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# General analysis of single top production and $W$ helicity in top decay

Chuan-Ren Chen <sup>a</sup>, F. Larios <sup>a,b,\*</sup>, C.-P. Yuan <sup>a</sup><sup>a</sup> *Department of Physics and Astronomy, Michigan State University, East Lansing, MI 48824, USA*<sup>b</sup> *Departamento de Física Aplicada, CINVESTAV-Mérida, A.P. 73, 97310 Mérida, Yucatán, Mexico*

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## Abstract

We provide a framework for the analysis of the  $W$  boson helicity in the decay of the top quark that is based on a general effective  $tbW$  coupling. Four independent coupling coefficients can be uniquely determined by the fractions of longitudinal and transverse  $W$  boson polarizations as well as the single top production rates for the  $t$ -channel and the  $s$ -channel processes. The knowledge of these coefficients can be used to discriminate models of electroweak symmetry breaking.

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## 1. Introduction

The top quark stands out as the heaviest elementary particle known to date. It lives very shortly and almost all of the time decays into a  $b$  quark and a  $W$  boson [1]. Because of the top quark mass being of order the electroweak symmetry breaking (EWSB) energy scale, studying the top quark interactions is of great interest. The knowledge of these interactions is required in order to discriminate mechanisms of EWSB. More-

over, because of the top's decay mode  $t \rightarrow bW$ , the  $tbW$  coupling plays a significant role in the physics of the top quark.

One of the main goals at the Fermilab Tevatron and at the CERN Large Hadron Collider (LHC) is to study the production and decay of top quarks. The measurement of single top production cross section has turned out to be a challenging task and no single top events have been observed so far [2]. This non-observation is translated into upper limits of order 5 pb (based on 230 pb<sup>-1</sup> integrated luminosity) for each production channel [2], far above the predictions of the Standard Model (SM) which are of order 1–2 pb. However, it is expected that more luminosity and improved analy-

\* Corresponding author.

E-mail address: [larios@pa.msu.edu](mailto:larios@pa.msu.edu) (F. Larios).

sis methods will eventually achieve detection of SM single top events.

There are three modes in the  $t \rightarrow bW$  decay, depending on the polarization state of the  $W$  boson. Each mode is associated with a fraction,  $f_0$ ,  $f_+$  or  $f_-$ , that corresponds to the longitudinal, right-handed or left-handed polarization, respectively. By definition, we have the constraint  $f_0 + f_+ + f_- = 1$ . Recent reports by the D0 and CDF Collaborations at Fermilab give the following (95% C.L.) results for the longitudinal and right-handed fraction of  $t \rightarrow bW$  in the  $t\bar{t}$  pair events [3]:

$$f_0 = 0.91 \pm 0.38 \text{ (CDF)},$$

$$f_0 = 0.56 \pm 0.32 \text{ (D0)},$$

$$f_+ \leq 0.18 \text{ (CDF)}, \quad f_+ \leq 0.24 \text{ (D0)}.$$

In this work we propose a new strategy to use the measurements on the single top production cross section and on the polarization of the  $W$  boson in the  $t \rightarrow bW$  decay in order to determine the general effective  $tbW$  vertex. Our strategy consists of using four measurements: (a)  $\sigma_s$  and  $\sigma_t$ , the cross sections of the two most important modes of single top quark production at the Tevatron, referred to as  $s$ -channel and  $t$ -channel [4], and (b) two of the three decay ratios,  $f_0$ ,  $f_-$  and  $f_+$ , to determine the four independent couplings that define the general effective  $tbW$  vertex. To emphasize the importance of measuring the  $tbW$  vertex, we will consider two different models of EWSB, and compare their predictions on  $tbW$ . In this manner, we show that the proposed analysis can help us to distinguish different models of EWSB.

## 2. The general approach to study top quark interactions

Currently, the only missing ingredient of the SM is the Higgs boson. This is the agent that causes the breaking of the electroweak symmetry, and LEP II searches have concluded that its mass must be greater than 115 GeV if such particle exists [5]. It is well known that the Higgs mechanism in the SM leaves many important questions unanswered; like what is the real origin of the fermion masses, or what is the explanation for a significant cancellation of higher order corrections to the Higgs mass. As a result, other theo-

ries of EWSB are given much attention in the particle physics community. Theories like the minimal supersymmetric Standard Model (MSSM), the technicolor models, and theories with new top quark interactions suggest some of the answers, but so far no indication of their validity has been found.

Another approach to study the physics that is responsible for EWSB is to focus our attention on the particles that we know exist. Whatever new physics interactions may exist, they must become apparent at an energy scale higher than what we have been able to probe so far. We do not know how high this scale may be. Maybe it lies much higher than the electroweak scale (246 GeV) and if so, the only way we can begin to get information about these interactions is by looking at the effects they produce on the interactions appearing at lower energies. Because of their big masses, the top quark, the  $W$  and the  $Z$  bosons are the prime candidates to show these effects through their interactions.

In this Letter we want to provide a general framework that describes all the possible effects from any physics beyond the SM. This framework is based on the non-linear electroweak chiral Lagrangian [6]. This Lagrangian satisfies the  $SU(2)_L \times U(1)_Y$  symmetry by a non-linear realization, and it is the most general Lagrangian that is consistent with the SM gauge symmetry and that can contain all the possible effects (decoupled and non-decoupled) coming from the physics at higher energy scales. Concerning the  $tbW$  system, it has been shown that the leading dimension 4 and dimension 5 interaction terms that are independent from each other are [7]:

$$\begin{aligned} \mathcal{L}_{(tbW)} = & -\frac{1}{\sqrt{2}} \left( (1 + \kappa_L^{(4)}) \bar{t} \gamma^\mu P_L b \right. \\ & \left. + \kappa_R^{(4)} \bar{t} \gamma^\mu P_R b \right) \mathcal{W}_\mu^+ \\ & + \frac{\kappa_{R(L)}^\sigma}{\Lambda} \bar{b} \sigma^{\mu\nu} P_{R(L)} t D_\mu \mathcal{W}_\nu^- \\ & + i \frac{\kappa_{R(L)}^t}{\Lambda} \mathcal{W}^{-\mu} \bar{b} P_{L(R)} D_\mu t \\ & + i \frac{\kappa_{R(L)}^w}{\Lambda} \bar{b} P_{R(L)} t D^\mu \mathcal{W}_\mu^- + \text{h.c.}, \end{aligned}$$

where  $P_{R(L)}$  are the right- and left-handed chiral projectors  $P_{R(L)} = (1 \pm \gamma_5)/2$ ,  $D_\mu$  is the electromagnetic  $U(1)$  covariant derivative and  $\Lambda$  is the energy scale at which the physics beyond the SM becomes

apparent. The  $t$ ,  $b$  and  $\mathcal{W}^+$  fields are not the usual fermion and vector boson fields. Rather, they are *composite* fields that involve Goldstone boson fields and that transform non-linearly under the gauge group [7]. In the unitary gauge they become the usual fields (e.g.,  $\mathcal{W}^+ = -gW^+$ ). In the remainder of this Letter,  $t$  and  $b$  denote the usual fermion fields for the top and bottom quarks. To simplify our analysis, the  $\kappa$  coefficients are taken to be real so that there are no CP violation effects.

The effective  $tbW$  coupling generated by this Lagrangian contains terms proportional to  $\gamma_\mu$ ,  $\sigma_{\mu\nu}q^\nu$ ,  $p_\mu$  and  $q_\mu$ , with  $p$  and  $q$  the momenta of the top quark and the  $W$  boson, respectively. We can make a simplification of this vertex that is valid for our study. First of all, since the  $t \rightarrow bW$  decay involves quarks on-shell, we can use the well known Gordon identity:

$$(m_b + m_t)\bar{b}\gamma_\mu t = \bar{b}(p_\mu + p'_\mu - i\sigma_{\mu\nu}q^\nu)t,$$

where  $p' = p - q$  is the momentum of the  $b$  quark, and reduce the degrees of freedom to three terms:  $\gamma_\mu$ ,  $\sigma_{\mu\nu}q^\nu$  and  $q_\mu$ . Because of the on-shell condition of the  $W$  boson, the term proportional to  $q_\mu$  will not contribute to the  $t \rightarrow bW$  decay amplitude. Furthermore, this  $q_\mu$  term will neither contribute to the single top production processes, because it will only generate a contribution proportional to the incoming state light quark masses which are usually taken as zero.

Therefore, the effects of our general effective Lagrangian to the processes considered here can be completely described by the following  $tbW$  vertex:

$$\begin{aligned} \mathcal{L}_{tbW} = & \frac{g}{\sqrt{2}} W_\mu^- \bar{b}\gamma^\mu (f_1^L P_L + f_1^R P_R) t \\ & - \frac{g}{\sqrt{2}M_W} \partial_\nu W_\mu^- \bar{b}\sigma^{\mu\nu} (f_2^L P_L + f_2^R P_R) t \\ & + \text{h.c.}, \end{aligned} \quad (1)$$

where we have changed the mass scale  $\Lambda$  to  $m_W$  to keep the same notation used in the literature [8,9].

In the SM the values of the form factors are  $f_1^L = V_{tb} \simeq 1$ ,  $f_1^R = f_2^L = f_2^R = 0$ . To focus on deviations from SM values, let us define  $f_1^L \equiv 1 + \epsilon_L$ .

It is well known that  $b \rightarrow s\gamma$  can impose a strong constraint on  $f_1^R$  and  $f_2^L$  to be less than 0.004 [10,11]. These constraints can be viewed as the result of an  $m_b$  suppression for right-handed bottom quark couplings [11]. On the other hand,  $b \rightarrow st^+l^-$  can be sensitive

to a left-handed bottom quark coupling like  $f_2^R$ , and it can impose a constraint of order 0.03 [11]. For  $\epsilon_L$ , the LEP precision data imposes some constraint but only in correlation with similar neutral current anomalous  $ttZ$  couplings. Assuming no deviations from the SM  $ttZ$  vertex we would have that  $\epsilon_L \leq 0.02$  [10]. To bear in mind, these constraints assume there are no other sources of new physics that could cancel the effects of these couplings on the data. Moreover, the dimension 5 couplings  $f_2^R$  and  $f_2^L$  may induce a bad high energy behavior in top quark production processes, hence, we will consider values at most of order 0.5 in order to satisfy the unitarity condition [12].

Studies of the dimension 5 couplings  $f_2^{L,R}$  in connection with the single top quark production at hadron colliders have shown that a sensitivity of order 0.2 (0.05) might be achieved at the Tevatron (LHC) [13]. Information on the helicity of the  $W$  boson in  $t \rightarrow bW$  can be obtained by measuring a forward–backward asymmetry ( $A_{\text{FB}}$ ) based on the angle between the charged lepton and the  $b$ -jet of the observed decay process [14]. Preliminary studies show that if  $A_{\text{FB}}$  is measured with 20% accuracy at the Tevatron, it may be sensitive to values of order  $f_2^{L,R} \sim 0.3$ ; similarly, if  $A_{\text{FB}}$  is measured with 1% accuracy at the LHC this may be translated to a sensitivity of order  $f_2^L \sim 0.03$  and  $f_2^R \sim 0.003$  [9].

We would like to point out that, since the observable  $A_{\text{FB}}$  is only proportional to the difference between  $f_+$  and  $f_-$  [14], it is clear that it does not provide any more information than the separate measurements of (two of) the ratios  $f_0$ ,  $f_-$  and  $f_+$ .

Let us summarize the status of the SM predictions for the observables of our study: the cross sections  $\sigma_t$  and  $\sigma_s$ , and the branching fractions  $f_0$ ,  $f_+$  and  $f_-$ . In Table 1 we show the leading order (LO) and the next-to-leading order (NLO) SM predictions for  $\sigma_t$  and  $\sigma_s$  at the Tevatron and at the LHC [4]. For the LO predictions the CTEQ6L1 parton distribution function (PDF) has been used [15]. For the NLO predictions the CTEQ6M PDF has been used [4]. In this Letter we are taking the mass of the top quark as  $m_t = 178$  GeV and the mass of the  $W$  boson as  $m_W = 80.4$  GeV.

Neglecting terms proportional to the bottom mass, the Born level values of the top quark width and its  $W$ -polarization ratios are  $\Gamma_t = 1.65$  GeV,  $f_0 = 0.71$ ,  $f_- = 0.29$  and  $f_+ = 0$ . In the SM, including terms

Table 1

SM single top production cross section predictions in units of pb [4]. The mass of the top quark is taken as  $m_t = 178$  GeV

Channel	Tevatron ( $t$ LO)	( $t$ NLO)	LHC ( $t$ LO)	( $t$ NLO)	LHC ( $\bar{t}$ LO)	( $\bar{t}$ NLO)
$t$ -channel	0.827	0.924	146.0	150.0	84.9	88.5
$s$ -channel	0.27	0.405	4.26	6.06	2.59	3.76

proportional to  $m_b$ , order  $\alpha_s^2$  QCD, electroweak, and finite  $W$  width corrections produce a 10% decrease in the top's width ( $\Gamma_t = 1.49$ ) and a small  $\sim 1\%$  variation for decay ratios ( $f_0 = 0.701$ ,  $f_- = 0.297$  and  $f_+ = 0.002$ ) [14].

In this work we will be interested in deviations from the SM values (up to the NLO) that come from the effects of the anomalous  $\epsilon_L$ ,  $f_1^R$ ,  $f_2^L$  and  $f_2^R$  couplings, cf. Eq. (1), induced by heavy new physics effects. In the following, we will write down the Born level contributions of these couplings on the observables  $f_0$ ,  $f_+$ ,  $f_-$ ,  $\sigma_t$  and  $\sigma_s$ .

### 3. Single top production and $W$ helicity in $t \rightarrow bW$ decay

The tree level  $t \rightarrow bW$  decay width of the top quark with the general  $tbW$  vertex can be easily obtained with the helicity amplitude method, and it is given by [8]:

$$\begin{aligned}
 \Gamma_t &= \Gamma_0 + \Gamma_- + \Gamma_+ \\
 &= \frac{g^2 m_t}{64\pi} \frac{(a_t^2 - 1)^2}{a_t^4} (a_t^2 L_0^2 + 2T_m^2 + 2T_p^2), \\
 L_0^2 &\equiv 1 + x_0 = \left( f_1^L + \frac{f_2^R}{a_t} \right)^2 + \left( f_1^R + \frac{f_2^L}{a_t} \right)^2, \\
 T_m^2 &\equiv 1 + x_m = (f_1^L + a_t f_2^R)^2, \\
 T_p^2 &\equiv x_p = (f_1^R + a_t f_2^L)^2, \\
 a_t &\equiv \frac{m_t}{m_W}. \tag{2}
 \end{aligned}$$

As the notation suggests,  $x_0$ ,  $x_m$  and  $x_p$  are the effective terms that originate the contribution to  $f_0$ ,  $f_-$  and  $f_+$ , respectively. Below, we will write down the explicit expressions for these decay ratios.

The  $t$ -channel total cross section at the parton level comes from two processes:  $ub \rightarrow dt$  and  $\bar{d}b \rightarrow \bar{u}t$ . For the first one the expression is:

$$\begin{aligned}
 \sigma(ub \rightarrow dt) &= \frac{g^4}{64\pi s} (I_0 L_0^2 + I_m T_m^2 + I_p T_p^2 - I_i x_i + I_5 x_5), \\
 I_0 &= x_t (C_b - C_a), \\
 I_m &= C_a - x_t C_b, \\
 I_p &= I_m + (1 + C_{tw})(x_w C_a - C_l) + 1 - x_t - x_w C_l, \\
 I_i &= \frac{\ln x_t + C_{tw} C_l}{x_t - x_w}, \\
 I_5 &= 1 - \frac{1 + \ln x_t}{x_t} - \frac{2I_i}{a_t^2}, \\
 x_5 &= a_t^2 (f_2^{L2} + f_2^{R2}), \\
 x_i &= 2a_t (f_1^L f_2^R + f_2^L f_1^R) \\
 &= \frac{a_t^2}{a_t^2 - 1} (x_m + x_p - x_0) - \frac{1 + a_t^2}{a_t^2} x_5, \tag{3}
 \end{aligned}$$

where  $s = (p_u + p_b)^2$  is the total energy squared of the colliding partons. We have defined the following terms:

$$\begin{aligned}
 x_t &= \frac{m_t^2}{s}, & x_w &= \frac{m_w^2}{s}, \\
 C_{tw} &= 1 - x_t + x_w, & C_l &= \ln \frac{C_{tw}}{x_w}, \\
 C_a &= \frac{1 - x_t}{x_w C_{tw}}, & C_b &= \frac{C_a}{x_t - x_w} - \frac{C_l + \ln x_t}{(x_t - x_w)^2}.
 \end{aligned}$$

The formula for  $\bar{d}b \rightarrow \bar{u}t$  can be obtained from Eq. (3) by interchanging the coupling coefficients  $f_1^L \leftrightarrow f_1^R$  and  $f_2^L \leftrightarrow f_2^R$  (or simply,  $T_m^2 \leftrightarrow T_p^2$ ). For the anti-top production we have  $\sigma(\bar{u}\bar{b} \rightarrow \bar{d}\bar{t}) = \sigma(\bar{d}\bar{b} \rightarrow \bar{u}\bar{t})$  and  $\sigma(\bar{d}\bar{b} \rightarrow \bar{u}\bar{t}) = \sigma(ub \rightarrow dt)$ .

The  $s$ -channel total cross section at the parton level is:

$$\begin{aligned}
 \sigma(u\bar{d} \rightarrow t\bar{b}) &= \frac{g^4}{128\pi s} \frac{(s - m_t^2)^2}{(s - m_t^2)^2 + m_w^2 \Gamma_w^2} \\
 &\quad \times (T_m^2 + T_p^2 - I_s), \\
 I_s &= \left( f_1^{L2} + f_1^{R2} - \frac{x_5}{x_t} \right) \frac{1 - x_t}{3}. \tag{4}
 \end{aligned}$$

Table 2

The single top production cross-section coefficients of Eqs. (7)–(8). In units of pb

$t$ -channel:	$a_0$	$a_m$	$a_p$	$a_5$
Tevatron	0.896	−0.069	−0.153	0.292
LHC ( $t$ )	165.2	−19.1	−34.2	71.7
LHC ( $\bar{t}$ )	105.8	−20.9	−12.5	44.5
$s$ -channel:	$b_0$	$b_m$	$b_p$	$b_5$
Tevatron	−0.081	0.352	0.352	0.230
LHC ( $t$ )	−1.41	5.67	5.67	6.34
LHC ( $\bar{t}$ )	−0.836	3.43	3.43	3.38

Where  $\Gamma_w = 2.1$  GeV is the  $W$  boson's width. The cross section formula for  $u\bar{d} \rightarrow t\bar{b}$  is the same as above. To write Eq. (4) in terms of the variables  $x_0$ ,  $x_m$ ,  $x_p$  and  $x_5$ , we can use the relation:  $f_1^L + f_1^R = 1 + x_m + x_p - x_5 - x_i$ .

In summary, the contributions of the effective  $tbW$  couplings to the observables of interest are:

$$f_0 = \frac{x_t^2(1+x_0)}{x_t^2(1+x_0) + 2(1+x_m+x_p)}, \quad (5)$$

$$f_+ = \frac{2x_p}{x_t^2(1+x_0) + 2(1+x_m+x_p)},$$

$$f_- = \frac{2(1+x_m)}{x_t^2(1+x_0) + 2(1+x_m+x_p)}, \quad (6)$$

$$\Delta\sigma_t = a_0x_0 + a_mx_m + a_px_p + a_5x_5, \quad (7)$$

$$\Delta\sigma_s = b_0x_0 + b_mx_m + b_px_p + b_5x_5, \quad (8)$$

where  $\Delta\sigma$  stands for the variation from the SM NLO prediction. The numerical values of the  $a_i$  and  $b_i$  coefficients are given in Table 2 for the Tevatron and the LHC. They have been obtained by integrating over the parton luminosities which are evaluated using the PDF CTEQ6L1 [15].

Eqs. (5)–(8) can be used to make a general analysis of the effective  $tbW$  vertex. We note that in case a new light resonance is found, like a scalar or vector boson, the  $s$ -channel process could be significantly enhanced and its production rate may not be dominated by a virtual  $W$ -boson  $s$ -channel diagram [16].

The above formulas (summarized in Eqs. (5)–(8)) also apply to models with extra heavy fermion ( $t'$ ), such as the little Higgs models [17], that couples to the SM  $b$  quark and  $W$  boson. The  $t'bW$  coupling in general has the same form of our general  $tbW$  coupling, and the expressions for single- $t'$  production cross sec-

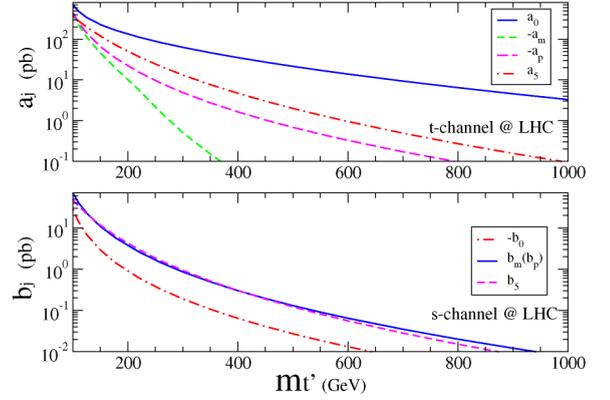


Fig. 1. The coefficients for the  $s$ - and  $t$ -channels of single  $t'$  production as given by Eqs. (7) and (8) at the LHC.

tions are exactly the same as single-top except for the heavy mass  $m_{t'}$ . The size of the coefficients in the production cross sections decrease drastically with a greater mass  $m_{t'}$ . In Fig. 1 we show their dependence with respect to  $m_{t'}$ . For instance, at  $m_{t'} = 500$  GeV the  $a_0$  coefficient decreases one order of magnitude with respect to the value for  $m_{t'} = 178$  GeV. Furthermore, in the  $t$ -channel single- $t'$  process, the  $a_0$  coefficient, corresponding to longitudinal  $W$  boson contribution, dominates its production cross section.

#### 4. Models of EWSB

For the second part of this Letter, we would like to illustrate how this approach can be used to make distinction among different models of EWSB beyond the SM. For simplicity, we assume that no right-handed bottom quark couplings are present, i.e.,  $f_1^R \simeq 0$ ,  $f_2^L \simeq 0$ . Thus, we only need two observables, like  $f_0$  and  $\sigma_t$ , to make our analysis.

At this time it is convenient to notice that  $f_0$  will not depend on  $\epsilon_L (\equiv f_1^L - 1)$  if the other three couplings are zero. In our simplified scenario, if  $f_0$  (and  $f_-$ ) departs from the SM prediction then  $f_2^R$  cannot be zero. In fact, the sign of  $\Delta f_- \equiv f_- - f_-^{\text{SM}}$  is fixed by the sign of  $f_2^R$ .

We would like to consider two models in particular:

- The minimal supersymmetric Standard Model (MSSM) with  $\tan\beta > 1$  studied in Ref. [18], and

- the topcolor assisted technicolor model (TC2) considered in Ref. [19].

Let us start with the case of the MSSM discussed in Ref. [18]. Concerning the  $W$ -polarization in  $t \rightarrow bW$  decay, electroweak-supersymmetry (SUSY) and QCD-SUSY corrections are of order a few percent and tend to cancel each other. The overall effect is to increase the left-handed decay mode at the expense of reducing the longitudinal mode. Thus, for most of the SUSY parameter space the prediction is for a positive  $f_2^R$ . It is not true that  $f_2^R$  must be positive for all of the MSSM parameter space, but we can consider the positive sign of this coupling as an indication of some scenarios of MSSM [18].

As for the second model, the TC2 scalars that couple strongly with the top quark will modify the  $tbW$  vertex in such a way as to reduce  $f_-$  in favor of  $f_0$  [19]. This means that in this case the sign of  $f_2^R$  must be negative.

From the above discussion we can see that these two models have a general tendency to predict opposite signs for the coupling  $f_2^R$ . The size and sign of the other coefficient  $\epsilon_L$  may depend on the corresponding set of parameters of each model, let us assume the following values as representative of each model:

$$\begin{aligned} \text{MSSM: } \quad \epsilon_L &= 0.01, & f_2^R &= 0.005, \\ \text{TC2: } \quad \epsilon_L &= -0.01, & f_2^R &= -0.005. \end{aligned} \quad (9)$$

These numerical values were chosen such that the predictions for the observables are consistent with the results shown in Refs. [18,19]. (In the TC2 model, the size of the allowed  $\epsilon_L$  and  $f_2^R$  could be much larger [19].) Here, we ignore the  $q^2$  dependence of the form factors. This is a reasonable approximation for the study of  $t \rightarrow bW$ . Furthermore,  $\sigma_t$  comes predominantly from the small region of the invariant mass of the  $t\bar{b}$  pair, where the variation on  $q^2$  can be ignored.

In Table 3 we show the predictions of the two models on the proposed observables. Here, we do not include possible new production channels for the  $s$ -channel single top events. For example, it can be produced from a  $W'$  resonance whose contribution to  $\sigma_s$  depends on the other parameters of the model. Nevertheless, the  $t$ -channel production rate  $\sigma_t$  is less sensitive to the other parameters because the heavy resonance state contribution is suppressed by its large

Table 3

Different model predictions for  $f_0$ ,  $f_-$ ,  $\sigma_t$ ,  $\sigma_s$  and  $\Gamma_t$ . Production of  $\bar{t}$  is not included

	MSSM	TC2
$\epsilon_L$	0.01	-0.01
$f_2^R$	0.005	-0.005
$\Delta f_0/f_0^{\text{SM}}$	-0.5%	0.5%
$\Delta f_-/f_-^{\text{SM}}$	1.2%	-1.2%
(Tevatron) $\Delta\sigma_t/\sigma_t^{\text{SM}}$	2.1%	-2.0%
(Tevatron) $\Delta\sigma_s/\sigma_s^{\text{SM}}$	3.2%	-3.1%
(LHC) $\Delta\sigma_t/\sigma_t^{\text{SM}}$	2.2%	-2.1%
(LHC) $\Delta\sigma_s/\sigma_s^{\text{SM}}$	3.4%	-3.3%
$\Delta\Gamma_t/\Gamma_t^{\text{SM}}$	3.5%	-3.4%

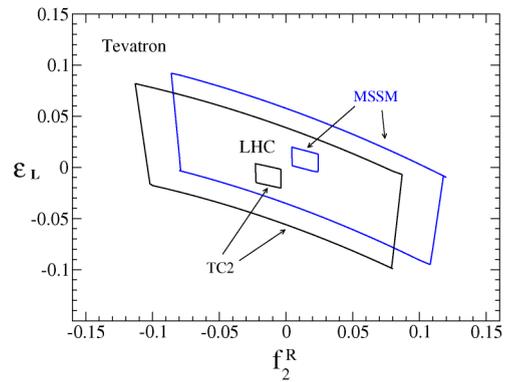


Fig. 2. Possible scenarios and the allowed  $f_2^R$  vs  $\epsilon_L$  region as given by measurements at the Tevatron and the LHC.

mass. Therefore, we shall concentrate on the measurements of  $f_0$  and  $\sigma_t$  in the following.

In Fig. 2 we show the sensitivity of the Tevatron and the LHC to the determination of the couplings  $\epsilon_L$  and  $f_2^R$  for the above two model scenarios. We assume that  $f_0$  ( $\sigma_t$ ) can be measured to 10% (10%) accuracy at the Tevatron, and to 1% (2%) accuracy at the LHC [1]. As for the LHC potential to measure single top production, the CKM matrix element  $V_{tb}$  could be measured down to less than one percent error (statistical error only) at the ATLAS detector [20]. We conclude that the MSSM and TC2 could be distinguished from each other at the LHC, but not at the Tevatron.

We want to emphasize that in general all four observables of Eqs. (5)–(8) are needed to determine the four couplings of the  $tbW$  vertex and to make a complete analysis that could test the different models of EWSB.

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