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IMPLICATIONS OF THE t-QUARK SIGNAL FOR STOP SQUARKS AND CHARGED HIGGS BOSONS

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ABSTRACT

If there exists a stop squark or a charged Higgs boson lighter than the t-quark, so that the top quark dominantly decays via the two-body mode $t \rightarrow \tilde{t}\tilde{\gamma}$ or $t \rightarrow bh$, the standard model t-quark signal may be expected to be modified. We discuss this difference for various Higgs boson, stop squark and photino masses. The UA1 data seem to rule out a Higgs boson with a mass less than $(m_t - m_b)$. A stop squark with mass $m_{\tilde{t}}$ less than $m_t - m_{\tilde{\gamma}}$ also appears unlikely. The possibility of detecting heavy charged Higgs at SLC or LEP is also discussed.

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The UA1 collaboration[1)] has recently reported evidence for the top quark produced via the decay of the W boson. The six reported candidates are consistent with the semi-leptonic decay of the top as calculated within the framework of the standard model. The separation of the top quark signal from the severe backgrounds from charm and bottom quark production was facilitated by various theoretical analyses[2)]. Confirmation of this signal is very important in that the existence of the top quark is essential for the cancellation of triangle anomalies which would otherwise occur in the standard model.

In the top quark search, the final state studied consists of the fast jet j_1 (usually $\bar{b}$) from the decay $W \rightarrow t\bar{b}$, and a lepton and a slow jet j_2 resulting from the decay $t \rightarrow b\ell\nu$. The escaping neutrino yields a missing transverse momentum $\not{p}_T$. As a result, the cluster transverse mass[2)] $m_{T_3} \equiv m_T(j_1 j_2 \ell, \not{p}_T)$ has a characteristic Jacobian peak at the W-boson mass, M_W confirming the W-boson as the parent whereas the cluster transverse mass $m_{T_2} \equiv m_T(j_2\ell, \not{p}_T)$ peaks near 40 GeV thereby implying the production and subsequent decay of a particle of mass $m_t \simeq 40$ GeV, identified as the top quark.

It is clear that if the top quark decayed by a different mechanism into the "same" final state, i.e., $t \rightarrow b+\ell+\not{p}_T$, the Jacobian peak signatures discussed above could well be substantially unaltered. For example, if there is a charged Higgs boson (h) such that the decay $t \rightarrow bh$ was possible, this two-body decay would dominate the semi-leptonic three-body decay. The Higgs would then decay via the Cabibbo-Kobayashi-Maskawa favoured decays $h \rightarrow \tau\nu_\tau$ or $h \rightarrow c\bar{s}$ or the suppressed (?) decay $h \rightarrow b\bar{c}$ followed by the subsequent decays of the τ or b or c-quark giving a lepton and $\not{p}_T$. As has already been pointed out[3)], the p_T of the lepton produced by this cascade is expected to be substantially degraded thereby enabling one to distinguish the decay into Higgs from the conventional three-body decay.

Another, and possibly more interesting, two-body decay of the top quark occurs in those SUSY models where one of the scalar partners of the top quark (the stop) is light enough so that the decay $t \rightarrow \tilde{t}\tilde{\gamma}$ is allowed. Here, $\tilde{\gamma}$ denotes the photino and $\tilde{t}$ the stop squark. We recall that the squark mass eigenstates are, in general, mixtures of the scalar partners of the left- and right-handed quarks. Since the top quark mass is large, this can result in a relatively light stop even when the other squarks are comparatively heavy[4)]. The precise value of the mass and mixing is model-dependent and is determined by the "A-parameter" of the model. If the stop is produced by the decay of the top, it decays via a (virtual) wino into a slepton, a lepton and a b-quark (which gives the slow jet) if the slepton is lighter than the stop. This may be so for the 0 (50 GeV) squark interpretation[5] of the CERN monojet events[6] reported by UA1. If the stop is lighter than the slepton, then the dominant decays are $\tilde{t} \to bq\bar{q}\tilde{\gamma}$ or $\tilde{t} \to b\ell\nu\tilde{\gamma}$ via a virtual W or a wino. The quark mode is, of course, more dominant. In this paper, we will mainly concentrate on the SUSY model with light sleptons. Unlike the Higgs case discussed earlier, the lepton produced here is likely to have a large p_T. The main difference from the usual t-decay is that in the present case two photinos and a neutrino constitute the missing energy. The purpose of this paper is to see whether the UA1 data[1] can be explained by other than canonical t-quark decays; if not new limits on stop squark and charged Higgs boson masses may be inferred from the presence of a t-quark signal. The latter is particularly important for SUSY model builders since the stop tends to be light in a variety of models[7]. In this context, we wish to answer the question: "Can one stop the top from being on top of the stop?". In our analysis, we assume a squark (other than stop) mass $m_{\tilde{q}} \gtrsim 50$ GeV so we do not consider stop production via $W \to \tilde{t}\bar{\tilde{b}}$. Other consequences of a light stop have been discussed in Ref. 4) and Ref. 8).

We note that the possibility that the UA1 top signal is faked by squark production has been suggested in Ref. 9). However, a detailed analysis of the resulting distributions[10] shows that this is unlikely.

We proceed by first analyzing the canonical semi-leptonic decay of the t-quark. Following Ref. 1), we calculate $p\bar{p} \to W \to t\bar{b}$, $t \to b\bar{\ell}\nu$ with the following cuts:

$$|\eta_e| < 3.0\,, \quad |\eta_\mu| < 1.3\,, \quad |\eta_{jet}| < 2.5\,;$$

$$|\vec{P}_{T_e}| > 15\,\mathrm{GeV}, \quad |\vec{P}_{T_\mu}| > 12\,\mathrm{GeV}, \quad |\vec{P}_{T_{j_1}}| > 8\,\mathrm{GeV}, \quad |\vec{P}_{T_{j_2}}| > 7\,\mathrm{GeV};$$

$$\Delta r_{j_1 j_2} \equiv \left(\Delta\eta^2 + \Delta\varphi^2\right)^{1/2} > 1.0 \quad \text{(two jet event selection)}$$

$$\left.\begin{array}{l} \Sigma\, E_T < 1\ \mathrm{GeV}\ \text{(electron)} \\ \\ \Sigma\, E_T < 0.2\, p_{T\mu}\ \text{(muon)} \end{array}\right\} \begin{array}{l}\text{where the sum is over a cone with} \\ \Delta r < 0.4 \text{ around the lepton track.}\end{array}$$

Also, for muon triggered events, we impose an enhanced isolation cut of no jet with $p_T > 7$ GeV within $\Delta r = 1$ of the muon track. We have also used the same structure functions, Q_T smearing and resolution smearing on the e, μ and hadrons as in Ref. 11) in which other possible signatures of light sleptons are also discussed. We have used a K-factor of 1.91 consistent with the structure functions used$^{12)}$. The cross-sections are shown in the Table from which we see that we expect 2.5 (2.6) events with an isolated electron (muon) and two jets from $W \to t\bar{b}, \bar{t}b$ in the case of canonical t-decay for an integrated luminosity of 120 nb^{-1}.

We now turn to the possibility that the $t \to hb$ decay fakes the collider top signal. To this end, we have considered a model with two Higgs doublets with vacuum expectation values (vevs) V and V'. We ignore the mixing of these Higgs. After the Higgs mechanism the coupling of the charged physical Higgs particle to the quarks is given by

$$\mathcal{L} = \bar{u}\,(x+y\gamma_5)\,d\,h, \qquad (1)$$

with $x = 2^{1/4}G_F^{\ 1/2}\,(m_d \tan\alpha + m_u \cot\alpha)$ and $y = 2^{1/4}G_F^{\ 1/2}\,(m_d \tan\alpha - m_u \cot\alpha)$. Here, $\tan\alpha = V'/V$ where V' is the vev of the field that gives the up quark mass and V the vev of the field that gives the down quark mass. The Lagrangian for the leptons is obtained by the replacement, $m_d \to m_\ell$, $m_u = 0$. Note that u and d denote the generic up and down quark and not necessarily the quarks of the first family. The rate for the Higgs to decay into quarks or leptons is obtained from the Lagrangian (1)*). We find

$$\Gamma(h\to fF) = \frac{N_c}{8\pi}\, m_h \left[(x^2+y^2)(1-A-B) - 2(x^2-y^2)\sqrt{AB}\right] \lambda^{\frac{1}{2}}(1,A,B), \qquad (2)$$

where $A = m_f^2/m_h^2$, $B = m_F^2/m_h^2$, $N_C = 1(3)$ for leptons (quarks) and $\lambda(x,y,z) = x^2+y^2+z^2 - 2xz - 2xy - 2yz$. If $m_h < m_t + m_b$ as we are considering here, the Higgs will dominantly decay via $h \to c\bar{s}$ or $h \to \tau\bar{\nu}_\tau$, the precise branching fraction being determined by $\tan\alpha$, the ratio of the vevs. For $\tan\alpha = 5$, 1 or 0.2, the corresponding branching fractions for $h \to \tau\nu_\tau$ about 90%, 30% or 2.5%, respectively, and are almost independent of m_h for 5 GeV $< m_h < m_t - m_b$. We have used $m_c = 1.5$ GeV and $m_s = 0.3$ GeV. If the decay of the Higgs boson into τ was

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*) The masses that enter in x and y are current quark masses whereas the other masses are constituent quark masses. We ignore this difference in our calculation since we restrict $m_h > 5$ GeV. In any case, in the Table we take the Higgs branching into τ to be 100%.

kinematically suppressed, then $h \to \mu\nu$ would dominate $h \to e\nu$ leading to almost only muonic events via the cascade $t \to bh \to b\mu\nu$ in contradiction with the UA1 data 1).

The cross-section for $W \to t\bar{b} \to bh\bar{b}$ mode incorporating the lepton cuts and resolutions discussed earlier is shown in the Table. Here, we have assumed that the Higgs decays 100% into the $\tau\nu$ mode (the τ branching fraction into e or μ is 17%) to give an upper bound to the leptonic signal from the top (the leptons from charm decay would not satisfy the isolation requirements). We see that in spite of this, the cross-section is small compared with the cross-section from the usual semi-leptonic decay of the top. Moreover, in $N = 1$ supergravity models with soft supersymmetry breaking terms induced by the superHiggs mechanism, $\tan\alpha \simeq 1$ if $m_t \simeq 40$-50 GeV. Then the cross-section shown in the Table is further reduced by the branching ratio of $\simeq 30\%$. This smallness of the cross-section is largely due to the lepton p_T cut: the p_T of the electron or muon is greatly degraded in the course of the cascade, $t \to bh \to b\tau\nu_\tau \to b\ell\nu_\ell\nu_\tau\nu_\tau$. Those events that survive the cuts tend to have the lepton p_T clustering near the edge of the lepton p_T cut to a larger extent than in the standard model. We thus see that a charged Higgs boson with a mass such that the decay $t \to bh$ is allowed is essentially ruled out by the existence of a t-quark signal in the collider data.

We now briefly discuss the possibility of producing charged Higgs heavier than $m_t - m_b$. Higgs pair production at SLC or LEP has been discussed, for instance, in Ref. 13). If the Higgs is too heavy to be pair produced, it may be possible to produce it singly via $e^+e^- \to t\bar{b}h$. There are six amplitudes contributing to this final state, viz. Z and γ exchange into $t\bar{t}^*$, $\bar{b}b^*$ or $h\bar{h}^*$ with the virtual t^*, b^* or $\bar{h}^*$ decaying into the final state. The cross-section for this is shown in Fig. 1. We see that except when the Higgs is light enough so that it is pair-produced, the cross-section is very small and so the detection of the Higgs via this mechanism seems unlikely.

We now turn to the possibility that the top decays dominantly via $t \to \widetilde{t\gamma}$ and ask whether this would be distinguishable from the canonical t-decay on the basis of he collider data$^{1)}$. As discussed earlier, the stop is a mixture of $\tilde{t}_L$ and $\tilde{t}_R$. The coupling of the mass eigenstate $\tilde{t} \equiv \tilde{t}_L \cos\delta + \tilde{t}_R \sin\delta$ to the photino can be readily calculated from the couplings of $\tilde t_L$ and $\tilde t_R$ to the photino*). We find that

$$\mathcal{L}_{t\tilde t\tilde\gamma} = ie\,\tilde t^{\dagger}\,\bar{\tilde\gamma}\,(a+b\gamma_5)\,t + h.c. \tag{3a}$$

where $a \equiv \frac{1}{2}(A_L \cos\alpha + A_R \sin\alpha)$ and $b = \frac{1}{2}(A_R \sin\alpha - A_L \cos\alpha)$ with

$$A_L = \frac{4}{3\sqrt{2}} + \frac{N_1 m_Z}{\mu_-}\left(\cot\theta_W - \frac{1}{3}\tan\theta_W\right)\epsilon_1 \quad \text{and} \quad A_R = \frac{4}{3\sqrt{2}} - \frac{4}{3}\,\frac{N_1 m_Z}{\mu_-}\tan\theta_W\,\epsilon_1$$

The parameters N_1 and μ_- are as defined in Ref. 14) and ϵ_1 as in Ref. 11b). The coupling of the wino (again, that mass eigenstate that has a large wino component) to the stop is given by

$$\mathcal{L}_{\tilde W\tilde t b} = g f_+ \cos\delta\;\tilde t^{\dagger}\,\bar{\tilde W}\,\frac{1}{2}(\alpha-\beta\gamma_5)\,b + h.c. \tag{3b}$$

with f_+ as defined in Ref. 11b). α and β are model-dependent parameters that differ from unity because of the Higgsino component of the wino mass eigenstate coupling with a possibly non-negligible coupling to the $\tilde t b$ system, i.e., for a light quark, $\alpha = \beta = 1$ implying the usual left-handed coupling to the wino. We find that varying α and β does not alter any of our conclusions since the distributions are dominantly governed by the cuts rather than the details of the matrix elements.

For the decay of the stop, we have essentially two possibilities to consider. First, we consider the case when the sleptons and other squarks are heavier than the stop. Then, the stop decays via $\tilde t \to bq\bar q\tilde g$ if the gluino is light enough. Otherwise the decay $\tilde t \to bq\bar q\tilde\gamma$ dominates. Also, the decays $\tilde t \to b\ell\bar\nu\tilde g$ (only via the virtual W) and $\tilde t \to b\ell\bar\nu\tilde\gamma$ are possible but these are suppressed relative to $bq\bar q\tilde g(\tilde\gamma)$ decays due to colour factors. The last of these could, in principle, mimic the top signal where the missing energy is carried by the $\tilde\gamma\tilde\gamma\nu$ system, but the lepton and slow jet p_T will be diminished compared to that from the canonical t-decay. In the 0 (100 GeV) squark$^{15)}$ or the 0 (40 GeV) gluino$^{16)}$ interpretation of the monojet data$^{6)}$, the squarks and sleptons are indeed likely to be heavier than a stop (if the stop mass is ~40 GeV as we are considering here) at least within the framework of supergravity models with soft SUSY

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*) By photino, we mean that mass eigenstate which would be the pure photino if there were no tree-level gaugino masses. These induce a mixing of the pure zino into the mass eigenstate causing the $\tilde t_L$ and $\tilde t_R$ to couple differently.

breaking terms induced by the superHiggs mechanism$^{7)}$. The leptonic mode is also suppressed by a branching ratio. Moreover, in the model of Ref. 15), the gluino is very light and hence the gluino modes dominate the photino modes by a factor $\alpha_s/\alpha \sin^2\theta_W$. At least naively, the stop decays into two jets, i.e., the top into three jets or two jets if there is a merger of the gluino and the b-quark to form a "fat" jet. Since we expect the signal to be suppressed by a leptonic branching and also the p_T of the lepton to be reduced compared to the standard model, we do not consider this possibility any further.

The other possibility for stop decay alluded to earlier is dominant in the 0(50 GeV) squark interpretation of the CERN monojet data with the gluino heavier than the squark$^{5)}$. In these models, the sleptons are expected to weigh 0(30 GeV) and so a stop could decay (through a virtual wino) via $\tilde{t} \to b\tilde{\ell}\nu$ or $\tilde{t} \to b\ell\tilde{\nu}$. A sneutrino of 0(30 GeV) would decay invisibly via a two-body $\nu\tilde{\gamma}$ mode$^{16)}$ and would thus contribute to missing p_T. The lepton that originates in the decay $\tilde{\ell} \to \ell\tilde{\gamma}$ will have a hard p_T spectrum whereas the lepton from the decay $\tilde{t} \to b\ell\tilde{\nu}$ will be much softer since we assume that $m_{\tilde{t}} < m_t \sim 0(40\text{-}50\ \text{GeV})$.

The decay rate for $t \to \tilde{t}\tilde{\gamma}$ and the matrix elements for the decays $\tilde{t} \to b\tilde{\ell}\nu$ and $\tilde{t} \to b\tilde{\nu}\ell$ used in our Monte Carlo program can be readily calculated from the Lagrangian (3). We find,

$$\Gamma(t \to \tilde{t}\tilde{\gamma}) = \frac{1}{8\pi m_t^3}\left[\frac{1}{2}(a^2+b^2)(m_t^2 - m_{\tilde{t}}^2 + m_{\tilde{\gamma}}^2) + (a^2-b^2)m_t m_{\tilde{\gamma}}\right] * \\ * \lambda^{1/2}(m_t^2, m_{\tilde{\gamma}}^2, m_{\tilde{t}}^2) \tag{4a}$$

and

$$|M(\tilde{t} \to b\tilde{\ell}\nu)|^2 = \frac{2g^4 f_+^4 \cos^2\delta}{[(\nu+\tilde{\ell})^2 - m_{\tilde{w}}^2]^2} * \\ \left\{\left(\frac{\alpha+\beta}{2}\right)^2 m_{\tilde{w}}^2\, \nu\cdot b - \left(\frac{\alpha^2-\beta^2}{2}\right)\nu\cdot\tilde{\ell}\, m_b m_{\tilde{w}} \right. \\ \left. + \left(\frac{\alpha-\beta}{2}\right)^2 [2\nu\cdot\tilde{\ell}\; b\cdot\tilde{\ell} - m_{\tilde{\ell}}^2\, \nu\cdot b]\right\} \tag{4b}$$

and

$$|M(\tilde{t}\to b\ell\tilde{\nu})|^2 = \frac{2g^4 f_+^4 \cos^2\delta}{[(\tilde{\nu}+\ell)^2 - m_{\tilde{W}}^2]^2} \left\{ \left(\frac{\alpha+\beta}{2}\right)^2 [2\ell\cdot\tilde{\nu}\, b\cdot\tilde{\nu} - m_{\tilde{\nu}}^2\, \ell\cdot b] \right.$$

$$\left. + \left(\frac{\alpha-\beta}{2}\right)^2 m_{\tilde{W}}^2\, \ell\cdot b - \left(\frac{\alpha^2-\beta^2}{2}\right) \ell\cdot\tilde{\nu}\, m_b m_{\tilde{W}} \right\} . \qquad (4c)$$

In Eqs. (4b) and (4c), the particle labels denote their four-momenta. As explained previously, α and β differ from unity only due to the possibly non-negligible (and model-dependent) coupling of the Higgsino to the $\tilde{t}b$ system.

Shown in Fig. 2 are our results for the distributions for the cluster transverse masses m_{T_2} and m_{T_3}. We have fixed $m_{\tilde{\ell}} = m_{\tilde{\nu}} = 30$ GeV and $m_{\tilde{W}} = 60$ GeV for definiteness. Since, as explained earlier, two photinos escape in addition to the neutrino, the distributions are smeared towards lower masses than for the standard $t \to b\ell\nu$ case, the effect being greater for bigger photino masses.

In our calculations, we have attempted to vary the t-quark, stop and photino masses so as to best reproduce the UA1 t-quark signal. Making the t-quark mass too large results in too small a cross-section for $p\bar{p} \to W \to t\bar{b}$ and a softer p_T distribution for the fast jet. Making the stop mass too small results in too soft a slow jet and lepton p_T distributions. We show two curves from $t \to \tilde{t}\tilde{\gamma}$ decays in Figs. 2 and 3. The first case is for t(47 GeV) → $\tilde{t}$(40 GeV) + $\tilde{\gamma}$(5 GeV), with $\tilde{t} \to b\nu\tilde{\ell}$ or $b\ell\tilde{\nu}$. These masses have been motivated by one interpretation$^{5)}$ of the CERN monojet events together with the supergravity models with soft SUSY breaking terms$^{7)}$. The second case shown t(47 GeV) → $\tilde{t}$(45 GeV) + $\tilde{\gamma}$(0.5 GeV) with the slepton mass maintained at 30 GeV is meant for illustrative purposes. An arbitrary reduction of the photino mass results in distributions and rates which are closer to those of canonical t-decay.

The $\not{p}_T$ distributions for the standard model and the two SUSY scenarios we are considering are shown in Fig. 3a. We see that the spectra in the SUSY cases are harder than in the standard model case. The six UA1 events are indicated as arrows in the Figure. We note that the data prefer softer $\not{p}_T$ spectra and thus favour the canonical t-decay.

Shown in Fig. 3b is the p_T distribution of the slow jet. In the SUSY scenarios considered, the t decays via $t \to \tilde{t}\tilde{\gamma} \to b\ell\nu$ resulting in a softer p_T distribution for the slow jet. This is due to the large slepton mass and also to more particles in the final state. We emphasize that even if $m_{\tilde{\ell}} > m_{\tilde{t}}$ so that the slepton is virtual and $t \to \tilde{t}\tilde{\gamma} \to b\ell\nu\tilde{\gamma}\tilde{\gamma}$ this softness of the b-jet would persist - in addition, the lepton p_T spectrum would also be soft. The SUSY cases prefer events to be clustered near the edge of the slow jet cut, in much the same way as the lepton p_T clusters near the lepton p_T cut in the decay, $t \to bh$. In this Figure, the data have a definite preference for the canonical t-decay. We note also that the total rates (see the Table) for the SUSY cases are smaller than the standard model rate by a factor 2-3 largely due to the p_T cut on the slow jet. Changing the slepton mass to 25 GeV does not substantially alter our results - the p_T cuts on the slow jet and the lepton tend to compensate.

We have also checked other distributions and mass scenarios. The p_T distribution of the fast jet is similar to the standard model since the first part of the decay chain $W \to t\bar{b}$ is unchanged except for small changes in the t-quark mass. We have also checked that the $p_{T\ell}$ distribution is similar for the SUSY and standard model cases we are considering. We do not include these for the sake of brevity.

In conclusion, we have analyzed the possibility that the UA1 signal for the top quark may be consistent with an unconventional two-body decay of the top quark. We find that we can reasonably rule out the presence of a charged Higgs boson below the top so that the decay $t \to bh$ is the dominant mode. Since the Higgs prefers to decay into heavy particles, the p_T of the electron or muon emerging from the cascade decay $t \to h \to \tau \to \ell$ is greatly degraded relative to standard model predictions; surviving events tend to cluster near the $(p_T)_{\rm lepton}$ cut thereby enabling us to distinguish this mode from the standard β decay of the t-quark[*] We have also shown that unless such a Higgs can be pair produced, it will be very difficut to detect even in e^+e^- colliders. The possibility that $t \to \tilde{t}\tilde{\gamma}$ followed by $\tilde{t} \to b\tilde{\ell}\lambda$ is also unlikely.

By varying the t-quark, stop and photino masses, one can produce better agreement in one distribution only at the expense of worse agreement in other distributions and possibly a further reduction in the size of the signal. Comparison of the standard model and SUSY t-quark decays to the UA1 data does not enable us to draw a definite conclusion from the m_{T_2} and m_{T_3} distributions but the distributions in $\not{p}_T$ and p_T for the slow jet together with the total

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[*] The charged SUSY Higgs in general are expected to be heavier than the W-boson[18].

observed rate favour the canonical decay of the t quark. The t-quark signal, if confirmed, is important for SUSY model builders since $m_{\tilde{t}} < m_t$ will provide one constraint on any model.

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NOTE ADDED

After completing this paper, we learned of the paper by Bigi and Rudaz[19] which also focuses on the possibility that the top decays into a stop and a photino. They concentrate mainly on the four-body decays of the stop but also consider the possibility that $t \rightarrow b\ell\tilde{\nu}$ where the sneutrino is light. Although their conclusions are similar to ours, their analysis is complementary to that of this paper.

Process	Masses	$\sigma(e)$ pb	$\sigma(\mu)$ pb
$t \rightarrow b e \nu$	$m_t = 40$ $m_b = 4.6$	21	22
$t \rightarrow bh;\ h \rightarrow \tau\nu$	$m_t = 50$ $m_h = 40$	3	5
$(BF(h \rightarrow \tau\nu) = 100\%$	$m_t = 40$ $m_h = 30$	4	5
$t \rightarrow \tilde{t}\tilde{\gamma};\ \tilde{t} \rightarrow b\tilde{\ell}\nu$	$m_t = 47$ $m_{\tilde{t}} = 40$ $m_{\tilde{\gamma}} = 5$	7	5
	$m_t = 47$ $m_{\tilde{t}} = 45$ $m_{\tilde{\gamma}} = 0.5$	14	11
$t \rightarrow \tilde{t}\tilde{\gamma};\ \tilde{t} \rightarrow b\ell\tilde{\nu}$	$m_t = 47$ $m_{\tilde{t}} = 40$ $m_{\tilde{\gamma}} = 5$	-	-
	$m_t = 47$ $m_{\tilde{t}} = 45$ $m_{\tilde{\gamma}} = 0.5$	-	-

Total expected rates for lepton + 2-jets + $\not{p}_T$ events in pb from $W^{\pm} \rightarrow t\bar{b}, \bar{t}b$, for various t decays, with experimental cuts as described in the text. We assume a slepton mass $m_{\tilde{\ell}} = m_{\tilde{\nu}} = 30$ GeV and a wino mass $m_{\tilde{W}} = 60$ GeV. We use a K-factor of 1.91, consistent with our choice of parton distributions, and in accord with the measured $W^{\pm} \rightarrow e\nu$ rate.

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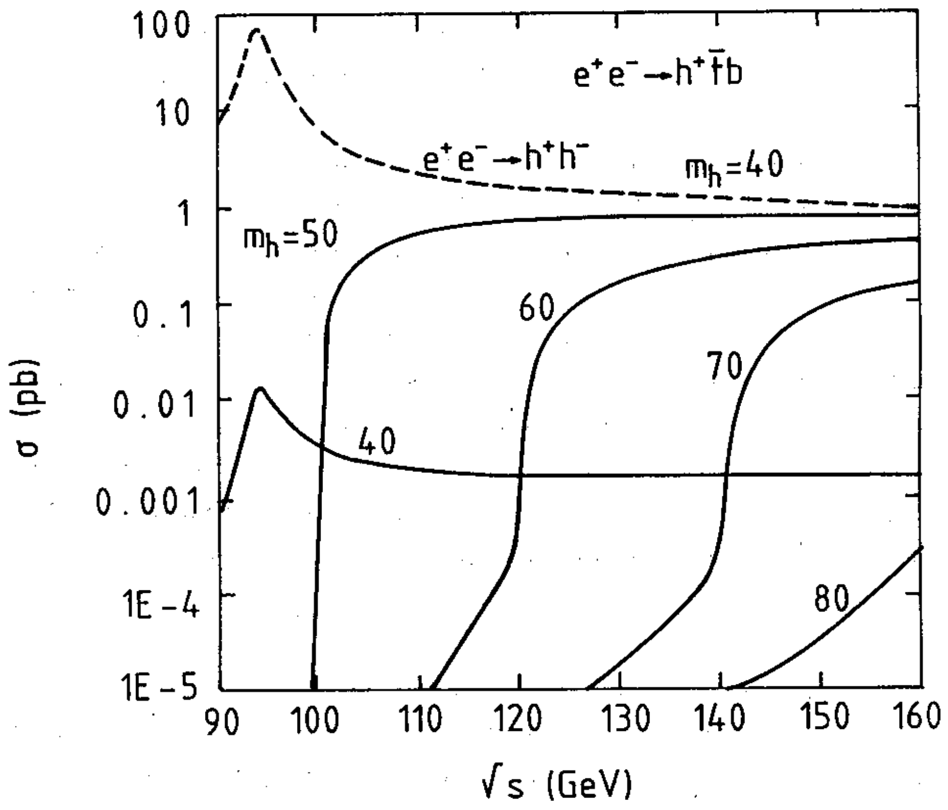
FIGURE CAPTIONS

Fig. 1 Total cross-section for $e^+e^- \to \bar{t}bh^+$ versus centre-of-mass energy $\sqrt{s}$ for various h^+ masses. The result shown is for ratio of vacuum expectation values $v'/v = 1$. Also shown for comparison is the contribution for $e^+e^- \to h^-h^+$ for $m_h = 40$ GeV, where the h^- decays to $\bar{c}s$ or $\tau\bar{\nu}_\tau$.

Fig. 2 Distributions in cluster transverse masses: a) $M_{T_2} = M_T\,(j_2\ell, \not{p}_T)$ and b) $M_{T_3} = M_T\,(j_1 j_2 \ell, \not{p}_T)$ for $W^\pm \to t\bar{b}, \bar{t}b$ origin of lepton plus two-jet events. The curves are summed over $\ell = e$ and $\ell = \mu$. Indicated are the standard model (SM) t decay, for $m_t = 40$ GeV, along with curves from supersymmetric decays $t \to \tilde{t}\tilde{\gamma}$. The parameters in the $\tilde{t}(40)$ curve are $m_t = 47$ GeV, $m_{\tilde{t}} = 40$ GeV, $m_{\tilde{\gamma}} = 5$ GeV, $m_{\tilde{\ell}} = 30$ GeV and $m_{\tilde{\omega}} = 60$ GeV. The parameters are the same in the $\tilde{t}(45)$ curve, except $m_{\tilde{t}} = 45$ GeV and $m_{\tilde{\gamma}} = 0.5$ GeV. For comparison, the six data points from the 1983 UA1 t-quark data sample are indicated as arrows1). Typical error bars are ±6 GeV for electron events and ±8 GeV for muon events.

Fig. 3 Distributions in a) missing p_T ($\not{p}_T$) and b) p_T (slow jet) for $W^\pm \to t\bar{b}, \bar{t}b$ decays. The parameters are the same as in Fig. 2. The cut in Fig. b) is at $p_T = 7$ GeV. The error bar on $\not{p}_T$ is typically ±6 GeV.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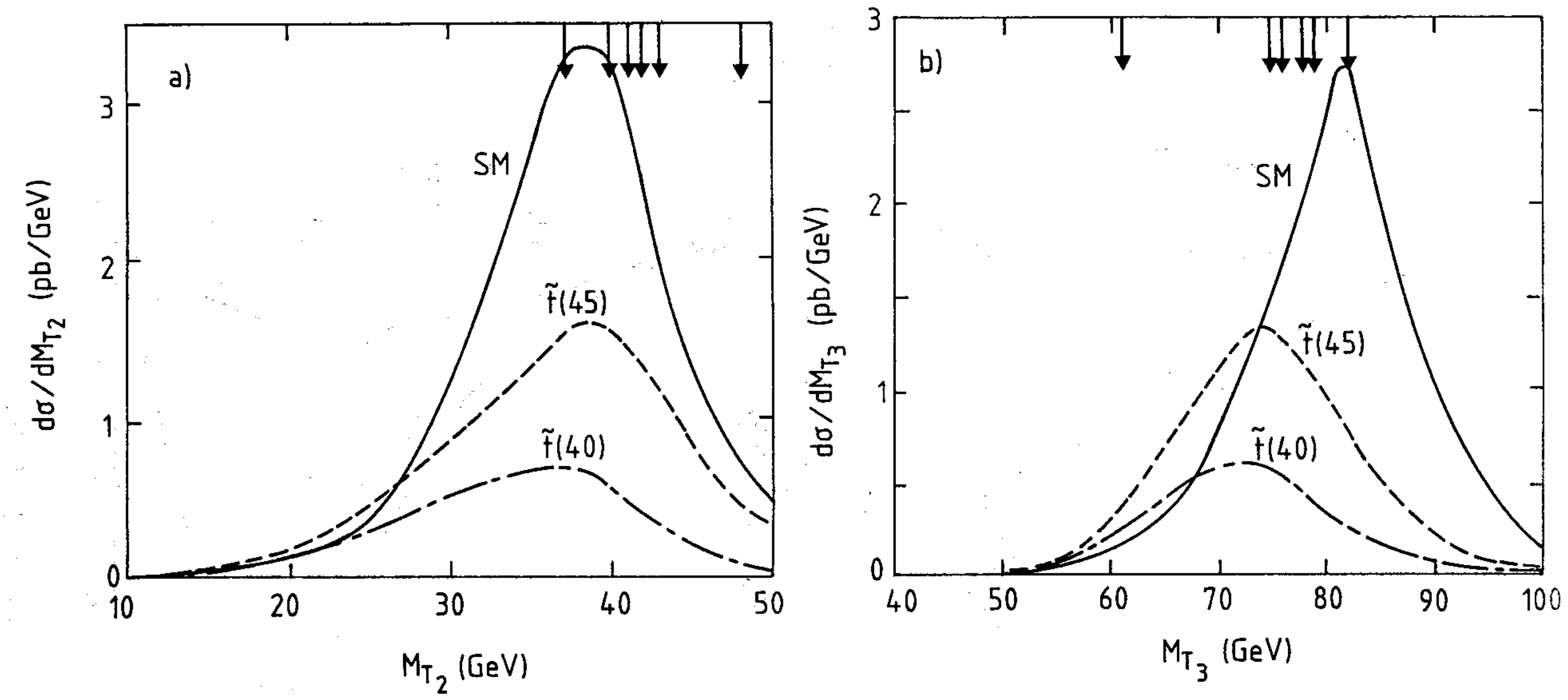
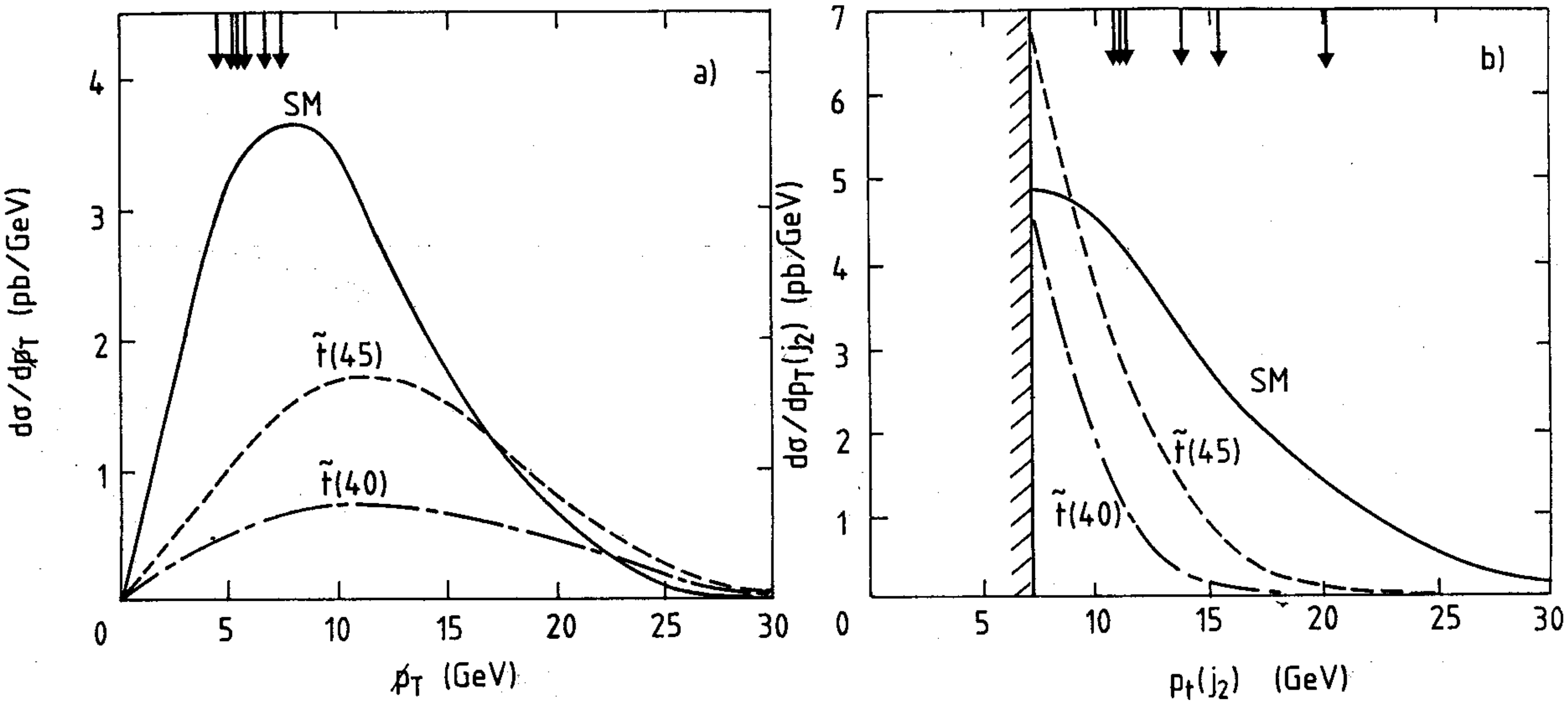
10
1
0.1
0.01
0.001
1E-4
1E-5
σ (pb)
90
100
110
120
130
140
150
160
√s (GeV)
e⁺e⁻ → h⁺t̄b
e⁺e⁻ → h⁺h⁻
m_h=40
m_h=50
60
70
80
40

- Figure 1 -


a)
SM
$\tilde{t}(45)$
$\tilde{t}(40)$
$d\sigma/dM_{T_2}$ (pb/GeV)
0
1
2
3
10
20
30
40
50
M_{T_2} (GeV)
b)
SM
$\tilde{t}(45)$
$\tilde{t}(40)$
$d\sigma/dM_{T_3}$ (pb/GeV)
0
1
2
3
40
50
60
70
80
90
100
M_{T_3} (GeV)

- Figure 2 -

a)
SM
$\tilde{t}(45)$
$\tilde{t}(40)$
$d\sigma/d\not{p}_T$ (pb/GeV)
0
1
2
3
4
0
5
10
15
20
25
30
$\not{p}_T$ (GeV)
b)
SM
$\tilde{t}(45)$
$\tilde{t}(40)$
$d\sigma/dp_T(j_2)$ (pb/GeV)
0
1
2
3
4
5
6
7
5
10
15
20
25
30
$p_t(j_2)$ (GeV)

- Figure 3 -