Beyond the standard model searches at the Tevatron

G. Sajot

Beyond the Standard Model Searches at the Tevatron

G. SAJOT, on behalf of the CDF and DØ Collaborations
LPSC 53 Avenue des Martyrs 38026 Grenoble France

Recent searches for non-SUSY exotics in $p\bar{p}$ collisions at a center-of-mass energy of 1.96 TeV at the Tevatron Run II are reported. The emphasis is put on the results of model-driven analyses which were updated to the full Run IIa datasets corresponding to integrated luminosities of about 1 fb^{-1}.

I. INTRODUCTION

Numerous searches for extensions of the Standard Model (SM) are conducted at the Tevatron Run II. In this report we concentrate on the model-driven analyses that were recently updated by CDF and D0 collaborations to the full Run IIa datasets, representing integrated luminosities of about 1 fb^{-1}. Details about these analyses can be found in reference [1]

The SM is constructed with the following ingredients : it's a quantum field theory where the matter fields are replicated into three families of quarks and leptons. This field theory is placed into a four-dimensional space-time. Its Lagrangian is invariant under the Poincaré group and under the $SU_C(3) \times SU_L(2) \times U_Y(1)$ gauge group. The electroweak symmetry breaking is provided by the Higgs mechanism. Up to now, all the experimental tests of the SM have shown no significant deviations with respect to its predictions. However the SM leaves many questions unresolved and is clearly not a full and a satisfactory theory. Therefore many theoretical ideas have been proposed to extend it. Among these ideas is a possible sub-structure of the particles considered as elementary in the SM. This could explain the replication of the quarks and leptons into three families.

Another path is a possible extension of the SM gauge symmetries. This enables to envisage a unification of the three fundamental interactions described by the SM at a very high energy scale, whilst explaining their differences at low energy as results of different symmetry breakings. One can also postulate the existence of extra space dimensions that could explain the hierarchy between the Planck and the electroweak scales as well as the relative weakness of the gravitational interaction with respect to the three other fundamental interactions.

Searches for fermions sub-structure are reported in sections II and III, section IV is devoted to a search for an additional quark generation and sections V and VI contain searches for hints of extended gauge symmetries and of extra space dimensions respectively. All the exclusion limits in this note are given at the 95% confidence level.

II. SEARCH FOR LEPTOQUARKS

As predicted by numerous extensions of the standard model, leptoquarks (LQ) are hypothetical bosons allowing lepton-quark transitions [2]. In hadron collisions, the pair production of scalar leptoquarks (LQ) is a pure QCD process : $q\bar{q} \rightarrow LQ\bar{LQ}$. Thus the cross section depends on the LQ mass and not on the unknown coupling (λ) between the LQ and its associated lepton and quark (if one neglects the contribution due to the t-channel lepton exchange which is very small compared with the theoretical uncertainties on the cross section).

D0 performed a search for second generation scalar LQ in the $LQ_2 + LQ_2 \rightarrow \mu\ \nu\ q'\ \bar{q}$ channel, in a dataset of $\int Ldt = 1.05 fb^{-1}$. Events containing a high p_T ($>$ 20 GeV) and isolated muon plus jets and large missing transverse energy ($\not{E}_T >$ 30 GeV) are selected. The left hand side of Figure 1 shows the LQ_2 reconstructed mass, i.e. the invariant mass of the muon-jet which is closer to the assumed leptoquark mass (and not differing from it by more than 100 GeV). On this plot, the leptoquark sample is generated with $M_{LQ} = 200$ GeV and $Br(LQ \rightarrow \mu\ q) = 0.5$. Clearly, the data are background-like. A limit excluding $M_{LQ_2} < 210$ GeV is set in the hypothesis of this semi-leptonic decay of the LQ_2 pairs.

FIG. 1: D0 collaboration : distribution of the reconstructed LQ_2 invariant mass (M_{LQ_2}) in a $LQ_2 + L\bar{Q}_2 \rightarrow \mu\nu q\bar{q}'$ search (left) and excluded domain in the plane Λ (compositeness scale) versus m_{e*} by a search for excited electrons (right).

III. SEARCH FOR EXCITED ELECTRONS

For the hypothesis of quarks and leptons compositeness as detailed in reference [3], the main parameters are the excited fermion mass M_f^* and the compositeness scale Λ. We report a search for excited electrons (e^*) carried by D0 with an integrated luminosity of 1.0 fb^{-1}. It is assumed that the excited electrons are produced via the contact interaction process $q\bar{q} \rightarrow e^{*\pm}e^{\mp}$ and that the $e^{*\pm}$ subsequently decays into the $\gamma + e^{\pm}$ mode. This leads to $\gamma e^{\pm}e^{\mp}$ final states. The analysis essentially consists in selecting events with two high p_T (> 35 GeV and > 15 GeV) and isolated electrons plus an energetic ($E_T > 15$ GeV) and isolated photon and to search for a resonance in the $M_{\gamma e^{\pm}}$ distribution. Since no excess of data is found with respect to the SM background, exclusion limits are derived in the Λ and $M_{e^{*\pm}}$ plane, as shown on right hand side of Figure 1. For example, for $\Lambda = 1$ TeV, e^* masses below 756 GeV are excluded.

IV. SEARCH FOR 4TH GENERATION QUARK b'

CDF searched for new particles that lead to a Z boson plus jets in the final state in a data sample with an integrated luminosity of 1.06 fb^{-1}. Z boson decays to ee and $\mu\mu$ are considered. A completely data-based method has been developed to predict the dominant background from standard-model Z+jet events. No significant excess above the background prediction is observed, and a limit is set using a fourth generation quark model to quantify the acceptance. Assuming $BR(b' \rightarrow bZ) = 100\%$ and using a leading-order calculation of the b' cross section, b' quark masses below 268 GeV are excluded (see Figure 2).

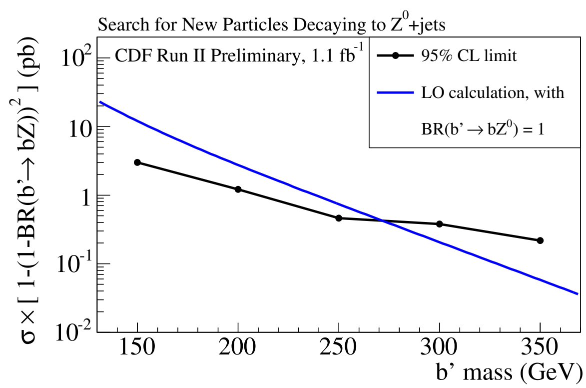

FIG. 2: CDF search for b' : cross section limit vs b' mass.

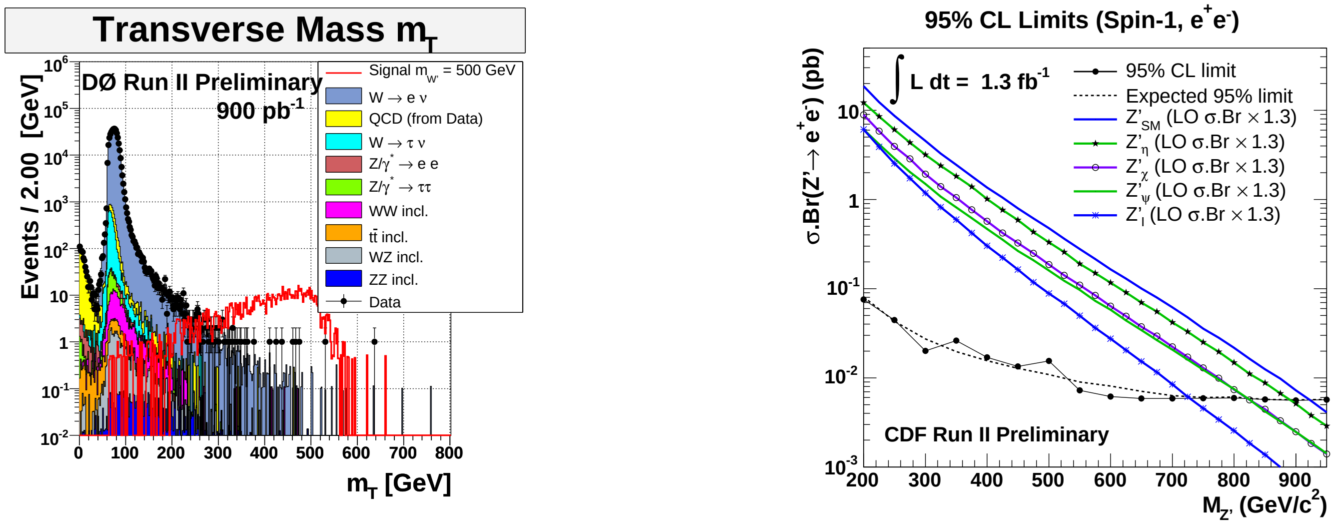

FIG. 3: Searches for new heavy gauge bosons : W' by D0 (left) and Z' by CDF (right)

V. EXTENDED GAUGE SYMMETRY

If there exists a grand unification of the strong and the electroweak interactions at a high energy scale, then the breakdown of the corresponding gauge group (i.e. SU(5), SO(10), E6,...) down to the SM gauge group occurs through a cascade of symmetry breakings where extra SU(2) and U(1) factors may appear. Such extra gauge group factors predict the existence of new and heavy W and Z bosons denoted W' and Z'.

We present a D0 search for the $W' \to e^{\pm}\nu$ process in a dataset of $\int Ldt = 0.9\ fb^{-1}$. The events are selected if they contain a high E_T ($>$ 30 GeV) and isolated electron and a significant missing transverse energy ($\not{E}_T >$ 30 GeV). The transverse mass $M_T(e^{\pm}, \not{E}_T)$ distribution displayed on the left hand part of Figure 3 is scrutinized especially above 150 GeV. No data excess is found on top of the SM background tail. Therefore a W' with a mass below 965 GeV is excluded.

We present a CDF search for the $Z' \to e^+e^-$ process using a data sample of $\int Ldt = 1.29\ fb^{-1}$. The analysis selects events with two high E_T ($>$ 25 GeV) and isolated electrons with at least one in the central part of the calorimeter and with a matching track. Here the signal region is defined as the tail (above 150 GeV) of the dielectron invariant mass. The data are in good agreement with the SM background causing a Z' with a mass lower than 923 GeV and SM-like couplings to be excluded (see right hand part of Figure 3).

VI. EXTENDED NUMBER OF SPACE DIMENSIONS

The lack of precision measurements of gravity in the sub-millimeter domain leaves some room for possible departures from the Newton's law in this distance range. Such exotic behaviors are obviously predicted in the assumption that space has more than three 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 $M_{Planck} \approx 10^{16}$ TeV, at which gravity is expected to become strong, and the scale of electroweak symmetry breaking $\approx$ 1 TeV.

One such model by Randall and Sundrum (RS) [4] localizes gravity on a (3+1)-dimensional brane, the Planck brane, that is separated from the standard model brane in a fifth dimension with warped metric. Gravity lives on the second brane where it isn't weak, but can propagate along the fifth dimension. The gravitons appear as towers of Kaluza-Klein excitations with masses and widths determined by the parameters of the model. 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 $\kappa\sqrt{8\pi}/M_{Planck}$.

The Arkani-Hamed, Dimopoulos and Dvali (ADD) model [5] also localizes the SM fields on one brane and allows gravity to propagate within a bulk possibly made of up to N = 7 large extra dimensions. Here Kaluza-Klein excitations of the gravitons cannot be resolved. At the Tevatron, gravitons can be produced recoiling against a quark or gluon jet. The large number of kinematically accessible states compensating for the small gravitational coupling to give a

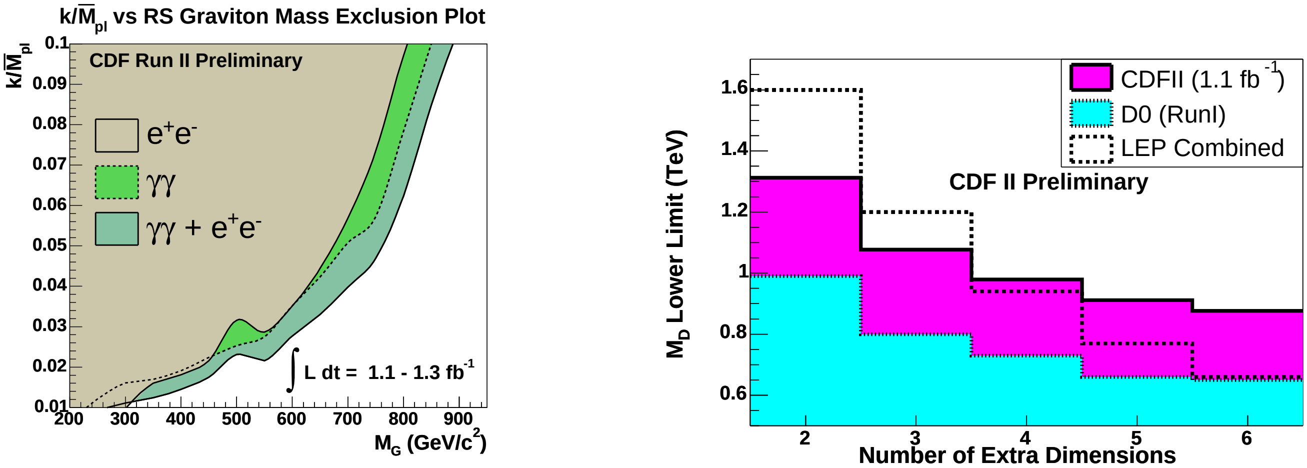

FIG. 4: CDF searches for extended number of space dimensions in the Randall-Sandrum (left) and the Arkani-Hamed, Dimopoulos and Dvali (right) models.

sizable cross section. The parameters are the number of extra dimensions N and the effective Planck scale M_D (i.e. the Planck scale in 4+N dimensions).

CDF has searched for RS gravitons in the two decay channels $G \rightarrow e^+e^-$ and $G \rightarrow \gamma\gamma$. The individual exclusion domain and the combination of the two are displayed at the left hand side of Figure 4. We also report on a CDF search for ADD gravitons in a $1.1 fb^{-1}$ dataset. In these LED models, gravitons that are produced directly in processes such as $q\bar{q} \rightarrow gG$, $qg \rightarrow qG$, or $gg \rightarrow gG$ escape undetected in the bulk of extra dimensions, leaving the final state quark or gluon to produce a single jet. Hence the analysis requires events with a very high E_T jet (> 150 GeV) contained in the central part of the calorimeter and confirmed by tracks. In order to allow for a gluon ISR or FSR a second soft jet (E_T jet < 60 GeV) is accepted. The discriminating variable is the $\not{E}_T$, which is compatible with the expected background. Consequently exclusion limits are derived as a function of the number of extra dimensions and the effective Planck scale, M_D, as shown on the right hand side of Figure 4.

VII. CONCLUSION

Many searches covering very different topologies have been studied at the Tevatron Run II by the CDF and D0 collaborations. Despite the recent updates of some of these analyses to the full Run IIa datasets of about $1 fb^{-1}$, no hints of exotic extensions of the SM have been found and more stringent exclusion limits have been derived.

[1] http://www-d0.fnal.gov/Run2Physics/WWW/results/np.html
http://www-cdf.fnal.gov/physics/exotics/exotic.html
[2] J.C. Pati and A. Salam, Phys. Rev. **D10**, 275 (1974)
H. Georgi and S.L. Glashow, Phys. Rev. Lett. **32**, 438 (1974)
W. Buchmuller and D. Wyler, Phys. Lett. **B177**, 377 (1986)
E. Eichten, K.D. Lane, and M.E¿ Peskin, Phys. Rev. Lett. **50** 811 (1983)
E. Eichtein, I. Hinchliffe, K.D. Kane, and, C. Quigg, Phys. Rev. **D34**, 1547 (1986)
[3] U. Baur et al., Phys. Rev. **D42**, 815 (1990)
[4] L. Randall and R; Sundrum, Phys. Rev. Lett. **83**, 3370 (1999)
[5] N. Arkani-Hamed, S. Dimopoulos, and D. Dvali, Phys. Lett. **B429**, 23 (1998)