PROCEEDINGS OF SCIENCE

Measuring luminosity with track counting in the ATLAS experiment

Paul Moder[a,*] **on behalf of the ATLAS collaboration**

[a] *Deutsches Elektronen-Synchrotron,*
Notkestraße 85, Hamburg, Germany

E-mail: paul.moder@cern.ch

The precise measurement of the luminosity is one of the key requirements for every ATLAS analysis at the Large Hadron Collider (LHC) at CERN. Particularly in high precision measurements, the uncertainty on the luminosity can be one of the main limitations. Therefore, its reduction is the prime goal of the ATLAS luminosity programme, requiring a precise understanding of the contributing factors. The two largest individual components are the calibration transfer (extrapolating the measurement from the calibration regime to the physics regime) and the long term stability (stability of the measurement typically over a whole year), both determinations involving the track counting luminosity measurement. This technique uses charged particle tracks to measure the delivered luminosity. The uncertainty of this measurement is dependent on the track selection and therefore, the performance of three selections is compared over different LHC fill configurations. The goal of this study is to determine the stability of the measurement and if possible correct observed effects.

40th International Conference on High Energy physics - ICHEP2020
July 28 - August 6, 2020
Prague, Czech Republic (virtual meeting)

*Speaker

https://pos.sissa.it/

PoS(ICHEP2020)811

1. Track Counting Luminosity Measurement

The delivered luminosity at the ATLAS detector [1] can be measured by counting the average number of charged particle tracks in events collected by a set of random triggers and stored in dedicated event streams. With the number of tracks N_{trks} and the number of bunch crossings N_{evts}, a variable proportional to the instantaneous luminosity can be defined:

$$\mathcal{L}_{\text{inst}} \sim n_b \frac{\langle\mu\rangle_{\text{vis}} \cdot f_r}{\sigma_{\text{vis}}}, \quad \langle\mu\rangle_{\text{vis}} = \frac{N_{\text{trks}}}{N_{\text{evts}}}. \tag{1}$$

In this case, n_b is the number of colliding bunch pairs, f_r the revolution frequency, σ_{vis} the visible cross-section of proton–proton collisions and $\langle\mu\rangle_{\text{vis}}$ the BCID[1] averaged visible interaction rate (i.e. the number of reconstructed tracks) per bunch crossing. In comparison to the inelastic cross-section σ and the BCID averaged number of inelastic interactions per bunch crossing $\langle\mu\rangle$, the visible component takes the efficiency ϵ of the detector into account [2], as described in equation 2.

$$\sigma_{\text{vis}} = \epsilon\sigma, \quad \langle\mu\rangle_{\text{vis}} = \epsilon\langle\mu\rangle \tag{2}$$

Different selections are used for the charged particle tracks when estimating the luminosity, leading to different efficiencies and fake rates either as a function of the value $\langle\mu\rangle$, the bunch configuration, or detector effects. Three different selections are compared, each featuring charged particle tracks based on the Tight Primary selection described in Ref. [3], a transverse momentum p_{T} of at least 900 MeV and an impact parameter significance $|d_0/\sigma_{d_0}| < 7$. The *2016 selection* further requires the charged particle pseudorapidity η to satisfy $|\eta| < 2.5$ and no missing hit in the pixel detector layers traversed by the track. The *2017 selection* includes a tighter requirement of $|\eta| < 1.0$, but allows one missing hit in one and only one of the pixel detector layers. The *2017+Si hit selection* includes the selection requirements of the 2017 selection and at least one additional silicon (pixel or SCT) hit. For every selection, σ_{vis} is calibrated in a special LHC fill that has an average $\langle\mu\rangle$ value of 0.5, isolated bunches and no crossing-angle between the colliding beams. The calibration factor determined in this fill is assumed to be constant when going into the physics regime where fills typically have $\langle\mu\rangle$ values around 100 times higher, bunch trains[2] instead of isolated bunches and a crossing-angle between the beams.

2. Bunch Structure Dependence

The stability of the aforementioned calibration is evaluated by comparing different selections when extrapolating from the calibration fill to an LHC fill that only differs by one configuration parameter from the calibration fill. In the following, the 2016 selection and 2017+Si hit selection are compared to the 2017 selection by analysing the ratio of the run-integrated luminosity in these fills. If the differences in selections had no impact on the measurement, the value in these cases would

[1]The bunch crossing identifiers describe the 3564 positions at the LHC that can be filled with proton bunches. The time between every BCID is 25ns, and each position can either be filled with a proton bunch or left empty, resulting in different bunch configurations depending on the LHC fill.

[2]A bunch train is defined as a number of consecutive filled BCIDs with no empty BCIDs in between.

PoS(ICHEP2020)811

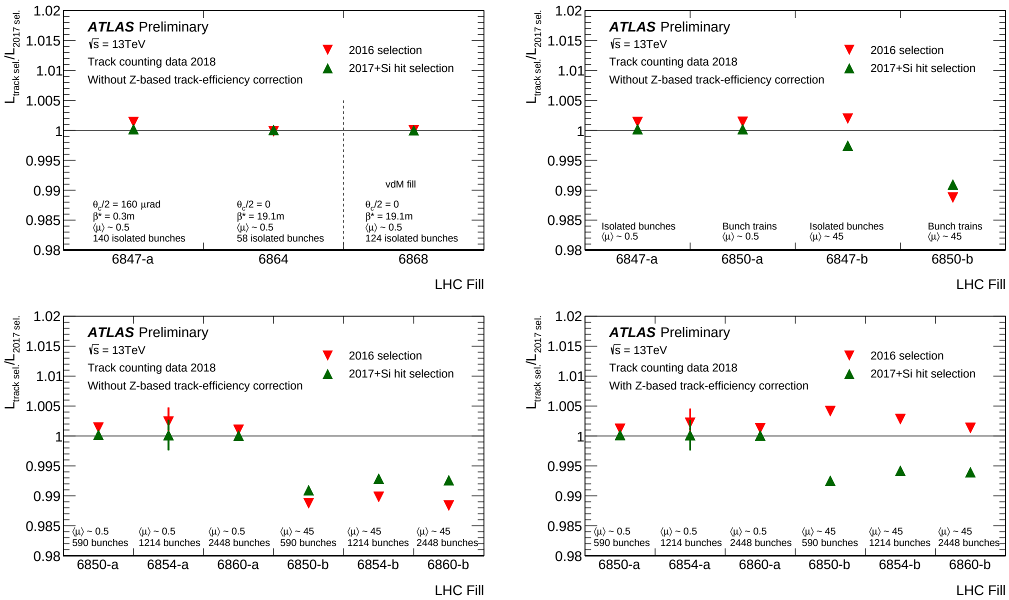

Figure 1: Ratio of the run-integrated track-counting luminosity, determined using two different sets of track-selection criteria, to that obtained using the baseline selection criteria (2017 selection). Shown are low pile-up fills (top left), low and high pile-up conditions with either isolated bunches or bunch trains (top right) and low and high pile-up conditions with bunch trains of 590 to 2448 colliding bunches without (bottom left) and with (bottom right) applied efficiency corrections based on $Z \rightarrow \mu\mu$ events [4].

be consistent with 1. This analysis was done for differences in crossing-angle of the two beams θ_c and beam-focusing parameter β^*[3], for differences in run-average $\langle\mu\rangle$ values and for differences in the bunch structure in these fills, either being isolated bunches or bunch trains. Figure 1 shows the effect of the different parameters. Extrapolating from fills with differences in θ_c and β^* does not affect the measurement in the three described selections. However, extrapolating from fills with $\langle\mu\rangle < 1$ to fills with average $\langle\mu\rangle$ values around 100 times higher, and extrapolating from fills with individual bunches to fills with bunch trains at $\langle\mu\rangle > 10$ both lead to a shift in ratio between the luminosity values of the 2016/2017+Si hit and 2017 selection of around 1%. The shift in the case of increasing $\langle\mu\rangle$ can be partially corrected in the 2016 selection by applying efficiency corrections based on $Z \rightarrow \mu\mu$ events. This leads to a slight overcorrection of around 0.4%.

In order to better understand the dependence on trains compared to individual bunches, the internal track counting ratios for the 2016 selection against the 2017 selection were investigated as a function of the bunch position as shown in Figure 2. In this case, $\langle\mu\rangle$ describes the average μ values over the whole run, but not the average over the BCID. The left figure shows the ratios between the two selections for first bunches in a train (green triangles) and first bunches in a subtrain (violet triangles)[4]. Bunches that correspond to first bunches of a (sub)train behave similarly to one another. Furthermore, the bunches that correspond to the first bunches of a train also behave like individual

[3] β^* indicates how squeezed the beams are at the interaction point (IP), by giving the distance after which the beams have widened to twice the size they have at the IP.

[4] If the number of empty bunches between two series of consecutive bunches is 7, then these series are treated like a large bunch train consisting of two or more smaller subtrains.

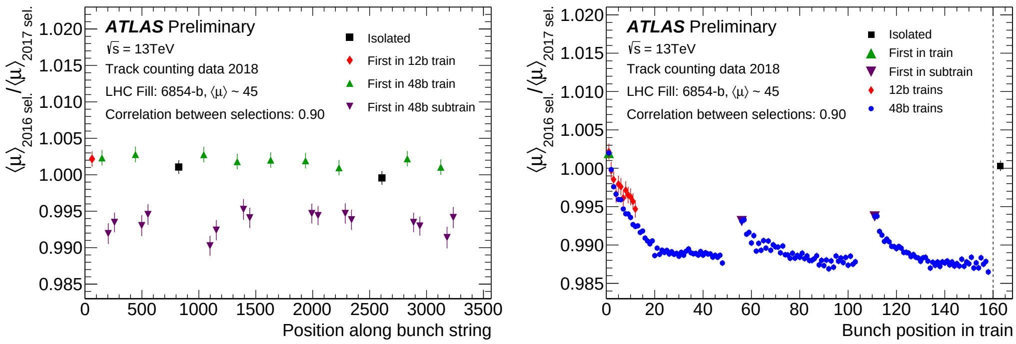

Figure 2: Ratio of the run-averaged pile-up parameter, defined as the mean number of inelastic proton–proton interactions per bunch crossing, determined by the track-counting technique using the 2016 selection, to that obtained using the baseline 2017 selection criteria, as a function of the position of the bunch along the bunch string (left) and as a function of the position of the bunch along the train (right). On the left side, the μ values are averaged over the whole run while on the right side, μ values are averaged over the whole run and the same bunch positions [4].

bunches, visible when comparing the green triangles with black squares. In the right figure, the different bunch trains of the fill are folded onto each other to reduce statistical uncertainty when investigating the behaviour inside a train. The ratio in run-averaged $\langle \mu \rangle$ values between the two selections decreases in all subtrains until a certain plateau is reached after around 20 bunches, beyond where it stays constant. The value for the plateau is independent of the subtrain. Furthermore, the effect caused by bunch trains is decreasing with time if there are empty BCIDs. However, a gap of 7 empty BCIDs as it is present between the individual subtrains is not enough to fully restore the ratio. The reason for the observed behaviour in bunch trains is still being investigated, but it is likely that charged particle tracks passing through the pixel detector have an effect on the efficiency for detecting signals a short time afterwards.

3. Summary

Measuring the luminosity is an important requirement for every ATLAS analysis at the Large Hadron Collider (LHC) at CERN. One technique, the track counting luminosity measurement, is based on counting the average number of charged particle tracks per event, and is used to determine the effect caused by extrapolating from the calibration regime to the physics regime. This measurement is already very stable, but has some dependence on $\langle \mu \rangle$ and the bunch train structure. The bunch train effect is still under investigation and is likely caused by bunch-train dependent inefficiencies in the pixel detector.

References

[1] ATLAS Collaboration, “The ATLAS Experiment at the CERN Large Hadron Collider”, 2008 JINST 3 S08003.

[2] ATLAS Collaboration, “Luminosity determination in *pp* collisions at $\sqrt{s}$ = 13 TeV using the ATLAS detector at the LHC”, ATLAS-CONF-2019-21, https://cds.cern.ch/record/2677054/, 2019.

[3] ATLAS Collaboration, “Early Inner Detector Tracking Performance in the 2015 data at $\sqrt{s}$ = 13 TeV”, ATL-PHYS-PUB-2015-051, http://cdsweb.cern.ch/record/2110140, 2015.

[4] ATLAS Collaboration, “Track-counting luminosity studies from the 2018 $\sqrt{s}$ = 13 TeV dataset”, https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/LUMI-2020-01/, 2020.