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Inclusive hadron production in proton-proton collisions at 8 TeV in CMS

Panagiotis Katsas*, **for the CMS Collaboration**
Deutsches Elektronen-Synchrotron (DESY)
E-mail: Panos.Katsas@desy.de

The pseudorapidity distributions of charged particles in proton-proton collisions at $\sqrt{s} = 8$ TeV are measured in the pseudorapidity range $|\eta| < 2.4$ by the CMS detector. Events were triggered by the TOTEM T2 telescopes that cover the pseudorapidity range $5.3 < |\eta| < 6.5$ for reconstructed tracks with $p_T > 40$ MeV. The measurement of the pseudorapidity distributions was performed for primary charged particles with $p_T > 0.1$ GeV and $p_T > 1$ GeV, for two different conditions: an inclusive sample obtained by requiring tracks reconstructed in the acceptance of the TOTEM T2 telescopes in either hemisphere, and a sample enhanced in non-single diffractive dissociation events by requiring tracks in T2 in both forward and backward hemispheres. For $p_T > 0.1$ GeV results are also presented combined with the corresponding measurement performed with the TOTEM detector. The p_T distribution of the leading tracks in the central region is also measured. The distribution integrated over the leading track transverse momentum, above a $p_{T,min}$ value, shows a transition from a steeply falling distribution at large p_T (perturbative region) to a flat distribution at small p_T (non-perturbative region) for $p_{T,min}$ of a few GeV.

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*Speaker.

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1. Introduction

Measurements of particle yields and their differential distributions in proton-proton (pp) collisions at the Large Hadron Collider (LHC), are essential for understanding the mechanisms of multi-particle production in high-energy hadronic collisions. Most of the particles produced in pp collisions at LHC energies arise from the fragmentation of (multi)partons scattered in semi-hard scatterings, at scales of $\mathcal{O}$(1–3) GeV. Such processes are modeled phenomenologically in the existing event generators for collider physics and require experimental results for the tuning of various model parameters. Results are presented for the measurement of the primary charged-particle multiplicity density ($dN_{ch}/d\eta$), at $\sqrt{s}$=8 TeV, in the largest pseudorapidity range, $|\eta| < 2.4$ and $5.3 < |\eta| < 6.5$, covered so far at the LHC. The transverse momentum distribution of the highest-p_T track, hereafter called the leading track, is also presented in $|\eta| < 2.4$. The integrated leading-track transverse momentum distribution, defined as $D(p_{T,min}) = \frac{1}{N}\Sigma_{p_{T,leading}>p_{T,min}} \Delta p_{T,leading}(dN_{ch}/d_{p_T,leading})$ has been proposed as an observable sensitive to the unitarity bound set by the inelastic pp cross section [1]. The pseudorapidity distributions are measured for different event topologies, from the most inclusive one to those dominated by particles produced in non-single diffractive (NSD) processes. Pseudorapidity and transverse momentum distributions of charged particles have been previously measured in pp and $p\bar{p}$ collisions for different centre-of-mass energies and phase space regions [2, 3, 4, 5, 6, 7, 8, 9]. We compare our results to models of hadronic interactions used commonly for collider and high-energy cosmic-rays physics [10].

2. Experimental methods

A detailed description of the CMS experiment can be found in Ref. [11]. The detectors used for the present analysis are the pixel and silicon-strip tracker, covering the region $|\eta| < 2.5$ and immersed in a 3.8 T axial magnetic field. The data were collected in July 2012 during a dedicated low pile up common CMS and TOTEM run with a non-standard $\beta*$ = 90 m optics configuration (see also Ref. [12]). They correspond to an integrated luminosity of $\mathcal{L}$ = 17.4 nb^{-1}. The TOTEM T2 telescopes [13], which cover the region $5.3 < |\eta| < 6.5$, were used for the event selection. The detailed Monte Carlo (MC) simulation of the CMS detector response is based on GEANT4 [14]. A minimum bias trigger was provided by the TOTEM T2 and was defined by the detection of at least one charged track, with $p_T > 40$ MeV, in the acceptance of the T2 telescopes in either hemisphere, i.e. $5.3 < \eta < 6.5$ or $-6.5 < \eta < -5.3$. With the requirement of at least one reconstructed track in the T2 detector, the visible cross-section seen by T2 has been estimated to be about 95% of the total inelastic cross-section.

The data were corrected to the stable particle level, defined to include charged particles with proper lifetime ($c\tau$) larger than 1 cm that originate from the pp collision or are decay products of particles with $c\tau < 1$ cm. An inclusive sample of events was selected by requiring at least one primary charged particle with $p_T > 40$ MeV within the acceptance of T2 ($5.3 < \eta < 6.5$ or $-6.5 < \eta < -5.3$). In addition to this inclusive selection, a sample enhanced in non-single diffractive (NSD) events was defined by requiring at least one primary charged particle with $p_T >$ 40 MeV within $5.3 < \eta < 6.5$ and $-6.5 < \eta < -5.3$. The selection of tracks in the CMS tracking system aimed to reduce the effect of beam background events, to minimize the contribution from

Table 1: Most significant systematic and statistical uncertainties. The values in parentheses apply to the leading-track dN_{ch}/dp_T measurement.

Source	Uncertainty (%)	
	Inclusive	NSD-enhanced
Tracking efficiency	4.0 (4.0)	4.0
Model dependence	1.0 (2.3)	1.0
T2 correction	1.5 (0.7)	1.0
Statistical	0.1 (0.3–14.6)	0.1
Total	4.4 (4.7–15.3)	4.2

misidentified tracks and tracks with poor momentum resolution, and to reject non-primary tracks from weak decays and secondary interactions with the detector material. Good quality tracks were selected, with $p_T > 0.1$ GeV and relative transverse momentum uncertainty less than 10%. In addition, a track-vertex association was applied by restricting the impact parameter with respect to the primary vertex position both in the transverse plane and along the z-axis. The analysis was restricted to a fiducial acceptance for the CMS tracker ($|\eta| < 2.4$), in order to avoid effects from tracks very close to the geometric edge of the detector. For the measurement of the leading-track p_T distributions, the transverse momentum of the tracks was chosen to be $p_T > 0.4$ GeV and the distributions were normalised to the number of events with at least one selected track in the CMS tracker. The pseudorapidity distributions were corrected for the trigger efficiency and the vertex reconstruction, as well as for the tracking efficiency, including corrections for non primary (secondary or misidentified tracks) and duplicate tracks. All corrections were calculated in bins of track multiplicity, p_T and η, from a detector simulation with the PYTHIA6 MC event generator and using the parameter set from tune Z2*[1]. For $p_T > 500$ MeV, the average tracking efficiency exceeds 80% while it drops significantly for the lowest p_T tracks. The correction for non-primary tracks takes its lowest values of 2% and 5% for $|\eta| < 1.5$ and $p_T > 500$ MeV, respectively. It reaches values as large as 15% at low transverse momentum ($p_T < 200$ MeV) and/or large pseudorapidity ($|\eta| > 1.5$). The correction factor for multiply reconstructed particles was found to be negligible. An additional correction was applied to account for triggered events without a charged primary particle in T2. This was evaluated from a detector simulation of T2 using two different event generators, EPOS (LHC tune) and PYTHIA8. It was found to be smaller than 4% and 8% for the inclusive and NSD-enhanced sample, respectively. The dominant systematic uncertainty is due to the uncertainty on the tracking efficiency which was estimated to be 4%. The model dependence of the corrections was determined by using different event generators and were found to differ by 0.1-1.5% per pseudorapidity bin. The uncertainties related to the primary vertex selection, the trigger efficiency and pile up events were found to be negligible, at the level of 0.1%. The leading track p_T distributions were corrected to stable particle level using PYTHIA6 tune Z2* and Pythia8 tune 4C. The model dependence was found to be 0.6–2.3% per p_T bin. The tracking efficiency uncertainty is dominant, except for the highest p_T bins where the statistical errors become larger. A summary

[1]The Z2* tune is derived from the Z1 tune [15] which uses the CTEQ5L parton distribution set, whereas Z2* is updated to CTEQ6L.

of the most important systematic uncertainties, averaged over η or p_T, is given in Table 1.

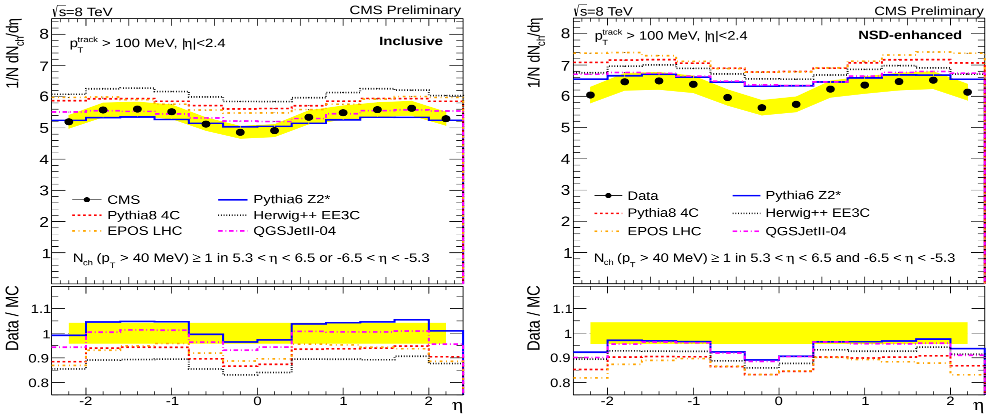

Figure 1: $dN_{ch}/d\eta$ distributions at $\sqrt{s} = 8$ TeV for tracks in $|\eta| < 2.4$ with $p_T > 0.1$ GeV for an inclusive sample obtained by requiring tracks in the range of any of the TOTEM T2 telescopes in either hemisphere (left) and an NSD-enhanced sample requiring tracks in the range of TOTEM T2 in both forward and backward hemispheres (right). The data are compared to different model predictions and their ratio is shown in the lower panels. The error bands show the total systematic uncertainty.

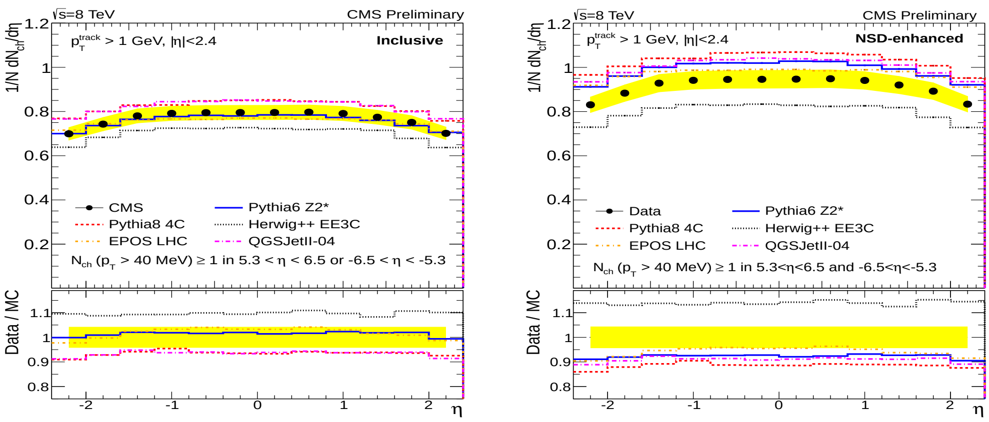

Figure 2: $dN_{ch}/d\eta$ distributions at $\sqrt{s} = 8$ TeV for tracks in $|\eta| < 2.4$ with $p_T > 1$ GeV. As in Fig. 1, results are shown for an inclusive sample (left) and a sample enhanced in non-single diffractive events (right). The data are compared to various model predictions and their ratio is shown in the lower panels. The error bars indicate the statistical uncertainty and the shaded area the correlated systematic uncertainty.

3. Results

The fully corrected pseudorapidity distributions of charged particles are presented in Figs. 1 and 2 for different event samples for tracks in $|\eta| < 2.4$ with transverse momentum $p_T > 0.1$ GeV and $p_T > 1$ GeV, respectively. For tracks with $p_T > 0.1$ GeV, the average multiplicity per unit of pseudorapidity was found to be 5.4 ± 0.2 for the most inclusive selection and 6.2 ± 0.3 for the NSD-enhanced sample. For tracks with $p_T > 1$ GeV the average multiplicity is 0.78 ± 0.03

for the most inclusive selection and 0.93 $\pm$ 0.04 for the NSD-enhanced sample. For the lowest transverse momentum threshold, the data are well described by PYTHIA6 Z2* and QGSJETII-04 for the inclusive selection. All models overestimate the data by up to 20% for the NSD-enhanced sample. For tracks with $p_T > 1$ GeV PYTHIA6 Z2*, PYTHIA8 4C, EPOS LHC and QGSJETII-04 are within the systematic uncertainties for most pseudorapidity bins, while HERWIG++ EE3 (with CTEQ6L1 PDF) underestimates the data. All models fail to describe the data well for the sample enhanced in non-single diffractive events, with the exception of EPOS LHC for $|\eta| < 1.5$. The pseudorapidity distributions are shown in Fig. 3 combined with the measurement performed by the TOTEM collaboration with T2 [12]. The data, as function of $|\eta|$, were derived by averaging the data points in the corresponding $\pm\eta$ bins. The leading-track p_T distribution and the integrated

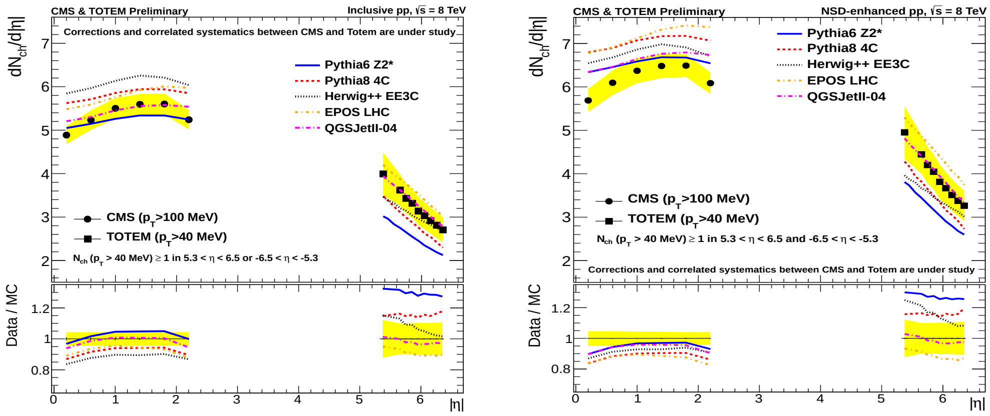

Figure 3: $dN_{ch}/d\eta$ distributions at $\sqrt{s}$ = 8 TeV for tracks in $|\eta| < 2.4$ with $p_T > 0.1$ GeV and in $5.3 < |\eta| < 6.5$ for $p_T > 40$ MeV, as measured by CMS and TOTEM, respectively. As in Fig. 1, results are shown for an inclusive sample (left) and a sample enhanced in non-single diffractive events (right). The data are compared to various model predictions and their ratio is shown in the lower panels. The error bars indicate the statistical uncertainty and the shaded area the correlated systematic uncertainty.

distribution, $D(p_T, min)$, are shown in Fig. 4. All theoretical predictions fail to describe the shape of the data. In the region of $1 < p_T < 10$ GeV, they overestimate or underestimate the data by up to 20%. The effect of multi-parton interactions is shown to have a small impact. The integrated distribution shows a transition from a steeply falling distribution at large p_T (perturbative region) to a flat distribution at small p_T (non-perturbative region) in the range of $p_{T,min}$ of a few GeV.

The measured charged-particle distributions can help constrain the modeling of semi-hard (multi)parton scatterings in pp collisions at the LHC over a large phase space in p_T and η.

References

[1] A. Grebenyuk et al., *Jet production and the inelastic pp cross section at the LHC*, *Phys. Rev. D* **86** (2012) 117501

[2] V. Khachatryan et al. (CMS Collaboration), *Transverse momentum and pseudorapidity distributions of charged hadrons in pp collisions at* $\sqrt{s}$*= 0.9 and 2.36 TeV*, *JHEP* **02** (2010) 041

[3] V. Khachatryan et al. (CMS Collaboration), *Transverse-momentum and pseudorapidity distributions of charged hadrons in pp collisions at* $\sqrt{s}$*= 7 TeV*, *Phys. Rev. Lett.* **105** (2010) 022002

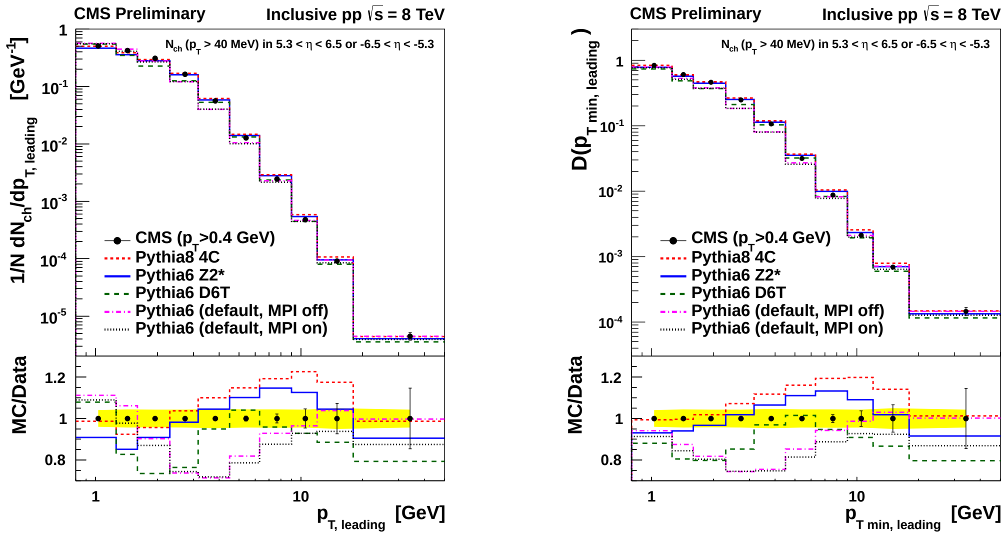

Figure 4: Normalised p_T-distribution (left) and normalised integrated p_T-distribution (right) of the leading charged particle in $|\eta| < 2.4$. Data are compared to PYTHIA6 and PYTHIA8 tunes. The error bars indicate the statistical uncertainty and the shaded area the systematic uncertainty.

[4] ATLAS Collaboration, *Charged-particle multiplicities in pp interactions measured with the ATLAS detector at the LHC*, *New J. Phys.*, **13** (2011) 053033

[5] ALICE Collaboration, *Charged-particle multiplicity measurement in proton–proton collisions at $\sqrt{s}$=7 TeV with ALICE at LHC*, *EPJ C* **68** (2010) 345

[6] CDF Collaboration, *Measurement of particle production and Inclusive Differential Cross Sections in $p\bar{p}$ Collisions at $\sqrt{s}$=1.96 TeV*, *Phys. Rev. D* **79** (2009) 112005

[7] CDF Collaboration, *Pseudorapidity distributions of charged particles produced in $p\bar{p}$ interactions at $\sqrt{s}$ = 630 GeV and 1800 GeV*, *Phys. Rev. D* **41** (1990) 2330

[8] UA1 Collaboration, *A study of the general characteristics of proton-antiproton collisions at $\sqrt{s}$=0.2 to 0.9 TeV*, *Nucl. Phys. B* **335** (1990) 261

[9] TOTEM Collaboration, *Measurement of the forward charged particle pseudorapidity density in pp collisions at $\sqrt{s}$ = 7 TeV with the TOTEM experiment*, *EPL* **98** (2012) 31002

[10] D. d' Enterria et al., *Constraints from the first LHC data on hadronic event generators for ultra-high energy cosmic-ray physics*, *Astrpart. Phys.* **35** (2011) 98

[11] S. Chatrchyan et al. (CMS Collaboration), *JINST* **3** (2008) S08004

[12] M. Berretti (TOTEM Collaboration), *Cross sections and forward multiplicities measurements with TOTEM*, XXI International Workshop on Deep-Inelastic Scattering and Related Subject - DIS2013, 22-26 April 2013, Marseilles, France

[13] TOTEM Collaboration, *The TOTEM Experiment at the CERN Large Hadron Collider*, *JINST* **3** (2008) S08007

[14] S. Agostinelli et al., *GEANT4: A simulation toolkit*, *Nucl. Inst. Meth. A* **506** (2003)

[15] R. Field, *Early LHC Underlying Event Data - Findings and Surprises* (2010) [hep-ph/1010.3558]