CDF note 8310

Combined limit for the trileptons analyses
Winter-Spring 2006

CDF Public Note

The CDF Collaboration
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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 310 and 750 pb^{-1}, we can exclude chargino masses up to $\simeq$ 127 GeV/c^2.

Preliminary Results for Spring 2006 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($\not\!\!E_T$). 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.

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 nine different analyses. Events are selected with large $\not\!\!E_T$ and two isolated leptons satisfying analysis dependent topological cuts. For three 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_T inclusive lepton triggers (indicated as "high-p_T") and the low-p_T dilepton triggers ("low-p_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_T thresholds of the leptons are specified in Table I, 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.

	$ee+\ell$ (**high-p_T**)	$\mu\mu+\ell$ (**low-p_T**)	$\mu\mu+\ell$ (**high-p_T**)	$\mu e(CEM)+\ell$ (**high-p_T**)	$\mu e(PLUG)+\ell$ (**high-p_T**)	ee **LS** (**high-p_T**)	$e\mu$ **LS** (**high-p_T**)	$\mu\mu$ **LS** (**high-p_T**)	$ee+track$ (**low-p_T**)
Luminosity	346 pb^{-1}	312 pb^{-1}	745 pb^{-1}	745 pb^{-1}	680 pb^{-1}	704 pb^{-1}	704 pb^{-1}	704 pb^{-1}	607 pb^{-1}
$\mathbf{p_T^{\ell_1}}, \mathbf{p_T^{\ell_2}}, \mathbf{p_T^{\ell_3,track}}$(GeV/$c$)	20,8,5	5,5,5	20,5,5	20,5,5	20,5,5	20,10	20,10	20,10	15,5,4
Expected number of SM background events	0.17$\pm$ 0.05	0.13$\pm$ 0.03	0.64$\pm$ 0.18	0.42$\pm$ 0.08	0.36$\pm$ 0.07	2.60$\pm$ 0.39	3.50$\pm$ 0.60	0.73$\pm$ 0.08	0.49$\pm$ 0.10
Number of observed events	0	0	1	0	0	4	5	0	1

TABLE I: *Blessed results of the analyses discussed in the text. The first uncertainty is statistical, the second 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.*

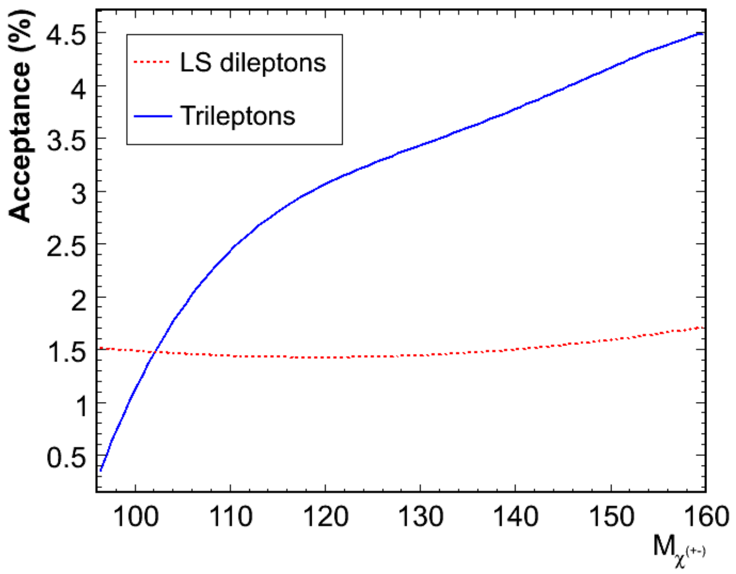

FIG. 1: *Acceptances for the trileptons and like-sign(LS) dilepton analyses as a function of the mass of the chargino for points considered in this study, in a MSSM scenario with* $M_{\tilde{e}_R} = M_{\tilde{\mu}_R} = M_{\tilde{\tau}_1}$. *The events are selected exclusively according to the method described in text.*

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 two scenarios, the standard mSUGRA scenario, and an mSUGRA-inspired Minimal-Supersymmetric (MSSM) scenario, where we have set all the slepton masses to the same value. The procedure to calculate the combined limit on the cross section times branching ratio uses a frequentist approach [6] 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.

IV. LIMIT CALCULATION

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

A : an **mSUGRA** scenario with $tan\beta = 3, A_0 = 0, \mu > 0, M_0 = 60$, with $M_{1/2}$ ranging between 160 and 200 GeV/c^2.

B : an **MSSM** scenario with the same sparticle spectrum as in point **A** but where the slepton masses have all been set to the same value, to facilitate the comparison with the results recently published by DØ [7].

The values of the chargino and slepton masses considered in this study are shown in Fig. 2, as a function of $M_{1/2}$ and the chargino mass in both scenarios. 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 $\sigma \times Br$ is plotted as a function of the chargino

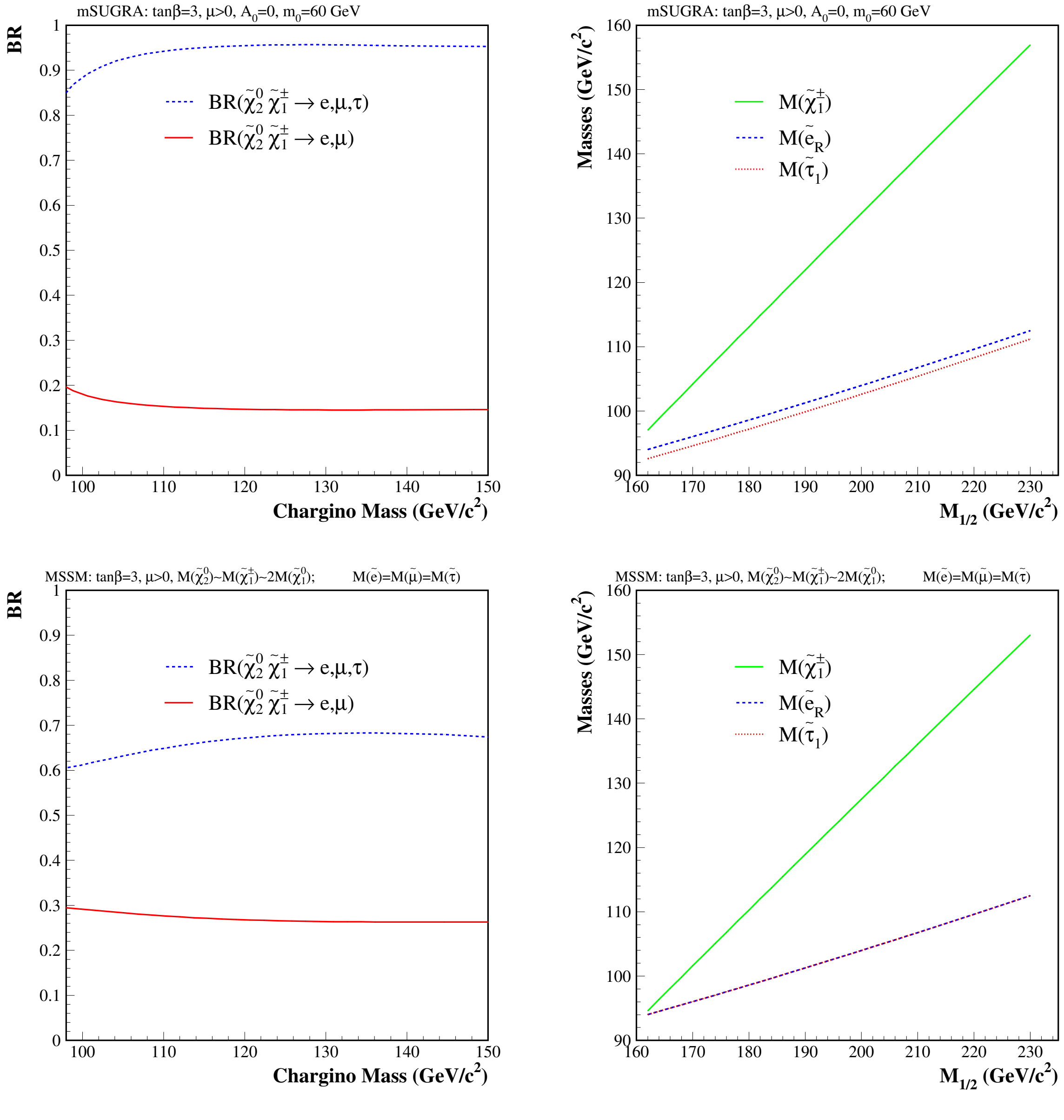

FIG. 2: *Branching fractions(left) and some sparticles masses(right) for the Monte Carlo points in mSUGRA scenario(upper plots), and in a MSSM scenario with*
$M_{\tilde{e}_R} = M_{\tilde{\mu}_R} = M_{\tilde{\tau}_1}$ *(bottom plots).*

mass in Figure 3 in the MSSM scenario described in point **B.** above. The expected limit is also shown, which is everywhere better than the observed limit due to the observation of 11 events. The bands correspond to the ± 1 and $\pm 2\sigma$s uncertainties on the expected limit calculation. According to these results in the MSSM scenario we can exclude masses of the $\tilde{\chi}_1^\pm$ of approximately 127 GeV/c^2 for values of $\sigma \times Br \simeq$0.25 pb. The expected limit on the mass of the chargino is approximately 140 GeV/c^2. The limit obtained in the mSUGRA scenario is shown in Figure 4. Both the observed and expected limits are worse in this scenario due to the enhancement of the decay of the chargino and neutralino into final states with tau leptons, favoured by the stau being lighter than selectron and smuon. 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.

V. CROSS CHECKS

We have cross checked the robustness of the result by performing various cross-checks.

- We have recalculated the limit setting all the systematic uncertainties to zero. The corresponding limit is shown in Figure 5. We conclude the systematics have little effect on the limit, as turning off all the systematics the limit improves on average of about 3%.
- The contribution of each analysis has been studied by dropping that analysis and recalculating the limit. The effect is shown in Figure 6 for the expected limit in the MSSM scenario. As expected, the expected limit always gains by adding more analyses. It can be noticed the importance of the LS dilepton analyses in the region of a light chargino, where the third lepton is very soft and thus not reconstructed by the trilepton analyses.

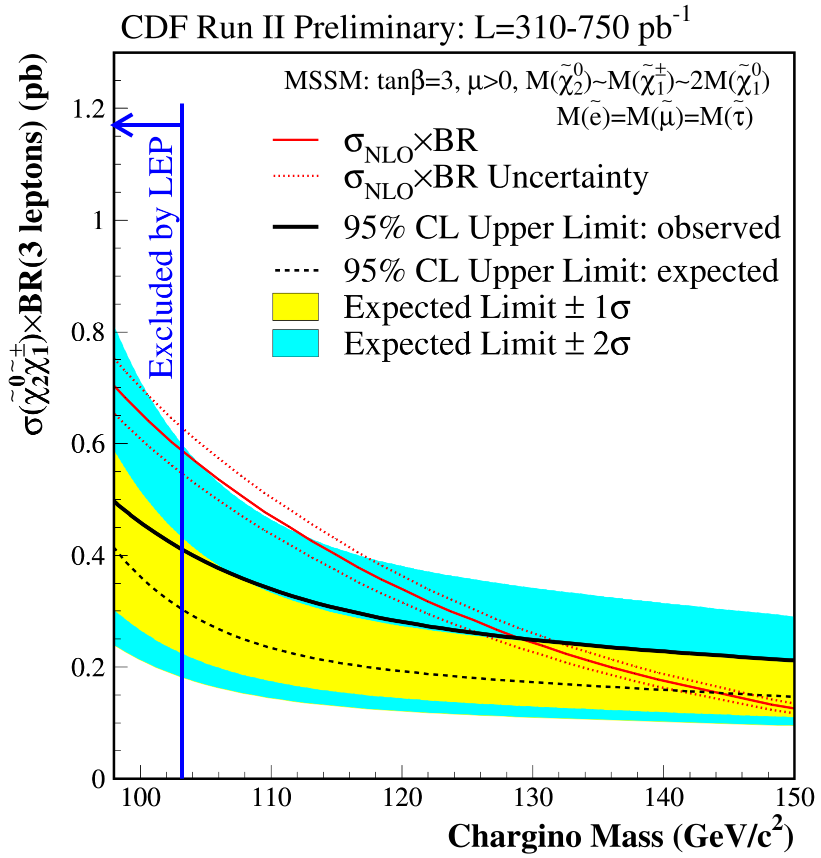

FIG. 3: *The excluded cross section limit is plotted as a function of the chargino mass from the Monte Carlo points considered in the text (black solid line) in a MSSM scenario with $M_{\tilde{e}_R} = M_{\tilde{\mu}_R} = M_{\tilde{\tau}_1}$. The expected limit (black dashed line) and the theory curve (red solid line) with its uncertainty (red dotted line) are also shown. The yellow and cyan bands represent the ±1 and ±2 sigmas uncertainties on the expected limit. The observed limit on the mass of the chargino is approximately 127* GeV/c^2 *and the expected one is ≃140* GeV/c^2.

VI. CONCLUSIONS

We have calculated the combined limit for a region of parameter space and found we can exclude masses of the chargino up to approximately 127 GeV/c^2 in a mSUGRA-like MSSM scenario with $M_{\tilde{e}_R} = M_{\tilde{\mu}_R} = M_{\tilde{\tau}_1}$. In the corresponding 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 140 GeV/c^2. These results improve over the Run I results and are in the region

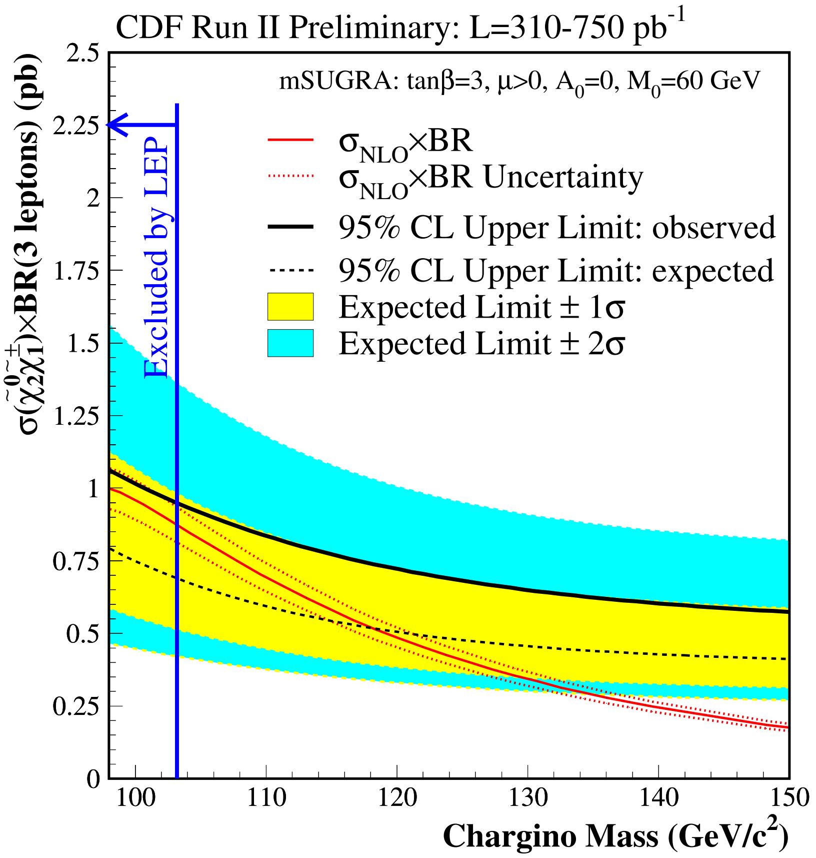

FIG. 4: *The excluded cross section limit is plotted as a function of the chargino mass from the Monte Carlo points considered in the text (black solid line) in the mSUGRA scenario described in the text. The expected limit (black dashed line) and the theory curve (red solid line) with its uncertainty (red dotted line) are also shown. The yellow and cyan bands represent the ± 1 and ± 2 sigmas uncertainties on the expected limit. The expected exclusion limit corresponds to a chargino mass of approximately 117* GeV/c^2.

not excluded by LEPII and DØ-Run II. We plan to improve these results by including the update of the $ee + \ell, e\mu + \ell$ analyses and more luminosity. We are also planning to scan more points in the parameter space and more models for which our acceptance should be enhanced.

Acknowledgments

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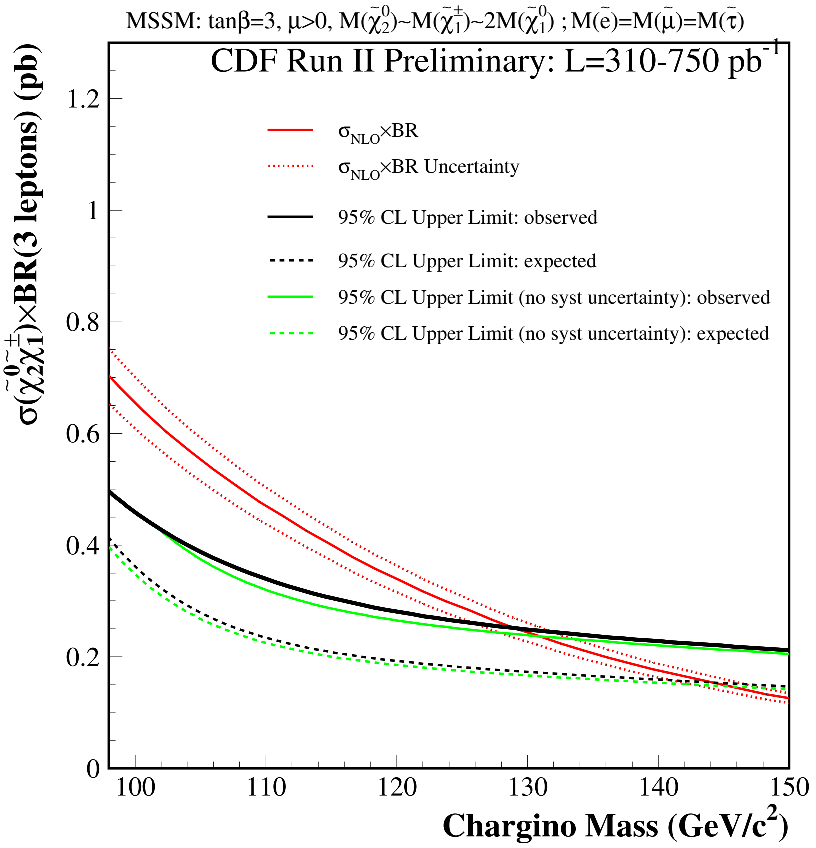

FIG. 5: *The excluded cross section limit is plotted as a function of the chargino mass for the MSSM scenario considered in the text (black solid line). The expected limit (black dashed line) and the theory curve (red solid line) with its uncertainty (red dotted line) are also shown. In green we show the observed (solid line) and expected (dashed line) limit, calculated without any systematic uncertainty.*

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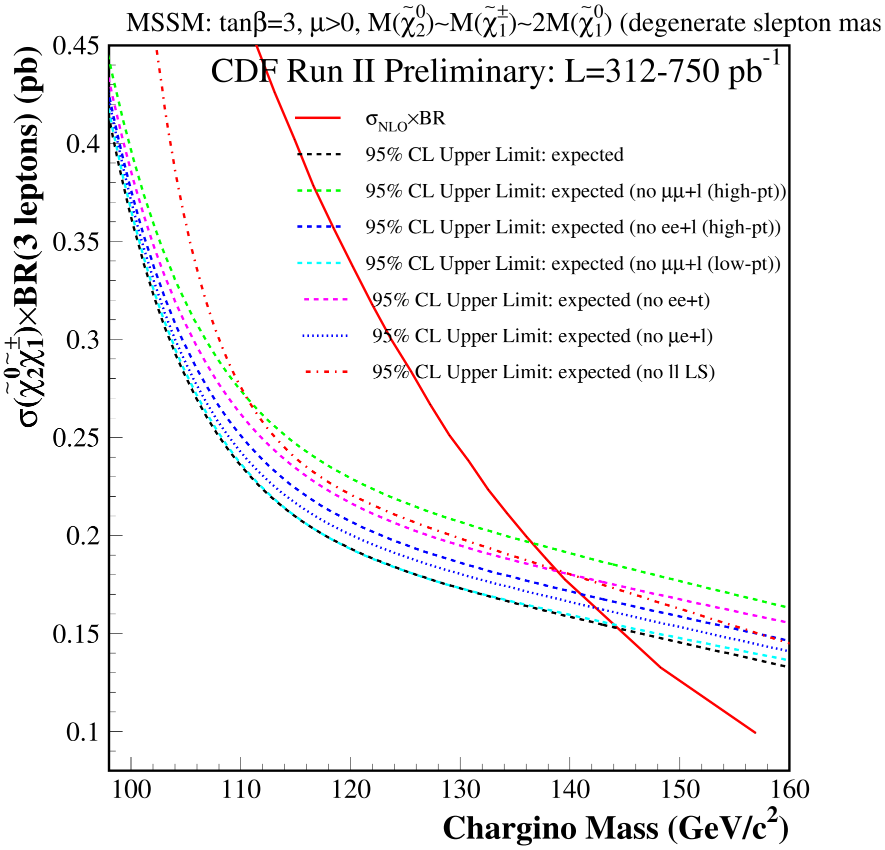

FIG. 6: *The excluded cross section limit is plotted as a function of the chargino mass for the MSSM scenario. The different curves correspond to the expected limit calculated when dropping one of the analyses at the time. The default version of the limit is also shown in black, and the theory cross section is shown in solid red.*

systematic uncertainty	correlation	$ee+\ell$		$\mu\mu+\ell$(**low pt**)		$\mu\mu+\ell$(**high pt**)		$\mu e(CEM)+\ell$		$\mu e(PLUG)+\ell$		ee **LS**		$e\mu$ **LS**		$\mu\mu$ **LS**		$ee+track$	
		signal	**background**	**signal**	**background**	**signal**	**background**	**signal**	**background**	**signal**	**background**	**signal**	**background**	**signal**	**background**	**signal**	**background**	**signal**	**background**
Luminosity	100%	6%	4%	6%	1%	6%	4%	6%	6%	6%	6%	6%	5%	6%	5%	6%	4%	6%	6%
PDFs	100%	2%	2%			2%	2%	2%	2%	2%	2%							2%	2%
ISR/FSR	100%	4.2%	4.1%			2%	4%	2%	4.0%	2%	4.0%							5.3%	10.8%
Jet Energy Scale	100%	1.0%	22.0%		0.0%	3%	4%	0.3%	7.0%		2.0%		0.0%		0.0%		0.0%	1%	16.6%
Electron ID	100%	3.3%	2.7%	6%	1%			2%	4%	5%	14%	0.6%	0.5%	0.6%	0.6%	0.0%	0.0%	2.6%	2.6%
Electron Energy Scale	100%	2.5%	2.9%	–	–							–	–	–	–	–	–	3.0%	3.0%
Muon ID	100%	0.7%	0.2%	6%	1.0%	5%	4%	7.0%	4.0%	5.0%	4.0%	0.0%	0.0%	0.6%	0.6%	1.5%	1.0%	–	–
Muon Isolation	100%	0.7%	0.1%	12%	2%	–	–					–	–	–	–	–	–	–	–
Lepton Fake Rate	100%	–	4.5%	–	21%	–	16%	–	13.0%	–	8.0%	–	3.7%	–	2.1%	–	4.4%	–	
Trigger Efficiency	0%	–	–	0.6%	0.1%	–	–	0.7%	0.7%	0.7%	0.7%	–	–	–	–	–	–	–	3.0%
Track Fake Rate	0%	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	22.2%
Conversion Removal	0%	–	0.7%	–	–	–	10%	–	7%	–	–	–	11.7%	–	12.6%	–	–	–	–
Heavy Flavour Background Method		–		–	6%	–	–	–		–	–	–	–	–	–	–	–	–	–
Theory Cross Section	100%	7%	6.5%			7%	5%	7%	4.0%	7%	7%	7%	4.7%	7%	4.9%	7%	4.6%	7%	6.5%

TABLE II: *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.*