An inclusive search for new physics in like-sign dilepton events at CDF with 6.1 fb$^{-1}$

The CDF Collaboration

URL http://www-cdf.fnal.gov

(Dated: April 9, 2011)

We present a search for new physics in events with two high $p_T$ leptons of the same electric charge using data with an integrated luminosity of 6.1 fb$^{-1}$. The observed data are consistent with standard model predictions.

I. INTRODUCTION

A wide variety of models of new physics predict events with two like-sign leptons, a signature which has very low backgrounds from the standard model. Examples include supersymmetry [1], heavy neutrinos [2], same-sign top quark production [3] and fourth-generation quarks [4].

CDF examined the like-sign dilepton data in RunI [5] and in RunII in 1 fb$^{-1}$ [6].

In this note, we present a study of the inclusive like-sign dilepton sample, comparing it to the standard model prediction and assessing the statistical consistency. Companion notes interpret the sample in terms of supersymmetry [7] and same-sign top quarks [8].

II. DATASET AND SELECTION

Events were recorded by CDF II [9, 10], a general purpose detector designed to study collisions at the Fermilab Tevatron $p\bar{p}$ collider at $\sqrt{s} = 1.96$ TeV. A charged-particle tracking system immersed in a 1.4 T magnetic field consists of a silicon microstrip tracker and a drift chamber. Electromagnetic and hadronic calorimeters surround the tracking system and measure particle energies. Drift chambers located outside the calorimeters detect muons. We examine data taken between August 2002 and September 2010, with integrated luminosity of 6.1 fb$^{-1}$.

The data acquisition system is triggered by $e$ or $\mu$ candidates [11] with transverse momentum ($p_T$[10]) greater than 18 GeV/$c$. Electrons and muons are reconstructed offline and selected if they have a pseudorapidity ($\eta$[10]) magnitude less than 1.1, $p_T \geq 20$ GeV/$c$ and satisfy the standard CDF identification and isolation requirements [11]. Jets are reconstructed in the calorimeter using the JETCLU [12] algorithm with a clustering radius of 0.4 in azimuth-pseudorapidity space and corrected using the standard techniques [15]. Jets are selected if they have $p_T \geq 15$ GeV/$c$ and $|\eta| < 2.4$. Missing transverse momentum [14] is reconstructed using fully corrected calorimeter and muon information [11].
We select events with

- A pair of isolated leptons of the same electric charge.
- The leading lepton must have $p_T > 20$ GeV/$c$, $|\eta| < 1.1$.
- The sub-leading must have $p_T > 10$ GeV/$c$, $|\eta| < 1.1$.
- The two leptons must come from the same primary vertex.
- The dilepton invariant mass $m_{\ell\ell}$ must be at least 25 GeV/$c^2$.
- We reject events which have two OS leptons in the $Z$ window, $m_{\ell\ell} \in [86, 96]$.
- We reject events which have two SS electrons in the $Z$ window, $m_{\ell\ell} \in [86, 96]$.

In each event, we calculate the $H_T$, the scalar sum of the lepton $p_T$, the jet $E_T$ and the missing transverse energy.

### III. BACKGROUNDS

Backgrounds to the like-sign dilepton signature with real like-sign leptons are rare in the SM; they are largely from $WZ$ and $ZZ$ production.

The dominant background comes from events in which the second lepton is due to the semi-leptonic decay of a $b$- or $c$-quark meson, largely from $W$+jets production or $t\bar{t}$ production with semi-leptonic decays. This (“fake”) background is described using a lepton misidentification model from inclusive jet data applied to $W$+jet events.

The second largest source of background comes from processes which produce electron-positron pairs; either the electron or positron emits a hard photon leading to an asymmetric conversion (e.g. $e_{\text{hard}} \rightarrow e_{\text{soft}}\gamma \rightarrow e_{\text{soft}}e^+_{\text{soft}}e^-_{\text{hard}}$) and the reconstruction of an same-charge pair. The major contributions via this mechanism are from $Z/\gamma^*+\text{jets}$ and $t\bar{t}$ production with fully leptonic decays.

Estimates of the backgrounds from $Z/\gamma^*+\text{jets}$ processes are made with PYTHIA normalized to data in opposite-sign events. The detector response for both $Z$+jets and $t\bar{t}$ processes is evaluated using CDFSIM, where, to avoid double-counting, the same-charge leptons are required to originate from the $W$ or $Z$ decays rather than from misidentified jets.

The dominant systematic uncertainty is due to uncertainty in the lepton misidentification model. Additional uncertainties are due to the jet energy scale [15], contributions from additional interactions, and descriptions of initial and final state radiation [16] and uncertainties in the parton distribution functions [17, 18].

### IV. OBSERVED DATA

#### A. Event Yield

Table I shows the observed and predicted event yields.

#### B. Event Kinematics

Figures 1-4 show kinematic distributions of observed and predicted same-sign lepton events.

We calculate the maximum Kolmogorov-Smirnov (KS) distance for the $m_{\ell\ell}$, MET, and $N_{jets}$ variables, lepton $p_T$ and $H_T$. In each case, the $p$-value does not indicate significant deviation from the background-only hypothesis, see Table II.

### V. CONCLUSIONS

We present a search for new physics in events with two high $p_T$ leptons of the same electric charge using data with an integrated luminosity of 6.1 fb$^{-1}$. The observed data are consistent with standard model predictions.
TABLE I: Predicted and observed event yields in same-sign lepton events.

<table>
<thead>
<tr>
<th>Process</th>
<th>Total $\ell\ell$</th>
<th>$\mu\mu$</th>
<th>$e\mu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t\bar{t}$</td>
<td>$0.1 \pm 0.0$</td>
<td>$0.0 \pm 0.0$</td>
<td>$0.0 \pm 0.0$</td>
</tr>
<tr>
<td>$Z \rightarrow e\mu$</td>
<td>$15.7 \pm 2.7$</td>
<td>$0.0 \pm 0.0$</td>
<td>$15.7 \pm 2.7$</td>
</tr>
<tr>
<td>$Z \rightarrow \mu\mu$</td>
<td>$8.7 \pm 2.0$</td>
<td>$0.0 \pm 0.0$</td>
<td>$0.0 \pm 0.0$</td>
</tr>
<tr>
<td>$WZ$</td>
<td>$2.2 \pm 0.9$</td>
<td>$0.0 \pm 0.0$</td>
<td>$1.3 \pm 0.6$</td>
</tr>
<tr>
<td>WW</td>
<td>$24.7 \pm 1.3$</td>
<td>$7.0 \pm 0.4$</td>
<td>$5.1 \pm 0.3$</td>
</tr>
<tr>
<td>ZZ</td>
<td>$0.2 \pm 0.1$</td>
<td>$0.0 \pm 0.0$</td>
<td>$0.1 \pm 0.1$</td>
</tr>
<tr>
<td>$W(\rightarrow \ell\nu)\gamma$</td>
<td>$3.5 \pm 0.2$</td>
<td>$0.9 \pm 0.1$</td>
<td>$0.8 \pm 0.1$</td>
</tr>
<tr>
<td>$W(\rightarrow \mu\nu)\gamma$</td>
<td>$7.8 \pm 1.7$</td>
<td>$0.0 \pm 0.0$</td>
<td>$7.8 \pm 1.7$</td>
</tr>
<tr>
<td>$W(\rightarrow \tau\nu)\gamma$</td>
<td>$7.8 \pm 1.7$</td>
<td>$0.0 \pm 0.0$</td>
<td>$0.0 \pm 0.0$</td>
</tr>
<tr>
<td>Fakes</td>
<td>$0.6 \pm 0.4$</td>
<td>$0.0 \pm 0.0$</td>
<td>$0.3 \pm 0.3$</td>
</tr>
<tr>
<td>Total</td>
<td>$123.0 \pm 24.6$</td>
<td>$16.1 \pm 5.4$</td>
<td>$33.3 \pm 9.5$</td>
</tr>
</tbody>
</table>

Data 145 14 66 65.

Acknowledgments

We thank the Fermilab staff and the technical staffs of the participating institutions for their vital contributions. This work was supported by the U.S. Department of Energy and National Science Foundation; the Italian Istituto Nazionale di Fisica Nucleare; the Ministry of Education, Culture, Sports, Science and Technology of Japan; the Natural Sciences and Engineering Research Council of Canada; the National Science Council of the Republic of China; the
Swiss National Science Foundation; the A.P. Sloan Foundation; the Bundesministerium für Bildung und Forschung, Germany; the Korean Science and Engineering Foundation and the Korean Research Foundation; the Particle Physics and Astronomy Research Council and the Royal Society, UK; the Russian Foundation for Basic Research; the Comisión Interministerial de Ciencia y Tecnología, Spain; in part by the European Community’s Human Potential Programme under contract HPRN-CT-2002-00292; and the Academy of Finland.

**TABLE II:** Results of KS-distance test for Standard Model prediction. The maximum KS distance and corresponding $p$-value is given for several kinematic distributions presented in this analysis.

<table>
<thead>
<tr>
<th>Distribution</th>
<th>$m_{t\bar{t}}$</th>
<th>$\ell\ell$</th>
<th>$ee$</th>
<th>$\mu\mu$</th>
<th>$e\mu$</th>
</tr>
</thead>
<tbody>
<tr>
<td>MET</td>
<td>0.19 (34%)</td>
<td>0.23 (27%)</td>
<td>0.24 (32%)</td>
<td>0.21 (69%)</td>
<td></td>
</tr>
<tr>
<td>$N_{jets}$</td>
<td>0.19 (56%)</td>
<td>0.31 (31%)</td>
<td>0.20 (57%)</td>
<td>0.21 (84%)</td>
<td></td>
</tr>
<tr>
<td>Lepton 1 $p_T$</td>
<td>0.16 (49%)</td>
<td>0.18 (47%)</td>
<td>0.25 (30%)</td>
<td>0.26 (60%)</td>
<td></td>
</tr>
<tr>
<td>Lepton 2 $p_T$</td>
<td>0.12 (66%)</td>
<td>0.21 (41%)</td>
<td>0.23 (33%)</td>
<td>0.40 (33%)</td>
<td></td>
</tr>
<tr>
<td>$H_T$</td>
<td>0.15 (45%)</td>
<td>0.22 (34%)</td>
<td>0.22 (32%)</td>
<td>0.24 (58%)</td>
<td></td>
</tr>
</tbody>
</table>


[7] CDF10455

[8] CDF10456


[10] CDF uses a cylindrical coordinate system with the $z$ axis along the proton beam axis. Pseudorapidity is $\eta \equiv -\ln(\tan(\theta/2))$, where $\theta$ is the polar angle relative to the proton beam direction, and $\phi$ is the azimuthal angle while $p_T = |p| \sin \theta$, $E_T = E \sin \theta$.


[14] Missing transverse momentum, $E_T$, is defined as the magnitude of the vector $-\sum E_T^n \vec{n}_i$ where $E_T^n$ are the magnitudes of transverse energy contained in each calorimeter tower $i$, and $\vec{n}_i$ is the unit vector from the interaction vertex to the tower in the transverse ($x, y$) plane.


