Measurement of the double-differential inclusive jet cross section at $\sqrt{s} = 8$ TeV

The CMS Collaboration

Abstract

A measurement of the double-differential inclusive jet cross section, as a function of jet transverse momentum $p_T$ and absolute jet rapidity $|y|$, is presented. Data from LHC proton-proton collisions at $\sqrt{s} = 8$ TeV, corresponding to an integrated luminosity of 19.71 fb$^{-1}$, have been collected with the CMS detector. Jets are reconstructed with the anti-$k_T$ clustering algorithm for a jet size parameter $R=0.7$ in a phase space region covering jet $p_T$ up to 2.5 TeV and jet rapidity up to $|y| = 3.0$. The measured jet cross section is corrected for detector effects and compared to predictions of perturbative QCD at next-to-leading order using various sets of parton distribution functions. From the measured double-differential jet cross section the strong coupling constant value is found to be $\alpha_s(M_Z) = 0.1164^{+0.0060}_{-0.0043}$, using the CT10 NLO parton distribution function set. Constraints on parton distribution functions based on the inclusive cross section measurement are presented.
1 Introduction

Proton-proton collisions leading to events with high transverse momentum jets are described by quantum chromodynamics (QCD) through parton-parton scattering. A fundamental quantity that can be measured and predicted within the framework of perturbative QCD (pQCD) is the inclusive jet cross section \( (p + p \rightarrow \text{jet} + X) \), where every jet is counted. A measurement of the jet cross section as a function of the rapidity \( y \) and the transverse momentum \( p_T \) of the jet is a sensitive probe for the calculation of the hard partonic cross section as well as for the parton densities. In the present analysis, double-differential inclusive jet cross section is measured as a function of jet transverse momentum \( p_T \) and absolute jet rapidity \( |y| \). Similar measurements have been carried out at the LHC by the ATLAS and CMS collaborations at 7 TeV centre-of-mass energy [1–4] as well as by experiments at other hadron colliders [5–9].

The measured inclusive jet cross section at \( \sqrt{s} = 7 \) TeV is in agreement within uncertainties with pQCD calculations at next-to-leading order (NLO) at small \( y \). Differences are on the contrary observed at large \( y \). The larger size of the 8 TeV sample allows one to probe with higher precision the high-\( p_T \) part of the differential cross section, where the sensitivity to the \( \alpha_S \) value is maximal. Additionally, it enables the evaluation of the ratio of differential cross sections at different energies. With a reduced sensitivity to scale uncertainties, this ratio constitutes a powerful constraint for parton distribution function (PDF) determination. The measured cross section is used to extract the value of the strong coupling constant at the Z boson mass scale, \( \alpha_S(M_Z) \), and to study the scale dependence of \( \alpha_S \) on a wider kinematic range than the one accessible at \( \sqrt{s} = 7 \) TeV. The measured cross section can be also used to further constrain PDFs. A QCD analysis is presented, where the addition of the current measurement to HERA data set allows a reduction of the gluon PDF uncertainties, compared to what can be achieved using the deep inelastic scattering (DIS) data alone.

The data was collected with the Compact Muon Solenoid (CMS) detector at the CERN Large Hadron Collider (LHC) during the 2012 run and corresponds to an integrated luminosity of 19.71 fb\(^{-1}\). The measured cross sections are corrected for detector effects and compared to the QCD predictions.

2 CMS detector

The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. Within the superconducting solenoid volume are a silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter (ECAL), and a brass/scintillator hadron calorimeter (HCAL). Muons are measured in gas-ionization detectors embedded in the steel return yoke outside the solenoid. A quartz-fibre Cherenkov calorimeter (HF) extends the coverage of the calorimetric system up to \( |\eta| = 5.2 \).

The silicon tracker measures charged particles within the pseudorapidity range \( |\eta| < 2.5 \). It consists of 1440 silicon pixel and 15148 silicon strip detector modules and is located in the 3.8 T field of the superconducting solenoid. For nonisolated particles of \( 1 < p_T < 10 \) GeV and \( |\eta| < 1.4 \), the track resolutions are typically 1.5% in \( p_T \) and 25–90 (45–150) \( \mu \)m in the transverse (longitudinal) impact parameter [10]. In the region \( |\eta| < 1.74 \), the HCAL cells have widths of 0.087 in pseudorapidity and 0.087 in azimuth (\( \phi \)). In the \( \eta-\phi \) plane, and for \( |\eta| < 1.48 \), the HCAL cells map on to 5 \( \times \) 5 ECAL crystals arrays to form calorimeter towers projecting radially outwards from close to the nominal interaction point. At larger values of \( |\eta| < 3 \), the size of the towers increases and the matching ECAL arrays contain fewer crystals. The HF calorimeters consist of iron absorbers with embedded radiation-hard quartz fibres, located at 11.2 m from
the interaction point on both sides of the experiment covering the region of $2.9 < |\eta| < 5.2$. Half of the HF fibres run over the full depth of the absorber, while the other half start at a depth of 22 cm from the front of the detector. The $\eta$–$\phi$ tower segmentation of the HF calorimeters is $0.175 \times 0.175$, except for $\eta$ above 4.7, where the segmentation is $0.175 \times 0.35$.

The first level (L1) of the CMS trigger system, composed of custom hardware processors, uses information from the calorimeters and muon detectors to select the most interesting events in a fixed time interval of less than 4 $\mu$s. The high-level trigger (HLT) processor farm further decreases the event rate from 100 kHz to around 400 Hz, before data storage. A more detailed description of the CMS detector can be found in Ref. [11].

3 Jet reconstruction and event selection

The measurement is based on data sets collected with six single-jet triggers in the HLT system, which require at least one jet in the event with corrected jet $p_T > 40, 80, 140, 200, 260,$ and $320 \text{ GeV}$, respectively. All except the highest-threshold trigger were prescaled during the 2012 run. The efficiency of each of the triggers is estimated using lower-$p_T$-threshold triggers, and it is found to exceed 99%. The corresponding effective integrated luminosity $L_{\text{int,eff}}$ of the analyzed data set and the $p_T$ thresholds of each trigger path are shown in Table 1. This analysis includes jets with a $p_T > 74 \text{ GeV}$, up to 2.5 TeV.

The particle-flow (PF) event algorithm reconstructs and identifies each individual particle with an optimized combination of information from the various elements of the CMS detector. The energy of photons is directly obtained from the ECAL measurement, corrected for zero-suppression effects. The energy of electrons is determined from a combination of the electron momentum at the primary interaction vertex as determined by the tracker, the energy of the corresponding ECAL cluster, and the energy sum of all bremsstrahlung photons spatially compatible with originating from the electron track. The energy of muons is obtained from the curvature of the corresponding track. The energy of charged hadrons is determined from a combination of their momentum measured in the tracker and the matching ECAL and HCAL energy deposits, corrected for zero-suppression effects and for the response function of the calorimeters to hadronic showers. Finally, the energy of neutral hadrons is obtained from the matched corrected ECAL and HCAL energy. In the forward region only the HF information is available.

Jets are reconstructed by clustering the PF particle candidates with the collinear- and infrared-safe anti-$k_T$ jet algorithm [12], as implemented in the FASTJET package [13], with a size parameter of $R=0.7$. Jet momentum is determined as the vectorial sum of all particle momenta in the jet, and (before corrections) is found from simulation to be within 5% to 10% of the true momentum over the whole $p_T$ spectrum and detector acceptance. Jet energy scale (JES) corrections are derived from simulation, using events generated with the PYTHIA version 6.4.22 [14] using tune ZZ* [15] and processed through the CMS detector simulation based on the GEANT 4 [16] package, and from in situ measurements exploiting the energy balance in dijet, photon+jet and Z +jet events [17]. These corrections account for residual nonuniformities and nonlinearities in the detector response. An offset correction is required to account for the extra energy clustered into jets due to additional pileup proton-proton interactions within the same or neighbouring bunch crossings. The JES correction, applied as a multiplicative factor to the four momentum jet vector, depends on the jet $\eta$ and $p_T$ values. For a jet with a $p_T$ of 100 GeV the typical correction is about 10%, and decreases with the increasing of $p_T$. The jet energy resolution (JER) amounts typically to 15% at 10 GeV, 8% at 100 GeV, and 4% at 1 TeV, to be compared to about 40%, 12%, and 5% obtained when the calorimeters alone are used for jet clustering.
Selected events are required to have at least one reconstructed vertex [18] along the beam line within 24 cm of the nominal interaction point. Additional selection criteria are applied to each event to remove spurious jet-like signatures originating from isolated noise patterns in certain HCAL regions. To suppress noise patterns, tight identification criteria are applied: each jet should contain at least two particles, one of which is a charged hadron, and the jet energy fraction carried by neutral hadrons and photons should be less than 90%. These criteria have an efficiency greater than 99% for genuine jets. Jets not satisfying the tight identification requirements are discarded. Events are selected if at least one jet remains above the threshold of the highest $p_T$ threshold trigger that recorded the event.

Table 1: HLT trigger thresholds and effective integrated luminosities used in the jet cross section measurement.

<table>
<thead>
<tr>
<th>HLT Path</th>
<th>PFJet40</th>
<th>PFJet80</th>
<th>PFJet140</th>
<th>PFJet200</th>
<th>PFJet260</th>
<th>PFJet320</th>
</tr>
</thead>
<tbody>
<tr>
<td>$p_T$ range (GeV)</td>
<td>74 - 133</td>
<td>133 - 220</td>
<td>220 - 300</td>
<td>300 - 395</td>
<td>395 - 507</td>
<td>507 - 2500</td>
</tr>
<tr>
<td>Integrated luminosity ($pb^{-1}$)</td>
<td>$7.9 \times 10^{-4}$</td>
<td>2.12</td>
<td>$5.57 \times 10$</td>
<td>$2.61 \times 10^2$</td>
<td>$1.06 \times 10^4$</td>
<td>$1.97 \times 10^4$</td>
</tr>
</tbody>
</table>

4 Measurement of the jet differential cross section

The double-differential inclusive jet cross section is defined as

$$\frac{d^2\sigma}{dp_T dy} = \frac{1}{\epsilon \mathcal{L}_{int,eff}} \frac{N_{jets}}{\Delta p_T (2 \cdot \Delta |y|)}$$

where $N_{jets}$ is the number of jets in a bin, $\mathcal{L}_{int,eff}$ is the effective integrated luminosity contributing to a bin, $\epsilon$ is the product of the trigger and jet selection efficiencies, which are found to be greater than 99%, and $\Delta p_T$ and $\Delta y$ are the transverse momentum and rapidity bin widths, respectively. The width of the $p_T$ bins increases progressively with $p_T$, proportional to the $p_T$ resolution. The phase space in rapidity $y$ is subdivided into six equally separated bins starting from $y = 0$ up to $|y| = 3$ with $\Delta y = 0.5$. The statistical uncertainty for each bin is computed according to the number of events contributing at least one entry per event [4], correcting for possible multiple entries per event. This correction is small, since in the entire phase-space considered here at least 90% of the observed jets in each bin originate from different events.

In order to compare the measured cross section with theoretical predictions at particle level, the smearing of the steeply falling spectra induced by the experimental resolution needs to be corrected. An unfolding procedure, based on the iterative d’Agostini method [19], as implemented in the RooUnfold package [20], is used to remove detector effects from the measured spectra. The response matrix is created by the convolution of theoretically predicted spectrum, discussed in Section 5, with the JER effects. The JER as a function of $p_T$ is evaluated with the CMS detector simulation, after correcting for the residual differences with data [17]. Through the unfolding procedure the final statistical uncertainties become correlated among bins. The size of these correlations vary typically between 10 to 20%.

The dominant contribution to experimental systematic uncertainty on the measured cross section is due to JES corrections, determined as discussed in [17]. For the data set used in this analysis, this uncertainty is decomposed into 24 independent sources, an extension of the set of contributions discussed in detail in [21]. The impact of each correction component on the measured cross section is separately evaluated.
The JES uncertainty is dependent on $p_T$ and $\eta$ and has been estimated to be 1–4% in the central region, extending from 6% to 45% for the highest $p_T$. The uncertainty sources are divided into several broad categories: pileup effects, relative calibration of jet energy scale versus $\eta$, absolute energy scale including $p_T$ dependence, and differences in quark- and gluon-initiated jets [4].

To account for residual effects of small inefficiencies from jet identification from both online and offline a conservative uncertainty of 1% uncorrelated across all jet $p_T$ and $y$ bins is assigned to each bin.

The unfolding procedure is affected by uncertainties in the JER parameterization, derived from the simulation. The fitted JER parameters are varied by one standard deviation up and down and the corresponding response matrices are used to unfold the measured spectra. The JER uncertainty amounts to about 10% [17], and introduces a 1-5% uncertainty on the cross section.

The uncertainty on the integrated luminosity, which propagates directly to the cross section, is 2.6% [22]. Other sources of uncertainties, such as the jet angular resolution and the model dependence of the unfolding result from the theoretical $p_T$ spectrum used to calculate the response matrix, have negligible effects on the cross section. The total experimental systematic uncertainty on the measured cross-section is obtained as a summation in quadrature of JES, JER and luminosity uncertainties.

5 Theory predictions

Theoretical predictions for the jet cross section are known at next-to-leading order (NLO) accuracy in pQCD [23, 24], and electroweak corrections have been computed in reference [25]. The pQCD NLO calculations are performed using the NLOJET++ (version 4.1.3) program [23, 24] as implemented into the FASTNLO (version 2.1) package [26]. The renormalization ($\mu_R$) and factorization ($\mu_F$) scales are set to the jet $p_T$. The calculations are performed using the six sets of parton distribution functions, computed at NLO, CT10 [27], MSTW2008 [28], NNPDF2.1 [29], NNPDF3.0 [30], HERAPDF1.5 [31], and ABM11 [32]. Each PDF set is available for a range of $\alpha_S(M_Z)$ values, both at NLO and next-to-next-to-leading order (NNLO) level. The number of active (massless) flavours chosen in NLOJET++ is five in all of the PDF sets except NNPDF2.1, where it is set to six. All the PDF sets use a variable flavour number scheme, except ABM11 which uses fixed flavour number scheme. The basic characteristics of each PDF set are summarized in Table 2.

The NLO parton level calculation has to be supplemented with corrections due to non-perturbative (NP) effects, i.e. hadronisation and multiparton interactions (MPI). The NP effects are estimated using both leading order (LO) and NLO event generators. In the former case, the correction is evaluated by averaging those provided by PYTHIA6 [14] (version 4.26), using tune Z2star, and HERWIG++ (version 2.4.2) [33], using tune UE. The size of these corrections ranges from 20% at low $p_T$ down to 1% at the highest $p_T$ of 2.5 TeV. The NLO NP correction is derived using POWHEG [34–37], interfaced with PYTHIA6 (version 4.26) for parton shower, MPI and hadronization. The NP correction factors are derived in this case averaging the results for two different tunes of PYTHIA6, Z2star and P11. Hadronization models have been tuned using LO calculations for the hard scattering, and applying these tunes on NLO-based calculations is not expected to provide optimal results. On the other hand, the application to data of NP corrections based on LO calculations to compare with NLO predictions, implicitly assume a behaviour of NP effects independent on the hard scattering description. In order to take into account both facts, the final number used for the NP correction $C_{NP}$ is an average of the LO- and NLO-based estimates $C_{NP} = \frac{1}{2}(C_{NP}^{LO} + C_{NP}^{NLO})$. Half the width of the envelope of these pre-
Table 2: PDF sets used in comparisons to the data together with the corresponding number of active flavours \(N_f\), the assumed masses \(M_t\) and \(M_Z\) of the top quark and of the Z boson, the default values of the strong coupling constant \(\alpha_S(M_Z)\) and the ranges in \(\alpha_S(M_Z)\) available for fits. For CT10 the updated versions of 2012 are taken.

<table>
<thead>
<tr>
<th>Base set</th>
<th>Refs.</th>
<th>Evol.</th>
<th>(N_f)</th>
<th>(M_t) (GeV)</th>
<th>(M_Z) (GeV)</th>
<th>(\alpha_S(M_Z))</th>
<th>(\alpha_S(M_Z)) range</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABM11</td>
<td>[32]</td>
<td>NLO</td>
<td>5</td>
<td>180</td>
<td>91.174</td>
<td>0.1180</td>
<td>0.110–0.130</td>
</tr>
<tr>
<td>ABM11</td>
<td>[32]</td>
<td>NNLO</td>
<td>5</td>
<td>180</td>
<td>91.174</td>
<td>0.1134</td>
<td>0.104–0.120</td>
</tr>
<tr>
<td>CT10</td>
<td>[27]</td>
<td>NLO</td>
<td>(\leq 5)</td>
<td>172.</td>
<td>91.188</td>
<td>0.1180</td>
<td>0.112–0.127</td>
</tr>
<tr>
<td>CT10</td>
<td>[27]</td>
<td>NNLO</td>
<td>(\leq 5)</td>
<td>172.</td>
<td>91.188</td>
<td>0.1180</td>
<td>0.110–0.130</td>
</tr>
<tr>
<td>HERAPDF15</td>
<td>[31]</td>
<td>NLO</td>
<td>(\leq 5)</td>
<td>180.</td>
<td>91.187</td>
<td>0.1176</td>
<td>0.114–0.122</td>
</tr>
<tr>
<td>HERAPDF15</td>
<td>[31]</td>
<td>NNLO</td>
<td>(\leq 5)</td>
<td>180.</td>
<td>91.187</td>
<td>0.1176</td>
<td>0.114–0.122</td>
</tr>
<tr>
<td>MSTW2008</td>
<td>[28]</td>
<td>NLO</td>
<td>(\leq 5)</td>
<td>(10^{10})</td>
<td>91.1876</td>
<td>0.1202</td>
<td>0.110–0.130</td>
</tr>
<tr>
<td>MSTW2008</td>
<td>[28]</td>
<td>NNLO</td>
<td>(\leq 5)</td>
<td>(10^{10})</td>
<td>91.1876</td>
<td>0.1171</td>
<td>0.107–0.127</td>
</tr>
<tr>
<td>NNPDF21</td>
<td>[29]</td>
<td>NLO</td>
<td>(\leq 6)</td>
<td>175.</td>
<td>91.2</td>
<td>0.1190</td>
<td>0.114–0.124</td>
</tr>
<tr>
<td>NNPDF21</td>
<td>[29]</td>
<td>NNLO</td>
<td>(\leq 6)</td>
<td>175.</td>
<td>91.2</td>
<td>0.1190</td>
<td>0.114–0.124</td>
</tr>
<tr>
<td>NNPDF30</td>
<td>[30]</td>
<td>NLO</td>
<td>(\leq 5)</td>
<td>175.</td>
<td>91.2</td>
<td>0.1180</td>
<td>0.115–0.121</td>
</tr>
<tr>
<td>NNPDF30</td>
<td>[30]</td>
<td>NNLO</td>
<td>(\leq 5)</td>
<td>175.</td>
<td>91.2</td>
<td>0.1180</td>
<td>0.115–0.121</td>
</tr>
</tbody>
</table>

The propagation of the PDF uncertainties for each PDF set leads to a 5 to 30% uncertainty on the predicted cross section in the entire \(p_T\) range for \(|y| < 1.5\). Beyond \(|y| = 1.5\) in the outer rapidity region the uncertainties become as large as 50% at high \(p_T\) and even increase up to 100% for the CT10 and HERAPDF1.5 sets. The NP correction induces an additional uncertainty, which is estimated to range, for central rapidity bin, between 1.4% for \(p_T\) around 100 GeV and less than...
Comparison of theory and data

0.06% at high jet $p_T$ around 2.5 TeV. Overall, the PDF uncertainty is dominant.

Electroweak effects, arising from virtual exchange of massive gauge bosons $W, Z$, induce effects whose magnitude is given by Sudakov logarithmic factors $\alpha_W \ln^2(Q^2/M_W^2)$, where $\alpha_W$ is the weak coupling constant, $M_W$ is the mass of $W$ boson, and $Q$ is the hard scale of interaction. For high $p_T$ jets, the values of the logarithm, and therefore the correction, become large. The derivation of the electroweak correction factor, applied to the NLO pQCD spectrum corrected for NP effects, is provided in [25]. Figure 2 shows the electroweak correction for two extreme rapidity regions as a function of jet $p_T$. In the most central rapidity bin for the high $p_T$ region, the correction factor goes up to 14% due to a large Sudakov logarithm factor.

![Electroweak Correction Factor](image)

Figure 2: Electroweak correction factor for the central (left) and outer most (right) rapidity bins as a function of jet $p_T$.

6 Comparison of theory and data

Figure 3 shows the double-differential inclusive jet cross section measurement, presented as a function of $p_T$ in the $|y|$ ranges considered, after unfolding for detector effects. This measurement is compared with the theory prediction discussed in section 5, based on the CT10 PDF set. The data are consistent with the theory predictions for a wide range of jet $p_T$ from 74 GeV up to 2.5 TeV.

The ratios of the data to the theoretical prediction in the various $|y|$ ranges are shown for the CT10 PDF set in Fig. 4. The total experimental and theoretical uncertainties are shown as bands around one. There is an overall good level of agreement within uncertainties in the whole studied kinematic range. Figure 5 presents the ratio of both data and theoretical predictions based on the alternative PDF sets considered to the CT10-based one. A $\chi^2$ value is computed based on the measurements, their covariance matrices and the theoretical predictions, as described in detail in Section 8. The values for the $\chi^2/N_{\text{bins}}$ for the comparison between data and theory based on different PDF sets, are summarized in Table 3.

In most cases the theory predictions agree quite well with the data within uncertainties, with the exception of the ABM11 PDF set, where significant discrepancies are visible. However, the theory predictions from different PDF sets differ from each other significantly in the high $p_T$ range. The CT10 PDF have the lowest $\chi^2$ among the sets explored for most rapidity ranges, while MSTW, ABM11 and HERA exhibit differences compared to data and CT10 up to more than 100% in highest $p_T$ range.
Figure 3: Double-differential inclusive jet cross section as function of jet $p_T$. Data (points) and NLO predictions based on CT10 PDF set corrected for the NP factor and electroweak correction factor (line). The comparison is carried out for six different $|y|$ bins at an interval of $\Delta|y| = 0.5$.

Table 3: Summary of the values $\chi^2/N_{\text{bins}}$ for the comparison in each $|y|$ range of data and theoretical predictions based on different PDF sets.

| $|y|$ | CT10 | HERA1.5 | MSTW2008 | NNPDF2.1 | ABM11 | NNPDF3.0 |
|------|------|---------|---------|----------|-------|----------|
| 0.0–0.5 | 49.2/37 | 66.3/37 | 68.0/37 | 58.3/37 | 136.6/37 | 62.5/37 |
| 0.5–1.0 | 28.7/37 | 47.2/37 | 39.0/37 | 35.4/37 | 155.5/37 | 42.2/37 |
| 1.0–1.5 | 19.3/36 | 28.6/36 | 27.4/36 | 20.2/36 | 111.8/36 | 25.9/36 |
| 1.5–2.0 | 65.7/32 | 49.0/32 | 55.3/32 | 54.5/32 | 168.1/32 | 64.7/32 |
| 2.0–2.5 | 38.7/25 | 32.0/25 | 53.1/25 | 34.6/25 | 80.2/25 | 36.0/25 |
| 2.5–3.0 | 14.5/18 | 19.1/18 | 18.2/18 | 15.4/18 | 43.8/18 | 16.3/18 |

7 Ratio of cross sections measured at 7 TeV and 8 TeV

The ratio of the double-differential cross sections measured at $\sqrt{s} = 8$ TeV and $\sqrt{s} = 7$ TeV as described in Ref. [4], is computed. Experimental correlations between different centre-of-mass energies are taken into account in the computation of the total experimental uncertainty band. Figures 6–8 show the ratio for each rapidity bin where measurements were performed at both centre-of-mass energies, comparing with the corresponding theoretical predictions based on the CT10 PDF set. Concerning the theoretical uncertainties, all sources are treated as completely correlated between 7 TeV and 8 TeV predictions, for all $p_T$ and $|y|$ bins.

The uncertainty on the ratio is smaller in size compared to absolute uncertainties, due to 100% positive correlation between part of the uncertainty sources at $\sqrt{s} = 7$ and 8 TeV respectively. Due to reduced uncertainties, this ratio can be used to constrain PDF to data.

The agreement between data and the theoretical predictions is generally satisfactory within one standard deviation, with some higher discrepancy observed in the highest part of the $p_T$ spectra, in particular in the $1 < |\eta| < 1.5$ range. They are mostly due to a discrepancy present in the 7 TeV data.
Figure 4: Ratio of data over theory prediction using the CT10 PDF set. For comparison the total theoretical (band enclosed by dashed lines) and the total experimental systematic uncertainty (shaded band) are shown as well. The error bars correspond to the statistical uncertainty of the data.
Figure 5: Ratio of data over theory prediction using the the CT10 PDF set. For comparison predictions employing five other PDF sets are shown in addition to the total theoretical (band enclosed by dashed black lines) and total experimental systematic uncertainty (shaded band). The error bars correspond to the statistical uncertainty of the data.
Figure 6: Ratio of double-differential inclusive jet cross sections between $\sqrt{s} = 8$ TeV and $\sqrt{s} = 7$ TeV for rapidity bins $0.0 < |y| < 0.5$ (left) and $0.5 < |y| < 1.0$ (right). In the top plots the yellow band shows the total experimental uncertainty, accounting for the correlation between different energies, and the theoretical prediction for the CT10 PDF set is overlaid. Bottom plots show the ratio of the measured cross section ratio to its theoretical prediction, with the experimental uncertainty shown as a full line band, and theoretical uncertainties as a shaded band.
Figure 7: Ratio of double-differential inclusive jet cross sections between $\sqrt{s} = 8\text{ TeV}$ and $\sqrt{s} = 7\text{ TeV}$ for rapidity bins $1.0 < |y| < 1.5$ (left) and $1.5 < |y| < 2.0$ (right). In the top plots the yellow band shows the total experimental uncertainty, accounting for the correlation between different energies, and the theoretical prediction for the CT10 PDF set is overlaid. The bottom plot shows the ratio of the measured cross section ratio to its theoretical prediction, with the experimental uncertainty shown as a full line band, and theoretical uncertainties as a shaded band.
Figure 8: Ratio of double-differential inclusive jet cross sections between $\sqrt{s} = 8$ TeV and $\sqrt{s} = 7$ TeV for the rapidity bin $2.0 < |y| < 2.5$. In the top plot the yellow band shows the total experimental uncertainty, accounting for the correlation between different energies, and the theoretical prediction for the CT10 PDF set is overlaid. Bottom plots show the ratio of the measured cross section ratio to its theoretical prediction, with the experimental uncertainty shown as a full line band, and theoretical uncertainties as a shaded band.
8 Determination of $\alpha_S$

Jet production measurements at hadron colliders provide a direct probe to measure the strong coupling constant $\alpha_S$. There have been previous extractions of $\alpha_S$, both from the CMS 7 TeV inclusive jet measurement [21], and from Tevatron experiments data [38–40]. The current analysis follows the same extraction procedure of $\alpha_S$ previously adopted. The extraction of $\alpha_S$ is performed by minimizing $\chi^2$ between measured data and theory prediction. The dependence on $\alpha_S$ of the differential inclusive jet production cross section at NLO is given by [40]:

$$\frac{d\sigma}{dp_T} = \alpha_S^2(\mu_R) \hat{X}^{(0)}(\mu_F, p_T)[1 + \alpha_S(\mu_R)K1(\mu_R, \mu_F, p_T)], \quad (2)$$

where $\frac{d\sigma}{dp_T}$ is the differential inclusive-jet production cross section as a function of jet $p_T$, $\mu_R$ and $\mu_F$ are the renormalization and factorization scales set equal to jet $p_T$, $\alpha_S^2(\mu_R) \hat{X}^{(0)}(\mu_F, p_T)$ is the leading order contribution to the differential inclusive-jet production cross section and $\alpha_S^2(\mu_R) \hat{X}^{(0)}(\mu_F, p_T)K1(\mu_R, \mu_F, p_T)$ is the NLO contribution. Corrections for NP and electroweak effects are applied to compare with data. A comparison with the measured spectrum gives an estimate of the input value of $\alpha_S$ for which the cross-section, predicted from theory, has the closest matching with data.

The extraction of $\alpha_S$ is performed by a least-square minimization of the function:

$$\chi^2(\alpha_S(M_Z)) = \sum_{i,j} (D_i - T_i(\alpha_S(M_Z)))^T C^{-1}_{ij} (D_j - T_j(\alpha_S(M_Z))), \quad (3)$$

where $C$ is the covariance matrix including all the experimental and theoretical uncertainties involved in the measurement, $D_i$ is the measured value of double-differential inclusive jet cross section for the $i$-th $p_T$ bin and $T_i(\alpha_S(M_Z))$ is corresponding theoretical cross section for a given value of $\alpha_S(M_Z)$.

The total covariance matrix $C$ is built from the individual components as:

$$C = Cov^{Stat} + Cov^{Unfolding} + \sum Cov^{JES} + Cov^{LUMI} + Cov^{PDF} + Cov^{NP} + Cov^{Uncor}, \quad (4)$$

where:

1. $Cov^{Stat}$ is the statistical covariance matrix, taking into account the correlation between different $p_T$ bins of the same rapidity range due to unfolding. Different rapidity ranges are considered as uncorrelated among themselves;
2. $Cov^{Unfolding}$ is accounting for the uncertainty induced by the JER parameterization in the unfolding procedure;
3. $Cov^{JES}$ describes the uncertainty due to JES uncertainties, obtained as the sum of 24 independent matrices, one for each source of uncertainty;
4. $Cov^{Uncor}$ accounts for all uncorrelated systematic uncertainties such as trigger and jet identification inefficiencies, and time dependence of the jet $p_T$ resolution;
5. $Cov^{LUMI}$ accounts for the 2.6% luminosity uncertainty on the differential cross section;
6. $Cov^{PDF}$ is related to uncertainties due to the PDF used in the theoretical prediction;
7. $Cov^{NP}$ accounts for the uncertainty due to NP corrections in the theoretical prediction.
The Unfolding, JES, Lumi, PDF and NP systematic uncertainties are considered as 100% correlated among all \( p_T \) and \(|y|\) bins.

The extraction of \( \alpha_S \) uses the CT10 NLO PDF set for the calculation, since it is found to provide the best agreement with measured data. This PDF set provides variants corresponding to 16 different \( \alpha_S(M_Z) \) values in the range \([0.112,0.127]\), in step of 0.001. The sensitivity of this prediction to \( \alpha_S \) is shown in Fig. 9, where the data to theory ratio is presented as a function of the strong coupling constant value. The equation 3 is computed, combining all \( p_T \) and \(|y|\) intervals, for each of the variant corresponding to a different \( \alpha_S \) value, as shown in Fig. 10. The distribution obtained in this way is fitted with a fourth order polynomial, and the minimum of the polynomial in the fit region determines the best \( \alpha_S(M_Z) \) value. Uncertainties are determined as the variations bringing to \( \alpha_S \) values corresponding to \( \chi^2 + 1 \), and are asymmetric. The individual contribution from each source listed in Eq. 4 is estimated as the difference in quadrature between the main result and the result of a fit where the source is neglected in the covariance matrix.

The uncertainty due to the renormalization and factorization scales is evaluated by variations of the default \( \mu_R/\mu_F \) choice, set to jet \( p_T \), in the following six combinations: \( (\mu_R/\mu_F/\mu_T) = (0.5,0.5), (0.5,1), (1,0.5), (1,2), (2,1), \) and \( (2,2) \). The \( \chi^2 \) minimization with respect to \( \alpha_S(M_Z) \) is repeated in each case, and the maximal upwards and downwards deviations of \( \alpha_S(M_Z) \) from the central result are taken as scale uncertainties.

In Table 4 results are presented for fitted values of \( \alpha_S \) in each rapidity bin separately, as well as using the whole range. The contribution to the uncertainty due to each individual source is also given, together with the best \( \chi^2_{min} \) value for each separate fit. The largest uncertainty source in the determination of \( \alpha_S \) is due to the choice of scales, pointing to the need for more precise theoretical calculations.

Table 4: \( \alpha_S(M_Z) \) results extracted using CT10 NLO PDF set. The fitted values for each \(|y|\) bins, the corresponding uncertainty components due to PDF, scale and NP and total experimental uncertainty are shown. The last row of the table shows the results of combined fitting of all the \(|y|\) bins simultaneously.

<table>
<thead>
<tr>
<th>YBin</th>
<th>Fitted ( \alpha_S(M_Z) )</th>
<th>PDF Unc</th>
<th>Scale Unc</th>
<th>NP Unc</th>
<th>Exp Unc</th>
<th>( \chi^2_{min}/N_{Bins} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0 - 0.5</td>
<td>0.1155</td>
<td>+0.0027</td>
<td>+0.0070</td>
<td>+0.0003</td>
<td>+0.0025</td>
<td>48.6/37</td>
</tr>
<tr>
<td>0.5 - 1.0</td>
<td>0.1156</td>
<td>+0.0023</td>
<td>+0.0069</td>
<td>+0.0003</td>
<td>+0.0026</td>
<td>28.4/37</td>
</tr>
<tr>
<td>1.0 - 1.5</td>
<td>0.1177</td>
<td>+0.0021</td>
<td>+0.0062</td>
<td>+0.0002</td>
<td>+0.0024</td>
<td>19.3/36</td>
</tr>
<tr>
<td>1.5 - 2.0</td>
<td>0.1163</td>
<td>-0.0029</td>
<td>-0.0019</td>
<td>-0.0002</td>
<td>-0.0027</td>
<td>65.6/32</td>
</tr>
<tr>
<td>2.0 - 2.5</td>
<td>0.1164</td>
<td>+0.0020</td>
<td>+0.0046</td>
<td>+0.0002</td>
<td>+0.0019</td>
<td>38.3/25</td>
</tr>
<tr>
<td>2.5 - 3.0</td>
<td>0.1158</td>
<td>-0.0030</td>
<td>-0.0025</td>
<td>-0.0006</td>
<td>-0.0038</td>
<td>14.3/18</td>
</tr>
<tr>
<td>Combined</td>
<td>0.1164</td>
<td>+0.0023</td>
<td>+0.0053</td>
<td>±0.0001</td>
<td>±0.0014</td>
<td>186.5/185</td>
</tr>
</tbody>
</table>

The best value obtained, using the CT10 NLO PDF set, is:

\[
\alpha_S(M_Z)(\text{NLO}) = 0.1164^{+0.0025}_{-0.0028}\,(\text{PDF})^{+0.0053}_{-0.0028}\,(\text{Scale}) \pm 0.0001\,(\text{NP})^{+0.0014}_{-0.0015}\,(\text{Exp}) = 0.1164^{+0.0060}_{-0.0043}.
\]

The value of \( \alpha_S \) is also determined using the CT10 NNLO PDF set, where the input value of \( \alpha_S(M_Z) \) varies from 0.1110 to 0.1130, to study the sensitivity to the PDF choice. The result so obtained is

\[
\alpha_S(M_Z)(\text{NNLO}) = 0.1154^{+0.0024}_{-0.0026}\,(\text{PDF})^{+0.0059}_{-0.0027}\,(\text{Scale}) \pm 0.0001\,(\text{NP})^{+0.0014}_{-0.0012}\,(\text{Exp}) = 0.1154^{+0.0065}_{-0.0039}.
\]
Figure 9: Ratio of data over theory prediction using the the CT10 NLO PDF set, where the $\alpha_S(M_Z)$ value is varied in the range 0.112-0.127 in steps of 0.001. The error bars correspond to the total uncertainty of the data.
Figure 10: The $\chi^2$ minimization with respect to $\alpha_S(M_Z)$ using the CT10 NLO PDF set and data from all rapidity bins. The uncertainty is obtained from the $\alpha_S(M_Z)$ values for which $\chi^2$ is increased by one with respect to the minimum value, indicated by the horizontal line. The curve corresponds to a fourth-degree polynomial fit through the available $\chi^2$ points.

with a $\chi^2/N_{\text{bins}}$ of 191.3/185, not very different from the value obtained using CT10 NLO PDF set. The value of $\alpha_S(M_Z)$ obtained is compatible with the best current world average $\alpha_S(M_Z) = 0.1185 \pm 0.0006$ [41].

The value of $\alpha_S$ depends on the scale $Q$ at which it is evaluated, decreasing with its increase. The measured $p_T$ interval [74, 2500] GeV is divided into nine different ranges, shown in the first column in Table 5, and $\alpha_S(M_Z)$ is determined for each of them. The scale dependence $\alpha_S(Q)$ is determined following the same fit procedure used in the previous section.

The Q scale corresponding to each $p_T$ range is evaluated as the cross section weighted average $p_T$ for that range. The extracted $\alpha_S(M_Z)$ values are evolved to the Q scale corresponding to the range, using 2-loop 5-flavour renormalization group (RG) evolution equation, providing the $\alpha_S(Q)$ values listed in Table 5. The same RG equation is used to obtain the corresponding uncertainties. The contributions to both the experimental and the theoretical uncertainties are shown in Table 6. A comparison of these results with those from other measurements of CMS [42–44], D0 [38, 39], H1 [45, 46] and ZEUS [47] experiments are shown in Fig. 11. We find that, within uncertainties, the current measurement is in very good agreement with results obtained by previous experiments. The present analysis constrains the $\alpha_S(Q)$ running for Q between 86 GeV and 1.5 TeV.
Figure 11: The running $\alpha_S(Q)$ as a function of the scale $Q$ is shown, as obtained using CT10 NLO PDF set. The solid line and the uncertainty band are obtained evolving the extracted $\alpha_S(M_Z)$ values with the 2-loop 5-flavour RG evolution. The dashed line represents the evolution of the world average value. The black dots in the figure show the numbers obtained from $\sqrt{s} = 8$ TeV inclusive jet measurement. Results from other CMS, D0, H1 and ZEUS measurements are superimposed.
The inclusive jet measurements at the LHC probe the gluon and the valence-quark distribution in the kinematic range \( x > 0.01 \), as demonstrated by the CMS collaboration [21] with the data collected with the CMS experiment at \( \sqrt{s} = 7 \) TeV.

In a similar way, the inclusive jet cross-section measurement at 8 TeV for \( p_T > 74 \) GeV, is used in a QCD analysis at NLO together with the combined HERA inclusive cross-section measurements [48]. The correlations of the experimental uncertainties for the jet measurements and for the inclusive DIS cross sections are taken into account. The treatment of experimental uncertainties for the HERA data follows the prescription of HERAPDF1.0 [31]. The theory predictions for the double-differential cross sections of jet production are calculated at NLO by using the \textsc{nlojet++} (version 4.1.3) program [23, 24] as implemented into the \textsc{fastnlo} (version 2.1) package [26]. The open-source QCD fit framework for PDF determination \textsc{herafitter} [49, 50], version 1.1.1, is used with the partons evolved by using the DGLAP equations [51–56] at NLO, as implemented in the \textsc{qcdnum} program [57].

The TR' [28, 58] general mass variable flavour number (GMVFN) scheme at NNLO is used for the treatment of heavy-quark contributions with the following conditions: (i) heavy-quark masses are chosen as \( m_c = 1.47 \) GeV and \( m_b = 4.5 \) GeV, (ii) renormalization and factorization scales are set to \( \mu_R = \mu_F = Q \), and (iii) the strong coupling constant is set to \( \alpha_s(M_Z) = 0.118 \).

The \( Q^2 \) range of HERA data is restricted to \( Q^2 \geq Q_{min}^2 = 7.5 \) GeV\(^2\). The procedure for the

### Table 5: The \( \alpha_s(M_Z) \) extracted values, the corresponding \( \alpha_s(Q) \) values at the Q scale for each \( p_T \) range, and \( \chi^2_{\text{min}}/N_{\text{Bins}} \) are shown. Uncertainties are given for both \( \alpha_s \) values.

<table>
<thead>
<tr>
<th>( p_T ) range (GeV)</th>
<th>Q (GeV)</th>
<th>( \alpha_s(M_Z) )</th>
<th>( \alpha_s(Q) )</th>
<th>( \chi^2_{\text{min}}/N_{\text{Bins}} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>74 - 133</td>
<td>86.86</td>
<td>0.1171</td>
<td>+0.0060</td>
<td>-0.0039 26.04/24</td>
</tr>
<tr>
<td>133 - 220</td>
<td>156.52</td>
<td>0.1159</td>
<td>+0.0061</td>
<td>-0.0037 19.47/24</td>
</tr>
<tr>
<td>220 - 300</td>
<td>247.10</td>
<td>0.1161</td>
<td>+0.0062</td>
<td>-0.0036 12.39/18</td>
</tr>
<tr>
<td>300 - 395</td>
<td>333.27</td>
<td>0.1163</td>
<td>+0.0063</td>
<td>-0.0039 19.48/18</td>
</tr>
<tr>
<td>395 - 507</td>
<td>434.72</td>
<td>0.1167</td>
<td>+0.0064</td>
<td>-0.0036 17.12/18</td>
</tr>
<tr>
<td>507 - 686</td>
<td>563.77</td>
<td>0.1170</td>
<td>+0.0064</td>
<td>-0.0039 23.25/21</td>
</tr>
<tr>
<td>686 - 905</td>
<td>755.97</td>
<td>0.1171</td>
<td>+0.0070</td>
<td>-0.0040 24.76/20</td>
</tr>
<tr>
<td>905 - 1410</td>
<td>1011.02</td>
<td>0.1160</td>
<td>+0.0065</td>
<td>-0.0050 24.68/28</td>
</tr>
<tr>
<td>1410 - 2500</td>
<td>1508.04</td>
<td>0.1162</td>
<td>+0.0070</td>
<td>-0.0062 18.79/14</td>
</tr>
</tbody>
</table>

### Table 6: Composition of the uncertainty on \( \alpha_s(M_Z) \) fit results in ranges of \( p_T \). For each range, the corresponding statistical, and experimental systematic uncertainty, and the components of the theoretical uncertainty are shown. The numbers are obtained using CT10 NLO PDF set.

<table>
<thead>
<tr>
<th>( p_T ) range (GeV)</th>
<th>PDF Unc</th>
<th>Scale Unc</th>
<th>NP Unc</th>
<th>Stat Unc</th>
<th>Sys Unc</th>
<th>Exp Unc</th>
</tr>
</thead>
<tbody>
<tr>
<td>74 - 133</td>
<td>+0.0007</td>
<td>+0.0004</td>
<td>+0.0004</td>
<td>+0.0016</td>
<td>+0.0020</td>
<td>+0.0026</td>
</tr>
<tr>
<td>133 - 220</td>
<td>-0.0009</td>
<td>-0.0028</td>
<td>-0.0004</td>
<td>-0.0015</td>
<td>-0.0021</td>
<td>-0.0026</td>
</tr>
<tr>
<td>220 - 300</td>
<td>-0.0009</td>
<td>-0.0029</td>
<td>-0.0005</td>
<td>-0.0008</td>
<td>-0.0019</td>
<td>-0.0021</td>
</tr>
<tr>
<td>300 - 395</td>
<td>-0.0013</td>
<td>-0.0028</td>
<td>-0.0005</td>
<td>-0.0003</td>
<td>-0.0019</td>
<td>-0.0018</td>
</tr>
<tr>
<td>395 - 507</td>
<td>+0.0018</td>
<td>+0.0006</td>
<td>+0.0002</td>
<td>+0.0007</td>
<td>+0.0014</td>
<td>+0.0016</td>
</tr>
<tr>
<td>507 - 686</td>
<td>-0.0019</td>
<td>-0.0027</td>
<td>-0.0005</td>
<td>-0.0008</td>
<td>-0.0014</td>
<td>-0.0016</td>
</tr>
<tr>
<td>686 - 905</td>
<td>+0.0024</td>
<td>+0.0002</td>
<td>+0.0002</td>
<td>+0.0004</td>
<td>+0.0019</td>
<td>+0.0021</td>
</tr>
<tr>
<td>905 - 1410</td>
<td>+0.0026</td>
<td>+0.0008</td>
<td>+0.0001</td>
<td>+0.0021</td>
<td>+0.0017</td>
<td>+0.0027</td>
</tr>
<tr>
<td>1410 - 2500</td>
<td>-0.0032</td>
<td>-0.0003</td>
<td>-0.0001</td>
<td>-0.0007</td>
<td>-0.0020</td>
<td>-0.0042</td>
</tr>
</tbody>
</table>

### 9 QCD analysis of the inclusive jet measurements
determination of the PDFs follows the approach used in the QCD analysis [21], for which the jet cross section measurements at $\sqrt{s} = 7$ TeV are replaced by those at $\sqrt{s} = 8$ TeV. The analysis is performed by fitting 18 parameters. At the initial scale of the QCD evolution $Q_0^2 = 1.9$ GeV$^2$ the parton distributions are represented by

\begin{align*}
x g(x) &= A_g x^{B_g} \cdot (1-x)^{C_g} \cdot (1 + E_g x^2) - A_g' x^{B_g'} \cdot (1-x)^{C_g'}, \quad (5) \\
x u(x) &= A_{u}(x)^{B_{u}} \cdot (1-x)^{C_{u}} \cdot (1 + D_{u} x), \quad (6) \\
x d(x) &= A_{d}(x)^{B_{d}} \cdot (1-x)^{C_{d}} \cdot (1 + D_{d} x), \quad (7) \\
x U(x) &= A_{\bar{u}} x^{B_{\bar{u}}} \cdot (1-x)^{C_{\bar{u}}} \cdot (1 + D_{\bar{u}} x), \quad (8) \\
x D(x) &= A_{\bar{d}} x^{B_{\bar{d}}} \cdot (1-x)^{C_{\bar{d}}} \cdot (1 + D_{\bar{d}} x). \quad (9)
\end{align*}

The normalization parameters $A_{u}, A_{d}, A_{g}$ are determined by the QCD sum rules, the $B$ parameter is responsible for small-$x$ behavior of the PDFs, and the parameter $C$ describes the shape of the distribution as $x \to 1$. A flexible form for the gluon distribution is adopted here, where the choice of $C'_{g} = 25$ is motivated by the approach of the MSTW group [28, 58]. Additional constraints $B_{\bar{u}} = B_{\bar{d}}$ and $A_{\bar{u}} = A_{\bar{d}}(1 - f_{s})$ are imposed with $f_{s}$ being the strangeness fraction, $f_{s} = \bar{s}/(\bar{d} + \bar{s})$, which is fixed to $f_{s} = 0.31 \pm 0.08$ as in Ref. [28], consistent with the determination of the strangeness fraction by using the CMS measurements of $W +$ charm production [59].

The PDF uncertainties are estimated in a way similar to the earlier CMS analyses [21, 59] according to the general approach of HERAPDF1.0 [31] in which experimental, model, and parametrization uncertainties are taken into account. A tolerance criterion of $\Delta \chi^2 = 1$ is adopted for defining the experimental uncertainties that originate from the measurements included in the analysis. Model uncertainties arise from the variations in the values assumed for the heavy-quark masses $m_{b}, m_{c}$ with $4.25 \leq m_{b} \leq 4.75$ GeV, $1.41 \leq m_{c} \leq 1.53$ GeV, following [48], and the value of $Q_{min}^2$ imposed on the HERA data, which is varied in the interval $5.0 \leq Q_{min}^2 \leq 10.0$ GeV$^2$. The strangeness fraction $f_{s}$ is varied by its uncertainty of 0.08. The parametrization uncertainty is estimated by extension of the functional form of all parton densities with additional parameters. The uncertainty is constructed as an envelope built from the maximal differences between the PDFs resulting from all the parametrization variations and the central fit at each $x$ value. The total PDF uncertainty is obtained by adding experimental, model, and parametrization uncertainties in quadrature. In the following, the quoted uncertainties correspond to 68% CL. The global and partial $\chi^2$ values for each data set are listed in Table 7, where the $\chi^2$ values illustrate a general agreement among all the data sets.

The inclusive jet measurements, together with HERA DIS cross section data, provide important constraints on the gluon and on the valence-quark distributions over the $x > 0.001$ range. This is illustrated in Figs. 12 and 13, where the distributions of the gluon and of the valence quarks are shown at the starting scale of $Q^2 = 1.9$ GeV$^2$ and of $Q^2 = 10^5$ GeV$^2$. The distributions are obtained both by using HERA DIS data alone, and by adding the CMS jet measurements at $\sqrt{s} = 8$ TeV. An improvement of the PDF uncertainty is observed in the latter. The breakdown of the uncertainties for the gluon distribution, as estimated by using the HERAPDF method for HERA-only and HERA+CMS jet analyses is shown in Fig. 14. The parametrization uncertainty is significantly reduced once the CMS jet measurements are included.

For direct comparison to the results of the earlier CMS QCD analysis [21] based on the inclusive jet measurements at 7 TeV and the subset of HERA DIS data [31], an alternative QCD analysis is performed, following exactly the data and model inputs of [21], but replacing the 7 TeV measurements of inclusive jet production with those at 8 TeV. In Fig. 15, the PDFs resulting in the
Table 7: Partial $\chi^2/n_{dp}$ per number of data points $n_{dp}$ for the data sets used in the QCD analysis. The global $\chi^2/n_{dof}$ per degrees of freedom of 1471/1216 is obtained, with correlated $\chi^2$ of 94.

<table>
<thead>
<tr>
<th>Data sets</th>
<th>Partial $\chi^2/n_{dp}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>HERA1+2 Neutral Current $e^+p$ $E_p$ = 920 GeV</td>
<td>440/377</td>
</tr>
<tr>
<td>HERA1+2 Neutral Current $e^+p$ $E_p$ = 820 GeV</td>
<td>416/379</td>
</tr>
<tr>
<td>HERA1+2 Neutral Current $e^+p$ $E_p$ = 575 GeV</td>
<td>214/254</td>
</tr>
<tr>
<td>HERA1+2 Neutral Current $e^+p$ $E_p$ = 460 GeV</td>
<td>210/204</td>
</tr>
<tr>
<td>HERA1+2 Neutral Current $e^-$</td>
<td>218/159</td>
</tr>
<tr>
<td>HERA1+2 Charged Current $e^+$</td>
<td>46/39</td>
</tr>
<tr>
<td>HERA1+2 Charged Current $e^-$</td>
<td>50/42</td>
</tr>
<tr>
<td>CMS inclusive jets 8 TeV $0 &lt; y &lt; 0.5$</td>
<td>53/36</td>
</tr>
<tr>
<td></td>
<td>34/36</td>
</tr>
<tr>
<td></td>
<td>35/35</td>
</tr>
<tr>
<td></td>
<td>52/29</td>
</tr>
<tr>
<td></td>
<td>49/24</td>
</tr>
<tr>
<td></td>
<td>4.9/18</td>
</tr>
</tbody>
</table>

Figure 12: Distributions of gluon (left), u-valence quark (middle) d-valence quark as functions of $x$ at the starting scale $Q^2 = 1.9$ GeV$^2$. The results of the fit to the HERA data and inclusive jet measurements at 8 TeV (shaded band), and to HERA only (hatched band) are compared with their total uncertainties, as determined by using the HERAPDF method. In the bottom panels the fractional uncertainties are shown.

fit [21] to the HERA DIS data and the CMS measurements at 7 TeV and, alternatively, at 8 TeV are compared. The observations are similar to those in the QCD analysis [21].

10 Summary

A measurement of the inclusive jet cross section is presented using 19.71 fb$^{-1}$ of data from proton-proton collisions at $\sqrt{s} = 8$ TeV collected with the CMS detector. The result is presented as a function of both jet transverse momentum $p_T$ and rapidity $y$ and covers a large range in jet $p_T$ from 74 GeV up to 2.5 TeV, in six rapidity bins up to $|y| = 3.0$. The parton momentum fractions $x$ probed in this measurement cover the range $0.019 < x < 0.625$.

Detailed studies of experimental and theoretical sources of uncertainty have been carried out.
Figure 13: Distributions of gluon (left), u-valence quark (middle) d-valence quark as functions of $x$ at the starting scale $Q^2 = 10^5 \text{GeV}^2$. The results of the fit to the HERA data and inclusive jet measurements at 8 TeV (shaded band), and to HERA only (hatched band) are compared with their total uncertainties, as determined by using the HERAPDF method. In the bottom panels the fractional uncertainties are shown.

Figure 14: Gluon PDF distribution as functions of $x$ at the starting scale $Q^2 = 1.9 \text{GeV}^2$ as derived from HERA inclusive DIS (left) and in combination with CMS inclusive jet data (right). Different contributions to the PDF uncertainty are represented by bands of different shades. In the bottom panels the fractional uncertainties are shown.

The obtained spectrum is used to extract the strong coupling constant. Using the entire probed
Figure 15: Distributions of gluon (left) and d-valence quark (right) as functions of $x$ at the starting scale $Q^2 = 1.9$ GeV$^2$. The results of the 13-parameter fit [21] to the subset [31] of the combined HERA data and inclusive jet measurements at 7 TeV (hatched band), and, alternatively, 8 TeV (shaded band) are compared with their total uncertainties, as determined by using the HERAPDF method. In the bottom panels the fractional uncertainties are shown.

$p_T$ range and six different rapidity bins, the best fitted value found to be $\alpha_s(M_Z) = 0.1164^{+0.0060}_{-0.0043}$ with CT10 NLO PDFset. The running of $\alpha_s(Q)$, measured for nine different values of renormalization scale between 86 GeV and 1.5 TeV, is in good agreement with previous experiments and extends the measurement to the highest values of the renormalization scale.

References


[7] CDF Collaboration, “Measurement of the Inclusive Jet Cross Section using the $k_T$ algorithm in $p\bar{p}$ Collisions at $\sqrt{s} = 1.96$ TeV with the CDF II Detector”, Phys. Rev. D 75
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