Sbottoms as probes to MSSM with Non-Holomorphic Soft Interactions

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BACKGROUND

- **The MSSM Lagrangian is usually claimed to include → all possible "soft supersymmetry breaking" terms**, i.e. terms which split the masses of the particles and their superpartners, but which do not remove the SUSY protection against large radiative corrections to scalar masses.
- $\lambda\lambda$, $\phi^*\phi$, ϕ^2, ϕ^3 are the standard gaugino mass term, non-analytic and analytic squared mass term and cubic scalar couplings.
- **Are there any more possible soft terms within MSSM?**
- In a most general framework, it has been shown that certain class of non-analytic cubic scalar couplings also qualify as soft terms, i.e. soft SUSY breaking sector is extended to include $\phi^2\phi^*$ type of interactions. [**Hall and Randall** PRL 1990, **Jack and Jones** PRD 2000; PLB 2004, **S. P. Martin** PRD 2000]

$$-\mathcal{L}'^{\phi^2\phi^*}_{soft} \supset \tilde{q}\cdot h_d^* A_u' \tilde{u}^* + \tilde{q}\cdot h_u^* A_d' \tilde{d}^* + \tilde{\ell}\cdot h_u^* A_e' \tilde{e}^* + h.c$$

Why these interactions are not generally considered

- **High Scale Suppression:**
  - ▷ In a hidden sector based SUSY breaking, Non-Holomorphic (NH) trilinear terms go as $\sim \frac{m_W^2}{M}$. M is a high scale, can be as large as Planck Scale.
- **Reappearance of divergences:**
  - ▷ If any of the chiral supermultiplets are singlets under the entire gauge group, these terms may lead to large radiative corrections, which is $\sim \frac{m_X^2}{m_s^2} ln(\frac{m_X^2}{m_s^2})$ where m_s, m_X : mass of the singlet field and of some heavy field.
    If $m_s \sim m_X$, then there is no problem. [**Hetherington, JHEP'01**]
    MSSM contains no singlet under the entire gauge group, so we can always safely include $\mathcal{L}^{\phi^2\phi^*}$ with the usual soft terms.

Phenomenological Implications

- **Structure of mass matrices**

$$M_{\tilde{b}}^2 = \begin{pmatrix} M^2_{\tilde{b}LL} & -m_b\{A_b - (\mu + A_b')\tan\beta\} \\ -\{A_b - (\mu + A_b')\tan\beta\} m_b & M^2_{\tilde{b}RR} \end{pmatrix}$$

Similarly top-squark and sleptons off-diagonal terms are $-m_t(A_t - (\mu + A_t')\cot\beta)$ and $-m_\ell(A_\ell - (\mu + A_\ell')\tan\beta)$ respectively.

- **Corrections to Bottom Yukawa Coupling**
  With NH terms, Neutralino loop and gluino loop has A_b' dependence. For the MSSM case, y_b corrections come from $\tilde{g} - \tilde{b}$ and $\tilde{\chi}^\pm - \tilde{t}$ loops.

$$y_b \approx \frac{y_{b0}}{\sqrt{2}}\Big[1 + \frac{y_t^2}{16\pi^2}\mu A_t I(m^2_{\tilde{t}_1}, m^2_{\tilde{t}_2}, \mu^2)\tan\beta + \frac{2\alpha_3}{3\pi} m_{\tilde{g}}(\mu + A_b') \\ I(m^2_{\tilde{b}_1}, m^2_{\tilde{b}_2}, m^2_{\tilde{g}})\tan\beta + \frac{y_b^2}{16\pi^2}\mu(\mu + A_b') I(m^2_{\tilde{b}_1}, m^2_{\tilde{b}_2}, \mu^2)\tan\beta\Big].$$

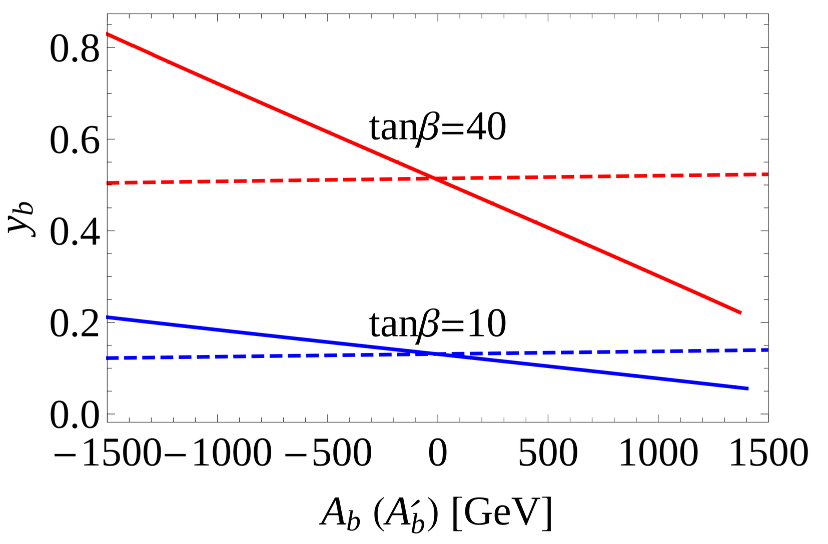

Figure 1: Variation of y_b as a function of A_b' (NHSSM with $A_b = 0$; bold lines) and A_b (MSSM; broken lines) for $\tan\beta = 10$ (in blue) and for $\tan\beta = 40$ (in red). Some of the fixed input parameters are $\mu = 200$ GeV, $M_1 = 500$ GeV and $M_2 = 1$ TeV.

Hence, y_b becomes a function of A_b' quite similar to $\tan\beta$ reliance.

- **Features of the couplings:**
  - ✓ Strength of sbottom state to a higgsino-like neutralino is always $\propto y_b$.
  - ✓ A left-like sbottom dominantly decays to $t\tilde{\chi}_1^- \implies$ small branching fraction for the $b\tilde{\chi}^0_{1,2}$ final state when $\tilde{\chi}^0_{1,2}$ are both higgsino-dominated and light.
  - ★ The presence of a non-vanishing A_b' alters the composition of the sbottom states in a nontrivial way.

RESULTS

- **Masses, mixings and decays of the lighter sbottom:**

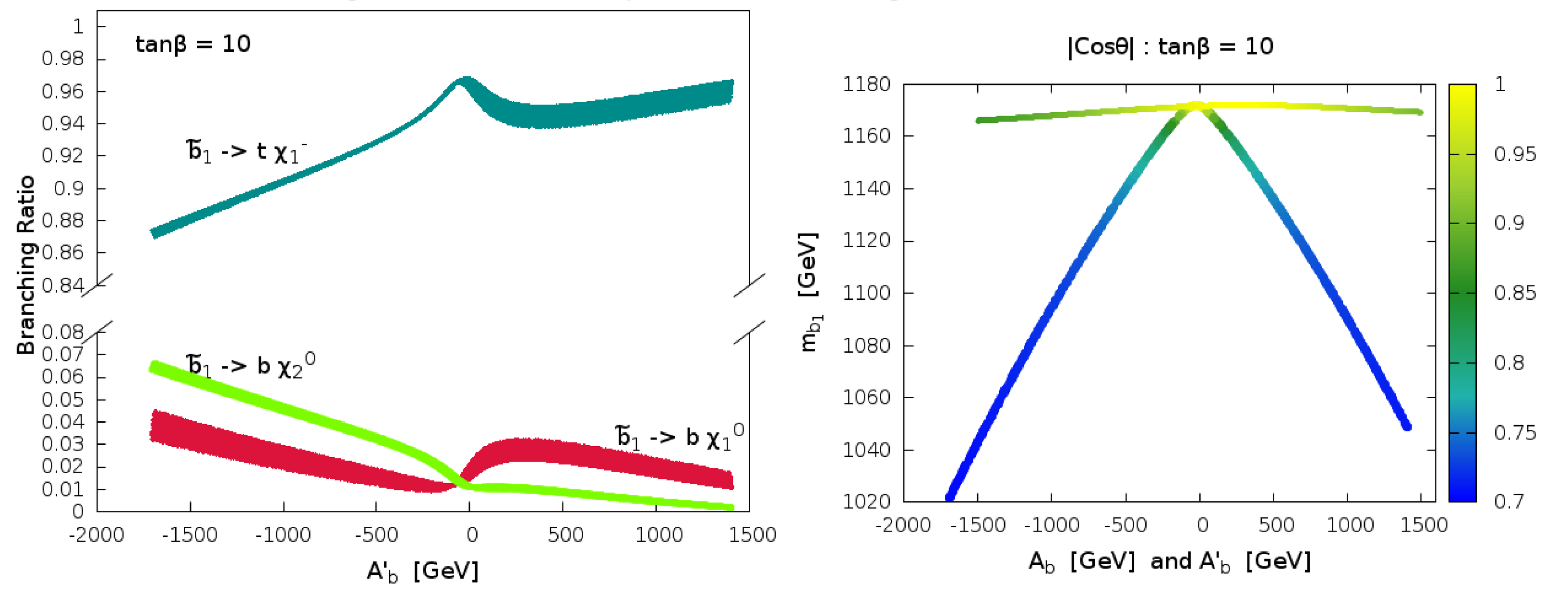

Figure 2: Branching fractions of $\tilde{b}_1$ as a function of A_b' follow the same profile of vertex strengths. The variation of $m_{\tilde{b}_1}$ as a function of A_b' (A_b) in the NHSSM (MSSM).

- ▷ Over the range of variation of A_b', $m_{\tilde{b}_1}$ could vary by $\leq$ **160** GeV.
- ▷ It is a significant variation : Corresponding number in the MSSM as a $f(A_b)$, reaches at most 20 GeV.
- ▷ The major effect, in the NHSSM, does not come directly from A_b', per se, in the off-diagonal element of the mass-squared matrix. Rather, a significant variation of y_b with A_b', induces such a big change in $m_{\tilde{b}_1}$.

Parton level yields: $pp \to \tilde{b}_1\tilde{b}_1^*$, $\tilde{b}_1 \to b\tilde{\chi}_1^0$

$$\alpha_{\tilde{b}_1} = \frac{(\sigma_{\tilde{b}_1\tilde{b}_1} \times \mathrm{BR}[\tilde{b}_1 \to b\tilde{\chi}_1^0]^2)_{NHSSM}}{(\sigma_{\tilde{b}_1\tilde{b}_1} \times \mathrm{BR}[\tilde{b}_1 \to b\tilde{\chi}_1^0]^2)_{MSSM}}$$

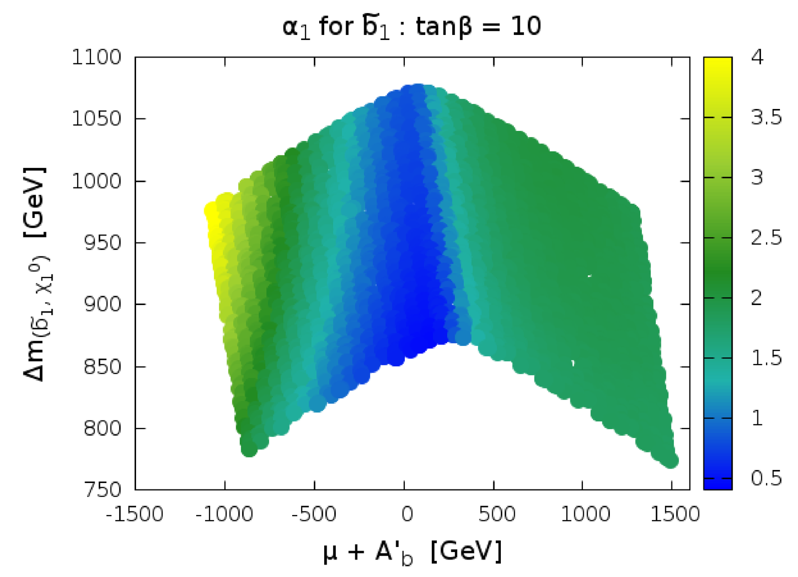

Figure 3: α = Ratio of Signal Strengths ($\sigma \times Br^2$)

- ▷ Up to a four-fold increased rates could be possible over the expected MSSM rates in the final state under consideration.
- ▷ The largest deviation is expected for $-A_b'$ for which y_b is much enhanced.
- ▷ Finds similar explanations in terms of how the effective interaction strengths vary.
- For the ranges of various parameters (like A_b' and $\tan\beta$), $m_{\tilde{b}_1}$ and $m_{\tilde{b}_2}$ may not be too different.

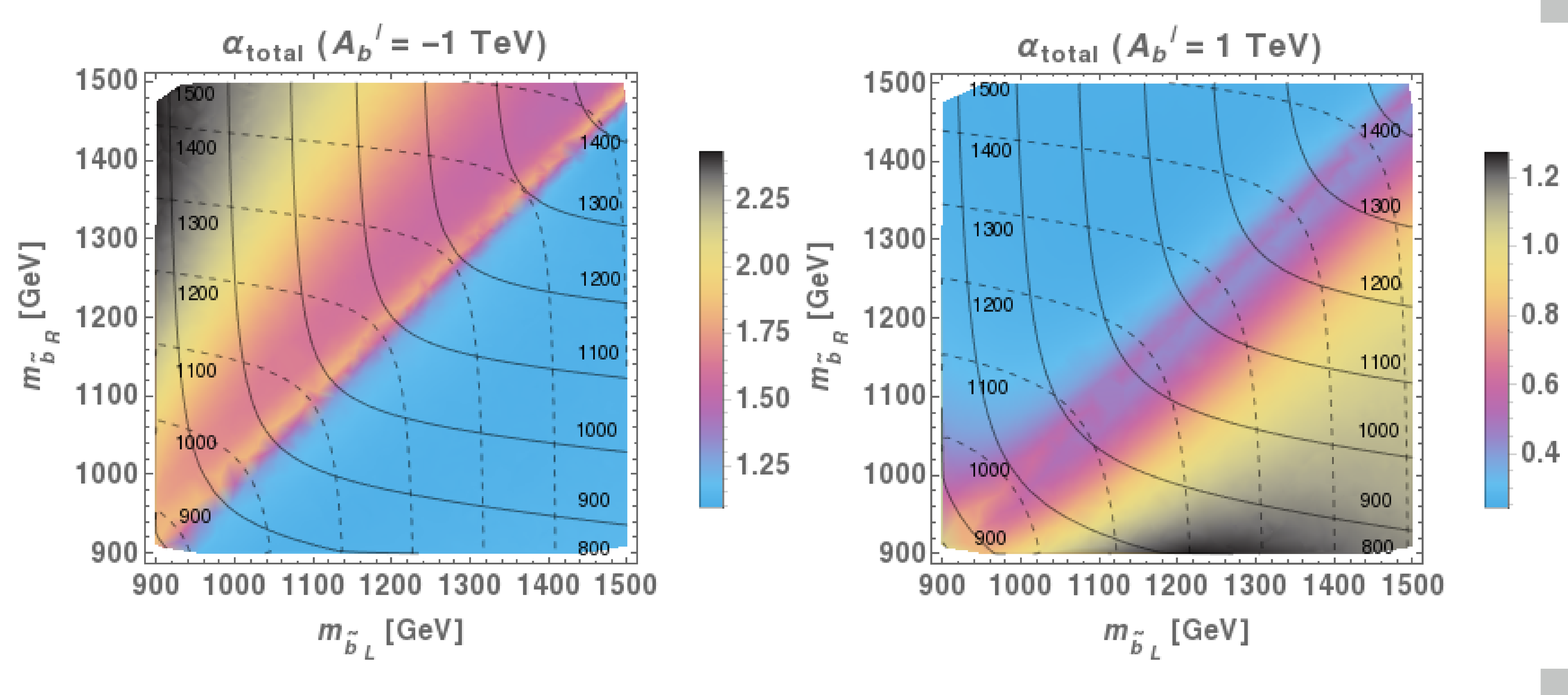

Figure 4: how the rates would compare when the masses of the sbottoms vary

α_{total} in the NHSSM and in the MSSM in the $m_{\tilde{b}_L}$ - $m_{\tilde{b}_R}$ plane for two fixed values of A_b' and for $\tan\beta = 40$. Contours of constant $m_{\tilde{b}_1}$ ($m_{\tilde{b}_2}$) are overlaid with solid (dashed) lines along the right (left) edges of the plots.

CONCLUSION

- An enhanced y_b, which is rather characteristic of the NHSSM scenario for large negative A_b' and large $\tan\beta$, could boost the yield in the $2b + \not{E}_T$ final state beyond its MSSM expectation, for similar masses of the lighter sbottom and the LSP.

In Collaboration with Utpal Chattopadhyay, Asesh K Datta, Abhaya K. Swain
Based on JHEP 1810 (2018) 202