ATLAS NOTE

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Searches for Technicolor in the Trilepton Final State

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Abstract

We perform a study with a parameterized simulation of the ATLAS detector of ρ_T and a_T production with a $WZ \to lll\nu$ decay signature. This exotic signature is found in a model of low scale walking Technicolor. This is the first time that the a_T signature has been considered. As a result we present the discovery potential of the ρ_T as a function of the Technicolor resonant masses and discuss the characteristic angular distribution of the final state at the LHC which could be established for some Technicolor models.

1 Introduction

Recent Technicolor models with a "walking" gauge coupling require many technihadron states. Previous Technicolor searches have focused on the discovery of the lowest mass states - the scalar mesons, the technipions π_T^{+-} and π_T^0, and vector mesons (ρ_T and ω_T). These technihadrons are expected to be produced with high rates at the Large Hadron Collider (LHC) [1]. A long standing problem with Technicolor models has been the introduction of an anomalous correction to the precision electroweak parameter S [2] [1)]. It was realized that this could be naturally suppressed if the first set of vector resonances and the first set of axial-vector resonances were nearly degenerate [1] - thus alleviating the constraints from precision electroweak measurements.

A modification to the PYTHIA [3] strawman model [4] was made [5] to introduce a new triplet of axial-vector resonances, the techni-a (a_T). In the PYTHIA Technicolor straw man model the techniparticles are included as entries in the charged-current and neutral-current propagator matrices. These were expanded to include the a_T and decay modes to gauge bosons, fermions, and ρ_T with gauge bosons were included. This version of PYTHIA was interfaced to the ATLAS software [6].

The values of the cross-section and branching ratios depend upon:

- the mass of the ρ_T, ω_T, and a_T mesons
- the mass difference between the vector mesons and the technipions (which determine which channels are kinematically accessible)

The decay of the ω_T and ρ_T to a transverse gauge boson is set by a dimension 5 or 6 operator, which require a mass scale in the denominator – this mass scale is M_V (for techni-vectors) or M_A (for a_T).

In this note we report on the work which was initiated at the Les Houches 2007 workshop and document the results which will become part of the Les Houches proceedings. We consider the trilepton final state which results when the vector and axial-vector mesons decay via a WZ pair ($\rho_T/a_T \to WZ \to lll\nu$). Final states with multiple leptons are particularly promising for processes with relatively large cross-sections in early data. With three high p_T leptons the trigger efficiency is expected to be close to 100% with relatively little instrumental background. This study was completed using the ATLFAST fast simulation program [7, 8] using release 12.0.6.

2 Technicolor Parameters

We choose three sets of parameters - primarily to vary the mass of the lowest lying technihadron states. There were several requirements that we kept in mind. First - we wanted to choose a set of masses that were not already excluded by previous experiments. At the same time we wanted to select a set of masses which would be accessible with early LHC data. The vector and axial-vector resonances were chosen to be almost degenerate in order to alleviate the constraints set by the precision electroweak S parameter. The technipions were chosen to be heavy enough such that $\rho_T \to \pi_T W$ decays were not kinematically accessible. Finally the M_V and M_A parameters were chosen to be identical and equal to the ρ_T and ω_T masses which were set as degenerate. It should be noted that the M_V mass parameter is unknown *a priori* and is responsible for the rate of $\omega_T \to \pi_T^0\gamma$. The proponents of the model [9] suggested a value of several 100 GeV from scaling to the known $\omega \to \gamma\pi^0$ rate. Table 1 shows the three parameter sets considered here.

[1)] Although it has also been pointed out that the validity of the calculation of the anomaly may be suspect due to the fact that Technicolor is a strongly interacting theory

Parameter Set	$m_{\rho_T} = m_{\omega_T}$ (GeV)	m_{a_T} (GeV)	m_{π_T} (GeV)	$M_V = M_A$ (GeV)	Cross Section $\times$ BR (fb)
A	300	330	175	300	115.2
B	400	440	225	400	33.0
C	500	550	275	500	14.8

Table 1: Parameter sets considered in the modified Technicolor Strawman Model

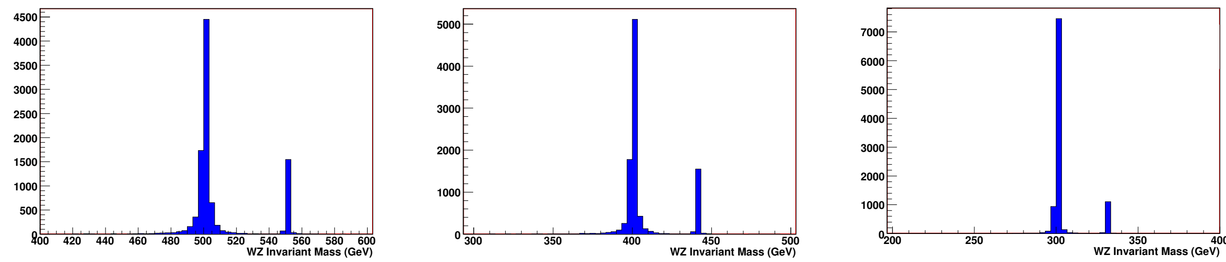

Figure 1: The generated WZ diboson invariant mass for the three parameter sets. In each case the larger and lighter resonance corresponds to the degenerate ρ_T and ω_T while the heavier resonance is the a_T.

3 Event Kinematics

Since this is not yet incorporated in a standard version of PYTHIA (although written by the authors) we present several generator level distributions from parameter set A to validate the generation. Figure 1 shows the invariant mass of the WZ pair in the three parameter sets. The larger resonance comes from the ρ_T while the smaller resonant peak is from the a_T

In Figure 2 the distribution for generator level leptons p_T, η, and ϕ are shown. These distributions are consistent with previous studies and in agreement with comparisons from [9].

4 Backgrounds

In principle, any process with a final state of three charged leptons and significant MET represents a background to this search. Previous studies [10] [11]indicate that the most important backgrounds are:

- WZ diboson production
- ZZ diboson production
- $t\bar{t}$ production

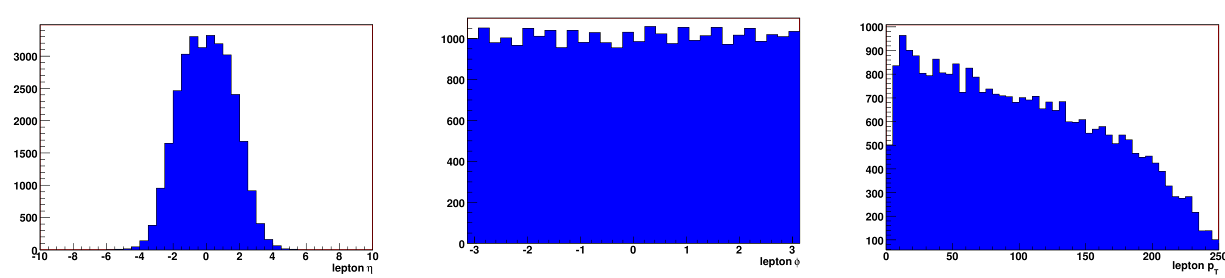

Figure 2: The generator lepton η (left), ϕ(center), and p_T (right) from dataset A.

Sample	Cross Section × Branching Ration	Requirements
WZ Diboson	877.5 fb	$W \to l\nu$ and $Z \to ll$ (electron/muon/tau)
ZZ Diboson	158.2 fb	Both $Z \to ll$ (electron/muon/tau)
$t\bar{t}$	24 pb	Both $W \to l\nu$ (electron/muon/tau)
Inclusive Z	3.5 nb	$Z \to ll$ (electron/muon)

Table 2: Backgrounds for the trilepton search. The cross-sections are leading order and taken from PYTHIA.

- Z + jet production

The WZ diboson production represents the "irreducible" background since the final state is identical to the signal. In the case of the ZZ diboson production one lepton can be either out of the geometric acceptance of the detector or simply not reconstructed. In the last two cases two leptons come from the hard process and a third lepton can either come from a heavy quark decay or from an instrumental fake. Note for the most signficant diboson backgrounds we also include the *tau* decays which contribute when a τ decays leptonically. The cross sections for the various backgrounds are shown in table 2. We also apply an additional 90% efficiency per lepton since this version of the fast simulation utilized for this study assumes 100% efficiency.

5 Event Reconstruction

The final state consists of three charged leptons and a neutrino. To begin the reconstruction of the WZ pair we require:

- Three charged leptons (electrons or muons) with $p_T > 10$ GeV and $|\eta| < 2.5$.
- Missing transverse energy , MET, > 30 GeV.

The selection of three high p_T transverse leptons reduces the contribution from background processes significantly. The requirement of significant missing transverse energy is applied to reduce the Z + jet and ZZ background. The MET distribution for signal and background is shown (normalized to unit area) in figure 3. For a variety of luminosities the optimum requirement was found to be approximately 30 GeV.

After this basic selection we attempt to reconstruct the WZ invariant mass by using the following algorithm. If two of the charged leptons are of the same flavor these two leptons are used to reconstruct the Z boson. If all three are of the same flavor, the lepton pair with an invariant mass closest to the known Z boson mass are assigned to the Z boson. In either case the third lepton is assumed to come from W boson.

In the case of the Z boson decay both decay products are reconstructed. Unfortunately, the neutrino escapes the ATLAS detector without interacting. However, we can use the invariant mass constraint from the W boson to attempt together with the MET to try to reconstruct the final state. We use the two components of the MET vector and assign them to the neutrino p_x and p_y components. A technique taken from the Tevatron can be used to estimate the p_z component of the neutrino. Since the unassigned lepton and neutrino are assumed to come from the W boson we set the invariant mass of the final lepton [2)] and the MET to that of the W boson. After solving for the p_z of the neutrino the invariant mass of the WZ pair can be evaluated.

[2)] In the case of more than three leptons we assign the highest p_T lepton not assigned to the Z boson to the W boson

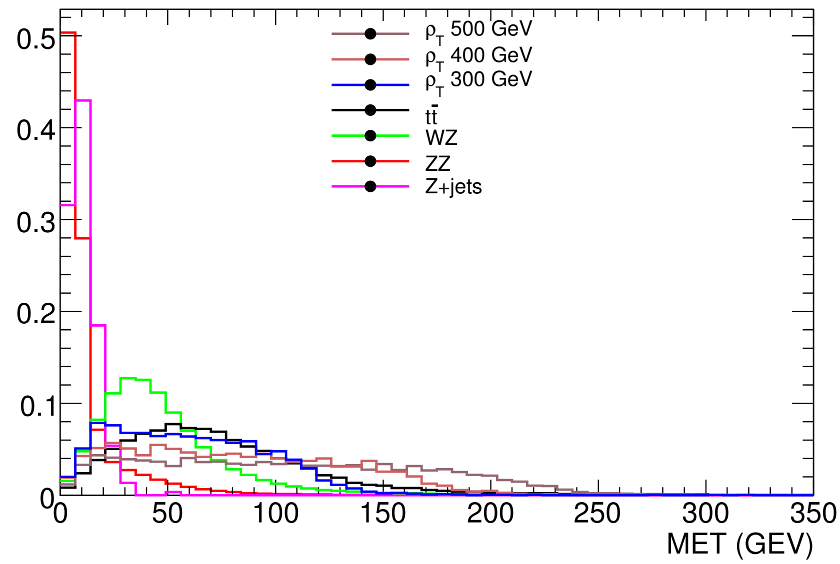

Figure 3: MET distribution normalized to unit area for three lepton events from signal and background.

There is one twist to this procedure. The equation arising from the procedure to reconstruct the W boson leads to a quadratic ambiguity. In the case where more than one real solution is found we attempted four reconstruction methods to find the correct p_z of the neutrino:

- Choose the solution that minimizes the W boson energy.
- Choose the solution that maximizes the W boson energy.
- Choose the solution that minimizes the opening angle between the lepton and neutrino.
- Choose the solution that maximizes the opening angle between the lepton and neutrino.

Minimizing the W boson energy was found to be the optimal solution at the Tevatron. It was thought that at the LHC the W boson could be more highly boosted and hence the correct solution might be found by choosing the solution for which the angle between the W boson decay products is smallest. Figure 4 indicates the result for parameter set A where the difference between the p_z solution and the true neutrino p_z is shown. The results are actually quite similar for all four cases with a slight preference for choosing the solution that minimizes the W boson energy. At higher masses, the RMS of the distribution found by minimizing the opening angle improves somewhat (as expected) but is still larger than the one found by minimizing the W boson energy.

6 Event Selection

After the initial object based selection described above (three charged leptons and MET) we require:

- Two leptons of the same flavor have an invariant mass consistent with a Z boson (within 12.5 GeV).
- The leptonic HT, defined as the scalar sum of the transverse momentum of the three leptons, is required to be greater than 150 GeV.

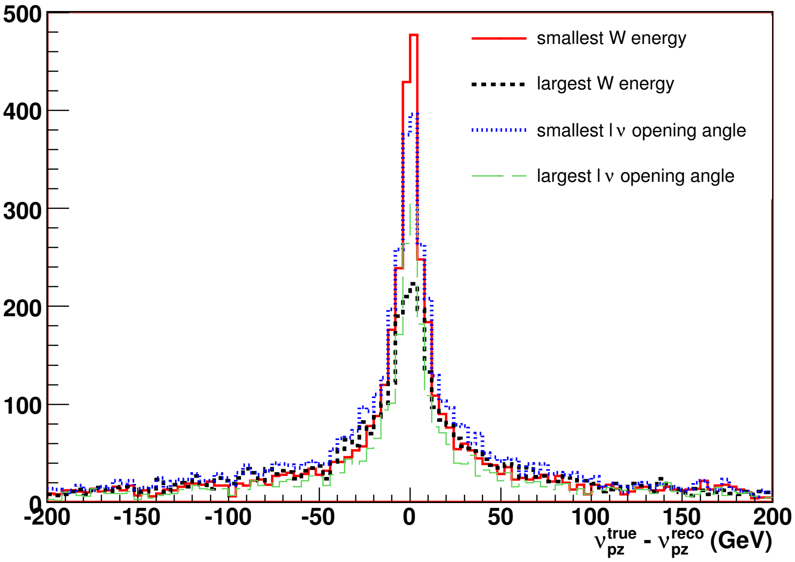

Figure 4: Plotted here is the difference between the z component of momentum of the Monte Carlo truth neutrino and the "reconstructed" neutrino described in the text.

- The transverse momentum of the reconstructed Z boson is greater than 50 GeV.
- The transverse momentum of the reconstructed W boson is greater than 50 GeV.

The first ensures that we have a well reconstructed Z boson candidate. Finally, in the signal sample the gauge bosons come from the decay of a heavy particle and hence tend to have a larger transverse momentum. The normalized distributions for the Z boson transverse momentum for both signal and background are shown in Figure 5. The selection on the W boson transverse momenta is seen to remove essentially all of the events from the inclusive Z boson production.

The invariant mass distributions after event selection are shown in figure 7. The dominant background appears to come from the irreducible Standard Model WZ background.

7 Discovery Potential for ρ_T

In order to evaluate the discovery potential we apply a simple event counting technique to estimate the signal and background yield by counting under the assumed mass peak. A more robust technique will be studied later but this suffices to understand roughly what integrated luminosity should be needed for this channel until such techniques become available. We choose a mass window of $\pm$ 30 GeV around the three mass points (centered at the ρ_T mass). The results are shown in figure 8. Note that no systematic uncertainties were applied. The 5 σ contours indicate that within the mass range considered, a discovery could be made with between 1 - 10 fb^{-1} of integrated luminosity.

8 Observation of the a_T

Because of its larger cross-section the ρ_T would clearly be discovered first. However, the a_T signal may be observable in the trilepton channel under certain conditions. It is assumed in this study that the a_T

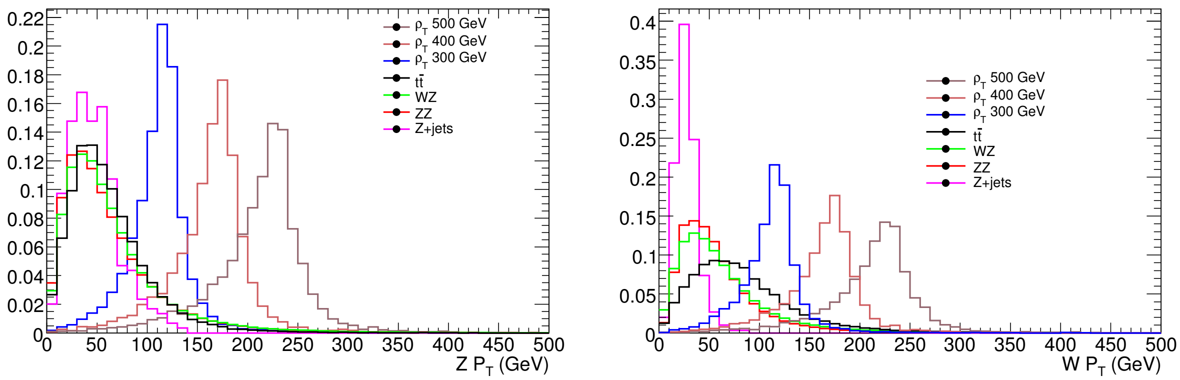

Figure 5: The normalized Z (left) and W (right) bosons' transverse momentum for signal and background.

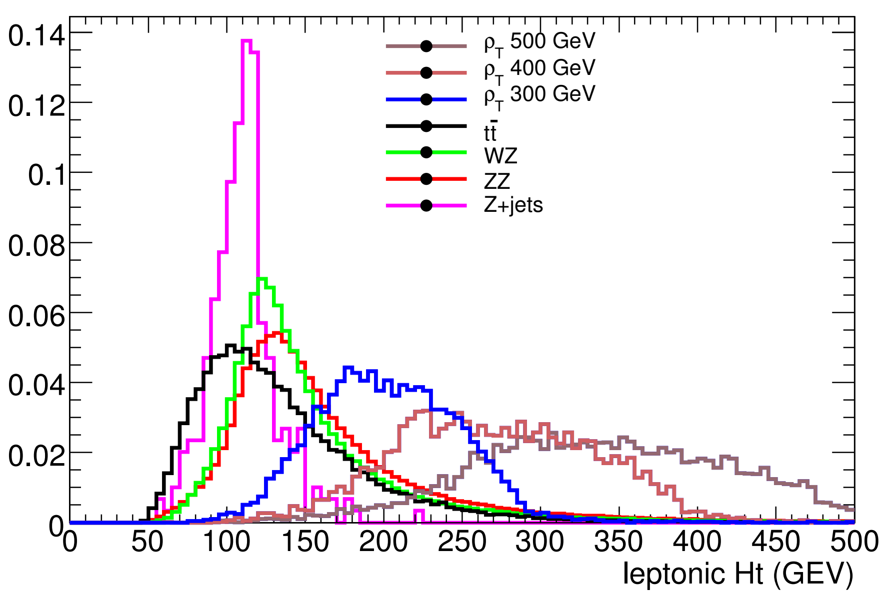

Figure 6: The leptonic HT of the signal and background all normalized to unit area.

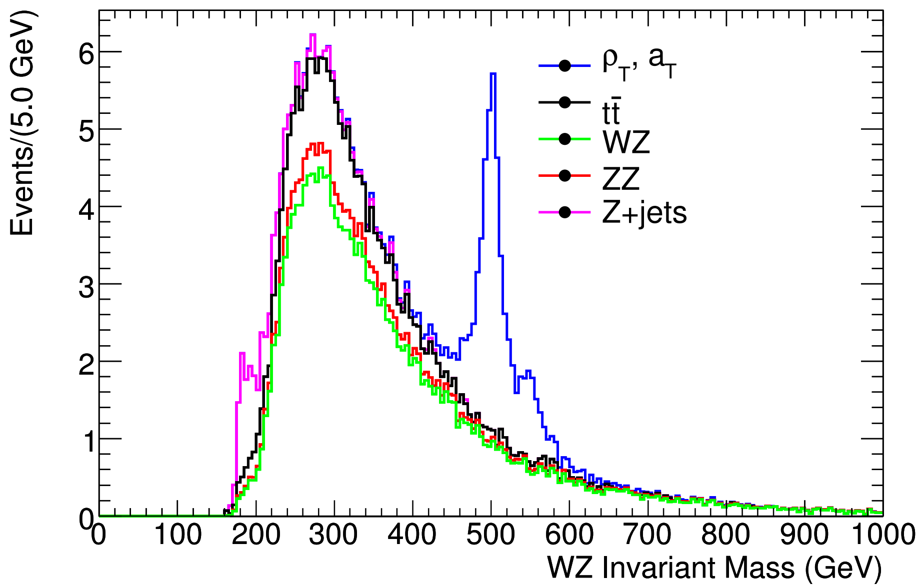

Figure 7: The reconstructed invariant mass of the WZ diboson pair for both signal and background for the 500 GeV ρ_T and 550 GeV a_T for an integrated luminosity of 10 fb^{-1}

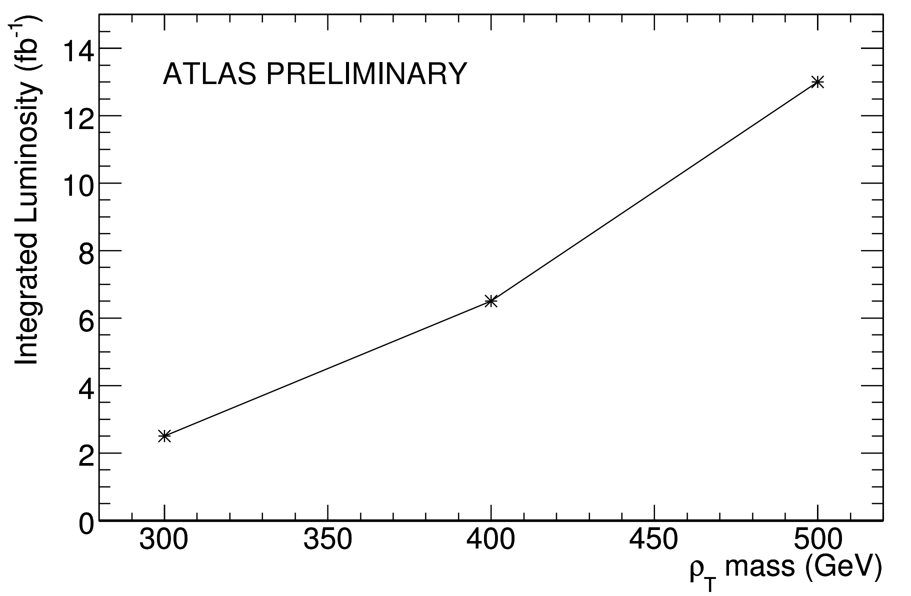

Figure 8: The integrated luminosity needed to reach 5 σ significance as a function of ρ_T mass.

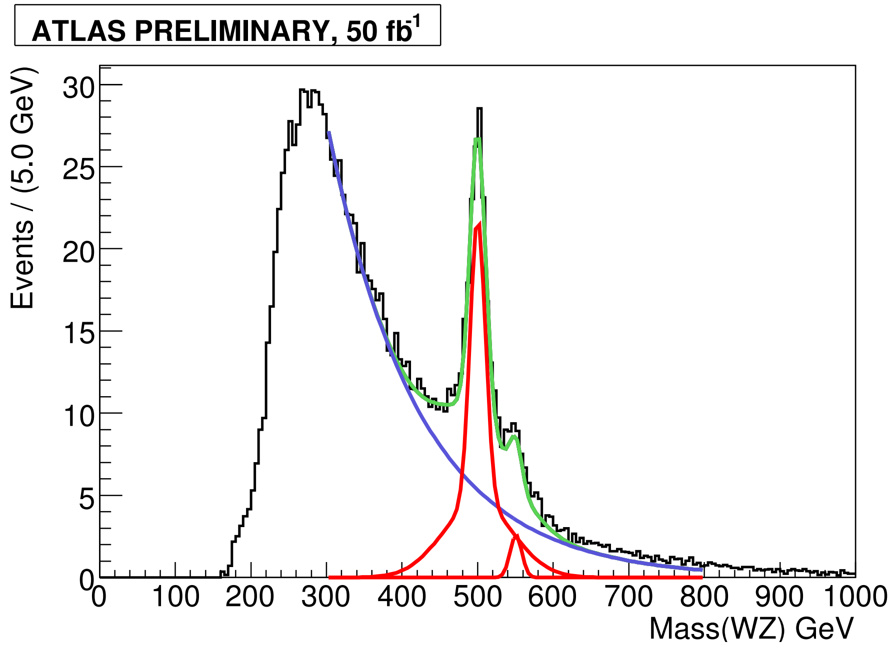

Figure 9: Fit of the WZ diboson reconstructed invariant mass with background assuming an integrated luminosity of 50 fb^{-1}. The two red curves represent the signal resonances, the blue the background, and the green is the combination of the curves. .

and ρ_T masses are separated by 10%. We examined the potential for distinguishing the a_T by trying to extract the resonance peak by fitting the Monte Carlo data and observing the angular distribution of the diboson pair.

8.1 Fitting Close Resonances

We developed a simple model to fit the diboson invariant mass to include both contributions from the ρ_T and a_T as well as the continuum background. We model the background - which is dominated by Standard Model WZ diboson production - by an exponentially decreasing function. Note that the kinematic requirements remove the invariant mass region which would otherwise continue to rise exponentially in the low invariant mass region until much lower masses. The ρ_T and $a_T$were modeled as a combination of Gaussian distributions. Since this was only meant as a proof of principle we assume an integrated luminosity of 50 fb^{-1} where the ρ resonance is clearly visible and can be seen above background with approximately 10 σ. The result of the fit is shown in Figure 9. As can be seen from the fit - the a_T can be seen in principle as a somewhat separated second resonance. It should be noted that the more degenerate the a_T is with the ρ_T the less visible it becomes. For a smaller mass difference or significantly worse resolution the second peak becomes a hard shoulder in the distribution and eventually indistinguishable. Further more detailed statistical tests are needed to quantify this statement.

8.2 Angular Distribution

After the discovery of such resonances, the angular distribution could also be used to help establish the correct underlying theory responsible for the experimental resonance. While the ρ_T is a vector meson the a_T is an axial-vector. The angular distribution of the decay products of the ρ_T (in the ρ_T rest frame) is proportional to $sin^2(\theta)$ while the decay products of the a_T are proportional to $1 + cos^2(\theta)$. If the two

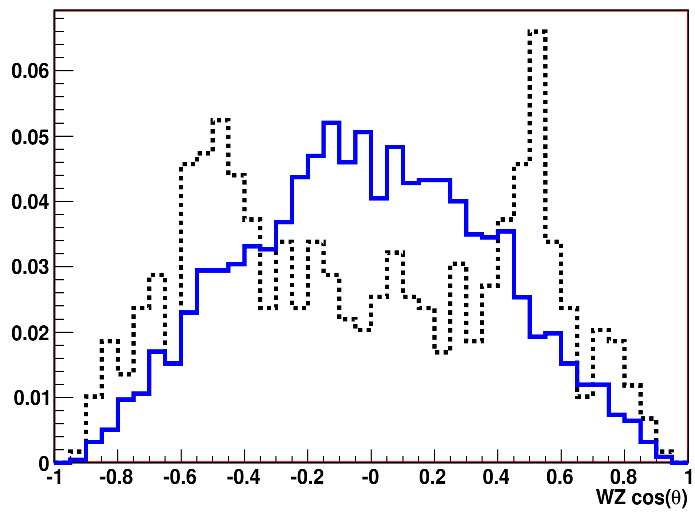

Figure 10: Comparison of the normalized WZ angular distribution for events under the ρ_T (solid) and a_T (dotted) peaks.

resonances could be established then we could look at the angular distribution of the events under the two mass peaks in an attempt to see the characteristic distributions. The reconstructed distribution with the mass of the ρ_T set to 500 GeV and the mass of the a_T set to 550 GeV is shown for events reconstructed within $\pm$ 20 GeV of the invariant mass peaks of the ρ_T and a_T is shown in figure 10.

The angular distribution for events under both peaks is shown including the background for 50 fb^{-1} of integrated luminosity in figure 11.The characteristic distributions can be clearly seen and established. A more detailed study of how much data would be needed to establish the distribution is underway.

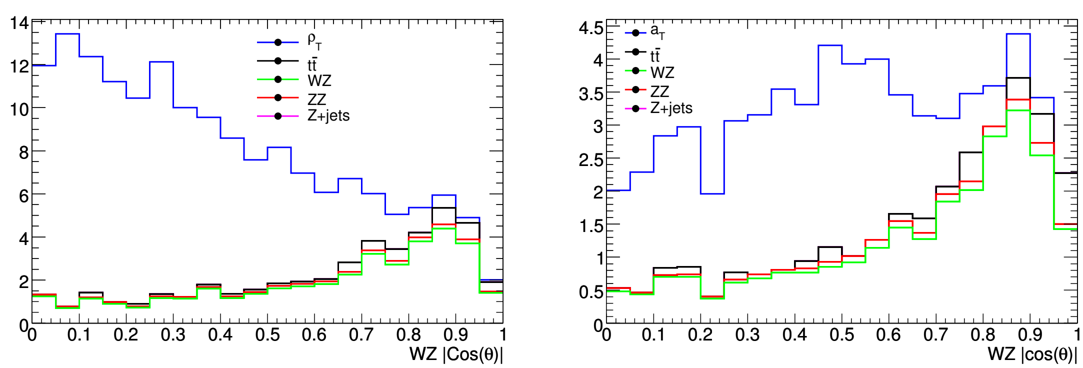

Figure 11: Reconstructed Distribution for the WZ invariant mass pair under the ρ_T peak (left) and the a_T peak (right) and background for an integrated luminosity of 50 fb^{-1} .

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