PROCEEDINGS OF SCIENCE

Reconstruction and identification of high-p_{T} muons in $\sqrt{s}$ = 13 TeV proton-proton collisions with the ATLAS detector

Damiano Vannicola on behalf of the ATLAS Collaboration[*†]

Sapienza University of Rome and INFN Sezione of Rome
E-mail: damiano.vannicola@cern.ch

The ability to reconstruct high-momentum muon tracks in ATLAS with good momentum resolution is closely connected to a good understanding of the ATLAS tracking detectors alignment and of the related uncertainties. Moreover, an optimal selection of muon candidates with transverse momentum of the order of TeVs is a critical factor in the sensitivity of analyses looking for new high-mass resonances, such as $\mathrm{Z}' \to \mu\mu$ and $\mathrm{W}' \to \mu\nu$ searches. This contribution provides an overview of the method used in muon reconstruction to account for the differences in position and orientation of the various detector elements, between the geometry assumed in tracking and the real detector. Furthermore, the requirements that define the identification of high transverse momentum (p_{T}) muons in the full Run II ATLAS dataset are detailed, together with several innovations. Such requirements have been tuned to select muons with the best possible momentum resolution, thus ensuring that candidates fulfilling the criteria are of the highest quality. The performance of the q/p criterion of the high-p_{T} muon selection is also discussed, based on the result of measurements performed in data and simulation samples corresponding to an integrated luminosity of 139 fb^{-1}.

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*Speaker.
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1. Introduction

A good muon momentum resolution in the region from hundreds of GeV to several TeV is crucial for searches for new physics, such as $W' \rightarrow \mu\nu$ and $Z' \rightarrow \mu\mu$ [1] at the LHC. A new physics signal in one of these channels could manifest itself as an excess over the Standard Model (SM) prediction in the form of a handful of muon candidates in the high-end tail of the transverse mass or invariant mass distribution. It is therefore important to reject poorly measured muons, where the reconstructed p_{T} is much higher than the true value, to avoid the contamination of the high-mass region with events migrating from lower masses. This document is focused on the reconstruction and identification of the high-p_{T} muons. After a general description of the ATLAS muon spectrometer alignment system and of the ATLAS high-p_{T} selection, a new study and its impact on $W' \rightarrow \mu\nu$ and $Z' \rightarrow \mu\mu$ searches will be presented.

2. ATLAS muon spectrometer alignment system

The ATLAS muon spectrometer (MS) [2] is designed to provide excellent momentum measurements of muons at the energy scales expected in several new physics scenarios. The transverse momentum is expected to have a resolution ($\Delta p_{\mathrm{T}}/p_{\mathrm{T}}$) at level of 10% for a muon with p_{T} of 1 TeV. Due to the magnetic field inside the spectrometer, the path of a 1 TeV muon will be bent by only 0.5-1.0 mm (depending on the pseudorapidity of the track). To measure the momentum with a precision better than 10%, the uncertainty on the track sagitta, s, must be less than 50 μm. Different techniques have been deployed to measure the relative alignment of the MS precision chambers [3]. First of all, the positions of the precision chambers were estimated using a sample of cosmic ray tracks with toroid magnets turned off. If truly straight tracks travel through the MS, the distribution of the sagitta should be centered at zero with a width dominated by multiple scattering, because most of the tracks have a transverse momentum of few GeVs. The misalignment is evaluated as the mean of the distribution of the sagitta. Considering that chambers can move as much as several mm when the magnet is switched on or off, an optical system made by more than 5800 optical sensors is used to monitor the relative alignment. Finally toroid-off proton-proton dedicated runs have been used to validate the alignment system. For each MS projective tower, composed by inner-middle-outer muon stations, the average sagitta μ_0 = <s> was calculated, as well as its correlation with the polar and azimuthal coordinates ($\mu_\theta = <(\theta-\theta_0)\cdot s>$, $\mu_\phi = <(\phi-\phi_0)\cdot s>$). The RMS distribution of μ_0, μ_θ and μ_ϕ is shown in Figure 1 for different types of towers.

3. High-p_{T} selection

The high-p_{T} selection aims at the optimization of the momentum resolution for tracks with transverse momentum above 100 GeV. It is optimized for searches for high-mass resonances. Muon candidates are identified by matching inner detector tracks to tracks reconstructed in the MS: these are called combined muons. The selection requires at least three hits in each of three layers of precision tracking chambers in the MS, and specific regions of the MS where the alignment is suboptimal are vetoed as a caution [4]. The muon high-p_{T} selection has an η-averaged efficiency[1]

[1]For samples with a flat η distribution and $|\eta| < 2.5$.

PoS(LHCP2019)041

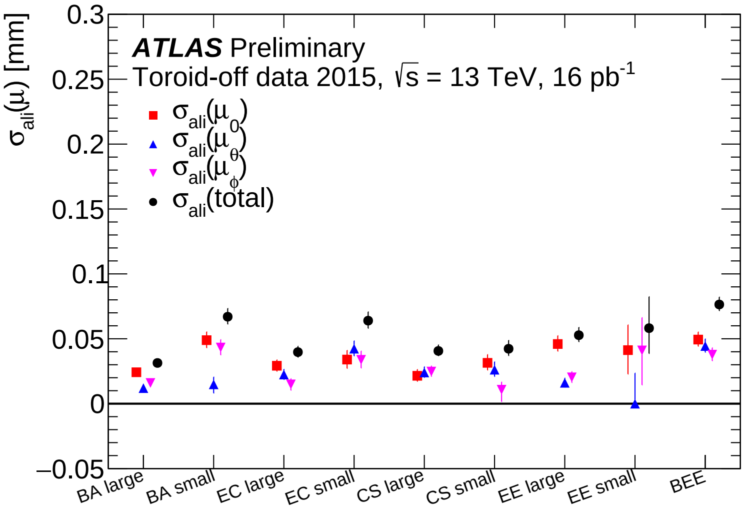

Figure 1: Performance of the MS alignment measured using pp collision runs with the toroidal magnetic field turned off. The figure shows the width of the distributions of the sagitta bias measurements ($\sigma_{\rm ali}$ (μ_0), $\sigma_{\rm ali}$ (μ_θ) and $\sigma_{\rm ali}$ (μ_ϕ)) with their statistical uncertainty. The quadratic sum of the three ($\sigma_{\rm ali}$ (total)) is also given, which measures the overall goodness of the alignment. Regions of the muon spectrometer are differentiated: bulk barrel towers in large or small sectors (BA large, BA small), bulk end-cap large or small towers (EC large, EC small), forward end-cap towers in large or small sectors (CS large, CS small), special end-cap towers (EE and BEE).

of 69% at 1 TeV which decreases to 64% at 2.5 TeV due to increased probability of occasional catastrophic energy loss at high-$p_{\rm T}$. Additionally, a set of selection criteria based on the relative uncertainty on the charge-to-momentum ratio (q/p) of reconstructed muon tracks (see section 4) is used to identify events containing high-$p_{\rm T}$ muons with optimal momentum resolution.

4. q/p criterion

The goal of the q/p criterion is to reject muons in the tails of the $\sigma_{p_{\rm T}}/p_{\rm T}$ distributions. The selection is based on a cut on the relative uncertainty of the q/p measurement. As the resolution worsens at high-$p_{\rm T}$, the efficiency would also decrease at high-$p_{\rm T}$. The expected resolution of the momentum measurement is parametrized as a function of $\rm p_T$ in five different η regions, following the usual parametrization: $\sigma_{rel}^{exp} = \sqrt{(p_0/p_{\rm T})^2 + p_1^2 + (p_2 \cdot p_{\rm T})^2}$. The η regions are chosen to coincide with specific regions of the ATLAS detector having different $\rm p_T$ resolution, and are defined as follows: $|\eta| \leq 1.05,\ 1.05 < |\eta| \leq 1.3,\ 1.3 < |\eta| \leq 1.7,\ 1.7 < |\eta| \leq 2.0$, and $|\eta| > 2.0$.

A cut on the relative uncertainty of the q/p measurement of the muon ($\frac{\sigma(q/p)}{(q/p)}$) is applied as:

$$\frac{\sigma(q/p)}{(q/p)} < C(p_{\rm T}) \cdot \sigma_{rel}^{exp} \tag{4.1}$$

where C($p_{\rm T}$) is a $p_{\rm T}$-dependent coefficient, which is constant for $p_{\rm T}$< 1 TeV and decreases linearly if $p_{\rm T}$ > 1 TeV. In the original formulation of the cut, used until 2018, the initial value of C($p_{\rm T}$) was equal to 1.8. A q/p criterion optimization study was undertaken in order to improve the efficiency of this criterion. Increasing the initial value of C(p_{T}) up to 2.5, the cut efficiency improves while still effectively removing the tails of the resolution distributions. An efficiency gain of up to 5% with respect to the previous definition of the q/p criterion, has been observed. This new q/p criterion formulation has been already used in [1] and will be used in all the future ATLAS analyses. This criterion is fully efficient below 1 TeV, and introduces an additional inefficiency of 7% at 2.5 TeV to the high-p_{T} selection.

4.1 q/p criteria uncertainty

A systematic uncertainty is applied on the rate of simulated events to account for possible differences of the q/p criteria between data and MC in the high-p_{T} selection. The efficiency of the q/p criteria has been evaluated separately in data and in MC samples in the following way:

$$\varepsilon^{data} = \frac{n_{data}^{pass\ cut}}{n_{data}}; \quad \varepsilon^{MC} = \frac{n_{MC}^{pass\ cut}}{n_{MC}} \tag{4.2}$$

where n_{data} and n_{MC} represent respectively the number of candidates included in the high-p_{T} selection in data and MC, while $n_{data}^{pass\ cut}$ and $n_{data}^{pass\ cut}$ are the high-p_{T} candidates accepted by the q/p criteria. The systematic uncertainty on the q/p criteria has been calculated as:

$$1 - \frac{\varepsilon^{data}}{\varepsilon^{MC}} \ . \tag{4.3}$$

Considering that the data-MC agreement depends on the η region, the q/p criteria uncertainties have been evaluated in three different slices: $|\eta| < 1.3$, $1.3 < |\eta| < 2.0$ and $2.0 < |\eta| < 2.5$. In Fig. 2 the q/p criteria uncertainties are presented as a function of the muon transverse momentum. The old uncertainties (blue) have been evaluated for the 2015-2016 Run2 dataset (36 fb^{-1}) using the initial value of C(p_{T}) equal to 1.8 at 1 TeV, while new uncertainties (red) have been evaluated for the full Run2 dataset (139 fb^{-1}), deploying the new q/p criterion optimization. In the p_{T} range between $1-3$ TeV, the new systematic uncertainties (red) are two times smaller than the old ones (blue).

5. Summary and outlook

All the results of the ATLAS measurements and searches using muon information depend on the understanding and the optimization of muon reconstruction and identification. In particular, in this document a focus on the high-p_{T} muons has been presented. A MS precision chamber alignment of 50 μm has been achieved in almost all the sectors. A new optimization of the q/p criteria has been presented. The associated systematic uncertainties have been evaluated using the full Run-2 dataset. The region in which the systematic uncertainty is less than 5% has been extended by approximately 1 TeV. A new dedicated study is being finalized to improve the efficiency of the high-p_{T} selection by including muons with segments reconstructed only in the two outermost high-precision layers. The results of this work led to a 5% improvement of the selection efficiency, and will be part of the high-p_{T} muon identification procedure used by future ATLAS analyses.

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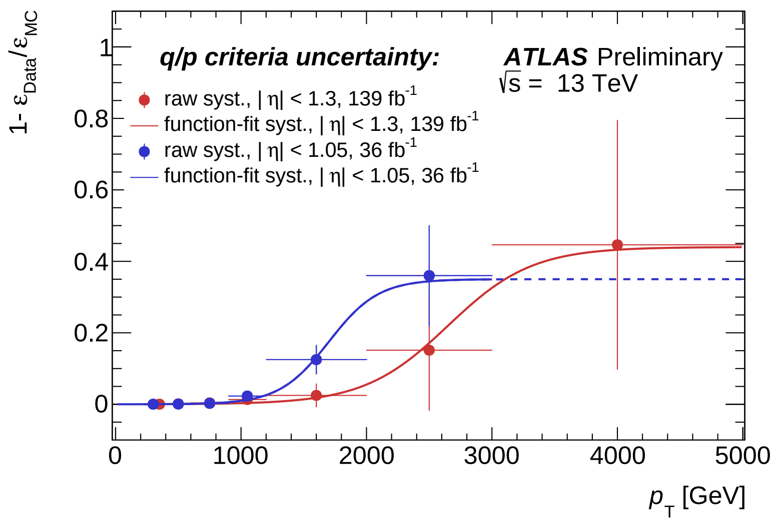

Figure 2: The systematic uncertainty on the q/p criteria, derived from the difference in selection efficiency between data and MC, reported as a function of the p_T of the reconstructed muon. The systematic uncertainties are presented as computed for an early Run-2 dataset (blue), corresponding to 36 fb^{-1} of pp collision data, and for the full Run-2 dataset (red), amounting to 139 fb^{-1} using a new cut. The data points are fitted with a sigmoid function. The extrapolation of the fitted curve of the early Run-2 dataset for p_T values larger than 3 TeV is shown with a dashed curve.

References

[1] ATLAS Collaboration, Search for high-mass dilepton resonances using 139 fb^{-1} of pp collision data collected at $\sqrt{s}$ = 13 TeV with the ATLAS detector, Phys.Lett. B796 (2019) 68-87.

[2] ATLAS Collaboration, The ATLAS experiment at the CERN Large Hadron Collider, J. Instrum., 3 (2008), Article S08003.

[3] S. Aefsky on behalf of the ATLAS Collaboration, Alignment of the Muon Spectrometer in ATLAS, Physics Procedia Volume 37, 2012, Pages 51-56.

[4] ATLAS Collaboration, Muon reconstruction performance of the ATLAS detector in proton-proton collision data at $\sqrt{s}$ = 13 TeV, Eur. Phys. J. C 76 (2016) 292.