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Search for Heavy Stable Charged Particles in pp Collisions at $\sqrt{s} = 7$ TeV

The CMS Collaboration[*]

Abstract

The result of a search at the LHC for heavy stable charged particles produced in pp collisions at $\sqrt{s} = 7$ TeV is described. The data sample was collected with the CMS detector and corresponds to an integrated luminosity of 3.1 pb^{-1}. Momentum and ionization-energy-loss measurements in the inner tracker detector are used to identify tracks compatible with heavy slow-moving particles. Additionally, tracks passing muon identification requirements are also analyzed for the same signature. In each case, no candidate passes the selection, with an expected background of less than 0.1 events. A lower limit at the 95% confidence level on the mass of a stable gluino is set at 398 GeV/c^2, using a conventional model of nuclear interactions that allows charged hadrons containing this particle to reach the muon detectors. A lower limit of 311 GeV/c^2 is also set for a stable gluino in a conservative scenario of complete charge suppression, where any hadron containing this particle becomes neutral before reaching the muon detectors.

[*]See Appendix A for the list of collaboration members

1 Introduction

Heavy stable (or quasi-stable) charged particles (HSCPs) appear in various extensions of the standard model (SM) [1–8]. If the lifetime of an HSCP produced at the Large Hadron Collider (LHC) is longer than a few nanoseconds, the particle will travel over distances that are comparable or larger than the size of a typical particle detector. In addition, if the HSCP mass is $\gtrsim 100$ GeV/c^2, a significant fraction of these particles will have a velocity, $\beta \equiv v/c$, smaller than 0.9. These HSCPs will be directly observable through the distinctive signature of a high momentum (p) particle with an anomalously large rate of energy loss through ionization (dE/dx).

Previous collider searches for HSCPs have often been performed under the assumption that these particles lose energy primarily through low-momentum-transfer interactions, even if they are strongly interacting, and are therefore likely to reach the outer muon systems of the detectors and be identified as muons [9–12]. The interactions with matter experienced by a strongly-interacting HSCP, which is expected to form a bound state (R-hadron) [13] in the process of hadronization, can lead to it flipping the sign of its electric charge or becoming neutral. A recent study [14] on the modeling of nuclear interactions of HSCPs traveling through matter, favours a scenario of charge suppression. In this model the probability is close to unity for an R-hadron containing a gluino, $\widetilde{g}$ (the supersymmetric partner of the gluon), or a supersymmetric bottom squark, to emerge as a neutral particle after traversing an amount of material typical of the detectors operating at LEP, the Tevatron, or LHC. If this model is correct, the majority of these HSCPs would not be observed in the muon system of a typical collider detector. Experimental strategies that do not rely on the muon-like behavior for the HSCPs are therefore of great importance. For instance, searches have been performed for very slow ($\beta \lesssim 0.4$) R-hadrons containing a gluino brought to rest in the detector [15, 16].

In this article we present a search for HSCPs produced in pp collisions at $\sqrt{s} = 7$ TeV at the LHC with the Compact Muon Solenoid (CMS) detector [17]. The search is based on the data sample collected between April and August 2010 corresponding to an integrated luminosity of 3.06 pb^{-1}. We use triggers requiring: a high-transverse-momentum muon ($p_T > 9$ GeV/c); or a dimuon pair ($p_T > 3$ GeV/c for each muon); or calorimeter-based missing transverse energy ($E_T^{miss} > 100$ GeV), to search for HSCPs failing muon identification or emerging mainly as neutral particles after traversing the calorimeters; or a high-transverse-energy jet ($E_T > 100$ GeV) to search for HSCPs accompanied by substantial hadronic activity. The analysis makes use of two approaches. In a first selection, referred to as "*tracker-only*", the HSCP candidates are searched for as individual tracks reconstructed in the inner tracker detector with large dE/dx and p_T. A second selection, referred to as "*tracker-plus-muon*", additionally requires that the track is identified as a muon in the outer muon detector. For both selections, the mass of the candidate is calculated from the measured p and dE/dx.

2 The CMS Detector

The central feature of the CMS detector is a 3.8 T superconducting solenoid of 6 m internal diameter surrounding a silicon pixel and strip tracker, a crystal electromagnetic calorimeter, and a brass-scintillator hadronic calorimeter. Muons are measured in gaseous detectors embedded in the iron return yoke. Centrally produced charged particles are measured in the tracker by three layers of silicon pixel detectors, followed by ten microstrip layers. At pseudorapidities ($\eta \equiv -\ln\tan(\theta/2)$, where θ is the polar angle measured with respect to the beam direction) above ≈ 1.5, particles are tracked in two pixel and twelve strip layers arranged in disks perpendicular to the beam axis. In this analysis, the dE/dx measurement is based only on the

information from the silicon strip detectors. The dE/dx measurement precision is limited by the silicon strip analogue-to-digital converter (ADC) modules that are characterized by a maximum number of counts per channel corresponding to about three times the average charge released by a minimum–ionizing particle (MIP) in 300 μm of silicon. This is the thickness of the modules mounted in the innermost silicon strip central layers. The p_T resolution for tracks measured in the central (forward) region of the silicon tracker is 1% (2%) for p_T values up to 50 GeV/c and degrades to 10% (20%) at p_T values of 1 TeV/c. The trigger and reconstruction efficiencies for HSCPs in the muon detectors are limited by the requirements on the arrival time of the particles at the muon system. These requirements affect the efficiency for detecting slow HSCPs. The dependence of the muon trigger efficiency on the particle velocity (β) is studied using data and Monte Carlo (MC) simulations and found to decrease, below $\beta = 0.7$. The muon trigger becomes completely inefficient at $\beta = 0.5$. A much more detailed description of the CMS apparatus can be found elsewhere [17].

3   Candidate Selection and Background Estimation

Candidate HSCPs are pre-selected by requiring a track with $|\eta| < 2.5$, $p_T > 15$ GeV/c, relative uncertainty on the p_T less than 15%, and transverse (longitudinal) impact parameter with respect to the reconstructed primary collision vertex less than 0.25 (2.0) cm. Candidate tracks are also required to have at least three measurements in the silicon-strip detector. For the tracker-plus-muon selection, we additionally require the track to be compatible with track segments reconstructed in the muon system. As an estimator of the degree of compatibility of the observed charge measurements with the MIP hypothesis, a modified version of the Smirnov-Cramer-von Mises [18, 19] discriminant is used (the modification applied to the original form of the discriminant eliminates the sensitivity to incompatibility with the MIP hypothesis due to low ionization):

$$I_{as} = \frac{3}{N} \times \left(\frac{1}{12N} + \sum_{i=1}^{N} \left[P_i \times \left(P_i - \frac{2i-1}{2N} \right)^2 \right] \right), \tag{1}$$

where N is the number of charge measurements in the silicon-strip detectors, P_i is the probability for a MIP to produce a charge smaller or equal to the i–th charge measurement for the observed path length in the detector, and the sum is over the track measurements ordered in terms of increasing P_i. The charge probability density function used to calculate P_i is obtained using tracks with $p > 5$ GeV/c in events collected with a minimum bias trigger. Non-relativistic HSCP candidates will have the value of the discriminant I_{as} approaching unity. Figure 1 shows normalized distributions of p_T and I_{as} in data and two MC samples, for candidates passing the tracker-only pre-selection. The first MC sample contains events from QCD processes. The second MC sample contains signal events from pair-production of stable $\widetilde{g}$ with a mass of 200 GeV/c^2. Both samples are generated with the PYTHIA v6.422 [20] MC package. More details on the simulation of the signal sample will be given below. The MC QCD simulations are found to reproduce the data, and the simulated signal is clearly separated. Because of the limited number of available simulated events with low transverse-momentum transfers, the MC QCD distributions display bin-to-bin variations in the size of the statistical errors.

The most probable value of the particle dE/dx is determined using a harmonic estimator I_h of grade $k = -2$:

$$I_h = \left(\frac{1}{N} \sum_i c_i^k \right)^{1/k}, \tag{2}$$

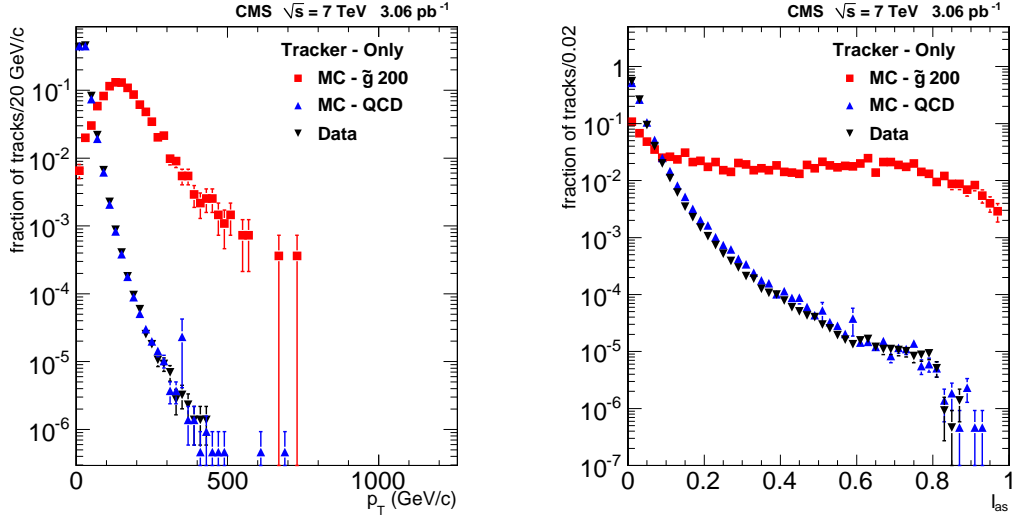where c_i is the charge per unit path length in the detector of the i-th measurement for a given

Figure 1: Normalized distributions of p_T (left) and I_{as} (right) in data and two MC samples, for candidates passing the tracker-only pre-selection. The two MC samples contain events from QCD processes and from pair-production of $\widetilde{g}$ with a mass of 200 GeV/c^2, respectively.

track. In order to estimate the mass (m) of highly ionizing particles, the following relationship between I_h, p, and m is assumed:

$$I_h = K\frac{m^2}{p^2} + C. \tag{3}$$

Equation 3 reproduces the Bethe-Bloch formula [21] with an accuracy of better than 1% in the range $0.4 < \beta < 0.9$, which corresponds to $1.1 < (dE/dx)/(dE/dx)_{MIP} < 4.0$. The empirical parameters K and C are determined from data using a sample of low-momentum protons, for which the fitted values are $K = 2.579 \pm 0.001$ MeV cm^{-1} c^2 and $C = 2.557 \pm 0.001$ MeV cm^{-1}, and the mass resolution is 7%. The reconstructed mass distribution for kaons and protons is in very good agreement with the one obtained from MC following this procedure [22]. For masses above 100 GeV/c^2, the mass resolution is expected to worsen because of the deterioration of the momentum resolution and because of the limit on the maximum charge that can be measured by the silicon strip tracker ADCs, which also affects the mass scale. For a 300 GeV/c^2 HSCP, the mass resolution is 12% and the reconstructed peak position is at 265 GeV/c^2.

The search is performed as a counting experiment. Signal candidates are required to have I_{as} and p_T greater than threshold values and the mass to be in the range of 75 to 2000 GeV/c^2, allowing sensitivity to HSCP masses as low as 100 GeV/c^2. The I_{as} distribution for the pre-selected tracks, and in particular its tail, depends strongly on the number of charge measurements on the track. Thus, to increase the sensitivity of the search, pre-selected tracks are divided into subsamples according to the number of silicon strip measurements. The I_{as} (p_T) threshold in each subsample is determined by requiring a constant efficiency on data for all subsamples, when the threshold is applied separately. A method that exploits the absence of correlation between the p_T and dE/dx measurements in data is used to estimate the background from MIPs. In a given subsample j, the number of tracks that are expected to pass both the final p_T and I_{as} thresholds set for the subsample is estimated as $D_j = B_j C_j / A_j$, where A_j is the number of tracks that fail both the I_{as} and p_T selections and B_j (C_j) is the number of tracks that pass only the I_{as} (p_T) selection. The B_j and C_j tracks are then used to form a binned probability density function in I_h (p) for the D_j tracks. Finally, using the mass determination (Eq. 3), the full mass spectrum of the background in the signal region D is predicted.

By comparing the predicted and observed number of tracks for several very loose selections in a control region of the mass spectrum, corresponding to masses below $75\,\mathrm{GeV}/c^2$, the prediction is found to underestimate systematically the observation by 12% (5%) for the tracker-only (tracker-plus-muon) selection. After correcting the predicted background by this amount, the remaining background systematic uncertainty is conservatively estimated as twice the r.m.s. of the prediction-to-observation ratio distribution The resulting uncertainty on the predicted background is 14% (17%).

As significant background rejection can be obtained without a sizable effect on the signal efficiency, the final selection is optimized by requiring the total expected background in the search region to be ~ 0.05 events. This low-background choice optimizes the discovery potential even if just a handful of events are observed, and at the same time maintains significant exclusion sensitivity in the case that no events are observed.

4   Results

In addition to the final "*tight*" selection, the result of a "*loose*" selection is reported in Table 1. The loose selection retains a relatively large number of background candidates and allows us to compare the background prediction with the observed data. Figure 2 shows good agreement between the observed and predicted mass spectrum obtained using the loose selection for the tracker-plus-muon and tracker-only candidates.
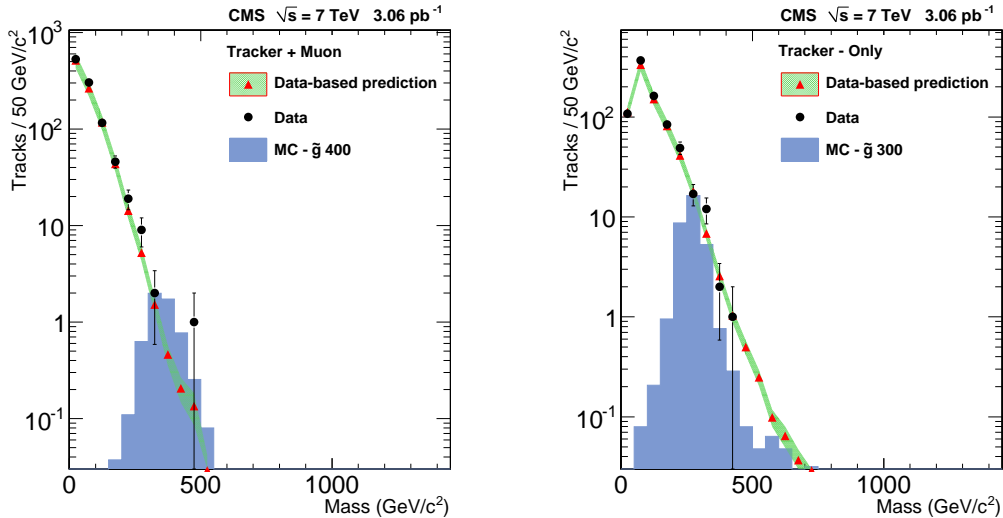

Figure 2: Mass spectrum for the loose selection defined in Table 1 for the tracker-plus-muon (left) and tracker-only (right) candidates. Shown are: observed spectrum (black dots with the error bars), data-based predicted background spectrum (red triangles) with its uncertainty (green band) and the spectrum predicted by MC for a signal of pair-produced stable $\widetilde{\mathrm{g}}$ with a mass of 400 (left) and 300 (right) GeV/c^2 (blue histogram).

The results of the search with the final selection are also presented in Table 1. No candidate HSCP track is observed in either the tracker-only or tracker-plus-muon analysis.

Given the null result, cross section upper limits at the 95% C.L. are set on the HSCP production for two benchmark scenarios: direct production of $\widetilde{\mathrm{g}}$ pairs and $\tilde{\mathrm{t}}_1$ pairs. For a given mass, the cross section for $\widetilde{\mathrm{g}}$ production is expected to be much larger than that for $\tilde{\mathrm{t}}_1$ production at both the Tevatron and the LHC. Thus higher mass limits can be set for the former at both machines.

Table 1: Selections used in the analysis and results of the search. The tracker-plus-muon and tracker-only selections are labeled as "Mu" and "Tk", respectively. As explained in the text, the actual I_{as} (p_T) thresholds are determined in the various subsamples by the requirement of a constant efficiency for candidate selection, ϵ_I (ϵ_{p_T}). These thresholds, indicated by I_{as}^{min} (p_T^{min}), are therefore reported as a range of values. Expected and observed number of candidates in the signal region are reported in the "Expected" and "Observed" rows, respectively. Top: loose selection. Bottom: tight selection.

LOOSE	**Mu**	**Tk**
ϵ_I	3.2×10^{-2}	1.0×10^{-2}
I_{as}^{min}	0.049 - 0.162	0.007 - 0.278
ϵ_{p_T}	1.0×10^{-1}	3.2×10^{-2}
p_T^{min} (GeV/c)	34 - 36	59 - 62
Expected	$281 \pm 2(stat.) \pm 49(syst.)$	$426 \pm 1(stat.) \pm 62(syst.)$
Observed	307	452
TIGHT	**Mu**	**Tk**
ϵ_I	1.0×10^{-4}	1.0×10^{-4}
I_{as}^{min}	0.184 - 0.782	0.186 - 0.784
ϵ_{p_T}	1.0×10^{-3}	3.2×10^{-4}
p_T^{min} (GeV/c)	115 - 118	154 - 210
Expected	$0.025 \pm 0.002(stat.) \pm 0.004(syst.)$	$0.074 \pm 0.002(stat.) \pm 0.011(syst.)$
Observed	0	0

However, as the mass of a produced particle increases, the ratio of the production cross section at the LHC to that at the Tevatron increases. For $\widetilde{g}$ masses in the region of 350 GeV/c^2, the increase in relative cross section outweighs the difference in integrated luminosity between the current Tevatron and LHC data sets, enabling the LHC to set the most sensitive limits on the search for $\widetilde{g}$.

Events with pair production of $\widetilde{g}$ and $\tilde{t}_1$, with mass values in the range 130-900 GeV/c^2, are generated with PYTHIA in order to compute the efficiency of our selection on these signals. The $\tilde{t}_1$ and $\widetilde{g}$ are treated as stable in all these samples and their hadronization is performed by PYTHIA. A parameter relevant to the $\widetilde{g}$ pair production, and not to the $\tilde{t}_1$ pair production, is the fraction, f, of produced $\widetilde{g}$ hadronizing into a $\widetilde{g}$-gluon state (R-gluonball). This fraction is an unknown parameter of the hadronization model and affects the fraction of R-hadrons that are neutral at production, which in turn affects the detection efficiency. In this study, results are obtained for two different values of f, 0.1 and 0.5, to show the effect of the hadronization model uncertainty on the sensitivity of the search. The interactions of the HSCPs with the CMS apparatus and the detector response are simulated in detail with the GEANT4 v9.2 [23, 24] toolkit. The R-hadron strong interactions with matter are modeled as in Ref. [25, 26]. This model, like a number of others [14, 27–29], assumes that the probability of an interaction between the heavy parton and a quark in the target nucleon is low since the cross section varies with the inverse square of the parton mass according to perturbative QCD. The adopted model chooses a pragmatic approach based on analogy with observed low energy hadron scattering. However, given the very large uncertainties on the dynamics underlying R-hadron interactions, an extremely pessimistic scenario of complete charge suppression, where each nuclear interaction suffered by the R-hadron causes it to become neutral, is also considered. The tracker-only selection is expected to have sensitivity even in such a scenario. The total signal efficiency is reported in Table 2 for some combinations of models and selections. Relatively small differences are found between the

Table 2: Total signal selection efficiency and cross section upper limits for different combinations of models and selections: pair production of supersymmetric stop and gluinos; tracker-plus-muon (Mu) and tracker-only (Tk) selections; different fractions, f, of R-gluonball states produced after hadronization and charge suppression (ch. suppr.) scenario.

gluino mass (GeV/c^2)	200	300	400	500	600	900
Theoretical cross section (pb)	606	57.2	8.98	1.87	0.470	0.0130
Mu; f=0.1						
Total efficiency (%)	7.17	10.4	13.1	15.1	14.5	9.18
Expected 95% C.L. limit (pb)	15.1	10.4	8.25	7.16	7.47	11.8
Observed 95% C.L. limit (pb)	14.5	9.98	7.92	6.88	7.17	11.3
Mu; f=0.5;						
Total efficiency (%)	3.84	5.46	7.03	8.23	8.10	4.98
Expected 95% C.L. limit (pb)	28.2	19.8	15.4	13.1	13.3	21.7
Observed 95% C.L. limit (pb)	27.1	19.0	14.8	12.6	12.8	20.9
Tk; f=0.1; ch. suppr.						
Total efficiency (%)	0.59	2.44	4.16	6.39	8.60	7.66
Expected 95% C.L. limit (pb)	188	45.5	26.7	17.4	12.9	14.5
Observed 95% C.L. limit (pb)	176	42.6	25.0	16.2	12.1	13.6
stop mass (GeV/c^2)	130	200	300	500	800	
Theoretical cross section (pb)	120	13.0	1.31	0.0480	0.00110	
Mu;						
Total efficiency (%)	2.99	9.50	14.7	19.6	14.0	
Expected 95% C.L. limit (pb)	36.1	11.4	7.35	5.52	7.71	
Observed 95% C.L. limit (pb)	34.7	10.9	7.06	5.30	7.39	
Tk; ch. suppr.						
Total efficiency (%)	0.02	1.19	3.55	7.27	7.68	
Expected 95% C.L. limit (pb)	5540	93.2	31.3	15.3	14.5	
Observed 95% C.L. limit (pb)	5180	87.2	29.2	14.3	13.5	

Table 3: Sources of systematic errors and corresponding relative uncertainties.

Source of Systematic Error	Relative Uncertainty (%)
Theoretical cross section	10 - 25
Integrated luminosity	11
Trigger efficiency	12
Muon reconstruction efficiency	5
Track reconstruction efficiency	< 5
Momentum scale	< 5
Ionization energy loss scale	< 3
Total uncertainty on signal acceptance	15

tracker-plus-muon and tracker-only selection except in the charge suppression scenario, where the tracker-plus-muon selection is completely inefficient.

This analysis is found to be complementary to the search for long-lived stopped particles presented in [16]. Indeed, for the case of $\widetilde{g}$ with $f = 0.1$ and mass values below 500 GeV/c^2, the fraction of HSCPs that have $\beta < 0.4$ and pass the final selection is less than 0.5%. Therefore the two analyses explore different ranges of produced particle velocities with no overlap.

The main sources of systematic uncertainty affecting the results presented in the following are summarized in Table 3. The uncertainty on the signal selection efficiency is estimated to be 15% for all considered combinations of models and selections. The main source of this uncertainty is an assumed 10% uncertainty on the jet energy scale [30], which affects both the jet and E_T^{miss} trigger efficiency by about 10%. In a more recent study [31], the estimate of the uncertainty on the jet energy scale has been reduced by a factor of two. However, in this analysis we have conservatively chosen to retain the earlier estimate of 10%. The uncertainty on the muon trigger efficiency and the impact of an imperfect simulation of the synchronization of the muon trigger and readout electronics are studied with data and MC. They result in an overall uncertainty on the signal selection efficiency of less than 5%. The uncertainty on the offline track reconstruction efficiency [32, 33], track momentum scale [34] and ionization energy loss scale [22] is also found to yield no more than 5% uncertainty on the overall signal selection efficiency. The uncertainty on the absolute value of the integrated luminosity is estimated to be 11% [35].

The upper limit on the cross section is computed at 95% C.L. using a Bayesian method with a flat signal prior and a log-normal prior used for integration over the nuisance parameters [18, 19, 21]. In order to obtain a conservative upper limit we set the expected background to zero. The tracker-plus-muon selection provides better limits than the tracker-only for all scenarios but the one with complete charge suppression. For each considered scenario, the cross section upper limit obtained with the most sensitive selection is reported in Table 2 and Fig. 3, along with the theoretical predictions for $\widetilde{g}$ and $\tilde{t}_1$ pair production computed at next-to-leading order (NLO) + next-to-leading log (NLL) [36–39] using the PROSPINO v2 program [40]. The $\widetilde{g}$ theoretical predictions refer to the case where the squarks and gluino are degenerate in mass. In the heavy squark limit these cross sections are about 10% higher. For the case of $\tilde{t}_1$, beyond LO, the cross section does not only depend on the $\tilde{t}_1$ mass, but also, though to a much lesser extent [41], on the $\widetilde{g}$ mass, the average mass of the first and second generation squarks and the stop mixing angle. For this reason, the $\tilde{t}_1$ theoretical predictions reported in Table 2 and Fig. 3 refer to the SPS1a' benchmark scenario [42]. All systematic uncertainties discussed above are included in the cross section upper limits reported in Table 2 and Fig. 3. From the intersection

of the cross section limit curve and the lower edge of the theoretical cross section band we set a 95% C.L. lower limit of 398 (357) GeV/c^2 on the mass of pair-produced $\widetilde{\mathrm{g}}$ with $f = 0.1(0.5)$, using the tracker-plus-muon selection. The analogous limit on the $\tilde{\mathrm{t}}_1$ mass is 202 GeV/c^2. In the charge suppression scenario we set, with the tracker-only selection, a 95% C.L. $\widetilde{\mathrm{g}}$ mass limit of 311 GeV/c^2 for $f = 0.1$.

5   Conclusions

In summary, the CMS detector has been used to identify highly ionizing, high-p_T particles and measure their masses. Two searches have been conducted: a very inclusive and model independent one that uses highly-ionizing tracks reconstructed in the inner tracker detector, and another requiring also that these tracks be identified in the CMS muon system. In each case, the observed distribution of the candidate masses is consistent with the expected background. We have set lower limits on masses of stable strongly interacting supersymmetric particles. For the case of $\widetilde{\mathrm{g}}$ with $f = 0.1$ and $\tilde{\mathrm{t}}_1$, a lower mass limit of 398 and 202 GeV/c^2, respectively, is set at the 95% C.L. with the analysis that uses muon identification. In a pessimistic scenario of complete charge suppression the above $\widetilde{\mathrm{g}}$ mass limit is reduced to 311 GeV/c^2 and is obtained with the tracker-only selection. The limits presented here on stable $\widetilde{\mathrm{g}}$ are the most restrictive to date.

6   Acknowledgements

References

[1] R. Barbieri, L. J. Hall, and Y. Nomura, "A constrained standard model from a compact extra dimension", *Phys. Rev.* **D63** (2001) 105007, `arXiv:hep-ph/0011311`. `doi:10.1103/PhysRevD.63.105007`.

[2] T. Appelquist, H.-C. Cheng, and B. A. Dobrescu, "Bounds on universal extra dimensions", *Phys. Rev.* **D64** (2001) 035002, `arXiv:hep-ph/0012100`. `doi:10.1103/PhysRevD.64.035002`.
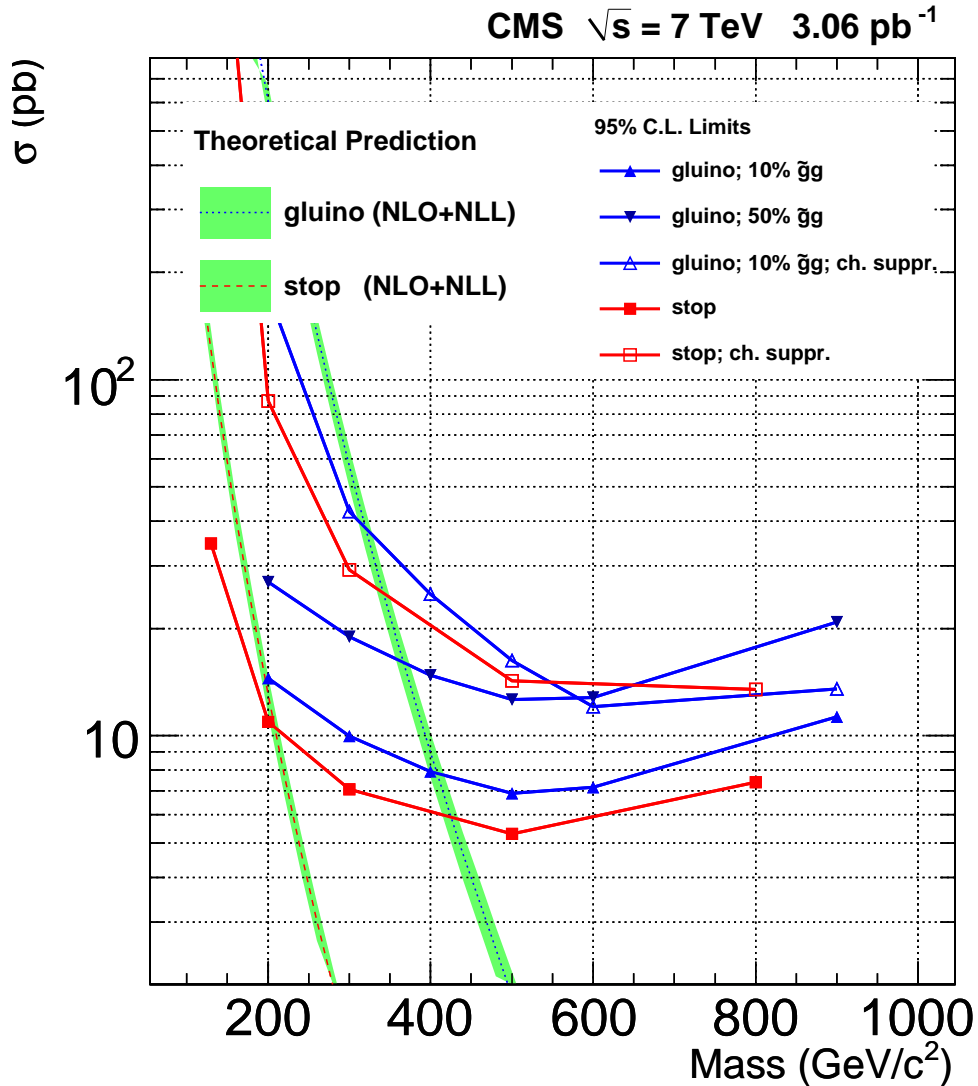
Figure 3: Predicted theoretical cross section and observed 95% C.L. upper limits on the cross section for the different combinations of models and scenarios considered: pair production of supersymmetric stop and gluinos; different fractions, f, of R-gluonball states produced after hadronization and charge suppression ("ch. suppr.") scenarios. Only the results obtained with the most sensitive selection are reported: tracker-only for the charge suppression scenarios and tracker-plus-muon for all other cases. The bands represent the theoretical uncertainties on the cross section values.

[3] P. H. Frampton and P. Q. Hung, "Longlived quarks?", *Phys. Rev.* **D58** (1998) 057704, `arXiv:hep-ph/9711218`. `doi:10.1103/PhysRevD.58.057704`.

[4] M. Dine, A. E. Nelson, and Y. Shirman, "Low-energy dynamical supersymmetry breaking simplified", *Phys. Rev.* **D51** (1995) 1362, `arXiv:hep-ph/9408384`. `doi:10.1103/PhysRevD.51.1362`.

[5] M. Dine, A. E. Nelson, Y. Nir et al., "New tools for low-energy dynamical supersymmetry breaking", *Phys. Rev.* **D53** (1996) 2658, `arXiv:hep-ph/9507378`. `doi:10.1103/PhysRevD.53.2658`.

[6] N. Arkani-Hamed and S. Dimopoulos, "Supersymmetric unification without low energy supersymmetry and signatures for fine-tuning at the LHC", *JHEP* **06** (2005) 073, `arXiv:hep-th/0405159`. `doi:10.1088/1126-6708/2005/06/073`.

[7] J. L. Feng, T. Moroi, L. Randall et al., "Discovering supersymmetry at the Tevatron in Wino LSP scenarios", *Phys. Rev. Lett.* **83** (1999) 1731, `arXiv:hep-ph/9904250`. `doi:10.1103/PhysRevLett.83.1731`.

[8] M. J. Strassler and K. M. Zurek, "Echoes of a hidden valley at hadron colliders", *Phys. Lett.* **B651** (2007) 374, `arXiv:hep-ph/0604261`. `doi:10.1016/j.physletb.2007.06.055`.

[9] CDF Collaboration, "Search for Long-Lived Massive Charged Particles in 1.96 TeV $\bar{p}p$ Collisions", *Phys. Rev. Lett.* **103** (2009) 021802, `arXiv:0902.1266`. `doi:10.1103/PhysRevLett.103.021802`.

[10] D0 Collaboration, "Search for Long-Lived Charged Massive Particles with the D0 Detector", *Phys. Rev. Lett.* **102** (2009) 161802, `arXiv:0809.4472`. `doi:10.1103/PhysRevLett.102.161802`.

[11] M. Drees and X. Tata, "Signals for heavy exotics at hadron colliders and supercolliders", *Phys. Lett.* **B252** (1990) 695. `doi:10.1016/0370-2693(90)90508-4`.

[12] M. Fairbairn et al., "Stable massive particles at colliders", *Phys. Rept.* **438** (2007) 1, `arXiv:hep-ph/0611040`. `doi:10.1016/j.physrep.2006.10.002`.

[13] G. R. Farrar and P. Fayet, "Phenomenology of the Production, Decay, and Detection of New Hadronic States Associated with Supersymmetry", *Phys. Lett.* **B76** (1978) 575.

[14] R. Mackeprang and D. Milstead, "An Updated Description of Heavy-Hadron Interactions", *Eur. Phys. J.* **C66** (2010) 493, `arXiv:0908.1868`. `doi:10.1140/epjc/s10052-010-1262-1`.

[15] D0 Collaboration, "Search for stopped gluinos from $p\bar{p}$ collisions at $\sqrt{s} = 1.96$ TeV", *Phys. Rev. Lett.* **99** (2007) 131801, `arXiv:0705.0306`. `doi:10.1103/PhysRevLett.99.131801`.

[16] CMS Collaboration, "Search for Stopped Gluinos in pp Collisions at $\sqrt{s} = 7$ *TeV*", *Phys. Rev. Lett.* **106** (2011) 011801, `arXiv:1011.5861`. `doi:10.1103/PhysRevLett.106.011801`.

[17] CMS Collaboration, "The CMS experiment at the CERN LHC", *JINST* **0803** (2008) S08004. `doi:10.1088/1748-0221/3/08/S08004`.

[18] W. T. Eadie, D. Drijard, F. E. James et al., "Statistical Methods in Experimental Physics". North Holland, Amsterdam, 1971.

[19] F. James, "Statistical Methods in Experimental Physics". World Scientific, Singapore, 2006.

[20] T. Sjostrand, S. Mrenna, and P. Z. Skands, "PYTHIA 6.4 Physics and Manual", *JHEP* **05** (2006) 026, `arXiv:hep-ph/0603175`. `doi:10.1088/1126-6708/2006/05/026`.

[21] Particle Data Group Collaboration, "Review of particle physics", *J. Phys.* **G37** (2010) 075021. `doi:10.1088/0954-3899/37/7A/075021`.

[22] CMS Collaboration, "CMS Tracking Performance Results from early LHC Operation", *Eur. Phys. J.* **C70** (2010) 1165–1192, `arXiv:1007.1988`. `doi:10.1140/epjc/s10052-010-1491-3`.

[23] S. Agostinelli, J. Allison, K. Amako et al., "G4–a simulation toolkit", *Nucl. Instrum. Meth.* **A506** (2003) 250. `doi:10.1016/S0168-9002(03)01368-8`.

[24] J. Allison et al., "Geant4 developments and applications", *IEEE Transaction on Nuclear Science* **53 No.1** (2006) 270. `doi:10.1109/TNS.2006.869826`.

[25] A. C. Kraan, "Interactions of heavy stable hadronizing particles", *Eur. Phys. J.* **C37** (2004) 91, `arXiv:hep-ex/0404001`. `doi:10.1140/epjc/s2004-01997-7`.

[26] R. Mackeprang and A. Rizzi, "Interactions of coloured heavy stable particles in matter", *Eur. Phys. J.* **C50** (2007) 353, `arXiv:hep-ph/0612161`. `doi:10.1140/epjc/s10052-007-0252-4`.

[27] Y. R. de Boer, A. B. Kaidalov, D. A. Milstead et al., "Interactions of Heavy Hadrons using Regge Phenomenology and the Quark Gluon String Model", *J. Phys.* **G35** (2008) 075009, `arXiv:0710.3930`. `doi:10.1088/0954-3899/35/7/075009`.

[28] H. Baer, K.-m. Cheung, and J. F. Gunion, "A Heavy gluino as the lightest supersymmetric particle", *Phys. Rev.* **D59** (1999) 075002, `arXiv:hep-ph/9806361`. `doi:10.1103/PhysRevD.59.075002`.

[29] A. Mafi and S. Raby, "An analysis of a Heavy Gluino LSP at CDF : The Heavy Gluino Window", *Phys. Rev.* **D62** (2000) 035003, `arXiv:hep-ph/9912436`. `doi:10.1103/PhysRevD.62.035003`.

[30] CMS Collaboration, "Jet Performance in pp Collisions at $\sqrt{s}$=7 TeV", *CMS Physics Analysis Summary* **CMS-PAS-JME-10-003** (2010).

[31] CMS Collaboration, "Jet Energy Corrections determination at 7 TeV", *CMS Physics Analysis Summary* **CMS-PAS-JME-10-010** (2010).

[32] CMS Collaboration, "Measurement of Tracking Efficiency", *CMS Physics Analysis Summary* **CMS-PAS-TRK-10-002** (2010).

[33] CMS Collaboration, "Performance of muon identification in pp collisions at $\sqrt{s}$ = 7 TeV", *CMS Physics Analysis Summary* **CMS-PAS-MUO-10-002** (2010).

[34] CMS Collaboration, "Measurement of Momentum Scale and Resolution using Low-mass Resonances and Cosmic Ray Muons", *CMS Physics Analysis Summary* **CMS-PAS-TRK-10-004** (2010).

[35] CMS Collaboration, "Measurement of CMS Luminosity", *CMS Physics Analysis Summary* **CMS-PAS-EWK-10-004** (2010).

[36] A. Kulesza and L. Motyka, "Threshold resummation for squark-antisquark and gluino-pair production at the LHC", *Phys. Rev. Lett.* **102** (2009) 111802, `arXiv:0807.2405`. `doi:10.1103/PhysRevLett.102.111802`.

[37] A. Kulesza and L. Motyka, "Soft gluon resummation for the production of gluino-gluino and squark-antisquark pairs at the LHC", *Phys. Rev.* **D80** (2009) 095004, `arXiv:0905.4749`. `doi:10.1103/PhysRevD.80.095004`.

[38] W. Beenakker et al., "Soft-gluon resummation for squark and gluino hadroproduction", *JHEP* **12** (2009) 041, `arXiv:0909.4418`. `doi:10.1088/1126-6708/2009/12/041`.

[39] W. Beenakker et al., "Supersymmetric top and bottom squark production at hadron colliders", *JHEP* **08** (2010) 098, `arXiv:1006.4771`. `doi:10.1007/JHEP08(2010)098`.

[40] W. Beenakker, R. Hopker, and M. Spira, "PROSPINO: A program for the PROduction of Supersymmetric Particles In Next-to-leading Order QCD", `arXiv:hep-ph/9611232`.

[41] W. Beenakker, M. Kramer, T. Plehn et al., "Stop production at hadron colliders", *Nucl. Phys.* **B515** (1998) 3, `arXiv:hep-ph/9710451`. `doi:10.1016/S0550-3213(98)00014-5`.

[42] J. A. Aguilar-Saavedra et al., "Supersymmetry parameter analysis: SPA convention and project", *Eur. Phys. J.* **C46** (2006) 43, `arXiv:hep-ph/0511344`. `doi:10.1140/epjc/s2005-02460-1`.

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