Simulation studies for the ATLAS track-counting luminosity measurement

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Abstract

A precise measurement of the luminosity is a key component of the ATLAS physics programme. ATLAS uses several detectors and algorithms to determine the luminosity. The absolute calibration of these algorithms is carried out in LHC runs with special beam conditions at low luminosity. The track-counting luminosity measurement is used to determine the calibration transfer from the low-luminosity regime to the high-luminosity conditions typical of standard physics data taking, and to monitor the long term stability of the default luminosity method.

The track-counting method works by counting the number of reconstructed tracks from charged particles inside the Inner Detector. The average number of charged particles in randomly-triggered events is proportional to the average number of inelastic collisions per event and can therefore be used to compute the luminosity. This poster presents simulation studies for the ATLAS track-counting luminosity measurement. A toy simulation model is used to study the underlying distribution of the number of tracks and to illustrate the linearity between the average number of tracks and the luminosity. Full ATLAS MC simulation is used to assess effects related to the reconstruction of the tracks and their effect on the linearity.

Method

The LHC bunch luminosity is given by

$$\mathcal{L}_\mathrm{b} = \frac{\mu f_\mathrm{r}}{\sigma_\mathrm{inel}} \qquad (1)$$

where μ is the average number of inelastic pp collisions per event, f_r the LHC revolution frequency, and σ_inel the pp inelastic cross-section.

- The track-counting measurement uses the average number of charged tracks of randomly triggered events to measure the luminosity.
- The *visible interaction rate* is given by

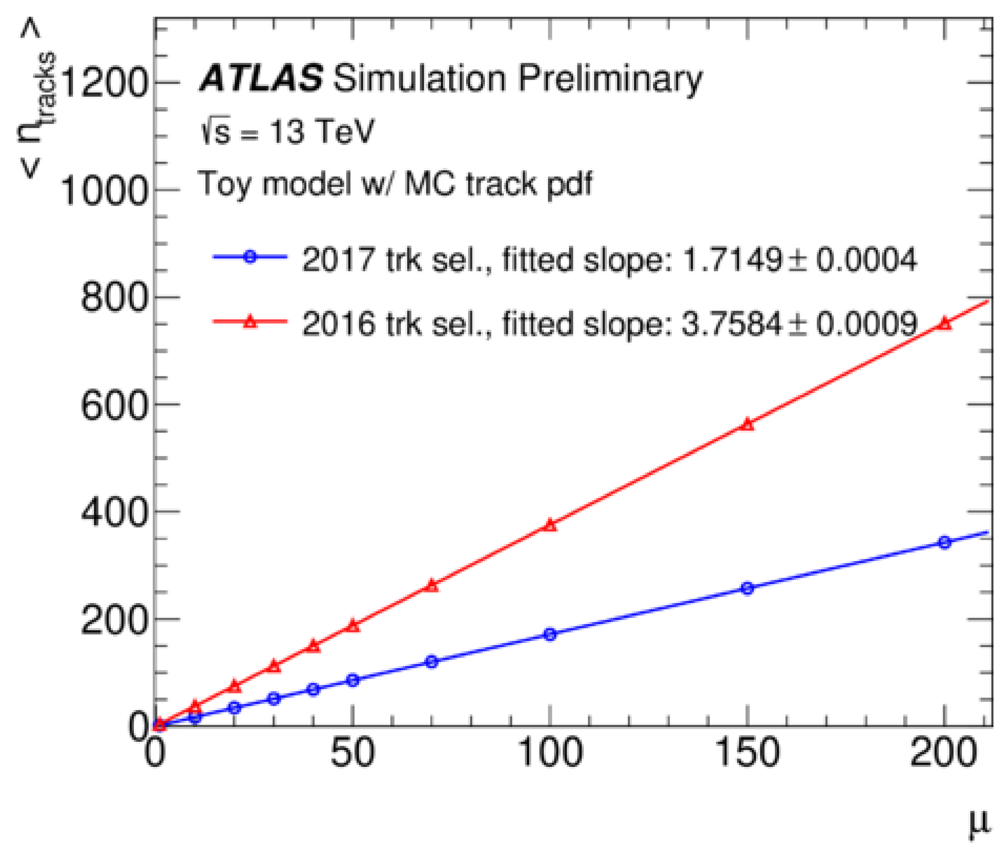
$$\mu_\mathrm{vis} = \langle N_\mathrm{tracks} \rangle = \frac{\sum_{i=1}^{N_\mathrm{events}} N^i_\mathrm{tracks}}{N_\mathrm{events}} \propto \mu. \qquad (2)$$

- Two different track selections are explored

Selection	$\lvert\eta\rvert$	$N^\mathrm{Pixel}_\mathrm{Holes}$	$\lvert d_0/\sigma_{d_0}\rvert$	p_T
2016	< 2.5	0	< 7	> 0.9 GeV
2017	< 1.0	≤ 1		

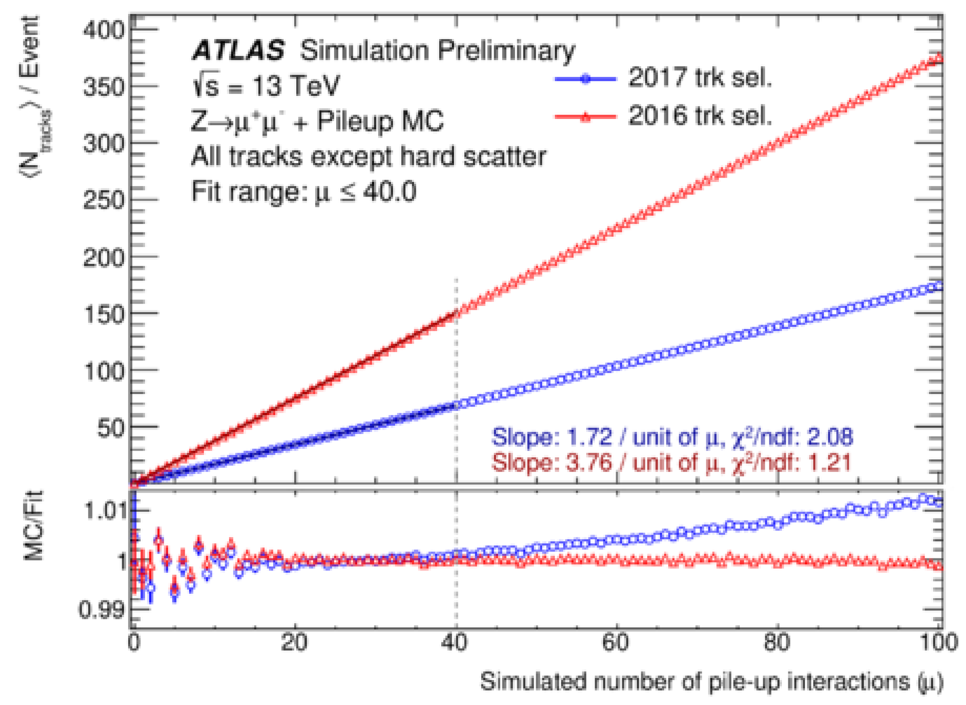
Track selections for the track-counting measurement, based on the TightPrimary selection defined in Ref. [1].

Linearity in toy simulation



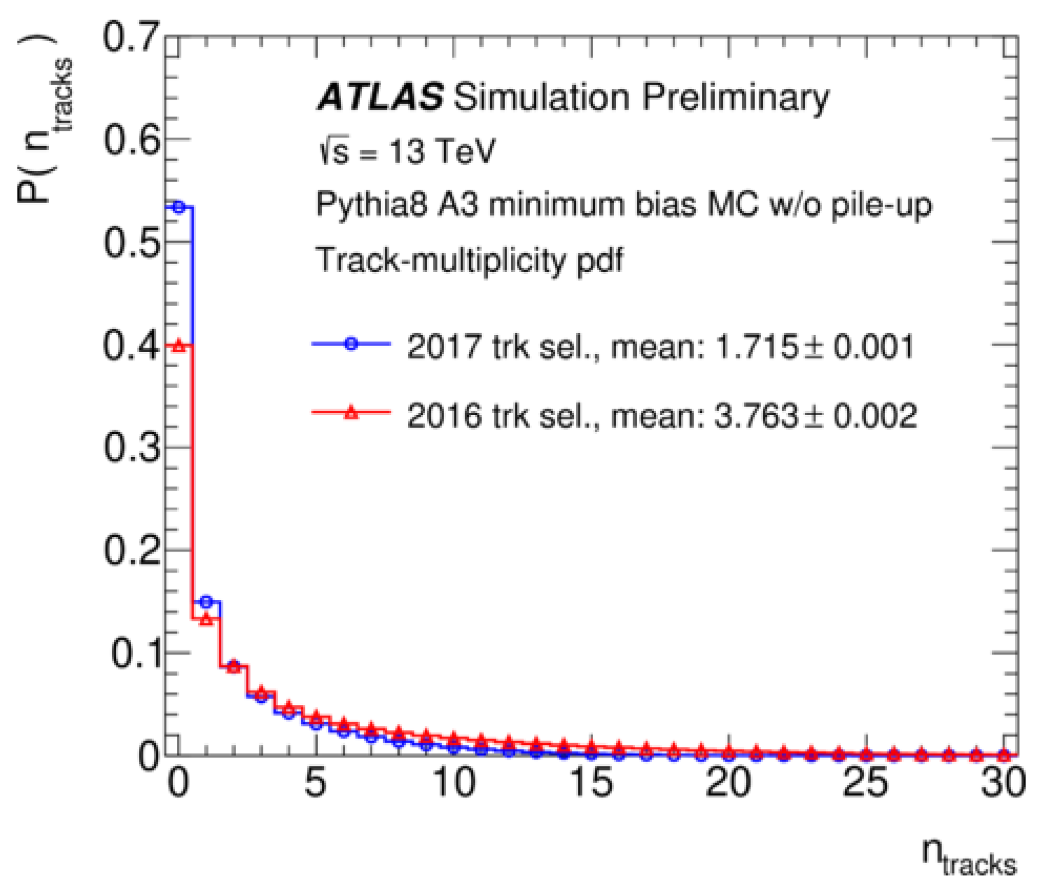
The linearity between μ_vis and μ illustrated in a toy simulation model. For each event, the number of interactions is determined from a Poisson distribution with mean μ. The number of tracks per interaction is then sampled from the track-multiplicity pdf. The resulting track distribution is used to determine the mean number of tracks per event for the specific value of μ. The proportionality constant between μ_vis and μ corresponds to the mean of the track-multiplicity pdf.

Linearity in full simulation



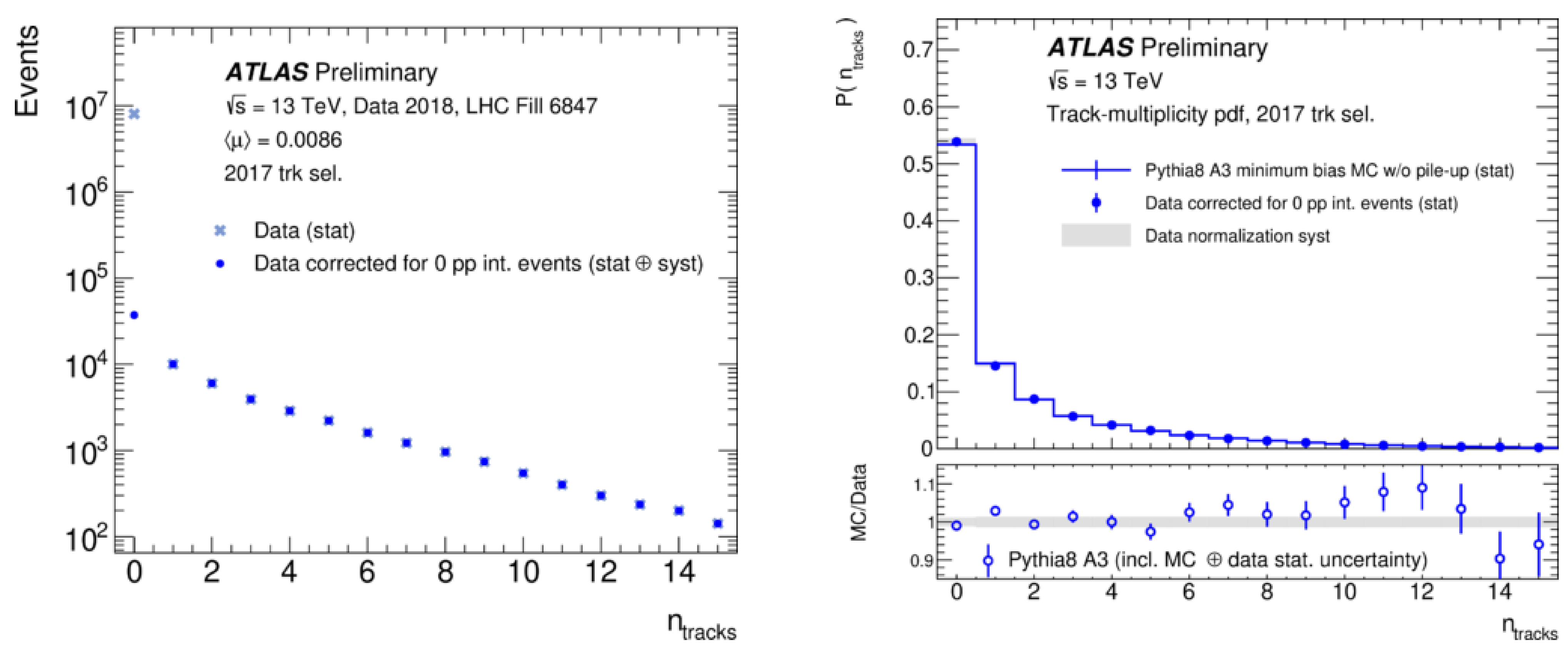
Relation between μ_vis and μ in full simulation. A $Z \to \mu\mu$ MC sample with overlaid minimum bias events as pileup is used for the study. Tracks from the hard scatter interaction are excluded in the number of reconstructed tracks. The μ-dependence is parameterised by a first-order polynomial, fitted in the range $\mu < 40$. The non-linearity results from the effects of track reconstruction efficiency and fake tracks. The higher non-linearity in the 2017 selection is likely due to the looser track-selection requirements.

Track-multiplicity pdf in MC



Normalized track distributions in a Pythia8 A3 minimum bias MC sample with exactly one pp interaction per event. The distributions can be interpreted as the track-multiplicity probability density functions (pdfs) for each track selection.

Track-multiplicity pdf in data



The 2017 track selection MC pdf is compared to data in order to assess the modelling of the track multiplicity. The data track-multiplicity pdf is derived from the distribution of the number of tracks per event in data with $\langle\mu\rangle \ll 1$ (left), selected for the purpose of eliminating events with more than one pp interaction. Events with zero tracks can arise either from bunch crossings where no pp interaction occurred ("empty crossings"), or from bunch crossings with one pp interaction in which no track satisfied the track-selection criteria. The zero-track bin is corrected for empty crossings using the Poisson probability for zero interactions based on the luminosity measured by the ATLAS default luminosity algorithm [2], and then subtracting the corresponding fraction of events. The systematic uncertainty on the corrected bin is estimated by varying the luminosity used in computing the correction by its 1.4% uncertainty. The normalized corrected distribution corresponds to the track-multiplicity pdf (right). The shaded error band on the data is computed from the difference in the normalization factor resulting from varying the content in the zero-track bin by its systematic uncertainty.

Pythia8 shows excellent modelling of the data track-multiplicity distribution.

References

[1] ATLAS Collaboration, *Early Inner Detector Tracking Performance in the 2015 Data at $\sqrt{s}$ = 13 TeV*, ATL-PHYS-PUB-2015-051

[2] ATLAS Collaboration, *Luminosity determination in pp collisions at $\sqrt{s}$ = 13 TeV using the ATLAS detector at the LHC*, ATLAS-CONF-2019-021