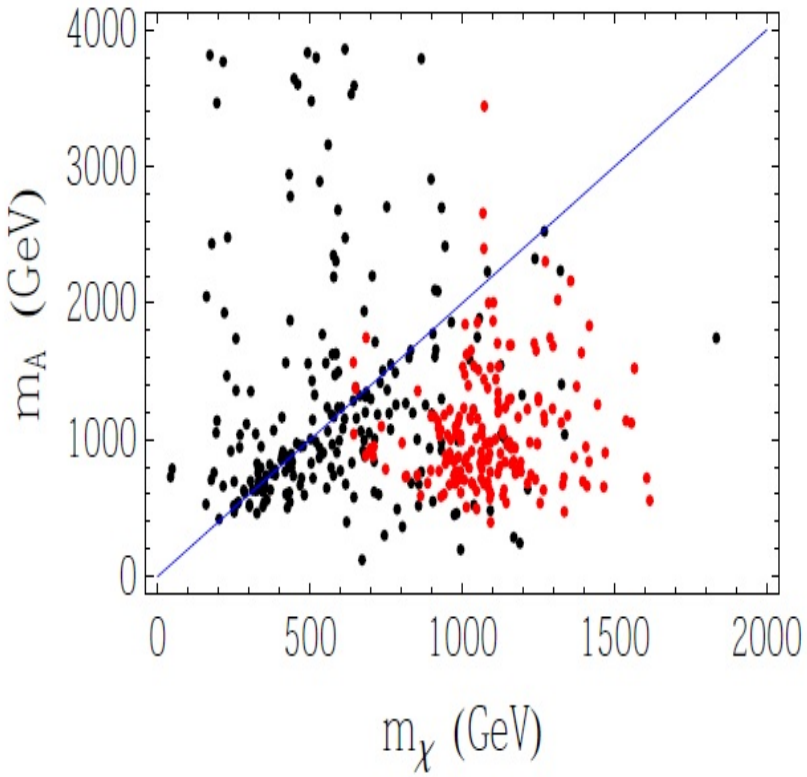



Figure: Upper (Lower) panel: without (with) relic density constraint

# Implications of CDF measurement on MSSM

(D. Hooper & C. Kelso, arXiv:1107.3858)

Constraints from direct detection experiments

- only a small fraction of allowed parameters are excluded
- next generation experiments can test large region

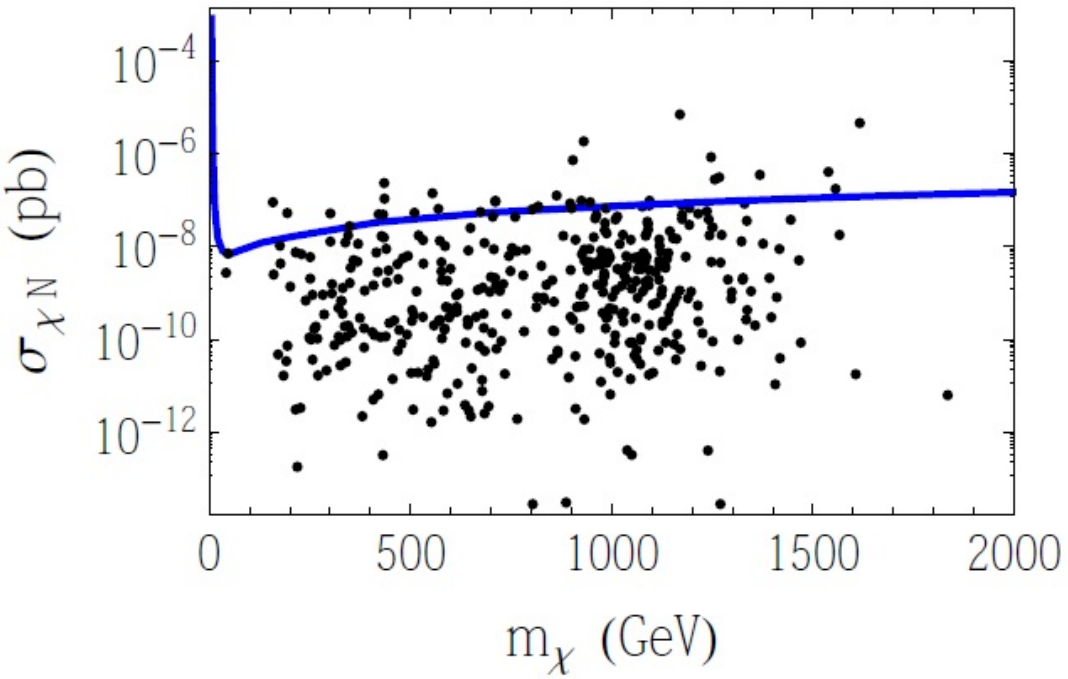


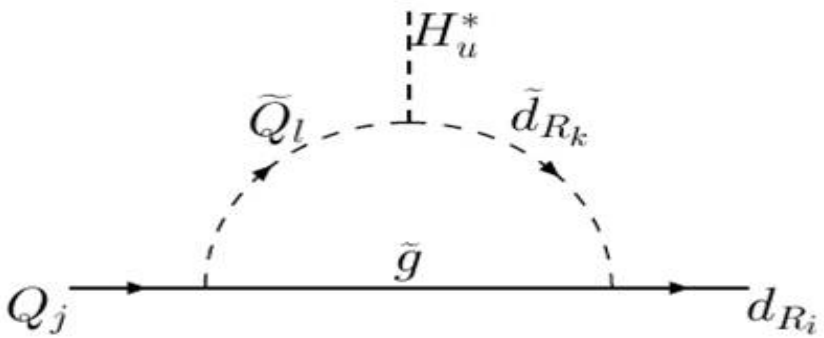

Figure: SI elastic scattering cross section for $\widetilde{\chi}_0$ with nucleons. Blue line: constraint from XENON-100.

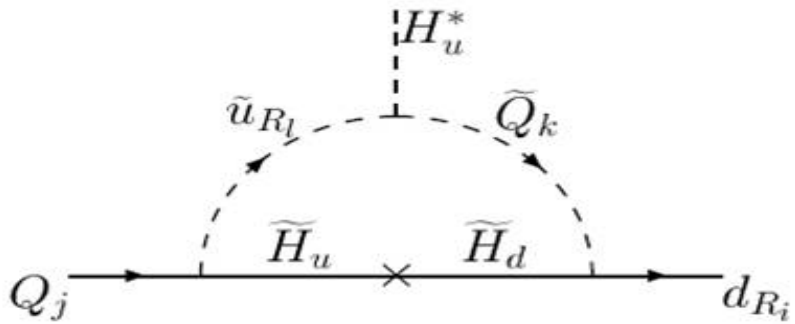
# SUSY breaking models

SB, P. Ko, W.Y. Song, PRL(2002); JHEP(2003)

- $B(B_s \to \mu^+\mu^-)$ be sensitive to SUSY models, mSUGRA, AMSB, GMSB, $\cdots$
  - different models predict different specta and SUSY parameters
  - large correction to $y_b$ at large $\tan\beta$ (HRS effect)

$$
\begin{aligned}
y_b &= \frac{g m_b}{\sqrt{2} m_W \cos\beta} \frac{1}{1+\Delta_b \tan\beta}, \\
\Delta_b &\approx \frac{2\alpha_s}{3\pi} \mu M_3 I(m_{\tilde{b}_1}, m_{\tilde{b}_2}, m_{\tilde{g}})
\end{aligned}
\tag{4}
$$

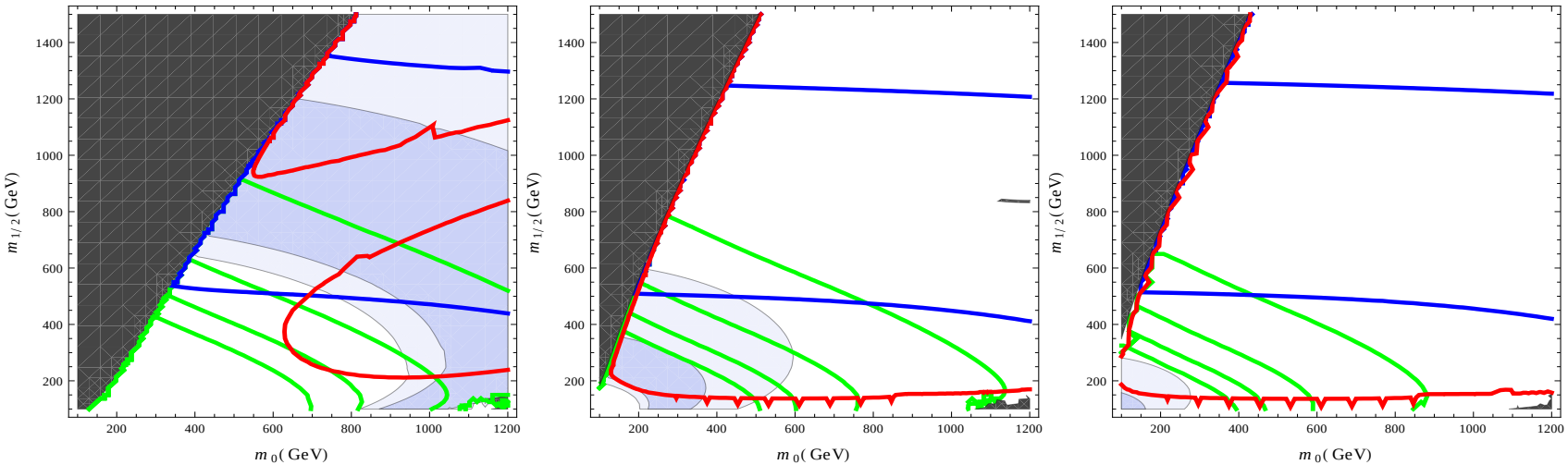


# mSUGRA

SB, P. Ko, W.Y. Song, PRL(2002); JHEP(2003)

- $m_0, m_{1/2}, a_0, \tan\beta, \mathrm{sign}(\mu)$ at GUT scale
- $M_1 : M_2 : M_3 = 1 : 2 : 6$, LSB=$\widetilde{B}$-like neutralino
- For $\tan\beta = 50$ both stau coannihilation and Higgs resonance region are allowed



# mSUGRA

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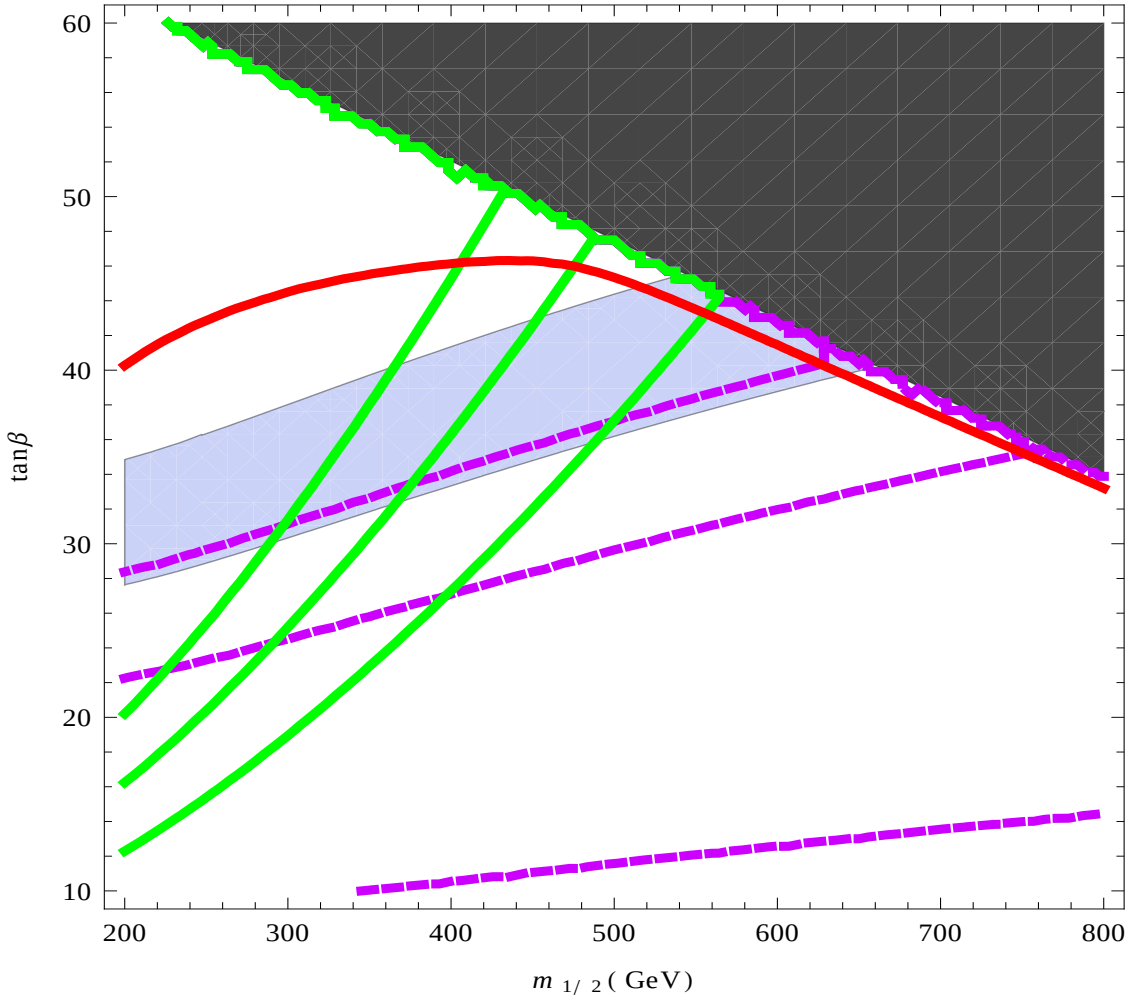
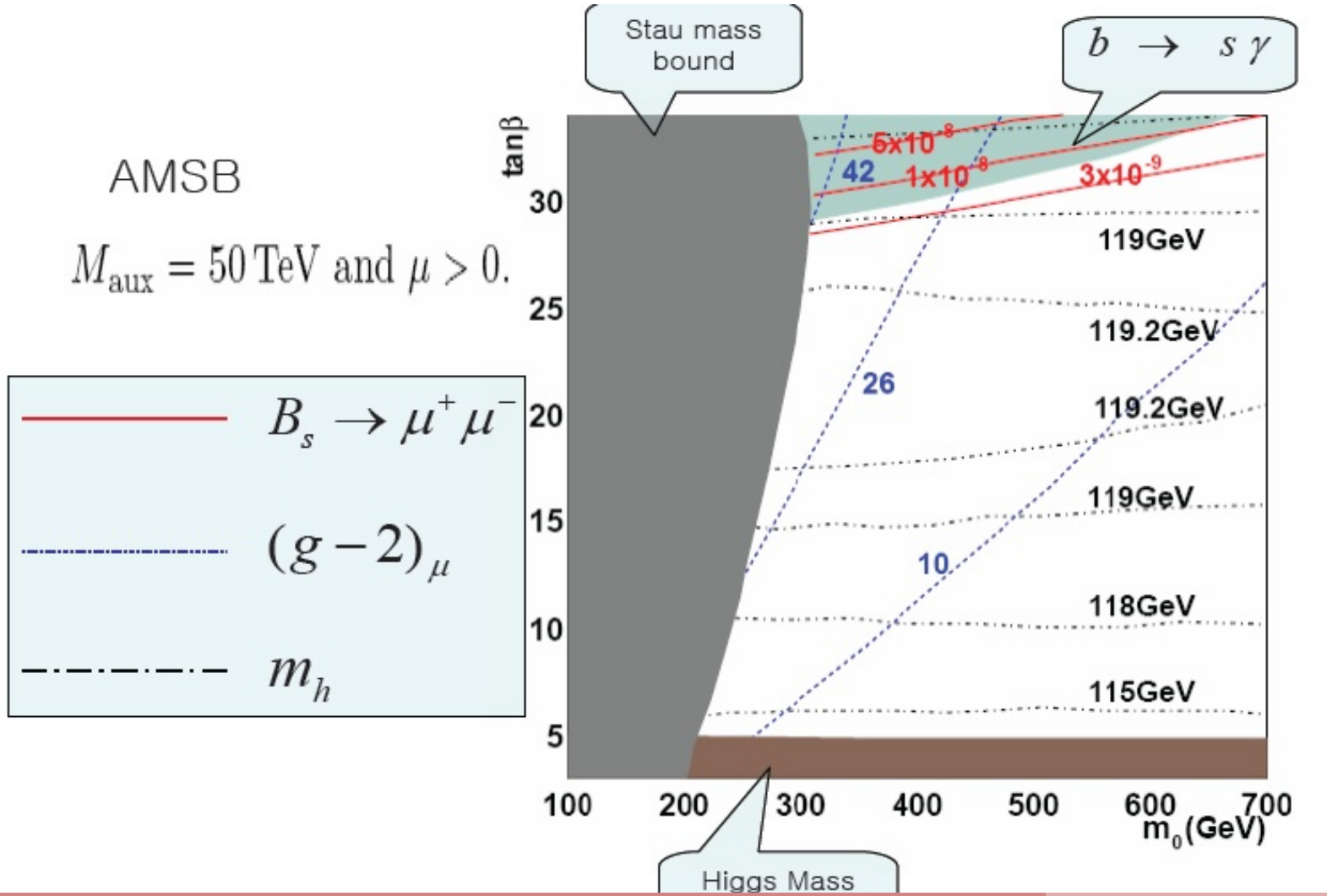


# mAMSB

SB, P. Ko, W.Y. Song, PRL(2002); JHEP(2003) Ruled out by the lower bound of CDF, although allowed by $(g-2)_\mu$ and Higgs mass

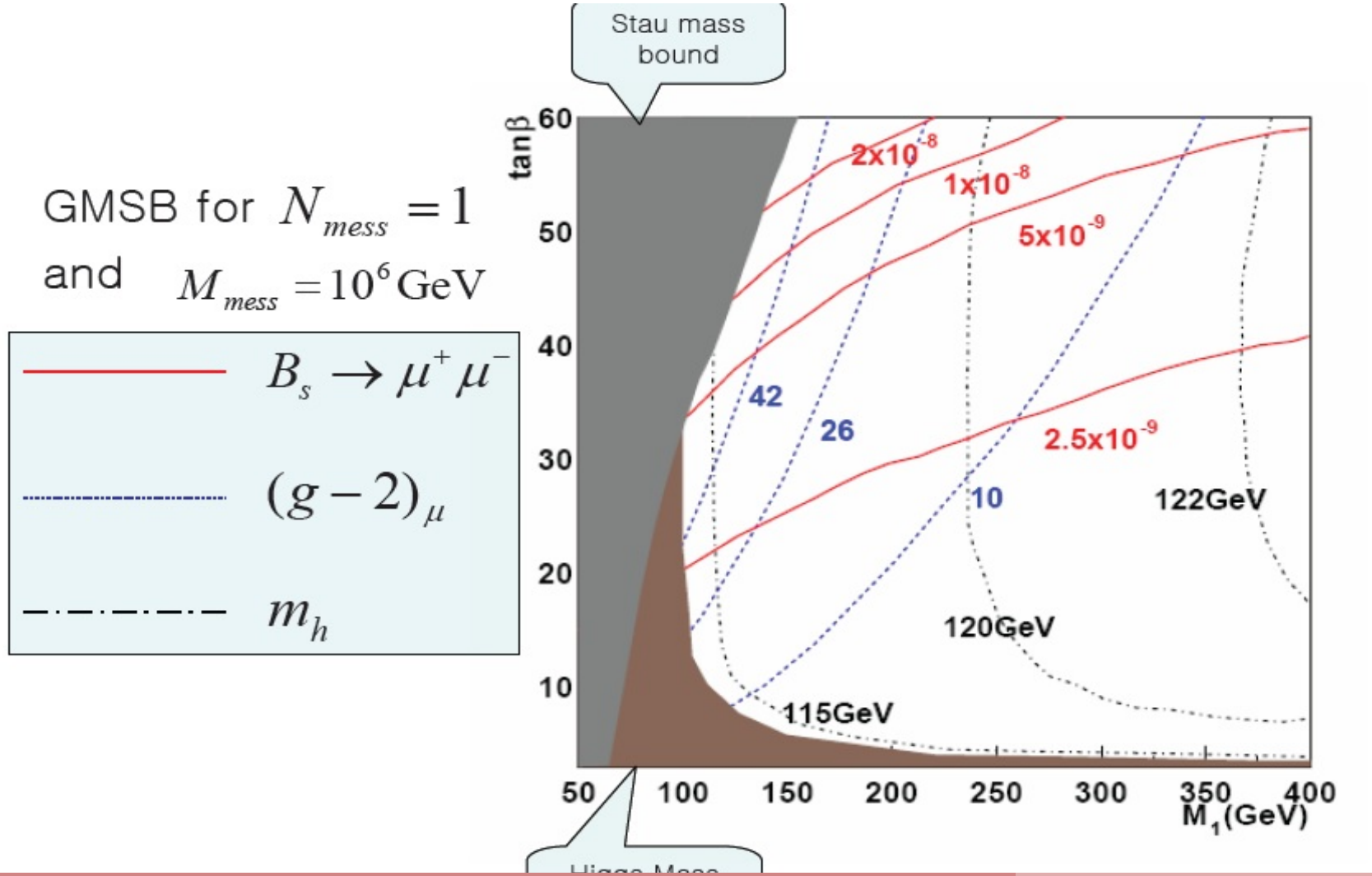
AMSB

$M_{\rm aux} = 50\,{\rm TeV}$ and $\mu > 0$.



# GMSB

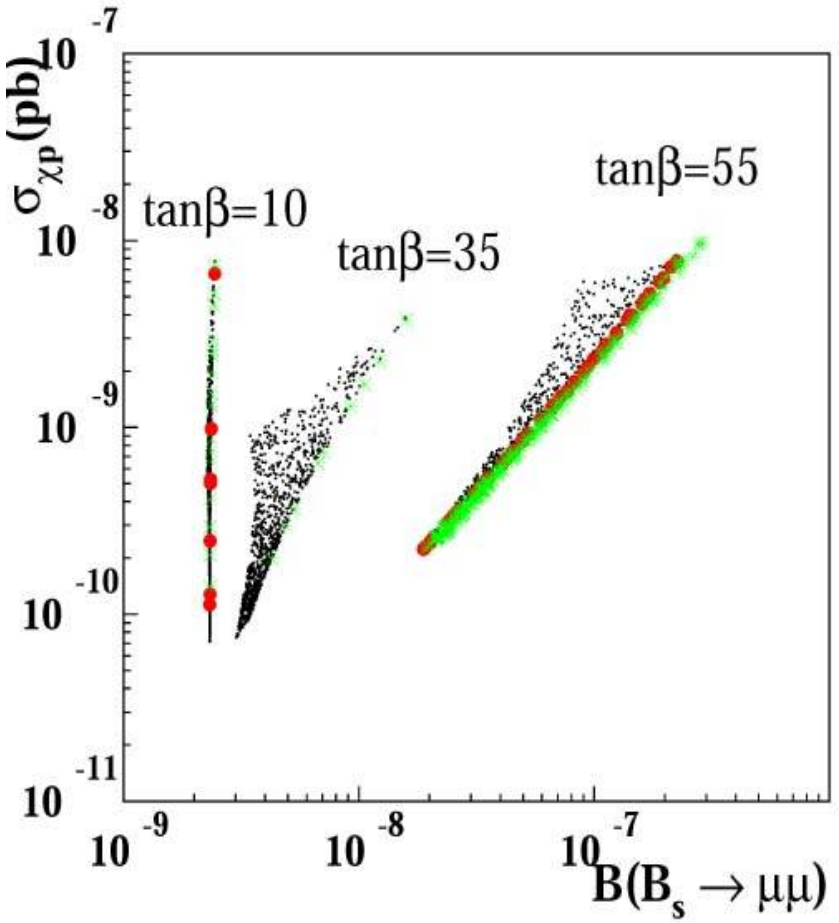
SB, P. Ko, W.Y. Song, PRL(2002); JHEP(2003) Allowed for large $\tan\beta$ if $B(B_s \to \mu^+\mu^-) \approx 1.0 \times 10^{-8}$.



# Correlation with direct detection experiments

SB, Y.G. Kim, P. Ko, JHEP(2005)

- For large $\tan\beta$ both $B_s \to \mu^+\mu^-$ and $\widetilde{\chi}N$ elastic scattering are dominated by heavy Higgs
- Strong correlation is expected
- $B_s \to \mu^+\mu^-$ constraint is much stronger than the most sensitive direct search bound



# Conclusions

- In MSSM, CDF excess of $B_s \to \mu^+\mu^-$: $\tan\beta \gtrsim 20$, correct relic density, most allowed region is sensitive to next generation direct detection experiments.
- $B_s \to \mu^+\mu^-$ plays unique role in probing and discriminating SUSY models
- mAMSB model is excluded by the CDF lower bound
- In some SUSY models $B_s \to \mu^+\mu^-$ constraint is much stronger than the DM direct search experiments