SEARCHES FOR SUSY AT LHC

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Searching for Supersymmetry is one of the main goals of the research program for the general purpose experiments at the LHC – ATLAS and CMS. Due to the model-dependence of the SUSY phenomenology, a variety of searches based on very general signatures ("inclusive searches") have been planned. In particular, signatures of missing transverse energy plus jets will be investigated, with different requirements on the number of leptons in the events. If a SUSY signal is found, detailed studies on the model parameters are foreseen.

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1 Introduction

At the Large Hadron Collider at CERN two general purpose experiments are ready to detect interactions produced at an unprecedented center-of-mass energy, allowing for precise studies of the Standard Model physics and, moreover, the potential to discover new physics. Among the proposed models for physics beyond the Standard Model, Supersymmetry (SUSY) is widely believed to be one of the most promising. Due to the large number of possible SUSY-breaking models, an inclusive approach has been chosen in order to have wide-ranging sensitivity. A description of some example approaches is given in the following, together with a brief description of some methods for obtaining a data-driven estimation of the background. The studies presented here have optimized for an center-of-mass energy of 14 TeV and an integrated luminosity of 1 fb^{-1}. Optimisations for the lower center-of-mass energy expected in early LHC running are in progress.
To evaluate the performance of their search algorithms, both ATLAS [1] and CMS [2] have defined benchmark points for which studies with detailed detector simulation have been performed.

2 Supersymmetry phenomenology

The Minimal Supersymmetric Standard Model (MSSM) is the SUSY extension of Standard Model with the minimal particle content. Non observation of supersymmetric partners with the same mass of Standard Model particles requires a breaking of the symmetry, which in the majority of the models is achieved by adding soft breaking terms of the Lagrangian. Most of the benchmark points have been chosen in the the mSUGRA scenario, which has the benefit of a small number of parameters. Since phenomenology varies significantly through the parameter space, an approach based on studies of very general signatures has been chosen. It is therefore necessary to identify common aspects from different scenarios.
Once R-parity conservation is assumed the lightest SUSY particle (LSP) in the model has to be stable. A typical SUSY event, therefore, involves a pair of sequential decays of SUSY particles,

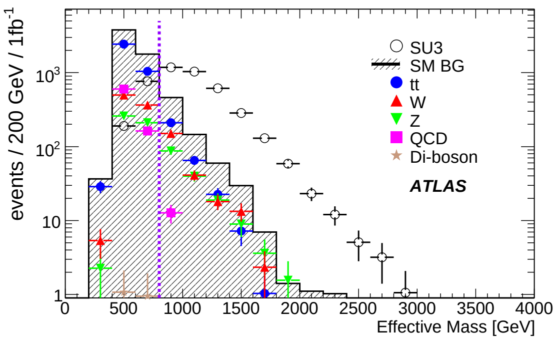

Figure 1: ATLAS: $M_{\rm eff}$ distribution for events surviving the selection cuts for the SU3 point and for various background contributions.

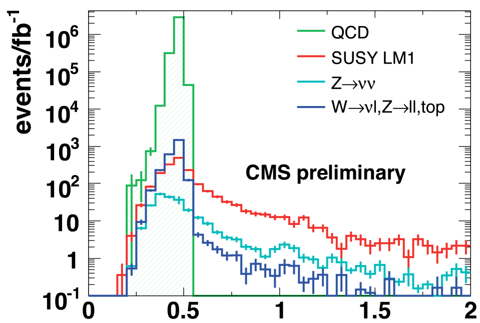

Figure 2: CMS: distribution of $\alpha_{\rm T}$ after all other selection cuts have been applied in the dijet events for different background events and exemplary for the point LM1.

finishing with the LSP, which is neutral and weekly interacting and escapes detection. The resulting large missing transverse momentum ($E_{\rm T}^{\rm Miss}$) signature is typical of such supersymmetric events.

At a hadron collider Supersymmetric particles are mainly produced by strong interaction, resulting in a large number of gluinos and squarks. Those particles decay in chains typically producing large multiplicity of high transverse energy jets. Moreover charginos and neutralinos can be present in the events, from either direct production or decay chains, and produce leptons in the cascades.

Hence a typical SUSY signature consist of $E_{\rm T}^{\rm Miss} + n$ jets ($+m$ leptons).

3 Background

In order to claim SUSY discovery the experiments must first have a good understanding of their detector. In particular the jet energy scale, any sources of fake $E_{\rm T}^{\rm Miss}$ and of mis-calibration have to be under control. Moreover the physics of the Standard Model at the appropriate center-of-mass energy should be well known. Since both of these aspects will be difficult to achieve in the early stage of the data taking, a background estimation from Monte Carlo cannot be relied on immediately, and need to be determined from the data. A common technique to do that is to identify a signal region, obtained by cut application, and a signal depleted region, indicated as control sample region. The latter is used to estimate the background level, that will be then extrapolated to the signal region. Dominant backgrounds for the SUSY events are expected to be from $t\bar{t}$, W+jets, Z+jets, jet production from QCD processes and diboson production.

4 Zero-lepton search

As an example of the described "inclusive" approach to SUSY search, the channel $E_{\rm T}^{\rm Miss} + n$ jets with no leptons is described, concerning both the event selection and the background estimation for both ATLAS and CMS.

4.1 ATLAS and CMS event selection

The zero-lepton channel is one of the most powerful and least model dependent signatures. One of the event selections for the channel with no leptons in ATLAS [3] is based on the selection of 4 high $p_{\rm T}$ jets in the central region, the most energetic of which has transverse momentum

$p_{\rm T} > 100$ GeV, a large missing transverse energy $E_{\rm T}^{\rm Miss} > 100$ GeV, with $E_{\rm T}^{\rm Miss} > 0.2\ M_{\rm eff}$[a] and with azimuthal angle difference $\Delta\phi(j, E_{\rm T}^{\rm Miss}) > 0.2$, $M_{\rm eff} > 800$ GeV ; a veto of events with an identified lepton with $p_{\rm T} > 20$ GeV and a transverse sphericity > 0.2 (Fig. 1) are also included. The CMS experiment will look for dijets events [4] generated by the process $\tilde{q}\tilde{q} \rightarrow (q\tilde{\chi}_1^0)(q\tilde{\chi}_1^0)$ which requires gluinos heavier than squarks. The event selection requires two high $p_{\rm T}$, well identified jets in the central region and a veto on additional jets with $p_{\rm T} > 50$ GeV. The angle between the jets and the $E_{\rm T}^{\rm Miss}$ - calculated using the two jets - should be less than 0.3. Also a lepton veto is included in the selection. The analysis requires $H_{\rm T} > 500$ GeV, with $H_{\rm T}$ the scalar sum of the 2 leading jets, and $\alpha_{\rm T} > 0.55$ where $\alpha_{\rm T} = (E_{\rm T}^{\rm j2})/(M_{\rm inv}^{\rm T}(j_1, j_2))$ (Fig. 2) Simulation shows that this selection is powerful in suppressing the background from QCD dijet events, which is several orders of magnitude larger than SUSY signal. It does not make explicit use of a calorimeter-based measurement of $E_{\rm T}^{\rm Miss}$.

4.2 Background estimation in zero-lepton signature

Backgrounds from QCD include both fake $E_{\rm T}^{\rm Miss}$ from instrumental effects and real $E_{\rm T}^{\rm Miss}$ from neutrinos produced in week decay chains. Due to its large cross section, the behaviour in the tails of the resolution functions is important and needs to be known to high precision. The rate and shape of these backgrounds are currently rather uncertain, therefore data driven estimations will be required. Such determinations also circumvent the problem of simulating unrealistically high numbers of QCD multijet events.

The estimation of the $Z \rightarrow \nu\nu +$ jets background from data cannot proceed through a direct measurement. The initial approach will be to select $Z \rightarrow ll$ events and to replace charged leptons with neutrinos. The control sample is selected with the same requirement as for zero-lepton SUSY search but requiring two additional electrons or muons in the event and defining the additional $E_{\rm T}^{\rm Miss}$ as $p_{\rm T}(l^+l^-) \sim p_{\rm T}(Z)$. Then, the numbers of background events will be estimated from the number of $Z \rightarrow l^+l^-$ events weighted with kinematical and fiducial corrections and the ratios of the branching fraction [3].

Beside the replacement technique the photon + jets and $W \rightarrow \mu\nu +$ jets events have also been studied [5]. The associated cross-sections are higher than for $Z \rightarrow \nu\nu +$jets, and they also provide useful cross-checks, since contamination of control sample may be different. The $E_{\rm T}^{\rm Miss}$ spectrum is obtained by removing identified photon or lepton and correcting for residual differences in these events. An example event selection requires $E_{\rm T}^{\rm Miss} > 200$ GeV and at least three jets in the central region with $E_{\rm T} > 30$ GeV, of which the leading jet should have $E_{\rm T} > 180$ GeV with $|\eta| < 1.7$ and the second leading jet $E_{\rm T} > 170$ GeV. A further cut requires $H_{\rm T} > 500$ GeV.

5 Discovery reach

In figures 3 and 4 the 5 σ reach contours for the multijet + $E_{\rm T}^{\rm Miss}$ + (n leptons) signatures for 1 fb^{-1} of integrated luminosity are shown for both ATLAS [3] and CMS [6] experiments, respectively. The expected uncertainties on background determination have been estimated by the ATLAS experiment to be 50% for the QCD backgrounds and 20% on $t\bar{t}$, W+jets and Z+jets backgrounds.

6 Measurements of supersymmetric particles

In order to establish that an observed signal is indeed due to SUSY, the new particles should be found to have spin quantum numbers differing by $\pm 1/2$ relative to their Standard Model partners,

[a]The effective mass is defined as the scalar sum of the four highest $p_{\rm T}$ of jets within $|\eta| < 2.5$, of the $p_{\rm T}$ of all identified leptons in the event and of the $E_{\rm T}^{\rm Miss}$.

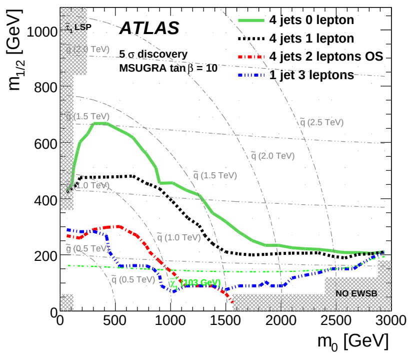

Figure 3: ATLAS: the 1 fb^{-1} 5 sigma reach contours for the 4-jet plus $E_T^{\rm Miss}$ analyses with various lepton requirements for mSUGRA as a function of the m_0 and $m_{1/2}$ parameters and for $\tan\beta = 10$.

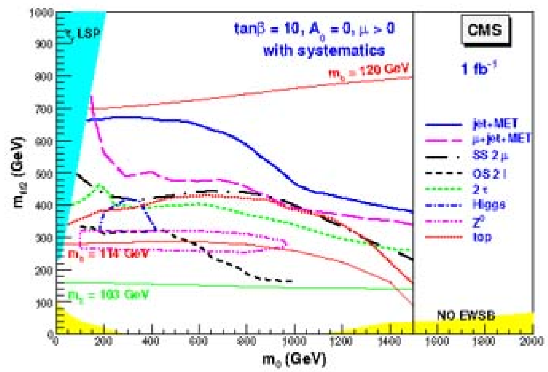

Figure 4: Region of m_0 versus $m_{1/2}$ plane showing the CMS 5-sigma reach when detector-related systematic uncertainties are included for 1 fb^{-1} integrated luminosity.

but the same gauge quantum number and couplings. In order to understand the Supersymmetry breaking mechanism, one would also like to understand the relationships between the particles' masses.

Since in R-parity conserved models the SUSY events contain two LSPs which escape the detector, a full mass peak reconstruction is not possible. Example techniques suggest employing kinematic constraints on long decay chains to relate kinematic features to known functions of the particle masses. Some details can be found in ATLAS [3] and CMS [7], [8] documents; other phenomenological studies can be found in the literature.

7 Conclusions

The discovery of SUSY at the LHC can be achieved with 1 fb^{-1} of integrated luminosity if the mass scale of the new strongly interacting particles is $\sim 1-2$ TeV. In fact the SUSY signatures are usually fairly clear, though good understanding of both the detector and the Standard Model background will be required. An inclusive search approach has been chosen by both ATLAS and CMS experiments, with a variety of signatures, the majority of which require many jets, missing transverse momentum and a specific number of charged leptons.

If a SUSY-like excess is found, subsequent work will be required to determine the detailed phenomenology, for example the mechanism of supersymmetry breaking. In order to do this more specific studies will be needed to determine model parameters.

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