SEARCHES FOR NEW PHYSICS IN LEPTON FINAL STATES

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Final states containing charged leptons could provide some of the most distinctive signatures for observing physics beyond the Standard Model. We present searches for new physics using $0.32 - 0.45$ fb^{-1} of data accumulated with the CDF II and DØ detectors at the Tevatron. No significant evidence of a signal is found, and in most cases the tightest constraints to date are set on the exotic processes investigated.

1 Introduction

The Standard Model (SM) of particle physics has withstood all experimental tests to date. Despite its numerous successes, it is believed that physics beyond the Standard Model should manifest itself at scales of the order of 1 TeV or higher. Some examples of theories proposed to describe the new physics are Supersymmetry (SUSY), extra dimensions, or lepton/quark compositeness theories. We present the results obtained from testing the existence of several of these exotic models using the Tevatron Run II data. We focus only on the final states containing one or more charged leptons. Requiring the presence of leptons significantly reduces the jet backgrounds abundant at the Tevatron. In addition, both collider detectors have very good electron and muon triggering and identification capabilities. Tau lepton identification suffers from the large associated background (QCD-produced jets faking tau signal) but can in many cases contribute significantly to improving signal the acceptance.

2 SUSY Searches

The SUSY extensions of the SM assume a new symmetry such that for each SM fermion there exists a SUSY boson, while for each SM boson there exists a SUSY fermion. Martin has written a comprehensive introduction to SUSY [1].

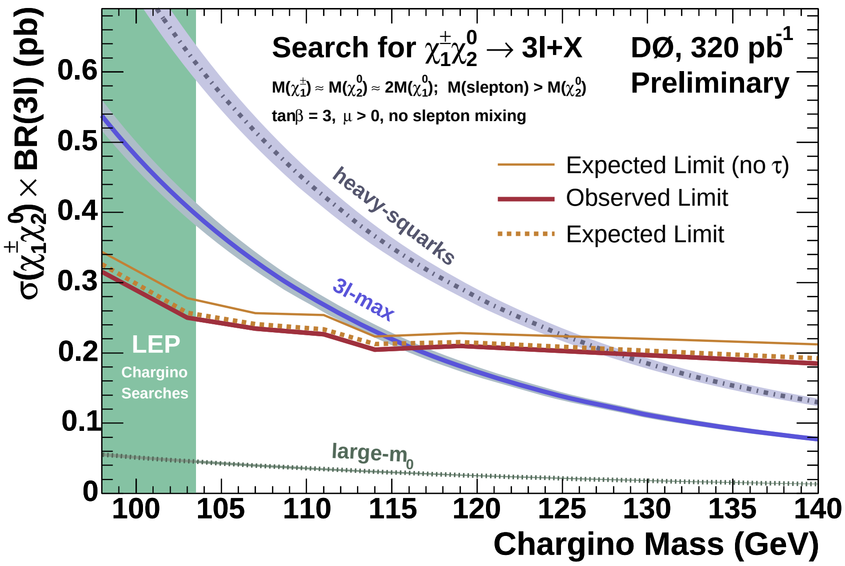

Figure 1: DØ limits on the total cross section for associated chargino and neutralino production with leptonic final states. Also shown are the expectations from three particular SUSY scenarios: "heavy-squarks", "3ℓ-max", and "large-m_0", respectively (defined in the text).

2.1 Chargino-Neutralino Searches

In the simplest supersymmetric extension of the Standard Model, MSSM, the SUSY partners of the Higgs fields and SM γ, W^+, W^-, and Z^0 bosons mix to form two chargino ($\tilde{\chi}^\pm$) and four neutralino $\tilde{\chi}^0$ mass eigenstates. The DØ Collaboration has searched [2] for the chargino-neutralino associated production $p\bar{p} \to \tilde{\chi}_1^\pm\tilde{\chi}_2^0$, where the lightest chargino $\tilde{\chi}_1^\pm$ and the second-lightest neutralino $\tilde{\chi}_2^0$ decay as: $\tilde{\chi}_1^\pm \to \ell^\pm\nu\tilde{\chi}_1^0$ and $\tilde{\chi}_2^0 \to \ell^\pm\ell^\mp\tilde{\chi}_1^0$. The $\tilde{\chi}_1^0$ particle is expected to be stable if R-parity conservation is assumed [a]. The final state for this process consists of three charged leptons and missing energy from the neutrino and the stable $\tilde{\chi}_1^0$ particles. The dominant background sources which contribute to this final state are Drell-Yan dilepton production with an additional lepton coming from jet misidentification or conversion processes, or diboson WZ production. The observed event yield agrees well with the expectation from SM sources alone, and upper limits are set on the chargino and neutralino cross section times branching fraction $\sigma\times$ BR (3ℓ). Figure 1 shows this limit as function of chargino mass, assuming no slepton mixing and the mSUGRA-inspired $m_{\tilde{\chi}_1^\pm} \approx m_{\tilde{\chi}_2^0} \approx 2m_{\tilde{\chi}_1^0}$. The three SUSY scenarios depicted in Fig. 1 are: models with heavy squark masses and low slepton masses (*heavy-squark* scenario), models with low sleptons masses in mSUGRA where $m_{\tilde{\ell}} \gtrsim m_{\tilde{\chi}_2^0}$ (3ℓ-*max*) , and models with large m_0 with the chargino and neutralino decaying via virtual gauge bosons (*large* m_0, essentially unconstrained by the data). Adding τ leptons to this analysis was found to improve these limits by about 2-3 GeV, depending on the SUSY scenario investigated [3].

2.2 Squark and Sneutrino Searches

Scalar Top Searches in MSSM

There are two stop particles $\tilde{t}_1$ and $\tilde{t}_2$ corresponding to the SM top quark. Due to the large mass of the latter, the effect of mixing on the $\tilde{t}$ mass is the largest among the squarks, and the lighter $\tilde{t}_1$ could be the lightest of all squarks. The DØ Collaboration has searched [4] for the stop

[a] $R_P = (-1)^{3(B-L)+2s}$ where B, L, and s denote the barionic and the leptonic numbers, and the spin, respectively.

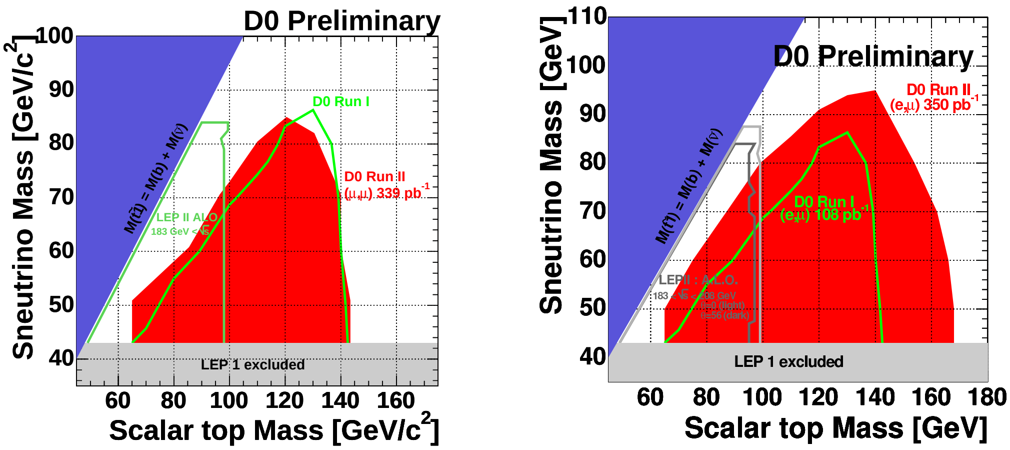

Figure 2: DØ 95% C.L. excluded region, compared to the LEP and Run I DØ results.

pair production $p\bar{p} \to \tilde{t}_1\bar{\tilde{t}}_1 \to b\tilde{\chi}^+\bar{b}\tilde{\chi}^-$. Only the decays $\tilde{\chi}^\pm \to e^\pm\tilde{\nu}, \mu^\pm\tilde{\nu}$ are considered, followed by the sneutrino decays: $\tilde{\nu} \to \nu\tilde{\chi}_1^0$ where the $\tilde{\chi}_1^0$ is assumed to be the lightest supersymmetric particle (LSP). The final state is therefore $b\bar{b}\ell^+\ell^-\tilde{\nu}\tilde{\nu}$, where the $\ell^+\ell^-$ pairs studied are $e^\pm\mu^\mp$ and $\mu^\pm\mu^\mp$. In addition to requiring a lepton pair, it is also required the events contain at least one b-jet as identified from using silicon vertex detector information. The dominant backgrounds to this analysis are top pair production, Drell-Yan ditau or dimuon production (for the $\mu^\pm\mu^\mp$ channel), jets misidentified as leptons ($e^\pm\mu^\mp$ channel), and diboson WW, WZ, and ZZ processes. The observed event count agrees well with that expected from SM background sources alone. Exclusion regions are determined in the $(m_{\tilde{t}_1}, m_{\tilde{\nu}})$ plane (Fig. 2), and found to extend the previous tightest constraints obtained in searches at the LEP I, LEP II and Run I Tevatron colliders.

Scalar Top Searches in R-parity violating SUSY

This search performed by the CDF Collaboration considers the stop pair production via R-parity conserving processes, followed by the R-parity violating decay of the two stop particles $\tilde{t}_1\bar{\tilde{t}}_1 \to \bar{\tau}b\tau\bar{b}$. The final state contains either an electron or a muon from the tau lepton decay $\tau \to e\bar{\nu}_e\nu_\tau$ or $\mu\bar{\nu}_\mu\nu_\tau$, a hadronically decaying tau (τ_h) lepton, and two or more jets. For this final state, the expected SM backgrounds are events with a true $\ell\tau_h$ pair from Drell Yan $Z/\gamma^* \to \tau\bar{\tau}$+jets, $t\bar{t}$ and diboson, and events with fake $\ell\tau_h$ combinations from W+jets and QCD events. As in the MSSM stop search, the event count is in good agreement with the background estimations. The cross section times branching fractions upper limit dependence on the stop mass is shown in Fig. 3. For the particular model considered, stop masses less than 155 GeV are excluded by the data at 95% C.L.

As an aside, we note that stop pair production is very similar to the pair production of the third generation leptoquark (LQ$_3$), and therefore the limit curves shown in Fig.3 can be alternatively interpreted in terms of LQ$_3$ mass.

Scalar Neutrino Searches in R-parity violating SUSY

The CDF Collaboration searched for the R-parity violating production and decay of the tau sneutrino: $d\bar{d} \to \tilde{\nu}_\tau \to e\mu$[6]. In the high reconstructed $e\mu$ mass region, the main backgrounds are top pair production $t\bar{t}$ and WW diboson events. Very good agreement between the CDF data

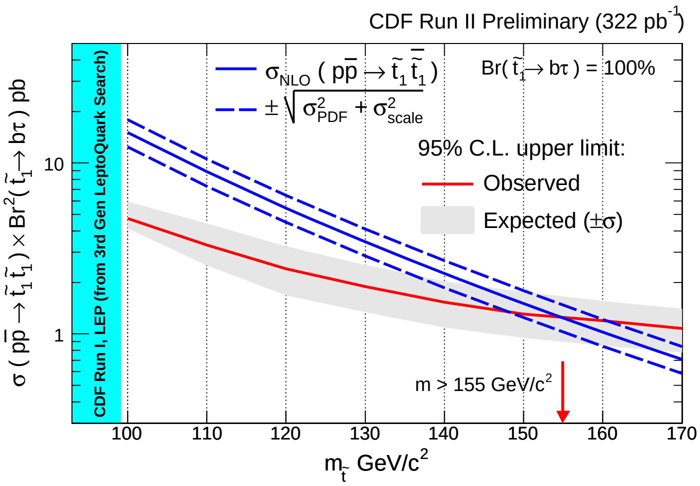

Figure 3: CDF 95% C.L. limit curve for the $\tilde{t}_1\bar{\tilde{t}}_1$ production, compared with NLO calculations (solid line). The dashed lines represent the uncertainties in the theoretical calculation due to the choice of parton distribution functions and renormalization scale.

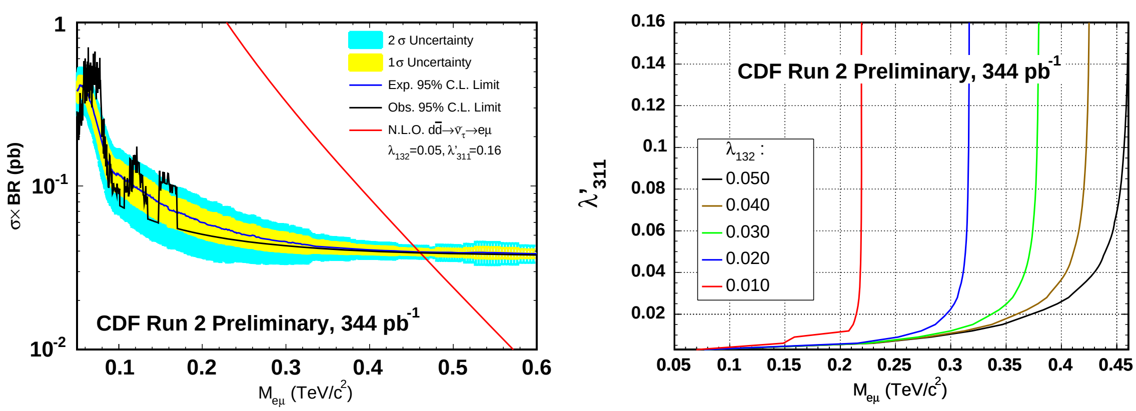

Figure 4: Left: CDF 95% C.L. expected and observed upper limit curves for the sneutrino production and decay $d\bar{d} \to \tilde{\nu}_\tau \to e\mu$, compared to the NLO theoretical calculations (red line). Right: $\lambda'_{311} - M_{e\mu}$ exclusion regions, for several λ_{132} values.

and the SM predictions is observed, with a p-value of 23%. The theoretical cross section for the $d\bar{d} \to \tilde{\nu}_\tau \to e\mu$ depends on the strength of two couplings in the SUSY Lagrangian, λ_{132} and λ'_{311}. The left plot of Fig. 4 shows the observed and expected upper limits and the theoretical cross section for this process calculated using the previous limits $\lambda_{132} = 0.05$ and $\lambda'_{311} = 0.17$. The right plot in Fig. 4 shows the exclusion regions in the $(M_{e\mu},\, \lambda'_{311})$ as functions of the assumed λ_{132} value. Compared to the previous results [7] there is a significant improvement in the limit obtained at the particular $(\lambda,\, \lambda')$ point, and more generally, $\tilde{\nu}_\tau$ masses are now excluded as a function of the two couplings.

3 Z' Boson, Contact Interaction and Excited Lepton Searches

3.1 Heavy Z' Searches

Many extensions of the SM gauge group predict the existence of electrically-neutral, massive gauge bosons commonly referred to as Z'. The CDF Collaboration recently searched [8] for

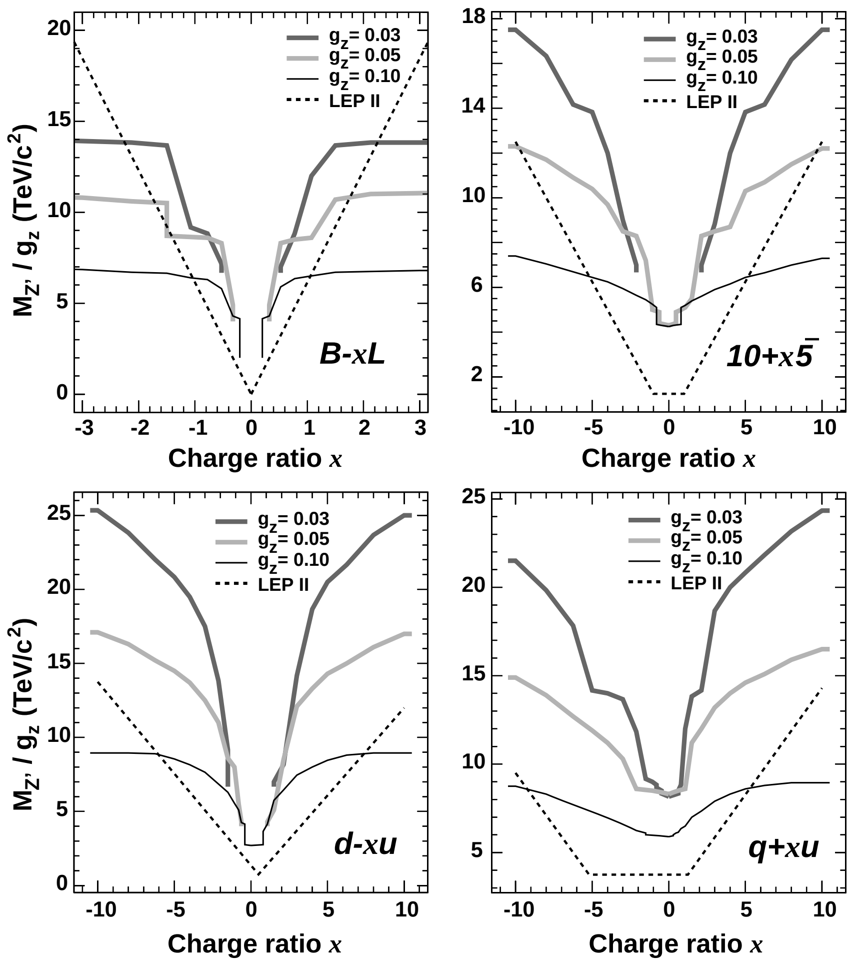

Figure 5: Exclusion contours for the $B - xL$, $10 + x\bar{5}$, $d - xu$, and $q + xu$ Z' families. The dotted lines represent the exclusion boundaries derived in Carena *et al.* [10] from the LEP II results [11]. The region below each curve is excluded by our data at 95% C.L. Only models with $M_{Z'}$ >200 GeV are tested, which explains the gap at small $|x|$ for some models.

$Z' \to e^+e^-$ decays in 0.45 fb^{-1} of the data using the two dimensional (M_{ee}, $\cos\theta*$) distribution [b]. In the search region $M_{ee} \geq 200$ GeV, the main background to $Z'/Z/\gamma^*$ process are the events with jets misidentified as electrons, and to a smaller extent diboson events. Good agreement is found between the data events and the expectation from SM sources. 95% C.L. upper limits are set on the Z' mass for traditional models such as the sequential Z' (850 GeV), the canonical superstring-inspired E_6 models: Z_ψ (740 GeV) , Z_χ (725 GeV), Z_η (745 GeV), Z_I (650), Z_N (710 GeV), and Z_{Sec} (680) [c]. A more general parametrization for Z' models was proposed [10], where a given Z' is specified by mass $M_{Z'}$, gauge coupling g_z, and a certain charge ratio x. Figure 5 shows the 95% C.L. exclusion regions for the four families of models advocated in Carena *et al.* [10], which, in the small $|x|$ and small g_z regions, improve the Z' bounds derived from LEP II contact interaction searches.

3.2 Contact Interaction Searches

The DØ Collaboration has used a similar technique to search [12] for evidence of four-fermion ($q\bar{q}\mu\bar{\mu}$) contact interactions (CI) in 0.4 fb^{-1} of data. An effective Lagrangian for the $q\bar{q}\mu\bar{\mu}$ CI

[b] $\theta*$ is the scattering angle of the electron pair in the Collins-Soper frame.

[c] The couplings for these models are summarized by Ciobanu *et al.* [9]

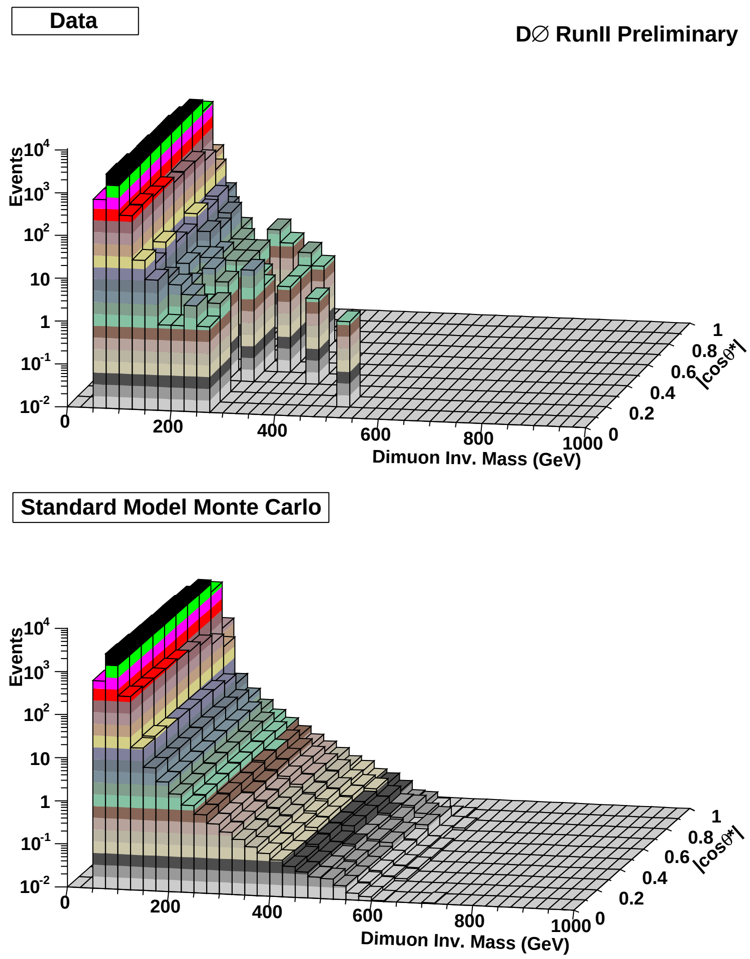

Figure 6: DØ: The bidimensional distribution ($M_{\mu\mu}$, $|\cos\theta^*|$) for data events (upper plot) and SM Monte Carlo processes normalized to the effective luminosity (lower plot).

can be written as: $\sum_q \sum_{i,j=L,R} 4\pi\eta\bar{\mu_i}\gamma^\mu\mu_i\bar{q_j}\gamma_\mu q_j/\Lambda_{ij}^2$, where Λ is the scale of the interaction, and $\eta = \pm\,1$ determines the interference structure with the Z/γ^* amplitudes [13]. A generation-universal interaction is assumed and lower limits are measured for Λ in eight helicity structure scenarios, shown in Table 1 .

3.3 Excited Lepton Searches

In the lepton and quark compositeness model, a quark or a lepton is a bound state of three fermions, or of a fermion and a boson, which may have a spectrum of excited bound states. Recently, the DØ Collaboration has searched for excited muons in 0.38 fb^{-1} of data [14]. This analysis considers the single production of an excited muon μ^* in conjunction with a muon via four-point CI $q\bar{q}\mu\bar{\mu}^*$, with the subsequent electroweak decay $\mu^* \to \mu\gamma$. This decay mode competes with the decay through the CI mechanism, and its branching ratio depends on the

Interaction	LL	RR	LR	RL	LL+RR	RL+LR	LL-RL	LR-RR	VV	AA
$\Lambda^+_{q\mu}$ limit (TeV)	4.19	4.15	5.32	5.31	5.05	6.45	4.87	5.07	6.88	5.48
$\Lambda^-_{q\mu}$ limit (TeV)	6.98	6.74	5.10	5.17	9.05	6.12	7.74	7.41	9.81	9.76

Table 1: DØ 95% C.L. lower limits for the $q\bar{q}\mu\bar{\mu}$ contact interaction mass scales.

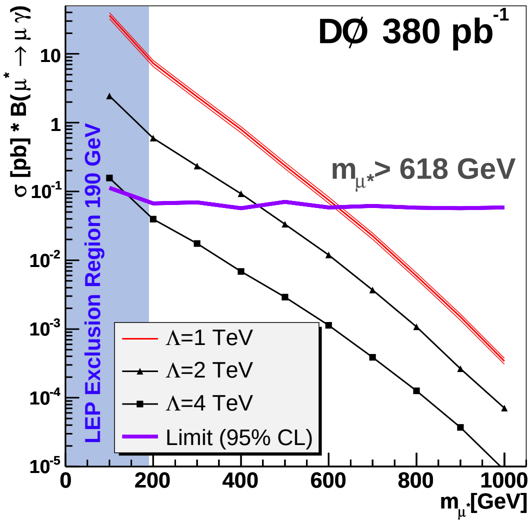

Figure 7: DØ: The 95% C.L. upper limit on the product of the cross section and branching fraction, compared to the CI model predictions for different scales Λ. For the case $\Lambda = 1$ TeV, the theoretical uncertainty of the model prediction is also shown.

ratio m_{μ^*}/Λ (Λ denotes the compositeness scale). The main background contributing to the $\mu\mu\gamma$ final state are $Z/\gamma^* \rightarrow \mu^+\mu^-(\gamma)$ decays, where the photon originates from initial or final state radiation. There are no observed data events in the signal region, consistent to the SM expectation. Figure 7 shows the limits on the product of cross section and branching ratio as functions of the mass of the excited muon. For $\Lambda = 1$ TeV, μ^* masses up to 618 GeV are excluded, at 95% C.L.

A similar search has been performed by the CDF Collaboration [15] in 0.37 fb^{-1} of data. In the gauge-mediated decay model, μ^* masses within 100−410 GeV range are excluded, for $f/\Lambda = 10^{-2}$ GeV^{-1} [d]. In the CI model [17] μ^* masses in the 107−853 GeV interval are excluded, for $m_{\mu^*} = \Lambda$. For the same μ^* model as considered in the DØ search, the CDF μ^* mass limit is 696 GeV.

4 Conclusions

In conclusion, we present several topics from exotic searches in lepton final states at the Tevatron. No significant excess for any of the signal models investigated is observed, and limits are set as functions of the relevant parameters of each model. The exotic physics program at the Tevatron is very mature and diverse, and both the DØ and CDF Collaborations are in a good position to observe new physics phenomena if these are indeed accessible at the Tevatron.

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[d] f is a phenomenological constant [16].

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