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SEARCH FOR ANOMALOUS KINEMATICS IN $t\bar{t}$ DILEPTON EVENTS AT CDF II

ANDREW IVANOV
(On behalf of the CDF Collaboration)

Department of Physics and Astronomy, University of Rochester
Rochester, NY 14627, USA

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We report on a search for anomalous kinematics of $t\bar{t}$ dilepton events in $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV using 193.5 pb^{-1} of data collected with the CDF II detector. We developed a new *a priori* technique designed to isolate the subset in a data sample revealing the largest deviation from Standard Model expectations and to quantify the significance of this departure. In the four-variable space considered, no particular subset shows a significant discrepancy and we find that the probability to obtain a data sample less consistent with the Standard Model than what is observed is 1.0–4.5%.

Keywords: Standard Model (SM); Kolmogorov-Smirnov (KS) test; p-value.

1. Introduction

Within the SM the top quark decays almost exclusively to Wb; the "dilepton" decay channel is the case where both W bosons from a $t\bar{t}$ pair decay into final states containing an electron or muon. The CDF and DØ measurements of the $t\bar{t}$ production cross section in the dilepton channel in Run I showed a slight excess over SM predictions [1]. Perhaps more interestingly, however, several of the events observed in the Run I data had missing transverse energy ($\not\!\!E_T$) and lepton p_T's large enough to call into question their compatibility with SM top decay kinematics [2].

Motivated by the possible anomalies in the top Run I dilepton sample, we devised a search for new physics based on the comparison of kinematic features of observed events with those expected from the SM. The method seeks to isolate the subset of events in a data sample with the largest concentration of possible non-SM physics and to assign a probability that quantifies its departure from the SM.

Ref. [3] provides a description of the CDF-II detector, the event selection, and the data and simulation samples used for this analysis. With this selection [a], the SM predicts a yield of 8.2 ± 1.1 $t\bar{t}$ events and 2.7 ± 0.7 events from other SM processes (mainly WW, W + associated jets, and Drell-Yan). Thirteen events are observed.

[a] We use the higher-purity selection referred to as "DIL" therein.

2. Search Technique

Expecting new physics to be associated with new heavy particles or phenomena beyond the presently known mass spectrum we focus our search on events with large $\not\!\!E_T$, large leading lepton p_T^ℓ, and large angle $\Phi_{\ell m}$ between the leading lepton and the direction of the $\not\!\!E_T$ in the plane transverse to the beam.

In addition, we attempt to reconstruct events under the $t\bar{t}$ dilepton decay hypothesis by imposing constraints on the final state products, $m(\ell\nu) = m_W$ and $m(b\ell\nu) = m_t$. We define a variable based on the difference between the reconstructed neutrino momentum sum ($\vec{\not\!\!E}_T{}^{pred}$) and the measured $\vec{\not\!\!E}_T$ ($\vec{\not\!\!E}_T{}^{obs}$):

$$T = \sqrt{\int\int\int \exp\left\{ -\left|\vec{\not\!\!E}_T{}^{pred} - \vec{\not\!\!E}_T{}^{obs}\right|^2 / 2\sigma^2_{\not E_T} \right\} d\not\!\!E_T{}^{pred}_x d\not\!\!E_T{}^{pred}_y}, \qquad (1)$$

where $\sigma_{\not E_T}$ is mismeasurement of the underlying event, and the integral is performed over the phase space of possible solutions of $\vec{\not\!\!E}_T{}^{pred}$. A non-$t\bar{t}$ dilepton event has on average a small value of T compared to $t\bar{t}$ events.

Next, each event is assigned a weight $W = (w_{\not E_T} \cdot w_{p_T^\ell} \cdot w_{\Phi_{\ell m}} \cdot w_T)^{1/4}$, where w represent probabilities (assuming the SM) for an event to have a $\not\!\!E_T$, p_T^ℓ, $\Phi_{\ell m}$ larger and a T smaller than that observed, respectively. We then construct 13 subsets ("K-subsets") of the data from K events with the lowest weights W.

To quantify the departure of the K-subsets from the SM predictions we do a shape comparison using the KS statistic for each of the four variables i. The KS probabilities $p_{K,i}$ are obtained by generating pseudoexperiments of randomly drawn events from large Monte Carlo samples of $t\bar{t}$ and SM backgrounds, and the overall agreement P_K of the K-subset with the SM expectation is quantified using the product of the four probabilities.

The subset of the Q events, such that $\mathcal{P} = P_Q = \min P_K$, is the most unlikely subset. The significance of discrepancy of the data with the SM is computed based on the probability distribution function $\mathcal{L}(\mathcal{P})$ obtained from pseudoexperiments. $\alpha = \int_0^{\mathcal{P}_{data}} \mathcal{L}(\mathcal{P})\, d\mathcal{P}$ is the p-value of the test, representing the probability to obtain a data sample less consistent with the SM than what is actually observed. Low values of α would indicate the presence of new physics in the data sample, and the Q events would represent the subset with the largest concentration of new physics.

3. Results

The distributions of the selected variables for $t\bar{t}$ dilepton events are presented in Figure 1. We find the most unlikely subset of events to be the entire data set (*i.e.* $Q = 13$), with a p-value = 1.6% (1.0% -4.5% with inclusion of all systematic effects). This result is entirely driven by the excess of leptons at low p_T seen in Figure 1b.

To investigate whether the low-p_T events can be attributed to non-$t\bar{t}$ SM processes, we present the bottom quark content (the number of jets containing a displaced secondary vertex) of the sample as well as the distribution of events in the

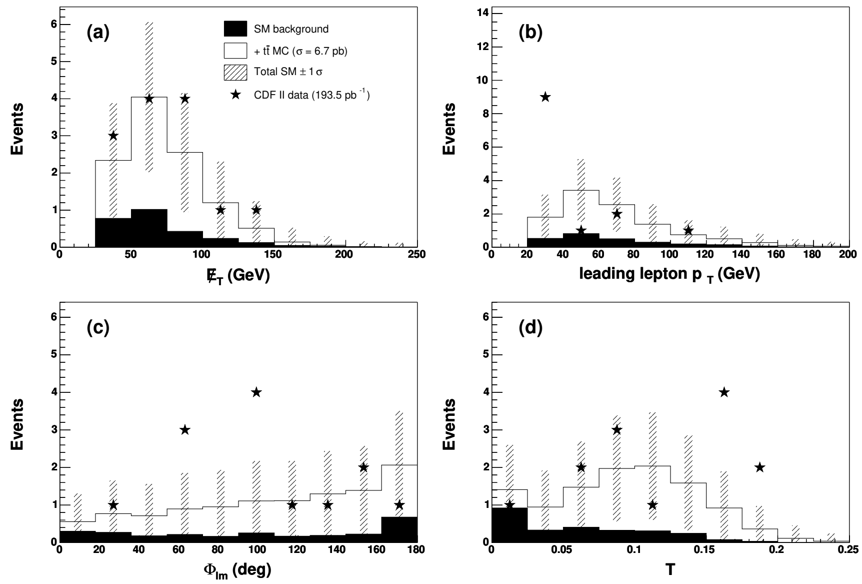

Fig. 1. $\not{E}_T$, leading lepton p_T, $\Phi_{\ell m}$, and T distributions for the top dilepton sample. The hatched regions represent the Poisson uncertainty on the expectation in a given bin.

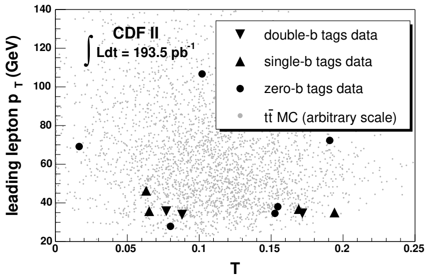

Fig. 2. Top dilepton events in (p_T, T) plane with b-tagging information.

(p_T, T) plane in Figure 2. Majority of the low-p_T events contain at least one identified b-jet, and/or are consistent with the $t\bar{t}$ kinematic hypothesis as evidenced by their large values of T. We also note that the leptons are well-isolated from any additional calorimeter activity, disfavoring the possibility that they arise from semileptonic b decays. We thus conclude that the low-p_T events are more likely to be top than background.

References

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