Possible Excess in Charged Current Events with High-$Q^2$ at HERA from Stop and Sbottom Production

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Abstract

We investigate a production process $e^+ p \rightarrow \tilde{t} X \rightarrow \tilde{b} W^+ X$ at HERA, where we consider a decay mode $\tilde{b} \rightarrow \bar{\nu}_e d$ of the sbottom in the framework of an R-parity breaking supersymmetric standard model. Both processes of the stop production $e^+ d \rightarrow \tilde{t}$ and the sbottom decay $\tilde{b} \rightarrow \bar{\nu}_e d$ are originated from an R-parity breaking superpotential $\lambda'_{131} \hat{L}_1 \hat{Q}_3 \hat{D}_c$. One of signatures of the process should be a large missing transverse momentum plus multijet events corresponding to hadronic decays of the $W$. It is shown that the signal could appear as an event excess in the charged current (CC) processes $e^+ p \rightarrow \nu X$ with the high $Q^2$ at HERA. We compare expected event distributions with the CC data recently reported by the H1 and ZEUS groups at HERA. Methods for extracting the signal from the standard CC processes are also discussed.
1 Introduction

Recently reported event excess at the high $Q^2$ region in the deep inelastic (DIS) process $e^+p \rightarrow e^+qX$ has very much excited theorists. Among its theoretical considerations proposed so far the supersymmetric (SUSY) model based approach seems to be an appealing possibility. It could be interpreted by the scalar top (stop) production $e^+p \rightarrow tX \rightarrow e^+dX$ in SUSY models with the R-parity breaking (RB) interactions proportional to $\lambda_{131}$. The excess events seem to be broadly distributed around $200\text{GeV} \sim 250\text{GeV}$ in the mass ($M = \sqrt{x_s}$, where $x$ is the Bjorken parameter).

In a previous paper we have shown that it could be simulated by our specific scenario if we consider almost degenerate two mass eigenstates $t_1$ and $t_2$ of the stops with masses $m_{t_1} \simeq 200\text{GeV}$ and $m_{t_2} \simeq 230\text{GeV}$.

D0 and CDF groups have recently obtained preliminary bounds on a leptoquark mass as $M_{LQ} > 194\text{GeV}$ and $210\text{GeV}$ for $\text{Br}(LQ \rightarrow e^+q) = 1.0$, respectively. These new results suggest that the stop (or leptoquark) with $\text{Br}(l \rightarrow e^+d) = 1.0$ and $m_{\tilde{t}} \sim 200\text{GeV}$ has been excluded. Consequently stops could decay into not only $e^+d$ but also $b\tilde{W}_1$ or $\tilde{b}W$ via R-parity conserving interactions as far as there exists a chargino $\tilde{W}_1$ or a scalar bottom ($\tilde{b}$ottom) lighter than the stops. So we can reconcile the interpretation of the high $Q^2$ anomaly at HERA data in terms of stop with the Tevatron bound provided that $\text{Br}(l \rightarrow e^+d) = 1\text{, } \text{Br}(l \rightarrow b\tilde{W}_1 \text{ or } \tilde{b}W) \lesssim 0.8$.

Taking into account such situation we are naturally led to examine the processes (1) $e^+p \rightarrow b\tilde{W}_1X$ or (2) $e^+p \rightarrow b\tilde{W}X$. They will presumably give us unique experimental signatures of our scenario. We have shown that a possible typical signature of (1) would be a high $P_T$ charged lepton plus jet(s) with a large missing transverse momentum $P_T$, i.e., one of the signals to be detected at HERA is characterized by the high $P_T$ spectrum of muons. Note that the lightest neutralino $\tilde{Z}_1$ and $\tilde{b}$ possibly decay into R-even particles via only non-zero RB coupling $\lambda'_{131}$. Altarelli et al. have pointed out that another possible signature of (1) could be a large $P_T$ plus mutijets, where the chargino decays into a neutrino plus quarks. Moreover, they have shown that such a signal could be observed as an event excess at the high $Q^2$ region in the charged current (CC) DIS, $e^+p \rightarrow \nu qX$, for a specific sparticle mass spectrum $m_{\tilde{e}} \lesssim 70\text{GeV}$ and $m_{\tilde{W}_1} \approx 180\text{GeV}$.

In the present letter we investigate the process (2) mentioned above, i.e., we are concerned with a case where the sbottom $\tilde{b}$ is lighter than the stops and has a mass smaller than about $120\text{GeV}$. Here we assume sufficiently heavy chargino $\tilde{W}_1 (\gtrsim 200\text{GeV})$ and neutralino $\tilde{Z}_1 (\gtrsim 100\text{GeV})$ for simplicity. In this case the stops cannot decay into $b\tilde{W}_1$ and the sbottom can only decay into $\tilde{\nu}_\ell d$ via the RB coupling $\lambda'_{131}$. First we will show that such a light sbottom has not been excluded from the present experiments. One of characteristic signatures of the process (2) would be a large missing transverse momentum plus mutijets corresponding to hadronic decays of the $W$. It could be observed as an event excess at the high $Q^2$ region in the CC DIS. We will compare expected event distributions with the CC data recently obtained by the H1 and ZEUS groups at HERA.

* Another interesting possibility for "strange stop" scenario, $e^+ s \rightarrow \tilde{t}_L$, with non-zero coupling $\lambda_{132}$ is discussed in detail by J. Ellis et al.
2 Model

We are based on the minimal SUSY standard model (MSSM) with an RB superpotential \cite{18};
\[ W_R = \lambda'_t \tilde{L}_1 \tilde{Q}_3 \tilde{D}_1, \]  
where 1 and 3 are generation indices. We can immediately obtain Yukawa-type interactions from the superpotential \cite{19} ,
\[ L = \lambda'_1 (\tilde{t}_L d P_L e + \tilde{e}_L d P_L t + d_R \tilde{e} P_L \nu_e - \tilde{e}_d P_L b - d_R \tilde{e} P_L b) + h.c., \]  
where \( P_L \) reads the left handed chiral projection operator. The first term in the Lagrangian (2) will be most suitable for the \( ep \) collider experiments at HERA because the stop \( \tilde{t}_L \) will be produced in the s-channel for \( e^+ - d \) sub-processes. The fourth term will contribute to the sbottom decay, \( \tilde{b}_L \rightarrow \bar{\nu}_e d \). Note that the stop \( \tilde{t}_L \) cannot couple to any neutrinos via the RB interactions. That is, no excess is expected in the standard CC events \( ep \rightarrow \nu q X \) in the squark scenarios. As has been pointed out, however, the CC like events could be expected if we consider some appropriate decay chains to the stops (see \[13\] and later).

Here we pay attention to a fact that the stops [sbottoms] \( (\tilde{t}_L, \tilde{t}_R) [\tilde{b}_L, \tilde{b}_R] \) are naturally mixed each other \cite{19} due to a large Yukawa coupling of their partner quark and the mass eigenstates \( (\tilde{t}_1, \tilde{t}_2) [(\tilde{b}_1, \tilde{b}_2)] \) are parametrized by a mixing angle \( \theta_t [\theta_b] \),
\[ \tilde{t}_L = \tilde{t}_1 \cos \theta_t - \tilde{t}_2 \sin \theta_t, \]  
\[ \tilde{b}_L = \tilde{b}_1 \cos \theta_b - \tilde{b}_2 \sin \theta_b. \]  
The interaction Lagrangian (3) can easily be rewritten in terms of the mass eigenstates. In particular, we should note that both stops \( \tilde{t}_1 \) and \( \tilde{t}_2 \) could be produced by the eq scattering through
\[ L_{t\bar{t}d} = \lambda'_1 (\cos \theta_t \tilde{t}_1 \tilde{d} P_L e - \sin \theta_t \tilde{t}_2 \tilde{d} P_L e) + h.c.. \]  

The most stringent upper bound on the coupling constant \( \lambda'_{t1} \) comes from the atomic parity violation (APV) experiments \cite{18, 20, 21, 22, 23, 24}. In the following discussion we adopt rather modest limit, \( \lambda'_{t1} \lesssim 0.1 \). We will come back to this point later.

3 Light sbottom scenario

Interestingly, in the MSSM there exists a theoretical upper bound on the mass of the lighter sbottom \( \tilde{b}_1 \). Since the left handed stop \( \tilde{t}_L \) and sbottom \( \tilde{b}_L \) form a \( SU(2) \) doublet, their masses include the same contribution from a soft scalar breaking mass \( \tilde{m}_{Q_3} \),
\[ m_{\tilde{t}_L}^2 = \tilde{m}_{Q_3}^2 + m_t^2 + m_{\tilde{b}_L}^2 \cos 2\beta \left( \frac{1}{2} - e_u \sin^2 \theta_W \right) \]  
\[ = \cos^2 \theta_t m_{\tilde{t}_1}^2 + \sin^2 \theta_t m_{\tilde{t}_2}^2, \]  
\[ m_{\tilde{b}_L}^2 = \tilde{m}_{Q_3}^2 + m_t^2 + m_{\tilde{b}_L}^2 \cos 2\beta \left( \frac{1}{2} - e_d \sin^2 \theta_W \right) \]  
\[ = \cos^2 \theta_b m_{\tilde{b}_1}^2 + \sin^2 \theta_b m_{\tilde{b}_2}^2, \]
where the last terms in (6) and (8) stand for the D-term contributions. Combining formulae (6) through (9), we obtain an upper bound on the sbottom mass $m_{\tilde{b}_1}^2$, as,

$$m_{\tilde{b}_1}^2 \leq \cos^2 \theta_t m_{\tilde{t}_1}^2 + \sin^2 \theta_t m_{\tilde{t}_2}^2 - m_{\tilde{t}_1}^2 + m_{\tilde{b}_1}^2 - m_{\tilde{W}}^2 \cos 2\beta$$  

(10)

$$\leq m_{\tilde{t}_2}^2 - m_{\tilde{t}_1}^2 + m_{\tilde{b}_1}^2 - m_{\tilde{W}}^2 \cos 2\beta.$$  

(11)

Thus the lighter sbottom $\tilde{b}_1$ cannot be heavy for relatively light $\tilde{t}_2$. For example, $\tilde{b}_1$ will be lighter than $\tilde{t}_1$ ($m_{\tilde{t}_1} \approx 200\text{GeV}$) for $m_{\tilde{t}_2} \lesssim 250\text{GeV}$ even in the extreme case of $\tan \beta = \infty$ ($\cos 2\beta = -1$).

Next we examine the decay modes of the stop. In the MSSM, the stop could be lighter than the other squarks in the first and second generations and the gluino. It can decay into various final states: $\tilde{t} \to t \tilde{Z}_k$ (a), $b \tilde{W}_i$ (b), $W b$ (c), $b \ell \tilde{\nu}$ (d), $b \nu \ell$ (e), $b W \tilde{Z}_k$ (f), $b f \tilde{f} \tilde{Z}_k$ (g), $c \tilde{Z}_i$ (h) and $e d$ (i), where $\tilde{Z}_k$ ($k = 1 \sim 4$), $W_i (i = 1, 2)$, $\tilde{\nu}$ and $\ell$, respectively, denote the neutralino, the chargino, the sneutrino and the charged slepton. (a) $\sim$ (h) are the $R$-parity conserving decay modes, while (i) is only realized through the RB couplings (8). If we consider the RB coupling with $\lambda'_{131} > 0.01$, the decay modes (d) to (h) are negligible due to their large power of a arising from multiparticle final state or one loop contribution. Moreover, in the present case ($m_{\tilde{t}_1} \approx 200\text{GeV}$) the mode (a) will kinematically be suppressed. Then only two body decay modes (b), (c) and (i) are left for our purpose.

Here we assume the stops can decay through the modes (c) and (i). In other words, we consider sufficiently heavy charginos, $m_{\tilde{W}_i} > m_{\tilde{t}_2} - m_b \gtrsim 220\text{GeV}$, and a light sbottom, $m_{\tilde{b}_1} < m_{\tilde{t}_1} - m_W \lesssim 120\text{GeV}$. The former condition can be easily realized if we take such large soft breaking gaugino mass as $M_2 \gtrsim 250\text{GeV}$ (and $|\mu| \gtrsim 100\text{GeV}$). As a result of this assumption, the lightest neutralino $\tilde{\chi}_1$ becomes inevitably heavier than about $110\text{GeV}$ because $m_{\tilde{\chi}_1} \approx 0.5m_{\tilde{W}_1}$ in the MSSM. Consequently, an $R$-parity conserving decay mode of the light sbottom, $\tilde{b}_1 \to b \tilde{\chi}_1$, is almost kinematically forbidden. We can naturally consider $\tilde{t}_1 \to \tilde{b}_1 W^+$ as the dominant decay mode. It should be noted that the assumption of relatively light sbottom is consistent with the theoretical upper bound on mass (2) for the light $\tilde{t}_2$ like $m_{\tilde{t}_2} \approx 230\text{GeV}$.

Decay widths of $\tilde{t}_1 \to \tilde{b}_1 W^+$ can be expressed as

$$\Gamma(\tilde{t}_1 \to \tilde{b}_1 W^+) = \frac{g^2}{16\pi} |f_{ij}|^2 \frac{p_j}{m_{\tilde{t}_1}^2} \left[ m_{\tilde{W}}^2 - 2 \left( m_{\tilde{t}_1}^2 + m_{\tilde{b}_1}^2 \right) + \frac{(m_{\tilde{t}_1}^2 - m_{\tilde{b}_1}^2)}{m_{\tilde{W}}^2} \right]^2, \quad (12)$$

where $p_j \equiv \sqrt{E_{\tilde{j}}^2 - m_{\tilde{b}_1}^2}$, $E_{\tilde{j}} \equiv (m_{\tilde{t}_1}^2 + m_{\tilde{b}_1}^2 - m_{\tilde{W}}^2)/(2m_{\tilde{t}_1})$ and $(f_{11}, f_{12}, f_{21}, f_{22}) = (+ \cos \theta_t \cos \theta_b, - \cos \theta_t \sin \theta_b, - \sin \theta_t \cos \theta_b, + \sin \theta_t \sin \theta_b)$. Note that $\Gamma(\tilde{t}_1 \to \tilde{b}_1 W^+)$ is proportional to $\cos^2 \theta_b$. In Fig.1, we show the branching ratio $\text{Br}(\tilde{t}_1 \to e^+ d) = 1 - \text{Br}(\tilde{t} \to \tilde{b}_1 W^+)$ as a function of $m_{\tilde{b}_1}^2$, where we take $\lambda'_{131} = 0.1$, $m_{\tilde{t}_1} = 210\text{GeV}$ and $\theta_t = 1.0$. We can find that the desirable branching ratio $\text{Br}(\tilde{t}_1 \to e^+ d) \lesssim 0.8$ can be obtained for a wide range of the mass $m_{\tilde{b}_1} \lesssim 120\text{GeV}$. It depends sensitively on the mixing angle $\theta_b$ through a factor $\cos^2 \theta_b$.  


It is natural for us to ask whether or not such a light sbottom, $m_{\tilde{b}_1} \lesssim 120$GeV, has already excluded experimentally. In fact, the CDF and D0 groups at Tevatron have excluded squarks lighter than about 200GeV [22]. We should note, however, that the limit has been obtained on the basis of assumptions of five degenerate squarks with $m_{\tilde{q}_L} = m_{\tilde{t}_R}$. That is, the expected cross sections will be significantly reduced by a factor ten when one sbottom $\tilde{b}_1$ is lighter than the other squarks. At present, the most stringent mass bound on the sbottom with the dominant decay mode $\tilde{b}_1 \rightarrow \tilde{\nu}_c d$ is

$$m_{\tilde{b}_1} \gtrsim 90\text{GeV}.$$  

This has been obtained from a stop mass bound $m_{\tilde{t}_1} \gtrsim 90$GeV for $m_{\tilde{Z}_1} = 0$ through search for a process, $p\bar{p} \rightarrow \tilde{t}_1\tilde{t}_1 X \rightarrow c\bar{c}Z_1\bar{Z}_1 X$ at the D0 [25]. Its physics background will be (1) the production processes for the stop and sbottom are almost the same at the Tevatron, to which SUSY-QCD diagrams are mainly contributed, and (2) experimental signatures of the stop and sbottom are the same, i.e., large $p_T$ plus jets.

Next we should examine constraints from the precision measurements at LEP1. Potentially, contributions from the $\tilde{t}_L$ and $\tilde{b}_L$ to the $\Delta \rho$ could become large if their masses are not so different from the weak mass scale of $m_Z$ [3, 10]. We have checked, however, contributions from the $\tilde{t}_1$ and $\tilde{b}_1$ to the $\Delta \rho$ could become small to such extent as $1 \times 10^{-3}$ even for $m_{\tilde{b}_1} = 100$GeV, $m_{\tilde{t}_1} = 200$GeV and $m_{\tilde{t}_2} = 230$GeV if we take large mixing angles $\theta_t \simeq \theta_b \gtrsim 1.0$ and a large tan $\beta \gtrsim 10$. Here we have used the formula for $\Delta \rho$ including mixings of both stops and the sbottoms [23].

## 4 Total cross sections

The analytical expression for the differential cross section of the sub-process $e^+d \rightarrow \tilde{b}_1 W^+$ is written as follows,

$$\frac{d\hat{\sigma}}{d\hat{t}} = \frac{g^2 \lambda_{131}^2}{128\pi s} \left[ \cos \theta_t f_{11} \frac{D_{t_1}}{D_{t_2}} - \sin \theta_t f_{21} \right]^2 \hat{s} \left[ m_W^2 - 2 \left( \hat{s} + m_{\tilde{b}_1}^2 \right) + \frac{(\hat{s} - m_{\tilde{b}_1}^2)^2}{m_W^2} \right]$$

$$+ \left( \frac{\cos \theta_b}{D_{\nu e}} \right)^2 \left[ -2 \hat{\phi} \left( \hat{s} + \hat{t} - m_W^2 - m_{\tilde{b}_1}^2 \right) - 2m_W^2 m_{\tilde{b}_1}^2 + \frac{m_{\tilde{b}_1}^2}{m_W^2} \right]$$

$$- 2 \cos \theta_b \frac{\text{Re} \left( \cos \theta_t f_{11} \frac{D_{t_1}}{D_{t_2}} - \sin \theta_t f_{21} \right)}{D_{\nu e}} \hat{s} \left( -\hat{i} + 2m_{\tilde{b}_1}^2 + \frac{\hat{t} (\hat{s} - m_{\tilde{b}_1}^2)}{m_W^2} \right),$$

where $D_{t_{1,2}} \equiv \hat{s} - m_{\tilde{t}_{1,2}}^2 + im_{\tilde{t}_{1,2}} \Gamma_{\tilde{t}_{1,2}}$, and $D_{\nu e} \equiv \hat{t}$. In this formula, we have included diagrams not only for the $\tilde{t}_{1,2}$ exchanges in the $s$-channel but also for the neutrino exchange in the $t$-channel.

In Fig.2 we show the $m_{\tilde{b}_1}$ dependence of the total cross section for the process,

$$e^+p \rightarrow \tilde{b}_1 W^+ X,$$  

(14)
where we take $m_{	ilde{t}_1} = 205\text{GeV}$, $m_{	ilde{t}_2} = 225\text{GeV}$ and $\chi_{131}^2 = 0.1$. Two sets of mixing angles (a) $(\theta_1, \theta_2) = (0.95, 1.0)$ and (b) $(1.2, 1.2)$ are adopted. They are suitable parameter sets for simulation of the excess events at the high $Q^2$ region in the NC DIS. Here we use MRS-G parton distribution [27]. We find that large cross sections of $\sigma \approx 1$ for the former case. However, the cuts on $P_T/E_T \equiv \sum_i E_i \sin \theta_i$ (summed over the calorimeter cells). Indeed, lower cuts on $P_T/E_T$ is efficient in discriminating mono-jet events from multijet events because $P_T/E_T \simeq 1$ for the former case. However, the cuts on $P_T/E_T$ are not so severe in actual analyses at HERA, i.e., $P_T/E_T > 0.4$ and 0.5 at the ZEUS [17] and H1 [1], respectively. Consequently, some mutijet events could be regarded as the CC DIS events after the selection.

We investigate the $Q^2$ and $M$ distributions of the expected events. In this analysis, we use the Jacquet-Blondel methods [18], in which $Q^2_B$ and $M_{JB}$ are determined from energies and scattering angles of the final jets. We combine the H1 and ZEUS data explicitly presented in refs. [16, 17]. Here we use MRS-G parton distribution [27] and the hadronization has been simulated à la JETSET [29].

Shown in Fig.3 are $Q^2_B$ and $M_{JB}$ distributions of the expected number of events together with the experimental data. Figure 3 corresponds to the case that two stops are almost degenerate in mass ($m_{\tilde{t}_1}$, $m_{\tilde{t}_2}$) = (205GeV, 225GeV) with the finite mixing angle $\theta_b = 0.95$. Parameters in the bottom sector are taken as $m_{\tilde{b}_1} = 100\text{GeV}$ and $\theta_b = 1.0$. In this case we obtain $\text{Br}(\tilde{t}_1 \rightarrow e^+d) \simeq 20\%$ and $\text{Br}(\tilde{t}_2 \rightarrow e^+d) \simeq 10\%$. That is, the parameter set has not certainly been excluded by the leptoquark searches at Tevatron. Note, moreover, that the broad mass (or $x$) distribution of the excess events in the NC DIS [1, 3] can be reproduced by the mass spectrum and the mixing parameters [8]. In Fig.3 we take $P_T > 50\text{GeV}$ and $P_T/E_T > 0.5$ as kinematical cuts. Additional cut, $Q^2 > 12,500\text{GeV}^2$, is adopted for $M_{JB}$ distribution. The tendencies for event excess at the high $Q^2_B$ and large $M_{JB}$ of the data are successfully reproduced by our scenario though in the limited statistics.

5 Event excess in CC process

Now we consider one of signatures for the process, $e^+p \rightarrow \tilde{b}_1W^+X$, followed by the decays, $\tilde{b}_1 \rightarrow \bar{v}_e d$ and $W^+ \rightarrow q\bar{q}'$. In this case a large $P_T$ plus multijets can emerge as its experimental signal. Such a signal could be observed as an event excess at the high $Q^2$ region in the CC DIS, because some multijets could not be distinguished from the mono-jet even after event selections of the CC DIS. In the next section, we will investigate the signal (A), which must be a clean signal of the process (14) because of $\text{Br}(W^+ \rightarrow q\bar{q}') = 2/3$. It is worth mentioning that we expect a few events of the type (B) for an integrated luminosity of 30pb$^{-1}$ and a typical efficiency of 50% due to $\sigma_{\text{tot}} \simeq 1\text{pb}$ and $\text{Br}(W^+ \rightarrow \nu\ell^+) = 1/9$. 

\[ \text{fig3.png} \]
We have to emphasize that the signal is characterized by the multijet events with a large $P_T$. It means that the signal has a broad $P_T/E_T$ distribution. Obviously it is different from the one for CC DIS, which has a sharp peak at $P_T/E_T \lesssim 1$. Therefore, we could extract the signal from the CC DIS by imposing a lower value of cut on $P_T/E_T$ such as $P_T/E_T > 0.3$. Needless to say, detailed jet-analyses will also be indispensable for certainty.

It should be mentioned that the possible event excesses in the $Q^2_{JB}$ and $M_{JB}$ distributions are originated from our choice of rather large coupling parameter $\lambda'_{131} = 0.1$. If more stringent upper limit, $\lambda'_{131} \lesssim 0.05$, will be established by elaborated analyses of the APV experiments [23, 24], expected events from the signal would be slightly decreased.

6 Concluding remarks

We have investigated the process $e^+ p \rightarrow \tilde{b}_1 W^+ X$ from the CC channel at HERA. Particularly, we considered a case where the sbottom $\tilde{b}$ is lighter than the stops and has a mass smaller than about 120GeV. Here we assume sufficiently heavy chargino $\tilde{W}_1$ ($\gtrsim 200\text{GeV}$) and neutralino $\tilde{Z}_1$ ($\gtrsim 100\text{GeV}$) for simplicity. In this case the stops cannot decay into $\tilde{b}\tilde{W}_1$ and the sbottom can only decay into $\tilde{\nu}_e d$ via the R-parity breaking coupling $\lambda'_{131}$. We have shown that such a light sbottom has not been excluded by the present experiments. One of characteristic signatures of the process could be a large missing transverse momentum plus multijets corresponding to hadronic decays of the $W$. It could be observed as an event excess at the high $Q^2$ region in the CC DIS. We have shown that expected event distributions are consistent with the CC data recently obtained by the H1 and ZEUS groups at HERA. Another signature of our process should be a high $P_T$ charged lepton ($e^+$ or $\mu^+$) plus mono-jet with a large $P_T$ corresponding to leptonic decays of the $W$. We can expect a few events of such a characteristic signal assuming the integrated luminosity of 30pb$^{-1}$. Detailed studies of the leptonic signal of our process are in progress.

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References

[1] C. Adloff et al., H1 Collab., DESY preprint, DESY 97-24, [hep-ph/9702012]
[2] J. Breitweg et al., ZEUS Collab., DESY preprint, DESY 97-25, [hep-ph/9702015]
[3] T. Kon and T. Kobayashi, Phys. Lett. B270, 81 (1991) ; T. Kon, T. Kobayashi and K. Nakamura, Proc. of the HERA Workshop : "Physics at HERA" 1991, eds. W. Buchmüller and G. Ingelman, Vol.2, p.1088
[4] D. Choudhury and S. Raychaudhuri, preprint CERN-TH/97-26, hep-ph/9702392
[5] H. Dreiner and P. Morawitz, preprint hep-ph/9703279
[6] G. Altarelli, J. Ellis, G. F. Giudice, S. Lola and K. L. Mangano, preprint CERN-TH/97-40, hep-ph/9703276
[7] J. Kalinowski, R. Rückl, H. Spiesberger and P. M. Zerwas, preprint BI-TP 97/07, hep-ph/9703288
[8] T. Kon and T. Kobayashi, preprint ITP-SU-97/02, hep-ph/9704221
[9] J. E. Kim and P. Ko, preprint SNUTP 97-026, hep-ph/9706387
[10] J. Ellis, S. Lola and K Sridhar, preprint CERN-TH/97-109, hep-ph/9705416
[11] D0 Collab., http://d0wop.fnal.gov/public/new/lq/lq_blurb.html
[12] R. Culbertson, talk at SUSY97, Philadelphia, May 27 ~ 31, 1997,
[13] G. Altarelli, G. F. Giudice and K. L. Mangano, preprint CERN-TH/97-101, hep-ph/9705287
[14] T. Kon, T. Kobayashi, S. Kitamura, K. Nakamura and S. Adachi, Z. Phys. C61, 239 (1994) ; T. Kon, T. Kobayashi and S. Kitamura, Phys. Lett. B333, 263 (1994) ; T. Kobayashi, S. Kitamura and T. Kon, Phys. Lett. B376, 227 (1996) ; Int. J. Mod. Phys. A11 1875 (1996)
[15] T. Matsushita, talk at Workshop on ”Electron Proton Interactions with High Transverse Energy”, June 26, 1997, KEK, Tanashi branch, Japan
[16] P. Schleper (H1 Collab.), talk at Fermilab (28. Feb, 1997) and at SLAC (6. March, 1997)
[17] K. Nagano (ZEUS Collab.), talk at Workshop on ”Electron Proton Interactions with High Transverse Energy”, June 26, 1997, KEK, Tanashi branch, Japan
[18] V. D. Barger, G. F. Giudice and T. Han, Phys. Rev. D40, 2987 (1989)
[19] J. Ellis and S. Rudaz, Phys. Lett. 128B, 248 (1983); G. Altarelli and R. Ruckl, Phys. Lett. 144B, 126 (1984); I. Bigi and S. Rudaz, Phys. Lett. 153B, 335 (1985) ; K. Hikasa and M. Kobayashi, Phys. Rev. D36, 724 (1987)
[20] S. Davidson, D. Bailey and B. A. Campbell, Z. Phys. C61 613 (1994)
[21] P Langacker, Phys. Lett. B256 277 (1991)
[22] Particle Data Group, Phys. Rev. D54, 1 (1996)
[23] C. S. Wood et al., Science 275 1759 (1997)
[24] L. Giusti and A. Strumia, preprint IFUP-TH/23-96, hep-ph/9706298
[25] D0 Collab., Phys. Rev. Lett. 76, 2222 (1996)
[26] C. S. Lim, T. Inami and N. Sakai, Phys. Rev. D29, 1488 (1984) ; M. Drees and K. Hagiwara, Phys. Rev. D42, 1709 (1990)

[27] A. D. Martin, W. J. Stirling and R. G. Roberts, Phys. Lett. B354, 155 (1995)

[28] F. Jacquet and A. Blondel, Proc. of the study of an ep facility for Europe, 1979, ed. U. Amaldi, p.391

[29] T. Sjöstrand, Comp. Phys. Com. 82, 74 (1994)
Figure 1: $m_{\tilde{b}_1}$ dependence of branching ratio \( \text{Br}(\tilde{t}_1 \to e^+ d) = 1 - \text{Br}(\tilde{t}_1 \to \tilde{b}_1 W^+) \). We take $\lambda'_{131} = 0.1$, $m_{\tilde{t}_1} = 210 \text{GeV}$ and $\theta_t = 1.0$. 
Figure 2: \( m_{\tilde{b}_1} \) dependence of the total cross section \( \sigma(e^+ p \rightarrow \tilde{b}_1 W^+ X) \). We take \( \lambda'_{131} = 0.1, m_{\tilde{t}_1} = 205\text{GeV} \) and \( m_{\tilde{t}_2} = 225\text{GeV} \).
Figure 3: $Q_{JB}^2$ and $M_{JB}$ distribution of the expected number of events together with the experimental data. We take $m_{\tilde{t}_1} = 205\text{GeV}$, $m_{\tilde{t}_2} = 225\text{GeV}$, $m_{\tilde{b}_1} = 100\text{GeV}$, $\theta_t = 0.95$, $\theta_b = 1.0$, $\lambda_{131} = 0.1$ and integrated luminosity $L = 34\text{pb}^{-1}$. As kinematical cuts, $P_T > 50\text{GeV}$ and $P_T/E_T > 0.5$ are adopted. Additional cut, $Q^2 > 12,500\text{GeV}^2$, is taken for $M_{JB}$ distribution. Dashed line corresponds to the SM CC expectation.