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Non-SUSY Exotics Searches at the Tevatron

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Abstract

The DØ and CDF experiments have collected more than 2 fb^{-1} in Run II of Fermilab's Tevatron, and have many recent search results which use 1 fb^{-1} or more. Here I summarize the results of a variety of searches for physics beyond the Standard Model with an emphasis on searches for very exotic phenomena. I will present the status of model-inspired searches for large extra dimensions, gravitons, extra quarks, new gauge bosons, leptoquarks, as well as a variety of signature-based searches.

1 Introduction

The CDF and DØ experiments have many recent results [1] from direct searches for evidence of physics beyond the standard model (SM), many of which use 1 fb^{-1} or more. These searches generally fall into two categories, those optimized for sensitivity to a particular new-physics model (model-inspired), and those designed to be generally sensitive to new physics in a particular final state or states (signature-based). Here I summarize the results of many of these recent searches. Slides from my presentation [2] include relevant plots from these searches.

2 Model-Inspired Searches

2.1 Searches for New Gauge Bosons

Many extensions of the standard model which attempt to unify the fundamental forces and solve the hierarchy problem include new massive gauge bosons which would appear as narrow resonances which couple to leptons. CDF has searched for a new neutral gauge boson in its decay to electrons with 1.3 fb^{-1}. The main background to this search is from SM Drell-Yan production, which is irreducible. Other sources of background include di-jet production and other electroweak processes. The dielectron invariant mass spectrum is scanned for narrow resonances in the range 150-900 GeV. The data are consistent with a background-only hypothesis, and limits are obtained on the production cross-section times branching fraction, $\sigma \times \text{BF}(Z' \to ee)$ as a function of m_{ee}, which is approximately 10 fb for much of the mass region searched. Assuming standard model couplings, this corresponds to $m_{Z'} > 923\,\text{GeV}/c^2$ at 95% CL.

DØ has searched for a charged gauge boson W' decaying to $e\nu$ in the $e+\not{E}_T$ channel with 0.9 fb^{-1} of data. The dominant background for this search is SM W production. Other background sources are small and include electroweak processes and QCD. No significant excesses are seen in the transverse mass m_T of the $e-\nu$ system, so limits are set on the production cross-section times branching fraction, $\sigma \times \text{BF}(W' \to e\nu)$ as a function of m_T. Assuming standard model couplings, this corresponds to $m_{W'} > 965\,\text{GeV}/c^2$ at 95% CL.

2.2 Extra Dimensions

Extra dimensions have been proposed as one possible way to explain the hierarchy of Planck and weak scales. In the ADD [3] model, gravity alone propagates in one or more large extra dimensions, each with some finite volume characterized by R. Because only gravity propagates in the extra dimensions, its strength is diluted relative to other forces. We therefore observe an effective

Table 1: *Limits on M_D for 2-6 extra dimensions.*

n	2	3	4	5	6
M_D (TeV/c^2)	> 1.33	> 1.09	> 0.99	> 0.92	> 0.88

lower-dimensional theory whose scale M_D is related to the the Planck scale and the number and size of the extra dimensions

$$M_{\text{Planck}} = R^n M_D^{2n+1}. \tag{1}$$

The ADD model predicts a Kaluza-Klein tower of graviton states which might be produced at the Tevatron. If produced, the graviton could propagate into the extra dimension(s), resulting in missing transverse energy ($\not\!\!E_T$) from the graviton recoiling against the parton involved in its production. CDF has searched for such a signature in 1.1 fb^{-1} of data by looking for events containing a single energetic jet and $\not\!\!E_T$. The main (irreducible) background for this search is SM Z^0 + jets production, where the Z^0 decays to neutrinos. Other backgrounds include W + jets, where the lepton from the W decay goes undetected, and QCD where $\not\!\!E_T$ is mis-measured. Since the rates for leptonic Z^0 decays are known, data $Z^0 \to ee$ control samples are used to predict the $Z^0 \to \nu\nu$ backgrounds. The background predictions agree well with the observed number and shape of the $\not\!\!E_T$ spectrum in data, so limits are set on the effective Planck mass depending on the number of extra dimensions of approximately 1 TeV, shown in Table 1.

In the simplest Randall-Sundrum warped extra dimension model [4)], the Standard model is confined to a lower-dimensional brane. Gravity propagates in the extra dimension and is localized near a second lower-dimensional brane, and is diluted in the warped extra dimension by a factor e^{-kr_c}. On one of the branes, this factor scales down the mass parameters in the higher dimensional Lagrangian, thereby generating a mass scale hierarchy. The product kr_c, where k is on the scale of the higher-dimensional Planck mass and r_c is the size of the extra dimension, can be chosen to obtain the observed electroweak-Planck hierarchy. Evidence of the extra dimension at particle Colliders would be observable in the form of a Kaluza-Klein tower of discrete, massive graviton resonances.

CDF has searched for such resonances with 1.1 fb^{-1} of data in the exclusive $G \to \gamma\gamma$ channel, which they combine with $G \to ee$ limits obtained from the dielectron search. DØ searches both ee and $\gamma\gamma$ final states simultaneously with 1.1 fb^{-1} of data by requiring energy deposits in their calorimeter be consistent with electromagnetic origin, but with no track requirement or veto. Neither DØ nor CDF sees any significant excess, and both set limits for an assumed coupling $k/M_{\text{pl}} = 0.1$ of $m_G > 865$ and 889 GeV/c^2 respectively.

Gravitons also couple to pairs Z^0 bosons with a larger branching fraction than ee or $\gamma\gamma$, and CDF has searched for this in 1.1 fb^{-1} of data in the four electron final state. The background for this mode is very small, and SM Z^0Z^0 production at high mass is negligible. Because of the branching fraction penalty for Z^0 to electrons, the expected signal is also only a fraction of an event. To maximize sensitivity, electron selection is very loose, and the kinematics of the two Z^0 resonances in the final state are utilized to reject backgrounds with a χ^2 variable encoding consistency of the two Z^0 masses. No high mass events are seen, but one lower mass event observed is consistent with SM Z^0Z^0 production.

2.3 Compositeness

If electrons are composite objects, their constituents could in principle be excited to higher-energy states. DØ has searched for evidence of compositeness by looking for evidence of an excited electron (e^*) produced in the contact interaction $p\bar{p} \to ee^*$, with e^* decaying to $e\gamma$. The main background for this search is Drell-Yan produced in association with a photon. No significant excess is observed, and limits are set as a function of the compositeness scale Λ. For $\Lambda = 1\,\text{TeV}$, $m_{e^*} > 756$ GeV/c^2 at 95% CL.

2.4 Leptoquarks

Leptoquarks, particles containing both lepton number and color may provide a connection between quark and leptons at higher energy scales. DØ has searched in 1 fb^{-1} of data for pair production of second-generation scalar leptoquarks, where one leptoquark decays to a muon and a c quark, and the other decays to a muon neutrino and an $\bar{s}$ quark. The signature is a muon, $\not\!\!E_T$, and two jets. The main background is from SM W+jets, which is estimated from Monte Carlo and normalized to data before final selection. No excess is observed, and they set a limit on the mass of the leptoquark at 214 GeV/c^2 at 95% CL.

2.5 New Heavy Quarks

CDF has performed a search for a fourth generation quark b' which couples to Z^0 in conjunction with jets in 1.1fb^{-1} of data. The coupling of a fourth generation quark is constrained to be small, so the direct decay to $W + c$ is suppressed, and the dominant decay would be through a loop to $Z + b$. Since the b' is expected to be pair produced, the signature is one Z, reconstructed in its decay to leptons, two b-jets, and two generic jets. To allow sensitivity to other possible physics beyond the standard model, no b-tagging is used. In this search, the dominant background, standard model production of Z + jets, is estimated with a technique using data. The method is cross-checked in a

Table 2: *Expected and observed events in CDF searches for leptons, photons, and* $\not\!\!E_T$.

Signature	$\gamma\gamma\gamma$	$\gamma\gamma e$	$\gamma\gamma\mu$	$\gamma\gamma\not\!\!E_T$
Expected	2.2 ± 0.7	6.8 ± 0.8	0.8 ± 0.1	0.24 ± 0.22
Data	4	3	0	0
Signature	$e\gamma\not\!\!E_T$	$\mu\gamma\not\!\!E_T$	$ee\gamma$	$\mu\mu\gamma$
Expected	95 ± 8	56 ± 7	39 ± 5	26 ± 3
Data	96	67	53	21

variety of control samples including W + jets data, where an excess consistent with $t\bar{t}$ production is found. They observe no significant excess in the Z^0 + jets signal region, and set limits on a fourth-generation b' quark model.

3 Signature-Based Searches

3.1 Search for New Physics in High-p_T Z^0

Massive new particles coupling to Z^0 bosons could impart significant transverse momentum to the Z^0. CDF has searched for new physics in 0.95 fb^{-1} of data in the transverse momentum spectrum of Z^0 bosons. The dominant background in this search is SM Drell-Yan production which is estimated with PYTHIA Monte Carlo. The Z p_T spectrum agrees well with background predictions, and limits on anomalous production of inclusive Z^0 bosons as a function of the boson p_T are set. In order to increase sensitivity, the sample is searched for additional leptons, photons, $\not\!\!E_T$, or large total sum transverse energy. These signatures have much smaller standard model rates and are sensitive to different backgrounds. Still, no significant excess is seen.

3.2 Anomalous Production of Leptons, Photons, and $\not\!\!E_T$

In Run 1, CDF observed a single event with two photons, two electron candidates, and $\not\!\!E_T$ was observed. In Run II, with many times the data available when that event was seen, CDF has several signature-based searches targeting anomalous production of similar events. Using 0.9-1.2 fb^{-1} of data, CDF has searched for anamalous production of $\gamma\gamma\gamma$, $\gamma\gamma e$, $\gamma\gamma\mu$, $\gamma\gamma\not\!\!E_T$, $l\gamma\not\!\!E_T$, and $ll\gamma$. Background expectations in these signatures range from a fraction of an event to a few tens of events. Expected and observed events in these searches are summarized in Table 2. No significant excesses are observed, nor are any events with two photons and two electrons like the one seen in Run 1.

3.3 Long-Lived Particles

Most searches for new particles assume prompt decays. It is possible that new physics might be longer-lived. CDF has searched for the decays of heavy, neutral, long-lived particles to photons with a new timing system for the electromagnetic calorimeter. Photon candidates from the decays of such a long-lived particle would arrive late compared to the products of the primary interaction. The final state $\gamma \not{E}_T$+jet is searched using all data available with timing information, 0.57 fb^{-1}, for late photons arriving 2 to 10 ns later than the primary interaction. The expected background is 1.7 events, and two are observed.

New massive charged massive particles (CHAMPs) with lifetimes long compared to their transit time through the detector would also escape detection by direct searches for their decay products. Such a charged massive particle would appear in the detector as a slow, highly-ionizing penetrating particle with large transverse momentum, and would be detected in the muon detectors (and reconstructed as a muon). CDF has searched in 1 fb^{-1} for such a particle in 1 fb^{-1} of data by measuring the time-of-flight of large transverse momentum tracks in events collected with a high p_T muon trigger. The particle's velocity, β, obtained from the timing measurement, and its momentum are used to compute the particle's mass. Backgrounds are estimated from muon samples in data. The results are consistent with background expectations, and model-independent cross section limits are set at 48 (10) fb at 95% C.L. for a single fiducial strongly (weakly) interacting CHAMP.

3.4 Model-Independent Algorithmic

In an attempt to divorce expectations about where new physics might appear from methodologies used to search, CDF has employed a broad algorithmic search targeting electroweak-scale new physics. The algorithm employed is as follows. First, events collected on a variety of high p_T triggers are classified by their object content. Backgrounds from SM processes are estimated with Monte Carlo samples. Next, a fit is performed to extract correction factors to the background estimation. These correction factors account for, among others, luminosity, inadequacy of NLO calculations used in the Monte Carlo, particle misidentification rates, trigger efficiencies, and jet energy scale. The data and background predictions are compared in each exclusive final state for differences in expected and observed events and differences in shape. Results from this broad search are expected soon.

4 Conclusions

The CDF and DØ experiments are searching many models and signatures for evidence of new physics. None is observed yet, but both experiments have now

recorded more that 2 fb^{-1}, and should have results with this doubling of the data soon. Most of the Run II data is yet to be collected and analyzed, and additional data continues to increase sensitivity to new physics signals.

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References

1. The CDF and DØ results discussed here are available at `www-cdf.fnal.gov` and `www-d0.fnal.gov`
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