Inclusive b-jet production in pp collisions at $\sqrt{s} = 7\,\text{TeV}$

The CMS collaboration

ABSTRACT: The inclusive b-jet production cross section in pp collisions at a center-of-mass energy of 7 TeV is measured using data collected by the CMS experiment at the LHC. The cross section is presented as a function of the jet transverse momentum in the range $18 < p_\text{T} < 200\,\text{GeV}$ for several rapidity intervals. The results are also given as the ratio of the b-jet production cross section to the inclusive jet production cross section. The measurement is performed with two different analyses, which differ in their trigger selection and b-jet identification: a jet analysis that selects events with a b jet using a sample corresponding to an integrated luminosity of $34\,\text{pb}^{-1}$, and a muon analysis requiring a b jet with a muon based on an integrated luminosity of $3\,\text{pb}^{-1}$. In both approaches the b jets are identified by requiring a secondary vertex. The results from the two methods are in agreement with each other and with next-to-leading order calculations, as well as with predictions based on the PYTHIA event generator.

Contents

1 Introduction

The experimental measurement of the b-quark production cross section has been pursued with interest at hadron colliders because of discrepancies between theoretical predictions and experimental results, e.g., at the Tevatron [1–4] and at HERA [5–8]. Substantial progress has been made in understanding the b-quark production and fragmentation processes, and the measurements are now in reasonable agreement with the predictions in most regions of the phase space [9–12]. Theoretical uncertainties are, however, sizable, and there is great interest in verifying the results at the higher center-of-mass energies provided by the LHC. Identification of b-quark jets by methods relying on the long b lifetime is almost independent of the details of the fragmentation of a b quark into a b hadron. Therefore, measuring the rate of b jets is a direct measurement of the b-quark production rate, with a negligible systematic uncertainty originating from fragmentation [13]. In addition, large logarithmic corrections due to hard collinear gluons are avoided when inclusive b jets are considered, leading to more sensitive comparisons between experimental results and theoretical calculations.

First results on b$\overline{\text{b}}$ production in pp collisions at $\sqrt{s} = 7$ TeV have been reported by the LHCb Collaboration using semi-inclusive decays in the forward rapidity region [14], and by the Compact Muon Solenoid (CMS) Collaboration [15] using inclusive b $\to \mu$X decays [16] in the central rapidity region and measuring the b-hadron production cross section as a function of the muon transverse momentum and pseudorapidity. CMS has also measured the production cross sections of fully reconstructed B$^+$ [17], B^0 [18], and B$_\text{s}$ [19] mesons, as well as the angular correlations between b and $\overline{\text{b}}$ hadrons, based on secondary vertex reconstruction [20]. The ATLAS Collaboration has measured the inclusive and dijet cross sections of b jets [21].

This paper presents CMS measurements of b-jet cross sections in several bins of jet rapidity y and transverse momentum p_T. The b-jet cross section presented in this paper is defined as the sum of the b and $\overline{\text{b}}$ jet contributions. Two independent analyses are presented: a jet analysis, selecting events with a b jet, and a muon analysis, requiring in addition a muon in the b jet. Despite the difference in the corresponding integrated luminosity ($34\,\text{pb}^{-1}$ and $3\,\text{pb}^{-1}$, respectively), the precisions of the two measurements are similar and dominated by systematic uncertainties, which differ because of the use of different triggers and b-jet identification criteria. Most of the analysis procedures are common in the two analyses, and the differences are explained in the sections concerned.

The inclusive b-jet production cross section is also presented as the ratio to the inclusive jet-production cross section measured by CMS in the same rapidity intervals [22]. The results are compared to theoretical predictions from next-to-leading order (NLO) perturbative quantum chromodynamics (QCD) calculations and to predictions from the PYTHIA event generator [23].

2 CMS detector

The central feature of the CMS apparatus is a superconducting solenoid, 13 m in length and 6 m in diameter, which provides an axial magnetic field of 3.8 T. The bore of the solenoid is instrumented with various particle detectors. Charged particle trajectories are measured with the silicon pixel and strip trackers, covering $0 < \phi < 2\pi$ in azimuth and $|\eta| < 2.5$ in pseudorapidity, where $\eta = -\ln[\tan\theta/2]$, with θ being the polar angle of the track with respect to the counterclockwise beam direction. The resolution is typically about $15\,\mu$m on the impact parameter and about 1% on the transverse momentum for charged particles with $p_\text{T} < 40$ GeV. A crystal electromagnetic calorimeter (ECAL) and a brass/scintillator hadron calorimeter (HCAL) surround the tracking volume. The forward region is covered by a an iron/quartz-fiber hadron calorimeter (HF). The ECAL provides coverage in $|\eta| < 1.5$ in a cylindrical barrel region and $1.5 < |\eta| < 3.0$ in two endcaps. The ECAL has an energy resolution of better than 0.5% for unconverted photons with transverse energies above 100 GeV. The hadron calorimeters cover $|\eta| < 5.0$ with a jet energy resolution of about $100\%/\sqrt{E}$, with the jet energy E in GeV. Muons are measured in gas-ionization detectors embedded in the steel return yoke, covering $|\eta| < 2.4$. A two-tier trigger system selects the most interesting pp collision events for use in physics analyses. A more detailed description of the CMS detector can be found elsewhere [15].

3 Monte Carlo simulation

A detailed Monte Carlo (MC) simulation was performed for comparisons with the data and to evaluate the selection efficiencies. Simulated events were generated with PYTHIA 6.422 [23] using tune Z2 [24] for the underlying event, a b-quark mass of 4.8 GeV, and the CTEQ6L1 [25] proton parton distribution functions (PDF). The generated events were processed through the full GEANT4 [26] detector simulation, trigger emulation, and event reconstruction chain.

The inclusive jet NLO theoretical prediction was calculated with NLOJET++ [27] using the CTEQ6.6M PDF set [25] and FASTNLO [28] implementation. The factorization and renormalization scales were set to $\mu_F = \mu_R = p_T$. The inclusive b-jet cross section prediction was calculated with MC@NLO [29, 30] using the CTEQ6M PDF set and the nominal b-quark mass of 4.75 GeV. The parton shower and hadronization were modeled using HERWIG 6.510 [31].

The uncertainty on the predicted cross section was calculated independently by varying the renormalization and factorization scales by factors of two, the b-quark mass by ± 0.25 GeV, and by using the CTEQ6.6M instead of the CTEQ6M parton distribution functions [25].

4 Event selection

The data used for this measurement were collected in 2010 and were required to pass the standard event quality criteria [16, 22], which reject data with anomalous or faulty behavior of the silicon tracker, calorimeters, or muon chambers. The total integrated luminosity amounts to $34\,\mathrm{pb}^{-1}$ for the jet analysis and to $3\,\mathrm{pb}^{-1}$ for the muon analysis.

The inclusive jet data were collected using a combination of minimum bias and single-jet triggers [15], where each trigger covers a separate continuous p_T range (18-37, 37-56, 56-84, 84-114, 114-153, and 153-196 GeV, for trigger thresholds of 0, 6, 15, 30, 50, and 70 GeV in uncorrected p_T, respectively). For each p_T bin, the trigger with the highest integrated luminosity is selected from those with >98% efficiency at all rapidities. For the muon analysis, the events are required to pass a trigger selection [15] that accepts events with muons having $p_T^\mu > 9\,\mathrm{GeV}$ and $|\eta^\mu| < 2.4$.

Jets are reconstructed using a particle-flow algorithm [22], which uses the information from all CMS sub-detectors to reconstruct different types of particles produced in the event. The basic objects of the particle-flow reconstruction are the tracks of charged particles reconstructed in the central tracker, and energy deposits reconstructed in the calorimetry. These objects are clustered with the anti-k_T algorithm [32, 33] using the jet clustering distance parameter $R = 0.5$. Tight jet identification criteria [34] are applied to protect against poorly modeled sources of calorimeter noise. The jet energies are corrected using estimates based on simulated events for the p_T dependence, while corrections measured from data [34] are applied for the absolute scale and the rapidity dependence.

The b jets are identified by finding the secondary decay vertex of the b hadrons [35]. The secondary vertices from b- and c-hadron decays can be distinguished by a selection on the relative distance from the primary vertex, using the three-dimensional decay-length

significance, which is typically larger for b jets than for c, light-quark, and gluon jets. In the jet analysis, a selection based on secondary vertices with at least three tracks containing signals from the silicon pixel detector provide a clean signal against light-quark and gluon-jet backgrounds. In the muon analysis, the minimum number of tracks to identify the secondary vertex is two, in order to keep the b-tagging efficiency high for semileptonic decays of b hadrons.

In the muon analysis, the offline selection requires at least one muon candidate in the p_{T} and η ranges of the trigger selection that fulfills a tight muon selection identical to that used in [16]. The reconstructed muon is associated with the highest-p_{T} b-tagged jet within a $\Delta R = \sqrt{(\Delta\eta)^2 + (\Delta\phi)^2} < 0.3$ cone, where $\Delta\eta$ and $\Delta\phi$ refer to the angular separation between the b-tagged jet and the muon. If several muons are associated with the b-tagged jet, the muon with the highest p_{T} is considered. According to the simulation, the average efficiency of associating the muon with the b-tagged jet is $(76 \pm 2)\%$. The probability of a random muon association with a jet is estimated to be less than 0.5%.

The two b-jet cross-section measurement samples are collected with different triggers and are essentially statistically independent. The effective trigger efficiency of the muon trigger is significantly higher, thereby compensating for an order of magnitude smaller integrated luminosity. A total of 43 046 jets pass the event and jet selection for the jet analysis while in the muon analysis a total of 113 561 events pass the event and jet selections, making the two analyses comparable in terms of statistical power.

5 Cross section measurement

The production cross section for b jets is calculated as a double differential,

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}p_{\mathrm{T}}\,\mathrm{d}y} = \frac{N_{\mathrm{tagged}}\,f_{\mathrm{b}}\,C_{\mathrm{unfold}}}{\epsilon\,\Delta p_{\mathrm{T}}\,\Delta y\,\mathcal{L}} \quad , \tag{5.1}$$

where N_{tagged} is the measured number of tagged jets per bin from the jet analysis and the number of jets tagged with muons from the muon analysis, Δp_{T} and Δy are the bin widths in p_{T} and y, f_{b} is the b-tagged sample purity, C_{unfold} is the unfolding correction, and $\mathcal{L}$ is the integrated luminosity. No distinction is made between b-quark jets and $\overline{\mathrm{b}}$-quark jets, so the cross section is the sum of b and $\overline{\mathrm{b}}$ production.

The p_{T} spectra are normalized by the respective integrated luminosities of the individual jet triggers [22], and then combined into a continuous jet p_{T} spectrum. Only one trigger is used for each p_{T} bin to simplify the analysis. In the jet analysis, the reconstructed p_{T} spectra are unfolded using the ansatz method [36, 37], with the jet p_{T} resolution obtained with data-based methods from dijet data [34]. In the muon analysis, an unfolding (jet migration) correction derived from simulated events is applied to the selection efficiency as the bin-by-bin ratio of the number of generated b jets in a given p_{T} or rapidity bin to the number of reconstructed b candidates in that bin. In the simulation, the generated jets are constructed by clustering the stable particles produced during the hadronization process including neutrinos in the muon analysis, but not in the jet analysis. The two unfolding methods produce consistent results within the uncertainties of the jet p_{T} spectrum and the jet p_{T}-resolution modeling, which are negligible compared to the total systematic uncertainty.

The efficiency ϵ includes the trigger efficiency, event selection efficiency, jet reconstruction and identification efficiency, and the efficiency of tagging b jets. For the muon analysis, the muon reconstruction efficiency is also included.

In the jet analysis, the efficiency is about 0.1% to mistag light-quark and gluon jets as b jets, and the b-tagging efficiency is between 5% at $p_T \approx 18\,\mathrm{GeV}$ and 56% at $p_T \approx 100\,\mathrm{GeV}$. The efficiency rises at higher p_T as the average b-hadron decay length increases. To moderate the statistical fluctuations in the simulation, the b-tagging efficiency in each rapidity bin is fitted to a functional parameterization versus p_T accounting for various effects such as the b-hadron proper time and the boost of secondary vertex decay products. The fit result is used in the analysis. In the muon analysis, the average b-tagging efficiency is about 60% in the barrel region ($|y| < 0.9$) and about 55% for the endcap region ($1.2 < |y| < 2.4$). It increases from 50% to 75% for b-jet transverse momenta from 30 to $100\,\mathrm{GeV}$. The data/simulation scale factor for the b-tagging efficiency applied in the analysis is 0.95, with an uncertainty of 10% [35].

In the jet analysis, the distribution of the invariant mass of the tracks originating from the secondary vertex is fitted with probability density functions corresponding to vertex mass distributions for light-, charm-, and b-flavor jets taken from simulated events. The relative normalizations for the combined light- and charm-flavor distribution and the b-flavor distribution are free parameters in the fit. The resulting estimates of f_b from data and simulated events are shown in figure 1 (left). The overall relative data/simulation scale factor is consistent with unity within uncertainties. Given the good agreement between data and simulation for $p_T > 37\,\mathrm{GeV}$, the latter is used to predict the p_T and y dependence of the purity, with no additional corrections, and to extrapolate it to $p_T < 37\,\mathrm{GeV}$.

In the muon analysis, the b-tagged sample purity is obtained from a fit to the distribution of the relative muon momentum p_T^{rel} with respect to the b-jet axis, which effectively discriminates between b events and background. Figure 1 (right) shows the result of the p_T^{rel} fit, using the expected shapes from the simulated events for the muons from b-hadron decays and background from charm quark and light-flavor jets. The normalizations of the three contributions are free parameters in the fit. A b fraction of $(86 \pm 5)\%$ is observed. The shapes obtained from the simulated events provide a reasonable description of the data. The p_T^{rel} fit to the data gives a light-quark and gluon contribution to the b-tagged jet sample of less than 3% for all bins in p_T and $|y|$. This is confirmed in the simulated events where the light-quark and gluon fraction of the b-tagged jets is estimated to be less than 2%.

6 Systematic uncertainties

The inclusive b-jet differential cross section can be affected by uncertainties on the yield in each of the p_T bins and on the measurement of the b-jet p_T itself, which determines the amount of smearing between the neighboring bins and is corrected by unfolding. The leading uncertainties affecting the yields are due to the b-tagging efficiency, the sample purity, and the integrated luminosity. The smearing of the p_T bin assignment is dominated by the jet energy scale. In the following, the systematic uncertainties common to the two analyses are discussed first, and those specific to each analysis are then described separately. All systematic uncertainties are summarized in table 1.
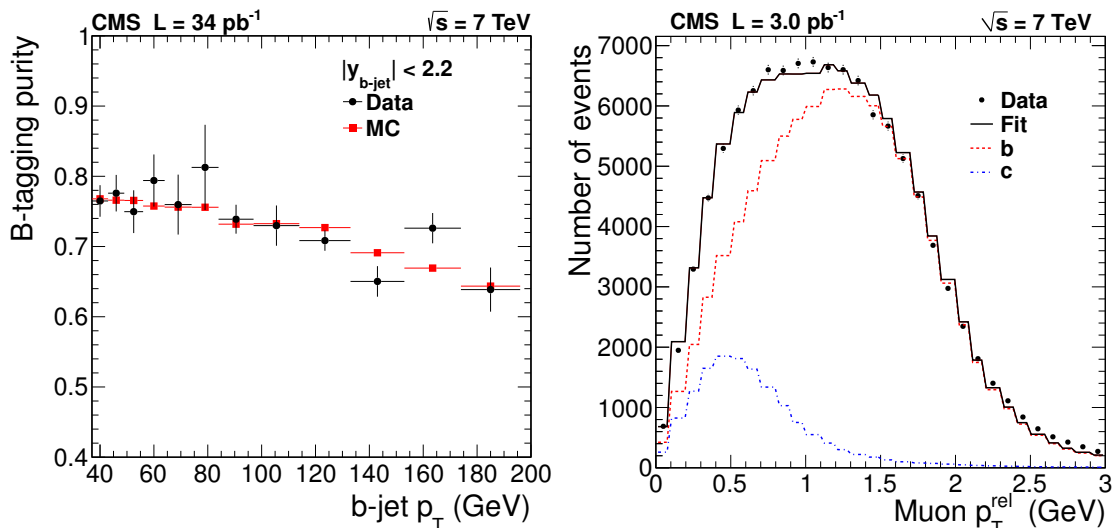
Figure 1. The b-tagged sample purity obtained using fits to the secondary vertex mass from data and simulated events as a function of the b-jet p_T (left). The distribution of the muon transverse momentum p_T^{rel} with respect to the closest b-tagged jet in data for $p_T > 30\,\text{GeV}$ and $|y| < 2.4$, together with the maximum-likelihood fit (solid line) and its components (dashed lines) (right). The light-flavor (udsg) distribution is not visible in the figure since its contribution from the fit is consistent with zero.

The uncertainty of the jet energy correction (JEC) is estimated using photon+jet events with the jet in the barrel region, and dijet events where one jet is measured in the barrel region and the other in one of the endcaps [34]. These uncertainty estimates are further confirmed by indirect observations using comparisons of jet substructure between data and MC simulations, the reconstruction of the π^0 mass peak for the ECAL energy scale, and the measurement of the single-particle response in the calorimeters using isolated charged hadrons. The uncertainty of the jet p_T resolution is estimated using a comparison of dijet p_T balance between data and simulated events [34].

The cross-section measurement uses the b-tagging efficiency obtained from simulated events and corrected by a scale factor measured in data. Several methods based on muon-tagged jets [35] or $t\bar{t}$ events [38, 39] are used to measure the b-tagging efficiency in data. The ratio between the efficiencies measured from data and estimated from simulated events determines the scale factor of 0.95 ± 0.10.

The difference between the inclusive-jet and the b-jet energy corrections is estimated from MC fragmentation studies with PYTHIA and HERWIG to be 0.5-1.5%, while studies based on data find the inclusive jet scale uncertainty to be about 1.5-3.5% for $p_T > 30\,\text{GeV}$ and $|y| < 2.2$. Because of the lack of direct constraints from data on the relative b-jet energy scale, the b-jet and the relative b-jet to inclusive JEC uncertainties are both taken to be the same as the inclusive JEC uncertainty [34]. Each 1% uncertainty in the JEC translates into a 2-5% uncertainty on the measured cross section because of the steeply falling p_T spectrum.

Signals from the HF calorimeters are used to determine the instantaneous luminosity with a systematic uncertainty of 4% [40].

Source	Jet analysis	Muon analysis
Jet energy correction (JEC)	6-8	4-6
b-tagging efficiency	10-22	10
b sample purity	4-20	3-13
Luminosity	4	4
Trigger efficiency	< 1	3
Muon reconstruction efficiency	—	3
Selection	< 1	2-6
Muon-jet association	—	2
b fragmentation	—	4
$b \rightarrow \mu$ branching fraction	—	2.5
Total	13-24	13-20

Table 1. Summary of the systematic uncertainties on the b-jet cross-section measurement, given in percent for the two analyses. The systematic uncertainties can vary depending on the b-tagged jet transverse momentum and rapidity, as indicated by the range in the table.

6.1 Systematic uncertainties specific to the jet analysis

The b-tagged sample purity from the fit of the secondary vertex mass distribution and the estimate from the simulated events are in agreement within 3-4%. The purity uncertainty is dominated by the uncertainty of the charm mistag rate across most of the kinematic range, leading to a small uncertainty variation versus p_T and y. The light-flavor mistag rate is generally negligible except at high p_T in the forward region, where the yields are too low to perform a reliable fit. This additional purity uncertainty is estimated by varying the light-quark and gluon mistag rate by $\pm 30\%$.

The dominant source of uncertainty is the b-tagging efficiency. In the ratio between the b-jet and the inclusive jet cross sections, the contribution from the luminosity uncertainty cancels, and the impact of the jet energy resolution is negligible. The contribution from the JEC in the ratio is not significantly reduced, however, because the relative b-jet JEC is assumed to be uncorrelated with the inclusive JEC. The JEC contributes 6-8% to the total uncertainty. The remaining systematic uncertainties from charm, light-quark, and gluon mistag rates contribute 3-4% to the b-tagged sample purity, except at high p_T and y, where a 30% variation in the light-quark and gluon mistag rate contributes up to 20%.

The consistency of the simulation-based corrections for the b-tagging efficiency, the b-tagged sample purity, the b-jet energy, and the inclusive jet energy scale, among others, is tested by running the full analysis chain on reconstructed simulated events and comparing the results to the particle-level p_T spectra. This closure test produces good agreement between the generated and reconstructed p_T spectra to within 5%. This level of agreement is consistent with the statistical uncertainty of the simulation and the systematic uncertainties of the parameterizations of the b-tagging efficiency and b-purity.

6.2 Systematic uncertainties specific to the muon analysis

The muon trigger efficiency is determined from data using independent jet triggers. A systematic uncertainty of 3% is assigned, which corresponds to the range of differences between trigger efficiencies derived from data for muons from Z decays, muons in b-tagged events, and muons with tight quality requirements.

The differences between the muon reconstruction efficiencies derived from data and simulated events is less than 2% in the barrel region and less than 3% in the endcap regions. A systematic uncertainty of 3% is assigned for the muon reconstruction efficiency.

The efficiency for associating a muon with a b-tagged jet agrees between data and simulation to within 2%.

The uncertainties due to variations in the p_T^{rel} distributions between data and simulated events range from 3% to 13%. This systematic uncertainty is estimated by varying the binning, including or not including the muon in the definition of the jet direction, using different Monte Carlo simulation tunes, and considering the overall difference between the data and fit results. The largest contribution (up to 12% for high-p_T b jets) is from the difference between the signal fraction obtained by the p_T^{rel} fit and by a fit to the secondary vertex mass distribution.

The uncertainty from the event selection is estimated from the variation of the muon selection cuts and the jet reconstruction, and ranges from 2% to 6%. The uncertainty of the b-quark fragmentation is determined by comparing the extrapolation factors to the total muon transverse momentum range between PYTHIA and HERWIG [41]. It leads to a 4% difference. The branching fraction of b semileptonic decays into muons is known [42] to a precision of 2.5%. The signal fraction is also determined with an event selection based on calorimetric jets [34]. The measured cross sections are consistent within the systematic uncertainty. The b fragmentation and b $\rightarrow \mu$ branching fraction uncertainties are taken into account only for the b-jet cross section measurement extrapolated to cover the full p_T and y range of the muons. The total systematic uncertainty is 13% at low jet p_T and increases to 20% for high-p_T b jets.

7 Results

7.1 Jet analysis

The measured b-jet cross section from the jet analysis is shown as a function of the jet p_T for different rapidity bins in figure 2 (left). The values have been multiplied by the arbitrary factors given in the figure for easier viewing. The cross section decreases by four orders of magnitude over the p_T range 18-200 GeV. This behavior is well described by the theoretical predictions from MC@NLO, shown by the solid lines in the figure. Figure 2 (right) shows the ratio between the measured cross section and the theoretical predictions. The MC@NLO values tend to be below the data in the central region ($|y| < 1.0$) for low p_T and above the data in the forward region ($|y| > 2.0$) at large p_T. The predictions from the PYTHIA generator, in contrast, agree with the data at high p_T, but overestimate the cross section significantly in the p_T region below 50 GeV, with the difference extending to higher p_T in the more forward region.
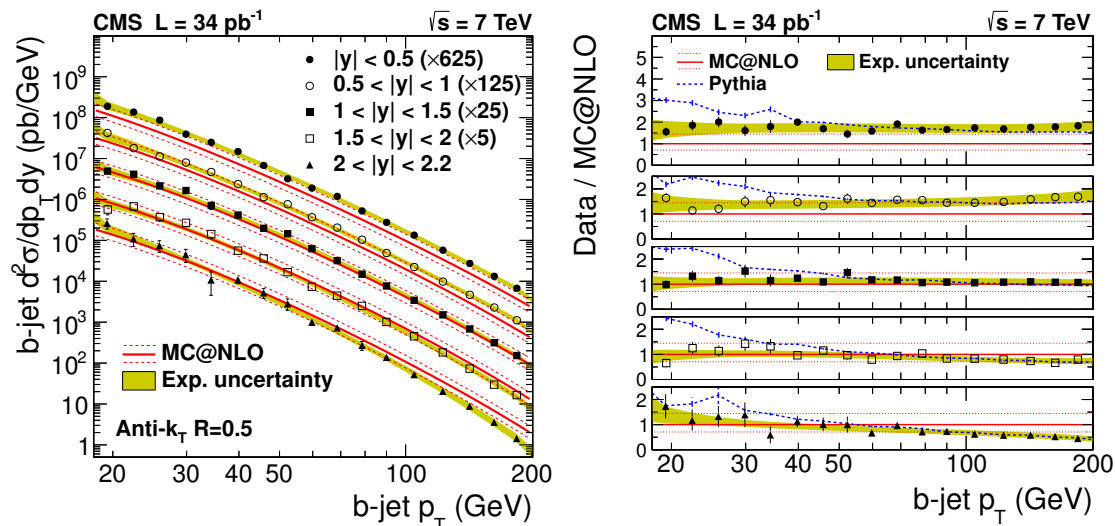
Figure 2. Measured b-jet cross section from the jet analysis, multiplied by the arbitrary factors shown in the figure for easier viewing, compared to the MC@NLO calculation (left) and as a ratio to the MC@NLO calculation (right). The experimental systematic uncertainties are shown as a shaded band and the statistical uncertainties as error bars. The MC@NLO uncertainty is shown as dotted lines. The PYTHIA prediction is also shown in the right panel.

The ratio of the b-jet and the inclusive jet cross sections [22] is shown in figure 3 as a function of p_T. The ratio increases as a function of p_T by up to a factor of 2, particularly in the central region. The measurements are compared to the MC@NLO prediction divided by the FASTNLO prediction of the inclusive jet cross section [22]. The non-perturbative corrections for the inclusive jet cross section prediction are the average of HERWIG6 [31] and PYTHIA (tune D6T [43]). The data and NLO predictions agree within experimental and theoretical uncertainties. Some difference between the NLO prediction and the data is observed in the central region, where the NLO values are lower than the data, and at $p_T > 100$ GeV and $|y| > 2$, where the NLO prediction is higher than the data. The PYTHIA prediction for the ratio between the inclusive b-jet and inclusive-jet cross sections is in agreement with the data across the full kinematic range of the measurement.

The total b-jet cross section is found by integrating the measured double-differential distributions over $|y| < 2.2$ and two different p_T ranges: $18 < p_T < 200$ GeV and $32 < p_T < 200$ GeV. The values and the corresponding MC@NLO and PYTHIA predictions are summarized in table 2.

The MC@NLO calculation predicts a total pp $\rightarrow$ b$\bar{\text{b}}X$ cross section of $238\,\mu$b. The systematic uncertainty of this prediction comes from varying the renormalization scale by factors of 0.5 and 2.0 ($+40\%$, -25%), from variations in the parameters of the CTEQ PDF ($+10\%$, -6%), and from the changing the b-quark mass from 4.5 to 5.0 GeV ($+17\%$, -14%). The total uncertainty on the theoretical calculation is shown by the shaded bands in figures 2 and 3.
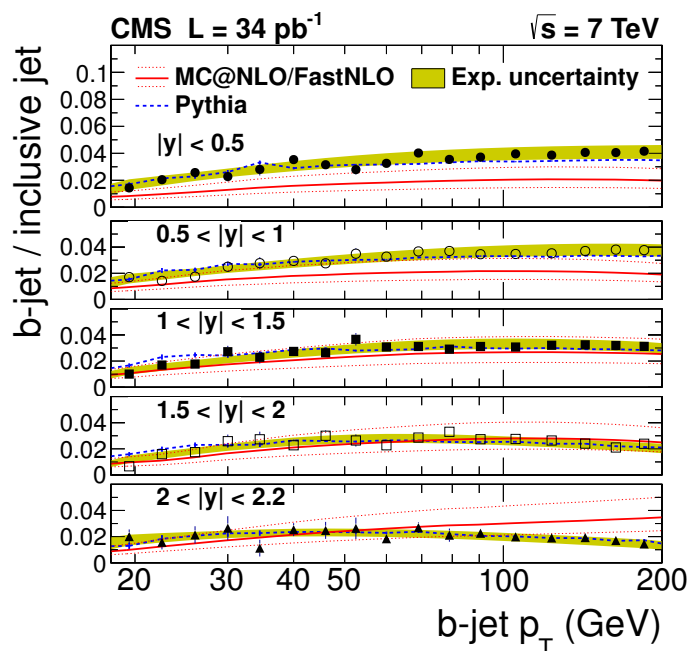
Figure 3. Ratio of the measured b-jet cross section from the jet analysis to the inclusive jet cross section [22], as a function of the b-jet p_{T} (the jet p_{T} in the inclusive case). The predictions from NLO calculations (MC@NLO/FASTNLO) and from PYTHIA are also shown.

7.2 Muon analysis

The measured differential cross sections for inclusive b-jet production of b hadrons decaying into a muon with $p_{\mathrm{T}}^{\mu} > 9\,\mathrm{GeV}$ and $|\eta^{\mu}| < 2.4$ are shown in figure 4 as a function of the b-jet p_{T} (left) and $|y|$ (right). They are compared with the MC@NLO and PYTHIA predictions. The dashed red lines illustrate the MC@NLO theoretical uncertainty from variations in the QCD scale, the b-quark mass, and the parton distribution functions. A difference between the PYTHIA prediction and the data is observed for b-jet $p_{\mathrm{T}} < 70\,\mathrm{GeV}$, where the PYTHIA values are higher than the data. The data are in agreement with the PYTHIA prediction for the rapidity dependence of the cross section. However, a significant difference in shape is observed between the data and the MC@NLO predictions for the rapidity dependence of the b-jet cross section. A similar behavior had been observed in an inclusive b measurement with muons [16]. The absolute normalization of the measured cross section is compatible with the NLO QCD predictions within the theoretical and experimental uncertainties.

The measured cross section for b jets with $p_{\mathrm{T}} > 30\,\mathrm{GeV}$, $|y| < 2.4$, and the b hadrons decaying into muons in the kinematic range $p_{\mathrm{T}}^{\mu} > 9\,\mathrm{GeV}$ and $|\eta^{\mu}| < 2.4$, is shown in table 2. The value is obtained by summing over all p_{T} bins.

The measurements in the restricted muon kinematic range are extrapolated to cover the full muon p_{T} and y ranges using the PYTHIA simulation, in order to obtain the b-jet cross section limited only by the b-jet p_{T} and y. The extrapolation also corrects for the branching fraction of b semileptonic decays into muons and for the muon acceptance. The extrapolation factor changes from 5% at low b-jet p_{T} to 20% at high p_{T}. The MC@NLO

		Data (μb)	MC@NLO (μb)	PYTHIA (μb)
Jet	$p_{\mathrm{T}} > 18\,\mathrm{GeV}$	$9.75 \pm 0.32 \pm 1.67 \pm 0.39$	$7.3\,^{+2.9}_{-1.8} \pm 1.2 \pm 0.7$	15.3
	$p_{\mathrm{T}} > 32\,\mathrm{GeV}$	$1.73 \pm 0.07 \pm 0.20 \pm 0.07$	$1.3\,^{+0.5}_{-0.3} \pm 0.2 \pm 0.1$	2.1
Muon	$p_{\mathrm{T}} > 30\,\mathrm{GeV}$ $p_{\mathrm{T}}^{\mu} > 9\,\mathrm{GeV}$ $|\eta^{\mu}| < 2.4$	$0.113 \pm 0.001 \pm 0.014 \pm 0.005$	$0.113\,^{+0.04}_{-0.023} \pm 0.003 \pm 0.005$	0.158
	$p_{\mathrm{T}} > 30\,\mathrm{GeV}$	$2.25 \pm 0.01 \pm 0.31 \pm 0.09$	$1.83\,^{+0.64}_{-0.42} \pm 0.05 \pm 0.08$	3.27

Table 2. The b-jet cross sections (in μb) measured from the jet and muon analyses. The b-jet rapidity range is $|y| < 2.2$ and $|y| < 2.4$ for the jet and muon analyses, respectively. The value for $p_{\mathrm{T}} > 30\,\mathrm{GeV}$ from the muon analysis is an extrapolated result. For the data, the first uncertainty is statistical, the second is systematic, and the third is associated with the estimation of the integrated luminosity. For the MC@NLO prediction, the first uncertainty is from the variations in the QCD scale, the second from the b-quark mass, and the third from the parton distribution functions.

extrapolation factors are similar to those of PYTHIA at high b-jet p_{T}, while they are about 20% larger at low p_{T}. The cross section measured in data and the corresponding MC@NLO and PYTHIA predictions are summarized in table 2.

7.3 Comparison of results

The measurements from the two analyses are compared in figure 5 by adjusting the b-jet cross section from the muon analysis to have the same visible phase space definition as the inclusive b-jet analysis, using PYTHIA for the extrapolation. The overall extrapolation factor is between 0.85 at $p_{\mathrm{T}} = 30\,\mathrm{GeV}$ and 0.82 at $p_{\mathrm{T}} = 200\,\mathrm{GeV}$, and accounts for the reduction in rapidity range from $|y| < 2.4$ to $|y| < 2.2$, exclusion of neutrinos from the particle jet definition, and for counting all b-jets in the event. No additional uncertainty is assigned to the displayed cross sections beyond the experimental uncertainties quoted in table 1 and discussed in section 6. The closed circles in figure 5 correspond to the measured inclusive b-jet p_{T} spectrum, and the closed squares show the b-jet p_{T} spectrum from the muon analysis, with the yellow band representing the total experimental uncertainty. Two sets of b-jet cross-section measurements from the ATLAS Collaboration [21], also found using a jet analysis and a muon analysis, are shown in the figure for comparison. The CMS results are in good agreement with each other and with the ATLAS measurements to within
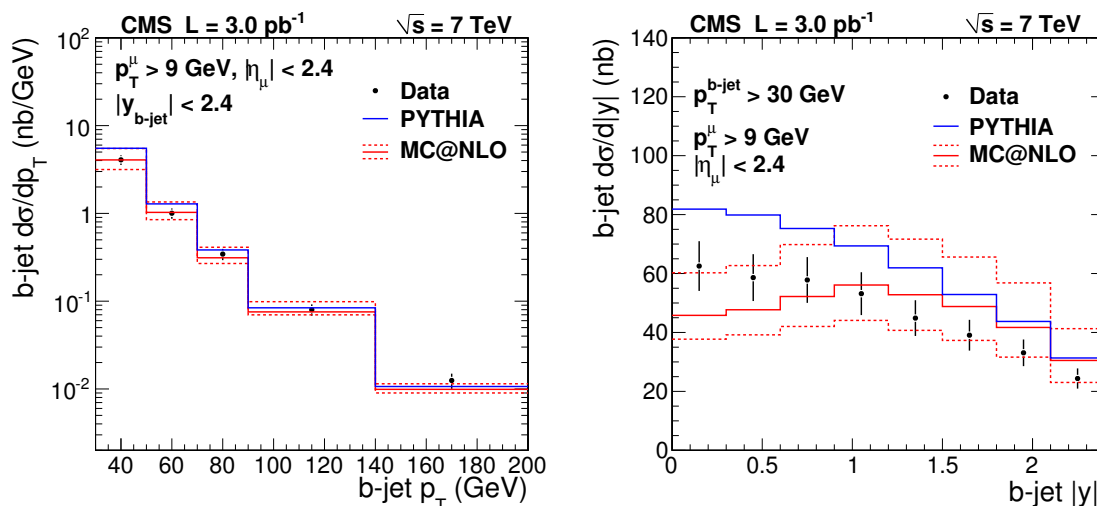
Figure 4. The differential b-jet cross section from the muon analysis as a function of the b-jet p_T (left) and $|y|$ (right), with $p_T^\mu > 9\,\text{GeV}$ and $|\eta^\mu| < 2.4$, and the predictions from PYTHIA and MC@NLO. The error bars on the points correspond to the experimental statistical and systematic uncertainties added in quadrature. The dashed lines represent the MC@NLO uncertainty.

their respective uncertainties. The theoretical prediction from the NLO calculation [29, 30] is displayed as the solid line in the figure, with the dotted lines showing the systematic uncertainties. The CMS results are consistent with the NLO predictions.

8 Summary

The b-jet production cross section has been measured in pp collisions at $\sqrt{s} = 7\,\text{TeV}$. The results were presented in several rapidity intervals as a function of the jet transverse momentum. The results were also given as the ratio of the b-jet production cross section and the inclusive jet production cross section. The results of two independent but compatible analyses were reported: a jet analysis selecting events with a b jet or a $\overline{\text{b}}$ jet, and a muon analysis requiring in addition the presence of a muon, based on integrated luminosities of $34\,\text{pb}^{-1}$ and $3\,\text{pb}^{-1}$, respectively.

The measured values of the cross section were found to lie between the MC@NLO and the PYTHIA predictions. The previous CMS measurements of B^+ [17], B^0 [18], and B_s [19] production cross sections, and an inclusive b-jet measurement with muons [16], also gave values between these two predictions. The measurement of the b-jet production cross section presented here will provide valuable input for testing various theoretical models of b production and for further constraining their parameters.
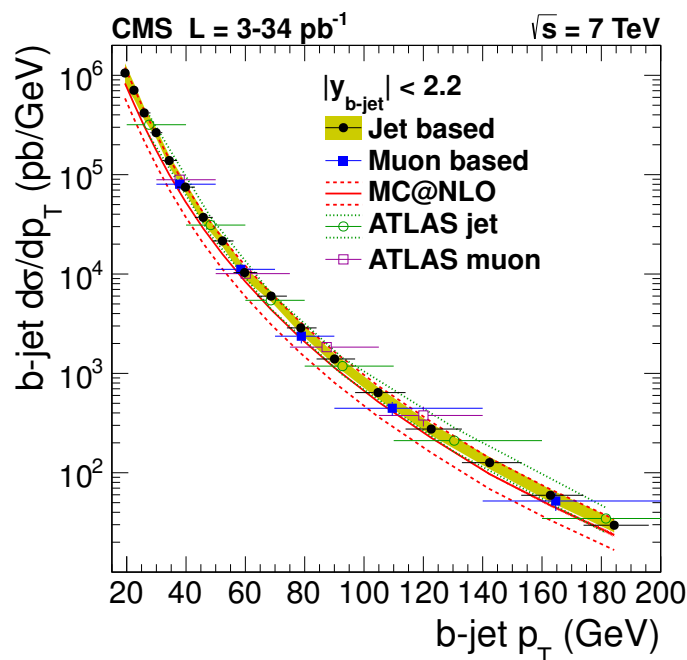
Acknowledgments

Figure 5. Measured b-jet cross sections in the jet and muon analyses as a function of the b-jet p_T, compared to the MC@NLO calculation and to measurements from ATLAS [21].

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