PROCEEDINGS OF SCIENCE

Search for heavy, long-lived, charged particles with large ionisation energy loss and time-of-flight with the ATLAS experiment

Martina Ressegotti[a,*] **on behalf of the ATLAS Collaboration**

[a] *INFN Genova,*
via Dodecaneso 33, Genova, Italy

E-mail: martina.ressegotti@ge.infn.it

We present a new search for hypothetical massive, charged, long-lived particles with the ATLAS detector at the LHC using an integrated luminosity of 140 fb^{-1} of proton-proton collisions at $\sqrt{s}$=13 TeV. These particles are expected to move significantly slower than the speed of light and should be identifiable by their high transverse momenta and anomalously large specific ionisation losses measured in the pixel detector. This information can be used in combination with the speed measured by Time-of-Flight in the ATLAS calorimeters. Results are presented covering particles with lifetimes down to O(3) ns and with masses ranging from 200 GeV to 3 TeV. Interpretations for pair-production of R-hadrons and staus in scenarios of supersymmetry compatible with these particles being long-lived are presented, with mass limits extending beyond those from previous searches in broad ranges of lifetime.

The European Physical Society Conference on High Energy Physics (EPS-HEP2023)
21-25 August 2023
Hamburg, Germany

[*] Speaker

PoS(EPS-HEP2023)484

1. Introduction

This paper presents a search for massive, charged, long-lived particles (LLPs) performed with the ATLAS detector at the LHC with 140 fb^{-1} of proton-proton collisions at $\sqrt{s}$=13 TeV of the Run 2 dataset [1]. Besides high transverse momentum, the first identification criterion used is an anomalously large specific ionisation loss measured in the pixel detector. This approach was used also in [2], in which a 3.3σ excess was observed at a mass of approximately 1.4 TeV. As signal particles are expected to move significantly slower than the speed of light, in this analysis a second identification criterion using the time of flight (ToF) measurement with the hadronic calorimeter is also applied.

Two mass measurements $m = p/\beta\gamma$ are obtained from two independent determinations of $\beta\gamma$: $\beta_{dE/dx}$ from the dE/dx measurement of the pixel detector using the Bethe-Bloch relation, and β_{ToF} from the ToF measurement of the calorimeter. This two-fold approach is less sensitive to fluctuations of individual variables and their systematic uncertainties compared to the usage of a single measurement of $\beta\gamma$, resulting in a strong background reduction for lifetimes approximately larger than 10 ns.

The search is model-independent and sensitive to many different models of new physics predicting the existence of new massive, long-lived particles.

2. Analysis

Signal region and mass windows The signal region (SR) is defined by selections on missing energy E_T^{miss}>170 GeV, on the pixel detector ionisation energy loss dE/dx>1.8 MeV g^{-1} cm^2 and on the calorimeter β_{ToF}<1-2$\sigma(\beta_{ToF})$, where $\sigma(\beta_{ToF})$ is the cell time resolution defined in η slices. Events in the SR are also required to be within a compatibility cone in the ($m_{dE/dx}$, m_{ToF}) plane, visible in Figure 3 (left). The search for specific target masses is performed in trapezoidal mass windows, subsets of the compatibility cone, defined to contain at least 70% of the signal and to maximize the sensitivity.

Background The sources of background are standard model processes with high momentum tracks superimposed with large dE/dx measurements from the tails of the Landau distribution of minimum ionizing particles and low ToF mismeasurements. The background is estimated with a fully data-driven approach, in which data control samples are used to parameterise momentum, dE/dx and β_{ToF} in η bins and used to build the background mass distributions of $m_{dE/dx}$ and m_{ToF}. The mass distributions are validated in two validation regions defined like the signal region but with inverted cuts either on the $\beta_{dE/dx}$ or the β_{ToF} variable. Some examples of the matching between data and background are shown in Figure 1.

Calibration A dedicated calibration is applied to the $\beta\gamma$ measurements. The same calibration detailed in [2] is applied to the pixel detector's $\beta_{dE/dx}$ measurement. The calorimeter β_{ToF} measurement is the weighted average of the β_i measured in all calorimeter cells with energy deposit greater than 500 MeV and its calibration consists of three steps: a time calibration to set t=0 for particles travelling at the speed of light, a pseudorapidity correction to account for different path length of tracks entering the cell at some distance from its center, and the calibration of each cell's

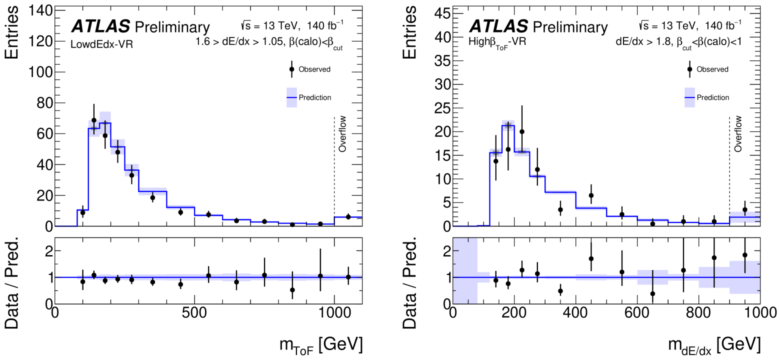

Figure 1: Comparison of the predicted background m_{ToF} (left) and $m_{dE/dx}$ (right) to data in the low-dE/dx (left) and high-β_{ToF} (right) validation regions [1].

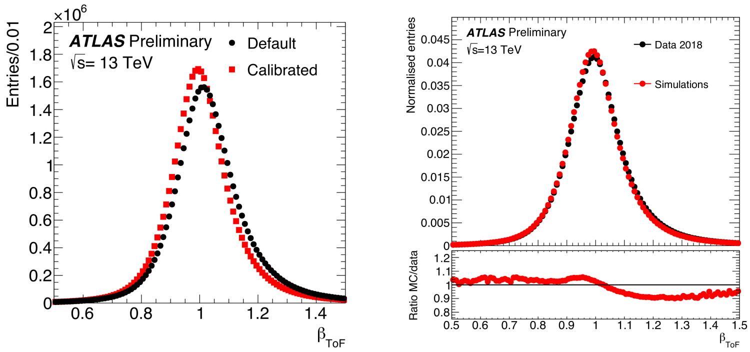

Figure 2: Left: β_{ToF} distribution obtained with isolated muons from $Z \rightarrow \mu\mu$ 2018 data with the default calibration (*Default*) and the calibration used in this analysis (*Calibrated*). Right: β_{ToF} distribution after the time smearing procedure is applied to $Z \rightarrow \mu\mu$ simulated events compared to events from 2018 data . The disagreement between data and simulation is well below 5% for β_{ToF}<1 [1].

time resolution σ_i from a fit to data with the formula $\sigma_i = \sqrt{p_0^2 + \frac{p_1^2}{E} + \frac{p_2}{E}^2}$. Figure 2 shows a comparison between this calibration and the default one. A smearing obtained from data is also applied to the simulated calorimeter cell time in Monte Carlo to account for real time reconstruction effects, whose effect is visible in Figure 2. The calorimeter calibrations and time smearing are obtained from $Z \rightarrow \mu\mu$ decays from 2018 data.

Systematics Several sources of systematic uncertainties were evaluated. The main contributions come from the template correlation, i.e. the verification of the assumption used in background generation that dE/dx and momentum are uncorrelated, and the impact of the choice of the η slicing on β_{ToF}.

3. Results and conclusions

Nine events (expected 5.1±0.5) were observed in the signal region, of which 6 (expected 3.7±0.4) in the compatibility cone (Figure 3 left). Results were interpreted in the context of pair-production of different long-lived SUSY particles: sleptons and gluinos which hadronize with

PoS(EPS-HEP2023)484

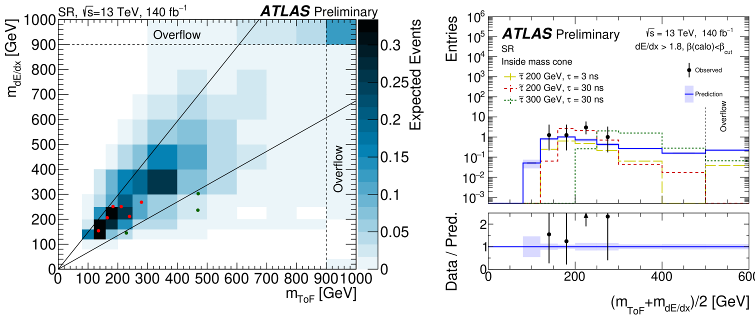

Figure 3: Left: distribution of data (dots) and predicted background (blue area) in the signal region. Red (black) dots are events falling inside (outside) the compatibility cone. The mass compatibility cone is also indicated. Right: distribution of the average mass between m_{ToF} and $m_{dE/dx}$ of events observed in the compatibility cone compared to the expected background (solid line). The yield for three example stau signal models are also shown (colored dotted lines) [1].

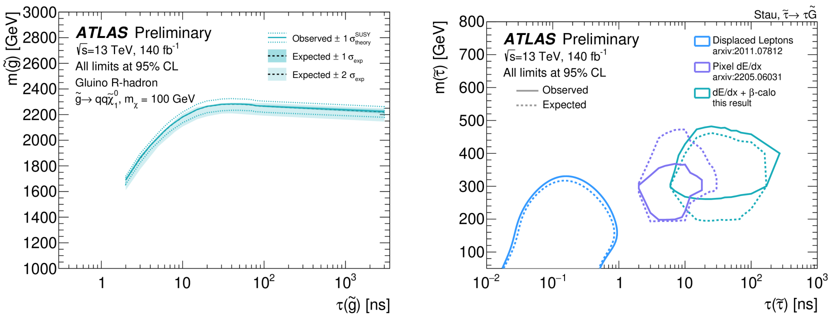

Figure 4: Left: lower limits on the gluino mass from gluino R-hadron pair production as function of gluino lifetime, the neutralino mass assumption $m(\tilde{\chi}_1^0)$=100 GeV. Right: comparison between this result [1] and the results in [2] and in [3].

Standard Model quarks to produce R-hadrons [1]. Some examples of new limits on masses and lifetimes are reported in Figure 4. In particular, this analysis sets the most stringent limits for detector unstable LLPs in the mass-lifetime plane for lifetimes greater than 10 ns and provides further constraints on R-hadron and stau production models.

References

[1] ATLAS Collaboration, *Search for heavy, long lived charged particles with large specific ionisation and low-beta in 140 fb^{-1} of p-p collisions at $\sqrt{s}$=13 TeV using the ATLAS experiment*, ATLAS-CONF-2023-044

[2] ATLAS Collaboration, *Search for heavy, long-lived, charged particles with large ionisation energy loss in pp collisions at $\sqrt{s}$=13 TeV using the ATLAS experiment and the full Run 2 dataset*, J. High Energ. Phys. 2023, 158 (2023)

[3] ATLAS Collaboration, *Search for Displaced Leptons in $\sqrt{s}$=13 TeV pp Collisions with the ATLAS Detector*, Phys. Rev. Lett. 127, 051802 (2021)