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Testing CDF's Dijet Excess and Technicolor at the LHC

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Abstract

Under the assumption that the dijet excess seen by the CDF Collaboration near 150 GeV in Wjj production is due to the lightest technipion of the low-scale technicolor process $\rho_T \to W\pi_T$, we study its observability in LHC detectors with $1-5\,\mathrm{fb}^{-1}$ of data. We find that cuts similar to those employed by CDF are unlikely to confirm its signal. We propose cuts tailored to the LSTC hypothesis and its backgrounds at the LHC that can reveal $\pi_T \to jj$. We also stress the importance at the LHC of the isospin-related channel $\rho_T^\pm \to Z\pi_T^\pm \to \ell^+\ell^-\,jj$ and the all-lepton mode $\rho_T^\pm \to WZ \to \ell^+\ell^-\ell^\pm\nu_\ell$.

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1. Introduction

The CDF Collaboration recently reported evidence for a resonant excess near 150 GeV in the dijet-mass spectrum, M_{jj}, of Wjj production [1]. For an integrated luminosity of $4.3\,\mathrm{fb}^{-1}$, CDF fit the excess to a simple Gaussian with $\sigma_{\rm resolution} = 14.3\,\mathrm{GeV}$ and determined its significance to be $3.2\,\sigma$ and its cross section to be "of order 4 pb". CDF has updated this paper using $\int \mathcal{L} dt = 7.3\,\mathrm{fb}^{-1}$, and the significance of the dijet excess is now $4.1\,\sigma$ [2]. The DØ Collaboration, on the other hand, has analyzed $4.3\,\mathrm{fb}^{-1}$ and reported no excess. A 4 pb cross section is rejected at the level of $4.3\,\sigma$, while the 95% confidence level upper limit on the cross section is 1.9 pb [3].

In Ref. [4] we proposed a low-scale technicolor (LSTC) explanation for CDF's dijet excess: A technirho ($\rho_T^{\pm,0}$) of mass $M_{\rho_T} = 290\,\mathrm{GeV}$ is produced as a very narrow s-channel resonance in $\bar{q}q$ annihilation and decays into a technipion ($\pi_T^{0,\pm}$) with $M_{\pi_T} = 160\,\mathrm{GeV}$ plus a W-boson which is mostly longitudinally polarized.[1] Using the LSTC model implemented in Pythia [5, 6, 7], we found $\sigma(\bar{p}p \to \rho_T \to W\pi_T \to Wjj) = 2.4\,\mathrm{pb}$. We closely matched CDF's dijet mass distribution for the signal and background. Motivated by the peculiar kinematics of ρ_T production at the Tevatron and $\rho_T \to W\pi_T$ decay, we also suggested cuts intended to enhance the π_T signal's significance and make $\rho_T \to Wjj$ visible. Several distributions — $p_T(jj)$, $\Delta\phi(jj)$, $\Delta R(jj)$ and M_{Wjj} — presented by CDF in Ref. [2] fit the expectations of the LSTC model quite well. This will be elaborated upon in an upcoming publication.

In this note we present the results of simulations of $\rho_T \to W\pi_T \to Wjj$ at the LHC. We predict that the cross section there is 8.0 pb. We find that the cuts employed by CDF in Refs. [1, 2] appear to be insufficient to extract the $\pi_T \to jj$ signal from the background, even for a data sample of $\sim 5\,\mathrm{fb}^{-1}$. We also find that, while cuts similar to the ones we proposed in Ref. [4] significantly enhance the signal-to-background, they cause the background to peak very near the signals themselves. We therefore propose qualitatively different ones that should give more isolated, observable π_T and ρ_T signals for at most a few fb^{-1}. The selections we consider are specific to our ρ_T explanation of the CDF excess and may not be useful for testing other proposals — which generally do not share the peculiar kinematics of ours (for a sampling of other proposed explanations of CDF's dijet excess, see Refs. [8, 9, 10, 11, 12, 13, 14, 15, 16]).

In Ref. [4] we mentioned other processes that can be sought at the Tevatron and LHC and which should be seen soon if the CDF signal is real and has the LSTC origin we proposed. We highlight two of these, $\rho_T^\pm \to Z\pi_T^\pm$ and $W^\pm Z$, at the end of this note.

[1] Other relevant LSTC masses are $M_{\omega_T} = M_{\rho_T}$; $M_{a_T} = 1.1 M_{\rho_T} = 320\,\mathrm{GeV}$; and M_{V_i,A_i} which appear in dimension-five operators for V_T decays to transverse EW boson; we take them equal to M_{ρ_T}. Other LSTC parameters are $\sin\chi = 1/3$, $Q_U = Q_D + 1 = 1$, and $N_{TC} = 4$.

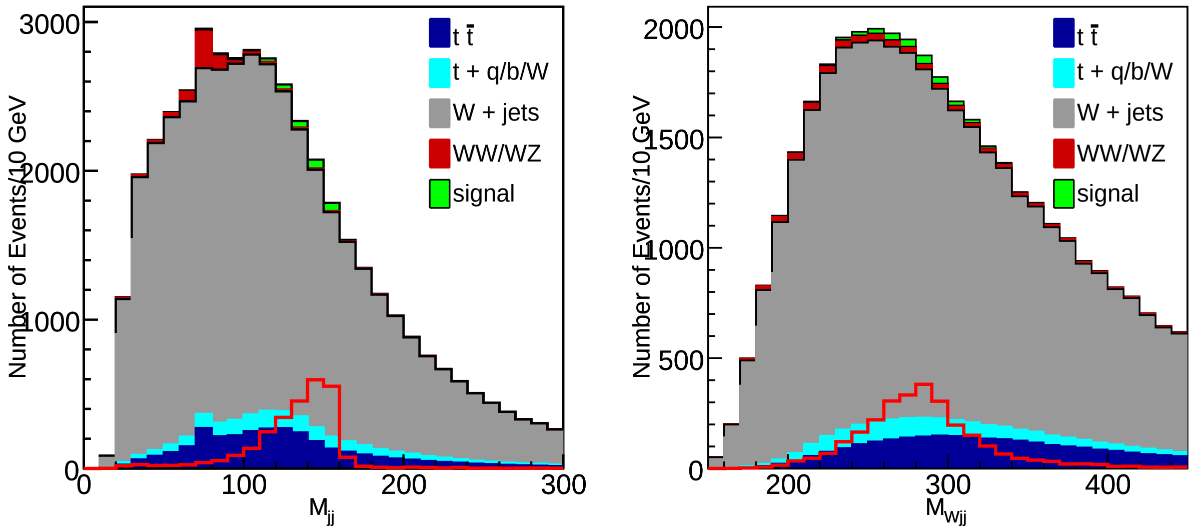


Figure 1: The M_{jj} and M_{Wjj} distributions of $\rho_T \to W\pi_T \to \ell\nu_\ell jj$ and its backgrounds at the LHC for $\int \mathcal{L}dt = 1\,\text{fb}^{-1}$. CDF-like cuts as described in the text are employed. The important backgrounds are indicated and the π_T and ρ_T signals $\times 10$ are shown as the thin red-lined histograms.

2. Simulations of the CDF Signal at the LHC

The obvious place to start is with the cuts employed by CDF [1].[2] However, for $\int \mathcal{L}dt =$ few fb^{-1}, we believe this will be fruitless. Fig. 1 shows the M_{jj} and M_{Wjj} distributions for $1\,\text{fb}^{-1}$ with CDF cuts except that we require that leptons have $p_T > 30\,\text{GeV}$ and $|\eta| < 2.5$, reflecting the greater acceptance of the LHC detectors.[3] As in Ref. [4], we do not include calorimetric energy smearing, hence the narrow $W/Z \to jj$ peak of diboson production near 80 GeV. This simplification does not affect our $\pi_T \to jj$ mass resolution which is due mainly to jet definition. The background under the dijet resonance in Fig. 1 is a factor of 5–6 times

[2]The CDF cuts are: exactly one lepton, $\ell = e, \mu$, with $p_T > 20\,\text{GeV}$ and $|\eta| < 1.0$; exactly two jets with $p_T > 30\,\text{GeV}$ and $|\eta| < 2.4$; $\Delta R(\ell, j) > 0.52$; $p_T(jj) > 40\,\text{GeV}$; $\not{E}_T > 25\,\text{GeV}$; $M_T(W) > 30\,\text{GeV}$; $|\Delta\eta(jj)| < 2.5$; $|\Delta\phi(\not{\boldsymbol{E}}_{\boldsymbol{T}}, j)| > 0.4$.

[3]Backgrounds were generated at matrix-element level using ALPGENv213 [17], then passed to PYTHIAv6.4 for showering and hadronization. We use CTEQ6L1 parton distribution functions and a factorization/renormalization scale of $\mu = 2M_W$ throughout. For the dominant W+jets background we generate $W + 2j$ (excl.) plus $W + 3j$ (inc.) samples, matched using the MLM procedure [18] (patron level cuts are imposed to ensure that $W + 0, 1$ jet events cannot contribute). After matching, the overall normalization is scaled to the NLO $W + jj$ value, calculated with MCFMv6 [19]. After passing through PYTHIA, final state particles are combined into (η, ϕ) cells of size 0.1×0.1, with the energy of each cell rescaled to make it massless. Isolated photons and leptons (e, μ) are removed, and all remaining cells with energy greater than 1 GeV are clustered into jets using FastJet (anti-kT algorithm, $R = 0.4$) [20].

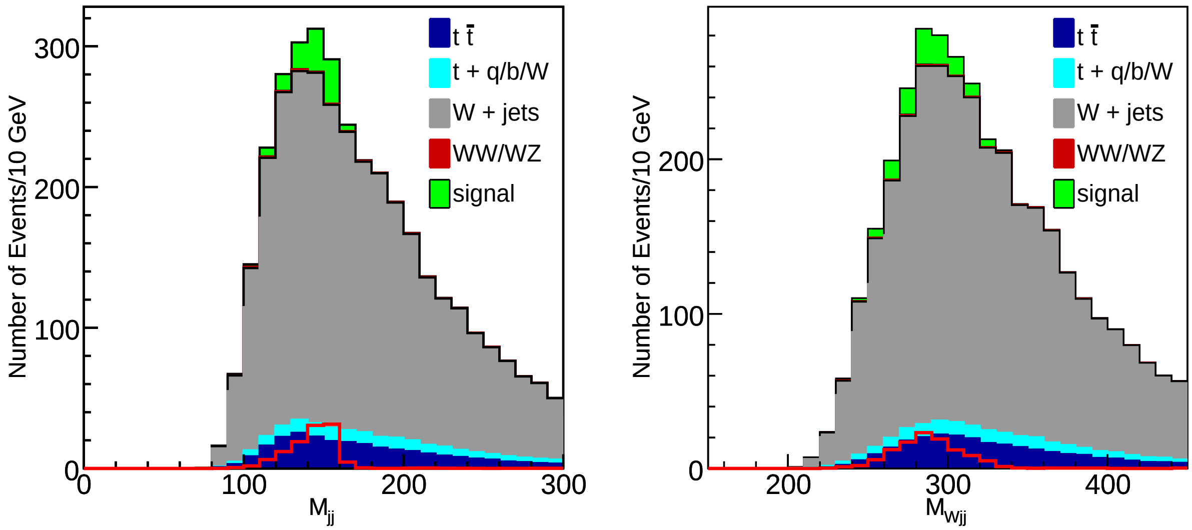
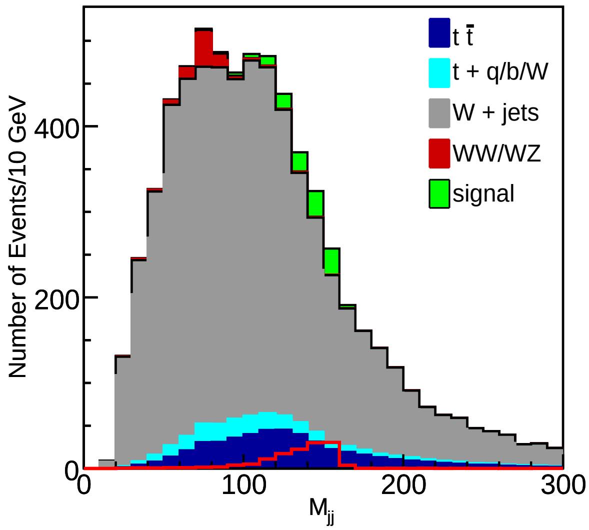


Figure 2: The M_{jj} and M_{Wjj} distributions of $\rho_T \to W\pi_T \to \ell\nu_\ell jj$ and its backgrounds at the LHC for $\int \mathcal{L}dt = 1\,\mathrm{fb}^{-1}$. Augmented CDF-like cuts, described in the text and similar to ones proposed in Ref. [4], are employed. They result in enhanced π_T and ρ_T signals appearing at the peaks of their backgrounds. The unscaled π_T and ρ_T signals are also shown as thin red-lined histograms.

greater than at the Tevatron; see Fig. 1 in Refs. [1, 4]. Counting events in the four bins from $M_{jj} = 120$ to $160\,\mathrm{GeV}$, we obtain $S/\sqrt{B} = 2.10$ and $S/B = 0.023$. Given this and the shape of the signal and background, it is doubtful that CDF-like cuts alone could provide confirmation of its dijet signal for even $5\,\mathrm{fb}^{-1}$ of data.

To improve the signal-to-background, we examined a variety of cuts motivated by $\rho_T \to W\pi_T$ kinematics and similar in character to those proposed in Ref. [4]. Fig. 2 was obtained applying the following requirements in addition to the CDF-like cuts: $\Delta\phi(jj) > 2.0$, $Q = M_{Wjj} - M_{jj} - M_W < 100\,\mathrm{GeV}$, $p_T(jj) > 60\,\mathrm{GeV}$ and $p_T(W) > 60\,\mathrm{GeV}$. The π_T signal now has $S/\sqrt{B} = 2.82$ and $S/B = 0.085$. Unfortunately, as can be seen in Fig. 2, these cuts cause the background to peak very near the dijet resonance so that the π_T's observation at the LHC would require not only very good understanding of the Wjj backgrounds just where they are largest, but probably considerably more data than the $\simeq 5\,\mathrm{fb}^{-1}$ expected to be collected this year.

We have obtained what we believe is an acceptable separation of the background peak from the π_T signal with the following cuts: $p_T(j_1) > 40\,\mathrm{GeV}$ while $p_T(j2) > 30\,\mathrm{GeV}$, $p_T(jj) > 45\,\mathrm{GeV}$, $p_T(W) > 60\,\mathrm{GeV}$, $\Delta\eta(jj) < 1.2$ (this was 2.5 in Refs. [1, 4]) and $Q > 20\,\mathrm{GeV}$. The results are shown in Fig. 3. Counting events gives $S/\sqrt{B} = 2.80$ and $S/B = 0.078$ for the $\pi_T \to jj$ signal and $\int \mathcal{L}dt = 1\,\mathrm{fb}^{-1}$. A valuable feature of this selection is the



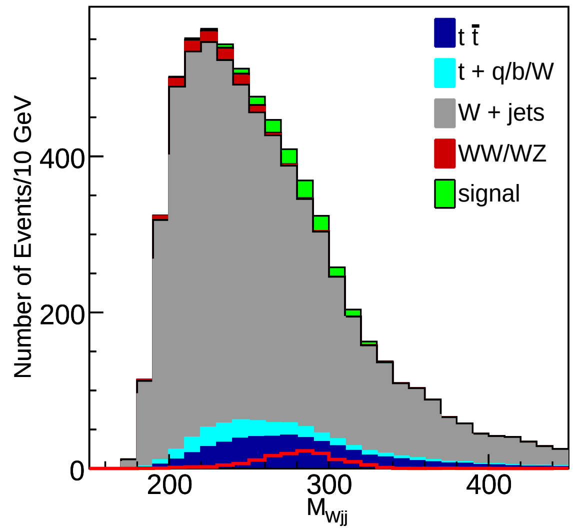


Figure 3: The M_{jj} and M_{Wjj} distributions of $\rho_T \to W\pi_T \to \ell\nu_\ell jj$ and its backgrounds at the LHC for $\int \mathcal{L}dt = 1\,\mathrm{fb}^{-1}$. Augmented CDF-like cuts as described in the text are employed. The enhanced π_T and ρ_T signals now appear below the peaks of their backgrounds. The unscaled π_T and ρ_T signals are also shown as thin red-lined histograms.

diboson production $W/Z \to jj$ peak near 80 GeV. It allows self-calibration of the background normalization at its peak. With proper cuts on only a few fb^{-1} of data, therefore, the LHC experiments should be able to confirm or exclude the π_T signal. The $\rho_T \to Wjj$ signal in the interval $260 < M_{Wjj} < 300$ GeV in Fig. 3 has $S/\sqrt{B} = 2.50$ and $S/B = 0.089$ for $1\,\mathrm{fb}^{-1}$. It should be observable with $\sim 5\,\mathrm{fb}^{-1}$.

3. The $\rho_T^\pm \to Z\pi_T^\pm$ and $W^\pm Z$ Modes

An important confirmation of the $\rho_T \to W\pi_T \to \ell\nu_\ell jj$ signal (albeit, one not free of all Wjj background issues) is observation of its isospin partner, $\rho_T^\pm \to Z\pi_T^\pm \to \ell^+\ell^- jj$. Because of the limited phase space in these decays, the Pythia cross section at the LHC for $\rho_T^\pm \to Z\pi_T^\pm$ is only 2.36 pb compared to 3.44 pb for $\rho_T^\pm \to W^\pm\pi_T^0$ [4] and 7.90 pb for both $\rho_T \to W\pi_T$ channels. The branching ratio for $Z \to e^+e^-$, $\mu^+\mu^-$ reduces this to 165 fb, 10% of the $\rho_T \to \ell\nu_\ell jj$ rate. Thus, for a similar ratio of backgrounds, we expect that ~ 10 times the luminosity needed for the $\rho_T \to W\pi_T$ signal would be required for the same sensitivity. Actually, because the Zjj background is less than 10% of the Wjj background, the situation is better than this and just $5\,\mathrm{fb}^{-1}$ are needed to give $S/\sqrt{B} = 3.12$ and $S/B = 0.18$; see Fig. 4. The cuts used there are: two electrons or muons of opposite charge with $p_T > 30$ GeV and $|\eta| < 2.5$, exactly

[4] This assumes $B(\pi_T^\pm \to \bar{q}'q)/B(\pi_T^0 \to \bar{q}q) \simeq 1$. The cross section ratio agrees well with $p_Z^3/p_W^3 = 0.69$.

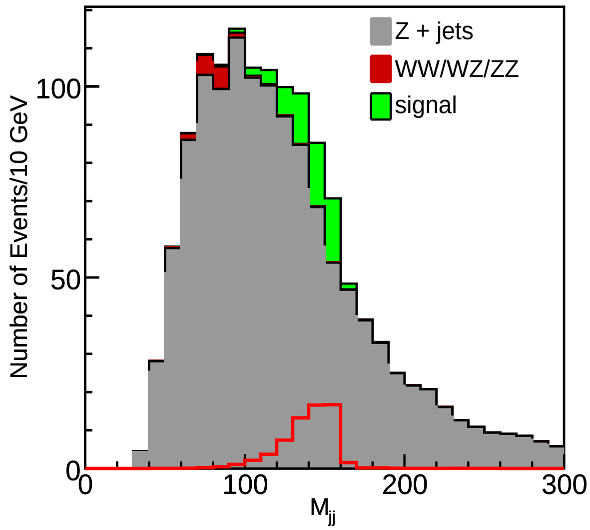


Figure 4: The M_{jj} and M_{Zjj} distributions of $\rho_T^\pm \to Z\pi_T^\pm \to \ell^+\ell^- jj$ and its backgrounds at the LHC for $\int \mathcal{L}dt = 5\,\text{fb}^{-1}$. The cuts are described in the text. The unscaled π_T and ρ_T signals are also shown as thin red-lined histograms.

two jets with $p_T > 30\,\text{GeV}$ and $|\eta| < 2.5$, $p_T(jj) > 40\,\text{GeV}$, $p_T(Z) > 50\,\text{GeV}$, $\Delta\eta(jj) < 1.75$, and $Q < 60\,\text{GeV}$.

Finally, the mode $\rho_T^\pm \to W^\pm Z \to \ell^\pm\nu_\ell\ell^+\ell^-$ is another important check on the LSTC hypothesis [21]. We expect $\sigma(\rho_T^\pm \to W^\pm Z)/\sigma(\rho_T^\pm \to W^\pm\pi_T^0) = (p(Z)/p(\pi_T))^3\tan^2\chi$. The PYTHIA rate agrees with this estimate; for $\sin\chi = 1/3$ and our input masses, $\sigma(pp \to \rho_T^\pm \to \ell^\pm\nu_\ell\ell^+\ell^-) = 25\,\text{fb}$ at the LHC. This should be observable with $\int \mathcal{L}dt \simeq 5\,\text{fb}^{-1}$.

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