CDF note 8653

Combined limit for the trileptons analyses
Summer 2006

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We present searches for Supersymmetry in multilepton signatures using data collected at a centre-of-mass energy of 1.96 TeV using the CDF II detector. The results are combined to obtain a limit on the cross section times branching ratio for chargino-neutralino production and decay into final states including two or more leptons. The limit is explored as a function of the chargino mass in two different scenarios. In the most favourable model, with a luminosity ranging between 700 and 1000pb^{-1}, we can exclude chargino masses up to $\simeq 130$ GeV/c^2. We also present projections on the sensitivity of the present searches with the increased luminosity expected in the future.

Preliminary Results for Winter 2007 Conferences

I. INTRODUCTION

Supersymmetry(SUSY) is one of the most appealing theories for physics beyond the Standard Model(SM), as it solves the hierarchy problem and could provide a good candidate for the cold dark matter(CDM) in the universe. SUSY predicts the existence of a super-partner for each SM particle, sharing the same quantum numbers but differing by half a unit of spin. Despite numerous attempts, SUSY particles have not yet been observed; this means that SUSY must be broken and sparticles must be heavier than their SM counterparts. A new quantum number is introduced, R-Parity(R_P), which is $+1$ for SM and -1 for SUSY particles. The conservation of R_P implies that the lightest supersymmetric particle(LSP) is stable and escapes the experimental apparatus undetected, causing a striking experimental signature of large missing transverse energy($\not\!\!E_{\rm T}$). Most SUSY theories predict the sparticle spectrum to become accessible at the TeV scale. In these scenarios the Tevatron would be able to discover SUSY before the advent of the LHC. We present searches for associated production of the lightest chargino($\tilde{\chi}_1^{\pm}$) and second to lightest neutralino($\tilde{\chi}_2^0$), (the mass-eigenstates of the super-partners of the gauge bosons) in signatures including missing energy and isolated leptons at the CDF II experiment. These results have been combined to obtain a limit on the mass of the chargino in R_P conserving models.

A. Charginos and Neutralinos in mSUGRA

The scenario of minimal Supergravity(mSUGRA) is a Grand Unification Theory which includes Gravity; owing to the small number of free parameters (M_0, $M_{1/2}$, A_0, $tan\beta$, $sign(\mu)$), mSUGRA is very popular in experimental searches. In mSUGRA R_P is conserved. The lightest neutralino($\tilde{\chi}_1^0$) is the LSP and a CDM candidate. The LEP2 limit of $M_{\tilde{\chi}_1^{\pm}} > 103.5$ GeV/c^2 implies squark($\tilde{q}$) and gluino($\tilde{g}$) masses to be $\gtrsim$300 GeV/c^2, meaning that strong sparticle production at the Tevatron would be suppressed. Thus, the associated production of $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ would be the dominant SUSY production mechanism if sparticles are accessible at these energies. We have explored the mSUGRA scenario as well as two Minimal Supersymmetric Standard Model (MSSM) scenarios whose details are given in section IV.

II. ANALYSES OVERVIEW

We have looked for the "tri-lepton" signal from $p\bar{p} \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$ followed by $\tilde{\chi}_2^0 \to \ell\bar{\ell}\tilde{\chi}_1^0$ and $\tilde{\chi}_1^{\pm} \to \ell\nu\tilde{\chi}_1^0$ with 14 different analyses. Events are selected with large $\not\!\!E_{\rm T}$ and two isolated leptons satisfying analysis dependent topological cuts. For six channels [1] we require the two most energetic leptons to be of the same charge and relax the third lepton requirement, to increase the acceptance in the region where the energy of the third lepton can be very low (Like-Sign(LS) analyses). In the other analyses ("trilepton" analyses), the third lepton can be a fully reconstructed electron or muon [2–4] or a track [5], to gain in acceptance and include both hadronic and leptonic decays of τ leptons. We use data collected with the high-$p_{\rm T}$ inclusive lepton triggers (indicated as "high-$p_{\rm T}$") and the low-$p_{\rm T}$ dilepton triggers ("low-$p_{\rm T}$") to explore a wide range in acceptance. The dominant SM background sources are dibosons and Drell-Yan events where the third lepton comes from the conversion of a bremsstrahlung photon. The flavours and $p_{\rm T}$ thresholds of the leptons are specified in Table I and II, together with the number of SM expected and observed events in each channel. The number of observed events are consistent with the Standard Model expectations.

	$ee(CEM)+\ell$	$ee(PLUG)+\ell$	$e\mu+\ell$	$\mu\mu+\ell$ **(high-$p_{\rm T}$)**	$\mu e(CEM)+\ell$	$\mu e(PLUG)+\ell$	$ee+track$	$\mu\mu+\ell$ **(low-$p_{\rm T}$)**
Luminosity	1034 pb^{-1}	954 pb^{-1}	1034 pb^{-1}	745 pb^{-1}	745 pb^{-1}	680 pb^{-1}	1013 pb^{-1}	976 pb^{-1}
$\mathbf{p_T^{\ell_1}, p_T^{\ell_2}, p_T^{\ell_3,track}}$(GeV/$c$)	20,8,5	20,8,5	20,8,5	20,5,5	20,5,5	20,5,5	15,5,4	5,5,5
Expected number of SM background events	0.44$\pm$ 0.08	0.34$\pm$ 0.10	0.28$\pm$ 0.09	0.64$\pm$ 0.18	0.42$\pm$ 0.08	0.36$\pm$ 0.07	0.97$\pm$ 0.28	0.42$\pm$ 0.12
Number of observed events	0	0	0	1	0	0	3	1

TABLE I: *Blessed results of the trilepton analyses considered in the combination. The uncertainty is the combined statistical, and systematic. The results for all the analyses are for the inclusive events, which will be scaled in the limit calculation following the method explained in section III.*

	ee **LS**	$e_{si}e$ **LS**	$e_{si}e_{si}$ **LS**	$e_{si}\mu$ **LS**	$e\mu$ **LS**	$\mu\mu$ **LS**
Luminosity	993 pb^{-1}	993 pb^{-1}	993 pb^{-1}	971 pb^{-1}	971 pb^{-1}	1087 pb^{-1}
$\mathbf{p_T^{\ell_1}}, \mathbf{p_T^{\ell_2}}$ (GeV/c)	20,10	20,10	20,10	20,10	20,10	20,10
Expected number of SM background events	0.10± 0.10	1.50± 0.30	1.30± 0.30	1.70± 0.20	2.30± 0.50	0.90± 0.10
Number of observed events	1	2	1	4	4	1

TABLE II: *Blessed results of the LS dilepton analyses considered in the combination. The uncertainty is combined statistical and systematic. The results for all the analyses are for the inclusive events, which will be scaled in the limit calculation following the method explained in III.*

III. COMBINATION OF THE ANALYSES

As no evidence of Supersymmetry has been observed in any of the analyses, we combine the results to obtain a limit on the cross section times branching ratio for a range of points in the parameter space of the model. We explore three scenarios, the standard mSUGRA scenario, and two mSUGRA-inspired Minimal-Supersymmetric (MSSM) scenarios, described in the following.

A **mSugra**.
For this model we have used a combination of Isajet 7.51 and Pythia 6.216 and requested a standard mSugra scenario with $tan\beta = 3, A_0 = 0, \mu > 0$ and values of $M_0 = 60$ with $M_{1/2}$ ranging between 162 and 230 GeV/c^2 in step of 10 GeV/c^2. All the relations among the masses and the branching ratios have been kept as in mSUGRA.

B **MSSM with no slepton mixing**.
In this scenario we have chosen an mSUGRA inspired version of the MSSM where we have kept the same relations as mSUGRA but turned the slepton mixing off by setting the diagonal terms of the mixing matrix to zero in Softsusy. This enhances the branching ratios of chargino and neutralino in electrons and muons (as shown in Figure 2) and allows a direct comparison with the results recently published by DØ [6] in the same scenario.

C **MSSM with W/Z decay**.
We have also investigated an MSSM scenario where we have kept $tan\beta = 3, A_0 = 0, \mu > 0$, and set artificially the relationships between the masses M($\tilde{\chi}_1^{\pm}$) = M($\tilde{\chi}_2^0$) = 2M($\tilde{\chi}_1^0$) and the branching ratios Br($\tilde{\chi}_1^{\pm} \to \ell + \nu + \tilde{\chi}_1^0$)=Br($W \to \ell + \nu$) and Br($\tilde{\chi}_2^0 \to \ell^+\ell^- + \tilde{\chi}_1^0$)=Br($Z^0 \to \ell^+\ell^-$). We investigated this model to be able to present our result in a "quasi" model independent way and allow easy comparison with new models which might become relevant in the future.

The procedure to calculate the combined limit on the cross section times branching ratio uses a frequentest approach [7] and incorporates the effects of systematic uncertainties and their correlations across channels and between signal and background for the same channel. In order to avoid double-counting of events, all the channels need to be treated as independent. We recalculated the acceptance for each channel in an exclusive way, avoiding the overlap among channels. We use the $S/\sqrt{Background}$ as a figure of merit when an event is contended by more than one analysis. In case of such an occurrence, the event will be assigned to the analysis with the higher $S/\sqrt{Background}$. The exclusive acceptances for the LS and trilepton analyses considered are shown in Fig. 1 as a function of the $M_{\tilde{\chi}_1^{\pm}}$ of the sample, for the three models described in the text. The leptonic branching ratios of the chargino and neutralino in scenario "A" and "B" are shown in Fig. 2. The leptonic branching ratios of chargino-neutralino for scenario "C" are constant around 3%.

IV. LIMIT CALCULATION

For the limit calculation we used the results summarised in Table I and II. The systematic uncertainties for each analysis and the correlation across analyses are reported in Table IV and Table IV. We calculate the acceptance for

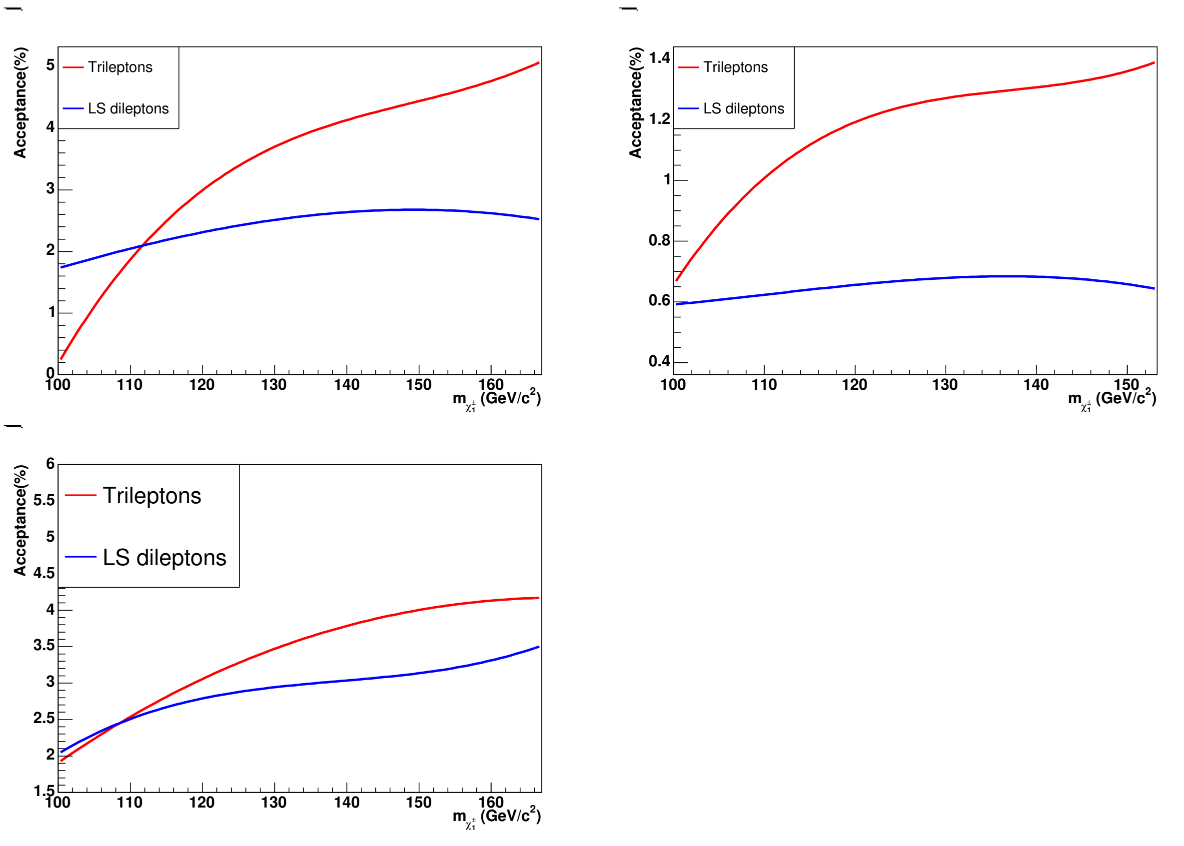

FIG. 1: *Acceptance for the eight trilepton analyses combined versus acceptance of the six like-sign dilepton analyses combined, for the mSUGRA model (scenario A-upper left), for the MSSM with no slepton mixing model (scenario B-upper right) and for the model described in scenario C (bottom left). The curves have been smoothed to avoid discontinuities due to poor statistics.*

each analysis using different Monte Carlo points. For each point a sample has been generated using a combination of Isajet 7.71 and Pythia 6.216 (scenario “A”) or Softsusy 2.0.7 and Pythia 6.325 (scenarios “B” and “C”). The cross section at Next-to-Leading-Order(NLO) has been calculated using the NLO program PROSPINO2 [8]. These values have been compared with the values obtained running PROSPINO2 with ISASUGRA and found to be consistent. The observed limit on the $\sigma \times Br$ for the three scenarios is plotted as a function of the chargino mass in Figure 3. The expected limit is also shown which is everywhere better than the observed limit due to the observation of 18 events with roughly 8 expected. The bands correspond to the ± 1 and $\pm 2\sigma$ uncertainties on the expected limit calculation. According to these results, in scenario “B” we can exclude masses of the $\tilde{\chi}_1^{\pm}$ of approximately 130 GeV/c^2 at 95% C.L. for values of $\sigma \times Br \simeq$0.25 pb. The expected limit on the mass of the chargino is 160 GeV/c^2 at 95% C.L., which corresponds to a $\sigma \times Br \simeq$0.10 pb. The observed limit is approximately 2σ away than the expected limit, which roughly reflects the number of observed events w.r.t. the number of expected ones from SM background. In scenario ”A” (where slepton mixing is on as requested by mSugra) both the observed and expected limits are worse than in scenario B due to the enhancement of the decay of the chargino and neutralino into final states with tau leptons, as it can be noticed by comparing the branching ratios for these two scenarios as done in Figure 2. In this case the acceptance suffers from the branching ratio of $\tau \to e, \mu$ and from the lower momenta of the electrons and muons in the final state. While we cannot exclude this scenario with the current results, we are sensitive to chargino masses(cross section times branching fraction) up to 122 GeV/c^2(0.42 pb) in this model. The limit is extracted in the same way as for scenario B. From the exclusion limits we achieve in model C it seems we are not sensitive yet to the mass of the chargino in this model, mostly due to the low values of the branching ratios of chargino and neutralino in three leptons.

V. OUTLOOK

We have calculated the expected limit for all analyses combined in the three scenarios we have considered with the luminosities of 2,4,8 and 16 fb^{-1}. In the projections we called "BASIC" we have assumed the same exact situation (same S/B, same uncertainties, etc.) we have now, and just scaled the number of signal and bakground events by the luminosity. The projections are shown in Figure 4, 5 and 6 for the three scenarios A,B and C respectively. Always shown is also the current limit obtained with 1 fb^{-1} for comparison.

In the MSSM with no-mixing scenarios the limit has been extrapolated to higher chargino masses when the Monte Carlo samples we had made did not cover the all range. The limit has been assumed constant as observed in the trend. In this case it is assumed the kinematic of the decays does not change at higher chargino masses. For this reason this limit is only valid up to chargino masses of approximately 190 GeV/c^2 before new decay channels open up. In the basic projections we can exclude masses up to 188(155) GeV/c^2 in the scenario B(A). The limit appears to be constant after chargino masses of about 150 $GeVCSq$, and less and less dependent on the luminosity in both scenarios. We do not have sensitivity to scenario C even with high luminosities.

VI. CONCLUSIONS

We have calculated the combined limit for a region of parameter space and found we can exclude masses of the chargino($\sigma \times Br$) up to approximately 130 GeV/c^2(0.25 pb) in a mSUGRA-like MSSM scenario with no mixing between the sleptons. In the same scenario we are sensitive to masses of $\tilde{\chi}_1^{\pm}(\sigma \times Br)\simeq$160 GeV/$c^2$(0.1 pb). In a standard mSUGRA scenario with M_0=60 GeV/c^2 , $M_{1/2}$=162-230 GeV/c^2 , A_0=0 , $tan\beta$=3 , μ >0 we are sensitive to chargino masses of about 122 GeV/c^2. We have also extracted the limits on the sigma times branching ratio for a fairly model independent scenario where we have assumed the mSUGRA relations among the masses of the gauginos and set the branching ratios Br($\tilde{\chi}_1^{\pm} \to \ell + \nu + \tilde{\chi}_1^0$)=Br($W \to \ell + \nu$) and Br($\tilde{\chi}_2^0 \to \ell^+\ell^- + \tilde{\chi}_1^0$)=Br($Z^0 \to \ell^+\ell^-$). These results improve over the Run I results and are in the region not excluded by LEPII and DØ-Run II.

Acknowledgments

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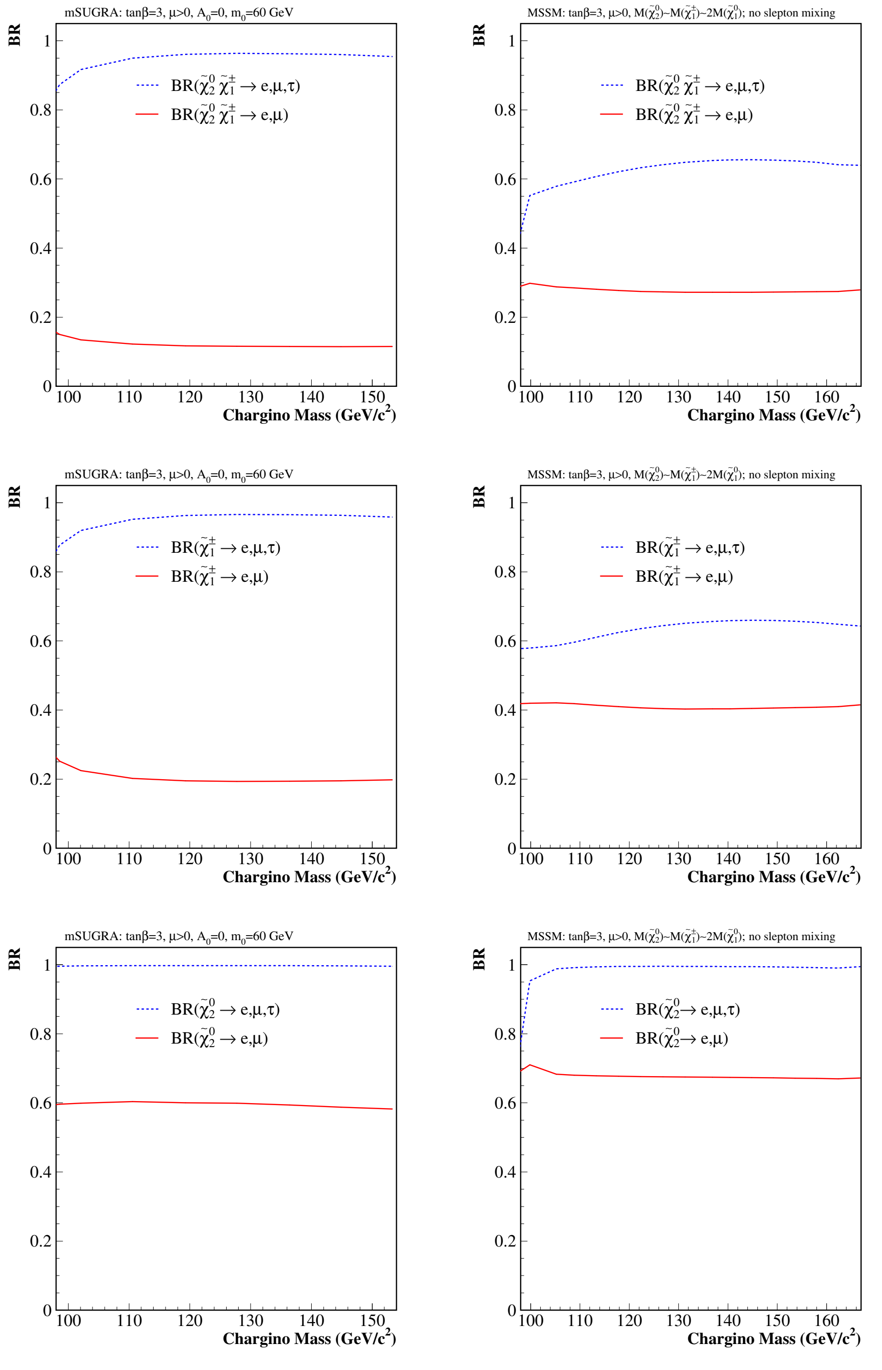

FIG. 2: *Branching fraction for $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to 3$leptons for the different chargino masses for mSugra (scenario B) (upper left) and MSSM with no slepton mixing (scenario A) (upper right). The single branching fractions of chargino into lepton (middle row) and neutralino into two leptons (bottom row) are also shown in both models. The branching fraction into e, μ includes the leptonic branching fraction of the tau. For the scenario C the branching fractions are set constant to the branching fractions of the W and Z bosons into leptons for all points in the parameter space.*

systematic uncertainty	correlation	$ee(CEM)+\ell$		$ee(PLUG)+\ell$		$e\mu+\ell$		$\mu\mu+\ell$(high pt)		$\mu e(CEM)+\ell$		$\mu e(PLUG)+\ell$		$ee+track$		$\mu\mu+\ell$(low pt)	
		signal	**background**	**signal**	**background**	**signal**	**background**	**signal**	**background**	**signal**	**background**	**signal**	**background**	**signal**	**background**	**signal**	**background**
Luminosity	100%	6%	4.9%	6%	4.7%	6%	5.0%	6%	4.0%	6%	4.0%	6%	5.0%	6%	6.0%	6%	1.0%
PDFs	100%	0.8%	2.2%	0.8%	2.2%	0.9%	2.4%	1.0%	3.0%	1.0%	2.0%	1.0%	2.0%	1.0%	2.8%	1.0%	0.4%
ISR/FSR	100%	4.5%	3.3%	12.0%	3.2%	6.8%	3.3%	2.0%	4.0%	2.0%	4.0%	2.0%	4.0	3.9%	5.0%	2.0%	4.0%
Jet Energy Scale	100%	1.7%	4.7%	2.5%	3.5%	3.0%	2.3%	3.0%	6.0%	0.3%	7.0%	0.0%	2.0%	1.0%	11.1%	0.0%	0.02%
Electron ID	100%	3.6%	2.5%	2.2%	6.8%	1.6%	1.7%	3.0%	5.0%	2.0%	4.0%	5.0%	14.0%	2.9%	1.1%	6.0%	1.0%
Muon ID	100%	0.8%	0.7%	0.5%	0.5%	2.1%	1.2%	5.0%	4.0%	7.0%	4.0%	5.0%	4.0%	–	–	13.0%	3.0%
Z Pt Reweight	100%	–	3.2%	–	3.7%	–	–	–	–	–	–	–	–	–	–	–	–
Lepton Fake Rate	100%	–	9.0%	–	10.5%	–	8.5%	–	16.0%	–	13.0%	–	8.0%	–	–	–	24.0%
Trigger Efficiency	100%	0.4%	0.3%	0.4%	0.3%	0.4%	0.3%	1.0%	1.0%	1.0%	1.0%	1.0%	1.0%	0.2%	0.2%	0.5%	0.1%
Track Fake Rate	0%	–	–	–	–	–	–	–	–	–	–	–	–	–	12.7%	–	–
Conversion Scale Factor	100%	6.1%	4.8%	2.2%	3.7%	1.3%	0.3%	–	10.0%	–	7.0%	–	–	–	–	–	–
Heavy Flavour Background Method		–		–	–	–	–	–		–	–	–	–	–	–	–	3.0%
Theory Cross Section	100%	10%	5.9%	10%	5.5%	10%	6.0%	10%	8.0%	10%	4.0%	10%	7.0%	10%	3.9%	10%	1.0%
Background Scaling Method	100	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
Monte Carlo Statistics	100%	6.8%	13.6%	12.3%	26.5%	7.9%	28.6%	6.0%	17.2%	7.0%	11.9%	10.0%	13.9%	10.0%	23.0%	7.6%	14.3%

TABLE III: *Systematic uncertainties from the considered analyses and their assumed correlations.*

systematic uncertainty	**correlation**	ee **LS**		$e_{si}e$ **LS**		$e_{si}e_{si}$ **LS**		$e_{si}\mu$ **LS**		$e\mu$ **LS**		$\mu\mu$ **LS**	
		signal	**background**	**signal**	**background**	**signal**	**background**	**signal**	**background**	**signal**	**background**	**signal**	**background**
Luminosity	100%	6.0%	4.6%	6.0%	5.2%	6.0%	4.3%	6.0%	3.6%	6.0%	5.5%	6.0%	3.5%
PDFs	100%	0.8%	2.1%	0.8%	2.1%	0.8%	2.1%	0.9%	2.3%	0.9%	2.3%	1.0%	1.4%
ISR/FSR	100%	4.3%	3.2%	4.3%	3.2%	4.3%	3.2%	2.0%	3.8%	2.0%	3.8%	2.0%	3.9%
Jet Energy Scale	100%	5.0%	3.9%	5.0%	4.3%	5.0%	3.6%	5.0%	3.0%	5.0%	0.0%	5.0%	2.9%
Electron ID	100%	3.0%	2.3%	3.0%	2.6%	3.0%	2.2%	1.5%	0.9%	1.5%	1.4%	–	–
Muon ID	100%	–	–	–	–	–	–	1.5%	0.9%	1.5%	1.4%	3.0%	1.7%
Lepton Fake Rate	100%	–	5.7%	–	3.4%	–	7.0%	–	10.2%	–	2.1%	–	10.4%
Trigger Efficiency	100%	0.3%	0.2%	0.3%	0.3%	0.3%	0.2%	0.3%	0.2%	0.3%	0.3%	0.3%	0.2%
Conversion Scale Factor	100%	–	12.2%	–	15.2%	–	9.3%	–	3.5%	–	16.2%	–	–
Theory Cross Section	100%	10.0%	5.5%	10.0%	5.9%	10.0%	4.5%	10.0%	4.2%	10.0%	5.9%	10.0%	4.1%
Background Scaling Method	100	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%	20%
Monte Carlo Statistics	100%	5.0%	30.0%	5.0%	8.7%	5.0%	13.8%	5.0%	10.0%	5.0%	10.1%	5.0%	4.4%

TABLE IV: *Systematic uncertainties from the considered analyses and their assumed correlations. The uncertainty on the theory cross sections for the signal SUSY samples is not included in the calculation of the limit.*

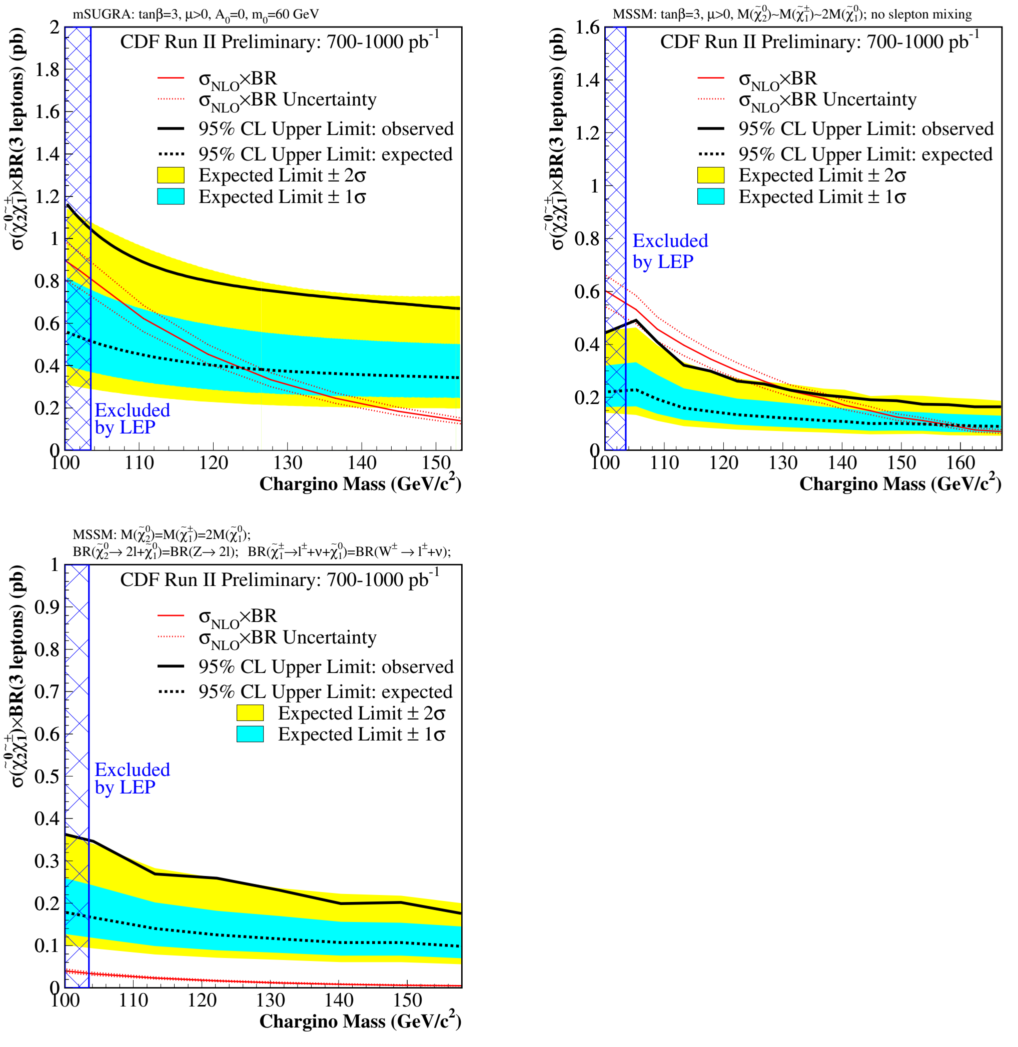

FIG. 3: *The excluded cross section limit is plotted as a function of the chargino mass from the Monte Carlo points considered in the text (black solid line) in scenario "A"(upper left), "B"(upper right) and "C"(bottom left). The expected limit (black dashed line) and the theory curve (red solid line) with its uncertainty (red dotted line) are also shown. The yellow and cyan bands represent the ± 1 and ± 2 sigma uncertainties on the expected limit. The limit curve for scenario "A" has been fitted to avoid discontinuities due to poor statistics.*

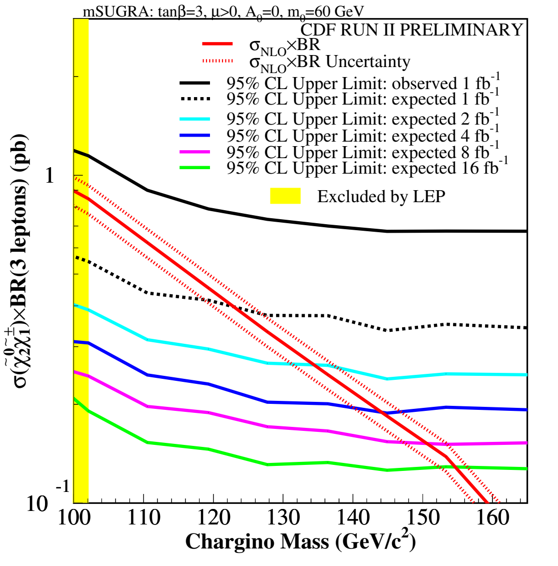

FIG. 4: *Expected limit for all analyses combined in the mSUGRA scenario A for 2,4,8 and 16* fb^{-1}*. Also shown in black is the current observed (solid line) and expected (dashed line) limit in the same scenario. The "BASIC" sets of projections are shown, according to the explanation given in the text.*

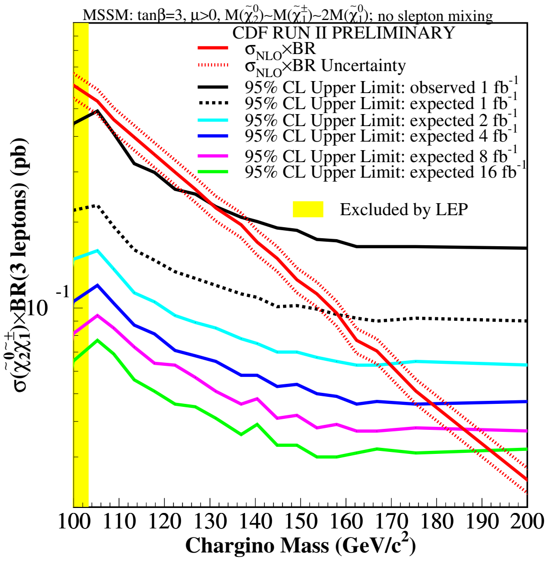

FIG. 5: *Expected limit for all analyses combined in the "no-mix" scenario B for 2,4,8 and 16* fb^{-1}*. Also shown in black is the current observed (solid line) and expected (dashed line) limit in the same scenario. The "BASIC" sets of projections are shown, according to the explanation given in the text.*

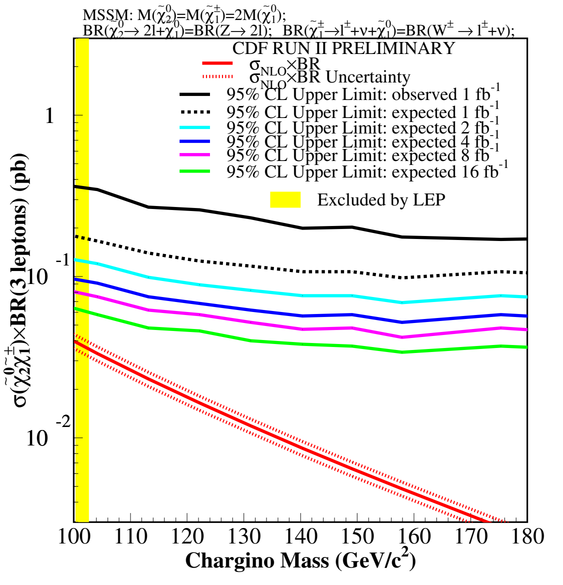

FIG. 6: *Expected limit for all analyses combined in the "W/Z Decay" scenario C for 2,4,8 and 16* fb^{-1}*. Also shown in black is the current observed (solid line) and expected (dashed line) limit in the same scenario. The "BASIC" sets of projections are shown, according to the explanation given in the text.*