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Non-SUSY Exotic Particle Searches at the Tevatron

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NON-SUSY EXOTIC PARTICLE SEARCHES AT THE TEVATRON

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for the

CDF AND DØ COLLABORATIONS

Between 1992 and 1995, the CDF and DØ collaborations collected data from $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV. Recently, several analyses of this data have been performed in search of evidence for various non-Supersymmetric exotic particles. As no evidence for the existence of these particles is observed, confidence level limits are established for exotic particle predictions from various theoretical models. Analyses presented here include searches for Standard Model Higgs, technicolor particles, topcolor-assisted technicolor bosons, and flavor-universal colorons.

1 Introduction

The CDF and DØ general purpose detectors have been designed for the investigation of high energy $p\bar{p}$ collisions at the Fermilab Tevatron Collider. While the experiments were designed with complementary capabilities, each consists of three major components: tracking chambers for charged particle detection, a calorimeter system for the measurement of electromagnetic and hadronic energies, and outer muon drift chambers.

Included in a broad range of physics analyses, the CDF and DØ collaborations have been involved in a variety of exotic particle searches with data from the 1992-1995 collider run. Briefly presented in this paper are several such analyses which rely on unique detector signatures and often employ the expertise of bottom quark identification which made possible the discovery of the top quark.

2 Standard Model Higgs Searches

In the coming millenium, one of the primary goals of particle physics is the discovery of the Higgs boson. According to the Standard Model, the Higgs mechanism manifests itself as a massive scalar particle and is responsible for the fermion and weak boson masses which result from electroweak symmetry breaking. Its discovery would only add to the predictive achievements of the remarkably successful standard model.

Due to reduced background rates relative to other production channels, Tevatron analyses presented here search for the Higgs produced in association with either a W- or Z-boson. Furthermore, these searches focus exclusively on the $b\bar{b}$ decay of the Higgs boson, the decay channel which is expected to dominate for Standard Model Higgs masses in the region ≈ 100 GeV/c^2.

2.1 CDF SM Higgs Searches

As a result of the difficulty associated with the identification of τ-leptons, the CDF search for Higgs production in association with a leptonically decaying W requires that $WH^0 \to e\nu b\bar{b}$ or $\mu\nu b\bar{b}$. The corresponding event selection requires two jets, the detection of either a central ($|\eta| < 1.0$) electron with $E_T > 20$ GeV or a central muon with $P_T > 20$ GeV/c, and missing transverse energy $\not\!\!E_T$ in excess of 20 GeV due to the undetected neutrino. In addition to rejecting Z-boson candidates and events which pass the top quark dilepton selection criteria[1], events with a second, opposite-sign lepton with $P_T > 15$ GeV/c are also excluded from the event sample.

To further reduce background rates, at least one jet is required to be identified as a b-quark jet by the detection of a displaced secondary vertex in the Silicon Vertex Detector (SVX tag). Dividing the event sample into exclusive single- and double-tagged samples, the second jet may also be identified as a b-jet via an SVX tag or by the observation of an additional lepton resulting from a semileptonic b decay (SLT tag). This analysis observes 36 single-tag (6 double-tag) events over an expected background contribution of 30 ± 5 (3.0 ± 0.6) events.

CDF has also investigated Higgs production in association with a hadronically decaying vector boson, V (*viz.*, either W or Z), with a final state signature of four jets, two of which are b-jets. Although this search benefits from higher statistics due to a large signal branching ratio, the QCD background rates are also significantly increased.

Selection for this VH^0 analysis requires that no isolated, high P_T leptons be present, but that events contain four or more jets, at least two of which are identified as a b-jet via an SVX displaced vertex tag. The b-tagged dijet invariant mass distribution for 589 events observed in 109 pb^{-1} of data is consistent with standard model background expectations.

Using a standard likelihood fitting procedure on the reconstructed invariant Higgs mass distributions, both analyses establish 95% confidence level limits for standard model VH^0 production, with H^0 decaying to $b\bar{b}$. The individual and combined results are shown in Figure 1.

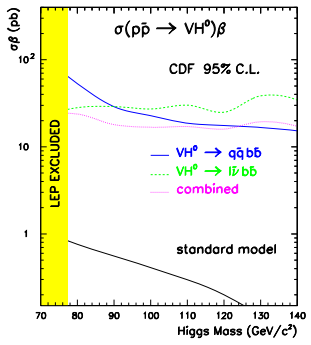

Figure 1: The CDF 95% confidence level upper limits on $\sigma(p\bar{p} \to VH^0)\beta$, where $\beta = B(H^0 \to b\bar{b})$.

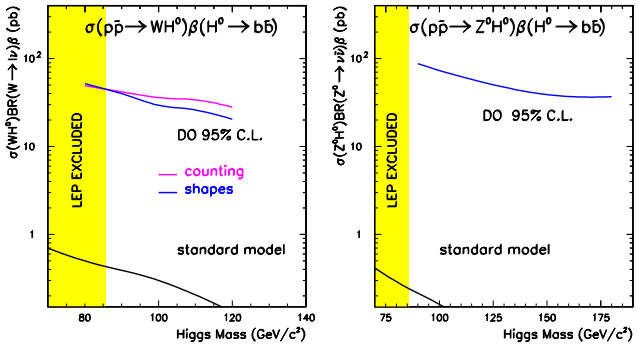

Figure 2: The DØ 95% confidence level upper limits on $\sigma(p\bar{p} \to WH^0)\beta$ and $\sigma(p\bar{p} \to ZH^0)\beta$, where $\beta = B(H^0 \to b\bar{b})$.

2.2 DØ SM Higgs Searches

The DØ collaboration has also performed a search for Higgs production in association with a leptonically decaying W in the $WH^0 \to e\nu b\bar{b}$ or $\mu\nu b\bar{b}$ channels. Event selection requires the detection of an isolated, high P_T electron or muon, at least 20 GeV of $\not\!\!E_T$ arising from the undetected neutrino, and two or more jets with $|\eta| \leq 2.0$ and $P_T \geq 15$ GeV. To further enhance signal acceptance, at least one jet is required to be identified as a heavy quark jet via the

detection of a nearby muon with $P_T \geq 4$ GeV. In this analysis of 100 pb^{-1} of data, 27 events are observed over an expected background contribution of 25.5 ± 3.3 events.

Finally, DØ has also investigated $H^0 \rightarrow b\bar{b}$ production in association with a Z decaying to $\nu\bar{\nu}$. Selected events are required to have $\not\!\!E_T$ in excess of 35 GeV as well as at least two jets, but no more than six. Furthermore, the event selection demands that at least one jet with $E_T > 10$ GeV have an associated muon, identifying it as a b-jet. If a second muon is present, it also must similarly identify an associated jet as a b and the dimuon invariant mass must exceed 8 GeV/c^2, thereby rejecting low mass resonances. When only one muon is present, the event must contain an additional jet with $E_T > 25$ GeV and $|\eta| < 1.5$. To improve b-quark identification and to reduce the acceptance rate for QCD W+jets events with $W \rightarrow \mu\nu$, additional cuts are imposed on the relative muon energy as well as the pattern of energy deposition around the muon. The application of two final cuts (which preferentially eliminate $t\bar{t}$ and mismeasured $\not\!\!E_T$ background) results in the observation of two data events compared to an expected background of 2.6 ± 0.7.

Again by using a standard likelihood fitting procedure and the reconstructed invariant Higgs mass distributions, both analyses, as shown in Figure 2, establish 95% confidence level upper limits for production of standard model Higgs decaying to $b\bar{b}$. One must exercise caution in directly comparing the CDF limits on $\sigma(p\bar{p} \rightarrow VH^0)\beta$ and the DØ individual limits on $\sigma(p\bar{p} \rightarrow WH^0)\beta$ and $\sigma(p\bar{p} \rightarrow ZH^0)\beta$. Direct comparison of limits on VH^0 and WH^0 (ZH^0) production requires multiplication of the latter by a factor of ≈ 1.7 (≈ 2.6).

3 Technicolor Searches

In technicolor models, electroweak symmetry is not broken spontaneously by a Higgs scalar field, but rather is broken dynamically as the result of a new strong gauge interaction which leads to the formation of technimesons ($\rho_T^{\pm,0}$, ω_T, $\pi_T^{\pm,0}$). Presented here are two searches for technicolor particles which would result from high energy $q\bar{q}$ annihilation.

3.1 CDF $\rho_T \rightarrow W\pi_T$ Search

The decay $\rho_T \rightarrow W\pi_T$ is expected to be the dominant channel for $M_{\rho_T} \sim 180$ GeV/c^2 and $M_{\pi_T} \sim 90$ GeV/c^2. The efforts of this search focus on a leptonically decaying W and a heavy flavor quark pair (either $b\bar{b}$ or bc) resulting from the decay of the π_T whose fermion coupling increases with fermion mass. This analysis of 109 pb^{-1} of data correspondingly requires that events contain an isolated electron with $E_T > 20$ GeV or an isolated muon with $P_T > 20$ GeV/c, $\not\!\!E_T$ in excess of 20 GeV, and exactly two jets with $E_T > 15$ GeV and $|\eta| < 2.0$. In order to reduce the amount of QCD W+2jet background, at least one of the jets is required to be identified as a b-jet via detection of an SVX displaced vertex. In an effort to increase the relative signal efficiency, M_{ρ_T},M_{π_T}-dependent requirements are imposed on both the P_T of the dijet system and the angle in the traverse plane between the two jets. The dijet invariant mass then corresponds to the measured π_T mass. Requiring that the lepton-neutrino system have an invariant mass equal to that of the W yields a determination of the longitudinal component of the neutrino momentum which is not measured directly. The measured ρ_T mass then simply corresponds to the invariant mass of the W and two jets.

Because no significant excess is observed in the dijet and W+2jet invariant mass spectra, 95% confidence level limits are established for ρ_T production as a function of the ρ_T and π_T masses. For a given point in the M_{ρ_T}-M_{π_T} plane, a final event selection requirement demands that the measured dijet (W+2jet) invariant mass be within $\pm$ 3 σ of the expected value determined from M_{π_T} (M_{ρ_T}) monte carlo simulations. Considering a specific technicolor model [2], the 95% C.L. upper limit for a particular point in the M_{ρ_T}-M$_{\pi_T}$ plane is determined by fitting the measured mass spectra to the corresponding background and expected signal distributions. The excluded

region of the plane is shown in Figure 3 as well as expected theoretical contours for several ρ_T cross-sections. This plot shows that in 109 pb^{-1} of data, the entire region corresponding to a ρ_T cross-section of 15 pb and the majority of the region corresponding to a 10 pb ρ_T cross-section can be excluded at the 95% confidence level.

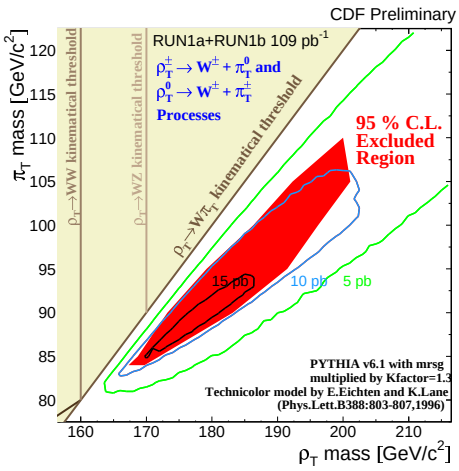

Figure 3: The 95% C.L. excluded region in the M_{π_T}-M_{ρ_T} plane. Theoretical contours represent cross-sections resulting from counting experiments of simulations of 5, 10, and 15 pb ρ_T production.

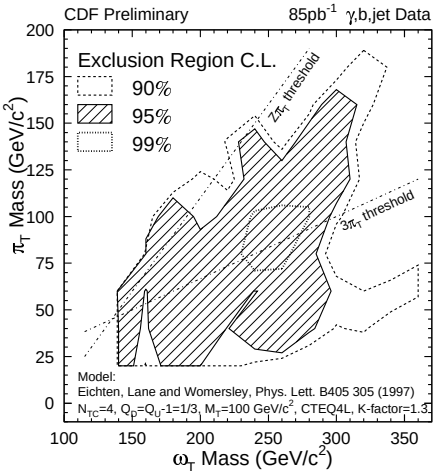

Figure 4: The regions of the M_{π_T}-M_{ω_T} plane which are excluded at the 90, 95, and 99% confidence levels. Limits are determined by fitting the measured $\Delta M = M_{\gamma jj} - M_{jj}$ spectrum to monte carlo shapes.

3.2 CDF $\omega_T \to \gamma\pi_T$ Search

The ω_T is expected to decay to $\gamma\pi_T$ according to the technicolor model considered here [3]. Presuming that $\pi_T \to b\bar{b}$, this analysis searches for events containing an electromagnetic cluster with $E_T > 25$ GeV and $|\eta| < 1.0$ plus two jets with $E_T > 30$ GeV and $|\eta| < 2.0$. Additionally, the SVX tagging algorithm must identify at least one of the jets a b-jet.

Because the 200 events observed in 85 pb^{-1} of data do not constitute a significant excess over standard model predictions, limits are established for this particular Technicolor model. For a given point in the ω_T-π_T mass plane, a final selection requirement insists that the measured dijet invariant mass, M_{jj}, be such that $|M_{jj} - M_{\pi_T}| < 0.36 M_{\pi_T}$. The $\Delta M = M_{\gamma jj} - M_{jj}$ distribution is then fit to the expected signal and background shapes in the region of $\Delta M > 50$ GeV/c^2 and corresponding 90, 95, and 99% confidence level limits are determined. As shown in Figure 4, a significant fraction of the 25 GeV/c^2 $< M_{\pi_T} <$ 160 GeV/c^2 and 150 GeV/c^2 $< M_{\omega_T} <$ 300 GeV/c^2 region can be excluded.

4 Topcolor Searches

The large mass of the top quark itself suggests new dynamics for electroweak symmetry breaking. The Topcolor-Assisted Technicolor model [4] accounts for the value of M_{top} while predicting the existence of a residual global symmetry at energies below ~ 1 TeV. The result of this residual symmetry is the existence "Topgluons" and a "Topcolor Z'" which would appear as wide and narrow $b\bar{b}/t\bar{t}$ resonances, respectively.

4.1 CDF Search for $b\bar{b}$ Resonances

This analysis of 87 pb^{-1} of data requires that events contain two SVX b-tagged jets with $|\eta| < 2.0$ and that the scattering angle in the dijet center-of-mass frame must satisfy $|\cos\theta^*| < 2/3$. Because this event selection yields no evidence for new physics beyond the expected background, 95% confidence level upper limits on Topcolor production are established. Figure 5 shows these limits as a function of mass for Topcolor Z' and Topgluons of various widths. The narrow resonance color octet technirho is excluded in the mass range of 350 to 440 GeV^2. Topgluons are excluded in the ranges of 280 to 670 GeV^2, 340 to 640 GeV^2, and 375 to 560 GeV^2 for widths of $\Gamma = 0.3$M, 0.5M, and 0.7M, respectively.

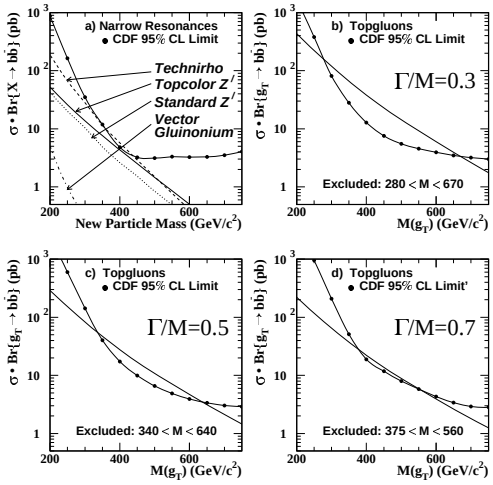

Figure 5: The 95% confidence level upper limits on $\sigma \cdot Br(\mathrm{X} \to b\bar{b})$ for narrow resonances and Topgluons.

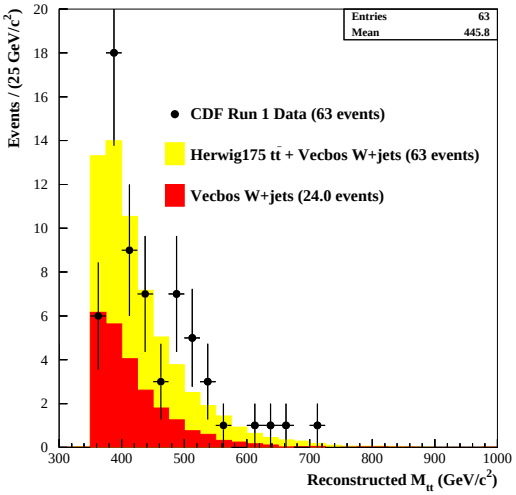

Figure 6: The CDF $t\bar{t}$ invariant mass spectrum used in the 109 pb^{-1} search for $\mathrm{X} \to t\bar{t}$. The expected $t\bar{t}$ + QCD background is normalized to the data.

4.2 CDF Search for $t\bar{t}$ Resonances

This optimized, model-independent search for narrow $t\bar{t}$ resonances builds upon the expertise developed in the top quark mass analysis [5]. Presuming that $t \to Wb$, this study focuses exclusively on the channel in which one W decays leptonically. Event selection then requires an isolated, high-P_T lepton (e or μ), $\not\!\!E_T$ in excess of 20 GeV due to the neutrino, and at least three jets with $E_T > 15$ GeV and $|\eta| < 2.0$ and one jet with $E_T > 8$ GeV and $|\eta| < 2.4$. To further enhance the signal, one of the four highest E_T jets must be identified as a b-jet either by an SVX or an SLT tag. If such a b-tag is not present, all four jets are required to satisfy the more restrictive jet requirements, *viz.*, $E_T > 15$ GeV and $|\eta| < 2.0$.

Of the 24 combinatoric possibilities for assigning partons, the selected solution agrees with the available tagging information and best satisfies the requirements that the W mass reconstruct to 80.2 GeV/c^2 and the top quark mass reconstruct to 175.0 GeV/c^2. To reduce wrong combinations, the top quark mass constraint is then released and the fitted top mass for the chosen solution is required to lie between 150 and 200 GeV/c^2. The resulting $t\bar{t}$ invariant mass spectrum for 109 pb^{-1} of data is shown in Figure 6. 95% confidence level limits are currently being established for narrow resonance production.

5 Flavor-Universal Coloron Search

Like Topcolor, the flavor-universal coloron model involves a minimal extension of strong interactions [6]. At low energies, the symmetry of the theory is broken yielding an octet of massive colorons. In this model, the QCD gauge group is extended to $SU(3)_1 \times SU(3)_2$ with gauge couplings ξ_1 and ξ_2 ($\xi_2 \gg \xi_1$) and the resulting coloron interaction strength is given by the ratio of the coloron mass (M_c) to $\cot\theta$ ($= \xi_2/\xi_1$).

In 92 pb^{-1} of data, DØ measures the dijet mass spectrum for dijet invariant masses > 200 GeV/c^2 and jets with $|\eta_{jet}| < 1.0$. To set limits on flavor-universal colorons, the investigated quantity is the ratio of spectra at $|\eta_{jet}| < 0.5$ and $0.5 < |\eta_{jet}| < 1.0$. Using a standard procedure to set 95% confidence level limits, the data distribution is fit to next-to-leading-order monte carlo simulations of various coloron interactions strengths. The excluded region of the M_c-$\cot^2\theta$ plane is shown in Figure 7. The 95% confidence level lower limit on $M_c/\cot\theta$ is 837 GeV/c^2.

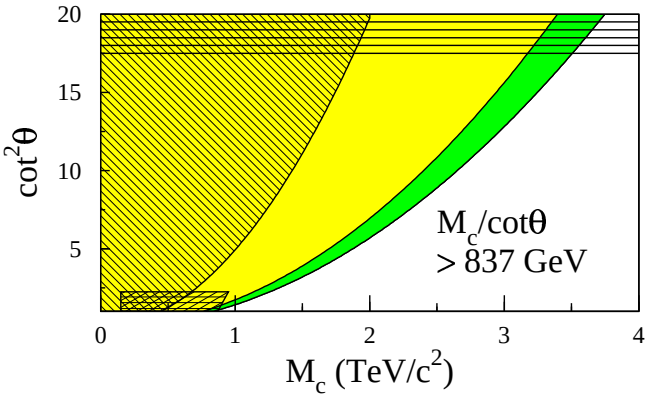

Figure 7: 95% C.L. exclusion region of coloron parameter space. The dark region represents the results of the study discussed in the text; other regions were excluded by earlier studies.

6 Conclusions

Limits have been established for a variety exotic particle searches performed by the CDF and DØ collaborations during the 1992-1995 collider run. The data collected in the next run beginning in 2001 will result in significantly tighter limits and possibly the observation of new physics.

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