PRAMANA — journal of physics
© Indian Academy of Sciences
Vol. 62, No. 3
March 2004
pp. 659–662

Study of $\tilde{t}$ and $\tilde{b}$ at LHC

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Abstract. In supersymmetric models a gluino can decay into $tb\tilde{\chi}_1^{\pm}$ through a stop or a sbottom. The decay chain produces an edge structure in the m_{tb} distribution. Monte Carlo simulation studies show that the end-point and the edge height would be measured at the CERN LHC by using a sideband subtraction technique. The stop and sbottom masses as well as their decay branching ratios are constrained by the measurement. We study interpretations of the measurement.

The minimal supersymmetric standard model (MSSM) is one of the promising extensions of the standard model. The model requires superpartners of the standard model particles (sparticles), and the large hadron collider (LHC) at CERN might confirm the existence of the new particles [1]. Among the sparticles the third generation squarks, stops ($\tilde{t}_i$) and sbottoms ($\tilde{b}_i$) ($i = 1, 2$), get special imprints from physics at the very high energy scale. Even if the scalar masses are universal at a high energy scale, the third generation squarks are much lighter than the first and second generation squarks due to the Yukawa running effect. On the other hand, some SUSY breaking models have non-universal boundary conditions for the third generation mass parameters at the GUT scale. Measurement of the sparticle masses provides a way to probe the origin of the SUSY breaking in nature.

At the LHC, we may be able to access the nature of the stop and sbottom provided that they are lighter than the gluino ($\tilde{g}$). In that case, they copiously arise from the gluino decay. The relevant decay modes for $\tilde{b}_i$ ($i = 1, 2$), $\tilde{t}_1$, to charginos $\tilde{\chi}_j^{\pm}$ ($j = 1, 2$) or neutralinos $\tilde{\chi}_j^0$ ($j = 1, 2, 3, 4$) are (indices to distinguish a particle and its anti-particle is suppressed unless otherwise stated): $(\mathrm{I})_j$ $\tilde{g} \to b\tilde{b}_1 \to bb\tilde{\chi}_j^0$ ($\to bbl^+l^-\tilde{\chi}_1^0$), $(\mathrm{II})_j$ $\tilde{g} \to t\tilde{t}_1 \to tt\tilde{\chi}_j^0$, $(\mathrm{III})_j$ $\tilde{g} \to t\tilde{t}_1 \to tb\tilde{\chi}_j^{\pm}$, $(\mathrm{III})_{ij}$ $\tilde{g} \to b\tilde{b}_i \to bW\tilde{t}_1 \to bbW\tilde{\chi}_j^{\pm}$, $(\mathrm{IV})_{ij}$ $\tilde{g} \to b\tilde{b}_i \to tb\tilde{\chi}_j^{\pm}$. In previous literatures [1,2], the lighter sbottom $\tilde{b}_1$ is often studied through the mode $(\mathrm{I})_2$, namely the $bb\tilde{\chi}_2^0 \to bbl^+l^-\tilde{\chi}_1^0$ channel. This mode is important when the second lightest neutralino $\tilde{\chi}_2^0$ has substantial branching ratios into leptons.

Recently we proposed to measure the edge position of the m_{tb} distribution for the modes $(\mathrm{III})_1$ and $(\mathrm{IV})_{11}$, where m_{tb} is the invariant mass of a top-bottom (tb) system [3,4]. We focused on the reconstruction of hadronic decays of the top quark, because the m_{tb} distribution of the decay makes a clear 'edge' in this case. The parton level m_{tb} distributions for the modes $(\mathrm{III})_j$ and $(\mathrm{IV})_{ij}$ are expressed as functions of $m_{\tilde{g}}$, $m_{\tilde{t}_1}$, $m_{\tilde{b}_i}$, and the chargino mass $m_{\tilde{\chi}_j^{\pm}}$: $\mathrm{d}\Gamma/\mathrm{d}m_{tb} \propto m_{tb}$.

The events containing tb are selected by requiring the following conditions in addition to the standard SUSY cuts: (1) two and only two b jets; (2) jet pairs consistent with a hadronic W boson decay, $|m_{jj} - m_W| < 15$ GeV; (3) the invariant mass of the jet pair and one of the b-jets, m_{bjj}, satisfies $|m_{bjj} - m_t| < 30$ GeV. The events after the selection contain misreconstructed events. We use a W side-band method to estimate the background distribution due to misreconstructed events. Monte Carlo simulations show that the distribution of the signal modes (III) and (IV) after subtracting the background is very close to the parton level distribution. The distribution is then fitted by a simple fitting function described with the end point $M_{tb}^{\rm fit}$, the edge height h per Δm bin, and a smearing parameter.

The edge position (end point) of the m_{tb} distribution M_{tb} for the modes $({\rm III})_1$ and $({\rm IV})_{11}$ are sometimes very close. When they are experimentally indistinguishable, it is convenient to define a weighted mean of the end points;

$$M_{tb}^{\rm w} = \frac{{\rm Br(III)}M_{tb}({\rm III})_1 + {\rm Br(IV)}_{11}M_{tb}({\rm IV})_{11}}{{\rm Br(III)} + {\rm Br(IV)}_{11}}, \tag{1}$$

where ${\rm Br(III)} \equiv {\rm Br(III)}_1 + {\rm Br(III)}_{11} + {\rm Br(III)}_{21}$.

The relation between $M_{tb}^{\rm w}$ and $M_{tb}^{\rm fit}$ for several model points are shown in figure 1(left). Here we generated 3×10^6 SUSY events for each model point. The fitted value $M_{tb}^{\rm fit}$ increases linearly with the weighted end-point $M_{tb}^{\rm w}$. The fitted value $M_{tb}^{\rm fit}$ tends to be lower than $M_{tb}^{\rm w}$, which is the effect of particles missed outside the jet cones.

We now discuss the relation between the edge height h and the number of reconstructed tb events. The number of the reconstructed 'edge' events $N_{\rm edge}$ arising from the decay chains (III) and (IV) may be estimated from $M_{tb}^{\rm fit}$, h per the bin size Δm as follows:

$$N_{\rm edge} \sim N_{\rm fit} = \frac{h}{2}\left(\frac{m_t}{M_{tb}^{\rm fit}} + 1\right) \times \frac{M_{tb}^{\rm fit} - m_t}{\Delta m}. \tag{2}$$

This formula is obtained by assuming the parton level distribution. The consistency between $N_{\rm edge} \sim N_{\rm fit}$ is checked by using the generator information in ref. [4].

In the mSUGRA model, the decay modes which involve W bosons (modes (II), (III) and (IV)) often dominate the gluino decays to bbX. In that case the numbers of events are approximately given as

$$\begin{aligned} N_{\rm fit} &\sim \epsilon_{tb}{\rm Br(edge)}\left[2N(\tilde{g}\tilde{g})\left(1 - {\rm Br}(\tilde{g} \to bbX)\right) + N(\tilde{g}\tilde{q}) + N(\tilde{g}\tilde{q}^*)\right], \\ N_{\rm all} &\sim \epsilon_{tb}{\rm Br}(\tilde{g} \to bbX)\left[2N(\tilde{g}\tilde{g})\left(1 - {\rm Br}(\tilde{g} \to bbX)\right) + N(\tilde{g}\tilde{q}) + N(\tilde{g}\tilde{q}^*)\right], \end{aligned} \tag{3}$$

where ${\rm Br(edge)} \equiv {\rm Br(III)}_1 + {\rm Br(III)}_{11} + {\rm Br(III)}_{21} + {\rm Br(IV)}_{11}$ and ${\rm Br}(\tilde{g} \to bbX)$ is the branching ratio of the gluino decaying into stop or sbottom, thus having two bottom quarks in the final state. Therefore ${\rm Br(edge)}/{\rm Br}(\tilde{g} \to bbX) \sim N_{\rm fit}/N_{\rm all}$ is expected.

In figure 1(right), we plot the ratio $N_{\rm edge}/N_{\rm all}$ as a function of ${\rm Br(edge)}/{\rm Br}(\tilde{g} \to bbX)$. The points tend to be on the expected line $N_{\rm edge}/N_{\rm all} = {\rm Br(edge)}/{\rm Br}(\tilde{g} \to bbX)$. Some points in the plots are away from the line. The point 'C' is off because the chargino has large branching ratios into leptons. At the point 'T1', the stop

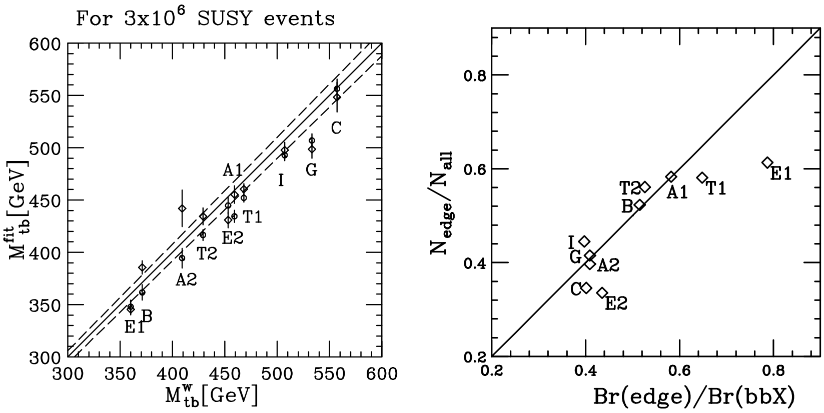

Figure 1. Left: Relation between M_{tb}^{w} and M_{tb}^{fit} for the sample points. The solid line corresponds to $M_{tb}^{\mathrm{w}} = M_{tb}^{\mathrm{fit}}$. Bars with a diamond and a circle correspond to PYTHIA and HERWIG samples, respectively. Right: Relation between $N_{\mathrm{edge}}/N_{\mathrm{all}}$ and $\mathrm{Br(edge)}/\mathrm{Br}(\tilde{g} \to bbX)$.

mass is significantly light and $\tilde{t}_1\tilde{t}_1^*$ productions contributes to N_{all}. The points 'E1' and 'E2' are significantly off because the first and the second generation squarks dominantly decay into the gluino, and the events containing two bottom quarks are not dominant [4a]. These exceptional cases will be easily distinguished by looking into the data from LHC or a proposed $O(1)$ TeV linear collider.

The M_{tb}^{fit} contains information on $\tilde{t}_1$ as can be seen in eq. (1). However, the definition also depends on the electroweak SUSY parameters and the SUSY parameters in the sbottom sector. Some model assumptions or inputs from the other measurements are necessary. In mSUGRA, the M_{tb} and h measurement constrain the trilinear coupling at GUT scale A_0. $\Delta A_0 \sim 50$ GeV for $m_{\tilde{g}} \sim m_{\tilde{q}} \sim 700$ GeV are found. On the other hand, if a e^+e^- collider at O (1 TeV) is built, the measurements of the sparticle productions at the LC would constrain the electroweak SUSY parameters precisely. In that case the sbottom and stop studies at LHC would be significantly improved so that stop and sbottom masses and their mixing angles are measured [5].

Acknowledgements

I thank J Hisano and K Kawawagoe for collaboration, and the ATLAS collaboration members for useful discussion. We have made use of the physics analysis framework and tools which are the result of collaboration-wide efforts. This work is supported in part by the grant-in-aid for Science Research, Ministry of Education, Science and Culture, Japan (No. 13135297 and No. 14046225 for JH, No. 11207101 for KK, and Nos 14540260 and 14046210 for MMN).

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