PROCEEDINGS OF SCIENCE

Searches for SUSY with lepton, jets, and missing ET

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Soon after the LHC goes online, one of the primary topics for the CMS experiment will be the search for new phenomena like Supersymmetry (SUSY). If SUSY manifests itself at a low mass scale it might be found already in the early phase of the LHC. A generic signature for SUSY in pp-collisions is a large multiplicity of hard jets, high missing transverse energy ($\not{E}_T$), and possibly leptons in the final state. The CMS search strategy and prospects for SUSY discovery in the all-hadronic final states and in events including additional charged leptons are reviewed.

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1. Introduction

Supersymmetric extensions of the Standard Model (SM) predict a counter partner for each known SM particle, sharing the same quantum numbers except the spin which differs by half a unit. For the presented studies a minimal supergravity model (mSUGRA) with conserved R-parity is used, which leaves five model parameters: the universal soft breaking mass parameter for all scalars at the unification scale, m_0; the common gaugino mass, $m_{1/2}$; a universal trilinear coupling, A_0; the ratio of the vacuum expectation values of the two neutral Higgs fields, $\tan\beta$; and the sign of the higgsino mixing mass parameter, $sgn(\mu)$.

At the LHC the production of sparticles is dominated by squarks and gluinos (current collider limits: $m_{\tilde{g}}, m_{\tilde{q}} > 300 - 400$ GeV), if they are not too heavy. Their cross section depends on the region within the mSUGRA parameter space (Figure 1) and is of the order of 10-100 pb for the low mass (LM) points. Typical SUSY events are characterized by large missing transverse energy (the lightest SUSY particles escape undetected), several hard jets emerging from the long decay chains, and possibly additional leptons. Thus, the expected dominant SM backgrounds consist of heavy bosons, top-pairs, di-bosons accompanied by hard jets, and multi-jet production (QCD). The Monte Carlo samples used, have been simulated with the full CMS detector simulation assuming a centre of mass energy of 14 TeV and a suitable alignment/calibration scenario.

2. All-Hadronic Searches

Given the branching ratios of the sparticles produced at the LHC, hadronic final states are preferred and are expected to result in the largest discovery range. However these events are also challenging since they require a good understanding of the detector and the SM backgrounds such as multi-jet production.

The inclusive all-hadronic search [1] requires a missing transverse energy $\not{E}_T > 200$ GeV and at least 3 jets within $|\eta| < 1.7/3/3$ and a transverse energy of $E_T > 180/110/30$ GeV, respectively. In addition the scalar sum of the missing transverse energy and the transverse energy of the

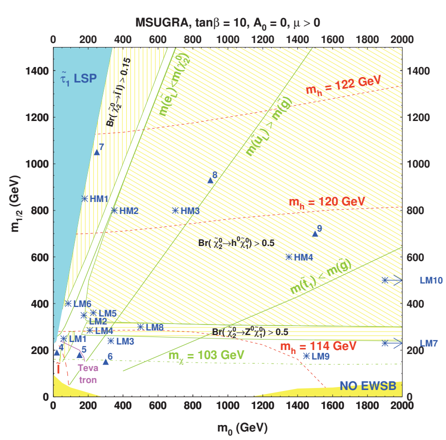

Figure 1: The CMS benchmark points within the mSUGRA m_0 versus $m_{1/2}$ plane.

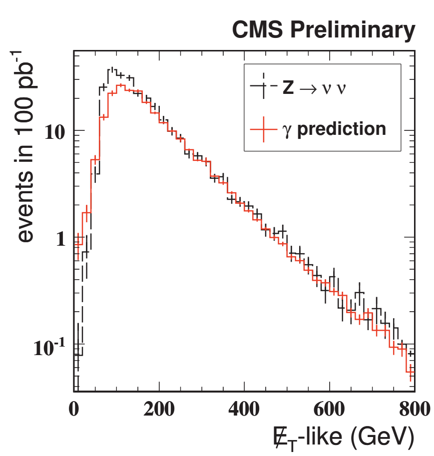

Figure 2: Utilizing γ+jet events the Z invisible background can be obtained in a data-driven way.

jets must exceed 500 GeV. An indirect lepton veto is applied to reject events with leptonic final states, but also cosmics and beam halo events. Further requirements of at least one primary vertex and a certain amount of electromagnetic energy and charged particle fraction in jets minimize the instrumental background. The initially dominant multi-jet background can be significantly reduced by topological cuts: QCD events do not contain genuine large missing transverse energy, but $\not\!\!E_T$ originating from mis-measured jets. Thus, in difference to SUSY events $\not\!\!E_T$ is expected to point along the direction of the hardest jets for QCD and are removed via an angular cut. About 13 % of the LM1 events survive the selection and lead to a signal/background ratio of $\sim$25. A discovery is expected with only 100 pb^{-1}, if the detector and the SM backgrounds (dominantly Z decaying invisibly and QCD) are understood.

3. Background Estimation from Data

For all SUSY searches the understanding of the SM backgrounds is a crucial prerequisite. The imperfect description of the MC generators require an estimation of those processes via data-driven methods. Various methods are currently explored within CMS:

For the leptonic channels isolation or identification variables can be relaxed or inverted. The resulting distribution should have the same shape, but with enriched statistics. The correct normalization is determined by a suitable signal-free control region.

"ABCD"-Method: Given two uncorrelated variables which separate the phase space via orthogonal cuts in three background (A, B, D) and one signal-enriched (C) regions. Then the background within the signal enriched region can be calculated from the three other regions via $C = D \cdot B/A$ where A is the region "diagonal" to the signal region.

"Jet Smearing": This method is used for the estimation of $\not\!\!E_T$ created by mis-measured jets. Utilizing a data sample with a well-measured jet spectrum e.g. from γ+jets one can extrapolate the distribution with low $\not\!\!E_T$ to the high $\not\!\!E_T$ region. The crucial point is the determination of the smearing function used for the extrapolation either from MC or data.

A different approach [2] is followed in the all-hadronic search. Here the dominant background is Z decaying invisibly into neutrinos. As a "standard candle" $Z \to \mu\mu$ data are used replacing the muons by neutrinos. This method is quite straightforward, and leads to a background estimate with an uncertainty of 20% within 1 fb^{-1}. The uncertainty is completely statistically limited due to the fact that BR($Z \to \mu\mu$) $\approx$ 1/6 BR($Z \to \nu\nu$).

One can improve the estimate utilizing that all bosons with high transverse momentum have similar kinematics. So instead of Z's one can use W's decaying leptonically, where the $\not\!\!E_T$ can be estimated replacing the lepton by a neutrino, or photons where the complete transverse energy is used as $\not\!\!E_T$-estimate. The gain is given by the large cross section ($\sigma(Z+\geq 2$jets) $\approx$ 1/3 $\sigma(W+\geq 2$jets) $\approx$ 1.2 $\sigma(\gamma+\geq 2$jets)), but also the larger amount of final states usable for the estimate: 20% of the W's decay into e/μ, and for photons the entire cross section can be used. With an integrated luminosity of 100 pb^{-1} a very clean estimate from photon events can be derived (Figure 2).

4. A Robust Extension of the All-Hadronic Search

At the LHC start-up the precise measurement of $\not\!\!E_T$ is expected to be challenging. A robust extension of the all-hadronic analysis [3] not relying on calorimetric $\not{E}_T$ investigates squark pairs each decaying directly into a quark and the lightest SUSY particle (this requires $m_{\tilde{q}} < m_{\tilde{g}}$). The signal/background separation is performed via a new variable α proposed by Randall and Tucker-Smith: $\alpha = E_{T,jet2}/M_{jet1,jet2} = E_{T,jet2}/(E_{jet1}E_{jet2}(1-cos\theta)) > 0.55$. Events with exactly two jets with E_T above 50 GeV and $E_{T,jet1} + E_{T,jet2} > 500$ GeV and no leptons are selected. Acceptance and angular cuts similar to the all-hadronic search are performed to reduce detector backgrounds and multi-jet events with "fake" $\not{E}_T$. Since multi-jet events do not contain genuine $\not{E}_T$, α is at most 0.5 for those events. Thus, the QCD background can be drastically suppressed as shown in Figure 3. The dominant background are invisible decays of the Z, which can be estimated from data as discussed above. For the benchmark point LM1 the discovery is expected within $L_{int} = 100\text{pb}^{-1}$.

5. Searches Including Leptons

Final states containing isolated leptons provide a clean signature complementary to the hadronic searches due to the suppression of multi-jets with its large cross section.
An inclusive muon analysis [1] investigates events with at least one isolated muon with a $P_T >$ 30 GeV, at least three jets with $E_T > 440/440/50$ GeV within a certain pseudorapidity, and $\not{E}_T >$ 130 GeV. Further angular cuts between the jets and $\not{E}_T$ ensure genuine $\not{E}_T$. All cuts are optimized on $L_{int} = 10\ \text{fb}^{-1}$ via a genetic algorithm and lead to a selection of $\sim$300 LM1 events and $\sim$10 background events. The same sign di-muon analysis [1], which is also optimized by a genetic algorithm, restricts the background even further: single boson events are not expected to result in same sign leptons, and multi-jet events with two isolated leptons are very rare. Both analyses are suitable for an early SUSY discovery and cover a broad region in the $(m_0, m_{1/2})$-plane (Figure 6).

6. The Model-Independent Search MUSiC

A complementary strategy is followed in the MUSiC analysis [4]. Without any focus on a specific theoretical model it tries to spot differences between the SM MC and the CMS data in a

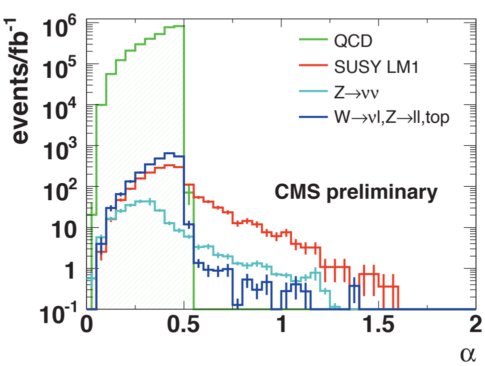

Figure 3: A good separation between signal (SUSY LM1) and background is possible via the new variable $\alpha > 0.55$.

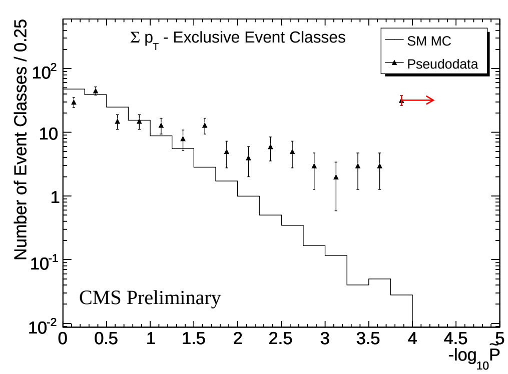

Figure 4: Distribution of the significance $\tilde{P}$ of all event classes for 1 fb^{-1}. The SM MC follows an expected distribution, while the pseudo-data including SUSY (LM4) show massive discrepancies.

systematic and automatized way in order not to miss any unexpected deviation. Events with at least one lepton (electron or muon) are sorted by their final state particle content (e, μ, γ, jet, $\not{E}_T$) into so called event classes (e.g. $1\mu 2e3jets$). Within each of the roughly 300 event classes, distributions expected to be sensitive to new physics like invariant masses or scalar sums of transverse momenta are compared to the data, and the region with the biggest discrepancy is evaluated, taking systematic uncertainties into account. At the CMS start-up this ansatz will help to detect MC shortcomings and spot detector effects, but it is also expected to be sensitive to new physics. If SUSY is realized in nature, a large amount of the event classes would show significant deviations (Figure 4).

7. Measurement of Sparticle Masses

The discovery of SUSY requires not only the detection of its signatures, but also the determination of its parameters. Due to the lightest supersymmetric particle emerging undetected from the detector, the direct measurements of e.g. masses via peaks is not possible. Instead shapes and endpoints need to be investigated. The decay $\tilde{\chi}_2^0 \rightarrow l^\pm l^\mp \tilde{\chi}_1^0$ provides a first constraint of the sparticles masses via the measurement of the endpoint of the opposite sign same flavour invariant lepton mass spectrum with an endpoint at $m_{ll}^{max} = m_{\tilde{\chi}_2^0}\sqrt{1-m_{\tilde{l}_R}^2/m_{\tilde{\chi}_2^0}^2}\sqrt{1-m_{\tilde{\chi}_1^0}^2/m_{\tilde{l}_R}^2}$. Suitable cuts and the data-driven estimation of $t\bar{t}$ and di-boson events via same sign different flavour di-lepton events leads for the benchmark point LM1 to the invariant mass distribution in Figure 5 (see [5]). An unbinned fit with 7 free parameters leads to a precise measurement of the endpoint with an uncertainty of less than 1 GeV.

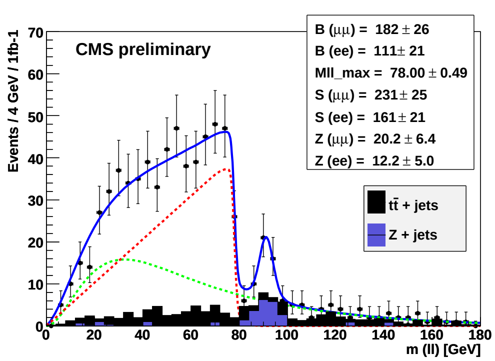

Figure 5: Simultaneous fit to the signal (red) and background (including SUSY, green) invariant di-lepton mass for the edge determination.

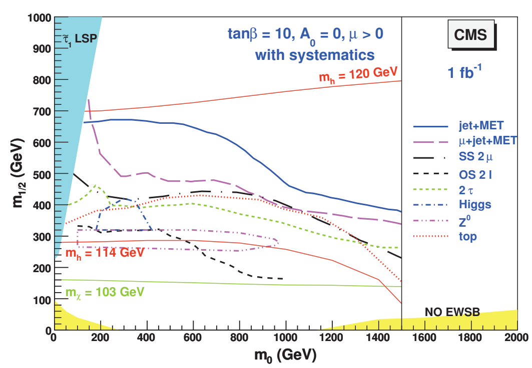

Figure 6: Discovery reach for the different CMS analyses within $L_{int} = 1\ \text{fb}^{-1}$.

References

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[2] The CMS Collaboration, CMS PAS SUS-08-002 (2008).

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