Searches for Physics beyond the Standard Model

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DOI: http://dx.doi.org/10.3204/DESY-PROC-2009-01/63

Abstract

Recent results on searches for new physics from Run II of the Tevatron are reported. The D0 and CDF experiments have already collected more than 4 fb^{-1} of integrated luminosity each, allowing for a large number of new phenomena searches in many different final states. No deviations from the standard model expectations are found, and the presented limits on new physics are in many cases the world's best.

A large number of solutions has been proposed for all of the deficits of the standard model (SM) that we know about since many years – be it the non-unification of couplings at a high scale, the quadratic divergences in the loop corrections to the Higgs boson mass, or the lack of a decent dark matter candidate. The most popular models of new physics involve supersymmetry. However, supersymmetry doesn't explain the number of fermion generations, or their mass spectrum and charges. In this talk, a few selected recent results from the D0 and CDF experiments of searches for manifestations of new physics are reported. Details for all Tevatron results can be found at [1].

1 Lepton compositeness

Both CDF and D0 have searched for excited electrons and muons as signs of lepton compositeness. Recently, an analysis of excited electron production has been published [2]. D0 searched for associated production of an electron and an excited electron, with the latter decaying to an electron and a photon. The production is approximated as a contact interaction, while the decay is assumed to proceed either exclusively through a gauge interaction, or a combination of gauge and contact interactions, with the relative fraction of the two depending on the mass of the excited electron and the compositeness scale Λ. The D0 result, based on 1.0 fb^{-1} of data, is shown in Fig. 1, excluding $m_{e^*} < 756$ GeV for $\Lambda = 1$ TeV at 95% C.L.; depending on the value of Λ and the assumed branching fractions, masses up to about 1 TeV are excluded.

2 Supersymmetry

In minimal supergravity, the two most interesting final states are firstly multiple jets and missing E_T, the generic signal of squark and gluino production, and secondly the trilepton signature, due to chargino and neutralino production. In the D0 analysis [3], based on 2.1 fb^{-1}, the observed event numbers in three dedicated analyses (2, 3, 4 jets plus $\not\!\!E_T$) are converted into an exclusion domain in the plane of the squark and gluino masses (Fig. 2 left). Squark masses below 379 GeV and gluino masses below 308 GeV are excluded, while the lower limit for equal squark and gluino masses is 390 GeV. Both in this result and in the CDF trilepton analysis [4], results are also presented in the $(m_0, m_{1/2})$ plane, as shown in Fig. 2 (right) for the trilepton analysis.

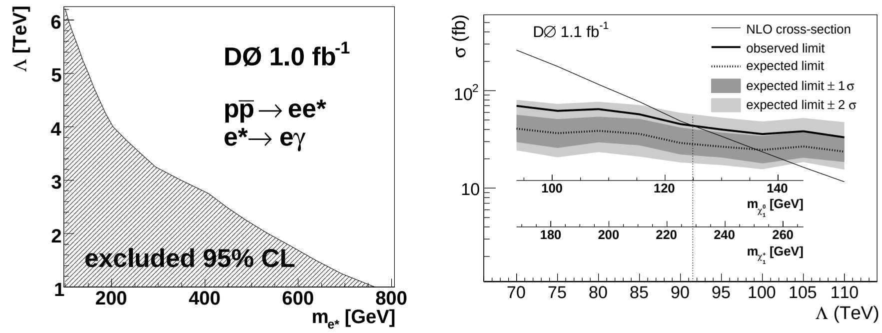

Fig. 1: (Left) Exclusion region in the search for excited electrons produced in contact interactions in the decay mode $e^* \to e\gamma$. (Right) Cross section limits and theoretical predictions in a model of gauge-mediated SUSY breaking.

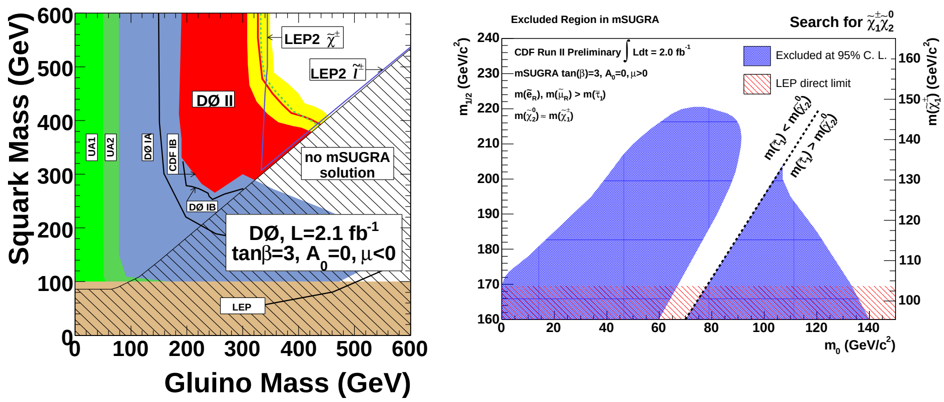

Fig. 2: (Left) Region in the plane of gluino and squark masses excluded by searches for supersymmetry in the jets plus $\not\!\!E_T$ channel. (Right) Region in the $(m_0, m_{1/2})$ plane excluded by searches in the trilepton channel.

Alternative SUSY scenarios include models with gauge-mediated SUSY breaking, where the gravitino is the lightest SUSY particle. The phenomenology depends on the next-to-lightest SUSY particle (stau or neutralino), and its lifetime. If the neutralino promptly decays to a gravitino and photon, the characteristic signature is $\gamma\gamma + \not\!\!E_T$. The latest result in this channel from D0 [5] is shown in Fig. 1 (right), excluding a lightest chargino with masses below 229 GeV.

3 Large extra dimensions

Models postulating the existence of extra spatial dimensions have been proposed to solve the hierarchy problem posed by the large difference between the Planck scale $M_{pl} \simeq 10^{16}$ TeV, at which gravity is expected to become strong, and the scale of electroweak symmetry breaking, $\simeq 1$ TeV. In the large extra dimensions model of Arkani-Hamed, Dimopoulos and Dvali, it is possible to produce gravitons which immediately disappear into bulk space, leading to an excess of events with a high transverse energy photon or jet and large missing transverse energy. A recent compilation by CDF [6] of their results in these two signatures is shown in Fig. 3 (left); the combined limits on the fundamental Planck scale range between $M_D > 1400$ GeV and $M_D > 940$ GeV at 95% C.L. for numbers of extra dimensions from 2 to 6.

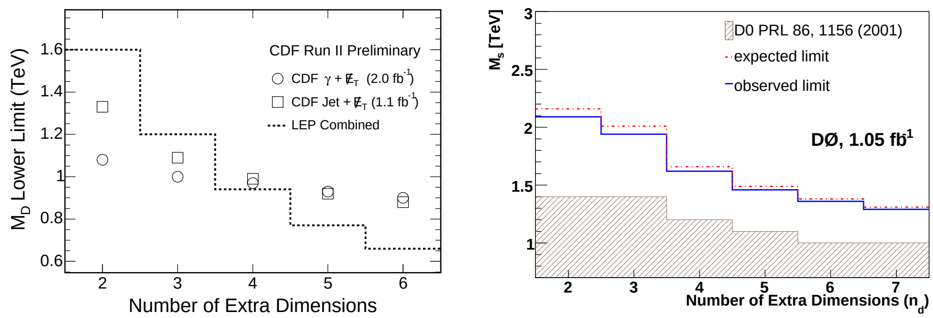

Fig. 3: (Left) Limits on the fundamental Planck scale M_D as a function of the number of extra dimensions in the single photon and single jet channels. (Right) Limits on the effective Planck scale M_s as a function of the number of extra dimensions obtained in the $ee/\gamma\gamma$ channel.

The virtual exchange of KK gravitons would modify the cross sections for SM processes like the production of fermion or boson pairs. The sensitivity is expressed in terms of the scale M_s, which is expected to be close to M_D. In a recent analysis [7] based on an integrated luminosity of 1.05 fb^{-1}, D0 has investigated the high mass e^+e^- and $\gamma\gamma$ mass spectrum, and has found no indications for large extra dimensions. Limits on M_s are set as shown in Fig. 3 (right), for example $M_s > 1.62$ TeV for $n_d = 4$ at 95% C.L.

4 Randall-Sundrum gravitons

In the model by Randall and Sundrum, gravity is located on a $(3+1)$-dimensional brane that is separated from the SM brane in a fifth dimension with warped metric. The gravitons appear as towers of KK excitations with masses and widths determined by model parameters. These parameters can be expressed in terms of the mass of the first excited mode of the graviton, M_1, and the dimensionless coupling to the standard model fields, $k\sqrt{8\pi}/M_{pl}$. If it is light enough, the first excited graviton mode could be resonantly produced at the Tevatron. D0 has published [8] new results in the search for Randall-Sundrum gravitons based on 1 fb^{-1}of data. The invariant mass spectrum in the e^+e^- and $\gamma\gamma$ final states has been used. General agreement between data and the background expectation is observed. Using a sliding mass window technique, upper cross section limits are derived, which are then translated into lower mass limits for the lowest excited mode of RS gravitons (Fig. 4 left). For a coupling parameter $k\sqrt{8\pi}/M_{pl} = 0.1$ (0.01), masses $M_1 < 900$ (300) GeV are excluded at 95% C.L.

The CDF dielectron spectrum [9] obtained in a data sample corresponding to 2.5 fb^{-1} is shown in Fig. 4 (right). An excess of data over background with a significance of 2.5σ after accounting for the 'trials factor' is found for an e^+e^- mass window at 240 GeV. In this analysis, RS gravitons with a mass $M_1 < 848$ GeV are excluded at 95% C.L. for $k\sqrt{8\pi}/M_{pl} = 0.1$.

5 New heavy gauge bosons

A possible way of resolving the inherent problems of the standard model is by extending the gauge sector of the theory. In the search for singly charged gauge bosons, D0 looked for a SM-like W' decaying to an electron and a neutrino [10]. The limit, obtained from a study of the

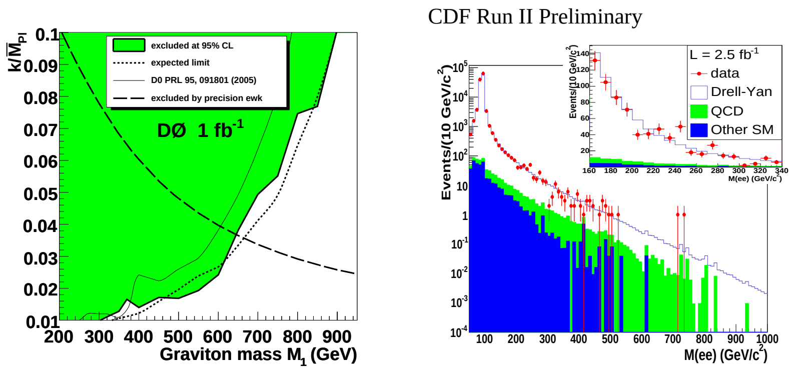

Fig. 4: (Left) Excluded region in the plane of $k\sqrt{8\pi}/M_{pl}$ and graviton mass. (Right) Invariant dielectron mass distribution. The inset shows the region around 240 GeV on a linear scale.

transverse mass spectrum in 1 fb^{-1} of data, requires $m(W') > 1.0$ TeV at 95% C.L. (Fig. 5 left). As an example of a search for a Z' decaying into charged leptons, Fig. 5 (right) shows the (inverse) invariant mass distribution CDF obtained in 2.3 fb^{-1} of dimuon data [11]. No significant excess above the standard model expectation is observed. For a SM-like Z', masses below 1.03 TeV are excluded at 95% C.L.

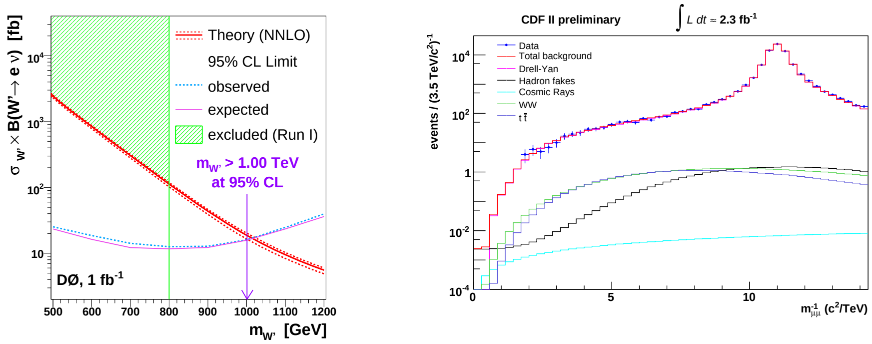

Fig. 5: (Left) Cross section upper limits for the production of a SM-like W'. (Right) Dimuon inverse invariant mass distribution used for resonance searches.

6 Leptoquarks

Leptoquarks (LQ) are a natural consequence of the unification of quarks and leptons into a single multiplet, and as such are expected to be gauge bosons as well. In some models they can be relatively light and accessible at colliders. Experimentally, it is customary to consider one LQ per generation. These are assumed to be very short-lived and decay to a quark and a lepton. The branching fraction to a charged lepton and a quark is then denoted as β. At hadron colliders, leptoquarks can be pair-produced through the strong interaction. Both experiments have searched for leptoquarks of all three generations in different decay modes. A typical result is the recent update [12] in the channel $e^+e^-q\bar{q}$, sensitive for first generation LQ with large β. A lower limit of 299 GeV at 95% C.L. on the mass of a scalar LQ with $\beta = 1$ is set (see Fig. 6 left).

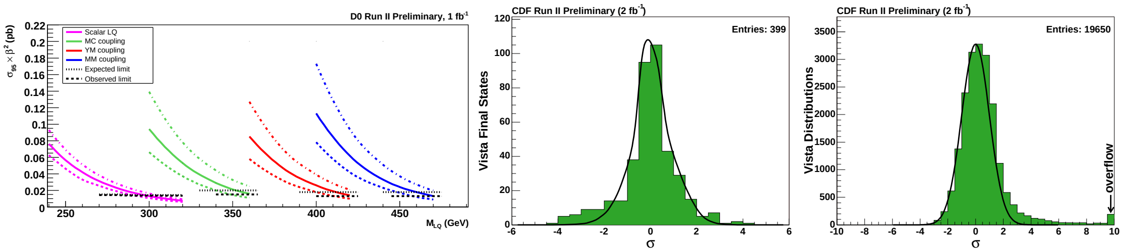

Fig. 6: (Left) Cross sections and limits as a function of the scalar and vector LQ mass (for three different coupling scenarios). The LO (vector LQ) or NLO (scalar) theoretical cross sections are drawn for different values of the renormalization scale. (Middle and Right) Overview of agreement between data and SM expectation in standard deviations for final states (middle) and kinematic distributions (right) in the model independent search.

7 Global search

The CDF collaboration has recently updated a model independent search for deviations from the SM with an integrated luminosity of 2 fb^{-1} [13]. Events are categorized in terms of their content in high p_T objects: electrons, muons, taus, photons, jets, b jets, and neutrinos ($\not{E}_T$). After applying several correction factors, the 399 final states are compared in terms of their normalization with the expectations from all SM processes. In a second step, a total of 19650 kinematic distributions are scrutinized. After accounting for the trial factors, remaining significant deviations (see Fig. 6) are interpreted as being due to the inadequate modeling of soft QCD effects.

8 Summary

D0 and CDF have searched for a wide variety of new phenomena beyond the SM. No signs for new physics have been found using an integrated luminosity of $1-3$ fb^{-1}. With more than 4 fb^{-1} recorded by each experiment, updates will remain interesting until the LHC delivers results.

References

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