NEW PHENOMENA I
SEARCHES FOR NEW PHYSICS AT CDF AND D0

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This paper summarizes results of recent searches for new phenomena with the CDF and D0 detectors at the Fermilab Tevatron. All results shown correspond to analysis from the past Run I data corresponding to a total integrated luminosity of $\sim$ 100 pb^{-1} per experiment. In particular, we show new results from stop quark searches, neutral supersymmetric Higgs boson searches, a reinterpretation of the CDF second and third generation leptoquark searches in terms of leptoquark resonant production through technicolor interactions and, finally, we report a new D0 search for large extra space dimensions from high mass Drell-Yan dielectron and diphoton events.

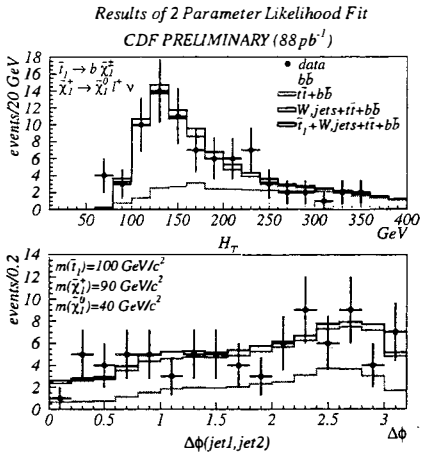

Figure 1: *Two-dimensional fit to the H_T and $\Delta\Phi(j_1, j_2)$ distributions when $\tilde{t}_1 \to b\tilde{\chi}_1^+$ with a 100% branching fraction.*

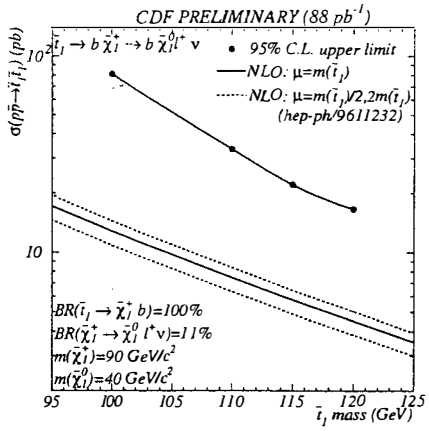

Figure 2: *CDF 95% C.L. upper limit for $\sigma(\bar{t}\bar{t})$ as a function of $m_{\tilde{t}_1}$. A 100% branching ratio for the decay $\tilde{t}_1 \to b\tilde{\chi}_1^+$ is assumed, with $m_{\tilde{\chi}_1^+} = 90$ GeV/c^2 and $m_{\tilde{\chi}_1^0} = 40$ GeV/c^2.*

1 Scalar Top Quark Searches

Scalar top quarks could be under the detection reach of the Fermilab Tevatron given the theoretical predictions for its low mass by a wide range of supersymmetric as well as many baryogenesis models [1]. At Tevatron, the lighter scalar top mass eigenstate can be produced either directly as $\tilde{t}_1\bar{\tilde{t}}_1$ pairs via gg fusion and $q\bar{q}$ annihilation, or depending on the stop mass, indirectly through top decays $t \to \tilde{t}_1\tilde{\chi}_1^0$, or sparticles, such as $\tilde{\chi}_i^\pm \to b\tilde{t}_1$. Both the CDF [2] and D0 [3] experiments have already reported searches for direct stop quark pair production ($p\bar{p} \to \tilde{t}_1\bar{\tilde{t}}_1$) through the decays $\tilde{t}_1 \to c\tilde{\chi}_1^0$. These searches have been interpreted under the Minimal Supersymmetric extension of the Standard Model (MSSM). CDF shows a maximum excluded value of the stop quark mass of $m_{\tilde{t}_1} = 119$ GeV/c^2 for $m_{\tilde{\chi}_1^0} = 40$ GeV/c^2, while the highest excluded value from D0 is $m_{\tilde{t}_1} = 93$ GeV/c^2 with a corresponding $m_{\tilde{\chi}_1^0}$ value of 8 GeV/c^2. The decay $\tilde{t}_1 \to c\tilde{\chi}_1^0$ dominates via a one-loop diagram if $m_{\tilde{t}_1} < m_b + m_{\tilde{\chi}_1^+}$ and $m_{\tilde{t}_1} < m_{W^+} + m_b + m_{\tilde{\chi}_1^0}$. Recently, both the CDF and D0 collaborations [4,5] have also studied the two-body decay $\tilde{t}_1 \to b\tilde{\chi}_1^+$ assuming it proceeds with a branching fraction of 100%. At least one of the charginos is required to decay via a virtual W to $\tilde{\chi}_1^+ \to l\bar{\nu}\tilde{\chi}_1^0$, with $l = e, \mu$. This chargino three-body decay dominates as long as the sleptons and squarks are heavy enough. For the case where $\tilde{t}_1 \to b\tilde{\chi}_1^+$ is not kinematically allowed, CDF also considers a second decay scenario in which $\tilde{t}_1 \to bl^+\tilde{\nu}$, with $\tilde{\nu}$ a scalar neutrino. The CDF search in both cases [4] requires at least one isolated lepton (electron or muon), missing transverse energy from the neutral LSP (assumed to be the lightest neutralino, $\tilde{\chi}_1^0$) and at least two jets from the b quarks. This signature can look similar to the top quark decay $t \to bW$, with kinematic differences due to the smaller $\tilde{t}_1$ mass, the presence of two massive neutralinos, and the absence of a real W in the final state. To identify secondary vertices from b quark decays, the microvertex detector is used in the CDF analysis, and events with at least one secondary vertex are selected. The standard model backgrounds include heavy flavor quark production, vector boson production with two or more accompanying jets, and inclusive jet production with real or fake leptons. CDF uses unbinned likelihood fits to the data to determine the number of signal events in the final data sample. The likelihood fits compare the shapes of the signal and background distributions, and Kolmogorov tests are used to determine the most sensitive kinematic distribution to use in the fit. For the $\tilde{t}_1 \to b\tilde{\chi}_1^+$ decay, the scalar sum of all

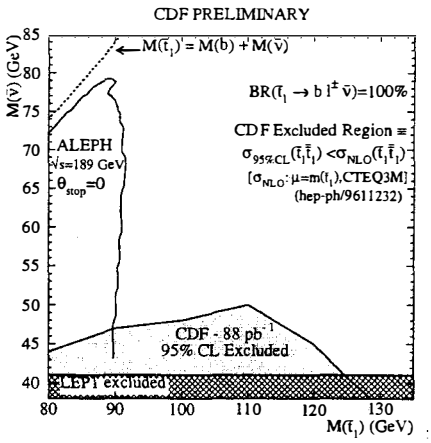

Figure 3: *95% C.L. exclusion region in the plane $m_{\tilde{t}_1}$ versus $m_{\tilde{\nu}}$ for $\tilde{t}_1 \to bl\tilde{\nu}$. Also shown are the LEP1 limits for $m_{\tilde{\nu}}$ and the ALEPH exclusion region.*

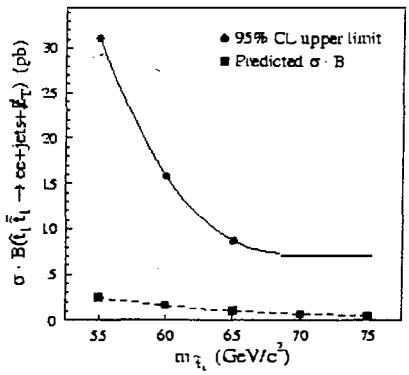

Figure 4: *D0 95% C.L. upper limits on $\sigma \times BR(\bar{t}\bar{t} \to ee + jets + \not\!\!E_T)$ as a function of $m_{\tilde{t}_1}$ for $m_{\tilde{\chi}_1^+} = 47$ GeV/c^2.*

transverse energy of the event, H_T, and the angular distribution between the leading jets of the event, $\Delta\Phi(j_1, j_2)$, are used in the fit. These fit distributions are shown in Figure 1. All fit results at all masses are consistent with zero signal events. The 95% C.L. cross section upper limits as a function of $m_{\tilde{t}_1}$ are shown in Figure 2. For the $\tilde{t}_1 \to bl^+\tilde{\nu}$, the sensitivity to the signal was greatest for a fit to the H_T. The resulting excluded region in the plane $m_{\tilde{t}_1}$ versus $m_{\tilde{\nu}}$ is shown in Figure 3. The D0 search for $\tilde{t}_1 \to b\tilde{\chi}_1^+$ decays[5] restrics to the dielectron channel $\tilde{t}_1\bar{\tilde{t}}_1 \to b\bar{b}\tilde{\chi}^+\tilde{\chi}^- \to ee + jets + \not\!\!E_T$. The signature is two electrons, one or more jets, and $\not\!\!E_T$. After a cut based optimization search two events remain in the final selected sample with a total predicted background of 4.4 ± 0.8 events. 95% C.L. upper limits on $\sigma \times BR$ are set from a Bayesian approach with flat prior distributions for the signal rates. The resulting upper limits are shown in Figure 4.

2 Search For Neutral Supersymmetric Higgs Bosons

CDF has recently performed a search for neutral supersymmetric Higgs bosons produced in association with b quarks in $b\bar{b}b\bar{b}$ final states. A distinct feature of the MSSM is the modified couplings of the Higgs particle with respect to the Standard Model (SM), in particular the enhancement of the bottom quark Yukawa coupling by either $\tan\beta$ or $1/\cos\beta$, with $\tan\beta$ the ratio between the vacuum expectation values of the two Higgs doublets of the theory. The CDF analysis exploits the enhanced bottom Yukawa couplings of the MSSM to test the large $\tan\beta$ sector of the theory by searching for the process $p\bar{p} \to b\bar{b}\varphi \to b\bar{b}b\bar{b}$ with $\varphi = h, H, A$. The data selection starts with a sample recorded with a trigger which requires four or more clusters of contiguous calorimeter clusters, each with $E_T \geq 15$ GeV and a total $\sum E_T \geq 125$ GeV. At least four jets with three or more b-tags are then required. The dominant backgrounds come from irreducible QCD heavy flavor production and electroweak $Wb\bar{b}/c\bar{c}$ and $Zb\bar{b}/c\bar{c}$ processes. After requiring further cuts on the mass and angular distribution of final state jets, 3 events are left with an expected background of 4.5 ± 1.4 events. Using the leading order theoretical cross sections for $\sigma(p\bar{p} \to b\bar{b}\varphi)\mathcal{BR}(\varphi \to b\bar{b})$ and the bottom Yukawa coupling calculated with a running bottom quark mass evaluated at the Higgs mass scale, $m_b(m_\varphi) \simeq 3$ GeV/c^2, Figures 5 and 6 show the excluded regions of parameter space for $m_h - \tan\beta$ and $m_A - \tan\beta$, respectively for two common choices of the stop quark mixing parameter X_t: *minimal mixing* ($X_t = 0$), and *maximal mixing* ($X_t = A_t - \mu\cot\beta = \sqrt{6}\, m_S$, with μ the supersymmetric Higgs mass parameter and A_t a soft breaking

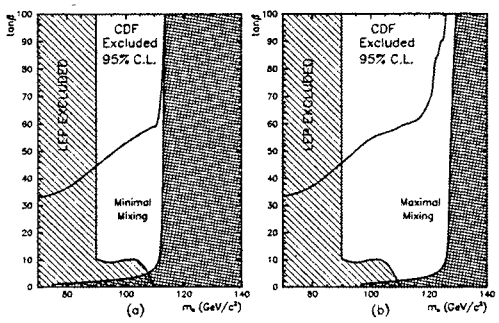

Figure 5: *CDF 95% C.L. excluded region in the parameter space $m_h - \tan\beta$ for the two stop mixing scenarios: (a) minimal mixing, and (b) maximal mixing. Also shown are the theoretically forbidden regions and the LEP exclusion region.*

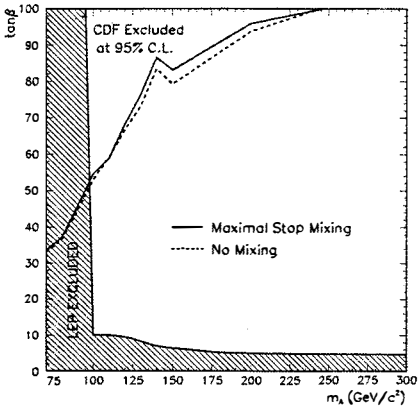

Figure 6: *CDF 95% C.L. excluded region in the parameter space $m_A - \tan\beta$ for the two stop mixing scenarios: minimal mixing (dashed lines) and maximal mixing (solid line). Also shown is the LEP exclusion region.*

parameter). In all cases m_S, the quadratic average of the two stop quark masses, is set to 1 TeV/c^2 and $m_t = 175$ GeV/c^2.

3 Search for Third Generation Leptoquark Production Via Technicolor Interactions

In the past both the CDF and D0 experiments have extensively searched for continuum pair production of all three generation of leptoquarks. Here we present new results from CDF on searches of second and third generation leptoquarks produced via technicolor interactions. In one of the most accepted technicolor formulations [6], color octet technirhos ($\rho^0_{T_8}$) and color triplet (π_{LQ}) and octet technipions (π_{T_8}) couple, in a Higgs-like fashion, to fermions and are thus expected to decay into heavy fermion pairs. The π_{LQ} is identified as a scalar leptoquark. CDF has already reported results from this type of leptoquarks in the channel $\tau\bar{\tau}b\bar{b}$ through the decays $\pi_{LQ} \to \bar{b}\tau^-$ [7]. Here, the decay modes $\pi_{LQ} \to b\bar{\nu}_\tau, c\bar{\nu}_\tau$ corresponding to $\beta = 0$ (with β the branching ratio of a leptoquark decaying to a final state with a charged lepton) are utilized to search for pair produced leptoquarks in events with heavy flavor jets, $\not\!\!E_T$, and the absence of leptons. The same data sample and selection criteria as the one used in the recent CDF search for stop and sbottom quarks [2] is utilized here. 11 observed events with an expected background of 14.5 ± 4.2 events are selected for the $c\bar{c}\nu_\tau\bar{\nu}_\tau$ channel, and 5 observed events with 5.8 ± 1.8 expected are selected for the $b\bar{b}\nu_\tau\bar{\nu}_\tau$ channel. Figures 7 and 8 show, respectively, the excluded regions at the 95% C.L. in the $M(\pi_{LQ})$ vs $M(\rho^0_{T_8})$ plane for three different values of the mass diference $\Delta M = M(\pi_{T_8}) - M(\pi_{LQ})$, $\Delta M = 0$, 50, and ∞ GeV/c^2.

4 Search for Extra Dimensions

Recently theories based on large spacial extra dimensions emerged as a possible solution of the hierarchy problem yielding a low-scale theory of quantum gravity testable at colliders [8]. In these theories,

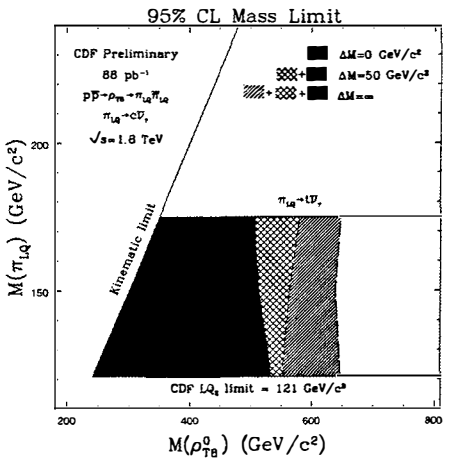

Figure 7: *95% C.L. exclusion region in the plane $M(\pi_{LQ})$ versus $M(\rho^0_{T_8})$ for the process $\rho^0_{T_8} \to \pi_{LQ}\bar{\pi}_{LQ} \to c\bar{c}\nu_\tau\bar{\nu}_\tau$.*

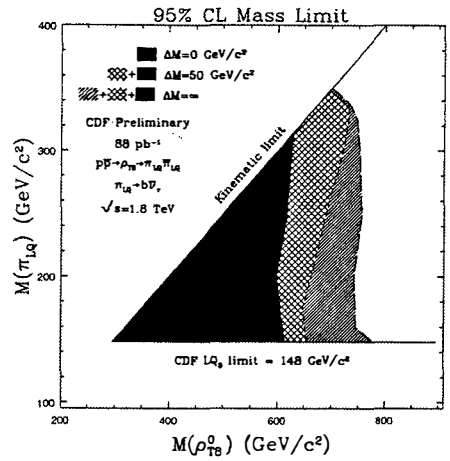

Figure 8: *95% C.L. exclusion region in the plane $M(\pi_{LQ})$ versus $M(\rho^0_{T_8})$ for the process $\rho^0_{T_8} \to \pi_{LQ}\bar{\pi}_{LQ} \to b\bar{b}\nu_\tau\bar{\nu}_\tau$.*

gravitational interactions become strong near the weak scale, and take place in n new large spatial dimensions. These theories manifest themselves through the existence of Kaluza-Klein towers of massive gravitons interacting with the SM fields, which would lead to extra contributions to processes involving dilepton and diphoton pair production at hadron colliders [9]. D0 has, for the first time [10], produced results on the effect of the K-K tower exchange on Drell-Yan dielectron and diphoton production. They use the invariant mass, M, and the central scattering angle, $\cos\theta^*$, of final state electrons and photons to analyze a selected dielectron and diphoton sample for possible deviations from SM contributions. The selection is similar to the published quark and lepton compositeness search [11], with some differences to optimize signal efficiency and maximize the discovery potential at high masses. The M and $\cos\theta^*$ distributions are shown in Figures 9 and 10, respectively, compared to the expected SM Drell-Yan, diphoton, and instrumental backgrounds (fakes). No excess of events is seen at high masses and low scattering angles where the signal is expected to reveal. In the absence of evidence for extra dimensions, D0 sets a 95% C.L. lower limit on $\mathcal{F}/M_S^4 > 0.5$ TeV^{-4}, where M_S is the effective Plank scale ("strong scale") at which gravity becomes strong and $\mathcal{F}$ a dimensionless parameter whose value is related to model dependent features like the number of extra dimensions n. For n values between 2 and 7, M_S values below 1.3-1.0 are, respectively, ruled out. CDF has also started a new designated search for large extra dimensions using the Drell-Yan dielectron and dimuon Run I sample. At this time results are not yet available although a Monte Carlo study to explore CDF sensitivity indicates similar expectations as D0 [13].

5 Conclusions

Both the CDF and D0 detectors at Fermilab continue the analysis of Run I data to search for new physics beyond the SM [12]. We have shown here new channels with new supersymmetric signatures used to seek for stop quark production and neutral supersymmetric Higgs bosons. In addition, new leptoquark models and new low-scale quantum gravity theories with large extra dimensions are being investigated by reinterpreting signatures utilized in previous analysis.

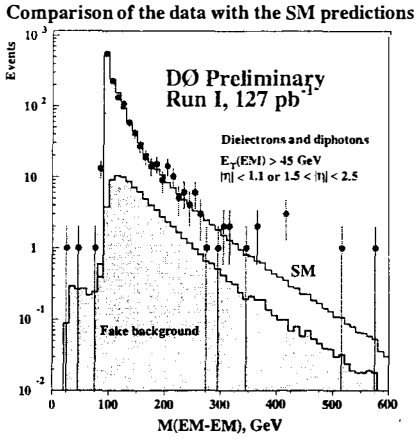

Figure 9: *D0 dielectron and diphoton invariant mass distribution compared to the expected SM Drell-Yan and instrumental background (fakes) contributions.*

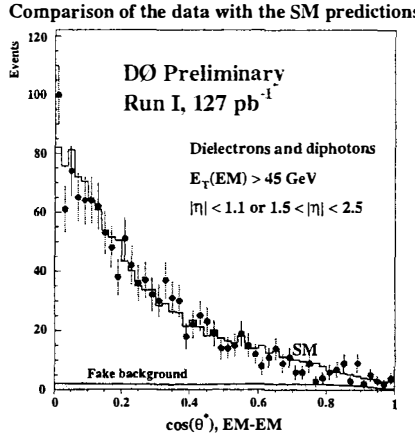

Figure 10: *D0 dielectron and diphoton* $\cos(\theta^*)$ *distribution compared to the expected SM Drell-Yan and instrumental background (fakes) contributions.*

6 Acknowledgements

I would like to thank D. Toback and G. Landsberg from D0 for providing me with their results. Thanks David for the great time at Moriond!

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