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SEARCH FOR NEW PARTICLES AT CDF II

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We report on the first results from the CDF experiment on search for physics beyond the Standard Model using data from the upgraded TeVatron collider running $p\bar{p}$ collisions at $\sqrt{s} =$ 1960 GeV. These first results, although obtained with a total integrated luminosity lower than the total integrated luminosity collected during Run I, are already competitive if not better, due to the increase in the center of mass energy and the improved detector capability.

1 Introduction: Run II collider and detector upgrades and search strategies at CDFII

1.1 TeVatron upgrades

The run I data taking period at the TeVatron ended in February 1996. Since then the collider and both the detectors (CDF and D0) underwent substantial upgrades.

The energy of the beams has been increased from 900 GeV to 980 GeV. A new syncrotron (" main injector") has been built in a new tunnel. The main injector together with a debuncher-accumulator-recycler complex allows for faster production of antiprotons and the possibility of reusing them after they are rescued in the recycler. In run I the luminosity reached $1.5\times10^{31}\text{cm}^{-2}\text{sec}^{-1}$ and was obtained with a 6 on 6 proton-antiproton bunches in the collider with an interbunch time of 3.5μsec. The luminosity ultimately planned for run II is $3.3\times10^{32}\text{cm}^{-2}\text{sec}^{-1}$ and it will be obtained with 36 on 36 proton-antiproton bunches with interbunch time of 396 ns. So far, about 120 pb^{-}1 of integrated luminosity has been delivered and CDF has used between 50 and 90 pb^{-}1 for its first physics results.

1.2 CDF Detector upgrades

Many components of the CDF detector have been replaced or improved with respect to Run I[1]. Only the central calorimeter, the solenoid and part of the muon system have been retained, although in general the electronics has been upgraded to cope with the new interaction time. Going from the inside to the outside of the detector, CDF has a new tracking system, composed of several silicon detectors (L00, SVXII and ISL) and a drift chamber. This improved tracking system allows for particle detection extremely close to the beam pipe (the inner most silicon layer sits at 2.5 cm from the beam pipe) and extends the coverage in η up to 2 (it was 1.4 in Run I). The z coverage has increased to cover the full luminous region. 3-D track reconstruction is possible with impact parameter resolution $\sigma_{phi} < 30$ μm and $\sigma_z <$ 60μm.

A completely new open cell drift chamber (Central Outer Tracker) with maximum drift time of 100 ns allows for better stereo capabilities in tracking reconstruction in respect to Run I ($\Delta p_T/p_T < 0.001$). It also provides dE/dx information.

Between the COT and the solenoid a new Time Of Flight detector has been installed. The TOF resolution of order 100 ps allows for 2σ $K\pi$ separation for transverse momentum up to 1.6 GeV.

The calorimeter has been retained from Run I in the central part, while a new scintillator based plug calorimeter is replacing the old gaseus calorimeter in the large η region. It extends to η up to 3.6 and maintains as much as possible the same $\eta\phi$ segmentation of the central calorimeter.

Finally, the muon system has been partially upgraded: the old Run I central muon detectors has been retained but equipped with new readout electronics, while a new extension and intermediate muon chambers will guarantee the muon trigger coverage from $|\eta| = 0.6$ to 1.0.

All the front end and DAQ electronics have been changed and upgraded. At Level 1(within 5μs) a new online processor reconstructing tracks has been implemented (eXtremly Fast Tracker) and at Level 2 (within 20 μs) a Silicon Vertex Trigger (SVT) links the Level 1 tracks (from the drift chamber) to the silicon hits and reconstructs offline-quality tracks (with about 40 μm impact parameter resolution). This is the first time such a device has been installed in a hadron collider detector and CDF relies upon it to collect large samples of hadronic b decays crucial for B_s^0 mixing and CP violation studies. On the other hand the device has been shown to be very powerful for high p_t physics, where it allows to select samples enriched in heavy flavors already at the trigger level, that can subsequently be used in analysis using heavy flavor tagging.

1.3 Search Strategies at CDFII

Two different approaches to search for physics beyond the Standard Model are actively pursued in Run II in a complementary fashion: model-based analysis and signature based studies.

In the more traditional model-driven approach, one picks a favorite theoretical model and/or a process, and the best signature is chosen. The selection cuts for acceptances are optimized based on signal MC. The expected background is calculated from data or Monte Carlo and, based on the number of events observed in the data, a discovery is made or the best limit on the new signal is set. In a signature-based approach a specific signature is picked (i.e. dijets+X) and the data sample is defined in terms of known SM processes. A signal region (blind box) might be defined with cuts which are kept as loose as possible and the background predictions in the signal region are often extrapolated from control regions. Inconsistencies with the SM predictions will provide indication of possible new physics. As the cuts and acceptances are often calculated independently from a model, different models can be tested against the data sample.

In the next sections we will present the first CDF results from both approaches.

2 Model based searches

2.1 Search for Z' and Randall-Sundrum graviton in high mass dileptons

Neutral gauge bosons in addition to the Standard Model Z are expected in many extension of the Standard Model. These models tipically specify the strenghts of the couplings of the Z' to quarks and leptons, but make no prediction for the Z' mass. A search improving the Run I result has been performed in the di-electrons and dimuons channel, as one of the primary observable effects would be anomalous dilepton production at large invariant mass via virtual exchange of the Z'.

Anomalous dilepton production at large mass can also be the result of Randall-Sundrum graviton, which would appear as a resonance of spin 2. Models with extra dimensions have been recently introduced to solve the hierarchy problem[2]. If the extra dimensions are large the effective Planck scale M_S can be in the TeV range. In the initial Arkani-Hamed, Dimopoulos, Dvali (ADD) models, gravity can propagate in large extra dimensions and the effect of gravity is enhanced at high energy due to the accessibility of numerous excited states of the graviton (called Kaluza Klein modes). In the Randall-Sundrum graviton model[3] a 4-dimensional metric is multiplied by a *warp* factor, which is a function of the compactification radius and changes exponentially with the additional dimension. Due to the presence of the warp factor, generating a large hierarchy does not require a large curvature radius or extra dimension. The masses and couplings of each individual Kaluza Klein states to matter are determined by the warp factor. This implies that these Kaluza Klein excitations of the graviton can be separately produced as resonances, enhancing the DY cross section at large mass.

The Drell Yan spectrum in the *ee* and $\mu\mu$ channel has been compared to the SM expectations and no excess has been observed. A 95% C.L. upper limit on the cross section as a function of Z' and RS graviton mass. The Z' limit is better than the Run I measurement in the *ee* channel (figure 1-4).

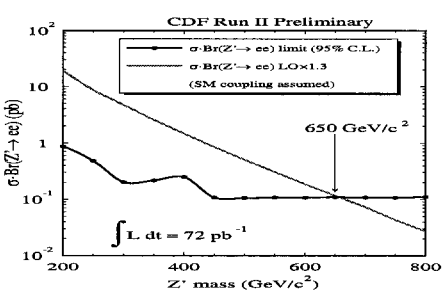

Figure 1: Cross section limit as function of the Z' mass, in the dielectron channel

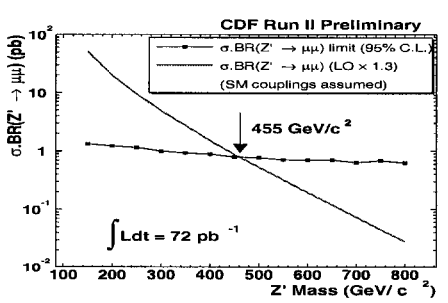

Figure 2: Cross section limit as function of the Z' mass, in the dimuon channel

2.2 Search for first generation leptoquarks in dielectrons and jets

Leptoquarks are hypothetical color-triplet particles carrying both baryon and lepton quantum numbers and are predicted by many extension of the Standard Model as new bosons coupling to a lepton-quark pair[4]. Their masses are not predicted. They can be scalar particles (spin 0) or vector (spin 1) and at high energy hadron colliders they would be produced directly in pairs, mainly through gluon fusion or quark antiquarks annihilation. The couplings of the leptoquarks to the gauge sector are predicted due to the gauge symmetries, up to eventual anomalous coupling in the case of vector leptoquarks, whereas the fermionic couplings are free parameters of the models. In most models leptoquarks are expected to couple only to fermions of the same generations because of experimental constraints as non observation of flavor changing

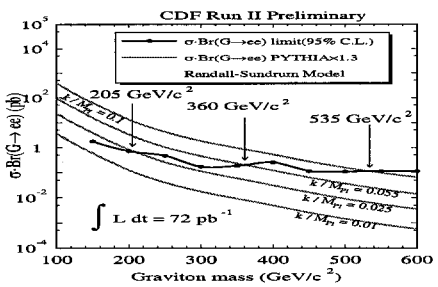

Figure 3: Cross section limit as function of the Randall Sundrum graviton mass, in the dielectron channel

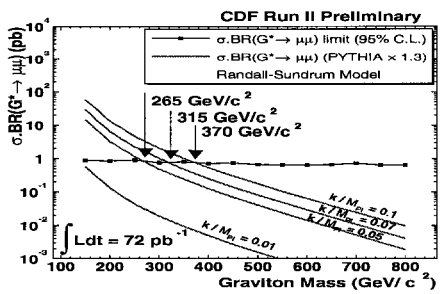

Figure 4: Cross section limit as function of the Randall Sundrum graviton mass, in the dimuon channel

neutral currents or helicity suppressed decays. The NLO cross section at $\sqrt{(s)} = 1960$ GeV is about 25% higher than at 1800 GeV/c^2[7]. The current CDF result is focusing on the search for first generation scalar leptoquarks, pair produced and decaying both into an electron and a quark. The analysis strategy is the following: a reduced data sample is derived from the high p_T inclusive electron trigger sample. The following cuts are applied:

- 2 electrons with $E_T > 25$ GeV;
- 2 jets with E_T(jet1) > 30 GeV and E_T(jet1) > 15 GeV;
- Removal of events lying in the Z mass window ($76 < M_{ee} < 110$ GeV/c^2);
- E_T(jet1) + E_T(jet2) > 85 GeV and E_T(e1) + E_T(e2) > 85 GeV;
- $\Sigma((E_T(jet1) + E_T(jet2))^2 + (E_T(e1) + E_T(e2))^2)) > 200$ GeV;

No events survive the analysis cuts.

The main background to the process is represented by production γ/Z decaying $\rightarrow ee$ events accompanied by jets due to radiation. The main component of this background is eliminated by cuts on M_{ee} around the mass of the Z boson and the ΣE_T cuts. Another source of background is represented by $t\bar{t}$ production where both the W decay into eν. Backgrounds from bb, Z$\rightarrow \tau\tau$, WW are expected to be negligible due to the an electron isolation cut and large electron and jet transverse energy requirements.

As no candidate events were found, a 95% C.L. upper limit on the cross section times a factor β^2 as a function of m(LQ) has been set, and it is reported in figure 5[a]. A mass limit is set at 230 GeV/c^2, better than the Run I result.

2.3 Search for doubly charged Higgs

Doubly-charged Higgs particles are predicted by left-right (LR) symmetric models, and SUSY LR models predict low-mass H^{++} (about 100 GeV/c^2 to 1 TeV)[5]. These particles decay to leptons, and CDF has searched 91 pb$^-$1 of CDF Run 2 data for evidence of their production. The search has been performed in the same-sign electron mass windows of $\pm$10% of a given H^{++} mass (about 3 sigma of the detector resolution). The search is sensitive to any doubly-charged particle decaying to dielectrons, whether it is produced singly or in pairs. In the 80-100 GeV/c^2 mass range, the dielectron search has little sensitivity due to the overwhelming background from Z production. The background occurs when the Z decays to opposite-sign electrons and one of the electrons radiates a photon, which subsequently converts. When the wrong sign

[a] β is the branching Br(LQ$\rightarrow$eq), assumed to be equal to 1 for this analysis.

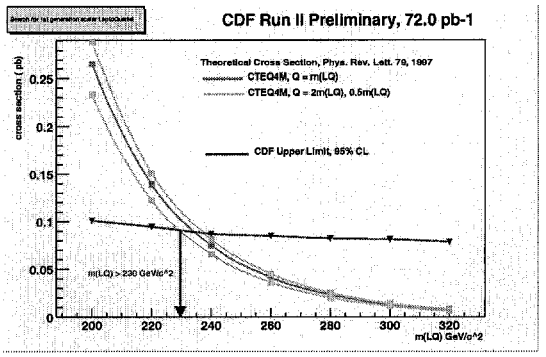

Figure 5: Limit cross section as a function of m(LQ) compared with the theoretical expectations calculated at NLO accuracy times branching ratio.

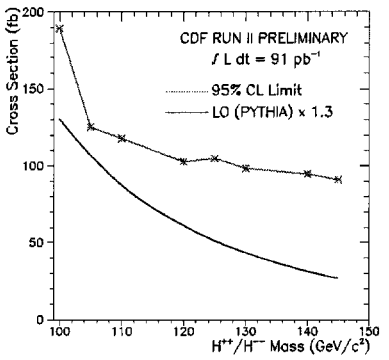

Figure 6: Limit cross section as a function of m(H++) compared with the theoretical expectations.

conversion track is associated with the electron cluster, the event is reconstructed with 2 same-sign electrons. The Z background has been evaluated using the data in the 80-100 GeV/c^2 mass range and the search has been performed in the region above 100 GeV/c^2. The mass region of 100-130 GeV/c^2 is dominated by this background; above this mass, QCD and Z processes are expected to contribute equally to the background

The low mass region (<80 GeV/c^2) has been used as a test of the background prediction, which is consistent with 0 events observed. In the search region (>100 GeV/c^2), 0 events are also observed. These results provide a 95% confidence level cross section limit for pair-production of doubly-charged particles, which is reported in Figure 6. As the limit cross section sits above the theoretical prediction it is still not possible to set a limit on the H^{++} mass.

3 Model based searches

3.1 Search for charged massive particles (CHAMPS)

A search has been performed for charged massive particles long lived enough to escape the CDF detector. As these particles are supposed to be highly isolated and slow moving, the high p_T muon trigger has been used to select the data sample. Particle with $p_T > 40$ GeV/c are selected to insure full tracking efficiency. These particles should also have a long time of flight through the detector and the new TOF system of CDF provides a sensitivity to higher $\beta\gamma$ than a dE/dx measurement (which was used in a similar search at other machines). The event t_0 is derived from tracks with $p_T > 20$ GeV/c and it has been tested with electrons coming from W decay. Candidate tracks are required to have a high $\Delta_{TOF} = TOF_{tracks} - t_0$. In figure 7 the predicted number of events is compared to the observed number of events in the signal region: $\Delta_{TOF} >$ 2.5 ns. This point has a background prediction of 2.9 $\pm$ 0.7 (stat) $\pm$ 3.1 (sys), with 7 events observed.

Several interesting SUSY-based model can be tested for the presence of slowly moving charged particles. In particular, models where SUSY is broken at low scale, as those including gauge-mediated supersymmetry breaking, are generally distinguished by the presence of a nearly massless Goldstino as the lightest supersymmetric particle and a stop or a stau as the NLSP. The next-lightest supersymmetric particle(s) (NLSP) decays to its partner and the Goldstino. Depending on the supersymmetry breaking scale, these decays can occur promptly or on a scale comparable to or larger than the size of a detector (as for CHAMPS)[6]. The stop case has been investigated in this analysis and a 95% C.L. limit on the cross section for stop production as a

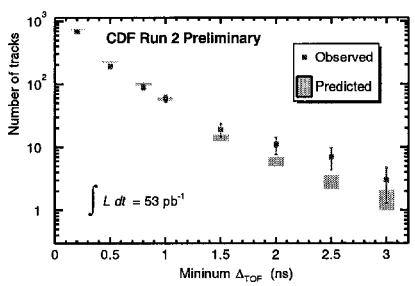

Figure 7: CHAMPS search: predicted number of events compared to those observed in the data.

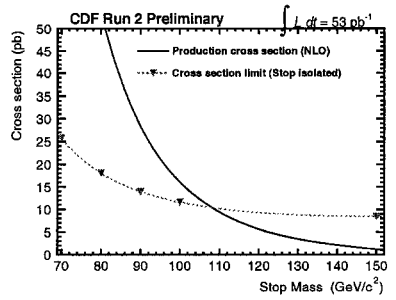

Figure 8: CHAMPS search: cross section limit as function of stop mass

function of the stop mass has been set. The resulting mass limit is M(stop) > 108 GeV at 95% CL and it reported in figure 8.

3.2 Search for mass bumps in the dijets spectra

A search for new particles decaying to dijets has been performed. The run 2 dijet mass spectrum begins at 180 GeV and falls steeply. The highest mass event has a dijet mass of 1364 GeV. Comparing the spectrum in Run I and Run II it is evident that the run 2 cross section at $\sqrt{(s)}$=1.96 TeV is everywhere above the run 1 spectrum at $\sqrt{(s)}$=1.80 TeV. The ratio of the cross section in Run II to that in Run I compares favorably with a lowest order parton level calculation.

To search for new particles the mass spectrum has been fitted with a simple background parameterization and a search for mass bumps comparable with the CDF mass resolution has been performed. The fit, the fractional difference between the data and the fit, and the statistical residuals between the data and the fit, show that there is no significant evidence for a new particle signal. Several 95% CL upper limits on the cross section times branching ratio for narrow dijet resonances are set and compared with the predictions for axigluons, flavor universal colorons, excited quarks, Color Octet Technirhos, E6 diquarks, W' and Z'. The limit plot is reported in figure 9. With the first run 2 data CDF excludes:

- axigluons or flavor universal colorons for masses between 200 and 1130 GeV.
- excited quarks with mass between 200 and 760 GeV.
- color octet technirhos between 260 and 640 GeV.
- E6 diquarks with mass between 280 and 420 GeV.
- W' with mass between 300 and 410 GeV.

All these limits are already better than the corresponding Run I limits.

3.3 Search for new physics in the involving photons in the final state

Analysis are under way in CDF with the aim of understanding our datasets in terms of known background contributions and possible deviation from it as a sign of new physics. Signatures involving photons are of particular interest to look for deviations from the SM predictions in the context of GMSB models. CDF is also using photon signatures as a first follow-up and check of anomalous events seen in Run I: in figure 10 the diphotons mass spectra is reported using approximately 81pb^{-1} of Run II data.

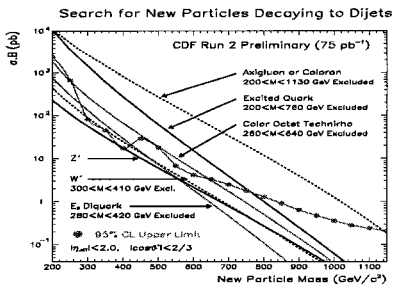

Figure 9: 95%CL upper limits on the cross section times branching ratio for narrow dijet resonances and compare them with the predictions for axigluons, flavor universal colorons, excited quarks, Color Octet Technirhos, E6 diquarks, W' and Z'.

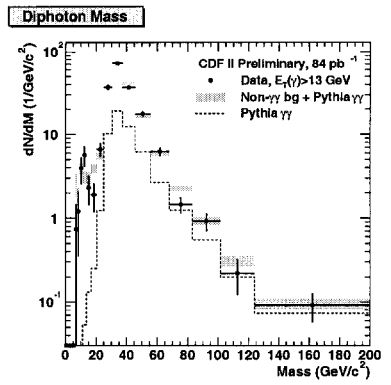

Figure 10: Diphoton mass spectrum compared to Standard Model expectation

Searches for events with one lepton and diphotons have been carried out and the result (0 events observed) are consistent with SM prediciton.

4 Conclusions

The CDF experiment is actively taking physics quality data at the upgraded TeVatron collider. The first results on search for physics beyond the Standard Model have been presented. In most of the cases they are already competitive if not better than Run I results, due to the increase in the center of mass energy and the improved detector capability.

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