Technicolor contribution to lepton + photon + $\not{E}_T$ events at the Fermilab Tevatron

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Events with one lepton, one photon, and missing energy are the subject of recent searches at the Fermilab Tevatron. We compute possible contributions to these types of events from the process $p\bar{p} \to \gamma l \nu_l \nu_\tau \bar{\nu}_\tau$, where $l = e$, μ in the context of a low scale technicolor model. We find that with somewhat tighter cuts than the ones used in the CDF search, it could be possible to either confirm or exclude this model in a small region of its parameter space.

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The standard model of the electroweak interactions has been extremely successful in describing all the high energy accelerator data collected so far [1]. However, there are several reasons to believe that the standard model is incomplete, such as the existence of nonbaryonic dark matter and nonzero neutrino masses. Furthermore, the infamous problems of triviality and naturalness related to the scalar Higgs sector of the theory point to the possibility that the standard model is an effective theory valid up to an as yet unknown high energy scale Λ. Extensions of the standard model such as supersymmetric models, models with extra dimensions (universal or otherwise) and models with dynamical electroweak symmetry breaking (DEWSB) are the main contenders for describing nature at energies above Λ. With the starting of the Large Hadron Collider at CERN one will be hopefully able to figure out in a few years what the completion of the standard model really is at around the TeV scale, if there is one.

Meanwhile, the Tevatron is accumulating data at $\sqrt{s} = 1.96$ TeV and it is of foremost importance to place constraints on these contenders using what is available now. In particular, motivated by signatures of new physics beyond the standard model, the CDF collaboration has recently performed a search for inclusive events with one lepton and one photon [2].

In this paper, we will focus on the interesting channel $p\bar{p} \to l + \gamma + \not{E}_T$, with $l = e$, μ where a 2.7σ excess from the standard model (SM) prediction was reported earlier using Run I data [3]. Although the more recent analysis of Ref. [2] finds no deviation from the SM prediction and thus can be used to set constraints on new physics contributions, we find that using the same cuts from [2] no bounds can be obtained in this channel. However, we show that tightening the cuts in the analysis may improve the sensitivity to signals beyond the SM. We will compute contributions to this process from models with DEWSB and find bounds on these models from recent Run II data using stronger cuts.

Models with DEWSB involve new interactions that become strong near the TeV scale [4]. The first models were inspired by a scaled-up version of QCD, with a new interaction called technicolor (TC) that causes new fermions in the fundamental representation of an $SU(N_{\rm TC})$, called technifermions (T), to condense and break both a global chiral and the electroweak symmetries [5]. Of the resulting Nambu-Goldstone bosons, called technipions (Π_T), three are "eaten" by the electroweak gauge bosons, which gain a longitudinal component and hence a mass term. No fundamental scalar fields are present. The correct gauge boson masses are obtained if one requires that the technipion decay constant F_T is fixed at $F_T = v = 246$ GeV. As it happens in QCD, the strong TC interaction is also responsible for the existence of resonances in the scattering of technipions. In consonance with the QCD analogy, the lightest vector resonances are called techni-rho (ρ_T) and techni-omega (ω_T). Naively, they would be expected to have masses around $4\pi F_T$.

These simple models become more baroque when one considers mechanisms to generate mass for the standard model fermions. A further interaction called extended technicolor (ETC), usually modeled via a broken gauged flavor symmetry, is introduced [6]. The massive ETC gauge bosons communicate the DEWSB to the standard model fermions, generating masses of the order of $\langle \bar{T}T \rangle / M_{\rm ETC}^2$. A difficulty immediately arises in the top sector: a very low ETC scale seems to be required in order to generate a heavy top quark mass. The combination of a low ETC scale with the large isospin violation necessary to explain the top-bottom mass difference proves fatal: precision electroweak measurements rule out a simple QCD-

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like TC model with a naive ETC mechanism [7]. However, further developments based on the so-called walking technicolor (where the TC coupling runs slowly between $M_{\rm ETC}$ and F_T) [8], which may or may not invoke technifermions in higher representations of the TC group combined with new precision measurements have shown that it is possible to reconcile more sophisticated models with current experimental data [9] and even possibly with unification ideas [10]. The walking property enhances both the standard fermions masses and, more importantly to this work, the technipion masses.

We will be interested in a variation of the basic technicolor models with far reaching phenomenological consequences. It concerns the possibility of lowering the TC scale F_T. This class of models, usually called low scale TC (LSTC) models, arise in cases where sectors with different condensation scales are present [11]. The vector resonances associated with the lowest scale can be light and hence accessible at the Tevatron.

The phenomenology of LSTC has been extensively studied in different machines [4]. In particular, the resonant associated production of a technipion with a gauge boson via a techni-rho or techni-omega, $p\bar{p} \to \rho_T^{\pm} \to W_L^{\pm}\Pi_T^0$ and $p\bar{p} \to \omega_T \to \gamma\Pi_T^0$ with the subsequent decay $\Pi_T^0 \to b\bar{b}$ was analyzed in detail [12]. The importance of the radiative decays ρ_T, $\omega_T \to \gamma\Pi_T^0$ was emphasized in [13]. We performed a study of the rarer but cleaner three-photon process $p\bar{p} \to \omega_T$, $\rho_T^0 \to \gamma\Pi_T^0 \to \gamma\gamma\gamma$ [14].

In this paper we will extend the analysis of [14] to study the process $p\bar{p} \to \rho_T^{\pm} \to \gamma\Pi_T^{\pm}$ with the subsequent decay $\Pi_T^{\pm} \to \tau\nu_\tau \to l\nu_l\nu_\tau\bar{\nu}_\tau$.

For definiteness we will at first adopt a techni-rho mass in the range $M_{\rho_T} = 210$–300 GeV and fix $M_{\Pi_T} = 110$ GeV. Hence the main decay modes of the techni-rho are $\rho_T^{\pm} \to \Pi_T^{\pm}\Pi_T^0$, $W^{\pm}\Pi_T^0$, $Z\Pi_T^{\pm}$ and $\gamma\Pi_T^{\pm}$. In particular, the amplitude for the process that is relevant for us can be written as [13,15]

$$\mathcal{M}(\rho_T^{\pm}(q) \to \gamma(p_1)\Pi_T^{\pm}(p_2)) = \frac{(Q_U + Q_D)e\cos\chi}{M_V}\epsilon^{\mu\nu\lambda\sigma}\varepsilon_\mu(q)\varepsilon_\nu^*(p_1)q_\lambda p_{1\sigma} \quad (1)$$

where χ is a mixing angle between isospin eigenstates and mass eigenstates in the technipion sector, Q_U ($Q_D = Q_U - 1$) is the charge of the techniquark up and M_V is a typical TC mass scale. We will adopt $\sin\chi = 1/3$, $Q_U = 4/3$ and $M_V = 100$ and 200 GeV. With these parameters, the total techni-rho width was calculated using Pythia [16].

The charged technipion coupling to fermions is proportional to their masses. Moreover, we assume here that the coupling is also proportional to Cabibbo-Kobayashi-Maskawa (CKM) mixing angles, which is reasonable if techniquarks are weak isodoublets. In our case we use $\mathrm{BR}(\Pi_T^{\pm} \to \tau\nu_\tau) = 25\%$, $\mathrm{BR}(\Pi_T^{\pm} \to cs) = 75\%$ (the decay into bc is CKM suppressed).

The production cross section can be estimated by using a generalized vector meson dominance argument [17] where there is a W–ρ_T mixing or equivalently by diagonalization of the W–ρ_T mass matrix [18]. In both cases the amplitude involves a mixing constant given by $g_{W-\rho_T} = M_{\rho_T}^2 g/(2g_T)$, where g is the $SU(2)_L$ electroweak gauge coupling and g_T is the techni-rho coupling to two technipions. We will fix $g_T = 5.3$, which arises from a simple QCD scaling.

As a simple figure of merit, the cross section for $p\bar{p} \to \rho_T^{\pm} \to \gamma\Pi_T^{\pm}$ (for $M_{\rho_T} = 210$ GeV and $M_V = 200$ GeV) with a simple cut in the photon transverse momentum, $p_T(\gamma) > 20$ GeV, is around 1.4 pb at the Tevatron, whereas the background $p\bar{p} \to \gamma W^{\pm}$ cross section with the same cut is around 5.6 pb. Including the appropriate branching ratios, it follows that the cross section for $p\bar{p} \to \gamma\Pi_T^{\pm} \to \gamma l\nu_l\nu_\tau\bar{\nu}_\tau$ is around 0.12 pb compared to 1.3 pb for $p\bar{p} \to \gamma W^{\pm} \to \gamma l + \not{E}_T$.

We implemented LSTC as a CompHEP [19] model using the diagonalization of the mass-matrix procedure. We used CompHEP for generating events for $p\bar{p} \to \rho_T^{\pm} \to \gamma\Pi_T^{\pm}$. Subsequently, they were processed by a FORTRAN code we wrote in order to generate the $\Pi_T^{\pm}$ decay products. The dominant background from $p\bar{p} \to \gamma W^{\pm}$ was generated using the same method. We checked that the background from $W \to \tau\nu_\tau$ is small and hence was not included.

In Fig. 1 we illustrate the photon transverse energy distribution for the signal and background for $p\bar{p} \to \gamma l^{\pm} + \not{E}_T$ for the Tevatron with an integrated luminosity of 1 fb^{-1}, where $l = e$, μ. We choose to show only two values of the techni-rho mass, namely $M_{\rho_T} = 210$ and 250 GeV with TC scale $M_V = 100$ and 200 GeV. We

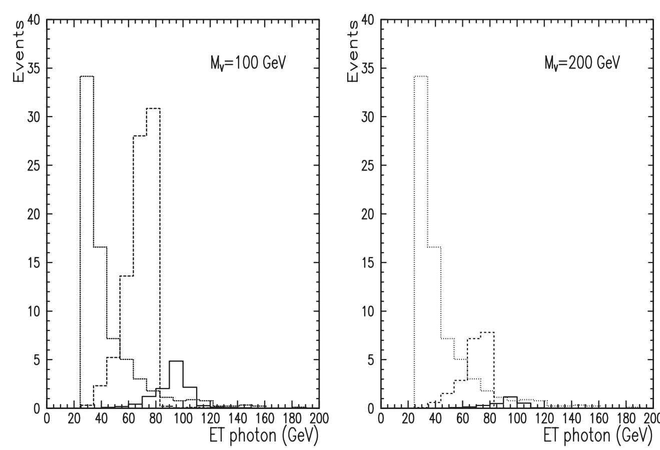

FIG. 1. Signal for $M_{\rho_T} = 210$ GeV (dashed line) and $M_{\rho_T} = 250$ GeV (solid line) for $M_V = 100$ GeV (left figure) and $M_V = 200$ GeV (right figure) compared to the SM background (dotted histogram) for the photon E_T distribution assuming a 1 fb^{-1} integrated luminosity with cuts described in the text.

used the same cuts as in the CDF paper [2], namely $|\eta_{l,\gamma}| < 1$ and $E_T^{l,\gamma}$, $\not{E}_T > 25$ GeV. The peak in the distribution is due to the 2-body resonant kinematics of the underlying process. We immediately notice that an improvement in the signal-to-background ratio can be gained if a tighter cut $E_T^\gamma > 50$ GeV is imposed.

In Fig. 2 we show the distribution of the variable H_T, defined as the total transverse energy of the event, including $\not{E}_T$, for the usual CDF cut $E_T^\gamma > 25$ GeV and for a tighter $E_T^\gamma > 50$ GeV cut. Again a tighter cut on the photon transverse energy results in a better significance of the signal at the expense of a reduced number of events.

The significance S can be estimated from a simple analysis involving the number of signal and background events in bins i of the H_T distribution with a tighter $E_T^\gamma > 50$ GeV, assuming Poisson statistics:

$$S = \frac{\sum_i N_{\rm signal}^{(i)}}{\sqrt{\sum_i N_{\rm back}^{(i)}}} \qquad (2)$$

and it is shown in Fig. 3 as a function of the techni-rho mass for $M_V = 100$ and 200 GeV. Notice that the $\rho_T \to \Pi_T \Pi_T$ channel is open in most of the techni-rho mass range plotted, as we fixed $M_{\Pi_T} = 110$ GeV (solid lines). Since there is a rapid drop in the significance due to the opening of the two-technipion decay channel at $M_{\rho_T} = 220$ GeV in this case, we have also studied the case with a fixed mass difference $2M_{\Pi_T} - M_{\rho_T} = 10$ GeV, in such a way that this channel is always closed (dashed line). We find that for a TC scale as low as $M_V = 100$ GeV a techni-rho mass below roughly $M_{\rho_T} = 250$ GeV is excluded at the 3σ level. However, for $M_V = 200$ GeV the process is

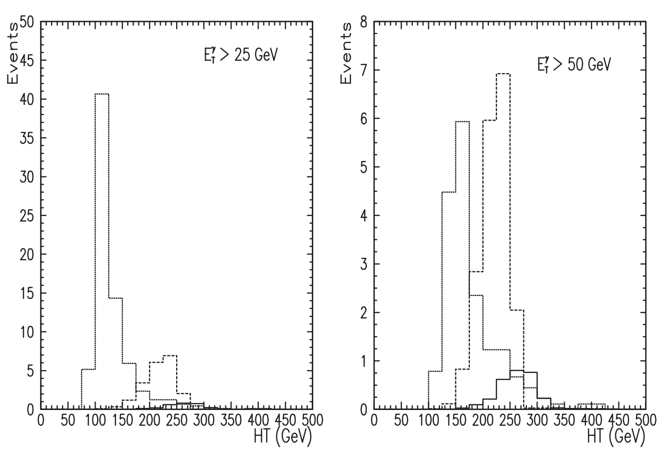

FIG. 2. Signal for $M_{\rho_T} = 210$ GeV (dashed line) and $M_{\rho_T} = 250$ GeV (solid line) for $M_V = 200$ GeV compared to the SM background (dotted line) for the H_T distribution assuming a 1 fb^{-1} integrated luminosity with cut $E_T^\gamma > 25$ GeV (left figure) and $E_T^\gamma > 50$ GeV (right figure).

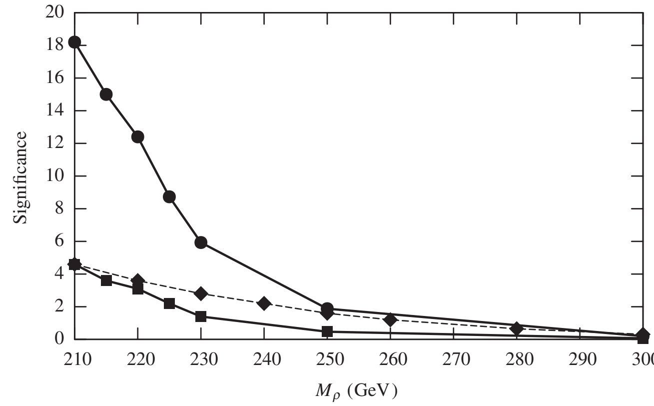

FIG. 3. Significance for the technicolor signal as a function of M_{ρ_T} for $M_V = 100$ GeV (dots) and $M_V = 200$ GeV (squares) for fixed $M_{\Pi_T} = 110$ GeV and for fixed $2M_{\Pi_T} - M_{\rho_T} = 10$ GeV for $M_V = 200$ GeV (diamonds).

suppressed but a 3σ could be seen for $M_{\rho_T} < 220$ GeV. For the softer CDF cut no signal would be observed.

At this point we should comment on the current bounds on technicolor particles from different experiments and channels. DELPHI looked for $e^+e^- \to \rho_T \to W_L W_L$, $W_L \Pi_T$, $\Pi_T \Pi_T$ and $\Pi_T \gamma$ excluding the region $90 < M_{\rho_T} < 206.7$ GeV and $M_{\Pi_T} < 79.8$ GeV [20]. D0 has searched for events coming from ρ_T, $\omega_T \to e^+e^-$ using Run I data [21]. They excluded $M_{\rho_T} = M_{\omega_T} < 200$ GeV provided that the decay channel into $W\Pi_T$ is closed. More recently, D0 also searched for techni-rho in the decay channel $\rho_T \to W\Pi_T$ at the Tevatron excluding techni-rho masses up to $M_{\rho_T} < 215$ GeV if $100 < M_{\Pi_T} < 110$ GeV at 95% CL with 390 pb^{-1} [22]. These bounds of course depend only the parameters g_T and M_V. The choice of g_T obtained from scaling QCD arguments is standard and was used in all the searches. The parameter M_V only affects channels with photons or transversely polarized gauge bosons in the final state. This is the case only in one channel of the DELPHI search.

In summary, we studied in this paper the contribution of a low scale technicolor model to the process $p\bar{p} \to \gamma l \nu_l \nu_\tau \bar{\nu}_\tau$, which falls in the class of events recently searched for at the Tevatron. We find that with a tighter cut in the photon transverse energy, it would be possible to either confirm or exclude this model in a small region of parameter space.

We would like to stress that our simulations are not fully realistic since they do not take into account the characteristics of the detector. However, we expect that the smearing of the final momenta be small since we have only photons and leptons in the final states. Our goal in this study is just to point out that the model adopted here can in fact contribute to the production of events with one lepton, one photon and missing energy and hence should be considered in more detailed experimental analysis.

Our analysis could be expanded in many ways if one considers hadronic final states. In particular, the dominant Π_T decay mode in $c\bar{s}$ may not be hopeless if a charm tagging can be implemented in the dijet mass distribution. Also, the case considered here of τ leptons in the final state, a signature of technicolor models, could be better explored by using their hadronic decay modes as well.

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