

Heavy Stable Charged Particle Searches at the LHC

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Abstract. This document focuses on the experimental techniques and perspectives for searches of Heavy Stable Charged Particles with the general purpose experiments ATLAS and CMS at the CERN Large Hadron Collider.

1. Heavy Stable Charged Particles phenomenology

Throughout this document a Heavy Stable Charged Particle (HSCP) is a stable or quasi stable particle that either possesses electric charge and/or interacts strongly. Mass values of the order of $100 \text{ GeV}/c^2$ or more are considered. HSCPs are predicted by a number of theoretical models [1] of physics beyond the Standard Model (SM) of fundamental interactions.

HSCPs could be produced by the Large Hadron Collider (LHC) as a result of direct pair production processes or as final products of the decay chain of heavier exotic particles. HSCPs with strong charge will hadronize and form mesons, baryons or glueballs. These particles are generically called R-hadrons. A distinctive feature of HSCPs produced at the LHC is that they are likely to be non relativistic. The two plots in figure 1 shows the β and transverse momentum (p_t) distribution of the R-hadrons resulting from gluinos of different mass values produced in pairs at the LHC. From the experimental point of view, a lepton like HSCP will basically behave as a muon in the detector. R-hadrons will experience nuclear interactions that are modelled [2] assuming that the heavy parton acts as a spectator. The resulting signature of an R-hadron notably features the possible conversion, after every nuclear interaction, into a different R-hadron species, which may have different electric charge (“charge flipping” effect). The energy loss of an R-hadron is expected to be sufficiently small as to allow it to easily reach the muon system of the LHC detectors.

2. Experimental techniques in ATLAS and CMS

In general, the identification of an HSCP is based on its low β and high momentum. Two independent measurements of these quantities allow the particle mass to be determined. The particle’s momentum is measured from the curvature of the track in the magnetic field in both the CMS [3] and ATLAS [4] experiments.

An indirect β measurement can be provided by the ionisation energy loss in the inner tracking silicon detectors. Instrumental aspects that must be kept under control are non linear response of the electronics, temperature dependence of the signal, saturation of the electronics dynamic range

(currently limited to about 3 m.i.p. in the CMS strip tracker), non synchronized sampling of the analog signal due to the particle delayed arrival, response equalization across all silicon modules and calibration of the absolute mass scale. The transition radiation tracker of ATLAS provides two additional methods to identify highly ionizing particles [5].

Techniques based on time of flight are also envisaged by both ATLAS and CMS to measure the particle speed. Precise (1 ns resolution) timing information is recorded by the drift chambers in the central rapidity region of the two experiments. Unlike standard muon track reconstruction, the particle β is left as a free parameter when the information from the staggered drift tubes is combined to extract the crossing points of the particle. The particle delay leads to complications in the readout timing: the minimum particle β to have a muon trigger signal synchronized with the signals produced by the particle in the inner detectors is about 0.65 and 0.75 for CMS and ATLAS, respectively. Moreover, given that the trigger electronics assumes particles traveling at the speed of light, additional muon trigger inefficiency is expected for slow HSCP. Finally, the charge flipping effect is expected to have a significant impact on the propagation of the reconstructed trajectory from the inner tracker to the muon system.

3. Feasibility studies

Two benchmark HSCP scenarios have been considered by CMS: stable gluinos (\tilde{g}), and stable scalar sleptons ($\tilde{\tau}_1$). Gluino masses of 100, 300 and 600 GeV/ c^2 produced in pairs with PYTHIA [6] have been generated. The fraction of produced gluino-balls was arbitrarily set to 0.1. Hadronization was performed with PYTHIA dedicated routines, while GEANT4 specific developments [7] were used to simulate the interactions of the R-hadrons in matter. Concerning the $\tilde{\tau}_1$ two points on the SPS line 7 [8] have been chosen. They result in a stable $\tilde{\tau}_1$ with a mass value of 152.3 and 242.9 GeV/ c^2 , respectively. The backgrounds considered are QCD b-jets, inclusive $t\bar{t}$, $W \rightarrow \mu\nu$ and Drell-Yan muon pair production. Events were fully simulated and reconstructed. Online event selection relies on the standard single muon trigger path, with increased cuts on the p_t applied after the Level-1 Trigger to relax the isolation requirements. Offline event selection is based on matching candidate HSCPs from the inner tracker (identification based on ionization energy loss) and muon system (identification with time of flight technique). Final mass reconstruction is done using the β value measured in the inner tracker because the measurement with the muon detectors is affected significantly by the energy loss in the calorimeters and iron yoke. The momentum measured with the inner tracker is used in the case of R-hadrons because the charge flipping effect is likely to bias the muon system measurement. Figure 2 shows the mass distribution of the remaining candidates for 2 (gluino mass of 100 and 300 GeV/ c^2) of the 4 studied scenarios. The integrated luminosity is 1 and 30 pb $^{-1}$, respectively.

An analysis strategy for stable gluinos has been studied also by ATLAS [5]. Simulation conditions are the same as in the CMS study with the exception that gluino mass values up to 2 TeV/ c^2 were considered and the fast simulation program was used. Events were selected with the standard ATLAS trigger table designed for a luminosity of 1033cm-2s-1 and by requiring the presence of high p_t (> 70 GeV/ c) track in the muon system having a time of flight exceeding by at least 3 ns the one expected from a muon with the same momentum. The signal significance obtained for an integrated luminosity of 1 fb $^{-1}$ and corresponding to the various mass values is reported in Table 1.

In conclusion both Collaborations have proven to be able to select HSCPs, if they are produced at the LHC. The stable gluino mass range that can in principle be explored with an integrated luminosity of 100 pb $^{-1}$ extends up to 1 TeV/ c^2 . Given the relatively simple experimental techniques involved, the HSCP searches could lead to one of the earliest discoveries at the LHC.

Table 1: Ratio of number of signal events over square root of number of background events after applying all cuts described in the text for several gluino masses and an integrated luminosity of 1 fb $^{-1}$.

Mass (GeV/ c^2)	100	300	600	900	1100	1300	1500	1700	1900
S / \sqrt{B}	5.9 10 ⁵	1.9 10 ⁴	9.8 10 ²	94	42.0	11.8	4.24	1.22	0.24

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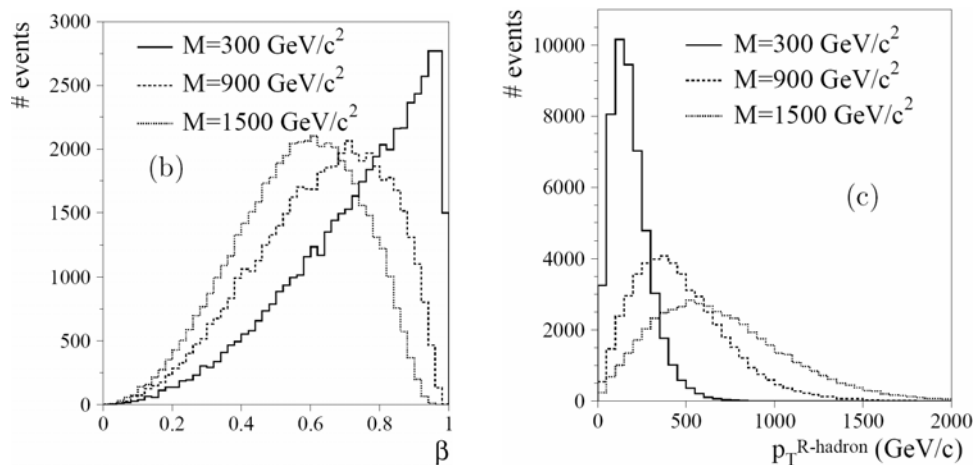


Figure 1: R-hadron β and p_T distribution at production for several gluino masses as indicated on the plots.

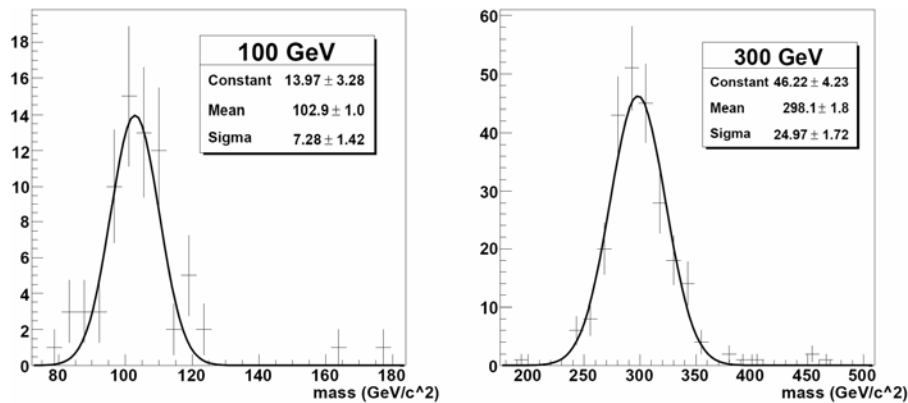


Figure 2: Reconstructed R-hadron mass after applying all cuts described in the text. R-hadrons result from gluino pair production events. Left (right) plot refers to a sample corresponding to gluinos of mass 100 (300) GeV/c^2 and integrated luminosity of 1 (30) pb^{-1} .