PROCEEDINGS OF SCIENCE

Measurement and QCD analysis of double-differential inclusive jet cross sections at 13 TeV

PoS(LHCP2022)269

Toni Mäkelä[a,*] **and Katerina Lipka**[a,b]

[a] *Deutsches Elektronen-Synchrotron, Notkestraße 85, Hamburg, Germany*

[b] *Fakultät für Mathematik und Naturwissenschaften, Bergische Universität Wuppertal, Gaussstrassse 20, Wuppertal, Germany*

E-mail: toni.maekelae@desy.de

A measurement of the inclusive jet production in proton-proton collisions at the LHC at $\sqrt{s}$ = 13 TeV is presented. The double-differential cross sections are measured as a function of the jet transverse momentum p_{T} and the absolute jet rapidity $|y|$. The anti-k_{T} clustering algorithm is used with distance parameter of 0.4 (0.7) in a phase space region with jet p_{T} from 97 GeV up to 3.1 TeV and $|y| < 2.0$. Data collected with the CMS detector are used, corresponding to an integrated luminosity of 36.3 fb^{-1} (33.5fb^{-1}). The measurement is used in a comprehensive QCD analysis at next-to-next-to-leading order, which results in significant improvement in the accuracy of the parton distributions in the proton. Simultaneously, the value of the strong coupling constant at the Z boson mass is extracted as $\alpha_S(m_{\mathrm{Z}}) = 0.1170 \pm 0.0019$. For the first time, these data are used in a standard model effective field theory analysis at next-to-leading order, where parton distributions and the QCD parameters are extracted simultaneously with imposed constraints on the Wilson coefficient c_1 of 4-quark contact interactions.

The Tenth Annual Conference on Large Hadron Collider Physics - LHCP2022
16-20 May 2022
online

*Speaker

The most fundamental process for studying quantum chromodynamics (QCD) is the production of jets. It allows extracting QCD parameters, such as the strong coupling constant, and obtaining a more precise understanding of proton structure, as well as probing physics beyond the standard model (BSM). However, the parton distribution functions (PDF) used for standard model (SM) predictions are derived assuming the validity of the SM at high jet transverse momentum p_{T}, where indirect searches expect the effects of new physics to be the most prominent. Since the SM prediction is based on these PDFs, this poses a risk of absorbing BSM effects into the SM prediction. This is avoided by following an unbiased search strategy. A suitable way to model new physics is to describe contact interactions (CI) between the fermions by utilizing an effective field theory (EFT) approach. In the recent work [1] by the CMS Collaboration [2], the production of jets and top quark-antiquark pairs in proton-proton collisions at the LHC is used in a SM analysis improved for EFT (SMEFT) to extract the QCD parameters simultaneously with the constraints on CI.

A measurement of the inclusive jet production cross section as a function of individual jet p_{T} and absolute rapidity $|y|$ is performed by the CMS Collaboration, using LHC proton-proton collision data at $\sqrt{s} = 13$ TeV. The present results involve jets reconstructed using the anti-k_{T} algorithm [3] with the distance parameter R=0.7, corresponding to an integrated luminosity of 33.5 fb^{-1}. The data are compared with fixed-order QCD predictions at NLO and NNLO, obtained using the NLOJet++ [4] and NNLOJET [5] programs, with the NLO calculations implemented in FastNLO [7]. The NLO cross-section is improved by next-to-leading logarithmic (NLL) corrections via joint threshold and jet-radius resummation [8]. Corrections for electroweak and nonperturbative effects are applied. A comparison of the experimental data with the theoretical predictions at NLO+NLL is shown in Fig. 1. Further details of the measurement, the theoretical predictions and the interpretation of the data are given in Ref. [1] and the references therein.

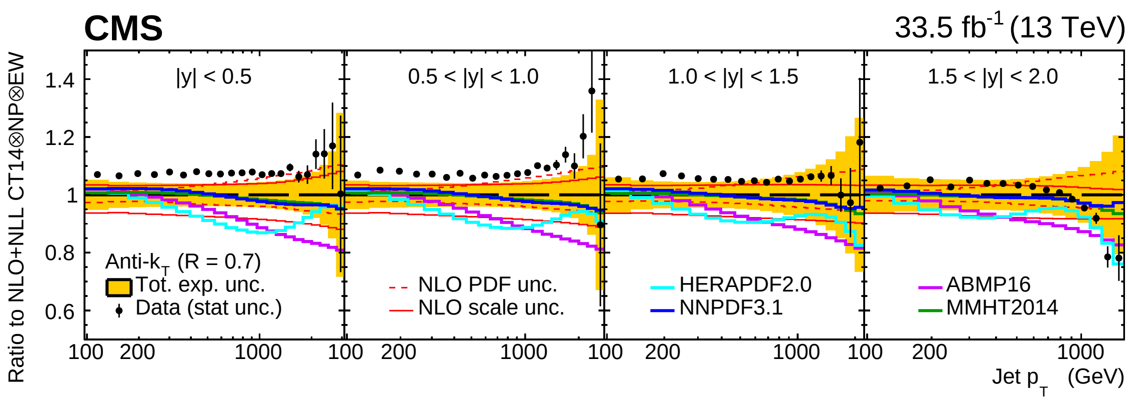

Figure 1: CMS measurements compared with the QCD prediction at NLO+NLL using different PDFs. The distributions are divided by the prediction obtained using the CT14 PDF [1].

The sensitivity of the present measurement to the proton PDFs and $\alpha_S(m_Z)$ is investigated in a comprehensive QCD analysis, where the inclusive jet production cross sections are used together with the charged and neutral current deep inelastic scattering (DIS) cross sections measured at HERA [9]. Additionally, the normalised triple-differential $\mathrm{t\bar{t}}$ cross section measured by the CMS Collaboration [6], is utilized. The QCD analysis [1] is performed at NLO and NNLO with the xFitter open-source QCD analysis framework version 2.2.1 [10]. In the QCD analysis, the NNLO predictions are approximated with k-factors, obtained as a ratio of the NNLO to NLO calculations using the CT14nnlo PDF [11] for each bin in p_T and $|y|$, and the factors are applied to the NLOJET++ prediction interfaced to xFITTER using the fast-grid techniques of FASTNLO. In the NLO analysis, the prediction is improved to NLO+NLL in a similar way. The QCD predictions for the normalised triple-differential cross section of the $t\bar{t}$ production are only available at NLO. The possible CI contributions are accounted for by extending the SM Lagrangian as $\mathcal{L}_{\mathrm{SMEFT}} = \mathcal{L}_{\mathrm{SM}} + \frac{4\pi}{2\Lambda^2}\sum_n c_n O_n$, where Λ is the scale of new physics, c_n are Wilson coefficients and O_n are dimension-6 operators for 4-quark CI. The present CI model allows investigations of purely left-handed, vector-like or axial vector-like colour singlet exchanges. For the SMEFT analysis, xFITTER is interfaced with the CIJET [12] computation providing the predictions for CI contributions to jet production at NLO. For the first time, the PDFs, $\alpha_S(m_Z)$, m_t and the Wilson coefficient c_1 of 4-quark CI are extracted simultaneously in the context of the SMEFT analysis.

The impact of the present CMS jet measurement on PDFs and $\alpha_S(m_Z)$ is investigated in an analysis at NNLO, using SM predictions. The significant improvement in the precision of the resulting PDFs is shown in Fig. 2. Simultaneously, the value of $\alpha_S(m_Z) = 0.1170 \pm 0.0019$ is obtained, which is thus far the most precise single measurement at the LHC.

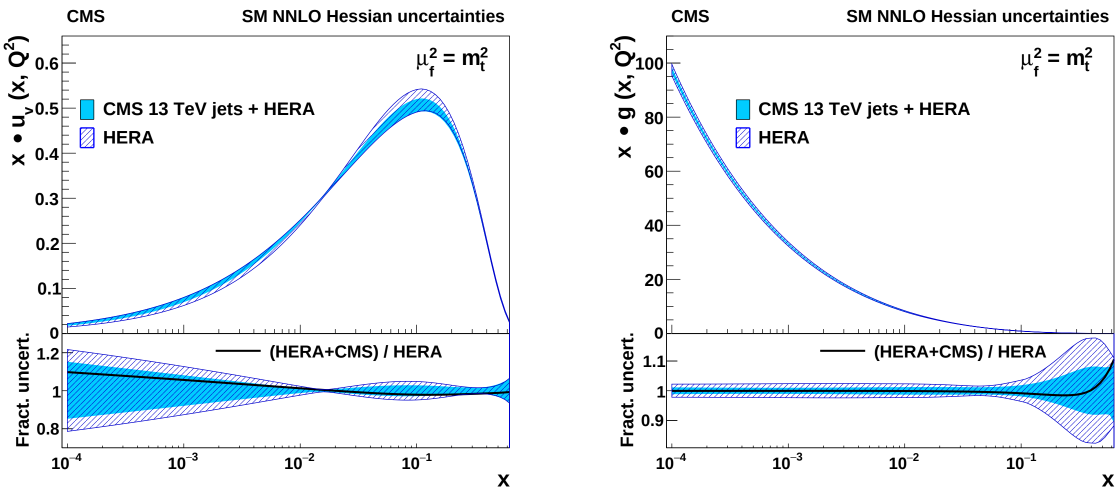

Figure 2: The u-valence (left) and gluon (right) distributions as a function of x at the scale $\mu_f \approx m_t$. The filled (hatched) band represents the results of the NNLO fit using HERA DIS and the CMS inclusive jet cross section at $\sqrt{s} = 13$ TeV (using the HERA DIS data only). The PDFs are shown with their total uncertainty. The lower panels show a comparison of the relative PDF uncertainties and the PDF ratios of the two fits [1].

Including the $t\bar{t}$ measurements in the SM fit at NLO permits a simultaneous extraction of the PDFs, $\alpha_S(m_Z)$ and the top quark pole mass m_t. The obtained value of $m_t = 170.4 \pm 0.7$ GeV agrees with the previous CMS result [6], while improving its precision.

In an alternative analysis performed using SMEFT predictions at NLO, the PDFs, $\alpha_S(m_Z)$, and m_t are extracted simultaneously with the Wilson coefficient c_1 for CI models corresponding to purely left-handed, vector-like or axial vector-like colour singlet exchanges. As the novelty and advantage of the SMEFT analysis, the simultaneous extraction of SM and EFT parameters ensures that no BSM effect is absorbed in the SM prediction. The PDFs and QCD parameters resulting from the SMEFT fit agree with those obtained in an alternative NLO fit performed using SM predictions, as detailed in Ref. [1]. A comparison of the PDFs resulting from the two fit variants is shown in Fig. 3. The ratio of the fitted c_1 to Λ^2 is presented for the different CI models in Fig. 4. The resulting negative c_1 implies constructive interference with the SM gluon exchange, but is statistically compatible with zero.

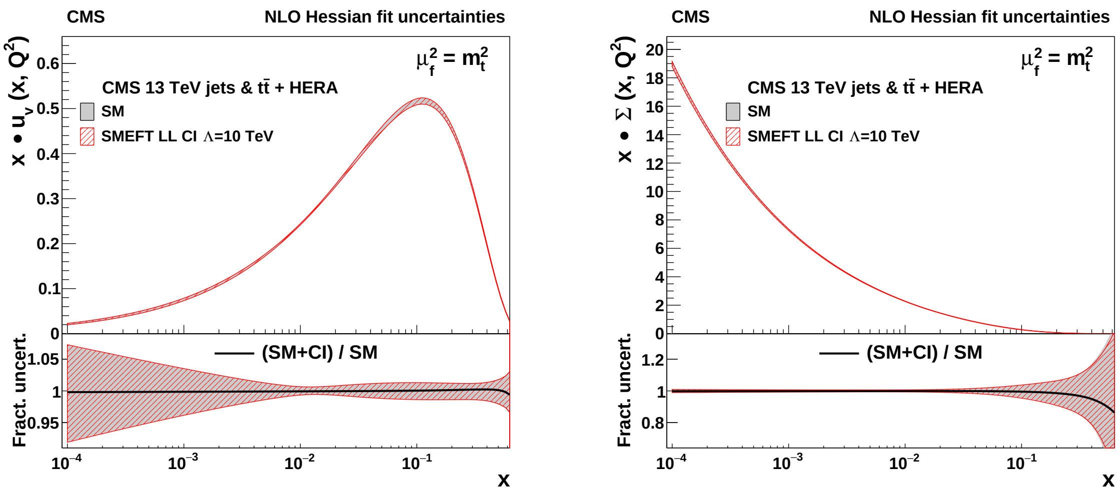

Figure 3: A comparison of the u-valence (left) and sea quark (right) distributions as a function of x at the scale $\mu_f \approx m_t$, resulting from the SMEFT and SM fits using HERA DIS together with the CMS jet and $t\bar{t}$ production cross section measurements at $\sqrt{s}$ = 13 TeV. The SMEFT result is obtained for the left-handed CI model with Λ = 10 TeV, and agrees with the results for all other investigated CI models and Λ values [1].

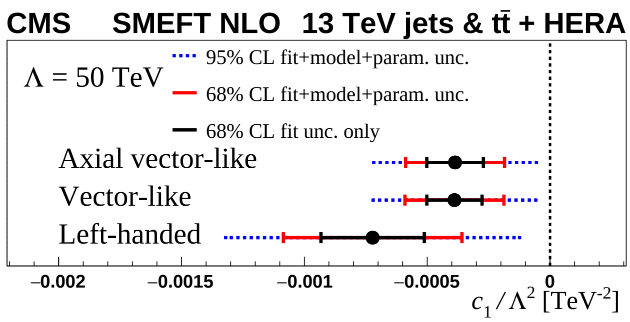

Figure 4: The Wilson coefficients c_1 obtained in the SMEFT analysis at NLO, divided by Λ^2, for Λ=50 TeV. The solid (dashed) lines represent the total uncertainty at 68 (95)% confidence level (CL). The inner (outer) error bars show the fit (total) uncertainty at 68% CL [1].

In conventional searches for CI, a scan for Λ is performed with c_1 fixed to $+1$ (-1) for destructive (constructive) interference with the SM gluon exchange. The results of the present fit are translated into unbiased 95% CL exclusion limits on Λ with $c_1 = -1$, yielding 24 TeV for left-handed, 32 TeV for vector-like, and 31 TeV for axial-vector-like CI. The most stringent comparable result is 22 TeV for left-handed CI with constructive interference, obtained by the ATLAS Collaboration from dijet production cross sections in pp collisions at $\sqrt{s}$ = 13 TeV [13].

References

[1] CMS Collaboration, *JHEP* **02** (2022) 142, doi:10.1007/JHEP02(2022)142 [arXiv:2111.10431 [hep-ex]].

[2] CMS Collaboration, *JINST* **3** S08004 (2008), doi:10.1088/1748-0221/3/08/S08004.

[3] Cacciari, Matteo and Salam, Gavin P. and Soyez, Gregory, *JHEP* **04** (2008) 063, doi:10.1088/1126-6708/2008/04/063 [arXiv:0802.1189 [hep-ph]].

[4] Z. Nagy, *Phys. Rev. Lett.* **88** (2002) 122003, doi:10.1103/PhysRevLett.88.122003 [arXiv:hep-ph/0110315 [hep-ph]]; Z. Nagy, *Phys. Rev. D* **68** (2003) 094002, doi:10.1103/PhysRevD.68.094002 [arXiv:hep-ph/0307268 [hep-ph]].

[5] J. Currie, E. W. N. Glover and J. Pires, *Phys. Rev. Lett.* **118** (2017) 072002, doi:10.1103/PhysRevLett.118.072002 [arXiv:1611.01460 [hep-ph]]; J. Currie, A. Gehrmann-De Ridder, T. Gehrmann, E. W. N. Glover, A. Huss and J. Pires, *JHEP* **10** (2018) 155, doi:10.1007/JHEP10(2018)155 [arXiv:1807.03692 [hep-ph]]; T. Gehrmann *et al.*, *PoS* **RADCOR2017** (2018) 074, doi:10.22323/1.290.0074 [arXiv:1801.06415 [hep-ph]].

[6] CMS Collaboration, *Eur. Phys. J. C* **80** (2020) 658, doi:10.1140/epjc/s10052-020-7917-7 [arXiv:1904.05237 [hep-ex]].

[7] fastNLO Collaboration, doi:10.3204/DESY-PROC-2012-02/165 [arXiv:1208.3641 [hep-ph]].

[8] X. Liu, S. O. Moch and F. Ringer, *Phys. Rev. D* **97** (2018) 056026, doi:10.1103/PhysRevD.97.056026 [arXiv:1801.07284 [hep-ph]].

[9] H. Abramowicz *et al.*, H1 and ZEUS Collaborations, *Eur. Phys. J. C* **75** (2015) 580, doi:10.1140/epjc/s10052-015-3710-4 [arXiv:1506.06042 [hep-ex]].

[10] S. Alekhin *et al.*, *Eur. Phys. J. C* **75** (2015) 304, doi:10.1140/epjc/s10052-015-3480-z [arXiv:1410.4412 [hep-ph]]; xFitter Developers' Team, *PoS* **DIS2017** (2018) 203, doi:10.22323/1.297.0203 [arXiv:1709.01151 [hep-ph]]; H. Abdolmaleki *et al.* [xFitter], [arXiv:2206.12465 [hep-ph]]; xFitter Developers' Team, https://www.xfitter.org/xFitter/

[11] S. Dulat *et al.*, *Phys. Rev. D* **93** (2016) 033006, doi:10.1103/PhysRevD.93.033006 [arXiv:1506.07443 [hep-ph]].

[12] J. Gao, *Comput. Phys. Commun.* **184** (2013) 2362, doi:10.1016/j.cpc.2013.05.019 [arXiv:1301.7263 [hep-ph]]; J. Gao, C. S. Li and C. P. Yuan, *JHEP* **07** (2012) 037, doi:10.1007/JHEP07(2012)037 [arXiv:1204.4773 [hep-ph]].

[13] M. Aaboud *et al.* [ATLAS], Phys. Rev. D **96** (2017) no.5, 052004 doi:10.1103/PhysRevD.96.052004 [arXiv:1703.09127 [hep-ex]].