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Search for new physics in the multijet and missing transverse momentum final state in proton-proton collisions at $\sqrt{s} = 7$ TeV

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Abstract

A search for physics beyond the standard model is performed in events with at least three jets and large missing transverse momentum produced in proton-proton collisions at $\sqrt{s} = 7$ TeV. No significant excess of events above the expected backgrounds is observed in 4.98 fb^{-1} of data collected with the CMS detector at the Large Hadron Collider. The results are presented in the context of the constrained minimal supersymmetric extension of the standard model and more generically for simplified models. These results significantly extend previous searches.

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Many extensions of the standard model (SM) of particle physics have been proposed to address the shortcomings of the SM, e.g., problems concerning the gauge hierarchy and identity of dark matter [1–3]. Supersymmetry (SUSY) is one such new physics model, which postulates a new symmetry that relates fermionic and bosonic degrees of freedom and introduces a superpartner for each SM particle. In R -parity conserving models [4], SUSY particles are produced in pairs, and the lightest SUSY particle (LSP) is stable. If the LSP is weakly interacting and neutral, it serves as a candidate for dark matter. At the Large Hadron Collider (LHC), squarks (\tilde{q}) and gluinos (\tilde{g}), the superpartners of the quarks and gluons, would be produced via the strong interaction and decay to SM particles and two LSPs. A typical signature is the all-hadronic final state, characterized by multiple jets arising from quarks and gluons, and large missing transverse momentum due to the unobserved LSPs.

Searches in this final state have been performed by experiments at the Fermilab Tevatron [5, 6] and at the LHC [7–14]. This Letter presents a search in events with multiple jets and large missing transverse momentum produced in 7 TeV pp collisions using a data sample corresponding to an integrated luminosity of $4.98 \pm 0.11 \text{ fb}^{-1}$ collected with the Compact Muon Solenoid (CMS) detector. The search strategy follows Ref. [7], but uses more than 100 times the amount of data. This search is not specifically optimized for a particular SUSY model, but is sensitive to a variety of new physics models that lead to the multijet and missing transverse momentum final state. The results of this search are interpreted in the context of the constrained minimal supersymmetric extension of the SM (CMSSM) [15–17] and in a more general context for simplified models [18, 19] of new particles decaying to one or two jets and a stable weakly interacting particle.

The central feature of the CMS detector [20] is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. Within the field volume are the silicon pixel and strip tracker, the lead-tungstate crystal electromagnetic calorimeter, and the brass/scintillator hadron calorimeter. Charged particles are measured by the silicon tracker, covering $0 < \phi < 2\pi$ in azimuth and $|\eta| < 2.5$, where the pseudorapidity η is defined as $\eta = -\ln[\tan(\theta/2)]$, with θ being the polar angle of the trajectory of the particle with respect to the counterclockwise proton beam direction. The calorimeters surrounding the tracking volume cover $|\eta| < 3$. Outside the field the quartz/steel forward hadron calorimeters extend the coverage to $|\eta| < 5$. Muons are identified in gas ionization detectors, covering $|\eta| < 2.4$, embedded in the steel return yoke of the magnet.

The recorded events are reconstructed using the particle-flow algorithm [21], which reconstructs particles, namely charged hadrons, photons, neutral hadrons, muons, and electrons, using the information from all sub-detectors. These particles are then clustered into jets using the anti- k_T clustering algorithm with distance parameter 0.5 [22]. Corrections are applied to account for the dependence of the jet response on transverse momentum p_T and η [23], and for the effects of additional (pileup) pp collisions overlapping with the collision of interest [24, 25].

The event sample for the search is selected by requiring at least three jets with $p_T > 50 \text{ GeV}$ and $|\eta| < 2.5$. The further selection is based on two variables: H_T , defined as $H_T = \sum p_T$ where the sum is carried out over jets with $p_T > 50 \text{ GeV}$ and $|\eta| < 2.5$, and \vec{H}_T , defined as $\vec{H}_T = -\sum \vec{p}_T$ where the sum is over jets with $p_T > 30 \text{ GeV}$ and $|\eta| < 5$. Events are required to have $H_T > 500 \text{ GeV}$ and $|\vec{H}_T| > 200 \text{ GeV}$, where $|\vec{H}_T|$ is the magnitude of the \vec{H}_T . The $|\vec{H}_T|$ requirement rejects most of the QCD multijet background. Events with \vec{H}_T aligned in azimuth with one of the two leading jets with $\Delta\phi < 0.5 \text{ rad}$ or along the third jet with $\Delta\phi < 0.3 \text{ rad}$ are removed to further reduce the QCD multijet background. Events containing isolated muons or electrons with $p_T > 10 \text{ GeV}$ are also vetoed in order to reject $t\bar{t}$ and W/Z -jets backgrounds

with leptons in the final state [7, 26, 27]. Events are also rejected if a jet with $p_T > 30$ GeV has an electromagnetic p_T fraction larger than 0.95 or a neutral hadron p_T fraction larger than 0.90. In addition, events affected by instrumental effects, particles from non-collision sources, and poor reconstruction quality are rejected (event cleaning) [7, 28]. All these requirements constitute the baseline selection [29]. The event sample used in this search is collected by triggering on both H_T and \cancel{H}_T or only on H_T . The triggers are fully efficient for the baseline event selection.

To increase the sensitivity of the search to the different kinematic regions of signal events, the sample of 1885 events passing the baseline selection is divided into 14 sub-samples defined in terms of the H_T and \cancel{H}_T values (search selections), as listed in the first column of Table 1.

The SM backgrounds mainly consist of $Z(\nu\bar{\nu})$ +jets events and $W(\ell\nu)$ +jets events from W or $t\bar{t}$ production ($\ell = e, \mu, \text{ or } \tau$). The $W(\ell\nu)$ +jets events pass the search selection when the e/μ escapes detection or a τ decays hadronically. The QCD multijet events also contribute to the background when leptonic decays of heavy flavor hadrons inside jets or jet energy mismeasurements lead to a large \cancel{H}_T . The contributions from other SM processes are found to be negligible. In this search all of the backgrounds are estimated from data [7].

Several Monte Carlo (MC) samples are used to model the signal as well as to develop and validate the background prediction methods. The $t\bar{t}$, W/Z +jets, and γ +jets samples are produced using the MADGRAPH5 [30] generator, interfaced with the PYTHIA 6.4.24 [31] parton-shower model, and scaled up to the next-to-leading order (NLO) or next-to-next-to-leading order (NNLO) cross section predictions [32, 33]. The QCD multijet and SUSY signal production is simulated with PYTHIA 6.4.24, the CTEQ6L [34] parton distribution functions (PDFs), and a CMS custom underlying event tuning [35]. The generated events are passed through a GEANT4-based [36] detector simulation, and have the same distribution of pileup pp interactions as observed in the data.

After the baseline selection, the SM background prediction from MC simulation is 1927 events, which is in reasonable agreement with 1885 events observed in data. These MC-based predictions are not used further in the search, as the uncertainties associated with event generation and detector simulation are difficult to evaluate.

The $Z(\nu\bar{\nu})$ +jets background contribution is estimated using γ +jets events by treating photons as neutrinos. The Z boson and photon exhibit similar kinematic properties at high p_T , and the hadronic component of events is similar in the two cases [37–40]. A γ +jets sample is collected by triggering on a γ candidate with or without an additional requirement on H_T depending on the data-taking period. The photon candidates [41] are required to be isolated from other particles in the tracker and calorimeters and to have the shower shape consistent with that for a prompt photon. In order to predict the $Z(\nu\bar{\nu})$ +jets background, the γ +jets sample is corrected for the γ reconstruction efficiency and purity, both measured from data [7], and the $Z(\nu\bar{\nu})$ +jets/ γ +jets production ratio, obtained from simulation, which also takes into account the detector acceptance for photons. The total multiplicative correction factor to obtain the $Z(\nu\bar{\nu})$ +jets background prediction from the γ +jets event yield is 0.28 ± 0.06 for the baseline selection. The dominant systematic uncertainties on this background estimation originate from the theoretical uncertainty on the γ/Z cross section ratio (20–40%), the detector acceptance (5–7%), and the γ reconstruction and isolation efficiency (1–10%), depending on the search regions.

As a cross check, the $Z(\nu\bar{\nu})$ +jets background is also estimated using $Z(\mu^+\mu^-)$ +jets events by treating muons as neutrinos and correcting for the acceptance and efficiencies of the $Z(\mu^+\mu^-)$ +jets event selection and the branching ratio $\mathcal{B}(Z \rightarrow \nu\bar{\nu})/\mathcal{B}(Z \rightarrow \mu^+\mu^-) = 5.95 \pm 0.02$ [42]. The $Z(\nu\bar{\nu})$ +jets background estimated with this method is found to be consistent with the one from

Table 1: Event yields for different backgrounds for the 14 search selections together with the total backgrounds, as determined from the collision data, and number of events observed in data. The quoted uncertainties are the combinations of the statistical and systematic uncertainties.

Selection		$Z \rightarrow \nu\bar{\nu}$	$\bar{t}\bar{t}/W$ $\rightarrow e, \mu + X$	$\bar{t}\bar{t}/W$ $\rightarrow \tau_h + X$	QCD multijet	Total background	Data
H_T (GeV)	\cancel{H}_T (GeV)						
500–800	200–350	359 \pm 81	327 \pm 47	349 \pm 40	119 \pm 77	1154 \pm 128	1269
500–800	350–500	112 \pm 26	48 \pm 9	62.5 \pm 8.7	2.2 \pm 2.2	225 \pm 29	236
500–800	500–600	17.6 \pm 4.9	5.0 \pm 2.2	8.7 \pm 2.5	0.0 \pm 0.1	31.3 \pm 5.9	22
500–800	>600	5.5 \pm 2.6	0.8 \pm 0.8	2.0 \pm 1.8	0.0 \pm 0.0	8.3 \pm 3.2	6
800–1000	200–350	48 \pm 19	58 \pm 15	56.3 \pm 8.3	35 \pm 24	197 \pm 35	177
800–1000	350–500	16.0 \pm 6.7	5.4 \pm 2.3	7.2 \pm 2.0	1.2 $^{+1.3}_{-1.2}$	29.8 \pm 7.5	24
800–1000	500–600	7.1 \pm 3.7	2.4 \pm 1.5	1.3 \pm 0.6	0.0 $^{+0.2}_{-0.0}$	10.8 \pm 4.0	6
800–1000	>600	3.3 \pm 1.7	0.7 \pm 0.7	1.0 \pm 0.3	0.0 $^{+0.1}_{-0.0}$	5.0 \pm 1.9	5
1000–1200	200–350	10.9 \pm 5.1	13.7 \pm 3.8	21.9 \pm 4.6	19.7 \pm 13.3	66 \pm 15	71
1000–1200	350–500	5.5 \pm 3.0	5.0 \pm 4.4	2.9 \pm 1.3	0.4 $^{+0.7}_{-0.4}$	13.8 \pm 5.5	12
1000–1200	>500	2.2 \pm 1.7	1.6 \pm 1.2	2.3 \pm 1.0	0.0 $^{+0.2}_{-0.0}$	6.1 \pm 2.3	4
1200–1400	200–350	3.1 \pm 1.8	4.2 \pm 2.1	6.2 \pm 1.8	11.7 \pm 8.3	25.2 \pm 8.9	29
1200–1400	>350	2.3 \pm 1.5	2.3 \pm 1.4	0.6 $^{+0.8}_{-0.6}$	0.2 $^{+0.6}_{-0.2}$	5.4 \pm 2.3	8
>1400	>200	3.2 \pm 1.8	2.7 \pm 1.6	1.1 \pm 0.5	12.0 \pm 9.1	19.0 \pm 9.4	16

the γ +jets events.

The $W(\ell\nu)$ +jets events ($\ell = e$ or μ) from W or top quark production constitute a background when an electron or muon is not identified or is non-isolated and therefore passes the lepton veto. This background is estimated from a μ +jets control sample, selected with the same criteria as those used for the search except that we require exactly one rather than zero isolated μ . The transverse mass $m_T = \sqrt{2p_T^\mu \cancel{E}_T(1 - \cos(\Delta\phi))}$ is required to be less than 100 GeV in order to select events containing a $W \rightarrow \mu\nu$ decay and to suppress possible new physics signal contamination, i.e., the signal events resulting in the μ +jets sample used for the background estimation. Here \cancel{E}_T is the missing transverse energy [28], and $\Delta\phi$ is the azimuthal angle between the μ and the \cancel{E}_T . Events are weighted according to $(1/\epsilon_{\text{iso}}^\mu) ((1 - \epsilon_{\text{reco}}^{e,\mu})/\epsilon_{\text{reco}}^\mu)$ and $(\epsilon_{\text{reco}}^{e,\mu}/\epsilon_{\text{reco}}^\mu) ((1 - \epsilon_{\text{iso}}^{e,\mu})/\epsilon_{\text{iso}}^\mu)$ in order to predict events with unidentified leptons and non-isolated leptons, where $\epsilon_{\text{reco}}^{e,\mu}$ and $\epsilon_{\text{iso}}^{e,\mu}$ are the reconstruction and isolation efficiencies of the electrons and muons. The lepton reconstruction efficiencies are obtained from MC simulation, while the isolation efficiencies are extracted by applying a “tag-and-probe” method [43] on the $Z(\ell^+\ell^-)$ +jets events in data. The lepton reconstruction and identification efficiencies are parametrized in lepton p_T and $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2}$ relative to the closest jet, in order to account for the kinematic differences between $Z(\ell^+\ell^-)$ +jets events and the $\bar{t}\bar{t}$ and W +jets events. Leptons that are out of acceptance and events lost due to the m_T requirement are accounted for using factors determined from simulation. This background estimation method based on the collision data is validated by applying it to a MC sample and comparing the predicted and the true detector-level background distributions.

The predicted background for each search region is listed in Table 1. On this background estimation, low statistics in the μ +jets control sample are the dominant source of uncertainty in most of the search regions. The modeling of the lepton reconstruction and isolation efficiencies yields a 10% uncertainty. An additional uncertainty of 4–20% varying for different search regions is assigned based on the statistical power of the validation of this background estimation method. A 3% uncertainty accounts for the effect of the presence of QCD, Z , or diboson events in the μ +jets sample, which are modeled by MC simulation.

The background from the hadronic decay of τ leptons (τ_h) is estimated from a sample of μ +jets events, selected from inclusive μ or $\mu + \geq 2$ -jet triggers by requiring exactly one μ with $p_T > 20$ GeV and $|\eta| < 2.1$. In this sample, the muon p_T is replaced with a jet p_T taken randomly from a simulated response function for a hadronically-decaying τ lepton. The H_T and \cancel{H}_T of the event are recalculated including this τ jet, and the search selections are applied to predict the τ_h background. The τ -jet response function for $p_T^{\text{jet}}/p_T^\tau$ is obtained from simulated $t\bar{t}$ and $W(\tau\nu)$ +jets events by matching the reconstructed τ jet with the generated τ . Corrections are applied to account for the trigger efficiency, acceptance, and efficiency of the μ selection, and the branching ratio $\mathcal{B}(W \rightarrow \tau_h\nu)/\mathcal{B}(W \rightarrow \mu\nu) = 0.69 \pm 0.05$ [42]. This τ_h background estimation method is validated by applying it to the W and $t\bar{t}$ MC samples, and 6–13% uncertainties are assigned mainly to reflect the statistical power of this validation. The other main systematic uncertainties arise from the μ acceptance ($\leq 13\%$), the τ -jet response function ($\leq 20\%$), and the subtraction of residual QCD multijet, $Z(\mu^+\mu^-)$ +jets, and $(t\bar{t} + W) \rightarrow \tau\nu + X \rightarrow \mu\nu + X$ backgrounds ($\leq 2\%$), where the quoted uncertainties apply to all search regions.

The QCD background is estimated from collision data [7] recorded with a set of triggers having H_T threshold ranging from 150 to 700 GeV. The data samples used include the electroweak contributions not removed by the lepton veto and any potential new physics events; however, their cross section is negligible compared to the QCD multijet cross section. First, the p_T values of the jets with $p_T > 15$ GeV in these events are adjusted within the jet p_T resolution, using a kinematic fit such that the events are balanced in the transverse plane. The jet p_T values in the rebalanced events are then smeared with the measured jet resolutions to predict the QCD multijet background. The jet p_T response functions are determined as a function of p_T and η using a QCD multijet MC sample that includes heavy-flavor quarks. The width and tail of the p_T response functions are subsequently adjusted to account for the differences in the resolutions measured in simulation and in data [23]. The width (σ) of the Gaussian part of the simulated response is 5 (30)% narrower than what is observed in the data for $|\eta| < 0.5$ ($2.3 < |\eta| < 5.0$). After correcting for this difference, the fraction of jets with response more than 2.5σ away from the mean value is consistent with that in the data within uncertainties. The main uncertainties in this QCD estimation method arise from the shape of the jet response functions including the Gaussian width, the tails, the heavy-flavor contribution, and the effect of pileup on jets in an event. The method has been validated in simulated QCD multijet events within the statistical uncertainties (30–50%), which are assigned as an additional uncertainty. The total uncertainty adds up to 60–70%.

The predicted yields of the SM background and the number of events observed in data are summarized in Table 1 for the 14 search regions. Figure 1 shows the H_T and \cancel{H}_T distributions predicted for the SM background, together with those observed in data. The data are consistent with the SM background estimates.

The 95% confidence level (CL) upper limits on the CMSSM signal cross section are set using a modified frequentist CL_s method, taking the profile likelihood as a test statistic [45–47]. The results from 14 exclusive search regions are combined into one test-statistic considering the bin-to-bin correlations of the systematic uncertainties. The CMSSM model has five independent parameters: m_0 and $m_{1/2}$ are the universal scalar and gaugino masses at the grand unification scale, A_0 is the trilinear coupling, $\tan\beta$ is the ratio of the vacuum expectation values of the two Higgs doublets, and $\text{sgn}(\mu)$ is the sign of the Higgsino mixing parameter. The signal cross section is calculated at NLO and next-to-leading-log (NLL) accuracy [48–50]. The H_T and \cancel{H}_T distributions predicted for a low-mass CMSSM benchmark parameter set LM5, $m_0 = 230$ GeV, $m_{1/2} = 360$ GeV, $A_0 = 0$, $\tan\beta = 10$, and $\text{sgn}(\mu) > 0$ are shown in Fig. 1.

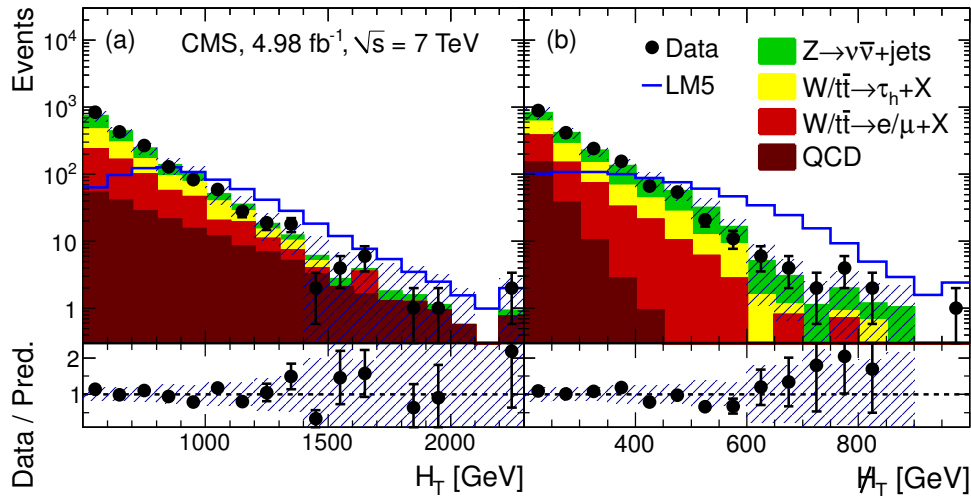


Figure 1: The (a) H_T and (b) $\#H_T$ distributions in the search data samples (circles) compared with histograms showing predictions of the SM background and SUSY signal (LM5, see text), for events passing the baseline selection. The hatched region indicates the uncertainties on the background predictions. The last bin contains all events above the maximum value of H_T and $\#H_T$ in the figures. The ratio of the observed data to the background predictions is also shown.

The acceptance times efficiency of the event selection for signal events is evaluated using the simulated CMSSM samples. The uncertainties on the background predictions, the luminosity determination (2.2%) [51], the signal acceptance and efficiency arising from the jet energy correction (8%), jet energy resolution (2%), PDF (6%), trigger inefficiency (2%), and the event cleaning [28] (3%) are taken into account by the limit-setting procedure. The possible overprediction of the backgrounds due to the presence of the signal in the data samples used for the background prediction is estimated to be about 3–20%, depending on $(m_0, m_{1/2})$ values, and subtracted when testing for the signal+background hypothesis in the CL_s method.

The upper limits on the CMSSM signal cross section are mapped into lower limits in the $(m_0, m_{1/2})$ plane (exclusion contour), as shown in Fig. 2 [29, 52]. The exclusion contours are also shown for the cases in which the signal cross section is varied by changing the renormalization and factorization scales by a factor of 2 and using the PDF4LHC recommendation [53] for the PDF uncertainty to illustrate the sensitivity of the exclusion to the signal cross section uncertainty. Conservatively, using the -1σ theory uncertainty values on the observed limit, squark masses below 1.2 TeV and gluino masses below 720 GeV are excluded for the chosen CMSSM parameter set.

The search results are also presented in a more general context of simplified models [18, 19] of new particles (\tilde{q} or \tilde{g}) decaying to one or two jets and an undetectable weakly interacting particle ($\tilde{\chi}^0$). The model used here includes the production of $\tilde{g}\tilde{g}$ and $\tilde{q}\tilde{q}$ pairs and their decays for a wide range of $(m(\tilde{g}), m(\tilde{\chi}^0))$ and $(m(\tilde{q}), m(\tilde{\chi}^0))$ values, and other SUSY particles are decoupled by being given masses beyond the reach of the LHC. The signal acceptance times efficiency [29] and its uncertainty are evaluated in the same way as used for the CMSSM, but using the simulated simplified model signal samples. The observed and expected 95% CL upper limits on the signal cross section of $\tilde{g}\tilde{g}$ and $\tilde{q}\tilde{q}$ production are shown in Fig. 3 in the $(m(\tilde{g}), m(\tilde{\chi}^0))$ and $(m(\tilde{q}), m(\tilde{\chi}^0))$ planes, together with contours where the signal cross sections from the NLO+NLL calculations [48–50] are excluded. The results are presented only in the region of $m(\tilde{g}, \tilde{q}) - m(\tilde{\chi}^0) > 150$ GeV, since the estimation of signal acceptance times ef-

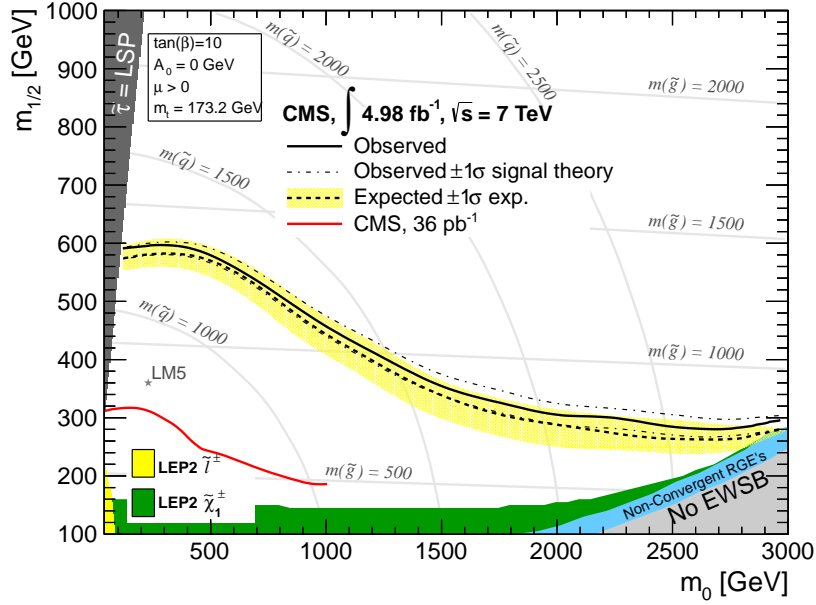


Figure 2: The observed and expected 95% CL limits in the CMSSM (m_0 , $m_{1/2}$) plane. The yellow-shaded region shows the $\pm 1\sigma$ variation in the expected limit, while the dot-dashed curves show the variation in the observed limit when the signal cross section is varied by its theoretical uncertainties. The remaining CMSSM parameters are $\tan \beta = 10$, $\mu > 0$, and $A_0 = 0$. The limits from an earlier CMS search [7] and from other experiments [44] are also shown.

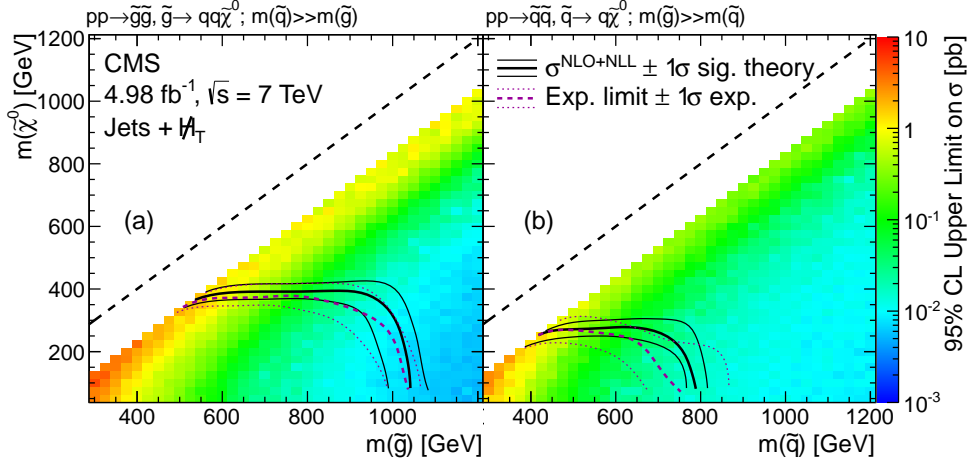


Figure 3: The observed and expected 95% CL upper limits on the (a) $\tilde{g}\tilde{g}$ and (b) $\tilde{q}\tilde{q}$ cross sections in the $(m(\tilde{g}), m(\tilde{\chi}^0))$, $(m(\tilde{q}), m(\tilde{\chi}^0))$ planes obtained with the simplified model. Also shown are the $\pm 1\sigma$ variation in the expected limit and the variation in the observed limit when the signal cross section is varied by its theoretical uncertainties.

efficiency becomes unreliable due to its strong dependence on the modeling of QCD radiation when the mass difference $m(\tilde{g}, \tilde{q}) - m(\tilde{\chi}^0)$ is smaller. In this model, the $m(\tilde{g})$ values below 1.0 TeV and $m(\tilde{q})$ values below 0.76 TeV are excluded for $m(\tilde{\chi}^0) < 200$ GeV.

In summary, a search for new physics has been performed in the multijet and large \cancel{E}_T final state using a data sample corresponding to an integrated luminosity of 4.98 fb^{-1} collected in 7 TeV pp collisions with the CMS detector at the LHC. The observed numbers of events are

consistent with the estimated SM background contributions, and 95% CL exclusion limits are set in the CMSSM parameter space, which significantly extend the previous results. For the simplified models of $\tilde{g}\tilde{g}$ and $\tilde{q}\tilde{q}$ production, the $m(\tilde{g})$ values below 1.0 TeV and $m(\tilde{q})$ values below 0.76 TeV are excluded for $m(\tilde{\chi}^0) < 200$ GeV.

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References

- [1] J. Wess and B. Zumino, "Supergauge transformations in four dimensions", *Nucl. Phys. B* **70** (1974) 39, doi:10.1016/0550-3213(74)90355-1.
- [2] H.-C. Cheng and I. Low, "TeV symmetry and the little hierarchy problem", *JHEP* **09** (2003) 051, doi:10.1088/1126-6708/2003/09/051, arXiv:hep-ph/0308199.
- [3] T. Appelquist, H.-C. Cheng, and B. A. Dobrescu, "Bounds on universal extra dimensions", *Phys. Rev. D* **64** (2001) 035002, doi:10.1103/PhysRevD.64.035002, arXiv:hep-ph/0012100.
- [4] 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, doi:10.1016/0370-2693(78)90858-4.
- [5] CDF Collaboration, "Inclusive Search for Squark and Gluino Production in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV", *Phys. Rev. Lett.* **102** (2009) 121801, doi:10.1103/PhysRevLett.102.121801, arXiv:0811.2512.
- [6] D0 Collaboration, "Search for squarks and gluinos in events with jets and missing transverse energy using 2.1 fb^{-1} of $p\bar{p}$ collision data at $\sqrt{s} = 1.96$ TeV", *Phys. Lett. B* **660** (2008) 449, doi:10.1016/j.physletb.2008.01.042, arXiv:0712.3805.
- [7] CMS Collaboration, "Search for new physics with jets and missing transverse momentum in pp collisions at $\sqrt{s} = 7$ TeV", *JHEP* **08** (2011) 155, doi:10.1007/JHEP08(2011)155, arXiv:1106.4503.
- [8] CMS Collaboration, "Search for supersymmetry in pp collisions at 7 TeV in events with jets and missing transverse energy", *Phys. Lett. B* **698** (2011) 196, doi:10.1016/j.physletb.2011.03.021, arXiv:1101.1628.

- [9] CMS Collaboration, “Search for Supersymmetry at the LHC in Events with Jets and Missing Transverse Energy”, *Phys. Rev. Lett.* **107** (2011) 221804, doi:10.1103/PhysRevLett.107.221804, arXiv:1109.2352.
- [10] CMS Collaboration, “Inclusive search for squarks and gluinos in pp collisions at $\sqrt{s} = 7$ TeV”, *Phys. Rev. D* **85** (2012) 012004, doi:10.1103/PhysRevD.85.012004, arXiv:1107.1279.
- [11] ATLAS Collaboration, “Search for squarks and gluinos using final states with jets and missing transverse momentum with the ATLAS detector in $\sqrt{s} = 7$ TeV proton-proton collisions”, *Phys. Lett. B* **701** (2011) 186, doi:10.1016/j.physletb.2011.05.061, arXiv:1102.5290.
- [12] ATLAS Collaboration, “Search for squarks and gluinos using final states with jets and missing transverse momentum with the ATLAS detector in $\sqrt{s} = 7$ TeV proton-proton collisions”, *Phys. Lett. B* **710** (2012) 67, doi:10.1016/j.physletb.2012.02.051, arXiv:1109.6572.
- [13] ATLAS Collaboration, “Search for new phenomena in final states with large jet multiplicities and missing transverse momentum using $\sqrt{s} = 7$ TeV pp collisions with the ATLAS detector”, *JHEP* **11** (2011) 099, doi:10.1007/JHEP11(2011)099, arXiv:1110.2299.
- [14] ATLAS Collaboration, “Hunt for new phenomena using large jet multiplicities and missing transverse momentum with ATLAS in 4.7 fb^{-1} of $\sqrt{s} = 7$ TeV proton-proton collisions”, (2012). arXiv:1206.1760. Submitted to *JHEP*.
- [15] A. H. Chamseddine, R. L. Arnowitt, and P. Nath, “Locally Supersymmetric Grand Unification”, *Phys. Rev. Lett.* **49** (1982) 970, doi:10.1103/PhysRevLett.49.970.
- [16] R. L. Arnowitt and P. Nath, “Supersymmetric mass spectrum in SU(5) supergravity grand unification”, *Phys. Rev. Lett.* **69** (1992) 725, doi:10.1103/PhysRevLett.69.725.
- [17] G. L. Kane, C. Kolda, L. Roszkowski et al., “Study of constrained minimal supersymmetry”, *Phys. Rev. D* **49** (1994) 6173, doi:10.1103/PhysRevD.49.6173, arXiv:hep-ph/9312272.
- [18] 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, doi:10.1103/PhysRevD.79.075020, arXiv:0810.3921.
- [19] LHC New Physics Working Group, “Simplified Models for LHC New Physics Searches”, (2011). arXiv:1105.2838.
- [20] CMS Collaboration, “The CMS experiment at the CERN LHC”, *JINST* **3** (2008) S08004, doi:10.1088/1748-0221/3/08/S08004.
- [21] CMS Collaboration, “Particle Flow Event Reconstruction in CMS and Performance for Jets, Taus and MET”, CMS Physics Analysis Summary CMS-PAS-PFT-09-001, (2009).
- [22] M. Cacciari, G. P. Salam, and G. Soyez, “The anti- k_t jet clustering algorithm”, *JHEP* **04** (2008) 063, doi:10.1088/1126-6708/2008/04/063, arXiv:0802.1189.

- [23] CMS Collaboration, “Determination of jet energy calibration and transverse momentum resolution in CMS”, *JINST* **6** (2011) P11002, doi:10.1088/1748-0221/6/11/P11002, arXiv:1107.4277.
- [24] M. Cacciari and G. P. Salam, “Pileup subtraction using jet areas”, *Phys. Lett. B* **659** (2007) 119, doi:10.1016/j.physletb.2007.09.077, arXiv:0707.1378.
- [25] M. Cacciari, G. P. Salam, and G. Soyez, “The catchment area of jets”, *JHEP* **04** (2007) 005, doi:10.1088/1126-6708/2008/04/005, arXiv:0802.1188.
- [26] CMS Collaboration, “Performance of muon identification in pp collisions at $\sqrt{s} = 7$ TeV”, CMS Physics Analysis Summary CMS-PAS-MUO-10-002, (2010).
- [27] CMS Collaboration, “Electron reconstruction and identification at $\sqrt{s} = 7$ TeV”, CMS Physics Analysis Summary CMS-PAS-EGM-10-004, (2010).
- [28] CMS Collaboration, “Missing transverse energy performance of the CMS detector”, *JINST* **6** (2011) P09001, doi:10.1088/1748-0221/6/09/P09001, arXiv:1106.5048.
- [29] See Supplemental Material for additional information of the event selection, the CMSSM exclusion contour in the $(m(\tilde{g}), m(\tilde{q}))$ plane for $\tan\beta = 10$, $\mu > 0$, and $A_0 = 0$, and the acceptance times efficiency of each search region for the simplified model $\tilde{g}\tilde{g}$ and $\tilde{q}\tilde{q}$ production.
- [30] J. Alwall, P. Dremin, S. de Visscher et al., “MadGraph/MadEvent v4: the new web generation”, *JHEP* **09** (2007) 028, doi:10.1088/1126-6708/2007/09/028, arXiv:0706.2334.
- [31] T. Sjöstrand, S. Mrenna, and P. Z. Skands, “PYTHIA 6.4 physics and manual”, *JHEP* **05** (2006) 026, doi:10.1088/1126-6708/2006/05/026, arXiv:hep-ph/0603175.
- [32] N. Kidonakis, “Next-to-next-to-leading soft-gluon corrections for the top quark cross section and transverse momentum distribution”, *Phys. Rev. D* **82** (2010) 114030, doi:10.1103/PhysRevD.82.114030, arXiv:1009.4935.
- [33] K. Melnikov and F. Petriello, “Electroweak gauge boson production at hadron colliders through $O(\alpha(s)^2)$ ”, *Phys. Rev. D* **74** (2006) 114017, doi:10.1103/PhysRevD.74.114017, arXiv:hep-ph/0609070.
- [34] J. Pumplin, D. R. Stump, J. Huston et al., “New Generation of Parton Distributions with Uncertainties from Global QCD Analysis”, *JHEP* **07** (2002) 012, doi:10.1088/1126-6708/2002/07/012, arXiv:hep-ph/0201195.
- [35] R. Field, “Early LHC Underlying Event Data - Findings and Surprises”, (2010). arXiv:1010.3558.
- [36] J. Allison, K. Amako, J. Apostolakis et al., “Geant4 developments and applications”, *IEEE* **53** **1** (2006) 270, doi:10.1109/TNS.2006.869826.
- [37] Z. Bern, G. Diana, L. J. Dixon et al., “Driving missing data at next-to-leading order”, *Phys. Rev. D* **84** (2011) 114002, doi:10.1103/PhysRevD.84.114002, arXiv:1106.1423.

- [38] J. H. Kuhn, A. Kulesza, S. Pozzorini et al., “Electroweak corrections to hadronic photon production at large transverse momenta”, *JHEP* **03** (2006) 059, doi:10.1088/1126-6708/2006/03/059, arXiv:hep-ph/0508253.
- [39] S. Ask, M. A. Parker, T. Sandova et al., “Using γ +jets production to calibrate the Standard Model $Z(\rightarrow \nu\bar{\nu})$ +jets background to new physics processes at the LHC”, *JHEP* **10** (2011) 058, doi:10.1007/JHEP10(2011)058, arXiv:1107.2803.
- [40] Z. Bern, G. Diana, L. J. Dixon et al., “Missing Energy and Jets for Supersymmetry Searches”, (2012). arXiv:1206.6064.
- [41] CMS Collaboration, “Measurement of the Differential Cross Section for Isolated Prompt Photon Production in pp Collisions at 7 TeV”, *Phys. Rev. D* **84** (2011) 052011, doi:10.1103/PhysRevD.84.052011, arXiv:1108.2044.
- [42] Particle Data Group Collaboration, “Review of Particle Physics”, *J. Phys. G* **37** (2010) 075021, doi:10.1088/0954-3899/37/7A/075021.
- [43] CMS Collaboration, “Measurement of the inclusive W and Z production cross sections in pp collisions at $\sqrt{s} = 7$ TeV with the CMS experiment”, *JHEP* **10** (2011) 132, doi:10.1007/JHEP10(2011)132, arXiv:1107.4789.
- [44] ALEPH, DELPHI, L3 and OPAL Collaborations, “Joint SUSY Working Group”, (2002). LEPSUSYWG/02-06-2.
- [45] A. L. Read, “Presentation of search results: the CLs technique”, *J. Phys. G* **28** (2002) 2693, doi:10.1088/0954-3899/28/10/313.
- [46] T. Junk, “Confidence level computation for combining searches with small statistics”, *Nucl. Instrum. Methods Phys. Res., Sect. A* **434** (1999) 435, doi:10.1016/S0168-9002(99)00498-2, arXiv:hep-ex/9902006.
- [47] ATLAS and CMS Collaborations, “Procedure for the LHC Higgs boson search combination in Summer 2011”, ATL-PHYS-PUB-2011-011, CMS NOTE-2011/005, (2011).
- [48] W. Beenakker, R. Hopker, M. Spira et al., “Squark and gluino production at hadron colliders”, *Nucl. Phys. B* **492** (1997) 51, doi:10.1016/S0550-3213(97)00084-9, arXiv:hep-ph/9610490.
- [49] A. Kulesza and L. Motyka, “Threshold Resummation for Squark-Antisquark and Gluino-Pair Production at the LHC”, *Phys. Rev. Lett.* **102** (2009) 111802, doi:10.1103/PhysRevLett.102.111802, arXiv:0807.2405.
- [50] M. Krämer, A. Kulesza, R. van der Leeuw et al., “Supersymmetry production cross sections in pp collisions at $\sqrt{s} = 7$ TeV”, (2012). arXiv:1206.2892.
- [51] CMS Collaboration, “Absolute Calibration of the Luminosity Measurement at CMS: Winter 2012 Update”, CMS Physics Analysis Summary CMS-PAS-SMP-12-008, (2010).
- [52] K. Matchev and R. Remington, “Updated templates for the interpretation of LHC results on supersymmetry in the context of mSUGRA”, (2012). arXiv:1202.6580.
- [53] S. Alekhin, S. Alioli, R. D. Ball et al., “The PDF4LHC Working Group Interim Report”, (2011). arXiv:1101.0536.

A Supplemental Material: Baseline and search event selections

The event selection starts from a baseline selection. Events passing the baseline selection are then divided into 14 exclusive search regions. The baseline selection requirements after trigger are:

- at least three jets with $p_T > 50$ GeV and $|\eta| < 2.5$;
- $H_T > 500$ GeV;
- $\cancel{H}_T > 200$ GeV;
- $|\Delta\phi(J_n, \vec{\cancel{H}}_T)| > 0.5$ rad, $n = 1, 2$ and $|\Delta\phi(J_3, \vec{\cancel{H}}_T)| > 0.3$ rad, where $\Delta\phi$ is the azimuthal angle difference between jet axis J_n and the $\vec{\cancel{H}}_T$ direction for the three highest- p_T jets in the event;
- no isolated muons or electrons in the event;
 - muons and electrons are required to have $p_T \geq 10$ GeV and a good quality track that is matched to the primary vertex within $200 \mu\text{m}$ transversely and 1 cm longitudinally;
 - they are required to be isolated, with a relative isolation variable, defined as $\left[\sum^{\Delta R < 0.3} p_T^{\text{charged hadron}} + \sum^{\Delta R < 0.3} p_T^{\text{neutral hadron}} + \sum^{\Delta R < 0.3} p_T^{\text{photons}} \right] / p_T$, smaller than 0.2, where $p_T^{\text{charged hadron}}$, $p_T^{\text{neutral hadron}}$, and p_T^{photons} are, respectively, the transverse momenta of charged hadrons, neutral hadrons, and photons, as reconstructed by the particle-flow algorithm, within a distance $\Delta R = 0.3$ in η - ϕ space of the lepton;
 - muons are required to have $|\eta| < 2.4$, whereas electrons should have $|\eta| < 2.5$ excluding the barrel-endcap transition region $1.44 < |\eta| < 1.57$;
- jets with $p_T > 30$ GeV have an electromagnetic p_T fraction less than 0.95 and a neutral hadron p_T fraction less than 0.90.

Events passing the baseline selection are divided into 14 search regions:

- for the H_T bins of 500–800 and 800–1000 GeV, \cancel{H}_T is binned into 200–350, 350–500, 500–600, and >600 GeV;
- for the H_T bin of 1000–1200 GeV, \cancel{H}_T is binned into 200–350, 350–500, and >500 GeV;
- for the H_T bin of 1200–1400 GeV, \cancel{H}_T is binned into 200–350 GeV and >350 GeV;
- for the H_T bin of $H_T > 1400$ GeV, $\cancel{H}_T > 200$ GeV.

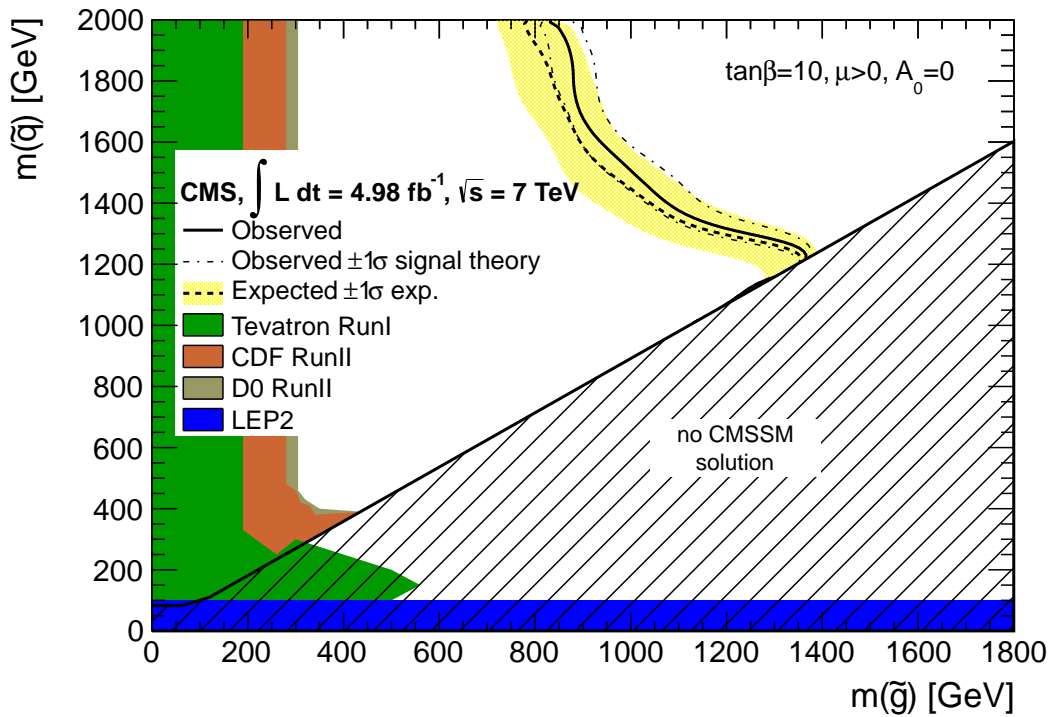


Figure 4: The observed and expected 95% CL lower limits in the CMSSM $(m(\tilde{g}), m(\tilde{q}))$ plane, for $\tan\beta = 10$, $\mu > 0$, and $A_0 = 0$. The yellow-shaded region shows the $\pm 1\sigma$ variation in the expected limit, while the dot-dashed curves show the variation in the observed limit when the signal cross section is varied by its theoretical uncertainties. The limits from earlier searches by other experiments [5, 6, 44] are also shown. Comparisons with earlier searches are shown for illustrative purpose only, as they are derived with different models or parameter choices.

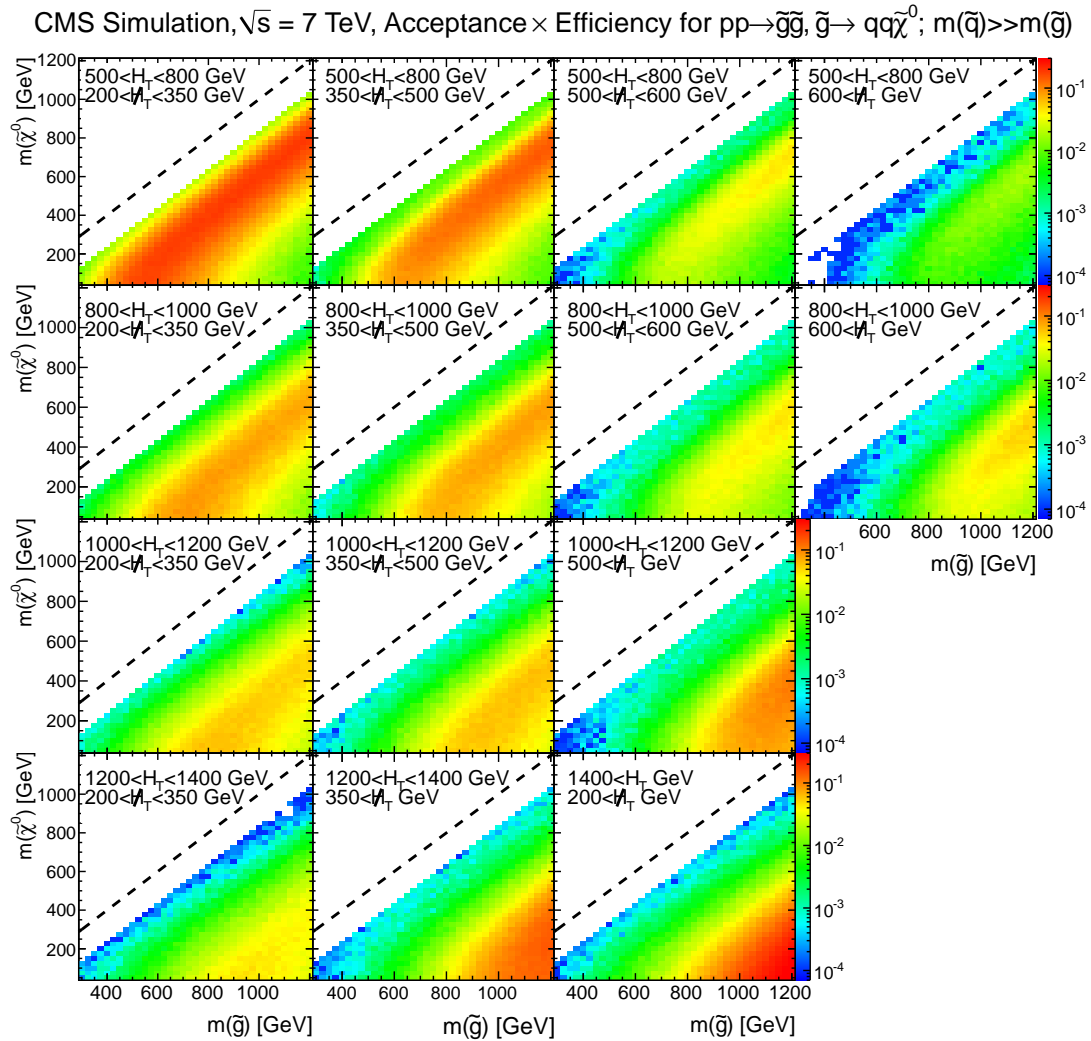


Figure 5: The acceptance times efficiency of the 14 search regions for the simplified model of $\tilde{g}\tilde{g}$ ($\tilde{g} \rightarrow qq\tilde{\chi}^0$) production in the $(m(\tilde{g}), m(\tilde{\chi}^0))$ plane. Empty points are due to the low acceptance times efficiency where no simulated signal events pass the search selection.

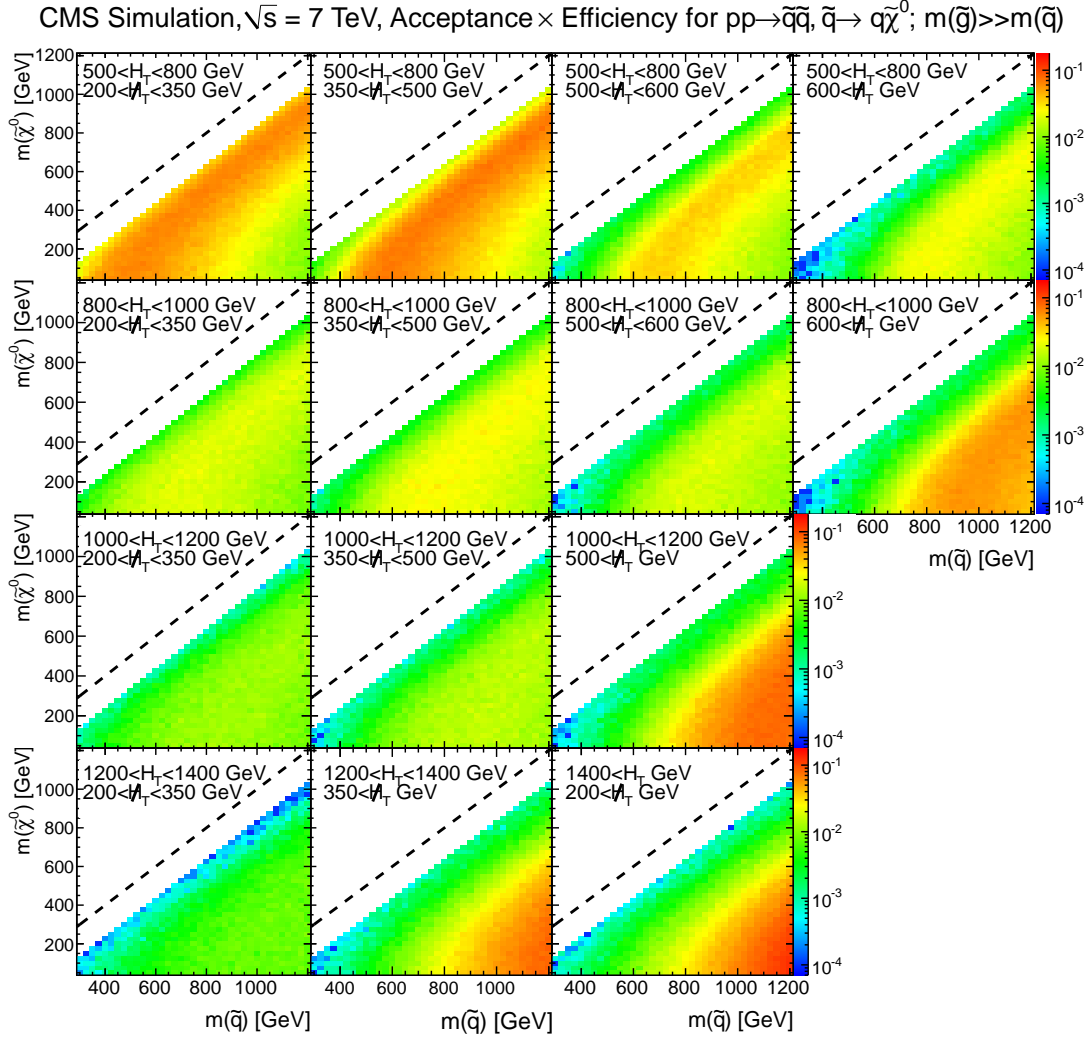


Figure 6: The acceptance times efficiency of the 14 search regions for the simplified model of $\tilde{q}\tilde{q}$ ($\tilde{q} \rightarrow q\tilde{\chi}^0$) production in the $(m(\tilde{q}), m(\tilde{\chi}^0))$ plane. Empty points are due to the low acceptance times efficiency where no simulated signal events pass the search selection.

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