SOFT QCD WITH THE ATLAS DETECTOR AT THE LHC

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Abstract. Soft QCD measurements using proton-proton collisions at $\sqrt{s} = 900$ GeV and 7 TeV recorded with the ATLAS detector at the LHC are presented. Charged particle distributions were measured using tracks reconstructed in the ATLAS inner detector. Activity in the underlying event was studied using independent measurements from tracking detectors and calorimeters. Two-particle angular correlations measurement is also presented. Finally, a new measurement of the inelastic cross-section at $\sqrt{s}=7$ TeV has been made using events counted by the Minimum Bias trigger. Results are compared to different Monte Carlo models.

1 Introduction

The processes of interest at hadron colliders are mostly hard scattering events. However, soft QCD processes are an unavoidable background to all the collider observables and they are generally not well understood due to the non-perturbative physics involved. These processes are described using phenomenological models that need to be tuned to data. The ATLAS experiment [1] at CERN has made available a large set of measurements to tune soft QCD models [2]. The ones presented in this proceeding have used the ATLAS Inner Detector, that provides precise position measurement for the reconstruction of charged particles for $|\eta| < 2.5$, and the ATLAS Calorimeters, which measure the energy deposition of charged and neutral particles for $|\eta| < 4.9$. Soft QCD events are selected using scintillation counters (MBTS) mounted in the forward region of ATLAS detector, covering a region of $2.09 < |\eta| < 3.84$.

2 Minimum-Bias and Underlying events

ATLAS performed minimum-bias [3] and underlying event [4, 5] measurements with 2010 low pileup data. Both of these analyses used tracks which are measured in events selected by the MBTS trigger. Measured track distributions were corrected back to particle-level using event-level corrections for trigger and vertex efficiency, and track-to-particle corrections for the track reconstruction efficiency. The track reconstruction efficiency was derived from detector simulation and constitutes the largest uncertainty on the results, mainly due to the uncertainty on the detector material description.

Minimum-bias is dominated by purely soft QCD scattering with minimal event selection criteria. In this analysis, charged particle distributions were measured in various regions of phase-space, defined by the minimum number

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of charged particles per event, n_{ch} and the minimum transverse particle momentum, p_T . The phase-space $p_T > 500$ MeV, $n_{ch} \geq 6$ was chosen to suppress diffractive processes, while the region $p_T > 100$ MeV, $n_{ch} \geq 2$ was chosen to provide the most-inclusive measurement possible in ATLAS. The left plot in figure 1 shows the measured charged particle multiplicity as a function of pseudorapidity for 3 different energies. The right plot shows the predictions from various Monte-Carlo (MC) generator tunes at $\eta = 0$. The main pre-LHC reference for ATLAS is the MC09 tune of the PYTHIA6 [6] Monte Carlo model. AMBT1 [7] is an update of MC09 that was tuned using ATLAS data from the diffractive suppressed phase-space region. The predictions from the AMBT1 tune are in good agreement with most of the results shown in figure 1, except for the most-inclusive phase-space where diffractive processes that are not well described by the model have larger contributions.

Underlying event (UE) activity is the soft QCD component which forms an irreducible background in events with an identified hard scattering. Two independent measurements of underlying event activity were made in ATLAS, one method used tracks from the inner detector to measure charged particles [4] while the other measured neutral and charged particles using three-dimensional energy clusters measured in the ATLAS calorimeters [5]. Underlying event activity is characterised by the particles measured in the transverse region of the event, defined as the region where the azimuthal angle of a particle with respect to the leading particle is $60 < |\phi| < 120^\circ$. The leading particle in the event is defined by the track with the highest transverse momentum, p_T , in the event for the track-based measurements, and as the cluster with the highest transverse energy in the event for the cluster-based measurement. Figure 2 shows that pre-LHC MC tunes considered a lower activity than the data in the transverse region UE distributions. The cluster p_T sum from UE, sensitive to both charged and neutral components was also measured for the first time [5] and is shown in right plot.

3 Two-Particle angular correlations

Correlations in the pattern of radiation emitted in proton-proton collisions can give an insight into the underlying particle production mechanism. The Two-Particle-Correlation function was measured by the ATLAS collaboration [8]. This function is defined as:

$$R(\Delta\eta, \Delta\phi) = \frac{\langle (N_{ch} - 1) F(N_{ch}, \Delta\eta, \Delta\phi) \rangle_{ch}}{B(\Delta\eta, \Delta\phi)} \langle N_{ch} - 1 \rangle_{ch}, \quad (1)$$

where $F(N_{ch}, \Delta\eta, \Delta\phi)$ represents the correlations between emissions in a single event (including correlated and uncorrelated pairs) normalised by the total number of events while $B(\Delta\eta, \Delta\phi)$ is the distribution of uncorrelated pairs normalised by its integral. The measured $\Delta\eta$ correlation distributions are shown in

Figure 1: (Left) Charged-particle multiplicities for events with $n_{ch} \geq 2$ within the kinematic range $p_T > 100$ MeV and $|\eta| < 2.5$ at $\sqrt{s} = 7, 2.36$ and 0.9 TeV. The panels compare the charged-particle multiplicities as a function of pseudorapidity. The vertical bars represent the statistical uncertainties, while the shaded areas show statistical and systematic uncertainties added in quadrature. (Right) The average charged-particle multiplicity per unit of rapidity for $\eta = 0$ as a function of the centre-of-mass energy. The results with $n_{ch} \geq 2$ within the kinematic range $p_T > 100$ MeV and $|\eta| < 2.5$ are shown alongside the results with $n_{ch} \geq 1$ within the kinematic range $p_T > 500$ MeV and $|\eta| < 2.5$ at $0.9, 2.36$ and 7 TeV. The data are compared to various particle level MC predictions. The vertical error bars on the data represent the total uncertainty.

figure 3, calculated by integrating $\Delta\phi$ over the limited near-side range ($0 : \pi/2$) and the away-side range ($\pi/2 : \pi$). The data distributions are compared to different MC tunes. By focusing on the particle pairs in the near-side, the distributions are dominated by the peak at $(0,0)$ so they are narrower and higher, showing a higher degree of correlations between nearby particles. Pythia 8 [9] and Phojet [10] have better agreement in the tails of the distribution while MC09 is closer in the peak. In the case of pairs in the away-side, the distributions are flatter and wider, dominated by longer range correlations and, with the exception of DW [11], the tunes seem to perform better in these distributions. The right plot in figure 3 shows the azimuthal correlation function obtained by integrating $\Delta\eta$ over the range $(0:2)$. This focuses on the short-range correlations displaying an “M” shaped structure, similar to that seen in some underlying event distributions associated to back-to-back recoil phenomena. Most of the tunes agree well with data in a small region around $\Delta\phi = \pi$.

4 Inelastic pp cross section

Inelastic pp collisions were measured in ATLAS [12] by counting the number of events triggered by requiring two or more hits in the MBTS. We define

Figure 2: In the transverse region as a function of $p_T^{(lead)}$ for $\sqrt{s} = 7$ TeV: (Left) average number of stable particles per event per unit interval in $\eta - \phi$, (Right) average scalar p_T sum for stable particles per unit area in $\eta - \phi$. The shaded band shows the statistical and systematic uncertainties added in quadrature.

$\xi = M_X^2/s$, calculated from the invariant mass, M_X^2 , of hadrons selected using the largest rapidity gap in the event. MBTS is not sensitive to events that only produce particles with $|\eta| > 3.84$. This corresponds to a limitation of the phase-space to $\xi > 5.10^{-6}$, in which the cross-section is measured. Here, the efficiency of the MBTS is greater than 50%. Experimentally, the cross-section is calculated using:

$$\sigma_{inel}(\xi > 5.10^{-6}) = \frac{N - N_{BG}}{\epsilon_{trig} \times Ldt} \times \frac{1 - f_{\xi > 5.10^{-6}}}{\epsilon_{sel}}, \quad (2)$$

where, N is the number of selected events, N_{BG} is the number of background events, $f_{\xi > 5.10^{-6}}$ is the fraction of events that pass the selection, Ldt is the integrated luminosity, and ϵ_{trig} and ϵ_{sel} are the trigger and offline event selection efficiencies in the selected ξ range. The result for the inelastic cross-section measurement in ATLAS is shown in figure 4. An inelastic cross-section of 60.3 ± 2.1 mb is measured for $\xi > 5.10^{-6}$. The main uncertainty on this measurement comes from the luminosity calibration which has a precision of 3.7%. The figure also shows the result for the model-dependent extrapolation to the full inelastic cross-section: $\sigma_{inel} = 69.4 \pm 2.4(exp.) \pm 6.9(extr.)$, where *extr.* expresses the additional uncertainty obtained using different model extrapolations. Data values are found to be lower than MC predictions, but the extrapolated value agrees with most analytic models.

Figure 3: Two-particle pseudorapidity correlation distributions for data and for different Monte Carlo tunes at 7 TeV. These are obtained by integrating over a $\Delta\phi$ range from 0 to $\pi/2$ (near-Side), over the $\Delta\phi$ range from $\pi/2$ to π (away-side) and over $\Delta\eta$ range from 0 to 2 (short-range). In data, the green bands correspond to the total uncertainties (statistical and systematic, added in quadrature)

Figure 4: The inelastic cross-section versus $\sqrt{s}$. The ATLAS measurement for $\xi > 5 \cdot 10^{-6}$ is shown as the red filled circle and compared with the predictions of Schuler and Sjöstrand and Phojet for the same phase space. Data (filled circles for pp data and unfilled circles for $\bar{p}p$ data) from several experiments are compared with the predictions of the pp inelastic cross-section from Schuler and Sjöstrand (as used by Pythia), by Block and Halzen and by Achilli et al. An extrapolation from the measured range of $\xi > 5 \cdot 10^{-6}$ to the full inelastic cross-section using the acceptance of $87 \pm 10\%$ is also shown (blue filled triangle). The experimental uncertainty is indicated by the error bar while the total (including the extrapolation uncertainty) is represented by the blue shaded area.

5 Summary

In the first years of LHC running, ATLAS successfully performed a number of different soft QCD measurements. An inelastic cross-section of 60.3 ± 2.1 is measured for $\xi > 5 \cdot 10^{-6}$ at $\sqrt{s}=7$ TeV, setting a new reference for the inelastic cross-section at this collision energy. Charged particle distributions, underlying event distributions, two-particle correlations in pp collisions at 900 GeV and 7 TeV have been presented. These are important inputs for MC tuning purposes, since most of the pre-LHC models do not show satisfactory agreement with data. The new AMBT1 and subsequent tunes represent first improvements for soft QCD results. Overall these studies show that there is still room for improvement of the phenomenological models that describe soft QCD at the new energy-scale accessible by the LHC.

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