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A Search for New Physics in Like-Sign Dileptons using the Inclusive High p_T Lepton Sample

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Abstract

We present a search for anomalous production of events with two leptons (e, μ) with same electric charge in $p\bar{p}$ collisions at a center-of-mass energy of 1.96 TeV. There are many new physics scenarios that produce events with two leptons of the same electric charge. The standard model backgrounds are small, which allows us to perform an inclusive selection with one lepton above 20 GeV and the other one above 10 GeV. We use 1 fb^{-1} of integrated luminosity recorded by the CDF II experiment. No statistically significant discrepancies between the standard model predictions and the data were found.

The Standard Model of particle physics has been impressively successful in describing all experimental data taken in high energy collison data so far. Despite its successes, there are strong indications that this model is only an effective low-energy model and new physics must be present at a higher energy scale. An ideal signature to search for deviations from the standard model is dilepton production with both leptons of same electric charge. This signature occurs naturally in many beyond the standard model predictions, and it occurs rather rarely within the standard model.

There are many new physics scenarios that can produce signatures with two or more leptons with same electric charge. For instance, any model that has a Majorana particle decaying through standard model-like bosons can lead to such a signature. Heavy Majorana neutrinos can be produced in $p\overline{p}$ collisions in association with a lepton through a virtual W boson [1] ($p\bar{p} \to \nu_R \ell^{\pm}$). This new particle can then subsequently decay to a W and another lepton ($\nu_R \to W\ell^{\pm}$). Given the Majorana nature of this neutrino, there is a 50% probability that the two leptons in the final state will have the same charge.

In supersymmetric extensions of the standard model, pair produced chargino-neutralino ($p\bar{p} \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$) can decay into final states with three leptons ($\tilde{\chi}_1^{\pm} \to l\nu\tilde{\chi}_1^0$ and $\tilde{\chi}_2^0 \to \ell^{\pm}\ell^{\mp}\tilde{\chi}_1^0$). Two of those three leptons will have the same charge. These are just few examples of new models which predict an excess in the same-charge lepton channels at hadron colliders.

In the standard model, there are few processes that can lead to final states with leptons with the same charge. This makes the same-charge dilepton channel a very good candidate in the search for physics beyond the standard model. The CDF collaboration investigated events with two same-charge leptons in Run I searches [2]. In this Note, we present a similar effort using data collected during the Tevatron's Run II data-taking phase with the CDF II detector. We select events as inclusively as possible without optimizing for a particular new physics scenario. Due to the low standard model backgrounds, the selection produces a relatively small data sample which we will investigate for deviation from standard model prediction both in total number for events and kinematic shapes. We use data collected between April 2002-October 2005 for a total integrated luminosity of 1 fb^{-1}.

The CDF II detector [3] is an azimuthally and forward-backward symmetric apparatus designed to study $p\overline{p}$ reactions at the Tevatron. The detector has a charged particle tracking system immersed in a 1.4 T magnetic field, aligned coaxially with the $p\overline{p}$ beams. A silicon microstrip detector (SVX) provides tracking over the radial range 1.5 to 28 cm [4]. A 3.1 m long open-cell drift chamber, the Central Outer Tracker (COT), covers the radial range from 40 to 137 cm [5]. The fiducial region of the silicon detector extends to $|\eta| \sim 2$ [10], while the COT provides coverage for $|\eta| \lesssim 1$.

Segmented electromagnetic and hadronic sampling calorimeters surround the tracking system and measure the energy flow of interacting particles in the pseudo-rapidity range $|\eta| < 3.6$ [6, 7]. A set of drift chambers located outside the central hadron calorimeters and another set behind a 60 cm iron shield detect energy deposition from muon candidates with $|\eta| \leq 0.6$ [8]. Additional drift chambers and scintillation counters detect muons in the region $0.6 \leq |\eta| \leq 1.0$. Gas Cherenkov counters located in the $3.7 < |\eta| < 4.7$ region [9] measure the average number of inelastic $p\overline{p}$ collisions per bunch crossing and thereby determine the beam luminosity.

We use data collected with the high-momentum central lepton trigger. We select events with a pair of same-charge leptons (electrons or muons) regardless of other activity in the event. This analysis uses the central detectors for lepton candidates with $|\eta| < 1.1$. The tracks associated with the leptons have to share a common vertex, *i.e.*, they come from the same $p\overline{p}$ interaction. The leading and subleading electrons (muons) are required to pass the following requirements on the transverse component of the energy (momentum): $E_T(p_T) > 20$ GeV and $E_T(p_T) > 10$ GeV, respectively. Cosmic events are removed using the timing information of the COT. We also place a minimum requirement on the invariant mass of the lepton pair $m_{ll} > 25$ GeV/c^2 to remove backgrounds associated with the heavy quark states decaying semi-leptonically. The leptons must be isolated from other particles in the event, both in the calorimeter and in the tracking chamber. A lepton is isolated in the calorimeter if the total sum of the transverse energy within a cone $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} \leq 0.4$, minus the lepton E_T, is $< 10\%$ of the lepton E_T. Similarly, if the total transverse momentum of all other tracks within a cone $\Delta R \leq 0.4$ around the lepton is less than 10% of the candidate track P_T, the lepton is considered to be isolated in the tracking chamber.

Events with untagged photon conversions represent the dominant background to this search. Photon conversions are tagged if a second track is close to the electron track and its properties are consistent with those expected from a photon conversion. Standard model backgrounds considered include Drell-Yan dilepton production with electromagnetic radiation off the final-state leptons ($q\bar{q} \to Z/\gamma^* \to \ell^{*+}\ell^-, \ell^* \to \ell\gamma$), diboson production ($WW, ZZ, WZ$[16],$W\gamma$ and $Z\gamma$), and $W(\to \ell\nu) + 1$ jet and $Z(\to \ell\ell)+1$ jet events where the jet is falsely identified as a lepton. Heavy flavor backgrounds ($t\bar{t}$, $b\bar{b}$, $c\bar{c}$) were found to be negligible.

We determine geometric and kinematic acceptance for the Drell-Yan and diboson backgrounds using Monte Carlo calculations followed by a GEANT3-based simulation of the CDF II detector [11]. We use the Monte Carlo generator described in [12] for the $W\gamma$ background, MadGRAPH for the WZ background [14] and PYTHIA for the other SM processes [13]. We use the CTEQ5L (???) parton distribution functions to model the momentum distribution of the initial-state partons [15]. The expected number of background events is determined as the product of the cross section, the luminosity of the sample and the acceptance of the detector. The latter is corrected for trigger efficiency and any difference in lepton reconstruction between data and simulation. These efficiencies are derived via studies of $W(\to l\nu)$ and $Z(\to ll)$ bosons.

Jets in W+jets events can be misidentified as leptons and paired with the lepton from the W decay to form a same-charge candidate event. We estimate this background by multiplying the number of isolated tracks, in the selected sample, by the misidentification probability ("fake rate"). This probability is measured in a sample triggered by at least one jet above $E_T > 50$ GeV and is defined as the number of identified leptons, divided by the total number of isolated tracks. We parameterize the fake rate as a function of P_T and η.

As a further handle on untagged photon conversions, we divide the electron condidates in two categories: with and without energy depositions ("hits") in the silicon tracking. Since most of the photon conversions occur either in the material of the silicon tracker or in the inner wall of the tracking chambers, electrons with hits in the silicon tracking are less likely to come from a conversion process. In this manner, we do not loose acceptance due to inefficiencies in the SVX detector but gain in signal/background by considering the pure category of electrons with SVX hits ($e_{\rm si}$) separately from those without (e).

We perform numerous tests to assure that we are able to model our backgrounds. These tests can be split into two categories: those that test the overall normalization of a background, and those that test our ability to model detector performance. To probe the overall normalization of the $Z + \gamma$ background estimate, we select two leptons and a photon with momentum thresholds of $20, 10, 10$ GeV, respectively. The predicted number of events for this selection is 257.8 ± 16.1, dominated by $Z + \gamma$ production. We observe 258 events, in good agreement. Similarly, we probe the normalization of the $W + \gamma$ background by selecting one lepton with transverse momentum above $P_T > 20$ GeV, a photon with transverse energy $E_T > 10$ GeV and an overall momentum imbalance $\not\!\!E_T > 15$ GeV. Using this selection, we expect to observe 1493.3 ± 89.7, dominated by $W + \gamma$ production. We observe 1540 events, in good agreement with our expectation. For both of the above measurements, we require the photon to be well separated from either electron, thereby effectively limiting the contribution from photons radiated in the material of the detector. We check our modeling of the material in the detector by selecting events with one electron and one photon and low missing transverse momentum ($\not\!\!E_T < 20$ GeV). These are mostly Drell-Yan events where one electron lost most of its energy to a radiated photon. For this selection, we predict 243.0 ± 14.6 events and observe 269, thereby validating our understanding of the detector material. Other backgrounds are tested in dedicated control regions. We obtain good agreement between the observed events and simulation both in integral counts and kinematic distributions in all regions considered.

In Tab. I, we present the expected and observed number of events with two same-charge leptons in all categories considered. Combining all channels, we predict 33.7 ± 3.5 events and observe 44. The probability that 33.7 events with an uncertainty of 3.5 events to fluctuate to 44 or more is 7.6%. In Tab. II, we present the expected and

	Observed	Predicted	Drell Yan	$W+(Z/\gamma)$	WW/ZZ	Fake Lepton	Prob (%)
$e_{\rm si}e_{\rm si}$	11	6.5± 0.8	3.2	1.4	0.4	1.4	7.3
ee	3	1.3± 0.3	0.9	0.1	0.0	0.2	13.9
$e_{\rm si}e$	9	9.1± 1.2	6.4	1.6	0.1	1.1	54.6
$e_{\rm si}\mu$	11	7.0± 0.8	0.8	2.8	1.1	2.2	10.6
$e\mu$	5	6.5± 0.9	3.4	1.9	0.2	1.0	74.9
$\mu\mu$	5	3.3 ± 0.3	0.1	1.4	0.8	0.9	23.1
sum	44	33.7± 3.5	14.9	9.3	2.5	6.9	7.6

TABLE I: Event counts in the signal region, expected and observed, per category. The uncertainties shown in the 'predicted' column are systematic only

observed number of events with the additional requirements to increase the signal-to-noise for a SUSY-like physics scenario. We require a large momentum imbalance ($\not\!\!E_T > 15$ GeV) and reject events where the invariant mass of one of our selected leptons and another lepton of the same flavor and opposite charge are consistent with a Z boson ($66 < m_{\ell^+\ell^-} < 116$ GeV/c^2). The last comlumn in Tab. I and Tab. II shows the probability that the predicted number of events, taking into account the systematic uncertainty on the prediction, would fluctuate to the observed number of events or more. To calculate this probability we first take a random number from a gaussian distribution centered on the expected number of events and with a width equal to the uncertainty on this expectation. This number is then Poisson deviated. We perform this procedure multiple times and obtain a distribution of possible outcomes given our expectations and the uncertainty on it. The probability of the expectation to fluctuate to the observed number of events is then taken to be integral of this distribution of possible outcomes from the observed value to infinity.

The uncertainty on the background prediction is dominated by the uncertainty on the luminosity measurement (6%) and the fake rate estimate. Other uncertainties include those associated with the standard model cross sections, lepton reconstruction, conversion modeling and the statistical uncertainty on the Monte Carlo acceptance

	Observed	Predicted	Drell Yan	$W+(Z/\gamma)$	WW/ZZ	Fake Lepton	Prob (%)
$e_{\rm si}e_{\rm si}$	1	1.3 ± 0.2	0.4	0.6	0.0	0.4	71.7
ee	1	0.1 ± 0.1	0.0	0.1	0.0	0.0	9.9
$e_{\rm si}e$	2	1.5 ± 0.1	0.1	1.2	0.0	0.2	43.8
$e_{\rm si}\mu$	4	1.7 ± 0.1	0.0	1.0	0.1	0.7	9.2
$e\mu$	4	2.3 ± 0.2	0.6	1.4	0.0	0.2	19.8
$\mu\mu$	1	0.9 ± 0.1	0.0	0.5	0.1	0.4	59.1
sum	13	7.9 ± 0.3	1.1	4.7	0.2	1.9	6.1

TABLE II: Event counts in the signal region with the additional requirements the momentum imbalance and Z veto.

calculation.

Fig. 1 shows the comparison between the prediction and the observed events for several kinematic distributions of interest.

In conclusion, we have performed a search for events with two leptons with same electric charge using the CDF Run II data. We find agreement between the number of events and the standard model predictions. The kinematic distributions do not show an anomalous excess in a particular region of the parameter space.

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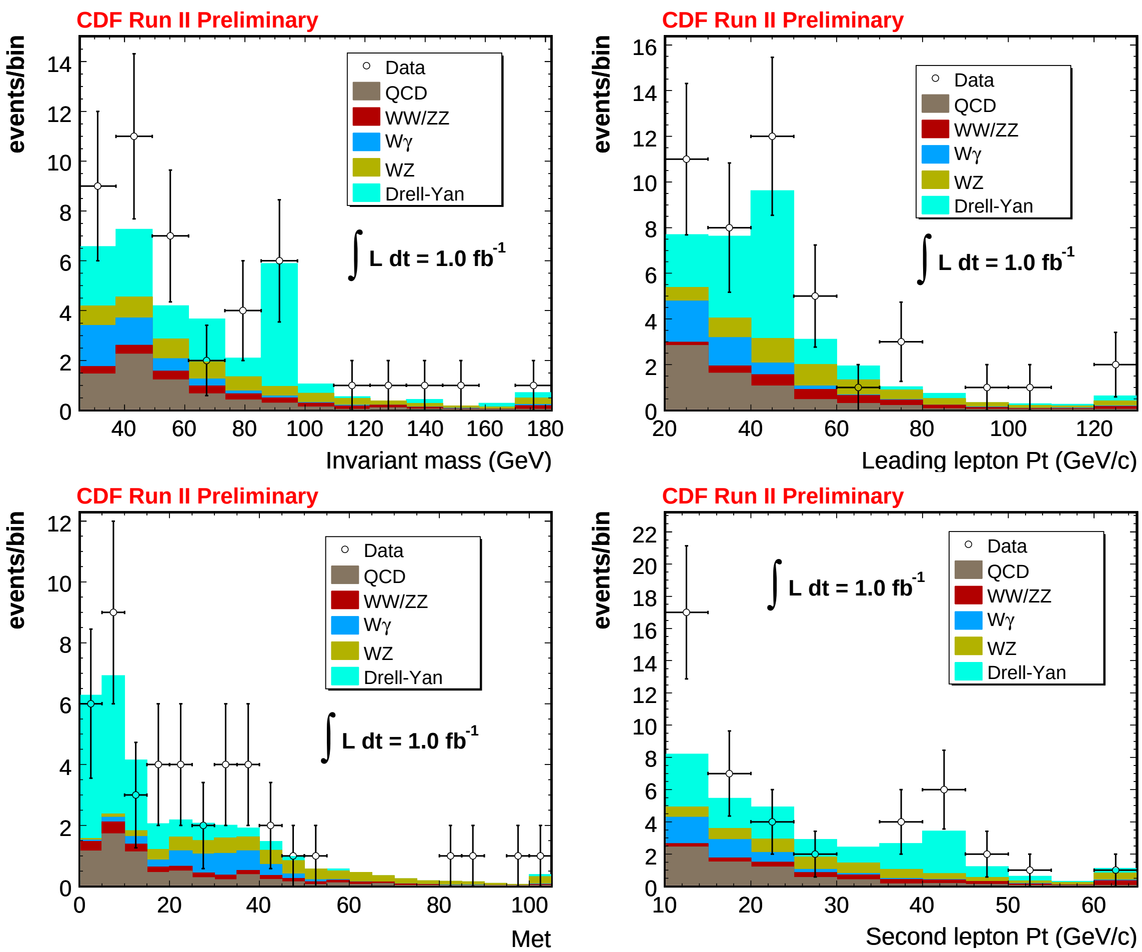

FIG. 1: Invariant mass distribution and the leading lepton transverse momentum in data and simulation

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