Physics Letters B 688 (2010) 21–42

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Charged-particle multiplicities in pp interactions at $\sqrt{s} = 900$ GeV measured with the ATLAS detector at the LHC ☆,☆☆

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ARTICLE INFO

Article history:
Received 16 March 2010
Received in revised form 22 March 2010
Accepted 22 March 2010
Available online 28 March 2010
Editor: W.-D. Schlatter

Keywords:
Charged-particle
Multiplicities
900 GeV
ATLAS
LHC
Minimum bias

ABSTRACT

The first measurements from proton–proton collisions recorded with the ATLAS detector at the LHC are presented. Data were collected in December 2009 using a minimum-bias trigger during collisions at a centre-of-mass energy of 900 GeV. The charged-particle multiplicity, its dependence on transverse momentum and pseudorapidity, and the relationship between mean transverse momentum and charged-particle multiplicity are measured for events with at least one charged particle in the kinematic range $|\eta| < 2.5$ and $p_T > 500$ MeV. The measurements are compared to Monte Carlo models of proton–proton collisions and to results from other experiments at the same centre-of-mass energy. The charged-particle multiplicity per event and unit of pseudorapidity at $\eta = 0$ is measured to be $1.333 \pm 0.003(\text{stat.}) \pm 0.040(\text{syst.})$, which is 5–15% higher than the Monte Carlo models predict.

1. Introduction

Inclusive charged-particle distributions have been measured in pp and $p\bar{p}$ collisions at a range of different centre-of-mass energies [1–13]. Many of these measurements have been used to constrain phenomenological models of soft-hadronic interactions and to predict properties at higher centre-of-mass energies. Most of the previous charged-particle multiplicity measurements were obtained by selecting data with a double-arm coincidence trigger, thus removing large fractions of diffractive events. The data were then further corrected to remove the remaining single-diffractive component. This selection is referred to as non-single-diffractive (NSD). In some cases, designated as inelastic non-diffractive, the residual double-diffractive component was also subtracted. The selection of NSD or inelastic non-diffractive charged-particle spectra involves model-dependent corrections for the diffractive components and for effects of the trigger selection on events with no charged particles within the acceptance of the detector. The measurement presented in this Letter implements a different strategy, which uses a single-arm trigger overlapping with the acceptance of the tracking volume. Results are presented as inclusive-inelastic distributions, with minimal model-dependence, by requiring one charged particle within the acceptance of the measurement.

This Letter reports on a measurement of primary charged particles with a momentum component transverse to the beam direction[1] $p_T >$ 500 MeV and in the pseudorapidity range $|\eta| < 2.5$. Primary charged particles are defined as charged particles with a mean lifetime $\tau > 0.3 \times 10^{-10}$ s directly produced in pp interactions or from subsequent decays of particles with a shorter lifetime. The distributions of tracks reconstructed in the ATLAS inner detector were corrected to obtain the particle-level distributions:

$$\frac{1}{N_{ev}} \cdot \frac{dN_{ch}}{d\eta}, \quad \frac{1}{N_{ev}} \cdot \frac{1}{2\pi p_T} \cdot \frac{d^2 N_{ch}}{d\eta \, dp_T}, \quad \frac{1}{N_{ev}} \cdot \frac{dN_{ev}}{dn_{ch}} \quad \text{and} \quad \langle p_T \rangle \text{ vs. } n_{ch},$$

where N_{ev} is the number of events with at least one charged particle inside the selected kinematic range, N_{ch} is the total number of charged particles, n_{ch} is the number of charged particles in an event and $\langle p_T \rangle$ is the average p_T for a given number of charged particles.

☆☆ Date submitted: 2010-03-16T16:00:52Z.

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[1] The ATLAS reference system is a Cartesian right-handed co-ordinate system, with the nominal collision point at the origin. The anti-clockwise beam direction defines the positive z-axis, while the positive x-axis is defined as pointing from the collision point to the centre of the LHC ring and the positive y-axis points upwards. The azimuthal angle ϕ is measured around the beam axis, and the polar angle θ is measured with respect to the z-axis. The pseudorapidity is defined as $\eta = -\ln\tan(\theta/2)$.

0370-2693/$ – see front matter 2010 Published by Elsevier B.V.
doi:10.1016/j.physletb.2010.03.064

Comparisons are made to previous measurements of charged-particle multiplicities in pp and $p\bar{p}$ collisions at $\sqrt{s} = 900$ GeV centre-of-mass energies [1,5] and to Monte Carlo (MC) models.

2. The ATLAS detector

The ATLAS detector [14] at the Large Hadron Collider (LHC) [15] covers almost the whole solid angle around the collision point with layers of tracking detectors, calorimeters and muon chambers. It has been designed to study a wide range of physics topics at LHC energies. For the measurements presented in this Letter, the tracking devices and the trigger system were of particular importance.

The ATLAS inner detector has full coverage in ϕ and covers the pseudorapidity range $|\eta| < 2.5$. It consists of a silicon pixel detector (Pixel), a silicon microstrip detector (SCT) and a transition radiation tracker (TRT). These detectors cover a sensitive radial distance from the interaction point of 50.5–150 mm, 299–560 mm and 563–1066 mm, respectively, and are immersed in a 2 T axial magnetic field. The inner-detector barrel (end-cap) parts consist of 3 (2×3) Pixel layers, 4 (2×9) double-layers of single-sided silicon microstrips with a 40 mrad stereo angle, and 73 (2×160) layers of TRT straws. These detectors have position resolutions of typically 10, 17 and 130 μm for the R–ϕ co-ordinate and, in case of the Pixel and SCT, 115 and 580 μm for the second measured co-ordinate. A track from a particle traversing the barrel detector would typically have 11 silicon hits (3 pixel clusters and 8 strip clusters), and more than 30 straw hits.

The ATLAS detector has a three-level trigger system: Level 1 (L1), Level 2 (L2) and Event Filter (EF). For this measurement, the trigger relies on the L1 signals from the Beam Pickup Timing devices (BPTX) and the Minimum Bias Trigger Scintillators (MBTS). The BPTX are composed of beam pick-ups attached to the beam pipe ±175 m from the centre of the ATLAS detector. The MBTS are mounted at each end of the detector in front of the liquid-argon end-cap calorimeter cryostats at $z = \pm 3.56$ m and are segmented into eight sectors in azimuth and two rings in pseudorapidity ($2.09 < |\eta| < 2.82$ and $2.82 < |\eta| < 3.84$). Data were collected for this analysis using the MBTS trigger, formed from BPTX and MBTS trigger signals. The MBTS trigger was configured to require one hit above threshold from either side of the detector. The efficiency of this trigger was studied with a separate prescaled L1 BPTX trigger, filtered to obtain inelastic interactions by inner detector requirements at L2 and EF.

3. Monte Carlo simulation

Low-p_T scattering processes may be described by lowest-order perturbative Quantum Chromodynamics (QCD) two-to-two parton scatters, where the divergence of the cross section at $p_T = 0$ is regulated by phenomenological models. These models include multiple-parton scattering, partonic-matter distributions, scattering between the unresolved protons and colour reconnection [16]. The PYTHIA [17] MC event generator implements several of these models. The parameters of these models have been tuned to describe charged-hadron production and the underlying event in pp and $p\bar{p}$ data at centre-of-mass energies between 200 GeV and 1.96 TeV.

Samples of ten million MC events were produced for single-diffractive, double-diffractive and non-diffractive processes using the PYTHIA 6.4.21 generator. A specific set of optimised parameters, the ATLAS MC09 PYTHIA tune [18], which employs the MRST LO* parton density functions [19] and the p_T-ordered parton shower, is the reference tune throughout this Letter. These parameters were derived by tuning to underlying event and minimum-bias data from Tevatron at 630 GeV and 1.8 TeV. The MC samples generated with this tune were used to determine detector acceptances and efficiencies and to correct the data.

For the purpose of comparing the present measurement to different phenomenological models describing minimum-bias events, the following additional MC samples were generated: the ATLAS MC09c [18] PYTHIA tune, which is an extension of the ATLAS MC09 tune optimising the strength of the colour reconnection to describe the $\langle p_T \rangle$ distributions as a function of n_{ch}, as measured by CDF in $p\bar{p}$ collisions [3]; the Perugia0 [20] PYTHIA tune, in which the soft-QCD part is tuned using only minimum-bias data from the Tevatron and CERN $p\bar{p}$ colliders; the DW [21] PYTHIA tune, which uses the virtuality-ordered showers and was derived to describe the CDF Run II underlying event and Drell–Yan data. Finally, the PHOJET generator [22] was used as an alternative model. It describes low-p_T physics using the two-component Dual Parton Model [23,24], which includes soft hadronic processes described by Pomeron exchange and semi-hard processes described by perturbative parton scattering. PHOJET relies on PYTHIA for the fragmentation of partons. The versions[2] used for this study were shown to agree with previous measurements [3,5,6,9].

The non-diffractive, single-diffractive and double-diffractive contributions in the generated samples were mixed according to the generator cross sections to fully describe the inelastic scattering. All the events were processed through the ATLAS detector simulation program [25], which is based on Geant4 [26]. They were then reconstructed and analysed by the same program chain used for the data. Particular attention was devoted to the description in the simulation of the size and position of the collision beam spot and of the detailed detector conditions during data taking.

4. Event selection

All data recorded during the stable LHC running periods between December 6 and 15, 2009, in which the inner detector was fully operational and the solenoid magnet was on, were used for this analysis. During this period the beams were colliding head-on in ATLAS. A total of 455,593 events were collected from colliding proton bunches in which the MBTS trigger recorded one or more counters above threshold on either side. In order to perform an inclusive-inelastic measurement, no further requirements beyond the MBTS trigger and inner detector information were applied in this event selection. The integrated luminosity for the final event sample, which is given here for reference only, was estimated using a sample of events with energy deposits in both sides of the forward and end-cap calorimeters. The MC-based efficiency and the PYTHIA default cross section of 52.5 mb were then used to determine the luminosity of the data sample to be approximately 9 μb^{-1}, while the maximum instantaneous luminosity was approximately 5×10^{26} $cm^{-2}\,s^{-1}$. The probability of additional interactions in the same bunch crossing was estimated to be less than 0.1%.

[2] PHOJET 1.12 with PYTHIA 6.4.21.