Search for Long-lived Charged Massive Particles at CDF

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A search for long-lived charged massive particles in CDF's Run1b data sample is presented. The search looks for highly ionizing tracks which would result from slowly moving massive particles. We search for strongly produced particles using a stable color triplet quark as a reference model, and a separate search was performed for weakly produced particles using long-lived sleptons in Gauge-Mediated Supersymmetry Breaking as a reference model. No excess over background was observed, and we derive limits on the cross-sections for production of these particles. Prospects for RunII are also discussed.

I. INTRODUCTION

Many models for new physics include particles which may live long enough to traverse our detector. Such a particle may be long-lived due to a new conserved quantum number (such as R-parity in SUSY), or its decays may be suppressed. If these particles are charged, they could be detected directly [1,2,4].

The most stringest limits from direct searches for such particles come from LEPII and CDF. LEPII has set mass limits of about 82 GeV/c^2 on stable sleptons within the framework of Gauge-Mediated Supersymmetry Breaking (GMSB) [5]. CDF set a limit of M > 139 GeV/c^2 on stable quarks from data taken in 88/89 [6]. Other searches have also been performed at LEP and other accelerators [7].

We have searched for Charged Massive Particles (CHAMPS) in 90 pb^{-1} of Run1B data at CDF. We have aimed to be as model independent as possible, but the search naturally divides into two separate searches, one for strongly produced particles and one for those produced via the weak interaction.

The strongly produced particles would have a larger production cross section, so the region of interest is at high mass where the background is expected to be low.. We expect that these particles would fragment into an integer charged meson within a jet. For the strong search, we use a 4th generation quark as a reference model.

Weakly interacting CHAMPS would have a lower production cross-section so the region of sensitivity is at lower mass where the background is higher. These weakly produced particles are expected to be isolated, which allows us to reduce the background significantly. We use Drell-Yan production of a slepton within a GMSB scenario as a reference model.

II. SIGNATURE

Massive particles will be produced with relatively low $\beta\gamma$, so the signature is a highly ionizing track. We use the Central Tracking Chamber (CTC) and the Silicon Vertex Detector (SVX) to independently measure dE/dx. For both searches, we make a cut of $\beta\gamma < 0.85$, and for the strong search we additionally look at $\beta\gamma < 0.70$ for added sensitivity at low mass. We searched track by track from events which came in on three different triggers – the muon trigger, $\rlap{/}{E}_T > 35$ GeV trigger, and the electron trigger. The muon trigger is directly sensitive to a CHAMP since massive particles would be penetrating and appear as muons, while all three triggers are sensitive to production of sleptons in cascade decays of other sparticles which produce in addition a neutrino, electron or muon.

III. KINEMATIC CUTS

All considered tracks are required to pass quality cuts which reduce backgrounds from misreconstructed tracks. Due to timing considerations, particles moving slower than $\beta\gamma = 0.4$ are not reconstructed. For a particle of mass 90 GeV/c^2, this corresponds to a minimum reconstructable momentum of 35 GeV. We therefore require that each track has a momentum greater than 35 GeV/c, which eliminates much of our low momentum background. We also cut on the mass M_{SVX} calculated from the dE/dx measurement in the SVX and momentum of the track. For the strong search, we perform a search in bins of mass M, and make a cut on $M_{SVX} > 0.6 \times M$. Our background falls off with momentum, and this M_{SVX} cut forces a stiffer dE/dx cut at low momentum where the background is higher. For the weak search, the mass cut is simply $M_{SVX} > 60 GeV/c^2$. These tracks must additionally pass an isolation cut, namely we require less than 4 GeV of calorimeter energy or total track pT within a cone of $0.4 = \sqrt{\Delta\eta^2 + \Delta\phi^2}$ of the track.

IV. BACKGROUND

The only background expected is from fakes, where a track has a dE/dx which fluctuated high, or where overlapping tracks reconstruct as a single track. In order to estimate the background, we use a control sample at low momentum ($15 < |\vec{p}| < 35$ GeV) to calculate the expected fake rate, then multiply the fake rate by the number of tracks which enter our sample in the signal region $|\vec{p}| > 35$ GeV to get the expected background. The fake rate is calculated in the control sample by taking the ratio of the number of tracks which pass the dE/dx cut in both the CTC and the SVX to the total number of tracks.

Since the fake rates are extrapolated from low momentum to high momentum, we plot the fake rate as a function of momentum and check that it is flat. We observe that the fake rate falls off below 20 GeV/c, especially in the CTC. This is because our control sample is contaminated with kaons, which are still along the relativistic rise on their dE/dx vs. p curve below 20 GeV/c and pull down the fake rate in this region in momentum. For the muon triggered data sample, we take the control sample to be tracks which lie in the momentum region $20 < |\vec{p}| < 35$ GeV and for the $\not{E}_T$ sample and the electron sample our control region is $25 < |\vec{p}| < 35$ GeV.

V. RESULTS

The results of each search are tabulated below.

TABLE I. Strong Search

Sample	Bkgd.	Obs.
Muon Trigger	12 ± 2	12
$\not{E}_T$ Trigger	63 ± 9	45
Muon Trigger ($\beta\gamma <0.70$)	2.5 ± 0.8	2

TABLE II. Weak Search (Includes Isolation Cut

Sample	Bkgd.	Obs.
Muon Trigger	0.85 ± 0.25	0
$\not{E}_T$ Trigger	4.0 ± 2.8	1
Electron Trigger	0.72 ± 0.54	0

We calculate the expected mass distributions from the control sample. To do this, we take the momentum of each track and calculate what its dE/dx would be if it came from a particle with mass M, and then use the control sample to find the probability that the track fakes that dE/dx. We do this for the entire range in M and sum over all tracks. The data and expected background distributions are shown in Figures 1 and 2. No excess over background is observed.
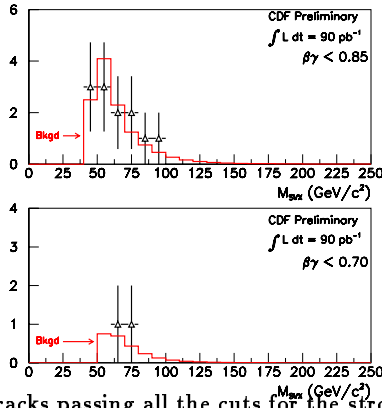

FIG. 1. Observed M_{SVX} distribution for tracks passing all the cuts for the strong search in the muon triggered data sample. The solid curves are the expected background distributions.
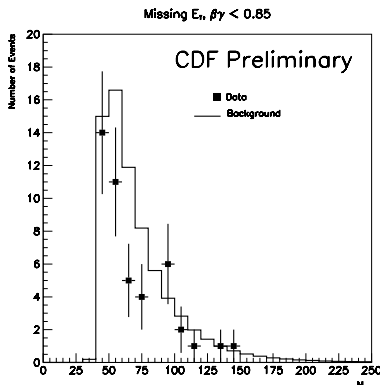

FIG. 2. Observed M_{SVX} distribution for tracks passing all the cuts for the strong search in the $\not{E}_T$ triggered data sample. The solid curve is the distribution of the 63 ± 9 expected background events.

VI. EFFICIENCIES AND SYSTEMATICS

For the strong search, the efficiency depends on the quark charge due to fragmentation effects. It increases from 1.5 - 3% for q=2/3 and 0.8-1.5% for q=1/3 in the mass range 100-240 GeV/c^2. The largest systematic uncertainties come from modeling interactions in the calorimeter. This gives an uncertainty of 20% for q=1/3 and 13% for q=2/3. Systematic uncertainties from luminosity (7.5%) and from the choice of PDF (7%) are also significant. The total systematic uncertainty is 23% and 17% for q=1/3 and q=2/3 respectively.

For the weak search, the total efficiency is 3% for Drell-Yan slepton production, to which only the muon trigger is sensitive. Once slepton production from cascade decays are included, the efficiency for finding sleptons using only the muon triggered data sample increases to 6%. The total efficiency after including cascades and all three triggers is 8%. The largest systematics on this efficiencies come from the luminosity (7.5%). Other systematics include track quality cuts (4.9%) and choice of PDF (5.5%). Once cascades are included, the $\not{E}_T$ trigger and initial/final state radiation

(ISR/FSR) become significant systematics.

VII. LIMITS

Figure 3 shows the cross-section limits we derive for heavy stable quarks from the results of our strong search. From comparison with the theoretical prediction, we conclude M > 195 GeV/c^2 for q=1/3 and M > 220 GeV/c^2 for q=2/3. These limits are the most stringent limits from a direct search to date.

Figure 4 shows the cross-section limits derived for Drell-Yan production of long-lived sleptons in a GMSB scenario with the stau as the Next-to-Lightest Susy Particle (NLSP). We are over an order of magnitude away from being sensitive to the theoretical prediction. When all sparticle production modes with cascade decays to a slepton are included, the efficiency goes up, bringing our limit down and the theoretically predicted slepton production cross section increases. This limit was derived for one model point with three slepton co-NLSP's (N$_5$=3, M/Λ=3, tanβ=3, μ > 0) and found to be $\sigma_{95\%} \approx 550 fb$, still nearly an order of magnitude away from the predicted 80 fb.
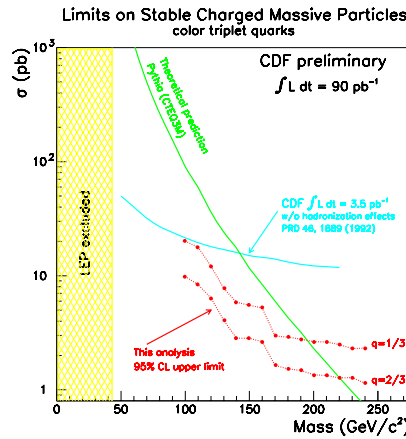

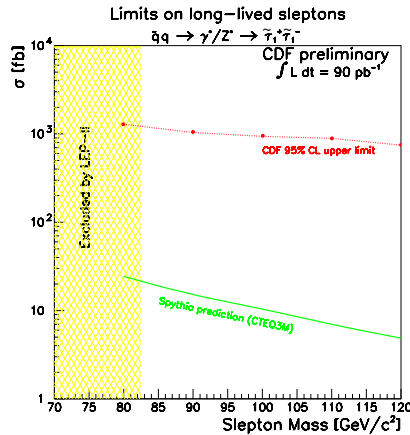FIG. 3. Limits on heavy stable quarks derived from results of the strong search.

FIG. 4. Limits on long-lived Drell-Yan sleptons derived from results of the strong search.

VIII. PROSPECTS FOR RUNII

RunII at the Tevatron will have an increased factor of 20 in luminosity and CDF will have a number of detector improvements. The upgraded detector will have double-sided silicon with stereo strips for z measurement, 7 silicon layers instead of 4, and smaller cell size in the new tracking chamber. This smaller cell size will cut down on the

background from overlapping tracks. Additionally, the now approved Time of Flight system with a resolution of approximately 0.1ns will greatly increase our region of sensitivity in momentum from ≈ 85 GeV/c to ≈ 175 GeV/c for a 100 GeV/c^2 particle.

IX. CONCLUSIONS

We have searched for heavy stable particles using $90pb^{-1}$ of Run1B data at CDF. No excess of events over background was observed. We set preliminary limits on heavy stable quarks at M > 195 GeV/c^2 and M > 220 GeV/c^2 for q=1/3 and q=2/3 respectively. Using GMSB with three slepton co-NLSP's as a reference model, we set a limit on slepton production at $\sigma_{95\%} < 550fb$. This limit is a factor of 7 away from the theoretical prediction. With increased luminosity and detector upgrades in RunII we expect to have sensitivity to slepton production in GMSB models.

X. ACKNOWLEDGEMENTS

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