

## Jet Results from CMS

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Using the proton-proton collision data delivered by the LHC in 2010, CMS has measured a variety of jet observables. These include inclusive and dijet cross sections, angular properties of dijet events, jet shapes as well as various multi-jet event observables. Jets from heavy objects have been measured as well, including the inclusive b-jet cross section and a first demonstration of the use of jet substructure algorithms for the identification of highly boosted W and top jets.

### §1. Introduction

Jets probe the high momentum transfer interactions of quarks and gluons which can be calculated in QCD at perturbative level (pQCD). In proton-proton collisions, the cross section for jet production can be calculated using a combination of 1. the parton distribution functions (PDFs) which quantify the probability distribution of interacting with quarks and gluons of certain momenta within the proton; 2. fixed order pQCD calculations or approximations of all order QCD calculations (resummation or shower); and 3. models for non-perturbative effects such as hadronization of quarks and gluons into particle jets and multiple parton interactions, typically implemented in Monte-Carlo (MC) event generators. Jet measurements are therefore crucial in three different fields: 1. testing and extending the measurements of the PDFs; 2. testing the theory of perturbative QCD; and 3. testing and tuning MC generator models. In particular the PDF measurements and validation of MC models are essential also for searches for new physics at the LHC which need a good understanding of the QCD interactions. The measurements presented in the following are based on the proton-proton collision data collected by the CMS experiment in 2010 at  $\sqrt{s} = 7$  TeV which corresponds to an integrated luminosity of  $36 \text{ pb}^{-1}$ .

### §2. Jet reconstruction in CMS

Jets in CMS<sup>1)</sup> can be clustered from four different collections of reconstructed objects making use of different detector components. These are calorimeter towers, charged particle tracks, a combination of the two (jet+tracks) and finally particle-flow which consists in reconstructing and identifying each single particle with an optimized combination of all sub-detector information. The default algorithm to cluster these objects into jets in CMS is the anti- $k_T$  algorithm with an R parameter of typically 0.5 or 0.7.

Crucial to all jet measurements is a precise calibration of the jet energy and a

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detailed knowledge of its resolution. CMS uses a factorized approach to calibrate the jet energy.<sup>2)</sup> First, a correction to account for pile-up and noise effects is applied. Second, the jet response is flattened as a function of pseudorapidity and transverse momentum using the detector simulation. Third, in-situ residual corrections are applied to correct for any difference observed between the data and the simulation. The pseudorapidity dependence is measured making use of the balance of dijet events while the absolute calibration as a function of transverse momentum is performed making use of the balance of photon+jet events where the photon energy is precisely measured using the electromagnetic calorimeter. Following this approach, the pseudorapidity dependence of the jet energy scale has been calibrated to better than 1% per unit of  $\eta$  and the total jet energy scale uncertainty at  $\eta = 0$  is better than 2% for jets with  $p_T > 30$  GeV. The jet energy resolution of the CMS detector has also been measured in dijet and photon+jet events and was found to be better than 10% at  $p_T > 100$  GeV. The angular resolution in  $\eta$  and  $\phi$  is 0.01 at  $p_T = 100$  GeV. The jet trigger efficiency is  $>99\%$  above a certain  $p_T$  threshold which changes with increasing luminosity.

### §3. Jet cross section measurements

CMS has performed two complementary measurements of the basic kinematic properties of jet events: the inclusive jet cross section<sup>3)</sup> and the dijet mass cross

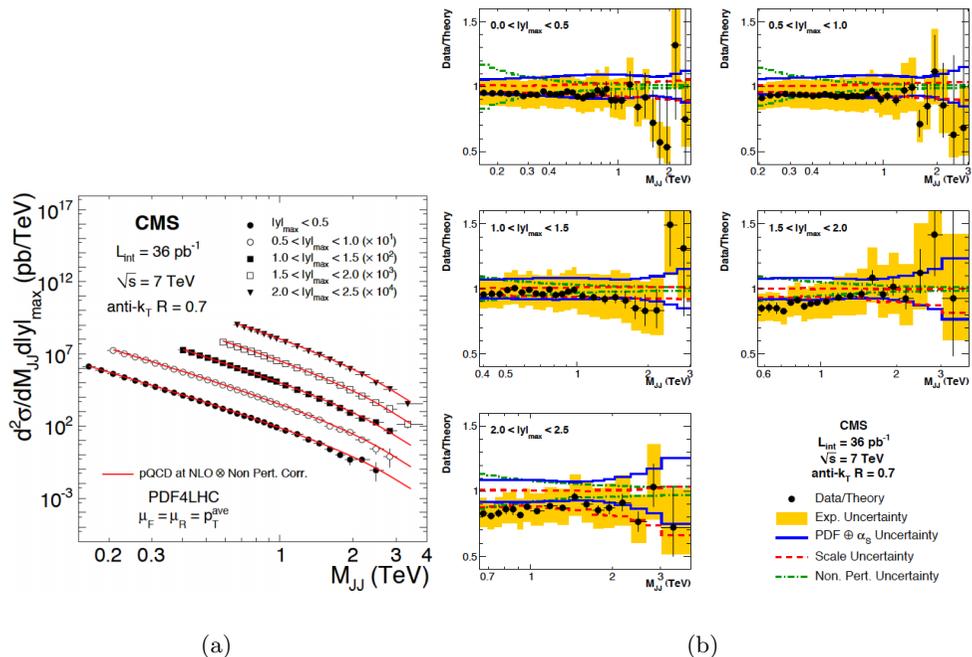


Fig. 1. (color online) (a) Dijet mass cross section. (b) Data/Theory ratio for the dijet mass cross section.

section.<sup>4)</sup> The second is a measurement of the cross section of events with  $\geq 2$  jets as a function of the dijet invariant mass  $M_{JJ} = \sqrt{(p_1 + p_2)^2}$  where  $p_1$  and  $p_2$  are four-momenta of the two jets with the leading  $p_T$  in the event and as a function of the maximum rapidity of the two leading jets  $|y|_{max} = \max(|y_1|, |y_2|)$ . The data shown in Fig. 1 is corrected for detector effects and is compared to a perturbative QCD calculation at next-to-leading order including non-perturbative corrections for hadronization and multiple parton interactions from MC event generators. The data over theory ratio in Fig. 1(b) shows good agreement within experimental and theoretical uncertainties, providing a positive test of pQCD. Predictions from different PDFs show that this measurement will be able to constrain PDFs once experimental uncertainties are reduced. In addition, the dijet mass cross section is an important channel to search for new physics models which predict resonant production of dijets.<sup>5)</sup>

#### §4. Jet angular and multi-jet measurements

Figure 2 shows two measurements of the angular properties of dijet events. The measurement of the dijet angular distributions<sup>7)</sup> in the variable  $\chi_{dijet} = e^{|y_1 - y_2|}$

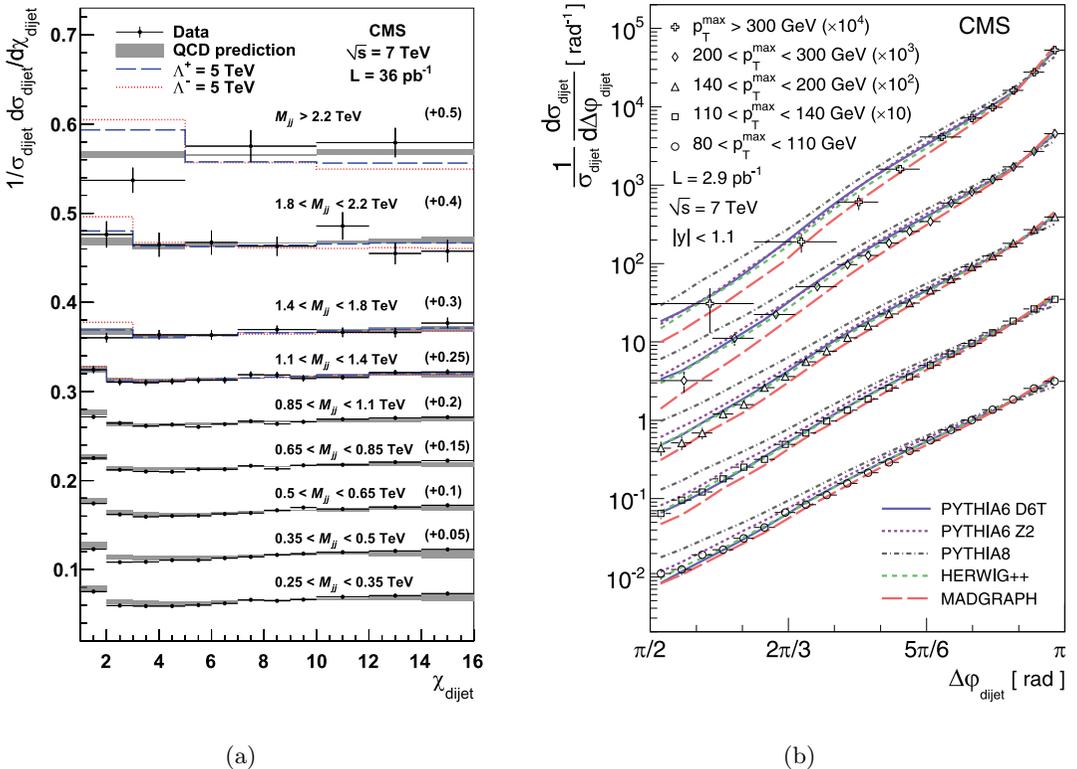


Fig. 2. (color online) (a) Dijet angular distributions. (b) Dijet angular decorrelation.

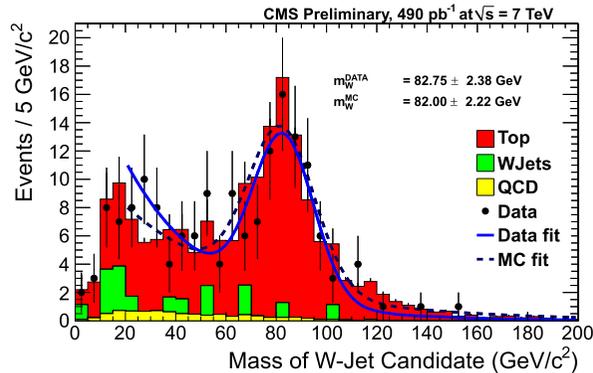


Fig. 3. (color online) Invariant mass distribution of W-tagged jets in hadronic  $t\bar{t}$  event data.

probes the parton-parton scattering angle. Good agreement with the predictions from pQCD is found and quark compositeness models leading to an additional contact interaction between quarks have been ruled out up to a scale of  $\Lambda^+ = 5.6$  TeV. The measurement of the polar angle  $\Delta\phi_{dijet}$ <sup>6)</sup> is sensitive to higher order radiation without explicitly measuring the radiated jets which lead to a decorrelation in  $\phi$ . This measurement is particularly useful to test and tune MC models and is compared to various MC models of which PYTHIA6 and HERWIG++ show best agreement with the data. Other views on multi-jet events are provided by the 3-jet over 2-jet cross section ratio<sup>8)</sup> and the hadronic event shapes<sup>9)</sup> measurements performed by CMS.

### §5. Jet tagging techniques

The inner structure of jets is essential to identify jets originating from different quarks and gauge bosons. A set of jet shape measurements<sup>10)</sup> by CMS provided a first validation of the modeling of the inner structure of light quark and gluon jets in MC event generators at the LHC. Jets originating from b-quarks can be identified in CMS using secondary vertex taggers. These allowed a measurement of the inclusive b-jet cross section.<sup>11)</sup> Rather new techniques, making use of jet substructure algorithms have recently been used to identify also highly boosted hadronically decaying W bosons and top quarks.<sup>12)</sup> Figure 3 demonstrates how such a W-tagger performs in identifying W-jets in fully hadronic  $t\bar{t}$  events.

### §6. Summary

In summary, CMS has a rich variety of jet results with rather precise measurements in the first year of LHC running. The global data characteristics is correctly described by QCD. Detailed measurements of jet and their characteristics constrain the model building. Jets as instruments to search for new physics have been evaluated on data.

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