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α_s from jets in pp collisions

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A determination of the strong coupling constant α_s from the single jet inclusive cross section measurements at the LHC is envisaged, using theoretical predictions at next-to-next-to-leading-order (NNLO) in QCD.

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The observation of jet production at hadron colliders directly probes the basic parton-parton scattering process in QCD. As such, a number of fundamental quantities can be inferred from these measurements, such as, for example, the QCD coupling constant. As will be shown below, the interplay between the sensitivity of the inclusive jet p_T-spectrum to α_s, and the experimental precision of the measurement is very favourable for a strong coupling extraction. This stems from the fact that for sufficiently high-p_T jets, the jet cross section has a large rate at the LHC and a clean and simple definition, allowing jet measurements to become very precise.

Single jet inclusive measurements at the LHC have been performed by the ATLAS and CMS experiments at $\sqrt{s}$ = 7 TeV [1, 2, 3], $\sqrt{s}$ = 8 TeV [4, 5] and $\sqrt{s}$ = 13 TeV [6, 7]. At present, the systematic uncertainty in the measurement is dominated by the jet energy scale (JES) at the 1–2% level, which, due to the steeply falling jet-p_T spectrum, translates to a $< 10\%$ uncertainty on the cross section as shown in Fig. 1. Over a wide range in jet-p_T, it is similarly observed in ATLAS and CMS a 5% systematic uncertainty in the measurement and a statistical uncertainty at the subpercent level, which paves the way towards jet precision physics studies at the LHC. To this end, the availability of multiple single jet inclusive datasets allows for an investigation of the consistency of the data and a possible simultaneous inclusion in a combined α_s determination.

In reference [4], an α_s extraction from the single jet inclusive observable was performed using 19.7 fb^{-1} of data recorded by the CMS detector from pp collisions at $\sqrt{s} = 8$ TeV. In this study, 185 data points of the double differential inclusive jet cross section in the p_T range 74 GeV to 2116 GeV and rapidity bins with $|y| < 3.0$, together with their statistical and systematic uncertainties and their correlation were used. The double differential inclusive jet cross section measurement [4] is shown in Fig. 2 (left) together with the NLO QCD prediction given by,

$$\frac{d\sigma}{dp_T} = \alpha_s^2(\mu_R)\hat{X}^{(0)}(\mu_F, p_T)\,[1 + \alpha_s(\mu_R)\mathrm{K1}(\mu_R, \mu_F, p_T)] \tag{1}$$

where α_s is the strong coupling, $\hat{X}^{(0)}(\mu_F, p_T)$ represents the LO contribution to the cross section and $\mathrm{K1}(\mu_R, \mu_F, p_T)$ is the NLO correction. A good agreement between the measured cross section and the theoretical prediction can be seen in Fig. 2 (right), within the errors of the NLO calculation, estimated by varying the renormalization and factorization scales in the following six combinations of scale factors: $(\mu_R/\mu, \mu_F/\mu)$ = (0.5, 0.5), (2, 2), (1, 0.5), (1, 2), (0.5, 1), (2, 1),

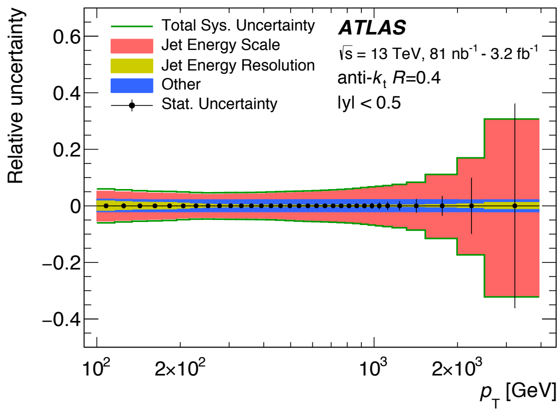

Figure 1: Relative systematic uncertainty for the inclusive jet cross-section as a function of the jet p_T [7].

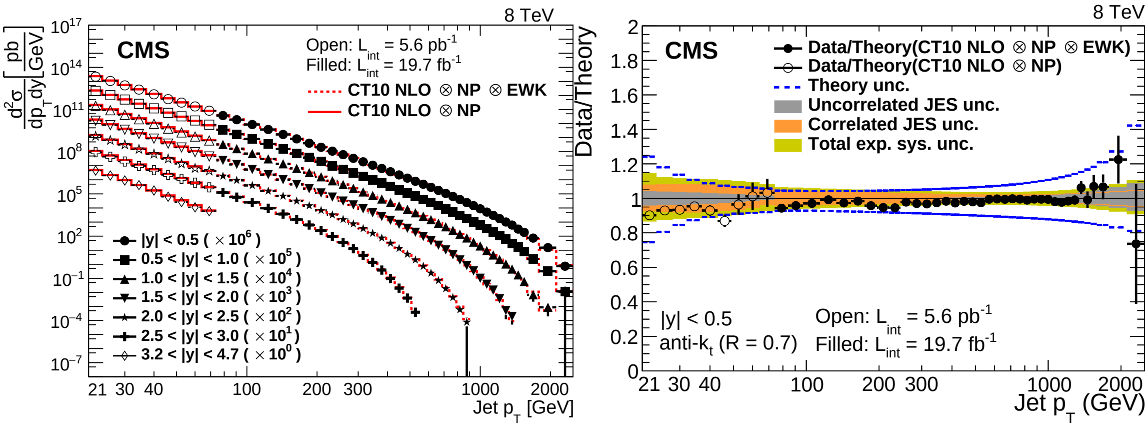

Figure 2: Left: Double-differential inclusive jet cross sections as function of jet p_T. Data and NLO predictions based on the CT10 PDF set [4]. Right: Ratios of data to the theory prediction using the CT10 PDF set. For comparison, the total theoretical (band enclosed by dashed lines) and the total experimental systematic uncertainties (band enclosed by full lines) are shown as well [4].

with μ the default choice equal to the jet p_T. The sensitivity of the theory prediction to the α_s choice in the PDF is illustrated in Fig. 3, where predictions corresponding to 16 different $\alpha_s(m_Z)$ values in the range 0.112 to 0.127 in steps of 0.001 are plotted [4].

A comparison with the measured spectrum using the CT10 NLO PDF set, gives the best fitted $\alpha_s(m_Z)$ value [4] of,

$$\alpha_s(m_Z)(\text{NLO}) = 0.1164^{+0.0025}_{-0.0029}(\text{PDF})^{+0.0053}_{-0.0028}(\text{scale}) \pm 0.0001(\text{NP})^{+0.0014}_{-0.0015}(\text{exp}) = 0.1164^{+0.0060}_{-0.0043},$$

where the largest source of uncertainty in the α_s determination comes from the scale uncertainty of the NLO theory prediction, a strong indicator to the need of including higher-order corrections in

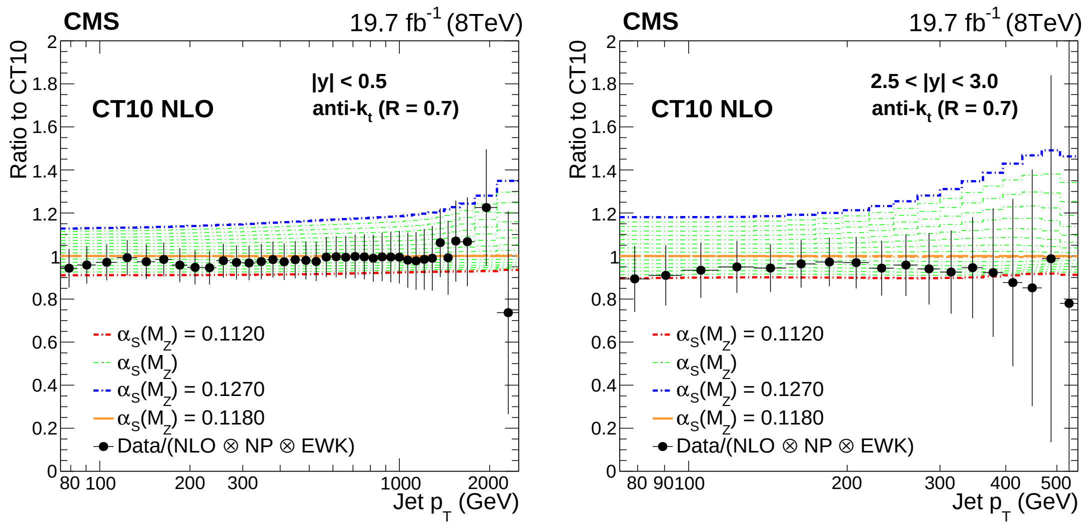

Figure 3: Ratio of data over theory prediction (closed circles) using the CT10 NLO PDF set, with the default $\alpha_s(m_Z)$ value of 0.118. Dashed lines represent the ratios of the predictions evaluated with different $\alpha_s(m_Z)$ values, to the central one. The error bars correspond to the total uncertainty of the data [4].

the theoretical calculation.

To this end, NNLO corrections to the single jet inclusive observable including the dominant leading colour contribution from all partonic subprocesses in all channels, have been computed recently in Refs. [8, 9]. These recent results provide new opportunities for QCD studies at hadron colliders, enabling precise theoretical predictions for jet observables to be used in α_s extractions from LHC jet data. In particular, the scale uncertainty of the jet cross section at NNLO has been thoroughly investigated in Ref. [9], leading to the observation that for this observable, the central scale choices $\mu = 2p_T$ and $\mu = \hat{H}_T$[1] are clearly found to be favoured in terms of stability and convergence of the predictions for single jet inclusive production.

In the remainder of this contribution we present our numerical predictions for the $\sqrt{s} = 8$ TeV single jet inclusive measurement from CMS [4], which are relevant for an α_s determination at NNLO. The high-precision differential QCD jet calculations to NNLO accuracy are performed by using the newly developed parton-level generator NNLOJET [10] with the MMHT2014 PDF set [11].

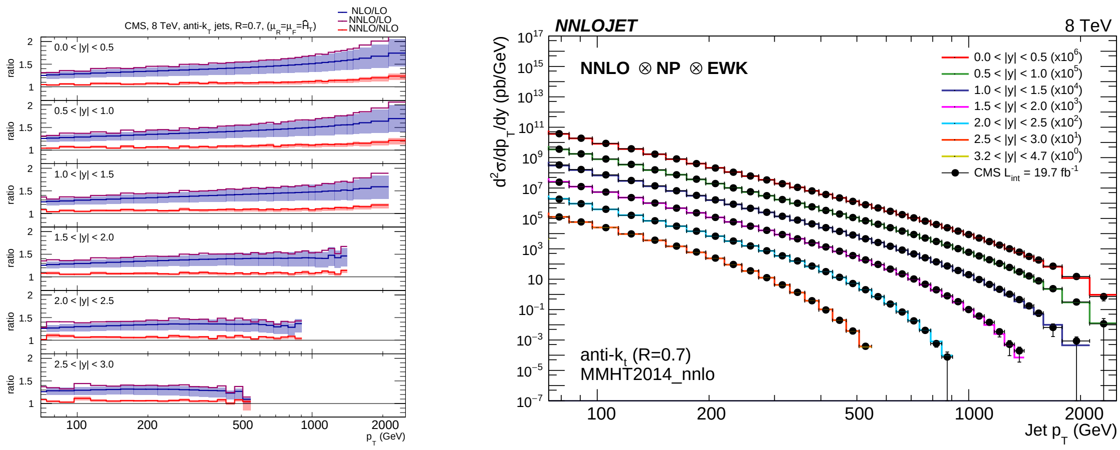

Figure 4: Left: Double-differential inclusive jet cross sections *k*-factors NNLO/NLO (red), NLO/LO (blue) and NNLO/LO (purple). The shaded bands represent the scale uncertainty of the theory predictions by varying μ_R and μ_F as described in the text. Right: The entire range of the CMS measurement compared to NNLO predictions corrected by non-perturbative (NP) and electroweak corrections (EWK) as estimated in the CMS publication [4].

In Fig. 4 (left) we show the impact of the newly computed NNLO contribution by plotting explicitly the ratio between the NNLO prediction and the NLO result (in red), together with the ratio between the NLO cross section and the LO result (in blue) for the central scale choice $\mu = \hat{H}_T$. The NNLO correction ranges from 10% at low-p_T to 20% at the highest-p_T of 2.5 TeV, with scale uncertainties at the 5% level, a significant reduction with respect to NLO. In the same figure, on the right, the entire range of the CMS measurement is compared to NNLO predictions corrected by non-perturbative (NP) and electroweak corrections (EWK) as estimated by the CMS collaboration [4].

The remarkable improvement in the description of the CMS data at NNLO can be seen more clearly in Fig. 5 that explicitly shows the CMS data (black data points) and the NNLO prediction

[1] Where $\hat{H}_T = \sum_{i \in \text{partons}} p_{T,i}$ is defined as the transverse momentum sum of all partons in the event.

(in red), normalised to the NLO result (in blue). Over a wide range in jet-p_T and rapidity $|y|$ we observe an excellent description of the jet spectrum at NNLO. A full α_s fit at NNLO to the CMS dataset requires now a fast evaluation of the NNLO cross section for different input PDF and α_s values.

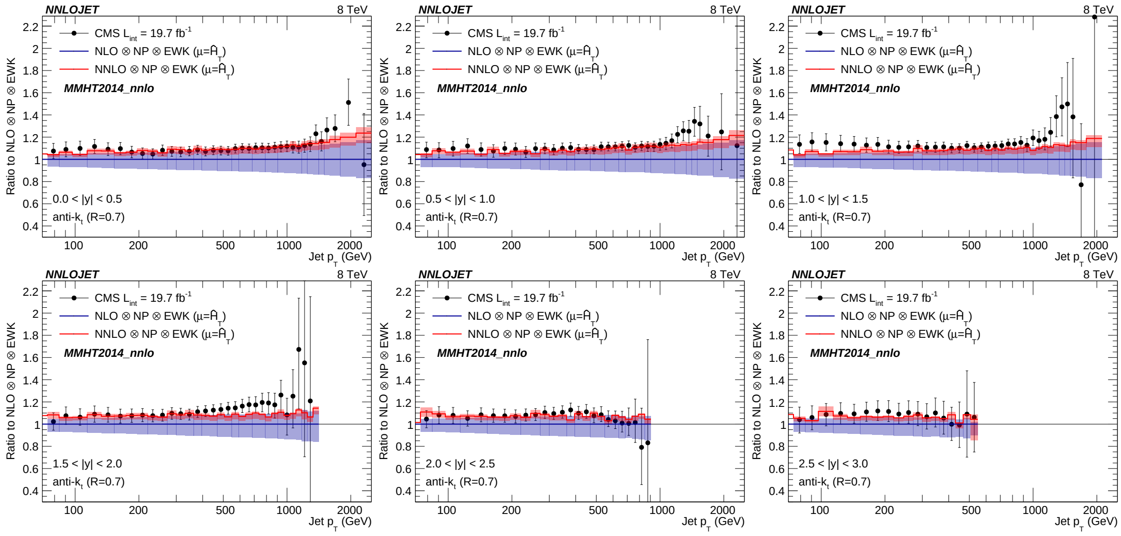

Figure 5: CMS data [4] (black data points) and NNLO prediction (in red) normalised to the NLO result (in blue) for the rapidity $|y|$ bins of the CMS $\sqrt{s}$ = 8 TeV single jet inclusive measurement. Non-perturbative (NP) and electroweak corrections (EWK) as estimated in the CMS publication [4] are applied multiplicatively on top of the perturbative QCD results.

To this end, in close collaboration with experts from the FASTNLO [12] and APPLGRID [13] collaborations, an APPLFAST interface to the program NNLOJET [10] is in development to provide a fast and flexible way to reproduce the results of full jet cross sections at NLO and NNLO for the first time, in both FASTNLO and APPLGRID formats, which are suitable for state-of-the-art fits of PDF and α_s with LHC jet data at NNLO.

It is anticipated that these results can substantially reduce the uncertainties on current determinations of α_s from jet production at the LHC, which are largely dominated by the scale uncertainty of the NLO prediction. The scale uncertainties at NNLO are below the 5% level, which, depending on the jet-p_T, correspond to a reduction by more than a factor of 2 with respect to NLO. The incorporation of NNLO corrections in α_s fits to jet cross sections at hadron colliders and a consistent combination of the multiple datasets available at the LHC, can in this way, open up a new contribution to the α_s PDG average [14] with a target precision at the ∼1–2% level in the upcoming years.

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