The Compact Muon Solenoid Experiment

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B-quark production at 7 TeV with the CMS experiment

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Abstract

Measurements performed by the CMS experiment of the cross section for inclusive b-quark production in proton-proton collisions at $\sqrt{s} = 7$ TeV are presented. The measurements are based on data collected in 2010. 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 measurements of the total and single differential cross sections for B^+ , B^0 , B_s mesons are also presented. The results are compared with predictions based on perturbative QCD calculations at leading and next-to-leading order.

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B-Quark Production at 7 TeV with the CMS Experiment

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Keywords: b-quark, cross sections, correlations, CMS experiment, LHC

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INTRODUCTION

CMS is a general-purpose detector at LHC [1]. By measuring production cross-sections of beauty hadrons and b-jets CMS provides sensitive tests of the QCD predictions of b-quark production in proton-proton collisions at the LHC. At the LHC new opportunities to improve our understanding of the physics of b quarks are available because of the high statistics data samples and the high centre-of-mass energy. Three mechanisms contribute to the beauty production at hadron colliders: gluon-gluon fusion and $q\bar{q}$ annihilation (flavor creation in hard QCD scattering), flavor excitation (semi-hard process) and gluon splitting (soft process). A distinction of the production mechanisms is meaningful only in the leading-order perturbative QCD (pQCD) picture. Inclusive b-quark production has been studied at other proton and electron colliders. The shape of the transverse momentum and angular distributions as well as the azimuthal angular correlations are reasonably well explained by pQCD [2]. The agreement is not complete and the improvement of the phenomenological description requires new experimental input.

CMS RESULTS ON B PRODUCTION

First B-production results in the central rapidity region from pp collisions at the LHC at $\sqrt{s} = 7$ have been reported by the CMS collaboration using semi-inclusive decays [3], inclusive b-jets [4] and fully reconstructed B^+ [5], B^0 [6] and B_s [7] hadron decays. A measurement of the angular correlations between beauty and anti-beauty hadrons based on secondary vertex reconstruction has been performed by the CMS in Ref. [8]. The B production cross section has been also measured by selecting pairs of muons and applying an impact parameter technique in Ref. [9].

The preliminary result on b-jet cross section [4] measurement is shown in Fig. 1(left). The ratio of b-jet to inclusive jet production is also measured. The b jets are identified with a secondary vertex tagger. A reasonable agreement between the MC@NLO [10] calculations and the measured b-jet fraction is found, but shape differences in p_T and rapidity are observed. The differential cross section of $B\bar{B}$ -pair production is measured [8] as a function of angular separation variables ΔR and $\Delta\phi$ as shown in Fig. 1(right), where the cross sections are measured for three leading-jet p_T regions. The data exhibit a substantial enhancement at small $B\bar{B}$ angular separation. The relative cross section in this region is found to increase with the leading jet p_T .

The CMS collaboration has measured the inclusive b-hadron production with muons as a function of the muon transverse momentum and pseudorapidity in the kinematic range $p_T^\mu > 6$ GeV and $|\eta^\mu| < 2.1$ [3]. The transverse momentum of the muon with respect to the closest jet axis discriminates b events from the background. The measured total cross section in the kinematic acceptance is $\sigma(pp \rightarrow b + X \rightarrow \mu + X') = (1.32 \pm 0.01(\text{stat}) \pm 0.30(\text{syst}) \pm$

FIGURE 1. Measured by CMS b-jet cross section compared to MC@NLO calculation (left plot). The differential cross section of $B\bar{B}$ -pair production (right plot) measured as a function of $B\bar{B}$ angular separation variable $\Delta\phi$.

FIGURE 2. Projection of the fit result for the process $pp \rightarrow b\bar{b}X \rightarrow \mu\mu Y$ superimposed to data.

$0.15(\text{lumi})\mu\text{b}$. The inclusive b-quark production cross section predicted by MC@NLO is $(0.95^{+0.41}_{-0.21}(\text{scale}) \pm 0.09(m_b) \pm 0.05(\text{pdf}))\mu\text{b}$. The PYTHIA prediction is $1.9\mu\text{b}$. The data lie between the MC@NLO and the PYTHIA predictions. The observed shapes for the muon transverse momentum and pseudorapidity are described reasonably well by both Monte Carlo programs.

The dimuon final state allows the selection of a sample with high $b\bar{b}$ event purity. The sources of experimental and theoretical uncertainties are complementary with respect to the jet-based approach. Signal fraction extraction is accomplished with a fit to the two-dimensional distribution of the muon impact parameters projected in the direction transverse to the beam axis. Fit projection integrated over the second muon is shown in Figure 2. Selecting pairs of muons with transverse momentum $p_T > 4\text{ GeV}$ and pseudorapidity $|\eta| < 2.1$, the value $\sigma(pp \rightarrow b\bar{b}X \rightarrow \mu\mu Y) = (26.18 \pm 0.14(\text{stat.}) \pm 2.82(\text{syst.}) \pm 1.05(\text{lumi.}))\text{nb}$ is obtained. The result is consistent with the NLO QCD expectations.

The decay channel $B_s^0 \rightarrow J/\psi \phi$ is of wide interest as the process offers a sensitive indirect search of physics beyond the standard model at the LHC. This decay proceeds via the $b \rightarrow c\bar{c}s$ transition that probes the CP-violating phase related to $B_s^0 - \bar{B}_s^0$ mixing. The standard model predicts this phase to be close to zero while new phenomena may alter the expected value. A sample of exclusive $B_s^0 \rightarrow J/\psi \phi$ decays, with $J/\psi \rightarrow \mu^+\mu^-$ and $\phi \rightarrow K^+K^-$, is reconstructed from the data corresponding to an integrated luminosity of 40 pb^{-1} . Figure 3 shows the fit projections for M_B and proper decay length ct from the inclusive sample with $8 < p_T^B < 50\text{ GeV}/c$ and $|y^B| < 2.4$. The number of signal events

FIGURE 3. Projections for exclusive $B_s^0 \rightarrow J/\psi \phi$ decays of the fit results in M_B (a) and proper decay length ct (b) for $8 < p_T^B < 50$ GeV/c and $|y^B| < 2.4$. The curves in each plot are: the sum of all contributions (solid line); signal (dashed); prompt J/ψ (dotted); and non-prompt J/ψ (dot-dashed).

FIGURE 4. Measured differential cross sections $d\sigma/dp_T$ (a) and $d\sigma/dy$ (b) for exclusive $B_s^0 \rightarrow J/\psi \phi$ decays compared with theoretical predictions.

in the entire data sample is 549 ± 32 , where the uncertainty is statistical only. The signal yields in each p_T^B and $|y^B|$ bin are obtained using an unbinned extended maximum-likelihood fit to M_B and ct . The differential cross sections times the branching fraction $\text{Br}(B_s^0 \rightarrow J/\psi \phi)$ as functions of p_T^B and $|y^B|$ are plotted in Fig. 4, together with predictions from MC@NLO and PYTHIA. The measured cross section lies between the theoretical predictions of PYTHIA and MC@NLO. The CMS cross-section measurements of B^+ [5] and B^0 [6] production in pp collisions at $\sqrt{s} = 7$, gave also values between the two theory predictions, indicating internal consistency amongst the three different B-meson results.

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