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α_S Extraction and PDF Constraints from Jet Measurements at CMS

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We present recent CMS results related to the extraction of the strong coupling constant, α_S, and constraints on parton distribution functions. Results are based on recent jet measurements performed with 2011 data taken at center-of-mass energy of 7 TeV. α_S extraction is based on measurements of multijet events and inclusive jet production cross sections, with the latest to be used also for setting constraints on the parton distribution functions.

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1. Introduction

The dominant production process at hadron-hadron colliders is the production of collimated streams of particles, called *jets*. At sufficiently high energy, these processes can be described by perturbative calculations in quantum chromodynamics (pQCD). Precise predictions of the cross section of such processes depend on a detailed knowledge of the underlying structure of the parton described by distribution functions (PDFs) and the strong coupling α_S. The PDF $f_i(x,Q)$ of a parton i gives the probability to find a corresponding parton at a scale Q with the fractional momentum x of the proton. Currently PDFs are mostly constrained by data from experiments with lower momentum transfer, thus resulting in larger uncertainties in the high-x kinematic region reached by the LHC. The experimental precision of jet measurements at 7 TeV provide stringent tests on QCD predictions and constrain the PDFs in this region.

2. Jet Measurements with the CMS Detector

A fundamental quantity to test QCD is the analysis of the inclusive jet production. Each jet is counted as a function of the jet transverse momentum p_{T} and the absolute rapidity of the jet $|y|$. CMS measured the inclusive jet cross section from proton-proton collision data at $\sqrt{s} = 7\,\mathrm{TeV}$ [1]. Figure 1 shows the unfolded inclusive jet spectrum in p_{T} and $|y|$. Additionally a next-to-leading (NLO) calculation in pQCD is shown. Over many orders of magnitude a quantitative agreement is observed within uncertainties.

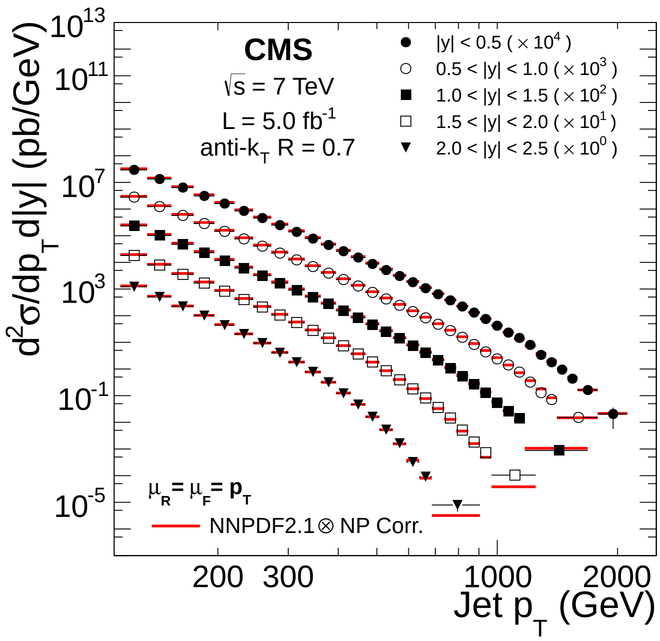

Figure 1: Double-differentially measured inclusive jet cross section for five bins in rapidity. The markers show the unfolded data points and the red line the NLO theory prediction using the NNPDF2.1 PDF set [1].

Figure 2 shows a more detailed comparison between predictions using several PDF sets and the unfolded data spectrum for the central rapidity bin and the most outer rapidity bin. Especially in the high-p_T region larger differences between the various PDF sets and the data are observed. Since the data discriminate between the predictions using different PDF sets, it is a valuable input in the derivation of themselves. Section 3 shows the impact of this measurement on PDFs derived using inclusive deep inelastic scattering (DIS) data only.

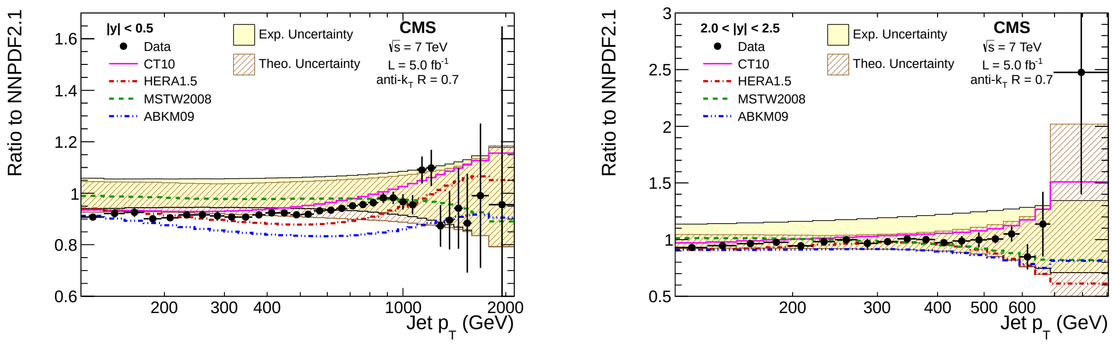

Figure 2: Ratio of the inclusive jet cross section to the theoretical prediction using the NNPDF2.1 PDF sets for the central rapidity and the most outer rapidity bin. Additionally the predictions using the CT10, HERAPDF1.5, MSTW2008 and ABKM09 PDF sets are shown [1].

It is also possible to extract α_S from this measurement, but in order to reach the highest scales or the best precision, other observables like the invariant three-jet mass or the ratio of the inclusive three-jet to two-jet cross section are favorable. CMS measured the invariant three-jet mass cross section at 7 TeV as a function of the maximum rapidity and the invariant mass of the three-jet system [2]. To extract the strong coupling with best possible precision from hadronic jet data, ratio measurements are the most promising approach. The measurement of the ratio R_{32} of the inclusive 3-jet cross section to the inclusive 2-jet cross section is proportional to α_S while many of the systematic uncertainties are cancelled or reduced [3].

3. Constraints on Parton Distribution Functions

The main ingredient in the derivation of the PDFs are inclusive DIS data measured by the HERA collider. These data cover large parts of the kinematic phase space, providing sufficient information for a comprehensive determination of the PDFs. However inclusive DIS data do not directly constrain the gluon PDF and can't access the high-x region. LHC measurements provide additional information to further constrain the PDFs in these regions. CMS performed an detailed analysis on the constraints of the PDFs of the inclusive jet cross section measurement [1] and extracted α_S from the data as well [4].

The kinematic region of expected impact by adding new data can be quantified by calculating the correlation between the PDFs and the cross section calculated using these PDFs. Figure 3 shows the correlation for the gluon and the d-quark PDF. High correlation is observed in the high-x region over a wide range of Q for the gluon PDF and at very high scales and high-x fractions of the proton momentum for the d-quark PDF.

The HERAFITTER project is an open source fitting framework designed to derive proton PDFs from data of various experiments [5, 6, 7]. HERAFITTER is employed to study the impact

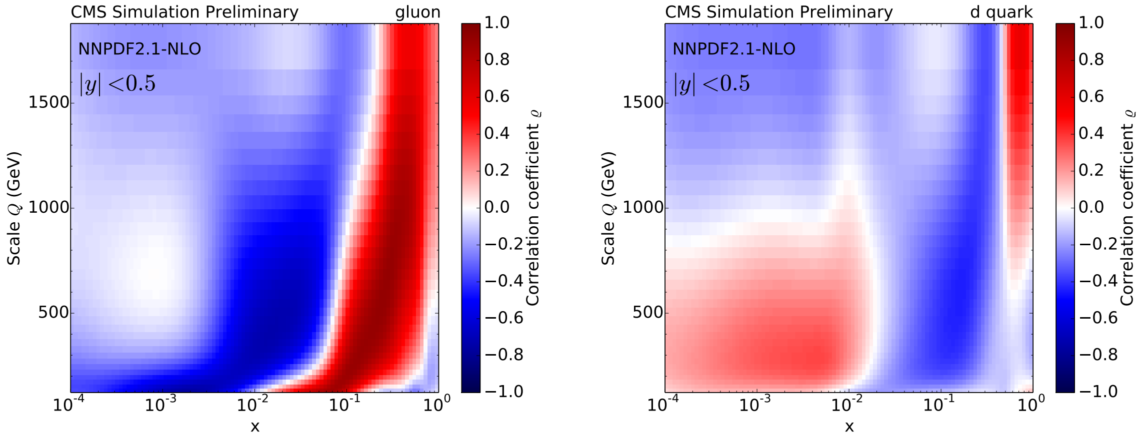

Figure 3: The correlation coefficient between the inclusive jet cross section and the gluon (left) and the d-quark PDF (right) as a function of the momentum fraction x of the proton and the momentum scale Q of the hard process. The correlation is shown for the central rapidity bin [4].

of the inclusive jet cross section measured by CMS on PDFs derived using inclusive DIS data of the HERA experiments by successively adding the CMS jet data in the fit. Following the prescription of the HERAPDF1.0 determination [5], a NLO PDF fit is performed. Detailed studies of the PDF uncertainties were performed by propagating three types of uncertainty on the PDFs. The experimental uncertainty of the measurements were propagated with the commonly used eigenvector method. Additional model parameter variations, which cover the assumption on the light quark masses and the strangeness fraction, were included in the PDF uncertainties. More flexible parametrizations have been studied and effects of these were also considered. Figure 4 shows the derived PDFs using their total uncertainty for a PDF fit with inclusive DIS data alone and after adding the CMS inclusive jet data. When comparing the shapes of the PDFs, a much harder gluon PDF is observed compared to the fit usind DIS data alone, while the changes on the d valence quark PDF are much smaller. Additionally a significant reduction of the uncertainty for the high-x gluon PDF is observed while smaller effects on the quark PDF are seen. This proves the inclusive jet cross section measurement to be an important input in global PDF fits.

4. Extraction of the Strong Coupling Constant

α_S has been extracted by CMS from inclusive jet cross section [4], multijet [2] and multijet ratio [3] measurements. While multijet and inclusive jet measurements probe $\alpha_S(Q)$ close or beyond the TeV range, ratio measurements yield the highest possible precision in determining $\alpha_S(Q)$ from hadronic jet measurements. For all three measurements separately, the best fit value of α_S was determined by minimizing the χ^2 between the data and the NLO theory prediction corrected for non-perturbative (NP) effects considering all bin-to-bin correlations. The inclusive jet measurements yields $\alpha_S(M_Z) = 0.1185 \pm 0.0019(\text{exp.}) \pm 0.0028(\text{PDF}) \pm 0.0004(\text{NP})^{0.0055}_{0.0022}(\text{scale})$. The determination from the 3-jet mass cross section reads as $\alpha_S(M_Z) = 0.1160 \pm^{0.0025}_{0.0023}(\text{exp,PDF,NP})^{0.0068}_{0.0021}(\text{scale})$ and the result of the 3-jet to 2-jet ratio measurement is $\alpha_S(M_Z) = 0.1148 \pm 0.0014(\text{exp.}) \pm 0.0018(\text{PDF}) \pm 0.0050(\text{theory})$. All of the obtained results are in agreement with the world average of $\alpha_S(M_Z)$

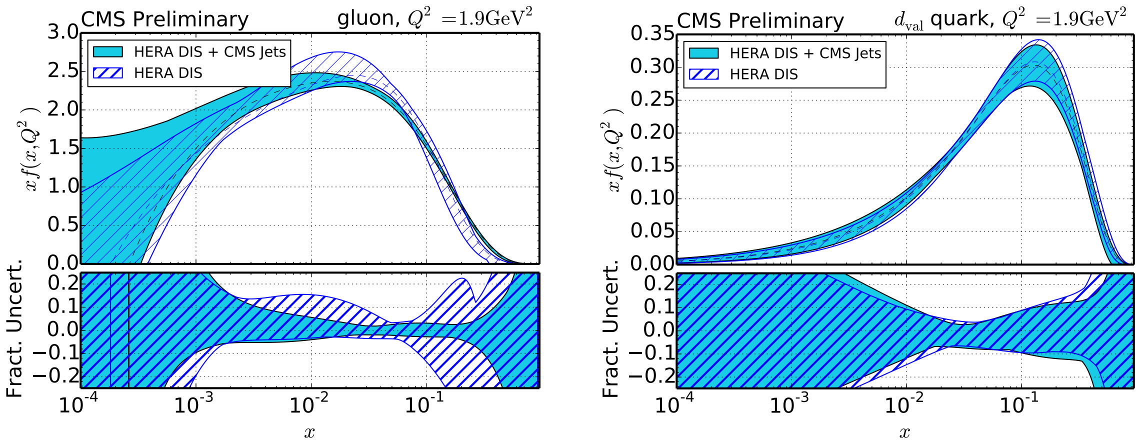

Figure 4: The gluon (left) and the d valence quark PDF (right) as a function of x as derived from HERA inclusive DIS data alone (blue hatched) and in combination with CMS inclusive jet data (cyan band). The PDFs are shown at the starting scale $Q^2 = 1.9\,\mathrm{GeV}$ [4].

within uncertainties. Furthermore the extraction has been performed in separate ranges of Q for all three measurements testing the predicted running of $\alpha_S(Q)$. Figure 5 shows various measurements of which α_S has been extracted as a function of Q. Additionally the central result of the inclusive jet cross section analysis with the total uncertainty obtained at $\alpha_S(M_Z)$ is evolved over the whole range of Q. Within uncertainty, all measurements are consistent with the predicted running of $\alpha_S(Q)$.

5. Conclusion

CMS jet measurements have been used to perform extensive QCD studies. The impact of the inclusive jet cross section measurement on the PDFs have been studied and it was found that the inclusion of the jet data in a PDF fit with inclusive DIS data leads to a significantly harder gluon distribution with smaller uncertainties in the high-x region.

Additionally the strong coupling constant has been extracted from inclusive jet and multijet measurements from CMS. All obtained results are in agreement with each other and the world average of $\alpha_S(M_Z) = 0.1184 \pm 0.0007$ [8]. The high-Q jet measurements from CMS extend the tested region of the momentum scale dependence of $\alpha_S(Q)$ beyond 1 TeV and find consistency with the running predicted by QCD.

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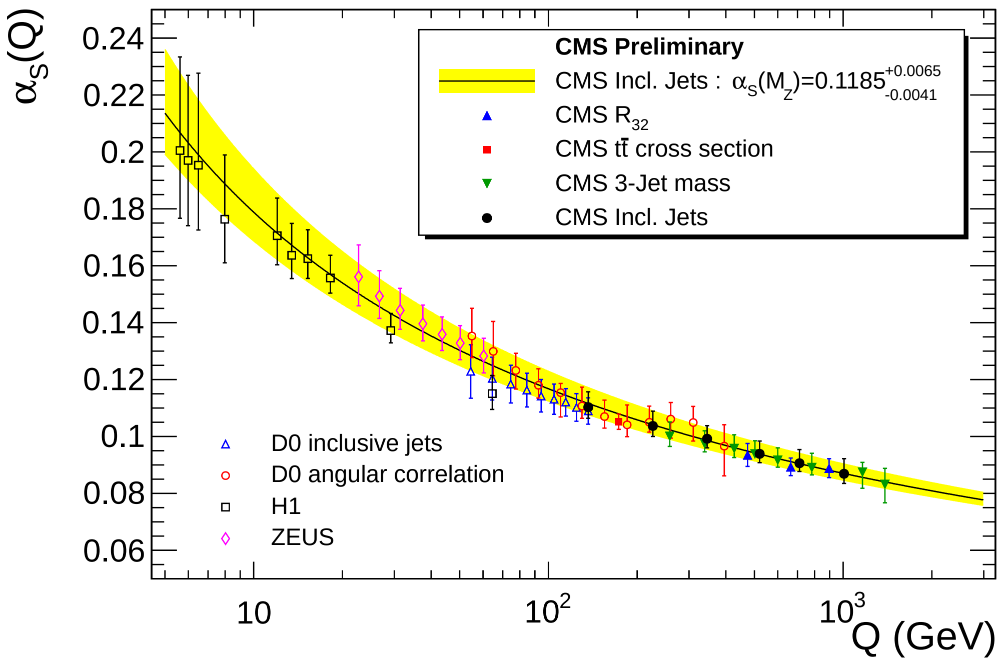

Figure 5: The running of the strong coupling $\alpha_S(Q)$ and the total uncertainty as determined from inclusive jet cross sections. The determinations of $\alpha_S(Q)$ in six separate ranges of p_T are shown together with results from HERA and TEVATRON colliders as well as recent CMS measurements. Figure from [4].

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