

## NON SUSY SEARCHES AT THE TEVATRON

R.Vilar Cortabitarte

*Instituto de Física de Cantabria - CSIC/UC,*

*Av. Los Castros s/n*

*Santander, 39005, Spain*

The Fermilab Tevatron collider experiments, CDF and DØ, have collected  $\approx 200 \text{ pb}^{-1}$  of data at  $\sqrt{s} = 1.96 \text{ TeV}$  since March 2002 (RunII). Both experiments have investigated physics beyond the standard model; this paper reviews some of the recent results on the searches for new phenomena, concentrating on  $Z'$ , extra dimensions, excited electrons and lepto quarks. No signal was observed, therefore stringent limits on the signatures and models were derived.

### 1 Introduction

The Standard Model of particle physics (SM) has confirmed many of its predictions which have been measured with great accuracy over the past years. In spite of its success, there are some hints that it can not be a complete model: the electroweak breaking symmetry mechanism is not explained, gravity is not unified, there are hierarchy problems, etc. Several extensions to the SM have been proposed to address these issues: Extra Dimensions (ED), Grand Unified theories (GUT), Technicolor (TC), SUSY, etc. These models predict distinguishable signatures that can be seen at the experiments at small rates such as dilepton events, lepton plus jets, jets plus missing transverse energy ( $\cancel{E}_T$ ), etc. CDF<sup>1</sup> and DØ<sup>2</sup> have searched for these processes using  $\approx 200 \text{ pb}^{-1}$  of proton-antiproton collisions at  $\sqrt{s} = 1.96 \text{ TeV}$  collected from March 2002 to October 2004.

### 2 $Z'$ searches

A heavy partner of the Z boson, the so-called  $Z'$  boson<sup>3</sup>, is predicted in many extensions of the SM, such as GUT, ED models and little Higgs models among many others. It is a spin-1 object. The couplings to the SM fermions could be SM-like or modified. Both experiments have search for a  $Z'$  with SM-like couplings, as a reference model for experimental comparisons, and also for a model inspired by GUT SO(10) and  $E_6$  model using the conventions on<sup>4</sup> and<sup>5</sup> where additional Z-bosons originating from low energy  $E_6$  are discussed:  $Z_I, Z_\psi, Z_\chi, X_\eta$ . The primary observable is an anomalous production of dilepton pairs at large invariant masses. CDF and DØ have looked in the dielectron channels using  $\approx 200 \text{ pb}^{-1}$  of data, requiring high  $P_T$  electromagnetic objects in the calorimeters ( $P_T > 25 \text{ GeV}$ ). The main background comes from Drell-Yan production and QCD, and a small contribution from electroweak processes. Neither experiment observed any deviation from expectations, as shown in Figure 1 (left). They set a 95% C.L. upper limit, Figure 1 (right). CDF based on spin 1 particle for acceptance as a function of the boson mass produced an upper limit of 750 GeV for the SM-like case. DØ has set upper limit of 780 GeV

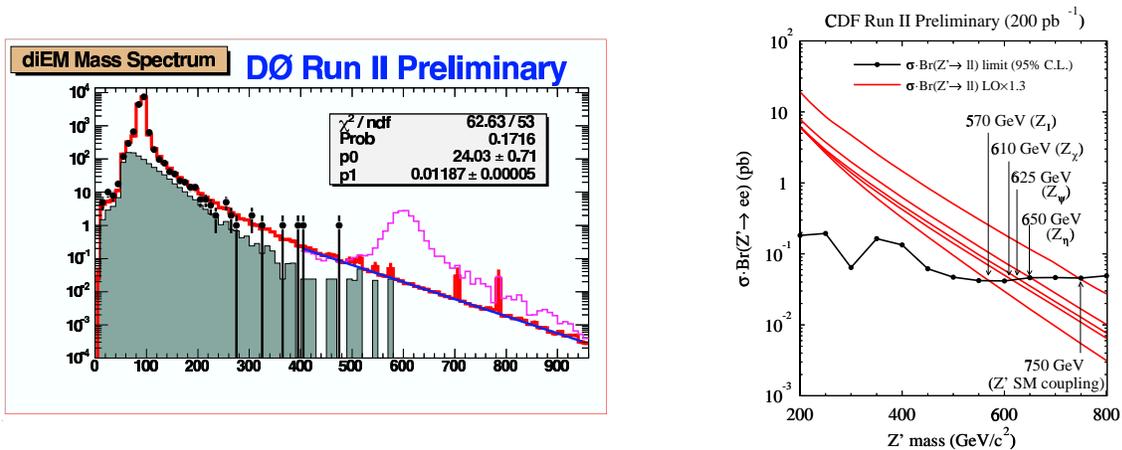


Figure 1: Left: Invariant mass distribution of the two electrons using the DØ detector. Points: data, shaded region: QCD background, open histogram: Drell-Yan plus QCD background. Blue line: fit to the background, magenta:  $Z'$  of 600 GeV. The fit parameter  $p1$  corresponds to the negative slope of the exponent while  $p0$  reflects the normalization. Right: CDF 95% C.L. upper limit for the different model of the  $Z'$  using the electron channel.

based on PYTHIA  $Z'$  simulation for acceptance and a search window optimized for each  $Z'$  mass. The limits were set in terms of  $Z'$  to  $Z$  cross section to reduce the systematic errors. For the  $E_6$  GUT model, lower limits found by CDF are 570, 610, 625 and 650 GeV respectively; while DØ found 575, 640, 650 and 680 GeV.

CDF has also used the muon channel, setting an upper limit of 735 GeV for the SM-like model and 518, 590, 620, 650 GeV for the  $E_6$ .

### 2.1 Little Higgs Model

This model<sup>6 7</sup> attempt to solve the hierarchy and fine tuning problems between the electroweak scale and the Planck scale. An explicit model<sup>7</sup> predicts new gauge bosons coupling to the SM fermions. The coupling, purely left-handed, are universal and scale linearly with the mixing angle. CDF has re-interpreted the result of the  $Z'$  analysis under this model assumption for both channels ( $e, \mu$ ), excluding a 95% C.L. region on the parameter space of the  $Z'$  mass and the mixing angle,  $\cot\theta$ . For  $\cot\theta = 1$ , masses are excluded up to 825(790) GeV for the electron (muon) channel.

## 3 Large Extra Dimensions (LED)

The hierarchy problem has motivated a number of models beyond the SM. In recent years, a number of models in ED have been proposed<sup>9</sup>: it might exist hidden dimensions in space of finite size  $R$  beyond the three we sense daily. In hadron-hadron collisions, real gravitons can be produced in association with jets or photons<sup>10</sup>. The graviton lives in the ED therefore invisible in the detector. The exact experimental observation is different for the different models.

### 3.1 ADD Extra Dimensions

In the so-called ADD<sup>11</sup> model, SM particles are confined to a 3D-brane, while gravity propagates freely in  $n$  ED, compact spatial dimensions, which explains its apparent weakness. The radius,  $\mathcal{R}$ , of these ED is  $\approx 1$  mm for  $n=2$  and less than 1nm for  $n>3$ . From direct gravitational measurement  $n<2$  is excluded<sup>12</sup>. The graviton is equivalent to a tower of Kaluza-Klein states, with a separation between different states of  $\mathcal{O}(10^{-4})$  due to the high energy of the experiments, therefore the mass spectrum is a continuum.

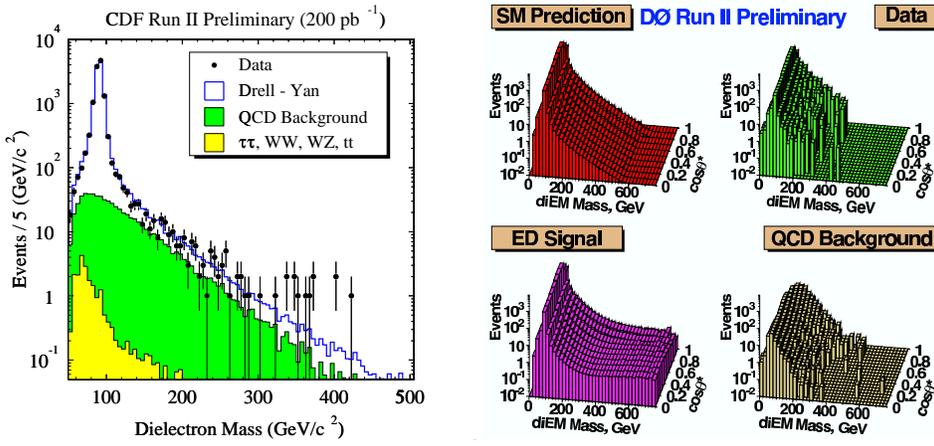


Figure 2: Left side: The invariant mass distribution of the two high  $P_T$  electrons in the event. Right side: The DØ diEM mass vs.  $\cos\theta$  distribution for backgrounds and signal

Both experiments have searched for these models. CDF has re-interpreted the result of the Z' analysis where no deviation of the invariant mass of the two high  $P_T$  electrons ( $E_T > 25$  GeV, and one of them  $\eta < 1.$ ) with respect to the SM predictions is observed, Figure 2 (left). DØ looks for high  $P_T$  ( $E_T > 25$  GeV and  $\eta < 1.1$ ) electromagnetic objects to maximize the efficiency. DØ sets limit using a 2-D fit to the invariant mass and the angular distributions, Figure 2 (right).

CDF set upper limit of  $M_S > 1.11$  TeV while the more optimized DØ (10-15% more sensitive) produces limit of  $M_S > 1.36$  TeV. DØ combines with the Run I results setting the most stringent limit to date,  $M_S > 1.43$ , in the GRW convention.

DØ looks also into the muon channel, only with  $100 \text{ pb}^{-1}$  of data, setting an upper limit  $M_S > 880$  GeV.

With a small sample of the data,  $85 \text{ pb}^{-1}$ , DØ starts a search for the real production of the graviton, where the graviton recoils against the jet and escapes undetected. The resulting topology is monojet-like, where the main backgrounds come from Z+jets production and a smaller contribution from W+jets production. The analysis<sup>13</sup> requires a high  $P_T$  leading jet ( $P_T > 150$  GeV in the central region), second jet ( $P_T < 50$  GeV),  $\cancel{E}_T > 150$  GeV, no leptons in the event and angular separation between the jet and  $\cancel{E}_T$ . The observed number of events is 63, the expected number is  $100 \pm 6 \pm 7$ . This gives an upper limit of 84 event while the expected limit is  $123.8 \pm 28$ . The current result is limited by the large MC and data jet energy scale uncertainties, which yields uncertainties of 20% for the signal efficiency and +50%, -30% for the background prediction. The result is an upper limit as a function of the number of ED, Figure 3

### 3.2 Randall-Sundrum Model

This model<sup>14</sup> proposes a large curvature of the ED to address the hierarchy problems by means of a non-factorisable geometry in a 5 dimensional space, with a constant negative curvature. Therefore the KK gravitons are very different to the ADD model, the mass and couplings of each KK state is determined by the warp factor, the spectrum of the KK states are discrete and unevenly spaced with a coupling strength of  $1/\text{TeV}$  for each resonance. The properties of the RS model are determined from the ratio of  $k/M_{pl}$ , where  $k$  is a scale of the order of the Planck scale and  $M_{pl}$  is the effective Planck scale.

CDF has done a search for the graviton particle in the dilepton channels ( $ee$  and  $\mu\mu$ ), reinterpreting the data used in the high mass dilepton search. There is no deviation from the SM prediction so they set an upper limit using the acceptance from a spin-2 particle and using a likelihood fit to the invariant mass distribution. They can exclude a region on the parameter

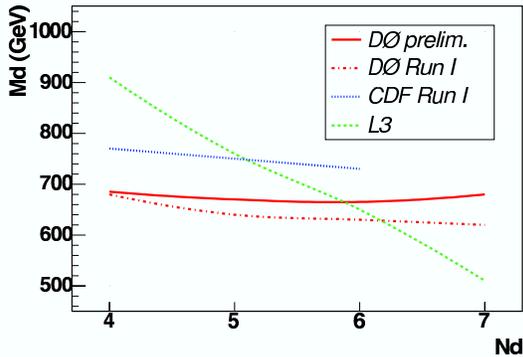


Figure 3: The  $D\bar{0}$  upper limit on the Planck scale as a function of the number of dimensions

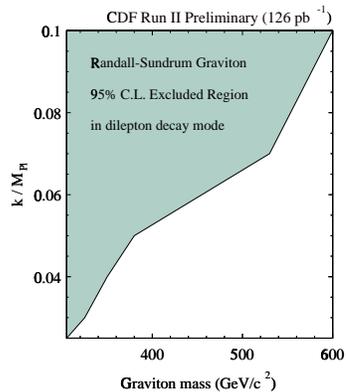


Figure 4: CDF 95% CL excluded region in the mass-coupling parameter for the Randall-Sundrum gravitons in the dielectron

space of the ratio and the graviton mass at 95% C.L, Figure 4.

### 3.3 $TeV^{-1}$ ED

In this model<sup>17</sup>, matter resides on a p-brane, with chiral fermions on the 3-brane internal to the p-brane and SM gauge bosons propagating in all p dimensions. The compactification scale in this model is of the order of  $1/M_c$ . The SM gauge bosons are equivalent to towers of Kaluza-Klein states with masses  $M_n = \sqrt{M_0^2 + n^2/R^2}$ . This rises mixing among the 0th and the nth-modes of the W/Z bosons and there is a direct production and virtual exchanges of the zeroth-states gauge bosons possible at high energies.  $D\bar{0}$  has performed a dedicated search in the dielectron channel, high  $P_T$  electron in the central region. This is the first direct search and it produces a limit of  $M_C > 1.12\text{TeV}$ . Indirect search at LEP imply  $M_c > 6.6\text{ TeV}$ .

## 4 Excited Electrons

The observation of excited particles would be a clear signal of the substructure of the matter. At hadron colliders excited electrons,  $e^*$ , could be produced through either contact interaction or gauge mediated interactions<sup>15</sup>. CDF has searched for  $e^*$  decaying into an electron and a photon using the  $200\text{ pb}^{-1}$ . An isolated central lepton with high  $P_T$  ( $P_T > 20\text{ GeV}$ ) and another EM object are required. There is no observation of any deviation from the SM prediction,  $Z\gamma$  + Drell-Yan,  $Z$ +jets, WZ, QCD multijets and  $\gamma\gamma$  + jets, after applying the selection criteria. Therefore upper limits are set and at 95% C.L a region in the parameter space of the electron mass and the  $M_{e^*}/\Lambda$  for the contact interaction model or  $f/\lambda$  for the gauge mediated model is excluded. The search for the contact interaction model is the first search done at hadron colliders. Figure 5 shows the excluded region for the two models.

## 5 LeptoQuarks

Leptonquarks(LQ) are color triplet bosons carrying both lepton and quark quantum numbers, they can be scalar(spin = 0) or vector(spin = 1). They are predicted in many extensions of the SM such as GUT, Technicolor, SUSY, etc<sup>18</sup>. At the Tevatron, they are pair produced mainly through gluon fusion or  $q\bar{q}$  annihilation. LQ can decay either into a charge lepton and a quark (branching ratio of LQ into charged lepton and a quark ( $\beta = 1$ ) or neutrino and a quark ( $\beta =$

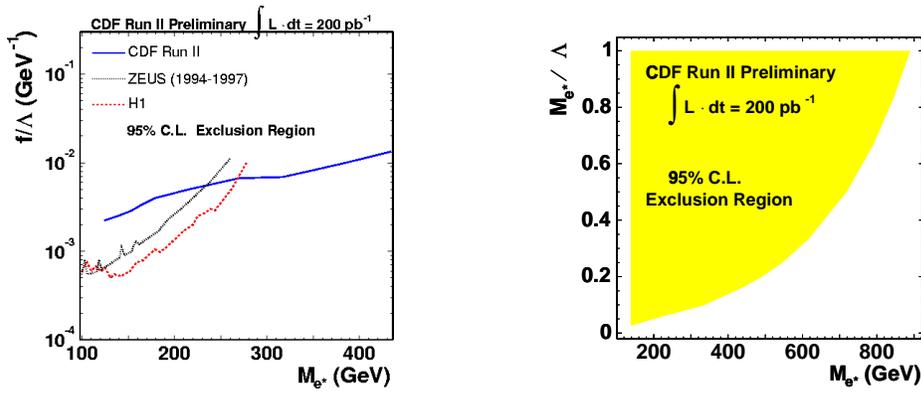


Figure 5: CDF 95% CL excluded region in the mass parameter versus  $f/\lambda$  for the gauge mediated model or versus  $M_{e^*}/\Lambda$  for the contact interaction model.

0). Both experiments have looked for scalar LQ, assuming that they only couple to quarks and leptons of the same generation.

### 5.1 First Generation LQ

DØ and CDF have looked into the  $LQLQ \rightarrow e^\pm e^\mp jj$  and  $LQLQ \rightarrow e^\pm \nu jj$ . DØ has used  $175 \text{ pb}^{-1}$  for both channels, CDF has used  $200 \text{ pb}^{-1}$  of data for the first while only  $72 \text{ pb}^{-1}$  for the latter. They required two electrons with high  $P_T$ ,  $E_T > 25 \text{ GeV}$  and at least two jets reconstructed in the calorimeter. To reduce the main backgrounds coming from Z/Drell-Yan,  $t\bar{t}$  and QCD, topological cuts are applied. There is no deviation from the expectations. DØ finds an upper limit on the LQ mass  $M > 238$  (194) GeV for the  $eejj(e\nu jj)$  channel, while CDF finds 230(166) GeV. The results from these channels have been combined and the derived lower mass limit as a function of the  $\beta$  is shown in Figure 6.

### 5.2 Second Generation LQ

CDF and DØ have done a search for the second generation LQ decaying through the channel  $LQLQ \rightarrow \mu\mu jj$ . CDF has done the analysis with  $198 \text{ pb}^{-1}$  of data, while DØ uses  $104 \text{ pb}^{-1}$ . The events are required to have at least two opposite-sign muons with high  $P_T$ ,  $P_T > 25 \text{ GeV}$  and two jets. To reduce the background coming from Z/Drell-Yan and  $t\bar{t}$ , kinematical and topological cuts are applied. The events passing the selection criteria are consistent with the SM expectation. LQ mass below 240 GeV is excluded by CDF, while DØ obtains a limit of  $M > 186 \text{ GeV}$ .

### 5.3 All Generation LQ

CDF has searched for all generation LQ in the  $LQ \rightarrow qq\nu\nu$  channel with  $191 \text{ pb}^{-1}$  of data. The events selected contain two or three jets and large  $\cancel{E}_T$ <sup>19</sup>, with different directions to reduce QCD background. Events with charged leptons ( $e$  or  $\mu$ ) are vetoed to reduce the  $W/Z$ +jets and  $t\bar{t}$  processes. The number of observed events is 124 consistent with the SM prediction of  $118 \pm 14$  events. At 95% C.L. a mass region from 78 GeV to 117 GeV is excluded, Figure 7.

## 6 Summary

The CDF and DØ collaborations are actively searching for new physics beyond SM using  $200 \text{ pb}^{-1}$  collected from March 2002 to October 2003 (RUNII). Although no evidence for new physics has been found so far, the results have already improved those of Run I. The discovery potential

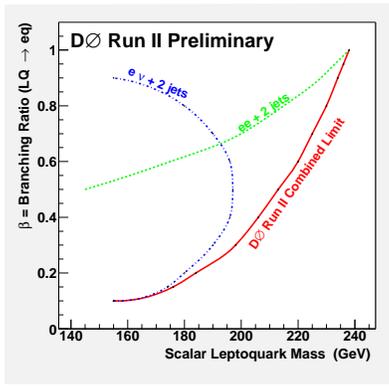


Figure 6: DØ 95% C.L. lower limit on the mass of the first generation LQ as a function of  $\beta$

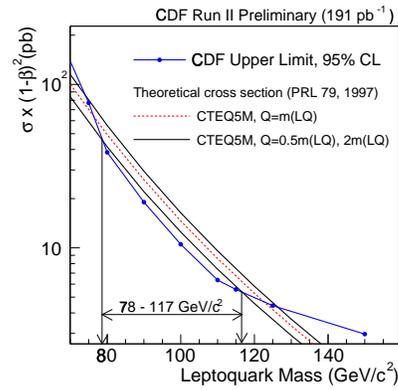


Figure 7: CDF 95% CL upper limit cross section times the squared branching ratio for scalar LQ pair production ( $\beta = 0$ ).

risers as the integrated luminosity increases, providing the best opportunity for finding it before LHC starts.

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