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# Recent jet measurements at CMS

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Several measurements of jet cross sections in proton-proton collisions at 5.02 and 13 TeV with the CMS experiment are presented. Jets are reconstructed using the anti-$k_T$ clustering algorithm with $R = 0.4$ and $R = 0.7$. Double-differential measurements of inclusive jet production at 5.02 and 13 TeV are performed as a function of the jet transverse momentum and jet rapidity; furthermore, a triple-differential measurement as a function of leading jet transverse momentum, dijet azimuthal correlations, and jet multiplicity and a double-differential measurement as a function of jet multiplicity and single-jet transverse momentum are also provided for multijet production at 13 TeV. The measured jet cross sections are corrected for detector effects and compared with the predictions from perturbative QCD. Finally, a QCD interpretation of the inclusive jet measurement with $R = 0.7$ at 13 TeV is also presented.

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# 1. Introduction

We present the measurement of several double-differential (2D) and triple-differential (3D) jet cross sections in proton-proton collisions performed with the CMS experiment [1] for jets with transverse momentum $p_\mathrm{T} \sim O(10^2 - 10^3)$ GeV.

Measurements of inclusive jet cross sections at both 5.02 [2] and 13 TeV [3] (Section 2) are used to test PDFs $f_i$ and fixed-order predictions (FO) at next-to-leading order (NLO), NLO completed with next-to-leading logarithms (NLO+NLL), and next-to-next-to-leading order (NNLO) of the partonic cross section. At 13 TeV, a QCD interpretation (Section 3) of the measurement is also performed to constrain $f_i$ and to extract the strong coupling constant $\alpha_S(M_Z)$; in addition, 4-quark contact interactions (CIs) are also investigated in the context of a SM effective field theory (SMEFT) [4].

Measurements of multijet cross sections [5] (Section 4) are useful to investigate the contributions from higher orders in perturbation theory with Monte Carlo generators (MC) in the partonic cross section. In particular, they allow comparisons to predictions with transverse-momentum-dependent PDFs with the parton branching method [6, 7] for the first time on a large phase space.

# 2. Measurements of inclusive jet production at 5.02 and 13 TeV

The 2D inclusive jet cross section is measured as a function of jet $p_\mathrm{T}$ and rapidity $y$. The measurement at 5.02 (13) TeV is performed with a dataset recorded in 2015 (2016) with low (high) pile-up[1], and includes jets with $p_\mathrm{T} > 64$ (97) GeV and $|y| < 2.0$. The 5.02 TeV analysis only includes jets clustered with $R = 0.4$ while the 13 TeV analysis includes both $R = 0.4$ and $R = 0.7$. Both measurements re-use the binning of the former measurements [8–11] with the only difference being that the $p_\mathrm{T}$ bins are merged in pairs during the procedure of unfolding.

The analysis strategy is similar as in former analyses by the CMS Collaboration, with a few differences that we will highlight in this section. Both measurements rely on a series of single-jet triggers to cover production rates of different orders of magnitude; the 5.02 TeV measurement uses the same approach as former measurement by applying a global normalisation factor all jets recorded by a given trigger, while the 13 TeV measurement relies on a per-event normalisation. Jet energy and pile-up corrections are considered in both analyses.

Detector and reconstruction effects are corrected via a procedure of unfolding. In former measurements, the unfolding was performed separately in each rapidity region with the iterative algorithm proposed by D'Agostini [12] and using toy response matrices (RMs) based on pure Gaussian $p_\mathrm{T}$ resolution. The present measurements both use the least-square minimisation implemented in the TUnfold package [13]. For the 5.02 TeV measurement, separate toy RMs are still used for each rapidity regions but include deviations from a pure Gaussian resolution; for the 13 TeV measurement, a global 2D RM is constructed directly from the full-simulation samples.

For both measurements, FO calculations at NLO and NNLO and with jet $p_\mathrm{T}$ and $H_T$ parton scale choices are obtained with the NNLOJET program [14, 15]; in addition, for the 13 TeV measurement, comparisons to NLO+NLL are also available [16]. The predictions are corrected

[1]The pile-up refers to the additional interactions occurring within the same or nearby proton bunch crossings in the CMS detector.

for non-perturbative and electroweak effects. Here, we only show the comparison of the 13 TeV measurement to NLO+NLL predictions with jet $p_T$ scale and to several PDF sets [17–21] in Fig. 1.

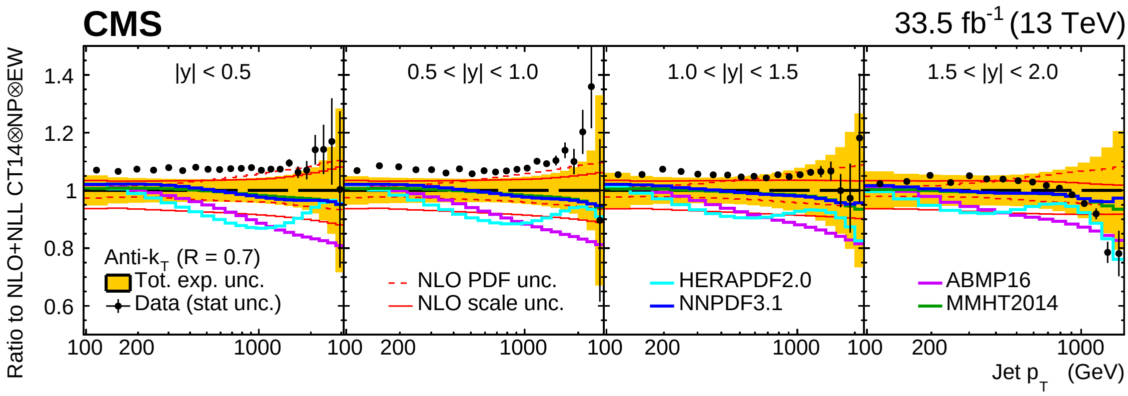


**Figure 1:** Comparison of inclusive jet measurement at 13 TeV to NLO+NLL predictions with different global PDF sets. Figure taken from Ref. [3].

## 3. Interpretation of inclusive jet production at 13 TeV

The inclusive jet production is sensitive to PDFs, especially the gluon PDF, and to $\alpha_S(M_Z)$. The measurement at 13 TeV with $R = 0.7$ is used, together with HERA DIS data [21] and the normalised 3D $t\bar{t}$ CMS measurement at 13 TeV [22], for a QCD interpretation following the approach of HERAPDF2.0 [21] with the xFitter program [23, 24]. As $t\bar{t}$ data are included, the top quark mass $m_t$ is also released in the fit. The results from the fit on the gluon PDF is shown on Fig. 2 (left).

Furthermore, CIs are also investigated in the context of a SMEFT. The results from the fit on the singlet PDF is shown on Fig. 2 (right), and the Wilson coefficient is included in the fit and found in agreement with 0; in other words, there is no evidence for CIs in $pp$ collisions.

## 4. Multijet production at 13 TeV

The multijet measurements rely on the same data samples and the same analysis strategy as the inclusive jet measurement at 13 TeV. Only jets clustered with $R = 0.4$ are considered. At least two jets are required for an event to be considered, with the leading (subleading) jet $p_T > 200$ (100) GeV; additional jets are only considered if $p_T > 50$ GeV. All jets must satisfy with $|y| < 2.5$.

Two multijet observables are measured: a 3D cross section as a function of the azimuthal angle formed by the two leading jets, the jet multiplicity of the event, and the leading jet $p_T$; and the single-jet spectra as a function of $p_T$ in di-, tri-, and four-jet configurations. The measurements are normalised to the measured inclusive dijet cross section. These observables are sensitive to higher-order corrections; in particular, they allow tests of initial- and final-state radiations.

In Fig. 3, one $p_T^{\text{leading}}$ bin of the 3D normalised cross section is compared to predictions from MadGraph_aMC@NLO [25] matched with shower algorithms from Pythia 8 [26] or Cascade 3 [6, 7].

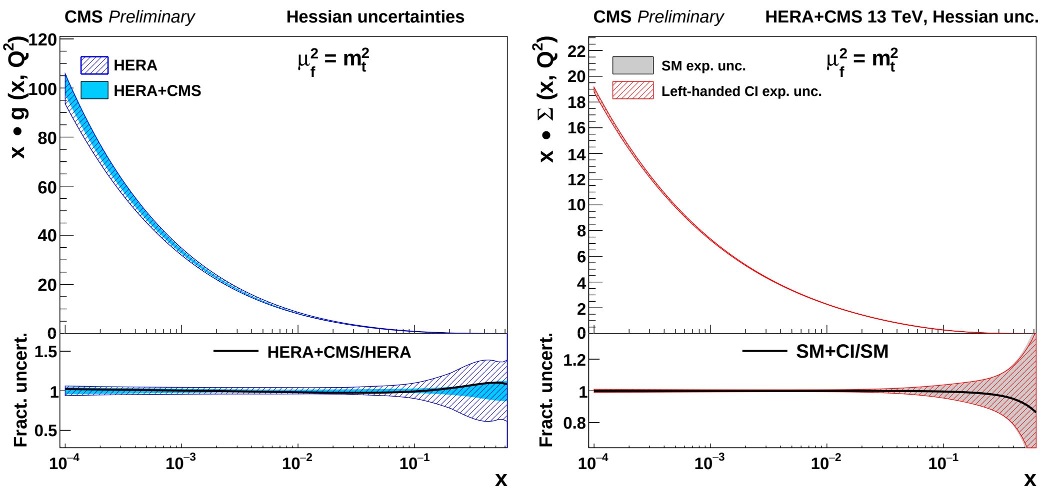


**Figure 2:** On the left: the hatched (filled) band corresponds to the gluon PDF obtained with HERA DIS data only (both HERA DIS data and CMS data), shown at the factorisation scale corresponding to the top mass in the context of a SM interpretation. On the right: the hatched (filled) band corresponds to the singlet PDF obtained with both HERA and CMS data at the same scale in the context of a SMEFT interpretation. The fits are performed with fixed-order prediction at NLO+NLL. Figure taken from Ref. [3].

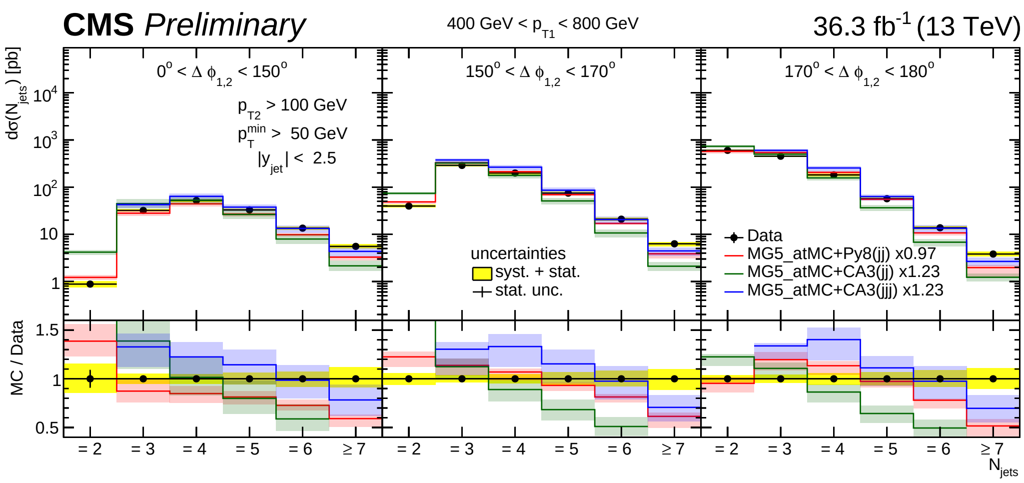


**Figure 3:** Comparison of the 3D cross section of the two leading jets at 13 TeV as a function of azimuthal decorrelation of the dijet system, the jet multiplicity of the event, and $p_T^{\text{leading}}$. Figure taken from Ref. [5].

## 5. Summary

The CMS Collaboration is preparing several publications about inclusive jet production in proton-proton collisions at 5.02 and 13 TeV, and multijet production at 13 TeV. Data are compared to fixed-order predictions at NLO, NLO+NLL, and NNLO, as well as to MC event generators. A novel QCD interpretation including profiling studies and unbiased search for CIs has been presented; no evidence for CIs has been found.

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