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Search for Exotic Particles at CDF

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SEARCH FOR EXOTIC PARTICLES AT CDF

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Abstract

We have searched for exotic particles in $\bar{p}p$ collisions at 1.8 TeV in data taken with the Collider Detector at Fermilab. We review our published limits on W' and Z' masses, and on the scale of lepton-quark compositeness. We also report preliminary mass limits based on searches for leptoquarks, supersymmetric quarks and gluons, and exotic, stable colored fermions.

INTRODUCTION

The Fermilab Tevatron provides a unique opportunity to search for new phenomena beyond the Standard Model at the highest available center of mass energies. The Standard Model has been extremely successful in describing elementary particle physics. Indeed, all experimental evidence to date is in excellent agreement with this model. However, there are many theoretical motivations for a more complete theory such as the large number of free parameters of the Standard Model and its failure to explain the fermion mass spectrum, fermion mixing, and the origin of symmetry breaking. In general, theories beyond the Standard Model predict the existence of exotic particles, and these yet unobserved particles tend to be heavy.

At the Collider Detector at Fermilab (CDF) we have searched for a number of exotic particles in ≈ 4 pb^{-1} of data taken during the 1988-1989 Tevatron collider run.

ADDITIONAL GAUGE BOSONS

W' Search

We have searched for a peak in the lepton-neutrino transverse mass ($M_\perp$) above the W mass.[1] We selected events with a $p_t > 30$ GeV electron or muon accompanied by a missing transverse energy $\not\!\!E_t > 30$ GeV. The transverse mass is measured as $M_\perp = \sqrt{2E_t\not\!\!E_t(1-cos\Delta\phi)}$, where $\Delta\phi$ is the angle between lepton and $\not\!\!E_t$ in the plane transverse to the beam direction. The observed $M_\perp$ distribution is consistent with W production and decay alone. In particular, we find no evidence for anomolous high $M_\perp$ events. The highest $M_\perp$ events observed are at 185 GeV/c^2 ($e\nu$) and 205 GeV/c^2 ($\mu\nu$) and are consistent with the tail of the W transverse mass. We place

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a limit on cross section times branching ratio (σB) for W' production as a function of W' mass. This limit is independent of the W' couplings and is valid for the W' coupling to a stable neutrino with mass less than 15 GeV/c^2. For a W' with standard strength couplings to three generations of light fermions, we set a limit of $M'_W > 520$ GeV/c^2 GeV at 95% confidence level (CL).

Z' Search

We have searched for a peak in the dilepton invariant mass above the Z resonance. [2] We select events with two electrons or muons with $p_t > 15$ or 20 GeV respectively. The distribution of dilepton invariant mass is entirely consistent with the Standard Model expectation and our detector resolution. We find 9 dielectron and 2 dimuon events above an invariant mass of 110 GeV/c^2 , with the highest mass events at 189 GeV/c^2 (electron) and 155 GeV/c^2 (muon). This corresponds to a cross section of 4 ± 1 pb where the Drell-Yan predition is 4 pb. Based on the observed invariant mass distribution in the combined electron and muon channels, we place a limit on σB as a function of Z' mass. This limit is essentially model independent, being insensitive to the Z' width (to a factor of 2) and independent of the Z' coupling to quarks. For a Z' with Standard Model couplings the mass limit at 95% CL is 412 GeV/c^2 . Limits in realistic models are typcially weaker as the coupling to quarks tends to be smaller than the Standard Model couplings, and consequently the Z' is harder to produce. For example, in the popular E_6 models, the σB limit implies limits of $Z_\psi > 320$ GeV/c^2 , $Z_\chi > 340$ GeV/c^2 , $Z_\eta > 340$ GeV/c^2 , and $Z_{LR} > 320$ GeV/c^2 . These limits do not include additional E_6 exotic fermions, which result in smaller leptonic branching ratios and still weaker limits.

Lepton-quark compositeness

If both lepton and quark are composite particles that share constituents, an effective contact interaction arises between them.[3] This interaction results in an enhancement of the dilepton differential cross section at high invariant mass. Based on the absence of high mass dilepton events, we have set limits on the scale of such an effective contact interaction.[4] For definiteness, we choose the scale parametrizing the interaction between left handed chiral currents,

$$\mathcal{L} = \mp \frac{4\pi}{\Lambda^{\mp}_{LL}{}^2} (\bar{l}_L \gamma^\nu l_L)(\bar{q}_L \gamma_\nu q_L),$$

where the $-(+)$ corresponds to constructive(destructive) interference with the dominant u quark Drell-Yan amplitude. We set limits at 95% CL in the electron and muon channels of [2]

$$\Lambda^-_{LL} > 2.2(1.6) \text{ TeV e}(\mu)$$

$$\Lambda^+_{LL} > 1.7(1.4) \text{ TeV e}(\mu).$$

LEPTOQUARKS

Leptoquarks are hypothetical particles with both baryon and lepton quantum numbers. Massive, charged, color triplet leptoquarks are predicted in many extensions of the Standard Model such as certain E_6 grand unification schemes. In order to suppress rare decays, the leptoquark-lepton-quark coupling (λ) is taken to be flavor diagonal, chiral, and generation diagonal. While in general the spin of the leptoquark is model dependent, in many models they occur as scalars. Here we report on a search for pair produced, first generation, color triplet, scalar leptoquarks. Since the leptoquarks are pair produced in strong interac-

tions, the production cross section is independent of the leptoquark coupling λ.

We search for events with two high E_t (> 20 GeV) electrons accompanied by two high E_t (> 20 GeV) jets, where the electron-jet pairs have masses consistent with a leptoquark mass. Monte Carlo calculations of the production cross section and our acceptance show that we are sensative out to masses of 125 GeV/c^2 , where we expect 2 events. The only significant background comes from Drell-Yan produced Z plus two jet events. In the neighborhood of ± 15 GeV/c^2 in dielectron invariant mass around the Z mass we find 4 events where we expect 4.2 ± 0.5 Z plus dijet events. Outside of this neighborhood find no events, consistent with the Drell-Yan expectation of 0.7 ± 0.1 events. We calculate a small ($10 \sim 20\%$), mass dependent inefficiency due to excluding the dielectron invariant mass region about the Z peak and place a limit on σB^2 at 95% CL as a function of leptoquark mass based on the absence of signal events (figure 1). Here B is the branching ratio to lepton plus quark. For a branching ratio of one and including next to leading order corrections to the cross section[5], we set a limit on leptoquark mass of $M_{LQ} > 116$ GeV/c^2 at 95% CL.

SUPER SYMMETRY

In supersymmetric theories where R parity is conserved, the supersymmetric partners of quarks ($\tilde{q}$) and gluons ($\tilde{g}$) will be pair produced and the lightest supersymmetric particle (LSP) will be stable and non-interacting. Current limits from LEP require that the lightest neutralino be lighter than the chargino, so that in the mass range of our search the LSP is neutral.[6] Thus the signal for supersymmetry is a large missing transverse energy ($\not\!\!E_t > 40$ GeV) plus at least two high E_t (> 15 GeV) jets.

The dominant background to this signal is mismeasured dijet events, where the signal to background is less than 10^{-5}. To suppress this background we make a cut on the $\not\!\!E_t$ significance, defined as the ratio of $\not\!\!E_t$ to the square root of the total E_t in the event, corresponding to a 5σ fluctuation in the dijet resolution. In addition we explicitly exclude events which have opposite dijets in the plane transverse to the beam, or single jets opposite to the direction of the $\not\!\!E_t$. After removing cosmic rays and events with high p_t leptons from W and Z decays we are left with 93 events: 71 two jet, 20 three jet, and 2 four jet events. We observe a distribution in $\not\!\!E_t$ that is steeply falling, with three events having $\not\!\!E_t > 100$ Gev. The highest $\not\!\!E_t$ events are a three jet event at 185.9 ± 7.4 GeV and a four jet event at 167.8 ± 6.9 GeV. The remaining backgrounds are calculated from Monte Carlo. We expect 4 ± 4 QCD jet events, all with $\not\!\!E_t < 55$. The high $\not\!\!E_t$ tail is entirely due to W and Z plus jet events. We expect 95 ± 19 events, 3 with $\not\!\!E_t > 100$. The shape of the expected background distribution in $\not\!\!E_t$ is consistent with our observation, although the two highest events are intriguingly far out on the tail.

Based on the absence of high $\not\!\!E_t$ events we place limits on $\tilde{q}$ and $\tilde{g}$ masses. To explore our sensitivity to supersymmetry, we consider the case where the gaugino masses are larger than the $\tilde{q}$ and $\tilde{g}$ masses. In this case the $\tilde{q}$ and $\tilde{g}$ will decay directly to the LSP and the cross section limit depends only on the $\tilde{q}$ and $\tilde{g}$ masses. For LSP masses less than 15 GeV/c^2 , we exclude a region in the $\tilde{q}$ and $\tilde{g}$ mass plane which asymptotically approaches the limits $M_{\tilde{g}} > 152$ GeV/c^2 and $M_{\tilde{q}} > 126$ GeV/c^2 at 90% CL. More realistically, in the five parameter space of the minimal supersymmetric model (MSSM) not already excluded by LEP data, the gauginos will be lighter than the

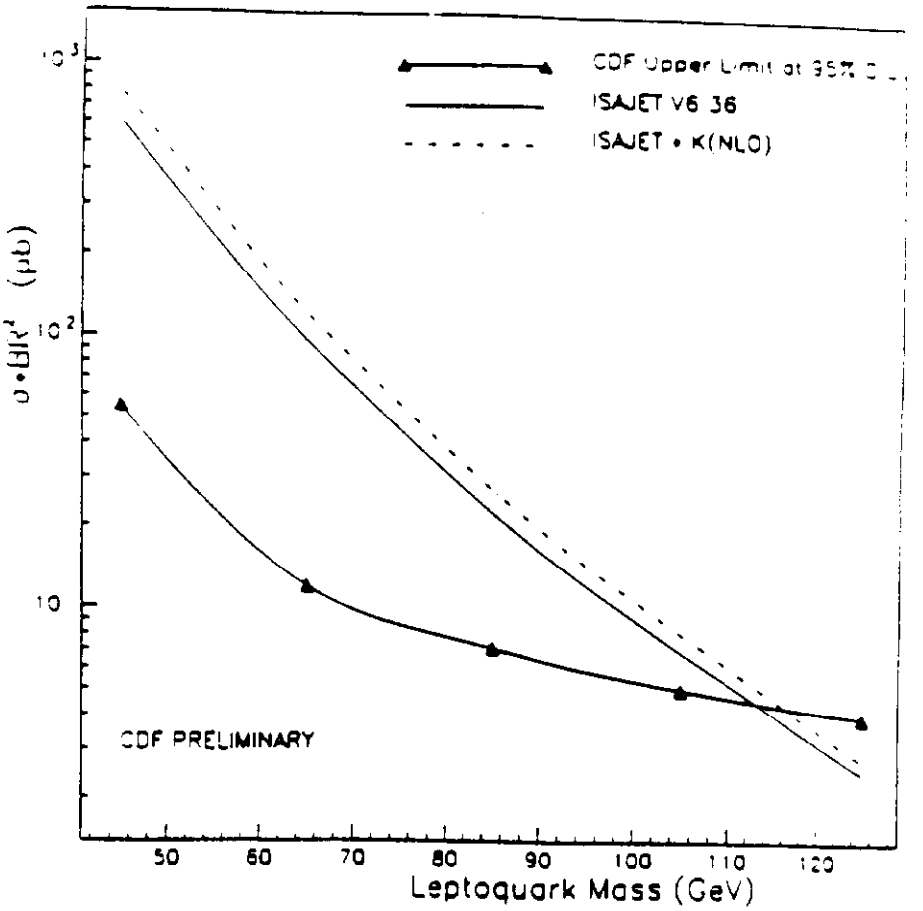

Figure 1. Limit on first generation leptoquark σB^2 as a function of mass. ISAJET cross section calculations are for B=1. The dot-dashed curve includes next to leading order corrections. We set a limit of $M_{LQ} > 116$ GeV/c^2 for B=1.

$\tilde{q}$ and $\tilde{g}$ allowing cascade decays.[6] Such cascade decays result in a degraded $\not\!\!E_t$ signal and consequently weaker limits. Figure 2 shows the region of the $\tilde{q}$ and $\tilde{g}$ mass plane excluded by our data for typical values of the MSSM parameters allowed by LEP data: higgsino mass mixing parameter $\mu = -250$ GeV, ratio of higgs vacuum expectation values $\tan\beta = 2$ and charged higgs mass $H^+ = 500$ GeV. This excluded region includes the effect of non-zero LSP mass calculated in the MSSM as well as cascade decays.

MASSIVE STABLE CHARGED PARTICLES

A number of models beyond the standard model predict the existence of very massive, stable, charged, colored particles. [7] Such stable particles (SP) would be strongly produced in pairs and would appear as low velocity ($\beta < 1$) charged hadrons which, by virtue of their large mass, would be highly penetrating. We have searched for massive, charged particles that have sufficiently long lifetimes ($\gamma\tau > 10^{-7}$ sec) to penetrate the muon chambers at a radius of 3.5 meters. We measure the velocity of the particles by hadron calorimeter scintillator timing (ΔT) with a resolution of 1.6 ns. The timing resolution limits the range of our search to $\beta < 0.65$ corresponding to SP masses $M_{SP} > 50$ GeV/c^2. We are insensitive to $M_{SP} > 500$ GeV/c^2 due to the expected fall off in cross section. For low hadron energy deposition ($E_{had} < 1.5$ GeV), the timing resolution degrades. We make use of the correlation between velocity and expected energy deposition to define a signal region in the ΔT - E_{had} plane for SP charges 2/3, 1, and 4/3. We find two events inside of our signal regions and one event just outside. These events are entirely consistent with background estimates

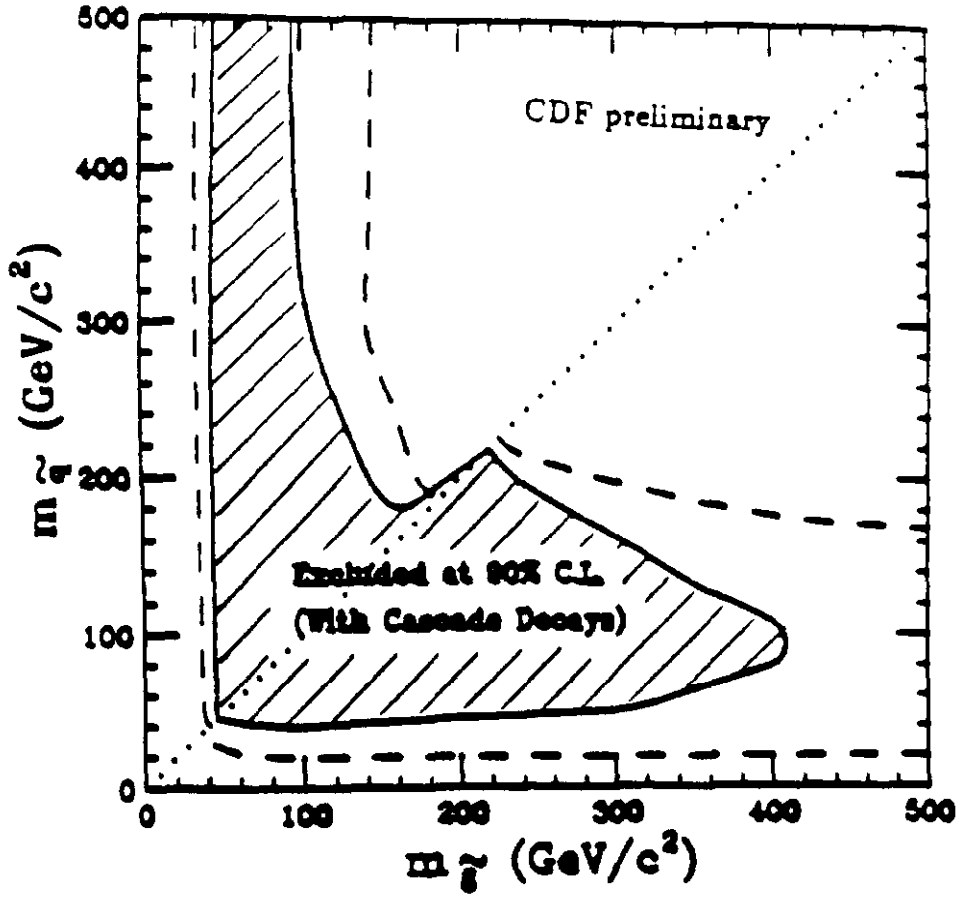

Figure 2. The shaded region of the $\tilde{q}$ and $\tilde{g}$ mass plane is excluded in the MSSM including effects of cascade decays and non-zero LSP mass. Typical values of allowed MSSM parameters have been used.

derived from low p_t muon data. However, the 95 % CL limit on cross section as a function of SP mass for a given charge conservatively considers these three events as "signal" (figure 3). Mass limits can be derived from cross section curves calculated for particular fermionic color multiplets. For a unit charge color triplet SP we find a limit of $M_{SP} > 139$ GeV/c^2 at 95% CL.

PROSPECTS

We anticipate the collection of more than five times the data analyzed here in the current collider run. Based on the expected improvement in statistics due to this larger data set and increased detector acceptance we will search for exotics up to the following masses:

$$M_{W'} \sim 680 \text{ GeV}$$

$$M_{Z'} \sim 590 \text{ GeV}$$

$$\Lambda^-_{LL} \sim 3.0 \text{ TeV}$$

$$M_{LQ} \sim 170 \text{ GeV}$$

$$M_{\tilde{g}}(M_{\tilde{q}}) \sim 180(150) \text{ GeV}$$

$$M_{SP} \sim 200 \text{ GeV}$$

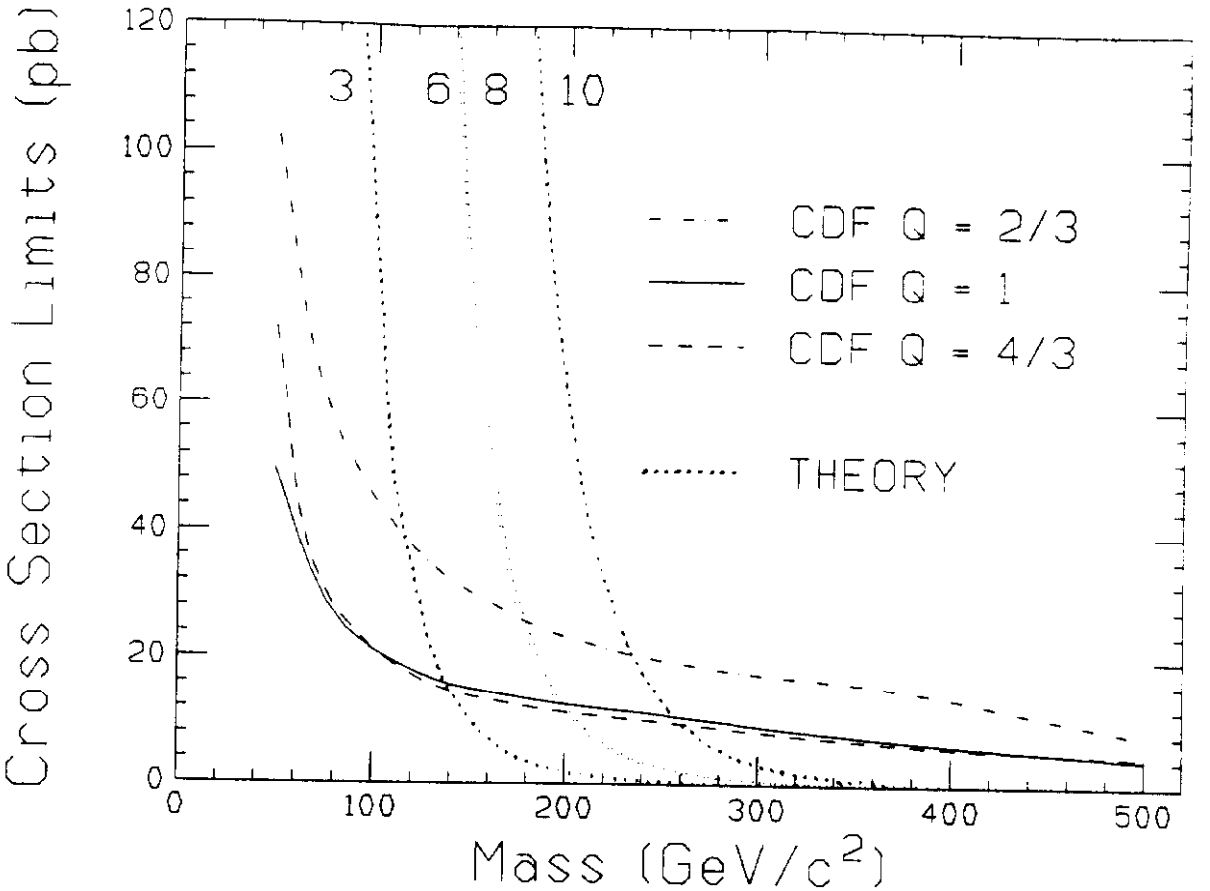

Figure 3. Cross section upper limits at 95 % CL for pair production of charge 2/3, 1, and 4/3 stable particles. Also shown are theoretical cross sections for the pair production of various fermionic color multiplets.

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