Non-SUSY Particle Searches at DØ

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We have searched approximately 100 pb^{-1}of $p\overline{p}$ data taken at $\sqrt{s}$=1.8 TeV by the DØ detector for evidence of excited quarks, fourth generation down-type quarks, and a heavy Z decaying to di-electrons. The null results are interpreted as 95% confidence level mass limits on these objects.

1 Introduction

The Tevatron, a $p\overline{p}$ collider operating at the $\sqrt{s}$=1.8 TeV, has just completed a run with an integrated luminosity of approximately 100 pb^{-1}. Using data taken with the DØ detector, we have searched for evidence of excited quarks, fourth generation down-type quarks, and a heavy Z decaying to di-electrons. The DØ detector [1] has three major subsystems: central tracking detectors (with no central magnetic field), nearly hermetic liquid argon calorimetry, and a muon spectrometer. The central tracking system is used to identify charged tracks in the pseudorapidity range $|\eta| \leq 3.5$. The calorimeters cover $|\eta| \leq 4$, and have energy resolution $15\%/\sqrt{E}$ for electrons and $50\%/\sqrt{E}$ for hadrons. The muon system covers $|\eta| \leq 3.3$ and consists of drift chambers and magnetized iron toroids.

2 Excited Quarks

Many extensions of the standard model predict new particles which decay to two jets, such as excited quarks, techni-rho's, heavy W's and heavy Z's. [2 3 4] The new particles would produce a resonance in the di-jet mass spectrum. We select di-jet events from approximately 91 pb^{-1}of data passing our single jet triggers with at least two jets passing the quality cuts used in the inclusive jet analysis. [5] In order to reject instrumental backgrounds, such as hot cells, cosmic rays, and energy deposits in the calorimeter from the main ring accelerator which passes through the DØ detector, we reject events with large missing transverse energy. We require the missing transverse energy be less than 70% the E_T of the leading jet. The efficiency of our data selection cuts is high. We make a small correction for the inefficiency. In order to improve signal to background, we require the two jets be in the central region of the calorimeter, $|\eta| \leq 1.0$, and that the pseudorapidity difference between the two jets be less than 1.6. A detailed description of the data selection and jet energy scale calibration is given in reference 5. The di-jet mass is calculated as $M_{jj}^2 = 2 \cdot E_{T1} \cdot E_{T2} \cdot (\cosh\Delta\eta - \cos\Delta\phi)$.

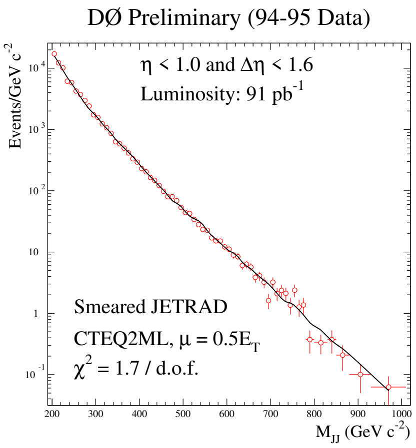

Figure 1: Fit to the dijet mass spectrum with the smeared JETRAD NLO calculation.

Figure 1 shows our data compared to a NLO calculation,[6] JETRAD, smeared with the DØ jet energy resolutions. The CTEQ2ML parton distribution functions are used, and the normalization is allowed to float. The agreement is good, with a χ^2/d.o.f of 1.7. We see no evidence of a resonance.

We interpret our null search as limits on the cross sections times branching ratio to di-jets times acceptance. We fit the spectrum to a linear combination of the same NLO calculation and a excited quark line shape from the PYTHIA event

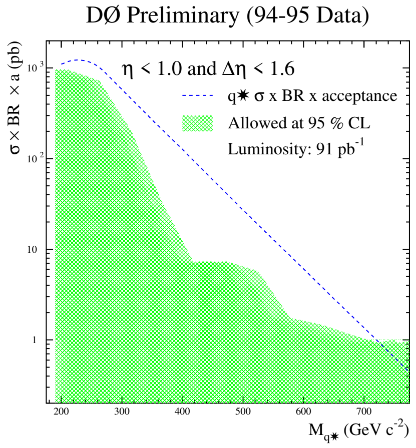

Figure 2: The calculated cross section and 95% confidence limits for excited quarks.

generator according to a model by Baur *et al.* [2] smeared with the DØ jet energy resolutions. The 95% confidence level limit as a function of mass is shown in figure 2. The limit includes an 8% uncertainty on the luminosity and a 2% uncertainty of the efficiency of the data selection cuts. The uncertainty in the mass scale is approximately 5% and is incorporated by plotting the CL at the mass which produces the most conservative limit. The theoretical cross section from the Baur *et al.* model is also shown. We exclude excited quarks with a mass less than 720 GeV/c^2 within this model.

3 Fourth Generation Down-type Quarks

Three generations of quarks are known to exist. Since the reason for this apparent redundancy in nature is not known, more generations might exist. The existence of a fourth generation of quarks is not excluded experimentally. Several constraints, however, do exist. A fourth generation of quarks with large mass splitting between the charge $-1/3$ quark and the charge $+2/3$ quark is excluded by measurements of the ρ parameter ($\rho = m_W^2/(m_Z^2 \cos^2\theta_W)$).[7] A fourth charge $-1/3$ quark (hereafter referred to as b') is excluded regardless of decay mode by direct and indirect searches at LEP up to $m_Z/2$.[8] Top quark searches at the Tevatron set limits on fourth generation quarks which decay to bW or cW.

We present here a search for a b' which decays via penguin diagrams, $b' \to bg$ or $b' \to b\gamma$. For the known quarks, such decays are highly suppressed compared to the normal charged current decays. However, if the b' quark happened to be lighter than the t quark, its charged current decay, $b' \to cW$, is a decay in which the generation number changes by two. For the b quark, $b \to uW$, a decay involving a change of 2 generations, is highly suppressed. We might thus expect the charged current b' decay to be suppressed as well. In this case, the penguin decays could be of equal or greater strength.[9] A b' quark could be pair-produced in $p\overline{p}$ collisions. The cross section is the same as that for $t\overline{t}$ production. The signature is two γ's and two b jets, one γ and two b jets and one gluon jet, or two gluon jets and two b jets. The last signature has large backgrounds. We present searches in the other two channels. Searches with final states containing photons may be of particular interest now because of the famous CDF event.[10]

In the first channel, γ, 2 b jets, and one gluon jet, we select events from 90 pb^{-1}of data which have at least one γ with $E_T>$ 20 GeV and $|\eta| \leq 1.1$, 3 or more jets with $E_T>$ 15 GeV and $|\eta| \leq 2.0$, one or more of the jets tagged as a b jet by the presence of a nearby muon, and the sum of the scalar E_T of the γ and the jets (H_T) greater than 1.5 times the mass of the b'. The tag muons have $p_T>$ 4 GeV and are required to be within $\Delta R = \sqrt{\Delta\eta^2 + \Delta\phi^2} < 0.5$ of a jet. The largest backgrounds are production of a direct photon plus jets, and multi-jet production, where one of the jets is mis-identified as a γ. Other backgrounds are negligible. The background rate is calculated using the tag rate method. We select events which pass all the above cuts, except the b tag. We scale this by an assumed universal per-jet tag rate for mixed flavor multi-jet processes. The tag rate function is parameterized as a function of the jet E_T, jet η, instantaneous luminosity, and time, and is approximately 0.5%. We assume that the tag rate function factorizes among these variables, and is proportional to the number of jets. We assign a systematic uncertainty of approximately 20% on the tag rate.

The total estimated background before the H_T cut is 59±11 events with 71 events observed in the data. There is no statistically significant excess. We calculate 95% confidence level limits on the cross section times branching ratio. The ac-

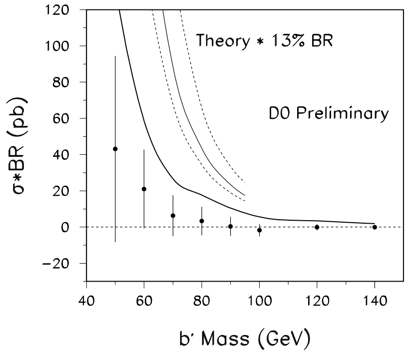

Figure 3: Cross section times branching ratio for $b'\bar{b}' \to \gamma$jet jet jet +b tag and 95% level upper limit compared to theory.

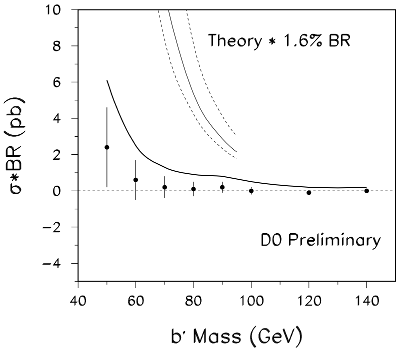

Figure 4: Cross section times branching ratio for $b'\bar{b}' \to \gamma\gamma$jet jet and 95% level upper limit compared to theory.

ceptance is calculated using the ISAJET version 7.14 event generator. The result is shown in figure 3. The theory curve stops at $m_{b'} \approx M_Z + m_b$, because at this point the decay $b' \to b\gamma$ becomes much less important than the decay $b' \to bZ$. We exclude b' quarks whose decays are dominated by the penguin diagrams from $m_Z/2$ up to this limit.

In the second channel, we select events from 77 pb^{-1}of data which have two γ's with $E_T >$ 20 GeV and $|\eta| \leq 2.0$, 2 or more jets with $E_T >$ 15 GeV and $|\eta| \leq 2.5$, and the sum of the scalar E_T of the jets greater than $m_{b'} - 20$GeV. Again, the dominant backgrounds come from direct photon production, and multi-jet events containing jets misidentified as photons. Other backgrounds are negligible. The background is calculated using γ plus multi-jet events, and applying the measured probability for a jet to be mis-identified as a γ. The total estimated background before the H_T cut is 14.2 ± 2.2 events with 20 events observed in the data. Limits on the cross section for this channel are shown in figure 4. We exclude b' quarks whose decays are dominated by the penguin diagrams from $m_Z/2$ up to this limit.

4 Heavy Z decaying to di-electrons

Additional heavy neutral gauge bosons are predicted is most extensions of the standard model.[11] We search for resonances in the mass spectrum from di-electron events. We select events from approximately 90 pb^{-1}of data which have at least two electrons which pass loose identification requirements and have $E_T >$ 25 GeV and $|\eta| \leq 1.1$ or $1.5 \leq |\eta| \leq 2.5$, have at least one electron with $|\eta| \leq 1.1$, and have at least one electron with $E_T >$ 30 GeV. 10% of the acceptance in the $|\eta| \leq 1$ region is excluded to avoid cracks in the calorimeter. Our identification requirements are the same as used in the cross section analysis.[12] Specifically, we only require one of the legs have a matching track in order to increase efficiency. There are 5684 events in the data sample. In the mass region around the Z peak, approximately 3% of the sample are di-jet events where the jets have been mis-identified as electrons. The mass spectrum is shown in figure 5. In the lower part of the figure, we compare the spectrum with the predicted shape for the Z plus the di-jet backgrounds. The Z shape is from the PYTHIA generator smeared with our detector resolutions. The background shape is obtained from events which pass the above kinematic cuts but fail the electron identification criteria. The agreement is good. For $m_{ee} >$ 300 GeV/c^2, we expect 5.8 events and observe 6. Above 500 GeV/c^2, we expect 0.3 events and observe one.

As we see no excess above the background prediction, we set a limit on the ratio of σB(Z' $\to$ ee) / σB(Z $\to$ ee). The event selection efficiency for the Z' and the Z are assumed to be the same. The ratio of acceptances for the Z' to the Z is calculated using PYTHIA, which models the Z' as

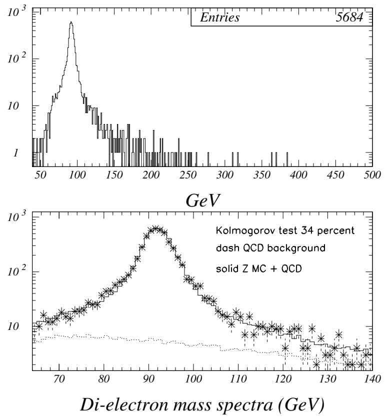

Figure 5: Invariant mass spectrum for di-electron events and compared to theory.

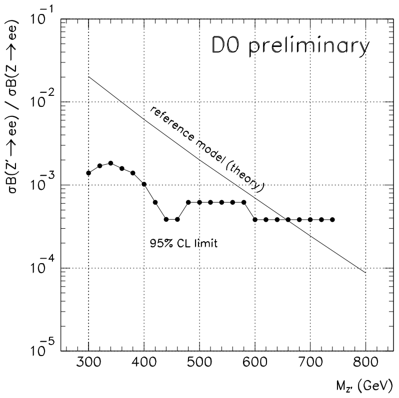

Figure 6: 95% confidence level upper limit on the ratio of the heavy Z cross section to the Z cross section and theory curve.

the standard model Z with a width that scales as $\Gamma_{Z'} = \frac{m_{Z'}}{m_Z} \times \Gamma_Z$. A conservative uncertainty of 10% is included in the ratio of the Z' to Z acceptance. No background subtraction is done. The region above the limit curve in figure 6 is excluded at 95% confidence level. The cross section for a Z' is calculated using the program of R. Hamberg *et al.*[13]. We exclude a Z' with the same couplings as the standard model Z with $m_{Z'} < 660$ GeV/c^2 at 95% confidence level. This limit may be combined with the limit obtained previously from 15 pb^{-1}of data. From a combined data set of 105 pb^{-1}, we exclude the existence of a Z' boson for $m_{Z'} < 670$ GeV/c^2.

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