IL NUOVO CIMENTO **44 C** (2021) 55
DOI 10.1393/ncc/i2021-21055-0

Communications: SIF Congress 2020

Measurement of the track impact parameters resolution with the ATLAS experiment at LHC using 2016–2018 data

C. Magliocca

Département de Physique Nucléaire et Corpusculaire, Université de Genève
Quai Ernest-Ansermet, Geneva, Switzerland

received 15 January 2021

Summary. — This study presents the measurement of the impact parameter distributions to test the resolution of the tracks reconstructed with the ATLAS inner detector at the LHC. It has been performed using proton-proton collision data collected at $\sqrt{s} = 13\,\text{TeV}$ between 2016 and 2018. The impact parameter is defined as the distance of closest approach of the track to the collision point. Its resolution is computed using an iterative Gaussian fit performed on the core of the impact parameters distribution. It has been observed a degradation of approximately 5% over the considered period. This degradation results from the convolution of changes in the running conditions and radiation damage, which modifies the intrinsic properties of the detector, affecting its performances. To investigate the behaviour of the resolution of the transverse impact parameter measurement in a high-density environment, the quantity has also been studied as a function of the angular separation between a track and the jet axis. A degradation of approximately 10% is observed in the proximity of the jet direction.

1. – Introduction

The identification of jets originating from the hadronization of b-quark —defined as *b-tagging* [1]— is of particular interest for many different analyses that aim to perform precise measurements of Standard Model processes or to probe New Physics scenarios.

The b-tagging technique relies on the distinctive properties of b-hadrons, namely their lifetime and high mass, which allow to distinguish jets originating from the hadronization of b-quarks from jets containing c-quarks or light-flavour quarks.

The b-hadrons high mass (greater than 5 GeV [2]) leads to a larger multiplicity of decay products with respect to jets coming from light partons [3]. Additionally, their lifetime τ, of the order of 1.5 ps [2] —corresponding to a proper decay length of $c\tau \approx 450\ \mu$m—, allows them to travel several millimetres from the primary interaction point before decaying, giving rise to displaced secondary vertices inside the jet cone. Such displaced vertices can be reconstructed by measuring the Impact Parameters (IP) —*i.e.*, the distance of closest approach of the track to the collision point— of the tracks of the charged particle decay products. For this reason, precise measurement of the tracks IP is crucial.

2. – Method

This article presents a study of the resolution of the transverse impact parameter d_0 measured by the ATLAS [4] Inner Detector (ID). The analysis has been performed using proton-proton collision data collected at a centre-of-mass energy of $\sqrt{s} = 13$ TeV between 2016 and 2018.

In sect. **3**, the results of the analysis will be presented in the pseudorapidity range $|\eta| < 0.8$ and in the transverse momentum p_T bin $5.0 < p_T < 7.0$ GeV to remove any dependence of the IP resolution on these two quantities.

The impact parameter resolution value is retrieved using an iterative Gaussian fit performed on the core of the impact parameter distribution. In fact, only the prompt tracks populate the core of the IP distribution and can be very well described by a single Gaussian function. On the other hand, a fraction of the tracks does not follow this resolution function and lies on the tails of the distribution. This can be caused by multiple reasons that are challenging to precisely simulate: reconstruction issues, contamination from poorer quality tracks, presence of secondary particles due to hadronic interactions with the material, and long-lived heavy-flavour hadrons. To exclude these track measurements, the fitting range is adjusted at each iteration until the fitted value of the resolution σ_{d_0} is stable within 0.5% [5].

3. – Results

Figure 1(a) shows the resolution of the transverse impact parameter σ_{d_0} as a function of the transverse momentum p_T. The ratio pad shows the distribution of the 2017 and 2018 data with respect to the 2016 data sample. As can be noted, for 2017 and 2018, the resolution of d_0 degrades by a factor of approximately 5%.

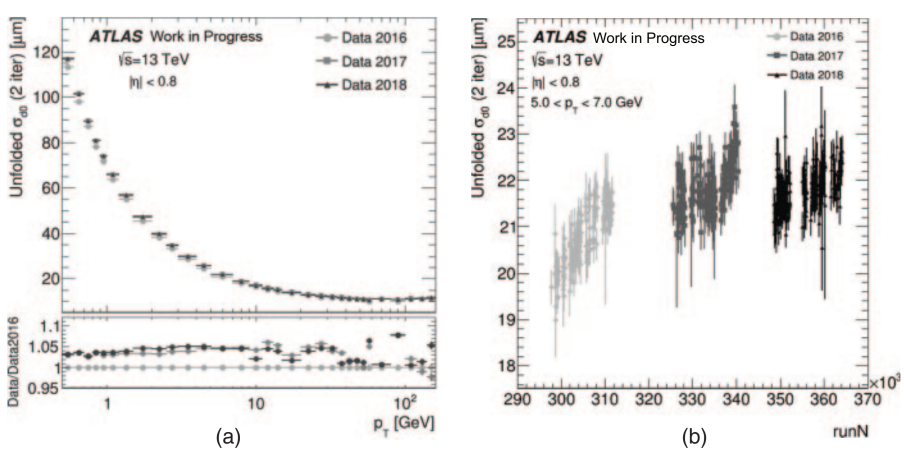

Fig. 1. – The transverse impact parameter resolution σ_{d_0} for the 2016, 2017 and 2018 data samples as a function of p_T (a) and as a function of the run number (b). Large errors in panel (b) are mostly due to low statistics.

To better see the time-dependence degradation of the IP resolution, this quantity has been plotted as a function of the run number in fig. 1(b).

The plot confirms the fact that the 2016 data sample presents the best σ_{d_0} value, which gets worse over time. This could be related to the radiation damage caused to the detector and/or to changes in the running conditions. To better investigate the causes, a study of σ_{d_0} on $\langle \mu \rangle$ —*i.e.*, mean number of interactions per bunch crossing— has also been performed. Studies divided by years are presented in fig. 2.

The 2016 data sample appears not to be stable (fig. 2(a)). However, this is strongly related to the changing running conditions during the LHC instantaneous luminosity ramp-up, and the week-by-week increase of $\langle \mu \rangle$.

Figure 2(b) shows the 2017 sample. It can be seen that, starting from $\langle \mu \rangle \approx 52$, the d_0 resolution degrades by ≈ 0.8 μm. This is due to the fact that, since September 2017, the LHC filling scheme changed. In fact, during the summer of that same year, LHC experienced unexpected beam losses. Since densely packed bunches were supposed to be one of the causes that could trigger such events, the standard LHC beam was replaced

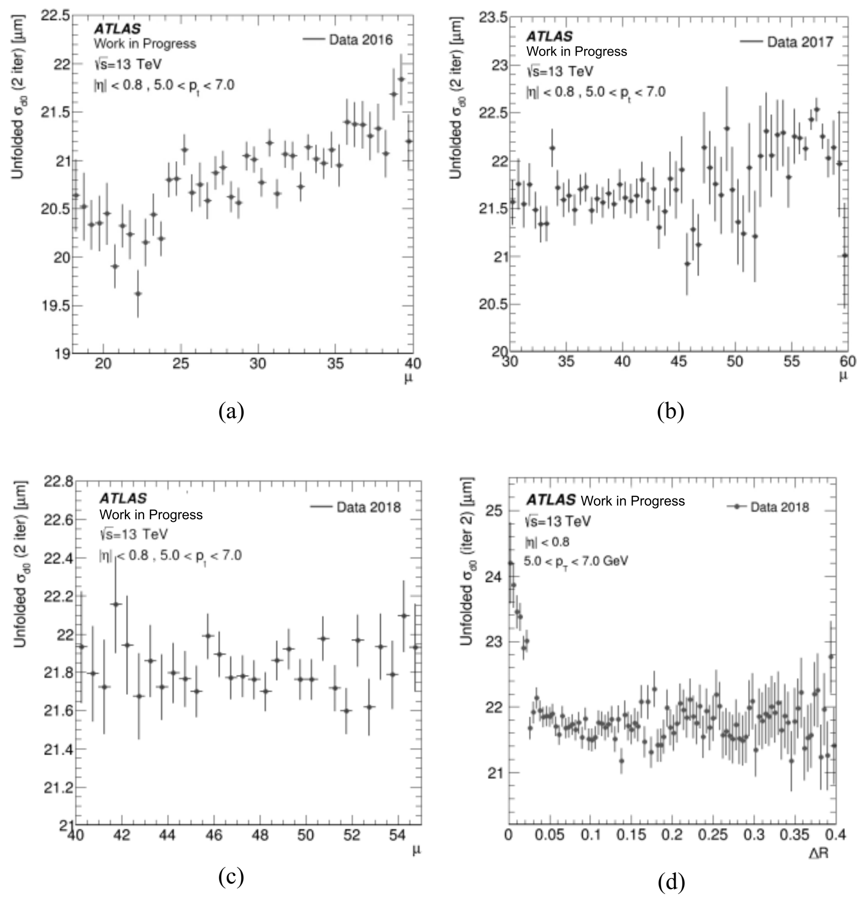

Fig. 2. – d_0 resolution as a function of $\langle \mu \rangle$ for the 2016 (a), 2017 (b) and 2018 (c) data samples. (d) σ_{d_0} dependence on track density for 2018 data sample.

by a so-called "8b4e" ("8 bunches" and "4 empty" slots) beam [6, 7]. The price to pay was a lower number of bunches in the LHC due to the empty bunch slots. Adjustments were made to reach the same luminosity as before, causing an increase in the number of pile-up interactions, which caused a reduction in the IP resolution.
Nevertheless, if the 2017 sample is treated separately, the d_0 resolution, before and after the filling scheme change, appears to be stable.

Computing a linear fit on the resolution distributions for each year of data taking, it can be noted that the data from 2018 presents the most stable behaviour (fig. 2(c)). It can be concluded that the IP resolution degradation is not only given by changes in the running conditions, but also by radiation damage, which badly affects the detector performances.

To investigate the behaviour of the resolution of the transverse impact parameter in a high-density environment, the quantity has been studied as a function of ΔR, defined as the angular separation between a track and the jet axis.

The plot for the 2018 data sample is presented in fig. 2(d). Same considerations are valid for 2016 and 2017 data. As can be seen, the d_0 resolution is stable for $\Delta R > 0.02$, while at a short distances from the jet axis —corresponding to $\Delta R < 0.02$— it gets worse approximately by a 10% factor. This is because inside the jet core, the particles density is so high that the charged-particle tracks begin to overlap and the energy deposits become too close to be individually resolved. This high-density environment results in a degradation of track reconstruction and, thus, of the IP resolution measurement.

4. – Conclusions

The transverse impact parameter resolution of the tracks has been measured by the ATLAS ID using a proton-proton collision data collected at a center-of-mass energy of $\sqrt{s} = 13$ TeV from 2016 to 2018. A degradation of the transverse impact parameters resolution of approximately 5% has been observed over the period considered. This is due to the convolution of changes in the running conditions —observed studying the resolution as a function of the mean number of interactions per bunch crossing $\langle\mu\rangle$— and radiation damage, which changes the intrinsic properties of the ATLAS ID.

Moreover, during 2017 the LHC filling scheme has been changed resulting in a degradation of the impact parameter resolution of approximately 0.8 μm.

REFERENCES

[1] The ATLAS Collaboration, *JINST*, **3** (2008) S08003.
[2] The ATLAS Collaboration, *Tech. Rep. ATL-PHYS-PUB-2014-014* (Aug. 2014).
[3] Tanabashi M. *et al.*, *Phys. Rev. D*, **98** (2018) 030001.
[4] The ATLAS Collaboration, *JINST*, **11** (2016) P04008.
[5] The ATLAS Collaboration, *Tech. Rep. ATLAS-CONF-2010-070* (CERN) 2010.
[6] Kahle K. and Steerenberg R., *LHC Report: Something in the Nothing* (CERN) 2017.
[7] Wenninger J., *LHC Report: Operation with Holes* (CERN) 2017.