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Search for electroweak production of charginos and neutralinos in WH events in proton-proton collisions at $\sqrt{s} = 13$ TeV

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Abstract: Results are reported from a search for physics beyond the standard model in proton-proton collision events with a charged lepton (electron or muon), two jets identified as originating from a bottom quark decay, and significant imbalance in the transverse momentum. The search was performed using a data sample corresponding to $35.9\,\mathrm{fb}^{-1}$, collected by the CMS experiment in 2016 at $\sqrt{s} = 13$ TeV. Events with this signature can arise, for example, from the electroweak production of gauginos, which are predicted in models based on supersymmetry. The event yields observed in data are consistent with the estimated standard model backgrounds. Limits are obtained on the cross sections for chargino-neutralino ($\widetilde{\chi}_1^{\pm}\widetilde{\chi}_2^0$) production in a simplified model of supersymmetry with the decays $\widetilde{\chi}_1^{\pm} \to \mathrm{W}^{\pm}\widetilde{\chi}_1^0$ and $\widetilde{\chi}_2^0 \to \mathrm{H}\widetilde{\chi}_1^0$. Values of $m_{\widetilde{\chi}_1^{\pm}}$ between 220 and 490 GeV are excluded at 95% confidence level by this search when the $\widetilde{\chi}_1^0$ is massless, and values of $m_{\widetilde{\chi}_1^0}$ are excluded up to 110 GeV for $m_{\widetilde{\chi}_1^{\pm}} \approx 450$ GeV.

Keywords: Hadron-Hadron scattering (experiments), Supersymmetry

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1 Introduction

Supersymmetry (SUSY) [1–8] is a theoretically attractive extension of the standard model (SM) that is based on a symmetry between bosons and fermions. SUSY predicts the existence of a superpartner for every SM particle, with the same gauge quantum numbers but differing by one half unit of spin. In R-parity conserving SUSY models, supersymmetric particles are created in pairs, and the lightest supersymmetric particle (LSP) is stable [9–11]. As a result, SUSY also provides a potential connection to cosmology as the LSP, if neutral and stable, may be a viable dark matter candidate.

Previous searches based on 13 TeV proton-proton collision data at the CERN LHC focused on strong production of colored SUSY particles [12–28]. Pair production of these particles would have the largest cross section for SUSY processes and therefore provides the strongest discovery potential with small datasets. However, the absence of signals in these searches suggests that strongly produced SUSY particles may be too massive to be found with the present data. In contrast, neutralinos ($\widetilde{\chi}^0$) and charginos ($\widetilde{\chi}^{\pm}$), mixtures of the superpartners of the SM electroweak gauge bosons and the Higgs bosons, can have masses within the accessible range. Because of the absence of color charge, the production cross

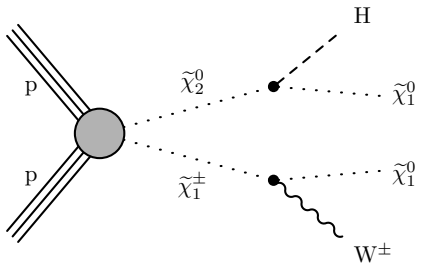

Figure 1. Diagram corresponding to the SUSY simplified model targeted by this analysis, i.e., chargino-neutralino production, with the chargino decaying to a W boson and an LSP, while the heavier neutralino decays to a Higgs boson and an LSP.

sections are lower, and these particles may have thus far eluded detection. This provides strong motivation for dedicated searches for electroweak SUSY particle production.

Depending on the mass spectrum, the charginos and neutralinos can have significant decay branching fractions to vector bosons V (W or Z) and the Higgs boson (H). Here, "H" refers to the 125 GeV Higgs boson [29], interpreted as the lightest CP-even state of an extended Higgs sector. The H boson is expected to have SM-like properties if all of the other Higgs bosons are much heavier [30]. The observation of a Higgs boson in a SUSY-like process would provide evidence that SUSY particles couple to the Higgs field, a necessary condition for SUSY to stabilize the Higgs boson mass. Pair production of neutralinos and/or charginos can thus lead to the HH, VH, and VV decay modes, with a large fraction of the possible final states containing at least one isolated lepton. Such events can be easily selected with simple triggers and do not suffer from large quantum chromodynamics multijet background.

In this paper we focus on a simplified model [31–35] of supersymmetric chargino-neutralino ($\widetilde{\chi}_1^\pm\widetilde{\chi}_2^0$) production with the decays $\widetilde{\chi}_1^\pm \to W^\pm\widetilde{\chi}_1^0$ and $\widetilde{\chi}_2^0 \to H\widetilde{\chi}_1^0$, as shown in figure 1. Both the $\widetilde{\chi}_1^\pm$ and $\widetilde{\chi}_2^0$ are assumed to be wino-like and have the same mass. The lightest neutralino $\widetilde{\chi}_1^0$, produced in the decays of $\widetilde{\chi}_1^\pm$ or the $\widetilde{\chi}_2^0$, is considered to be the stable LSP, which escapes detection. When the W boson decays leptonically, this process typically results in a signature with one lepton, two jets that originate from the decay $H \to b\bar{b}$, and large missing transverse momentum from the neutrino in the W boson decay and the LSPs.

Results of searches for electroweak pair production of SUSY particles were previously reported by the ATLAS and CMS Collaborations using data sets of 8 TeV proton-proton (pp) collisions [36–38] in a variety of event topologies and final states. No excesses above the SM expectations were observed, and the results of those searches were used to place lower limits on the mass of pair-produced charginos and neutralinos. Assuming mass-degenerate $\widetilde{\chi}_1^\pm$ and $\widetilde{\chi}_2^0$, and sleptons (the SUSY partners of the SM leptons) with lower masses, the searches probed masses up to approximately 700 GeV. For the WH decays assumed here, the strongest mass limit was around 270 GeV. With the increase of the LHC collision energy from 8 to 13 TeV, and a significantly larger data set, searches based on 13 TeV data have the potential to quickly surpass the sensitivity of the previous analyses.

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This paper presents the result of a search using a data set corresponding to an integrated luminosity of 35.9 fb^{-1} of pp collisions collected at a center-of-mass energy of 13 TeV with the CMS detector in 2016. The results are interpreted in the simplified SUSY model with chargino-neutralino production depicted in figure 1.

2 The CMS detector

The central feature of the CMS apparatus is a superconducting solenoid, 13 m in length and 6 m in diameter, which provides an axial magnetic field of 3.8 T. Within the field volume are several particle detection systems. Charged-particle trajectories are measured with silicon pixel and strip trackers, covering $0 \leq \phi < 2\pi$ in azimuth and $|\eta| < 2.5$ in pseudorapidity, where $\eta \equiv -\ln[\tan(\theta/2)]$ and θ is the polar angle of the trajectory of the particle with respect to the counterclockwise beam direction. The transverse momentum, the component of the momentum p in the plane orthogonal to the beam, is defined in terms of the polar angle as $p_{\mathrm{T}} = p \sin\theta$. A lead-tungstate crystal electromagnetic calorimeter and a brass and scintillator hadron calorimeter surround the tracking volume, providing energy measurements of electrons, photons, and hadronic jets in the range $|\eta| < 3.0$. Muons are identified and measured within $|\eta| < 2.4$ by gas-ionization detectors embedded in the steel flux-return yoke of the solenoid. Forward calorimeters on each side of the interaction point encompass $3.0 < |\eta| < 5.0$. The detector is nearly hermetic, allowing momentum imbalance measurements in the plane transverse to the beam direction. A two-tier trigger system selects pp collision events of interest for use in physics analyses. A detailed description of the CMS detector, together with a definition of the coordinate system used and the relevant kinematic variables, can be found in ref. [39].

3 Event samples, reconstruction, and selection

3.1 Object definition and preselection

Event reconstruction is based on the particle-flow (PF) algorithm [40, 41], which combines information from the tracker, calorimeter, and muon systems to reconstruct and identify PF candidates, i.e., charged and neutral hadrons, photons, muons, and electrons. To select collision events, we require at least one reconstructed vertex. The reconstructed vertex with the largest value of summed physics-object p_{T}^2 is taken to be the primary pp interaction vertex. The physics objects are the objects returned by a jet finding algorithm [42, 43] applied to all charged tracks associated with the vertex, plus the corresponding associated missing transverse momentum. The missing transverse momentum vector, $\vec{p}_{\mathrm{T}}^{\mathrm{miss}}$, is defined as the negative vector sum of the momenta of all reconstructed PF candidates projected onto the plane perpendicular to the proton beams. Its magnitude is referred to as $E_{\mathrm{T}}^{\mathrm{miss}}$. Events with possible contributions from beam halo processes or anomalous noise in the calorimeter can have large values of $E_{\mathrm{T}}^{\mathrm{miss}}$ and are rejected using dedicated filters [44].

Data events are selected using triggers that require the presence of an isolated electron or muon with p_{T} thresholds of 27 GeV or 24 GeV, respectively. Muon events may also be accepted using a trigger that does not require isolation but instead requires $p_{\mathrm{T}} > 50$ GeV.

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The trigger efficiency, measured using a data sample of $Z/\gamma^\star \to \ell\ell$ events, varies in the range 70–95% (85–92%) depending on the η and p_T of the electron (muon).

Selected events are required to have exactly one lepton (electron or muon), with electrons (muons) satisfying $p_T > 30(25)$ GeV and $|\eta| < 1.44(2.1)$. Electron candidates are reconstructed starting from a cluster of energy deposits in the electromagnetic calorimeter. The cluster is then matched to a reconstructed track. The electron selection is based on the shower shape, track-cluster matching, and consistency between the cluster energy and the track momentum [45]. Muon candidates are reconstructed by performing a global fit that requires consistent hit patterns in the tracker and the muon system [46]. For both lepton flavors, the impact parameter with respect to the primary vertex is required to be less than 0.5 mm in the transverse plane and 1 mm along the beam direction.

Leptons are required to be isolated from other activity in the event. A measure of lepton isolation is the scalar p_T sum (p_T^{sum}) of all PF candidates not associated with the lepton within a cone of radius $\Delta R \equiv \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} = 0.3$, where $\Delta\eta$ and $\Delta\phi$ are the distances between the lepton and the PF candidates at the primary vertex in η-ϕ space [47]. Only charged PF candidates compatible with the primary vertex are included in the sum. The average contribution of particles from additional pp interactions in the same or nearby bunch crossings (pileup) is subtracted from p_T^{sum}. We require that p_T^{sum} be less than 5 GeV. Typical lepton identification and isolation efficiencies, measured in samples of $Z/\gamma^\star \to \ell\ell$ events, are approximately 80–85% (85–90%) for electrons (muons), depending on p_T and η.

Particle-flow candidates are clustered to form jets using the anti-k_T clustering algorithm [42] with a distance parameter of 0.4, as implemented in the FastJet package [43]. Only charged PF candidates compatible with the primary vertex are used in the clustering. The pileup contribution to the jet energy is estimated on an event-by-event basis using the jet area method described in [48] and is subtracted from the overall jet p_T. Corrections are applied to the energy measurements of jets to account for non-uniform detector response and are propagated consistently as a correction to $\vec{p}_T^{miss}$ [49, 50]. The selected lepton can also be reconstructed as a jet, so any jets within $\Delta R = 0.4$ of the lepton are removed from the list of considered jets.

Selected events are required to contain exactly two jets with $p_T > 30$ GeV and $|\eta| < 2.4$. Both of these jets must be consistent with containing the decay products of a heavy-flavor (HF) hadron, as identified using the combined secondary vertex (CSVv2) tagging algorithm [51]. Such jets are referred to as b jets. The CSVv2 algorithm has three main operating points: loose, medium, and tight. We require both jets to be tagged according to the loose operating point, and at least one of them to be tagged with the medium operating point. The efficiency of this algorithm for jets arising from b quarks with p_T between 30 and 400 GeV is in the range 60–65% (70–75%) for the medium (loose) working point. The misidentification rate for jets arising from light quarks or gluons is approximately 1% (10%) for the medium (loose) working point.

The largest background in this search arises from $t\bar{t}$ and tW events with decays into two-lepton final states in which one of the leptons is not reconstructed or identified. In order to reduce these backgrounds, we search for a second electron or muon with $p_T > 5$ GeV and looser identification and isolation requirements, and reject events where such a lepton

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is found. Second leptons are required to satisfy $p_{\mathrm{T}}^{\mathrm{sum}}/p_{\mathrm{T}} < 0.1$, where $p_{\mathrm{T}}^{\mathrm{sum}}$ is calculated here with a cone radius of $\Delta R = 0.2$ for $p_{\mathrm{T}}^{\mathrm{lep}} \leq 50$ GeV, and $\Delta R = \max(0.05, 10\,\mathrm{GeV}/p_{\mathrm{T}}^{\mathrm{lep}})$ at higher values of lepton transverse momentum. We also reject events with reconstructed hadronically decaying tau leptons with $p_{\mathrm{T}} > 20\,\mathrm{GeV}$ [52], or isolated tracks with $p_{\mathrm{T}} > 10\,\mathrm{GeV}$ and opposite electric charge relative to the selected lepton. For this purpose, a track is considered isolated if $p_{\mathrm{T}}^{\mathrm{sum}}/p_{\mathrm{T}} < 0.1$ and $p_{\mathrm{T}}^{\mathrm{sum}} < 6\,\mathrm{GeV}$, where $p_{\mathrm{T}}^{\mathrm{sum}}$ here is constructed with charged PF candidates compatible with the primary vertex, the cone radius is $\Delta R = 0.3$, and p_{T} is the transverse momentum of the track.

The final two requirements that complete the preselection are $E_{\mathrm{T}}^{\mathrm{miss}} \geq 125\,\mathrm{GeV}$ and $M_{\mathrm{T}} > 50\,\mathrm{GeV}$, where M_{T} is the transverse mass of the lepton-$E_{\mathrm{T}}^{\mathrm{miss}}$ system, defined as

$$M_{\mathrm{T}} = \sqrt{2p_{\mathrm{T}}^{\ell} E_{\mathrm{T}}^{\mathrm{miss}}[1 - \cos(\Delta\phi)]}, \tag{3.1}$$

where p_{T}^{ℓ} is the transverse momentum of the lepton and $\Delta\phi$ is the angle between the transverse momentum of the lepton and $\vec{p}_{\mathrm{T}}^{\mathrm{miss}}$.

3.2 Signal region definition

The signal regions are defined by additional requirements on the kinematic properties of preselected events. The invariant mass of the two b jets is required to be in the range $90 \leq M_{\mathrm{b\bar{b}}} \leq 150\,\mathrm{GeV}$, consistent with the Higgs boson mass within the resolution. The $M_{\mathrm{b\bar{b}}}$ distribution for signal and background processes is shown in figure 2 (top left), displaying a clear peak for signal events near the Higgs boson mass.

To suppress single-lepton backgrounds originating from semileptonic $\mathrm{t\bar{t}}$, $\mathrm{W}+\mathrm{jets}$, and single top quark processes, the preselection requirement on M_{T} is tightened to $>150\,\mathrm{GeV}$. This is because the M_{T} distribution in these processes with a single leptonically decaying W boson has a kinematic endpoint $M_{\mathrm{T}} < m_{\mathrm{W}}$, where m_{W} is the W boson mass. The endpoint can be exceeded by off mass-shell W bosons or because of detector resolution effects. The M_{T} requirement significantly reduces single-lepton backgrounds, as shown in figure 2 (bottom left).

In order to further suppress both semileptonic and dileptonic $\mathrm{t\bar{t}}$ backgrounds, we utilize the contransverse mass variable, M_{CT} [53, 54]:

$$M_{\mathrm{CT}} = \sqrt{2p_{\mathrm{T}}^{\mathrm{b1}} p_{\mathrm{T}}^{\mathrm{b2}}[1 + \cos(\Delta\phi_{\mathrm{bb}})]}, \tag{3.2}$$

where $p_{\mathrm{T}}^{\mathrm{b1}}$ and $p_{\mathrm{T}}^{\mathrm{b2}}$ are the transverse momenta of the two jets, and $\Delta\phi_{\mathrm{bb}}$ is the azimuthal angle between the pair. As shown in refs. [53, 54], this variable has a kinematic endpoint at $(m^2(\delta) - m^2(\alpha))/m(\delta)$, where δ is the pair-produced heavy particle and α is the invisible particle produced in the decay of δ. In the case of $\mathrm{t\bar{t}}$ events, when both jets from b quarks are correctly identified, the kinematic endpoint corresponds to the top quark mass, while signal events tend to have higher values of M_{CT}. This is shown in figure 2 (bottom right). We require $M_{\mathrm{CT}} > 170\,\mathrm{GeV}$.

After all other selections, we define two exclusive bins in $E_{\mathrm{T}}^{\mathrm{miss}}$ to enhance sensitivity to signal models with different mass spectra: $125 \leq E_{\mathrm{T}}^{\mathrm{miss}} < 200\,\mathrm{GeV}$ and $E_{\mathrm{T}}^{\mathrm{miss}} \geq 200\,\mathrm{GeV}$. The $E_{\mathrm{T}}^{\mathrm{miss}}$ distribution is shown in figure 2 (top right).

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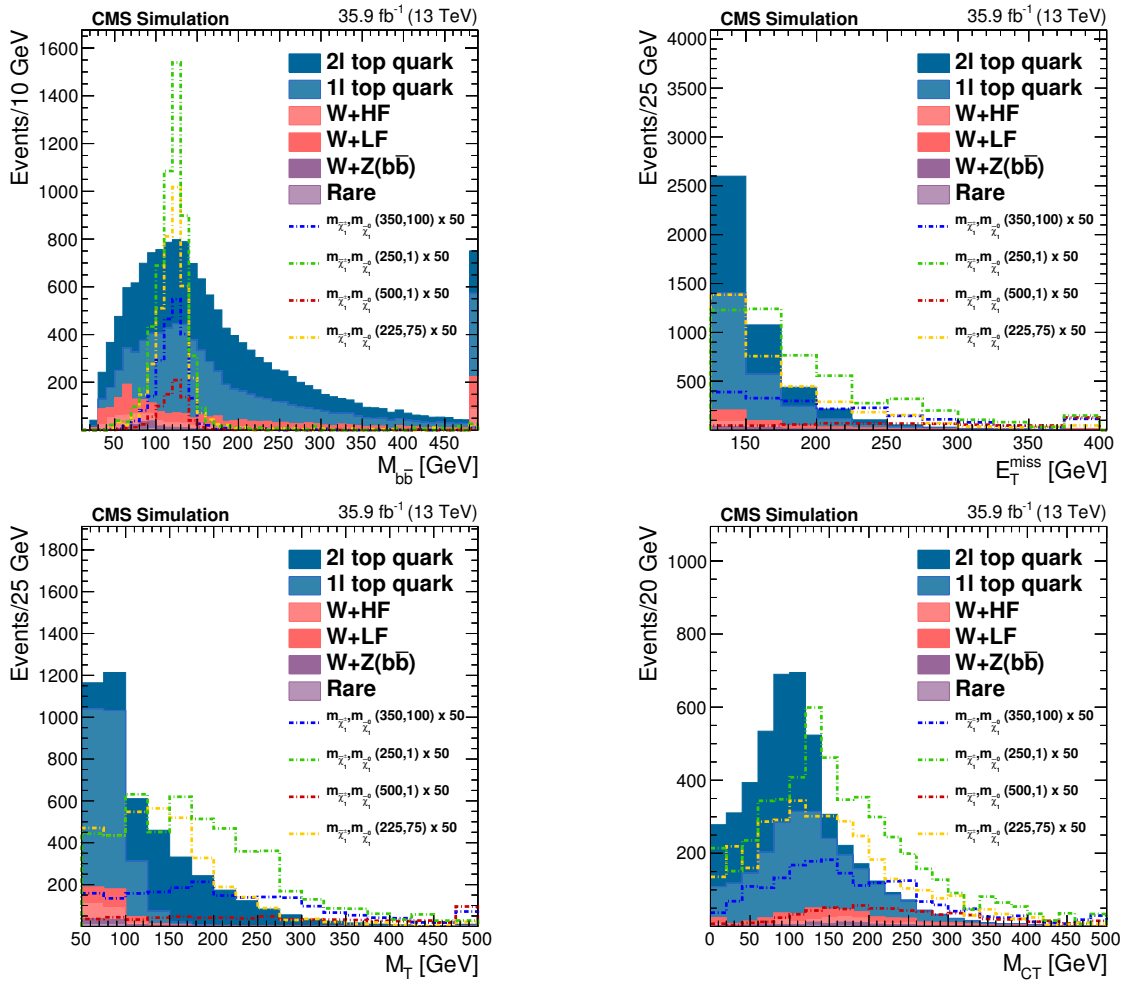

Figure 2. Distributions in $M_{\mathrm{b\bar{b}}}$ (top left), $E_{\mathrm{T}}^{\mathrm{miss}}$ (top right), M_{T} (bottom left), and M_{CT} (bottom right) for signal and background events in simulation after the preselection. The $E_{\mathrm{T}}^{\mathrm{miss}}$, M_{T}, and M_{CT} distributions are shown after the $90 < M_{\mathrm{b\bar{b}}} < 150\,\mathrm{GeV}$ requirement. Expected signal distributions are also overlaid as open histograms for various mass points, with the signal cross section scaled up by a factor of 50 for display purposes. The legend entries for signal give the masses $(m_{\widetilde{\chi}_1^{\pm}}, m_{\widetilde{\chi}_1^0})$ in GeV and the factor by which the signal cross section has been scaled.

3.3 Signal and background simulation

Samples of $\mathrm{t\bar{t}}$, $\mathrm{W}+\mathrm{jets}$, and $\mathrm{Z}+\mathrm{jets}$ events, as well as $\mathrm{t\bar{t}}$ production in association with a vector boson, are generated using the MadGraph5_aMC@NLO 2.2.2 [55] generator at leading order (LO) with the MLM matching scheme [56], while tW and single top quark t-channel events are generated at next-to-leading-order (NLO) using POWHEG V2 [57–59]. A top quark mass of $m_{\mathrm{t}} = 172.5\,\mathrm{GeV}$, and the NNPDF3.0 LO or NLO [60] parton distribution functions (PDFs) are used in the event generation. Single top quark s-channel production is simulated using MadGraph5_aMC@NLO 2.2.2 at NLO precision with the FxFx matching scheme [61]. Samples of diboson (WW, WZ, and ZZ) events are generated with either POWHEG or MadGraph5_aMC@NLO at NLO precision. Normalization of the

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simulated background samples is performed using the most accurate cross section calculations available [55, 62–72], which generally correspond to NLO or next-to-NLO precision.

The chargino-neutralino signal samples are also generated with MadGraph5_aMC@NLO at LO precision. For these samples we improve on the modeling of initial-state radiation (ISR), which affects the total transverse momentum ($p_{\mathrm{T}}^{\mathrm{ISR}}$) of the system of SUSY particles, by reweighting the $p_{\mathrm{T}}^{\mathrm{ISR}}$ distribution in these events. This reweighting procedure is based on studies of the p_{T} of Z bosons [73]. The reweighting factors range between 1.18 at $p_{\mathrm{T}}^{\mathrm{ISR}} = 125\,\mathrm{GeV}$ and 0.78 for $p_{\mathrm{T}}^{\mathrm{ISR}} > 600\,\mathrm{GeV}$. We take the deviation from 1.0 as the systematic uncertainty in the reweighting procedure.

Parton showering and fragmentation in all of these samples are performed using pythia V8.212 [74] with the CUETP8M1 tune [75]. For both signal and background events, additional simultaneous proton-proton interactions (pileup) are generated with pythia and superimposed on the hard collisions. The response of the CMS detector for SM background samples is simulated using Geant4-based model [76], while that for new physics signals is performed using the CMS fast simulation package [77]. All simulated events are processed with the same chain of reconstruction programs as that used for collision data.

Small differences between the b tagging efficiencies measured in data and simulation are corrected using data-to-simulation scale factors. Corrections are also applied to account for differences between lepton selection efficiencies (trigger, reconstruction, identification, and isolation) in data and simulation.

4 Backgrounds

The backgrounds for this search are classified into six categories. The first and most important category, referred to as dilepton top quark events, consists mainly of events from top quark pair production with both quarks decaying leptonically, but also including contributions from the associated production of a single top quark with a W boson, both of which decay leptonically. The second to fifth categories include processes with a single leptonically decaying W boson. Events with a single W are divided into two categories: those with b jets (W+HF, for "heavy flavor") and those without (W+LF, for "light flavor"). A separate category comprises WZ events in which the Z boson decays to $\mathrm{b\bar{b}}$ ($\mathrm{WZ} \to \ell\nu\mathrm{b\bar{b}}$). Events with one leptonically decaying top quark, either from $\mathrm{t\bar{t}}$ or from single top quark t- or s-channel production, are included in the fifth category ("single-lepton top quark"). Finally, other SM processes contribute a small amount to the expected yield in the signal region and are grouped together in the "rare" category. This includes events from Z + jets, WW, WZ (except the decays described above), ZZ, triboson, $\mathrm{t\bar{t}W}$, $\mathrm{t\bar{t}Z}$, and $\mathrm{WH} \to \ell\nu\mathrm{b\bar{b}}$ processes.

All background processes are modeled using MC simulation. Three data control regions (CRs) are defined by inverting the signal region selection requirements, as summarized in table 1. The CRs are defined at both preselection and signal region selection levels. The CRs at the preselection level are defined with looser cuts in order to check the modeling of key discriminant variables. The CRs after the signal region level selections are used to validate the modeling of the main backgrounds and to assign systematic uncertainties in the background predictions. The regions CRM$\mathrm{b\bar{b}}$ and CR0b are split into two bins in $E_{\mathrm{T}}^{\mathrm{miss}}$

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Selection	Signal regions	CR2ℓ	CR0b	CRMb$\bar{\text{b}}$
N(leptons)	=1	=1 or 2	=1	=1
Isolated track veto	✓	inverted if 1ℓ	✓	✓
Tau candidate veto	✓	inverted if 1ℓ	✓	✓
Number of b tags	=2	=2	=0	=2
Preselection level				
$M_{\text{b}\bar{\text{b}}}$ [GeV]	—	—	$\in$[90,150]	$\notin$[90,150]
$E_{\text{T}}^{\text{miss}}$ [GeV]	$\geq$125	$\geq$125	$\geq$125	$\geq$125
M_{T} [GeV]	>50	>150	>50	>150
M_{CT} [GeV]	—	—	>170	—
Signal region selection level				
$M_{\text{b}\bar{\text{b}}}$ [GeV]	$\in$[90,150]	not used	$\in$[90,150]	$\notin$[90,150]
$E_{\text{T}}^{\text{miss}}$ [GeV]	$[125, 200), \geq 200$		[125,200), $\geq$200	$[125, 200), \geq 200$
M_{T} [GeV]	>150		>150	>150
M_{CT} [GeV]	>170		>170	>170

Table 1. Event selections in signal and control regions. The region CR2ℓ is only used at the preselection level.

to mirror the signal region selection. The expected signal contribution in any of the CRs is always less than 1% of the total SM yields, and typically much smaller.

The dilepton top quark background can be isolated in the CR2ℓ control region by selecting dilepton events. In addition to a lepton passing the analysis selections, events must contain one of the following: a second electron or muon, an isolated track candidate, or a tau lepton candidate. The latter categories are included to accept hadronically decaying tau leptons. If all the kinematic selections used for the signal regions are applied, the number of events in CR2ℓ is too low to validate the modeling of the dilepton top quark background. Therefore, this CR is used primarily to validate the modeling of $M_{\text{b}\bar{\text{b}}}$.

Since the signal produces a resonant peak in the $M_{\text{b}\bar{\text{b}}}$ distribution, the requirement on $M_{\text{b}\bar{\text{b}}}$ is inverted to define the background-dominated control region CRMb$\bar{\text{b}}$, which includes a mixture of all backgrounds in proportions similar to those in the signal region. Consequently, this control region is dominated by the dilepton top quark background and is used to validate the modeling of these processes in the kinematic tails of the $E_{\text{T}}^{\text{miss}}$, M_{T}, and M_{CT} distributions.

The CR0b region is designed to study the W + LF background. It is used to validate the modeling of the kinematic tails in $E_{\text{T}}^{\text{miss}}$, M_{T}, and M_{CT} for W + jets processes. In this region, the dijet mass M_{jj} computed from the two selected jets is used in place of $M_{\text{b}\bar{\text{b}}}$.

The background estimation and the associated uncertainties are described in the following sections.

4.1 Dilepton top quark backgrounds

The dilepton top quark process contributes to the event sample in the signal region when the second lepton is not reconstructed or identified. Due to the presence of two neutrinos,

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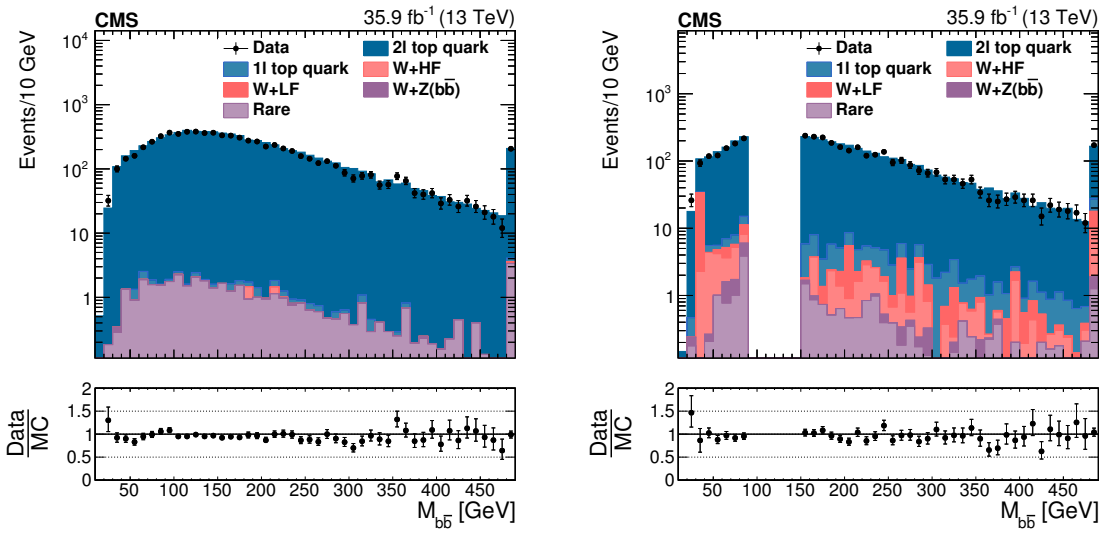

Figure 3. (left) Distribution in $M_{\mathrm{b\bar{b}}}$ in CR2ℓ after the preselection level cuts defined in table 1, comparing data to MC simulation. (right) Distribution in $M_{\mathrm{b\bar{b}}}$ in CRMb$\bar{\mathrm{b}}$ after preselection level cuts defined in table 1. The signal region range of $90 \leq M_{\mathrm{b\bar{b}}} \leq 150$ GeV has been removed from the plot.

these events tend to have higher $E_{\mathrm{T}}^{\mathrm{miss}}$ than the single-lepton backgrounds, and their M_{T} distribution is not bounded by the W boson mass. However, as mentioned above, the M_{CT} requirement significantly suppresses dilepton top quark events. The modeling of this background is validated in two steps. First, the modeling of the $M_{\mathrm{b\bar{b}}}$ distribution is validated in CR2ℓ; second, the modeling in the kinematic tails of the $E_{\mathrm{T}}^{\mathrm{miss}}$, M_{T}, and M_{CT} distributions is validated in CRMb$\bar{\mathrm{b}}$. Distributions of $M_{\mathrm{b\bar{b}}}$ in CR2ℓ and CRMb$\bar{\mathrm{b}}$, after the preselection level cuts defined in table 1, are displayed in figure 3 (left) and figure 3 (right), respectively.

In CR2ℓ, we observe agreement between data and MC, validating the modeling of the $M_{\mathrm{b\bar{b}}}$ distribution. We then use CRMb$\bar{\mathrm{b}}$ at the signal region selection level to derive a scale factor for the dilepton top quark background separately in each of the analysis $E_{\mathrm{T}}^{\mathrm{miss}}$ bins. All other background components are subtracted from the observed data yields, and the result is compared to the dilepton top quark MC prediction. Agreement is observed in the higher $E_{\mathrm{T}}^{\mathrm{miss}}$ bin within statistical uncertainties. For the lower $E_{\mathrm{T}}^{\mathrm{miss}}$ bin, we find fewer events in data than predicted, and we derive a scale factor of 0.72 for the dilepton top quark background in this bin. From the statistical precision of the data, we assign a systematic uncertainty of 30% in the prediction for both bins. This accounts for any effects that could impact the modeling of this background in simulation, including generator assumptions on factorization and renormalization scales, and PDFs, as well as experimental uncertainties in the jet energy scale, the lepton identification and isolation, trigger, and b tagging efficiencies.

4.2 W boson backgrounds

The M_{T} requirement (>150 GeV) effectively suppresses the contribution from W + jets events. However, as discussed above, events from W + jets can still enter the M_{T} tail due

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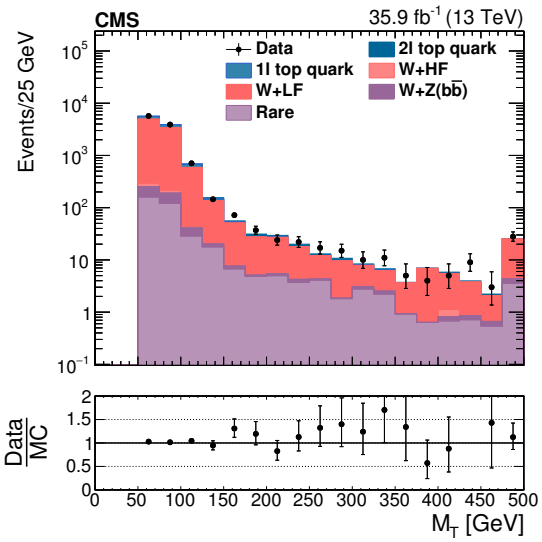

Figure 4. Distribution in M_{T} in CR0b after the preselection level cuts defined in table 1.

to off-shell W production or $E_{\mathrm{T}}^{\mathrm{miss}}$ resolution effects. The control region CR0b consists mostly of W + LF events and is therefore used to validate the modeling of W + jets in the tails of all kinematic variables such as M_{T}.

Figure 4 shows the M_{T} distributions of data and simulated events in CR0b after the preselection requirements. The data and simulation agree within uncertainties. The observed yields in data are then compared with MC predictions after applying all the kinematic requirements at signal region selection level defined in table 1. We find agreement within statistical uncertainties. Based on the statistical precision of the data, we assign a 10% systematic uncertainty in the W + jets prediction. This procedure directly tests the W + jets background prediction in the kinematic phase space of the signal region, including experimental uncertainties in the jet energy scale, in the efficiencies for trigger, lepton identification and isolation. It also accounts for most generator assumptions. Additional uncertainties for effects not tested by this procedure are discussed below.

For the W + LF background, the uncertainty due to the b tagging requirements is evaluated by varying the b tagging efficiencies within their measured uncertainties. The uncertainty in the yield in the signal regions is 1%.

For the W + HF background the effects contributing to the kinematic tails are similar to those in W + LF. In this case the tail of the M_{T} distribution receives contributions from off-shell W boson production and $E_{\mathrm{T}}^{\mathrm{miss}}$ resolution effects, but also from neutrinos in semileptonic decays within the b jets. Since this last effect is accounted for in the event generation, we do not apply any additional correction or uncertainty for kinematic tail modeling beyond the one derived above in CR0b.

The most uncertain aspect of the prediction for the W + HF background is the estimate of its cross section relative to the W + LF process. We assign a 50% uncertainty to the normalization of this background [78]. This uncertainty is validated by comparing data to simulation in a CR with $60 < M_{\mathrm{T}} < 120$ GeV and with one or two jets, where the dominant

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contribution to the event sample is from W + jets. We find that the 50% uncertainty conservatively covers differences between data and simulation as a function of the number of b jets. Finally, the uncertainty in this prediction due to the uncertainty in the b tagging efficiency is also evaluated and found to be 5%.

The effects discussed above also contribute to the tail of the M_{T} distribution in $\mathrm{WZ} \to \ell\nu\mathrm{b}\bar{\mathrm{b}}$ events. As a result, the tail modeling systematic uncertainty for this background is taken to be the same as those evaluated in CR0b. An additional uncertainty of 12% is applied to the normalization of the $\mathrm{WZ} \to \ell\nu\mathrm{b}\bar{\mathrm{b}}$ background, based on the CMS cross section measurement of inclusive WZ production at 13 TeV [79]. A unique aspect of the $\mathrm{WZ} \to \ell\nu\mathrm{b}\bar{\mathrm{b}}$ background is that $M_{\mathrm{b}\bar{\mathrm{b}}}$ peaks at the Z boson mass, at the lower edge of the $M_{\mathrm{b}\bar{\mathrm{b}}}$ selection used in this analysis. Uncertainties in the jet energy scale can therefore strongly impact the prediction of this background. By varying the jet energy scale within its uncertainty, we derive an uncertainty of 27% in the $\mathrm{WZ} \to \ell\nu\mathrm{b}\bar{\mathrm{b}}$ background prediction. While this uncertainty is large, the absolute magnitude of this background remains very small in the signal region. Finally, the uncertainty in the background prediction for this process due to the uncertainty in the b tagging efficiency is 2%.

4.3 Other backgrounds

The single-lepton top quark backgrounds are highly suppressed by several of the selections applied in this analysis. Since these contain exactly one leptonically decaying W boson, the M_{T} requirement is an effective discriminant against them. Requiring exactly two jets also suppresses the $\mathrm{t}\bar{\mathrm{t}} \to \ell +$jets background, which typically has four jets in the final state. As a result, this background comprises a small fraction of the expected SM prediction in the signal region.

Isolating the single-lepton top quark background in a region kinematically similar to the signal region is difficult since dilepton top quark events tend to dominate when requiring large M_{T}. The main source of uncertainty in the prediction of this backgrounds is the modeling of the $E_{\mathrm{T}}^{\mathrm{miss}}$ resolution, which was found to be well modeled in the study of CR0b.

Additional studies of $E_{\mathrm{T}}^{\mathrm{miss}}$ resolution are performed using γ + jets events following the method used in ref. [78]. The resolution in data is found to be up to 20% worse than in simulation, leading to higher single-lepton top quark yields than expected from simulation. However, the impact of this effect on the total background prediction is negligible. Due to the difficulties in defining a dedicated control region for this process, we assign a conservative uncertainty of 100% to the single lepton top quark background prediction.

The "rare" backgrounds contribute less than 15% of the expected yield in the signal region. We apply an uncertainty of 50% on the event yields from these processes.

5 Results

Figure 5 shows the distributions of $M_{\mathrm{b}\bar{\mathrm{b}}}$ in data compared with the SM background prediction after all signal region requirements except the $M_{\mathrm{b}\bar{\mathrm{b}}}$ selection. No significant deviations from the predictions are observed. Table 2 shows the expected SM background yields in the signal region compared to the observation, as well as predicted yields for several signal

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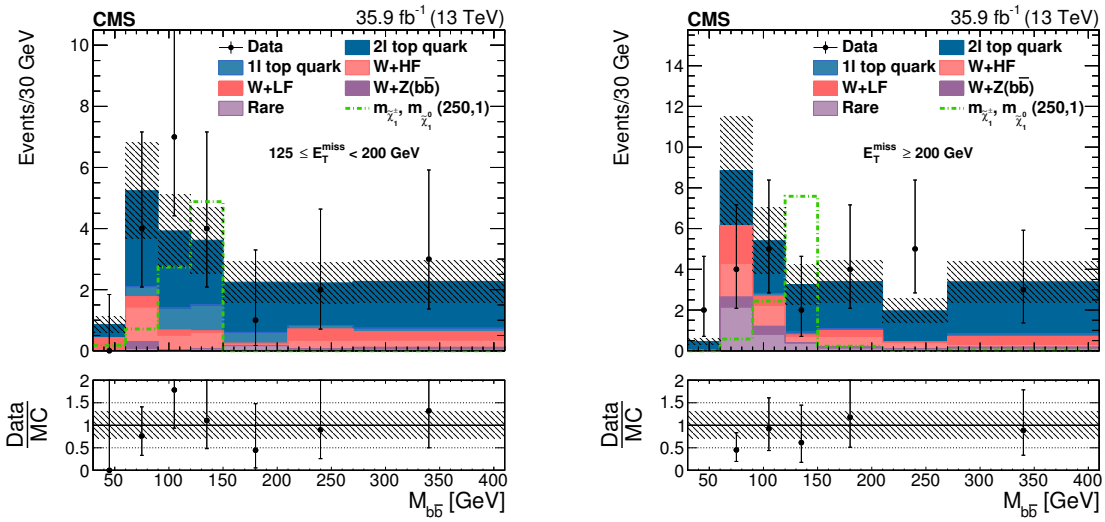

Figure 5. Distributions in $M_{\mathrm{b\bar{b}}}$ after all signal region kinematic requirements for the two exclusive $E_{\mathrm{T}}^{\mathrm{miss}}$ bins (left: $125 \leq E_{\mathrm{T}}^{\mathrm{miss}} < 200\,\mathrm{GeV}$, right: $E_{\mathrm{T}}^{\mathrm{miss}} \geq 200\,\mathrm{GeV}$). The signal region is $90 \leq M_{\mathrm{b\bar{b}}} \leq 150\,\mathrm{GeV}$. The hatched band shows the total uncertainty in the background prediction, including statistical and systematic components. The expected signal distribution for a reference SUSY model is overlaid as an open histogram, and the legend (on the last line) gives the masses as $(m_{\widetilde{\chi}_1^{\pm}}, m_{\widetilde{\chi}_1^0})$ in GeV.

models with the masses $(m_{\widetilde{\chi}_1^{\pm}}, m_{\widetilde{\chi}_1^0})$ indicated in GeV. The correlation coefficient for the background prediction between the two bins is 0.61. The correlation is incorporated in the likelihood model described below for the interpretation of the results, and it can be used to reinterpret these results in other signal models [80].

6 Interpretation

The results of this analysis are interpreted in the context of the simplified SUSY model depicted in figure 1, $\widetilde{\chi}_1^{\pm}\widetilde{\chi}_2^0 \rightarrow \mathrm{W}^{\pm}\mathrm{H}\widetilde{\chi}_1^0\widetilde{\chi}_1^0$. The $\widetilde{\chi}_1^{\pm}$ and $\widetilde{\chi}_2^0$ are assumed to have the same mass, and the branching fractions for the decays listed above are taken to be 100%. The W and Higgs bosons are taken to decay according to their SM branching fractions. Cross section limits as a function of the SUSY particle masses are set using a modified frequentist approach, employing the $\mathrm{CL_s}$ criterion and an asymptotic formulation [81–84]. Both signal regions are considered simultaneously in setting limits. The "expected" limit is that under the background-only hypothesis, while the "observed" limit reflects the data yields in the signal regions. The production cross sections are computed at NLO plus next-to-leading-log (NLL) precision in a limit of mass-degenerate wino $\widetilde{\chi}_1^{\pm}$ and $\widetilde{\chi}_2^0$, light bino $\widetilde{\chi}_1^0$, and with all the other sparticles assumed to be heavy and decoupled [85, 86]. The uncertainty in the cross section calculation includes variations of factorization and renormalization scales, and of the PDFs.

The systematic uncertainties in the signal yield are summarized in table 3. The signal models with the largest acceptance uncertainties are those with $\Delta m = m_{\widetilde{\chi}_2^0} - m_{\widetilde{\chi}_1^0} \simeq m_{\mathrm{H}}$.

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	$125 \leq E_{\mathrm{T}}^{\mathrm{miss}} < 200\,\mathrm{GeV}$	$E_{\mathrm{T}}^{\mathrm{miss}} \geq 200\,\mathrm{GeV}$
Dilepton top quark	4.6 ± 1.5	4.9 ± 1.7
W + LF	0.2 ± 0.1	0.5 ± 0.4
W + HF	1.0 ± 0.9	1.3 ± 1.0
$\mathrm{WZ} \to \ell\nu\mathrm{b}\overline{\mathrm{b}}$	0.1 ± 0.1	0.4 ± 0.2
Single-lepton top quark	1.6 ± 1.6	0.3 ± 0.4
Rare	$0.0^{+0.2}_{-0.0}$	1.2 ± 0.7
Total SM background	7.5 ± 2.5	8.7 ± 2.2
Data	11	7
$\widetilde{\chi}_1^{\pm}\widetilde{\chi}_1^0$ (225,75)	2.4 ± 0.4	2.3 ± 0.4
$\widetilde{\chi}_1^{\pm}\widetilde{\chi}_1^0$ (250,1)	7.6 ± 1.0	10.0 ± 1.2
$\widetilde{\chi}_1^{\pm}\widetilde{\chi}_1^0$ (500,1)	0.9 ± 0.1	6.3 ± 0.2
$\widetilde{\chi}_1^{\pm}\widetilde{\chi}_1^0$ (500,125)	1.0 ± 0.1	5.5 ± 0.2
$\widetilde{\chi}_1^{\pm}\widetilde{\chi}_1^0$ (350,100)	2.7 ± 0.3	8.0 ± 0.5

Table 2. Expected and observed event yields in the signal regions. The uncertainties shown include both statistical and systematic sources. The correlation coefficient for the background prediction between the two bins is 0.61. Predicted yields are shown also for several signal models with the masses $(m_{\widetilde{\chi}_1^{\pm}}, m_{\widetilde{\chi}_1^0})$ indicated in GeV and with statistical-only uncertainties.

For these models, the kinematic properties of the events are most similar to those from SM backgrounds, and as a result, the acceptance is smaller than for models with larger Δm. For these models with compressed mass spectra, the largest uncertainties in the signal yields arise from the jet energy scale (up to 40%), $E_{\mathrm{T}}^{\mathrm{miss}}$ resolution in fast simulation (up to 50%), and limited size of MC samples (up to 60%). These uncertainties reach their maximal values only for models where the acceptance of this analysis is very small and the sensitivity is similarly small. For models with large Δm, where this analysis has the best sensitivity, these uncertainties typically amount to only a few percent. Other experimental and theoretical uncertainties are also considered and lead to small changes in the expected yields. These include effects from the renormalization and factorization scales assumed in the generator on the signal acceptance, the b tagging efficiency, the lepton reconstruction, identification, and isolation efficiency, the trigger efficiency, and the modeling of pileup. Finally, the uncertainty in the integrated luminosity is 2.5% [87].

Figure 6 shows the expected and observed 95% confidence level (CL) exclusion limits for $\widetilde{\chi}_1^{\pm}\widetilde{\chi}_2^0 \to \mathrm{W}^{\pm}\mathrm{H}\widetilde{\chi}_1^0\widetilde{\chi}_1^0$ as a function of $m_{\widetilde{\chi}_1^{\pm}}$ assuming $m_{\widetilde{\chi}_1^0} = 1\,\mathrm{GeV}$ (left) and then in the two-dimensional plane of $m_{\widetilde{\chi}_1^{\pm}}$ and $m_{\widetilde{\chi}_1^0}$ (right). This search excludes $m_{\widetilde{\chi}_1^{\pm}}$ values between 220 and 490 GeV when $m_{\widetilde{\chi}_1^0} = 1\,\mathrm{GeV}$, and $m_{\widetilde{\chi}_1^0}$ values up to 110 GeV when $m_{\widetilde{\chi}_1^{\pm}}$ is around 450 GeV.

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Source	Typical range of values [%]
Integrated luminosity	2.5
Size of MC samples	2–60
Pileup	1–5
Renormalization and factorization scales	1–3
ISR modeling	1–5
b tagging efficiency	2–8
Lepton efficiency	2–5
Trigger efficiency	1–5
Jet energy scale	1–40
Fastsim $E_{\mathrm{T}}^{\mathrm{miss}}$ resolution	1–50

Table 3. Sources of systematic uncertainty in the estimated signal yield, along with their typical values. The ranges represent variation across the signal masses probed.

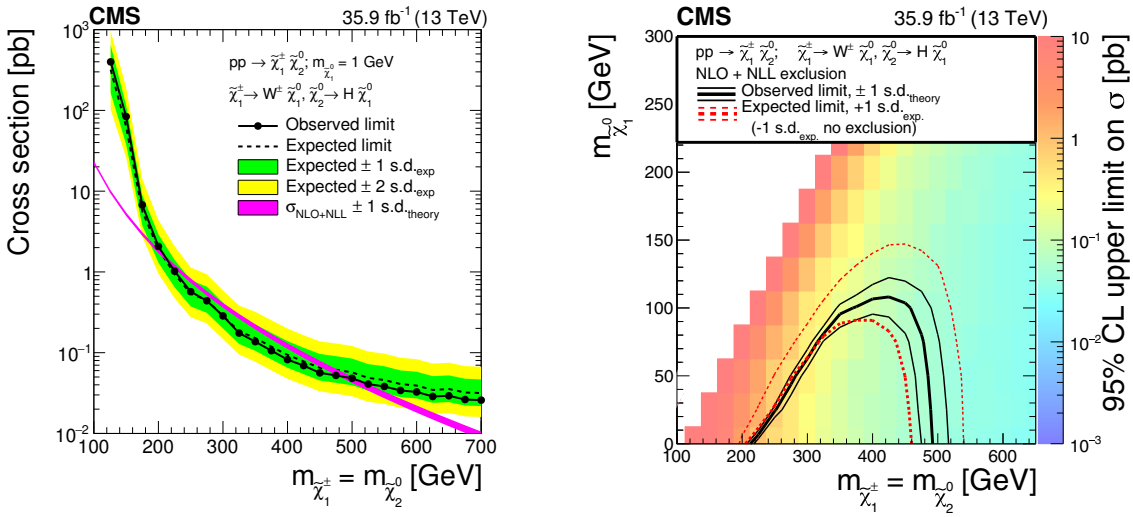

Figure 6. (left) Cross section exclusion limits at the 95% CL are shown for $\widetilde{\chi}_1^{\pm}\widetilde{\chi}_2^0 \to \mathrm{W}^{\pm}\mathrm{H}\widetilde{\chi}_1^0\widetilde{\chi}_1^0$ as a function of $m_{\widetilde{\chi}_1^{\pm}}$, assuming $m_{\widetilde{\chi}_1^0} = 1\,\mathrm{GeV}$. The solid black line and points represent the observed exclusion. The dashed black line represents the expected exclusion, while the green and yellow bands indicate the ±1 and 2 standard deviation (s.d.) uncertainties in the expected limit. The magenta line shows the theoretical cross section with its uncertainty. (right) Exclusion limits at the 95% CL in the plane of $m_{\widetilde{\chi}_1^{\pm}}$ and $m_{\widetilde{\chi}_1^0}$. The area below the thick black (dashed red) curve represents the observed (expected) exclusion region. The thin dashed red line indicates the +1 s.d.$_{\mathrm{exp.}}$ experimental uncertainty. The -1 s.d.$_{\mathrm{exp.}}$ line does not appear as no mass points would be excluded in that case. The thin black lines show the effect of the theoretical uncertainties (±1 s.d.$_{\mathrm{theory}}$) on the signal cross section.

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7 Summary

A search is performed for beyond the standard model physics in events with a leptonically decaying W boson, a Higgs boson decaying to a $b\bar{b}$ pair, and large transverse momentum imbalance. The search uses proton-proton collision data recorded by the CMS experiment in 2016 at $\sqrt{s} = 13\,\text{TeV}$, corresponding to an integrated luminosity of $35.9\,\text{fb}^{-1}$. The event yields observed in data are consistent with the estimated standard model backgrounds. The results are used to set cross section limits on chargino-neutralino production in a simplified supersymmetric model with degenerate masses for $\widetilde{\chi}_1^{\pm}$ and $\widetilde{\chi}_2^0$ and with the decays $\widetilde{\chi}_1^{\pm} \to \text{W}^{\pm}\widetilde{\chi}_1^0$ and $\widetilde{\chi}_2^0 \to \text{H}\widetilde{\chi}_1^0$. Values of $m_{\widetilde{\chi}_1^{\pm}}$ between 220 and 490 GeV are excluded at 95% confidence level by this search when the $\widetilde{\chi}_1^0$ is massless, and values of $m_{\widetilde{\chi}_1^0}$ are excluded up to 110 GeV for $m_{\widetilde{\chi}_1^{\pm}} \approx 450\,\text{GeV}$. These results significantly extend the previous best limits, by up to 270 GeV in $m_{\widetilde{\chi}_1^{\pm}}$ and up to 90 GeV in $m_{\widetilde{\chi}_1^0}$.

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References

[1] P. Ramond, *Dual theory for free fermions*, *Phys. Rev.* **D 3** (1971) 2415 [INSPIRE].

[2] Yu. A. Golfand and E.P. Likhtman, *Extension of the algebra of Poincaré group generators and violation of p invariance*, *JETP Lett.* **13** (1971) 323 [*Pisma Zh. Eksp. Teor. Fiz.* **13** (1971) 452] [INSPIRE].

[3] A. Neveu and J.H. Schwarz, *Factorizable dual model of pions*, *Nucl. Phys.* **B 31** (1971) 86 [INSPIRE].

[4] D.V. Volkov and V.P. Akulov, *Possible universal neutrino interaction*, *JETP Lett.* **16** (1972) 438 [*Pisma Zh. Eksp. Teor. Fiz.* **16** (1972) 621] [INSPIRE].

[5] J. Wess and B. Zumino, *A Lagrangian model invariant under supergauge transformations*, *Phys. Lett.* **B 49** (1974) 52 [INSPIRE].

[6] J. Wess and B. Zumino, *Supergauge transformations in four-dimensions*, *Nucl. Phys.* **B 70** (1974) 39 [INSPIRE].

[7] P. Fayet, *Supergauge invariant extension of the Higgs mechanism and a model for the electron and its neutrino*, *Nucl. Phys.* **B 90** (1975) 104 [INSPIRE].

[8] H.P. Nilles, *Supersymmetry, supergravity and particle physics*, *Phys. Rept.* **110** (1984) 1 [INSPIRE].

[9] G.R. Farrar and P. Fayet, *Phenomenology of the production, decay and detection of new hadronic states associated with supersymmetry*, *Phys. Lett.* **B 76** (1978) 575 [INSPIRE].

[10] C. Boehm, A. Djouadi and M. Drees, *Light scalar top quarks and supersymmetric dark matter*, *Phys. Rev.* **D 62** (2000) 035012 [hep-ph/9911496] [INSPIRE].

[11] C. Balázs, M. Carena and C.E.M. Wagner, *Dark matter, light stops and electroweak baryogenesis*, *Phys. Rev.* **D 70** (2004) 015007 [hep-ph/0403224] [INSPIRE].

[12] ATLAS collaboration, *Search for new phenomena in final states with large jet multiplicities and missing transverse momentum with ATLAS using* $\sqrt{s} = 13$ *TeV proton-proton collisions*, *Phys. Lett.* **B 757** (2016) 334 [arXiv:1602.06194] [INSPIRE].

JHEP11(2017)029

[13] ATLAS collaboration, *Search for new phenomena in final states with an energetic jet and large missing transverse momentum in pp collisions at $\sqrt{s} = 13$ TeV using the ATLAS detector*, Phys. Rev. **D 94** (2016) 032005 [arXiv:1604.07773] [INSPIRE].

[14] ATLAS collaboration, *Search for squarks and gluinos in final states with jets and missing transverse momentum at $\sqrt{s} = 13$ TeV with the ATLAS detector*, Eur. Phys. J. **C 76** (2016) 392 [arXiv:1605.03814] [INSPIRE].

[15] ATLAS collaboration, *Search for pair production of gluinos decaying via stop and sbottom in events with b-jets and large missing transverse momentum in pp collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector*, Phys. Rev. **D 94** (2016) 032003 [arXiv:1605.09318] [INSPIRE].

[16] CMS collaboration, *Search for new physics with the M_{T2} variable in all-jets final states produced in pp collisions at $\sqrt{s} = 13$ TeV*, JHEP **10** (2016) 006 [arXiv:1603.04053] [INSPIRE].

[17] CMS collaboration, *Search for supersymmetry in multijet events with missing transverse momentum in proton-proton collisions at 13 TeV*, Phys. Rev. **D 96** (2017) 032003 [arXiv:1704.07781] [INSPIRE].

[18] CMS collaboration, *Inclusive search for supersymmetry using razor variables in pp collisions at $\sqrt{s} = 13$ TeV*, Phys. Rev. **D 95** (2017) 012003 [arXiv:1609.07658] [INSPIRE].

[19] CMS collaboration, *A search for new phenomena in pp collisions at $\sqrt{s} = 13$ TeV in final states with missing transverse momentum and at least one jet using the α_{T} variable*, Eur. Phys. J. **C 77** (2017) 294 [arXiv:1611.00338] [INSPIRE].

[20] ATLAS collaboration, *Search for supersymmetry at $\sqrt{s} = 13$ TeV in final states with jets and two same-sign leptons or three leptons with the ATLAS detector*, Eur. Phys. J. **C 76** (2016) 259 [arXiv:1602.09058] [INSPIRE].

[21] CMS collaboration, *Search for physics beyond the Standard Model in events with two leptons of same sign, missing transverse momentum and jets in proton-proton collisions at $\sqrt{s} = 13$ TeV*, Eur. Phys. J. **C 77** (2017) 578 [arXiv:1704.07323] [INSPIRE].

[22] ATLAS collaboration, *Search for top squarks in final states with one isolated lepton, jets and missing transverse momentum in $\sqrt{s} = 13$ TeV pp collisions with the ATLAS detector*, Phys. Rev. **D 94** (2016) 052009 [arXiv:1606.03903] [INSPIRE].

[23] ATLAS collaboration, *Search for new phenomena in final states with large jet multiplicities and missing transverse momentum with ATLAS using $\sqrt{s} = 13$ TeV proton-proton collisions*, Phys. Lett. **B 757** (2016) 334 [arXiv:1602.06194] [INSPIRE].

[24] ATLAS collaboration, *Search for gluinos in events with an isolated lepton, jets and missing transverse momentum at $\sqrt{s} = 13$ TeV with the ATLAS detector*, Eur. Phys. J. **C 76** (2016) 565 [arXiv:1605.04285] [INSPIRE].

[25] CMS collaboration, *Search for supersymmetry in the all-hadronic final state using top quark tagging in pp collisions at $\sqrt{s} = 13$ TeV*, Phys. Rev. **D 96** (2017) 012004 [arXiv:1701.01954] [INSPIRE].

[26] CMS collaboration, *Search for supersymmetry in events with one lepton and multiple jets in proton-proton collisions at $\sqrt{s} = 13$ TeV*, Phys. Rev. **D 95** (2017) 012011 [arXiv:1609.09386] [INSPIRE].

JHEP11(2017)029

[27] CMS collaboration, *Search for new phenomena with multiple charged leptons in proton-proton collisions at $\sqrt{s} = 13$ TeV*, *Eur. Phys. J.* **C 77** (2017) 635 [arXiv:1701.06940] [INSPIRE].

[28] CMS collaboration, *Search for supersymmetry in pp collisions at $\sqrt{s} = 13$ TeV in the single-lepton final state using the sum of masses of large-radius jets*, *JHEP* **08** (2016) 122 [arXiv:1605.04608] [INSPIRE].

[29] ATLAS and CMS collaborations, *Measurements of the Higgs boson production and decay rates and constraints on its couplings from a combined ATLAS and CMS analysis of the LHC pp collision data at $\sqrt{s} = 7$ and 8 TeV*, *JHEP* **08** (2016) 045 [arXiv:1606.02266] [INSPIRE].

[30] S.P. Martin, *A supersymmetry primer*, *Adv. Ser. Direct. High Energy Phys.* **18** (1998) 1 [*Adv. Ser. Direct. High Energy Phys.* **21** (2010) 1] [hep-ph/9709356] [INSPIRE].

[31] N. Arkani-Hamed et al., *MARMOSET: the path from LHC data to the new Standard Model via on-shell effective theories*, hep-ph/0703088 [INSPIRE].

[32] J. Alwall, P. Schuster and N. Toro, *Simplified models for a first characterization of new physics at the LHC*, *Phys. Rev.* **D 79** (2009) 075020 [arXiv:0810.3921] [INSPIRE].

[33] J. Alwall, M.-P. Le, M. Lisanti and J.G. Wacker, *Model-independent jets plus missing energy searches*, *Phys. Rev.* **D 79** (2009) 015005 [arXiv:0809.3264] [INSPIRE].

[34] LHC New Physics Working Group collaboration, D. Alves, *Simplified models for LHC new physics searches*, *J. Phys.* **G 39** (2012) 105005 [arXiv:1105.2838] [INSPIRE].

[35] CMS collaboration, *Interpretation of searches for supersymmetry with simplified models*, *Phys. Rev.* **D 88** (2013) 052017 [arXiv:1301.2175] [INSPIRE].

[36] CMS collaboration, *Searches for electroweak neutralino and chargino production in channels with Higgs, Z and W bosons in pp collisions at 8 TeV*, *Phys. Rev.* **D 90** (2014) 092007 [arXiv:1409.3168] [INSPIRE].

[37] CMS collaboration, *Searches for electroweak production of charginos, neutralinos and sleptons decaying to leptons and W, Z and Higgs bosons in pp collisions at 8 TeV*, *Eur. Phys. J.* **C 74** (2014) 3036 [arXiv:1405.7570] [INSPIRE].

[38] ATLAS collaboration, *Search for the electroweak production of supersymmetric particles in $\sqrt{s} = 8$ TeV pp collisions with the ATLAS detector*, *Phys. Rev.* **D 93** (2016) 052002 [arXiv:1509.07152] [INSPIRE].

[39] CMS collaboration, *The CMS experiment at the CERN LHC*, 2008 *JINST* **3** S08004 [INSPIRE].

[40] CMS collaboration, *Particle-flow event reconstruction in CMS and performance for jets, taus and MET*, CMS-PAS-PFT-09-001, CERN, Geneva Switzerland, (2009).

[41] CMS collaboration, *Commissioning of the particle-flow event reconstruction with the first LHC collisions recorded in the CMS detector*, CMS-PAS-PFT-10-001, CERN, Geneva Switzerland, (2010).

[42] M. Cacciari, G.P. Salam and G. Soyez, *The anti-k_t jet clustering algorithm*, *JHEP* **04** (2008) 063 [arXiv:0802.1189] [INSPIRE].

[43] M. Cacciari, G.P. Salam and G. Soyez, *FastJet user manual*, *Eur. Phys. J.* **C 72** (2012) 1896 [arXiv:1111.6097] [INSPIRE].

JHEP11(2017)029

[44] CMS collaboration, *Missing transverse energy performance of the CMS detector*, 2011 *JINST* **6** P09001 [arXiv:1106.5048] [INSPIRE].

[45] CMS collaboration, *Performance of electron reconstruction and selection with the CMS detector in proton-proton collisions at* $\sqrt{s} = 8$ *TeV*, 2015 *JINST* **10** P06005 [arXiv:1502.02701] [INSPIRE].

[46] CMS collaboration, *Performance of CMS muon reconstruction in pp collision events at* $\sqrt{s} = 7$ *TeV*, 2012 *JINST* **7** P10002 [arXiv:1206.4071] [INSPIRE].

[47] CMS collaboration, *Description and performance of track and primary-vertex reconstruction with the CMS tracker*, 2014 *JINST* **9** P10009 [arXiv:1405.6569] [INSPIRE].

[48] M. Cacciari and G.P. Salam, *Pileup subtraction using jet areas*, *Phys. Lett.* **B 659** (2008) 119 [arXiv:0707.1378] [INSPIRE].

[49] CMS collaboration, *Determination of jet energy calibration and transverse momentum resolution in CMS*, 2011 *JINST* **6** P11002 [arXiv:1107.4277] [INSPIRE].

[50] CMS collaboration, *Jet energy scale and resolution in the CMS experiment in pp collisions at* 8 *TeV*, 2017 *JINST* **12** P02014 [arXiv:1607.03663] [INSPIRE].

[51] CMS collaboration, *Identification of b-quark jets with the CMS experiment*, 2013 *JINST* **8** P04013 [arXiv:1211.4462] [INSPIRE].

[52] CMS collaboration, *Reconstruction and identification of* τ *lepton decays to hadrons and* ν_τ *at CMS*, 2016 *JINST* **11** P01019 [arXiv:1510.07488] [INSPIRE].

[53] D.R. Tovey, *On measuring the masses of pair-produced semi-invisibly decaying particles at hadron colliders*, *JHEP* **04** (2008) 034 [arXiv:0802.2879] [INSPIRE].

[54] G. Polesello and D.R. Tovey, *Supersymmetric particle mass measurement with the boost-corrected contransverse mass*, *JHEP* **03** (2010) 030 [arXiv:0910.0174] [INSPIRE].

[55] J. Alwall et al., *The automated computation of tree-level and next-to-leading order differential cross sections and their matching to parton shower simulations*, *JHEP* **07** (2014) 079 [arXiv:1405.0301] [INSPIRE].

[56] J. Alwall et al., *Comparative study of various algorithms for the merging of parton showers and matrix elements in hadronic collisions*, *Eur. Phys. J.* **C 53** (2008) 473 [arXiv:0706.2569] [INSPIRE].

[57] P. Nason, *A new method for combining NLO QCD with shower Monte Carlo algorithms*, *JHEP* **11** (2004) 040 [hep-ph/0409146] [INSPIRE].

[58] S. Frixione, P. Nason and C. Oleari, *Matching NLO QCD computations with parton shower simulations: the POWHEG method*, *JHEP* **11** (2007) 070 [arXiv:0709.2092] [INSPIRE].

[59] S. Alioli, P. Nason, C. Oleari and E. Re, *A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX*, *JHEP* **06** (2010) 043 [arXiv:1002.2581] [INSPIRE].

[60] NNPDF collaboration, R.D. Ball et al., *Parton distributions for the LHC run II*, *JHEP* **04** (2015) 040 [arXiv:1410.8849] [INSPIRE].

[61] R. Frederix and S. Frixione, *Merging meets matching in MC@NLO*, *JHEP* **12** (2012) 061 [arXiv:1209.6215] [INSPIRE].

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[62] S. Alioli, P. Nason, C. Oleari and E. Re, *NLO single-top production matched with shower in POWHEG: s- and t-channel contributions*, *JHEP* **09** (2009) 111 [*Erratum ibid.* **02** (2010) 011] [arXiv:0907.4076] [INSPIRE].

[63] E. Re, *Single-top Wt-channel production matched with parton showers using the POWHEG method*, *Eur. Phys. J.* **C 71** (2011) 1547 [arXiv:1009.2450] [INSPIRE].

[64] T. Melia, P. Nason, R. Rontsch and G. Zanderighi, *W^+W^-, WZ and ZZ production in the POWHEG BOX*, *JHEP* **11** (2011) 078 [arXiv:1107.5051] [INSPIRE].

[65] M. Beneke, P. Falgari, S. Klein and C. Schwinn, *Hadronic top-quark pair production with NNLL threshold resummation*, *Nucl. Phys.* **B 855** (2012) 695 [arXiv:1109.1536] [INSPIRE].

[66] M. Cacciari, M. Czakon, M. Mangano, A. Mitov and P. Nason, *Top-pair production at hadron colliders with next-to-next-to-leading logarithmic soft-gluon resummation*, *Phys. Lett.* **B 710** (2012) 612 [arXiv:1111.5869] [INSPIRE].

[67] P. Bärnreuther, M. Czakon and A. Mitov, *Percent level precision physics at the Tevatron: first genuine NNLO QCD corrections to $q\bar{q} \to t\bar{t} + X$*, *Phys. Rev. Lett.* **109** (2012) 132001 [arXiv:1204.5201] [INSPIRE].

[68] M. Czakon and A. Mitov, *NNLO corrections to top-pair production at hadron colliders: the all-fermionic scattering channels*, *JHEP* **12** (2012) 054 [arXiv:1207.0236] [INSPIRE].

[69] M. Czakon and A. Mitov, *NNLO corrections to top pair production at hadron colliders: the quark-gluon reaction*, *JHEP* **01** (2013) 080 [arXiv:1210.6832] [INSPIRE].

[70] M. Czakon, P. Fiedler and A. Mitov, *Total top-quark pair-production cross section at hadron colliders through $O(\alpha_S^4)$*, *Phys. Rev. Lett.* **110** (2013) 252004 [arXiv:1303.6254] [INSPIRE].

[71] R. Gavin, Y. Li, F. Petriello and S. Quackenbush, *W physics at the LHC with FEWZ* 2.1, *Comput. Phys. Commun.* **184** (2013) 208 [arXiv:1201.5896] [INSPIRE].

[72] R. Gavin, Y. Li, F. Petriello and S. Quackenbush, *FEWZ* 2.0*: a code for hadronic Z production at next-to-next-to-leading order*, *Comput. Phys. Commun.* **182** (2011) 2388 [arXiv:1011.3540] [INSPIRE].

[73] CMS collaboration, *Search for top-squark pair production in the single-lepton final state in pp collisions at $\sqrt{s} = 8$ TeV*, *Eur. Phys. J.* **C 73** (2013) 2677 [arXiv:1308.1586] [INSPIRE].

[74] T. Sjöstrand, S. Mrenna and P.Z. Skands, *A brief introduction to PYTHIA* 8.1, *Comput. Phys. Commun.* **178** (2008) 852 [arXiv:0710.3820] [INSPIRE].

[75] CMS collaboration, *Event generator tunes obtained from underlying event and multiparton scattering measurements*, *Eur. Phys. J.* **C 76** (2016) 155 [arXiv:1512.00815] [INSPIRE].

[76] GEANT4 collaboration, S. Agostinelli et al., *GEANT4: a simulation toolkit*, *Nucl. Instrum. Meth.* **A 506** (2003) 250 [INSPIRE].

[77] S. Abdullin, P. Azzi, F. Beaudette, P. Janot and A. Perrotta, *The fast simulation of the CMS detector at LHC*, *J. Phys. Conf. Ser.* **331** (2011) 032049 [INSPIRE].

[78] CMS collaboration, *Searches for pair production of third-generation squarks in $\sqrt{s} = 13$ TeV pp collisions*, *Eur. Phys. J.* **C 77** (2017) 327 [arXiv:1612.03877] [INSPIRE].

[79] CMS collaboration, *Measurement of the WZ production cross section in pp collisions at $\sqrt{s} = 13$ TeV*, *Phys. Lett.* **B 766** (2017) 268 [arXiv:1607.06943] [INSPIRE].

[80] CMS collaboration, *Simplified likelihood for the re-interpretation of public CMS results*, CMS-NOTE-2017-001, CERN, Geneva Switzerland, (2017).

JHEP11(2017)029

[81] A.L. Read, *Presentation of search results: the CL_s technique*, *J. Phys.* **G 28** (2002) 2693 [INSPIRE].

[82] T. Junk, *Confidence level computation for combining searches with small statistics*, *Nucl. Instrum. Meth.* **A 434** (1999) 435 [hep-ex/9902006] [INSPIRE].

[83] G. Cowan, K. Cranmer, E. Gross and O. Vitells, *Asymptotic formulae for likelihood-based tests of new physics*, *Eur. Phys. J.* **C 71** (2011) 1554 [*Erratum ibid.* **C 73** (2013) 2501] [arXiv:1007.1727] [INSPIRE].

[84] ATLAS, CMS collaborations and the LHC Higgs Combination Group, *Procedure for the LHC Higgs boson search combination in Summer* 2011, ATL-PHYS-PUB-2011-011, CERN, Geneva Switzerland, (2011) [CMS-NOTE-2011-005].

[85] B. Fuks, M. Klasen, D.R. Lamprea and M. Rothering, *Gaugino production in proton-proton collisions at a center-of-mass energy of* 8 *TeV*, *JHEP* **10** (2012) 081 [arXiv:1207.2159] [INSPIRE].

[86] B. Fuks, M. Klasen, D.R. Lamprea and M. Rothering, *Precision predictions for electroweak superpartner production at hadron colliders with resummino*, *Eur. Phys. J.* **C 73** (2013) 2480 [arXiv:1304.0790] [INSPIRE].

[87] CMS collaboration, *CMS luminosity measurements for the* 2016 *data taking period*, CMS-PAS-LUM-17-001, CERN, Geneva Switzerland, (2017).

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