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

M.Ressegotti* on behalf of the ATLAS Collaboration
*INFN sezione di Genova, Italy

References
[1] ATLAS collaboration, Search for heavy, long-lived, charged particles with large ionisation energy loss in pp collisions at √s = 13 TeV using the ATLAS experiment and the full Run 2 dataset, J. High Energ. Phys. 2023, 158 (2023)
[2] ATLAS-CONF-2023-044

Introduction

New round of analysis to extend the reach of the previous dE/dx analysis [1] for slow, charged, heavy particles with lifetimes exceeding ≈10 ns

- In [1] a 3.3 sigma excess approximately of mass 1.4 TeV was observed!
  - large time of flight (ToF) was not confirmed by the calorimeter and the muon system
  - **in this new round the ToF is included in the analysis**
  - the new search uses the same 140 fb^{-1} of Run2 pp collision data of the ATLAS experiment (centre-of-mass energy of 13 TeV)
- Target: **slow, charged, heavy** (m>100 GeV) particles with **lifetimes τ>3 ns**
- **Model-independent**: sensitive to many different models of new physics predicting the existence of new massive, long-lived particles (LLPs)

SIGNAL: isolated ***high-momentum*** tracks with ***large ionization energy loss*** (*dE/dx*) in the pixel detector and ***significantly slower than the speed of light*** from the calorimeter time-of-flight (ToF)

MAIN OBSERVABLES: **particle mass m ≡ p/ βγ** from two independent determinations of βγ
- $\beta_{dE/dx}$: using the Bethe-Bloch relationship between βγ and the *dE/dx* measured by the pixel detector
- β_{ToF} : using the time of flight measured by the hadronic calorimeter *NEW*

STRATEGY: Combination of two independent variables → Less sensitive to fluctuations of individual variables and their systematics → **Strong background reduction** for $\tau \gtrsim 10$ ns

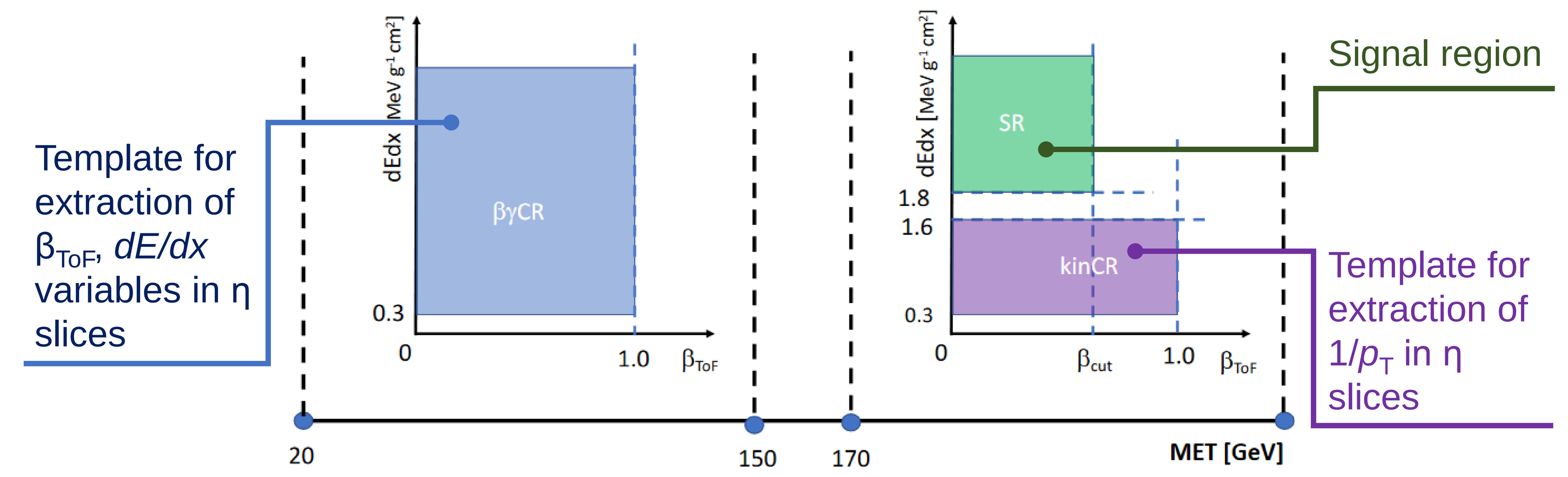
Background

Sources: standard model processes with high-p_T tracks, large *dE/dx* from tails of the Landau distribution of MIPs and low β_{ToF} by ToF mismeasurements

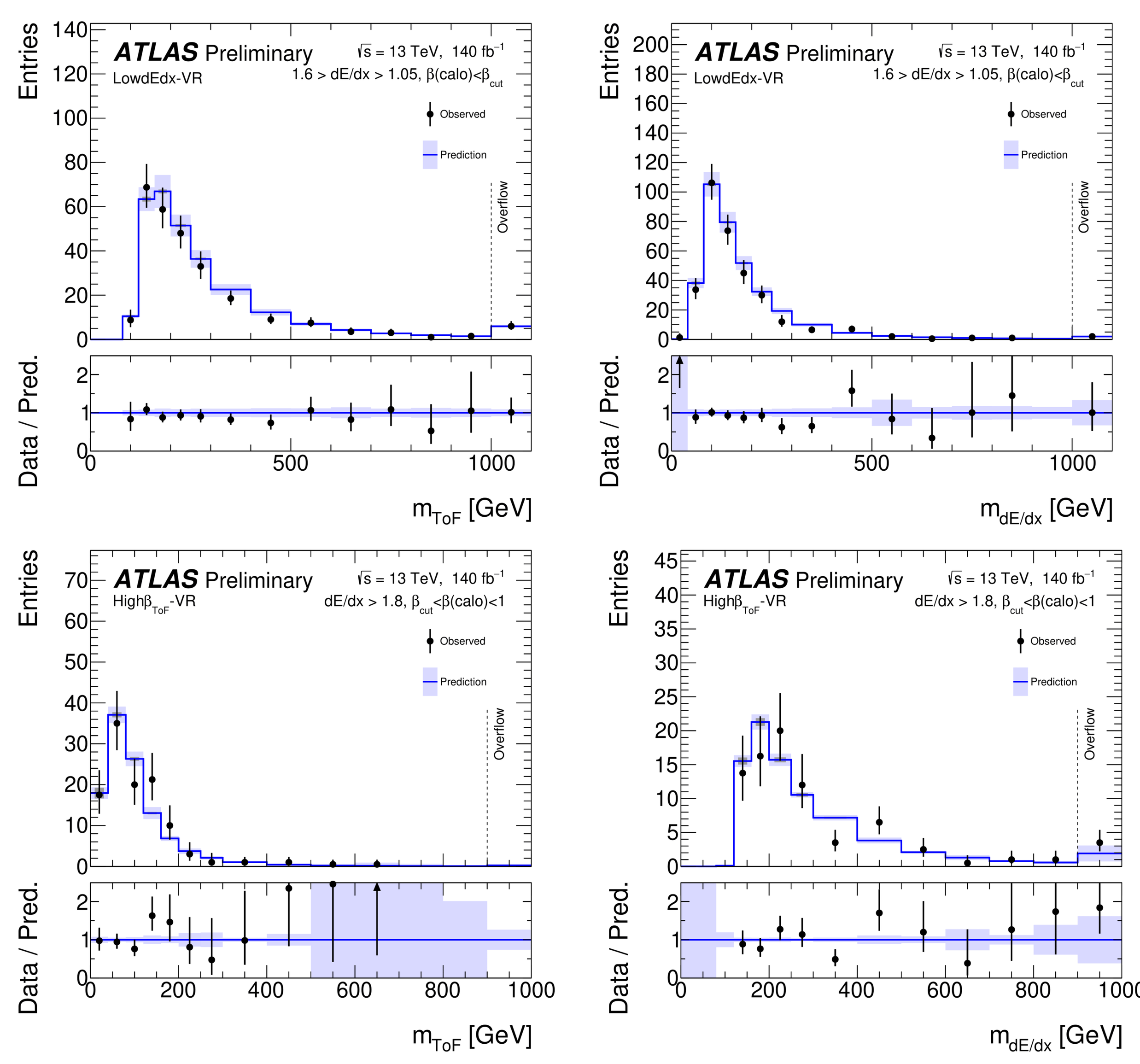
Estimation: ***fully data-driven approach*** → data control samples used to parameterise momentum, *dE/dx* and β_{ToF} distributions and their interdependence

Variables extraction: Extraction of β_{ToF}, *dE/dx*, $1/p_T$ samples from corresponding control regions (in η slices)
→ **Mass calculation**: Two values of mass *m=p/βγ* are calculated using β_{ToF} or βγ from *dE/dx*
→ **Normalization**: Normalization of mass distribution to a sub-region of the kin-CR depleted in signal (β_{ToF}>β_{cut}, $m_{dE/dx}$ and m_{ToF}<160 GeV)
→ **Validation**: The mass distribution is validated in two validation regions defined like the SR, but with inverted cuts on key variables (either β_{ToF} or *dE/dx*)

NEW ***Improved validation strategy** in the new analysis: validation regions have no p_T upper limit hence the background can be generated also at high masses*



Validation: the matching of the mass distribution between data and background in signal depleted regions validates the background generation process



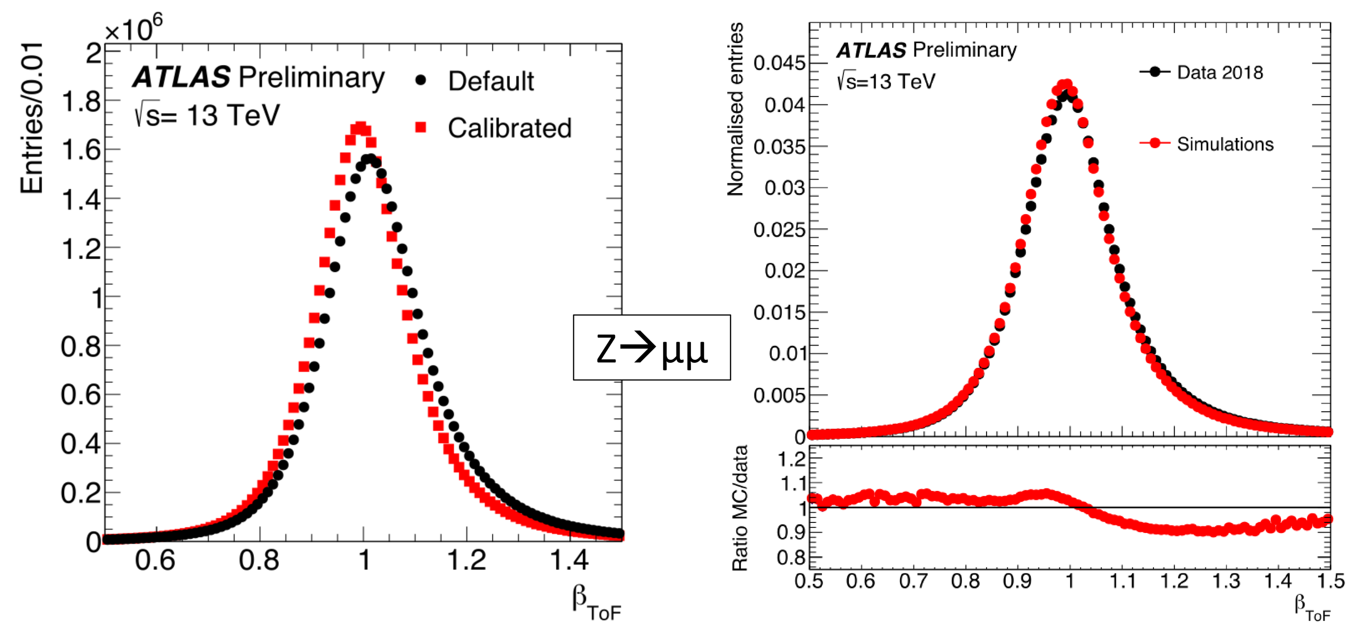
Calibration

Pixel Detector (Same as in previous round of analysis [1])
- Reconstruction of low-momentum tracks allows to extract βγ from dE/dx by measuring the most probable value (MPV) of dE/dx distributions of pions, kaons, protons and deuterons in momentum slices and fitting to the Bethe-Bloch formula
- Corrections dependent on run and |η| based on data to account for response changes with position and time (received fluence)

Calorimeter *NEW*
- The measured β_{ToF} is the weighted average of β_i measured in all calorimeter cells with energy above 500 MeV (weights $1/\sigma_i^2$, σ_i gaussian time resolution of a cell)
- Three corrections are applied to a cell's β_i measurement (from Z→μμ data):

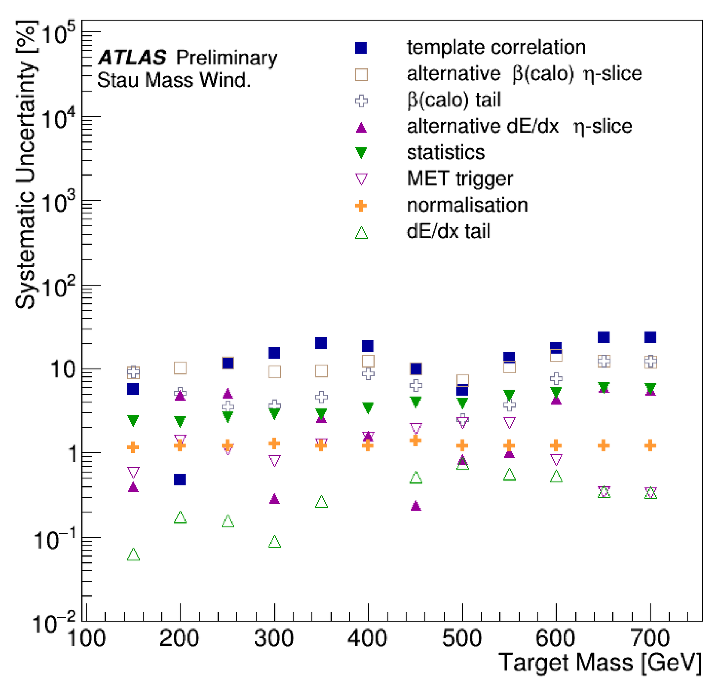
Time calibration	subtractive constant equal to the mean value of the Gaussian fit of the time measurement distribution (by data-taking year) to make t=0 for particles travelling at the speed of light
Pseudorapidity correction	provided by the linear fit of mean reconstructed time as a function of the distance in η between the track's impact point on the cell and the cell center. Accounts for different path length in the same cell (greater effect at larger η)
Calibration of time resolution	the cell time resolution improves with the energy deposit as $\sigma_i = \sqrt{p_0^2 + \frac{p_1^2}{E} + \left(\frac{p_2}{E}\right)^2}$, where p_0, p_1, p_2 are determined with fit to data for each calorimeter radial compartment

- β_{ToF} in Monte Carlo samples smearing obtained from 2018 data to account for real time reconstruction effects, with an agreement well below 5% for β_{ToF}<1



Systematics

Main contributions
- **Template correlation**: verification of the assumption that dE/dx and p_T are uncorrelated
  - All kinematic, dE/dx, and β_{ToF} templates are extracted from the same region (βγ-CR of SR) to generate a background distribution, then compared to data in a subset of this same region applying the dE/dx and β_{ToF} cuts
- **Impact of η slicing on β_{ToF}**: alternative η slicing used to generate an alternative background and calculate an alternative η-slice uncertainty



Results

- The signal region (SR) is defined by cuts E_T^{miss}>170 GeV, *dE/dx*>1.8 MeV g^{-1} cm^2, β_{ToF}<β_{cut} (β_{cut} = 1-2$\sigma(\beta_{ToF})$) where $\sigma(\beta_{ToF})$ is the cell time resolution defined in η slices)
- The search is performed **in the ($m_{dE/dx}$, m_{ToF}) plane with trapezoidal mass windows**, defined to contain at least 70% of the signal and to maximize sensitivity for different signal masses
- **9 events observed** (expected 5.1 ± 0.5) in the signal region, of which **6 in the compatibility cone** (expected 3.7 ± 0.4)
- Results interpreted in the context of pair-production of different long-lived SUSY particles: sleptons and gluinos which hadronize with Standard Model quarks to produce R-hadrons
- Masses smaller than 2.3 TeV excluded (95% CL) for gluino R-hadrons with τ=30 ns and $m(\tilde{\chi}_1^0)$ = 100 GeV. Mass limit for compressed-scenario R-hadrons with $\Delta m(\tilde{g}, \tilde{\chi}_1^0)$ = 30 GeV and τ>200 ns is 2.2 TeV
- Stau masses in range 280–420 GeV excluded for lifetimes of 10 ns. Mass limits for staus extend up to about 100 ns, lower mass limit staying constant in the 10–100 ns lifetime range
- Set the most stringent limits for detector unstable LLPs in the mass–lifetime plane for τ>10 ns and provide further constraints on R-hadron and stau production models