ATLAS NOTE

ATL-PHYS-PUB-2011-014

November 21, 2011

Further ATLAS tunes of PYTHIA 6 and Pythia 8

The ATLAS Collaboration

Abstract

We present the latest developments of the ATLAS MC generator tuning project for the Pythia family of event generators, including the C++ Pythia 8 code.

The PYTHIA 6 tunes presented here complete the previous tunes by addition of parton shower and multi-parton interaction model tunings with three next-to-leading order (NLO) parton distribution functions (PDF) in addition to the leading-order and Monte-Carlo (MC) adapted PDFs previously presented. The Pythia 8 MPI tunes in this note have been constructed for six different PDFs, making use of a new x-dependent hadronic matter distribution model. Multiple Parton Interaction (MPI) eigentunes are constructed for the PDFs intended for use in ATLAS MC production.

1 Introduction

In previous notes [1,2] we presented new tunes of the PYTHIA 6 [3] Pythia 8 [4] and HERWIG/JIMMY [5, 6] event generators using ATLAS analysis data from the 2010 data-taking period. These tunes were named AMBT2B and AUET2B (for PYTHIA 6 and HERWIG/JIMMY), and AM1 and AU1 (for Pythia 8) depending on whether minimum bias or underlying event data was used in the MPI stage of the tuning.

PYTHIA 6 continues to be used as a major generator in ATLAS for the bulk production of simulation samples, including in connection with the POWHEG [7–9] MadGraph [10] and AlpGen [11] higher-order matrix element generators. The AUET2B tunes provide optimised descriptions of hadronic jet structure and multi-parton interaction (MPI) effects with PYTHIA 6, for use with a variety of PDFs to allow flexibility in the matching of matrix elements to appropriate PDFs. This note completes the set of PDFs covered by the AUET2B tune series by tuning to three NLO PDFs.

The Pythia 8 generator is the intended long-term replacement for PYTHIA 6, and the migration of simulation samples to use the new C++ code in ATLAS is underway. Pythia 8 is currently used in ATLAS for the modelling of all simulated pile-up interactions, including much improved diffractive simulation relative to PYTHIA 6, so there is great interest in obtaining the best possible description of minimum bias interactions in addition to jet observables and the underlying event in hard-scale "signal" simulation. In this note, Pythia 8 tunes have been performed using a newly introduced feature in version 8.153, where the width of the transverse matter distribution varies depending on the momentum fraction of the interacting partons. As for PYTHIA 6, the Pythia 8 tunes in this note now also include two NLO PDFs in addition to the leading order and MC-adapted PDFs [12–14] used in reference [2].

As for the previous tunings, all tuning was performed using the Rivet [15] analysis toolkit and the Professor [16] MC tuning system, now updated to versions 1.6.0 and 1.3.1 respectively.

This note is organized as follows: PYTHIA 6 shower and MPI tunes are described in Section 2. In Section 3, Pythia 8 MPI tunes and the systematic variation eignentunes are discussed and finally a short summary is presented in Section 4.

2 PYTHIA 6

The AMBT2B and AUET2B tunes of PYTHIA 6 described in a previous note [2] were constructed with equal fitting weights for several PDFs constructed using leading-order (LO) matrix elements and the modified LO (mLO) approach (mLO PDFs employ a degree of sum-rule relaxation and changes in the evolution of α_s to in principle better match MC event generator usage).

The previous note did not include tunes with next-to-leading-order (NLO) PDFs, as it was found that these led to sufficiently different results in MPI model tuning that the fit results were not reliable. In this note we present PYTHIA 6 parton shower and MPI tunes constructed for three NLO PDFs – CT10, CTEQ 6.6, and the NNPDF 2.1 NLO "central" set.

In all these tunes, the e^+e^--tuned hadronisation and final state shower parameters from previous AMBT2B and AUET2B tunes are used. The tuning is hence again split into two stages: a 3-parameter shower tune and a 5-parameter MPI tune. For the details of each tuning step and the tuning methodology we refer the reader to reference [2].

Tune type	PDF	PARP(62)	PARP(64)	PARP(72)
A∗T2B	CTEQ 6.6	0.948	1.032	0.398
	CT10	0.312	0.939	0.537
	NNPDF 2.1 NLO	1.246	0.771	0.418

Table 1: The optimised parameters of the PYTHIA6 A∗T2B shower tunes to NLO PDFs. The roles of the PARP(n) parameters are as follows for the various n: 62 = ISR $p_\perp$ cut-off, 64 = ISR scale factor on α_S evaluation scale, 72 = Λ_{QCD} for FSR showering from ISR parton emissions.

2.1 Shower tunes

The observables and weights for shower tuning are the same as were used in [2], and again only the $p_\perp$-ordered shower model is used. The resulting tune parameters are presented in Table 1, and comparisons to ATLAS data are shown in Figure 1. A good agreement with the data is reached as for the other PDFs.

In this tune set, PARP(62) is seen to be lower than for all the LO and mLO PDFs in reference [2], except for NNPDF 2.1 NLO. The CT10 tune in particular has a very low value of 312 MeV, which is comparable to the 5-flavour Λ_{QCD} of 226 MeV for CT10: this leaves very little room between the perturbative shower and non-perturbative hadronisation, which may be regarded either as a modelling success or a problem. This hence results in three quite distinct groupings of ISR shower cut-off scale for different PDF types, with NLO PDFs favouring the lowest values, LO PDFs next, and the highest cut-offs being obtained for the mLO PDFs. Another notable trend is that PARP(64) is higher than for all LO and mLO PDF tunes other than MSTW2008LO. The tuned values of PARP(72) are very similar to those obtained for the LO and mLO shower tunings.

2.2 MPI tunes

As in the case of the AUET2B tuning of MPI parameters for LO and mLO PDFs, we use a five-parameter tuning space and numerically optimise the description of MPI-sensitive data from ATLAS and CDF, with weighted emphasis on the ATLAS observables.

As there is neither theoretical nor practical motivation for use of NLO PDFs in description of minimum bias observables, and mLO PDFs were observed in the previous tuning to introduce strong and untuneable deviations from data in minimum bias, we only attempt to describe underlying event (UE) observables here: in other words we extend the PDF coverage of the AUET2B tune series, but not the AMBT2B one.

The same observables and tuning weights were used as for the other AUET2B tunes, but the parameter sampling ranges were extended, in particular to encompass lower values of the PARP(90) parameter which governs the $\sqrt{s}$ evolution of the MPI screening PARP(82) variable. The parameter sampling ranges are tabulated in Table 2, and the final tune parameters are in Table 3.

The tuned parameter values are very similar to each other, with the exception of the weakly constrained PARP(77) "fast string" colour reconnection suppression variable. Significantly, the PARP(82) and PARP(90) parameters which directly affect the MPI screening cutoff, PTMIN($\sqrt{s}$), are both systematically lower for all three NLO PDFs than for the LO and mLO PDFs in the AUET2B series: $\mathrm{PARP(82)}_{\mathrm{NLO}} \sim 1.9$ GeV as compared to $\mathrm{PARP(82)}_{\mathrm{LO/mLO}} \sim 2.3$ GeV (with the exception of the MSTW2008LO PDF which also favoured a low value), and $\mathrm{PARP(90)}_{\mathrm{NLO}} \sim 1.8$ as compared to $\mathrm{PARP(90)}_{\mathrm{LO/mLO}} \sim 2.4 - 2.7$. It is these significant and consistent deviations from the "normal" pa-

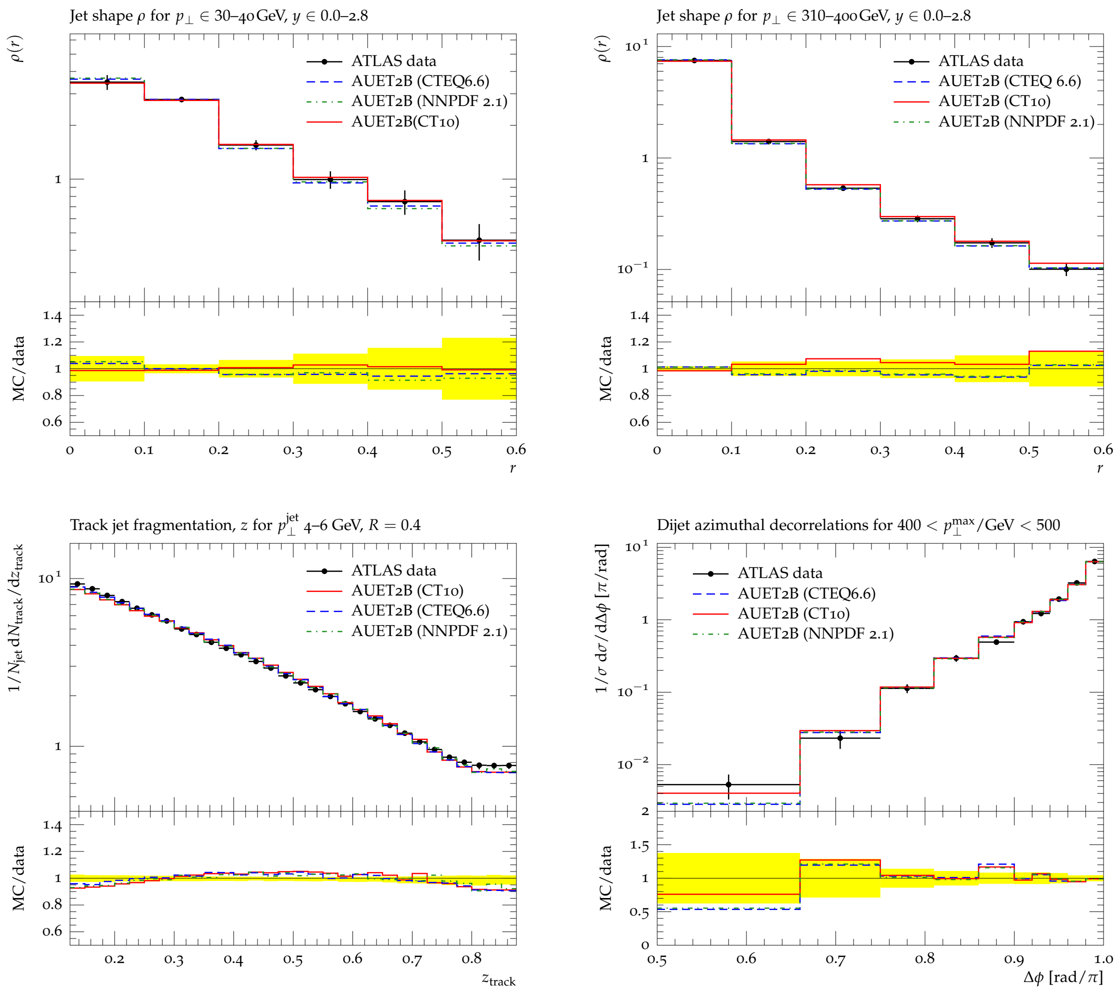

Figure 1: Comparison plots of the new AUET2B PYTHIA6 tunes to ATLAS jet data at 7 TeV [17–19], for NLO PDFs. The yellow shaded areas represent data uncertainty.

Param. name	Function	Sampling range
PARP(77)	High-$p_\perp$ suppression of colour reconnection	0.0 – 1.0
PARP(78)	Strength of colour reconnection	0.0 – 1.0
PARP(82)	MPI $p_\perp$ cutoff at $\sqrt{s} = 1800$ GeV	1.5 – 2.5
PARP(84)	Rel. radius of core proton matter distribution	0.0 – 1.0
PARP(90)	MPI cutoff energy evolution exponent	0.15 – 0.25

Table 2: PYTHIA 6 MPI parameters varied in this tuning, with descriptions and extended sampling ranges suitable for NLO PDFs. The fraction of the proton matter distribution contained in the core Gaussian is given by PARP(83) and was, as for the other AUET2B tunes, fixed to the AMBT1/AUET2 value of 0.356.

PDF	PARP(77)	PARP(78)	PARP(82)	PARP(84)	PARP(90)
CTEQ 6.6	0.505	0.385	1.87	0.561	0.189
CT10	0.125	0.309	1.89	0.415	0.182
NNPDF 2.1 NLO	0.498	0.354	1.86	0.588	0.177

Table 3: Tuned MPI parameters for the AUET2B PYTHIA 6 tunings to NLO PDFs.

rameter ranges which led to MPI tuning difficulties and was addressed by the increased parameter sampling ranges in Table 2.

The behaviour of the resulting tunes in ATLAS UE observables at 7 TeV [20,21] is shown in Figure 2. The description of UE data with these NLO PDF tunes is generally very good, although slightly less so than for the best of the previously constructed tunes to LO PDFs.

3 Pythia 8

3.1 MPI tunes

For Pythia 8, so far in ATLAS, tune 4C [22] with the leading order CTEQ6L1 PDF has been used. Subsequently tune 4Cx [23], based on tune 4C, but using the x-dependent matter profile was performed by the authors using this particular new feature. The tunes described in this note have been performed using this new feature (MultipleInteractions:bProfile = 4). The parameters tuned are MultipleInteractions:ecmPow (subsequently referred to as ecmPow), MultipleInteractions:pT0Ref (subsequently refereed to as pT0Ref), BeamRemnants:reconnectRange (subsequently referred to as reconnectRange) and MultipleInteractions:a1 (subsequently referred to as a1). The description of the first three parameters can be found in the previous note [2]. The MultipleInteractions:a1 parameter represents the constant in the Gaussian matter distribution width. The other parameters are same from tune 4C, except, SpaceShower:rapidityOrder is turned off, as there are some indications from multi-jet matching results that the shower gets closer to the matrix-element results when it is switched off. The tuning strategy employed was to tune only to published ATLAS $\sqrt{s} = 7$ TeV minimum bias (MB) [24] and leading track and cluster underlying event (UE) [20,21] data, since it has already been seen that tuning to LHC and Tevatron data with three different centre-of-mass energies is very challenging. The observables tuned to, with the corresponding tune weights can be found in [2]. More weight was put on 7 TeV distributions, and on distributions with $p_\perp \geq 0.5$ GeV, as before.

The tuning was done separately for six different PDFs, CTEQ6L1 and MSTW2008lo (LO), CT10 and

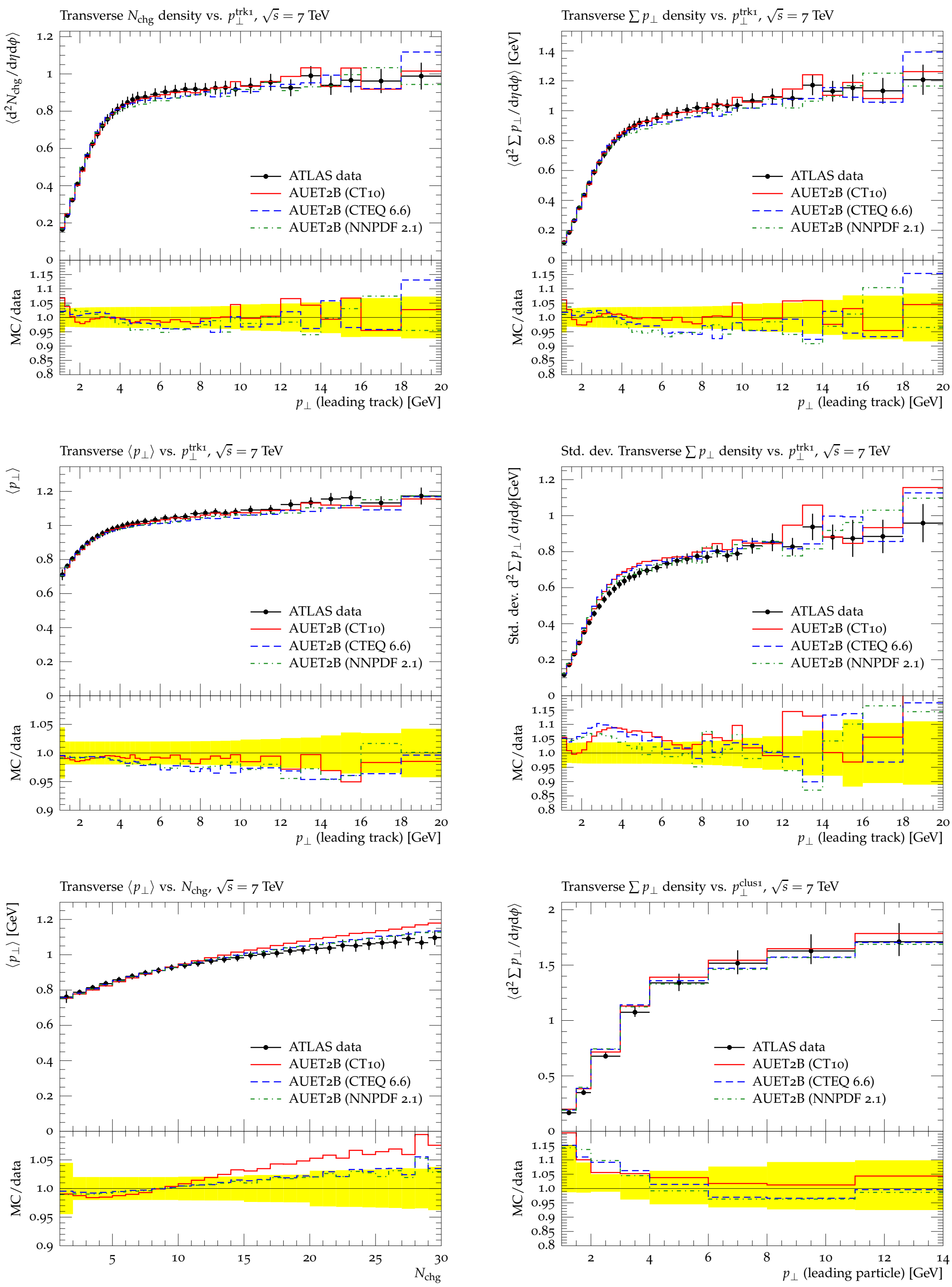

Figure 2: Comparison plots of the new AUET2B PYTHIA 6 tunes to ATLAS data at 7 TeV for NLO PDFs. All plots are compared to charged particle data from the ATLAS leading-track UE analysis [21], except that in the bottom right which is compared to data from the ATLAS leading-cluster UE analysis citeAad:2011qe which includes the charge-neutral component of the UE. The yellow shaded areas represent data uncertainty.

PDF	pT0Ref	ecomPow	a1	reconnectRange
CTEQ 6L1	2.18	0.22	0.06	1.55
MSTW2008 LO	1.90	0.30	0.03	2.28
CTEQ 6.6	1.73	0.16	0.03	5.12
CT10	1.70	0.16	0.10	4.67
MRST2007 LO*	2.39	0.24	0.01	1.76
MRST2007 LO**	2.57	0.23	0.01	1.47

Table 4: Tuned MPI parameters for the A2/AU2 Pythia 8 tunings.

CTEQ66 (NLO) and MRST2007 LO* and MRST LO** (mLO). It was found that with the LO PDFs, a common tune (named A2) for minimum bias and underlying event could be obtained, however, for higher order PDFs, this was not the case, and underlying event (AU2) tunes were performed. Table 4 shows the tune parameters for all the tunes corresponding to different PDFs.

Technical notes: The Pythia 8 version used was 8.153, with the PDFs taken from LHAPDF version 5.8.5 [25]. For LO, no difference was observed with using the PYTHIA-provided internal PDF set. Soft-QCD events were generated with single and double diffraction turned on, with particles having $c\tau > 10$ mm kept stable.

Table 4 clearly shows that the different PDFs prefer particular values of the tuning parameters. The tunes corresponding to two LO PDFs need very different set of tune values, although they behave very similarly in MB and UE plots. The behaviour of tunes corresponding to mLO PDFs (LO* and LO**) are very similar, however they almost reduce back to the single Gaussian matter distribution. This is in fact a common feature for all the tunes, with very low a1 values. However this is very different from tune 4Cx, which has a much higher value (0.15) of this a1 parameter. This perhaps necessitates tuning with single Gaussian matter distribution.

Figure 3 shows the new LO MB tunes (and tune 4C and 4Cx), compared with ATLAS minimum bias data at $\sqrt{s} = 7$ TeV. Figure 4 and Figure 5 show the tunes for all PDFs compared with ATLAS underlying event data at $\sqrt{s} = 7$ TeV. The NLO and the mLO tunes do a good job for UE distributions, however they completely fail to describe MB data, therefore making any common UE and MB tune impossible.

Comparing the tune A1 (CTEQ 6L1) against 4Cx, while the former gives a slightly better description of MB data at $\sqrt{s} = 7$ TeV, the trend is opposite for the UE distributions. In fact, putting more weight on UE distributions results in the tune preferring much stronger colour reconnection, which is not consistent at all with the MB and UE mean p_{T} against multiplicity distributions. However, it is clear that tune 4Cx is overall a better tune for these data than the current default tune in ATLAS, 4C. However, the agreement of the tunes with UE data increases as we move to NLO and modified LO PDFs, leading to as good, or better description than 4Cx. The tunes corresponding to NLO PDFs seem to demand a stronger colour reconnection strength than the others, but somewhat lower MPI p_{T} cutoff and energy exponent.

3.2 MPI eigentunes

The Professor MC tuning system provides several mechanisms for estimating systematic errors in MC tunes, the most convenient of which is the “eigentunes” approach, described in details in [2]. We use the eigentune mechanism to construct variation tunes for the MPI tuning stage, around the A1 tune only. The reason for this restriction is that this is the main production Pythia 8 tune in ATLAS and

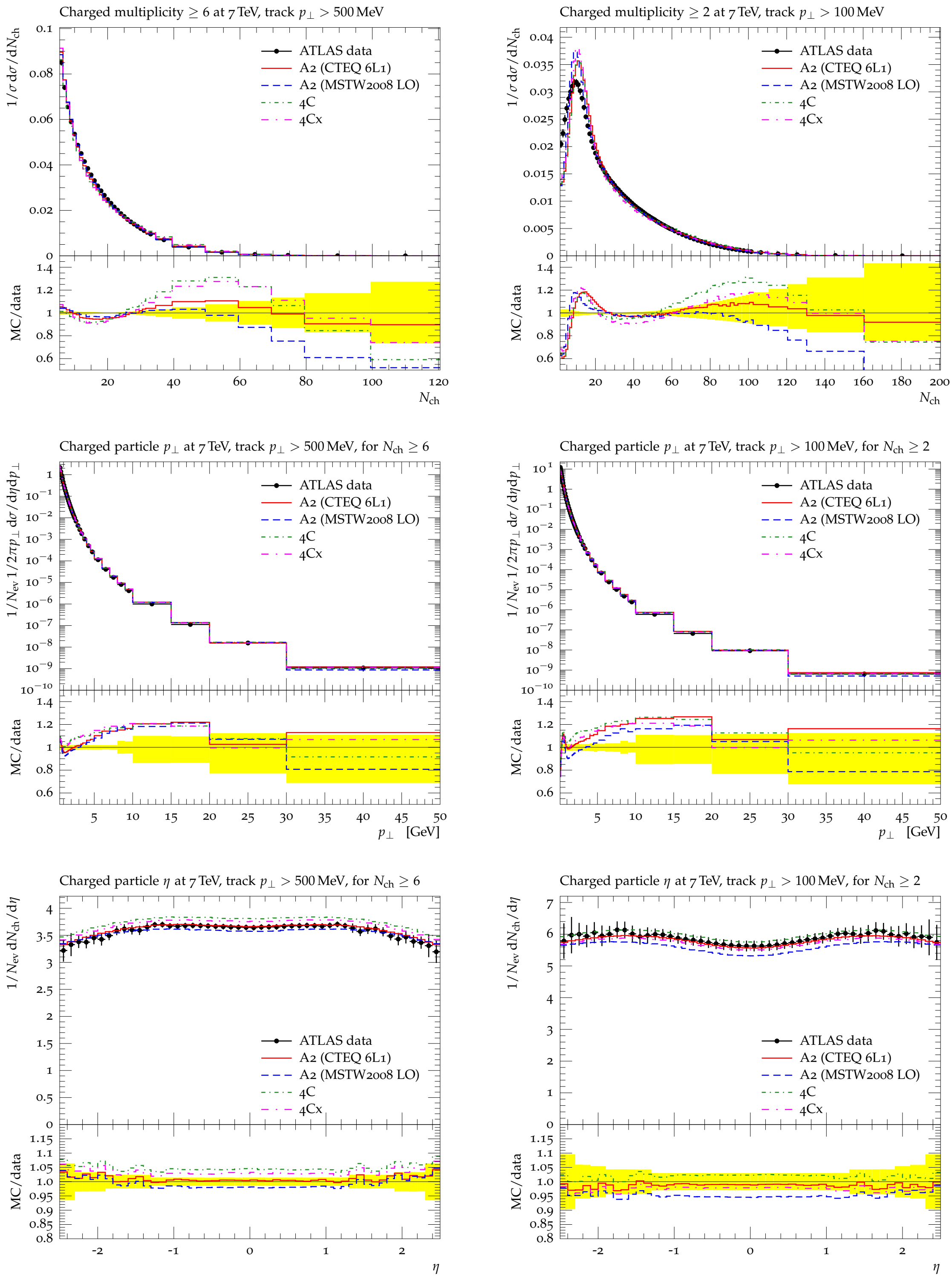

Figure 3: Comparison plots of the new Pythia 8 tunes to ATLAS minimum-bias event data [24] at 7 TeV. The yellow shaded areas represent data uncertainty.

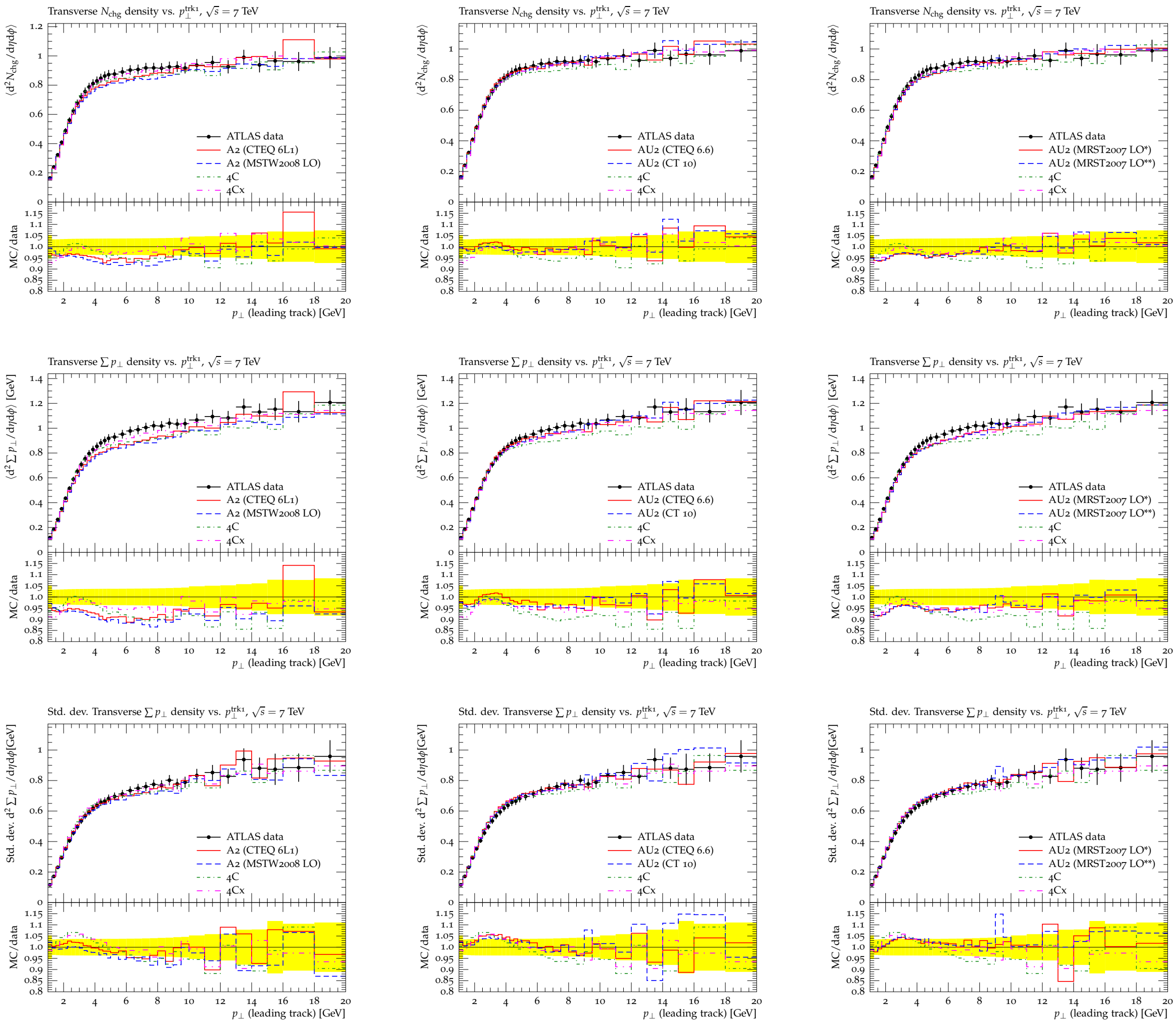

Figure 4: Comparison plots of the new Pythia 8 tunes to ATLAS underlying event data at 7 TeV [20, 21]. The tunes corresponding to LO, NLO and mLO PDFs are shown respectively in the left, centre and right columns. The yellow shaded areas represent data uncertainty.

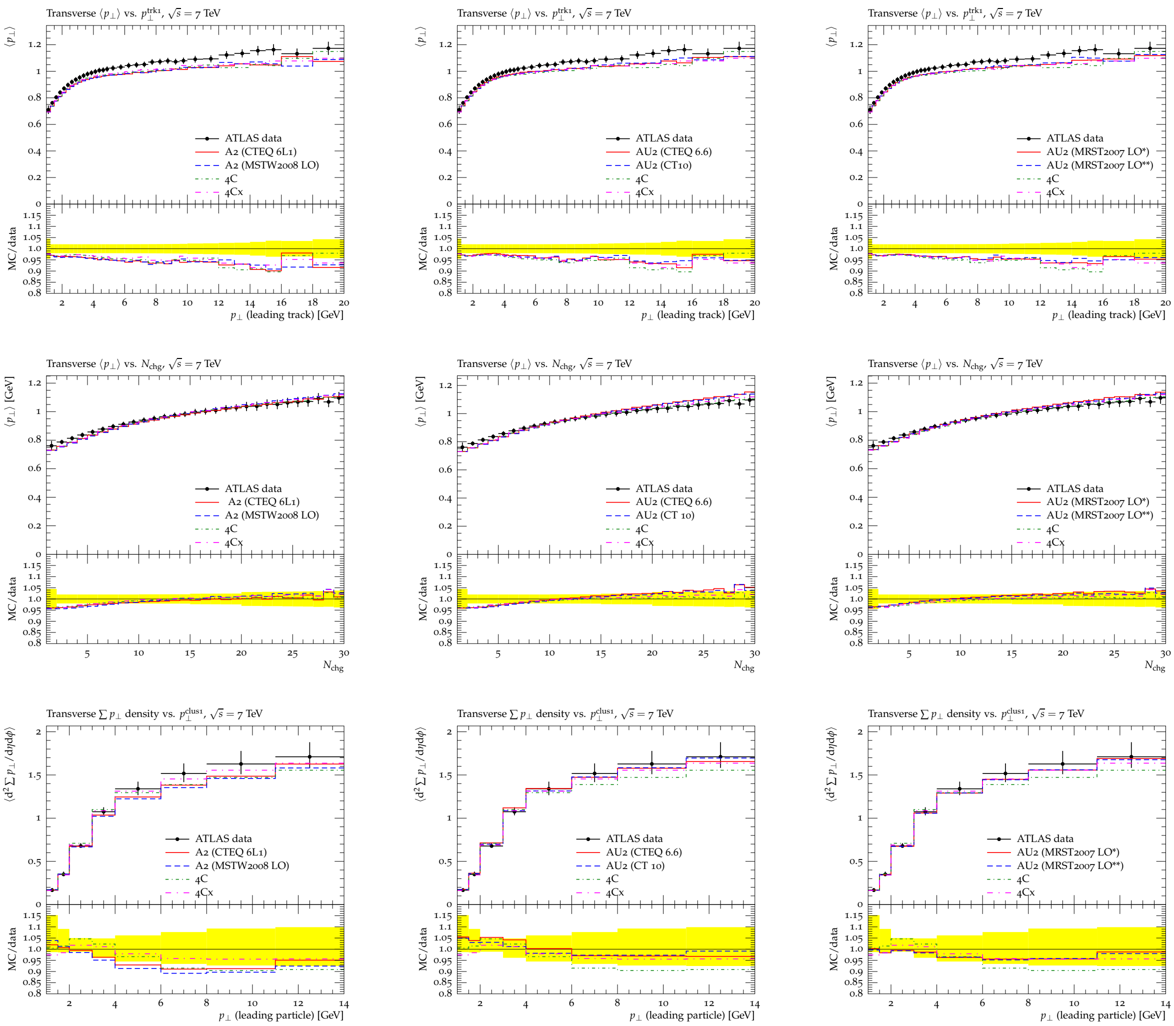

Figure 5: Comparison plots of the new Pythia 8 tunes to ATLAS underlying event data at 7 TeV [20, 21]. The tunes corresponding to LO, NLO and mLO PDFs are shown respectively in the left, centre and right columns. The yellow shaded areas represent data uncertainty.

Tune	Variation	pT0Ref	ecomPow	a1	reconnectRange
A1 CTEQ6L1		2.182	0.217	0.060	1.547
A1 CTEQ6L1	MPI 1-	2.184	0.213	0.067	1.148
	MPI 1+	2.180	0.222	0.052	2.052
	MPI 2-	2.177	0.240	0.133	1.549
	MPI 2+	2.187	0.196	0.000	1.547
	MPI 3-	2.221	0.226	0.060	1.548
	MPI 3+	2.143	0.209	0.061	1.548
	MPI 4-	2.187	0.200	0.067	1.548
	MPI 4+	2.178	0.236	0.054	1.547

Table 5: 4-parameter MPI eigentune variations on the A1 CTEQ6L1 Pythia 8 tune.

hence its MPI variations provide systematic variations in the underlying event simulation for many signal processes. There are 8 eigentunes, as we simultaneously tuned 4 parameters in the Pythia 8 MPI model. Indeed, we provide 8 such variations, listed in Table 5. The behaviours of the 4-parameter eigentunes on ATLAS UE and MB observables are shown in Fig. 6.

Comparison plots of the PYTHIA 6 AUET2B MPI eigentunes to ATLAS underlying event data at 7 TeV. Left column: 5-parameter eigentunes. Right column: 3-parameter eigentunes without colour-reconnection variations. The "− direction" variations are shown as solid lines, and their "+ direction" partners as dashed lines of the same colour. The MC curves shown in these plots are parameterisations built by the Professor tool.

4 Summary

In this note we have presented new tunes of the PYTHIA 6 and Pythia 8 event generators, which extend the PDF coverage of the PYTHIA 6 AUET2B tune series to include NLO PDFs, provide the first ATLAS tunes of Pythia 8 to make use of the new x-dependent proton matter distribution feature (again including NLO PDFs).

The PYTHIA 6 MPI tuning has produced a set of very consistent optimal parameters for the CT10, CTEQ 6.6, and NNPDF 2.1 NLO PDFs, which confirm previous informal observations that NLO PDFs prefer lower values of the `PARP(82)` and `PARP(90)` MPI parameters than are typically favoured by LO and mLO PDFs, and the same feature is seen for Pythia 8. Respectively these parameter shifts mean that NLO PDF tunes have less MPI cross-section screening (i.e. more activity) at Tevatron energies than LO/mLO equivalents, and the increase in screening scale with centre-of-mass energy is slower than for LO/mLO PDF tunes. The Pythia 8 MPI tunes used the new matter distribution feature, but it is interesting to observe that it almost reduces to a single Gaussian matter distribution. This however leads to better description of UE data for NLO and modified LO PDFs.

References

[1] The ATLAS Collaboration, *New ATLAS event generator tunes to 2010 data*, 2011. http://cdsweb.cern.ch/record/1345343. ATL-PHYS-PUB-2011-008.

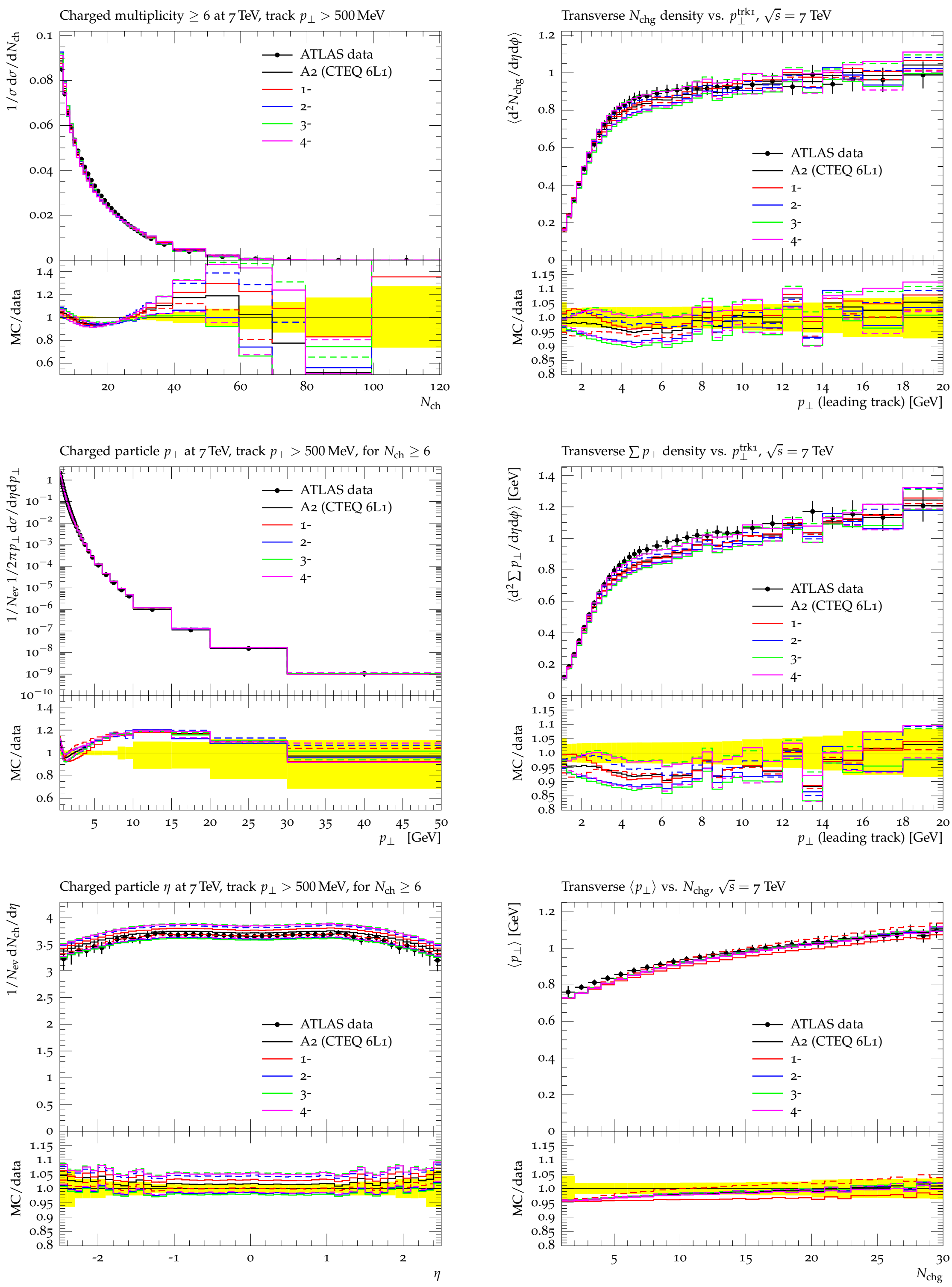

Figure 6: Comparison plots of the Pythia 8 A2 MPI eigentunes to ATLAS minimum bias [24] (left column) and underlying event [20, 21] (right column) data at 7 TeV. The "− direction" variations are shown as solid lines, and their "+ direction" partners as dashed lines of the same colour. The yellow shaded areas represent data uncertainty. The MC curves shown in these plots are parameterisations built by the Professor tool.

[2] The ATLAS Collaboration, *ATLAS tunes of PYTHIA 6 and PYTHIA 8 for MC11*, 2010. http://cdsweb.cern.ch/record/1363300. ATL-PHYS-PUB-2011-009.

[3] T. Sjostrand, S. Mrenna, and P. Skands, *PYTHIA 6.4 physics and manual*, JHEP **05** (2006) 026, hep-ph/0603175.

[4] T. Sjostrand, S. Mrenna, and P. Skands, *A brief introduction to Pythia 8.1*, Comput. Phys. Commun. **178** (2008) 852–867, arXiv:0710.3820 [hep-ph].

[5] G. Corcella et al., *HERWIG 6.5 release note*, arXiv:hep-ph/0210213.

[6] J. M. Butterworth, J. R. Forshaw, and M. H. Seymour, *Multiparton interactions in photoproduction at HERA*, Z. Phys. **C72** (1996) 637–646, arXiv:hep-ph/9601371.

[7] P. Nason, *A new method for combining NLO QCD with shower Monte Carlo algorithms*, JHEP **11** (2004) 040, arXiv:hep-ph/0409146.

[8] S. Frixione, P. Nason, and C. Oleari, *Matching NLO QCD computations with Parton Shower simulations: the POWHEG method*, JHEP **11** (2007) 070, arXiv:0709.2092 [hep-ph].

[9] S. Alioli, P. Nason, C. Oleari, and E. Re, *A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX*, JHEP **06** (2010) 043, arXiv:1002.2581 [hep-ph].

[10] J. Alwall et al., *MadGraph/MadEvent v4: The New Web Generation*, JHEP **09** (2007) 028, arXiv:0706.2334 [hep-ph].

[11] M. L. Mangano, M. Moretti, F. Piccinini, R. Pittau, and A. D. Polosa, *ALPGEN, a generator for hard multiparton processes in hadronic collisions*, JHEP **07** (2003) 001, arXiv:hep-ph/0206293.

[12] A. Sherstnev and R. S. Thorne, *Parton distributions for LO generators*, Eur. Phys. J. **C55** (2008) 553–575, arXiv:0711.2473 [hep-ph].

[13] A. Sherstnev and R. Thorne, *Different PDF approximations useful for LO Monte Carlo generators*, arXiv:0807.2132 [hep-ph].

[14] H.-L. Lai, J. Huston, S. Mrenna, P. Nadolsky, D. Stump, W.-K. Tung, and C.-P. Yuan, *Parton distributions for event generators*, arXiv:0910.4183 [hep-ph].

[15] A. Buckley, J. Butterworth, L. Lonnblad, H. Hoeth, J. Monk, et al., *Rivet user manual*, arXiv:1003.0694 [hep-ph].

[16] A. Buckley, H. Hoeth, H. Lacker, H. Schulz, and J. E. von Seggern, *Systematic event generator tuning for the LHC*, arXiv:0907.2973 [hep-ph].

[17] The ATLAS Collaboration, *Study of jet shapes in inclusive jet production in pp collisions at $\sqrt{s} = 7$ TeV using the ATLAS detector*, Phys.Rev. **D83** (2011) 052003, arXiv:1101.0070 [hep-ex].

[18] The ATLAS Collaboration, *Measurement of Dijet Azimuthal Decorrelations in pp collisions at $\sqrt{s} = 7$ TeV*, arXiv:1102.2696 [hep-ex].

[19] The ATLAS Collaboration, *Properties of jets measured from tracks in proton-proton collisions at center-of-mass energy sqrt(s) = 7 TeV with the ATLAS detector*, arXiv:1107.3311 [hep-ex].

[20] The ATLAS Collaboration, *Measurements of underlying-event properties using neutral and charged particles in pp collisions at 900 GeV and 7 TeV with the ATLAS detector at the LHC*, Eur. Phys. J. **C71** (2011) 1636, arXiv:1103.1816 [hep-ex].

[21] The ATLAS Collaboration, *Measurement of underlying event characteristics using charged particles in pp collisions at $\sqrt{s} = 900$ GeV and 7 TeV with the ATLAS detector*, Phys. Rev. D **83** (2011) 112001, arXiv:1012.0791 [hep-ex].

[22] R. Corke and T. Sjostrand, *Interleaved parton showers and tuning prospects*, JHEP **03** (2011) 032, arXiv:1011.1759 [hep-ph].

[23] R. Corke and T. Sjostrand, *Multiparton Interactions with an x-dependent Proton Size*, JHEP **05** (2011) 009, arXiv:1101.5953 [hep-ph].

[24] The 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].

[25] M. R. Whalley, D. Bourilkov, and R. C. Group, *The Les Houches Accord PDFs (LHAPDF) and LHAGLUE*, arXiv:hep-ph/0508110.