PROCEEDINGS OF SCIENCE

BSM (non SUSY) searches at Tevatron

Marie-Claude Cousinou*
On behalf of the CDF and D0 collaborations
E-mail: cousinou@cppm.in2p3.fr

Many extensions of the Standard Model, other that Supersymmetry, predict the existence of new heavy resonances or heavy quarks, the existence of extra dimensions which will manifest themselves by the presence of gravitons states, or a possible compositeness of quarks and leptons. Results of some of the "Beyond Standard Model" searches made by the CDF and D0 collaborations at the Tevatron are presented. These analyses are using data corresponding to an integrated luminosity up to 4.1 fb^{-1}. Searches for Z', W', graviton, a new quark b', quark compositeness, Leptoquarks or new long-lived particles are described here.

XXth Hadron Collider Physics Symposium
November 16 – 20, 2009
Evian, France

*Speaker.

PoS(HCP2009)031

1. Searches for high mass resonances decaying in l^+l^- or dibosons

Many extensions of the SM model predict new heavy resonances decaying in fermion-antifermion or dibosons, such as Z' , W' or gravitons. Both collaborations have searched for such new states. Results on W' or Z' are given using a Sequential Standard Model (SSM) parametrization. Results on Z' are also given in the scheme of E_6 models. In these models two additional neutral massive spin 1 gauge bosons, than can mix with an arbitrary angle, are predicted. The different Z' types studied correspond to specific values of the mixing angle. In extra spatial dimensions models such as the Randall-Sundrum model used in these analyses, the gravitons G propagate in the extra dimension. The parameters of the models are the mass M_G of the first excited mode of the graviton and the dimensionless coupling to the SM fields k/M_{pl}, where k^2 is the space time curvature in the extra dimension and M_{pl} the reduced Planck mass. k/M_{pl} is expected to be between 0.01 and 0.1.

1.1 Search for high mass ee or $\mu\mu$ resonances

CDF [1], using a sample of data corresponding to an integrated luminosity of 2.5 fb^{-1}, and D0 on a sample of 3.6 fb^{-1} have selected events with two high P_T electrons. CDF has observed a 2.5σ excess of events around an ee invariant mass equal to 240 GeV. This excess has not been confirmed by D0. Both experiments gave limits at 95 % C.L. on the Z' mass which are summarized in Tab. 1. Lower limits have been also given on the mass of the graviton as a function of the parameter k/M_{pl} by CDF and for two values of this parameter by D0. As an example if $k/M_{pl} = 0.1$, the observed mass limits obtained by CDF and D0 are equal to 848 GeV and 786 GeV respectively.

	Obs. lower limits on Z' masses (GeV)						
Z' model	Z'_{SM}	Z'_{Ψ}	Z'_{χ}	Z'_{η}	Z'_{I}	Z'_{seq}	Z'_{N}
CDF ($Z' \to ee$)	963	851	862	930	735	792	837
D0 ($Z' \to ee$)	950	763	800	810	692	719	744
CDF ($Z' \to \mu\mu$)	1030	878	892	904	789	821	861

Table 1: Limits on the mass of a Z' decaying in ee or in $\mu\mu$ for different Z' models

CDF has made a search for a Z' or a graviton decaying in $\mu^+\mu^-$ in a sample of events corresponding to an integrated luminosity of 2.3 fb^{-1} [2]. They looked for a pair of oppositely charged muons with high P_T values. No excess of events compared to the Standard Model expectation has been observed and the limits obtained on a Z' mass are given in Tab. 1. The 95 % C.L. limit on the cross-section times the branching fraction of the G in $\mu^+\mu^-$ is shown on Fig .1. The graviton mass lower limit varies between 293 GeV if $k/M_{pl} = 0.01$ to 921 GeV if $k/M_{pl} = 0.1$.

1.2 Search for high mass dibosons resonances

A search for WW and WZ resonances has been done by CDF, using a sample of data corresponding to an integrated luminosity of 2.9 fb^{-1}. They selected events with an electron and missing transverse energy corresponding to the W boson decay and two or three high E_T jets which are used to form the other W or Z boson. An additional cut on the sum of all transverse energies $H_T > 150$ GeV is applied. At the end of these cuts, a good agreement between the number of data left and the

expected background is observed and limits on Z', W' and G masses are derived. They are obtained using higher E_T cuts tuned to find the best expected cross-section limit for each object and each mass. They are shown on Fig. 1 for the Z'. The observed exclusion range for the W' is 284 - 515 GeV and the observed lower limit on a graviton G mass is equal to 600 GeV.

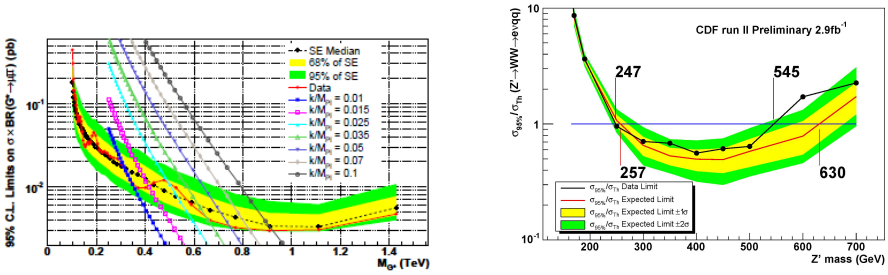

Figure 1: Left: 95% C.L limit on the $\sigma \times BR(G \to \mu^+\mu^-)$ as a function of M_G. Right: Ratio of the $\sigma * BR(Z' \to WW)$ limit and the theoretical σ as a function of $M_{Z'}$.

D0 [3] (4.1 fb^{-1}) has searched for a WZ resonance in a final state corresponding to a full leptonic decay of the two bosons : $l^{\pm}l^{\mp}l^{\pm}\nu$. The two highest P_T charged leptons are used to form the Z and the third lepton and the transverse missing energy to build the W. Cuts are applied in the η - ϕ plane, to insure that the two leptons associated to the Z are isolated from the W direction.
9 events are observed , which is in good agreement with a total expected SM background equal to 10.2$\pm$ 1.2 events. Assuming a SSM parametrization, a W' with a mass between 188 and 520 GeV is excluded. On Fig.2 the exclusion in the plane of the ratio of the $W'WZ$ and SSM coupling strengths versus the W' mass is shown. The same analysis is used to constraint the low scale Technicolor model (LSTC). In this model the branching fraction of the ρ_T into WZ depends strongly on the relative masses of the technipion π_T and the ρ_T. If M_{π_T} is smaller or of the order of M_{ρ_T}, the ρ_T decays predominantly in WZ. On Fig.2 showing the exclusion area in the plane M_{π_T} versus M_{ρ_T}, one can see that most of the allowed phase space where $\rho_T \to WZ$ is dominant is excluded.

Finally CDF has made a search for a ZZ resonance using the full leptonic decays of both Z ($l^{\pm}l^{\mp}l^{\pm}l^{\mp}$), where l denotes an e or a μ and the decay channels ($l^{\pm}l^{\mp}$) + 2 jets. Several analyses, using data samples with an integrated luminosity varying between 2.5 and 2.9 fb^{-1} have been combined. For the four leptons channels, the two leptons pairing is chosen as the combination which minimizes a χ^2 variable quantifying consistence between the dilepton masses and the Z pole mass. No excess of events have been observed and a lower mass limit M_G equal to 491 GeV has been found for a Kaluza-Klein Graviton if k/M_{pl}=0.1.

2. Searches for quark compositeness and extra spatial dimensions

Both CDF (1.1 fb^{-1}) and D0 (0.7 fb^{-1}) [4] have searched for quark compositeness in events with at least two jets. They measure distributions in the dijet variable $\chi_{dijet} = exp(|y_1 - y_2|)$ in

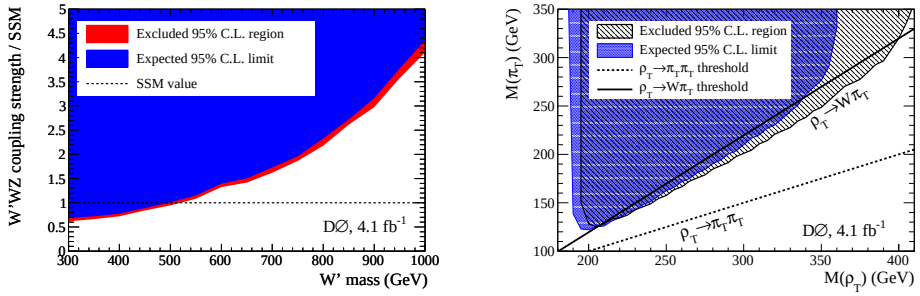

Figure 2: Left: limits in the plane: ratio of the $W'WZ$ and SSM coupling strengths versus $M_{W'}$. Right: limits in the plane M_{π_T} versus M_{ρ_T}

regions of dijet invariant mass M_{jj}, where y_1 and y_2 are the rapidities of the two jets with highest transverse momentum. The χ_{dijet} variable is related to the polar scattering angle in the partonic center-of-mass frame. An excess at large M_{jj} and small χ_{dijet} would be a sign of new physics processes such as substructure of quarks or the existence of extra dimensions. On Fig.3 the result obtained by D0 is shown. The agreement observed between the data and the expectation of the SM allows both experiments to give limits on the energy scale Λ for the quark compositeness. Λ has been found to be greater than 2.4 TeV by CDF and greater than 2.9 TeV by D0. D0 has also discussed their result in the scheme of two Large Extra Dimensions models. As an example for the *ADD LED* model, they found the effective planck scale $M_S > 1.97$ TeV (for n_d number of extra dimensions = 3). In the $TeV^{-1}ED$ model, they gave a lower limit equal to 1.59 TeV on the compactification scale.

3. Searches for fourth generation down type quark b'

A search for a heavy particle decaying in $W + top$ has been performed by CDF (2.7 fb^{-1}). The events with two same-charge leptons (e or μ), where at least one lepton is isolated, at least 2 jets including one b-tag jet and missing transverse energy are selected. The main backgrounds come from W production in association with a light-flavor jet which is misidentified as a lepton, or from $t\bar{t}$ production with semi-leptonic decays. Two events (1 $\mu\mu$ and 1 $e\mu$) passed all the cuts, in agreement with the expected background equal to 1.9 ± 1.4 events. To calculate the most likely signal cross-section, a binned maximum-likelihood fit to the number of reconstructed jets is performed. The cross-section limit result at 95 % C.L. is plotted on Fig.3. This limit is converted in the exclusion of a fourth generation quark b' with a mass above 325 GeV. This is the most restrictive direct lower limit on the mass of a down-type fourth-generation quark.

4. Searches for Leptoquarks

Leptoquarks (LQ) are predicted by many extensions of the SM connecting the quark and lepton sectors. LQ states could be scalar or vector. They couple directly to leptons ($l^{\pm}$ or ν) and quarks. In the following β denotes the branching fraction of a LQ to a charged lepton and a quark. Three generations of LQ are predicted corresponding to the three families of the SM. They will be noted

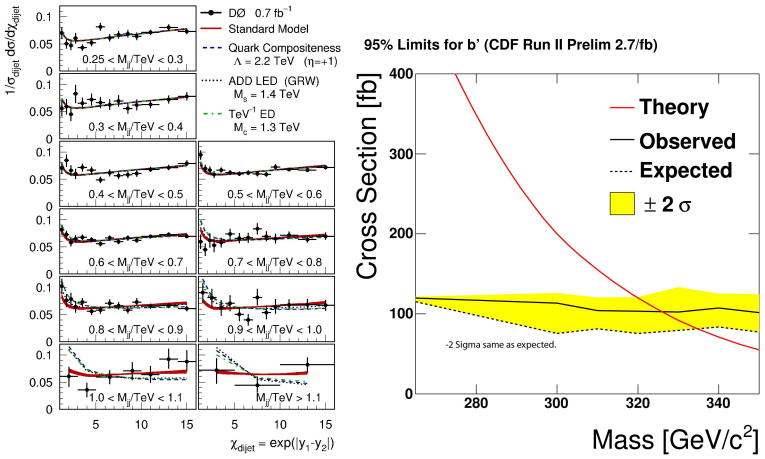

Figure 3: Left: Angular dijet distributions as a function of χ_{dijet} for different M_{jj} bins. Right: b' cross section limit as a function of the b' mass.

LQi $i = 1,3$ below. At the Tevatron LQ's are predominantly produced in pairs. Both CDF and D0 have made searches for LQ. In case where both LQ's decay in $\nu + q$ the final state consists in two jets plus missing transverse energy. CDF and D0 [5] using data corresponding to an integrated luminosity of 2 fb^{-1} and 2.5 fb^{-1} respectively, and assuming that $\beta = 0$, obtained lower mass limits, for the LQ1 or LQ2 indistinctly, equal to 190 GeV (CDF) and 205 GeV (D0). A specific search for pair production of LQ3, both decaying in a b quark and a ν_{tau} has been performed by D0 (4 fb^{-1}). The limit obtained on the cross-section times the square of the LQ branching ratio is shown on Fig. 4. This study excludes a LQ3 with $M_{LQ} \leq 252$ GeV. Searches for pair production of scalar LQ of first and second generations decaying in $l^{\pm}q$ or νq have also been done by D0 [6, 7] based on an integrated luminosity of 1 fb^{-1}. Limits are given in the plane of β versus M_{LQ}. As an example the LQ2 mass lower mass limit is equal to 316 GeV, assuming that β=1. The limit obtained in the LQ1 case is given on Fig.4, where the results shown for low values of β result from a combination with the analysis [5] of a final state with two jets and missing transverse energy. In the LQ1 analysis, a search has been made also for a pair production of vector LQ's. Lower mass limits are given, as a function of anomalous couplings. Assuming β=1 and the anomalous coupling values which give the highest LQ cross-section, a lower mass limit equal to 472 GeV is found.

5. Searches for Long Lived Neutral Particles (LLNP)

In the scheme of the Hidden-Valley (HV) models, the production of particles which hadronize producing "v-hadrons" which could be long-lived is predicted. The D0 experiment has made a search for pair production of Neutral Long-Lived Particles decaying to $b\bar{b}$. They look for pair of displaced vertices in a sample of data which corresponds to an integrated luminosity of 3.6 fb^{-1} [8]. In the model used as a benchmark it corresponds to the interaction $g + g \rightarrow H \rightarrow v - hadron + v - hadron \rightarrow (b\bar{b})(b\bar{b})$, where H stands for the Higgs of the Standard Model. No significant excess has been observed and upper limits are set in the context of the HV benchmark model used. Depending on the signal parameters, Higgs boson production about 1-10 times the SM cross-

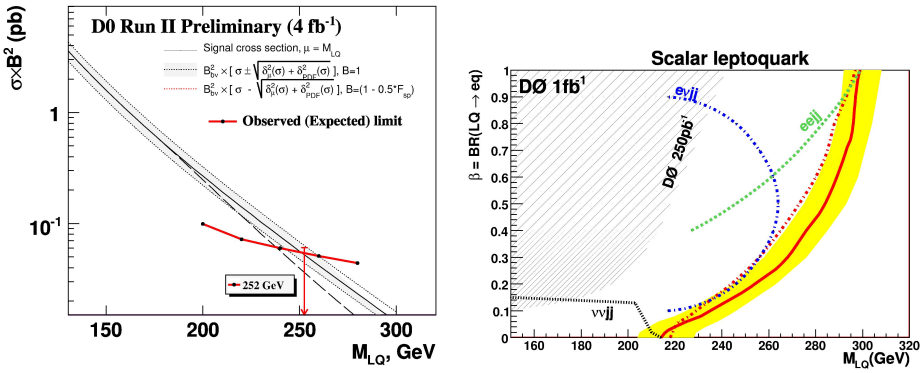

Figure 4: Left: 95% C.L limit on the $\sigma \times BR^2$ as a function of M_{LQ} for a pair production of scalar LQ3. Right: Limit for pair production of a scalar LQ1 in a plane β versus M_{LQ}

section is excluded , if the Higgs boson always decays to a pair of long-lived $v-hadrons$ decaying only to $b\bar{b}$.

6. Conclusion

CDF and D0 have both covered many BSM searches using an integrated luminosity of up to 4.1 fb^{-1}. No significant excess of events over the Standard Model expectations has been observed and they gave limits on the production cross sections and the masses of new particles. Both collaborations are now analysing on 6.5 fb^{-1} already recorded by each experiment. The Tevatron is performing better than ever and will deliver up to 12 fb^{-1} by 2011.

References

[1] CDF collaboration, PRL 102, 031801(2009).

[2] CDF collaboration, PRL 102, 091805(2009).

[3] D0 collaboration, PRL 104, 061801(2010).

[4] D0 collaboration, PRL 103, 191803(2009).

[5] D0 collaboration, PLB 668, 357(2008).

[6] D0 collaboration, PLB 681, 224(2009).

[7] D0 collaboration, PLB 671, 224(2009).

[8] D0 collaboration, PRL 103, 071801(2009).