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SUSY Searches at the Tevatron

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On Behalf of the CDF and D0 Collaborations

Abstract — The search for supersymmetry is one of the primary goals of the Run II of the Tevatron. Both the CDF and D0 collaborations have been very active in this field by searching for SUSY signals in a variety of channels. Although no evidence has been found so far, several models based on low energy supersymmetry have been probed and, as a result, limits were set on the SUSY spectrum as well as on the cross-sections of the considered processes.

1 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 suggest, as convenient extensions of the SM, models that rely on low energy supersymmetry (SUSY).

Both the CDF and D0 collaborations, after extensive detector upgrades, have been involved in searching for SUSY signals in a variety of channels. Details of these searches and preliminary results based on samples collected in the first two years of data-taking are given in the following.

2 Direct Searches

Although indirect indications of new physics can be inferred from processes below threshold by comparing precision measurements with predictions provided by the SM, a definitive evidence for the existence of SUSY can be provided only by direct searches. For the time being, after the end of LEP and before the LHC turn-on, the Tevatron detectors are the only experiments having the potential to make a direct discovery.

2.1 Higgs Sector

Since its birth in the early 70s, the SM has been proved to be a very successful model. A whole generation of experiments were build to investigate its characteristics and, so far, no significant deviation has been observed. Nevertheless, one of the SM basic components, the Higgs boson, remains undiscovered. Due to this fact, the dynamics responsible for the electroweak symmetry breaking is still unknown.

If the existence of a Higgs boson is crucial for the survival of the SM in its current form, this is even more stringent for SUSY models. Low energy SUSY models, in fact, provide viable extensions of the SM by predicting a light Higgs boson, in general embedded in a richer Higgs sector; however, contrary to the SM, where the mass of the Higgs boson is a free parameter, the mass of the lightest Higgs boson (conventionally indicated as h) is constrained by an upper bound.

Accurate calculations relying on the general framework of the Minimal Supersymmetric Standard Model (MSSM) suggest that the value of this constraint on m_{h} ranges between 120 and $135\,\mathrm{GeV}/c^2$ [1] according to the level of $\tilde{\mathrm{t}}$-mixing and to the value of m_{t}, the mass of the top quark. Higher values (up to $150\,\mathrm{GeV}/c^2$) are indeed possible, even though discouraged by theoretical arguments.

The effect of the upper bound on $m_{\rm h}$ can be evaluated by exploiting the similarities between the SM Higgs boson, $\rm H_{SM}$, and the neutral scalar Higgs bosons of the MSSM, h and H; in this way, the results of the searches for $\rm H_{SM}$ (see [2] for recent updates) can be reinterpreted in the MSSM framework. More specifically, since at tree level the Higgs sector of the MSSM is completely controlled by two parameters, conventionally chosen as $m_{\rm A}$, mass of the pseudo-scalar Higgs boson, and $\tan\beta$, ratio of the vacuum expectation values of the two Higgs doublets, the limits on $m_{\rm H_{SM}}$ can be mapped onto the $m_{\rm A} - \tan\beta$ plane. This unfolding process is illustrated in figure 1, where the estimated SM Higgs sensitivity is translated in terms of the MSSM parameters $m_{\rm A}$ and $\tan\beta$ [3]. The effect of the upper bound on $m_{\rm h}$ results in an almost complete exclusion of the MSSM parameter space already with an integrated luminosity of $5\,{\rm fb}^{-1}$ even in the less favourable scenario of maximal $\tilde{\rm t}$-mixing.

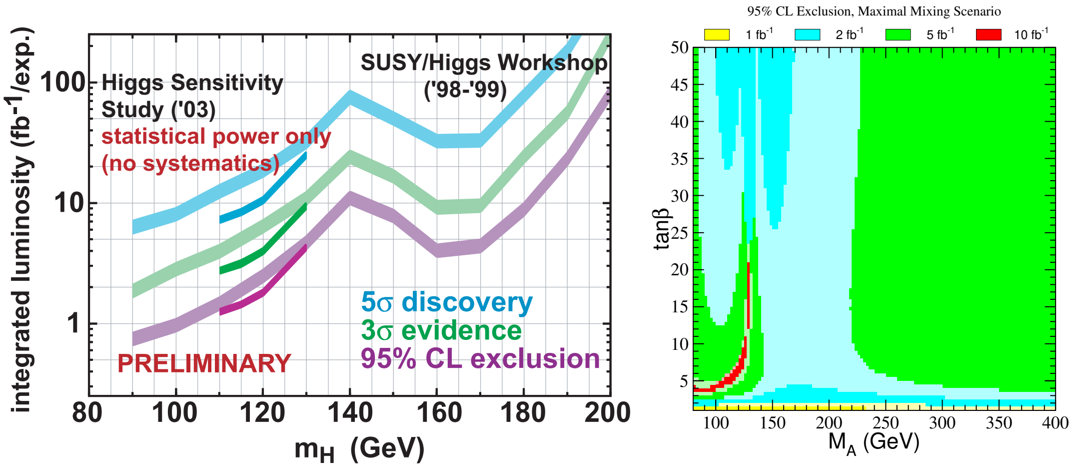

Figure 1: Run II expectations for the SM Higgs searches at the Tevatron (left) and their interpretation in terms of the MSSM scenario (right).

The reinterpretation of the SM Higgs searches provides an indirect method for investigating the MSSM; however, there are specific examples of processes that, although not playing a dominant role in the SM, can be boosted by suitable choices of the MSSM parameters. For instance, high values of $\tan\beta$ enhance the production mechanism $\rm gg\,, q\bar{q}^{(\prime)} \to \Phi b\bar{b}$ ($\Phi = \rm h, H, A$), which, in conjunction with the decay $\Phi \to \rm b\bar{b}$ (dominant for a light Φ), produces multi-jet final states with four b-jets.

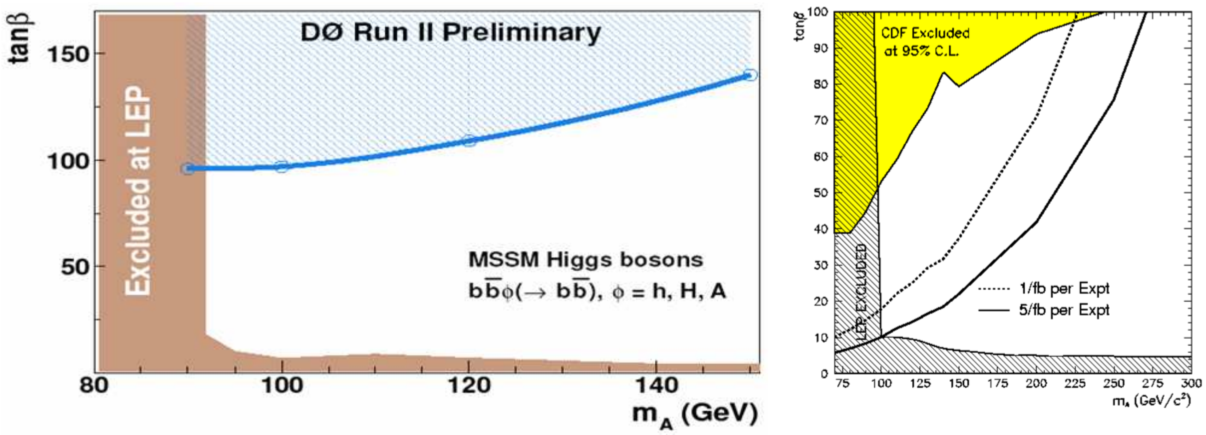

Figure 2: Search for neutral MSSM Higgs bosons in the four b-jets final state: 95% *C.L.* exclusion contours obtained by D0 based on $130\,{\rm pb}^{-1}$ of Run II data (left) compared to the CDF Run I result (right). The dotted and solid lines delimit the projected 95% *C.L.* exclusion regions for 1 and $5\,{\rm fb}^{-1}$ respectively.

The strong characterization provided by the heavy flavour content is the key for separating the signal from the QCD $\rm gg \to b\bar{b}b\bar{b}$ background: a minimum of three high-p_T jets were required to be compatible with the hypothesis of being generated from the decay of b quarks on the basis of the secondary vertex reconstruction technique. A topological selection, relying on the wider angular separation expected for the b-jets emerging from the decay of the Higgs boson, provides further refinement. The results obtained by the Tevatron collaborations are shown in figure 2, in which the D0 Run II result is compared to the CDF Run I exclusion contour [4].

2.2 Missing E_T Signature

The presence of missing transverse energy is one of the signatures characterizing SUSY processes: when the R parity symmetry is conserved, the lightest supersymmetric particle (LSP) is stable and therefore escape the detectors giving rise to missing E_T. However, there are several factors that weaken this signature: first, the LSP is likely to emerge from cascade decays, therefore being expected to carry low energy; second, there are multiple sources of missing energy in an event, not only because the LSPs are necessarily produced in pairs, but also for standard sources of missing energy, such as neutrinos. As a consequence, only moderate levels of missing E_T are expected even when SUSY 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, when in conjunction with the request of jets, is expected to achieve the highest sensitivity on squark and gluino masses. As for the missing energy, also the jets emerging from a $\tilde{q}\bar{\tilde{q}}$, $\tilde{g}\tilde{g}$, $\tilde{q}\tilde{g}$, $\tilde{q}\tilde{q}$ system are mainly the result of cascade decays and therefore are not expected to carry large momenta. The signature is therefore characterized by a moderate missing E_T (of the order of $30\,\mathrm{GeV}$) and by two or more jets. D0 has completed a preliminary analysis based on $85\,\mathrm{pb}^{-1}$ of Run II data; the results, interpreted according to a mSUGRA scenario with $m_0 = 25\,\mathrm{GeV}/c^2$, $\tan\beta = 3$, $A_0 = 0$ and $\mu < 0$, have pushed the 95% *C.L.* beyond the Run I limit [5], reaching $m_{\tilde{g}} > 333\,\mathrm{GeV}/c^2$ and $m_{\tilde{q}} > 292\,\mathrm{GeV}/c^2$.

2.3 Third Generation Sfermions

The process leading to 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; indicating with $\tilde{q}$ the generic light-flavoured squark, these are: $\tilde{g} \to \tilde{q}\bar{q}$, $\tilde{b}\bar{b}$, $\tilde{t}\bar{t}$, $g\tilde{\chi}_1^0$ and, for the three-body decays, $q\bar{q}\tilde{\chi}_1^0$, $q\bar{q}'\tilde{\chi}_1^{\pm}$. Given that only $\tilde{b}$ and $\tilde{t}$ squarks can be light due to the large mixing interesting the third sfermion generation and keeping into account the large mass of the top quark, it is $\tilde{g} \to \tilde{b}\bar{b}$ that provide a striking signature due to the $\tilde{b} \to b\tilde{\chi}_1^0$ decay: in fact, if both gluinos decay according to this scheme, the final state is characterized by four b-jets and missing E_T.

CDF has been searching events selected in terms of moderate jet activity (three or more $10\,\mathrm{GeV}$ jets reconstructed within the silicon vertex detector's acceptance), heavy flavour content (one or two jets being identified as originated from a b quark) and missing transverse energy above $50\,\mathrm{GeV}$. The number of observed events after selection (4 in the single and 1 in the double tag samples) is compatible with the SM predictions (5.65 ± 1.34 and 0.5 ± 0.1 in the single and double tag samples respectively); the resulting limits, set on the $\tilde{g}\tilde{g}$ production cross-section and in the $m_{\tilde{b}} - m_{\tilde{g}}$ plane, have improved the existing limits already with $38\,\mathrm{pb}^{-1}$. The results are shown in figure 3.

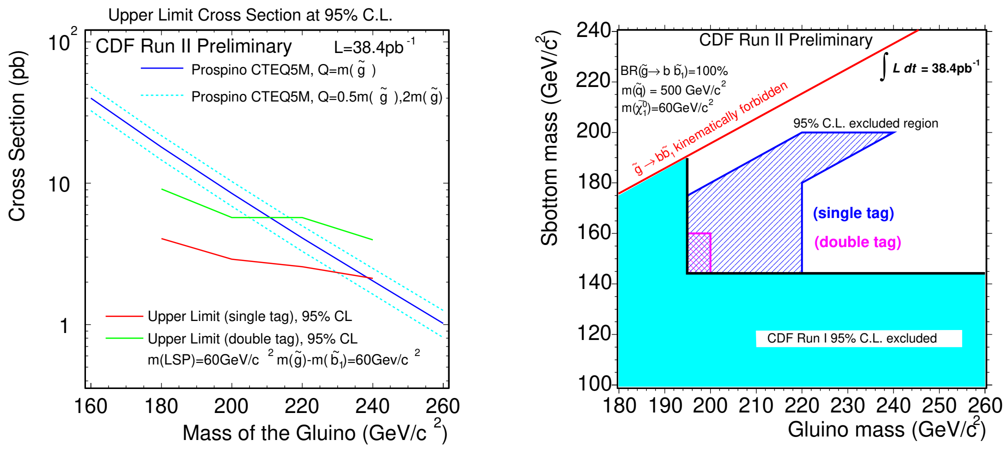

Figure 3: Search for gluino decaying into sbottom: limits for CDF Run II.

2.4 Multilepton-based Signatures

The SM predicts several processes leading to final states containing two leptons with opposite sign; this is not true for the production of events characterized by two same-sign leptons or by more than two leptons. In this case, the processes are rare and typically with tiny cross-sections. On the other hand, leptons represent powerful discriminating signatures at hadron colliders; this is why, despite the fact that leptonic branching ratios are not always favourable, signals of new physics can easily become competitive with respect to SM backgrounds when searched in multi-lepton final states.

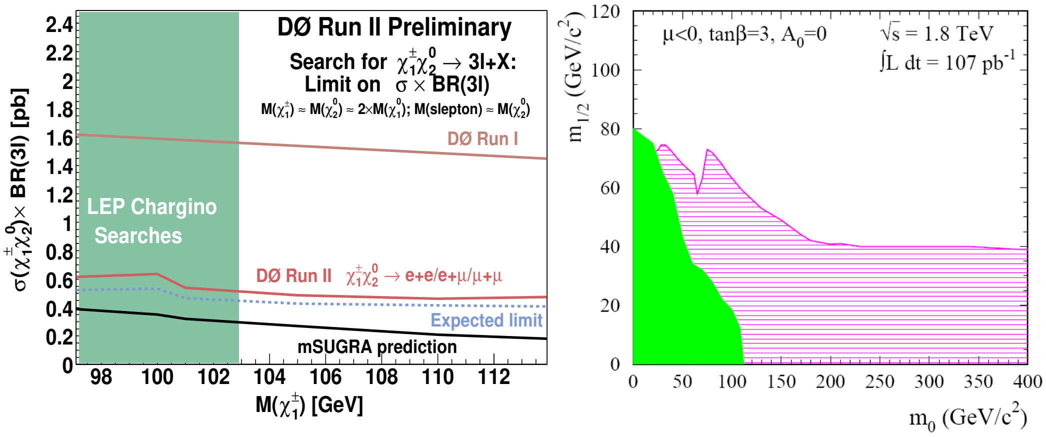

Figure 4: Search for chargino-neutralino decaying into multi-lepton final states: limits from the trilepton channel (D0 Run II – left) and from the same-sign dilepton channel (CDF Run I – right).

A typical example of exploitable multi-lepton signature is given by the chargino-neutralino case, where the three-lepton mode ($\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 \nu_{\ell'} \ell' \, \tilde{\chi}_1^0 \ell^+ \ell^-$) represents the golden search channel at the Tevatron. The first Run II preliminary results in this study have been obtained by D0, where the trilepton signature is achieved by the combination of an electron or muon pair (with typical p_T of the order of $10\,\mathrm{GeV}/c$) with an isolated low-p_T track[1)] and complemented by a weak requirement of missing E_T (at least $15\,\mathrm{GeV}$); alternatively, the three-lepton requirement is relaxed to a same-sign dilepton request (for muon pairs only). The results are summarized in figure 4, which shows the measured limit being close to the mSUGRA prediction for a considered dataset corresponding to $175\,\mathrm{pb}^{-1}$. Figure 4 displays also a recent CDF result obtained on $107\,\mathrm{pb}^{-1}$ of Run I data by following the same-sign dilepton approach.

2.5 Photon+Missing E_T Signatures

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

Both CDF and D0 have searched for an inclusive signature characterized by two photons ($E_T > 13\,\mathrm{GeV}$ for CDF and $E_T > 20\,\mathrm{GeV}$ for D0) and missing energy larger than $40\,\mathrm{GeV}$. The results – based on samples corresponding to 84 and $185\,\mathrm{pb}^{-1}$ for CDF and D0 respectively – are reported in figure 5. Due to the larger dataset, D0 sets new limits at $m_{\tilde{\chi}_1^0} > 105\,\mathrm{GeV}/c^2$ and $m_{\tilde{\chi}_1^{\pm}} > 180\,\mathrm{GeV}/c^2$ at 95% *C.L.*, which improve the previous LEP result.

2.6 CHAMPs

The existence of charged massive particles (CHAMPs) is predicted by many SUSY models whenever – due to couplings and kinematical constraints – a slepton, a squark or a gaugino becomes stable on experimental time-scales; therefore, the peculiarity of the CHAMP is its capability of traversing the whole detector volume at a low speed (relative to c) without decaying. In other words, in terms of detection, a CHAMP is likely to be reconstructed as a high-p_T, slowly-moving muon with an anomalously large ionization energy loss in the tracking volume.

[1)] Relaxing the third lepton requirement to an isolated low-p_T track increases the sensitivity of the search to τ leptons, whose contribution becomes dominant in high $\tan\beta$ scenarios [6].

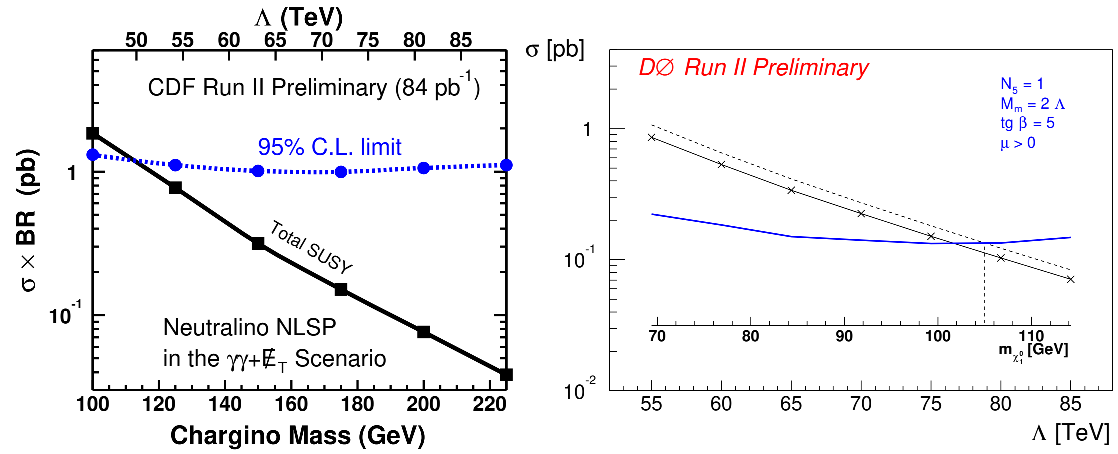

Figure 5: Run II limits on the chargino mass from GMSB SUSY diphoton events with large missing E_T: CDF ($84\,\mathrm{pb}^{-1}$) and D0 ($185\,\mathrm{pb}^{-1}$) results. D0 compares experimental limit with LO and LO corrected by K-factor predictions (solid and dotted curves respectively).

A natural way to detect CHAMPs at CDF is by exploiting the information collected by the time-of-flight (TOF) detector, which provides a measurement of the time taken to a particle to fly from the primary vertex to the outer radius of the central tracking region; long-lived charged particles can be discriminated by means of the quantity Δ_{TOF}, the difference between its time of flight and the time of flight expected for a particle travelling with speed c. After identifying as signal region Δ_{TOF} values above $2.5\,\mathrm{ns}$, no relevant excess with respect to the expected background was observed; this has led CDF to set limits on $\tilde{\mathrm{t}}$ pair production cross-section (see figure 6) and on the $\tilde{\mathrm{t}}$ mass – being the $\tilde{\mathrm{t}}$ a likely candidate for a CHAMP. Masses of the $\tilde{\mathrm{t}}$ below $108\,\mathrm{GeV}/c^2$ are excluded at 95% *C.L.*.

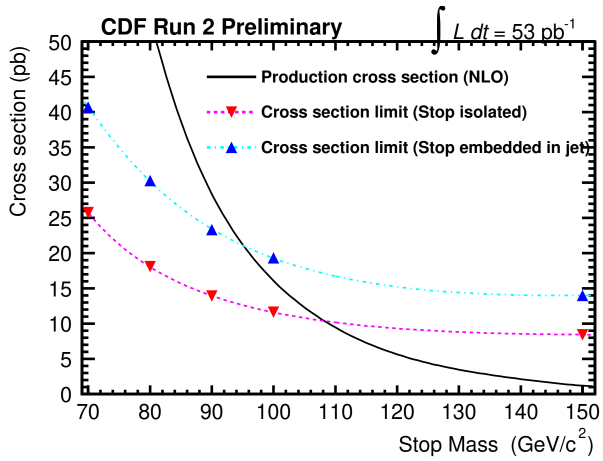

Figure 6: Search for charged massive particles: CDF limits for massive stop.

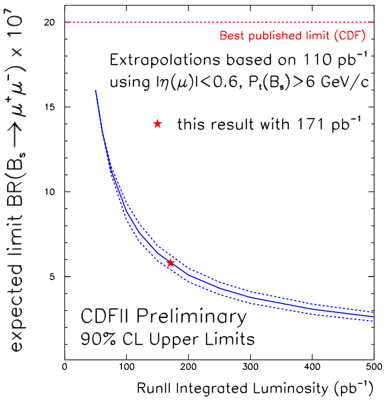

Figure 7: Indirect searches: CDF limits for $\mathrm{B_s} \to \mu^+\mu^-$.

3 Indirect Searches

An enticing way to probe the existence of SUSY is through the study of the decay $\mathrm{B_s} \to \mu^+\mu^-$, a process never observed experimentally. Due to the natural suppression of flavour changing neutral currents at tree level within the SM, the corresponding branching ratio is expected at the level of 3.4×10^{-9} if no new physics comes into play. However, in many SUSY models [7, 8, 9] the value of this branching ratio could be enhanced by several orders of magnitude, making the process one of the most sensitive indicators of new physics at the Tevatron.

A blind analysis has been optimized to search for $\mathrm{B} \to \mu^+\mu^-$ decays; the most discriminating variables have been identified in the dimuon invariant mass, the $c\tau$ for the $\mathrm{B_s}$, the azimuthal separation between the direction of flight of the $\mathrm{B_s}$ and the position of its decay vertex and the $\mathrm{B_s}$ isolation. The CDF search improves the previously published result [10], setting the new 95% *C.L.* (90% *C.L.*) limits at 7.5×10^{-7} (5.8×10^{-7}) for *B.R.*$(\mathrm{B_s} \to \mu\mu)$ and at 1.9×10^{-7} (1.5×10^{-7}) for *B.R.*$(\mathrm{B_d} \to \mu\mu)$. The expected behaviour of the limit on the *B.R.*$(\mathrm{B_s} \to \mu\mu)$ as a function of integrated luminosity (without re-optimizing the selection) is shown in figure 7; a new blind analysis, therefore allowing the re-optimization of the selection requirements, will be performed with $400\,\mathrm{pb}^{-1}$ and with a larger detector acceptance aimed at extending up to $|\eta| < 1$ the muon coverage.

4 Conclusions

A review of recent results achieved by the Tevatron collaborations in the searches for SUSY processes has been presented; particular emphasis has been put on the analyses that have been carried out on the datasets collected during Run II, which accounts approximately for $0.3\,\mathrm{fb}^{-1}$ of physics quality data recorded so far.

Both CDF and D0 are actively searching for SUSY signals in a large variety of channels; no evidence has been observed. The limits achieved in Run II are rapidly approaching – and in some cases surpassing – the limits set by previous experiments.

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