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November 22, 1993

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Sincerely
Y.Kato (FNALD::KATOY)

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November 21, 1993

SUSY Searches at CDF

CDF Collaboration

presented at Tsukuba 1993 $\overline{p}p$ Collider Workshop by

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Abstract

A search for supersymmetry (SUSY) particles was made using trilepton events in $p\overline{p}$ collisions at $\sqrt{s} = 1.8$ TeV. In the Minimal Supersymmetric Standard Model (MSSM), the trilepton events are expected from chargino-neutralino ($\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$) pair production and their decays into leptons. In all possible combinations of electron and muon channels in 18 pb^{-1} data, we observe no event which passes our trilepton selection criteria. Within the framework of MSSM and a GUT hypothesis, our preliminary analysis excludes $M(\tilde{g})$ <150 GeV/c^2 ($M(\tilde{\chi}_1^{\pm})$ <48 GeV/c^2) at μ=−350 GeV and $M(\tilde{g})$ <160 GeV/c^2 ($M(\tilde{\chi}_1^{\pm})$ <50GeV/c^2) at μ=−450 to −350 GeV at tanβ=4 and M($\tilde{q}$)=1.2M($\tilde{g}$). No treatment of systematic errors has been attempted in this result.

1 Introduction

The first indication of supersymmetric grand unification arose from the precision measurement at LEP and elsewhere of the Standard Model (SM) coupling constants $\alpha_1(M_Z)$, $\alpha_2(M_Z)$, $\alpha_3(M_Z)$ at scale $Q = M_Z$ [1]. It might suggest the validation of the combined ideas of supersymmetry (SUSY) and grand unification. Searching for SUSY particles is, therefore, of great interest in testing the Minimal Supersymmetric Standard Model (MSSM) [2].

The signatures of pair-produced gluinos ($\tilde{g}\tilde{g}$), squarks ($\tilde{q}\tilde{q}$), gluino-squark and chargino-neutralino ($\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$) will appear as multi-jets associated with a large missing transverse energy ($\not{E}_T$), same-sign dilepton and trilepton events. The search with multi-jets+$\not{E}_T$ events is for $\tilde{g}\tilde{g}$, $\tilde{g}\tilde{q}$ and $\tilde{q}\tilde{q}$ productions followed by their direct cascade decays. The data analysis begins with a $\not{E}_T$ sample ($\not{E}_T$ >35 GeV). The cross section is large, but the better understanding of the missing E_T measurement is crucial. Same-sign dilepton events are for $\tilde{g}\tilde{g}$ production and its cascade decays. Since the cross section is expected to be very small, we will have to collect more data in future runs. Lastly, the search using trilepton events is one of the most promising channels for the discovery of SUSY at a hadron collider [3]. Chargino-neutralino ($\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$) is pair-produced (via a virtual W in the s-channel and virtual squarks in the t-channel) followed by the subsequent decays $\tilde{\chi}_1^{\pm} \rightarrow \ell\nu\tilde{\chi}_1^0$ and $\tilde{\chi}_2^0 \rightarrow \ell\bar{\ell}\tilde{\chi}_1^0$. The striking signature of these decays is then three isolated leptons without significant jet activity. We also expect backgrounds from the Standard Model processes to the three isolated leptons to be small.

A data sample with an integrated luminosity of 21 pb^{-1} in $p\bar{p}$ collisions has been accumulated using the Collider Detector at Fermilab (CDF) [4] under the successful operation of the Fermilab Tevatron at $\sqrt{s} = 1.8$ TeV in 1992-93. High statistics of the data sample allow us to search for such new particles. In this paper we present preliminary analysis of a search for trilepton events based on 18 pb^{-1}.

2 Theoretical Prediction of MSSM

We obtained the theoretical calculation of the cross sections and its branching ratios using ISAJET V7.02 [5]. Since the default SM values in ISAJET refer to the old LEP results, we use the most updated SM values [6] for the present analysis. The important change is the value of α_3 from 0.112 to 0.120. The MSSM parameter space for the present analysis is: $M(\tilde{g}) = 140$, 160, 180 and 200 GeV/c^2; $\mu = -450$, -400, -350 and -300 GeV. The other fixed parameters are $\tan\beta = 4$, $M(H^{\pm}) = 500$ GeV/c^2, $M(\tilde{t}) = M(\tilde{q}) = 1.2\ M(\tilde{g})$, and $M(top) = 160$ GeV/c^2. Our standard choice of the structure function is the CTEQ1M (NLL) structure function at $Q^2 = 2\hat{s}\hat{t}\hat{u}/(\hat{s}^2 + \hat{t}^2 + \hat{u}^2)$.

With these parameters, we summarize the SUSY cross-sections and its branching ratios, and the masses of $\tilde{\chi}_1^{\pm}$, $\tilde{\chi}_1^0$ and $\tilde{\chi}_2^0$ in Table 1.

3 Data Analysis

The range of $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ masses which are accessible with the present integrated luminosity is 50-70 GeV/c^2. Therefore, the three-way split of the energies of each of the $\tilde{\chi}_1^{\pm}$ and $\tilde{\chi}_2^0$ between two leptons and the lightest neutralino ($\tilde{\chi}_1^0$) lead to lepton transverse momenta which are typically lower than the transverse momenta of leptons from W and Z^0 decays. Thus, our analysis begins with the inclusive electron and muon data samples.

We define two class of leptons: 'gold' and 'ordinary'. The gold leptons should match with (or be tighter than) the inclusive electron or muon trigger requirements. The minimum $P_T(\ell)$ is 10 GeV/c and the electron and muon are found in $|\eta| < 1.1$ and $|\eta| < 0.6$, respectively. The ordinary leptons have lower E_T or P_T thresholds and generally pass looser cuts. The minimum value is 5 GeV for electrons and 4 GeV/c for muons. The electron and muon are selected in $|\eta| < 2.4$ and $|\eta| < 1.2$, respectively. The detail selection criteria of electrons and muons can be found in Ref.[7].

The trilepton events are required to contain at least one gold lepton with (a) $ISO < 2$ GeV, (b) $\Delta R_{\ell\ell} > 0.4$, (c) existence of e^+e^- or $\mu^+\mu^-$ pair and (d) mass cuts for unlike sign pairs. The ISO variable is the total transverse energy within a cone of $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.4$ around the lepton. The $\Delta R_{\ell\ell}$ variable is an opening angle between two leptons in the η-ϕ space. The mass ranges removed are 80-100 GeV/c^2 for Z^0, 9-11 GeV/c^2 for Υ and 2.9-3.3 GeV/c^2 for J/ψ. Table 2 shows the number of events left after each trilepton selection cuts. Finally, we are left with zero event candidate.

Table 1: SUSY masses, cross sections and branching ratios with $\tan\beta = 4$ and $M(\tilde{q}) = 1.2\ M(\tilde{g})$.

SUSY Inputs		SUSY Masses			SUSY Cross Sections		
μ (GeV)	$M(\tilde{g})$ (GeV/c^2)	$M(\tilde{\chi}_1^\pm)$ (GeV/c^2)	$M(\tilde{\chi}_1^0)$ (GeV/c^2)	$M(\tilde{\chi}_2^0)$ (GeV/c^2)	$\sigma(\tilde{\chi}_1^\pm\tilde{\chi}_2^0)$	BR $\tilde{\chi}_1^\pm\tilde{\chi}_2^0 \to 3\ell X$	$\sigma \cdot BR$
−300							
	140	46.0	21.4	46.5	64.2 pb	2.57 %	1.65 pb
	150	48.6	22.9	49.0	34.9 pb	2.53 %	0.88 pb
	160	51.3	24.3	51.6	23.7 pb	2.46 %	0.58 pb
	170	53.9	25.7	54.2	17.7 pb	2.39 %	0.42 pb
−350							
	140	45.4	21.3	45.8	65.0 pb	2.65 %	1.72 pb
	160	50.7	24.1	51.0	28.2 pb	2.59 %	0.73 pb
	180	56.0	27.0	56.3	15.1 pb	2.45 %	0.37 pb
	200	61.3	29.8	61.5	9.30 pb	2.28 %	0.21 pb
−400							
	140	44.8	21.2	45.2	75.1 pb	2.72 %	2.04 pb
	160	50.2	24.0	50.5	30.1 pb	2.67 %	0.80 pb
	180	55.6	26.8	55.8	15.0 pb	2.56 %	0.38 pb
	200	60.9	29.7	61.2	9.60 pb	2.42 %	0.23 pb
−450							
	140	44.3	21.0	44.7	80.5 pb	2.76 %	2.22 pb
	160	49.8	23.9	50.0	33.2 pb	2.75 %	0.91 pb
	180	55.2	26.7	55.4	16.5 pb	2.64 %	0.44 pb
	200	60.6	29.5	60.8	9.82 pb	2.51 %	0.25 pb

4 Detection Efficiency

The total detection efficiency for $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ is obtained from

$$\epsilon^{tot} = \epsilon^{MC} \cdot \epsilon^{trig} \cdot \epsilon^{ISO},$$

where ϵ^{MC} is the detection efficiency with all analysis cuts without efficiencies (ϵ^{ISO}, ϵ^{trig}) for isolation ($ISO < 2$ GeV) and trigger. We estimate the detection efficiency ϵ^{MC} of our cuts using $\tilde{\chi}_1^\pm\tilde{\chi}_2^0$ events generated by ISAJET. The efficiencies ϵ^{ISO} and ϵ^{trig} were estimated from data [7]. We estimate the efficiency of each final state, $eee, ee\mu, e\mu\mu, \mu\mu\mu$, because there are different efficiency of electron and muon tagging.

The estimated numbers of $\epsilon^{tot} = \epsilon_{eee} + \epsilon_{ee\mu} + \epsilon_{e\mu\mu} + \epsilon_{\mu\mu\mu}$ vary from 16% at $M(\tilde{g}) = 140$ GeV/c^2 to 27% at $M(\tilde{g}) = 200$ GeV/c^2.

Table 2: Events left after trilepton cuts in 18 pb^{-1} data

Cut	Muon Stream	Electron Stream
Original Sample	2,404,920	3,166,571
Dilepton Selection	25,483	29,361
Trilepton Selection	172	94
Trilepton Event Selection		
∘ $ISO(0.4) < 2$ GeV	25	4
∘ $\Delta R_{\ell\ell} > 0.4$	2	2
∘ Require e^+e^- or $\mu^+\mu^-$	2	2
∘ Z^0 removal (80-100 GeV/c^2)	1	0
∘ Υ removal (9-11 GeV/c^2)	0	0
∘ J/ψ removal (2.9-3.3 GeV/c^2)	0	0

Table 3: Preliminary results of background estimation

Background	$N_{3\ell}$ (18pb^{-1})	Comments
$Z^0 + W$	0.004	MC
$Z^0 + Z^0$	4.5×10^{-4}	MC
$Z^0 + X$	0.78	$W^{\pm} \rightarrow \ell^{\pm}\nu$ Data + MC
$Z^0 \rightarrow \tau^+\tau^-$	0.47	MC
$b\bar{b}$	$< \mathcal{O}(1)$	16pb^{-1} MC sample
DY	under study	
Total	1.2+	

5 Backgrounds

The major Standard Model backgrounds in our final selection are diboson (WZ, ZZ), Z^0+X and $b\bar{b}$ events. The diboson events are expected to be few because the production cross section is small and Z^0 is well-identified. However, the $Z^0 + X$ event could look like the trilepton signal when its dilepton ($Z^0 \rightarrow \ell^+\ell^-$) mass is outside our Z^0 mass window and it is associated with a single isolated track from a heavy flavor decay into a lepton ($b \rightarrow \ell X$) or jet fragmentation into a "lepton"-like track (fake lepton) or decay in flight, hadron punch through for muon. In case of $b\bar{b}$ event, it contains three (or more) lepton candidates from $b\bar{b}$ production. Substantial reduction is expected with a tight isolation requirement. Table 3 shows the expected background events in our final sample. The background is consistent with our observation of no signal events in 18 pb^{-1} data.

Table 4: SUSY $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ search summary

μ (GeV/c^2)	$M(\tilde{g})$ (GeV/c^2)	$\sigma \cdot BR$ $\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \to 3\ell X$	ϵ^{tot}	95% C.L. Upper Limit
−300				
	140	1.65 pb	0.164	1.02
	150	0.88 pb	0.183	0.91
	160	0.58 pb	0.228	0.73
	170	0.42 pb	0.245	0.68
−350				
	140	1.72 pb	0.166	1.00
	160	0.73 pb	0.225	0.74
	180	0.37 pb	0.259	0.64
	200	0.21 pb	0.293	0.57
−400				
	140	2.04 pb	0.148	1.13
	160	0.80 pb	0.217	0.77
	180	0.38 pb	0.249	0.67
	200	0.23 pb	0.319	0.52
−450				
	140	2.22 pb	0.149	1.12
	160	0.91 pb	0.191	0.87
	180	0.44 pb	0.248	0.67
	200	0.25 pb	0.274	0.61

6 Excluded Regions of the MSSM

We set a 95% confidence level (C.L.) upper limit of 3.0 events on the mean number of events predicted. These events come from the sum of four final states; $e^+e^-e^+$, $e^+e^-\mu^+$, $e^+\mu^-\mu^+$, and $\mu^+\mu^-\mu^+$. The branching ratio for each of these final states is the same; $BR(\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \to eeeX) = BR(\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \to e\mu\mu X) = BR(\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \to ee\mu X) = BR(\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \to \mu\mu\mu X) \equiv BR(\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \to 3\ell X)$. Therefore, we derive an upper limit on $\sigma \cdot BR(\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \to 3\ell X)$ as

$$\sigma \cdot BR(\tilde{\chi}_1^\pm \tilde{\chi}_2^0 \to 3\ell X) < \frac{3.0}{18\ \mathrm{pb}^{-1} \cdot \epsilon^{tot}}.$$

The resultant limits are provided in Table 4, with the predicted cross-section times branching ratio for $\tilde{\chi}_1^\pm \tilde{\chi}_2^0$ trilepton production.

We can rule out $M(\tilde{g})$ less than 160 GeV/c^2 between $\mu = -450$ to -350 GeV and less than 150 GeV/c^2 at $\mu = -300$ GeV. Figure 1 shows the region excluded by CDF compared to the LEP result.

The $\tilde{g}$ masses between 140 and 160 GeV/c^2 appears to correspond to $\tilde{\chi}_1^\pm$ masses between 44 GeV/c^2 and 49 GeV/c^2. The value of 44 GeV/c^2 has barely been ruled out by LEP measurements. However, this is only because of a nearly linear relationship in the model between the chargino and neutralino masses and the gluino mass, which comes about because of the hypothesis that the chargino and neutralino masses become equal at the GUT scale (SUSY unification hypothesis). This is not a necessary feature of the MSSM, but is often used as a simplifying assumption to limit the number of free parameters in the model.

No treatment of systematic errors is performed in this result. We provide a brief and tentative summary of the major systematic uncertainties in this analysis; the first being our integrated luminosity measurement which presently has a quoted uncertainty of 10%. Also, our trigger efficiency estimate is inaccurate, in part because we have taken estimates of single lepton efficiencies and the trilepton efficiencies may be higher, and also because we do not at present have a full understanding of the lepton trigger efficiencies for leptons near the E_T and P_T thresholds. To this effect, we also assign an uncertainty of 10%. The systematic uncertainty due to parton distribution functions ought to be similar to the uncertainties in W and Z production, which are produced also via Drell-Yan at similar $\hat{s}$ values. These uncertainties are estimated in the CDF analysis of the R ratio, *i.e.* the ratio of $W^\pm \rightarrow \ell^\pm \nu$ to $Z^0 \rightarrow \ell^+\ell^-$ production, as about 2%, *i.e.* negligible. Finally, we should estimate the efficiency of the lepton selection criteria. No hard data exists as yet on this, but if we nonetheless assign a systematic uncertainty of 5% to each lepton, we get a total of 15% systematic error on the trilepton acceptance. Adding all of these errors in quadrature leads to a total systematic error of about 21%. With study, particularly using Z^0 leptonic decays, these errors can be greatly reduced.

If we take the 21% systematic error, the 95% C.L. upper limit should be estimated with 3.2 events instead of 3.0 events. However, a complete data analysis of 21 pb^{-1} data will cancel the change. It should be noted that we expect the above statement will not change even if we have one or two event candidates in 21 pb^{-1}, because we also expect about two background events. Therefore, we will still have the same result.

7 Conclusion

We have searched for evidence of the production and decay of SUSY chargino-neutralino pairs into trilepton events from 18 pb^{-1} of $p\bar{p}$ collision data at $\sqrt{s} = 1.8$ TeV by CDF. Using all possible electron and muon decay channels, no events are observed in our trilepton selection. This result is compared to a theoretical prediction based on MSSM with unification hypothesis at a particular parameter space of $M(\tilde{g})$ vs μ at $\tan\beta = 4$ and $M(\tilde{q}) = 1.2\ M(\tilde{g})$. We exclude the gluino masses below 160 GeV/c^2 at μ between -450 and -350 GeV, and masses below 150 GeV/c^2 at $\mu = -300$ GeV. This is equivalent to excluding the chargino masses below about 50 GeV/c^2.

Acknowledgements

I would like to thank my colleagues in the CDF group for their help in preparing the present talk. I also acknowledge the organizing committee for successful run of this meeting.

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Figure 1: Comparison of the region of parameter space ruled out by LEP with the area ruled out by CDF.