PROCEEDINGS OF SCIENCE

Vector boson plus heavy flavor jets and constraints to PDFs

J. P. Fernández[*][†]
CIEMAT
E-mail: juanpablo.fernandez@ciemat.es

Measurements of the associated production of vector bosons, W or Z (decaying to one or two leptons), and jets originating from heavy-flavour quarks are reported using data corresponding to integrated luminosities of 19.7 (35.7) fb^{-1}, at centre-of-mass energies of 8 (13) TeV collected by the CMS detector at the CERN LHC. Total and differential cross sections as a function of several kinematic observables are measured and compared with several theoretical predictions. The production of a Z boson associated with a c-quark allows probing and constraining the charm quark content of the proton and may give insight into the existence of an intrinsic charm quark component inside the proton. The production of a W boson associated with a c-quark allows probing and constraining the strange quark content of the proton.

39th International Conference of High Energy Physics - ICHEP2018,
July 4-11, 2018
Seoul (Korea, Republic of)

[*]Speaker.
[†]On behalf of CMS Collaboration

PoS(ICHEP2018)499

1. W+c associated production:

At the LHC, W+c production is dominated by $\bar{q}g \to W^+ + \bar{c}$ and $qg \to W^- + c$ contributions at the hard scattering level. A key property of a general $qg \to W + c$ process is the presence in the final state of a charm quark and a W boson with opposite sign charges (OS). Gluon splitting processes like $d\bar{u} \to W^- + g \to W^- + c\bar{c}$ also give rise to final states with a W and a charm quark, but in this case, there is an additional charm quark with the same sign (SS) as the W boson. Most of the background processes deliver evenly OS and SS events, whereas $qg \to W + c$ is always OS. A pure sample of c-jets can thus be obtained by statistical OS-SS subtraction. Measurements are presented of the associated production of a W boson and a charm quark $(W + c)$ in proton-proton collisions at a center-of-mass energy of 13 TeV [1]. The data correspond to an integrated luminosity of 35.7 fb^{-1}. The W bosons are identified by their decays into a muon and a neutrino. The charm quark is identified by the full reconstruction of the $D^{*\pm}(2010)$ meson in its decay $D^{*-}(2010) \to \bar{D}^0 + \pi^-_{slow} \to K^+ + \pi^- + \pi^-_{slow}$ (+c.c.). The measurements are performed for the transverse momentum of the muon from the W boson decay greater than 26 GeV in the pseudorapidity range $|\eta^\mu| < 2.4$ and for transverse momentum of the charm quark greater than 5 GeV. Measurements of the associated production of a W boson and a charm quark $(W + c)$ are presented as total cross section, differential cross section as a function of the pseudorapidity of the muon from the W decay and the $\sigma(pp \to W^+ + \bar{c})/\sigma(pp \to W^- + c)$ cross section ratio both inclusively and differentially. The total cross section of $\sigma(pp \to W + c) = 1026 \pm 31(\text{stat.})^{+76}_{-72}(\text{syst.})$ pb is obtained. The measured inclusive and differential cross sections of $W + c$ are compared to QCD predictions at NLO ($\mathscr{O}(\alpha_s^2)$), obtained using MCFM [2] (Fig. 1 (a)). Several PDF sets are used (ABMP16nlo [3], ATLASepWZ16nnlo [4], CT14nlo [5], MMHT14nlo [6], NNPDF3.0nlo [7] and NNPDF3.1nlo [8]). Good agreement between NLO predictions and the measurements is observed, except for the prediction using ATLASepWZ16nnlo. For the cross section ratio $\sigma(pp \to W^+ + \bar{c})/\sigma(pp \to W^- + c)$, all theoretical predictions are in good agreement with the measured value. The present measurement of the $W + c$ production cross section is used in a QCD analysis because of its potential to access the strange quark distribution directly through the processes above. The measurements of a previous QCD analysis [9] are also included as well as earlier inclusive DIS measurements [10] and results from CMS on the lepton charge asymmetry in W production at 8 TeV [11]. The xFitter [12] fit framework for PDF determination is used. The strange quark distribution and strangeness suppression factor obtained in the fit agree with results from neutrino-scattering experiments (Fig. 1 (b)).

2. Z+c associated production:

A measurement of the production cross section of a Z boson and at least one jet originating from a c-quark $(Z + c)$ and the cross section ratio $\sigma(pp \to Z + c + X)/\sigma(pp \to Z + b + X)$ in pp collisions at a center-of-mass energy of 8 TeV is presented. [13]. The analysis is conducted with a data sample corresponding to an integrated luminosity of 19.7 fb^{-1}.The Z-boson candidates are identified through their decay into a pair of leptons (electrons or muons). Jets originating from heavy flavour quarks are identified using semileptonic decays of c- or b-flavoured hadrons and hadronic decays of charm hadrons. The measurements are restricted to: two leptons with

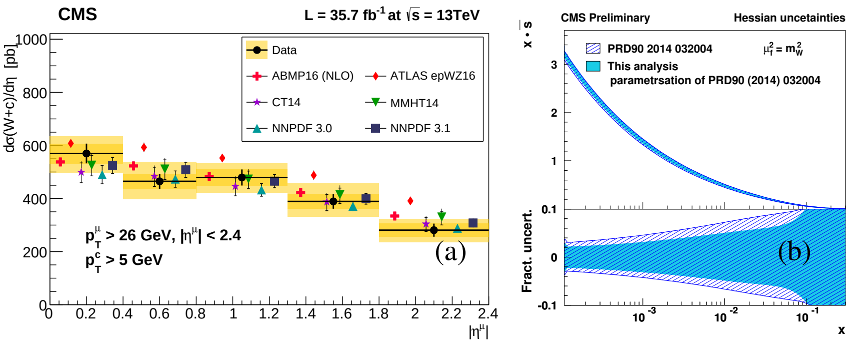

Figure 1: (a) Differential cross section of $\mathrm{W+c}$ production as a function of the pseudorapidity of the muon from the W decay. (b) The s-quark distribution (upper panel) in the proton and its relative uncertainty (lower panel) as functions of x at the factorisation scale m_W^2 [1]. The PDF uncertainties resulting from the fit are shown. In the bottom panels the distributions are normalized to 1.

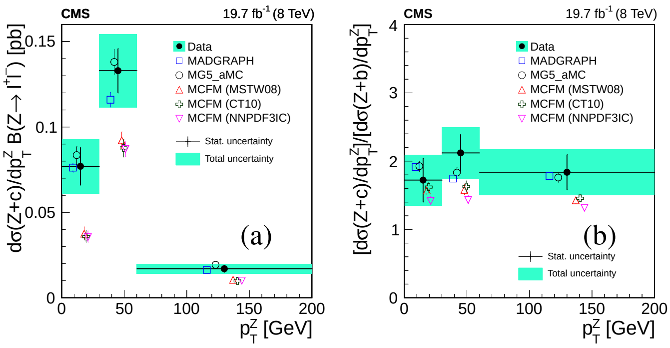

Figure 2: (a) Differential cross section of $\mathrm{Z+c}$ production and (b) cross section $\mathrm{Z+b/Z+c}$ ratio as a function of the transverse momentum of the Z boson [13].

$\mathrm{p_T}^l > 20$ GeV, pseudorapidity $|\eta^l| < 2.1$, and with the dilepton invariant mass consistent with the mass of the Z boson, $71 < m_{ll} < 111$ GeV, and a c- (b-) jet with $\mathrm{p_T}^{jet} > 25$ GeV, pseudorapidity $|\eta^{jet}| < 2.5$ and separated from the leptons from the Z-boson candidate by a distance $\Delta R(jet,l) = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} > 0.5$.

The cross sections obtained in the electron and muon decay channels are consistent and are averaged to obtain the final cross section.The $\mathrm{Z+c}$ production cross section is measured to be $\sigma(\mathrm{pp} \to \mathrm{Z+c+X}) = 8.6 \pm 0.5$ (stat.) ± 0.7 (syst.) pb. The ratio of the $\mathrm{Z+c}$ and $\mathrm{Z+b}$ production cross sections is measured to be $\sigma(\mathrm{pp} \to \mathrm{Z+c+X})/\sigma(\mathrm{pp} \to \mathrm{Z+b+X}) = 2.0 \pm 0.2$ (stat.) $\pm$ 0.2 (syst.). The $\mathrm{Z+c}$ production cross section and the cross sections ratio are also measured differentially as a function of transverse momentum of the Z boson (Fig. 2 (a)) and of the heavy flavour jet (Fig. 2 (b)). The measurements are in agreement with the LO predictions from MADGRAPH [14] + PYTHIA6 [15] and NLO predictions from MADGRAPH5_AMC@NLO [16] + PYTHIA8 [17]. Predictions from the MCFM program are lower than the measured $\mathrm{Z+c}$ cross section, both inclusive and differentially. This difference can be explained by the absence of parton shower development and nonperturbative effects in the MCFM calculation. A better description is reached in terms of the $\mathrm{Z+c/Z+b}$ cross sections ratio. Measurements in the highest $\mathrm{p_T}^Z(\mathrm{p_T}^{jet})$ region analyzed, 60 $< \mathrm{p_T}^Z(\mathrm{p_T}^{jet}) < 200$ GeV, would be sensitive to the existence of an intrinsic charm (IC) component inside the proton if this IC component were large enough to induce a significant enhancement in the Z+c production cross section. A 2% charm quark component (intrinsic + perturbative) would end in a 20-25% increase in the production of Z+c events with a ${p_T}^Z \approx$100 GeV. However, our measurements of the Z+c cross section and (Z+c)/(Z+b) cross section ratio are consistent with predictions using PDF sets with no IC component.

In summary, the s PDF obtained from the $\mathrm{W+c}$ analysis is in agreement with previous measurements and we have presented the first measurement of Z+c in the central region. Good prospects for new results in vector boson and heavy flavor with full statistics will be offered by Run II with the more than 150 fb^{-1} collected at 13 TeV.

References

[1] CMS Collaboration, "https://cds.cern.ch/record/2314570," CMS Physics Analysis Summary CMS-PAS-SMP-17-014, CERN, Geneva, 2018.

[2] J. M. Campbell and R. K. Ellis, "MCFM for the Tevatron and the LHC," *Nucl. Phys. Proc. Suppl.*, vol. 205, p. 10, 2010.

[3] S. Alekhin, J. Blümlein, and S. Moch, "NLO PDFs from the ABMP16 fit," 2018.

[4] M. Aaboud *et al.*, "Precision measurement and interpretation of inclusive W^+ , W^- and Z/γ^* production cross sections with the ATLAS detector," *Eur. Phys. J. C*, vol. 77, p. 367, 2017.

[5] S. Dulat, T.-J. Hou, J. Gao, M. Guzzi, J. Huston, P. Nadolsky, J. Pumplin, C. Schmidt, D. Stump, and C. P. Yuan *Phys. Rev. D*, vol. 93, p. 033006, 2016.

[6] L. A. Harland-Lang, A. D. Martin, P. Motylinski, and R. S. Thorne *Eur. Phys. J. C*, vol. 75, p. 204, 2015.

[7] R. D. Ball *et al.*, "Parton distributions for the LHC Run II," *JHEP*, vol. 04, p. 040, 2015.

[8] R. D. Ball *et al. Eur. Phys. J. C*, vol. 77, p. 663, 2017.

[9] S. Chatrchyan *et al.*, "Measurement of the muon charge asymmetry in inclusive $pp \to W+X$ production at $\sqrt{s} = 7$ TeV and an improved determination of light parton distribution functions," *Phys. Rev. D*, vol. 90, p. 032004, 2014.

[10] H1 and ZEUS Collaborations, "Combination of measurements of inclusive deep inelastic $e^{\pm}p$ scattering cross sections and QCD analysis of HERA data," *Eur. Phys. J. C*, vol. 75, p. 580, 2015.

[11] V. Khachatryan *et al.*, "Measurement of the differential cross section and charge asymmetry for inclusive $\mathrm{pp} \to \mathrm{W}^{\pm}+X$ production at $\sqrt{s} = 8$ TeV," *Eur. Phys. J. C*, vol. 76, p. 469, 2016.

[12] S. Alekhin *et al.*, "HERAFitter," *Eur. Phys. J. C*, vol. 75, p. 304, 2015.

[13] CMS Collaboration, "Measurement of associated Z + charm production in proton-proton collisions at $\sqrt{s}$= 8 TeV," *Eur. Phys. J. C*, vol. 78, p. 287, 2018.

[14] J. Alwall, M. Herquet, F. Maltoni, O. Mattelaer, and T. Stelzer, "Madgraph 5 : Going beyond," *JHEP*, vol. 06, p. 128, 2011.

[15] T. Sjostrand, S. Mrenna, and P. Z. Skands, "PYTHIA 6.4 Physics and Manual," *JHEP*, vol. 05, p. 026, 2006.

[16] J. Alwall, R. Frederix, S. Frixione, V. Hirschi, F. Maltoni, O. Mattelaer, H. S. Shao, T. Stelzer, P. Torrielli, and M. Zaro *JHEP*, vol. 07, p. 079, 2014.

[17] T. Sjostrand, S. Mrenna, and P. Z. Skands, "Introduction to PYTHIA 8.1," *Comput. Phys. Commun.*, vol. 178, pp. 852–867, 2008.