Track-counting luminosity measurement in ATLAS

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Abstract:
At the LHC, the number of inelastic proton-proton collisions per second is proportional to the luminosity. Track counting is one of the methods for luminosity measurement in the ATLAS experiment. It is done by counting the number of charged-particle tracks reconstructed in the inner detector in unbiased triggers, where the number of tracks scales with the number of interactions. Therefore, as long as the performance of track reconstruction and selection are independent of the luminosity and time, the average number of tracks per event can be used to measure the luminosity. A new track selection, which is less sensitive to changes in the inner detector conditions and shows a more stable performance over a large luminosity range, was introduced in 2017. Results from 2017 and 2018 data have shown a good agreement between track counting and other algorithms, including LUCID which is the dedicated online and offline luminometer of the ATLAS detector.

ATLAS and its Inner Detector

The ATLAS detector [1] is a general-purpose detector at the LHC, composed of several sub-detector systems. The closest system to the interaction point is the Inner Detector (ID), which consists of silicon detectors and drift tubes. It determines the momenta and impact parameters of charged particles by measuring their tracks in the ID [2].

Track selection

Track selection	2016	2017
p_T [MeV]	> 900	
$\|\eta\|$	< 2.5	< 1.0
$\|d_0/\sigma_{d_0}\|^*$	< 7	
Number of silicon hits	$\geqslant 9$	
Number of pixel holes	0	1
$\geqslant 1$ hit on one of the two innermost pixel layers		

* The absolute transverse impact parameter with respect to the luminous centroid

The 2016 track selection has been changed to the 2017 selection in order to reduce the dependence on the ID running conditions.

Luminosity

Luminosity is an essential parameter for the ATLAS physics programme. The integrated luminosity is used when measuring the cross-section of a process and when deriving the expected number of events (N_{event}) originating from a certain process. There are several detectors and algorithms used in ATLAS to measure luminosity in order to control the systematic uncertainties [3].

Bunch luminosity: $$\mathcal{L}_b = \frac{\mu f_r}{\sigma_{inel}}$$

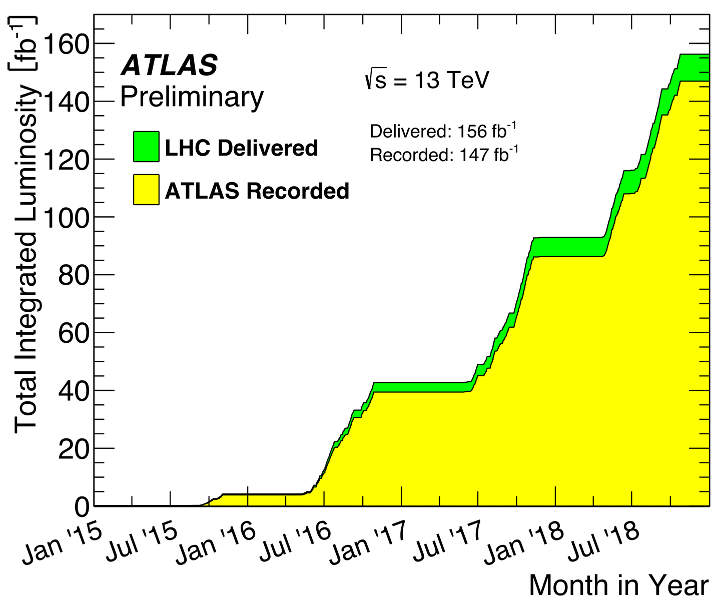
- μ: Average number of inelastic *pp* collisions per bunch crossing (pile-up parameter)
- f_r: LHC revolution frequency
- σ_{inel}: *pp* inelastic cross-section

Total instantaneous luminosity: $$\mathcal{L} = \sum_{b=1}^{n_b} \mathcal{L}_b = n_b < \mathcal{L}_b > = n_b \frac{<\mu> f_r}{\sigma_{inel}}$$

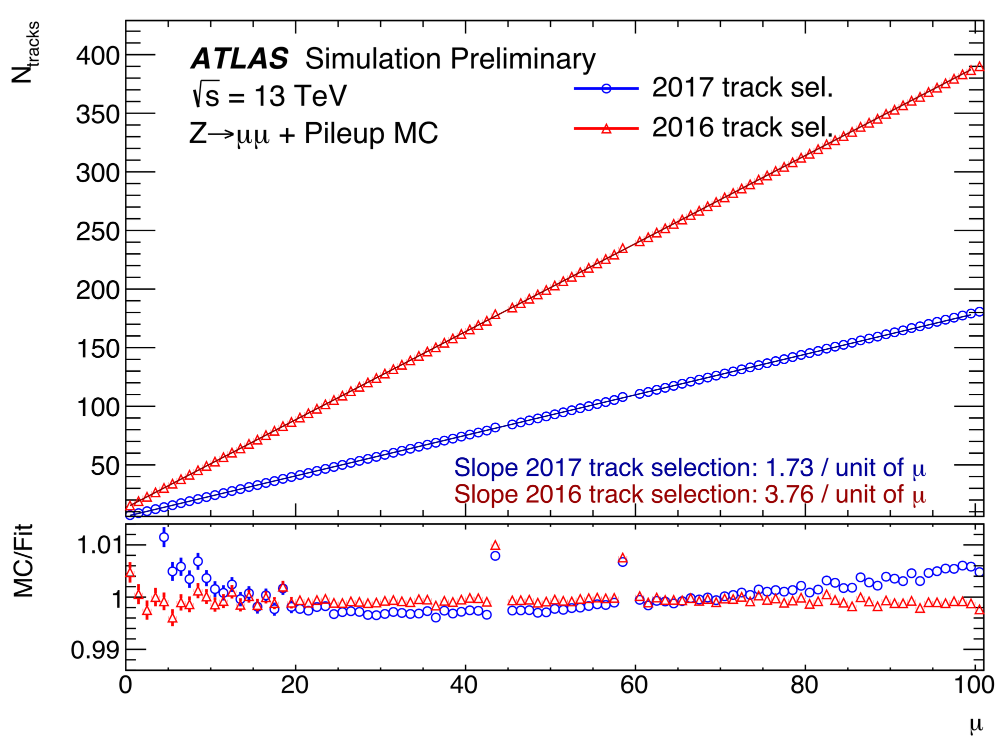
- n_b: Number of colliding bunch pairs
- $<\mu>$: Bunch-averaged pile-up parameter

Integrated luminosity: $$\mathcal{L}_{int} = \int \mathcal{L} dt = \frac{N_{event}}{\sigma}$$

- t: time
- σ: Process cross-section

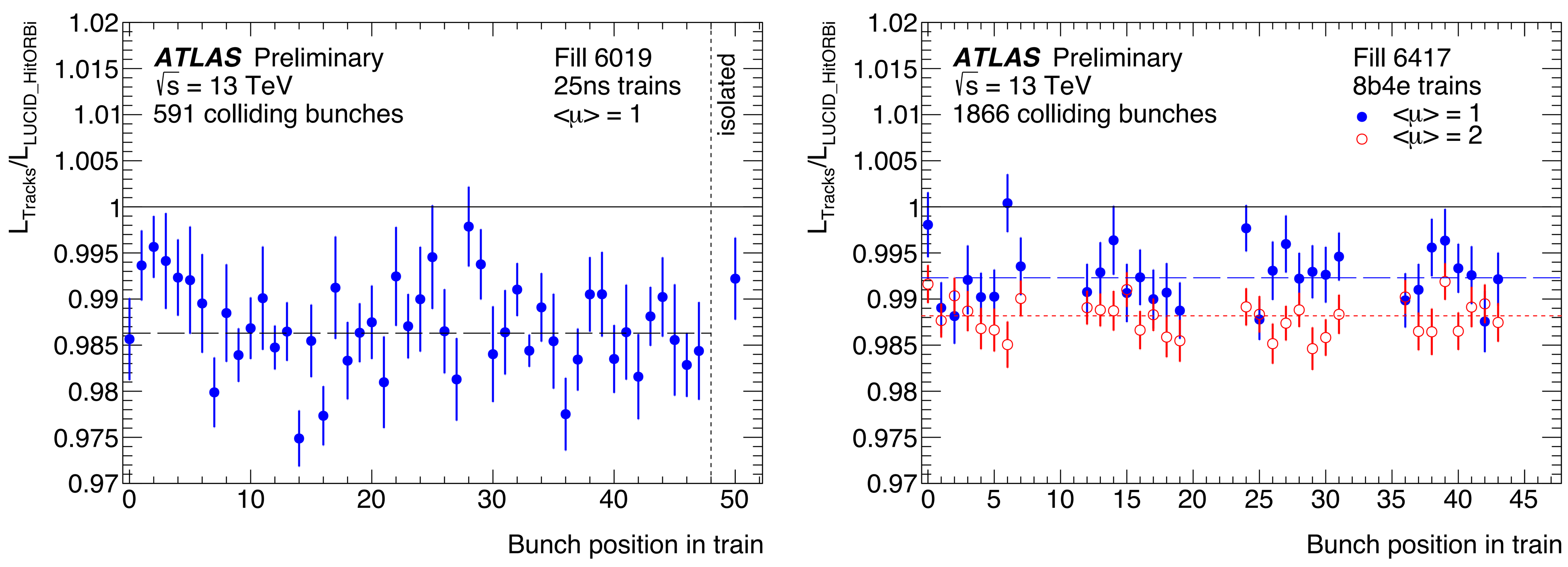


Track-counting luminosity



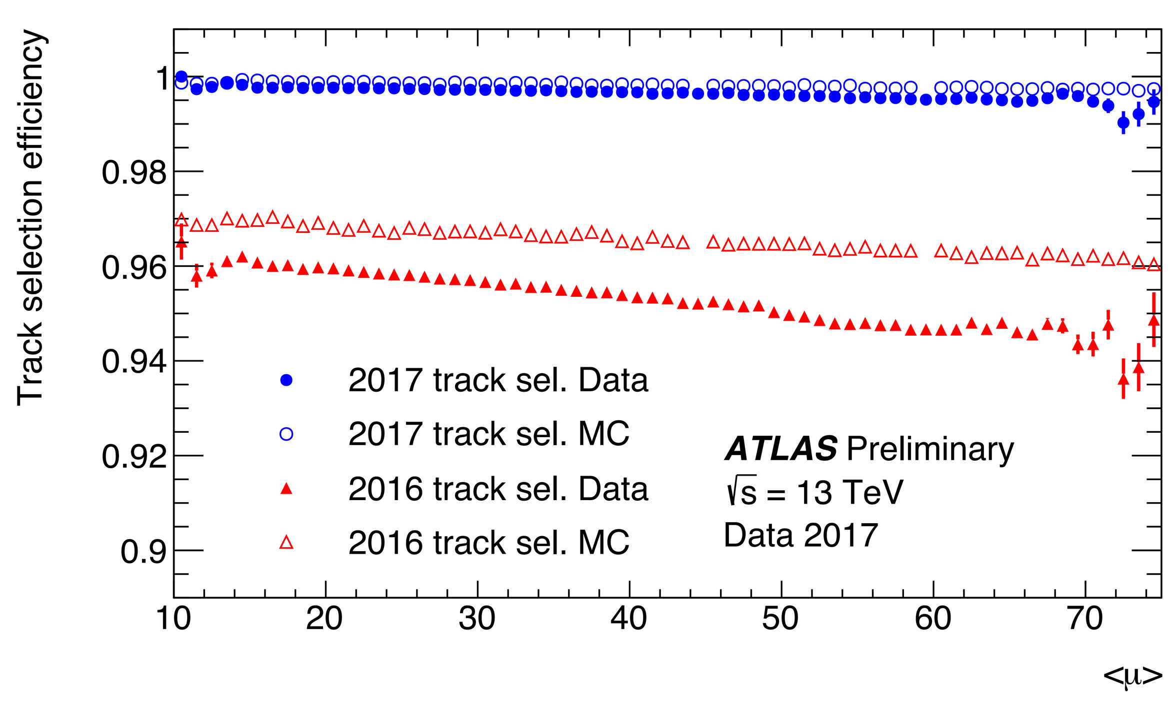
Track counting is one of the ATLAS luminosity algorithms. It is done by counting the number of charged-particle tracks (N_{tracks}) in unbiased random triggers, where $N_{tracks} \propto \mu$ as shown in the plot above [4].

Dependence on the LHC bunch structure



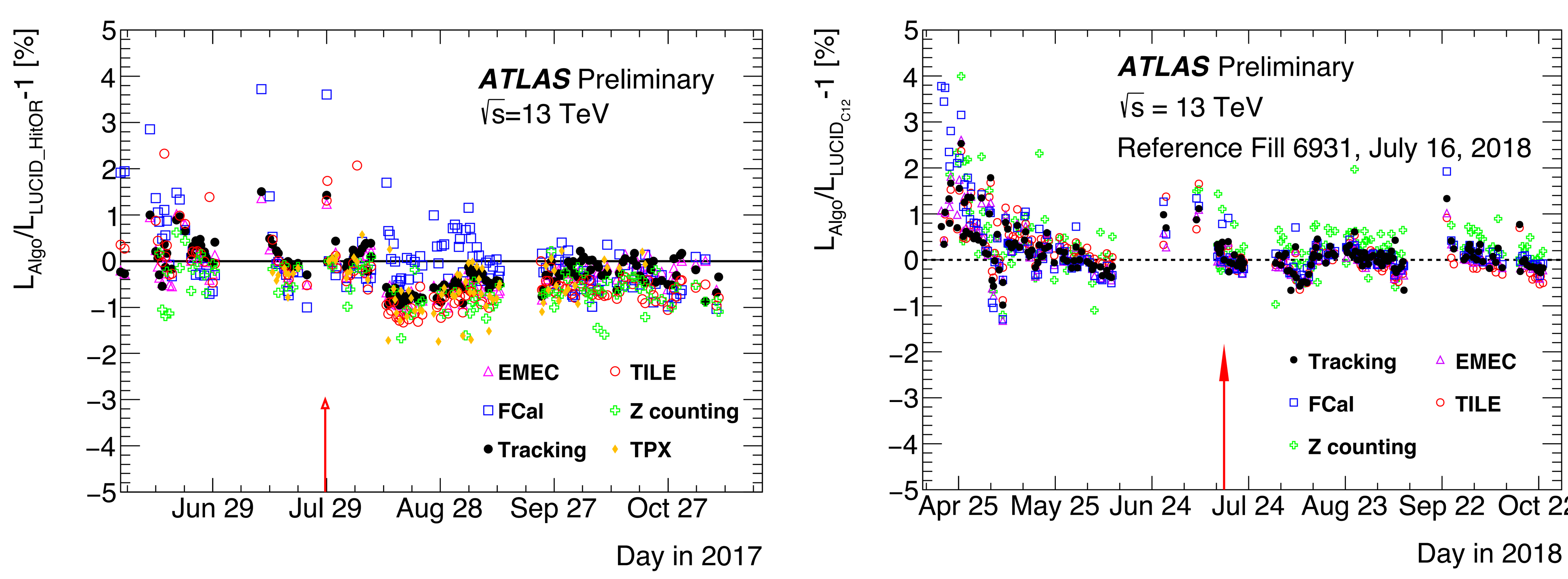
In both patterns, the track/LUCID luminosity ratio at $<\mu> = 1$ is significantly different from unity (filled blue circles). This relative μ-dependence is confirmed by the data at $<\mu> = 2$ (open red circles). With the possible exception of the first 8 bunch slots in the 25ns pattern (Fill 6019, left), there is no evidence, in either pattern, for a bunch-position dependence of the track/LUCID beyond purely statistical fluctuations.

Performance as a function of luminosity



Both data and MC simulation with the 2017 track selection show better efficiency over the $<\mu>$ range than those with the 2016 selection [4]. The efficiency is obtained with a tag-and-probe method applied to the muon tracks from the $Z \to \mu^+\mu^-$ events that pass the track-counting selection.

Stability throughout 2017 and 2018



The track-counting luminosity, using the 2017 track selection, shows good agreement with the luminosities measured by LUCID [5], EMEC, FCal, TILE, Z counting, and TPX in the ATLAS runs recorded during 25ns bunch-train running in 2017 (left) and 2018 (right) [4]. A pile-up dependent correction has been applied to LUCID, using the track-counting run marked by the red arrow as a reference.

References

[1] The ATLAS Experiment at the CERN Large Hadron Collider, ATLAS Collaboration, JINST 3 (2008) S08003.
[2] Early Inner Detector Tracking Performance in the 2015 Data at √s = 13 TeV, ATLAS Collaboration, ATL-PHYS-PUB-2015-051.
[3] Luminosity Determination in pp Collisions at sqrt(s) = 8 TeV using the ATLAS Detector at the LHC, The ATLAS Collaboration, Eur. Phys. J. C 76 (2016) 653, arXiv:1608.03953 [hep-ex].
[4] https://twiki.cern.ch/twiki/bin/view/AtlasPublic/LuminosityPublicResultsRun2
[5] The new LUCID-2 detector for luminosity measurement and monitoring in ATLAS, G. Avoni et al., JINST(2018) 13 P07017.