Physics Letters B 771 (2017) 435–456

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Measurement of the differential inclusive B^+ hadron cross sections in pp collisions at $\sqrt{s} = 13$ TeV

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ARTICLE INFO

Article history:
Received 3 September 2016
Received in revised form 20 May 2017
Accepted 24 May 2017
Available online 30 May 2017
Editor: M. Doser

Keywords:
CMS
Physics
B-physics

ABSTRACT

The differential cross sections for inclusive production of B^+ hadrons are measured as a function of the B^+ transverse momentum p_T^B and rapidity y^B in pp collisions at a centre-of-mass energy of 13 TeV, using data collected by the CMS experiment that correspond to an integrated luminosity of 48.1 pb^{-1}. The measurement uses the exclusive decay channel $B^+ \to J/\psi K^+$, with J/ψ mesons that decay to a pair of muons. The results show a reasonable agreement with theoretical calculations within the uncertainties.

1. Introduction

Measuring the production of hadrons that contain b quarks plays an important role in testing quantum chromodynamics (QCD). Such studies have been carried out by several experiments, including UA1 [1,2] at CERN, as well as CDF [3–6] and D0 [7,8] at Fermilab. The most recent measurements are from the ATLAS [9,10], CMS [11–17], and LHCb [18–20] Collaborations at the CERN LHC in pp collisions at centre-of-mass energies at 7 and 8 TeV. Similar studies at the higher LHC energy of 13 TeV provide a new test of theoretical calculations [21,22].

This Letter describes a measurement of the inclusive B^+ differential production cross sections as a function of the transverse momentum (p_T^B) and rapidity (y^B) of the B^+ meson (charge conjugation is implied throughout this paper). The analysis is based on data collected at the LHC with 50 ns bunch spacings by the CMS experiment at $\sqrt{s} = 13$ TeV that correspond to an integrated luminosity of 48.1 pb^{-1}. The measurement is based on the inclusive channel $pp \to B^+X \to J/\psi K^+X$, with the J/ψ mesons decaying into a pair of muons. The measured cross sections are compared to PYTHIA [23] and FONLL [24,25] calculations.

2. The CMS detector and trigger

The central feature of the CMS apparatus is a superconducting solenoid of 6 m internal diameter, providing a magnetic field of 3.8 T. A silicon pixel and strip tracker, a lead tungstate crystal electromagnetic calorimeter, and a brass and scintillator hadron calorimeter reside within the magnetic volume of the solenoid. The inner tracker measures charged particles within the pseudorapidity range $|\eta| < 2.5$. Muons are measured with detectors made using three technologies: drift tubes, cathode strip chambers, and resistive-plate chambers. Matching stubs in the muon system to tracks measured in the silicon tracker result in a transverse momentum (p_T) resolution better than 1.5% for a typical muon in this analysis [26]. A more detailed description of the CMS detector, together with a definition of the coordinate system and kinematic variables, can be found in Ref. [27].

The triggers have two levels of activation: the first-level (L1) trigger is based on the information provided by the muon detectors, while the “high-level trigger” (HLT) uses information from the silicon tracker to filter the events. Two L1 trigger requirements are used: one requires two muons in the barrel region ($|\eta| < 1.6$), without explicitly imposing a minimum p_T value; the other accepts two muons with relaxed pseudorapidity restrictions (i.e. $|\eta| < 2.4$) but requires at least one muon to have $p_T > 10$ GeV. The HLT requires the two muons to be of opposite charge, to lie within $|\eta| < 2.4$, and to have $p_T > 4$ GeV. The dimuon invariant mass must be in the range 2.9–3.3 GeV, and the χ^2 probability of the dimuon fit (imposing a common vertex) must be greater than 10%. Furthermore, the signal purity from the trigger is enhanced by requiring the distance between the dimuon vertex and the interaction point (the mean pp collision position or beam spot, which is determined for each set of events collected during a period of 23 seconds) in the transverse plane be larger than three times

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http://dx.doi.org/10.1016/j.physletb.2017.05.074

its uncertainty; this requirement preferentially selects dimuons from "nonprompt" J/ψ meson decays, while rejecting almost all promptly produced J/ψ mesons. Also, the J/ψ meson momentum vector reconstructed at the HLT stage must point back to the interaction point in the transverse plane. This condition is imposed by requiring $\cos(\alpha) > 0.9$, where α is the angle between the J/ψ momentum vector and the vector pointing from the interaction point to the dimuon vertex. Finally, the J/ψ candidate is combined with any other charged particle of $p_T > 0.8\,\text{GeV}$, and the three-track fit to a common secondary vertex is performed. The HLT requires at least one of the fits to have a χ^2 per degree of freedom smaller than 10.

3. Event reconstruction and selection

The first step in the reconstruction of the $B^+ \to J/\psi K^+$ decays is the selection of events containing a pair of muons originating from the decay of a J/ψ meson. The muons are required to have at least one reconstructed segment in the muon detectors that matches the extrapolated position of a track reconstructed in the silicon tracker, to satisfy $p_T > 4.2\,\text{GeV}$, $|\eta| < 2.1$, and to have good quality in the fit to a track. The muon tracks are required to intersect a cylinder of 0.3 cm radius in the transverse plane and 20 cm length along the beam line relative to the interaction point.

Candidate J/ψ mesons are reconstructed by combining pairs of oppositely charged muons having an invariant mass within ±150 MeV of the nominal J/ψ meson mass [28]. Each J/ψ candidate must have $p_T > 8\,\text{GeV}$, and a χ^2 probability for a fit to the dimuon vertex larger than 10%. Both muons must be either within $|\eta| < 1.6$ or one of the muons must have $p_T > 11\,\text{GeV}$. Candidate B^+ mesons are reconstructed by combining a J/ψ candidate with each charged track in the event having $p_T > 1\,\text{GeV}$. A kaon mass hypothesis is assumed for the tracks and the χ^2 per degree of freedom of the track fit is required to be less than 5. A kinematic fit is performed to the dimuon-track combination, constraining the dimuon mass to the nominal J/ψ mass. The three-track combination must be compatible with having a common vertex with a χ^2 probability larger than 10% and a reconstructed invariant mass, $M_{J/\psi K}$, in the range 5–6 GeV. The significance in the transverse decay length, defined as the distance between the $\mu\mu K$ vertex and the interaction point in the transverse plane, divided by its uncertainty, is required to exceed 3.5. Also, the cosine of the angle between the B^+ candidate momentum and the vector pointing from the interaction point to the $\mu\mu K$ vertex in the transverse plane must be greater than 0.99. Most of the selected B^+ candidates have a transverse decay length greater than 300 μm. Only a small fraction (<1%) of events contain two reconstructed B^+ candidates; all reconstructed candidates are included in the analysis. This analysis is insensitive to the number of proton–proton interactions occurring in the same or nearby bunch crossings.

The combinatorial background arises from the spurious combination of a promptly produced J/ψ meson or a J/ψ meson from a B hadron decay with an uncorrelated charged particle. The former case is suppressed by the requirement on the reconstructed decay length of the B^+ candidate. Given the excellent dimuon mass resolution at the J/ψ mass and the good muon identification performance of the CMS detector, the background level under the J/ψ peak is very small. Other backgrounds arise from misreconstructed b hadron decays, such as $B \to J/\psi + \text{hadrons}$ (including, e.g. $J/\psi K^*(892)$), which contribute a broad structure in the mass region $M_{J/\psi K} < 5.15\,\text{GeV}$. Additional background from Cabibbo–Kobayashi–Maskawa-suppressed $B^+ \to J/\psi\pi^+$ decays with a mass misassignment to the pion track forms a tiny excess just above the $J/\psi K^+$ signal.

4. Reconstruction efficiency and acceptance

The detection and trigger efficiencies and the geometrical acceptance are evaluated through Monte Carlo simulation studies using large samples of signal events generated in PYTHIA 8.205 (using the CUETP8M1 tune [29] and the NNPDF2.3 parton distribution functions [30]) and processed by the simulation framework of the CMS detector based on GEANT4 [31]. The decays $B^+ \to J/\psi K^+$ are modelled with the SVS model of the EVTGEN 1.3.0 [32] generator. The product of the efficiency and acceptance is defined as the fraction of simulated $B^+ \to J/\psi K^+ \to \mu^+\mu^- K^+$ decays, generated in the phase-space region of $10 \le p_T^B < 17\,\text{GeV}$ and $|y^B| < 1.45$, and in the region of $17 \le p_T^B < 100\,\text{GeV}$ and $|y^B| < 2.1$, that survive the selection criteria. These values range from 0.8% for $p_T^B \approx 10\,\text{GeV}$ to 20% for $70 < p_T^B < 100\,\text{GeV}$, and from 3.6% for $|y^B| \approx 0$ to 2.5% for $1.8 < |y^B| < 2.1$.

The trigger and muon reconstruction efficiencies are also measured from a data sample consisting of inclusive $J/\psi \to \mu^+\mu^-$ decays, using a technique similar to that described in Ref. [33], where one muon is identified with stringent quality requirements and the second muon is identified using information either from the tracker (to measure the trigger and muon identification efficiencies) or from the external muon system (to measure the silicon tracker efficiency). These efficiencies are compared to those from simulation studies, in bins of muon p_T and η, and are found to agree within their uncertainties. The measured efficiencies of the track reconstruction and of the vertex-quality requirement are also found to be compatible with the simulations.

5. Extraction of the signal

The B^+ differential cross section $d\sigma/dp_T^B$ is measured in 2 bins of p_T^B between 10 and 17 GeV in a restricted y^B range ($|y^B| < 1.45$) and in 7 bins of p_T^B in the extended y^B range ($|y^B| < 2.1$) for p_T^B between 17 and 100 GeV. The corresponding differential cross section $d\sigma/dy^B$ is measured in 6 (2) bins of $|y^B|$ for p_T^B between 10–100 GeV (17–100 GeV). The signal yield is extracted with an extended unbinned maximum-likelihood fit to the invariant mass distribution of the B^+ candidates in each of the p_T^B or $|y^B|$ bins. The signal component is modelled by the sum of two Gaussian functions (representing the "core" and a "tail"). The relative mean of the tail Gaussian function is fixed with respect to that of the core Gaussian function, following the shapes obtained from simulated samples. The relative normalization and width of the tail Gaussian function are also fixed to the parameters obtained from simulated samples for the p_T^B bins above 50 GeV and $|y^B|$ bins above 1.45, to account for the limited size of the data sample. The combinatorial background from the inclusive J/ψ meson production is modelled by an exponential function. The background from misreconstructed $B \to J/\psi + \text{hadrons}$ decays is represented by an error function. The normalization of misreconstructed $B \to J/\psi + \text{hadrons}$ decays relative to the signal is determined from a fit to all selected B^+ candidates, and is fixed to this value in the fits that are performed in individual p_T^B or $|y^B|$ bins. The contribution from the decay $B^+ \to J/\psi\pi^+$ is modelled through a sum of three Gaussian functions; the relative yield of the $J/\psi\pi^+$ to the signal $J/\psi K^+$ is fixed by their decay branching fractions [28]. Fig. 1 shows the invariant mass distribution of all the B^+ candidates, compared to the corresponding sum of the signal and background distributions obtained from the maximum-likelihood fit. Typical invariant mass distributions of the B^+ candidates in one of the p_T^B bins and

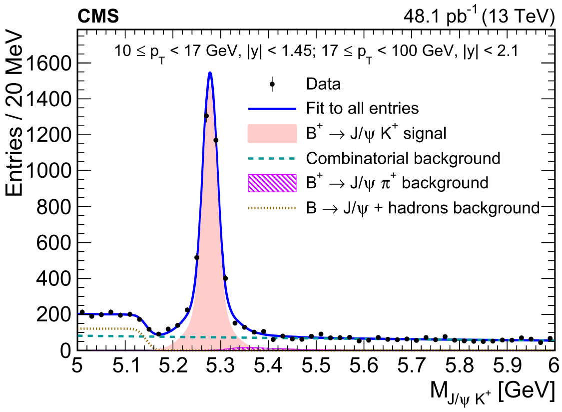

Fig. 1. Invariant mass distribution of $B^+ \to J/\psi K^+$ candidates, integrated over the phase-space region of $10 \le p_T^B < 17\,\text{GeV}$ and $|y^B| < 1.45$, and of $17 \le p_T^B < 100\,\text{GeV}$ and $|y^B| < 2.1$. The solid curve shows the result of the fit. The shaded and hatched areas represent, respectively, the $J/\psi K^+$ signal and the $J/\psi\pi^+$ component, while the dashed and dotted curves represent the combinatorial and misreconstructed $B \to J/\psi +$ hadrons backgrounds, respectively.

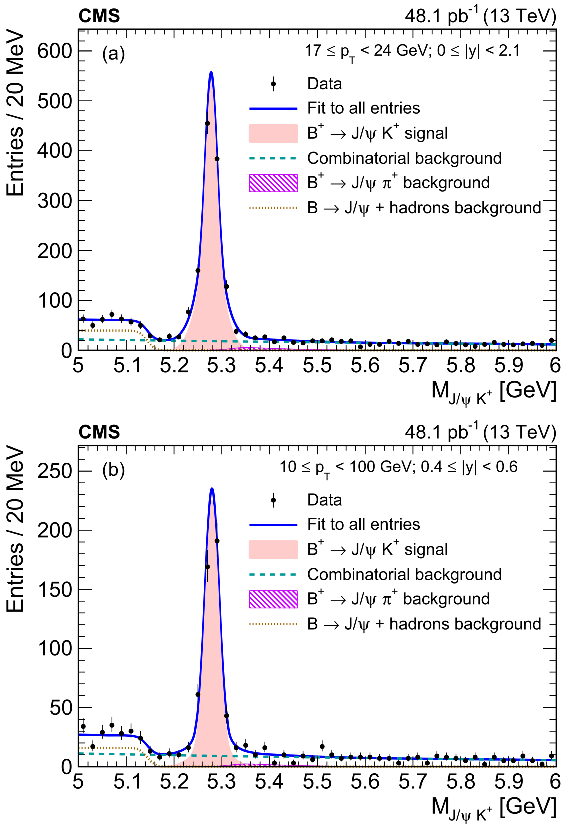

Fig. 2. Invariant mass distributions of the $B^+ \to J/\psi K^+$ candidates in the regions of (a) $17 \le p_T^B < 24\,\text{GeV}$, $|y^B| < 2.1$, and (b) $10 \le p_T^B < 100\,\text{GeV}$, $0.4 \le |y^B| < 0.6$. The solid curve shows the result of the fit. The shaded (hatched) area represents the signal ($B^+ \to J/\psi\pi^+$) component, while the dashed and dotted curves represent the combinatorial and misreconstructed $B \to J/\psi +$ hadrons background components, respectively.

in one of the $|y^B|$ bins are shown in Fig. 2. The $B^+ \to J/\psi\pi^+$ background, shown by the hatched area, is centred around 5.4 GeV, but is so small as to be almost invisible in the figures. The dip in the measured invariant mass distributions around 5.17 GeV is caused by the shape of the $B \to J/\psi +$ hadrons background distribution, which falls abruptly in that region.

Table 1
Summary of the relative systematic uncertainties in the measured B^+ production cross sections. The ranges given reflect the uncertainties over the p_T^B and y^B bins.

Systematic sources	Relative uncertainties (%)
Muon trigger, identification, and reconstruction	6.0–14
Detector alignment	2.8
B^+ vertex reconstruction	1.4
Size of simulated samples	0.5–3.9
Track reconstruction efficiency	3.9
$B^+ \to J/\psi(\to \mu^+\mu^-)K^+$ branching fraction	3.1
Model in likelihood fits	1.0–6.4
Bin-to-bin migration	0.4–3.7
B^+ kinematic distributions	0.4–11
Parton distribution functions	0.1–0.7
B^+ lifetime	0.3
Total (excluding the integrated luminosity)	9.1–16
Integrated luminosity	2.3

6. Systematic uncertainties

The measured cross section is affected by systematic uncertainties in the extraction of signal, efficiencies, branching fractions, and integrated luminosity, as summarized in Table 1. The dominant effects are associated with the models used in the likelihood fits, the B^+ kinematic distributions, and the estimation of the muon identification and reconstruction. The total uncertainty is evaluated as the sum in quadrature of the individual contributions.

The uncertainty associated with the trigger criteria is evaluated by comparing the trigger efficiencies in data and simulations for an event sample recorded using an inclusive J/ψ trigger with higher-p_T thresholds. The muon identification and reconstruction performances are studied using a large sample of inclusive $J/\psi \to \mu^+\mu^-$ events. The efficiencies in data and simulated events are found to be consistent, and residual differences are considered as systematic uncertainties. The uncertainty associated with the alignment of the detector is examined by comparing events simulated with different detector conditions, and assigning an uncertainty of 2.8%. Through a comparison of χ^2 distributions in data and simulations, the uncertainty in the B^+ vertex reconstruction efficiency is estimated to be 1.4%. In addition, the uncertainty coming from the finite size of the simulated samples and a systematic uncertainty of 3.9% in the charged-particle track reconstruction efficiency [34] are also taken into account. The integrated luminosity is measured with an uncertainty of 2.3% [35], while the uncertainty associated with the $B^+ \to J/\psi K^+ \to \mu^+\mu^- K^+$ branching fraction is 3.1% [28].

The systematic uncertainty associated with the modelling of the signal shape is evaluated by changing the model to the sum of three Gaussian functions, or a Gaussian function plus a Crystal Ball function [36]. The uncertainty from the model of the combinatorial background is evaluated by changing the exponential function to a second-order polynomial. The systematic uncertainty associated with the modelling of the mass distribution of misreconstructed $B \to J/\psi +$ hadrons events is evaluated by shifting the mass-threshold parameter in the error function by ±10 MeV. The uncertainty associated with the $B^+ \to J/\psi\pi^+$ component is estimated by changing its branching fraction by its uncertainty [28], and by shifting its mass value by ±15 MeV in the likelihood fits. Systematic uncertainties owing to the finite resolution of the reconstructed p_T^B and y^B are determined by examining the generator information in the simulated samples; half of the bin-to-bin-migrated events are taken as the corresponding uncertainty. The uncertainties associated with the p_T^B and y^B distributions in the generation of simulated events are evaluated with event-by-event weights determined from the differences between the distributions in PYTHIA and the FONLL calculations. The latter uses

Table 2

The ranges in p_T^B and $|y^B|$, signal yields n_{sig}, acceptance times efficiency $A\epsilon$, and measured differential cross sections $d\sigma/dp_T^B$ and $d\sigma/dy^B$, compared to the FONLL and PYTHIA predictions. The three uncertainties in the measured cross sections refer to the statistical, systematic, and integrated luminosity uncertainties, respectively. The uncertainties in $A\epsilon$ and in the FONLL predictions are the total uncertainties. The last row ("Inclusive bin") presents the measured total cross section and the FONLL and PYTHIA predictions for the phase-space region of $10 \le p_T^B < 17$ GeV and $|y^B| < 1.45$, and $17 \le p_T^B < 100$ GeV and $|y^B| < 2.1$.

p_T^B [GeV]	$\|y^B\|$	n_{sig}	$A\epsilon$ [%]	$d\sigma/dp_T^B$ [µb/GeV]	FONLL [µb/GeV]	PYTHIA [µb/GeV]
10–13	<1.45	408^{+52}_{-53}	0.78 ± 0.10	$3.0 \pm 0.4 \pm 0.4 \pm 0.1$	$1.4^{+0.5}_{-0.4}$	2.6
13–17	<1.45	755^{+47}_{-45}	3.6 ± 0.3	$0.88 \pm 0.05 \pm 0.08 \pm 0.02$	$0.62^{+0.21}_{-0.14}$	1.12
17–24	<2.1	1140^{+40}_{-39}	7.1 ± 0.6	$0.39 \pm 0.01 \pm 0.04 \pm 0.01$	$0.30^{+0.08}_{-0.06}$	0.48
24–30	<2.1	519^{+30}_{-28}	13 ± 1	$0.12 \pm 0.01 \pm 0.01 \pm 0.00$	0.10 ± 0.02	0.14
30–40	<2.1	404^{+24}_{-23}	17 ± 2	$(4.1 \pm 0.2 \pm 0.4 \pm 0.1) \times 10^{-2}$	$(3.3^{+0.6}_{-0.5}) \times 10^{-2}$	4.4×10^{-2}
40–50	<2.1	157 ± 13	20 ± 2	$(1.3 \pm 0.1 \pm 0.2 \pm 0.0) \times 10^{-2}$	$(1.0^{+0.2}_{-0.1}) \times 10^{-2}$	1.3×10^{-2}
50–60	<2.1	49 ± 8	21 ± 2	$(4.0^{+0.7}_{-0.6} \pm 0.5 \pm 0.1) \times 10^{-3}$	$(3.9^{+0.6}_{-0.5}) \times 10^{-3}$	4.5×10^{-3}
60–70	<2.1	23^{+6}_{-5}	21 ± 3	$(1.9^{+0.5}_{-0.4} \pm 0.3 \pm 0.0) \times 10^{-3}$	$(1.7 \pm 0.2) \times 10^{-3}$	1.8×10^{-3}
70–100	<2.1	24^{+5}_{-4}	20 ± 3	$(6.7^{+1.4}_{-1.3} \pm 1.0 \pm 0.2) \times 10^{-4}$	$(5.0 \pm 0.6) \times 10^{-4}$	5.0×10^{-4}
p_T^B [GeV]	$\|y^B\|$	n_{sig}	$A\epsilon$ [%]	$d\sigma/dy^B$ [µb]	FONLL [µb]	PYTHIA [µb]
10–100	0.0–0.2	460^{+43}_{-33}	3.6 ± 0.5	$5.5^{+0.5}_{-0.4} \pm 0.8 \pm 0.1$	$3.2^{+1.1}_{-0.7}$	5.7
10–100	0.2–0.4	511 ± 32	3.8 ± 0.5	$5.7^{+0.3}_{-0.4} \pm 0.8 \pm 0.1$	$3.2^{+1.1}_{-0.7}$	5.7
10–100	0.4–0.6	455^{+28}_{-27}	4.0 ± 0.5	$4.8 \pm 0.3 \pm 0.6 \pm 0.1$	$3.2^{+1.1}_{-0.7}$	5.6
10–100	0.6–0.85	576^{+30}_{-29}	4.4 ± 0.6	$4.5 \pm 0.2 \pm 0.6 \pm 0.1$	$3.1^{+1.1}_{-0.7}$	5.6
10–100	0.85–1.1	622^{+36}_{-35}	4.2 ± 0.6	$5.0 \pm 0.3 \pm 0.7 \pm 0.1$	$3.1^{+1.0}_{-0.7}$	5.4
10–100	1.1–1.45	671^{+42}_{-41}	3.5 ± 0.4	$4.6 \pm 0.3 \pm 0.6 \pm 0.1$	$2.9^{+1.0}_{-0.7}$	5.2
17–100	1.45–1.8	188^{+18}_{-17}	4.4 ± 0.4	$1.05^{+0.10}_{-0.09} \pm 0.11 \pm 0.02$	$0.68^{+0.18}_{-0.13}$	1.05
17–100	1.8–2.1	35 ± 8	1.4 ± 0.2	$0.74^{+0.18}_{-0.16} \pm 0.09 \pm 0.02$	$0.61^{+0.16}_{-0.12}$	0.96
		n_{sig}	$A\epsilon$ [%]	σ [µb]	FONLL [µb]	PYTHIA [µb]
Inclusive bin		3477^{+86}_{-84}	3.9 ± 0.5	$15.3 \pm 0.4 \pm 2.1 \pm 0.4$	$9.9^{+3.3}_{-2.2}$	17.2

a fixed-order perturbative QCD approach, with a next-to-leading-logarithm approximation, and the NNPDF3.0 parton distribution functions [37]. The uncertainty associated with the parton distribution functions is found to be less than 0.7%, which is estimated using the PDF4LHC prescription [38,39] with the uncertainty sets provided by the NNPDF2.3 [30]. The effect of the systematic uncertainty in the B^+ lifetime (0.3%) is also included.

7. Results

The differential cross sections for B^+ production as a function of p_T^B, for $|y^B| < 1.45$, or for $|y^B| < 2.1$, $d\sigma/dp_T^B$, and as a function of $|y^B|$ (averaged for positive and negative rapidity) for $10 < p_T^B < 100$ GeV, or for $17 < p_T^B < 100$ GeV, $d\sigma/dy^B$, are defined as

$$\begin{aligned}
\frac{d\sigma(pp \to B^+X)}{dp_T^B} &= \frac{n_{sig}(p_T^B)}{2\,A(p_T^B)\,\epsilon(p_T^B)\,\mathcal{B}\,\mathcal{L}\,\Delta p_T^B}, \\
\frac{d\sigma(pp \to B^+X)}{dy^B} &= \frac{n_{sig}(|y^B|)}{2\,A(|y^B|)\,\epsilon(|y^B|)\,\mathcal{B}\,\mathcal{L}\,\Delta y^B},
\end{aligned} \tag{1}$$

where $n_{sig}(p_T^B)$ and $n_{sig}(|y^B|)$ are the signal yields in the p_T^B or $|y^B|$ bins, obtained in the maximum-likelihood fits; and Δp_T^B and $\Delta y^B = 2\Delta|y^B|$ are the corresponding bin widths; $\mathcal{L}$ is the integrated luminosity. The total branching fraction $\mathcal{B}$ is the product of the individual $\mathcal{B}(B^+ \to J/\psi K^+) = (1.026 \pm 0.031) \times 10^{-3}$ and $\mathcal{B}(J/\psi \to \mu^+\mu^-) = (5.961 \pm 0.033) \times 10^{-2}$ values [28]. The factor of two in the denominator reflects the choice used to quote the cross section for a single charge (taken to be the B^+), where n_{sig} includes both charge states. Efficiencies and signal yields for B^+ and B^- are found to be compatible within uncertainties. The products of efficiency and acceptance, $A(p_T^B)\,\epsilon(p_T^B)$ and $A(|y^B|)\,\epsilon(|y^B|)$, are calculated for each bin.

Table 2 summarizes the event yields, efficiencies, and the differential cross sections for the various p_T^B and y^B bins. The differential cross sections as a function of p_T^B, integrated over $|y^B| < 1.45$ or over $|y^B| < 2.1$, and as a function of y^B, integrated over $10 < p_T^B < 100$ GeV or over $17 < p_T^B < 100$ GeV, are shown in Fig. 3 (a) and (b), respectively, where they are compared to FONLL [24,25] (shaded boxes) and PYTHIA (dashed lines) calculations. The uncertainties in the FONLL calculations include the effects from the renormalization and factorization scales, the mass of the bottom quark, and the uncertainties in the parton distribution functions, which are calculated according to the NNPDF3.0 uncertainty sets [37]. The bottom panels display the ratio of the data to the FONLL predictions; the ratios of the PYTHIA to the FONLL calculations are shown as dashed lines. The previous CMS measurements from $\sqrt{s} = 7$ TeV data [11] are presented as a function of p_T^B, scaled to the phase-space region of $|y^B| < 2.1$ or $|y^B| < 1.45$, and as a function of y^B, scaled to $10 < p_T^B < 100$ GeV or $17 < p_T^B < 100$ GeV. The extrapolations are carried out using the kinematic distributions from generated PYTHIA events, and an additional systematic uncertainty is included based on a comparison of extrapolations obtained with PYTHIA to those obtained with FONLL. Measurements are in good agreement with the theoretical predictions of both FONLL and PYTHIA at high p_T^B, while, at low p_T^B, the measurements tend to favour a higher cross section than estimated by FONLL and smaller than estimated by PYTHIA. The differential cross section as a function of $|y^B|$ is in agreement with both predictions, within the uncertainties. The ratios of the differential cross section measurements at $\sqrt{s} = 13$ TeV and $\sqrt{s} = 7$ TeV, as well as the FONLL and PYTHIA calculations, are shown in Fig. 4. The correlated uncertainties, including muon identification, decay branching fractions, tracking and vertexing, cancel out or are reduced in the evaluations of the ratios, and the measurements prefer higher values compared to the predictions along both p_T^B and $|y^B|$.

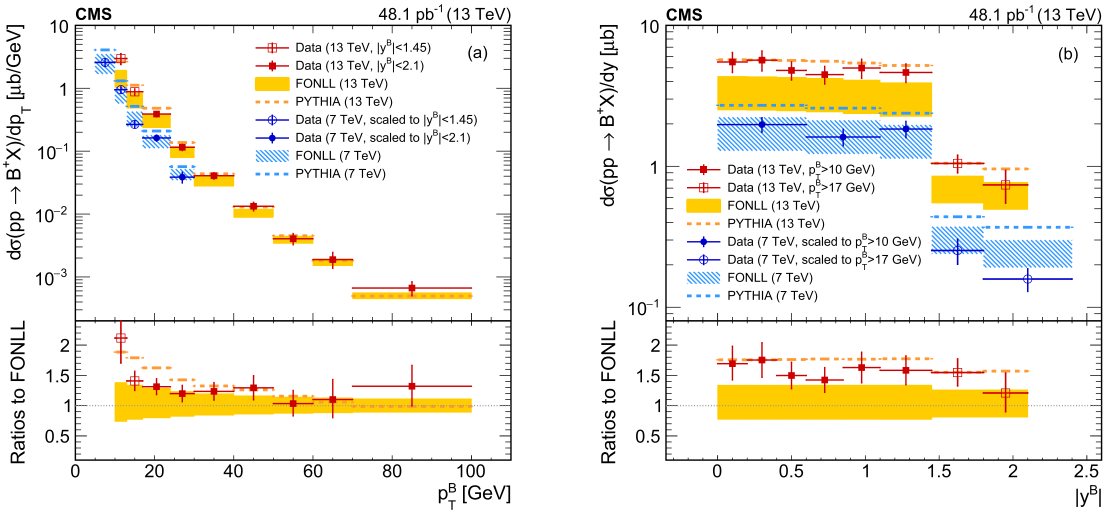

Fig. 3. B^+ differential production cross sections (a) $d\sigma/dp_T^B$ for $|y^B| < 1.45$ or $|y^B| < 2.1$, and (b) $d\sigma/dy^B$ for $10 < p_T^B < 100\,\text{GeV}$ or $17 < p_T^B < 100\,\text{GeV}$, at $\sqrt{s} = 13\,\text{TeV}$ (squares, this measurement). The previous CMS measurements from $\sqrt{s} = 7\,\text{TeV}$ data [11] (circles) are also presented as a function of p_T^B (y^B), scaled to the phase-space region of $|y^B| < 2.1$ or $|y^B| < 1.45$ ($10 < p_T^B < 100\,\text{GeV}$ or $17 < p_T^B < 100\,\text{GeV}$). The vertical bars show the total uncertainty in the measured cross sections, and the horizontal bars represent the bin width. The calculations from FONLL and PYTHIA are shown as shaded boxes and dashed lines, respectively. The bottom panels display the ratio of the data at 13 TeV to the FONLL predictions (points) and the ratios of the PYTHIA to the FONLL calculations (dashed lines), with the shaded region displaying the uncertainties in the FONLL predictions.

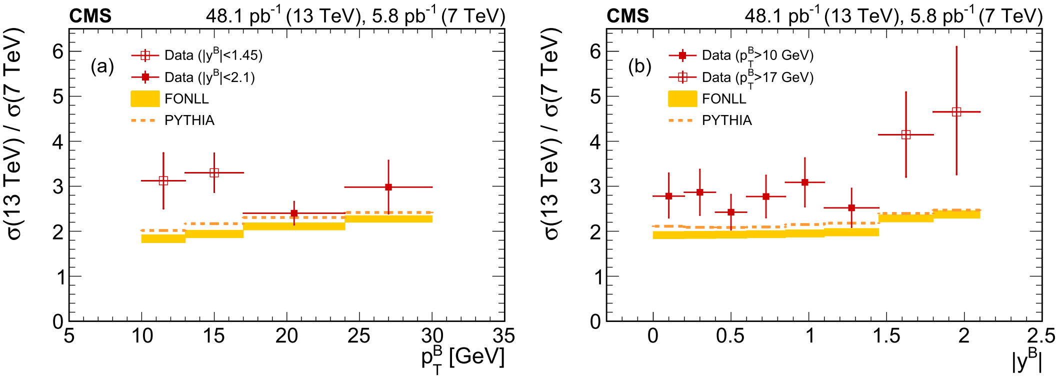

Fig. 4. Ratios of B^+ differential production cross sections at $\sqrt{s} = 13\,\text{TeV}$ and at $\sqrt{s} = 7\,\text{TeV}$ as (a) a function of p_T^B for $|y^B| < 1.45$ or $|y^B| < 2.1$ and (b) as a function of $|y^B|$ for $10 < p_T^B < 100\,\text{GeV}$ or $17 < p_T^B < 100\,\text{GeV}$. The vertical bars show the total uncertainty in the measured ratios of the cross sections, and the horizontal bars represent the bin width. The calculations from FONLL and PYTHIA are shown as shaded boxes and dashed lines, respectively.

8. Summary

The differential cross sections for B^+ meson production in pp collisions at $\sqrt{s} = 13\,\text{TeV}$ have been measured for the first time by the CMS experiment using the decay channel $B^+ \to J/\psi K^+$, with $J/\psi \to \mu^+\mu^-$, as a function of p_T^B for $|y^B| < 1.45$ or $|y^B| < 2.1$, and as a function of y^B for $10 < p_T^B < 100\,\text{GeV}$ or $17 < p_T^B < 100\,\text{GeV}$. The total cross section summed over all bins is measured to be $15.3 \pm 0.4\,(\text{stat}) \pm 2.1\,(\text{syst}) \pm 0.4\,(\text{lumi})\,\mu\text{b}$. The measured distributions show reasonable agreement in terms of shape, as well as normalization, with FONLL calculations and with the prediction of the PYTHIA event generator, within the uncertainties. The ratios between the measurements at 13 and at 7 TeV tend to prefer higher values compared to the predictions. This study provides the first measurement of a b hadron cross section through the $B^+ \to J/\psi K^+$ exclusive decay channel at the centre-of-mass energy of 13 TeV.

Acknowledgements

We congratulate our colleagues in the CERN accelerator departments for the excellent performance of the LHC and thank the technical and administrative staffs at CERN and at other CMS institutes for their contributions to the success of the CMS effort. In addition, we gratefully acknowledge the computing centres and personnel of the Worldwide LHC Computing Grid for delivering so effectively the computing infrastructure essential to our analyses. Finally, we acknowledge the enduring support for the construction and operation of the LHC and the CMS detector provided by the following funding agencies: BMWFW and FWF (Austria); FNRS and FWO (Belgium); CNPq, CAPES, FAPERJ, and FAPESP (Brazil); MES (Bulgaria); CERN; CAS, MOST, and NSFC (China); COLCIENCIAS (Colombia); MSES and CSF (Croatia); RPF (Cyprus); SENESCYT (Ecuador); MoER, ERC IUT and ERDF (Estonia); Academy of Finland, MEC, and HIP (Finland); CEA and CNRS/IN2P3 (France); BMBF, DFG, and HGF (Germany); GSRT (Greece); OTKA and NIH (Hungary); DAE and DST (India); IPM (Iran); SFI (Ireland); INFN (Italy); MSIP and NRF (Republic of Korea); LAS (Lithuania); MOE and UM (Malaysia); BUAP, CINVESTAV, CONACYT, LNS, SEP, and UASLP-FAI (Mexico); MBIE (New Zealand); PAEC (Pakistan); MSHE and NSC (Poland); FCT (Portugal); JINR (Dubna); MON, ROSATOM, RAS and RFBR (Russia); MESTD (Serbia); SEIDI and CPAN (Spain); Swiss

Funding Agencies (Switzerland); MST (Taipei); ThEPCenter, IPST, STAR and NSTDA (Thailand); TUBITAK and TAEK (Turkey); NASU and SFFR (Ukraine); STFC (United Kingdom); DOE and NSF (USA).

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