Searches for Charginos and Neutralinos with the D0 Detector

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Within the framework of supersymmetry, charginos and/or neutralinos are often the preferred topics of searches for experimental evidence. This is due to the facts that in much of parameter space they are the lightest supersymmetric partners and they offer unique final states to separate from standard model backgrounds. The D0 experiment has performed several recent searches including the traditional trilepton final state and a decay chain involving dark photons.

1. Introduction

The beyond the standard model (BSM) of supersymmetry (SUSY) has been explored theoretically [1] for several decades. While no experimental evidence has been found, searches for supersymmetry continue to be an important part of the physics programs at high energy colliders.

The spectrum of sparticle masses is determined by the SUSY model and the choice of parameters. However, in many variations (e.g. mSUGRA) the lightest sparticles may be charginos and neutralinos, mixtures of the wino and bino which are the superpartners of the W and Z bosons. If the lightest neutralino $\chi_1^0$ is also the lightest supersymmetric particle (LSP) and $R$-parity is conserved, then the $\chi_1^0$ escapes detection in collider experiments and appears only as a contribution to missing transverse energy. Therefore, pair production of $\chi_1^0$ becomes difficult to observe. A more interesting process is associated production of a chargino and the second lightest neutralino ($p\bar{p} \to \tilde{\chi}_1^± \tilde{\chi}_2^0$) where some of the decay products of the $\tilde{\chi}_1^±$ and $\chi_2^0$ can be observed.

The D0 experiment at the Fermilab Tevatron has collected data on $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV since 2001. The detector consists of an inner tracking system (with solenoid magnet), a liquid argon calorimeter, and an outer muon spectrometer. A full description is available in Ref. [2].

2. Trileptons

A traditional search for associated chargino and neutralino production involves looking for events with three leptons plus missing transverse energy [2]. In this case, the chargino decays via $\tilde{\chi}_1^± \to \ell^± \nu \chi_1^0$ while the neutralino decays via $\chi_2^0 \to \ell^± \ell'^± \chi_1^0$ (Fig. 1). Here, $\ell$ and $\ell'$ may or may not be the same lepton flavor while the neutrinos and lightest neutralinos escape undetected.

Six final state particles means that some of the time, one or more of the charged leptons has low $p_T$. This can be particularly true depending on the sparticle mass relationships. Figure 2 shows the $p_T$ of the three charged leptons (in order of decreasing $p_T$) for one model point. Therefore, techniques have been developed to include low $p_T$ leptons in the analysis. In this case, we allow the third lepton to be identified as an isolated track with low $p_T$. This recovers part of the acceptance that would be lost by requiring it to be identified as a high quality lepton. Another technique (not used here) is to search for like sign leptons.

One reason this channel is considered a “golden channel” is that there are very few standard model processes that may produce trilepton events. The primary source of events with three real leptons is via diboson production (e.g. $WZ$) which has a small cross section. Single boson production ($W$ or $Z$) contributes only through a fake third isolated track and/or fake missing transverse energy.

2.1. Event selection

Event selection criteria are optimized in two regions, one “low-$p_T$” and one “high-$p_T$”, to take advantage of the different kinematics in different regions of mSUGRA parameter space. The data is searched in four final states: (1) di-electron plus lepton ($ee\ell$), (2) di-muon plus lepton ($\mu\mu\ell$), (3) electron plus muon plus lepton ($e\mu\ell$), and (4) muon plus tau ($\mu\tau$). The third lepton is identified as an isolated track without using the lepton identification criteria. Details on the selection criteria are given in Ref. [3].

The inclusion of the $\mu\tau$ channel is new for the trilepton analysis. Here, hadronic decays of the tau are considered. Leptonic decays and single hadron decays ($\tau \to \pi^±\nu$) had previously been included when they passed other lepton requirements. The inclusion of this final state allows for greater sensitivity at higher values of $\tan\beta$. The $\mu\tau$ channel is broken down into two subsets: $\mu\tau\tau$ and $\mu\tau\ell$ where the difference is whether a second reconstructed tau or a isolated track is required. The $\mu\tau$ channels are not optimized separately for low and high $p_T$.

2.2. Results

Comparisons of data and expected background for the various channels is given in Tab. 1. Good agree-
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Figure 1: Feynman diagrams for the associated production of a chargino and a neutralino with decay into the trilepton final state.

Figure 2: Distribution of charged lepton $p_T$ for the trilepton final state. The red histogram is the highest $p_T$ lepton, the green the second highest $p_T$ lepton, and the blue is the third highest $p_T$ lepton.

3. Dark photons

Recent experimental evidence for an excess of positrons and/or electrons within the cosmic ray spectrum [4, 5] have inspired a new model of a 1 TeV dark matter candidate that can annihilate with itself. This annihilation can create two light (< 3 GeV) gauge bosons called dark photons that are force carriers of a hidden valley sector [6, 7]. These gauge bosons can decay via mixing with the standard model photon to produce pairs of standard model fermions. The branching ratios into fermion types depends upon the mass of the dark photon.

D0 has searched for evidence of dark photons through pairs of electrons or muons with very small opening angle using 4.1 fb$^{-1}$ of data [8].

Table I Numbers of events for data and expected background for the four final states and both the low-$p_T$ and high-$p_T$ optimizations in the trilepton search.

|        | Data  | Expected Background |
|--------|-------|---------------------|
| $e\ell$ | 2     | 1.8 ± 0.2           |
| low-$p_T$ | 0     | 0.8 ± 0.1           |
| high-$p_T$ | 0    | 0.5 ± 0.1           |
| $e\mu\ell$ | 2   | 0.8 ± 0.2           |
| low-$p_T$ | 0     | 0.5 ± 0.1           |
| high-$p_T$ | 4    | 1.2 ± 0.2           |
| $\mu\ell$ | 4     | 2.0 ± 0.3           |
| $\mu\tau$ | 1     | 0.8 ± 0.2           |
| $\mu\tau\ell$ | 0  | 0.8 ± 0.1           |

Figure 3: 95% C.L. limits on the mSUGRA model in the $m_{1/2}$ versus $m_0$ plane. The orange indicates the expected limits while the green shows the observed limits. Previously published results from LEP and CDF are also shown. Figure 4 shows a Feynman diagram for the production and decay of dark photons at the Tevatron. In this scenario, the production still creates an associated chargino and neutralino (as in the previous search), but the observ-
3.1. Selection criteria

Events are selected by requiring a photon with $p_T > 30$ GeV and missing transverse energy $>20$ GeV. Pairs of oppositely signed tracks with $R < 0.2$ (where $R = \sqrt{(\Delta \eta)^2 + (\Delta \phi)^2}$) and $\Delta s_{\text{vertex}} < 2$ cm are dark photon candidates. They must have momentum greater than 10(5) GeV for the leading(2nd leading) track. Previous analyses likely would have missed such a signal due to isolation criteria. Here, isolation variables are calculated after accounting for the second nearby particle.

Dark photon candidates are divided into two types: electron or muon. In the electron case, the tracks must match a single EM cluster (since the two electrons overlap in the calorimeter). In the muon case, one of the tracks must be matched to a reconstructed muon.

3.2. Results

The invariant mass distribution for the electron or muon pairs is studied for evidence of a dark photon resonance. The background estimate is created by combining three data samples with one or more selection criteria inverted. Figure 6 shows the data, background estimate, and simulated signal. No evidence for a narrow resonance is seen.

Limits on the production cross section are extracted from the invariant mass distributions (Fig. 7). Figure 8 shows the limits on the dark photon mass as a function of the chargino mass for a branching ratio of $\tilde{\chi}_1^0 \rightarrow \gamma_D \tilde{X}$ of 0.5. Figure 9 shows the limit on the chargino mass as a function of this branching ratio for three different dark photon masses.
4. Summary

The D0 experiment has recently completed two searches for production of charginos and neutralinos in the Tevatron Run II data set. The first was a traditional search in the trilepton final state including $e\ell\ell$, $\mu\mu\ell$, and $\mu\tau$ channels. The second was a novel search for spatially close lepton pairs as a signature of a dark photon resulting from a neutralino decay. Neither search observed an excess of data over expectation and limits on the production cross section and model parameters were set.

References

[1] S. P. Martin, arXiv:hep-ph/9709356.
[2] V. M. Abazov et al. [D0 Collaboration], Nucl. Instrum. Meth. A 565, 463 (2006).
[3] V. M. Abazov et al. [D0 Collaboration], Phys. Lett. B 680, 34 (2009).
[4] O. Adriani et al. [PAMELA Collaboration], Nature 458, 607 (2009).
[5] J. Chang et al., Nature 456, 362 (2008).
[6] N. Arkani-Hamed, D. P. Finkbeiner, T. R. Slatyer and N. Weiner, Phys. Rev. D 79, 015014 (2009).
[7] M. J. Strassler and K. M. Zurek, Phys. Lett. B 651, 374 (2007).
[8] V. M. Abazov et al. [D0 Collaboration], Phys. Rev. Lett. 103, 081802 (2009) [arXiv:0905.1478 [hep-ex]].
[9] V. M. Abazov et al. [D0 Collaboration], Phys. Lett. B 659, 856 (2008).