 Searches for BSM (non-SUSY) physics at the Tevatron

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Abstract. As of July 2005, the Tevatron at Fermilab has delivered $\approx 1 \text{ fb}^{-1}$ of data to the CDF and DØ experiments. Each experiment has recorded more than 80\% of the delivered luminosity. Results of searches for physics (non-SUSY and non-Higgs) beyond the Standard Model using 200 \text{ pb}^{-1} to 480 \text{ pb}^{-1} at DØ and CDF are presented.

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1 Introduction

The discovery of anomalous behavior in data collected at high energy physics experiments could provide non-SUSY and non-Higgs explanations to questions associated with the Standard Model and provide deeper understanding to the fundamental particles and interactions in nature. Such questions include whether quarks and leptons are composite particles, the existence of extra dimensions, and the answer to the hierarchy problem in the Standard Model (SM).

Generally, a search is approached by first understanding the SM prediction for a given signal and detector backgrounds which could mimic that signal. Analyses are optimised for signal, not according to model, prior to looking in the signal region of the data. If no anomalous behavior is found, the signal acceptance of various models can be used to set limits.

Searches for $Z'$, Lepton-Quark compositeness, Randall-Sundrum Gravitions, Large Extra Dimensions, $W'$, Leptoquarks and Excited Electrons are presented here.

2 High Mass Dilepton Searches

High mass dilepton searches are experimentally motivated by the small source of background, with the exception of the well-understood, irreducible Standard Model $Z/\gamma^*$ production. Search results can be used to study many theories: extended gauge theories ($Z'$), technicolor, lepton-quark compositeness, large extra dimensions (LED), and Randall-Sundrum gravitons.

2.1 $Z'$

The majority of extensions to the SM predict new gauge interactions, many of which naturally result in the production of neutral or singly charged bosons, such as a highly massive $Z'$ particle.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{fig1.png}
\caption{Expected and observed dielectron mass distributions.}
\end{figure}

2.1.1 $Z'$ Searches using $M_{ee}$ and $\cos \theta^*$

Using 448 \text{ pb}^{-1} of data, CDF searched for $Z'$ production by studying the distributions dielectron mass at high mass and the angular distribution $\cos \theta^*$ in the Collins-Soper frame[4]. Figures 1 and 2 show the $M_{ee}$ and $\cos \theta^*$ distributions, respectively.

Having observed no evidence of a signal, limits at the 95\% confidence level (C.L.) are set for the sequential $Z'$[1] and E6 $Z'$ models[2], as shown in Table 1. With 448 \text{ pb}^{-1}, using the $\cos \theta^*$ information effectively increases the amount of data by $\approx 25\%$ for the sequential $Z'$ model.

Additionally, a general formalism for $Z'$ which uses $M_{ee}$ and $\cos \theta^*$[3] and allows for new models to be easily checked is studied. The formalism consists of four general
model classes and are each defined by three parameters: mass ($M_{Z'}$), strength ($g_{Z'}$) and coupling parameter ($x$). Figure 3 shows the CDF exclusion regions for one of the model classes for two values of $g_{Z'}$. The area below the black curves represent LEP II [3] exclusion regions obtained via indirect searches for contact interactions.

2.1.2 Traditional $Z'$ Searches

CDF and DØ both performed “traditional” $Z'$ searches which focus on the dilepton mass distributions. All three channels - electron, muon, and tau - were studied with no evidence for a signal beyond the Standard Model expectations. Table 1 shows a summary of the limits set at the 95% C.L. for various $Z'$ models.

<table>
<thead>
<tr>
<th>Channel</th>
<th>$Z'_{ee}$</th>
<th>$Z'_{e\mu}$</th>
<th>$Z'_{\mu\mu}$</th>
<th>$\tau\tau$</th>
<th>Luminosity (pb$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDF</td>
<td>750</td>
<td>735</td>
<td>815</td>
<td>394</td>
<td>200</td>
</tr>
<tr>
<td>CDF with cos $\theta$</td>
<td>845</td>
<td></td>
<td></td>
<td></td>
<td>448</td>
</tr>
<tr>
<td>DØ</td>
<td>780</td>
<td>680</td>
<td></td>
<td></td>
<td>200-250</td>
</tr>
</tbody>
</table>

For energies accessible at the Tevatron, the inference term (the second term) dominates and quark-lepton compositeness would be discovered as an excess in the tail of the dilepton distributions, an example of which is shown in Figure 4.

No evidence for signal is found in a dilepton search of 271 pb$^{-1}$ or in a dimuon search of 400 pb$^{-1}$ at DØ. The dimuon results are shown in Figure 5. Limits are set on $\Lambda$ for several models as shown in Table 2.

2.2 Quark-Lepton Compositeness

Contact Interaction composite models introduce hypothetical constituents of quarks and leptons called “preons” which are bound together by a characteristic energy scale known as the compositeness scale ($\Lambda$)[5]. The differential cross-section can be written as in Equation 1.

$$ \frac{d\sigma_T}{dM} = \frac{d\sigma_{SM}}{dM} + \frac{I}{\Lambda^2} + \frac{C}{\Lambda^4} $$  \hspace{1cm} (1)
along with the background prediction and observed data for 200 pb$^{-1}$ of dielectron and diphoton data at DØ. Figure 7 shows no anomaly in the $ee, \gamma \gamma \cos \theta^*$ distribution.

2.3.2 Warped Extra Dimensions

The Warped Extra Dimension model predicts one extra dimension that is highly curved and the production of Randall-Sundrum (RS) gravitons\cite{RS}. The model depends on $k/M_{P1}$, where $k$ is the curvature scale. CDF and DØ search for RS gravitons by studying the $M_{ee}$, $M_{\mu\mu}$, and $M_{\gamma\gamma}$ distributions for a resonance which would depend on $k/M_{P1}$. Two-dimensional exclusion regions in the $k/M_{P1}$--$M_G$ plane are established as shown in Figure 8.

3 Charged Heavy Vector Boson ($W'$)

The production of charged heavy vector bosons, referred to as $W'$ particles, are predicted in theories based on the extension of the gauge group\cite{Wprime}. The $W'$ is modeled to
Fig. 9. The left plot has transverse mass distributions of the expected background overlaid with three $W'$ mass choices. The right plot shows the transverse mass distributions of the irreducible SM $W \to e\nu$ multijet, and total background sources. The data is plotted and agrees well with the expectation.

decay to an electron and neutrino, where the neutrino is assumed to be SM-like: light and stable. Thus, the final state signature in the detector is a high $p_T$ electron with high missing $E_T$. CDF performs a direct search for $W'$ production and Figure 9 shows the background due to SM $W \to e\nu$ production with the predicted transverse mass distributions for $W'$ production at three different $W'$ masses.

Figure 9 shows the expected background distributions and the observations in the data. No $e\nu$ signal above the SM expectation is observed. However, the agreement between the data and the background prediction indicate good understanding of the calorimeter energy at CDF and the detector missing energy.

Having observed no signal above the SM expectation, the limit at the 95% C.L. is set on $W'$ production using a binned likelihood fitting method. The CDF Run II search excludes $W'$ masses less than 842 GeV/c$^2$. The CDF Run I limit was $M_{W'^{SM}} > 754$ GeV/c$^2$.

4 Leptoquarks

Many extensions of the SM assume additional symmetry between lepton and quarks which requires the presence of a “new” particle, a leptoquark (LQ)[9]. Leptoquarks, which could be scalar or vector particles, carry both lepton and baryon numbers. They are assumed to couple to quarks and leptons of the same generation; thus, there are three generation of leptoquarks for which one could search.

Leptoquarks would be pair produced at the Tevatron. Their decay is controlled by parameter $\beta$, where $\beta = B.R.(LQ \to lq)$. There are three final state signatures for LQ pair production at the tevatron: two charged leptons and two jets ($lljj$); one charged, one neutral lepton and two jets ($lujj$); and two neutral leptons and two jets ($ujjj$). The experimental signal is a resonance in the lepton-jet invariant mass spectrum.

No evidence of LQ production is found at DØ or CDF. Figure 10 shows the two dimensional exclusion region established by DØ for the first generation with $ejjj$ and $eujj$. 

Fig. 10. Exclusion region established by DØ for first generation leptoquarks.
(e*) in association with an oppositely charged electron, where the e* decays to an electron and a photon. Thus, the final state signature is two electrons and a photon where the search signal is a resonance in the electron+photon invariant mass spectrum.

Two models are studied: a Contact Interaction (CI) model[10] and a Gauge Mediated (GM) model[11]. The CI model depends on the mass of the e* (M_e^*) and the composite energy scale (Λ). In the GM model, an excited electron is produced via the decay of SM γ*/Z. This model depends on M_e^* and f/Λ, where f is a phenomenological coupling constant.

In the first search for excited leptons at a hadron collider, CDF found no excess of dielectron+photon events in 200 pb^{-1} of data. Exclusion regions for each model are established. Figure 12 shows the exclusion region at the 95% C.L. in the M_e^*/Λ-M_e^* parameter space. There are no previously published limits for e* production using the CI model. For the GM model, it is conventional to plot the 95% C.L. exclusion region in the f/Λ-M_e^* parameter space, as shown in Figure 13. CDF extends the previously published limits from 280 GeV/c^2 to ~ 430 GeV/c^2.

6 Summary

Searches for physics beyond the Standard model using 200 pb^{-1} to 450 pb^{-1} of data collected at CDF and DØ are presented. Currently, the experiments are actively pursuing further exotic topics and analyzing up to the full 1 fb^{-1} of delivered luminosity. New and exciting results are coming out quickly. Further information regarding the analyses presented in this paper and new results can be found at[12] and[13].

References