PROCEEDINGS OF SCIENCE

Jet physics measurements at CMS

Piergiulio Lenzi[∗†]
INFN Sez. di Firenze
E-mail: piergiulio.lenzi@cern.ch

After the end of an extremely successful LHC Run 1 we review recent results of the CMS collaboration in the field of QCD precision measurements.

XXI International Workshop on Deep-Inelastic Scattering and Related Subject -DIS2013,
22-26 April 2013
Marseilles,France

[∗]Speaker.
[†]On behalf of the CMS collaboration.

PoS(DIS 2013)146

1. Introduction

A detailed understanding of QCD phenomenology is a fundamental prerequisite for any search at the LHC. During the LHC Run 1 the CMS [1] collaboration has carried out a rich program of QCD precision measurements, studying observables that probed several different aspects of QCD phenomenology. In this note we review the status of these measurements and highlight their relevance with respect to the comparison of modern QCD calculations, and their impact on parton density functions (PDFs) fits.

This note is organized as follows: in Sec. 2 we briefly review the jet reconstruction algorithms used in CMS, in Sec. 3 we discuss recent inclusive jet measurement; di-jet measurements are discussed in Sec. 4; finally we concentrate on jet substructure in Sec. 5

2. Jet reconstruction at CMS

Jets are defined in CMS with the anti-k_T algorithm [2]. The input to the algorithm is Particle-Flow (PF) candidates: with this term we refer to the four-momenta of particles reconstructed with the global Particle-Flow event reconstruction [3]. This technique aims at making an optimal use of the different sub-detectors to reconstruct particles as close as possible to the correct energy scale. In a nutshell, this is achieved exploiting the precision of CMS tracker and the fine segmentation of calorimeters that allows the association of tracks with calorimeter energy deposits. While on the one hand this allows the use of the precise momentum reconstruction of the tracker for charged particles, on the other hand it allows the identification of neutral particles deposits in the calorimeters. Jets reconstructed with PF candidates as input still need relatively small jet energy corrections. These are achieved in two steps [4]: first a correction derived purely from the Monte Carlo simulation is computed, comparing true and reconstructed jets in the simulation. Then, in order to account for simulation inaccuracies, techniques like di-jet transverse momentum (p_T) balancing and γ plus jet or Z plus jet p_T balancing are applied both on the data and on the simulation and the ratio is used as a final correction factor. This technique allows to reduce the impact of p_T balancing techniques systematics. The final jet energy scale uncertainty is shown in Fig. 1 [5] for central jets.

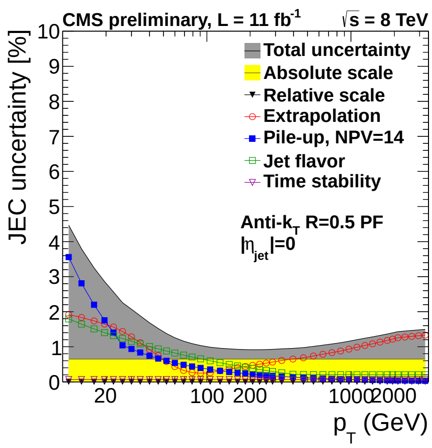


Figure 1: Contributions to jet energy scale uncertainty.

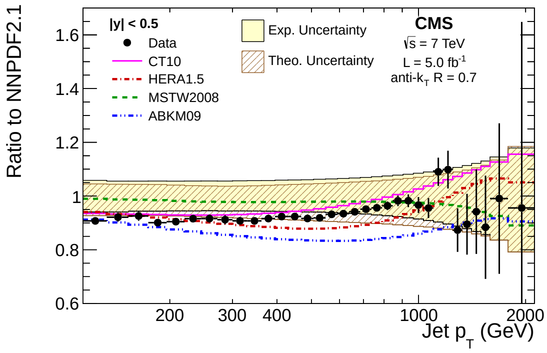


Figure 2: Data over theory comparison for the inclusive jet p_T spectrum for jet rapidity smaller than 0.5.

3. Inclusive jets

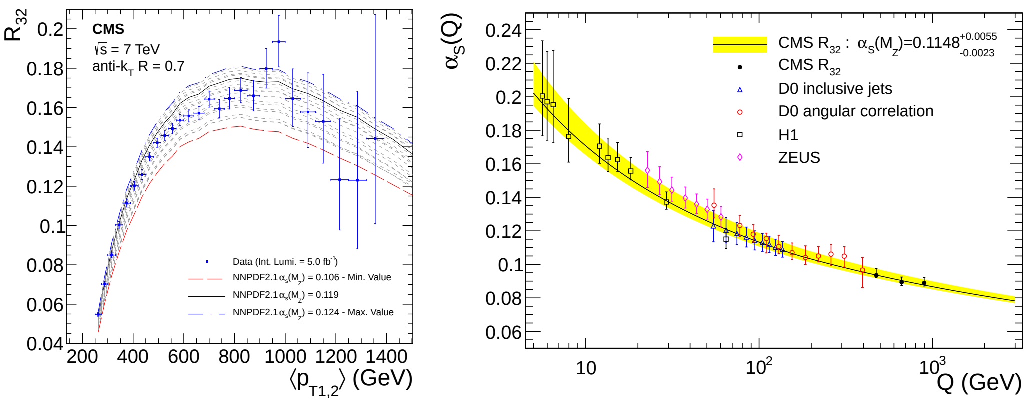
CMS recently measured inclusive jet p_T spectrum using the full 2011 5 fb^{-1} dataset, in five bins of jet rapidity, up to 2.5 units [6]. These measurements are in good agreement with the predictions of NLO QCD, as implemented in the NLOJet++ [7] parton level generator, with a slight tendency of the predictions to overestimate the cross section especially at central rapidities. This behavior is shown in Fig. 2 where the ratio of data over theory is shown for the central jet rapidity bin. The theory and experimental error bands are both shown around 1. The theory band corresponds to scale and PDF uncertainty for the PDF set MSTW2008 [8]. The central values of other PDF fits are shown as dashed lines. This comparison clearly shows the power of this measurement in constraining PDF fits.

4. Di-jets

CMS measured the di-jet cross section differentially in the di-jet mass in [6], for jet masses up to 4.5 TeV. This measurement has good constraining power for PDF fits. CMS also measured recently in [9] the value of the strong coupling constant α_s, using an observable called R_{32}, which correspond to the ratio of the number of events with at least three jets over the number of events with at least two jets, as a function of the average p_T of the two leading jets. This measurement was carried out using the full 5 fb^{-1} dataset collected in 2011. The sensitivity of R_{32} to the value of α_s is shown in Fig. 3 (a). The value of α_s was obtained by fitting Monte Carlo templates corresponding to different values of α_s to the measured spectrum. The measurement was performed in three bins of average p_T of the di-jet system. The result is shown in Fig. 3 (b), and compared to previous experiments. Combining the three measurements and evolving the value of α_s to a scale equal to the Z mass yields a final result of $\alpha_s(M_Z) = 0.1148 \pm 0.0014(\text{exp.}) \pm 0.0018(\text{PDF})^{+0.0050}_{-0.0000}(\text{scale})$.

5. Jet substructure

Jet substructure techniques have become more and more important at the LHC as a way to study the decay of boosted objects, that get merged in a single jet. They are extremely powerful and are absolutely necessary for example when searching for heavy objects decaying to pairs of



(a) (b)

Figure 3: The sensitivity of CMS R_{32} observable to the value of α_s is shown in (a). The values of α_s determined by CMS in three bins of the average p_T of the di-jet system is compared to previous measurements in (b). The band represents the extrapolation of the CMS uncertainty.

boosted vector bosons. Several techniques have been developed to reveal jet substructure, that we cannot describe here in detail [10, 11, 12, 13]. The common ingredient of all these techniques is the fact that the components of each jet are reclustered with different algorithms, possibly with criteria that aim at removing the underlying event, or pile up contribution to the jet. Moreover, the clustering algorithm is stopped before the last recombination step, thus obtaining two sub-jets for each initial jet, representing the possible decay products of a boosted object. When studying QCD jets these jet substructure techniques become very powerful event shape variable, that can be used to discriminate between different phenomenological descriptions of the structure of a jet. CMS released a jet substructure analysis for QCD jets in di-jet and W/Z+jet events [14]. As an example, the sub-jet mass spectrum in Z plus jet events in different bins of jet p_T is shown in Fig. 4. Data are compared with the predictions of two parton shower event generators (PYTHIA [15] and HERWIG [16]), showing very nice agreement.

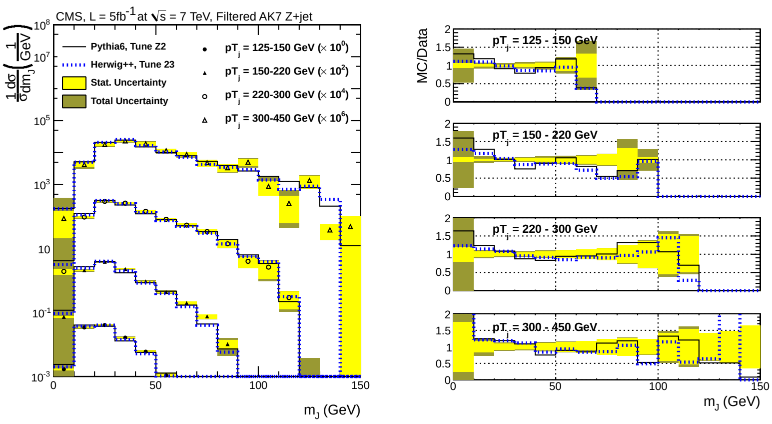


Figure 4: Mass spectrum of the sub-jets reconstructed in Z+jets events with the "filtering" technique.

6. Conclusion

Thanks to an extremely successful LHC Run 1 and a detailed understanding of the detector CMS has carried out a complete QCD program, improving our understanding of QCD with precise measurements, that show experimental errors in several cases of the same order or smaller of the corresponding theory errors.

References

[1] CMS Collaboration , S. Chatrchyan *et al.*, "The CMS experiment at the CERN LHC", *JINST* **3** (2008) S08004.

[2] M. Cacciari, G. P. Salam, and G. Soyez, "The Anti-k(t) jet clustering algorithm", *JHEP* **0804** (2008) 063, `arXiv:0802.1189 [hep-ph]`.

[3] CMS Collaboration , "Commissioning of the Particle-Flow reconstruction in Minimum-Bias and Jet Events from pp Collisions at 7 TeV", Tech. Rep. CMS-PAS-PFT-10-002, CERN, Geneva, 2010.

[4] CMS Collaboration , S. Chatrchyan *et al.*, "Determination of Jet Energy Calibration and Transverse Momentum Resolution in CMS", *JINST* **6** (2011) P11002, `arXiv:1107.4277 [physics.ins-det]`.

[5] CMS Collaboration , "Status of the 8 TeV Jet Energy Corrections and Uncertainties based on 11 fb^{-1} of data in CMS", Tech. Rep. CMS-DP-2013-011, May, 2013.

[6] CMS Collaboration , 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.* **D87** (2013) 112002, `arXiv:1212.6660 [hep-ex]`.

[7] Z. Nagy, "Next-to-leading order calculation of three jet observables in hadron hadron collision", *Phys.Rev.* **D68** (2003) 094002, `arXiv:hep-ph/0307268 [hep-ph]`.

[8] A. Martin, W. Stirling, R. Thorne, and G. Watt, "Parton distributions for the LHC", *Eur.Phys.J.* **C63** (2009) 189–285, `arXiv:0901.0002 [hep-ph]`.

[9] CMS Collaboration , 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", `arXiv:1304.7498 [hep-ex]`.

[10] J. M. Butterworth, A. R. Davison, M. Rubin, and G. P. Salam, "Jet substructure as a new Higgs search channel at the LHC", `arXiv:0810.0409 [hep-ph]`.

[11] D. Krohn, J. Thaler, and L.-T. Wang, "Jet Trimming", *JHEP* **1002** (2010) 084, `arXiv:0912.1342 [hep-ph]`.

[12] S. D. Ellis, C. K. Vermilion, and J. R. Walsh, "Techniques for improved heavy particle searches with jet substructure", *Phys.Rev.* **D80** (2009) 051501, `arXiv:0903.5081 [hep-ph]`.

[13] S. D. Ellis, C. K. Vermilion, and J. R. Walsh, "Recombination Algorithms and Jet Substructure: Pruning as a Tool for Heavy Particle Searches", *Phys.Rev.* **D81** (2010) 094023, `arXiv:0912.0033 [hep-ph]`.

[14] CMS Collaboration , S. Chatrchyan *et al.*, "Studies of jet mass in dijet and W/Z + jet events", *JHEP* **1305** (2013) 090, `arXiv:1303.4811 [hep-ex]`.

[15] T. Sjostrand, S. Mrenna, and P. Z. Skands, "PYTHIA 6.4 Physics and Manual", *JHEP* **0605** (2006) 026, arXiv:hep-ph/0603175 [hep-ph].

[16] G. Corcella, I. Knowles, G. Marchesini, S. Moretti, K. Odagiri, *et al.*, "HERWIG 6: An Event generator for hadron emission reactions with interfering gluons (including supersymmetric processes)", *JHEP* **0101** (2001) 010, arXiv:hep-ph/0011363 [hep-ph].