PROCEEDINGS OF SCIENCE

Measurement of the inclusive b production cross section in pp collisions at $\sqrt{s} = 7$ TeV

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Measurements of the cross section for inclusive b production in proton-proton collisions at $\sqrt{s} = 7$ TeV by the CMS experiment are presented. The measurements are based on different methods, such as inclusive jet measurements with secondary vertex tagging or selecting a sample of events containing jets and at least one muon, where the transverse momentum of the muon with respect to the closest jet axis discriminates b events from the background. The data are compared with QCD Monte Carlo predictions at LO and NLO accuracy.

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1. Introduction

The expected cross section for producing beauty quarks in proton-proton collisions at the Large Hadron Collider (LHC) can be computed in QCD. Calculations have been carried out at next-to-leading order (NLO) in perturbation theory. The experimental measurement of the b-production cross section has been pursued with interest at hadron colliders, due to discrepancies between theoretical predictions and experimental results [1]. 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. However, theoretical uncertainties are sizable and there is great interest in verifying the results at the higher center-of-mass energies provided by the LHC. While the investigation of b-quark production is interesting on its own, events containing b quarks also represent an important background to most of the searches for new physics at the LHC.

The first measurements of the inclusive b-quark production cross section with the CMS experiment are presented. A detailed description of the CMS detector can be found elsewhere [2]. The b-quark production is measured using two complementary methods with different systematic uncertainties and covering different regions in phase space.

The first approach [3] exploits the semileptonic decay of b quarks into muons and jets. The muons provide a clean signal in the detector which permits their identification and detection already at the trigger level. Muons from b- and c-quark decays can be distinguished by their momentum distribution: the transverse momentum of the muon relative to the jet (p_T^{rel}) is on average larger in b-decays than in charm decays and for muons from light hadrons.

The second method [4] relies on the reconstruction of b-quark decay vertices within jets. Secondary vertices from b-decays are discriminated from background events based on the 3D flight length significance and the track multiplicity at the vertex.

The measurements use data recorded by the CMS detector during the first proton-proton collisions at the LHC at a center-of-mass energy of $\sqrt{s} = 7$ TeV, corresponding to an integrated luminosity of 8 and 60 nb^{-1}, respectively. The results are compared to the NLO QCD predictions and various MC models.

2. Open beauty production with muons

The events of interest are selected by a single muon trigger with a transverse momentum threshold of $p_T > 3$ GeV. Background from non-collision events is reduced by requiring a reconstructed primary vertex with more than three associated tracks. At least one muon with transverse momentum $p_T > 6$ GeV, pseudorapidity $|\eta| < 2.1$ and a longitudinal distance from the interaction point below 20 cm is required.

The p_T^{rel} variable is defined with respect to the axis of the fragmentation jet which is reconstructed from charged particle tracks only. In events satisfying the trigger and offline event selection, all tracks with $p_T > 0.3$ GeV are clustered into track jets by the anti-k_T jet algorithm [5] with $R = 0.5$. The b-jet is defined as the track jet containing the muon. The track energy is calculated assuming the pion mass hypothesis and is required to fulfill $E_T > 1$ GeV (excluding the muon track).

The efficiency for finding a track jet around the muon depends on the muon p_T and rises from 74% to almost 100% for muons with $p_T > 20$ GeV. A total of 16826 data events pass the selection.

A binned log-likelihood fit to the observed p_T^{rel} spectrum, based on templates obtained from simulation (signal and charm background) and data (the remaining background), is used to determine the fraction of signal events among the selected events. Since the shape of the p_T^{rel} distribution of muons from charm decays and muons from light hadrons cannot be distinguished by the fit, a fit discriminating the signal component against a single background component is implemented.

The inclusive b-quark production cross section is then calculated according to

$$\sigma(pp \to b + X \to \mu + X', p_T^{\mu} > 6\,\mathrm{GeV}, |\eta^{\mu}| < 2.1) = \frac{f_b \cdot N^{data}}{\mathscr{L} \cdot \varepsilon},$$

where f_b is the fitted fraction of b-events among the selected events, N^{data}, and $\mathscr{L}$ the integrated luminosity. The efficiency ε includes the trigger efficiency (82%), the muon reconstruction efficiency (97%), and the efficiency for associating a track jet to the reconstructed muon (77%).

The result of the inclusive b-quark production cross section within the kinematic range is

$$\sigma = (1.48 \pm 0.04_{\mathrm{stat}} \pm 0.22_{\mathrm{syst}} \pm 0.16_{\mathrm{lumi}})\,\mu\mathrm{b}.$$

For comparison, the inclusive b-quark production cross section predicted by PYTHIA [6] and MC@NLO [7] are:

$$\begin{aligned} \sigma_{\mathrm{PYTHIA}} &= 1.8\,\mu\mathrm{b}, \\ \sigma_{\mathrm{MC@NLO}} &= [0.84^{+0.36}_{-0.19}(\mathrm{scale}) \pm 0.08(m_b) \pm 0.04(\mathrm{pdf})]\,\mu\mathrm{b}. \end{aligned}$$

The results of the differential b-quark production cross section measured as a function of the muon transverse momentum and of the pseudorapidity are shown in Fig. 1. The data tends to be higher than the MC@NLO prediction at low p_T and central pseudorapidities.

The systematic errors of this analysis are dominated by the description of the light quark background (up to 10%) and of the underlying event (10%). The modeling of b-quark production, semileptonic b-hadron decays, and the signal efficiency is better understood and has less impact on the systematic error. At the early stage of the CMS experiment, the integrated luminosity recorded is known to about 11%.

3. Inclusive b-jet Production

The inclusive b-jet production cross section is measured for transverse jet momenta $18 < p_T < 300$ GeV and for rapidities $|y| < 2$. The inclusive jet data is collected using a combination of minimum bias and single jet triggers, which are consecutively used in the lowest p_T range where the triggers are fully efficient. The jets are reconstructed with the anti-k_T algorithm ($R = 0.5$) using Particle Flow objects [8]. This allows for a reliable jet energy reconstruction and good energy resolution down to low p_T. The jet energies are corrected for the absolute scale, transverse momentum and rapidity dependence [9].

The b-jets are identified using a secondary vertex tagger [10]. At least three tracks are required to be associated to the secondary vertex and b-quark decays are discriminated using the 3D decay

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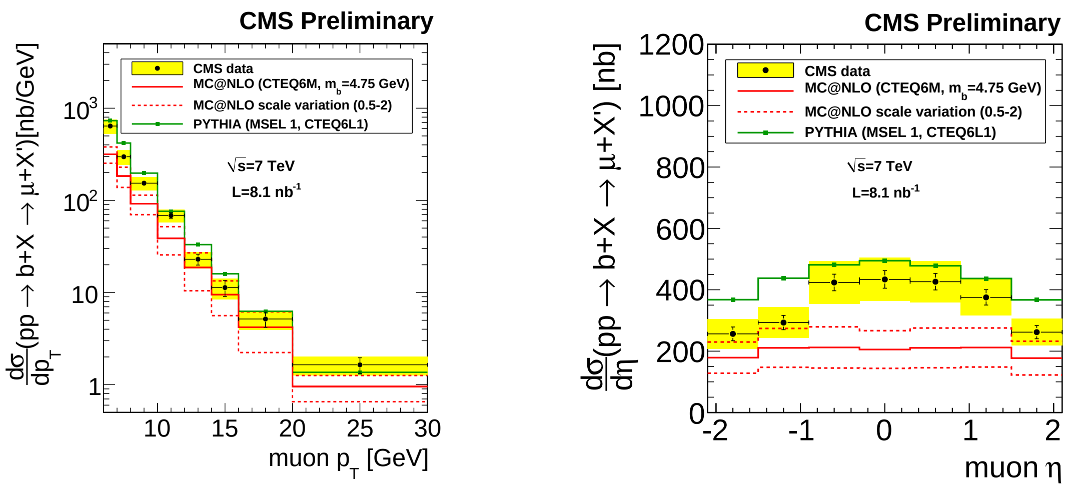

Figure 1: Differential b-quark cross section as a function of the muon transverse momentum (left) and pseudorapidity (right) compared to the PYTHIA and MC@NLO predictions. The yellow band shows the quadratic sum of statistical and systematic errors. The systematic error (11%) of the luminosity measurement is not included.

length significance. The b-tagging efficiency and the mistag rates from c-jet and light jet flavors are taken from the MC simulation and constrained by a data-driven measurement. The b-tagging efficiency is between 6% and 60% at $p_T > 18$ GeV and $|y| < 2.0$.

The b-tagged sample purity is taken from MC. Additionally, the purity is measured from a fit to the secondary vertex invariant mass distribution based on template function derived from MC. This fit allows for a robust estimate of the b-tagged sample purity and constrains the mistag rate uncertainty from c-jets. The purity obtained from MC simulation and from the template fit are compatible within the statistical uncertainty.

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

$$\frac{d^2\sigma}{dp_T dy} = \frac{N_{tagged} f_b C_{smear}}{\varepsilon_{jet} \varepsilon_b \Delta p_T \Delta y},$$

where N_{tagged} is the measured number of b-tagged jets per bin, Δp_T and Δy are the bin widths in p_T and y, f_b is the fraction of tagged jets containing a b-hadron, ε_b is the efficiency of tagging b-jets, ε_{jet} is the jet reconstruction efficiency and C_{smear} is the unfolding correction to correct the measured jet p_T back to particle level.

The measured b-jet cross section is shown as a stand-alone measurement and as a ratio to the inclusive jet p_T spectrum [11] in Fig. 2. The results are found to be in good agreement with PYTHIA and in reasonable agreement with MC@NLO. The NLO calculation is found to describe the overall fraction of b-jets at $p_T > 18$ GeV and $|y| < 2.0$ well, but with significant shape differences in p_T and y.

The leading uncertainties for the inclusive b-jet production are those coming from jet energy scale (12% at low p_T up to 40% at high p_T), luminosity, b-tag efficiency (about 20%), and mistag rates (15% at high p_T and forward rapidities). The uncertainty of the b-tagging efficiency and mistag rates are dominated by the statistical uncertainty in the data-driven method.

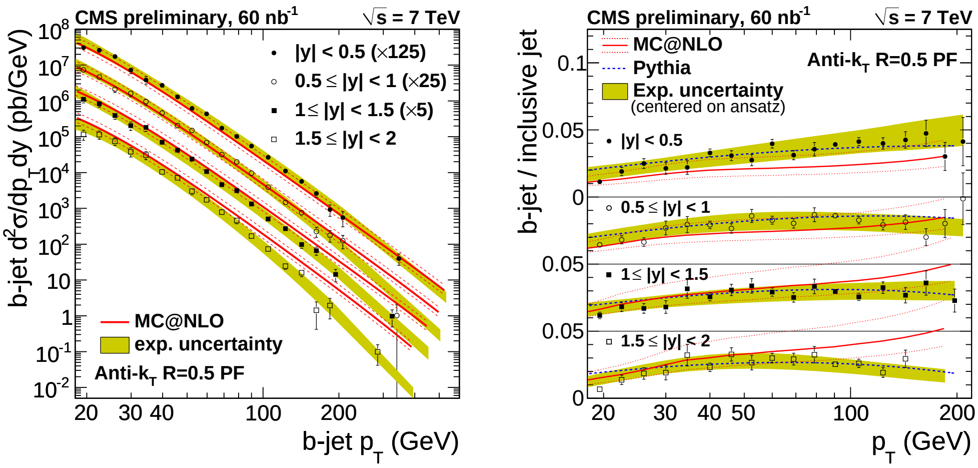

Figure 2: Measured b-jet cross section as a stand-alone measurement (left) and as a ratio to inclusive jet cross section (right). The NLO theory and Pythia MC predictions are shown for comparison.

4. Conclusion

First measurements of the inclusive b-quark production cross section into muons and the inclusive b-jet production cross section at a center-of-mass energy of $\sqrt{s} = 7$ TeV have been presented. The measurement are based on data corresponding to an integrated luminosity of 8.1 and 60 nb^{-1}, respectively. The result were compared to MC predictions at LO and NLO accuracy. The data tends to be higher than the MC@NLO prediction. Furthermore, significant shape differences are observed. In case of the cross section measurement with muons the discrepancies are confined to low p_T and central pseudorapidities, while the b-jet cross section is underestimated at high p_T and forward rapidities.

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