The Compact Muon Solenoid Experiment

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Inclusive Jet cross section and strong coupling constant measurements at CMS

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Inclusive Jet Cross Section and Strong Coupling Constant Measurements at CMS

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INTRODUCTION

The main goal of studies of quantum chromodynamics (QCD), describes the interaction among sub-nuclear colored partons, is to improve our detailed description of the Standard Model (SM) physics. The fixed order perturbative QCD (pQCD) calculations along with non-perturbative (NP) hadronization model and PDF parametrization, predict the dynamics and cross-section of a hadron collision processes within uncertainty limits.

Jets, collimated streams of particles, are abundantly produced in high energetic proton-proton collisions at the LHC. Jet measurements become an important and interesting study to test and validate QCD theory predictions at the LHC in unexplored kinematic regimes. The hadronization and parton shower models can be optimized by using the jet variables and also the parameters of PDFs can be constrained. The running of strong coupling constant α_s in the new kinematic regimes can also be extracted using the jet observables. QCD processes act as a major background to other SM process and new physics searches. A precise estimation of QCD background becomes essential in those studies, which can be accurately done using jet observables. The data presented here were collected by the Compact Muon Solenoid (CMS) experiment, whose detailed description can be found elsewhere [1].

JET RECONSTRUCTION AND CALIBRATION

Several event reconstruction techniques are used in the CMS detector. The most widely used one is the particle flow (PF) [2] event reconstruction which consists in reconstructing and identifying each single particle with an optimised combination of all sub-detector information, and the particle-flow candidates obtained this way are clustered into jets with the anti- k_T [3] clustering algorithm. PF reconstruction benefits from precise trackers, highly granular electromagnetic calorimeter (ECAL), hadronic calorimeter (HCAL) and strong magnetic field. The strong magnetic field and ECAL help to separate charged particles from the neutral particles. The jet reconstruction algorithm is applied on the final state stable particles in order to reconstruct the jets. The jet energy corrections (JEC) are obtained with the dijet asymmetry method which explicitly takes into account the initial and final state radiations by extrapolating additional jet activity to zero and by subtracting the particle level imbalance determined from Monte Carlo in order to account for the underlying event and out-of-cone radiations. The measured PF energy fractions are shown in Figure 1 (Right)

as a function of p_T [4]. Good agreement between data and simulation is observed. The JEC uncertainties for each subcorrection are summarized in Figure 1 (Left). The uncertainties are provided as systematic sources which keeps correlation across p_T and η for physics analyses.

FIGURE 1. Left: Summary of JES systematic uncertainties, for different values of jet p_T for $|\eta_{jet}| = 0$. Markers represent the single effect of different sources whereas the grey band the cumulative total uncertainty. The total uncertainty, when excluding the effects of time dependence and flavor, is also shown in yellow. Right: PF jet composition for data and simulation as a function of η at $56 < p_T < 74$ GeV.

RESULTS

Measurements of the double-differential inclusive jet ($p + p \rightarrow \text{jet} + X$) and dijet ($p + p \rightarrow \text{jet} + \text{jet} + X$) production cross sections are traditional tools for studying the proton structure. The measurement of the inclusive jet cross section as functions of jet rapidity y and either jet transverse momentum p_T or dijet invariant mass M_{jj} has been performed at $\sqrt{s} = 7$ TeV [5] by the CMS collaboration. The measured cross sections are corrected for detector effects and compared to the QCD predictions. Figure 2 (Left) shows the comparison of differential inclusive jet cross section to perturbative QCD predictions at next-to-leading order (NLO) and good agreement is found in the entire phase space. The ratio of CMS data to the theoretical prediction using the central value of the NNPDF2.1 PDF [6] set is shown in Figure 2 (Right). The experimental uncertainty is comparable to the theoretical uncertainty.

The inclusive jet cross section measurements [7, 8] are performed in pp collisions at $\sqrt{s} = 8$ TeV data collected by the CMS detector. The anti- k_T jet clustering algorithm with distance parameter $R = 0.7$ is used in the rapidity range of $|y| < 4.7$ for $21 < p_T < 2000$ GeV. Figure 3 (Left) shows the comparison of differential inclusive jet cross sections measured at low and high transverse momenta to NLO theory using NNPDF2.1 PDF set and corrected for non-perturbative (NP) effects. The NP factor is applied on NLO spectrum to account for hadronization effects and multi parton interactions (MPI). The NP correction factor is determined with two generators, PYTHIA version 6.4.22 [9] and HERWIG++ version 2.4.2 [10]. The difference in the factor obtained from these two event generators is counted as the uncertainty introduced due to NP correction on the measured cross section. The ratio of both data and theoretical predictions based on the NNPDF 2.1 is shown in Figure 3 (Right). A good level of agreement is observed between data and theory within the uncertainties throughout the kinematic range covered. NLO theoretical calculations are repeated with five different PDF sets, ABM11 [11], CT10 [12], HERAPDF1.5 [13], and MSTW2008 [14]. Three sources of theoretical uncertainties PDF, scale and $\alpha_S(M_Z)$ are considered.

Certain jet observables, with small renormalization and factorization scale uncertainty on the theory side and reduced jet energy scale uncertainty on the experimental side, can be used to measure α_S . The inclusive jet spectrum measured by the CMS collaboration is also used to constrain PDFs [15], and mainly the gluon PDF which is highly

FIGURE 2. Left: The measured double differential inclusive jet production cross-section for five different rapidity bins in pp collisions at $\sqrt{s} = 7$ TeV. Right: Ratio of inclusive jet cross sections compared to theoretical prediction using the central value of NNPDF2.1 PDF set for $|y| < 0.5$.

FIGURE 3. Left: Differential inclusive jet cross sections comparison to the theoretical prediction using the central value of the NNPDF2.1 PDF set times the NP correction factor. Right: Ratio of data and over the theory prediction using NNPDF2.1 PDF set for the innermost rapidity bin $|y| < 0.5$. The error bars represent the statistical uncertainty of the data.

correlated to this observable. Figure 4 (left) shows the running of α_s recent CMS measurements covering 1 TeV region and also the measurements from other collider experiments at lower Q . Overall, the α_s measurements with jets are in agreement with the world-average value $\alpha_s(M_Z) = 0.1185 \pm 0.0006$. These measurements are also used to test the renormalization group evolution at the highest momentum scales. An overview of the gluon, sea, u valence (u_V), and d valence (d_V) PDFs at starting scale $Q^2 = 1.9 \text{ GeV}^2$ is shown in Figure 4 (right). A significant improvement of precision is observed in the high- x region by including the CMS data with DIS data at HERA. For the gluon distribution, the parametrization and model uncertainties are reduced significantly for almost all x range, while for the

sea quark distribution some reduction in their uncertainty is visible at high x .

FIGURE 4. Left: The running of the strong coupling as a function of Q . Results from HERA and Tevatron colliders are shown with the results from the four CMS measurements covering 1 TeV region. Right: The PDF fit outcome from the HERAPDF method at the starting scale of the evolution of $Q^2 = 1.9 \text{ GeV}^2$. The band around the central fit result represents the total uncertainty including the CMS inclusive jet data.

SUMMARY

The large dataset of pp collisions has been accumulated by CMS during the Run I data taking period. The CMS collaboration has already provided extensive list of measurements on the jets and the strong coupling constant based on different observables. All measurements are found to have good agreement with the world average value and the running of α_s is confirmed for the first time at the TeV scale. The inclusive jet spectrum is used to provide additional constraints to PDFs, thus improving the gluon and the valence-quark distributions.

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