Searching the hidden stop from sbottom decays

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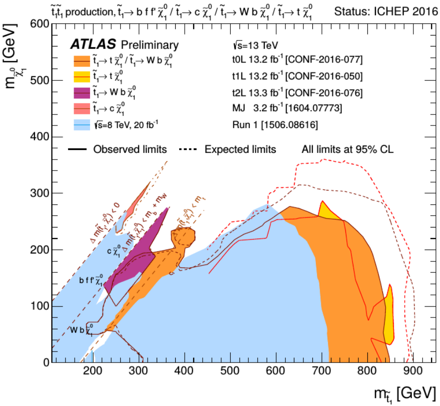
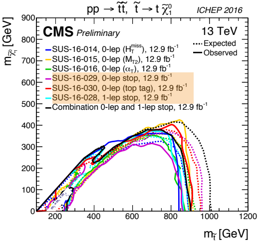
based on current work with Haipeng An and Lian-Tao Wang

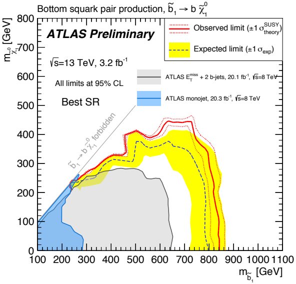
motivation

- Natural SUSY requires light stop. LHC is pushing up the bound on stop mass.
- It is possible that the stop is hiding in the compressed regions, making it hard to be discriminated from background.
  - $m_{\tilde{t}} \approx m_t + m_\chi$,
  - $m_{\tilde{t}} \approx m_W + m_b + m_\chi$,
  - $m_{\tilde{t}} \approx m_\chi$.
- The region $m_{\tilde{t}} \approx m_\chi$ has important implications on coannihilation, and the strongest bound is from the mono-jet searches ($m_{\tilde{t}} \gtrsim 323$ GeV from ATLAS with $3.2\,\mathrm{fb}^{-1}$ data at $\sqrt{s} = 13$ TeV).
- If the sbottom is not too heavy and the branching ratio of $\tilde{b} \to \tilde{t}\,W$ is significantly large, it could be ideal to search for the hidden stop from sbottom decays.
- If the branching ratio of $\tilde{b} \to b\,\chi$ is small, the bound on sbottom mass from the traditional searches in the $\boldsymbol{2b} + \boldsymbol{E}_{\mathrm{T}}^{\mathrm{miss}}$ channel is weak.

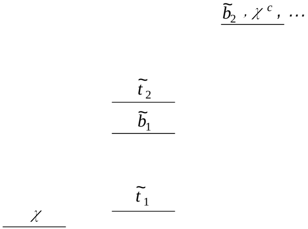
current bounds







model spectrum



- χ is (mostly) bino, $\tilde{t}_2$ is not too heavy, $\tilde{b}_1$ is (mostly) left-handed and is lighter than $\tilde{t}_2$ due to stop mass mixing.
- $\tilde{t}_1$ is preferably mostly righthanded so that the mass gap between $\tilde{b}_1$ and $\tilde{t}_1$ can be large.
- $\tilde{b}_1$ has two decay channels, $\tilde{b} \to \tilde{t}\, W$ and $\tilde{b} \to b\,\chi$.
- $\tilde{t}_1$ has two decay channels, $\tilde{t} \to bW^{*}\chi \to bl\nu\chi/bjj\chi$ and $\tilde{t} \to c\chi$.

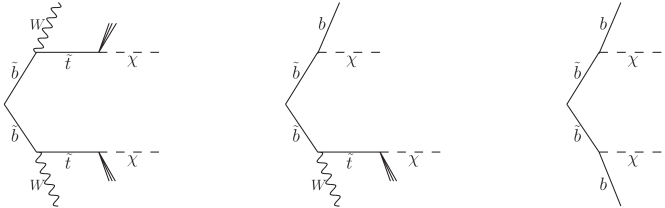
sbottom decay

- Two decay channels, $\tilde{b} \to \tilde{t}\, W$ and $\tilde{b} \to b\,\chi$.
- In viable regions of the model parameter space, $\tilde{b} \to \tilde{t}\, W$ tends to dominate. (Good for us!)
  - $\Gamma(\tilde{b} \to \tilde{t}\, W)$ is enhanced by a factor of $m^2_{\tilde{b}}/m^2_W$ due to the longitudinal contribution,
  - large stop mixing is preferred by the Higgs mass (at least in MSSM),
  - $\tilde{b} \to b\,\chi$ is suppressed by the small hypercharge of $\tilde{b}_L$ $(-1/6)$,
  - the stop mixing term need to be tuned very small for $\Gamma(\tilde{b} \to \tilde{t}\, W)$ and $\Gamma(\tilde{b} \to b\,\chi)$ to be comparable.

$$\frac{\Gamma(\tilde{b} \to \tilde{t}\, W)}{\Gamma(\tilde{b} \to b\,\chi)} \approx 150 \frac{X_t^2}{m^2_{\tilde{b}}} \,.$$

- Nevertheless, we will treat the branching ratio as a free parameter in order to cover as much parameter space as possible.

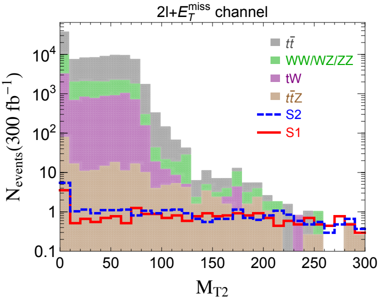
signal



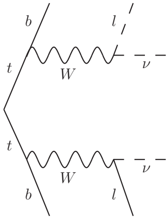
- A sbottom pair has 3 ways to decay.
- We consider searches in 3 channels with final states
  - $2\ell + E_T^{miss}$, best channel if $\Gamma(\tilde{b} \to \tilde{t}\, W)$ dominates;
  - $1b1\ell + E_T^{miss}$, best channel if $\Gamma(\tilde{b} \to \tilde{t}\, W)$ and $\Gamma(\tilde{b} \to b\, \chi)$ are comparable;
  - $2b + E_T^{miss}$, best channel if $\Gamma(\tilde{b} \to b\, \chi)$ dominates (conventional channel for sbottom search).

$2\ell + E_{\mathrm{T}}^{\mathrm{miss}}$

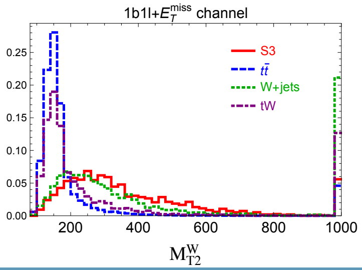
- This channel has already been used for the searches of electroweakinos and sleptons.
- The dominant backgrounds ($t\bar{t}$, WW, tW) contain two Ws both decaying leptonically, with $E_{\mathrm{T}}^{\mathrm{miss}}$ mostly coming from the two neutrinos.
- The variable M_{T2} can very efficiently remove this type of background.



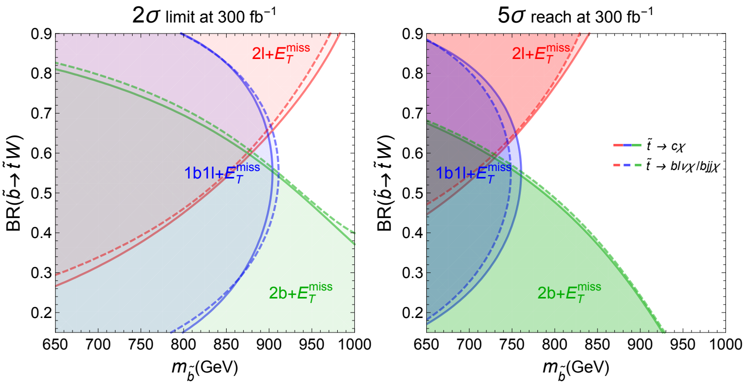
$1b1\ell + E_T^{\mathrm{miss}}$



- This channel is very similar to the semi-leptonic channel of the conventional stop search.
- The dominate background is dileptonic $t\bar{t}$ with one lepton not reconstructed.
- The M_{T2}^{W} variable helps reducing this background. [JHEP 1207 (2012) 110, Bai, Cheng, Gallicchio, JG]

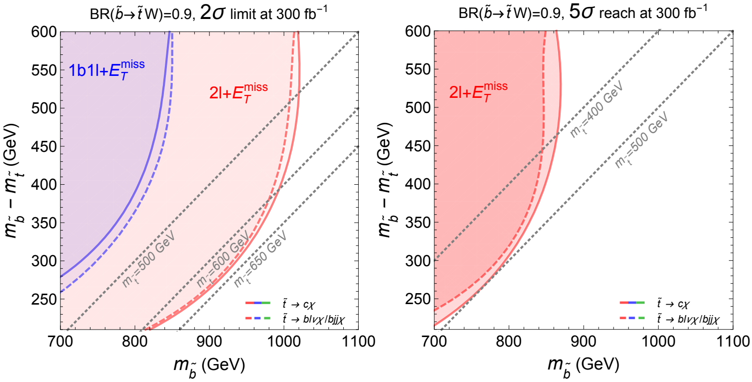


results



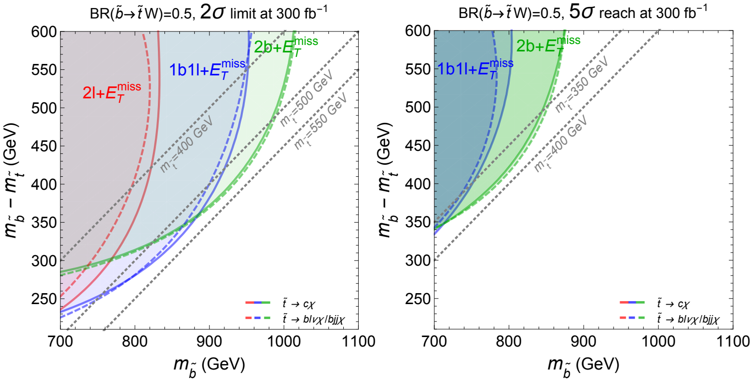
- $m_{\tilde{b}} - m_{\tilde{t}} = 400\,\text{GeV}$, $m_{\tilde{t}} - m_{\chi} = 30\,\text{GeV}$, 13 TeV LHC with $300\,\text{fb}^{-1}$ data.

results



- $\mathrm{BR}(\tilde{b} \to \tilde{t}W) = 0.9$, $m_{\tilde{t}} - m_{\chi} = 30\,\mathrm{GeV}$, 13 TeV LHC with $300\,\mathrm{fb}^{-1}$ data.

results



- $\mathrm{BR}(\tilde{b}\to\tilde{t}W)=0.5$, $m_{\tilde{t}}-m_{\chi}=30\,\mathrm{GeV}$, 13 TeV LHC with $300\,\mathrm{fb}^{-1}$ data.
- The $2b+E_{\mathrm{T}}^{\mathrm{miss}}$ channel does not directly constrain $m_{\tilde{t}}$.

conclusion

- A light stop with mass almost degenerate with the lightest neutralino has important implications on naturalness and dark matter relic abundance, and is hard to search at colliders.
- We study the potential of searching for such stop particles at the LHC from sbottom decays, focusing on two channels with final states $\boldsymbol{2\ell + E_{\mathrm{T}}^{\mathrm{miss}}}$ and $\boldsymbol{1b1\ell + E_{\mathrm{T}}^{\mathrm{miss}}}$.
- If $m_{\tilde{b}} \lesssim 1$ TeV and the decay $\tilde{b} \to \tilde{t}\,W$ has a significant branching ratio, a stop almost degenerate with neutralino can be excluded up to about 500–600 GeV at the 13 TeV LHC with $300\,\mathrm{fb}^{-1}$ data. (The mono-jet search needs $\sim 3000\,\mathrm{fb}^{-1}$ to reach the same bound.)
- The searches we proposed are complementary to the conventional searches and other searches.
- Our goal is to convince the experimentalists to do the searches we proposed, which are very easy to implement.

backup slides

sbottom decay

- The decay width are given by

$$\Gamma(\tilde{b}_1 \to \tilde{t}_1 W) = \frac{g_2^2 \sin^2\theta_t \cos^2\theta_b}{32\pi} \frac{[(m_{\tilde{b}}^2 - (m_{\tilde{t}} + m_W)^2)(m_{\tilde{b}}^2 - (m_{\tilde{t}} - m_W)^2)]^{3/2}}{m_W^2 m_{\tilde{b}}^3} ,$$

$$\Gamma(\tilde{b}_1 \to b\,\chi) = \frac{g_1^2}{32\pi} \frac{(m_{\tilde{b}}^2 - m_\chi^2)^2}{m_{\tilde{b}}^3} 4 \left[\left(-\frac{1}{3}\right)^2 \sin^2\theta_b + \left(\frac{1}{6}\right)^2 \cos^2\theta_b \right] ,$$

- where the mixing angles are defined as

$$\begin{pmatrix} \tilde{t}_1 \\ \tilde{t}_2 \end{pmatrix} = \begin{pmatrix} \cos\theta_t & \sin\theta_t \\ -\sin\theta_t & \cos\theta_t \end{pmatrix} \begin{pmatrix} \tilde{t}_R \\ \tilde{t}_L \end{pmatrix} , \qquad \begin{pmatrix} \tilde{b}_1 \\ \tilde{b}_2 \end{pmatrix} = \begin{pmatrix} \cos\theta_b & \sin\theta_b \\ -\sin\theta_b & \cos\theta_b \end{pmatrix} \begin{pmatrix} \tilde{b}_L \\ \tilde{b}_R \end{pmatrix} .$$

sbottom decay

- The stop mass matrix is

$$M^2_{\tilde{t}} = \begin{pmatrix} m^2_{Q_3} + m^2_t + \Delta_{\tilde{u}L} & m_t X_t \\ m_t X_t & m^2_{u_3} + m^2_t + \Delta_{\tilde{u}R} \end{pmatrix} ,$$

where $X_t = A_t - \mu \cot\beta$.

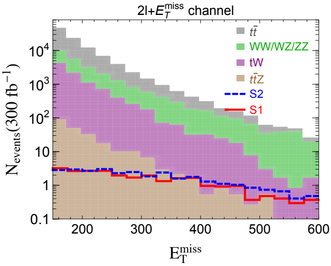
- The decay widths are given by

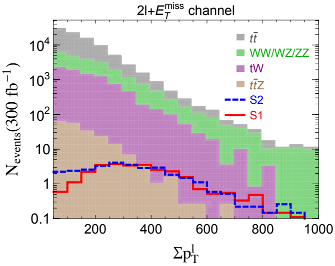
$$\Gamma(\tilde{b}_1 \to \tilde{t}_1\, W) \approx \frac{X_t^2}{16\pi m_{\tilde{b}}} , \qquad \Gamma(\tilde{b}_1 \to b\,\chi) \approx \frac{\alpha_{\rm em} m_{\tilde{b}}}{72\cos^2\theta_W} ,$$

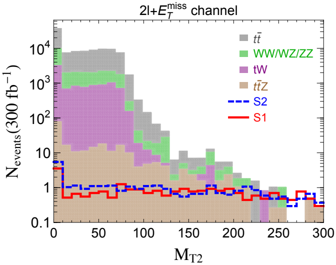
$$\frac{\Gamma(\tilde{b}_1 \to \tilde{t}_1\, W)}{\Gamma(\tilde{b}_1 \to b\,\chi)} \approx 150\,\frac{X_t^2}{m^2_{\tilde{b}}} .$$

- $\Gamma(\tilde{b}_1 \to \tilde{t}_1\, W)$ dominates unless X_t is very small.

$2\ell + E_T^{miss}$ channel ($m_{\tilde{b}} = 1000$ GeV, $m_{\tilde{t}} = 600$ GeV, $m_\chi = 570$ GeV)







$1b1\ell + E_T^{miss}$ channel ($m_{\tilde{b}} = 900$ GeV, $m_{\tilde{t}} = 500$ GeV, $m_\chi = 470$ GeV)