

1 Introduction

Several theoretical extensions of the Standard Model (SM), including Super Symmetry (split SUSY and MSSM), Gauge mediated Symmetry Breaking (GMSB), Hidden-Valley, Extra dimensions, and several others, predict the existence of heavy particles with long lifetime. If produced with lifetime larger than a few nanoseconds, these particles can pass through part of the detector before decaying, and therefore appear as stable. Depending on the mass and the charge of the HSCP particle, anomalously high rates of energy losses through ionization (dE/dx) with respect to the typical energy loss for SM particles ($\approx 3\text{MeV/cm}$ for SM particles with 10-1000 GeV momentum) can be expected. This feature is exploited to search for heavy stable (or quasi-stable) charged particles (HSCPs) by measuring the energy loss in the CMS silicon Tracker, discriminating heavily ionizing particles (HIPs) from minimum ionizing particles (MIPs).

2 Samples

Two benchmark scenarios are employed to account for a wider range of possible signatures of HSCP production at LHC.

A first kind of signal considered in this study is the production of gluino (\tilde{g}) pairs, that interact via the strong, electromagnetic, and weak interactions. In this model, HSCPs can also bound with SM quarks to form R-hadrons by strong interaction, leading to modifications of their quark constituents and therefore of their electric charge during the propagation through the detector material. Signal gluino have been generated with masses in the range 600-2600 GeV under the Split SUSY scenarios under the high squark mass (10 TeV) assumption, by the PYTHIA v8.xxx generator with the tune CUETP8M1. The fraction f of produced \tilde{g} hadronizing into a \tilde{g} -g state (R-gluonball) is an unknown parameter of the hadronization model and affects the fraction of R-hadrons that are neutral at production, and for this study results are obtained under the $f = 0.1$ assumption.

The second kind of signal consists of lepton-like HSCPs, which interacts via electromagnetic and weak forces behaving similarly to muons, as they tend to be deeply penetrating into the detector. The benchmark chosen for lepton-like HSCP is the minimal gauge mediated supersymmetry breaking (mGMSB) model, where production of supersymmetric quasi-stable leptons ($\tilde{\tau}$) can proceed either directly or via production of heavier supersymmetric particles (mainly squarks and gluino pairs) further decaying to one or more $\tilde{\tau}$ particles. The mGMSB model is chosen as benchmark using the SPS7 slope, which has the stau as the next-to-lightest supersymmetric particle (NLSP). The particle mass spectrum and the decay table are produced with the program ISASUGRA version 7.69. The mGMSB parameter Λ is varied

from 31 to 160 TeV, with fixed parameters $N_{\text{mes}} = 3$, $\tan\beta = 10$, $\mu > 0$, $C_{\text{grav}} = 10000$, and $M_{\text{mes}}/\Lambda = 2$. The large value of C_{grav} results in a long-lived stau, while $\Lambda = 31 - 510$ TeV gives a stau mass of 200 to 1600 GeV. Signal is generated using PYTHIA v8.xxx with the default tune CUETP8M1.

SM background samples have been used to simulate tracks produced as the result of proton-proton interactions in the CMS detector. For this purpose, Minimum Bias samples have been used, generated assuming a proton-proton inelastic cross section of xxx mb. To simulate high transverse momentum muons traversing the detector, a samples of Drell-Yan production is also used, to exploit muons from the leptonic Z boson decay.

All the signal and background samples used in this analysis have been subjected to the full simulation of the CMS detector with the phase 2 geometry (2023-D4) using GEANT 4. For all samples, three different configuration have been produced, to account for additional events produced in association with the primary collision in the same beam crossing (pileup): no pileup, 140 pileup, and 200 pileup.

3 Event Selection

Events are selected by requiring the presence of at lease one muon with transverse momentum $p_T > 55$ GeV, as reconstructed form the particle-flow algorithm to emulate a typical single muon trigger requirement. Single muon triggers are especially indicated for lepton-like HSCPs, which interact weakly with the detector and thus are normally reconstructed as muons inside the detector. To help recover some efficiency for hadron-like HSCPs, for which R-hadrons can change charge as they propagate through the detector and become neutral within or outside the tracker, trigger relying on the missing transverse momentum reconstructed in the detector could be exploited, although not included in this study.

All events are further required to have a candidate track produced with $p_T > 55$ GeV (as measured in the tracker detector only) in the tracker detector accept, with a relative uncertainty on p_T less than 25%, pseudorapidity in the tracker acceptance $|\eta| < 4$, track fit $\chi^2/\text{dof} < 5$, and magnitudes of the longitudinal and transverse impact parameters with respect to the primary vertex less than 0.5 cm. Candidates tracks must have at least XXX measurements in the silicon pixel detector.

4 Ionizing Particle Discriminator

An estimator of the degree of compatibility of the track with the hypothesis of it being generated by a MIP is defined. The dE/dx discriminator I_{as} is define as:

Table 1: Simulated samples used for this study. All the samples have been produced in three different pileup configurations: NoPU, 140PU, and 200PU.

Sample	σ
/HSCPggluino_M_600_TuneCUETP8M1_14TeV_pythia8/PhaseIFall16DR82-*_90X_upgrade2023_realistic_v1-v1/GEN-SIM-RECO	xxx
/HSCPggluino_M_1000_TuneCUETP8M1_14TeV_pythia8/PhaseIFall16DR82-*_90X_upgrade2023_realistic_v1-v1/GEN-SIM-RECO	xxx
/HSCPggluino_M_1800_TuneCUETP8M1_14TeV_pythia8/PhaseIFall16DR82-*_90X_upgrade2023_realistic_v1-v1/GEN-SIM-RECO	xxx
/HSCPggluino_M_1400_TuneCUETP8M1_14TeV_pythia8/PhaseIFall16DR82-*_90X_upgrade2023_realistic_v1-v1/GEN-SIM-RECO	xxx
/HSCPggluino_M_2600_TuneCUETP8M1_14TeV_pythia8/PhaseIFall16DR82-*_90X_upgrade2023_realistic_v1-v2/GEN-SIM-RECO	xxx
/HSCPggluino_M_2200_TuneCUETP8M1_14TeV_pythia8/PhaseIFall16DR82-*_90X_upgrade2023_realistic_v1-v1/GEN-SIM-RECO	xxx
/HSCPppstau_M_200_TuneCUETP8M1_14TeV_pythia8/PhaseIFall16DR82-*_90X_upgrade2023_realistic_v1-v1/GEN-SIM-RECO	xxx
/HSCPppstau_M_432_TuneCUETP8M1_14TeV_pythia8/PhaseIFall16DR82-*_90X_upgrade2023_realistic_v1-v1/GEN-SIM-RECO	xxx
/HSCPppstau_M_651_TuneCUETP8M1_14TeV_pythia8/PhaseIFall16DR82-*_90X_upgrade2023_realistic_v1-v1/GEN-SIM-RECO	xxx
/HSCPppstau_M_871_TuneCUETP8M1_14TeV_pythia8/PhaseIFall16DR82-*_90X_upgrade2023_realistic_v1-v1/GEN-SIM-RECO	xxx
/HSCPppstau_M_1218_TuneCUETP8M1_14TeV_pythia8/PhaseIFall16DR82-*_90X_upgrade2023_realistic_v1-v1/GEN-SIM-RECO	xxx
/HSCPppstau_M_1599_TuneCUETP8M1_14TeV_pythia8/PhaseIFall16DR82-*_90X_upgrade2023_realistic_v1-v1/GEN-SIM-RECO	xxx
/MinBias*_TuneCUETP8M1_14TeV_pythia8/PhaseIFall16DR82-*_90X_upgrade2023_realistic_v1-v1/GEN-SIM-RECO	xxx
/DYJetsToLL_M-50_TuneCUETP8M1_14TeV-madgraphMLM-pythia8_ext1/PhaseIFall16DR82-*_90X_upgrade2023_realistic_v1-v1/GEN-SIM-RECO	xxx

Table 2: Selection criteria

Variable	cut
p_T	$> 55 \text{ GeV}$
$ \eta $	< 4
d_z and d_{xy}	$< 0.5 \text{ cm}$
$\sigma(p_T)/p_T$	< 0.25
track χ^2/dof	> 5
pixel hits	$> X$
strip hits	$> X$
dE/dx measurements	$> X$

DUMMY

Figure 1: DeDxVsP

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

where N is the number of measurements in the silicon-tracker detectors, P_i is the probability for a minimum-ionizing particle to produce a charge smaller or equal to that of the i -th measurement for the observed path length in the detector, and the sum is over the track measurements ordered in terms of increasing P_i .

Pixel measurements are used for the computation of the discriminator due to the high resolution of the dE/dx measurements. The measurement produced by the silicon PS modules are instead exploited to add additional information to the already available dE/dx measurements produced by the pixel [TO BE MODIFIED ACCORDING TO THE LATEST VERSION OF THE I_{as} IMPLEMENTATION].

DUMMY

Figure 2: ROC

Table 3: Selection criteria

region	n. events
A	X
B	X
C	X
D	X

5 Background Estimation

The HSCP candidates are selected using the I_{as} discriminator by requiring tracks with criteria are $p_{\text{T}} > 65$ GeV and $I_{\text{as}} > 0.3$ (region D). The SM background is predicted relying on two non-correlated variables discriminating between signal and background. The background yield is in fact estimated from the Minimum Bias and Drell-Yan MC samples with a "ABCD" procedure by correcting the number of events passing the I_{as} requirement only (region B), for the ratio of the events yields passing the p_{T} requirement alone (region C) divided by the number of events failing both requirements (region A): $D = BC/A$.

6 Results

The expected performances of the analysis in absence of signal are shown in terms of cross-section reach, defined as the cross-section for which we expect to observe signal with a significance of at least 5 standard deviations (5σ). The results are presented for the three pileup scenarios (NoPU, 140PU, 200PU) for an integrated luminosity of 3000 fb^{-1} .

DUMMY

Figure 3: Limit