Searches for New Particles/Phenomena at CDF

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1 Overview

Recent results from the searches for new particles and phenomena using data collected by CDF are presented. Most results are from the data taken during 1994-95 period (Run I), but some preliminary results from the current data taking period (Run IIa) are presented as well.

2 Searches for New Gauge Bosons

A simple way to search for a W' boson is to look for $W' \rightarrow e\nu$ and $\mu\nu$ decay channels, which would appear as an excess in the transverse mass distribution. These analyses required an electron (muon) with $E_T > 25$ GeV ($p_T > 20$ GeV/ c) and $\cancel{E}_T > 25$ (20) GeV [1,2]. The transverse mass distributions were found to be consistent with the background prediction and, assuming the standard model strength couplings, the 95% CL lower mass limits were set at 755 GeV/ c^2 for the electron channel, 660 GeV/ c^2 for the muon channel, and 786 GeV/ c^2 for channels combined.

Also, the W' boson was searched for using the $W' \rightarrow t\bar{b} \rightarrow b\bar{b}l\nu$ decay channel [3]. This channel, along with the dijet decay channel, provides the sensitivity to a case of very heavy right-handed neutrinos (ν_R), $M_{W'} < M_{\nu_R}$, where the leptonic decay channels of a W' boson are kinematically suppressed. This analysis required an electron (muon) with $E_T > 20$ GeV ($p_T > 20$ GeV/ c), $\cancel{E}_T > 20$ GeV, and two or three jets with $E_T > 15$ GeV with at least one of them to be identified as coming from a b -jet. The “ $l\nu jj$ ” invariant mass distribution was formed with a $l\nu$ invariant mass constrained to the W boson mass. No excess over background expectation was observed in the distribution and the limits were set on the production cross section times branching fraction of $W' \rightarrow t\bar{b}$ as a function of $M_{W'}$ for the following two cases; $M'_{W'} \gg M_{\nu_R}$ and $M'_{W'} < M_{\nu_R}$. The 95% CL limits are shown in Fig. 1. For the standard model strength couplings, the mass region of $225 < M_{W'} < 536$ (566) GeV/ c^2 is excluded for $M_{W'} \gg M_{\nu_R}$ ($M_{W'} < M_{\nu_R}$) case.

Fig. 1. The upper limits on the W' boson production cross section as a function of the W' boson mass. Limits are shown for the case $M_{W'} \gg M_{\nu_R}$ (*solid*) and $M_{W'} < M_{\nu_R}$ (*dashed*). The intercepts at $\frac{\sigma_B(W' \rightarrow tb)}{\sigma_B(W' \rightarrow tb)_{SM}} = 1$ correspond to the 95% CL limits on the W' boson mass with Standard Model strength couplings

CDF searched for Z' boson production in the Drell-Yan channel in Run I [4]. This analysis required two isolated high E_T (p_T), oppositely charged electrons (muons) and set a lower limit on the Z' mass at $690 \text{ GeV}/c^2$ at 95% CL assuming the standard model strength couplings. In Run IIa, using 10 pb^{-1} of electron data and 16 pb^{-1} of muon data, CDF has set the limits at $450 \text{ GeV}/c^2$ and $270 \text{ GeV}/c^2$, respectively [5]. With the expected 2 fb^{-1} of data accumulated by the end of Run IIa, Z' boson mass up to $1 \text{ TeV}/c^2$ can be excluded [6].

An analysis to search for the Z' boson from topcolor-assisted technicolor was performed by looking for resonance in the $t\bar{t}$ production [7]. This analysis looked for one W boson from a top quark decaying leptonically and the other decaying hadronically. The analysis required a high p_T electron or muon, a large $\cancel{E}_T$, and four or more jets with at least one of them to be b -tagged. A kinematic fit was performed for each event to determine the $t\bar{t}$ invariant mass value. The observed invariant mass distribution was found to be consistent with the standard model prediction and the 95% CL lower limits on the leptophobic Z' boson mass was set at 780 (480) GeV/c^2 for $\Gamma = 0.04$ (0.012) $M_{Z'}$.

3 Large Extra Dimensions

The existence of the large extra dimension can manifest itself in $p\bar{p}$ collisions through exchanges of a Kaluza-Klein tower of gravitons, which subsequently produce a l^+l^- or $\gamma\gamma$ pair [8,9]. In Run I CDF searched for the graviton

exchange processes in the dielectron and diphoton final states, looking for excess in the invariant mass distributions, and found no excess [10]. The 95% CL lower limits on the effective Planck scale in the extra dimensions, M_S , were set at 989 (853) GeV for $\Lambda_{Hewett} = -1(+1)$ [11].

The Randall-Sundrum graviton [12] was searched for using data collected in Run IIa, 10 pb⁻¹ for dielectron channel and 16 pb⁻¹ for dimuon channel. The 95% CL limits were set at 340 GeV/ c^2 and 255 GeV/ c^2 for dielectron and dimuon channels, respectively, for $k/M_{Pl} = 0.1$ [5].

Another way to search for the Large Extra Dimensions is to look for emission of a graviton and a photon or a jet recoiling against it, where the graviton does not interact with detector leaving a large $\cancel{E}_T$ [9]. CDF has searched for photon-graviton final state using Run I data [13]. This analysis required a photon with $E_T > 50$ GeV, $\cancel{E}_T > 40$ GeV, and no jets and tracks with significant E_T and p_T , respectively. The number of observed events was 11 and the number of expected background events was 11.0 ± 2.2 . The main backgrounds are from cosmic rays and $Z\gamma \rightarrow \nu\nu\gamma$. The 95% CL limits were set as $M_S > 549$ GeV ($n = 4$), 581 GeV ($n = 6$), and 602 GeV ($n = 8$), where n is the number of extra dimensions.

4 Search for Long-Lived Heavy Charged Particles

A search for CHAMPs, heavy charged particles that are long-lived enough to leave the detector, was performed at CDF at Run I [14]. This analysis looked for high- p_T track with a large ionisation loss in the detector. The observed number of events was consistent with the background prediction and a lower limit of 220 (190) GeV/ c^2 was set at 95% CL for a long-lived up (down) type 4th generation quark.

In Run II, CDF is developing an analysis employing the newly installed time-of-flight detector. This analysis searches a high- p_T track with a large time-of-flight indicating a heavy slowly moving charged particle.

5 Leptoquark Searches

CDF searched for the direct production of three generations of leptoquarks using the data taken during Run I [15–17]. The 95% CL lower mass limit of the first generation scalar leptoquark in the $eejj$ decay channel with a branching ratio $\beta \equiv \mathcal{B}(LQ \rightarrow lq) = 1$ was set at 213 GeV/ c^2 . The lower mass limits were set for the second generation scalar leptoquarks at 202 GeV/ c^2 , 164 GeV/ c^2 , and 122 GeV/ c^2 for $\mu\mu jj$ ($\beta = 1$), $\mu\nu jj$ ($\beta = 0.5$), and $\nu\nu cc$ ($\beta = 0$) decay channels, respectively. The limits on the second generation scalar leptoquarks were combined to give the lower mass limit of 183 GeV/ c^2 at $\beta = 0.5$. The lower mass limits on the third generation scalar leptoquarks are 99 GeV/ c^2 and 149 GeV/ c^2 for the $\tau\tau bb$ ($\beta = 1$) and $\nu\nu bb$ ($\beta = 1$) decay channels, respectively.

6 New Physics with Inclusive Lepton and Photon Final States

Observation of a single $ee\gamma\cancel{E}_T$ event at CDF in Run I data [18] prompted a search for anomalous production of events with a high E_T photon and a lepton (e or μ) in the final state [19]. Also, events with additional photons and leptons as well as large $\cancel{E}_T$ were analysed. The search is based on 86 pb^{-1} of data taken during Run I.

The results are shown in Table 1. They were found to be consistent with the standard model expectations with a possible exception of $l\gamma\cancel{E}_T$ where 7.6 ± 0.7 events were expected from the standard model and 16 events were observed.

Table 1. The results for the inclusive lepton and photon final state analysed. Shown here are the mean number of events predicted by the standard model, μ_{SM} , the observed number of events, n_o , and the likelihood of the observation being consistent with μ_{SM} , $P(n \geq n_o | \mu_{SM})$

Category	μ_{SM}	n_o	$P(n \geq n_o \mu_{SM})$
Two-body $l\gamma X$	24.9 ± 2.4	33	9.3%
Multi-body $l\gamma X$	20.2 ± 1.7	27	10.0%
Multi-body $ll\gamma X$	5.8 ± 0.6	33	68.0%
Multi-body $l\gamma \cancel{E}_T X$	7.6 ± 0.7	16	0.7%

7 Search for Gluinos and Scalar Quarks

This analysis searched for the production and decay of gluinos and scalar quarks (squarks) in the ≥ 3 -jet events with large $\cancel{E}_T$ at CDF [20]. The three or more jets are expected from the hadronic decays of the gluinos and/or squarks. The presence of large $\cancel{E}_T$ would originate from the two LSPs in the final states of the gluino and squark decays, assuming R -parity conservation.

This analysis required at least three jets satisfying $E_T^{(1)} > 70\text{ GeV}$, $E_T^{(2)} > 30\text{ GeV}$, and $E_T^{(3)} > 15\text{ GeV}$, and also required $\cancel{E}_T > 70\text{ GeV}$. Also, the three highest E_T jets were required not to be near the $\cancel{E}_T$ direction. In addition, $H_T \equiv E_T^{(2)} + E_T^{(3)} + \cancel{E}_T > 150\text{ GeV}$ was required for the expected signal region. Events with large $\cancel{E}_T$ and ≥ 3 jets in the final state were expected primarily from QCD, $Z(\rightarrow \nu\nu) + \geq 3$ jets, $W(\rightarrow \tau\nu) + 2$ jets, and $t\bar{t}$ processes. We expected 76 ± 13 events from the standard model processes and observed 74 events. The $\cancel{E}_T$ and H_T requirements were then optimised to increase the

sensitivity to the signal in the context of MSSM and mSUGRA models in the $m_{\tilde{q}}-m_{\tilde{g}}$ plane. The resulting 95% CL limit is shown in Fig. 2. This search excludes $m_{\tilde{g}} < 190 \text{ GeV}/c^2$, independent of $m_{\tilde{q}}$, and $m_{\tilde{g}} < 300 \text{ GeV}/c^2$ in the case of $m_{\tilde{g}} \simeq m_{\tilde{q}}$.

Fig. 2. The 95% confidence level limit curve in the $m_{\tilde{q}} - m_{\tilde{g}}$ plane got $\tan \beta = 3$. The hatched area is newly excluded by this analysis. Results from previous searches are also shown

8 Scalar Top Quark Searches

8.1 R -Parity Conserving Stop Decay

This analysis searched for a pair production of scalar top quarks (stops) decaying through a R -parity conserving process [21]. For the very heavy charged sleptons, it was assumed that the stop decays only to $b\tilde{l}$ ($l = e, \mu, \tau$). The signature searched for was two oppositely charged leptons, $\cancel{E}_T > 15 \text{ GeV}$, and ≥ 1 jets, where $\cancel{E}_T$ comes from $\tilde{\nu}\tilde{\nu}$.

After the further selection requirements optimised for small mass difference between the stop and sneutrino, the expected number of backgrounds was $1.52 \pm 0.26(\text{stat.}) \pm 0.32(\text{syst.})$ events mostly coming from lepton misidentification, $Z(\rightarrow ll)+\text{jets}$, and $t\bar{t}$ production. No events survived the selection cuts and the 95% CL exclusion region in the $m_{\tilde{\nu}}-m_{\tilde{t}}$ plane was calculated as shown in Fig. 3.

8.2 R -Parity Violating Stop Decay

This analysis searched for a stop pair production in which a stop decays into τb through R -parity violating processes [22]. Assuming that either the stop

Fig. 3. The 95% CL exclusion region in $m_{\tilde{\nu}}-m_{\tilde{t}}$ plane for $\tilde{t} \rightarrow l\tilde{\nu}b$ for the R -parity conserving supersymmetry

is the LSP or the dominant decay mode for stop is $\tilde{t} \rightarrow \tau b$ when the stop is NLSP, the stop is expected always to decay to τb .

The final state searched for was $l\nu_l\nu_\tau\tau_h b\bar{b}$ ($l = e, \mu$) where one τ decays leptonically and the other decays hadronically (τ_h). An electron (muon) was required to have $E_T > 10$ GeV ($p_T > 10$ GeV/ c) and τ_h was identified by a track based τ_h identification including π_0 reconstruction. In order to reduce the background further, it was required that the transverse mass of $(l, \cancel{E}_T)$ be < 35 GeV, $E_T^c(p_T^\mu) + \cancel{E}_T + p_T(\tau_h) > 75$ GeV, and two or more jets.

The expected number of background was $3.2^{+1.4}_{-0.3}$ dominated by $Z(\rightarrow \tau\tau)+\text{jets}$ and no candidate event was found. This analysis excluded at 95% CL the $\tilde{t}\tilde{t}^*$ production cross section as a function of stop mass. The results are shown in Fig. 4. The 95% CL lower mass limits for stop was set at 119 GeV/ c^2 .

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Fig. 4. The 95% CL limits on the production cross section of the stop through R -parity violating decay, $\tilde{t}_1 \tilde{t}_1^* \rightarrow \tau^+ b \tau^- \bar{b}$, and the theory calculation as a function of its mass. The regions above the curves are excluded

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