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LHC SUSY discovery potential

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Abstract

The SUSY discovery potential of CMS and ATLAS detectors at the LHC is evaluated in different regions of the mSUGRA parameter space. In inclusive searches the parameters can be constrained by considering the event topology. The observation of kinematic end points at large statistics makes possible to infer the SUSY mass spectrum. The LHC SUSY discovery region extents up to the mass scale of 2 TeV at $\mathrm{L}_{int} > 10\mathrm{fb}^{-1}$ and is limited by uncertainties in the Standard Model backgrounds.

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1 Introduction

The potential of the Large Hadron Collider (LHC) to discover supersymmetry(SUSY) has been studied in detail in the past decade. Each new step in this study involves more detailed detector simulation and advanced analysis of signal signatures. Any deviation from the Standard Model (SM) predictions will be tested against SUSY hypothesis and the SUSY discovery would mean observation of at least one or several new sparticles predicted by the model: squarks($\tilde{q}$) and sleptons ($\tilde{l}, \tilde{\nu}$), gauginos($\chi^0_{2,3,4}$, $\chi^{\pm}_{1,2}$), gluino ($\tilde{g}$) or heavy Higgses($H^{\pm}$,H_0,A). In the minimal Supergravity (mSUGRA) model the mass spectrum and couplings are defined by only five free parameters: the universal gaugino $m_{1/2}$ and scalars masses m_0, the Higgs-sfermions trilinear coupling A_0, the ratio of Higgs vacuum expectation values tanβ and sgn(μ). The lightest SUSY particle (LSP) in R-parity conserved scenario is the neutralino (χ^0_1) being an attractive candidate for the relic Dark Matter(DM). The mSUGRA m_0-$m_{1/2}$ parameters plane is constrained at large m_0 by the ElectroWeak Symmetry Breaking (EWSB) requirements and at low m_0 the LSP is a charged stau disfavored by the relic DM interpretation. The experimental limits from LEP on the light Higgs boson ($m_h < 114$ GeV) and the $b \to s\gamma$ ([3.43±0.36] 10^{-4}) branching ratio from b-factories already exclude low mass region (m_0 <1000GeV and $m_{1/2}$ <300 GeV)[1]. The LEP mass limit on the chargino mass excludes region with $m_{1/2}$ <140 GeV for all m_0. Further constraints can be obtained from the relic DM density measurement by WMAP and indirect DM search with gamma rays [2]. At the LHC a typical search strategy have two major steps. First, all possible mSUGRA final states can be detected with an inclusive search which is a 'counting like' experiment. All uncertainties in the background calculations are very important in this search which can hardly be used to identify the underlying model. In the second step the sparticles decay chain can be analyzed. The invariant mass distributions of different particles combinations have the particular kinematic end points related to the mass differences of sparticles participating in the cascade [4]. With a sufficient statistics and large signal to noise ratio the mass spectrum, and therefore the SUSY Lagrangian can be reconstructed.

In this report the expected mSUGRA discovery potential is summarized for the CMS and ATLAS detectors, ready for operation in 2008 at the LHC. The results are based on the full(CMS:ORCA) or fast(CMS:FAMOS, ATLAS:ATLFAST) detector simulations and are presented in the CMS Physics TDR [3] or recent ATLAS publications [5, 6].

2 SUSY signal and background signatures at LHC

The mSUGRA production cross section at LHC depends on the SUSY mass scale $min(m_{\tilde{q}}, m_{\tilde{g}})$ and drops fast at larger $m_{1/2}$ ($m_{\tilde{g}} \sim 2.7 m_{1/2}$) and m_0. The regions in Fig.1 correspond to the dominating squarks $\tilde{q}\tilde{q}$ (1) or gluino $\tilde{g}\tilde{g}$ (3) production and in the region (2) both $\tilde{q}\tilde{g}$ can be produced. For larger m_0 >2000 GeV the direct gauginos production ($\chi^{\pm}_1\chi^{\pm}_1$, $\chi^0_2\chi^{\pm}_1$) dominates.

The signal topology is defined by the cascade decays of produced sparticles: the general signal signatures can be written as $N_{leptons}$+N_{jets}+Missing Transverse Energy(MET). The number of hard central jets N_{jets}($E^j_T > 30GeV$, $|\eta| < 2.4$), MET, highest lepton P^l_T and highest jet E_T will depend on the mSUGRA parameters m_0 and $m_{1/2}$, see Fig.2. The MET and jets E_T are decreasing toward the EWSB limit and can be quite small at low $m_{1/2}$ making the background suppression with the MET and N_{jets} cuts very difficult in this region. The largest jets multiplicity is achieved in the region (2) where $m_{\tilde{q}}$ and $m_{\tilde{g}}$ are almost degenerate in mass and the cascades are long. The leptons P_T is increasing with $m_{1/2}$ where the gauginos, main source of hard leptons, are heavier ($m_{\chi^0_2} \sim 0.8 m_{1/2}$).

Some important SM backgrounds with large MET, high jets multiplicity and hard leptons are listed in Table 1 together with some CMS test points ($m_{1/2}$,m_0,tanβ, A_0=0). The largest average MET is expected for the $t\bar{t}$ events. The ZW, DY, W+jets, Z+jets channels are producing relatively hard leptons. The QCD, W+jets have large cross sections and can be important for the multijet final states. There are more backgrounds important for the specific exclusive studies.

3 mSUGRA discovery reach

For most of inclusive searches the SUSY events are selected with large MET and jets multiplicity. One hard lepton or two same sign (SS) and opposite sign (OS) same flavor (SF) leptons can be added to the selection. A summary of considered final states and some important selection requirements used in the CMS studies with the full simulation is presented in Table 2. The background suppression is optimized for a particular mSUGRA test point, usually at low mass, and then extrapolated to the whole parameter space [3]. A typical L1 trigger for SUSY events is jet+MET (in CMS E^j_T >88GeV, MET>45GeV) or dileptons ($P^{\mu}_T > 3GeV/c$, $P^e_T > 17GeV/c$). Trigger efficiency

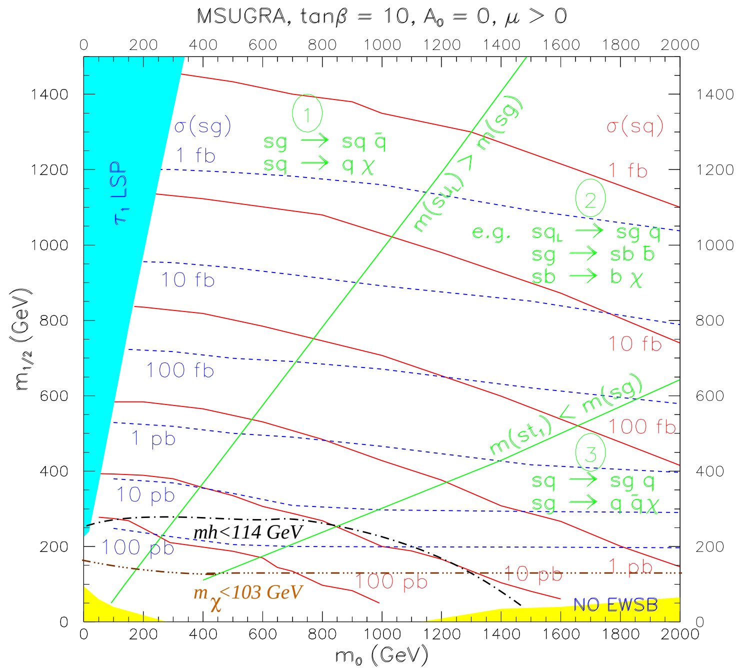

Figure 1: mSUGRA regions in the m_0-$m_{1/2}$ mass plane and contours for the inclusive gluino $\sigma(sg)$ and squarks $\sigma(sq)$ production.

Table 1: SM backgrounds and mSUGRA test points($m_{1/2}$,m_0,tanβ, A_0=0) cross sections [pb], reconstructed average MET [GeV] and jets multiplicity (E_T >30 GeV)

channel	σ	MET	N_j
$t\bar{t}$	830 ^{NLO}	69	2.8
W($l\nu$)+jets(> 50GeV)	42 10^3 ^{LO}	51	1.8
Z(ll)+jets(> 20GeV)	14 10^3 ^{LO}	25	1.6
DY(ll)	53 10^3 ^{LO}	22	0.7
QCD (> 50 GeV)	2.4 10^7 ^{LO}	18	1.8
ZW(lll)	52 ^{NLO}	41	0.6
SUSY(60,250,10)	55 ^{NLO}	240	2.8
SUSY(1450,175,50)	40 ^{NLO}	105	3.1

is $\sim$ 98% for the low mass region and is decreasing to $\sim$ 70% for large m_0 >2000 GeV. The SM background rejection up to $\sim 10^3$ is obtained with MET> 150GeV. Jets multiplicity N_{jets}, hard leptons $N_{leptons}$ and cuts on some angular variables ($\theta(j_1 j_2)$,$\theta(j_1 MET)$, η) increase the rejection further to $\sim 10^{5-6}$. The 5 σ discovery reaches in mSUGRA mass plane is shown in Fig.3 for L_{int}=10 fb^{-1}. The signal significance is calculated by taking into account theoretical and reconstruction systematic uncertainties which can contribute up to 20% to the background uncertainties.

4 Determination of model parameters.

The reconstruction of SUSY mass spectrum from kinematic end points is discussed in [4, 5, 6]. This technique works well at $m_{1/2}$ <500 GeV m_0 <300 GeV, where two body decays dominate: $\tilde{g} \rightarrow q_1\tilde{q} \rightarrow q_1 q_2 \chi^0_2 \rightarrow q_1 q_2 l^{\pm}\tilde{l}^{\mp} \rightarrow q_1 q_2 l^{\pm} l^{\mp} \chi^0_1$. The kinematic end point in invariant masses of OSSF leptons M_{ll} and different combinations of jets (q_1, q_2) and leptons M_{llq}, M_{lq} are related to the mass differences $m_{\chi^0_2}$-$m_{\chi^0_1}$, $m_{\tilde{g}}$-$m_{\tilde{q}}$, $m_{\tilde{q}}$-$m_{\chi^0_2}$, etc. System of equations involving all end points is overestimated and all mass differences can be reconstructed in principle. However, the sparticles are produced in pairs and one needs a correct association to the cascade chain. This can be done with $\sim$ 80% efficiency by grouping particles around two axes $a_{1,2}$ and for ex. maximizing the scalar product $\vec{p}\vec{a}$ [3]. The mass spectrum of sparticles can be reconstructed from the end points with an accuracy below 10% [5] for low mass region, see Fig. 4. The uncertainties can cause an another ghost solution for the

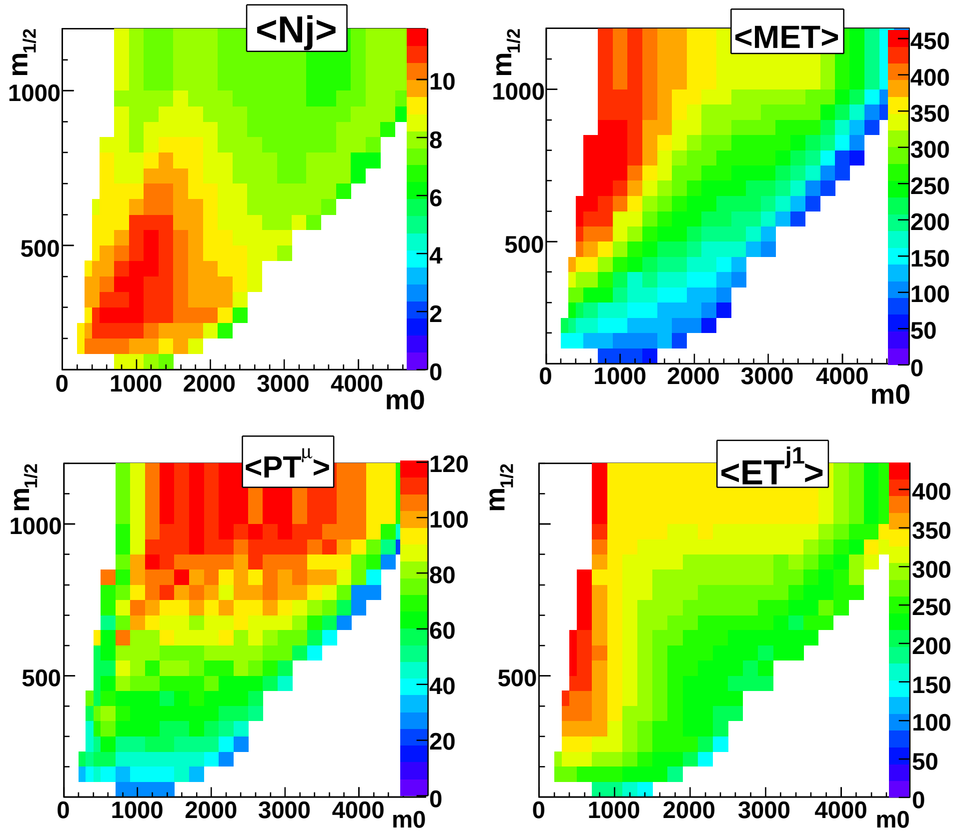

Figure 2: Average jets multiplicity $N_{jets}(E_T^{jets} > 30, |\eta| < 2.4)$, MET [GeV], highest lepton P_T^{μ} [GeV/c] and highest jet E_T [GeV] for mSUGRA(tanβ=50) at generator level.

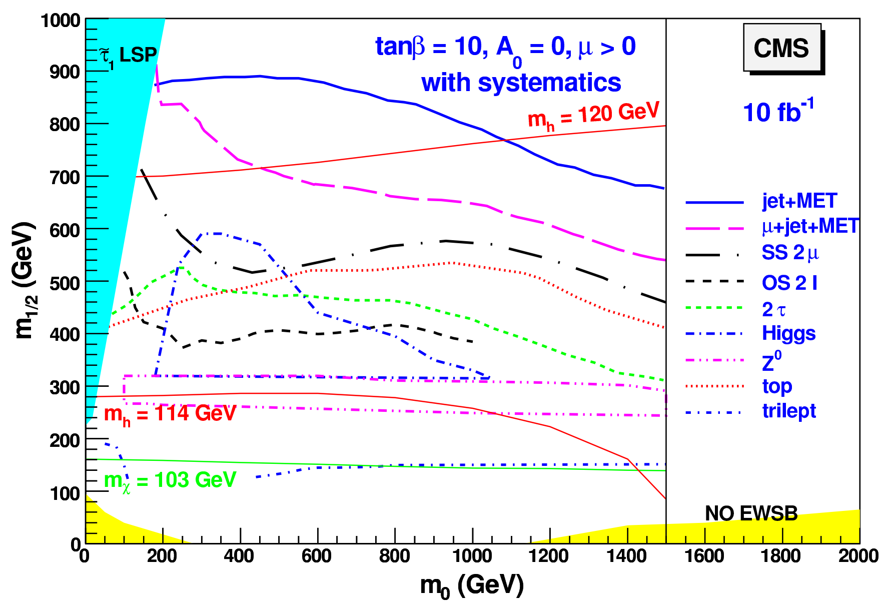

Figure 3: CMS 5 σ mSUGRA discovery reaches for different channels at L_{int}=10 fb^{-1}.

Table 2: Summary of the CMS mSUGRA inclusive studies with full simulations. The selection cuts on MET, jets and leptons are presented together with number of signal and background events at the optimization point.

signature	MET [GeV]	N_{jets} ($E_T^i >$ GeV)	$N_{leptons}$ ($P_T >$GeV/c)	Nsig, $10fb^{-1}$ ($m_0, m_{1/2}, tan\beta$)	Nbkg, $10fb^{-1}$
jet+MET	>200	≥3 (180,110,30)	-	$6\ 10^4$ (60,250,10)	$2.5\ 10^3$ (qcd,$t\bar{t}$)
μ+jets+MET	>130	≥3 (440,440,50)	≥1μ (30)	311 (60,250,10)	2.5 (Wjets,$t\bar{t}$)
SS 2μ+jets+MET	>200	≥3 (175,130,55)	SSμ (10)	341 (60,250,10)	1.5 ($t\bar{t}$)
OS 2τ+jets+MET	>150	≥2 (150,150)	OS τ	1140 (185,350,35)	427 ($t\bar{t}$)
OS 2l+jets+MET	>200	≥2 (100,60)	OSSF (10)	$8.5\ 10^3$ (60,250,10)	$2\ 10^3$ ($t\bar{t}$, Wjets)
top+jet+MET	>150	4 (30)	≥ e,μ (5)	380 (60,250,10)	220 ($t\bar{t}$)
Z_0+MET	>255	-	OSSF $M_{ll}=m_Z$	1289 (210,285,10)	440 ($t\bar{t}$)
h_0+jets+MET	>200	≥4 (200,150,50,30)	-	$1.4\ 10^4$ (60,250,10)	200 ($t\bar{t}$)
sleptons (OSSF+MET)	>130	0 veto	OSSF (20)	60 (60,250,10)	45 ($t\bar{t}$, WZ)
trilept (OSSF+lept.)	-	0 veto	OSSF (μ:10,e:17)+l(10)	53 (1450,175,50)	157 (DY,Zjets,$t\bar{t}$)

masses (blue or gray curves) which can be rejected considering in addition the cross section information [6]. The mSUGRA parameters can be reconstructed from the masses with an accuracy of $\Delta m_0 \sim 2\%$, $\Delta m_{1/2} \sim 0.6\%$, $\Delta tan\beta \sim 9\%$, $\Delta A_0 \sim 16\%$ in the low mass region [5].

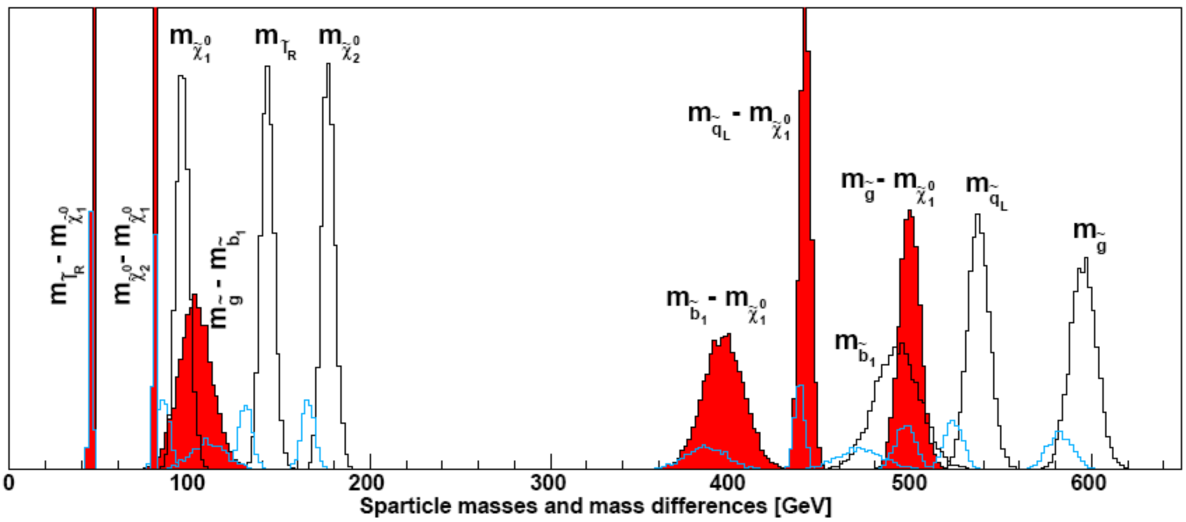

Figure 4: Reconstructed mass spectrum for mSUGRA(m_0=100 $m_{1/2}$=250,tanβ=10) at L=300 fb^{-1} using ATLAS fast simulations.

The kinematic end point method may not be so effective for the focus point region at large m_0. In this case the different signal topologies can be used to constrain mSUGRA regions already in inclusive search, without reconstruction of the whole cascade chain.

5 Conclusion

The discovery of SUSY at LHC will be possible at $L_{int} \sim 1\ fb^{-1}$ in low mass region, after 10 fb^{-1} the mSUGRA region $m_{1/2}$ <1000 GeV and m_0 <2000 GeV will be exploited in details with the mass reconstruction method. The higher $m_{1/2}$ are limited by the SUSY production cross section and backgrounds uncertainties. The focus point region at large m_0 is difficult for the LHC and will require a good understanding of all backgrounds.

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