IL NUOVO CIMENTO Vol. 37 C, N. 1 Gennaio-Febbraio 2014
DOI 10.1393/ncc/i2014-11663-0

Colloquia: IFAE 2013

Searches for long-lived particles with the ATLAS detector at the LHC

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ricevuto l'1 Ottobre 2013

Summary. — Data taken in 2011 with the ATLAS detector at the Large Hadron Collider have been used to search for physics beyond the Standard Model. Results are presented based on luminosities between 2 and 5 fb^{-1} of $\sqrt{(s)} = 7\,\text{TeV}$ proton-proton collisions focusing on final states with long-lived particles. No evidence of new physics is found.

PACS 12.60.-i – Models beyond the Standard Model.

1. – Introduction

The Standard Model (SM) of particle physics has proven extremely successful, but despite its many successes still remains incomplete. New particles with long lifetimes (LLP, Long-Lived Particles) are predicted in many models of physics beyond the SM, such as Hidden Valley (HV) scenarios or Supersymmetry (SUSY) with Gauge-Mediated Supersymmetry Breaking (GMSB), Anomaly-Mediated Supersymmetry Breaking (AMSB) or R-parity violation (RPV). These particles may be neutral and decay into SM and/or weakly interacting particles that escape the detection. This note presents the searches with ATLAS detector [1] for LLPs based on data collected during 2011 at $\sqrt{s} = 7\,\text{TeV}$.

2. – Heavy stable charged particles

2·1. *Long-lived charginos in AMSB model.* – The results presented are interpreted in the context of AMSB scenario. The chargino ($\chi_1^{\pm}$) decays to a neutralino and a low energy pion, resulting in a disappearing track in the inner tracker with few associated hits in the outer region of the tracking system, namely in the Transition Radiation Tracker (TRT). The selection cut flow is based on the number of hits in the TRT and the p_T of the track, starting from events triggered by a single jet from initial state radiation. The transverse momentum spectrum of candidate tracks is found to be consistent with the expectation from the SM background processes and constraints on chargino properties

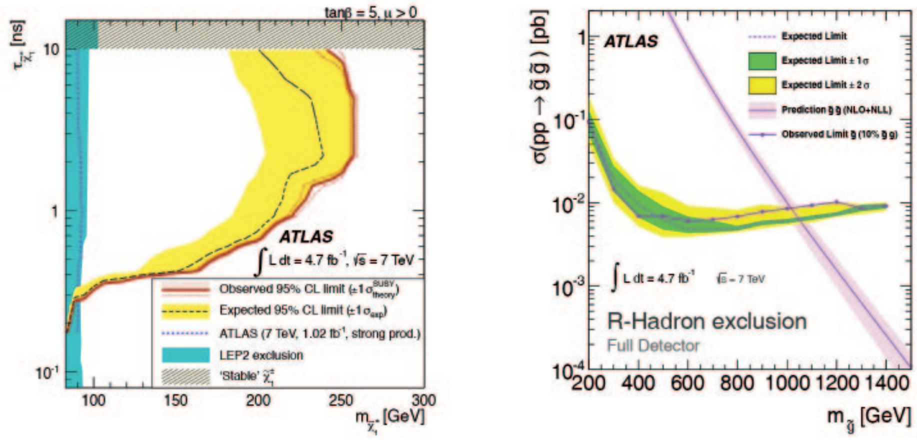

Fig. 1. – Left: constraint on the lifetime ($\tau_{\chi_1^\pm}$)-mass ($m_{\chi_1^\pm}$) parameter space in the search for long-lived charginos. Right: Cross-section upper limits at 95% CL for gluino R-hadrons in the full-detector search are shown. Both the expected limit with $\pm1, 2\sigma$ uncertainty bands and the observed upper limit are given. In addition the theoretical prediction for the production cross-section calculated at NLO+NLL and its uncertainty are drawn.

are obtained based on $4.7\,\text{fb}^{-1}$ of data [2]. For a mass difference between chargino and neutralino of $\sim 160\,(170)$ MeV the chargino mass is excluded up to 103 (85) GeV at 95% CL. The constraint on the lifetime ($\tau_{\chi_1^\pm}$) - mass ($m_{\chi_1^\pm}$) parameter space is shown in fig. 1 (left).

2·2. *R-hadrons and sleptons*. – Many extensions of the SM include heavy, long-lived, charged particles that have speed β, significatively less than 1 and/or electric charge not equal to $\pm$1e. Sleptons are predicted to be metastable in GMSB models. R-hadrons, bound states formed by squark and gluinos, are predicted to be metastable and their electric charge can change due to nuclear scattering in the detector. With lifetimes greater than a few nanoseconds, these particles can travel distances larger than the typical collider detector and appear as stable. The analysis strategy is driven by the large amount of energy lost via ionization ($\mathrm{d}E/\mathrm{d}x$) and/or through the long time-of-flight (TOF) needed to reach the outer detectors. The analyses fall into multiple topologies and strategies: requiring tracks reconstructed in both the inner detectors and the muon system, as in the tracker+TOF analysis; requiring tracks reconstructed only in the inner silicon detectors, as in the tracker-only analysis; requiring tracks reconstructed only in the muon system, as in the muon-only analysis. Many different searches for R-hadrons and sleptons have been presented with ATLAS data collected at 7 TeV. No significant excess is observed with $4.7\,\text{fb}^{-1}$ of data [3]. Long-lived stau's in the GMSB model considered, for $\tan\beta = 5$–20, are excluded at 95% CL for masses up to 300 GeV, while directly produced long-lived sleptons, or sleptons decaying to long-lived ones, are excluded at 95% CL up to a stau mass of 278 GeV. Long-lived R-hadrons containing a gluino (stop, sbottom) are excluded for masses up to 985 GeV (683 GeV, 612 GeV) at 95% CL, for a generic interaction model. Cross-section upper limits at 95% CL for gluino R-hadrons in the full-detector search are shown in fig. 1 (right).

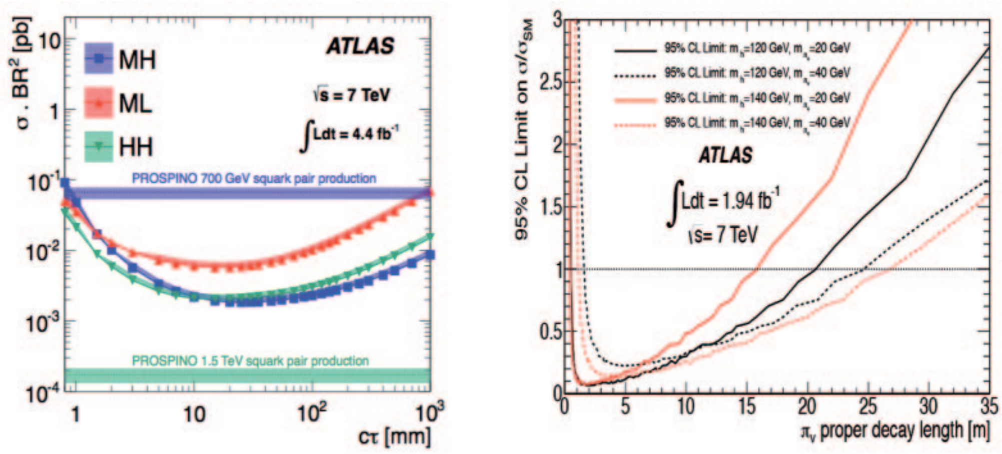

Fig. 2. – Left: Upper limits at 95% confidence level on $\sigma \times BR^2$ *vs.* the neutralino lifetime for different combinations of squark and neutralino masses, based on the observation of zero events in a 4.4 fb^{-1} data sample. The shaded areas around these curves represent the $\pm 1\sigma$ uncertainty bands on the expected limits. The horizontal lines show the cross sections calculated from PROSPINO for squark masses of 700 GeV and 1500 GeV. The shaded regions around these lines represent the uncertainties on the cross sections. Right: Observed 95% upper limits on the process $h \to \pi_v \pi_v$ vs the π_v proper decay length, expressed as a multiple of the SM cross section for Higgs production. Exclusion limits assume 100% branching ratio for the Higgs decaying to π_v's.

3. – Displaced vertexes

3·1. *Displaced neutralino decay in RPV SUSY*. – The results presented are interpreted in the context of an RPV scenario. The signature under consideration corresponds to the displaced decay of the lightest supersymmetric particle, resulting in a muon and many high-p_T charged tracks originating from a single displaced vertex. The muon is used for triggering the events. A dedicated vertex reconstruction has been developed. No events passing the signal selection are observed and limits are set on the production cross section for supersymmetric particles, multiplied by the square of the branching ratio for a neutralino to decay to charged hadrons and a muon, as a function of the neutralino lifetime. To allow these limits to be used in a variety of models, they are presented, as shown in fig. 2 (left) [4], for a range of squark and neutralino masses: MH: medium-mass squark (700 GeV), heavy neutralino(494 GeV); ML: medium-mass squark (700 GeV), light neutralino (108 GeV); HH: heavy squark (1500 GeV) and heavy neutralino (494 GeV).

3·2. *Hidden sector neutral particles*. – Decays far from the interaction point are signatures of long-lived neutral particles. ATLAS has performed a search based on 1.9 fb^{-1} for pairs of back-to-back particles decaying to heavy fermions in the muon system [5]. Such decays are signatures, for example, of Higgs decays to pairs of long-lived neutral particles $h \to \pi_v \pi_v$, where π_v is a pseudoscalar from a Hidden Sector weakly coupled to the Standard Model sector. Limits have been set as a function of the proper decay length of the π_v excluding the range 0.5–23 m depending on the Higgs mass (120–140 GeV) and on the π_v mass (20–40 GeV). Exclusion limits are shown in fig. 2 (right).

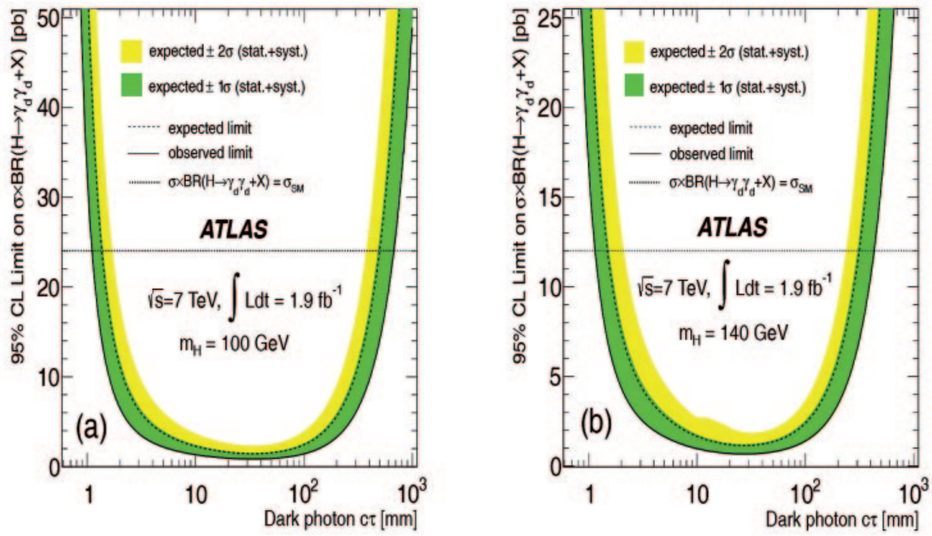

Fig. 3. – The 95% upper limits on the $\sigma \times BR$ for the process $H \to \gamma_d\gamma_d + X$ as a function of the dark photon $c\tau$ for $m_H = 100\,\text{GeV}$ and with $m_H = 140\,\text{GeV}$. The expected limit is shown as the dashed curve and the solid curve shows the observed limit. The horizontal lines correspond to the Higgs boson SM cross sections at the two mass values.

A specific model of a neutral long-lived, spinless, exotic particle which has a nonzero branching fraction to dileptons has been used in the search for displaced clusters of leptons (leptonjets). This scenario predicts up to two displaced dilepton vertices in the tracking volume per event. In the study, the model consists of a Higgs boson decaying to new hidden sector particles which finally produce two sets of collimated muon pairs: $h \to f_{d_1} + f_{d_1}$, $f_{d_1} \to f_{d_2} + \gamma_d$, $\gamma_d \to l^+l^-$ where f_{d_1} is a fermion from the hidden sector, f_{d_2} is a stable fermion from the hidden sector, and γ_d is a dark photon decaying to pairs of leptons. In $1.9\,\text{fb}^{-1}$ of data [6] no events consistent with this Higgs boson decay mode are observed. 95% CL upper limits on the cross section times branching ratio ($\sigma \times BR$) has been evaluated for the process $H \to \gamma_d\gamma_d + X$ (X refers to the two stable f_{d_2} fermions) with the γ_d mass set to 0.4 GeV. The ($\sigma \times BR$) is given as a function of the γ_d mean lifetime, expressed as $c\tau$ for an Higgs mass of 100 and 140 GeV. These limits are shown on fig. 3. Table I shows the ranges in which the γ_d $c\tau$ is excluded at the 95% CL for $H \to \gamma_d\gamma_d + X$ branching ratios of 100% and 10%.

TABLE I. – *Ranges in which γ_d $c\tau$ is excluded at 95% CL for 100 and 140 GeV Higgs masses, assuming 100% and 10% branching ratio of $H \to \gamma_d\gamma_d + X$.*

Higgs boson mass [GeV]	Excluded $c\tau$ [mm] $BR(100\%)$	Excluded $c\tau$ [mm] $BR(10\%)$
100	$1 \leq c\tau \leq 670$	$5 \leq c\tau \leq 159$
140	$1 \leq c\tau \leq 430$	$7 \leq c\tau \leq 82$

4. – Conclusions

The search for new phenomena beyond the Standard Model is a very active field at the ATLAS experiment. Recent results for long-lived particle searches at ATLAS are presented 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. The reader is invited to read the detailed papers on each of these analyses.

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