PROCEEDINGS OF SCIENCE

PDF constraints and α_s results from CMS experiment

Engin Eren[*†]
Deutsches Elektronen-Synchrotron (DESY), Hamburg (Germany)
E-mail: engin.eren@desy.de

We present and discuss the impact of the most recent CMS data on the precision measurement of α_s and parton density functions.

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*Speaker.
†On behalf of CMS collaboration

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1. Introduction

Cross sections in proton-proton collisions are calculated by collinear-factorization theorem. It says that any Standard Model (SM) process can be factorized by convolution of parton densities and hard scattering cross section :

$$\sigma(s) = \sum_{i,j} \int_{\tau_0}^{1} \frac{d\tau}{\tau} \cdot \frac{dL_{ij}(\mu_F^2)}{d\tau} \hat{s} \cdot \hat{\sigma}_{ij}. \tag{1.1}$$

These two quantities are main ingredients for SM predictions for pp collisions at LHC. The term in equation above :

$$\frac{dL_{ij}(\mu_F^2)}{d\tau} \sim \int_0^1 dx_1 dx_2 \left(x_1 f_i(x_1, \mu_F^2)) \cdot x_2 f_j(x_2, \mu_F^2)\right) + (1 \leftrightarrow 2)\delta(\tau - x_1 x_2) \tag{1.2}$$

represents the parton luminosity, which is dependent on Parton Distribution Functions (PDF). PDFs are universal functions of x (partonic fraction of proton momentum) and energy scale Q of the process. The Q dependence of PDFs is calculated by perturbative QCD (pQCD), while the x dependence should be determined from data. The PDFs of both interacting protons enter multiplicatively into the calculation of the particular cross-sections. Therefore, a precise knowledge of the PDFs is of particular importance for cross-section predictions[1].

Determination of PDFs follows this procedure :

1. The x-shape of PDFs is parametrized at starting scale Q_0^2.
2. PDFs are evolved to $Q^2 > Q_0^2$ via DGLAP evolution equation.
3. Expected cross-sections are calculated.
4. χ^2-fit is done to the experimental data.

Here we present W muon charge asymmetry[2] and inclusive jet cross section[3] at 8 TeV measured with the CMS detector[4], and their impact on global PDF fits.

2. QCD analysis of W charge asymmetry data

Differential cross-section and muon charge asymmetry of the process $pp \to W^{\pm} + X \to \mu^{\pm}\nu + X$ provide important constraints on the valence and sea quark distributions in the proton. Uncertainties in the PDFs have become a limiting factor for precision of many inclusive and differential cross section calculations[2]. Since there are two u-valance quarks in the proton, W^+ bosons are produced more often than W^-. The precise measurement of the charge asymmetry as a function of the muon η,

$$\mathscr{A}(\eta) = \frac{\sigma_\eta^+ - \sigma_\eta^-}{\sigma_\eta^+ + \sigma_\eta^-} \tag{2.1}$$

$$\sigma_\eta^{\pm} = \frac{d\sigma}{d\eta}(pp \to W^{\pm} + X \to \mu^{\pm}\nu + X) \tag{2.2}$$

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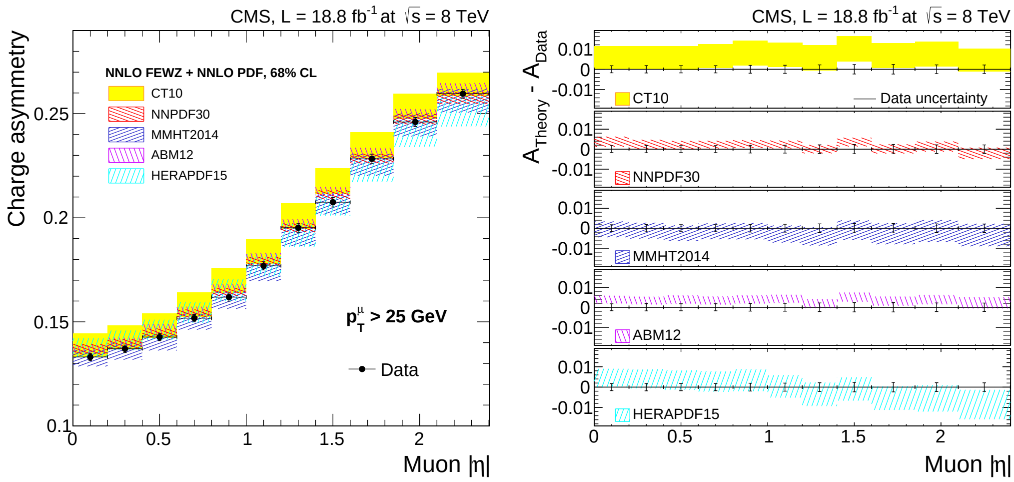

Figure 1: Charge asymmetry as a function of muon η along with theory predictions via FEWZ, with different PDFs (left). Data/Theory comparison is also presented (right)

provides significant constraints on the ratio of u and d quark distribution in the proton for values of x between 10^{-3} and 10^{-1}. The measurement is presented in Figure 1.

A QCD analysis is performed at NNLO together with the combined measurements of neutral- and charged-current cross sections of deep inelastic electron(positron)-proton scattering (DIS) at HERA[5]. The correlations of the experimental uncertainties for the muon charge asymmetry and for the inclusive DIS cross sections are taken into account. The theoretical predictions are calculated at NLO by using the MCFM 6.8 program[6, 7], which is interfaced to APPLGRID 1.4.56[8]. The NNLO corrections are obtained by using k-factors, defined as ratios of the predictions NNLO to the ones at NLO, both calculated with FEWZ 3.1[9] program, using NNLO CT10[10] PDFs. Version 1.1.1 of the open-source QCD fit framework Xfitter[11] is used. The global and partial χ^2 values for the data sets used are listed Table 1. The final combined HERA DIS data currently provide the most significant constraints on the valence quark distributions. By adding W muon charge asymmetry measurements, the constraints can be significantly improved, as illustrated in Figure 2. The $x \cdot u_v$ and $x \cdot d_v$ distributions are shown at the scale of m_W^2, relevant for W boson production.

3. QCD analysis of inclusive jets data and α_s extraction

The inclusive jet cross section ($p+p \rightarrow \text{jet}+X$) is a fundamental quantity that can be measured and predicted by pQCD. This cross section is a sensitive probe for the calculation of the hard partonic cross section as well as for the parton densities. Furthermore, it allows to probe with higher precision at the high p_T part of the differential cross section, where the sensitivity to the α_s value is maximal. QCD analysis presented here is based on measurement of inclusive jet cross section by CMS experiment[3] and combined HERA inclusive cross-section measurements[5]. The correlations of the experimental uncertainties for the jet measurements and for the inclusive DIS cross sections are taken into account. Theory predictions for the double-differential cross-sections of jet production are calculated at NLO by using NLOJET++ (version 4.1.3) program[12, 13]. The

Table 1: Partial χ^2 per number of data points, $n_{\rm dp}$, and the global χ^2 per degrees of freedom, $n_{\rm dof}$, as obtained in the QCD analysis of HERA DIS and the CMS muon charge asymmetry data. For HERA measurements, the energy of the proton beam is listed for each data set, with electron energy being $E_e = 27.5$GeV.

Data sets	Partial $\chi^2/n_{\rm dp}$
HERA1+2 neutral current, e^+p, $E_p = 920$GeV	440/377
HERA1+2 neutral current, e^+p, $E_p = 820$GeV	69/70
HERA1+2 neutral current, e^+p, $E_p = 575$GeV	214/254
HERA1+2 neutral current, e^+p, $E_p = 460$GeV	210/204
HERA1+2 neutral current, e^-p, $E_p = 920$GeV	218/159
HERA1+2 charged current, e^+p, $E_p = 920$GeV	46/39
HERA1+2 charged current, e^-p, $E_p = 920$GeV	50/42
Correlated χ^2 of HERA1+2 data	141
CMS $W^\pm$ muon charge asymmetry $\mathscr{A}(\eta)$, $\sqrt{s} = 8$ TeV	3/11
Global $\chi^2/n_{\rm dof}$	1391/1143

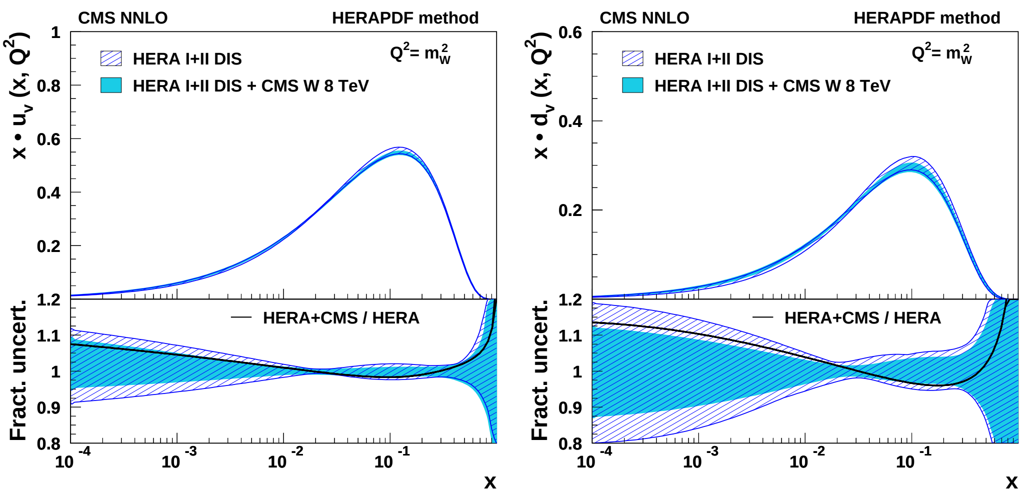

Figure 2: Distributions of u valence (left) and d valence (right) quarks as a function of x at the scale $Q^2 = m_W^2$.

open-source QCD fit framework for PDF determination Xfitter [11](version 1.1.1) is used with the partons evolved using DGLAP equations[14, 15] at NLO, as implemented in the QCDNUM program[16].

Inclusive jet measurements, together with combined HERAI+II DIS cross section data, provide important constraints on the gluon over the $x > 0.001$ range. This is illustrated in Figure 3, where the distributions of gluon at the starting scale of $Q^2 = 1.9\,\mathrm{GeV}^2$ and of $Q^2 = 10^5\,\mathrm{GeV}^2$. The distributions are obtained both by using HERAI+II DIS data alone, and by adding CMS jet data at $\sqrt{s} = 8\,\mathrm{TeV}$. The global and partial χ^2 values for each data set are listed in Table 2.

Jet production measurements at hadron colliders gives us a direct probe to measure the strong coupling constant α_s. The extraction of α_s is performed by minimizing χ^2 between measured data

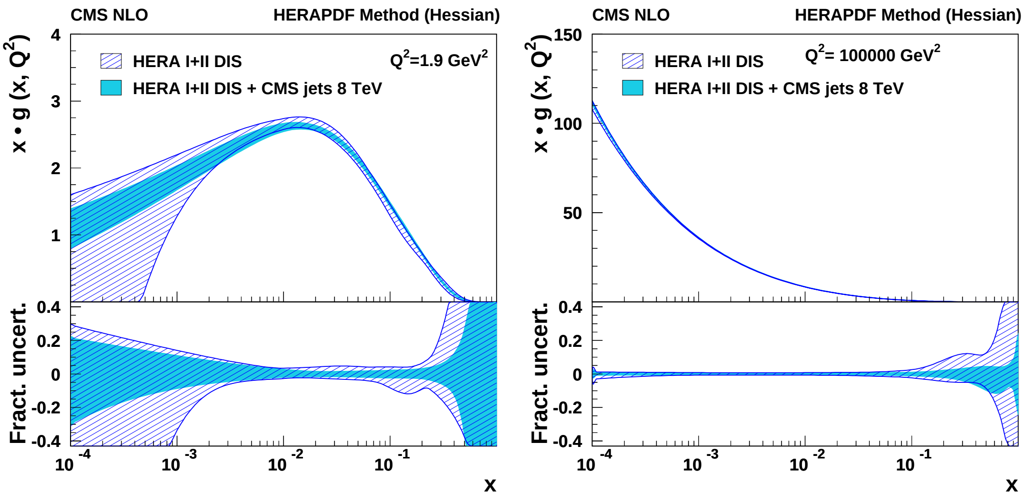

Figure 3: Distribution of gluon at $Q^2 = 1.9\,\mathrm{GeV}$ (left) and of gluon at $Q^2 = 10^5\,\mathrm{GeV}^2$ (right).

Table 2: Partial χ^2 per number of data points, n_{dp}, and the global χ^2 per degrees of freedom, n_{dof}, as obtained in the QCD analysis of HERA DIS and the CMS incusive jets asymmetry data. For HERA measurements, the energy of the proton beam is listed for each data set, with electron energy being $E_e = 27.5$ GeV.

Data sets		Partial χ^2/n_{dp}
HERA1+2 neutral current, e^+p, $E_p = 920\mathrm{GeV}$		376/332
HERA1+2 neutral current, e^+p, $E_p = 820\mathrm{GeV}$		61/63
HERA1+2 neutral current, e^+p, $E_p = 575\mathrm{GeV}$		197/234
HERA1+2 neutral current, e^+p, $E_p = 460\mathrm{GeV}$		204/187
HERA1+2 neutral current, e^-p, $E_p = 920\mathrm{GeV}$		219/159
HERA1+2 charged current, e^+p, $E_p = 920\mathrm{GeV}$		41/39
HERA1+2 charged current, e^-p, $E_p = 920\mathrm{GeV}$		50/42
CMS inclusive jets at 8 TeV	0 < |y| < 0.5	53/36
	0.5 < |y| < 1.0	34/36
	1.0 < |y| < 1.5	35/35
	1.5 < |y| < 2.0	52/29
	2.0 < |y| < 2.5	49/24
	2.5 < |y| < 3.0	4.9/18
Correlated χ^2		94
Global χ^2/n_{dof}		1471/1216

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and theory prediction by a least-square minimization of the function :

$$\chi^2(\alpha_s(M_Z)) = \sum_{i,j}(D_i - T_i(\alpha_s(M_Z)))^T C_{ij}^{-1}(D_j - T_j(\alpha_s(M_Z))) \tag{3.1}$$

where C is the covariance matrix including all the experimental and theoretical uncertainties involved in the measurement[3]. D_i is the measured value of double-differential 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 $\alpha_s(M_Z)$. CT10 NLO PDF set is used for the calculation. 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. Finally, equation 3.1 is calculated, combining all p_T and $|y|$ intervals, for each of variant corresponding to different α_s value. 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 α_s value as shown in Figure 4.

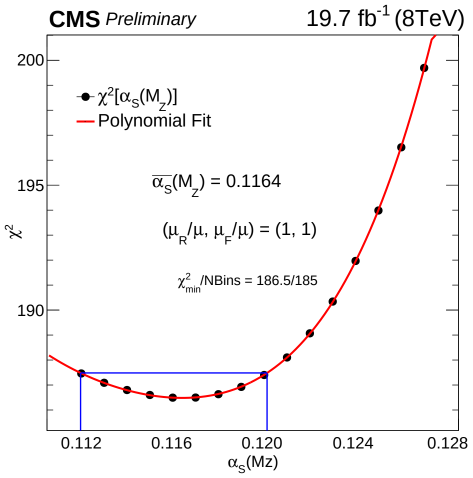

Figure 4: The χ^2 minimization with respect to $\alpha_s(M_Z)$ using the CT10 NLO PDF set and data from all rapidity bins.

Final result on $\alpha_s(M_Z)$ is,

$$\alpha_s(M_Z) = 0.1164\,^{+0.0025}_{-0.0029}(\text{PDF})^{+0.0053}_{-0.0028}(\text{Scale}) \pm 0.0001\,(\text{NP})^{+0.0014}_{-0.0015}(\text{Exp}) \tag{3.2}$$

4. Summary and Conclusions

It has been demonstrated that CMS W muon charge asymmetry data at $\sqrt{s}$ =8 TeV provides significant constraints on the valence quark distribution. It is also demonstrated that CMS inclusive jet data at $\sqrt{s}$ =8 TeV provide important constraints especially on the gluon distribution. Additionally, extraction of strong coupling α_s has been performed with CMS inclusive jets data. These two data sets can be used by PDF collaborations in global PDF fits.

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