SEARCH FOR NEW PHENOMENA IN CDF

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Abstract

We present the most recent results and perspectives of the searches for new phenomena at the CDF experiment of the Tevatron collider.
1 Introduction

The Run II of the Tevatron collider began in spring 2001. The accelerator provides $pp$ collisions at a center-of-mass energy $\sqrt{s}$ of 1.96 GeV. The CDF detector has undergone substantial upgrades since the end of Run I. A detailed description of the new devices can be found in reference 1).

2 Drell-Yan Dilepton Production

High mass dileptons allow to search for new particle production. In particular, the CDF collaboration has recently looked for new neutral gauge boson $Z'$ and Randall-Sundrum gravitons in approximately 72 pb$^{-1}$ of Run II data.

2.1 Search for New Neutral Gauge Boson $Z'$ in Dielectron Channel

High $p_T$ electron data have been used to search for $Z'$ boson decaying into an electron pair $q\bar{q} \rightarrow Z' \rightarrow e^+e^-$. The event selection is based on the detection of a good central electron with $E_T > 25$ GeV and a second good electron with $E_T > 25$ GeV either in the central or in the plug calorimeter. A cut on the missing transverse energy significance, $E_T/\sum E_T < 2.5$, is also applied to remove $W+jets$ background. The observed dielectron mass spectrum agrees with background expectation (fig. 1). 95% CL upper limit on the production cross section times branching ratio into electrons is set as a function of $Z'$ mass. When Standard Model couplings are assumed, a 95% CL lower limit on the $Z'$ mass is established at 650 GeV/c$^2$. 

Figure 1: Dielectron mass spectrum. 

Figure 2: Dimuon mass spectrum.
Figure 3: 95% CL excluded regions in the mass-coupling parameter plan for Randall-Sundrum gravitons in the dielectron (left) and dimuon (right) channels.

2.2 Search for New Neutral Gauge Boson $Z'$ in Dimuon Channel

The search for $Z'$ boson production in the dimuon channel is based on the selection of two good muons with transverse momentum $P_T > 20 \text{ GeV}/c$. Cuts on the track impact parameter and isolation are applied to remove cosmic ray and QCD background respectively. No excess over the Standard Model prediction is observed in the dimuon mass distribution (fig.2), and 95% CL upper limit on the production cross section times branching ratio into muons is set as a function of the $Z'$ boson mass. Finally, by assuming Standard Model couplings, a 95% CL lower limit on the $Z'$ mass is set at 455 GeV/$c^2$.

2.3 Results for Graviton Searches

The Randall-Sundrum model provides a small extra-dimension solution to the hierarchy problem by means of a non-factorizable geometry $^2$, $^3)$. Excited gravitons in 5 dimensions are expected to be observable. Results for resonance searches in high mass dileptons have also been used to draw excluded regions in the graviton mass-coupling parameter $k/M_{PL}$ plan (fig.3).
3 Leptoquark Searches in Run II

Leptoquarks are generally pair produced in $p\bar{p}$ collisions\(^4\). They decay into a lepton-quark pair, with generation mixing suppressed by FCNC constraints\(^5\). A search for first generation leptoquark has been recently performed in the dielectron+jets channel at CDF. 72 $pb^{-1}$ of inclusive electron data have been selected by requiring two central electrons with $E_T > 5$ GeV and two jets ($E_T > 30$ GeV and 15 GeV respectively). No events are observed after kinematic cuts. 95% CL upper limits on the production cross section as a function of the leptoquark mass are set (fig.4). By assuming $Br(LQ \rightarrow lq) = 1$ and using the NLO theoretical estimate, a scalar leptoquark with mass below 230 GeV/c\(^2\) is excluded.

4 CHArged Massive Particles

Physics theories extending the Standard Model usually predicts new conserved quantum numbers leading to stable particles. Long-lived CHArged Massive Particles (CHAMPS) escaping CDF detector can be detected by high-$P_T$ muon triggers. Moreover, due to their large mass, these particles are expected to move slowly, leading to long Time-Of-Flight (TOF) through the detector. CHAMP production has been investigated by exploiting the new TOF system, providing sensitivity to higher $\beta\gamma$ values than the $dE/dx$ measurement used in Run I analyses. 52 $pb^{-1}$ of high-$P_T$ muon data have been used. In order to have full tracking efficiency on CHAMPS with mass larger than 100 GeV/c\(^2\), a cut at 40 $GeV/c$ is applied on the transverse momentum of the candidate tracks. The time $t_0$ at which the interaction is occurred is estimated by averaging.
the measured time for tracks with $P_T < 20$ GeV/$c$. Tracks with high time of flight difference $\Delta t$ with respect to $t_0$ are looked for. The maximum probability of discovery has been found to be guaranteed by a cut $\Delta t > 2.5$ ns. Tracks with $20 < P_T < 40$ GeV/$c$ are used to predict the background (fig.5): $2.9 \pm 0.7 (stat.) \pm 3.1 (sys.)$ events are expected, while 7 events are observed. Production cross section upper limits are established for a stable stop model\(^6\). By assuming NLO predictions, a 95% CL lower limit on the stop mass is set at 107 GeV/$c^2$.

5 Dijet Mass Bumps

75 pb\(^{-1}\) of inclusive jet samples have been used to search for new particles decaying into dijets. The two highest $E_T$ jets in each event are used to compute the dijet invariant mass spectrum (fig.6). QCD production in the t-channel pole is suppressed by requiring the dijet satisfies

$$|\tanh(\Delta \eta/2)| < 2/3.$$  \hspace{1cm} (1)

No evidence for new particles is observed, and excluded mass regions for several models are drawn (fig.7).
Table 1: Missing $E_T$ and photon triggers.

<table>
<thead>
<tr>
<th>MET45</th>
<th>$E_T &gt; 45$ GeV</th>
</tr>
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<tbody>
<tr>
<td>MET_13ps100</td>
<td>$E_T &gt; 25$ GeV &amp; prescale 100</td>
</tr>
<tr>
<td>MET35+2JETS</td>
<td>$E_T &gt; 35$ GeV &amp; 2 jets w/ $E_T &gt; 10$ GeV</td>
</tr>
<tr>
<td>MET+BJET</td>
<td>$E_T &gt; 20$ GeV &amp; 2 displaced tracks ($</td>
</tr>
</tbody>
</table>

Photon Triggers

| INCLUSIVE PHOTON | $E_T^\gamma > 25$ or 50 or 70 GeV |
| DIPHOTON | $E_T^\gamma > 12$ or 18 GeV |
| TRIPHOTON | $E_T^\gamma > 10$ GeV |
| PHOTON+BJet | $E_T^\gamma > 10$ GeV & 1 displaced track ($|d_0| > 120$ $\mu$m) |
| PHOTON+MUON | $E_T^\gamma > 16$ GeV & $P_T^\mu > 4$ GeV/c |
| PHOTON+DIJET | $E_T^\gamma > 18$ GeV & $E_T^{\gamma 1} > 18$ GeV, $E_T^{\gamma 2} > 10$ GeV |

Table 2: Observed and expected number of diphoton events with additional electron or muon.

<table>
<thead>
<tr>
<th></th>
<th>Obs.</th>
<th>Exp. $E_T^\gamma &gt; 13$ GeV</th>
<th>Exp.</th>
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<tbody>
<tr>
<td>$e\gamma\gamma$</td>
<td>0</td>
<td>0.27 ± 0.10 ± 0.14</td>
<td>0.04 ± 0.03 ± 0.02</td>
</tr>
<tr>
<td>$\mu\gamma\gamma$</td>
<td>0</td>
<td>0.04 ± 0.007 ± 0.02</td>
<td>0.007 ± 0.005 ± 0.004</td>
</tr>
</tbody>
</table>

6 Exclusive Missing $E_T$ + Jets Searches in Run I

Missing transverse energy signature has been recently used to test extra dimension solution to the hierarchy problem 7) with Run I data. Gravitons are expected to be produced in association with an extra parton. Required experimental signature is large missing $E_T$ ($\not{E}_T > 80$ GeV) plus an extra jet: 284 events are observed while 271 ± 16 events are expected mainly from $Z \rightarrow \nu\bar{\nu}$ background. By assuming a number of 2, 4 or 6 extra dimension, an effective Planck scale below 1.0, 0.77 and 0.71 TeV respectively has been excluded at 95% CL.

7 Inclusive Missing $E_T$ and Photon Searches in Run II

Several triggers have been implemented to study weakly interacting particle production and new phenomena leading to photons in the final states (tab.1). Large samples are being collected and tested. In particular, the diphoton sample has been deeply studied: 1365 events have been selected by requiring two
central photons with $E_T > 13$ GeV (95 events with $E_T > 25$ GeV). Diphoton mass spectrum and missing transverse energy have been investigated (fig.8 and 9). The number of events with additional electron or muon has also been studied (tab.2). Background expectation agrees with data. These samples provide an important testing bench for new physics beyond the Standard Model.

8 Tau Lepton Based Searches

Tau leptons provide an other crucial experimental signature for new phenomena searches. In particular, large cross sections into final states with $\tau$ are expected for supersymmetric Higgs production at large $\beta$ values. Tau detection has been largely improved in Run II and specific $\tau + E_T$ and ditau triggers have been implemented. Improved tau reconstruction also offers interesting perspectives for supersymmetric searches like for example $R$-parity violating stop decays

$$p\bar{p} \to \ell\ell + X \to (b\tau^+) (\bar{b}\tau^-) + X$$

and Chargino-Neutralino production

$$p\bar{p} \to W^\pm \to \chi^\pm_1 \chi^0_2 \to (\tau^+\nu\chi^0_1)(\tau^-\tau^+\chi^0_1).$$

9 $R$-Parity Violating Decaying Particles

The CDF collaboration has recently performed two searches for new particles decaying via $R$-parity violating interactions with Run I data.
In the first analysis, stop pair production has been considered, with both the stop quarks decaying into $\tau b^8$. A tau is required to decay leptonically, while the second tau is required to decay hadronically: the searched signature is an opposite sign lepton-tau pair plus two jets. After kinematic cuts, no events are observed, while $3.2^{+1.4}_{-0.3}$ events are predicted by Standard Model processes. By assuming $Br(\tilde{t} \rightarrow \tau b) = 1$ and NLO cross sections, a 95% CL lower limit on the stop mass is set at 122 GeV/$c^2$.

In the second search, $\tilde{\nu}_\tau$ production of a scalar neutrino $\tilde{\nu}$ is considered. Flavour-violating $\tilde{\nu}$ decays into opposite sign leptons are looked for. Events are selected by requiring an opposite sign muon-electron pair, back to back in the azimuthal direction. No excess over the background expectation is observed, and 95% CL upper limits on the production cross section times the branching ratio are derived (fig.10).

10 Search for Doubly-Charged Higgs

The observed lack of symmetry between left- and right-handed weak interactions suggests a more fundamental left-right symmetric lagrangian spontaneously broken at higher energies $^9, 10, 11)$. The see-saw mechanism, designed
in the context of the left-right symmetric model, successfully predicts light neutrino mass 12, providing a powerful motive to that model. Finally, supersymmetric extensions 13, 14 suggest low mass doubly-charged Higgs, whose same-sign lepton decay mode provides a strong experimental signature.

95 pb⁻¹ of inclusive electron data have been recently used at CDF to search for doubly-charged Higgs production via same-sign central electron pair observation. No events are observed in a search region of ±10% of the Higgs mass around each Higgs mass considered, and 95% CL upper limits on the production cross section are established (fig.11). We remark that this experimental search is sensitive to the production of any new doubly-charged particle decaying to dielectrons.

11 Conclusions

CDF detector is collecting data from March 2001. RunII searches for new phenomena have already started. First limits using dileptons and dijet mass spectra have been set for various phenomena and specific theories beyond the Standard Model have been tested. Moreover, the new Time-Of-Flight system has been exploited to search for CHAMPS. Results are already improving RunI ones. Larger samples are being collected and tested for searches based on tau lepton, missing transverse energy and photon signature. High integrated luminosity will provide the best opportunity for new physics discovery until LHC starts to run.

References