PROCEEDINGS OF SCIENCE

Measurements of underlying-event properties with the ATLAS detector

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A correct modelling of the underlying event in proton-proton collisions is important for the proper simulation of kinematic distributions of high-energy collisions. The ATLAS collaboration extended previous studies at 7 TeV with a leading track or jet or Z boson by a new study of Drell-Yan events in 1.1 fb^{-1} of data collected at a center-of-mass energy of 7 TeV. In this new study the distributions of several topological event-shape variables based on charged particles are measured, both integrated and differential in the transverse momentum of the Drell-Yan lepton pair. These measurements are sensitive to the underlying-event as well as the onset of hard emissions. The results have been compared with the predictions of several state-of-the-art MC generators. The collaboration has also performed a first study of the number and transverse-momentum sum of charged particles as a function of pseudorapidity and azimuthal angle in a special data set taken with low beam currents at a center-of-mass energy of 13 TeV. The results are compared to predictions of several MC generators.

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1. Introduction

To perform high precision measurements or search for new physics processes at hadron colliders, a good understanding is essential not only of the hard scattering process, but also of the accompanying interactions of the rest of the proton. The parts of the final state arising from a collider event which are not identified with the hard process are collectively referred to as the *underlying event* (UE).

The UE is sensitive to the effects of multiple parton interactions, colour connections between partons and beam remnants and processes typically associated with the hard process, such as QCD initial- and final-state radiation (ISR, FSR). It is impossible to unambiguously distinguish the UE from the hard scattering process on an event-by-event basis. Observables which are are particularly sensitive to the UE must therefore be measured.

In these proceedings measurements made with pp collisions by the ATLAS experiment at the CERN Large Hadron Collider (LHC) which are sensitive to UE are described. Event-shape observables measured in events containing Drell-Yan processes are presented [1]. Measurements are also shown of distributions of charged particle tracks relative to a leading track in order to study phase space regions most sensitive to UE effects [2].

2. Event shapes in Drell-Yan events

Measurements have been made of event shape distributions for an inclusive sample of events containing a Z-boson which decays to a pair of electrons or muons. The measurements were made for proton-proton collisions at a centre-of-mass energy of 7 TeV corresponding to an integrated luminosity of 4.6 fb^{-1}. Since the Z-boson does not possess colour charge, it does not influence hadronic activity in the collision. The Z-boson decay products were therefore not included in the set of charged particles used for the event shapes estimations. As the track-based observables are sensitive to pile-up effects, the analysis was restricted to a subsample of 1.1 fb^{-1} integrated luminosity of the 2011 dataset, in which the mean number of pp collisions per bunch crossing was typically around five. After the event and track selection the event-shape observables were corrected first for pile-up and then for background contamination prior to corrections being made for detector effects.

The distributions $f_{\mathscr{O}} = 1/N_{\text{ev}} \cdot \text{d}N/\text{d}\mathscr{O}$ were measured for selected events, N_{ev}, for the following observables $\mathscr{O}$:

- The charged-particle multiplicity, N_{ch}.
- The scalar sum of transverse momenta of selected charged particles, $\sum p_t$.
- The beam thrust, $\mathscr{B}$ [3]. This is similar to $\sum p_t$ except that in the sum over all charged particles the transverse momentum of each particle is weighted by a factor depending on its pseudorapidity, η. Consequently, contributions from particles in the forward and backward direction are suppressed with respect to centrally produced particles.
- The transverse thrust, $\mathscr{T}$ [4].

- The spherocity, $\mathscr{S}$ [4].
- The $\mathscr{F}$-parameter defined as the ratio of the smaller and larger eigenvalues, λ_1 and λ_2, of the transverse momentum tensor

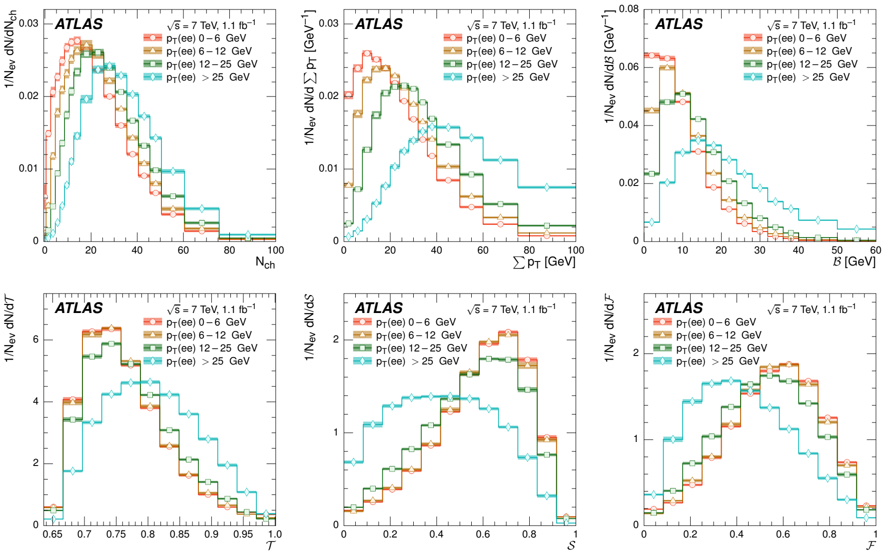

Figure 1: Distributions of the event-shape variables : charged-particle multiplicity N_{ch}, summed transverse momenta $\sum p_t$, beam thrust $\mathscr{B}$, transverse thrust $\mathscr{T}$, spherocity $\mathscr{S}$, and $\mathscr{F}$-parameter, measured in $Z \to e^+e^-$ events for the different ranges of the transverse momentum of the e^+e^- system. The bands show the sum in quadrature of the statistical and all systematic uncertainties. The distributions are from Ref. [1].

Pencil-like events, containing, for example, two partons emitted back-to-back in the transverse plane, possess values of $\mathscr{S}$, $\mathscr{T}$, and $\mathscr{F}$ near to 0, 1, and 0 respectively. For spherical events, containing, for example, a number of partons emitted isotropically, the values of these observables are near to 1, $2/\pi$, and 1 respectively. While the event-shape observables $\mathscr{S}$, $\mathscr{T}$, and $\mathscr{F}$ are highly correlated between themselves, they are weakly correlated with N_{ch}, $\sum p_t$, and beam thrust $\mathscr{B}$.

Several representative measurements from Ref. [1] are given in these proceedings. Figure 1 shows distributions of the event-shape variables for $Z \to e^+ + e^-$ events. The data are shown for various ranges of the transverse momentum of the dielectron system. As the transverse momentum increases this corresponds to a rise in the transverse momentum of recoiling jets. This leads to an increase in N_{ch}, $\sum p_T$ and transverse thrust, while the spherocity becomes smaller. In Figure 2 the distribution of summed transverse momentum in $Z \to \mu^+ + \mu^-$ events is given for different ranges of the transverse momentum of the dimuon system. The predictions of various Monte Carlo generators are confronted with the data. No model gives a good description of the full set of distributions shown. The largest model-data differences occur the lowest p_T region (p_T:0–6 GeV) which is most sensitive to underlying event activity given the low jet activity in such events. In general, calculations from PYTHIA8 [5] and HERWIG7 [6] come closest to the data while SHERPA2.2 [7] predictions lie further away.

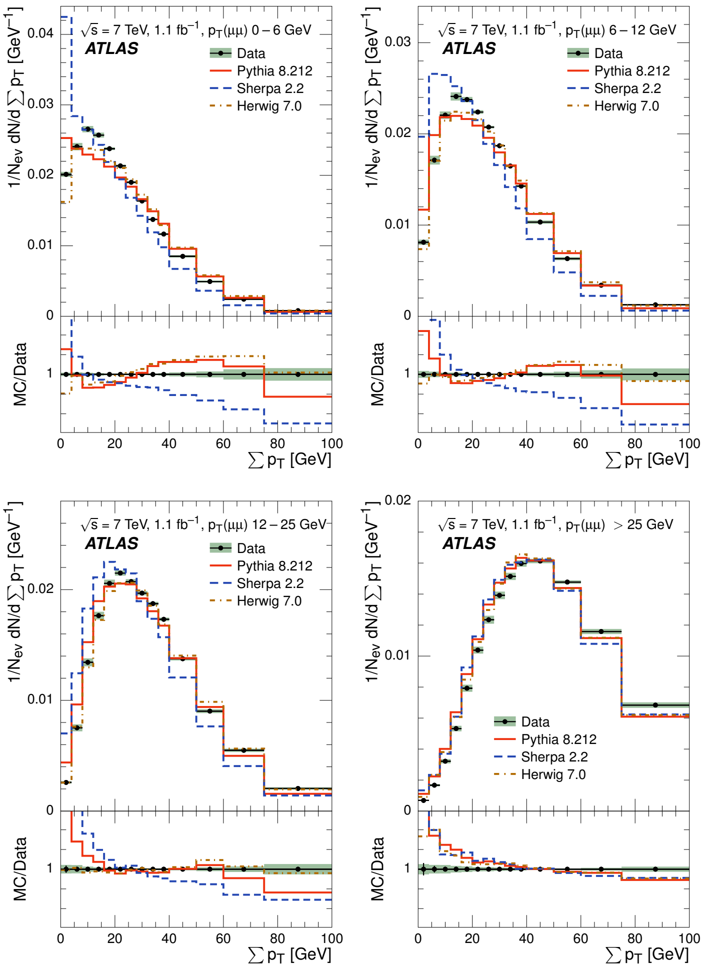

Figure 2: Summed transverse momenta $\sum p_t$ distribution of charged particles for $Z \to \mu^+\mu^-$ with statistical (error bars) and total systematic (band) uncertainties for the four ranges of the transverse momentum of the $\mu^+ + \mu^-$ pair (0–6 GeV, 6–12 GeV, 12–25 GeV, > 25 GeV) compared to the predictions from MC generators. The ratio of the MC simulation to the data is also shown for each distribution. The distributions are from Ref. [1].

3. Detector level leading track underlying event distributions

A minimum bias (MB) dataset produced from 13 TeV collisions and corresponding to an integrated luminosity of 170 μb^{-1} was used in which events contain a leading track of transverse momentum greater than 1 GeV. The direction of the leading track is used to define regions in the azimuthal plane which possess different UE-sensitivities. Regions are defined according to different values of angular difference $|\Delta\phi| = |\phi - \phi_{lead-track}|$ as follows: $|\Delta\phi| < 60^o$ (the *toward* region), $60^\circ < |\Delta\phi| < 120^o$ (the *transverse* region), and $|\Delta\phi| > 120^o$ (the *away* region). The transverse region is most sensitive to the UE as it is perpendicular to the direction of the hard scatter.

The following observables were measured: $< \frac{d^2N_{ch}}{d\eta d|\phi|} >$ (the number of tracks per unit $\eta - \phi$) and $< \frac{d^2\sum p_T}{d\eta d|\phi|} >$ (the scalar sum of track p_T per unit $\eta - \phi$). Distributions were studied at the detector level.

In Figures 3a and 3b distributions of $< \frac{d^2 \sum p_T}{d\eta d|\phi|} >$ and $< \frac{d^2 N_{ch}}{d\eta d|\phi|} >$ versus $|\Delta\phi|$ are shown. Spectra are given for leading-track transverse momentum thresholds of $p_T^{lead} > 1$ GeV and $p_T^{lead} > 5$ GeV. As the threshold increases the events undergo a transition from being inclusive MB-like to containing a hard scattering process. Various MC generator predictions are confronted with the data. MB tunes such as PYTHIA8 A2 [9] and EPOS [8, 12] perform better for the low p_T^{lead} selection. UE tunes such as A14, Monash [11] and HERWIG++ [13] UEEE5 [14] do better for the higher p_T^{lead} slice. Figures 3c and 3d show the dependence of $< \frac{d^2 \sum p_T}{d\eta d|\phi|} >$ and $< \frac{d^2 N_{ch}}{d\eta d|\phi|} >$ on p_T^{lead} in the transverse region. Both distributions show a gradual rise leading to an approximate plateau. Among the MC models, PYTHIA8 A14, Monash and HERWIG++ UEEE5 calculations lie closest to data in the plateau. However, none of the models provide a good description of the initial rise.

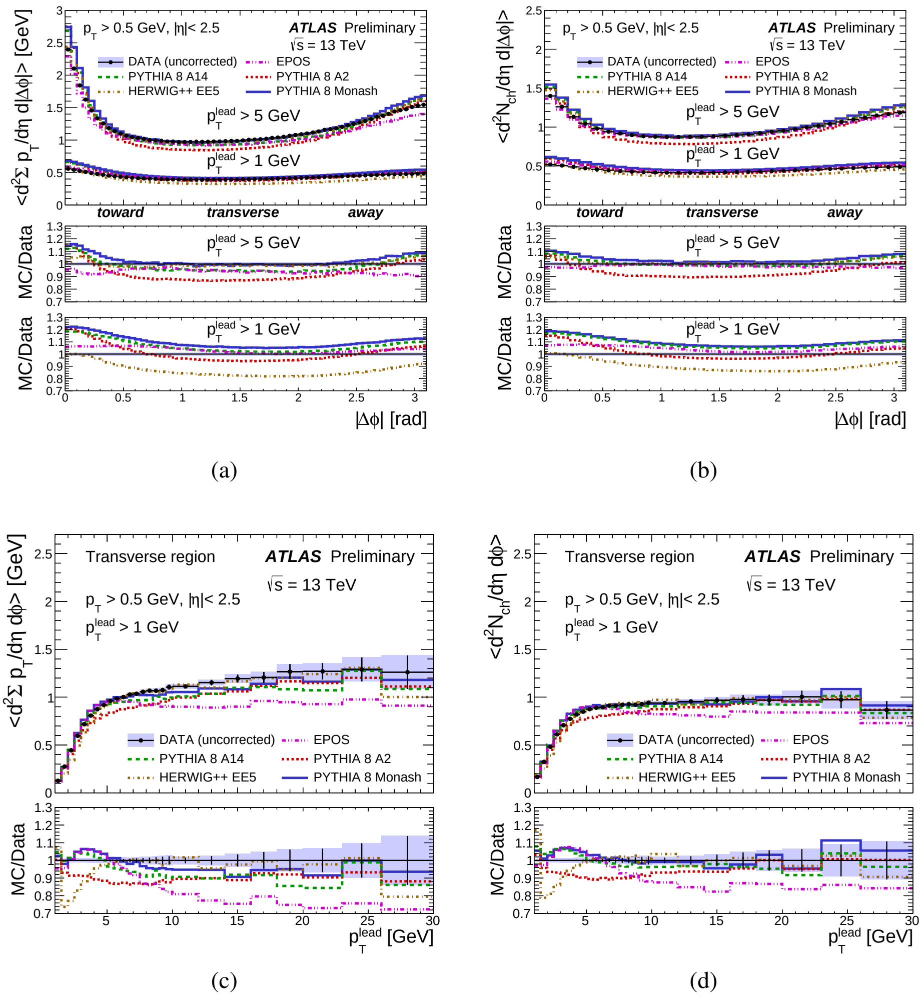

Figure 3: The average scalar transverse momentum sum density of tracks and average track multiplicity density as a function of $|\Delta\phi|$ [(a) and (b), respectively] and p_T^{lead} [(c) and (d), respectively]. Distributions of the ratio of MC expectation and data are also shown. The distributions are from Ref. [2].

4. Summary

Measurements of quantities sensitive to the underlying event in pp collisions have been made by the ATLAS experiment at the LHC. Distributions of event shape observables in Drell-Yan events were presented, as were detector-level measurements of track distributions in a minimum bias data sample. Final state predictions of QCD-based Monte Carlo models were tested against the data.

References

[1] ATLAS Collaboration, Eur. Phys. J. C **76** (2016), 375, doi:10.1140/epjc/s10052-016-4176-8 [arXiv:1602.08980 [hep-ex]].

[2] ATLAS Collaboration, ATL-PHYS-PUB-2015-019 (2015), https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2015-019/

[3] C. F. Berger *et al.*, JHEP **1104** (2011) 092, doi:10.1007/JHEP04(2011)092 [arXiv:1012.4480 [hep-ph]].

[4] A. Banfi, G. P. Salam and G. Zanderighi, JHEP **1006** (2010) 038, doi:10.1007/JHEP06(2010)038 [arXiv:1001.4082 [hep-ph]].

[5] T. Sjostrand, S. Mrenna and P. Z. Skands, Comput. Phys. Commun. **178** (2008) 852, doi:10.1016/j.cpc.2008.01.036 [arXiv:0710.3820 [hep-ph]].

[6] J. Bellm *et al.*, Eur. Phys. J. C **76** (2016) no.4, 196, doi:10.1140/epjc/s10052-016-4018-8 [arXiv:1512.01178 [hep-ph]].

[7] T. Gleisberg *et al.*, JHEP **0902** (2009) 007, doi:10.1088/1126-6708/2009/02/007 [arXiv:0811.4622 [hep-ph]].

[8] K. Werner *et al.*, Phys. Rev. C **83** (2011) 044915, doi:10.1103/PhysRevC.83.044915 [arXiv:1010.0400 [nucl-th]].

[9] ATLAS Collaboration, ATL-PHYS-PUB-2011-014, CERN, Geneva, Nov, 2011, https://cds.cern.ch/record/1400677

[10] ATLAS Collaboration, ATL-PHYS-PUB-2014-021, CERN, Geneva, Nov, 2014, http://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2014-021/

[11] P. Skands, S. Carrazza and J. Rojo, Eur. Phys. J. C **74** (2014) no.8, 3024, doi:10.1140/epjc/s10052-014-3024-y [arXiv:1404.5630 [hep-ph]].

[12] T. Pierog *et al.*, Phys. Rev. C **92** (2015) no.3, 034906, doi:10.1103/PhysRevC.92.034906 [arXiv:1306.0121 [hep-ph]].

[13] M. Bahr *et al.*, Eur. Phys. J. C **58** (2008) 639, doi:10.1140/epjc/s10052-008-0798-9 [arXiv:0803.0883 [hep-ph]].

[14] S. Gieseke, C. Rohr and A. Siodmok, Eur. Phys. J. C **72** (2012) 2225, doi:10.1140/epjc/s10052-012-2225-5 [arXiv:1206.0041 [hep-ph]].