Not reviewed, for internal circulation only

ATLAS NOTE

ATL-PHYS-PUB-2016-017

5th August 2016

The Pythia 8 A3 tune description of ATLAS minimum bias and inelastic measurements incorporating the Donnachie-Landshoff diffractive model

The ATLAS Collaboration

Abstract

A tune of the Pythia 8 event generator suitable for inclusive QCD modelling is presented. The A3 tune uses the early Run 2 charged particle distribution and inelastic cross section results from ATLAS in addition to the Run 1 data used previously to construct minimum-bias tunes. For the first time in ATLAS, the tuning considers diffraction modelling parameters and a diffractive model other than the Pythia 8 default is used. This results in a better description of the measured inelastic cross-sections and a level of agreement that is comparable to the previous A2 tune for the other distributions considered. This can lead to improved modelling of additional proton-proton collisions in simulation.

© 2016 CERN for the benefit of the ATLAS Collaboration.
Reproduction of this article or parts of it is allowed as specified in the CC-BY-4.0 license.

Not reviewed, for internal circulation only

1 Introduction

The Pythia 8 [1] Monte Carlo (MC) event generator is used for many purposes in ATLAS simulation. One important role of Pythia 8 is that it is used as the main source of additional proton–proton collisions to model the effect of multiple proton–proton collisions in a single bunch-crossing (referred to as pile-up). The pile-up events add particles to each beam bunch crossing a and impact upon the reconstruction of jets, photons, electrons and missing transverse energy. An accurate description of such pile-up effects is therefore important.

Pile-up activity is dominated by events with little transfer of transverse momentum (p_{T}) from initial to final state and is modelled by inclusive inelastic events. Such events are generally described by phenomenological models in MC event generators. These models contain many parameters whose values are *a priori* unknown and thus need to be constrained by data. This optimisation process is known as *tuning*, and the resulting parameter sets are referred to as tunes.

Pythia 8 uses a mixture of perturbative parton shower (PS), Lund-string hadronisation, multiple parton interaction (MPI) and colour reconnection (CR) models to complement the leading-order QCD matrix element (ME) calculations. Non-diffractive events dominate the most inclusive sample of events that can be measured at ATLAS. This sample is referred to as minimum-bias. For describing the minimum-bias distributions, MPI and CR are the most important contributions, as well as diffraction where one or both protons dissociate independently.

ATLAS has previously used Run 1 data at center-of-mass energy (ECM) $\sqrt{s} = 7$ TeV to tune Pythia 8's MPI parameters, resulting in the A2 tune for minimum-bias (MB) & pile-up event simulation [2]. However, although the A2 tune describes the ATLAS Run 2 charged particle distributions [3] reasonably well, it overestimates the fiducial inelastic cross-section compared to the ATLAS measurements at both $\sqrt{s} = 7$ TeV [4] and $\sqrt{s} = 13$ TeV [5].

In ATLAS, such mismodelling is absorbed into the Poisson rate used to determined the number of pile-up events added to simulation. The average number of inelastic proton–proton interactions per bunch crossing is denoted as $< \mu >$. When comparing data with simulation in the presence of pile-up interactions, the $< \mu >$ distribution in simulation is reweighted to match that measured in data. Since the simulation and the data do not have the same cross section for emissions into the visible acceptance region of the detector, the μ in simulation is rescaled by comparing the fraction of the visible cross section to the total inelastic cross section for data and for MC. With the currently used A2 tune, this rescaling factor is about 1.11, but has large associated uncertainties.

The motivation for this study was to attempt to improve modelling of the fiducial inelastic cross-section by exploring Pythia 8's range of diffraction models, while retaining good agreement with ATLAS charged particle distributions. This also marks a switch to a newer parton distribution function (PDF), as described in Section 2, thereby placing this at the same footing as other Pythia 8 tunes used in ATLAS.

The Rivet analysis toolkit [6] and the Professor MC tuning system [7] have been used, at versions 2.4.1 and 1.4.beta respectively. The Pythia 8 version used was 8.186, with the PDFs taken from LHAPDF version 6.1.3 [8].

Not reviewed, for internal circulation only

Parameter	Sampling range
`MultipartonInteractions:pT0Ref`	1.00 – 3.60
`MultipartonInteractions:ecmPow`	0.10 – 0.35
`MultipartonInteractions:coreRadius`	0.40 – 1.00
`MultipartonInteractions:coreFraction`	0.50 – 1.00
`BeamRemnants:reconnectRange`	0.50 – 10.0
`Diffraction:PomFluxEpsilon`	0.02 – 0.12
`Diffraction:PomFluxAlphaPrime`	0.10 – 0.40

Table 1: Tuning parameters and sampling range

2 Tuning setup

2.1 Tuning parameters

The parameters considered include the MPI p_T regularisation parameter, **`MultipartonInteractions:pT0Ref`**, the power law dependence of the MPI screening scale on ECM, **`MultipartonInteractions:ecmPow`** and the strength of the phenomenological colour-string reconnection mechanism **`BeamRemnants:reconnectRange`**. The **`MultipartonInteractions:bProfile`** controls the MPI matter overlap profile. The diffractive model setting is controlled by **`DiffractionPomFlux`** parameter. The reader is referred to the Pythia 8 online documentation for a more detailed description of the tuned parameters. The tuned parameters are listed in Table 1, along with the sampling range used for each parameter.

The starting point of the tune is the Monash tune [9], and the remaining parameters were left unchanged from the Monash tune values. Monash uses the NNPDF23LO [10] leading-order (LO) PDF. This PDF is used in other ATLAS Pythia 8 tunes, which are used in high p_T physics, and gives a good description of charged particle p_T spectra at both $\sqrt{s} = 7$ TeV and 13 TeV [3, 11].

Two important changes were made with respect to Monash:

- The Monash configuration uses an exponential overlap function (**`MultipartonInteractions:bProfile = 3`**, with an exponent **`MultipartonInteractions:expPow`**) as opposed to the Gaussian matter distribution with a width that varies according to the selected x-value of an interaction of the A2 tune (with **`MultipartonInteractions:bProfile = 4`**). The double Gaussian profile (with **`MultipartonInteractions:bProfile = 2`**) is used here with two free parameters, **`MultipartonInteractions:coreRadius`** and **`MultipartonInteractions:coreFraction`**.
- Monash, and indeed all previous and current Pythia 8 tunes have used the default Schuler and Sjöstrand [12] diffraction model. This model over-estimates the inelastic cross-section measured by ATLAS at 7 TeV and at 13 TeV; alternative models are therefore considered here. Changing the diffractive model affects the charged particle distributions not only at the low multiplicity or low p_T region, but also at intermediate values, and in each case, the MPI and CR parameters need retuning in order to preserve reasonable agreement with data. The Donnachie and Landshoff [13] model is found to give the best description of the minimum-bias observables, and the measured fiducial inelastic cross-section [5]. The Donnachie and Landshoff model (**`Diffraction:PomFlux = 4`**) comes with two tunable parameters, **`Diffraction:PomFluxEpsilon`**, and **`Diffraction:PomFluxAlphaPrime`**, which control the Pomeron Regge trajectory.

Not reviewed, for internal circulation only

$\sqrt{s}$	Measurement type	Rivet name
13 TeV	MB	ATLAS_2016_I1419652 [3]
13 TeV	INEL XS	MC_XS [5]
7 TeV	MB	ATLAS_2010_S8918562 [11]
7 TeV	INEL XS	ATLAS_2011_I89486 [4]
7 TeV	RAPGAP	ATLAS_2012_I1084540 [15]
7 TeV	ETFLOW	ATLAS_2012_I1183818 [14]
900 GeV	MB	ATLAS_2010_S8918562 [11]
2.36 TeV	MB	ATLAS_2010_S8918562 [11]
8 TeV	MB	ATLAS_2016_I1426695 [16]

Table 2: Names of the River routines. The last two were not used in tuning, but are stated for completeness as the final tune is compared to them. The ATLAS 13 TeV INEL XS routine was not available at the time of this work, but the analysis is identical to ATLAS 7 TeV INEL XS, except the fiducial phase space definition and easily implementable in MC_XS routine.

2.2 Tuning process

The following measurements were used in this tuning:

ATLAS $\sqrt{s}$ = 13 TeV: charged particle minimum-bias distributions [3] (referred as MB) and fiducial inelastic cross-section [5] (referred to as INELXS);

ATLAS $\sqrt{s}$ = 7 TeV: charged particle distributions [11], transverse energy flow [14] with the same event selection as the charged particle distributions, but including neutrals (referred to as ETFLOW), rapidity gaps [15] (referred to as RAPGAP) and fiducial inelastic cross-section [4];

ATLAS $\sqrt{s}$ = 900 GeV: charged particle minimum-bias distributions [11].

The above information, and the corresponding Rivet routine names are shown in Table 2.

The previous ATLAS tunes were performed using the Professor automated tuning tool, where each bin of each observable was parametrised as a N-dimensional 3rd order polynomial based on the sampled tune points in the parameter hypercube (N being the number of tuned parameters). These parametrisations were then used to calculate a χ^2 with respect to the reference data, which was numerically minimised in the parameter space to find the best tune point. Weight factors were used in the χ^2 and degree of freedom, N_{df}, calculation to place increased emphasis on certain observables.

In the current tuning, a different approach was taken in which different parameters were tuned independently. A full Professor tune varies all parameters simultaneously and includes the possibility of correlations between the optimal values for different parameters. Tuning some parameters independently reduces the ability to account for such correlations, which are anticipated to be small in the case of this more limited tuning dataset.

The tune was performed in several steps:

1. One and half million soft-QCD inelastic pp events were generated for five hundred parameter points from the hypercube of these seven parameter ranges. This was done for each of the three center of mass energies.

Not reviewed, for internal circulation only

Parameter	Center-of-mass energy (TeV) 0.9	7	13
Charged particle pseudorapidity	(0.5,1),(0.1,2),(0.5,6),(0.1,20), (2.5,1)	(0.5,1),(0.1,2),(0.5,6),(0.1,20), (2.5,1)	(0.5,1)
Charged multiplicity	(0.5,1),(0.1,2),(0.5,6),(0.1,20), (2.5,1)	(0.5,1),(0.1,2),(0.5,6),(0.1,20), (2.5,1)	(0.5,1)
Charged particle p_T	(0.5,1),(0.1,2),(0.5,6),(0.1,20), (2.5,1)	(0.5,1),(0.1,2),(0.5,6),(0.1,20), (2.5,1)	(0.5,1)
Charged mean p_T against multiplicity	(0.5,1),(0.1,2)	(0.5,1),(0.1,2)	(0.5,1)

Table 3: Observables and weights used for the three different ECM tunes. The (x, y) pair denotes the charged particle p_T threshold, and minimum number of charged particles required, respectively, and thus each (x, y) number represents one distribution at that ECM. Each bracketed pair of numbers therefore corresponds to a unique distribution that is given a weight of unity in the tune.

2. Tuning was performed, individually at the three ECMs by keeping the **`MultipartonInteractions:ecmPow`** parameter fixed at Monash value. The motivation for this was to probe the behaviour of the energy independent tuning parameters at the three different ECMs. Different measurements were available at different ECMs (*i.e.* the inelastic cross-section measurement is not available at $\sqrt{s} = 900$ GeV, or the transverse energy flow is only available at $\sqrt{s} = 7$ TeV). To ensure consistent treatment of all energies, a first pass of the tuning was performed using only MB distributions. The Professor framework uses weight factors to place increased emphasis on certain observables. The weights used at this stage are listed in Table 3, where each (x, y) number represents a unique distribution that is given a weight of unity in the tune. Therefore, a distribution effectively receives a weight of five if there are five (x, y) pairs.

3. The ETFLOW, RAPGAP and INELXS distributions were then added in a second pass and the effect of these distributions on the tuned parameters was assessed.

4. Finally, several tunes were obtained using the Professor framework. These included all available observables from all ECMs. The weights were varied to get better description of certain observables, but only the tunes in which tuned parameters remained close to the values obtained in Step 2 and 3 above were considered. This was to ensure that the general behaviour of the tunes stay consistent across all ECMs. Then generator runs were performed around these preliminary tune values, (*i.e.* in the much reduced parameter space) and a final tune was decided on.

3 Results

3.1 Inputs to the final tune

To understand the energy dependence of the parameters, the tuning results at different ECM individually using just MB distributions were initially determined. For each parameter at each ECM, a tuned value was determined and then compared to values of that same parameter when a subset of sampling runs are used. The spread of these points were an indication of the statistical and extrapolation uncertainty on the tune, as well as how well constrained that tuned value is from the observables used. The next step was to determine the sensitivity of each of these parameters to different observables, by successively adding distributions other than those from the MB analysis, and varying the relative weight.

The following observations describe the main feature observed in this study in the step 2 and step 3 described in Section 2.2, which is also documented in Table 4.

Not reviewed, for internal circulation only

Parameter	Observation from Step 2	Observation from Step 3
`MultipartonInteractions:pT0Ref`	Within 2.4 and 2.5	-
`MultipartonInteractions:ecmPow`	Fixed at 0.21	Fixed at 0.21
`MultipartonInteractions:coreRadius`	Poorly constrained	Around 0.5
`MultipartonInteractions:coreFraction`	Poorly constrained	Poorly constrained
`BeamRemnants:reconnectRange`	Around 6 or between 1.5 to 2	Between 1.5 to 2
`Diffraction:PomFluxEpsilon`	Not constrained	Between 0.055 and 0.075
`Diffraction:PomFluxAlphaPrime`	Not constrained	0.25

Table 4: Summary from the step 2 and step 3 as described in Section 2.2

- The `MultipartonInteractions:pT0Ref` parameter was very well constrained by MB observables in step 2. It was not seen to be very sensitive to ECM, but it did show a weak upward trend with increasing ECM. This did not change in step 3.
- `BeamRemnants:reconnectRange` is known to be very sensitive to the event-wise correlation of mean charged particle p_{T} with charged particle multiplicity, as can be seen in [3]. The tuned value in step 2 for each ECM was around 6, the 13 TeV and 900 GeV distributions had also shown some clustering around a lower value of 2. Also, at $\sqrt{s}$ = 900 GeV, the tune was seen to be more poorly constrained than at the other two ECMs. However, at step 3, to describe the mean charged particle p_{T} against multiplicity better at all ECMs, a much lower value of `BeamRemnants:reconnectRange` parameter was needed, in the range of 1–2. Additionally, it was seen that the lower value improves the p_{T} distribution at $\sqrt{s}$ = 13 TeV as well. Consequently, `BeamRemnants:reconnectRange` parameter was kept between 1 and 2.
- The double Gaussian matter distribution parameters, `MultipartonInteractions:coreRadius` parameter and `MultipartonInteractions:coreFraction` parameter were poorly constrained by MB distributions alone in step 2. In step 3, the `MultipartonInteractions:coreRadius` parameter was seen to have a strong effect on most of the observables. The chosen lower `BeamRemnants:reconnectRange` parameter value requires a lower of `MultipartonInteractions:coreRadius` parameter of about 0.5 to maintain the consistency with the other observables.
- The diffraction parameters were not constrained at all in step 3 by the MB distributions. However in step 3, by tuning with INELXS and RAPGAP results, `Diffraction:PomFluxEpsilon` parameter preferred a tuned value around 0.070 – 0.085, and `Diffraction:PomFluxAlphaPrime` parameter preferred a value around 0.25. This was subsequently fixed at 0.25. However, the ETFLOW distribution strongly pulls `Diffraction:PomFluxEpsilon` parameter to a much lower value, to about 0.010, while MB ones prefer intermediate values. An intermediate range of values (0.055 – 0.075) were thus probed for the final tune. From previous experience [2] it has been seen that a good description of the central pseudorapidity bins of the ETFLOW is necessary for a good description of reconstructed level $\sum E_{\mathrm{T}}$ and missing-E_{T} distributions.
- Note that in this study, the `MultipartonInteractions:ecmPow` parameter was fixed at 0.21.

Not reviewed, for internal circulation only

Parameter	A3 value	A2 value	Monash value
`MultipartonInteractions:pT0Ref`	2.45	1.90	2.28
`MultipartonInteractions:ecmPow`	0.21	0.30	0.215
`MultipartonInteractions:coreRadius`	0.55	-	-
`MultipartonInteractions:coreFraction`	0.90	-	-
`MultipartonInteractions:a1`	-	0.03	-
`MultipartonInteractions:expPow`	-	-	1.85
`BeamRemnants:reconnectRange`	1.8	2.28	1.8
`Diffraction:PomFluxEpsilon`	0.07 (0.085)	-	-
`Diffraction:PomFluxAlphaPrime`	0.25 (0.25)	-	-

Table 5: Parameters of the Pythia 8 A3, A2 and Monash tunes. The blank entries represent the parameters not tuned in that particular tune. The numbers in parenthesis following the diffractive parameters represent their default values.

3.2 Final tune

In order to get a final tune, consistent across all ECMs, weight files containing all available measurements at all ECMs were constructed to be used in Professor framework. The relative weights on different observables were varied in order to get better description of INEL XS and MB observables at $\sqrt{s}$ = 13 TeV, and the central bins of ETFLOW distribution. However, only the tunes with tuned parameters satisfying the constrains arrived at Section 3.1 were considered further. This heuristic method has a similar outcome to using a reduced parameter space in a Professor tune. Furthermore, `MultipartonInteractions:ecmPow` was fixed at Monash value. A few different tune candidates were obtained.

Observing the trend from these tunes, a number of generator runs were performed, varying `BeamRemnants:reconnectRange` parameter between 1.6 – 2.2, `Diffraction:PomFluxEpsilon` parameter between 0.055 – 0.075 and `MultipartonInteractions:coreRadius` parameter between 0.55 – 0.65. The final tune was decided based on which combination resulted in the best description of MB observables at $\sqrt{s}$ = 13 TeV, but do not give dramatic disagreement with MB distributions at lower ECMs. Finally, since a major motivation was to describe INELXS better, that was controlled by ensuring that `Diffraction:PomFluxEpsilon` parameter was within an appropriate range. Table 5 shows the parameters of the final tune, named “A3”.

3.3 Comparison of A3 with previous tunes

In Figs. 1–5, the performance of the A3 tune can be seen for charged particle, transverse energy flow and rapidity gap distributions, compared to the previous A2 and Monash tunes. The predicted values of fiducial inelastic cross-section at $\sqrt{s}$ = 7 TeV and 13 TeV for the tunes compared with data are shown in Table 6. The A2 and Monash tunes both used the default Schuler–Sjöstrand model, so they both predict the same value, denoted by SS. The fiducial inelastic cross section predictions from A3 are about 5% lower compared to SS, which is somewhat closer to the values from data. This does not come at a cost of sacrificing agreement with other distributions.

Fig. 1 shows that the new tune provides a small improvement in the modelling of charged particle pseudorapidity distributions at $\sqrt{s}$ = 8 TeV, and to a lesser extent, at $\sqrt{s}$ = 13 TeV, at the expense of a larger deterioration of the modelling of $\sqrt{s}$ = 900 GeV data. Since the aim is to model soft collisions for pile-up at $\sqrt{s}$ = 13 TeV, the A3 tune’s mis-modelling of $\sqrt{s}$ = 900 GeV data is acceptable.

Not reviewed, for internal circulation only

	ATLAS data (mb)	SS (mb)	A3 (mb)
At $\sqrt{s} = 13$ TeV	68.1 ± 1.4	74.4	69.9
At $\sqrt{s} = 7$ TeV	60.3 ± 2.1	66.1	62.3

Table 6: Fiducial inelastic cross-section measured by ATLAS at $\sqrt{s} = 13$ TeV [5] and at $\sqrt{s} = 7$ TeV [4] compared with A3 and Schuler and Sjöstrand (SS) model predictions. The SS model is used in both A2 and Monash tunes. A3 uses the DL model, with two tuned parameters **Diffraction:PomFluxEpsilon** = 0.07 and **Diffraction:PomFluxAlphaPrime** = 0.25.

In Fig. 2 for charged particle multiplicity, A3 is comparable to other tunes except at $\sqrt{s} = 900$ GeV. At $\sqrt{s} = 13$ TeV, A2 describes the low multiplicity part better than A3 in the range of 40–60 charged particles. The shape of the distribution predicted by the new tune is consistent across the ECMs. Compared to A2, A3 provides a slightly worse description of the charged particle multiplicity distribution, which coincides with an improved charged particle p_T distribution that performs similarly to Monash, as shown by Fig. 3. In all cases, $\sqrt{s} = 8$ TeV results are very similar to those at $\sqrt{s} = 7$ TeV. In Fig. 4, which shows the mean p_T against charged particle multiplicity correlation, the choice of lower colour reconnection strength led to slight improvement over A2.

Although the $\sqrt{s} = 2.36$ TeV [11] and $\sqrt{s} = 8$ TeV charged particle distributions [16] were not used in tuning, comparisons are made with those distributions for completeness.

In Fig. 5, the A3 performs at the same level as A2 for the important first two bins of $\sum E_T$ distribution. The rapidity gap distributions are better described by A3 when a high p_T threshold is present, and a more ambiguous change when the lowest p_T threshold is used; A3's description of the lowest p_T threshold distribution shows an improved average, but a greater degree of structure relative to data. The rise of the gap activity as a function of $\Delta\eta$ is governed by the Pomeron intercept in diffractive models, so tuning the diffractive model should improve the description of these distributions. The A3 tune does not improve the description of the low p_T region dominated by diffraction, which can be looked at in the future by using the data only at high $\Delta\eta$, as was done in the measurement [15].

One of the main determinants of the size of any $< \mu >$ rescaling that is used in the simulation of pile-up is the tune's ability to describe the observed reconstructed $\sum E_T$ that is deposited in the calorimeter. Although A2 overestimates the mean p_T at high multiplicity, it also underestimates the number of high multiplicity events, and those two deficiencies tend to cancel out when considering the total energy deposited in the calorimeter, leading to a satisfactory performance. Further studies involving a full simulation of the detector are required in order to show whether A3 provides an equally good description as A2 when used to model events with large pile-up.

Finally, in Table 7, the χ^2 values are shown for the A2, Monash and A3 tunes, divided by the number of degrees of freedom for the distributions, which evaluates the compatibility of the measured data with the distribution predicted by each tune. The full range of distributions are considered for χ^2 calculations, although the tuning does not concentrate on the high-multiplicity or high p_T tails of the distributions.

Not reviewed, for internal circulation only

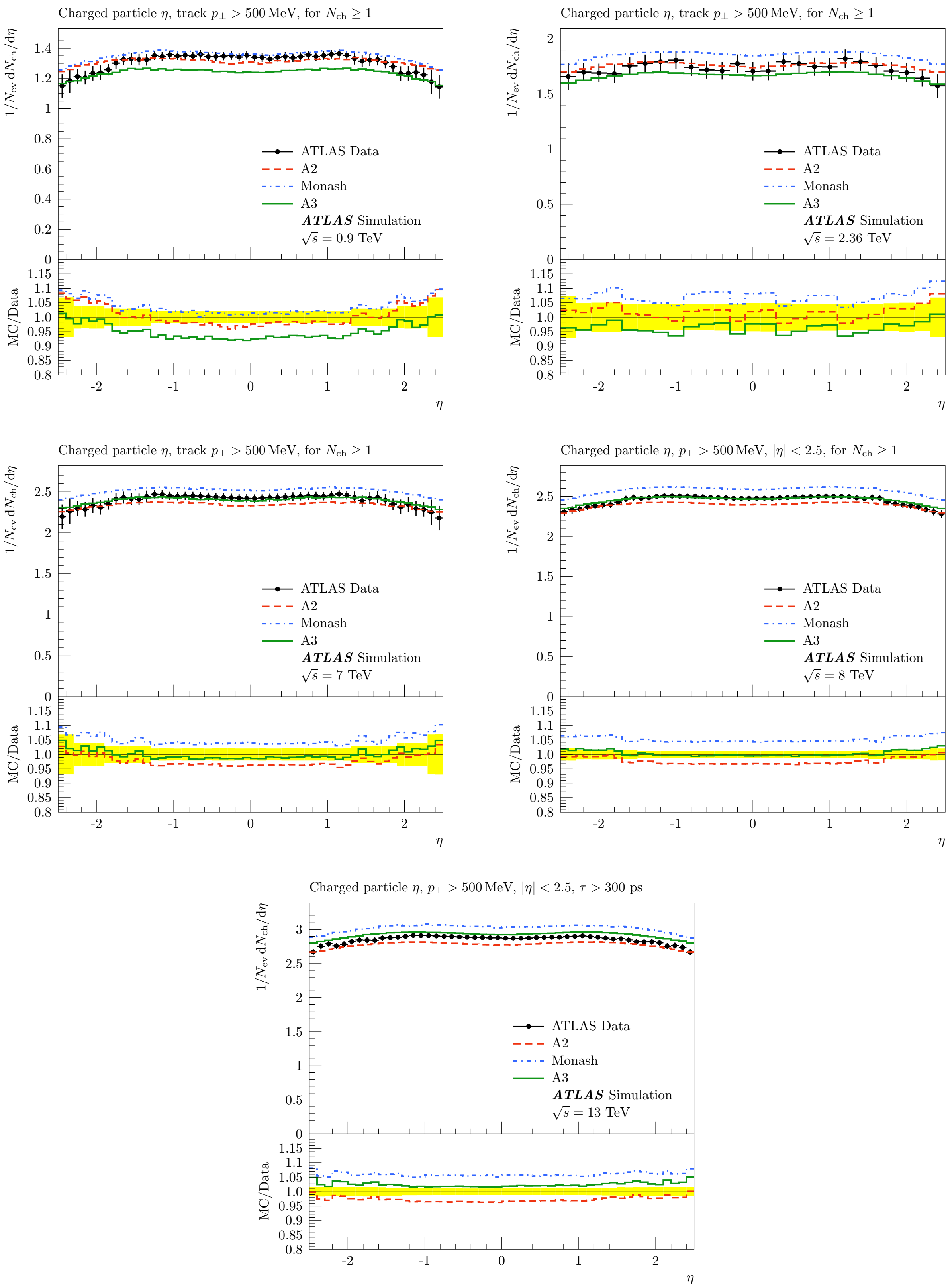

Figure 1: The Pythia 8 A3, A2 and Monash tune predictions compared with ATLAS charged particle pseudorapidity distributions at five different center-of-mass energies [3, 11, 16], 900 GeV(top left), 2.36 TeV(top right), 7 TeV(middle left), 8 TeV(middle right), and 13 TeV(bottom). The yellow shaded areas represent the measurement uncertainty.

Not reviewed, for internal circulation only

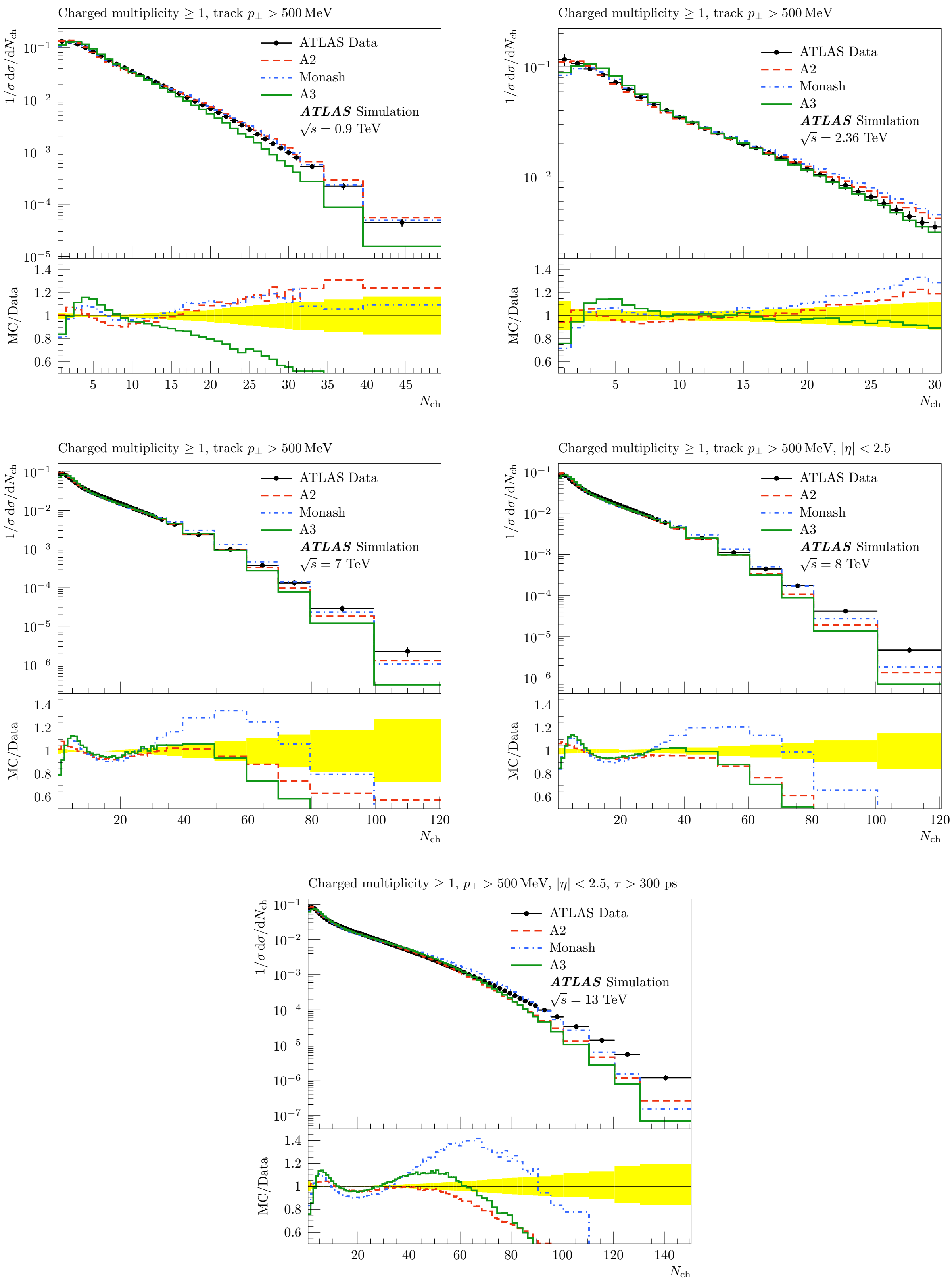

Figure 2: The PYTHIA 8 A3, A2 and Monash tune predictions compared with ATLAS charged particle multiplicity distributions at five different center-of-mass energies [3, 11, 16], 900 GeV(top left), 2.36 TeV(top right), 7 TeV(middle left), 8 TeV(middle right), and 13 TeV(bottom). The yellow shaded areas represent the measurement uncertainty.

Not reviewed, for internal circulation only

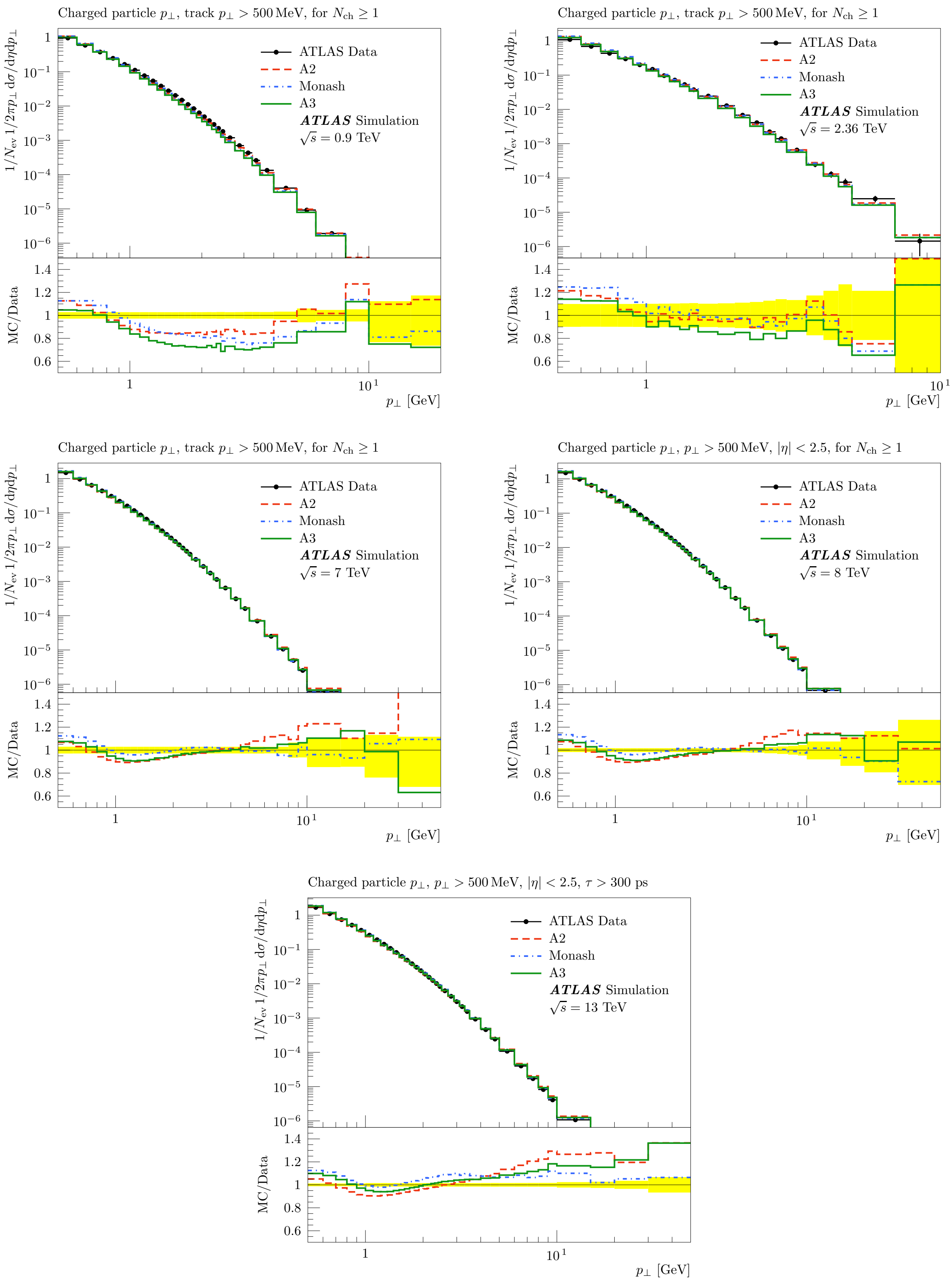

Figure 3: The Pythia 8 A3, A2 and Monash tune predictions compared with ATLAS charged particle transverse momentum distributions at five different center-of-mass energies [3, 11, 16], 900 GeV(top left), 2.36 TeV(top right), 7 TeV(middle left), 8 TeV(middle right), and 13 TeV(bottom). The yellow shaded areas represent the measurement uncertainty.

Not reviewed, for internal circulation only

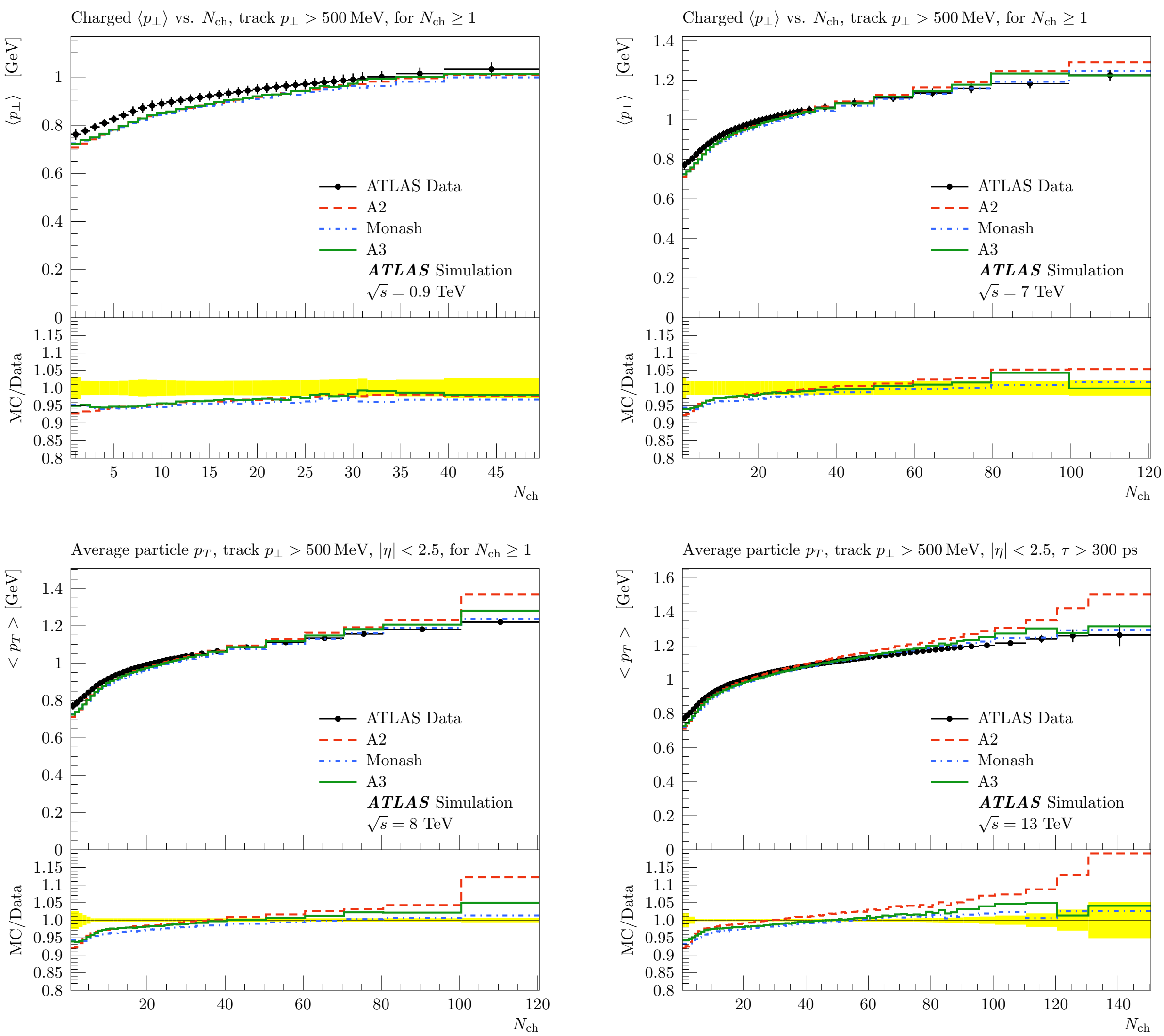

Figure 4: The Pythia 8 A3, A2 and Monash tune predictions compared with ATLAS charged particle mean transverse momentum against multiplicity distributions at four different center-of-mass energies [3, 11, 16], 900 GeV(top left),7 TeV(top right), 8 TeV(bottom left), and 13 TeV(bottom right). The yellow shaded areas represent the measurement uncertainty.

Not reviewed, for internal circulation only

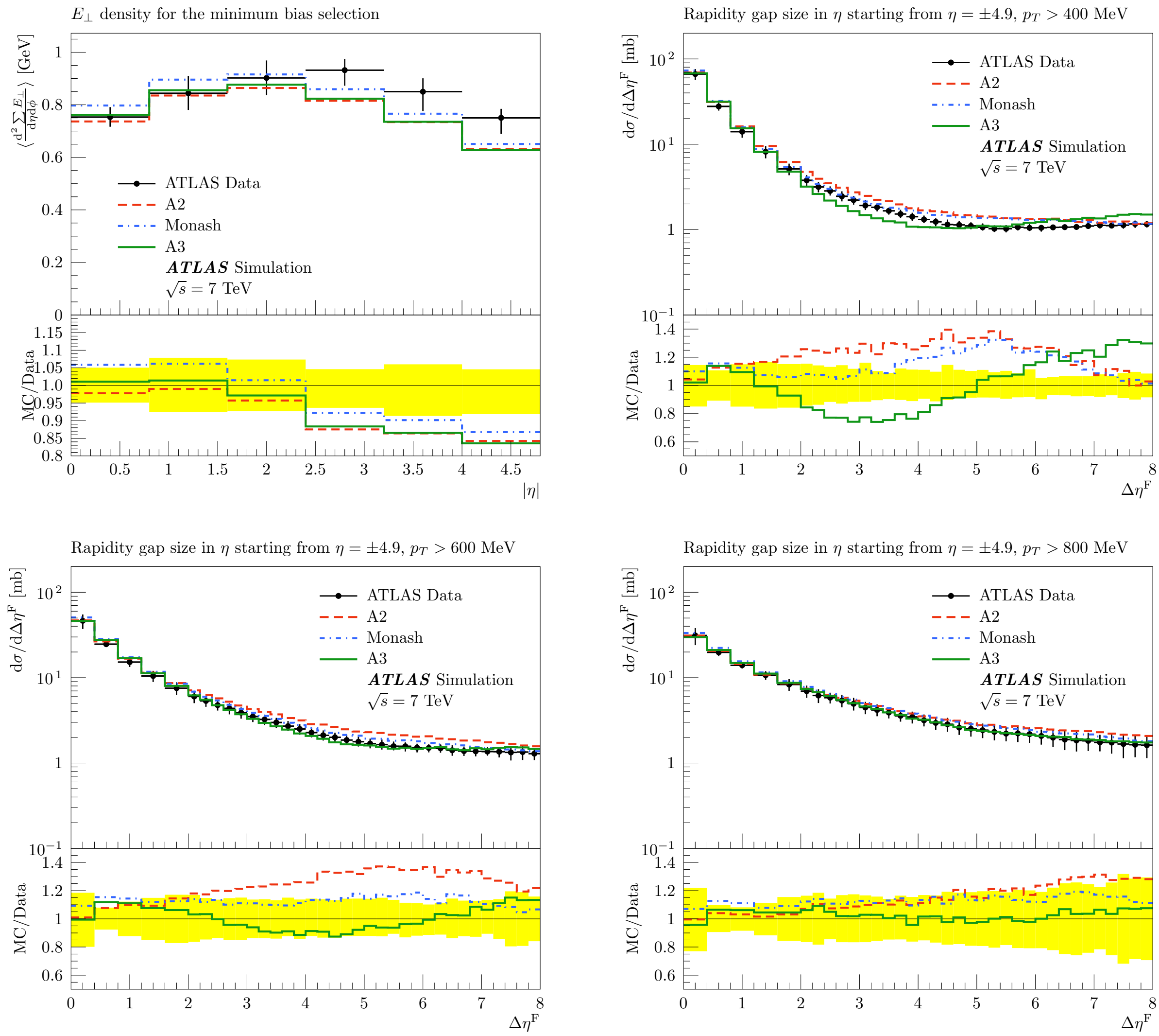

Figure 5: The Pythia 8 A3, A2 and Monash tune predictions compared with ATLAS transverse energy flow [14] (top left) and rapidity gap [15] distributions for different p_T requirements at 7 TeVcenter-of-mass energy. The yellow shaded areas represent the measurement uncertainty.

Not reviewed, for internal circulation only

	A2	Monash	A3	Ndof
Charged particle pseudorapidity				
At $\sqrt{s} = 0.9$ TeV	1.1	1.4	6.5	50
At $\sqrt{s} = 2.36$ TeV	0.3	2.2	0.7	25
At $\sqrt{s} = 7$ TeV	1.7	3.0	0.3	50
At $\sqrt{s} = 8$ TeV	4.0	13.3	0.4	50
At $\sqrt{s} = 13$ TeV	5.1	20.5	3.5	50
Charged particle multiplicity				
At $\sqrt{s} = 0.9$ TeV	11.1	10.5	34.5	34
At $\sqrt{s} = 2.36$ TeV	0.3	1.0	0.2	11
At $\sqrt{s} = 7$ TeV	14.7	33.8	26.5	39
At $\sqrt{s} = 8$ TeV	12.3	19.2	14.0	39
At $\sqrt{s} = 13$ TeV	32.5	64.4	94.2	81
Charged particle transverse momentum				
At $\sqrt{s} = 0.9$ TeV	18.3	27.8	54.2	31
At $\sqrt{s} = 2.36$ TeV	0.7	1.2	1.3	22
At $\sqrt{s} = 7$ TeV	4.8	1.6	2.9	36
At $\sqrt{s} = 8$ TeV	13.5	4.8	8.4	36
At $\sqrt{s} = 13$ TeV	35.1	18.3	16.6	37
Charged particle mean transverse momentum against multiplicity				
At $\sqrt{s} = 0.9$ TeV	3.3	4.1	2.1	34
At $\sqrt{s} = 7$ TeV	2.2	2.9	1.9	39
At $\sqrt{s} = 8$ TeV	16.3	26.8	14.2	39
At $\sqrt{s} = 13$ TeV	28.3	33.1	21.6	81
Transverse energy flow				
	1.8	1.3	1.7	6
Rapidity gap				
$p_T > 400$ MeV	6.2	3.5	4.2	35
$p_T > 600$ MeV	4.4	1.1	0.4	35
$p_T > 800$ MeV	0.7	0.6	0.1	25

Table 7: For each distribution shown in Fig. 1 to Fig. 5, The χ^2/Ndof values for A2, Monash and A3 tunes are shown, along with Ndof values for each distribution. The χ^2 values are computed over all bins with respect to the ATLAS data points for the specific distribution. The systematic uncertainties in different bins are correlated, and these correlations are not included in the calculation of the χ^2.

Not reviewed, for internal circulation only

4 Conclusions

This note presents the new A3 parameter set for the Pythia 8 event generator. A3 is aimed at modelling low-p_T QCD processes. A3 uses the same NNPDF 2.3LO PDF set as other recent ATLAS tunes of Pythia 8. The A3 tune includes the effects of early ATLAS Run 2 soft-QCD results at a centre-of-mass energy of $\sqrt{s} = 13$ TeV for the first yime, in addition to the Run 1 data used in previous such studies. Within the ATLAS fiducial acceptance region, A3 predicts lower inelastic cross-sections than A2 at $\sqrt{s} = 7$ TeV and $\sqrt{s} = 13$ TeV, which are closer to the measured values. Compared to A2, other distributions at $\sqrt{s} = 7$ TeV and $\sqrt{s} = 13$ TeV predicted by A3 show a broadly comparable, or better, level of agreement. A3 provides a demonstration that an acceptable description of data can be achieved by using the Donnachie-Landshoff model for diffraction, and can be viewed as a possible starting point for further systematic studies of soft-QCD tunes. The results shown here provide good reasons to believe that an improved and more reliable simulation of pile-up overlay can be obtained.

Acknowledgements

We would like to thank Peter Skands for useful discussions during this tuning process.

References

[1] T. Sjostrand, S. Mrenna and P. Skands, *A brief introduction to PYTHIA 8.1*, Comput. Phys. Commun. **178** (2008) 852, arXiv: 0710.3820 [hep-ph].

[2] ATLAS Collaboration, *Summary of ATLAS Pythia 8 tunes*, ATL-PHYS-PUB-2012-003, 2012, URL: https://cds.cern.ch/record/1474107.

[3] ATLAS Collaboration, *Charged-particle distributions in $\sqrt{s}$=13 TeV pp interactions measured with the ATLAS detector at the LHC*, Phys. Lett. **B758** (2016) 67, arXiv: 1602.01633 [hep-ex].

[4] ATLAS Collaboration, *Measurement of the Inelastic Proton-Proton Cross-Section at $\sqrt{s} = 7$ TeV with the ATLAS Detector*, Nature Commun. **2** (2011) 463, arXiv: 1104.0326 [hep-ex].

[5] ATLAS Collaboration, *Measurement of the Inelastic Proton-Proton Cross Section at $\sqrt{s} = 13$ TeV with the ATLAS Detector at the LHC*, (2016), arXiv: 1606.02625 [hep-ex].

[6] A. Buckley et al., *Rivet user manual*, (2010), arXiv: 1003.0694 [hep-ph].

[7] A. Buckley et al., *Systematic event generator tuning for the LHC*, (2009), arXiv: 0907.2973 [hep-ph].

[8] A. Buckley et al., *LHAPDF6: parton density access in the LHC precision era*, Eur. Phys. J. **C75** (2015) 132, arXiv: 1412.7420 [hep-ph].

[9] P. Skands, S. Carrazza and J. Rojo, *Tuning PYTHIA 8.1: the Monash 2013 Tune*, European Physical Journal C **74** (2014) 3024, arXiv: 1404.5630 [hep-ph].

[10] R. D. Ball et al., *Parton distributions with LHC data*, Nucl. Phys. **B867** (2013) 244, arXiv: 1207.1303 [hep-ph].

Not reviewed, for internal circulation only

[11] ATLAS Collaboration,
Charged-particle multiplicities in pp interactions measured with the ATLAS detector at the LHC,
New J. Phys. **13** (2011) 053033, arXiv: 1012.5104 [hep-ex].

[12] G. A. Schuler and T. Sjöstrand,
Hadronic diffractive cross sections and the rise of the total cross section,
Phys. Rev. D **49** (5 1994) 2257,
URL: http://link.aps.org/doi/10.1103/PhysRevD.49.2257.

[13] A. Donnachie and P. Landshoff, *Total cross-sections*, Phys.Lett. **B296** (1992) 227,
arXiv: hep-ph/9209205 [hep-ph].

[14] ATLAS Collaboration, *Measurements of the pseudorapidity dependence of the total transverse energy in proton-proton collisions at* $\sqrt(s) = 7$ *TeV with ATLAS*, JHEP **1211** () 033,
arXiv: 1208.6256 [hep-ex].

[15] ATLAS Collaboration,
Rapidity gap cross sections measured with the ATLAS detector in pp collisions at $\sqrt{s} = 7$ *TeV*,
Eur. Phys. J. **C72** (2012) 1926, arXiv: 1201.2808 [hep-ex].

[16] ATLAS Collaboration, *Charged-particle distributions in pp interactions at* $\sqrt{s} = 8$ *TeV measured with the ATLAS detector at the LHC*, (2016), arXiv: 1603.02439 [hep-ex].