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SEARCHES FOR NEW PHYSICS AT TEVATRON

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Abstract

This paper reviews the most recent results on searches for physics beyond the Standard Model at Tevatron. Both the collider experiments: CDF and DØ are performing a large variety of searches such as searches for scalar top and scalar bottom particles, search for new gauge bosons, search for long-lived massive particles and general searches for new particles decaying into dijets. The results, summarized here, are a selection of what obtained recently by both the collaborations using the Run II data, collected so far.

1 Introduction

In the past two decades, Collider facilities have been places where searches for physics beyond the Standard Model (SM), as well as precise SM tests, have been pursued with great determination. Since March 2001, CDF and DØ [1][2], the two Tevatron Experiments, are collecting data at the world highest colliding beam machine energy ($\sqrt{s} = 1.96\ TeV$). At the present, April 2003, $\sim 150\ pb^{-1}$ have been accumulated by each experiment. Most of the analysis described in this paper are based on an integrated luminosity ranging between 30 and 76 pb^{-1}.

2 Search for new particles decaying to dijets

Many models predict the existence of new particles decaying, with large branching fraction, in two partons. The dijet final states, arising from such a decays, are often difficult to search because of the large associated QCD background and the poor mass resolution achievable. However, these disadvantages are partially compensated by the large dijet statistics available. This allows exclusion cross sections that are a small fraction of the total dijet cross section. Figure 1 (left) shows the comparison between the Run I and Run II dijet spectrum. CDF-II has obtained generic 95% C.L. upper limits on the cross sections for narrow new resonances as a function of the mass. The obtained upper limits have been compared to the production cross sections for a variety of model as Axigluons, Flavor Universal Colorons, Excited Quarks and E_6 diquarks. The extracted 95% C.L. limits, obtained for the different models under consideration, are quoted in Table 1. Most of these limits extends already Tevatron Run I exclusions into previously unexcluded mass regions.

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MODEL	Run II (GeV/c^2)	Run I (GeV/c^2)
Axigluon	$200 < M_A < 1130$	$200 < M_A < 980$
Excited Quarks	$200 < M_* < 760$	$200 < M_* < 570$
		$580 < M_* < 760$
Color Octet Technirhos	$260 < M_\rho < 640$	$260 < M_\rho < 480$
E_6 diquarks	$280 < M_{E_6} < 420$	$290 < M_{E_6} < 420$
W'	$300 < M_{W'} < 410$	$300 < M_{W'} < 420$
Randall-Sundrum Gravitons	$K/M_{Pl} = 0.3$, $220 < M < 840$	--

Table 1: Results on searches for new particles looking for dijet narrow resonances; all the limits are expressed at 95% C.L. (CDF-II).

3 Search for long-lived charged massive particles

The existence of long-lived CHArged Massive Particles (CHAMPs) is predicted in several theoretical models. Typically, CHAMPs are expected to decay promptly. Most searches, consequently, attempt to isolate distinctive decay signatures involving leptons, jets and missing transverse energy ($\not{E}_T$). There are, anyhow, circumstances in which, one or more of these new massive particles, can acquire a lifetime, that is long compared to the typical time required to pass through an experimental setup such as a high energy physics detector. If CHAMPs are long-lived enough to escape from the detector, then, the signature will be essentially a slow heavy charged particle, that can be detected using the large dE/dx or the large time of flight. Between the models that predict the existence of long-lived CHAMPs, there are SUSY extensions of SM with one compactified extra dimension [3]. These models provide a highly specific prediction. CHAMPs are a stop squarks with a mass around 200 GeV/c^2. CHAMPs are also expected within the context of Gauge Mediated SUSY Breaking models (GMSB) [4]. In this case, if the scale of the SUSY breaking sector is sufficiently large, the next to lightest SUSY particle (NLSP) can be stable. In particular, third generation SUSY partners, as stau and stop, are possible candidates for NLSP CHAMPs. CHAMPs can also arise in models with 4 generations in the case in which the fourth generation is weakly coupled to the other three families. In this case, the fourth generation quark is a CHAMP.
An analysis searching for such long-lived CHAMPs has been performed by the CDF-II collaboration. This search used the new CDF-II Time Of Flight detector (TOF) that provides a better sensitivity to $\beta\gamma$ compared to any deductible dE/dx information. The analysis used 75 pb^{-1} of data, collected with the high-P_T inclusive central muon trigger, selecting then offline tracks with $P_T > 40$ GeV/c. The information about the time, in which the interaction occurred (T_0), is obtained using low momentum tracks ($P_T < 20$ GeV/c). Then CHAMPs are searched looking for tracks with large traversing time: $\Delta T = T_{tracks} - T_0 > 2.5$ ns. There are 7 events that passed the analysis cuts. The number of expected background events is 2.9 $\pm$ 0.7 ($Stat$) $\pm$ 3.1 ($Syst$) and it has been evaluated using tracks with $20 < P_T < 40$ GeV/c. The resulting mass limit, for the stop scenario, is given in Figure **1** (right) and corresponds to a value of $M(\tilde{t}_1) > 108$ GeV/c^2.

4 Search for Leptoquarks

Leptoquarks (LQ) are predicted in many extensions of the SM such as Grand Unified Theories (GUT), Technicolor, *etc.* At Tevatron, they can be pair produced through strong interactions: $p\bar{p} \rightarrow \bar{L}QLQ + X$ and decay in one of the following final states: $\ell^{\pm}\ell^{\mp}q\bar{q}$ and $\ell^{\pm}\nu q\bar{q}$ and $\nu\bar{\nu}q\bar{q}$. Both Tevatron experiments searched in the past for LQ by looking at final states containing one or two leptons.

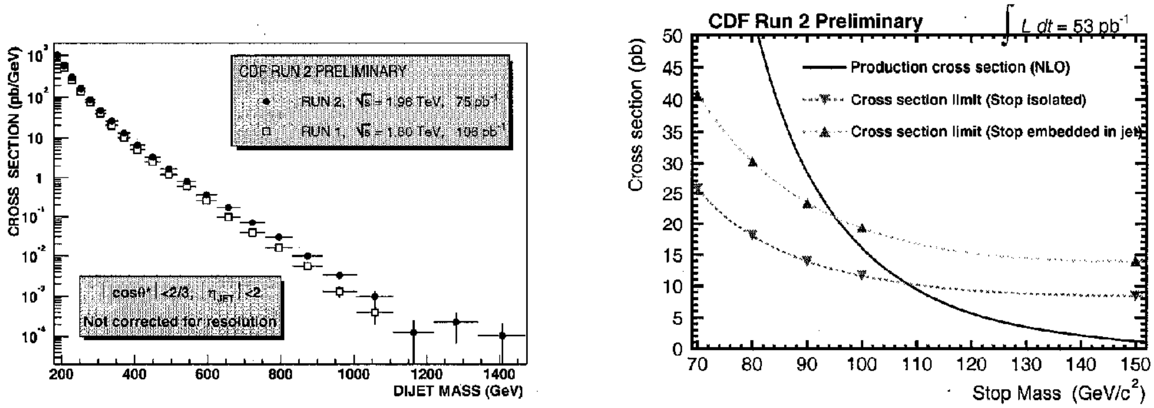

Figure 1: (Left) Comparison of Run I and Run II dijet spectrum (CDF-II); (Right) NLO top squark production cross section and the 95% C.L. limit as obtained from the search. The resulting mass limit is $M(\tilde{t}_1) > 108\ GeV/c^2$. The NLO calculation assumes $\sqrt(s) = 1.96\ TeV$, a factorization scale $= M(\tilde{t}_1)$ and the parton distribution function CTEQ4M [5]. Varying the factorization scale by $\pm 1\,\sigma$ we get a variation of about $\pm 3\ GeV/c^2$ in the obtained limit (CDF-II).

4.1 First Generation Leptoquarks: dilepton-dijet channel

Here we report the latest CDF-II analysis performed by looking at the channel $\bar{LQ}_1 LQ_1 \to eeqq$. Events were selected by requiring the presence of two electrons with $E_T^e > 25\ GeV$ and two jets with $E_T^{jet}(1) > 30\ GeV$ and $E_T^{jet}(2) > 15\ GeV$. Topological cuts have been applied in order to reduce the SM background. No events have been found using $72\ pb^{-1}$ of data. The number of background events expected from SM processes is 3.4 ± 3.0. The corresponding 95% C.L. limit is : $M(LQ_1) > 230\ \ GeV/c^2$ (see Figure 2 left).

Also DØ searched for First Generation Leptoquarks by studying the same decay channel and following a similar approach. The number of events observed, in the analysis, were 0 with an expected background of 0.08 ± 0.02. The obtained limit at 95% C.L. is $M(LQ_1) > 179\ GeV/c^2$ and already improve the previous Run I DØ result.

4.2 First Generation Leptoquarks: jet+ $\not{E}_T$ channel

CDF-II searched also for First Generation Leptoquarks production considering the LQ_1 decaying into neutrino and quark ($LQ_1 \to \nu\bar{\nu}q\bar{q}$) which yields missing transverse energy and several high-E_T jets in the final state. The analysis have been performed using $76\ pb^{-1}$ of data. The number of events observed in the signal region is 42 with an expected background of 42 ± 11. Therefore no evidence for leptoquark production has been observed. The resulting 95% C.L. limit on the cross section times squared branching ratio is given in Figure 2 (right). We exclude the mass interval: $60\,GeV/c^2 < M(LQ_1) < 107\,GeV/c^2$

4.3 Second Generation Leptoquarks

Another analysis performed by DØ collaboration, using $30\ pb^{-1}$ of data, is the search for Second Generation Leptoquarks decaying trough the channel: $LQ_2\bar{LQ}_2 \to \mu^+\mu^- qq$. Events were selected by requiring the presence of two opposite sign muons with $P_T^{\mu} > 15\ GeV/c$ and two jets with $E_T^{jet} > 20\ GeV$. The dominant background for this process is $Z/\gamma^* \to \mu^+\mu^-$ associated with two jets. The number of events that passed the cuts is 0; the corresponding 95% C.L. limit on LQ_2 is $M(LQ_2) < 157\ GeV/c^2$. The previous Run I limit, based on the full statistics, was: $M(LQ_2) < 200\ GeV/c^2$.

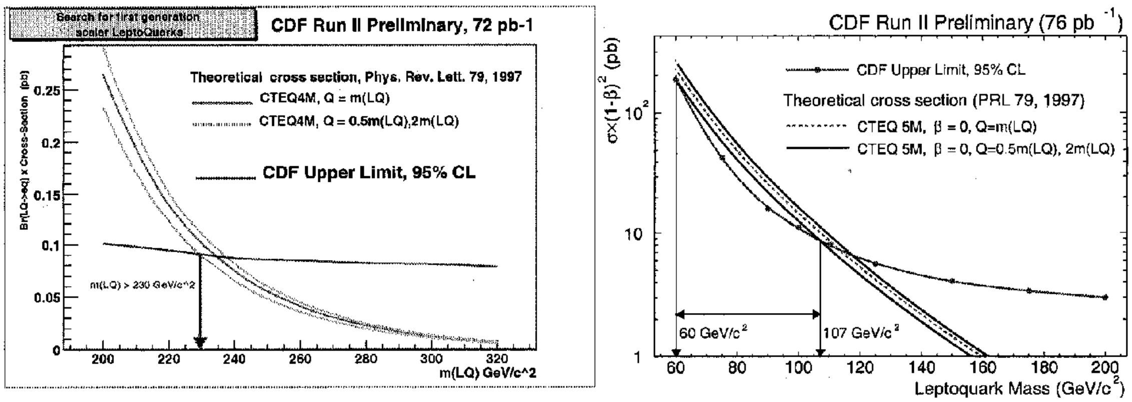

Figure 2: (Left) CDF-II limit on the cross section as a function of $M(LQ_1)$ compared with the theoretical expectations calculated at NLO accuracy. At the intersection point between experimental and theoretical curves we find a lower limit on $M(LQ_1)$ at 166 GeV/c^2. ($\beta = 0.5$); (Right) Search for $p\bar{p} \to LQ_1\bar{LQ}_1$, with $LQ_1 \to q + \nu$. The signature for this process is large missing transverse energy and two energetic jets (CDF-II).

5 Search for doubly-charged Higgs (dielectron channel)

Doubly-charged Higgs particles ($H^{\pm\pm}$) are expected in several theoretical frameworks. Such particles are members of Higgs triplets that occur in theories with extensions to the Higgs sector of the SM [6], left-right (LR) symmetric models [7] and SUSY LR symmetric models [8]. Because of the charge conservation, the $H^{\pm\pm}$ must decay to either two same-sign leptons, two same-sign W bosons, two same-sign singly-charged Higgs bosons or a singly-charged Higgs and a W boson. In particular, SUSY LR models predict low-mass $H^{\pm\pm}$ (~ 100 GeV/c^2 to ~ 1 TeV/c^2). CDF-II have searched for these particles decaying into two leptons using 91 pb^{-1} of data, collected between March 2002 and January 2003. Even if SUSY LR models provides motivations to search for low mass doubly-charged Higgs particles, a search in the same sign (SS) di-electron data is sensitive to any doubly charged particle decaying to electrons. CDF-II searched for same-sign good central electrons passing the following kinematical cuts: $E_T^e > 30$ GeV and track $P_T > 10$ GeV/c. The mass resolution is about 3% of $M(H^{\pm\pm})$. The search region is defined as a mass window of $\pm 10\%$. The search has been performed using a SS sample in the mass region above the Z pole ($M_{e^\pm e^\pm} > 100$ GeV/c^2) to avoid possible contamination coming from Z events with a charged leg misinterpreted. No events have been observed in the search region of same sign mass above 100 GeV/c^2. These results provide a 95% C.L. limit for pair-production of doubly-charged particles.

6 Search for New Gauge Bosons

CDF and DØ searched for new neutral gauge boson Z' and Randall-Sundrum gravitons decaying into dileptons. From an experimental point of view such particles are generally high mass states produced by $q\bar{q}$ annihilation and decaying into a pair of opposite sign leptons. The primary observable effect will be an anomalous dilepton production at large invariant masses enhancing the Drell-Yan cross section. From a theoretical point of view, the existence of neutral gauge bosons in addition to the Standard Model Z is predicted in many extension of the SM. These models specify the strengths of the couplings of the Z' to quarks and to leptons. In the Randall-Sundrum model, Kaluza-Klein (KK) excitations can be produced as resonances enhancing the SM Drell-Yan production cross section at large mass. The CDF analysis is based on 72 pb^{-1} of data collected between March 2002 and January 2003 using high-P_T electron data. Events where selected by requiring two electrons with : $E_T^e > 25\,GeV/c$. Specific cuts are applied in order to reduce the QCD W + $jets$ background. The corresponding CDF-II

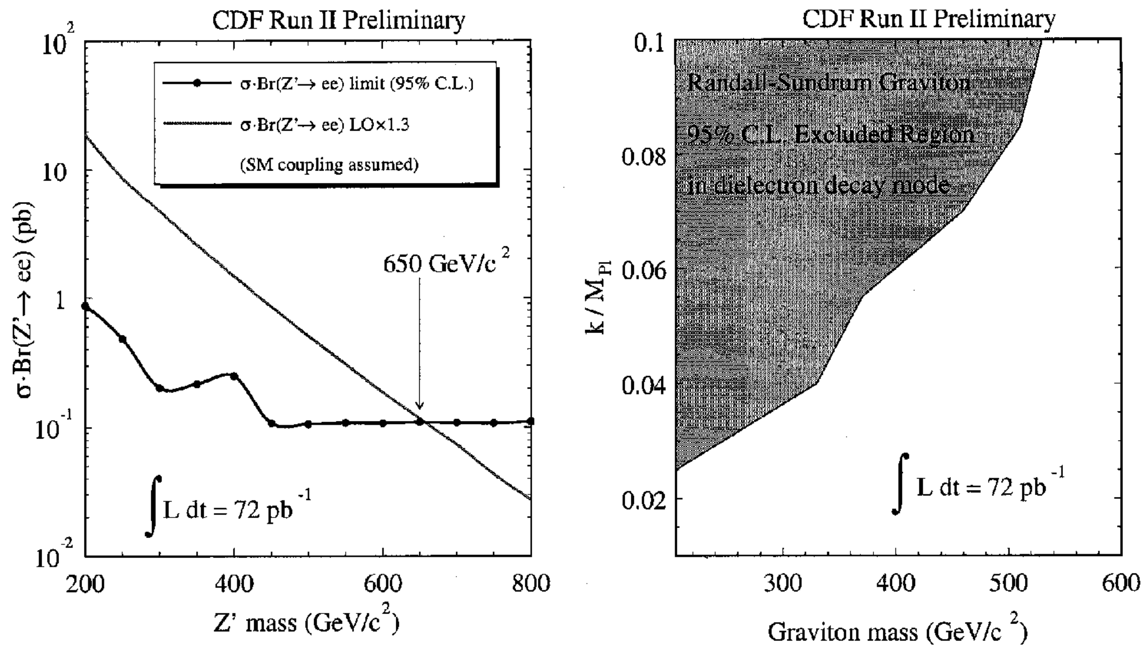

Figure 3: (Left) CDF-II search for new gauge bosons: 95% C.L. limit on $Z' \to e^+e^-$ search; (Right) Randall-Sundrum Graviton excluded region.

limit on the Z' mass is 650 GeV/c^2 as shown in Figure 3 (left). The DØ limit on the same channel is 455 GeV/c^2. The limit obtained for the Randall-Sundrum scenario is given in Figure 3 (right).

7 Physics with Taus in the final state

The study of processes containing τ leptons in the final state will play an important role at Tevatron Run II. Such final states is relevant both for electroweak studies and measurements as well as in searches for physics beyond the Standard Model. In particular to search for a variety of new physics scenarios such as SUSY, SUSY with $\mathcal{R}_{\mathcal{P}}$-parity violation (RPV), SUSY with Bilinear parity violation (BRPV) or models with the violation of lepton flavor (LFV). For this purpose a new set of triggers have been implemented able to select events containing tau candidates in the final state.

7.1 The CDF-II Tau Triggers

The CDF-II τ Triggers are a set of Triggers integrated into all 3 levels of the general CDF-II Trigger system [1]. At the present CDF-II has five different τ triggers operating:

- Central Muon Plus Track;
- CMX Muon Plus Track;
- Central Electron Plus Track;
- Di-Tau Trigger;
- Tau $+\not{E}_T$;

These Triggers were installed in the CDF-II trigger tables in January 2002. Naturally, the design of these triggers has evolved in time. At the present they are all working properly collecting data in stable, non prescaled way. In particular the lepton plus track triggers are a class of low momentum dilepton triggers able to select events containing charged leptons, including τ's, in the final state.
As taus in $\sim$ 35 % of cases promptly decay into leptons and the rest of times in hadrons, then dilepton events, where both leptons are τ's, can be identified by accessing both purely leptonic di-τ decays: $\tau_e\,\tau_e$, $\tau_e\,\tau_\mu$ or mixed leptonic-hadronic di-τ decays: $\tau_e\,\tau_h$ or $\tau_\mu\,\tau_h$. Then the full accessible final states are: $e\,e$, $e\,\mu$, $e\,\tau_h$, $\mu\,\mu$, $\mu\,\tau_h$. Hadronic decays of taus result in jets that must be distinguished from jets arising from QCD processes. In this case the "τ-jetiness" is ensured by the isolation criteria applied around the second track at Level 3. As a corollary, this prevents the track from being a product of a light quark or heavy flavored quark jet. At the present many analysis are underway using data collected with these triggers. Results will be released soon.

8 Conclusions

The search for new physics is a primary goal for a hadron collider. CDF and DØ following an important Run I tradition are pursuing with great determination a large variety of exotic searches. Many Run I limits have been already enhanced using the data collected so far.

9 Acknowledgements

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