Measurements of Correlations in Minimum Bias Interactions with the ATLAS Detector

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This report presents a brief summary of recent minimum bias measurements using data recorded with the ATLAS detector at the LHC. Measurements done with inelastic proton-proton collisions at different centre-of-mass energies are shown and discussed. In this report we present results on forward-backward multiplicity correlations, two-particle angular correlation and the azimuthal ordering of charged particles.

1 Introduction

Inclusive charged-particle distributions have been measured in proton-proton (pp) collisions at the Large Hadron Collider (LHC) for different centre-of-mass energies [1, 2, 3]. These measurements provide insight into the strong interaction (QCD) at low energy scales and show that predictions of current phenomenological models cannot fully describe the measured observables in all regions of phase-space.

Some of these discrepancies may be reduced through the development of parametrisations for the models of non-perturbative QCD, or tunes, that better match model predictions to the latest measurements of particles produced at very low-p_T. Nevertheless, it is also possible that a new formulation of certain components of these phenomenological models is needed. Many of the difficulties in accurately describing observables dominated by low-p_T QCD phenomena stem from the fact that there is often a combination of non-perturbative effects, including soft diffraction, low-p_T parton scattering and hadronisation. These effects act simultaneously in a given region of phase-space and are difficult to separate experimentally.

This report presents a brief summary of recent minimum bias measurements using data recorded with the ATLAS detector [4] at the LHC. We will discuss ATLAS results on forward-backward multiplicity correlations [5], two-particle angular correlation [6] and the azimuthal ordering of charged hadrons [7].

2 Results

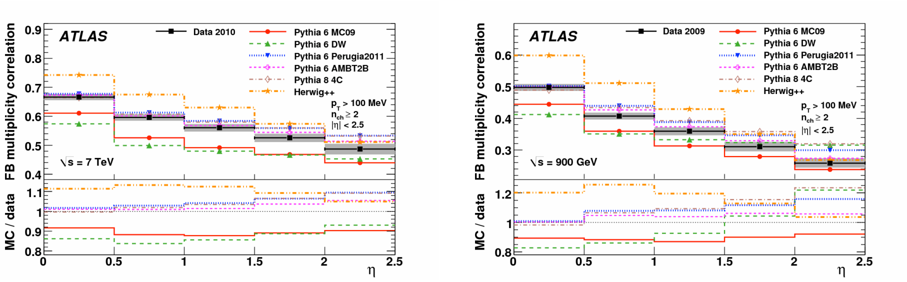
2.1 Forward-backward correlation

Using inelastic pp interactions at $\sqrt{s}$ = 900 GeV and 7 TeV measurements have been made of the correlations between forward and backward charged-particle multiplicities in intervals of pseudorapidity (η).

The forward-backward (FB) multiplicity correlation, ρ^n_{fb}, between two particle multiplicities is the normalised covariance between the two distributions, relative to the mean value of each. For a given data sample or Monte Carlo (MC) sample, it is defined as

$$\rho^n_{fb} = \frac{\langle (n_f - \langle n_f \rangle)(n_b - \langle n_b \rangle) \rangle}{\sqrt{\langle (n_f - \langle n_f \rangle)^2 \rangle \, \langle (n_b - \langle n_b \rangle)^2 \rangle}}. \tag{1}$$

Here, n_f and n_b are the respective charged-particle multiplicities in two chosen forward and backward η intervals in an event, $\langle\rangle$ denotes a mean over the events in the sample. Charged-particle multiplicities are obtained for particles with transverse momentum (p_T) above a given minimum (p_T^{min}). Figure 1 shows the FB multiplicity correlation in symmetrically opposite η intervals for events with at least two charged particles with $p_T > 100$ MeV and $|\eta| < 2.5$. Corrected data at 7 TeV (a) and 900 GeV (b) is compared to a selection of MC simulations [5]. The systematic uncertainties are indicated by a grey band; the statistical uncertainties are too small to be visible on the figure. The multiplicity correlations are substantially lower at 900 GeV than at 7 TeV. The comparisons indicate that model predictions vary considerably depending on the tune chosen; the shapes of the distributions are generally similar but some of the tunes show systematically different trends from the data. The correlations given by Pythia 6 AMBT2B are the most consistent with the data; AMBT2B was tuned to these event samples using different variables but not these correlations.



(a) (b)

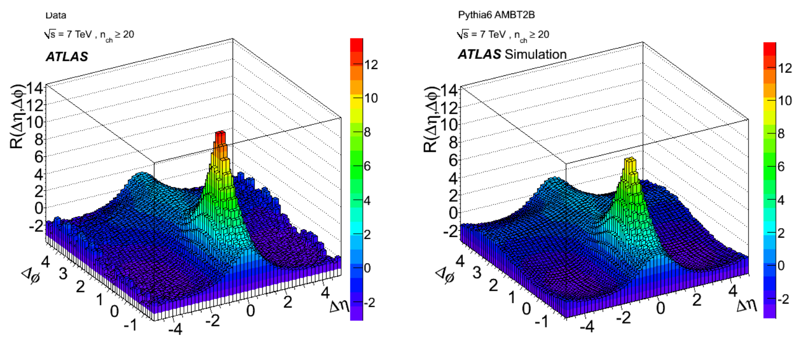
Figure 1: Forward-backward multiplicity correlation in symmetrically opposite η intervals for events with at least two charged particles with $p_T > 100$ MeV and $|\eta| < 2.5$. Data at 7 TeV (a) and 900 GeV (b), compared to a selection of MC simulations [5].

2.2 Inclusive two-particle angular correlation

Two-particle angular correlations in pp collisions at $\sqrt{s} = 900$ GeV and 7 TeV were also measured with the ATLAS detector [6]. The two-particle angular correlation is defined as

$$R(\Delta\eta, \Delta\phi) = \frac{\langle (n_{ch} - 1) F(n_{ch}, \Delta\eta, \Delta\phi) \rangle_{ch}}{B(\Delta\eta, \Delta\phi)} - \langle n_{ch} - 1 \rangle_{ch} \,. \tag{2}$$

In eq. (2), the foreground distribution, $F(n_{ch}, \Delta\eta, \Delta\phi)$, describes the angular separation in azimuth ($\Delta\phi$) and pseudorapidity ($\Delta\eta$) between pairs of particles emitted in the same event of charged multiplicity n_{ch} and $B(\Delta\eta, \Delta\phi)$ is a multiplicity independent background distribution



(a) (b)

Figure 2: Corrected $R(\Delta\eta, \Delta\phi)$ two-particle correlation functions at $\sqrt{s} = 7$ TeV for $n_{ch} \geqslant 20$ (a) data and (b) Monte Carlo (Pythia 6 - AMBT2B). These plots are symmetric around $\Delta\eta = 0$ by construction [6].

of uncorrelated pairs from different events. The correlations were measured for charged particles produced in the kinematic range of $p_T > 100$ MeV and $|\eta| < 2.5$. Figure 2 shows the corrected $R(\Delta\eta, \Delta\phi)$ two-particle correlation functions at $\sqrt{s} = 7$ TeV for $n_{ch} \geqslant 20$ for both data (a) and MC Pythia 6 AMBT2B (b). While Pythia 6 AMBT2B and many of the models investigated in this study reproduce the general features of the two-particle correlation function, none of them provide a good quantitative description of the strength of the correlations. In order to properly describe the correlations, the phenomenology of soft particle production needs further improvement. Similar results are obtained for comparisons between data and MC at $\sqrt{s} = 900$ GeV [6].

2.3 Measurement of the azimuthal ordering of charged hadrons

The presence of azimuthal ordering, stemming from the underlying QCD string structure formed during hadronisation, should be observable with the help of a power spectrum suitably defined to expose the properties of the string fragmentation. The ordering of charged hadrons in the azimuthal angle relative to the beam axis (ϕ) in high-energy pp collisions at the LHC was recently measured by the ATLAS Collaboration [7]. A spectral analysis of correlations between longitudinal and transverse components of the momentum of the charged hadrons was performed with the power spectrum defined as

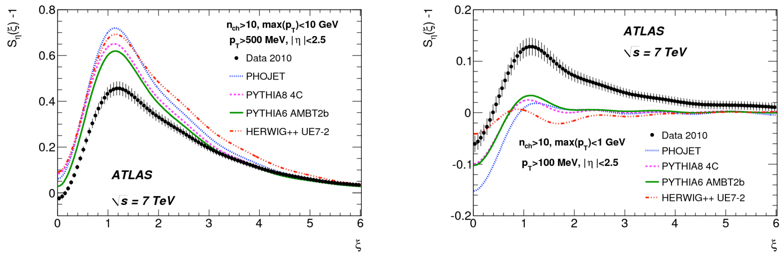
$$S(\xi) = \frac{1}{N_{ev}} \sum_{event} \frac{1}{n_{ch}} |\sum_{j}^{n_{ch}} \exp(i(\xi\eta_j - \phi_j))|^2, \quad (3)$$

where ξ is a parameter and η_j (ϕ_j) is the pseudorapidity (azimuthal angle) of the j-th hadron, N_{ev} is the number of events, and n_{ch} is the number of charged hadrons in the event. The inner sum runs over charged hadrons in the event and the outer sum over events in the sample.

Figure 3 shows the measured S_η distribution (corrected for detector effects) compared to particle level predictions from various MC models using conventional hadronisation algorithms.

The comparisons are made for two samples with different particle selection cuts: (a) low-p_T depleted sample (particle p_T cut-off: $p_T > 500$ MeV) and (b) low-p_T enhanced sample ($p_T > 100$ MeV, and selection of events with no particles with $p_T^{max} > 1$ GeV).

Predictions generated with MC tunes typically produce a spectrum with more correlations than seen in data for the low-p_T depleted sample as shown in fig. 3(a). The correlations measured in a phase space region dominated by low-p_T particles are not well described by conventional models of hadron production, as shown in fig. 3(b). The measured spectra show features consistent with the fragmentation of a QCD string represented by a helix-like gluon chain [7].



(a) (b)

Figure 3: Measured S_η distribution compared to particle level predictions from various MC models using conventional hadronisation algorithms. The error bars correspond to the combined statistical and systematic uncertainties: (a) low-p_T depleted sample and (b) low-p_T enhanced sample [7].

3 Summary

Recent measurements of correlations in minimum bias interactions with the ATLAS Detector have been presented and indicate that the phenomenology of soft particle production needs further improvement. In many cases this can be addressed by re-tuning the MC generators, but the data suggest fundamental re-thinking of the models is also necessary.

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