Search for supersymmetry in final states with missing transverse energy and 0, 1, 2, or ≥3 b jets in 8 TeV pp collisions

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Abstract

A search for supersymmetry in the jets and missing transverse energy final state is performed in pp collisions at a centre of mass energy of at $\sqrt{s} = 8$ TeV. The data sample corresponds to an integrated luminosity of 3.9 fb$^{-1}$ collected by the CMS experiment at the LHC. In this search, a kinematic variable, $\alpha_T$, is used as the main discriminator between events with genuine and misreconstructed missing transverse energy. The search is performed in a signal region that is binned in the scalar sum of the transverse energy of jets and the number of jets identified to originate from a bottom quark. No excess of events over the standard model expectation is found. Exclusion limits are set in a simplified model of gluino pair production and decay to a final state of two top-antitop quark pairs and two neutralinos.
1 Introduction

Supersymmetry (SUSY) is generally regarded as one of the most likely extensions to the Standard Model of particle physics (SM) [1–8]. It is a well-established theory based on the unique extension of the space-time symmetry group underpinning the SM, introducing a relationship between fermions and bosons. If the multiplicative quantum number R-parity is conserved [9], SUSY particles such as squarks and gluinos are produced in pairs and decay to the lightest SUSY particle (LSP), which is generally assumed to be a weakly interacting massive particle. Hence, a typical final-state signature is rich in jets and contains a significant amount of missing transverse energy \( (E_T) \).

The search described below is therefore designed to be sensitive to missing transverse energy signatures in events with two or more energetic jets. These events are categorised according to the number of reconstructed jets originating from bottom quarks (b jets) per event. This approach improves the sensitivity to third-generation squark signatures while maintaining the ability to identify a wide variety of SUSY event topologies, which arise from the main production mechanisms of massive coloured sparticles at the LHC, namely squark-squark, squark-gluino and gluino-gluino pairs. This analysis follows closely that described in Ref. [10], which is in turn based on previous inclusive searches [11, 12]. The results presented here are based on a data sample of pp collisions collected in 2012 at a centre-of-mass energy of 8 TeV, which corresponds to an integrated luminosity of 3.9 fb\(^{-1}\).

In 2010 and 2011 the CMS and ATLAS experiments performed various searches [11–19] for the production of massive coloured sparticles and their subsequent decay to a final state of jets and missing transverse energy. These searches were performed with a dataset of pp collisions at \( \sqrt{s} = 7 \) TeV, and no significant deviations from SM expectations were observed. The majority of these searches were interpreted in the context of a specific model of SUSY-breaking, the constrained minimal supersymmetric extension of the standard model (CMSSM) [20–22]. The simplifying assumption of universality at an energy scale of \( \mathcal{O}(10^{16}) \) GeV makes the CMSSM a useful framework to study SUSY phenomenology at colliders, and to benchmark the performance of experimental searches. However, these universality conditions result in significant restrictions on the possible SUSY particle mass spectra. For example, the CMSSM prevents the realisation of compressed mass spectra, where the mass difference between the initially produced squark or gluino and the LSP is small.

Alternatively, simplified models [23–26] can be used to interpret the search results presented below. Each model is characterised by a single production and decay mode involving a limited set of SUSY and SM particles. These models allow comprehensive studies of individual SUSY event topologies, which are performed in a two-dimensional parameter space of different sparticle masses and mass splittings. One such simplified model is used to interpret the result presented below, which is gluino pair production and decay to a final state of two top-antitop quark pairs and two neutralinos.

2 The CMS apparatus

The central feature of the CMS detector is a superconducting solenoid, which provides an axial magnetic field of 3.8 T. The bore of the solenoid is instrumented with several particle detection systems. Silicon pixel and strip tracking systems measure charged particle trajectories with full azimuthal (\( \phi \)) coverage and a pseudorapidity acceptance of \( |\eta| < 2.5 \), where \( \eta = -\ln[\tan(\theta/2)] \) and \( \theta \) is the polar angle with respect to the counterclockwise beam direction. The resolutions on the transverse momentum and impact parameter of a charged particle with \( p_T < 40 \text{GeV} \)
Selection of multi-jet events with missing transverse energy

The offline selection criteria and event reconstruction follows the procedure described in [11, 12]. Jets are reconstructed from energy deposits in the calorimeter towers, clustered by the anti-

\( k_T \) algorithm [28] with a size parameter of 0.5. The raw jet energies measured by the calorimeter systems are corrected to remove the effects of overlapping pp collisions (pile-up) [29, 30], and to establish a uniform relative response in \( \eta \) and a calibrated absolute response in transverse momentum \( p_T \) [31]. Jets considered in the analysis are generally required to have transverse energy \( E_T > 50 \text{ GeV} \). Events are vetoed if any additional jet satisfies both \( E_T > 50 \text{ GeV} \) and \( |\eta| > 3 \), or rare, spurious signals are identified in the calorimeters [32, 33]. The highest-\( E_T \) jet is required to be within the central tracker acceptance (\( |\eta| < 2.5 \)) and the two highest-\( E_T \) jets must each have \( E_T > 100 \text{ GeV} \). To suppress SM processes with genuine \( E_T \) from neutrinos, events containing an isolated electron [34] or muon [35] with \( p_T > 10 \text{ GeV} \) are vetoed. To select a pure multi-jet topology, events are vetoed in which an isolated photon [36] with \( p_T > 25 \text{ GeV} \) is found.

The presence of a b jet is identified through a vertex that is displaced with respect to the primary interaction, using the combined secondary vertex algorithm [37] which incorporates several variables related to the vertex to build a discriminator between jets originating from bottom quarks and other sources. These include jets from c quarks and light-flavour quarks. Discriminator values above a certain threshold are used to tag jets as reconstructed b jets. This threshold is chosen such that the mis-tagging rate, i.e. the probability to tag jets originating from light-flavour quarks as b jets, is approximately 1% for jets with a transverse momenta of 100 GeV [37, 38]. This typically results in a b tagging efficiency, i.e. the probability to correctly tag jets originating from b quarks, in the range 60 – 70% [37, 38].

The following two variables characterize the visible energy and missing momentum in the transverse plane: the scalar sum of the transverse energy \( H_T \) of jets, defined as \( H_T = \sum_{i=1}^{N_{\text{jet}}} E_T \), and the magnitude of the vector sum of the transverse momenta \( \vec{p}_T \) of jets, defined as \( H_{\vec{p}_T} = \left| \sum_{i=1}^{N_{\text{jet}}} \vec{p}_T \right| \), where \( N_{\text{jet}} \) is the number of jets with \( E_T > 50 \text{ GeV} \). Significant hadronic activity in the event is ensured by requiring \( H_T > 275 \text{ GeV} \). Following these selections, the background from multi-jet production, a manifestation of quantum chromodynamics (QCD), is still several orders of magnitude larger than the typical signal expected from SUSY.

Selection of multi-jet events with missing transverse energy

The \( \alpha_T \) kinematic variable, first introduced in Refs. [39–41], is used in the selection of multi-jet events to efficiently reject events either without significant \( E_T \) or with transverse energy mis-measurements, whilst retaining a large sensitivity to new physics with genuine \( E_T \) signatures.

is typically 1% and 15 \( \mu \)m, respectively. A lead tungstate crystal electromagnetic calorimeter (ECAL) and a brass/scintillator hadron calorimeter surround the tracking volume. The forward region is covered by an iron/quartz-fiber hadron calorimeter. The ECAL covers \( |\eta| < 3.0 \) and provides an energy resolution of better than 0.5% for unconverted photons with transverse energies above 100 GeV. The hadron calorimeters cover \( |\eta| < 5.0 \) with a resolution in jet energy, \( E \) (GeV), of about 100%/\( \sqrt{E} \). Muons are identified in gas-ionization detectors, covering \( |\eta| < 2.4 \), embedded in the steel return yoke. The CMS detector is nearly hermetic, which allows for momentum-balance measurements in the plane transverse to the beam axis. A detailed description of the CMS detector can be found elsewhere [27].
For dijet events, the $\alpha_T$ variable is defined as:

$$\alpha_T = \frac{E_T^{1z}}{M_T}, \quad M_T = \sqrt{\left(\sum_{i=1}^{2}E_T^{i}\right)^2 - \left(\sum_{i=1}^{2}p_x^{i}\right)^2 - \left(\sum_{i=1}^{2}p_y^{i}\right)^2}.$$ (1)

where $E_T^{1z}$ is the transverse energy of the least energetic jet of the two, and $M_T$ is the transverse mass of the dijet system. For a perfectly measured dijet event with $E_T^{1z} = E_T^{2z}$ and jets back-to-back in $\phi$, and in the limit of large jet momenta compared to their masses, the value of $\alpha_T$ is 0.5. In the case of an imbalance in the measured transverse energies of back-to-back jets, $\alpha_T$ is smaller than 0.5. Values significantly greater than 0.5 are observed when the two jets are not back-to-back, recoiling against genuine $E_T$.

For events with three or more jets, an equivalent dijet system is formed by combining the jets in the event into two pseudo-jets. The $E_T$ of each of the two pseudo-jets is calculated as the scalar sum of the measured $E_T$ of the contributing jets. The combination chosen is the one that minimizes the $E_T$ difference ($\Delta H_T$) between the two pseudo-jets. This simple clustering criterion provides the best separation between multi-jet events and events with genuine $E_T$.

Events with extremely rare but large stochastic fluctuations in calorimetric measurements of jet energies can lead to values of $\alpha_T$ slightly above 0.5. Such events are rejected by requiring $\alpha_T > 0.55$. A similar behaviour is observed in events with reconstruction failures, severe energy losses due to detector inefficiencies, or jets below the $E_T$ threshold that result in significant $H_T$ relative to the value of $E_T$ (as measured by the calorimeter systems, which is not affected by jet $E_T$ thresholds). These classes of events are rejected by applying dedicated vetoes, described further in Ref. [12]. The leakage above 0.5 becomes smaller with increasing $H_T$. This is due in part to increasing average jet energy and thus improving jet energy resolution. Further, the relative impact of jets falling below the $E_T$ threshold is reduced as the scale of the event (i.e. $H_T$) increases.

The signal region is defined by $H_T > 275$ GeV and $\alpha_T > 0.55$, which is divided into eight bins in $H_T$: two bins of width 50 GeV in the range $275 < H_T < 325$ GeV, five bins of width 100 GeV in the range $375 < H_T < 875$ GeV, and a final open bin, $H_T > 875$ GeV. As in Ref. [12], the jet $E_T$ threshold is scaled down to 37 GeV and 43 GeV for the regions $275 < H_T < 325$ GeV and $325 < H_T < 875$ GeV, respectively. The highest-$E_T$ jet threshold is also scaled accordingly. This is done in order to maintain a background composition and event kinematics similar to those observed for the higher $H_T$ bins. Candidate events are further categorised according to whether they contain exactly zero, one, two, or at least three reconstructed b jets.

Events in the signal sample are recorded with multiple trigger conditions that must satisfy requirements on both $H_T$ and $\alpha_T$ in the range ($H_T > 250$ GeV and $\alpha_T > 0.55$) to ($H_T > 400$ GeV and $\alpha_T > 0.51$). The trigger efficiency is defined as the probability with which events that satisfy the signal sample selection criteria also satisfy the trigger conditions, which is measured from data to be $89.6 \pm 0.6$ % and at least $98.5 \pm 0.5$ % for the regions $275 < H_T < 325$ GeV and $H_T > 325$ GeV, respectively.

A disjoint hadronic control sample consisting predominantly of multi-jet events is defined by inverting the $\alpha_T$ requirement for a given $H_T$ region, which is used primarily in the estimation of any residual background from multi-jet events. These events are recorded by a set of $H_T$ trigger conditions.
5 Background estimation from data

Once all selection requirements have been imposed, the contribution from multi-jet events is expected to be negligible. The remaining significant backgrounds in the hadronic signal region stem from SM processes with genuine $E_T$ in the final state. In the case of events where no $b$ jets are identified, the largest backgrounds with genuine $E_T$ arise from the production of $W$ and $Z$ bosons in association with jets. The weak decay $Z \rightarrow \nu \nu$ is the only relevant contribution from $Z + \text{jets}$ events. For $W + \text{jets}$ events, the two relevant sources are leptonic $W$ decays, in which the lepton is not reconstructed or fails the isolation or acceptance requirements, and the weak decay $W \rightarrow \tau \nu$ where the $\tau$ decays hadronically and is identified as a jet. For events with one or more reconstructed $b$ jets however, top quark production followed by semi-leptonic weak decays becomes the most important single background source. For events with only one reconstructed $b$ jet, the contribution of both $W + \text{jets}$ and $Z + \text{jets}$ backgrounds are of a similar size to the top background. For events with two reconstructed $b$ jets, $t \bar{t}$ production dominates, whilst events with three or more reconstructed $b$ jets originate almost exclusively from $t \bar{t}$ events, in which one or several jets are misidentified as $b$ jets.

In order to estimate the contributions from each of these backgrounds, three data control samples are used, which are binned in the same way as the signal sample. A $\mu + \text{jets}$ data sample provides an estimate of the contributions from top quark and $W$ production leading to $W + \text{jets}$ final states. The remaining irreducible background of $Z \rightarrow \nu \nu + \text{jets}$ events in the hadronic signal region is estimated from both a data sample of $Z \rightarrow \mu\mu + \text{jets}$ and $\gamma + \text{jets}$ events, which share kinematic properties but have different acceptances. The $Z \rightarrow \mu\mu + \text{jets}$ events have identical kinematic properties when the two muons are ignored, but a smaller branching ratio, while the $\gamma + \text{jets}$ events have similar kinematic properties when the photon is ignored [42, 43], but a larger production cross section. The event selection criteria for the control samples are defined to ensure that any potential contamination from multi-jet events is negligible. Further, the selection also suppress signal contamination from a wide variety of SUSY models, including those considered in this analysis, to a negligible level.

5.1 Definition of data control samples

The $\mu + \text{jets}$ sample is recorded using a trigger strategy which requires an isolated muon above a $p_T$ threshold of 24 GeV and within $|\eta| < 2.1$. The event selection requires exactly one isolated muon that satisfies stringent quality criteria, with $p_T > 30$ GeV and $|\eta| < 2.1$, in order for the trigger to be maximally efficient, around $88.0 \pm 2.0\%$. The transverse mass of the muon and $E_T$ system must be larger than 30 GeV to ensure a sample rich in $W$ bosons. The muon is required to be separated from the closest jet in the event by $\Delta \eta$ and $\Delta \phi$ such that the distance $\Delta R \equiv \sqrt{\Delta \eta^2 + \Delta \phi^2} > 0.5$. Further, the event is rejected if a second muon candidate is identified that does not satisfy all quality criteria or is outside acceptance, and the two muon candidates have an invariant mass that is within a window of $\pm 25$ GeV around the mass of the $Z$ boson. The requirement $\alpha_T > 0.55$ is imposed when zero $b$ jets are reconstructed per event; for all other event categories, in which at least one $b$ jet is reconstructed, no $\alpha_T$ requirement is used [10].

The $\mu\mu + \text{jets}$ sample follows the same trigger strategy and muon identification criteria as the $\mu + \text{jets}$ sample, except that in the event selection criteria, the threshold for the muon with the lower $p_T$ is 10 GeV. This leads to a trigger efficiency of $95 \pm 2\%$ rising to $98 \pm 2\%$ with increasing $H_T$. The event selection requires exactly two oppositely charged, isolated muons satisfying stringent quality criteria, and an invariant mass within a window of $\pm 25$ GeV around the mass of the $Z$ boson. Both muons are required to be separated from their closest jets in the event by
The $\gamma + \text{jets}$ sample is selected using a dedicated photon trigger condition requiring a localized, large energy deposit in the ECAL with $E_T > 150$ GeV that satisfies loose photon identification and isolation criteria [36]. The offline selection requires $H_T > 375$ GeV, $\alpha_T > 0.55$, and a single photon to be reconstructed with $E_T > 165$ GeV, $|\eta| < 1.45$, satisfying tight isolation criteria, and with a minimum distance to any jet of $\Delta R > 1.0$. For these selection criteria, the photon trigger condition is found to be fully efficient.

5.2 Method for estimating genuine $E_T$ background

The method used to estimate the background contributions in the hadronic signal region relies on the use of translation factors, which are constructed per bin in the two dimensions of $H_T$ and number of reconstructed $b$ jets per event, $n_{b\text{reco}}$. Each factor, determined from simulation, is defined as the ratio of yields in a given bin of the hadronic signal sample ($N_{\text{MCsignal}}$) and corresponding bin of the control sample ($N_{\text{MCcontrol}}$). The factors are used to translate the observed yield measured in a control sample bin ($N_{\text{controlobs}}$) into an expectation for the yield in the corresponding bin of the hadronic signal sample ($N_{\text{signalpred}}$):

$$N_{\text{signalpred}}(H_T, n_{b\text{reco}}) = N_{\text{controlobs}}(H_T, n_{b\text{reco}}) \times \frac{N_{\text{MCsignal}}}{N_{\text{MCcontrol}}}(H_T, n_{b\text{reco}}).$$

(2)

The number of reconstructed $b$ jets per event ($n_{b\text{reco}}$) is estimated from a method based on truth-level information contained in the simulation, namely: the numbers of jets originating from underlying $b$ quarks, $n_b$, and from light quarks, $n_q$, per event. All relevant combinations of $n_b$ and $n_q$ are considered, and event counts are recorded in bins of $H_T$ for each combination, $N(n_b, n_q)$. The $b$ tagging efficiency, $\epsilon$, and a flavour-averaged mistagging rate, $m$, are measured also from simulation for each $H_T$ bin, with both quantities averaged over jet $p_T$ and $\eta$. Corrections are applied to both $\epsilon$ and $m$ in order to match the corresponding measurements with data [37, 38]. The aforementioned information is sufficient to determine an accurate prediction for $n_{b\text{reco}}$. For example, an estimate for the number of events with zero reconstructed $b$ jets is given by the expression:

$$n_{0\text{reco}} = \sum_{n_b \geq 0, n_q \geq 0} N(n_b, n_q) \times (1 - \epsilon)^{n_b} \times (1 - m)^{n_q}$$

(3)

A similar treatment is used for the other $b$ jet multiplicity categories. The yields from simulation, binned according to $H_T$ and $n_{b\text{reco}}$ as determined with the method described above, are found to be in good agreement with the yields obtained directly from the simulation. The method exploits the ability to make precise measurements of $N(n_b, n_q)$, $\epsilon$ and particularly $m$, which means that predicted event yields for a given $b$ jet category can be made with a higher statistical precision than obtained directly from simulation. This is particularly important for events with $n_{b\text{reco}} \geq 3$, which requires the presence of mistagged jets in the event. In this case, the most probable (albeit small) background is $t\bar{t}$, with two correctly tagged $b$ jets and an additional mistagged jet.

Any mismodelling in the simulation of the event kinematics or instrumental effects observed in data are expected to largely cancel in the ratio of yields used to construct the translation factors, given that the data control and signal samples, and the corresponding event samples from simulation, are defined to be kinematically similar. However, a systematic uncertainty
Background estimation from data is assigned to each translation factor to account for theoretical uncertainties [43] and residual biases in the simulation modelling [11]. The magnitudes of the systematic uncertainties are determined from a representative set of closure tests in data, in which yields from one of the three independent control samples, along with the corresponding translation factors obtained from simulation, are used to predict the yields in another control sample, following the same prescription defined in Equation 2. The contamination from multi-jet events and any potential signal is expected to be negligible. Therefore, the closure tests carried out between control samples probe the properties of the relevant SM backgrounds.

A set of five closure tests, which probe key ingredients of the simulation modelling that may introduce biases to the translation factors, and the $H_T$-dependent systematic uncertainties are shown in Fig. 1. The first three closure tests are carried out within the $\mu + \text{jets}$ sample, and probe the modelling of the $\alpha_T$ distribution in genuine $E_T$ events (circles), the relative composition between $W + \text{jets}$ and top events (squares), and the modelling of the reconstruction of $b$ jets (triangles), respectively. The fourth test (crosses), connecting the $\mu + \text{jets}$ and $\mu\mu + \text{jets}$ control samples, addresses the modelling of the relative contributions of $Z + \text{jets}$ to $W + \text{jets}$ and top events while the fifth test (stars) deals with the consistency between the $Z \rightarrow \mu\mu + \text{jets}$ and $\gamma + \text{jets}$ samples.

All individual closure tests demonstrate, within the statistical precision of each test, that there are no significant biases inherent in the translation factors obtained from simulation. The level of closure achieved in these tests is used to determine systematic uncertainties that are assigned to the translation factors. For each of the three regions $275 < H_T < 575\,\text{GeV}$, $575 < H_T < 775\,\text{GeV}$ and $H_T > 775\,\text{GeV}$, the systematic uncertainties are defined such that at least 90% of the closure test points in each $H_T$ region are covered. This conservative procedure yields values of 20%, 30% and 70% for the three $H_T$ regions defined above. Uncertainties related to the modelling of $b$ jets in simulation are found to be negligible in comparison to the aforementioned uncertainties after corrections are applied to the efficiency and mis-tagging rates of $b$ jets obtained from simulation, in order to account for residual differences with respect to measurements in data.
6 Results and interpretation

A binned likelihood fit using all four data samples is carried out to obtain a consistent prediction of the SM background:

$$L_{\text{total}} = L_{\text{hadronic}} \times L_{\mu+\text{jets}} \times L_{\mu\mu+\text{jets}} \times L_{\gamma+\text{jets}} n_b < 3$$  \hspace{1cm} (4)

$$L_{\text{total}} = L_{\text{hadronic}} \times L_{\mu+\text{jets}} n_b \geq 3$$  \hspace{1cm} (5)

The fit maximizes the total likelihood simultaneously in eight bins of $H_T$ for each of the four categories of $b$ tag multiplicity. $L_{\text{hadronic}}$ describes the $H_T$-binned observations in the hadronic sample, while the terms $L_{\mu+\text{jets}}$, $L_{\mu\mu+\text{jets}}$, and $L_{\gamma+\text{jets}}$ describe the $H_T$ binned yields in the $\mu + \text{jets}$, $\mu\mu + \text{jets}$, and $\gamma + \text{jets}$ samples respectively. For each bin, the expected yields in the control samples are related to the components of the SM expectations in the hadronic signal sample via translation factors from simulation. Since for $n_b \geq 3$ the only relevant SM background arises from top events, only the $\mu+\text{jets}$ control sample is used in the likelihood to determine the background in the hadronic signal region for this $b$ jet multiplicity. However, the translation factors account also for any possible (residual) contributions from $W + \text{jets}$, $Z \rightarrow \nu\bar{\nu} + \text{jets}$, and other relevant SM backgrounds. Three nuisance parameters per data control sample are used to accommodate the $H_T$-dependent systematic uncertainties on the translation factors. In addition, any potential contribution from the multi-jet background in the hadronic sample is estimated by exploiting the $H_T$ dependence of the ratio of events that result in a value of $\alpha_T$ above and below some threshold value. This dependence on $H_T$ is modelled as a falling exponential function, $A e^{-k H_T}$ [12]. The parameters $A$ and $k$ are the normalisation and exponential decay constants, respectively. Values of $A$ and $k$ are determined by the fit independently for each category of reconstructed $b$ jets. The value of $k$ is constrained via measurements in a multi-jet–enriched data side-band satisfying the criteria $H_T < 575 \text{GeV}$ and $0.52 < \alpha_T < 0.55$. A further side band, defined by inverting the $H_T/E_T$ cleaning cut [12], is used to confirm that this method provides an unbiased estimator for $k$ and to estimate a systematic uncertainty.

In order to test the compatibility of the observed yields with the expectations from SM processes only, the likelihood function is maximized over all fit parameters. A comparison of the observed yields and the SM expectations in bins of $H_T$ for events with exactly zero, one, two, and at least three reconstructed $b$ jets are shown in Figures 2, 3, 4 and 5, respectively, for the hadronic signal region, and the three control samples. For all four $b$ jet categories, no significant excess above the SM expectation is observed in the hadronic signal region, and the control samples are well described by the SM hypothesis.

Limits are set in a simplified model of gluino pair production, where each gluino decays to two top quarks and a neutralino, leading to a four-top final state: $pp \rightarrow g\tilde{g} \rightarrow t\bar{t}\tilde{\chi}_0^\pm t\bar{t}\tilde{\chi}_0^0$. Figure 6 shows the upper limit at 95% CL on the cross section as a function of $m_{\tilde{g}}$ and $m_{\tilde{\chi}_0}$. Experimental uncertainties on the SM background predictions (20 – 70%), the luminosity measurement (4.4%), and the total acceptance times efficiency of the selection for the signal model (13%) are included in the calculation of the limit. Any potential signal contamination in the control samples has been accounted for.
Figure 2: Comparison of the observed yields and SM expectations given by the simultaneous fit in bins of $H_T$ for the (a) hadronic, (b) $\mu +$ jets, (c) $\mu\mu +$ jets and (d) $\gamma +$ jets samples when requiring exactly zero reconstructed b-jets. The event selection criteria for all three data control samples include the requirement $\alpha_T > 0.55$. The observed event yields in data (black dots) and the expectations and their uncertainties, as determined by the simultaneous fit, for all SM processes (light blue solid line with dark blue bands) are shown. For illustrative purposes only, the expected yields from pair produced gluinos ($m_{\text{gluino}} = 800$ GeV), each decaying to a top-antitop quark pair and a neutralino ($m_{\text{LSP}} = 100$ GeV), are superimposed on top of the SM expectation (magenta solid line).
Figure 3: Comparison of the observed yields and SM expectations given by the simultaneous fit in bins of $H_T$ for the (a) hadronic, (b) $\mu +$ jets, (c) $\mu\mu +$ jets and (d) $\gamma +$ jets samples when requiring exactly one reconstructed b-jet. The event selection criteria for the two muon data control samples do not include any requirement on $\alpha_T$. The observed event yields in data (black dots) and the expectations and their uncertainties, as determined by the simultaneous fit, for all SM processes (light blue solid line with dark blue bands) are shown. For illustrative purposes only, the expected yields from pair produced gluinos ($m_{\text{gluino}} = 800$ GeV), each decaying to a top-antitop quark pair and a neutralino ($m_{\text{LSP}} = 100$ GeV), are superimposed on top of the SM expectation (magenta solid line).
Figure 4: Comparison of the observed yields and SM expectations given by the simultaneous fit in bins of $H_T$ for the (a) hadronic, (b) $\mu +$ jets, (c) $\mu\mu +$ jets and (d) $\gamma +$ jets samples when requiring exactly two reconstructed b-jets. The event selection criteria for the two muon data control samples do not include any requirement on $\alpha_T$. The observed event yields in data (black dots) and the expectations and their uncertainties, as determined by the simultaneous fit, for all SM processes (light blue solid line with dark blue bands) are shown. For illustrative purposes only, the expected yields from pair produced gluinos ($m_{\text{gluino}} = 800$ GeV), each decaying to a top-antitop quark pair and a neutralino ($m_{\text{LSP}} = 100$ GeV), are superimposed on top of the SM expectation (magenta solid line).
Figure 5: Comparison of the observed yields and SM expectations given by the simultaneous fit in bins of \( H_T \) for the (a) hadronic and (b) \( \mu + \) jets samples when requiring at least three reconstructed b-jets. The event selection criteria for the \( \mu + \) jets data control sample does not include any requirement on \( \alpha_T \). The observed event yields in data (black dots) and the expectations and their uncertainties, as determined by the simultaneous fit, for all SM processes (light blue solid line with dark blue bands) are shown. For illustrative purposes only, the expected yields from pair produced gluinos \((m_{\tilde{g}} = 800 \text{ GeV})\), each decaying to a top-antitop quark pair and a neutralino \((m_{\tilde{\chi}_0} = 100 \text{ GeV})\), are superimposed on top of the SM expectation (magenta solid line).

Figure 6: Upper limit on cross section at 95% CL as a function of \( m_{\tilde{g}} \) and \( m_{\tilde{\chi}_0} \) for gluino pair production, with each gluino decaying to a top-antitop pair and a neutralino: \( pp \to \tilde{g} \tilde{g} \to t\bar{t} + 2\text{ LSP}; m(t) > m(\tilde{g}) \). The solid thick black line indicates the observed exclusion region assuming NLO+NLL SUSY production cross section. The thin black lines represent the observed excluded region when varying the cross section by its theoretical uncertainty. The dashed purple lines indicate the median (thick line) \( \pm 1\sigma \) (thin lines) expected exclusion regions.
7 Summary

In summary, a search for supersymmetry based on a data sample of pp collisions collected at \( \sqrt{s} = 8\) TeV, corresponding to an integrated luminosity of 3.9 fb\(^{-1}\), has been reported. Final states with two or more jets and significant \( E_T \), as expected from high-mass squark and gluino production and decays, have been analysed. An exclusive search has been performed in a binned signal region defined by the scalar sum of the transverse energy of jets, \( H_T \), and the number of jets identified to originate from a bottom quark. The sum of standard model backgrounds per bin has been estimated from a simultaneous binned likelihood fit to hadronic, \( \mu + \text{jets} \), \( \mu \mu + \text{jets} \), and \( \gamma + \text{jets} \) samples. The observed yields are found to be in agreement with the expected contributions from standard model processes and limits on a simplified model of gluino pair production and decay to two top-antitop quark pairs and two neutralinos have been set. In this simplified model, gluino masses below 850 GeV are excluded at 95% CL for a neutralino mass of 50 GeV. No limit can be set for neutralino masses above approximately 250 GeV.

References


