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# PDF constraints and $\alpha_S$ from CMS

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The measurement of the strong coupling constant based on four different observables is presented. The four observables are the inclusive jet spectrum, the 3-jet production cross section, the ratio of the inclusive 3-jet cross section to the inclusive 2-jet cross section, and the top quark pair production cross section in the dilepton channel. The data samples used for these measurements were collected at a proton-proton centre-of-mass energy of 7 TeV with the CMS detector at the LHC. The extracted values of the strong coupling constant are in good agreement with the world average value and the running of the strong coupling is confirmed for the first time at the TeV region. Additionally, results on constraining the gluon and the valence-quark PDFs using the inclusive jet spectrum and the muon charge asymmetry in the inclusive W production are also presented.

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## 1. Introduction

The strong coupling constant ($\alpha_S$) and the Parton Distribution Functions (PDFs) are a key ingredient for precision measurements at hadron colliders. The recent Large Hadron Collider (LHC) data allow the determination of $\alpha_S$ at energies beyond 1 TeV, and provide additional information on PDFs in a previously unexplored energy region.

In these proceedings four different measurements of $\alpha_S$ are presented, based on the analysis of data collected at $\sqrt{s}$ = 7 TeV with the Compact Muon Solenoid (CMS) detector [1] at the CERN LHC. Additionally, results on constraining PDFs using the inclusive jet spectrum and the muon charge asymmetry in the inclusive W production are also presented.



## 2. The $\alpha_S$ measurements

The first determination of $\alpha_S(M_Z)$ is based on the measurement of the inclusive jet production cross section as function of jet $p_{\mathrm{T}}$ and rapidity. The CMS collaboration has delivered this measurement [2] for five different rapidity bins, at it is shown in Fig. 1 (on the left) in comparison to next-to-leading order (NLO) predictions using the NNPDF2.1 PDF set times the non-perturbative (NP) correction factor.

The inclusive jet spectrum is proportional to ${\alpha_S}^2$ and is used to extract the strong coupling constant, see Ref. [3]. Figure 1, on the right, shows the ratio of the inclusive jet cross section to theoretical predictions using the CT10 PDF set for one rapidity bin, where the $\alpha_S(M_Z)$ value is varied in the range 0.112-0.126 in steps of 0.001, demonstrating thus the sensitivity of the inclusive jet spectrum to $\alpha_S$. The $\alpha_S(M_Z)$ is extracted by performing a generalized $\chi^2$ fit over the five rapidity bins using the CT10-NLO PDF set. The renormalization ($\mu_r$) and factorization ($\mu_f$) scale was set to $\mu_r = \mu_f = p_{\mathrm{T}}$. The result is $\alpha_S(M_Z) = 0.1185 \pm 0.0019(exp) \pm 0.0028(PDF) \pm 0.0004(NP)^{+0.0055}_{-0.0022}(scale)$ dominated by the scale uncertainties.

The differential 3-jet production cross section as a function of the invariant mass $m_3$ and the maximum rapidity $|y|_{\mathrm{max}}$ of the 3-jet system is an observable proportional to ${\alpha_S}^3$. The CMS collaboration has published the measurement in Ref. [4] for two rapidity bins with $|y|_{\mathrm{max}} < 1$ and $1 \leq |y|_{\mathrm{max}} < 2$ using an integrated luminosity of $5\,\mathrm{fb}^{-1}$ collected with the CMS detector during 2011. Figure 2, on the left, shows the comparison of the measured 3-jet production cross section with the NLO prediction multiplied by the NP correction factors for the two regions using the CT10-NLO PDF set. The same figure on the right shows the sensitivity of the observable to $\alpha_S$. The $\alpha_S(M_Z)$ is extracted by performing a generalized $\chi^2$ fit over the two rapidity bins using the CT10-NLO PDF set. The result is $\alpha_S(M_Z) = 0.1171 \pm 0.0013(exp) \pm 0.0024(PDF) \pm 0.0008(NP)^{+0.0069}_{-0.0040}(scale)$ dominated also by the scale uncertainties.

The ratio $R_{32}$ of the inclusive 3-jet cross section to the inclusive 2-jet cross section is an observable proportional to $\alpha_S$. In Ref. [5] the CMS collaboration has delivered this measurement using an integrated luminosity of $5\,\mathrm{fb}^{-1}$ collected with the CMS detector during 2011. Figure 3, on the left, shows the ratio $R_{32}$ together with the NLO predictions using the NNPDF2.1 NNLO PDF sets for a series of values of $\alpha_S(M_Z)$. The result of a generalized $\chi^2$ fit gives $\alpha_S(M_Z) = 0.1148 \pm 0.0014(exp) \pm 0.0018(PDF) \pm 0.0050(Theory)$, dominated by scale uncertainties.

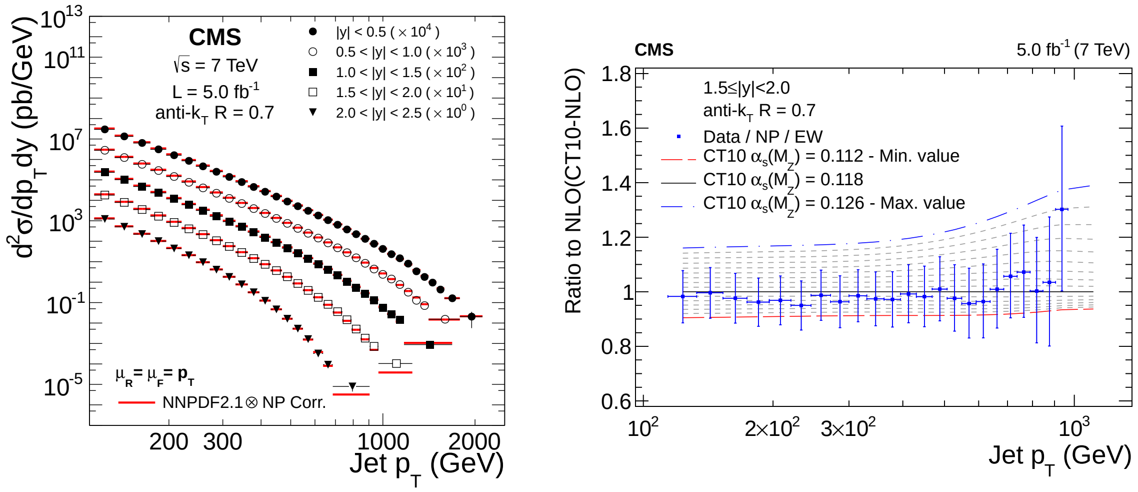


**Figure 1:** On the left: the inclusive jet cross sections for the five different rapidity bins, for data (markers) and theory (thick lines) using the NNPDF2.1 PDF set. On the right: the ratio of the inclusive jet cross section to theoretical predictions using the CT10-NLO PDF set for one rapidity bin, where the $\alpha_S(M_Z)$ value is varied in the range 0.112-0.126 in steps of 0.001. The error bars correspond to the total uncertainty.

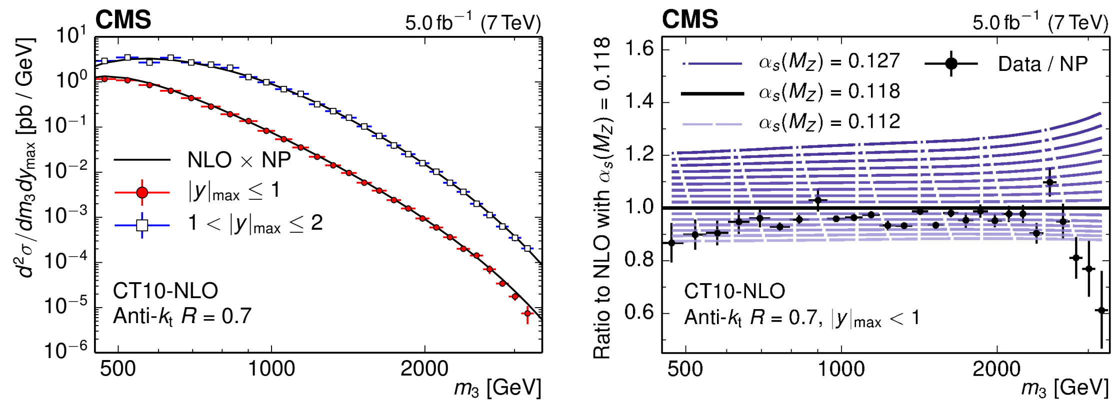


**Figure 2:** On the left : the comparison of the measured 3-jet mass cross section with the NLO prediction multiplied by the NP correction factors for the two regions using the CT10-NLO PDF set. On the right: the ratio of the measured 3-jet mass cross section in the inner rapidity region, divided by the theory prediction at NLO while using the CT10-NLO PDF set and for different values of $\alpha_S(M_Z)$ ranging from 0.112 up to 0.127.

The top quark pair production cross section in the dilepton channel [6] is sensitive to the $m_t^{pole}$ and $\alpha_S$ . By constraining $m_t^{pole}$ to the latest average from direct mass measurements the determination of $\alpha_S$ is possible [7]. Figure 3, on the right, shows the predicted $t\bar{t}$ cross section at NNLO+NNLL, as a function of the strong coupling constant, using five different NNLO PDF sets, compared to the cross section measured by CMS assuming $m_t = m_t^{pole}$. The result of the fit using the NNPDF2.3-NNLO PDF is $\alpha_S(M_Z) = 0.1151^{+0.0017}_{-0.0018}(exp)^{+0.0013}_{-0.0011}(PDF) \pm 0.0013(m_t^{pole}) \pm 0.0013(E_{LHC})^{+0.0009}_{-0.0008}(PDF)$ and it is the most precise measurement at a hadron colider.

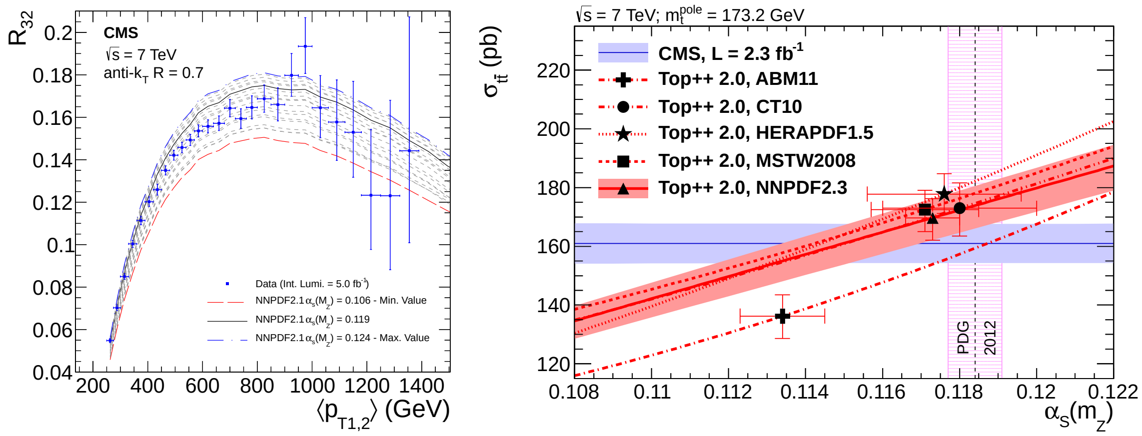


**Figure 3:** On the left : the ratio $R_{32}$ together with the NLO predictions using the NNPDF2.1 NNLO PDF sets for a series of values of $\alpha_S(M_Z)$ . On the right: the predicted $t\bar{t}$ cross section at NNLO+NNLL, as a function of the strong coupling constant, using five different NNLO PDF sets, compared to the cross section measured by CMS assuming $\mathrm{m}_t = m_t^{pole}$ .

Table 1 summarizes the CMS collaboration measurements of $\alpha_S(M_Z)$ . All results are in agreement with the world average value $\alpha_S(M_Z) = 0.1185 \pm 0.0006$ [8]. These measurements are used also to investigate the running of the strong coupling, by splitting the fitted region in various bins of $p_{\mathrm{T}}$ or mass, depending the observable. The extracted $\alpha_S(M_Z)$ values are evolved to the corresponding energy scale Q using the two-loop solution of the renormalization group equation (RGE). Figure 4 shows the running of the strong coupling using the four CMS measurements which cover the 1 TeV region, and also measurements from other experiments at lower Q. No deviation of the predicted running of $\alpha_S$ is observed.

**Table 1:** The CMS collaboration measuremets on $\alpha_S(M_Z)$ .

| Observable | $\alpha_S(M_Z)$ |
|---|---|
| Inclusive Jets | $0.1185 \pm 0.0019(exp) \pm 0.0028(PDF) \pm 0.0004(NP)^{+0.0055}_{-0.0022}(scale)$ |
| 3-Jets | $0.1171 \pm 0.0013(exp) \pm 0.0024(PDF) \pm 0.0008(NP)^{+0.0069}_{-0.0040}(scale)$ |
| $R_{32}$ | $0.1148 \pm 0.0014(exp) \pm 0.0018(PDF) \pm 0.0050(Theory)$ |
| $t\bar{t}$ | $0.1151^{+0.0017}_{-0.0018}(exp)^{+0.0013}_{-0.0011}(PDF) \pm 0.0013(m_t^{pole}) \pm 0.0013(E_{LHC})$ $^{+0.0009}_{-0.0008}(PDF)$ |

## 3. Constraining PDFs

The inclusive jet spectrum measured by the CMS collaboration is also used to constrain PDFs [3], and mainly the gluon PDF which is highly correlated to this observable. This is demonstrated in Fig. 5 presenting the gluon (left) and sea quark (right) PDFs versus x as derived from HERA-I inclusive DIS data alone (dashed line) and in combination with CMS inclusive jet data

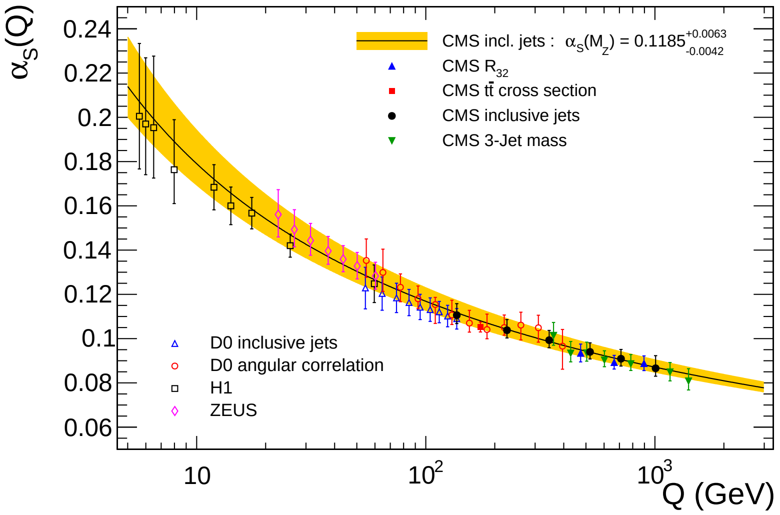


**Figure 4:** The strong coupling running using the four CMS measurements, which cover the 1 TeV region, and also measurements from other experiments at lower Q.

(full line). For the gluon distribution, the parametrization and model uncertainties are reduced significantly for almost all x range, while for the sea quark distribution some reduction in their uncertainty is visible at high x.

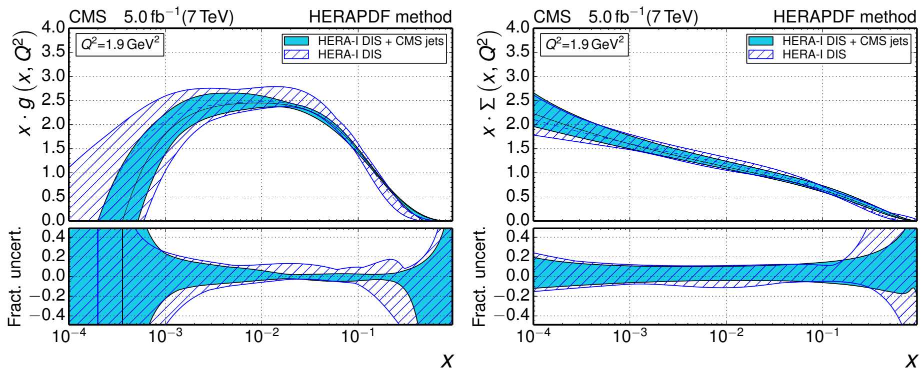


**Figure 5:** The gluon (left) and sea quark (right) PDFs versus x as derived from HERA-I inclusive DIS data alone (dashed line) and in combination with CMS inclusive jet data (full line). The PDFs are determined employing the HERAPDF method with a $Q^2_{min} = 7.5$ GeV$^2$ selection criterion.

The muon charge asymmetry in the inclusive W production probes the valence-quark distributions. The asymmetry, as measured by CMS [9], is shown in Fig. 6 (on the left) in comparison to NLO predictions calculated using the FEWZ3.1 MC tool interfaced with four different PDF sets. The same figure depicts the u valence (center) and d valence (right) quark distributions versus x as derived from HERA-I inclusive DIS data alone (dashed line) and in combination with CMS muon asymmetry data (full line). A reduction of the uncertainties and a change in the distribution shapes within the total uncertainties is observed.

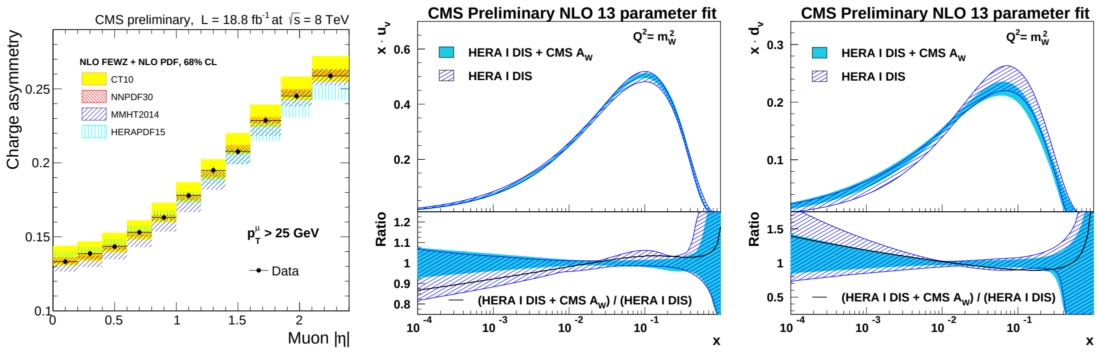


**Figure 6:** Comparison of the measured muon charge asymmetry (left) to NLO predictions calculated using the FEWZ3.1 MC tool interfaced with four different PDF sets. Distributions of u valence (center) and d valence (right) quark PDFs as function of x at the scale $Q^2 = m_W^2$. The results of the fit to the HERA data and muon asymmetry measurements (light shaded band), and to HERA only (dark hatched band) are compared.

## 4. Conclusions

The CMS collaboration has already provided four measurements of the strong coupling constant based on different observables. All measurements are in good agreement with the world average value and the running of $\alpha_S$ is confirmed for the first time at the TeV scale. The inclusive jet spectrum and the muon charge asymmetry in the inclusive W production is used to provide additional constraints to PDFs, thus improving the gluon and the valence-quark distributions.

## 5. Acknowledgments

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