PROCEEDINGS OF SCIENCE

Search for new physics with Long-Lived Particles at the LHC

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Several extensions of the Standard Model, including Hidden Valley models and few supersymmetric models, predict the existence of long-lived particles decaying far from the interaction point or traveling inside the detector with beta significantly smaller than one. Searches for new long-lived particles using 2011 and 2012 LHC data have been carried by ATLAS [1] and CMS [2] experiments at the Large Hadron Collider. The sensitivity of these searches is reviewed.

VI Italian workshop on p-p physics at the LHC,
8-10 May 2013
Acquario di Genova, Ponte Spinola, Area Porto Antico, Genova, Italy

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1. Introduction

The standard model (SM) of particle physics has proven extremely successful, but still remains incomplete. There are many proposed models, which address the open issues of the SM. Long-lived particles (LLP) are predicted by several of them, such as hidden valley (HV) scenarios or supersymmetry (SUSY) with gauge-mediated symmetry breaking (GMSB) or anomaly-mediated symmetry breaking (AMSB). These particles may be charged or neutral, decaying into SM and/or weakly interacting particles that escape detection. The identification of the LLP's is based on specific signatures: large energy loss (dE/dx) because of their small $\beta\gamma$, delayed signals compared to SM particles because of the small β, displaced decay vertex identified either with the tracker or with off-pointing energy deposits with calorimeters.

2. Heavy Stable Charged Particles

2.1 R-hadrons and sleptons

Many extensions of the SM include heavy, long-lived, charged particles that have β significantly less than 1 and/or charge not equal to $\pm 1e$. Sleptons are predicted to be metastable in GMSB models. R-hadrons, bound states formed by squark or gluinos and SM particles, are predicted to be long-lived and their electric charge can change due to nuclear scattering in the detector. With lifetimes greater than a few nanoseconds, these particles can travel distances larger than the typical collider detector and appear stable. The analysis strategy is driven by the measured dE/dx and/or through the long time-of-flight (TOF) measured in the outer detectors. The dE/dx allows also for the identification of particles with multiple/fractional charge. There are different analysis strategies in order to have sensitivity to the different LLP's. The approach based on tracks reconstructed in both the inner detectors and the muon system maximizes the slepton discovery potential while the analyses based on tracks reconstructed only in the inner silicon detectors or only in the muon system allow for the possibility of charge flipping (charged to neutral or vice versa) within the calorimeter or tracker material. R-hadrons and sleptons have been searched by ATLAS and CMS with 7 and 8 TeV data and no significant excess is observed [3, 4]. Mass limits for gluinos, stops, staus, fractionally charged particles, and multiply charged particles are reported in Figure 1 (left).

CMS also performs a search for long-lived particles that have stopped in the detector, when there were no proton-proton collisions, namely during gaps between LHC beam crossings [6]. Limits on long-lived particle pair production are set. In Figure 1 (right) the exclusion in the plane $m_{\tilde{g}} - m_{\tilde{\chi}^0}$ for gluino lifetimes in the range 10 μs and 1000 s, and assuming BF($\tilde{g} \to g\tilde{\chi}_1^0$) = 100% is shown.

2.2 Long-lived charginos in AMSB model

In the context of the AMSB scenario with R-parity violation (RPV), the chargino can decay to a neutralino and a low energy pion, resulting in a disappearing track in the inner tracker. This ATLAS analysis, based on 2011 collisions, uses the number of hits in the outer tracker and the transverse momentum (p_T) of the track, starting from events triggered by a high-p_T jet from initial state radiation. The selected events are consistent with the expectation from the SM background

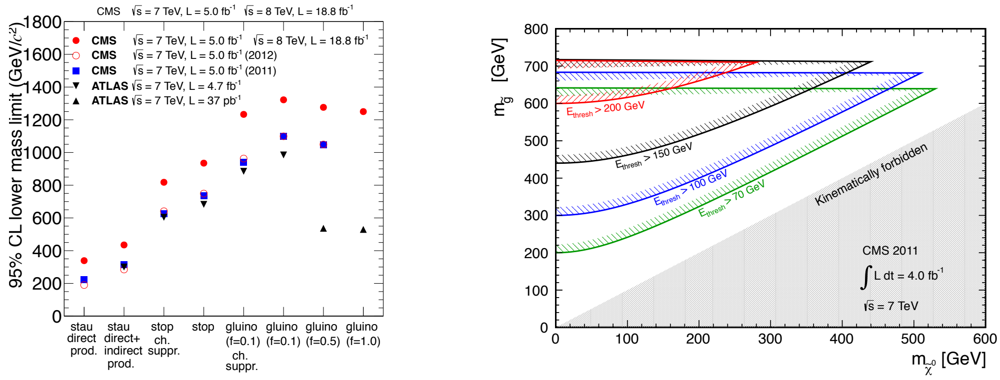

Figure 1: Left: Lower mass limits at 95%CL for gluinos, stops, staus, fractionally charged particles, and multiply charged particles. Right: Excluded region in the $m_{\tilde{g}} - m_{\tilde{\chi}^0}$ plane for analysis on stopped particles, valid for gluino lifetimes 10^{-5} s $< \tau_{gluino} < 10^3$ s, using several jet energy thresholds (E_{thresh}).

processes and constraints on chargino properties are obtained. For $\Delta M(chargino - neutralino) \sim$ 160 (170) GeV the chargino mass is excluded up to 103 (85) GeV at 95% CL [5].

3. Displaced vertexes with tracks

3.1 Displaced neutralino decay in RPV SUSY

In some RPV SUSY scenarios, the lightest supersymmetric particle (neutralino) can be a LLP and decays in muon and many high-p_T charged tracks originating from a single displaced vertex. The results presented here are obtained with the ATLAS detector on 2011 data. The muon is used to trigger the event and a dedicated vertex reconstruction has been developed for the analysis. No events excess is observed and limits are set as a function of the neutralino lifetime. To allow these limits to be used in a variety of models, they are presented for a range of squark and neutralino masses as shown in Figure 2 (left) [11].

3.2 Hidden sector neutral particles

In models where there is an extra sector weakly coupled to the SM heavy particles (e.g. Higgs boson) decay to particles of the hidden sector and back to the SM particles. In these scenarios a neutral long-lived, spinless, exotic particle is the LLP and decays to dileptons in the tracking volume. In both ATLAS and CMS studies, the model consists of a Higgs boson decaying to new hidden sector particles which finally produce two pairs of displaced leptons. In ATLAS the topological signature is represented by lepton jets, i.e. collimated pairs of muons, reconstructed with the muon system. These arise if light unstable particles with masses in the MeV to GeV range (for example dark photons, γ_d) reside in the hidden sector and decay predominantly to SM particles. In the CMS analysis, the displaced lepton vertex is reconstructed in the inner tracker. Both experiments see no excess and set upper limits. ATLAS analysis uses 1.9 fb^{-1}, and limits are determined assuming the SM production rate for a 140 GeV Higgs boson and γ_d are excluded in the range 1.2 mm $< c\tau <$ 431 mm [9]. In CMS, limits are set on the $\sigma \times BR$ to $H \to XX$ as a function of the long-lived X particle mean lifetime for m$_H$ = 125 GeV as shown in Figure 2 [10].

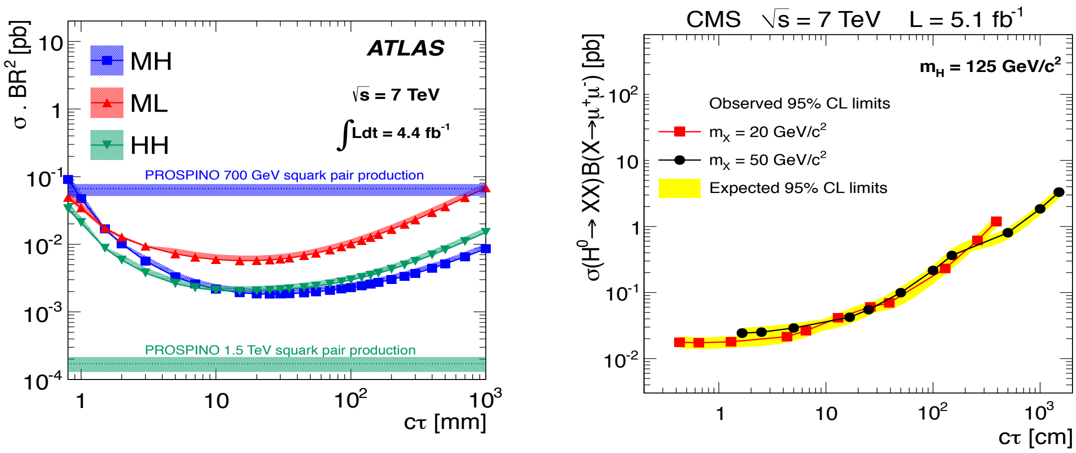

Figure 2: Left: Upper limits at 95% confidence level on σBR^2 vs the neutralino lifetime for different combinations of squark and neutralino masses. Right: The 95% CL upper limits on σBR for the muon channel for a Higgs mass of 125 GeV.

4. Displaced Photons

In some GMSB scenarios, the neutralino is the next-to-lightest supersymmetric particle (NLSP) and decays almost exclusively into a photon and a weakly interacting gravitino. The gravitino gives rise to a momentum imbalance in the transverse plane by leaving the detector without depositing energy. The dominant production mode of the neutralino is through a pair of gluinos via the strong interaction decaying via cascades. The neutralino is expected to be produced in association with high transverse momentum jets. The long-lived NLSP scenario introduces the possibility of a photon being produced after a finite delay and with a flight direction that does not point back to the primary vertex of the event. The analysis strategy exploites the capabilities of the ATLAS and CMS electromagnetic calorimeters. In ATLAS, thanks to the longitudinally segmented calorimeter, the flight direction of photons is used to identify such events. In CMS the time delay, due to the extra flight length added by the neutralino decay, is measured taking advantage of the excellent time resolution of the electromagnetic calorimeter. Both experiments have shown a good agreement with SM events [7, 8]. For instance, CMS sets an upper limit on the mass of the neutralino at 220 GeV for $c\tau < 600$ mm at 95% CL.

5. Conclusions

The search for new phenomena beyond the Standard Model is a very active field in ATLAS and CMS. Recent results for searches of new long-lived particles have been reviewed in this note. These searches take advantage of the unique detector signatures predicted by the different models. No excess over the Standard Model expectation has been observed and limits are placed on the various models. Updates using the full collected statistics are expected soon and many improvements will be included in order to make these searches less model-dependent. In the meanwhile, the discussion has started in view of the upgrade of the detectors for the phase of higher LHC luminosities. The search for long-lived particles has to be taken in account in designing the upgraded detectors, since their reconstruction capabilities have to be preserved, as well as dedicated trigger algorithms to identify such signatures.

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PoS(LHCPP2013)012