PROCEEDINGS OF SCIENCE

# Searches for Same Sign Dilepton Events and $WZ$ Resonances at the Tevatron

**Adam L. Lyon**[*†]
*Fermi National Accelerator Laboratory, Batavia IL, 60510, USA*
*E-mail:* lyon@fnal.gov

Events with same-sign charged leptons are extremely useful for investigating physics beyond the Standard Model. In addition, searches involving $WW$ or $WZ$ resonances may also reveal new physics. Such analyses from the Tevatron experiments, CDF and D0, are discussed in these proceedings. Limits are set on a wide range of models and phenomena, including fourth generation fermions, maximal flavor violation in the quark sector, extended gauge models, extra dimensions, and models with a heavy $W'$.

*35th International Conference of High Energy Physics - ICHEP2010,*
*July 22-28, 2010*
*Paris France*

*Speaker.
†On behalf of the CDF and D0 Collaborations



PoS(ICHEP 2010)406

In these proceedings we describe analyses from the Tevatron experiments that search for physics Beyond the Standard Model (BSM). Three analyses utilize the event signature of two leptons of the same charge (same-sign dileptons). With extremely small contributions from Standard Model (SM) processes, same-sign dileptons are an ideal vehicle for new physics discoveries. In addition, two analyses are also described that search for new physics via $WW$ and $WZ$ resonances. A wide range of BSM models is explored.

The Tevatron is a $p\bar{p}$ collider with $\sqrt{s} = 1.96$ TeV located at Fermilab. CDF and D0 are the two massive collider detectors optimized for high $p_T$ physics. Both detectors are described elsewhere [1, 2].

Events with same-sign dileptons are very uncommon in the SM. In general, there are four categories of backgrounds that survive analysis requirements,

- On and off shell dibosons ($WW$, $WZ$)
- Drell-Yan with a radiated photon converting asymmetrically, producing a spurious electron or positron
- $W$ and $Z$ production in association with jets where a jet is misidentified as a lepton (and similarly for semi-leptonic $t\bar{t}$ decays with a jet misidentified as a lepton)
- Events with oppositely charged leptons, but the charge of one is reconstructed incorrectly.

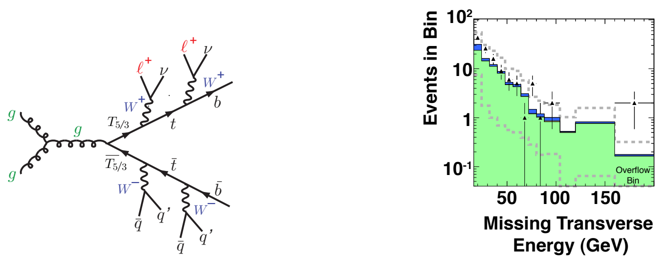


**Figure 1:** For the CDF fourth generation fermion search: an example of production and decay of $T_{5/3}$ (left). The missing transverse energy distribution of the data sample at the pre-selection stage is also displayed (right). The green region is the contribution from jets misidentified as electrons and the blue region is from $Z$ and diboson events. Leptons from $t\bar{t}$ are negligible. The triangles represent the data.

The first analysis described here is a search for fourth generation fermions using same-sign dileptons at CDF[3]. In particular, the case where a heavy fermion ($Q$) decays to a top quark and a $W$ boson, $Q \rightarrow tW^{\mp}$, is investigated. $Q$ is considered to be a quark-like composite particle $B$ or $T_{5/3}$ (the latter a particle with electric charge $5/3\,e$, where $e$ is the charge of the electron). The existence of the $T_{5/3}$ implies that the $B$ must exist, and so the event rate doubles. (Note that $Q$ may also be considered to be a down-type fourth generation quark $b'$; that case is covered in an article by Scodellaro elsewhere in these proceedings). An example Feynman diagram is shown in Fig. 1, illustrating how events with same-sign dileptons are produced. The full event signature is two leptons of the same charge, a $b$-jet, a light quark jet, and large missing transverse energy. Data corresponding to 2.7 fb$^{-1}$ were observed. $1.6 \pm 1.4$ events are expected from background processes

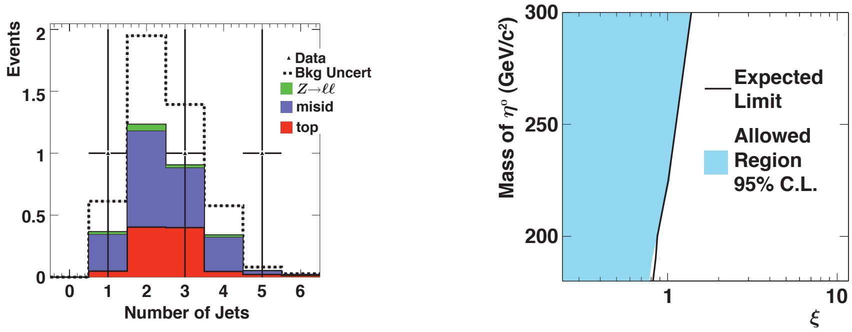


**Figure 2:** Jet multiplicity for the CDF maximal flavor violation analysis (left). The resulting limit contour is also shown (right).

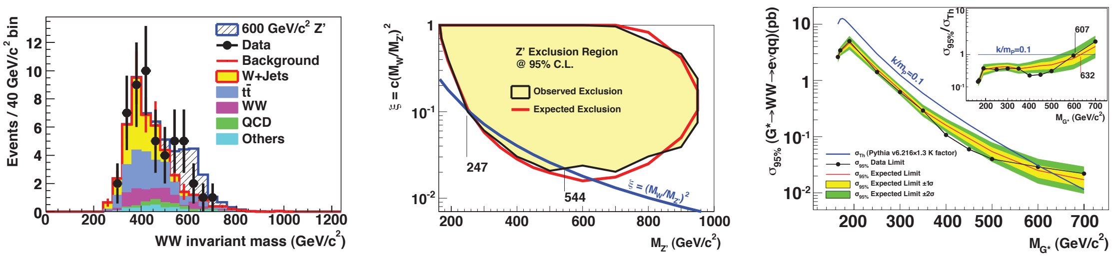


**Figure 3:** CDF $Z'$ search (left): $WW$ invariant mass spectrum indicating data, backgrounds, and expected $Z'$ signal; and (middle) excluded region in the $\xi - M_{Z'}$ plane. CDF $G^*$ search (right): cross section limit vs. $M_{G^*}$.

and 2 events were observed. The missing transverse energy distribution is shown in Fig. 1. Since no excess is observed, 95% C.L. limits are set excluding $m_B < 338$ GeV/$c^2$ and $m_{T_{5/3}} < 365$ GeV/$c^2$.

Another same-sign dilepton analysis at CDF is a search for maximal flavor violating scalars[4]. In the SM quark sector flavor violation is minimal. Does new physics follow this rule as well? Perhaps not, and so the case of *maximal* flavor violation is investigated. Here, a new scalar field with particles $\eta^0$ and $\eta^+$ is introduced that couples the first and third quark generations maximally. Possible production and decays are $ug \to t\eta^0 \to tt\bar{u}$, $u\bar{u} \to \eta^0\eta^0 \to tt\bar{u}\bar{u}$, and $uu \to tt$. The striking signature is two same-sign top quarks, thus leading to requiring events with two same-sign dileptons, a $b$-jet, and large missing transverse energy. In 2 fb$^{-1}$ of data, $2.1 \pm 1.8$ events are expected and three events are observed. Therefore, a limit contour in the $\eta^0$ mass vs. coupling parameter $\xi$ is produced. The jet multiplicity distribution and the limit are shown in Fig. 2. CDF also performed an inclusive model-independent search for new physics using same-sign dileptons with 1 fb$^{-1}$ of data and is described elsewhere[5].

Another class of BSM searches involve diboson resonances resulting from decays of exotic particles. CDF investigates extended gauge models with a heavy $W'$ or $Z'$ as well as extra dimensions with a Randall-Sundrum Graviton ($G^*$)[6]. The assumed decays of these particles are to a $WW$ or $WZ$ resonance, with the $W$ decaying to $e\nu$ and the other boson decaying to jets. Large missing transverse energy is also required. The $W$ and $Z$ candidates are reconstructed to form the diboson pair, and then the resulting $WW$ or $WZ$ invariant mass is investigated for evidence of resonance

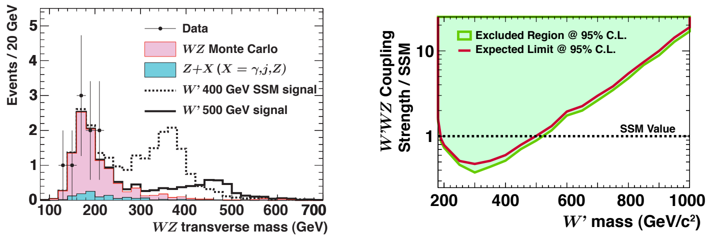


**Figure 4:** D0 $W'$ search: the $WZ$ invariant mass (left) showing data, backgrounds, and expected signal. Also, the $W'$ exclusion contour (right).

structure (see Fig. 3 for an example). The analysis requirements are optimized for each exotic object. In 2.9 fb$^{-1}$ of data, no such structure is observed, and so limits are set on model parameters at 95% C.L. For extended gauge models, the SM coupling strength is modified $g\cos\theta_W \to \xi g\cos\theta_W$, where $\xi = C(M_W/M_V)^2$ ($C$ sets the coupling strength and $M_V$ is the mass of the new gauge boson). For $Z' \to WW$, 51 events are observed with $43\pm6$ events expected. The resulting limit in the $\xi - M_{Z'}$ plane is shown in Fig. 3. The $Z'$ is excluded for masses $247-544$ GeV/c$^2$. Similarly, for $W' \to WZ$, 38 events are observed with $41\pm7$ events expected. The $W'$ is excluded for masses $285-516$ GeV/c$^2$. For the $G^*$, 75 events are observed with $75\pm12$ events expected. The $G^*$ is excluded for masses below 607 GeV/c$^2$ (see Fig. 3 for the cross section limit).

Finally, D0 investigated a heavy $W'$ decaying with a resonance in $WZ$[7]. In this analysis, the fully leptonic ($\ell\nu\ell\ell$) signature is required to reconstruct the $W$ and $Z$. In 4.1 fb$^{-1}$, 9 events are observed with $10.2\pm1.6$ events expected. The $WZ$ invariant mass is displayed in Fig. 4. To set limits on models with a $W'$, the "sequential Standard Model" (couplings strengths are the same as in the SM) is used for comparison. The $W'$ with the same coupling as in the SM is excluded for masses $188-520$ GeV/c$^2$, as shown in Fig. 4. (See the article by Grenier in these proceedings for an interpretation resulting in limits on technicolor models).

For all of the analyses described here, no excess of events beyond SM predictions were observed. Therefore, CDF and D0 set limits on a wide variety of BSM phenomena. Given that both experiments have accumulated several times the amount of data utilized here, one should expect updates on these analyses and new analyses in the near future.

## References

[1] D. Acosta et al., Phys. Rev. D**71**, 032001 (2005).

[2] V. Abazov et al., Nucl. Instrum. Methods Phys. Res., Sect. A**565**, 463 (2006); M. Abolins et al., Nucl. Instrum. Methods Phys. Res., Sect. A**584**, 75 (2008); R. Angstadt et al., Nucl. Instrum. Methods Phys. Res., Sect. A**622**, 298 (2010).

[3] T. Aaltonen et al., Phys. Rev. Lett. **104**, 091801 (2010).

[4] T. Aaltonen et al., Phys. Rev. Lett. **102**, 041801 (2009).

[5] A. Abulencia et al., Phys. Rev. Lett. **98**, 221803 (2007).

[6] T. Aaltonen et al., Phys. Rev. Lett.**104**, 241801 (2010).

[7] V.M. Abazov et al., Phys. Rev. Lett.**104**, 061801 (2010).