The Compact Muon Solenoid Experiment
Conference Report

Mailing address: CMS CERN, CH-1211 GENEVA 23, Switzerland

19 August 2015 (v3, 29 August 2015)

Jet production and α_s measurements at CMS

Giannis Flouris for the CMS Collaboration

Abstract

The measurements of inclusive jet, dijet and trijet cross sections, of the dijet azimuthal decorrelations, the ratio of the inclusive 3-jet to 2-jet cross sections are presented. The measurements use the samples of proton-proton collisions collected with the CMS detector at the LHC at a center-of-mass energy of 7 and 8 TeV.

Presented at *QCD15 18th High Energy Physics International Conference in Quantum Chromodynamics (QCD)*

Jet production and α_s measurement at CMS. ^{*}

 Giannis Flouris ¹

Department of Physics, University of Ioannina, Greece

Abstract

The measurements of inclusive jet, dijet and trijet cross sections, of the dijet azimuthal decorrelations, the ratio of the inclusive 3-jet to 2-jet cross sections are presented. The measurements use the samples of proton-proton collisions collected with the CMS detector at the LHC at a center-of-mass energy of 7 and 8 TeV.

Keywords: QCD, Jets, Strong coupling constant, CMS

1. Introduction

Jets are streams of particles clustered together; they are signatures of quarks and gluons in the detector. Despite the fact that jets are long-distance objects unlike constrained quarks, the factorization theorem can isolate the long distance contributions and render perturbative quantum chromodynamics (pQCD) into a useful tool for predictions and comparisons to experiment. QCD can be treated as a perturbative theory as long as the asymptotic freedom assumption is valid.

LHC produces jets in galore in high scales, allowing the study of the pQCD validity and measure the strong coupling constant and its running. This proceeding present five CMS measurements, two of them measured the strong coupling constant at mass of Z boson, $\alpha_s(M_Z)$. The inclusive jet differential cross section at 8 TeV [1][2], the dijet cross section at 8 TeV [3], the dijet azimuthal decorrelations at 8 TeV [4], the ratio of the inclusive 3-jet to the inclusive 2-jet cross section and the extraction of the strong coupling constant at 7 TeV[5], and the measurement of the 3-jet mass cross section at 7 TeV and determination of $\alpha_s(M_Z)$ [6].

2. The Measurements

CMS measured the double differential cross section on transverse momentum, p_T , and rapidity, $|y|$, as a function of p_T in bins of $|y|$.

Figure 1: Double differential inclusive jet cross section measurement at 8 TeV compared to theory (red) using NNPDF2.1 and corrected for NP effects.

Figure 1 shows the measurement compared to theory (red line). The measurement consists of two datasets, one low pile-up (PU) and one high PU, corresponding to

^{*}Talk given at 18th International Conference in Quantum Chromodynamics (QCD 15, 30th anniversary), 29 June - 3 July 2015, Montpellier - FR

¹Speaker, on behalf of the CMS Collaboration.

low and high p_T region respectively. The cross section has been measured in six bins of $\Delta|y| = 0.5$ up to $|y| < 3.0$ and in one additional bin in the forward region $3.2 < |y| < 4.7$.

The theory in fig.1 has been calculated at next to leading order (NLO) using the NLOJet++[7, 8] parton generator within the fastNLO [9] framework. The parton density function (PDF) set used is the NNPDF2.1[10] and the theory is corrected for non-perturbative (NP) effects calculated from monte-carlo (MC) generators that simulate parton shower (PS) and multi-parton interactions (MPI). Theoretical calculations repeated with five different PDF sets, ABM11[11], CT10[12], HERAPDF1.5[13], and MSTW2008 [14]. Figure 2 shows the ratio of data over theory using CT10 of the innermost rapidity bin $|y| < 0.5$. Theoretical uncertainties consist of three sources, PDF, scale and $\alpha_s(M_Z)$ uncertainty. Most of the PDF sets describe data within uncertainties.

Figure 2: Ratio of data over theory using CT10 for the innermost rapidity bin $|y| < 0.5$. Error bars represent the statistical uncertainty.

Double differential cross section on dijet mass, M_{jj} and $|y|_{max}$ as a function of M_{jj} has also been measured by CMS at 8 TeV. The $|y|_{max}$ is defined by the maximum rapidity of the two leading jets $|y|_{max} = \max(|y_1|, |y_2|)$. The measurement is performed in five bins of $\Delta|y|_{max} = 0.5$ and it recorded events with dijet invariant mass up to $M_{jj} = 5.5$ TeV. Figure 3 shows the comparison of data with NLO theoretical calculations using NNPDF2.1 and corrected for NP and electroweak (EWK) effects. Figure 4 shows the comparisons of data with theory using various PDF sets in the $|y|_{max} < 0.5$ region. The data are well described by most of the PDF sets within

Figure 3: Dijet cross section measurement at 8 TeV compared to NLO theoretical calculations using NNPDF2.1.

uncertainties.

Figure 4: Dijet cross section measurement at 8 TeV compared to NLO theoretical calculations using NNPDF2.1.

The measurement of the dijet azimuthal decorrelations between the two leading jets at 8 TeV was studied in [4]. The analysis measured the normalized differential cross section on $\Delta\phi_{Dijet}$ as a function of $\Delta\phi_{Dijet}$ in bins of p_T^{max} . The $\Delta\phi_{Dijet}$ is defined as the azimuthal angle between the two leading jets and the p_T^{max} is the p_T of the leading jet. It is performed in seven p_T^{max} regions and it recorded jets up to $p_T = 2.2$ TeV. The measurement of the dijet azimuthal decorrelations probes multijet events by measuring only the azimuthal separation of the two leading jets. It is compared with 3-jet calculation at NLO and with various Monte Carlo event generators matched to PS. Figure 5 shows the measurement compared to the 3-jet NLO calculation

using CT10. The calculation deviates significantly in

Figure 5: The normalized dijet cross section differential in $\Delta\phi_{Dijet}$ for seven p_T^{max} bins. The cross sections of p_T^{max} bins are scaled with multiplicative factors for presentation purpose. Theoretical calculations using CT10 are overlaid.

the region $\Delta\phi_{Dijet} < \frac{2\pi}{3}$ where it becomes leading order (LO). Figure 6 shows the ratio of MC over data using Pythia6 TuneZ2*[15, 16], Herwig++[17], Pythia8 4C[18, 19], Madgraph5[20] + Pythia6 TuneZ2*, and POWHEG[21, 22, 23] + Pythia6 Z2*. Predictions from Monte Carlo generators overshoot data besides predictions from Madgraph5 that describes data throughout the entire $\Delta\phi_{Dijet}$ region.

The next analysis reported in this proceeding is the ratio of the inclusive 3-jet to the inclusive 2-jet cross section and the extraction of the strong coupling constant at 7 TeV. This analysis measured the ratio of the inclusive 3-jet to the inclusive 2-jet cross section as a function of the average p_T of the two leading jets, $\langle p_{T1,2} \rangle$. It recorder jets with $p_T > 150$ GeV and $|y| < 2.5$. The measurement compared to NLO calculations using four different PDF sets, ABM11, CT10, MSTW2008, and NNPDF2.1, in most of the cases theory describes the measurement at the whole range of $\langle p_{T1,2} \rangle$. The upper part of figure 7 shows the measured R_{32} compared to

Figure 6: Ratios of various Monte Carlo predictions with data. The yellow band shows the total experimental uncertainties and the error bars the statistical uncertainty of the simulated events.

NLO calculations and the PDF (green) and scale (red) uncertainties. The bottom part of the figure shows the ratio of data over theory and the fractional uncertainties. The sensitivity of R_{32} to $\alpha_s(M_Z)$ variations was shown by repeating the calculations with various $\alpha_s(M_Z)$ values. The minimization of the χ^2 value between various calculations with different $\alpha_s(M_Z)$ and the data extracted the value of $\alpha_s(M_Z)$. The result extracted from data in the region $420 < \langle p_{T1,2} \rangle < 1390$ GeV is $\alpha_s(M_Z) = 0.1148 \pm 0.0014(exp.) \pm 0.0018(PDF) \pm 0.0050(theory)$.

The fifth measurement reported in this proceeding is the measurement of the 3-jet mass cross section at 7 TeV and determination of $\alpha_s(M_Z)$. The double differential cross section on three jet mass, m_3 , and $|y_{max}|$ is measured as a function of the invariant mass of the three leading jets, $m_3^2 = (p_1 + p_2 + p_3)^2$ in two regions of their maximum rapidity $|y_{max}| \leq 1$ and $1 \leq |y_{max}| \leq 2$. Where maximum rapidity is defined as $y_{max} = \text{sgn}(|\max(y_1, y_3, y_3)| - |\min(y_1, y_3, y_3)|) \cdot \max(|y_1|, |y_2|, |y_3|)$. The measurement studied events with jets $p_T > 100$ GeV. Figure 8 shows the comparison of the measured 3-jet cross section with the NLO calculation, using the CT10-NLO PDF set, corrected for NP effects. The measurement is also compared with

Figure 7: Measurement of the R_{32} and NLO predictions using NNPDF2.1 NNLO PDF set. The upper part of the plot shows the measurement and the theoretical prediction for R_{32} while the bottom part shows the ratio of data over theory.

ABM11, HERAPDF1.5 MSTW2008, and NNPDF2.1 with NLO and NNLO evolutions. Most of the PDF sets describe within uncertainties the 3-jet cross section. The minimization of the χ^2 value between data and theoretical predictions, in the region $m_3 > 664$ GeV, used to determine the $\alpha_s(M_Z)$ value. The CT10-NLO PDF set is employed to extract the strong coupling constant and data are combined from both $|y_{\max}|$ bins. The $\alpha_s(M_Z)$ value is found to be $\alpha_s(M_Z) = 0.1171 \pm 0.0013(\text{exp.}) \pm 0.0024(\text{PDF}) \pm 0.0008(\text{NP})^{+0.0069}_{-0.0040}(\text{scale})$.

CMS has reported four measurements of $\alpha_s(M_Z)$, two of them reported in this proceeding. The other two measurements are from inclusive jet cross sections [24] and $t\bar{t}$ cross sections [25]; results are presented in Table 1. In the three cases the analyses also tested the running of the strong coupling shown in figure 9.

Table 1: Strong coupling constants from CMS measurements.

	Ref.	$\alpha_s(M_Z)$	Exp	Theory
R32	[5]	0.1148	0.0014	0.0053
Inclusive jets	[24]	0.1185	0.0019	$+0.0060$ -0.0037
3-jet mass	[6]	0.1171	0.0013	$+0.0073$ -0.0047
$t\bar{t}$	[25]	0.1151	(total)	$+0.0028$ -0.0027

Figure 8: Comparison of the 3-jet mass cross section with NLO calculations using CT10.

Figure 9: The running of the strong coupling as a function of Q . Results from HERA and Tevatron colliders are shown with the results from CMS-LHC.

3. Conclusions

This proceeding reported five measurements performed by the CMS collaboration with jets found in the final state. Comparison with MC generators interfaced to PS shows, that better description of the multijet production is needed. Comparisons with NLO calculations show that pQCD describes the data reasonably well. Two out of the five measurements presented here extracted the $\alpha_s(M_Z)$ and tested its running, the extracted values agree well with the world average.

4. Acknowledgements

This research has been co-financed by the European Union (European Social Fund - ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding Program: ARISTEIA. Investing in knowledge society through the European Social Fund.

References

- [1] Measurement of jet cross sections at low transverse momentum in proton-proton collisions at 8 TeV, Tech. Rep. CMS-PAS-FSQ-12-031 (2013).
- [2] Measurement of the double-differential inclusive jet cross section at $\sqrt{s} = 8$ TeV with the CMS detector, Tech. Rep. CMS-PAS-SMP-12-012 (2013).
- [3] Measurements of differential dijet cross section in proton-proton collisions at $\sqrt{s} = 8$ TeV with the CMS detector, Tech. Rep. CMS-PAS-SMP-14-002 (2014).
- [4] Measurement of dijet azimuthal decorrelations in pp collisions at $\sqrt{s} = 8$ TeV, Tech. Rep. CMS-PAS-SMP-14-015 (2015).
- [5] S. Chatrchyan, et al., Measurement of the ratio of the inclusive 3-jet cross section to the inclusive 2-jet cross section in pp collisions at $\sqrt{s} = 7$ TeV and first determination of the strong coupling constant in the TeV range, Eur. Phys. J. C 73 (2013) 2604. doi:10.1140/epjc/s10052-013-2604-6.
- [6] S. Chatrchyan, et al., Measurement of the inclusive 3-jet production differential cross section in proton-proton collisions at 7 TeV and determination of the strong coupling constant in the TeV range, The European Physical Journal C 75 (5). doi:10.1140/epjc/s10052-015-3376-y.
- [7] Z. Nagy, Three-jet cross sections in hadron-hadron collisions at next-to-leading order, Phys. Rev. Lett. 88 (2002) 122003. arXiv:hep-ph/0110315, doi:10.1103/PhysRevLett.88.122003.
- [8] Z. Nagy, Next-to-leading order calculation of three-jet observables in hadron-hadron collisions, Phys. Rev. D 68 (2003) 094002. arXiv:hep-ph/0307268, doi:10.1103/PhysRevD.68.094002.
- [9] D. Britzger, K. Rabbertz, F. Stober, M. Wobisch, New features in version 2 of the fastNLO project (2012) 217 arXiv:1208.3641, doi:10.3204/DESY-PROC-2012-02/165.
- [10] R. D. Ball, V. Bertone, F. Cerutti, L. Del Debbio, S. Forte, et al., Impact of heavy quark masses on parton distributions and LHC phenomenology, Nucl. Phys. B 849 (2011) 296. arXiv:1101.1300, doi:10.1016/j.nuclphysb.2011.03.021.
- [11] S. Alekhin, J. Blumlein, S. Moch, Parton distribution functions and benchmark cross sections at next-to-next-to-leading order, Phys. Rev. D 86 (2012) 054009. arXiv:1202.2281, doi:10.1103/PhysRevD.86.054009.
- [12] H.-L. Lai, M. Guzzi, J. Huston, Z. Li, P. M. Nadolsky, et al., New parton distributions for collider physics, Phys. Rev. D 82 (2010) 074024. arXiv:1007.2241, doi:10.1103/PhysRevD.82.074024.
- [13] F. Aaron, et al., Combined measurement and QCD analysis of the inclusive e^+p scattering cross sections at HERA, JHEP 1001 (2010) 109. arXiv:0911.0884, doi:10.1007/JHEP01(2010)109.
- [14] A. D. Martin, W. J. Stirling, R. S. Thorne, G. Watt, Parton distributions for the LHC, Eur. Phys. J. C 63 (2009) 189. arXiv:0901.0002, doi:10.1140/epjc/s10052-009-1072-5.
- [15] T. Sjöstrand, S. Mrenna, P. Z. Skands, PYTHIA 6.4 physics and manual, JHEP 05 (2006) 026. arXiv:hep-ph/0603175, doi:10.1088/1126-6708/2006/05/026.
- [16] S. Chatrchyan, et al., Study of the underlying event at forward rapidity in pp collisions at $\sqrt{s} = 0.9, 2.76$, and 7 TeV, JHEP 2013. arXiv:1302.2394, doi:10.1007/JHEP04(2013)072.
- [17] M. Bähr, S. Gieseke, M. A. Gigg, D. Grellscheid, K. Hamilton, O. Latunde-Dada, S. Plätzer, P. Richardson, M. H. Seymour, A. Sherstnev, B. R. Webber, Herwig++ physics and manual, Eur. Phys. J. C 58 (2008) 639. arXiv:0803.0883, doi:10.1140/epjc/s10052-008-0798-9.
- [18] T. Sjöstrand, S. Mrenna, P. Z. Skands, A Brief Introduction to PYTHIA 8.1, Comput. Phys. Commun. 178 (2008) 852. arXiv:0710.3820, doi:10.1016/j.cpc.2008.01.036.
- [19] R. Corke, T. Sjöstrand, Interleaved parton showers and tuning prospects, JHEP 03 (2011) 032. arXiv:1011.1759, doi:10.1007/JHEP03(2011)032.
- [20] J. Alwall, M. Herquet, F. Maltoni, O. Mattelaer, T. Stelzer, MadGraph 5: going beyond, JHEP 06 (2011) 128. arXiv:1106.0522, doi:10.1007/JHEP06(2011)128.
- [21] S. Frixione, P. Nason, C. Oleari, Matching NLO QCD computations with parton shower simulations: the POWHEG method, JHEP 11 (2007) 070. arXiv:0709.2092, doi:10.1088/1126-6708/2007/11/070.
- [22] S. Alioli, P. Nason, C. Oleari, E. Re, A general framework for implementing NLO calculations in shower Monte Carlo programs: the POWHEG BOX, JHEP 06 (2010) 043. arXiv:1002.2581, doi:10.1007/JHEP06(2010)043.
- [23] P. Nason, A new method for combining NLO QCD with shower Monte Carlo algorithms, JHEP 0411 (2004) 040. arXiv:hep-ph/0409146, doi:10.1088/1126-6708/2004/11/040.
- [24] S. Chatrchyan, et al., Measurements of differential jet cross sections in proton-proton collisions at $\sqrt{s} = 7$ TeV with the CMS detector, Phys. Rev. D 87 (2012) 112002. doi:10.1103/PhysRevD.87.112002.
- [25] S. Chatrchyan, et al., Determination of the top-quark pole mass and strong coupling constant from the $t\bar{t}$ production cross section in pp collisions at $\sqrt{s} = 7$ TeV, Phys. Lett. B 728 (2014) 496. doi:10.1016/j.physletb.2013.12.009.