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# Searches for unconventional signatures and long-lived particles

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Many extensions of the standard model predict new particles with long lifetimes as well as giving rise to other unconventional signatures. Some examples include displaced signatures from heavy neutral leptons, disappearing tracks, displaced jets and dark photons. We present recent results of CMS and ATLAS searches for such long-lived particles and other unconventional signatures obtained using data recorded in LHC.

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## 1. Introduction

Long-lived particle (LLPs) existence are often predicted by the models of new physics beyond the Standard Model (BSM), giving rise to distinct signatures at colliders. Recently the CMS [1] and the ATLAS [2] experiment reported new results in searches for LLPs in displaced vertex and muon [3], displaced jets [4, 5], reinterpretation of displaced hadronic jets with RECAST framework [7, 8], disappearing tracks [10] and neural network based LLP search [11]. No sign of LLPs were observed and results are interpreted in the context of different BSM models.

## 2. Displaced vertex and muon

A search presented here targets long-lived particles decaying into hadrons and at least one muon [3], using proton-proton collisions data at $\sqrt{s}$ = 13 TeV collected with the ATLAS detector and corresponds to an integrated luminosity of the 136 fb$^{-1}$. In this search, a dedicated tracking (large radius tracking [6]) and vertexing algorithms are employed to retain selection efficiency for such LLP signatures. The analysis select events based on two mutually exclusive trigger selection : muon trigger or missing-transverse momentum trigger and contain a displaced muon track and a displaced vertex. The background in this search arises from cosmic ray muons, reconstruction algorithm fakes, and muons from in-flight decays of SM hadrons, are estimated from data. The observed event yield is in agreement with the background expectation. 95% CL upper limits are set on the scenarios with pair production of long-lived top squarks that decay via a small R-parity-violating coupling into a quark and a muon and are shown in Figure 1. For the mean proper life-time of 0.1 ns, top squark with masses up to 1.7 TeV are excluded and masses below 1.3 TeV are excluded for lifetimes between 0.01 ns and 30 ns.

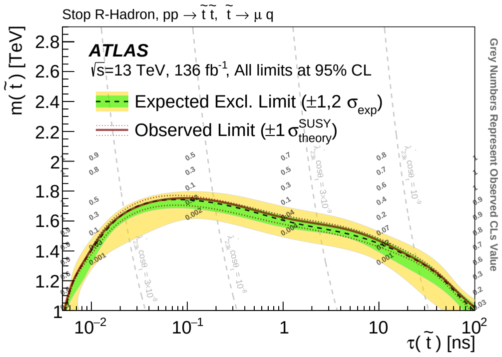


**Figure 1:** Expected and observed exclusions as a function of $\tilde{t}$ mass and mean proper lifetime.

## 3. Displaced jets

An inclusive search for long-lived particles decaying into jets is presented, using proton-proton collision data at $\sqrt{s}$ = 13 TeV collected with the CMS experiment, corresponds to an integrated luminosity of the 132 fb$^{-1}$ [4]. This search targets distinctive topology of displaced tracks and displaced vertices within a di-jet system. Since a large number of models predict long-lived particles decaying into displaced jets, we made the search as much model-independent as possible. For a simplified model, where pair-produced long-lived neutral particles decay into quark-antiquark pairs, pair production cross sections larger than 0.07 fb are excluded at 95% confidence level for long-lived particle masses larger than 500 GeV. For Exotic decay of SM Higgs model, branching fractions larger than 1% is excluded for mean proper decay lengths between 1 mm and 1 m. 95% CL limits long-lived top squark model in the mass-lifetime plane, assuming a 100% branching fraction for $\tilde{t} \to bl$ decays are shown in Figure 2. For GMSB and SUSY RPV models, the most restrictive limits are set.

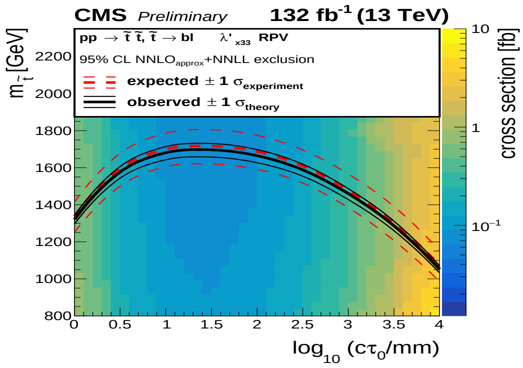


**Figure 2**

## 4. Displaced hadronic jets and reinterpretation of displaced jets with RECAST framework

A displaced hadronic jets [5] search targets the neutral long lived particles decaying mainly in the hadronic calorimeter (HCal) or at the outer edge of the electromagnetic calorimeter (ECal) of the ATLAS detector, using proton-proton collision data at $\sqrt{s}$ = 13 TeV collected with the ATLAS experiment, corresponds to an integrated luminosity of 33 fb$^{-1}$.

The displaced hadronic jets search of the ATLAS collaboration has been preserved in RECAST framework [7] and used to constrain three new physics models [8] which were not studied in the original work. RECAST is a framework designed to reuse estimates of backgrounds, systematic uncertainties and observations to test alternate signal hypothesis model. Three models studied are : A Stealth SUSY model and a Higgs-portal baryogenesis model, both predicting long-lived particles and therefore displaced decays, and a dark sector model predicting Higgs and heavy boson decays to collimated hadrons via long-lived dark photons.

In dark sector model, the final state is predicted to have either two or four dark photons, which in this model, is the LLP. Three separate search regions are considered, designed to correspond to both LLPs decaying leptonically ($\mu$DPJ-$\mu$DPJ), both decaying hadronically (hDPJ-hDPJ), and for the mixed case ($\mu$DPJ-hDPJ). 95% CL limits are set on the $\sigma_H \times BR_{H\to N\gamma d+X}$ as a function of LLP decay length (where N in $BR_{H\to N\gamma d+X}$ can be 2 or 4) and are shown in Figure 3. For $m_H$=800 GeV, results are compared to previous published ATLAS result [9] of collimated leptons or light hadrons (only considered hDPJ-hDPJ). The limit covers a region complementary to the existing constraints from previous ATLAS results [9].

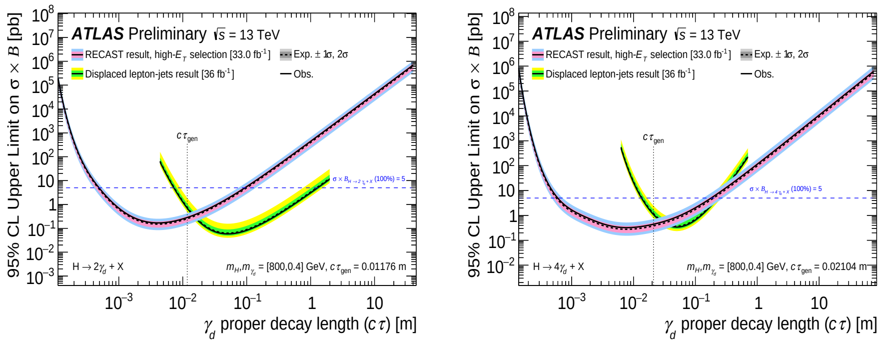


**Figure 3:** 95% CL limits on the $\sigma_H \times BR_{H\to N\gamma d+X}$ as a function of LLP decay length for $m_H$ =800 GeV for the two dark photon final state(left) and the four dark photon final state(right).

## 5. Disappearing tracks

A search presented here targets long-lived charged particles that will decay within the tracker material of the CMS detector, using proton-proton collisions data at $\sqrt{s}$ = 13 TeV collected with the CMS detector and corresponds to an integrated luminosity of the 101 fb$^{-1}$ recorded in 2017 and 2018. If the decay products of such particle are not detected, either because it interacts very weakly or it has too low momentum to be reconstructed, it would result in a "disappearing track [10]" signature. We would identify this signature in the CMS detector as isolated track that has missing hits in the outer layers of the silicon tracker, and also has little associated energy deposited in the calorimeters and no hits in the muon detector. The background process would mainly consists of failures of particle reconstruction or track finding algorithms as the SM processes would rarely produce such signature. 95% CL upper limits are placed on the chargino production in the context of anamoly-mediated supersymmetry breaking (AMSB) model for wino and higgsino neutralino searches. Two-dimensional constraints derived from the intersection of the theoretical predictions with the expected and observed upper limits, for each chargino mass and mean proper lifetime considered are shown in Figure 4. In the higgsino case, the first constraints are placed on the charginos masses, excluding below 750 (175) GeV for a lifetime of 3 (0.05) ns. Charginos in the wino LSP case with a lifetime of 3 (0.2) ns are excluded up to a mass of 884 (474) GeV.

## 6. Neural Network based LLP search

This search makes use of a deep neural network to tag jets that are significantly displaced from pp collisions region in the CMS detector at the LHC [11]. The tagger is a multiclass classifier based on a deep neural network, which is parameterized according to the proper decay length of the LLP. A novel scheme is defined to reliably label jets from LLP decays for supervised learning. To perform the training on the neural network, a sample of pp collision data, recorded by the CMS detector at a centre-of-mass energy of 13 TeV, and simulated events are used. A search for long-lived gluinos which is a manifestation of split supersymmetric models, is used to demonstrate the performance of tagger. The tagger provides a jet tagging efficiency for LLP of 30-80% for gluinos

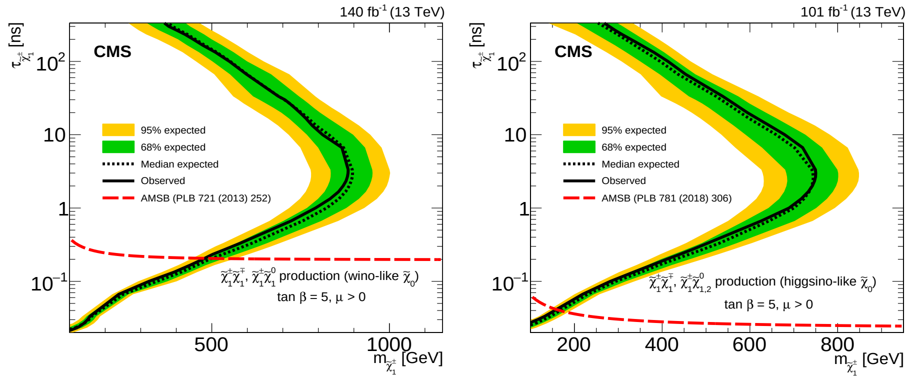


**Figure 4:** The expected and observed constraints on chargino lifetime and mass for a purely wino LSP(left) and higgsino(right) in the context of AMSB, where the chargino lifetime is explicitly varied. The region to the left of the curve is excluded at 95% CL.

with proper lifetime between 1 mm and 10m and a rejection factor of 10000 for jets from standard model processes.

95% CL lower limits on $m_{\tilde{g}}$ as a function of $c\tau_0$ for simplified models of split SUSY that assume the production of gluino pairs is shown in Figure 5. The left (right) plot in the shows the expected mass exclusion for models with an uncompressed(compressed) mass spectrum. This search using neural network tagger is competitive with respect to a dedicated reconstruction technique reported in [12]

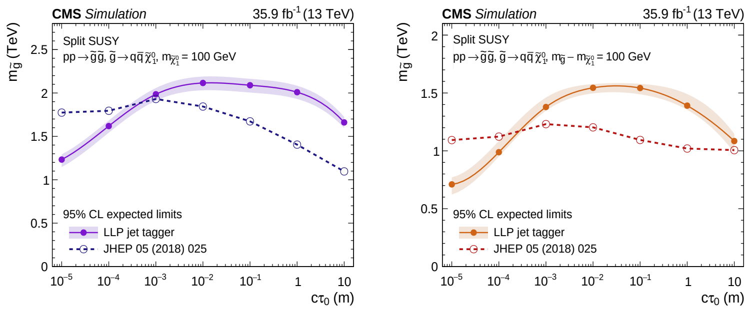


**Figure 5:** Expected 95% CL lower limits on $m_{\tilde{g}}$ as a function of $c\tau_0$ for split SUSY models with an uncompressed (left) and a very compressed (right) mass spectrum.

## 7. Summary

Results are presented for the search of unconventional and long-lived searches using data sample of proton-proton collisions at $\sqrt{s}$ = 13 TeV, recorded with the CMS and ATLAS experiment at the LHC. Different long-lived signatures have been presented, for example, displaced jets, disappearing tracks, displaced vertex and muon, displaced hadronic jets using RECAST framework and neural network based search. The observed event yield is in agreement with the background expectation and therefore results are interpreted in the context of different BSM models.

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