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Search for Supersymmetry at CMS in all-hadronic final states

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Abstract

Searches for Supersymmetry in final states with jets and missing transverse energy are presented. They were performed with data samples corresponding to up to 1.1 fb^{-1} of integrated luminosity collected by the CMS experiment at the LHC in pp -collisions at a center-of-mass energy of 7 TeV. No excess of events was observed above the expected Standard Model background, which has been measured using various data-driven techniques. Exclusion limits on the parameters of the constrained minimal supersymmetric extension to the Standard Model were derived.

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Search for Supersymmetry at CMS in All-Hadronic Final States

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Abstract. Searches for Supersymmetry in final states with jets and missing transverse energy are presented. They were performed with data samples corresponding to up to 1.1 fb^{-1} of integrated luminosity collected by the CMS experiment at the LHC in pp -collisions at a center-of-mass energy of 7 TeV. No excess of events was observed above the expected Standard Model background, which has been measured using various data-driven techniques. Exclusion limits on the parameters of the constrained minimal supersymmetric extension to the Standard Model were derived.

Keywords: cms, supersymmetry, jets, missing momentum, hadronic final states

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Supersymmetry (SUSY) [1] is a promising theory addressing various shortcomings of the Standard Model (SM) of particle physics. At the Large Hadron Collider (LHC) at CERN, SUSY particles can be produced, predominantly via the strong interaction. Due to their high masses, they subsequently decay in cascades into SM particles with large momenta. In case R-parity is conserved, SUSY particles will be produced in pairs and the lightest SUSY particle will be stable. If only weakly interacting, it can not be detected directly but will result in missing transverse energy ($\cancel{E}_T$).

In the following, searches conducted by the CMS experiment [2] in all-hadronic final states are discussed, which are characterized by several high- p_T jets, large $\cancel{E}_T$, and no isolated leptons. This channel has the largest branching ratio but at the same time faces a huge background from SM processes with the same signature, such as $Z \rightarrow \nu\bar{\nu}$ +jets events as well as $t\bar{t}$ +jets and W +jets events, where the W either decays into light leptons which are not identified or into hadronically decaying τ leptons. In those cases, genuine $\cancel{E}_T$ is caused by neutrinos. A different major background arises from QCD multi-jet events where one or more jets are severely mismeasured because of leptonically decaying heavy flavor hadrons inside the jet or instrumental effects.

Several complementary analyses are performed, all of which employ data-driven techniques to predict the SM background with minimal dependence on the Monte Carlo (MC) simulation. The inclusive, model-independent search with jets and missing momentum [3] aims at a detailed understanding of the different background contributions, while both the razor [4] and the α_T analysis [5] use kinematic variables to identify events originating in decays of pair-produced heavy particles. The first two searches were conducted as cut-and-count experiments on the data collected in 2010 corresponding to an integrated luminosity of 36 pb^{-1} ; the α_T analysis was performed as a shape analysis on a data set of 1.1 fb^{-1} collected in 2011. Further analyses are presented in [6].

JETS AND MISSING MOMENTUM ANALYSIS

The strategy of this analysis is to precisely understand the different SM backgrounds in order to be most inclusive w. r. t. new physics resulting in all-hadronic like final states. The central observables are H_T , the scalar sum of the jet transverse momenta, and $\cancel{H}_T$, the magnitude of the negative vectorial sum of jet transverse momenta. The event selection starts from a baseline region requiring at least three jets with $p_T > 50 \text{ GeV}$ and $|\eta| < 2.5$, $H_T > 300 \text{ GeV}$, $\cancel{H}_T > 150 \text{ GeV}$, and no isolated leptons. Additionally, the $\cancel{H}_T$ is to be non-aligned with any of the leading jets to suppress QCD. Two search regions were defined by tightening the baseline selection requirements in order to increase the sensitivity for different SUSY models: a high- $\cancel{H}_T$ region at $\cancel{H}_T > 250 \text{ GeV}$ and a high- H_T region at $H_T > 500$.

The QCD background contribution was estimated from a sample of inclusive multi-jet data using the “rebalance+smear” method: an estimator of the particle level $\cancel{H}_T$ distribution is obtained by rebalancing the jet momenta in each event, taking into account the jet p_T resolution. Finally the rebalanced momenta are smeared by the full jet p_T response distribution to predict the multi-jet kinematics. The jet response distribution was taken from the MC simulation and adjusted to the data by factors obtained from photon+jet and di-jet data [7]. Background contributions from

$t\bar{t}$ and W +jets events were estimated from a muon+jets control sample: The number of events with a lost lepton was predicted by scaling the control sample with the lepton reconstruction and identification efficiencies as well as acceptance factors, and the number of events with hadronically decaying tau leptons by replacing the muon by a simulated jet using a tau response template. The $Z \rightarrow \nu\bar{\nu}$ background contribution was estimated from a photon+jets control sample, where the photon was ignored to model the impact of the neutrinos and corrected by the ratio of photon+jets and Z +jets distributions as predicted by the theory [8]. In the high- H_T region, 40 events have been observed and 15 in the high- $\cancel{E}_T$ region, which is compatible with the SM expectations of 43.8 ± 9.2 and 18.8 ± 3.5 , respectively.

RAZOR ANALYSIS

This analysis aims at a kinematic identification of events with pair-produced, heavy particles. Hence, two or more jets were required for the baseline selection, and they were combined into two “mega-jets” using an event hemisphere algorithm in order to approximate the visible part of the decay products.

FIGURE 1. Left: M_R distribution for $R > 0.5$ in data (circles) compared to the SM backgrounds predicted from data (solid lines) and two SUSY benchmark scenarios (dashed lines) [4]. Right: α_T distribution measured in data (circles) and expected from the MC simulation for the SM backgrounds (solid lines) and two SUSY benchmark scenarios (dashed lines) [5].

In each event, the kinematic variables R (“razor”) and M_R are computed from the energies and momenta of the “mega-jets” as well as the $\cancel{E}_T$. For signal events, R is expected to peak at ≈ 0.5 and M_R at a characteristic scale, which depends on the mass difference of the initial heavy particle and the invisible part of the decay products. In contrast, SM events, in particular QCD events, feature lower values of R and M_R [10]. Above a certain value that depends mostly on the trigger efficiencies, the M_R distribution of QCD multi-jet events with $R < R_{max}$ drops exponentially, as shown in Fig. 1 (left). The slope of the exponential function was found to be proportional to R_{max}^2 , which is the key property exploited in the background prediction: the slopes for low R_{max} were fitted with a linear function of R_{max}^2 and extrapolated into the search region, defined as $R > 0.5$, $M_R > 500$ GeV. The overall normalization was obtained by fitting the predicted M_R distribution to the data in a control region with $80 < M_R < 400$ GeV. The other SM backgrounds were estimated similarly. Seven events were observed in the search region, in agreement with the SM expectation of 5.5 ± 1.4 .

α_T ANALYSIS

In this analysis, the QCD multi-jet background is strongly reduced using the kinematic variable α_T [9] as a discriminator between events with real and fake $\cancel{E}_T$. Again, two pseudo-jets were constructed in each event from all jets with $E_T > 50$ GeV and $|\eta| < 3$, and α_T is computed from their energies and momenta. In case of QCD multi-jet events, where the transverse jet momenta balance, α_T is expected to be < 0.5 while it can have larger values for processes with genuine $\cancel{E}_T$, as shown in Fig. 1 (right). Therefore, the search region is defined as $\alpha_T > 0.55$.

The residual QCD contribution and the other SM backgrounds in the search region were predicted by scaling the yields for $\alpha_T < 0.55$ in different control samples by R_{α_T} , the ratio of the number of events with $\alpha_T > 0.55$ and

$\alpha_T < 0.55$. In case of QCD multi-jet events, where $\cancel{E}_T$ is caused by jet mismeasurements, R_{α_T} is expected to fall with increasing H_T because the jet p_T resolution improves with H_T . However, no dependence of R_{α_T} on H_T has been observed in data. This is expected for events with real $\cancel{E}_T$, demonstrating the QCD depletion in the search region. Hence, R_{α_T} was modeled exponentially falling with H_T for the QCD contribution and constant for the other SM processes. The final background prediction was obtained by a maximum-likelihood fit of the expected background yields in each H_T bin to the data. A muon+jets sample was used as control sample for the $t\bar{t}$ and W +jets contributions, a photon+jets sample for the Z +jets contribution, and the QCD contribution was estimated from a multi-jet sample collected without requirements on $\cancel{E}_T$ at trigger level. Good agreement between the measured yields and the best fit was found with a p -value of 0.56, indicating an appropriate parametrization of R_{α_T} and compatibility of number of events observed in data with the SM expectation.

RESULTS AND CONCLUSIONS

Complementary searches for SUSY in the all-hadronic final states have been performed by CMS. The observed event yields are consistent with the SM background expectations, which have been predicted from data. Consequently, limits have been set on the parameters of the constrained minimal supersymmetric extension to the SM (CMSSM). They are shown in Fig. 2. The CMS searches exceed the sensitivity of previous collider experiments already with the 36 pb^{-1} of data collected in 2010; with 1.1 fb^{-1} , squark masses lower than 1.1 TeV are excluded at the 95% confidence level.

FIGURE 2. Exclusion limits in the $m_0 - m_{1/2}$ parameter space of the CMSSM at the 95% confidence level. Left: observed limits of the 2010 analyses [6]. Right: observed (solid and dashed lines) and expected (dotted line) limits of the 2011 α_T analysis [5]. Regions excluded by previous collider experiments are shown for comparison.

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