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Observability of R-Hadrons at the LHC

A. Rizzi

ETH Zurich, HPK F 24, Schafmattstrasse 20, 8093 Zurich, Switzerland

Abstract

Heavy long lived charged particles are predicted in several theories extending the Standard Model. If such particles are coloured they show up as hadrons. These hadrons can be detected in LHC experiments with the very first data exploiting their unique signatures of slow, high momentum particles.

1 Introduction

Several theoretical models predict the possible existence of new long-lived charged particles behaving in collider experiments as stable particles. The predicted particles can be charged under $U(1)$ gauge group (electrically charged) and/or under $SU(3)$ color group. In the latter case hadronized states are expected to appear and interact in the LHC detectors.

The common feature of this class of models is a signature consisting in an high mass stable particle, typically crossing the whole detector as a muon.

Two theoretical models have been studied in details in LHC experiments as benchmarks for a larger classes of scenarios that predict similar signatures: the Gauge Mediated Supersymmetry Breaking models (GMSB)[1] that predict a stable slepton ($\tilde{\tau}$) and the Split Supersymmetry models (Split SUSY)[2] that predict a long lived gluino. In both cases the new quasi-stable particles are expected to have lifetime high enough to cross the detector and a mass higher then ~ 100 GeV.

Here the focus is on the latter class of models, in that case gluinos are the long lived particle and they show up in hadronized states called “R-Hadrons”.

The main feature of Split Supersymmetry models is that the masses of scalars are set to a high energy scale ($\Lambda \gtrsim 10^6$ GeV). The gluinos are hence long lived because, being the Next to Lightest Supersymmetric Particle (NLSP) they can only decay into a neutralino (LSP) via a virtual sfermion.

Other models predicting coloured long-lived particles are:

- SuSY breaking with a boundary condition on an extra dimension [3]
- Stable Kaluza-Klein excitation [4],[5]
- Fourth generation fermions [6].

Different R-hadrons types can be formed from a gluino or a squark. The charge of the resulting R-hadron is determined by the quarks bounded to it. While crossing the matter an R-hadron suffers hadronic interactions in which the light quarks bounded to the heavy parton may change, in this case the electric charge of the R-hadron changes.

In order to understand LHC observability the R-hadrons a first crucial step is to understand the effect of the hadronic interactions that a R-hadron suffer when crossing the LHC detectors. The amount of energy loss and the effects of charge flipping should be studied.

2 Simulation of R-Hadron interactions

Some models have been proposed for R-hadrons matter interaction (a review of different models is available[7]) and some of them have been implemented in the simulation programs used for LEP (Geant3 based[8]) and LHC (Geant4 based[9]) experiments.

Two common starting point are usually assumed in those models. First the heavy parton is considered as completely not interacting, acting as a spectator and a reservoir of kinetic energy. Second, the asymptotic cross section value for high Q^2 is tuned on the pion-nucleon cross section, with a rescaling simply based on light quark counting (e.g. 2 quarks in case of gluino-mesons and 3 quarks for gluino-baryons).

The energy loss per interaction as a function of γ, as computed by the Geant 4 models[9] are shown in figure 1. The typical energy loss per interaction is of the order of 1 GeV at $\gamma = 2$, to be compared with the total kinetic energy $E_{kin} > 100$ GeV (for a particle with mass $m > 100$ GeV). This means that the particle is not going to suffer a hadronic showering when crossing calorimeters, and hence is unlikely to be absorbed in the experiments.

A remarkable effect of the several interactions occurring to a R-hadron crossing the LHC experiments calorimeters is that, according to the heavy-parton type (gluino, stop or antistop) they tend to convert to a single hadron type. This is due to the fact that interacting with ordinary matter, made of quarks, final states with more antiquark are less probable. So in case of gluino and stop the R-hadrons will become R-baryons after few interaction, while for antistop the preferred state would be the R-meson.

In figure 1 the fraction of R-hadrons converted as function of the penetration depth in iron is shown. Since the interaction cross section are different in case of R-baryons and R-mesons, a scenario in which stop/antistop are long lived can be distinguished, with respect to the gluino case, by the presence of different energy deposits in calorimeters showing some correlation with the particle charge.

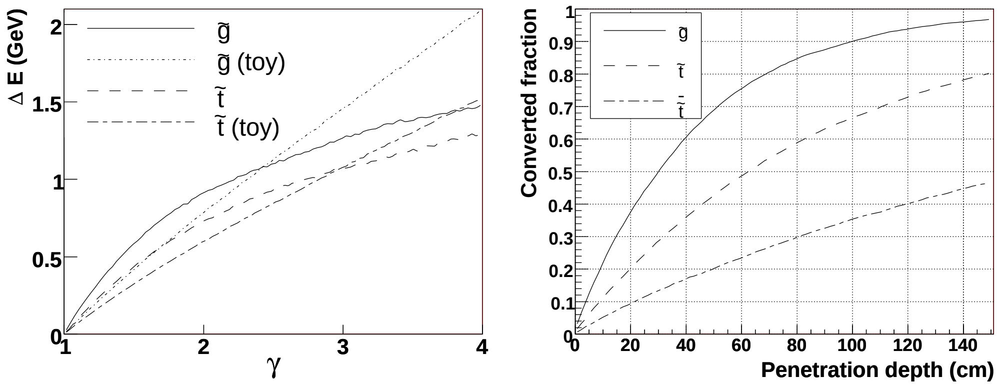

Figure 1: Energy loss per interaction in two different Geant 4 models (left). Fraction of R-hadrons converted in gluino/stop baryons or anti-stop mesons as a function of the penetration depth in iron (right).

3 LHC production and detection

The LHC production of Split Susy gluinos is like that of ordinary Susy gluinos. The production happens mainly via gluon-gluon interaction, with a high total cross section which goes from $\sigma = 50$ nb for a gluino mass of $m = 100$ GeV to $\sigma = 0.1$ pb at $m = 1$ TeV. This means that in this mass range a large number of gluinos are produced even with the first LHC data ($L \sim 1$ fb^{-1}).

The velocity and momentum spectra of gluino for masses of $m = 100, 300, 600$ GeV as generated with Pythia[10] are shown in figure 2. A good fraction of the gluinos have a velocity in the range $0.3 < \beta < 0.9$. In this range

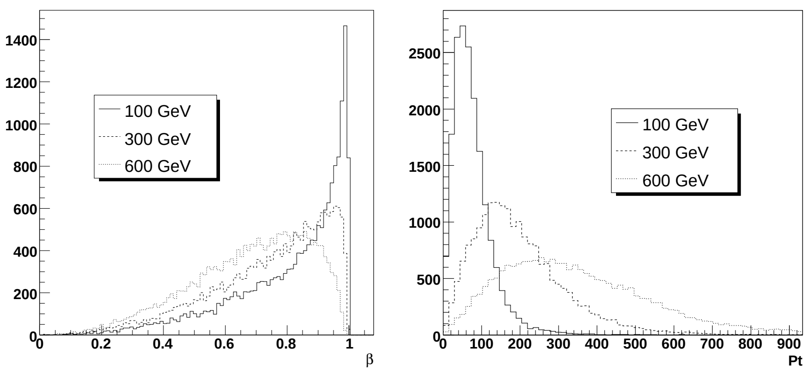

Figure 2: Velocity (left) and transverse momentum (right) for three different gluino masses.

particles are fast enough not to be absorbed in the detector (lower β would mean very high ionization energy loss) but also significantly different from ultra-relativistic particles such as ordinary particles at momenta in this range ($P > 50$ GeV).

This difference in β can be exploited in order to identify heavy long lived charged particles but also lead to some experimental problems due to the fact that LHC experiments are designed with a very short time response (of order of 25 ns) to separate events of different LHC bunch crossing.

In order to identify such particles we need to measure their momenta and their velocity, so that a mass can be reconstructed and they can be distinguished from Standard Model particles. If the particle is charged the momentum can be easily measured in the LHC tracking detectors. The same detectors may provide information on the amount of ionization energy released ($\frac{dE}{dX}$). Inverting the Bethe-Bloch formula in the range $0.1 < \beta < 0.9$ it is possible to reconstruct the particle β given its $\frac{dE}{dX}$. A complementary approach for the measurement of the average β of a particle reaching the muon systems of LHC experiment is measuring the time of flight using the Drift Tube detectors used in muon spectrometers of CMS and ATLAS.

It is possible to trigger events containing such particles by using muon triggers that can be fired by the long-lived particle itself. This approach has the advantage of being model independent and is hence the preferred way. Complementary approach may rely on the event to be triggered by other high energy particles in the event producing

jets or lepton candidates. The main limit of the muon triggers for slow particles is that a minimum velocity of $\beta \gtrsim 0.6$ is required in order to have the event be assigned to the correct LHC bunch crossing. The bunch cross assignment is then used to read the correct data from other subdetectors. If the event is assigned to the wrong bunch crossing the event may fail the higher level trigger and so it may be lost. Nevertheless an high fraction of events are expected to have gluinos with $\beta > 0.6$ so this trigger is still the more promising one. The charge flipping of R-hadrons may add some additional inefficiency in the trigger process so a full simulation of R-hadrons events including hadronic energy loss and charge flipping has been performed in ATLAS and CMS to study the detectability. The result, obtained with some conservative assumption, is that an overall $\sim 15\%$ efficiency can be obtained in CMS for gluinos with $m = 600$ GeV.
If R-hadrons events can be triggered using muon triggers the main backgrounds are expected to be Standard Model events with muons. The best way to distinguish R-hadrons, as well as any heavy stable charged particle, from muons is measuring its velocity and then reconstructing its mass. The mass measurement itself is also interesting being a free parameter in the various models. It has been proved in CMS that using $\frac{dE}{dX}$ and time of flight it is possible to measure velocity with a few % precision and almost completely separate the signal and backgrounds. The resolution obtained combining the two measurements is shown as a function of the particle velocity in figure 3. The optimal region for mass measurement is for $0.6 < \beta < 0.8$ in which the measurement is less biased and

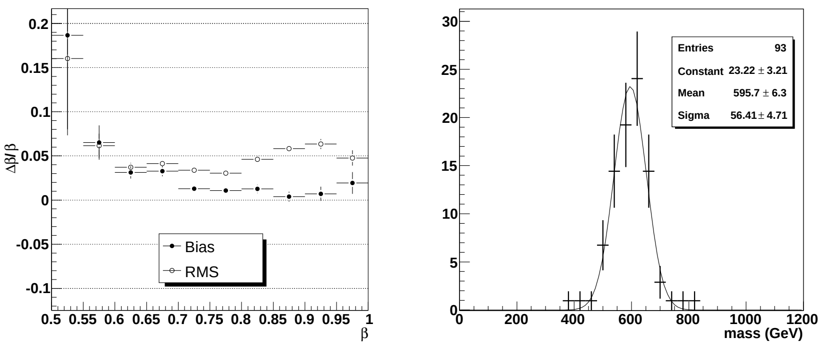

Figure 3: β resolution as a function of the simulated β (left) and reconstructed mass (right) for a 600 GeV gluino.

with a better resolution. The mass distribution obtained for a 600 GeV gluino with 0.5 fb^{-1} is also shown in figure 3.

4 Conclusion

Using two different techniques for measurement of β it will be possible in LHC experiment to search for heavy stable charged particle, including R-hadrons or similar particle originated by a long lived coloured particle. The two methods for β measurement have different backgrounds so it is possible, by combining them, to perform a robust and model independent data analysis. Detailed detector understanding, starting with the detectors commissioning in 2007, is needed to give a precise estimate of the discovery reach of LHC experiments with first data.
For long-lived gluinos the discovery should be possible with the first 1 fb^{-1} up to about $m \sim 1$ TeV; for other models the results should be scaled with the production cross section in a proton-proton interaction at 14 TeV.

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