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Searches for New Physics at CDF

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Abstract. The search for physics beyond the Standard Model is one of the primary motivations of the Run II at the Tevatron. The CDF collaboration has been very active in this field by searching in a variety of final states for signals of new physics processes. The observation of no significant deviation from the Standard Model has led to limits on the cross-sections of the considered processes, which, in turn, have been used to constrain several models that predict such new physics scenarios.

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INTRODUCTION

Despite all the efforts devoted to precision measurements aimed at probing the current theory of high energy physics, the Standard Model (SM), the question concerning what physics scenario to expect beyond the electroweak scale is still open. Several theoretical arguments support the idea that new physics is likely to be expected above this energy boundary and several models for extending the SM have been suggested.

The CDF collaboration, after extensive detector upgrades, has been involved in searching for new physics signals in a wide range of final states. Details of these searches and preliminary results based on samples collected in the first three years of data-taking are given in the following.

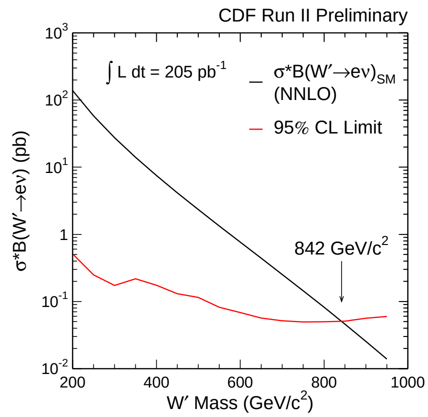

FIGURE 1. 95% *C.L.* limit on $\sigma(\mathrm{W}')\cdot B(\mathrm{W}'\to \mathrm{e}\nu_{\mathrm{e}})_{\mathrm{SM}}$ as a function of $m(\mathrm{W}')$.

SINGLE-LEPTON FINAL STATES

CDF investigated the production of additional charged vector bosons, W′, in events characterized by single isolated leptons in the final state. The existence of such bosons is predicted by models that embed the SM gauge symmetry in a larger group [1]. These models usually specify the strength of the coupling of such bosons to fermions without making any prediction upon their mass. Although not suggested by a specific theoretical model, a W′ with SM couplings represents a convenient term of comparison.

CDF has performed a W′ search in the assumption that the neutrino emerging from the boson is light and stable. Therefore, events have been selected by requiring a highly energetic isolated electron ($p_{\mathrm{T}} > 25\,\mathrm{GeV}/c$) and large missing E_{T} ($> 25\,\mathrm{GeV}$), which is expected to emerge due to the neutrino; the dominating QCD background is reduced by balancing the transverse energy associated to the electron candidate with the transverse missing energy recorded for the event.

The number of events selected from data matches, within experimental errors, the predictions of the SM in all the investigated W′ mass range ($200 \div 1000\,\mathrm{GeV}/c^2$), as shown in figure 1; the sensitivity achieved by the study reaches the level of $50 \div 100$ fb and allows to set a 95% *C.L.* lower limit on $m(\mathrm{W}'_{\mathrm{SM}})$ at $842\,\mathrm{GeV}/c^2$.

DILEPTON FINAL STATES

A very clean signature of the production of new neutral massive states at hadron colliders is given by their decay into a lepton pair ($\ell = \mathrm{e}, \mu, \tau$); examples of such states include tau sneutrinos decaying leptonically in violation of the *R*-parity [2], additional neutral vector bosons (Z′) [3, 4, 5] and Randall-Sundrum (RS) gravitons [6].

The dilepton mass spectrum obtained from events characterized by the presence of two highly energetic, isolated leptons of equal flavour and opposite electric charge can be directly compared to the expectations from different models once the spin-dependent acceptance has been taken into account. Due to the neutrinos generated in the leptonic decay of the tau lepton, the visible mass:

$$m_{vis} \equiv m\left(\ell, \tau_h, E_{\mathrm{T}}^{miss}\right) \qquad (1)$$

(where τ_h indicates a tau lepton decaying hadronically) has been used instead of $m_{\ell\ell}$ in the $\tau\tau$ channel.

No high-mass bump in the dilepton spectra has been observeded and data show a good agreement with the SM predictions; the sensitivity achieved by this search ranges at the $50 \div 100$ fb level (see figure 2), allowing to exclude at 95% *C.L.* masses up to 725 GeV/c^2 for the *R*-parity violating $\tilde{\nu}_\tau$, 815, 690, 715, 670, 610, 875 GeV/c^2 respectively for Z'_{SM}, Z'_ψ, Z'_η, Z'_χ, Z'_{I}, Z'_{H}, 320 GeV/c^2 for straw-man Technicolor ω_{T} and ρ_{T} and 700 GeV/c^2 for RS gravitons[1].

Given the fact that, at least from the experimental point of view, photons resemble electrons[2], a search for high-mass diphotons can be carried out in the same way as for electrons. This procedure, which has been applied to the RS graviton, whose rate of decay to diphotons can be sizable, has shown to have a better sensitivity than the dilepton channel in the high mass end; preliminary results show that, for 345 pb^{-1}, the reach in terms of exclusion is approximately that of the combined ee, $\mu\mu$ channels with 200 pb^{-1}.

LEPTONS PLUS JETS SIGNATURES

Typical signatures of leptoquark decays include energetic isolated leptons accompanied by jets. Leptoquarks are hypothetical color triplet bosons of unknown mass that are predicted by several extensions of the SM, such as Grand Unified models; their peculiarity is to carry both lepton and baryon quantum numbers, which makes possible their decay into a lepton-quark pair, with both fermions belonging to the same generation in order not to enhance flavour changing neutral currents beyond the experimental limits. This suggests a natural classification of leptoquarks into first, second and third generation, according to the fermion family they decay into. At the Tevatron, the dominant leptoquark production mechanism is the pair-production through $q\bar{q}$, gg fusion; considering a subsequent decay of each leptoquark into a lepton-quark pair, this leads to events characterized by

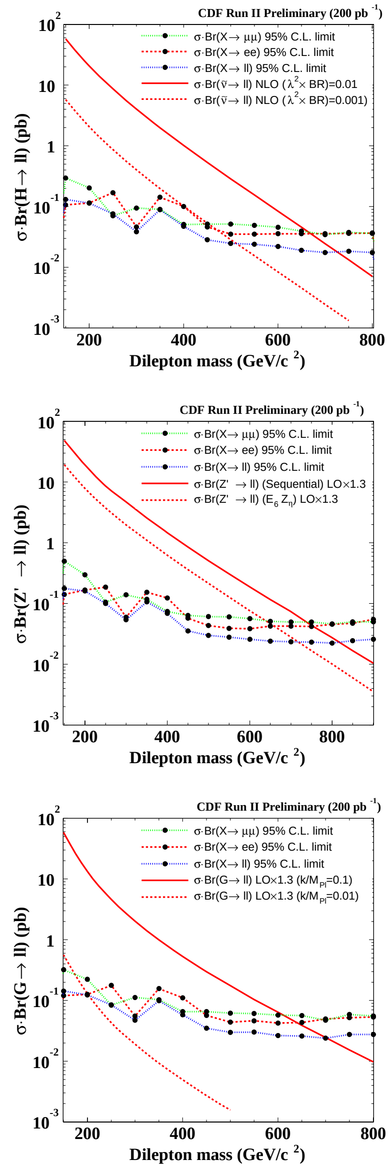

FIGURE 2. 95% *C.L.* limits on $\sigma(\mathrm{X}) \cdot B(\mathrm{X} \to \ell\ell)$ ($\ell = \mathrm{e}, \mu$) for spin 0 (top), 1 (center) and 2 (bottom) X as functions of $m(\mathrm{X})$.

one or two energetic charged leptons – or, alternatively, by large missing E_{T} (> 60 GeV) due to the two neutrinos – accompanied by typically two jets. Despite both scalar and vector leptoquarks being supported by theory, the coupling of vector leptoquarks to gluons is model-dependent, which makes scalar leptoquarks the most studied from an experimental point of view.

The major contaminations to the signal come from QCD multijet, Z/W plus jets and $t\bar{t}$ with at least one W decaying leptonically. Background reduction is performed differently according to the signal topology: by

[1] All quoted lower mass bound refer to the combined ee, $\mu\mu$ search; a 95% *C.L.* exclusion at 394 GeV/c^2 has been achieved on $m(Z'_{\mathrm{SM}})$ by considering the $\tau\tau$ channel independently.

[2] Photons are in fact identified as electromagnetic clusters reconstructed in the calorimeter that – conversely of electrons – are not associated to any track.

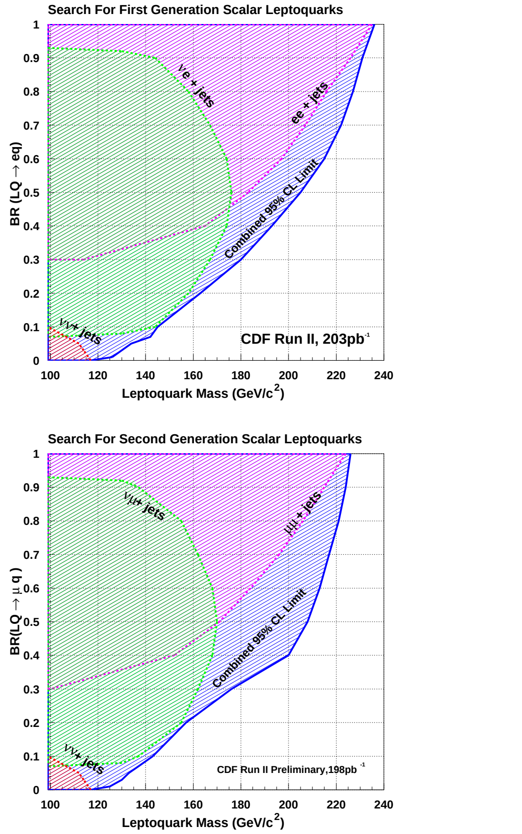

FIGURE 3. 95% *C.L.* exclusion contours in the $\beta - m(\mathrm{LQ})$ plane (β being the branching fraction of $\mathrm{LQ} \to \ell \mathrm{q}$).

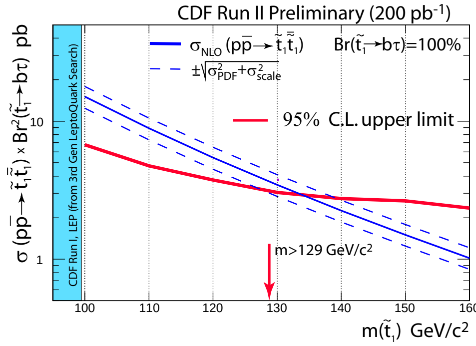

FIGURE 4. 95% *C.L.* limit on $\sigma(\tilde{\mathrm{t}}_1 \bar{\tilde{\mathrm{t}}}_1) \cdot B^2(\tilde{\mathrm{t}}_1 \to \mathrm{b}\tau)$ as a function of $m(\tilde{\mathrm{t}}_1)$ (same applies to third generation LQ).

vetoing values of $m(\ell\ell)$ or $m_{\mathrm{T}}(\nu\ell)$ compatible with $m(\mathrm{Z})$ or $m_{\mathrm{T}}(\mathrm{W})$ for $\ell\ell jj$ and $\nu\ell jj$; or by vetoing energetic leptons and by requiring both jets and missing E_{T} being all well isolated for $\nu\nu jj$. The number of events selected from data is in all cases compatible with the SM prediction; first and second generation leptoquark masses have therefore been excluded at 95% *C.L.* up to 235 and 224 GeV/c^2 respectively, as shown in figure 3.

Third generation leptoquarks, on the other hand, are characterized by a more challenging experimental signature: due to the decay of the tau leptons, the most powerful final state configuration is that of a lepton accompanied by jets and missing E_{T} (corresponding to the case in which one tau lepton decays leptonically, the other decaying into hadrons). This same signature can be used to probe the *R*-parity violating decay of a stop pair $(\mathrm{gg}, \mathrm{q\bar{q}} \to \tilde{\mathrm{t}}_1 \bar{\tilde{\mathrm{t}}}_1 \to \mathrm{b}\tau^+ \bar{\mathrm{b}}\tau^-)$. The major background originates from Z plus jets, with $\mathrm{Z} \to \tau^+\tau^-$, and is reduced by requiring the visible mass (m_{vis}, see equation (1)) being outside the Z mass window. The number of events selected from data is compatible with the SM prediction, which allows a 95% *C.L.* exclusion for third generation leptoquarks and *R*-parity violating stops up to 129 GeV/c^2, as shown by figure 4.

MISSING TRANSVERSE ENERGY SIGNATURE

The presence of missing transverse energy is one of the most characterizing signatures of exotic processes: for instance in SUSY models with *R*-parity conserved, the lightest supersymmetric particle (LSP) is stable and therefore escape the detector giving rise to missing E_{T}. However, several factors weaken this signature: first, LSPs are likely to emerge from cascade decays, therefore being expected not to be very energetic; second, there are multiple sources of missing energy in an event, coming not only from new, undetected particles (as the LSPs), but also from standard sources, such as neutrinos. As a consequence, only moderate levels of missing E_{T} are expected even when exotic processes are considered; this requires a high degree of understanding of beam and detector effects – typically complicated to model – which makes this signature hard to exploit.

Despite its intrinsic difficulty, the missing E_{T} signature, especially when considered in conjunction with photons, jets or leptons, is expected to achieve the highest sensitivities in the search for new phenomena.

Models relying on gauge-mediated SUSY breaking (GMSB) predict that, if the gravitino is the LSP, then the role of next to lightest supersymmetric particle (NLSP) is played either by the neutralino or by a slepton. If the former is true, then $\tilde{\chi}^0_1 \to \gamma\tilde{\mathrm{G}}$ is the only decay mode kinematically accessible by the NLSP; the resulting GMSB signatures are then similar to mSUGRA final states (where the $\tilde{\chi}^0_1$ is the LSP) complemented by a photon pair.

A signature characterized by two energetic photons and large missing E_{T} (> 40 GeV) has been investigated

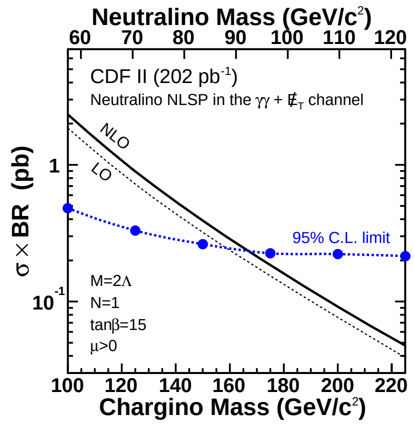

FIGURE 5. 95% *C.L.* limit on $\sigma \cdot BR$ as a function of $m(\tilde{\chi}_1^{\pm})$ and $m(\tilde{\chi}_1^0)$ in the light gravitino scenario.

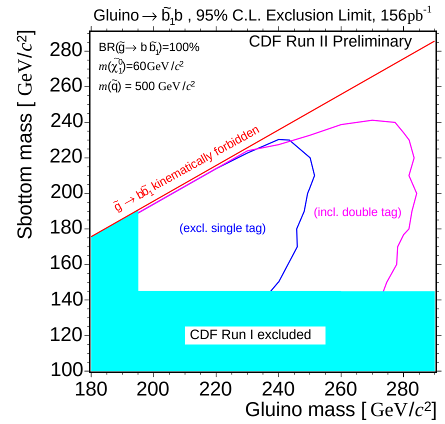

FIGURE 6. 95% *C.L.* exclusion contours in the $m(\tilde{\mathrm{b}}) - m(\tilde{\mathrm{g}})$ plane.

by CDF [7]. The missing E_{T} spectrum observed from data (before the missing E_{T} cut) is in good agreement with the SM prediction, which is dominated by QCD processes (multijet events with production or misidentification of photons); no excess has been observed from data. As shown in figure 5, a 95% *C.L.* exclusion for GMSB charginos has been set up to 167 GeV/c^2.

Another process involving the production of missing E_{T} is the decay of gluino pairs, particles that are again predicted by SUSY models. The production of gluino pairs is of particular interest at the Tevatron, where its cross-section can be fairly large. Several different signatures can characterize the events yielded by this process, depending on the decay mode of the gluino. As an effect of the large mixing affecting the third generation, which can push the $\tilde{\mathrm{b}}_1$ and $\tilde{\mathrm{t}}_1$ squarks mass eigenstates to low mass values, the $\tilde{\mathrm{g}} \rightarrow \tilde{\mathrm{b}}\bar{\mathrm{b}}$ becomes most interesting in conjunction with the decay $\tilde{\mathrm{b}} \rightarrow \mathrm{b}\chi_1^0$. In fact, if both gluinos decay according to this scheme, the final state is characterized by a spectacular four b-jets and missing E_{T} signature.

CDF has searched for events selected in terms of moderate jet activity (three or more 10 GeV jets within the silicon vertex detector's acceptance), heavy flavour content and missing E_{T} above 50 GeV. The missing E_{T} spectra observed in the data samples with one and two jets identified as originated from a b quark before any missing E_{T} requirement have been checked against the SM predictions and are in good agreement. The number of observed events passing the selection is compatible with the SM predictions in both single and double tag samples; the resulting 95% *C.L.* limits exclude gluino and sbottom masses up to 280 and 240 GeV/c^2 respectively, as shown in figure 6.

CONCLUSIONS

A collection of results obtained by the CDF collaboration in the searches for new physics has been presented; particular emphasis has been put on the most recent analyses that are based on the first 350 pb^{-1} collected during the Run II.

CDF is actively searching for new physics signals in a large variety of channels; no evidence has been observed so far. The limits achieved in Run II are rapidly extending those set by previous experiments.

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