CDF note 9093

Search for Gluino and Squark Production in Multijets Plus Missing $\mathrm{E_T}$ Final States

The CDF Collaboration
URL http://www-cdf.fnal.gov

(Dated: November 7, 2007)

We present preliminary results on a search for squarks and gluinos in proton-antiproton collisions with a center-of-mass energy of 1.96 TeV and based on 1.4 fb^{-1} of data collected by the CDF detector in the Tevatron Run II. Events with multiple jets of hadrons and large missing transverse energy in the final state are studied within the framework of minimal supergravity and assuming R-parity conservation. No excess with respect to Standard Model predictions is observed and new limits on the gluino and squark masses are extracted.

I. INTRODUCTION

Supersymmetry (SUSY) [1] is regarded as one of the most promising fundamental theories to describe physics at arbitrarily high energies beyond the Standard Model (SM). Over the last decades, the Minimal Supergravity (mSUGRA) [2] scenario has been extensively studied. In mSUGRA, symmetry breaking is achieved via gravitational interactions and the vast SUSY parameter space is reduced to only five parameters that determine the low energy phenomenology from the scale of Grand Unification(GUT): the common scalar mass m_0, the common gaugino mass $m_{1/2}$, the common soft trilinear SUSY breaking parameters A_0, the ratio of the Higgs vacuum expectation values at the electroweak scale $\tan\beta$, and the sign of the Higgsino mass term $\mathrm{sgn}(\mu)$. When R-parity [3] is conserved, supersymmetric particles have to be produced in pairs and ultimately decay into the lightest supersymmetric particle (LSP), usually identified as the lightest neutralino $\tilde{\chi}_1^0$, which constitutes a valid candidate for cold dark matter.

At the Tevatron, the production of squarks ($\tilde{q}$) and gluinos ($\tilde{g}$), superpartners of quarks and gluons, constitutes one of the most promising channels because of the strong couplings involved. The cascade decay of gluinos and squarks into quarks and gluons will result in a final state consisting of several jets plus missing transverse energy ($\not\!\!E_{\mathrm{T}}$) coming from the neutralinos, which leave CDF undetected. In this document, we discuss preliminary results on a search for squarks and gluinos carried out on 1.4 fb^{-1} of data collected by the CDF detector in Run II. A complete set of plots and results are collected at `http://www-cdf.fnal.gov/physics/exotic/r2a/20070809.squark_gluino/public.html`.

II. SIGNAL AND BACKGROUND SAMPLES

A mSUGRA scenario with $A_0 = 0$, $\mathrm{sgn}(\mu)$=-1 and $\tan\beta$=5 is assumed. The gluino-squark mass plane is scanned via variations of the parameters m_0 (0-500 $\mathrm{GeV/c^2}$) and $m_{1/2}$ (50-200 $\mathrm{GeV/c^2}$). The PYTHIA [4] Monte Carlo program is used to generate samples for each mSUGRA point, and ISASUGRA 7.74 is implemented to predict the SUSY spectrum at the TeV scale. Light-flavor squark masses are considered degenerate, while 2-to-2 processes involving stop ($\tilde{t}$) and sbottom ($\tilde{b}$) production are excluded to avoid a strong theoretical dependence on the mixing in the third generation. Each squark/gluino production subprocess (corresponding to one of the final states $\tilde{g}\tilde{g}$, $\tilde{q}\tilde{q}$, $\tilde{q}\bar{\tilde{q}}$, $\tilde{q}\tilde{g}$ and c.c.) is normalized to next-to-leading order (NLO) predictions as estimated using PROSPINO V.2 [5]. The cross sections are computed using CTEQ6.1M PDFs and the renor-

malization/factorization scale is set to the average mass of the two final-state supersymmetric particles.

SM backgrounds are dominated by QCD multijet processes where the observed $\not\!\!E_T$ comes from partially reconstructed jets in the final state. Monte Carlo samples have been generated using PYTHIA TUNE A, and data in a low $\not\!\!E_T$ region are used to determine the absolute normalization. Other sources of backgrounds are Z and W production in association with jets, and top and diboson production. For these processes, $\not\!\!E_T$ might result from mis-reconstructed jets, the presence of neutrinos and muons in the final state, or both. ALPGEN v2.1 [6] interfaced with parton shower from PYTHIA is used to estimate W and Z+jets backgrounds, taking the normalization from the measured inclusive Drell-Yan cross sections [7]. Top and diboson processes are estimated using PYTHIA TUNE A Monte Carlo samples normalized to the NLO theoretical predictions [8]. Finally, the generated samples are recontructed using the full CDF detector simulation.

III. EVENT SELECTION

Events are required to have a reconstructed primary vertex with z-position within 60 cm of the nominal interaction point, $\not\!\!E_T$ >70 GeV and a tracking activity consistent with the energy measured in the calorimeter to reject cosmics and beam-halo background.
Depending on the relative masses of squarks and gluinos, different event topologies are expected. If squarks are significantly lighter than gluinos, $\tilde{q}\tilde{q}$ production is enhanced. The squark tends to decay according to $\tilde{q} \rightarrow q\tilde{\chi}_1^0$, and a dijet topology is favoured, along with $\not\!\!E_T$ due to the two neutralinos in the final state. If gluinos are lighter than squarks, $\tilde{g}\tilde{g}$ process dominates. Gluinos decay via $\tilde{g} \rightarrow q\bar{q}\chi_1^0$, leading to topologies containing a large number of jets (≥ 4) and moderate $\not\!\!E_T$. For $M_{\tilde{g}} \approx M_{\tilde{q}}$, a topology with at least three jets in the final state is expected. Three different analyses are carried out in parallel, requiring at least 2, 3 or 4 jets in the final state, respectively. In each case, the transverse energy of the jets must be above 25 GeV, and one of the leading jet is required to be central ($|\eta|$ <1.0). A minimum azimuthal distance between the jets and the $\not\!\!E_T$ is required to reduce the QCD multijets contribution, and lepton vetoes are applied to reject boson+jets, dibosons and $t\bar{t}$ backgrounds.

For each final state, a dedicated study has been carried out to define the selection criteria that enhance the sensitivity to the mSUGRA signals. The signal significance, $S/\sqrt{B}$, with S denoting the signal and B the background number of events, is maximized. Jet transverse energies, $\not\!\!E_T$ and H_T, defined as the sum of the transverse energy of the jets, are the variables employed in

the optimization. Table 1 summarizes the thresholds applied on these variables in the different analyses. For the 3-jet analysis, three set of thresholds, intended for different squark/gluino masses, are defined in order to further improve the signal significance across the plane where $M_{\tilde{g}} \approx M_{\tilde{q}}$.

IV. CONTROL REGIONS

Monte Carlo predictions for SM processes are tested in background-dominated regions, referred as control regions, defined by reversing the selection requirements introduced to suppress specific background processes. Two different types of control regions are identified:

- *QCD-dominated region*: at least one of the leading jets is required to be aligned with the $\not\!\!E_T$ azimuthal direction.
- *EWK/Top-dominated region*: lepton vetoes are reversed, and at least one electron or muon, identified via the presence of an electromagnetic cluster or isolated track, is required in the event.

Figure 1 shows, for the 4-jet analysis, the $\not\!\!E_T$ and H_T distributions in the QCD-dominated sample, where the shaded band indicates the total systematic uncertainty on the background estimation (see below). Good agreement is found between data and SM Monte Carlo predictions. Similar agreement is observed in all control samples considered for each separately analysis.

V. SYSTEMATIC UNCERTAINTIES

The dominant systematic uncertainty on the signal efficiencies and SM background yields comes from the 3% uncertainty on the jet energy scale. This translates into a 10% and 20% uncertainty

[GeV]	4-jet	3-jet(A)	3-jet(B)	3-jet(C)	2-jet
H_T	280	230	280	330	330
$\not\!\!E_T$	90	75	90	120	180
E_T^{jet1}	95	95	120	140	165
E_T^{jet2}	55	55	70	100	100
E_T^{jet3}	55	25	25	25	–
E_T^{jet4}	25	–	–	–	–

TABLE I: Set of thresholds employed in the analysis.

on the signal and background estimations, respectively. Systematic uncertainties related to the modeling of the initial and final state radiation (ISR/FSR) in mSUGRA signal and $t\bar{t}$ Monte Carlo samples translates into an uncertainty on the signal efficiency between 3% to 6% depending on the $\tilde{q}/\tilde{g}$ masses, and in a 8% uncertainty on the top background contribution, as defined using additional samples generated with modified parton showers. Other uncertainties specific for the different background processes include: a 10% uncertainty on the diboson production cross section due to the uncertainties on PDFs and the choice of renormalization scale, a 2% systematic uncertainty on boson+jets production cross section, and a 10% uncertainty on the $t\bar{t}$ theoretical cross section. Finally, a 6% uncertainty on the integrated luminosity is also included.

Systematic uncertainties on the mSUGRA cross sections are dominated by PDFs and renormalization scale uncertainties. The Hessian method [9] is used to compute the uncertainty due to PDFs. This translates into an uncertainty on the theoretical cross section that varies between 20% and 34%, depending on the mSUGRA point. The uncertainty due to the renormalization and factorization scale is determined by re-evaluating the cross section using twice and half the nominal scale set in PROSPINO for each production subprocess. The resulting systematic uncertainty varies between 17% and 23%, depending on the mSUGRA point.

VI. RESULTS

The number of observed and SM expected events corresponding to a total integrated luminosity of 1.4 fb^{-1} are reported in Table 2, separately for the five analyses. Good agreement is found between data and Monte Carlo predictions. Figure 2 shows the $\not\!\!E_T$ and H_T distributions for the 3-jet(C) and 4-jet analyses. All selection criteria have been applied except the one on the variable that is represented. Each Figure shows the data superimposed on the expected SM background and the total systematic uncertainty. For illustration purposes, one representative mSUGRA point is shown for each analysis region. In case of the 3-jet(C) region, a point with $M_{\tilde{g}} = 349$ GeV/c^2 and $M_{\tilde{q}} = 389$ GeV/c^2 is chosen. For the 4-jet region, a point with $M_{\tilde{g}} = 287$ GeV/c^2 and $M_{\tilde{q}} = 439$ GeV/c^2 is considered.

Since no significant deviation from the SM predictions is observed, results are translated into exclusion limits on gluino and squark production as a function of gluino and squark masses. A Bayesian approach at 95% C.L. is used, where statistical and systematic uncertainties are included in the limit calculation taking into account correlations between signal and background uncertainties. The uncertainties on the NLO signal cross sections are also included.

Region	Observed data Evts	SM Expected Evts
4-jets	29	$27 \pm 2 \pm 9$
3-jets(A)	616	$607 \pm 16 \pm 146$
3-jets(B)	166	$154 \pm 7 \pm 44$
3-jets(C)	22	$25 \pm 2 \pm 8$
2-jets	13	$11 \pm 2 \pm 3$

TABLE II: Observed number of data events for the five selection analyses in 1.4 fb^{-1}, compared with the expected events from SM processes. The quoted systematic uncertainty on the background include 6% uncertainty on the luminosity.

Figure 3 shows the PROSPINO NLO cross section as a funtion of the squark masses for $M_{\tilde{g}} = 230$ GeV/c^2, and as a function of the gluino mass for $M_{\tilde{g}} \approx M_{\tilde{q}}$. The yellow band indicates the total systematic uncertainties on the NLO predictions.

The figure also shows the curves for expected and observed limits, where the crossing point with the nominal NLO prediction would define the maximum values for squark/gluino masses as resulting by this analysis. The obtained exclusion limits from different squark and gluino masses are mapped out in Figure 4 where exclusion regions, as determined by other experiments, are also presented.

This search excludes masses up to 380 GeV/c^2 at 95% C.L. in the region where gluino and squark masses are similar, gluino masses up to 280 GeV/c^2 for every squark mass, and gluino masses up to 410 GeV/c^2 for squark masses below 375 GeV/c^2, in a mSUGRA scenario with $A_0 = 0$, $\mu < 0$ and $\tan\beta = 5$.

The results of this analysis in terms of $M_{\tilde{g}}$-$M_{\tilde{q}}$ can also be translated into the mSUGRA parameters at the GUT scale. Figure 5 shows the excluded regions in the m_0-$m_{1/2}$ plane for tanβ=5, A_0=0 and μ <0. This search improves on the limits from indirect searches as determined by LEP2 [10] for m_0 values between 75 and 250 GeV/c^2 and for $m_{1/2}$ values between 130 and 165 GeV/c^2.

VII. CONCLUSION

We have presented preliminary results on searches for squarks and gluinos in proton-antiproton collisions with a center-of-mass energy of 1.96 TeV at the Tevatron, based on 1.4 fb^{-1} of data collected by the CDF detector in Run II. In a mSUGRA scenario with $A_0 = 0$, $\mu < 0$ and

$\tan\beta = 5$, we exclude masses up to about 380 GeV/c^2 at 95% C.L. in the region where gluino and squark masses are similar, gluino masses up to 280 GeV/c^2 for every squark mass, and gluino masses up to 410 GeV/c^2 for squark masses below 375 GeV/c^2. In the future, Tevatron is expected to deliver a total integrated luminosity of about 6 fb^{-1}. This will allow either a discovery or further improvement on the current limits on squark and gluino masses.

Acknowledgments

We thank the Fermilab staff and the technical staffs of the participating institutions for their vital contributions. This work was supported by the U.S. Department of Energy and National Science Foundation; the Italian Istituto Nazionale di Fisica Nucleare; the Ministry of Education, Culture, Sports, Science and Technology of Japan; the Natural Sciences and Engineering Research Council of Canada; the National Science Council of the Republic of China; the Swiss National Science Foundation; the A.P. Sloan Foundation; the Bundesministerium fuer Bildung und Forschung, Germany; the Korean Science and Engineering Foundation and the Korean Research Foundation; the Particle Physics and Astronomy Research Council and the Royal Society, UK; the Russian Foundation for Basic Research; the Comision Interministerial de Ciencia y Tecnologia, Spain; and in part by the European Community's Human Potential Programme under contract HPRN-CT-20002, Probe for New Physics.

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http://lepsusy.web.cern.ch/lepsusy/

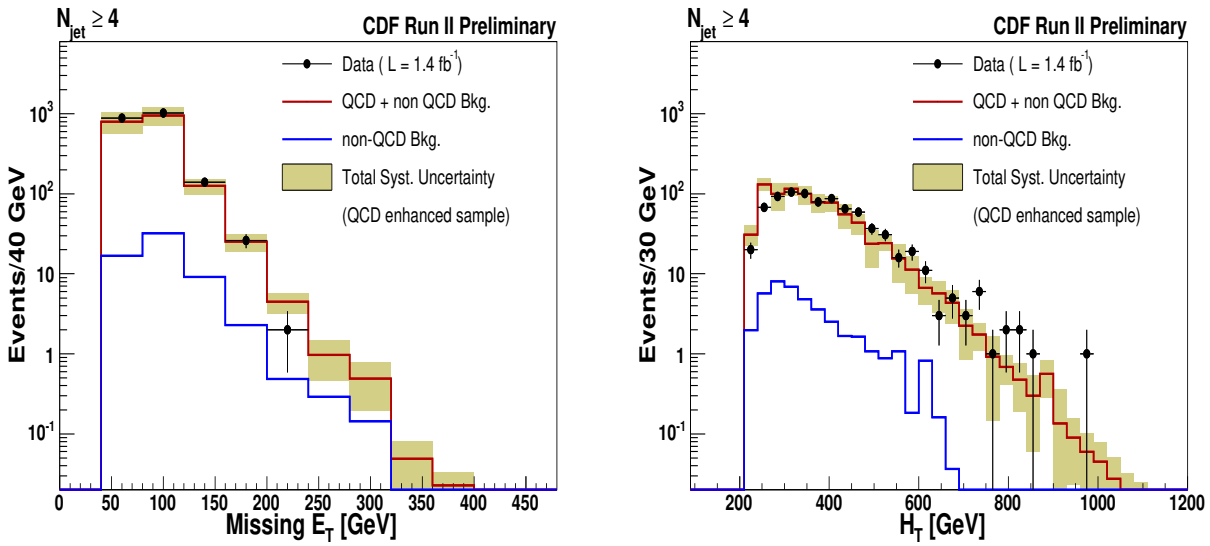

FIG. 1: $\not\!\!E_T$ and H_T in QCD-dominated samples, after all selection cuts for the 4-jet region: data are superimposed to QCD$\oplus$non-QCD background with total systematics uncertainties. All cuts have been applied except the one on the variable that is represented.

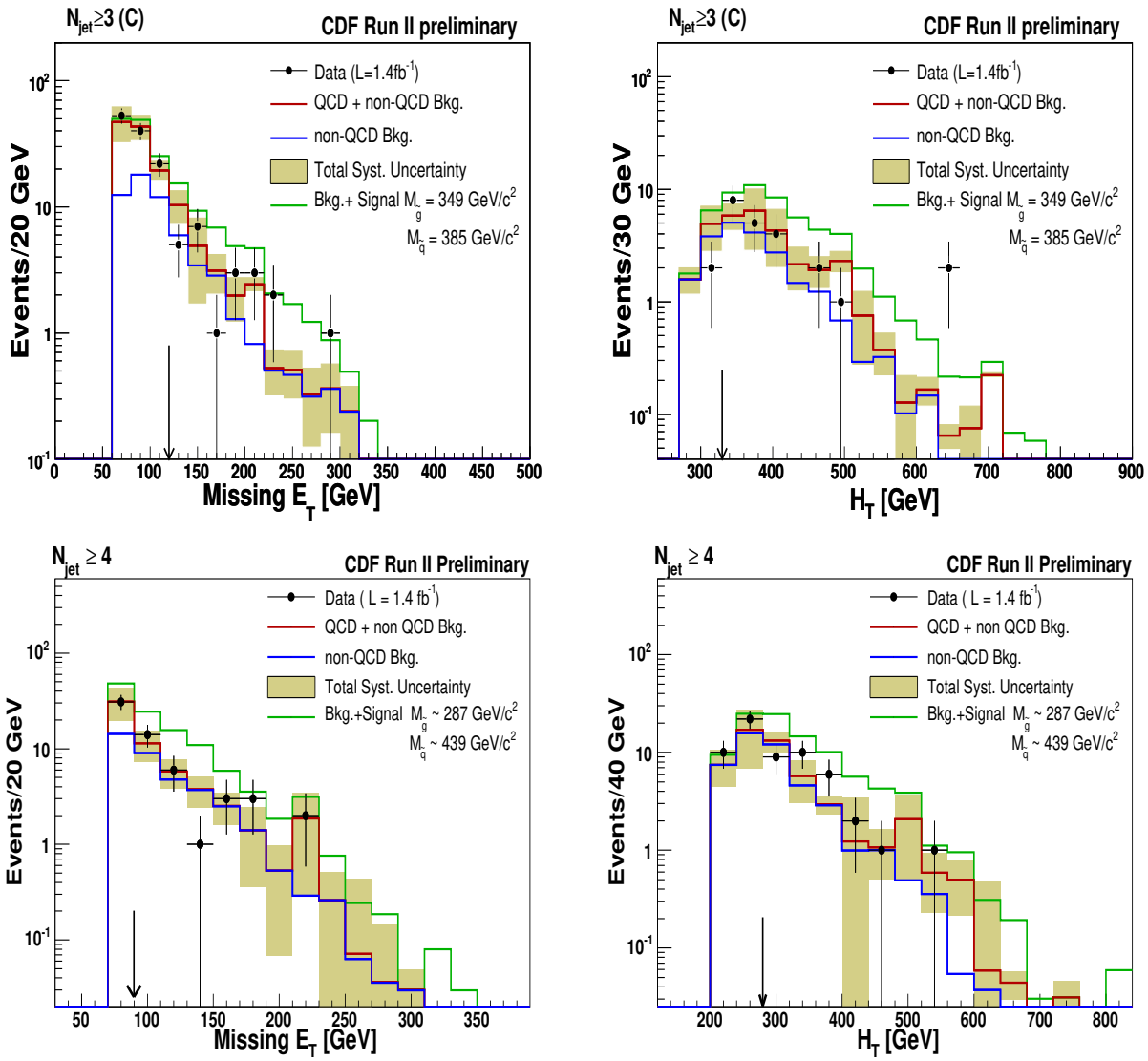

FIG. 2: $\not\!\!E_T$ and H_T after all selection cuts for the 3-jet(C) (top) and 4-jet (bottom) analyses: data are superimposed to QCD and non-QCD background with total systematics uncertainties. Distributions for a representative signal point is shown for both 3-jet(C) and 4-jet analysis regions. In these plots, all cuts have been applied except the one on the variable that is represented.

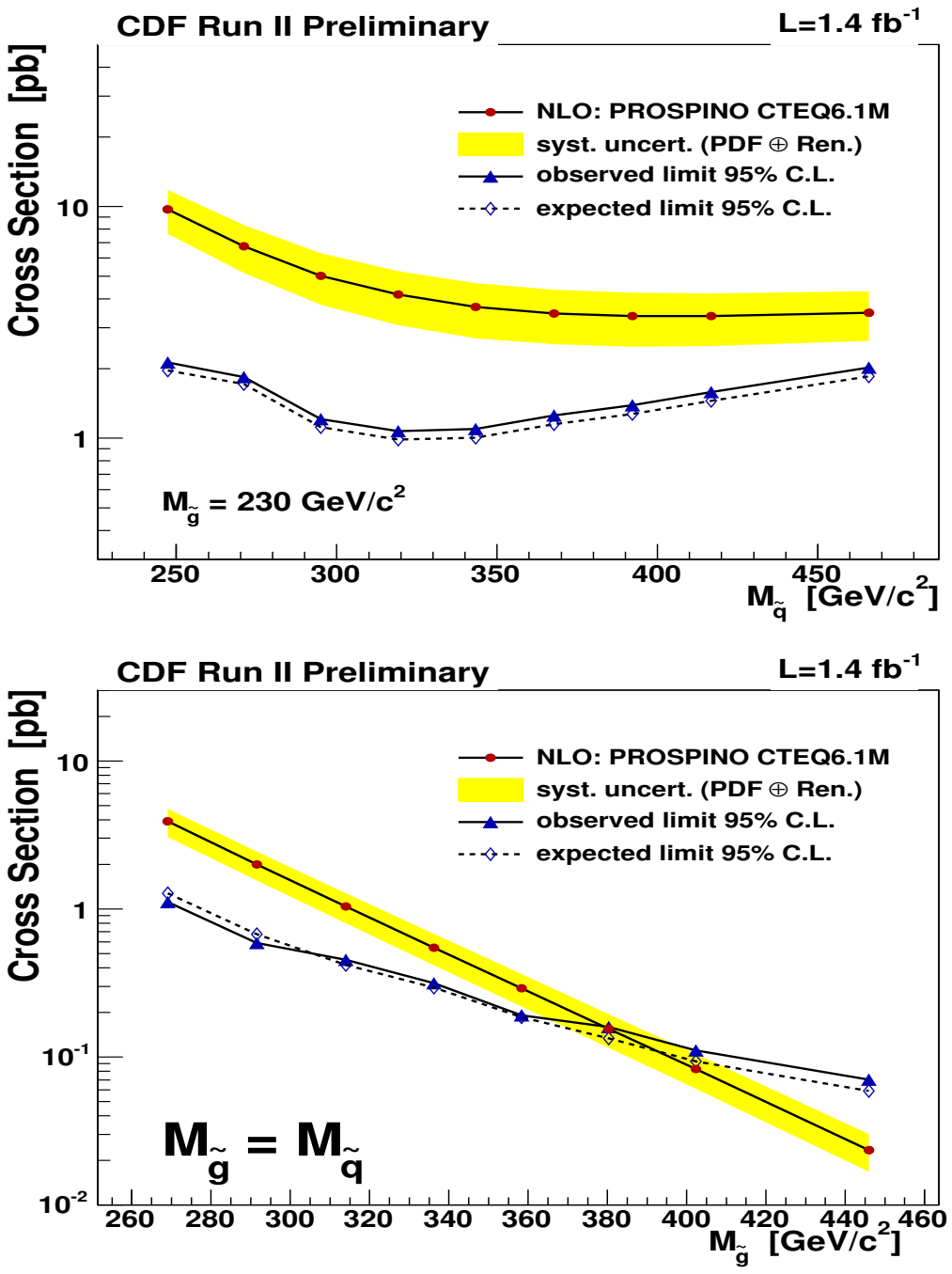

FIG. 3: Cross section as a function of gluino/squark masses in the case of $M_{\tilde{g}} = 230$ GeV/c^2 (top) and $M_{\tilde{q}} \approx M_{\tilde{g}}$ (bottom). The observed and expected limits at 95% C.L. are also shown. The yellow band indicates the total systematic uncertainties on the NLO prediction. In case of $M_{\tilde{g}} = 230$ GeV/c^2, squark masses are excluded up to arbitrarily high values. In case $M_{\tilde{q}} \approx M_{\tilde{g}}$, squark and gluino masses are excluded up to 380 GeV/c^2.

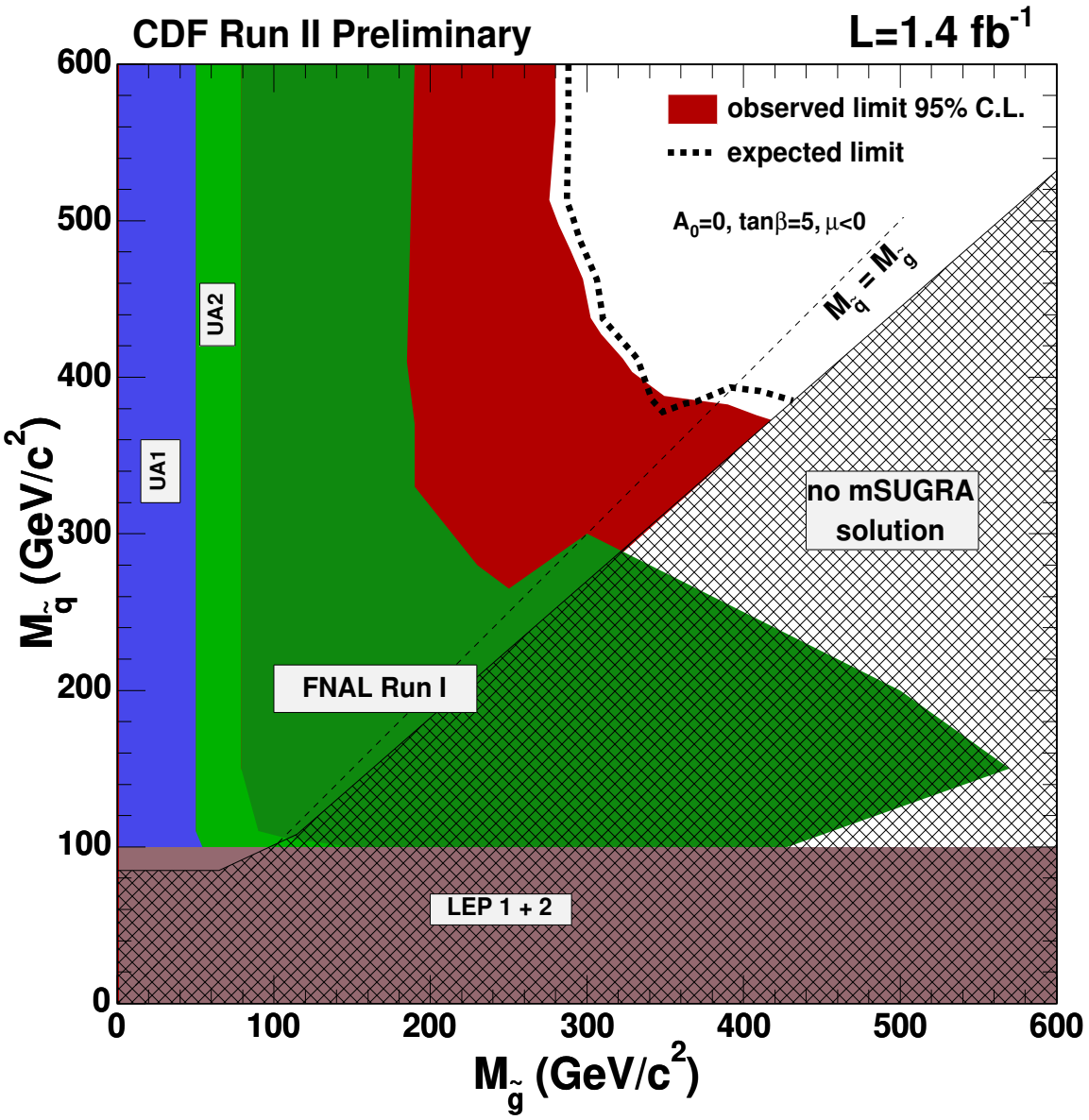

FIG. 4: Observed(red region) and expected (dashed-line) exclusion limits at the 95 % C.L in the $M_{\tilde{q}}$ - $M_{\tilde{g}}$ mass plane. Regions excluded by previous experiments are shown, together with no-mSUGRA solution region.

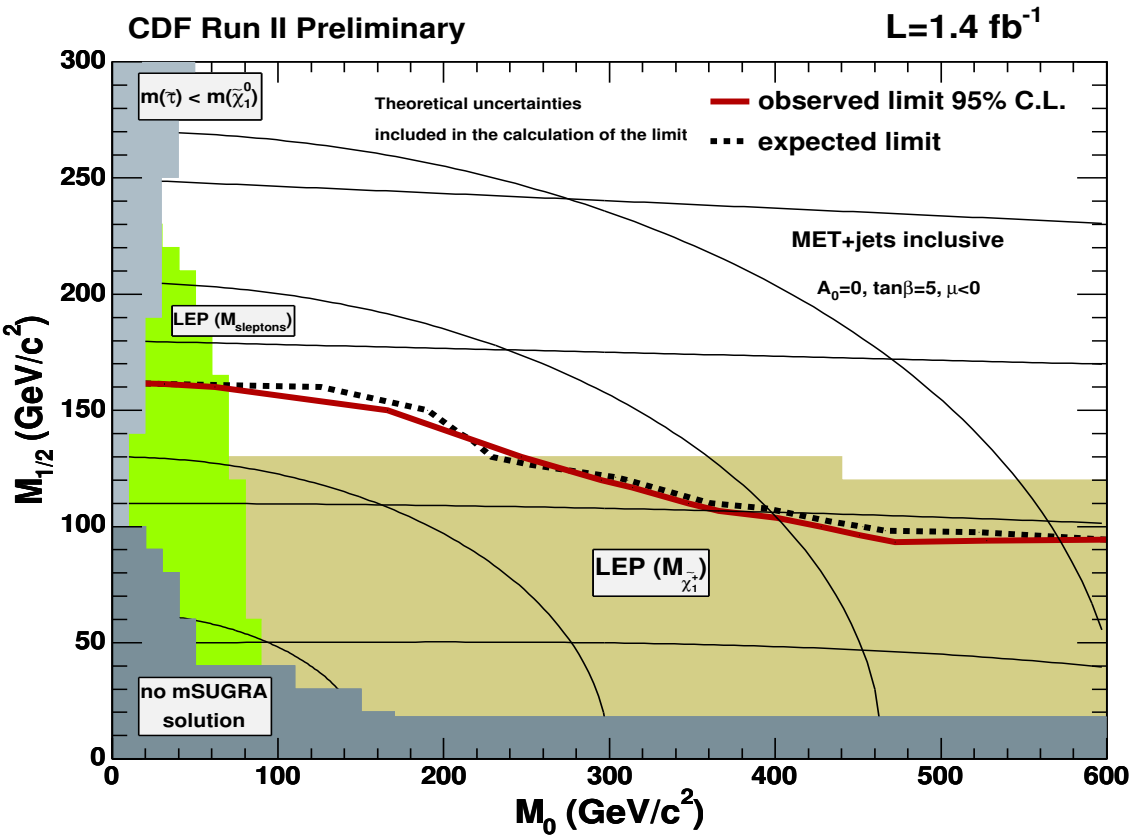

FIG. 5: Observed(solid line) and expected (dashed line) exclusion limits at the 95% C.L. in the (m_0,$m_{1/2}$) plane. The light-grey region indicates the region where $m(\tilde{\tau}) < m(\tilde{\chi}_1^0)$. The beige and green regions are excluded by LEP2 chargino and slepton searches[10], respectively. No mSUGRA solution is found in the dark-grey region. The black lines are the iso-mass curves for gluinos (horizontal) and squarks (elliptic) corresponding to masses of 150, 300, 450 and 600 GeV/c^2.