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Searches for New Neutral Gauge Bosons and Leptoquarks at the Tevatron

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This contribution reports on some of the most recent searches for new heavy neutral bosons and leptoquarks performed at the Tevatron experiments.

1 Introduction

Despite of its tremendeous success in describing wealth of existing experimental data, the Standard Model (SM) has significant shortcomings, e.g. the hierarchy problem and the failure to explain origin of the electroweak symmetry breaking, matter-antimatter asymmetry, and apparent presence of dark matter. Many of the extensions proposed to resolve some or most of these problems predict the existence of new heavy particles. Heavy neutral bosons appear in many models, e.g. Z''s appearing in the string-inspired E6 models [2], Randall-Sundrum (RS) gravitons [3], heavy new bosons appearing in "little higgs" [4] and left-right symmetric models [5], sneutrinos in R-parity violating SUSY[6], as well as strongly interacting excited axigluons [7], colorons [8], techni-ρ's [9]. Similarly, leptoquarks appear in models intending to explain the apparent lepton-quark symmetry of the SM [10]. Another example is SUSY with R-parity violation where a leptoquark role can be taken by scalar quarks. While different models have varying predictions for the new particle production and decay mechanisms and dynamics, they all share similar experimental signatures and have been the subject of exhaustive experimental searches at both CDF and D0 experiments at the Tevatron. This contribution reviews some of the most recent of those searches.

2 New Boson Searches in Dilepton and Dijet Channels

In many schemes of GUT symmetry-breaking, U(1) gauge groups survive to relatively low energies [11], leading to the prediction of neutral gauge vector bosons, generically referred to as Z′ bosons. Such Z′ bosons typically couple with electroweak strength to SM fermions, and can be observed at hadron colliders as narrow, spin-1, dilepton resonances from $q\bar{q} \to Z' \to l^+l^-$. Many other SM extensions, such as the left-right symmetric [5] and the "little Higgs" models [4], also predict heavy neutral gauge bosons. Additional spatial dimensions are a possible explanation for the gap between the electroweak symmetry breaking scale and the gravitational energy scale M_{Planck}. In the Randall-Sundrum (RS) scenario [3], the ground-state wave function of the graviton is localized on a three-dimensional "brane" separated in a fourth spatial dimension from the SM brane. The wave function varies exponentially in this fourth dimension, causing its overlap with the SM brane to be suppressed and explaining the apparent weakness of gravity and the large value of M_{Planck}. This model predicts excited Kaluza-Klein modes of the graviton which are localized on the SM brane. These modes appear as spin-2 resonances G^* in the process $q\bar{q} \to G^* \to l^+l^-$, with a narrow intrinsic width when $k/M_{Planck} < 0.1$, where k^2 is the spacetime curvature in the extra dimension.

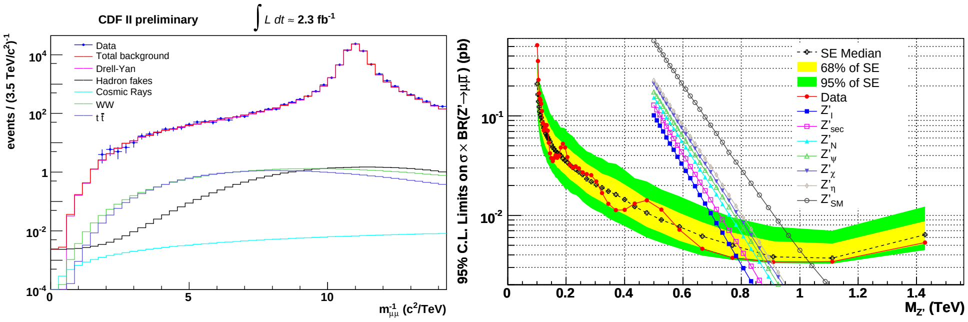

Figure 1: Invariant mass distribution of muon pairs and corresponding limit on Z-prime

Spin-0 resonances such as the sneutrino $\tilde{\nu}$ in the process $q\bar{q} \to \tilde{\nu} \to l^+l^-$ are predicted by supersymmetric theories with R-parity violation [6]. Experimentally, these new bosons are sought by looking for narrow resonances in di-electron or di-muon spectra. These final states are nearly free of instrumental backgrounds and are dominated by the irreducible Drell-Yan contribution. CDF has recently published results on searches for Z' and ED graviton in di-electron and di-muon channels [12] using 2.5 fb^{-1} and 2.3 fb^{-1} of data, respectively. Analysis in the muon channel requires two oppositely charged tracks with $p_T > 30$ GeV/c, consistent with the hypothesis that they are minimum ionizing particles. Figure 1 shows the invariant mass distribution demonstrating impressive agreement between data and the SM expectation. With no excess, the cross-section limit is calculated and is shown in Fig. 1 for different Z' species. For RS G^*, the limit is $G^* > 921$ GeV/c^2 for $k/M_{Planck} = 0.1$. A similar search in the di-electron channel yields $m(G^*) > 807$ GeV/c^2.

There are several compelling scenarios motivating searches for heavy new resonances decaying to quarks and gluons. In chiral color models, the SU(3) gauge group of QCD results from the spontaneous breaking of the chiral color gauge group of $SU(3) \times SU(3)$, leading to the presence of the axigluon, a massive axial vector gluon, that decays to $q\bar{q}$ [7]. The E_6 GUT model also predicts the presence of a diquark which decays to qq or $\bar{q}\bar{q}$ [13]. The flavor-universal coloron model [8] predicts the presence of a color-octet coloron which decays to $q\bar{q}$, models of extended technicolor and topcolor-assisted technicolor [9] predict the presence of a color-octet techni-ρ (ρ_{T8}) decaying to $q\bar{q}$ or gg. Together with dilepton analyses, searches with dijets improve sensitivity to the models predicting Z' bosons and ED gravitons discussed earlier. In the case of RS model, dijet channels may have special importance as the effective coupling of G^* to the SM particles can be enhanced or suppressed depending on their localization [14]. A recent CDF study [15] examines the dijet spectrum looking for evidence of a new resonance on top of the QCD dijet spectrum using 1.1 fb^{-1} of data collected using jet triggers. After removing instrumental backgrounds, e.g. beam losses and cosmic rays, jets are corrected for non-uniformities and non-linearities in the calorimeter response, and the two highest E_T jets are used to calculate the dijet mass m_{jj}. After correcting for smearing due to calorimeter resolution and offline selection requirements, the resulting m_{jj} spectrum is shown in Fig. 2. The search for dijet mass resonances is performed by parameterizing the shape of the dijet distribution with a smooth function and fitting data for statistically significant deviations consistent with the new dijet resonances. Figure 2 depicts the expected shape of the "bump" due to a new physics resonance using

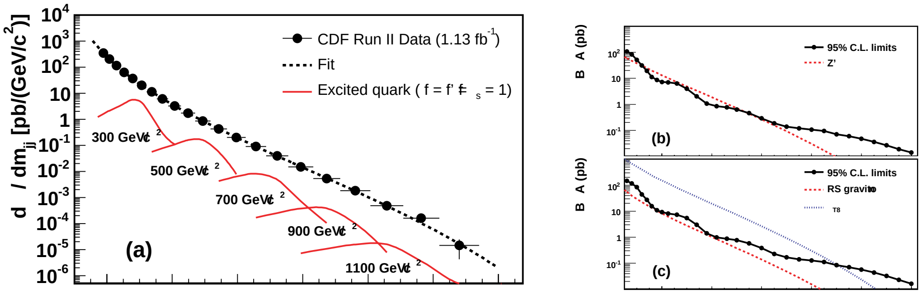

Figure 2: Dijet invariant mass spectrum and the corresponding cross-sections versus new particle mass plots showing exclusion levels for several scenarios.

an excited quark model as an example. Note that the shape is nearly independent of the type of resonance as it is dominated by the calorimeter resolution. With no excess, the data are used to restrict allowed cross-section for new particle production in several new physics scenarios as well as the new particle masses. Figure 2 shows corresponding exclusion plots for benchmark Z' and RS graviton G^* scenarios. The search excludes $260 < m < 1250$ GeV/c^2 for the axigluon and flavor-universal coloron, $290 < m < 630$ GeV/c^2 for the E6 diquark, $260 < m < 1100$ GeV/c^2 for ρ_{T8}.

3 New Boson Searches in Di-Boson Final States

Searches for new heavy bosons decaying to a pair of SM gauge bosons, e.g. WW or ZZ, can provide an important complementarity to the dilepton channels. Furthermore, if for some reason the coupling of new bosons to fermions is suppressed, the di-boson mode can hold the key to discovery of new physics, e.g. as modified RS scenarios discussed earlier where SM particles can be in the bulk, e.g. leading to reduced effective couplings of G^* to leptons [14]. CDF has recently performed a search [15] for heavy new resonance decaying to WW using 2.9 fb^{-1} of data. The search is performed using the ejj+MET final state, where one of the W's decays leptonically and the other one is allowed to decay into a pair of jets to enhance the acceptance of the analysis compared to the purely leptonic mode. Selected events are required to have an isolated electron ($E_T > 30$ GeV), a missing $E_T > 30$ GeV, 2 or 3 jets with $|\eta| < 2.5$ and $E_T > 30$ GeV, and an overall $H_T > 150$ GeV. H_T is defined as the sum of the electron E_T, the missing E_T and the jet E_T of all jets in the event. To reconstruct the WW topology, the electron and missing E_T are used to solve for missing E_Z under the assumption that the electron momentum and missing energy comprise the W mass. The event is dropped if no solution is possible. Events are further required to have a pair of jets with the di-jet invariant mass consistent with the W mass within resolution. The final step is to optimize selections for either the G^* or SSM Z' hypothesis, and separately for several possible mass ranges of the new boson. This is achieved by selecting sub-samples with varying minimum thresholds for missing E_T, lepton and jet E_T. The reconstructed

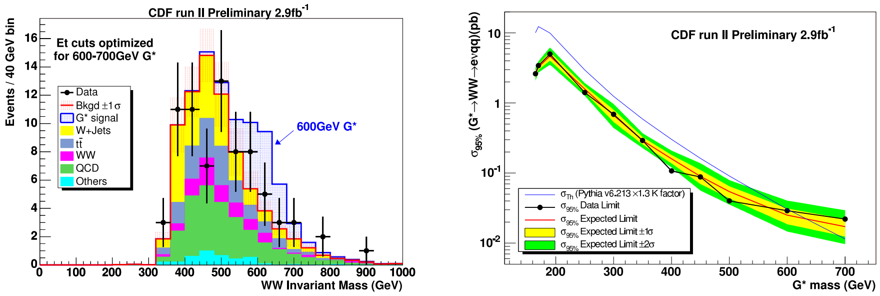

Figure 3: Invariant mass of WW candidate events and the 95% C.L. limit on $\sigma(p\bar{p} \to G^*)$ as a function of $m(G^*)$.

invariant mass of candidate events for one of such sub-samples is shown in Fig. 3. With no statistically significant excess of data over SM, limits are set on the production cross-section of Z' and G^*. Using standard RS gravition and SSM Z' as a benchmark, the excluded mass ranges are $m(G^*) < 607$ and $247 < m(Z') < 545$ GeV/c^2.

4 Searches For Leptoquarks

Models attempting to explain the symmetry of the lepton and quark sectors in the SM often predict the existence of leptoquarks (LQ) [10]. Those are scalar or vector particles carrying both a lepton and a baryon quantum number. At hadron colliders, new colored particles predicted by various extensions of the standard model (SM) would be abundantly produced if they are light enough. To satisfy experimental constraints on changing neutral current interactions, leptoquarks couple only within a single generation. Leptoquarks decay into a charged lepton and a quark with a branching ratio β, or into a neutrino and a quark with a branching ratio $\beta - 1$. Pair production of leptoquarks assuming $\beta = 0$ therefore leads only to a final state consisting of two neutrinos and two quarks. The corresponding experimental signature is the presence of jets and missing transverse energy resulting from the decay of those particles. A recent D0 analysis [17] explores the jj+missing E_T channel by analyzing events with the topology consisting of exactly two jets and missing E_T using 2.5 fb^{-1} of data. Because the final state has no leptons, the analysis has similar acceptance to leptoquarks belonging to any of the three possible generations. Before final optimization, the event selection requires presence of exactly two acoplanar jets ($\Delta\phi(j_1, j_2) < 170^o$) with $E_T > 35$ GeV in the central part of the detector and missing E_T over 75 GeV. To minimize instrumental mismeasurements of missing energy and suppress large QCD multi-jet background contamination, the missing E_T in selected events is required to point away from any of the jets in the event. Events containing identified lepton or isolated track candidates are removed to reduce the W+jet and $t\bar{t}$ backgrounds. Figure 4 shows the distribution of H_T defined as a scalar sum of the transverse energies of the jets in the event and the missing E_T. At this stage, the analysis is split into two separate searches targeting signals of either lower or higher leptoquark mass. Best sensitivity to lighter leptoquark signal is achieved by additionally requiring $H_T > 150$ GeV, while the higher mass search requires $H_T > 300$ GeV and uses a tighter cut on missing E_T of 125 GeV. Neither of the two sub-analyses

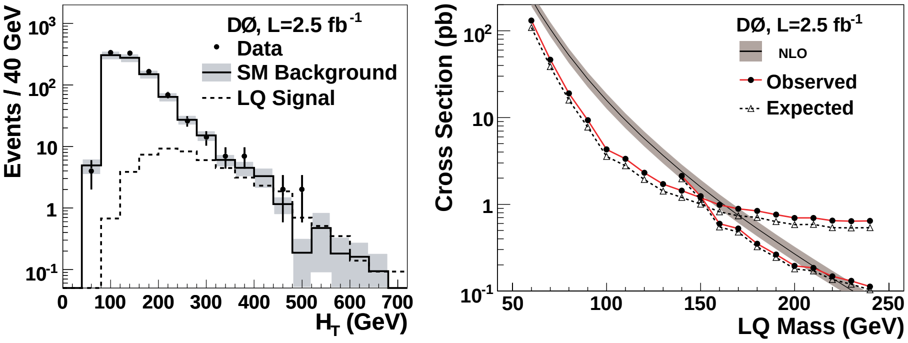

Figure 4: Distribution of H_T for selected candidate events and the corresponding 95% C.L. limit on $\sigma(p\bar{p} \to LQ)$ vs leptoquark mass.

found significant excesses of data over the SM expectation. The 95% C.L. upper bound on the leptoquark production cross-section for $\beta = 0$ is shown in Fig. 4. The corresponding leptoquark mass limit is 205 GeV/c^2 using NLO predicted cross-section [10].

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