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Search for New Phenomena with the CDF Detector

Patrizia Azzi
For the CDF Collaboration

I.N.F.N. Padova
Via Marzolo 8, I-35131 Padova, Italy

Fermi National Accelerator Laboratory
P.O. Box 500, Batavia, Illinois 60510

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SEARCH FOR NEW PHENOMENA WITH THE CDF DETECTOR

Patrizia Azzi
(for the CDF Collaboration)
I.N.F.N. Padova, Via Marzolo 8, I-35131 PADOVA, Italy

Abstract

We present the results of the searches for new phenomena in $p\bar{p}$ collisions at $\sqrt{s} = 1.8$ TeV with the CDF detector using the full data sample of 110 pb^{-1} collected between 1992 and 1995. We have searched for new physics in events with two photons, testing some of the hypotheses proposed to explain the appearance of the CDF $ee\gamma\gamma\not{E}_T$ event. New results on the search for a heavy neutral scalar object, charged Higgs bosons ($H^{\pm}$) and the scalar top quark ($\tilde{t}$) are presented. Finally we summarize the CDF results on the search for third generation leptoquarks.

Presented at "ElectroWeak Interactions and Unified Theories, XXXIInd Rencontres de Moriond", Les Arcs, France, March 15-22, 1997

1 Introduction

This proceeding describes some of the most recent results obtained by the CDF collaboration in the search for new phenomena beyond the Standard Model. The CDF experiment operates at the Tevatron $p\bar{p}$ collider at Fermilab. An integrated luminosity of about $\mathcal{L}_{int} = 110$ pb^{-1} has been collected during the 1992-1995 collider run. Since no evidence for any signal has been found, the high statistics of the data sample allowed several limits on masses, cross sections and branching ratios, to be significantly extended. In addition to the high statistics major improvements were achieved with new techniques developed for b jets and τ lepton identification.

The b identification algorithm is based on the precise track reconstruction provided by the silicon microstrip vertex detector (see Ref.[1]) that allows the identification of the b hadrons decay as a secondary vertex significantly displaced from the primary interaction vertex. A tag is defined as positive (negative) if the projection of the secondary vertex displacement points along (opposite) the jet direction in the plane transverse to the beam line. Due to tracking and resolution effects, light quark or gluon jets can also be misidentified as b candidates (fake tags) and are equally likely to have positive or negative tags.

The τ lepton identification method, described in Ref.[2], combines tracking and calorimeter information. A jet is identified as a τ jet if it contains one or three charged particle tracks with total electric charge ± 1 within a $10°$ cone around the jet axis, and if it is isolated, i.e. if there is no additional charged particles in a $30°$ cone around that axis. In addition, the jet mass determined in that cone from tracking and calorimetry must be consistent with m_τ.

Finally, the data sample enriched in SM $t\bar{t}$ candidate events has now become a *tool* for new particle searches. This data sample consists of events selected with the standard $t\bar{t}$ analysis (hereafter called the SM top sample). The topologies considered here are those where one (the *lepton + jets* sample) or both (the *dilepton* sample) W's, originating from the top decays, subsequently decay leptonically, W $\rightarrow \ell\nu$ where $\ell = e, \mu$. As is described in the following, several new particles may manifest themselves among the top quark decay products, as is the case for a light $\tilde{t}$ or the charged Higgs.

In CDF, three different approaches have been used to search for new particles:

- look for a contamination of data samples selected in the context of a purely standard model inspired analysis (e.g. effect of charged Higgs bosons or a light $\tilde{t}$ in the SM top sample, see *Section* 4.2 and 5.1);
- look for, in case of a hint for a new phenomenon (e.g., the $ee\gamma\gamma\not{E}_T$ event in *Section* 2), other consequences, in alternative final states and/or data samples, of the possible theoretical explanations proposed;
- and of course, look for completely new processes, or direct production of new particles (e.g. search for $\tilde{t}$ or leptoquarks, see *Sections* 5.2 and 6).

2 Searches in diphoton events

The appearance of the CDF $ee\gamma\gamma\not{E}_T$ event has provoked an enormous interest in the past year. At CDF, besides a detailed scrutiny of the event itself (still in progress), we are studying the characteristics of events with one or two photons produced in association with other objects (leptons, jets, $\not{E}_T$). This allows some of the proposed hypotheses to be tested: the results presented here are not yet quantitative but we expect to obtain a similar sensitivity as in Ref.[3].

The diphoton event selection requires at least two central and isolated photons with $E_T(\gamma) >$ 25 GeV. Details about photon identification at CDF can be found in Ref.[4].
Two particular hypotheses were qualitatively tested: the anomalous WW$\gamma\gamma$ production and the MSSM Light Gravitino scenario [5, 6].

- Anomalous WW$\gamma\gamma$ production: the number of $ee\gamma\gamma\not{E}_T$ events expected from the WW$\gamma\gamma$ production with both W's decaying into eν is about 8×10^{-5}. However, given the fact that we have observed that particular *one* event, we can estimate the effective anomalous cross section and thus predict the number of expected events with diphotons accompanied by other objects due to other decays of the two W's. In Fig.1 we show the distribution of the jet multiplicity ($E_T(jet) > 10$ GeV and $|\eta(jet)| < 4$) in diphoton events: we observe no events with two photons and more than two jets. Instead, in the hypothesis of anomalous WW$\gamma\gamma$ production we would expect about 40 events with ≥ 3 jets.

- MSSM Light Gravitino scenario: in this model the gravitino ($m_{\tilde{G}} \approx 1$ keV/c^2) is the lightest supersymmetric particle (LSP) and the favoured decay of the next-to-LSP is $\chi_1^o \rightarrow \gamma\tilde{G}$ making $\gamma\gamma\not{E}_T$ a typical event signature. However the magnitude of the $\not{E}_T$ in diphoton events predicted by this model is much higher than what it is observed in the data, as shown in Fig.2. Since the background is dominated by fakes, the shape used in Fig.2 has been taken from Drell-Yan dielectron events that have very similar characteristics from the detector point of view, both being events with two clean electromagnetic energy deposits and almost nothing else.

Based on these preliminary results no quantitative statements are made yet, but we have shown that the distributions for $\not{E}_T$ and $N(jet)$ in diphoton events are consistent with the background.

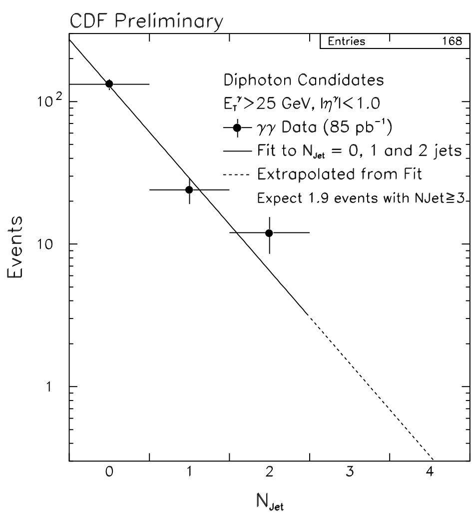

Figure 1: *Jet multiplicity distribution in diphoton events. The extrapolation to $N(jet) \geq 3$ comes from the fit to the data in the first three bins*

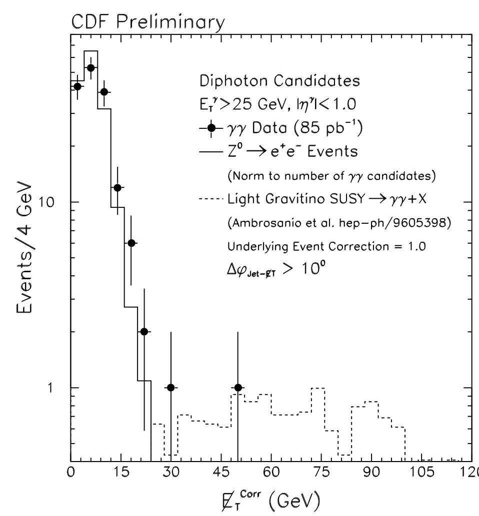

Figure 2: *$\not{E}_T$ distribution of diphoton events (bullet) compared to the background (solid histogram) and the prediction of a MSSM model configuration with a light gravitino (dashed)*

3 Search for a heavy neutral scalar particle in multijet events

We have searched for the production of a neutral heavy scalar particle produced in association with a vector boson via the process: $p\bar{p} \to \mathrm{W/Z} + X^o$. The neutral scalar X^o is assumed to decay 100% into $b\bar{b}$ and only the hadronic decays of the vector boson are considered here.

The data sample selected contains at least four jets ($E_T(jet) > 15$ GeV, $|\eta(jet)| < 2.1$) where two of them are b-tagged. An additional cut of $p_T(b\bar{b}) > 50$ GeV/c is imposed in order to reduce the QCD background from direct heavy flavour production. If we compare the invariant mass of the two tagged jets with the prediction from QCD $b\bar{b}$ and $c\bar{c}$ production (PYTHIA) and fake tags (evaluated from data) we see no excess due to the production of a massive scalar object decaying to $b\bar{b}$, see Fig.3.

Hence we use a maximum likelihood method to fit the distribution to a combination of QCD, fakes and signal and set an upper limit on the cross section for this process. Since the "Rencontres de Moriond" the full evaluation of the systematical uncertainties for this analysis has become available. The new upper limit is shown in Fig.4 compared to the latest D0 results.

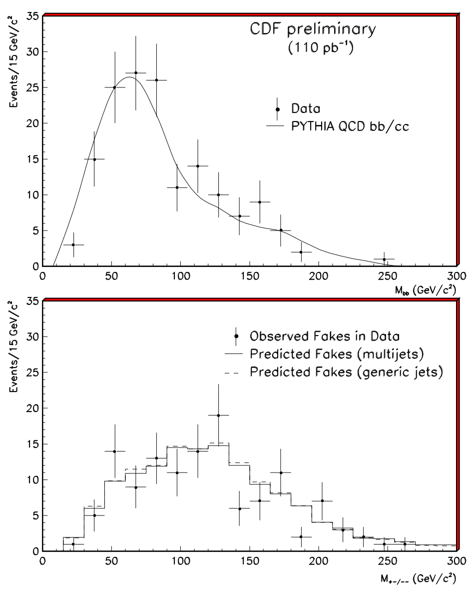

Figure 3: *Invariant mass of the two tagged jets for data (top) and the QCD $b\bar{b}/c\bar{c}$ Monte Carlo events; distribution for the fake tags in data compared with the predictions from other data samples (bottom)*

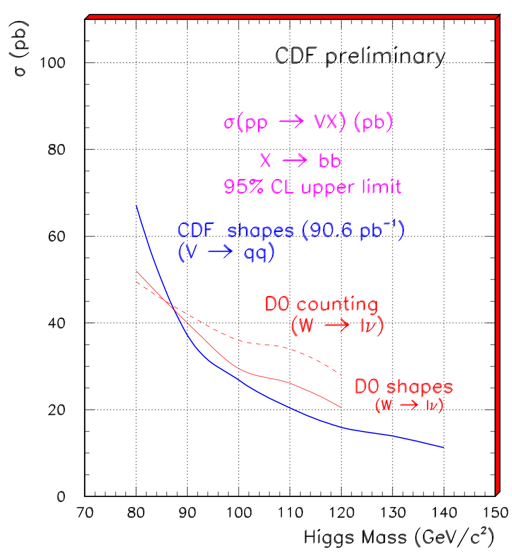

Figure 4: *CDF results for the 95% C.L. upper limits on the total production cross section of a neutral heavy scalar produced in association with a vector boson*

4 Search for the charged Higgs bosons

Two Higgs doublet extensions of the Standard Model predict the existence of two charged Higgs bosons. The parameter $\tan\beta$ controls the dominant decay modes for the top quark and the charged Higgs in these models, as is shown in Fig.5 for $m_t = 175$ GeV/c^2 and $m_{H^\pm} = 100$ GeV/c^2. We describe here two searches for charged Higgs boson optimized for two different regions of $\tan\beta$.

In the following we make the assumption that $m_t \geq m_{H^\pm} + m_b$ so that the charged Higgs boson is produced in the decay of a top quark via the process $t \to H^+ b$. The top quark has then two possible decay modes open, $t \to Wb$ and $t \to H^\pm b$, with branching fractions dependent on $\tan\beta$.

4.1 Search at high $\tan\beta$

At high values of $\tan\beta$ the favoured top decay is in $t \to Hb$ followed by $H^+ \to \tau\nu_\tau$. The strategy is to look for $t\bar{t}$-like events that contain a τ lepton.

The selection requires: one τ lepton hadronically decayed with $E_T(\tau) \geq 20$ GeV, significant $\not{E}_T \geq 30\ GeV$, high jet multiplicity, $N(jet) \geq 2$, and at least one of the jet b-tagged. Since at the Tevatron the top quarks are pair produced via $q\bar{q} \to t\bar{t}$, another object($=e, \mu, \tau, jet$) with $p_T \geq 10$ GeV is required to account for the other top decay.

We find 6 events with the $\tau jjj + \not{E}_T$ topology and 1 $\tau jje + \not{E}_T$, consistent with the expected background of 7.4 ± 2.0 events.

The exclusion contour shown in Fig.6 is evaluated for $m_t = 175$ GeV/c^2 and depends on the $t\bar{t}$ production cross section. The highest mass value we exclude is $m_{H^\pm} < 147(158)$ GeV/c^2 for large $\tan\beta$ and $\sigma_{t\bar{t}} = 5(7.5)$ pb.

4.2 Search at low $\tan\beta$

At low $\tan\beta$ ($\tan\beta < 1.5$) the dominant decay mode for a charged Higgs boson is $H \to c\bar{s}$, we study the impact of the presence of the charged Higgs boson decays on the $t\bar{t}$ *dilepton* and $lepton + jets$ final states, characterized by the presence of high p_T leptons. If the $t \to Hb$ decay happens with a significant ratio, followed by a $H^\pm$ hadronic decay, fewer events would be expected in the top *dilepton* and $lepton + jets$ channels than if the $t \to Wb$ were the only decay mode.

For $\mathcal{L}_{int} = 109$ pb^{-1}, the total number of expected $t\bar{t}$ events in the charged Higgs hypothesis is calculated as a function of $\tan\beta$. This number is compared to the number of events observed in each channel: 9.0 ± 3.0 events in the *dilepton* and 34.0 ± 5.8 events in the $lepton + jets$ case. Since at very low $\tan\beta$ the number of expected events in each channel is much smaller than the observed number, a large fraction of the parameter space in this low $\tan\beta$ region can be excluded at 95% C.L.. The two channels are combined by summing the number of *dilepton* and $lepton + jets$ events since there is no overlap in the definition of the two samples.

The exclusion contour is shown in Fig.6, we exclude $m_{H^\pm} \leq 150(165)$ GeV/c^2 for $\sigma_{t\bar{t}} = 7.5(5.0)$ pb and for $\tan\beta < 1.5$ at 95% C.L..

5 Search for the scalar top quark ($\tilde{t}$)

Two searches for the supersymmetric partner of the top quark, the $\tilde{t}$ squark, using a $\mathcal{L}_{int} = 110$ pb^{-1} are reported here.

5.1 Search for $\tilde{t}$ in top decays

This search is based on the assumption that a light $\tilde{t}$ squark exists and the top quark could decay, in addition to the decay $t \to Wb$, with appreciable branching ratio via the process $t \to \tilde{t}\chi^o$ where the χ^o is the lightest supersymmetric particle as is predicted, e.g. in the MSSM. This search targets the kinematic region where the dominant $\tilde{t}$ decay mode is $\tilde{t} \to \chi^\pm b$ (see Ref.[9] for the complementary region where the dominant decay is $\tilde{t} \to c\chi^o$).

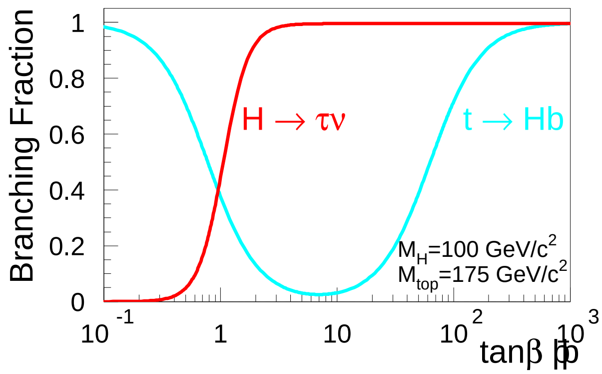

Figure 5: *Branching Fraction for* $t \to Hb$ *and* $H \to \tau\nu$ *as a function of* $\tan\beta$ *for models with a two Higgs doublet extension*

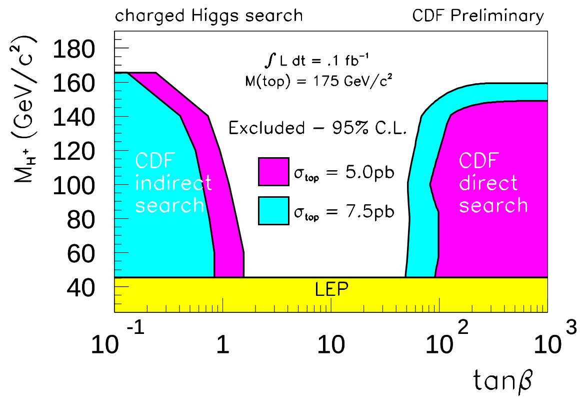

Figure 6: *Charged higgs exclusion region at the 95% C.L. as a function of* $\tan\beta$ *for* m_t = *175* GeV/c^2. *Shown for* $\sigma_{t\bar{t}} = 5.0$ *pb (theory) and* $\sigma_{t\bar{t}} = 7.5$ *pb (CDF measured)*

The strategy is then to look for $t\bar{t}$ events where one top quark decays via $t \to Wb$ followed by W $\to \ell\nu$ ($\ell = e, \mu$) while the other decays via $t \to \tilde{t}\chi^o$, followed by a hadronic decay of the chargino. For this analysis, the *lepton + jets* data sample selected for the SM kinematic top analysis (Ref.[8]) has been used.

However, the presence of SUSY decays makes the $t\bar{t}$ final state more similar to the QCD W + *jets* background events, since jets produced in the $\tilde{t}$ decay are less energetic than those produced in a W boson decay. On the other side, the magnitude of the missing transverse energy for event with SUSY decay of the top quark is higher with respect to QCD W + *jets* due to the presence of the LSP.

In order to kill most of the QCD background while keeping a reasonable efficiency on the $t\bar{t}$ SUSY events we apply an additional selection to the data. The cut on the energy of the third jet is lowered to $E_T(j_3) \geq 15$ GeV, a cut on $P_T(W) \geq 50$ GeV/c is added, and the $\not{E}_T$ requirement is increased to $\not{E}_T \geq 45$ GeV.

Finally, using the kinematic characteristics of the events, we build a relative likelihood function (R_L) that is able to discriminate between SM and SUSY events. Supersymmetric events would populate the region at negative R_L (top plot of Fig.7): as it is evident from the distribution for real data (lower plot of Fig.7) we observe no signal of such SUSY decays. Given the large number of SM top candidate events observed at CDF we are able to exclude $BR(t \to \tilde{t}\chi^o)$ down to 50% at 95% C.L. for a wide $\tilde{t}$ mass range, as shown in Fig.8.

5.2 Direct $\tilde{t}\tilde{t}$ production

Using the *lepton + jets* data sample, a search for the direct production of $\tilde{t}\tilde{t}$ pair, followed by the decay $\tilde{t} \to \chi^{\pm}b$, has been also performed. However, the cuts on the transverse energy of the lepton and the jets ($E_T(lepton, jet) \geq 20$ GeV) already imposed on the data sample, are too strong to provide a high efficiency for this search. Moreover, the direct $\tilde{t}\tilde{t}$ production has a theoretical cross section $\sigma_{\tilde{t}\tilde{t}}$ that is about one tenth of the $\sigma_{t\bar{t}}$.

Since there is no real W boson produced in the decay of $\tilde{t}$ squark we use the transverse invariant mass reconstructed with the lepton and the $\not{E}_T$ and make a simultaneous likelihood fit of this distribution and of the $\Delta\phi(\ell, j2)$ to a combination of QCD W + *jets*, $t\bar{t}$ and $\tilde{t}\tilde{t}$ events, see Fig.9. With the preliminary, not yet optimized, selection we are able to set only an upper limit on the $\tilde{t}\tilde{t}$ pair production cross section as shown in Fig.10.

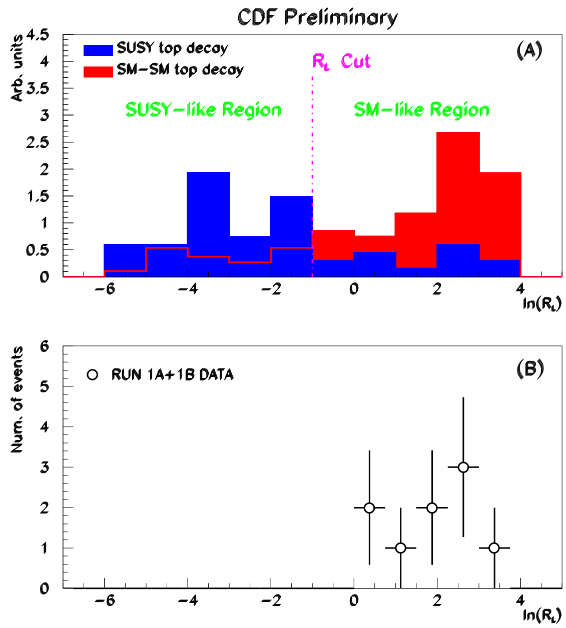

Figure 7: *Distribution of the relative* log *likelihood function for SM and SUSY events (ISAJET) (top); R_L distribution for the Run 1 data (bottom)*

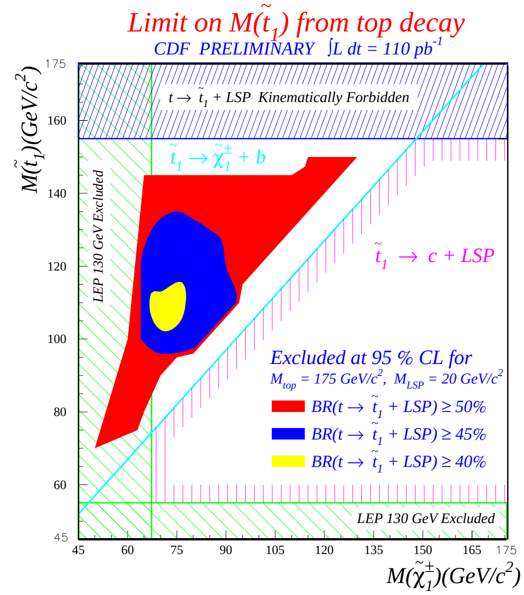

Figure 8: *The 95% C.L. excluded $BR(t \to \tilde{t} + LSP)$ is shown in the $m_{\chi^{\pm}}$ versus $m_{\tilde{t}}$ plane for* $m_{LSP} = 20\ GeV/c^2$

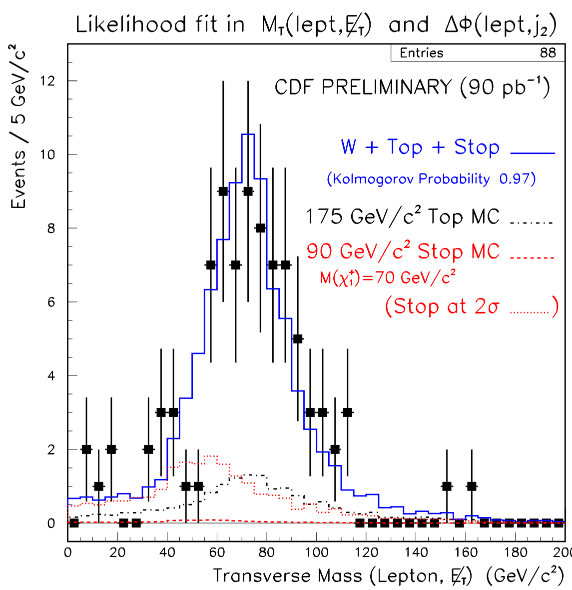

Figure 9: *Likelihood fit of the $M_T(lepton, \not{E}_T)$ to a combination of $\tilde{t}\bar{\tilde{t}}$, $t\bar{t}$ and* W + *jets events*

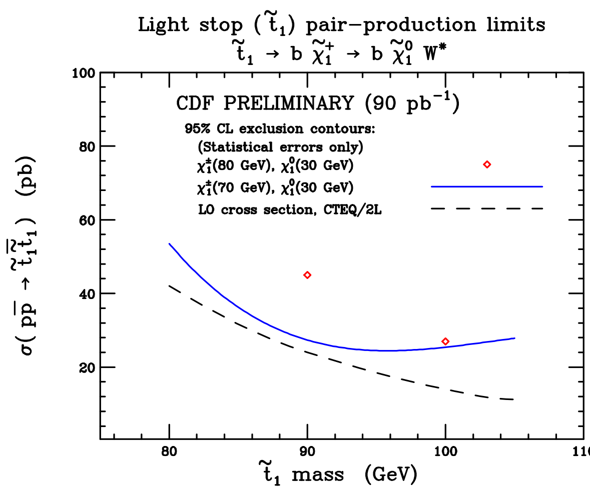

Figure 10: *95% C.L. limit on the $\tilde{t}\bar{\tilde{t}}$ pair production cross section*

6 Search for third generation leptoquark

Many extensions of the Standard Model that join the quark and lepton sectors at a fundamental level predict the existence of leptoquarks (LQ), color triplet bosons that couple directly to ql or $\bar{q}l$ pairs. The results summarized here (published in Ref.[10]) consider leptoquarks that couple only to third generation fermions (LQ3).

At the Tevatron leptoquarks are assumed to be pair produced and to decay into τb or $\nu_\tau b$

with branching ratio β or $1-\beta$, respectively.

This analysis searches for the reaction $p\bar{p} \to LQ3\ LQ3\ X \to (b\tau^+)(b\tau^-)X$ which produces a $\tau\tau jj$ final state with braching fraction β^2. The $\tau\tau jj$ candidate events are selected with one τ decaying leptonically and the other decaying into an hadronic jet. The lepton from τ decay is required to be an isolated, central, high-p_T lepton ($E_T(e) > 20$ GeV or $p_T(\mu) > 20$ GeV/c). The hadronic τ is defined as an isolated, central, high E_T jet ($E_T(jet) > 15$ GeV) satisfying hadronic τ identification cuts, with charge opossite to that of the other lepton.

After a Z $\to \ell\ell$ candidate removal, we require that $\Delta\phi(\ell, \not{E}_T) \leq 50^o$ to reduce W + $jets$ events, where $\Delta\phi(\ell, \not{E}_T)$ is the azimuthal angle between the direction of the lepton and the $\not{E}_T$. Finally, to suppress the Z $\to \tau\tau$ background, we require $N(jet) \geq 2$, where a jet is defined with $E_T(jet) \geq 10$ GeV and $|\eta(jet)| < 4.2$.

In 110 pb^{-1} one $\tau\tau jj$ candidate event is found with a background of $2.4^{+1.2}_{-0.6}$ events (dominated by Z $\to \tau\tau$). Taking into account full systematic uncertainties in the signal efficiency and integrated luminosity and the uncertainties in the background estimation, we place upper limits on $\sigma(p\bar{p} \to LQ3\ LQ3) \cdot \beta^2$ as a function of the leptoquark mass, m_{LQ3}.

For $\beta = 1$, scalar leptoquarks with $m_{LQ3} < 99$ GeV/c^2, gauge vector leptoquarks with $m_{LQ3} < 225$ GeV/c^2 and non-gauge vector leptoquarks with $m_{LQ3} < 170$ GeV/c^2, have been excluded at 95% C.L.. Limits are shown in Fig.11.

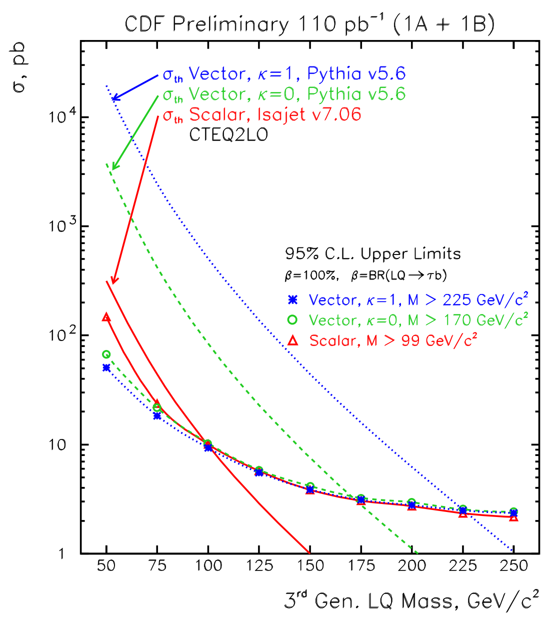

Figure 11: *95% C.L. upper limit on σ for $\beta = BR(LQ3 \to \tau b) = 1$ as a function of m_{LQ3}*

7 Conclusions

We have described some of the most recent results of the searches for new phenomena in $p\bar{p}$ collision at $\sqrt{s} = 1.8$ TeV with the CDF detector using the full data sample of 110 pb^{-1}.

Properties of events with two photons have been studied: no quantitative conclusions have been drawn yet, but a qualitative test seems to exclude the possibility of an anomalous WW$\gamma\gamma$ production cross section and of a MSSM scenario with a light gravitino.

We have put an upper limit on the cross section for a heavy neutral scalar object decaying to $b\bar{b}$ produced in association with a W/Z boson.

Limits on the charged Higgs boson mass have been obtained for high and low values of $\tan\beta$.

A search for direct and indirect production of the $\tilde{t}$ squark has been performed and we have excluded a $BR(t \to \tilde{t}\chi^o)$ down to 50% for a wide set of $\tilde{t}$ masses.

Finally, CDF mass limits for third generation leptoquarks have been summarized.

References

[1] F. Abe *et al.* (CDF Collaboration), Phys. Rev. Lett. **74**, 2626 (1995)

[2] F. Abe *et al.* (CDF Collaboration), FERMILAB-PUB-97-058-E, (1997)

[3] S. Abachi *et al.* (D0 Collaboration), FERMILAB-PUB-96/446-E (1996)

[4] F. Abe *et al.* (CDF Collaboration), Phys. Rev. Lett. **73**, 2662 (1994)

[5] S. Ambrosanio *et al.* Phys. Rev. **D55**, 1372–1398 (1997)

[6] K.S. Babu *et al.*, Phys. Rev. Lett. **77**, 3070–3073 (1996) and hep–ph/9605408

[7] D. Gerdes for the CDF Collaboration, *these proceedings*

[8] F.Abe *et al.* (CDF Collaboration), Phys. Rev. **D52**, 2605–2609 (1995)

[9] S. Abachi *et al.* (D0 Collaboration), FERMILAB-PUB-96/449-E (1996)

[10] F.Abe *et al.* (CDF Collaboration), Phys. Rev. Lett. **78**, 2906–2911 (1997)