Searches for Heavy Long Lived Particles at Tevatron.

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Abstract. We present the results of searches for heavy, long-lived particles in \( p\bar{p} \) collisions at \( \sqrt{s} = 1.96 \) TeV at Tevatron Run II. Three new analysis are presented: the search for Charged Massive Particles (CHAMP), the first direct search for the delayed photons produced by neutralinos with non-zero lifetime \( \chi^0_1 \rightarrow \gamma G \), and the first direct search for long lived gluinos that are stopped in the detector. There is no excess for any of the channels.

1. Introduction
Since the Standard Model (SM) is known to be incomplete [1], there is a world-wide program to look for hints of new physics. Recent theoretical and experimental advances have brought a new focus on models with heavy, long-lived particles. Such particles are common in Gauge Mediated Supersymmetry Breaking (GMSB) [2] and other Supersymmetric (SUSY) models [3]. There is a wealth of possible signatures predicted by those theories. Here we focus on three fundamental ones: charged massive particles penetrating the detector, decays in the middle of a detector, and particles that are stopped in the middle of a detector.

2. Search for Charged Massive Particles at CDF
New massive particles arising from physics beyond the Standard Model might have lifetimes that are long compared to the transit time through the detector. If such a particle is charged, it will appear in the detector as a slowly moving, highly ionizing and highly penetrating track with large transverse momentum (\( P_T \)) that will typically be reconstructed as a muon. The search is done by looking for charged massive stable particles by measuring the Time-of-Flight (TOF) of high \( P_T \) tracks in events collected using a high \( P_T \) muon trigger. The result is consistent with the background expectations.

This signature-based search isolates heavy, high momentum particles by using the measured velocity and momentum of the particle to calculate the mass. A heavy particle creates a peak in the resulting mass distribution, while background predominantly populates the low mass region. We present both a model-independent result for a single CHAMP, while the result is interpreted within the context of a reference model for stable stop squark pair production. Since the leading order contributions to stop squark production depend only upon the stop mass [4], the result will generally apply to all stable stop production models. To measure the velocity, we exploit the precision timing provided by TOF detector [5] located at the perimeter of the tracking volume, augmented by additional timing information from the drift chamber (COT) [6].

The tracks with \( P_T > 40 \) GeV/c are classified as signal region tracks. The vast majority of CHAMPs with mass greater than 100 GeV/c\(^2\) should fall into this category. Tracks with
Figure 1. Momentum for the control region and signal region in the central muon dataset. The plot on the right shows $\beta$ for the control region and signal region.

Figure 2. Mass calculated from $\beta_{TOF}$ and the track momentum for the central muon dataset. The histogram is for events after cleanup cuts, while the red line is the prediction using the $20 < P_T < 40$ GeV control-region $\beta$. The blue line shows the additional events expected for a 220 GeV/c$^2$, and the magenta line shows the additional events expected for a 220 GeV/c$^2$ stop. On the right one can see the theoretical NLO cross section for stop production plotted as a function of stop mass (red), along with the observed limit.

20 < $P_T$ < 40 GeV/c are control region tracks since they are dominated by $W \rightarrow \mu\nu$ decays. To identify a CHAMP signal among candidate tracks, we use the velocity and momentum to calculate the TOF mass of the candidate particle. The track velocity for all candidate and control tracks is measured by dividing the path length of the track by its TOF. The TOF is measured by subtracting the event $t_0$ measured with reconstructed $P_T$. The momentum and velocity distributions for the control and signal region tracks are shown on Figure 1.

Figure 2 shows the observed and predicted TOF mass distribution for signal region muons. We find one candidate muon with a mass above 100 GeV/c$^2$ and none above 120 GeV/c$^2$, consistent with predicted background. From this result, we set a model-independent upper limit on the production cross section for a single, isolated, strongly interacting CHAMP with $P_T > 40$ GeV/c and $\sigma < 48$ fb at 95% C.L. Similarly, the cross section limit for a weakly interacting CHAMP under the same assumptions is $\sigma < 10$ fb at 95% C.L. Within the context of a general model of stable stop pair production, we set a lower stop mass limit of 250 GeV/c$^2$ at 95% C.L.

3. Search for Delayed Photons at CDF

We present the results of the first direct search at the Tevatron for heavy, long-lived particles that decay to photons in a sample of $\gamma + E_T + \text{Jet}$ events. Candidate events are selected based on the delayed arrival time of the photon at the calorimeter as measured with the EMTiming
Figure 3. LHS: A schematic drawing of a heavy $\chi_1^0$ decay into a photon and a gravitino in the detector. It takes the photon more time to reach the detector compared to the photon directly produced at the collision point. RHS: The timing for photons passing all cuts but the final timing requirement for the background predictions, data, and a GMSB signal for an example point at $m_{\chi_1^0} = 100 \text{ GeV}/c^2$, $\tau_{\chi_1^0} = 5 \text{ ns}$ (dashed). The Monte Carlo is normalized to the number of expected signal events of 5.8±0.7.

Figure 4. LHS: Contours of constant 95% cross-section C.L. for a GMSB model. The contours are {0.1, 0.2, 0.35, 0.5, 1.0} pb. RHS: The exclusion region as a function of $\chi_1^0$ lifetime and mass. The predicted and the observed regions are shown separately.

system [7] that was recently installed on the CDF electromagnetic calorimeter. Gauge Mediated Supersymmetry Breaking (GMSB) models [2] are an example theory that can produce such particles as long-lived neutralinos that can decay into photons and missing transverse energy ($E_T$). The lightest neutralino ($\chi_1^0$) is the next- to- lightest Supersymmetric particle (NLSP) and decays into a photon and a gravitino ($G$), which is the lightest Supersymmetric particle (LSP). The $G$ escapes the detector undetected and gives rise to $E_T$. The lifetime of the neutralino is a free parameter, and can be quite large. Since the neutralino can travel a significant distance before decaying, the neutralino could leave the detector completely without interacting, or if it decays in the detector could produce a photon that would appear to be arriving at the face of the calorimeter with a slight delay relative to the expectation for promptly produced photons. This is shown in Figure 3.

There are two major sources of the backgrounds: collision and non-collision photon...
candidates. Collision photons are presumed to be from the Standard Model interactions (e.g. $\gamma + j \rightarrow \text{Fake } E_T; jj + \text{Fake } E_T, j \text{ fakes } \gamma; W \rightarrow e\nu$, electron fakes $\gamma$). The non-collision photon candidates are produced by cosmic rays and beam effects. Cosmic rays are not correlated in time with collisions, and therefore their timing shape is flat in time. The photon candidates from beam halo have negative time. We use events in the time regions that do not overlap with prompt photons to estimate the overall non-collision backgrounds. All three are estimated using data.

Using a sample of 570 pb$^{-1}$ of collision data we observe 2 events in the signal region of $2.0 < t^\gamma < 10$ ns, consistent with the background estimate of 1.3±0.7 events (see Figure 3). We show exclusion regions and set limits on Gauge Mediated Supersymmetry Breaking models with long-lived neutralinos that decay to a photon and a gravitino, $\tilde{\chi}_1^0 \rightarrow \gamma G$. The results are in Figure 3.

4. Search for Long Lived Gluinos at DØ

This analysis searches for decays of the particles stopped in the detector, occurring up to 100 hours after their production and not synchronized with an accelerator bunch crossing. In split Supersymmetry [9] a gluino after hadronization can become charged and lose enough momentum through ionization to come to rest in dense particle detectors. Due to the scalars’ high masses, gluino decays are suppressed, and the gluino can be long-lived. The analysis uses 410 pb$^{-1}$ of data. The signature of such “stopped gluinos” decaying into a gluon and a neutralino ($\tilde{\chi}_1^0$) is a wide reconstructed jet, missing energy, and no underlying collision. The gluino lifetime is assumed to be long enough such that the decay event is closest in time to an accelerator bunch crossing later than the one that produced the gluino. The efficiency for recording the gluino decay is modeled as a function of the gluino lifetime, up to 100 hours.

The primary source of background is cosmic muons, which are able to fake a gluino signal if they initiate a high-energy shower within the calorimeter. Hard bremsstrahlung is responsible for the majority of the showers. These showers tend to be very short, since they are electromagnetic in nature and thus have small lengths compared to hadronic showers. The background is estimated by the convolution of the observed number of wide-jet plus a muon with the muon ID efficiency. The data agree with the estimated background as shown on Fig 4. There is no significant excess in any jet energy range. Given an observed number of candidate events, an expected number of background events, and a signal efficiency in a certain jet energy range, we can exclude at the 95% C.L. a calculated rate of signal events giving jets of that energy,
taking systematic uncertainties into account using a Bayesian approach. This is a fairly model-independent result, limiting the rate of any out-of-time mono-jet signal of a given energy.

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