Constraining anomalous top quark couplings at the Fermilab Tevatron

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We explore the influence of an anomalous chromomagnetic moment κ on the production characteristics of top quark pairs at the Fermilab Tevatron with a center-of-mass energy of $\sqrt{s} = 1.8$ TeV. We find that for top quarks in the 175 GeV mass range, present measurements are probing values of κ of order 0.25. We discuss a class of technicolor models with techniscalars which may produce such large values of κ in conjunction with the generation of m_t. For κ's in this range we find that significant enhancements in both the $q\bar{q}$, $gg \to t\bar{t}$ production cross sections are obtained. Once sufficient statistics have been accumulated and QCD uncertainties are under control, future high precision measurements at the Fermilab Tevatron will eventually be sensitive to values of κ with magnitudes smaller than $\simeq 0.1$.

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The discovery of the top quark at the Fermilab Tevatron by the Collider Detector at Fermilab (CDF) and D0 Collaborations [1,2] in the mass range anticipated by precision electroweak data [3] represents a great triumph for the standard model (SM). Once more data become available, a detailed study of the nature of the top quark (e.g., width, couplings, production properties) at both hadron [4] and e^+e^- [5] colliders may yield significant information on new physics which lies somewhere beyond current energy scales. Existing indirect constraints on several of the top quark's properties from low energy data are relatively poor [6] and leave plenty of room for new physics. At the present time the CDF and D0 results seem to be *roughly* in accord with the expectations of QCD [7]. However, the cross section as determined by both CDF and D0 does appear to be somewhat above the SM prediction which has prompted much theoretical speculation [8] as to new dynamics which may be present. This is shown explicitly in Fig. 1 which compares the data from both the CDF and D0 Collaborations with the most recent next-to-leading order (NLO) theoretical calculations by Laenen, Smith, and van Neerven, which include soft gluon resummation [7]. A well-established difference between the predictions of QCD and the Tevatron experiments would indicate the presence of new physics. If the source of this new physics is at the TeV scale, then the leading effect should, as a first approximation, be parametrized by a QCD chromomagnetic dipole moment since this is the lowest dimension CP-conserving operator arising from an effective Lagrangian contributing to the gluon–top-quark coupling.

In this paper we will (i) consider the possibility that the top quark possesses a nonzero anomalous chromodynamic dipole moment κ in its coupling to gluons and explore the implications of such a scenario for top pair production at the Tevatron with a center of mass energy of $\sqrt{s} = 1.8$ TeV, (ii) present a model based on extended technicolor ideas, but with ETC gauge bosons replaced by techniscalars that yields values of κ in the interesting range, and (iii) explore the limits that future Tevatron data may impose on the allowed range of κ. To get an idea of how large κ might be due to new physics, one notes that if the gluon is removed from a chromodynamic dipole moment graph one is often left with a finite contribution to the top quark mass. If this is the origin of the top quark mass, dimensional analysis implies that κ is $O(m_t^2/\Lambda^2)$, where Λ is the scale of new physics. As we will see, this suggests that there is new physics below 1 TeV if there is a substantial increase in the $t\bar{t}$ production cross section due to nonzero κ. Chromomagnetic dipole moments in association with quark mass generation can occur quite naturally in composite models and in technicolor models. Following a phenomenological discussion we will show that in a class of scalar technicolor models [9,10] it may be possible to obtain $\kappa \sim \frac{1}{4}$, resulting in an $\sim$50% increase in the $t\bar{t}$ production cross section at the Tevatron.

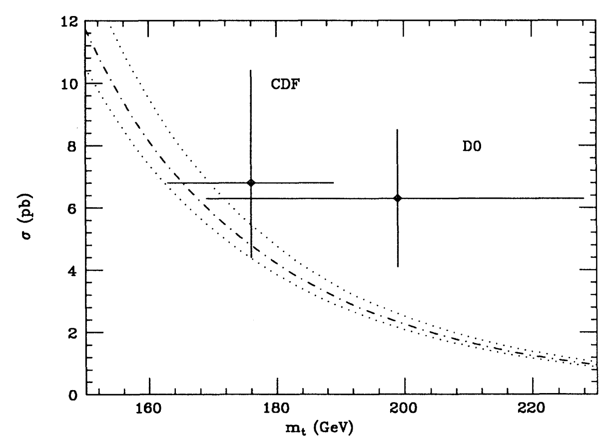

FIG. 1. Theoretical NLO cross section (dash-dotted curve) for $t\bar{t}$ production at the Tevatron, including gluon resummation, as a function of the top quark mass from the work of Laenen *et al.* [7] and the corresponding anticipated uncertainty due to scale choice (dotted curves). The data points are the CDF and D0 results.

At this point we remind the reader that by "anomalous" magnetic moment we mean a value over and above that which may be induced by loop corrections within the SM or any of its simpler extensions. These weak effects are generally of order α/π, a value far smaller than the range of interest which we will deal with below, i.e., $\kappa \simeq 0.1$. We assume that all these small corrections will be included in any high precision comparison between the theoretical predictions of the top cross section and what is actually measured by either CDF or D0.

To begin our analysis, we consider the piece of the Lagrangian which governs the $t\bar{t}g$ coupling:

$$\mathcal{L} = g_s \bar{t} T_a \left(\gamma_\mu + i \frac{F_2}{2m_t} \sigma_{\mu\nu} q^\nu \right) t G_a^\mu , \tag{1}$$

where g_s and T_a are the usual $\mathrm{SU}(3)_c$ coupling and generators, m_t is the top quark mass, q is the gluon momentum, and F_2 represents a q^2-dependent form factor. For $|q^2| \ll \Lambda^2$, the intrinsic scale in the form factor, we define $F_2 = \kappa$ following the usual notation. In order to examine the effects of nonzero κ on $t\bar{t}$ production, we must first calculate the parton-level $q\bar{q} \to t\bar{t}$ and $gg \to t\bar{t}$ differential cross sections. For the $q\bar{q}$ case we obtain [11,12]

$$\frac{d\sigma_{q\bar{q}}}{d\hat{t}} = \frac{8\pi\alpha_s^2}{27\hat{s}^2} \left[\left(1 + \frac{2m_t^2}{\hat{s}} \right) + 3F_2 + F_2^2 \left(\frac{\hat{s}}{8m_t^2} + 1 \right) + \frac{\beta^2}{4}(3z^2 - 1) \left(1 - \frac{\hat{s}}{4m_t^2} F_2^2 \right) \right] , \tag{2}$$

with $\hat{s}$ being the parton level center of mass energy, $\beta^2 = 1 - 4m_t/\hat{s}$, and z being the cosine of the corresponding scattering angle θ^* as defined via the usual relations

$$\hat{t} = \frac{-\hat{s}(1-\beta z)}{2} + m_t^2 , \qquad \hat{u} = \frac{-\hat{s}(1+\beta z)}{2} + m_t^2 , \tag{3}$$

with $\beta = (1 - 4m_t^2/\hat{s})^{1/2}$. In this expression, F_2 is evaluated at $q^2 = \hat{s}$; note the quadratic dependence on F_2. Since top quark pair production at the Tevatron for masses near 175 GeV is dominated by the threshold region of the $q\bar{q}$ annihilation process (at least for κ near zero), a brief discussion of the influence of finite F_2 on the parton-level process is relevant. For $\hat{s} \simeq 4m_t^2$, we see that F_2 has two important effects on the differential cross section: (i) the angular dependence is softened and (ii) the total cross section has a minimum at $F_2 = -\frac{1}{2}$ and grows rapidly as F_2 increases in a positive manner away from zero. For example, the near-threshold cross section for $F_2 = 0.5$ is 2.5 times larger than for $F_2 = 0$. We expect these qualitative results to be maintained even after folding with the parton distributions and all integrations are performed as will be verified by explicit calculation below.

In ordinary LO and NLO QCD, for top quarks in the mass range of interest, one finds that the $q\bar{q} \to t\bar{t}$ subprocess contributes almost 90% of the entire cross section. As we will see below, the dominance of this process remains even when κ is nonzero provided its magnitude is not too large, say, $\kappa < 1$. It is thus worthwhile to briefly explore the influence of F_2 with Λ finite on the LO $q\bar{q} \to t\bar{t}$ subprocesses. To do this, we simply fold the above differential distribution with the structure functions of the CTEQ Collaboration [13], thus obtaining the results presented in Fig. 2. We assume for these results that F_2 can be simply expressed in the simple form

$$F_2 = \kappa \left(1 + \frac{\hat{s}}{\Lambda^2} \right)^{-n} , \tag{4}$$

at least as a first approximation. (For simplicity we assume $n = 1$ in what follows but our results are easily generalized.) We see immediately that once Λ approaches 1–2 TeV there is not much influence from Λ being finite as expected from the discussion above. The reason for this is the fact that most of the weight of the subprocess cross section comes from the threshold region. For simplicity, we will take Λ to infinity in our phenomenological calculations below. However, we will use the results of Fig. 2 to estimate the effects of finite Λ on the total $t\bar{t}$ production cross section. The sensitivity of the LO $q\bar{q} \to t\bar{t}$ subprocess to finite κ is clearly demonstrated by this figure as we see that the cross section scales by factors of order 5–10 as κ varies between 1 and -1. This sensitivity will persist in the more detailed calculations below.

The case of the $gg \to t\bar{t}$ differential cross section is much more complicated; let us for simplicity again consider the limit where $\Lambda \gg \hat{s}$ so that we can make the replacement $F_2 \to \kappa$. Even in this "simpler" situation, we must add an additional, dimension-5, four-point $t\bar{t}gg$ interaction proportional to κ to maintain gauge invariance [14]. This term arises from the non-Abelian part of the product $\sigma_{\mu\nu} G_a^{\mu\nu}$, where $G_a^{\mu\nu}$ is the gluon field strength tensor. Defining the kinematic abbreviations

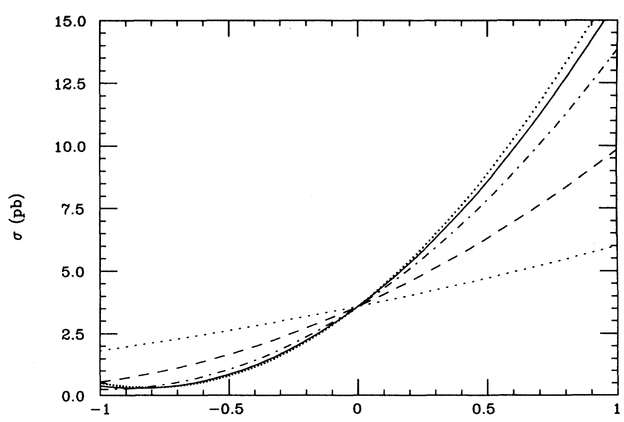

FIG. 2. LO calculation of $q\bar{q} \to t\bar{t}$ production cross section using CTEQ2 structure functions assuming $m_t = 170$ GeV as a function of κ. The dotted (dashed, dash-dotted, solid, square-dotted) curves correspond to $\Lambda = 0.25$ (0.5, 1, 2, ∞) TeV, respectively.

$$x = \frac{m_t^2}{\hat{s}},$$
$$K = \frac{\kappa}{2\sqrt{x}}, \tag{5}$$
$$d = 1 - z^2 + 4xz^2,$$

the resulting differential cross section can be written as

$$\frac{d\sigma_{gg}}{d\hat{t}} = \frac{\pi\alpha_s^2}{64\hat{s}^2}[T_0 + T_1K + T_2K^2 + T_3K^3 + T_4K^4] \ , \tag{6}$$

a quartic polynomial in κ, where the T_i can be written as

$$\begin{aligned} T_0 &= 4(36xz^2 - 7 - 9z^2)(z^4 - 8xz^4 + 16x^2z^4 - 32x^2z^2 + 8xz^2 + 32x^2 - 8x - 1)/3d^2 \ , \\ T_1 &= -32(36xz^2 - 7 - 9z^2)\sqrt{x}/3d \ , \\ T_2 &= -16(72x^2z^2 - 46xz^2 + 7z^2 - 16x - 7)/3d \ , \\ T_3 &= 32(-7z^2 + 28xz^2 - 5x + 7)\sqrt{x}/3d \ , \\ T_4 &= 16(-8xz^4 + 16x^2z^4 + z^4 - 4x^2z^2 + 9xz^2 - 2z^2 + 1 - x + 4x^2)/3d \ . \end{aligned} \tag{7}$$

This result is easily seen to reduce to the more conventional one when $\kappa \to 0$. One might expect that the sensitivity of the $gg \to t\bar{t}$ differential cross section may be somewhat greater than the $q\bar{q}$ case since it is a quartic function of κ. As in the $q\bar{q}$ case, near threshold the $gg \to t\bar{t}$ cross section increases as κ increases in the positive direction. For $\kappa = 0.5$, the cross section is more than twice as large as what one finds for $\kappa = 0$. When finite Λ corrections become important the calculation of the $gg \to t\bar{t}$ cross section becomes even more intricate since the form factors would then be evaluated at $q^2 = 0$ in the $\hat{t}$- and $\hat{u}$-exchange diagrams, but at $q^2 = \hat{s}$ in both the s-channel and four-point diagrams. The fact that different scales are involved results in a further violation of $SU(3)_c$ gauge invariance because delicate gauge cancellations are no longer taking place. To cure this new problem, we need to add an *additional* four-point interaction, as was discussed in Ref. [14], whose contribution to the amplitude is proportional to the difference $F_2(\hat{s}) - F_2(0)$. Since the cross section is dominated by the threshold region and we are working in the large Λ limit, these additional contributions to the $gg \to t\bar{t}$ amplitude can be ignored. Indeed, since the gg contributions to $t\bar{t}$ production remain subleading in comparison to those from $q\bar{q}$ for top quark masses in the 175 GeV range and values of κ of interest to us, we will set $F_2(\hat{s}) = F_2(0) = \kappa$ in the gg contribution in what follows.

To proceed further, we follow Ref. [7] and include NLO and gluon resummation corrections; note that these are the *conventional* QCD corrections and not the additional κ-dependent ones that can arise in higher order. Our philosophy will be to treat the new κ-dependent terms in LO only and include just the SM NLO corrections in the analysis below. Putting this all together we arrive at Fig. 3 which shows the separate contributions of the $q\bar{q} \to t\bar{t}$ and $gg \to t\bar{t}$ subprocesses as well as their sum in comparison with both the CDF and D0 results as a function of κ assuming that $m_t = 176$ GeV, the central value obtained by CDF. In order to compare directly with [7] and the Tevatron data, we make use of the parton densities of Martin-Roberts-Stirling set A (MRSA) [15]. Here we see explicitly some of the general features discussed above (i) For $\kappa >$ (<)0, the cross section is larger (smaller) than the SM prediction; certainly, negative values of κ are not favored by the existing data. (ii) For $\kappa \neq 0$, the relative weights of the gg and $q\bar{q}$ subprocesses are altered although $q\bar{q}$ remains dominant for $\kappa > 0$. For $-1 \leq \kappa \leq -0.5$ we see that both contributions are small and have comparable magnitudes. (iii) To increase the total cross section to near the *central values* of the results found by CDF and D0 would require values of κ in the approximate range 0.2–0.3. From Fig. 2 we see that this conclusion will not be substantially altered for finite values of $\Lambda \geq \frac{1}{2}$ TeV. Clearly, new top quark production cross section determinations from both the CDF and D0 collaborations are eagerly awaited.

If κ is nonzero, are the detectors' acceptances and efficiencies for finding the top quark altered significantly? As we will see below, the rapidity, p_t, pair invariant mass, and center of mass production angle distributions for top are *not* significantly altered in shape when κ is in the range of interest to us. In addition, the presence of κ does not alter in any significant manner the various top decay branching fractions from SM expectations. This implies that to a very good approximation $t\bar{t}$ production with a small, nonzero κ is essentially indistinguishable

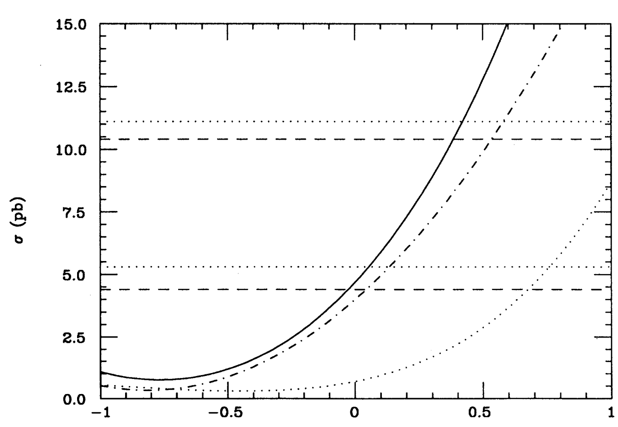

FIG. 3. NLO cross sections for the $q\bar{q} \to t\bar{t}$ (dash-dotted curve) and $gg \to t\bar{t}$ (dotted curve) subprocesses as well as the total cross section (solid curve) at the Tevatron as functions of κ for $m_t = 176$ GeV, the central value from CDF, using the MRSA parton distribution functions. The horizontal dashed (dotted) lines provide the $\pm 1\sigma$ CDF (D0) cross section determinations.

from the SM except in overall rate.

If the top cross section eventually settles down to its SM value we can use the results in Fig. 3 to estimate limits on the value of κ. Of course, there are many sources of both theoretical and experimental error which play important roles in determining the allowed κ range. (For purposes of demonstration we will use the results obtained by CDF to estimate potential future constraints on the value of κ.) On the theoretical side, one has to deal with (a) scale ambiguities, (b) variations in parton densities, and (c) NNLO corrections; the size of these uncertainties we can estimate from the literature. Laenen *et al.* [7] provide us with an estimate of the uncertainty in the total cross section due to various scale choices: +14.5%, −8.6%, for top quarks in the mass range of interest. In a recent paper, Martin, Stirling, and Roberts (MRS) [16] have discussed the variation in the $t\bar{t}$ production cross section at the Tevatron with the choice of (modern) parton densities (PD's). From their analysis, and the fact that top pairs are dominantly produced at large x, we see that the PD uncertainty is rather small with the variations in the central value of the top cross section being of order 2–3 %. In order to estimate the potential size of the NNLO corrections, we compare the MRS NLO result with that given by Laenen *et al.*, which includes soft gluon resummation for the same choice of PD's. The difference between the two predictions is only about 4%. *If* this resummation procedure represents the dominant part of the NNLO corrections, then we can conclude that these NNLO corrections at most, yield an additional 4% uncertainty in the cross section. Of course, a complete NNLO calculation has *not* yet been performed. In Ref. [7], the authors have actually presented us with three estimates of the $t\bar{t}$ cross section [17] at the Tevatron: (1) a full NLO calculation with soft collinear gluons resummed and a "conservative" value of α_s, (2) an improved all-orders resummed calculation with a conservative value of the scale parameter μ to minimize the contribution of higher order terms, and (3) a similar calculation assuming a smaller value of μ which implies larger higher order terms. In principle, these authors believe that even smaller values of μ (and, hence, a larger cross section) may be possible [17], but would lead us to strongly question the numerical convergence of perturbation theory. A full NNLO calculation is really mandatory in addressing these issues.

However, for our purposes, we believe that by including in the overall theoretical uncertainty contributions from scale choices, parton densities, as well as this difference between the NLO and resummed cross sections we should already cover any of the *additional* uncertainties associated with the lack of a full NNLO calculation. We can imagine that once the Tevatron-integrated luminosity approaches 1–5 fb^{-1}, the luminosity range where such high precision studies are potentially possible, such calculations will be available to incorporate into future analyses of anomalous top couplings. As our estimates below will show, by the time such high luminosities are reached the major source of error in the limits that can be imposed on κ arise from the above-mentioned theoretical uncertainties and not from lack of statistics.

If we combine in quadrature the theoretical uncertainties listed above with the overall scale error due to the Tevatron luminosity as determined by CDF [1] of 3.6%, we arrive at a total uncertainty of approximately +15.6%, −10.3%. To get a quasiestimate of the experimental uncertainty, we assume that all of the error, from both statistics and systematics (apart from the machine luminosity), scales with the increase in statistics; this yields an error of $(+52.8\%, -35.1\%)\sqrt{67/\mathcal{L}}$, with $\mathcal{L}$ being the integrated luminosity in pb^{-1}. (This crude approximation has been used by CDF itself to estimate future sensitivity to new physics associated with the top quark [18].) Combining all errors in quadrature leads to estimates of the total error for $\mathcal{L} = 100$ (250, 500, 1000, 5000) pb^{-1} of (+45.9, −30.5), (31.5, −20.9), (24.8, −18.3), (20.7, −13.7), and (16.8, −11.1), respectively. At 95% C.L., these errors yield the following allowed ranges for κ for the above integrated luminosities: $-0.35 \leq \kappa \leq 0.30$, $-0.21 \leq \kappa \leq 0.22$, $-0.18 \leq \kappa \leq 0.17$, $-0.11 \leq \kappa \leq 0.14$, and $-0.10 \leq \kappa \leq 0.12$, respectively. Here we see that eventually these limits become systematics dominated and that better theoretical calculations are necessary in order to increase the sensitivity to nonzero κ. These estimates should only be considered indicative of what may eventually be possible at the Tevatron and demonstrate the need to reduce the theoretical uncertainties.

Apart from the total $t\bar{t}$ production cross section, various distributions involving the top may show some sensitivity to finite κ. In Fig. 4 we show the p_t, rapidity(y), and $t\bar{t}$ invariant mass (M) distributions for different values of κ. As a first approximation, we see that the dominant effect of finite κ, especially in the case where κ is positive, is to apply an approximate rescaling of the SM result by the ratio of total cross sections. Although this might appear at first surprising, it is merely a reflection of the fact that most of the $t\bar{t}$ cross section arises from $\hat{s}$ values not far above threshold. Of course, at the highest values of p_t or M, one begins to see small deviations from this simple qualitative picture, especially for values of κ far from zero, but the cross sections in those parameter space regions are always very small. For example, the ratio of the p_t distribution for $\kappa = 1$ and the SM case is approximately flat for p_t's less than about 300 GeV. However, as the p_t is further increased, this ratio rises significantly; i.e., there is a high p_t tail induced by finite κ. Of course, the cross sections for p_t's > 300 GeV are quite small and the $\kappa = 1$ case is an extreme example. For κ's in the 0–0.5 range, there is very little sensitivity to increased κ values in the distributions apart from the overall rescaling factor.

As emphasized above, the dominant effect of nonzero κ in the threshold region is simply an approximate rescaling of the SM cross section. Of course, near particular values of κ this approximation breaks down; a special example of this situation for the $q\bar{q} \to t\bar{t}$ subprocess, $\kappa = -1$, can be seen immediately from Eq. (2). For all $\kappa \neq -1$, the expression in the square brackets in Eq. (2) is finite whereas it vanishes for that particular value. Among other things, this would imply that the $t\bar{t}$ center of mass scattering angle (z) distribution should be quite different when $\kappa = -1$ from all other cases. This expectation is borne out by the results shown in Fig. 5, which shows the $z = \cos\theta^*$ distribution after integration over M and y, summing both the $q\bar{q}$ and gg contributions. Here we see that in all cases the angular dependence is

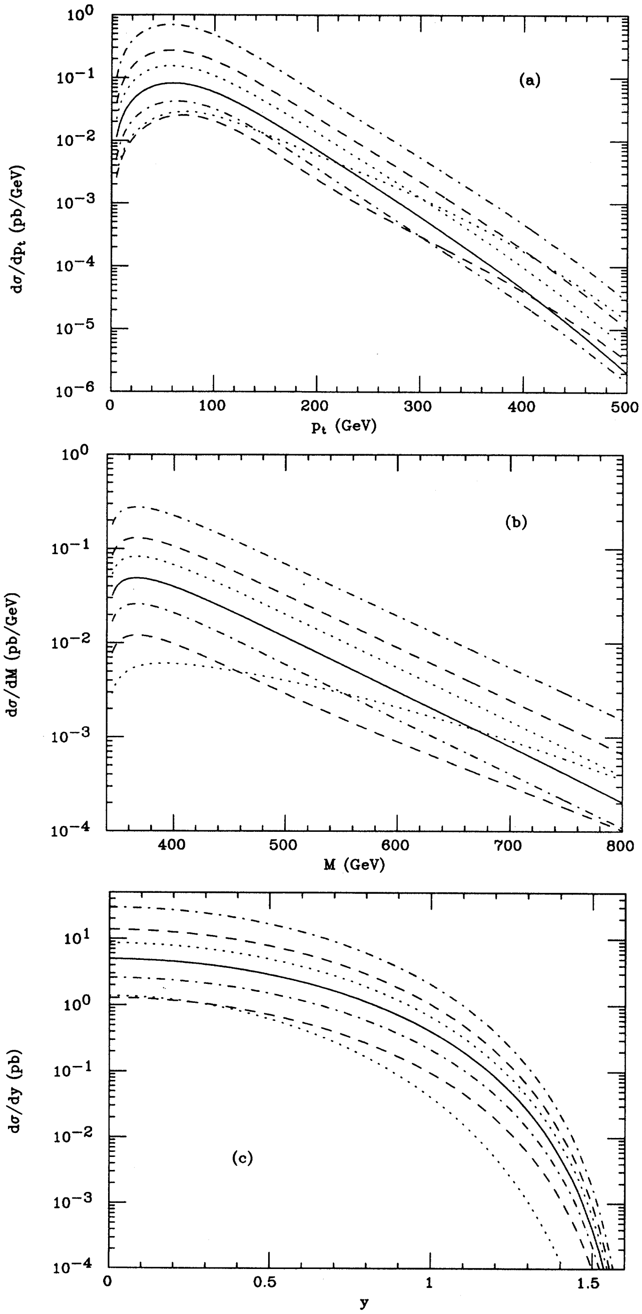

FIG. 4. (a) p_t distribution for top quark pairs produced at the Tevatron assuming $m_t = 170$ GeV and CTEQ2 PD's. The solid curve is the SM prediction and the upper (lower) dash-dotted, dashed, and dotted curves correspond to κ=1, 0.5, 0.25 (-1, -0.5, -0.25), respectively. (b) Top pair invariant mass distributions for the same cases as shown in (a). (c) Top quark rapidity distributions for the same cases as shown in (a).

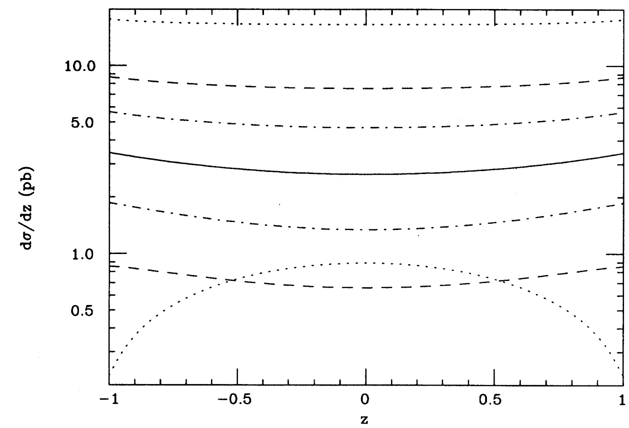

FIG. 5. $\cos\theta^*$ distribution for top pair production as in Fig. 4, except that the upper (lower) dash-dotted, dashed, and dotted curves correspond to $\kappa = 0.25$, 0.5, 1 (-0.25, -0.5, -1), respectively.

quite mild, owing to threshold dominance, except for the case $\kappa = -1$. From Figs. 4 and 5 it is clear that additional information on κ will be difficult to obtain from distribution measurements so that we simply have to rely on total cross section results to constrain κ.

In order to further motivate our analysis we briefly discuss a class of technicolor models [9,10] with nonzero κ. Consider the gauge group G=SU$(N)_{\rm TC}$ $\times$ SU$(3)_C$ $\times$ SU$(2)_L$ $\times$ U$(1)_Y$, together with the following technicolored fields: a right-handed SU$(2)_L$ doublet of technileptons $T_R(N,1,2,0) = (U_R, D_R)^T$, two left-handed SU$(2)_L$ singlet technileptons $U_L(N,1,1,1/2)$, $D_L(N,1,1,-1/2)$, all with charges $\pm\frac{1}{2}$, and a charge $\frac{1}{6}$ color triplet techniscalar $\omega(\bar{N},3,1,1/6)$. Transformation properties with respect to the technicolor group SU$(N)_{\rm TC}$ and the standard model gauge group have been included in parentheses. For the purpose of our discussion we can ignore the first two quark families. Yukawa couplings to the third family are given by

$$\mathcal{L}_Y = \lambda_Q \omega \overline{Q_L} T_R + \overline{\lambda_t} \omega^* \overline{U_L} t_r + \overline{\lambda_b} \omega^* \overline{D_L} b_R + \text{H.c.}, \quad (8)$$

where Q_L is the left-handed SU$(2)_L$ doublet of quarks, and t_R, b_R are the right-handed SU$(2)_L$ singlet quarks. ω acquires a mass from the scalar sector of the Lagrangian and a "constituent" mass from technicolor dynamics.[1]

Technifermion condensates will induce top and bottom quark masses via techniscalar exchange,[2] in analogy with

[1]Scalar technicolor models can be supersymmetrized in order to protect the masses of the scalars. In turn, supersymmetric flavor-changing neutral currents can be suppressed since a multi-TeV supersymmetry breaking scale is natural in this framework [19].

[2]Additional quark masses can be generated by adding more techniscalars, technileptons, or Higgs doublets which acquire small vacuum expectation values by coupling to the technilepton condensates. Radiative mass contributions could, in principle, also play a role for light quark masses.

fermion mass generation via gauge boson exchange in extended technicolor models. In the limit $m_\omega \gg \Lambda_{\rm TC}$, where $\Lambda_{\rm TC} \sim 1$ TeV, ω can be integrated out and one obtains

$$m_t \approx \lambda_Q \overline{\lambda_t} \frac{\langle \bar{U}U \rangle}{4m_\omega^2}, \quad m_b \approx \lambda_b \overline{\lambda_b} \frac{\langle \bar{D}D \rangle}{4m_\omega^2} \ . \tag{9}$$

The magnitude of the condensates is estimated to be [20]

$$\langle \bar{D}D \rangle = \langle \bar{U}U \rangle \approx \left(\frac{3}{N_{\rm TC}}\right)^{1/2} 4\pi \left(\frac{v}{\sqrt{N_D}}\right)^3 \ {\rm GeV}^3 \ , \tag{10}$$

where $v = 246$ GeV and N_D (equal to one above) is the number of technifermion doublets T_R. Chromomagnetic dipole moments are due to emission of a gluon by the exchanged techniscalar. One obtains

$$\frac{\kappa}{2m_t} \approx \frac{m_t(m_\omega)}{m_\omega^2} \tag{11}$$

at m_ω. Leading-order QCD evolution from TeV scales to $\mu \sim 2m_t$ will reduce κ by a few percent and can be neglected for our purposes.

For κ to have a substantial effect on the $t\bar{t}$ production cross section, m_ω must be small. Unfortunately, for $m_\omega \sim \Lambda_{\rm TC}$ we can no longer simply integrate ω out to obtain expressions for m_t and κ since strong technicolor dynamics become important.[3] Nevertheless, we expect the above expressions to give the correct orders of magnitude and we defer a more sophisticated treatment to future investigation. Guided by estimates of the technifermion constituent mass [21], obtained by scaling of the QCD constituent mass [one obtains $m_{\rm TC} \sim (300$ MeV$)(\frac{v}{\sqrt{N_D} f_\pi})$ or 800 GeV for $N_D = 1$, 550 GeV for $N_D = 2$], we assume that $m_\omega \gtrsim 0.5$ TeV is a reasonable range to take[4] in Eqs. (9) and (11). So for $m_t \approx 170$ GeV we expect $\kappa \lesssim \frac{1}{4}$. Assuming a form factor of the form given in Eq. (4), with Λ identified with m_ω, Figs. 2 and 3 imply that $\sim 50\%$ increases in the Tevatron $t\bar{t}$ production cross section may be possible.

In this paper, we have considered the influence of a nonzero chromomagnetic moment for the top quark, κ, on the production of $t\bar{t}$ pairs at the Tevatron for top masses near 175 GeV. Nonzero values of κ may be present in both compositeness and technicolor scenarios. In particular, our results can be summarized as follows.

(i) We have obtained Born-level expressions for $q\bar{q}, gg \to t\bar{t}$ for arbitrary values of κ and used the SM NLO and gluon resummation "K factors" from [7] to obtain total cross sections and various distributions for top pair production at the Tevatron.

(ii) We explored the possible influence of including form factors with a finite scale parameter Λ instead of a simple constant value for κ. We found, since the cross section was dominated by $t\bar{t}$-invariant masses not far from threshold, that values of Λ in the 1–2 TeV range or above were essentially indistinguishable from $\Lambda = \infty$. However, for smaller values of Λ, the κ dependence was found to be softened.

(iii) For top quark masses in the $m_t = 175$ GeV range, we demonstrated that the top pair production cross section was quite sensitive to the value of κ. Values of κ in the range 0.2–0.3 were shown to increase the SM cross section to the *central values* reported by CDF and D0. Since κ is $O(m_t^2/\Lambda^2)$ if associated with top mass generation, such large values would likely be due to new physics at a scale Λ below 1 TeV. If the cross section was eventually found to agree with the SM expectations, we estimated the bounds on κ obtainable at the Tevatron as the integrated luminosity increases. Included in this analysis are uncertainties due to scale ambiguities, structure function variations, luminosity uncertainties, and estimates of NNLO contributions, as well as statistics. We found that from the total cross section alone the Tevatron will be able to probe values of $|\kappa| < 0.10$–0.15 in the not too distant future, potentially providing us with a new window to physics in the TeV region. Significantly better constraints are possible once the current set of theoretical ambiguities is dealt with.

(iv) We discussed a class of technicolor models with techniscalars in which both the top quark mass and $\kappa \sim \frac{1}{4}$ could be due to exchange of a techniscalar with 0.5 TeV mass. It is interesting that with the techniscalar mass at 0.5 TeV (flavor-changing) chromomagnetic dipole moments can also lead to suppression of the B semileptonic branching ratio and substantial $\Delta I = \frac{1}{2}$ enhancement in K decays [10].

(v) We explored the possibility that p_t, rapidity (y), top pair mass (M), and center of mass scattering angle ($\cos\theta^*$) distributions may provide additional constraints on a potential nonzero value for κ. This analysis found that once these distributions were rescaled by the ratio of the κ dependent to SM cross section almost all of the sensitivity was found to lie in parameter regions where differential cross sections were very small. Our conclusion is that these various distributions are probably not too useful in obtaining additional constraints on κ beyond those obtainable from the total cross section.

If an anomalous chromomagnetic moment for the top quark exists, it will open a new window to new physics beyond the standard model.

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[3]For example, it may be that the exchanged techniscalar and technifermion bind so that the quark's mass can be attributed to mixing with composite heavy quarks.

[4]Quark-techniscalar Yukawa couplings can vary substantially so that all quark masses can be generated with ~ 0.5 TeV techniscalars. Furthermore, such light techniscalar masses do not pose a danger for flavor-changing neutral currents since the latter first arise at the one-loop level.

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