arXiv:1006.0948v2 [hep-ex] 22 Jun 2010

Inclusive distributions of charged hadrons in pp collisions at $\sqrt{s} = 0.9$ and 2.36 TeV

Gábor I. Veres on behalf of the CMS Collaboration
CERN, Geneva[1]

Abstract. Measurements of inclusive charged-hadron transverse-momentum (p_T) and pseudorapidity (η) distributions are presented for proton-proton collisions at $\sqrt{s} = 0.9$ and 2.36 TeV. For non-single-diffractive interactions, the average p_T of charged hadrons is measured to be 0.46 ± 0.01 (stat.) $\pm$ 0.01 (syst.) GeV/c at 0.9 TeV and 0.50 ± 0.01 (stat.) $\pm$ 0.01 (syst.) GeV/c at 2.36 TeV, for $|\eta| < 2.4$. At these energies, the measured pseudorapidity densities in the central region, $dN_{\mathrm{ch}}/d\eta|_{|\eta|<0.5}$, are 3.48 ± 0.02 (stat.) $\pm$ 0.13 (syst.) and 4.47 ± 0.04 (stat.) $\pm$ 0.16 (syst.), respectively. The results at 2.36 TeV represent the highest-energy measurements ever published at a particle collider at the time of the presentation at the Lake Louise Winter Institute.

1. Introduction

Measurements of particle yields and kinematic distributions are an essential first step in exploring a new energy regime of particle collisions. Such studies contribute to our understanding of the physics of hadron production and help construct a solid foundation for other investigations. In the complicated environment of LHC *pp* collisions [1], such studies are needed to distinguish rare signal events from the much larger backgrounds of soft hadronic interactions. They will also serve as points of reference for Pb-Pb collisions in the LHC. Soft collisions are commonly classified as elastic scattering, inelastic single-diffractive (SD) dissociation, double-diffractive (DD) dissociation, and inelastic non-diffractive (ND) scattering [2]. All presented results refer to inelastic non-single-diffractive (NSD) interactions. Primary charged hadrons are defined to include decay products of particles with proper lifetimes less than 1 cm. Products of secondary interactions and leptons are excluded. The observables reported here are $dN_{\mathrm{ch}}/d\eta$ and $dN_{\mathrm{ch}}/dp_{\mathrm{T}}$ in the $|\eta| < 2.4$ range [3]. The data for this study were recorded with the Compact Muon Solenoid (CMS) experiment [4] in December 2009, during a few hours of the early LHC operation at $\sqrt{s} = 0.9$ and 2.36 TeV.

2. Experimental methods

A detailed description of the CMS experiment can be found in Ref. [4]. The detectors used for the present analysis are the pixel and silicon-strip tracker (SST), covering the region $|\eta| < 2.5$ and immersed in a 3.8 T axial magnetic field. The pixel tracker consists of three barrel layers and two end-cap disks at each barrel end. The forward calorimeter (HF), which covers the region $2.9 < |\eta| < 5.2$, was also used for event selection. The detailed Monte Carlo simulation (MC) of the CMS detector response is based on GEANT4 [5]. The inelastic *pp* collision rate was about 3-11 Hz. The fraction of the events in the data with more than one collision was less than

---

[1] On leave from Eötvös Loránd University, Budapest

2×10^{-4} and was neglected. Any hit in the beam scintillator counters (BSC, $3.23 < |\eta| < 4.65$) coinciding with colliding proton bunches was used for triggering the data acquisition. In addition, a reconstructed primary vertex (PV) was required using the tracker, together with at least one HF tower in each end with more than 3 GeV total energy. The fraction of beam-halo and other beam-background events were suppressed below 0.1%. The number of selected events was finally 40,320 and 10,837 at 0.9 and 2.36 TeV, respectively.

The event selection efficiency was estimated with simulated events using the PYTHIA [6] and PHOJET [7, 8] event generators. The relative event fractions of SD, DD, and ND processes and their respective event selection efficiencies are different for the two models, but the estimated fractions of SD events in the selected data samples are similar: 5.2% (4.9%) at 0.9 TeV and 6.3% (5.0%) at 2.36 TeV for PYTHIA (PHOJET), respectively. The selection efficiency of NSD processes as a function of multiplicity, and the above fraction of SD events are corrected for.

The $dN_{\mathrm{ch}}/d\eta$ distributions were obtained with three methods, based on counting the following quantities: (i) reconstructed clusters in the barrel part of the pixel detector; (ii) pixel tracklets composed of pairs of clusters in different pixel barrel layers; and (iii) tracks reconstructed in the full tracker volume. The third method also allows a measurement of the $dN_{\mathrm{ch}}/dp_{\mathrm{T}}$ distribution. All these methods rely on the reconstruction of a PV [9]. The three methods are sensitive to the measurement of particles down to p_T values of about 30, 50, and 100 MeV/c, respectively.

The measurements were corrected for the geometrical acceptance, efficiency, fake and duplicate tracks, low-p_T particles curling in the axial magnetic field, decay products of long-lived hadrons and photon conversions and inelastic hadronic interactions in the detector material. The PYTHIA D6T tune was chosen to determine the corrections.

3. Results

For the measurement of the p_{T} distribution, charged-particle tracks with $p_T > 0.1$ GeV/c were used in 12 different $|\eta|$ bins, from 0 to 2.4. The average charged-hadron yields in NSD events are shown in Fig. 1a as a function of p_T and $|\eta|$. The Tsallis parametrization [10, 11, 12],

$$E\frac{d^3N_{\mathrm{ch}}}{dp^3} = \frac{1}{2\pi p_T}\frac{E}{p}\frac{d^2N_{\mathrm{ch}}}{d\eta\, dp_T} = C\frac{dN_{\mathrm{ch}}}{dy}\left(1 + \frac{E_{\mathrm{T}}}{nT}\right)^{-n}, \tag{1}$$

was fitted to the data. The p_T spectrum of charged hadrons measured in the range $|\eta| < 2.4$, is shown in Fig. 1b for data at 0.9 and 2.36 TeV. The average p_T, calculated from a combination of the measured data points and the low- and high-p_T contributions as determined from the fit, is $\langle p_T \rangle = 0.46 \pm 0.01(stat.) \pm 0.01(syst.)$ GeV/c and $0.50 \pm 0.01(stat.) \pm 0.01(syst.)$ GeV/c at 0.9 and 2.36 TeV, respectively.

Experimental uncertainties related to the trigger and event selection are common to all the analysis methods. The uncertainty related to the presence of SD and DD events in the final sample was estimated to be 2%, based on consistency checks between data and simulation for diffractive event candidates. The total event selection uncertainty, which also includes the selection efficiency of the BSC and HF, was found to be 3%. Additional 3% and 2% uncertainties were assigned to the tracklet and track reconstruction algorithm efficiencies, respectively. Corrections at the percent level were applied to the final results to extrapolate to $p_T = 0$. The uncertainty on these extrapolation corrections was found to be less than 1%. The final systematic uncertainties for the pixel counting, tracklet, and track methods were found to be 5.4%, 4.9%, and 4.0%, respectively, and are strongly correlated.

For the $dN_{\mathrm{ch}}/d\eta$ measurements, the results from the three different methods were averaged. The final $dN_{\mathrm{ch}}/d\eta$ distributions are shown in Fig. 2a for $\sqrt{s} = 0.9$ and 2.36 TeV. For $|\eta| < 0.5$, the average charged multiplicity density is 3.48 ± 0.02 (stat.) $\pm$ 0.13 (syst.) and 4.47 ± 0.04 (stat.) $\pm$ 0.16 (syst.) for NSD events at 0.9 and 2.36 TeV, respectively. The $\sqrt{s}$ dependence of the measured $dN_{\mathrm{ch}}/d\eta|_{\eta\approx 0}$ is shown in Fig. 2b, which includes data from the NAL

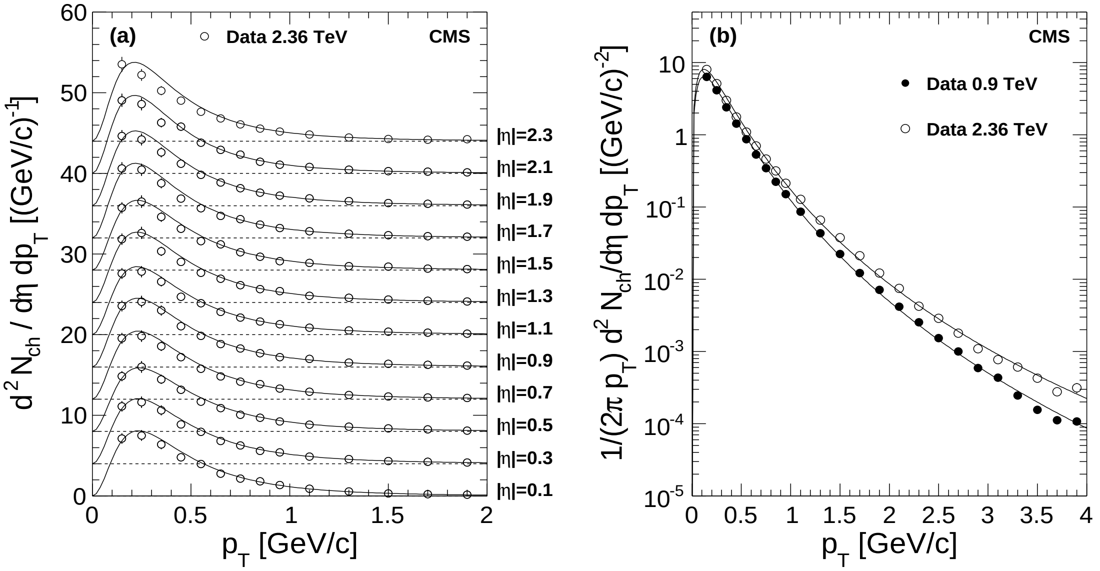

Figure 1. (a) Measured differential yield of charged hadrons in the range $|\eta| < 2.4$ in 0.2-unit-wide bins of $|\eta|$ for the 2.36 TeV data. The measured values with systematic uncertainties (symbols) and the fit functions (Eq. 1) are displayed. The values with increasing η are successively shifted by four units along the vertical axis. (b) Measured yields of charged hadrons for $|\eta| < 2.4$ with systematic uncertainties (symbols), fitted with the empirical function (Eq. 1).

Bubble Chamber [13], the ISR [14], and UA1 [15], UA5 [16], CDF [17], STAR [18], PHOBOS [19] and ALICE [20]. The $dN_{\mathrm{ch}}/d\eta$ results reported here show a rather steep increase between 0.9 and 2.36 TeV, which is measured to be $(28.4 \pm 1.4\,(\mathrm{stat.}) \pm 2.6\,(\mathrm{syst.}))\%$, significantly larger than the 18.5% (14.5%) increase predicted by PYTHIA (PHOJET).

In summary, charged-hadron p_T and η distributions have been measured in proton-proton collisions at $\sqrt{s} = 0.9$ and 2.36 TeV. The measured increase of the pseudorapidity density between these energies is higher than most predictions and provides new information to constrain ongoing improvements of soft particle production models and event generators. The mean p_T of charged hadrons has been also measured, extrapolated to the full p_T range. These studies are the first steps in the exploration of particle production at the new centre-of-mass energy frontier, and contribute to the understanding of the dynamics in soft hadronic interactions.

Acknowledgements. We congratulate and express our gratitude to our colleagues in the CERN accelerator departments for the excellent performance of the LHC. We thank the technical and administrative staff at CERN and other CMS institutes, and acknowledge support from: FMSR (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, and FAPESP (Brazil); MES (Bulgaria); CERN; CAS, MoST, and NSFC (China); COLCIENCIAS (Colombia); MSES (Croatia); RPF (Cyprus); Academy of Sciences and NICPB (Estonia); Academy of Finland, ME, and HIP (Finland); CEA and CNRS/IN2P3 (France); BMBF, DFG, and HGF (Germany); GSRT (Greece); OTKA and NKTH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); NRF and WCU (Korea); LAS (Lithuania); CINVESTAV, CONACYT, SEP, and UASLP-FAI (Mexico); PAEC (Pakistan); SCSR (Poland); FCT (Portugal); JINR (Armenia, Belarus, Georgia, Ukraine, Uzbekistan); MST and MAE (Russia); MSTDS (Serbia); MICINN and CPAN (Spain); Swiss Funding Agencies (Switzerland); NSC (Taipei); TUBITAK and TAEK (Turkey); STFC (United Kingdom); DOE and NSF (USA). The author thanks the Hungarian Scientific Research Fund (H07-C74248, K81614 and NK81447) for its support.

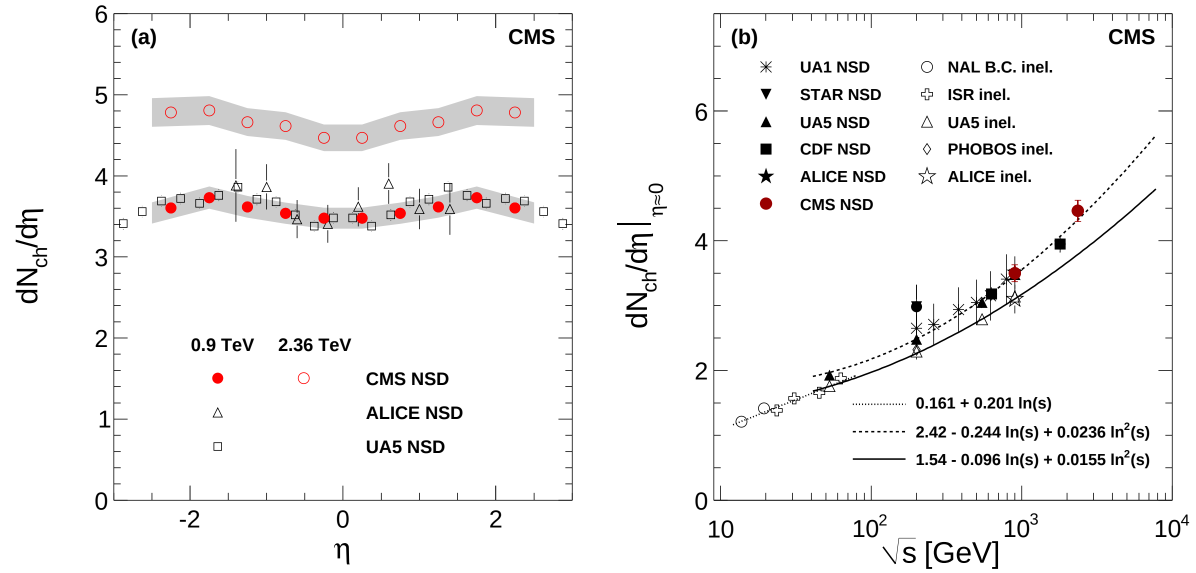

Figure 2. (a) Reconstructed $dN_{\rm ch}/d\eta$ distributions averaged over the cluster counting, tracklet and tracking methods (circles), compared to data from the UA5 (open squares) and from the ALICE (open triangles) experiments at 0.9 TeV, and the averaged result over the three methods at 2.36 TeV (open circles). The CMS and UA5 data points are symmetrized in η. The shaded band represents systematic uncertainties of this measurement, which are largely correlated point-to-point. The error bars on the UA5 and ALICE data points are statistical only. (b) Charged-hadron pseudorapidity density in the central region as a function of centre-of-mass energy in pp and $p\overline{p}$ collisions including lower energy data, together with various empirical parameterizations fit to the data corresponding to the inelastic (solid and dotted curves with open symbols) and to the NSD (dashed curve with solid symbols) event selection. The error bars indicate systematic uncertainties, when available.

References

[1] L. Evans, (ed.) and P. Bryant, (ed.), *JINST* **3** (2008) S08001.
[2] W. Kittel and E. A. De Wolf, “Soft Multihadron Dynamics”, World Scientific, Singapore, 2005.
[3] **CMS** Collaboration, *JHEP* **1002**, (2010) 041.
[4] **CMS** Collaboration, *JINST* **3** (2008) S08004.
[5] **Geant4** Collaboration, *Nucl. Instrum. and Methods* **A506** (2003) 250.
[6] T. Sjöstrand, S. Mrenna, and P. Skands, *JHEP* **05** (2006) 026; v6.420, tune D6T.
[7] F. W. Bopp, R. Engel, and J. Ranft, `arXiv:hep-ph/9803437v1`.
[8] R. Engel, J. Ranft, and S. Roesler, *Phys. Rev.* **D52** (1995) 1459.
[9] F. Siklér, `arXiv:0911.2767`.
[10] C. Tsallis, *J. Stat. Phys.* **52** (1988) 479.
[11] G. Wilk and Z. Włodarczyk, *Eur. Phys. J.* **A40** (2009) 299.
[12] T. S. Biró, G. Purcsel and K. Ürmössy, *Eur. Phys. J.* **A40** (2009) 325.
[13] J. Whitmore, *Phys. Rept.* **10** (1974) 273.
[14] **Aachen-CERN-Heidelberg-Munich** Collaboration, *Nucl. Phys.* **B129** (1977) 365.
[15] **UA1** Collaboration, *Nucl. Phys.* **B335** (1990) 261.
[16] **UA5** Collaboration, *Z. Phys.* **C33** (1986) 1.
[17] **CDF** Collaboration, *Phys. Rev.* **D41** (1990) 2330.
[18] **STAR** Collaboration, *Phys. Rev.* **C79** (2009) 034909.
[19] **PHOBOS** Collaboration, *J. Phys.* **G30** (2004) S1133.
[20] **ALICE** Collaboration, *Eur. Phys. J.* **C65** (2010) 111.