SEARCH FOR SUPERSYMMETRY AT THE TEVATRON

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This paper reviews some of the most recent results from CDF and DØ experiments on searches for supersymmetry (SUSY) at the Tevatron. We focus on searches for chargino/neutralino, stop, sbottom, and long lived massive SUSY particles, on data samples up to ~ 1 fb^{-1}. No signal was observed, and constraints are set on the SUSY parameter space.

1 Introduction

Supersymmetry is an extension to the standard model (SM) of particle physics that overcomes some of the theoretical problem in the SM by introducing a new symmetry between fermions and bosons. In this model each SM particle has a superpartner with spin differ by 1/2. The symmetry in SUSY is believed to be broken, and several models (mSUGRA, GMSB, AMSB,...) have been developed to describe the breaking mechanism. In some SUSY models the $R-$parity [a] quantum number is conserved. In this case SUSY particles must be produced in pairs, and the lightest SUSY particle (LSP) is stable. Cosmological constraints require the LSP to be neutral and colorless [1]. Thus, the LSP interacts only weakly and escapes detection leading to experimental signature of missing transverse energy ($\not\!\!E_{\rm T}$). In the mSUGRA model, the LSP is usually the lightest neutralino ($\tilde{\chi}_1^0$), and in the GMSB model, the LSP is the gravitino ($\tilde{G}$). CDF and DØ search for SUSY based on their unique signatures in the final states. In this paper we report on recent SUSY search results from CDF and DØ based on ~ 300 pb^{-1} to ~ 1 fb^{-1} of $p\bar{p}$ collision data at $\sqrt{s} = 1.96$ TeV. The limits presented in this paper are all obtained at 95% confidence level (C.L.) .

[a] $R-\text{parity} = (-1)^{3(B-L)+2s}$

2 Searches for Chargino and Neutralino

The cross section for associated production of chargino ($\tilde{\chi}_1^{\pm}$) and neutralino ($\tilde{\chi}_2^0$) is expected to be relatively small compared to other SUSY production via strong interactions. However $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ can decay leptonically ($\tilde{\chi}_1^{\pm} \to l\nu\tilde{\chi}_1^0$, $\tilde{\chi}_2^0 \to l^{\pm}l^{\mp}\tilde{\chi}_1^0$) leading to final states with multiple leptons and large $\not\!\!E_{\rm T}$ from the escaping ν and $\tilde{\chi}_1^0$. This is a very clean final state since the SM background contribution is very small. The background is mainly from production of di-boson, Z/γ^*+jets, W+jets, and $t\bar{t}$. CDF and DØ search for $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ production in 3-lepton plus $\not\!\!E_{\rm T}$ final states, and in two like-sign lepton plus $\not\!\!E_{\rm T}$ final states, in a data sample of ~ 1 fb^{-1}. The number of observed data events and expected SM background events, after applying all the selection cuts, are shown in Table 1. The result indicate no evidence of SUSY and both experiments extract the 95% C.L. upper limit production cross sections, which are shown in Figure 1 and 2. The limits are obtained in the mSUGRA framework, with $\tan\beta = 3$, and with no slepton mixing. The CDF's result exclude chargino mass below 130 GeV/c^2. The DØ's result exclude chargino mass below 141 GeV/c^2, in the scenario where $m(\tilde{l}) \sim m(\tilde{\chi}_2^0)$ such that the leptonic decay is maximally enhanced.

Table 1: The number of observed data events and expected SM background events in the search for associated production of chargino and neutralino. CDF's $ee+l$ and $\mu\mu+l$ channels are performed on samples collected with low $P_{\rm T}$ threshold. The DØ's like-sign channel only consists of $\mu^{\pm}\mu^{\pm}$.

	Channel	$ee+l$	$\mu\mu+l$	ell	μll	$e\mu l$	$l^{\pm}l^{\pm}$
CDF	L (fb^{-1})	1	1	1	0.75		1
	# Observed	3	1	0	1		13
	# SM Expected	0.97 ± 0.28	0.40 ± 0.12	0.75 ± 0.36	1.26 ± 0.27		7.8 ± 1.1
DØ	L (fb^{-1})	1.1	1.1			1.1	0.9
	# Observed	0	2			0	1
	# SM Expected	0.76 ± 0.67	$0.32^{+0.73}_{-0.03}$			$0.94^{+0.40}_{-0.13}$	1.1 ± 0.4

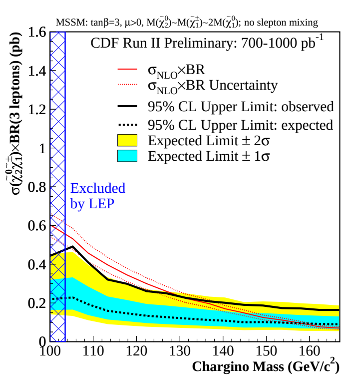

Figure 1: The 95% C.L. upper limit on $\sigma \times BR$ for $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ production as function of $\tilde{\chi}_1^{\pm}$ mass from CDF.

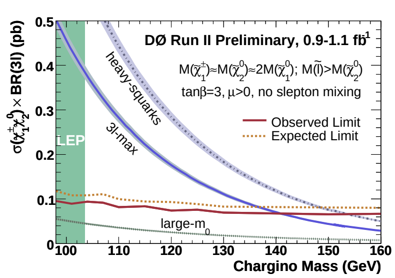

Figure 2: The 95% C.L. upper limit on $\sigma \times BR$ for $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ production as function of $\tilde{\chi}_1^{\pm}$ mass from DØ .

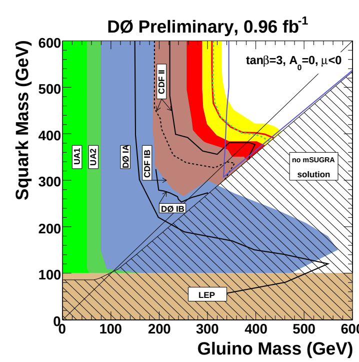

Figure 3: The 95% C.L. excluded region for the squark and gluino pair production search by DØ .

3 Searches for SUSY in Jets and Missing Energy

3.1 Squark and Gluino

At the Tevatron squark ($\tilde{q}$) gluino ($\tilde{g}$) can be pair produced, and their cascade decays can lead to multiple jets and large $\not{E}_{\mathrm{T}}$ final state. The main SM backgrounds are from the production of $Z(\rightarrow \nu\nu)$+jets, $W(\rightarrow l\nu)$+jets, $t\bar{t}$, and QCD multijets. The $\not{E}_{\mathrm{T}}$ in QCD multijet background is usually a result of jet energy mis-measurement. DØ search for pair production of squark and gluino in the 2, 3 and 4-jet plus $\not{E}_{\mathrm{T}}$ final states, which are respectively, optimized for $\tilde{q}\tilde{q}$, $\tilde{q}\tilde{g}$, and $\tilde{g}\tilde{g}$ productions. To select these events in a data sample of 0.96 fb^{-1}, cuts on the jets' transverse energy (E_{T}), the event $H_{\mathrm{T}} = \sum_{\mathrm{jets}} E_{\mathrm{T}}$, and $\not{E}_{\mathrm{T}}$ are applied. No evidence of squark or gluino production is found, and a limit in the mSUGRA framework is set as a function of squark and gluino mass. This is shown in Figure 3. CDF has also performed a similar search in the 3-jet plus $\not{E}_{\mathrm{T}}$ final state, using a data sample of 1.1 fb^{-1}. Its selection cuts are optimized for different gluino mass ranges. Similarly no evidence of SUSY is observed, and CDF excludes glunino mass up to $m(\tilde{g}) > 380$ GeV/c^2 for the case where $m(\tilde{g}) \sim m(\tilde{q})$.

3.2 Stop and Sbottom

In SUSY, one of the stop and sbottom squarks can be much lighter than the other light flavor squarks. This is due to possible large mixing in the left and right handed weak eigenstates. Therefore, stop and sbottom may be produced at a relatively higher rate than the other squarks at the Tevatron. CDF and DØ search for pair production of stop and sbottom in the heavy flavor jets and $\not{E}_{\mathrm{T}}$ final state, using data samples of $\sim$ 300 pb^{-1}. In these searches it is assumed that the stop decay via a flavor changing neutral current loop ($\tilde{t}_1 \rightarrow c\tilde{\chi}_1^0$), and the sbottom decay in the channel $\tilde{b}_1 \rightarrow b\tilde{\chi}_1^0$. To select these events, both experiments require two or three jets in the final state, at least one of the jet tagged as a c or b jet, and the event should have large $\not{E}_{\mathrm{T}}$ ($\not{E}_{\mathrm{T}} > 50$ GeV) and no isolated lepton. After the event selections, the observed data events are consistent with the expected SM backgrounds, which are mainly from $Z(\rightarrow \nu\nu)$+jets, $W(\rightarrow l\nu)$+jets, $t\bar{t}$, and QCD multijets. The interpretation of the null results from both stop and sbottom searches are presented as a 95% C.L. exclusion region in the mass planes of $m(\tilde{\chi}_1^0)$ vs $m(\tilde{t}_1)$ (Figure 4), and $m(\tilde{\chi}_1^0)$ vs $m(\tilde{b}_1)$. Both CDF and DØ exclude stop mass up to $\sim$ 140 GeV/c^2 at $m(\tilde{\chi}_1^0) = 55$ GeV/c^2. The sbottom mass is excluded up to 222 GeV/c^2 by DØ , and 195 GeV/c^2 by CDF.

4 Searches for Long Lived SUSY Particles

4.1 Searches for Long Lived Neutrino

CDF has performed a search for massive long lived particles that decay into photons inside the detector. The search is focused on the GMSB model where the neutralino $\tilde{\chi}_1^0$, which is the next lightest SUSY particle (NLSP), is long lived and decays into a γ and a $\tilde{G}$ inside the detector. The $\tilde{G}$ escapes detection and this leads to $\not{E}_{\mathrm{T}}$ signature in the final state. The γ from the $\tilde{\chi}_1^0$ decay arrives at the face of the detector at a later time compared to the other photons that are promptly produced at the interaction point. For this search the events are selected with at least one photon with $E_{\mathrm{T}} > 30$ GeV, one or more jet with $E_{\mathrm{T}} > 35$ GeV, and $\not{E}_{\mathrm{T}} > 40$ GeV. The arrival time of the photon candidate is measured in the electromagnetic section of the calorimeter, and is corrected for the time-of-flight assuming that the photon is coming from the primary interaction point. The background consists of prompt photons produced in $p\bar{p}$ collisions, and fake photons from beam halo and cosmic. The signal is searched in the photon time window of $2 - 10$ ns. In this time window two events are observed in the data, and 1.3 ± 0.7 events are expected from the background. Using this result, an exclusion region in the neutralino lifetime vs neutralino mass plane is determined, and it is shown in Figure 5.

4.2 Searches for Charge Massive Particles

Some particles predicted in SUSY carry electrical charge and are massive (CHAMPs). These particles are expected to be slow moving and are very penetrating, just like a "slow muon". They could decay outside the detector is they are long lived. CDF and DØ have searched for signatures of CHAMP particles inside their detectors. In the search the experiments look for events that contain μ-like particles that are slow moving. CDF makes use of its Time-of-Flight (ToF) and tracking detectors to measure the CHAMP candidates' velocities and momenta, and then determine its masses. DØ identifies the slow moving μ-like particles based on the timing measurements recorded in the muon detector. No evidence of CHAMP is observed in the data of both experiments. Within the SUSY model with one compactified extra dimension [2] where the stop is the LSP, CDF excludes the mass of a stable stop up to 250 GeV/c^2 (shown in Figure 6). DØ presents its limits in two models. In the GMSB model DØ assumes stau ($\tilde{\tau}$) is the CHAMP particle, and they obtain an upper limit on the production cross section from 0.62 pb to 0.06 pb for various $\tilde{\tau}$ mass. In the stable chargino model (ref) where the chargino $\tilde{\chi}_1^{\pm}$ is assumed to be the CHAMP particle, DØ excludes the chargino mass up to 174 GeV/c^2.

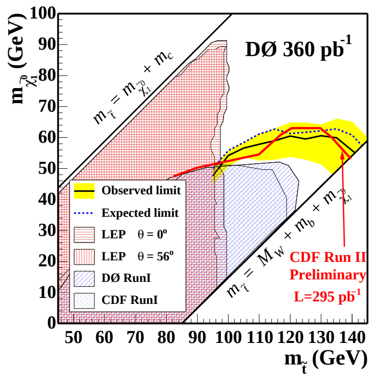

Figure 4: The 95% C.L. exclusion region in the mass plane of $m(\tilde{\chi}_1^0)$ vs $m(\tilde{t}_1)$ for the search of pair production of stop.

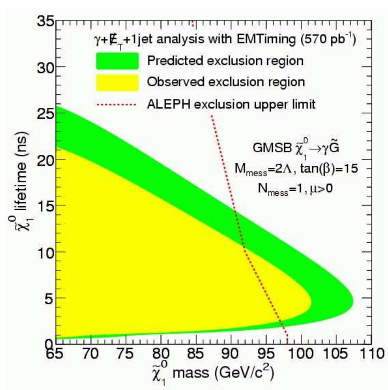

Figure 5: The 95% C.L. exclusion region in the $\tilde{\chi}_1^0$ lifetime vs $\tilde{\chi}_1^0$ mass plane for long lived $\tilde{\chi}_1^0$ search.

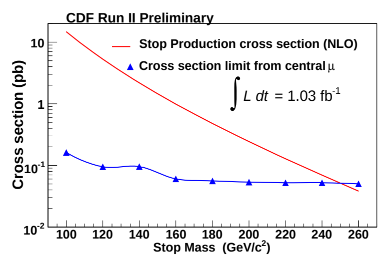

Figure 6: The 95% C.L. upper limit stop production cross section as function of the stop mass.

5 Summary

CDF and DØ have searched for SUSY in up to 1 fb^{-1} of data sample, and have not yet found evidence of its existence. Some of the limits set on the SUSY model parameters are the world's best (example the masses of the squarks and gluino). The Tevatron machine and the experiments are now working optimally. We expect more significant improvement in the SUSY searches at the Tevatron with increase in integrated luminosity and with smarter analysis techniques.

References

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