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A search for charged massive long-lived particles at D0

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Historically, the discovery of the strange, long-lived kaons started a new era in particle physics. Today some extensions of Standard Model and some SUSY models suggest the existence of another kind of massive long-lived particles (MLLP)[1]. Existence of these particles could solve some of the puzzles that have no answers yet, namely, dark matter in the universe. Lithium abundance, which is not explained by the model of big bang nucleosynthesis (BBN) might be explained by the existence of a MLLP that decays during or after the time of BBN [2]. These massive long-lived particles could have colour and/or electric charge. They appear in many Supersymmetric (SUSY) models as bound states of squarks or gluinos (R-hadrons) or as sleptons or charginos. Current results are from a search of Charged Massive Long-Lived Particles (CMLLP) performed with 5.2 fb^{-1} of data collected by the D0 experiment at the Tevatron $p\overline{p}$ collider at $\sqrt{s} = 1.96$ TeV.

1. Models

We have used SUSY models to study the CMLLPs. However, CMLLPs can occur in models other than SUSY and our search will have some sensitivity for other types of CMLLPs which have similar production kinematics. We know from cosmology that in SUSY models the Lightest Supersymmetric Particle (LSP) is stable and must be neutral. Next-to-Lightest Supersymmetric Particles (NLSP) could be long lived due to weak couplings to LSPs or due to mass degeneracy with the LSPs. Such NLSPs could be CMLLP candidates. Four different types of CMLLPs are considered in this analysis. In the Gauge Mediated SUSY Breaking (GMSB) models, a tau slepton (stau) NLSP can be a CMLLP if its decay to the gravitino LSP is suppressed. A chargino can be a CMLLP candidate in those models where it is the NLSP and its mass difference with the LSP of the model is small. Two extreme scenarios are explored, where the chargino is mostly a gaugino or it is mostly a higgsino. The top squark (stop) can be a CMLLP candidate if it is the lightest coloured particle. In some Hidden Valley theories stop is an LSP and hence long lived [3].

2. The D0 Detector and CMLLP signatures

The D0 detector is a multipurpose detector which consists of three primary systems: a central tracking system, calorimeters, and a muon spectrometer [4]. The parts relevant for this search are the Muon System for the Time of Flight measurement and the Silicon Microstrip Tracker (SMT) for the dE/dx measurement. The muon system has wire chambers for muon tracking and scintillation counters for triggering on muons. There are three layers in the muon system with a 1.8 Tesla toroid between the first and the second layer. The SMT is the innermost part of the tracking system and has a six-barrel longitudinal structure, where each barrel consists of a set of nine layers in the central region and gives an accurate momentum and dE/dx measurement.

The properties of CMLLPs which can be used to detect them are, charge, due to which they leave a track in the tracker, long lifetime, due to which they do not decay inside the detector, large mass (compared to muons), due to which they have low speed. From these properties one can conclude that the CMLLPs act like muons but because they are much heavier, their Time of Flight to the muon system and dE/dx in the SMT are expected to be much larger than those of muons produced in $p\overline{p}$ collisions. For this search, events with one or more muons have been chosen and the highest p_T muon is required to satisfy the criteria of being a CMLLP candidate.

3. Signal, Background, and Data Samples

To obtain signal samples, CMLLP pairs are generated using PYTHIA(6.409) [5]. Cascade decays are not included to keep the analysis model independent. Staus, stops, and charginos (gaugino-like and higgsino-like) are generated at masses of 100, 150, 200, 250, and 300 GeV. Stop quarks are hadronized by linking an external routine with PYTHIA [6]. These samples are then processed through a GEANT3 based simulation of the D0 detector. The background contribution comes from mismeasured muons (wrong speed (β) and dE/dx), the biggest source of which is $W \rightarrow \mu\nu$ events.

This search is based on 5.2 fb^{-1} of data taken during June 2006 to June 2009. Events are triggered by a single high p_T(>20 GeV) muon. These events are then checked further using the following selection criteria. There should be at least one isolated muon of good quality in the event with $p_T > 60$ GeV, $|\eta| < 1.6$, and $\beta < 1$. The muon track in the muon chamber should have a matching partner in the SMT and the speeds of the muon measured in the different layers of the muon system should be consistent with each other. Since background events are mostly $W \rightarrow \mu\nu$ decays, the shape of the background is determined using a W-rich dataset selected by requiring $M_T < 200$ GeV [$M_T = \sqrt{(E_T + \not{E}_T)^2 - (p_x + \not{E}_x)^2 - (p_y + \not{E}_y)^2}$]. The background normalization is determined using a signal free dataset chosen with β >1.

4. Analysis Technique

It is observed that the requirement of $p_T > 60$ GeV for the highest p_T muon in the event reduces the background from W decays substantially. Addtionally the two variables, β and dE/dx help to further distinguish signal from background events. This can be seen in Fig. 1.

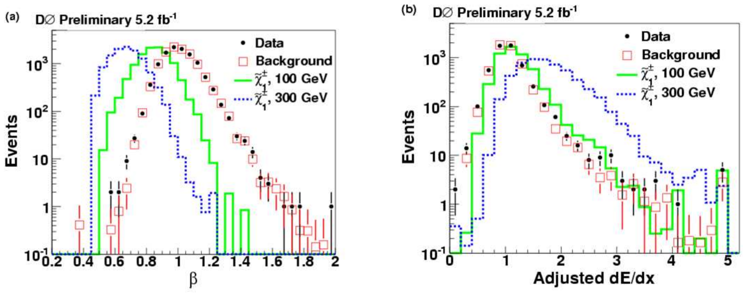

Figure 1: β and dE/dx distributions of the highest p_T muon in the event for data, background, and gaugino-like charginos. Each distribution is normalised to have the same number of events and the last bin contains all the overflow events.

The following unique feature of stop hadrons is treated separately. Stop quarks hadronize into neutral and charged mesons and baryons[7]. These hadrons flip charge due to nuclear interactions while passing through matter. In order to be detected in the D0 detector they have to be charged, at least at the entry point to the SMT and at the entry and exit points in the muon system. This requirement reduces the efficiency of stop detection. This analysis requires at least one of stop or anti-stop hadrons in the event to be charged for the event to be selected. The probability for that is 38%. This is used as an additional efficiency factor after imposing the other selection criteria.

The multivariate technique Boosted Decision Tree (BDT) is used for final signal selection. The BDT is trained on signal and background distributions of β, dE/dx and several related variables. The BDTs are applied to signal, background, and data distributions to derive a final variable (BDT output) distribution. Figure 2 shows the BDT distributions for 300 GeV gaugino-like chargino signal, background, and data. A CLs method is used to get limits at 95% C.L. on production cross sections of CMLLPs [8]. Inputs to the limit setting procedure are the BDT distributions and systematic errors.

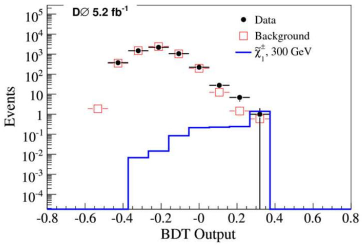

Figure 2: BDT output for data, background, and signal (gaugino-like chargino of mass 300 GeV) are shown. The signal histogram is normalized to the expected number of events.

5. Results and conclusions

We searched for pair produced Charged Massive Long-Lived particles in 5.2 fb^{-1} of data from the D0 experiemnt. We obtained a lower mass limit for stop quarks of 265 GeV. This limit is enhanced to 281 GeV if it is assumed that stop hadrons do not flip charge in a nuclear interaction. The lower mass limit for gaugino-like chargino is 251 GeV and that for higgsino-like chargino is 230 GeV. Cross section limits for staus are obtained as 0.04 to 0.006 pb for stau masses between 100 and 300 GeV. The mass limits on the charginos are the currently the best in the world. A paper based on this search has now been submitted for publication [9].

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