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A search for Technicolor in the tri-lepton final state

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Abstract

We present a feasibility study of ρ_T and a_T production using the $\rho_T/a_T \to WZ \to ll l\nu$ final state. Such a signature is found in low scale walking Technicolor models. We perform this study using CMS fast simulation samples and conclude that it is possible to observe ρ_T with masses up to 500 GeV in data samples ranging from 2-10 fb^{-1} of integrated luminosity. We also find that the $a_T \to WZ$ process may be seen under the assumptions that $M_{a_T} \simeq 1.1 M_{\rho_T}$ (for $M_{\rho_T} = 500$ GeV) and that the MET resolution from data will be in reasonable agreement with the simulation.

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1 Introduction

Technicolor (TC) is a strongly interacting gauge theory which allows for the dynamical breakdown of electroweak symmetry [1, 2]. Recent versions with a slowly-running or "walking" gauge coupling enable extended technicolor (ETC) to generate realistic masses for fermions and techni-pions and also to evade the unwanted flavor changing neutral current interactions [3]. An additional consequence is that the walking tends to make the technicolor scale lower than previously expected, and the spectrum of this low-scale technicolor (LSTC) [4] thereby becomes more accessible at the LHC center-of-mass energy, $\sqrt{s} = 14$ TeV. The lightest ρ_T and ω_T are expected to have masses below ≈ 500 GeV, and their decays channels (for eg. $\rho_T \rightarrow WZ$) have distinctive signatures with narrow resonant peaks.

A long standing problem with walking technicolor has been a very large value for the precision-electroweak S-parameter [5]. Recent models incorporate the idea that the S-parameter can be naturally suppressed if the lightest ρ_T and its axial-vector partner, a_T, are nearly degenerate. The phenomenology of these techni-hadrons is described in the "Technicolor Straw-Man Model" (TCSM) [6].

This study was initiated during the Les Houches 2007 workshop and considers the tri-lepton final state resulting from the ρ_T and a_T decay via a WZ pair ($\rho_T/a_T \rightarrow WZ \rightarrow lll\nu$). The major sources of background are WZ di-boson production, ZZ di-boson production, $t\bar{t}$, and Z+jet production.

2 Event Samples and Simulation

For this study we concentrated on three TCSM mass points not excluded by other experiments and that cover a range accessible with early LHC data ($<\approx 10$ fb^{-1} of integrated luminosity). These masses along with the signal cross sections are listed in Table 1. These signal samples were generated using an updated version of PYTHIA [7]. This updated version includes both the vector and axial-vector resonances, ρ_T and a_T, respectively, with $M_{a_T} = 1.1 M_{\rho_T}$. This helps to naturally suppress the electroweak parameter S since the first set of vector resonances (ρ_T) and the first set of axial-vector resonances (a_T) are nearly degenerate. In addition, the Technicolor parameters, M_V (for techni-vectors) and M_A (for a_T) were set to be equal to M_{ρ_T} and M_{ω_T}. Furthermore, new decay modes for a_T were incorporated in this version of PYTHIA in order to fully model its behavior. This implementation of a_T has been studied for the first time in a CMS analysis - an older analysis [8] used the previous modeling of TCSM to study the $\rho_T \rightarrow WZ$ channel i.e. $a_T \rightarrow WZ$ was not included[1)].

Parameter Set	$m_{\rho_T} = m_{\omega_T}$ (GeV)	$m_{a_T}(GeV)$	m_{π_T} (GeV)	$M_V = M_A$ (GeV)	$\sigma\times$ BR (fb)
A	300	330	175	300	112
B	400	440	225	400	37
C	500	550	275	500	16

Table 1: Parameter sets for the signal samples used in the study. BR refers to the branching ratios of the W and Z to electrons and muons. Cross-sections quoted are computed by PYTHIA to leading-order(LO).

Figure 1 shows the invariant mass of the WZ pair for parameter set C (from Table 1). The larger resonant peak comes from the ρ_T while the smaller peak to its right denotes the a_T resonance. The generator level samples were then processed using CMS Fast Simulation[2)]. Background samples were also generated using PYTHIA and leading-order (LO) cross-sections were used for normalization.

3 Event Selection

The final state signature consists of three charged leptons and a neutrino. The following selection criteria were imposed in order to enhance the signal to background ratio:

- Three isolated charged leptons (electrons or muons), with $p_T > 15$ GeV and $|\eta| < 2.5$. Tracker-based isolation is used for both electrons and muons with the isolation for electrons being defined as:

1) The current analysis also employs somewhat different selection criteria in order to preserve the ability to study the decay angular distributions that could be used to differentiate between the vector and axial-vector resonances.

2) This analysis uses release CMSSW_1_6_7 and the following tags: V00-07-09 FastSimulation/Configuration; V03-03-03 FastSimulation/EventProducer

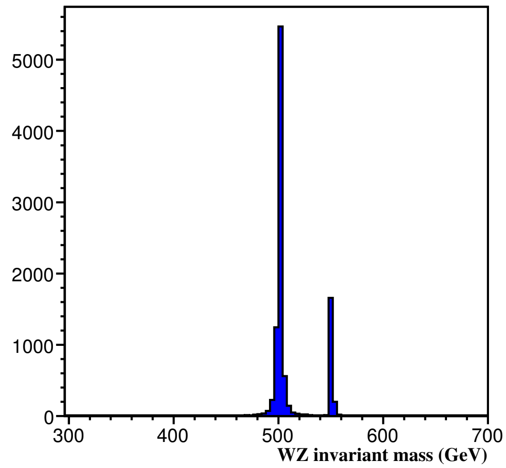

Figure 1: Generator-level WZ invariant mass distribution for Parameter Set C. The resonance at 500 GeV corresponds to the degenerate ρ_T while the smaller resonance to its right corresponds to a_T.

$$\sum_{track}(\frac{p_T^{track}}{p_T^{ele}})^2 < 0.02$$

where all tracks with $p_T^{track} > 1.5$ GeV, within an $\eta - \phi$ annular isolation cone centered on the reconstructed electron, are summed, and the cone has limits, $0.02 < \Delta R < 0.6$ where $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ and p_T^{ele} is the momentum of the reconstructed electron. For muon isolation the sum of p_T of tracks in a cone of radius $\Delta R = 0.3$ is required to be less than 3.0.

- Missing transverse energy, MET > 40 GeV.
- Leptonic HT, defined as the scalar sum of the transverse momentum of the three leptons, is required to be greater than 150 GeV.

While the requirement of three high p_T leptons reduces the contribution from background processes in general, the requirement of large missing transverse energy helps to reduce the Z+jet and ZZ background considerably. The MET distribution for signal and background events is shown in Fig. 2. The other kinematic variable, leptonic HT, also serves as a good discriminating variable for distinguishing signal from background and is shown in Fig. 3.

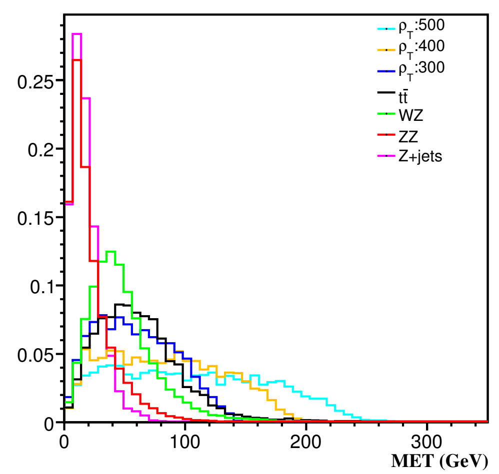

Figure 2: MET distributions for signal and background samples. The distributions are normalized to unit area.

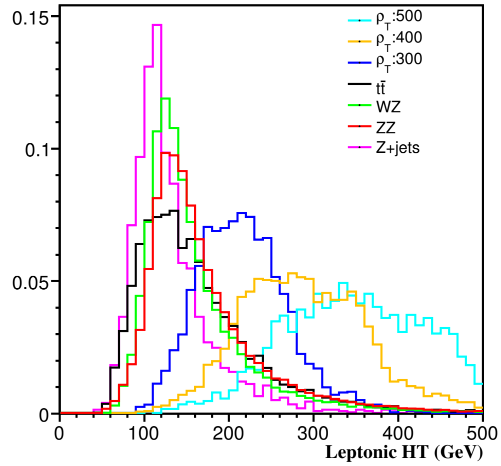

Figure 3: Leptonic HT distributions for signal and background samples. The distributions are normalized to unit area.

4 Event Reconstruction

After the above selection, the WZ invariant mass is reconstructed using the following procedure:

- Reconstructing the Z boson:
  - If two of the charged leptons have the same flavor, then they are used to reconstruct the Z boson. If all three have the same flavor, the lepton pair with an invariant mass closest to the Z boson mass (within 12.5 GeV) is assigned to the Z candidate. In either case, the third lepton in the event is assigned to the W candidate. (In the case of more than three leptons, the highest p_T lepton not assigned to the Z boson is used to reconstruct the W candidate.)
  - The transverse momentum of the reconstructed Z boson is required to be greater than 65 GeV.
- Reconstructing the W boson:
  - The unassigned (third) lepton and neutrino are assumed to have come from the W boson. The W invariant mass constraint is used along with the MET vector to reconstruct the final state.
  - The transverse momentum of the reconstructed W boson is required to be greater than 65 GeV.

The Z p_T and W p_T distributions are shown in Figs. 4 and 5. The reconstructed WZ invariant mass plot corresponding to the generator-level parameter set (in Fig. 1) is shown in Fig. 6. The ρ_T and a_T resonances are no longer as degenerate as in the generator level case owing to MET resolution effects incorporated in the detector simulation. However, both ρ_T and a_T can still be seen as shown by the red and blue curves, respectively, in Fig. 6. The final event selection efficiencies for the signal samples are 0.20, 0.29 and 0.34 for parameter sets corresponding to ρ_T masses 300 GeV, 400 GeV and 500 GeV, respectively.

5 Discovery Potential

Fig. 7 shows the WZ invariant mass distributions for both signal (Parameter Set C) and background events after event selection and reconstruction. The distributions are stacked on top of each other and a clear signal peak is visible around 500 GeV. A simple event counting technique based on $S/\sqrt{(S+B)}$ was then used to estimate the signal and background yield under the mass peak. A mass window of 1.4 σ was chosen around the ρ_T mass peak and the discovery potential was evaluated for different luminosity settings. The results are shown in Fig. 8. The number of signal and background events used in the computation are listed in Table 2. No systematic uncertainties have been applied yet. The plot indicates that for the mass range in consideration, a discovery could be made with 2-10 fb^{-1} of integrated luminosity.

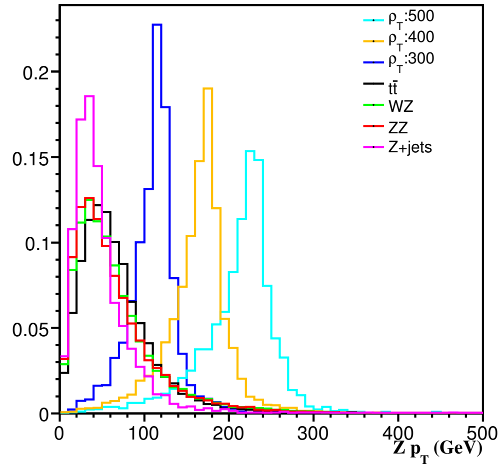

Figure 4: Z p_T distributions for signal and background samples. The distributions are normalized to unit area.

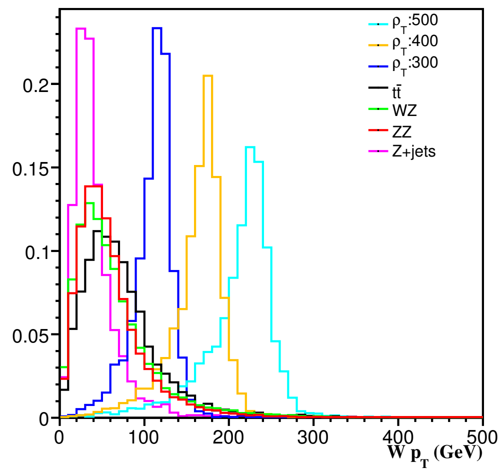

Figure 5: W p_T distributions for signal and background samples. The distributions are normalized to unit area.

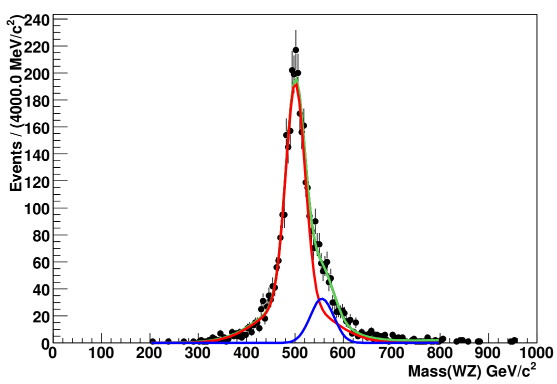

Figure 6: The reconstructed WZ invariant mass distribution for Parameter Set C. The resonance corresponds to the ρ_T and a_T combination. The distribution is fitted to show the ρ_T component in red and the a_T component in blue while the green curve corresponds to the total. Background contributions are not shown in this plot.

Parameter Set	m_{ρ_T}	Signal Events	Background Events	Lumi (fb)
A	300	36	15	2.4
B	400	36	16	4.9
C	500	34	12	9.5

Table 2: Total number of signal and background events in the signal mass window for the three parameter sets. These numbers correspond to the 5σ discovery points. The column on the extreme right denotes the integrated luminosity needed for discovery.

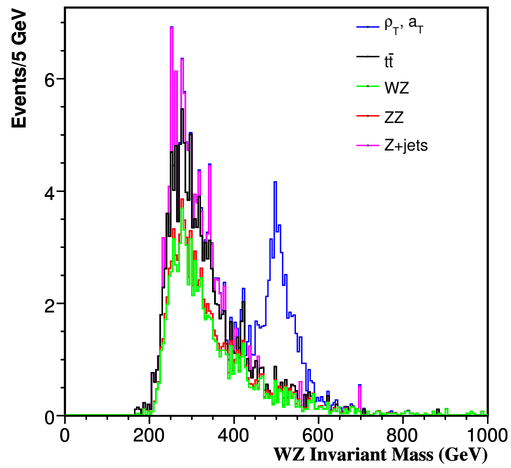

Figure 7: Stacked WZ invariant mass distributions for signal and background samples. The distributions are normalized to an integrated luminosity of 10 fb^{-1}.

6 Conclusion

We have performed a feasibility study to search for technihadrons - ρ_T and a_T - using final state WZ invariant mass distributions. We find that is is possible to observe ρ_T up to masses of about 500 GeV during the early phase of LHC data-taking using between 2-10 fb^{-1} of integrated luminosity. Additionally we find that the $a_T \to WZ$ process may also be seen under the assumption that $M_{a_T} \simeq 1.1 M_{\rho_T}$ and with $M_{\rho_T} = 500$ GeV. This also assumes that the MET resolution from data will be in reasonable agreement with the current simulation.

We should note that this is a feasibility study using fast simulation samples and hence should be considered a work in progress. More detailed studies using samples with pileup are underway. Additional analysis improvements are also planned: full detector simulations of the signal and background samples, better lepton identification and fake removal. These should further enhance the sensitivity. This updated version of the analysis will also include a detailed study of systematic uncertainties.

7 Acknowledgment

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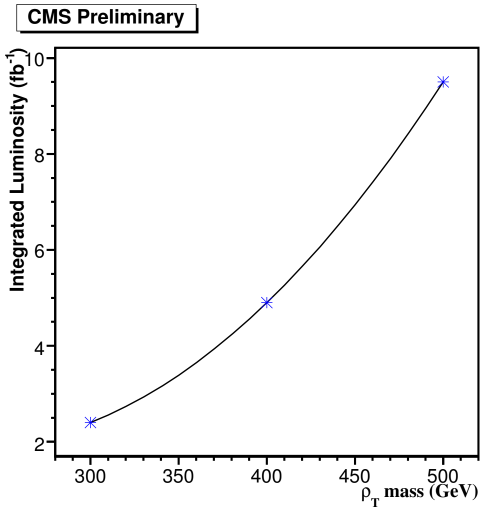

Figure 8: Integrated luminosity needed to reach 5σ significance as a function of ρ_T mass.

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