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B hadron properties at CMS

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Precise measurements of B hadron properties are crucial to improve or constrain models based on non-perturbative quantum chromodynamics, that provide predictions of mass, lifetime, cross section, polarization, and branching ratios (among several other properties) of B hadrons. Measurements of CP violation in B_s^0 decays and properties of rare B decays also provide many opportunities to search for new physics. This paper presents some B hadron property results obtained by CMS using Run I (2011-2012) data, and prospects for the Run II (2015-2018) data taking period.

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1. Introduction

During the LHC Run I, CMS collected an integrated luminosity of about 25 fb^{-1} of pp collisions at $\sqrt{s} = 7$ and 8 TeV. At these energies, the LHC produced a large amount of B hadrons, allowing for several precision measurements and rare decay searches. In CMS, about 10% of the data acquisition is allocated to physics related to B hadrons, filtered by dedicated trigger algorithms designed by the CMS B Physics (BPH) group. The BPH trigger paths rely mainly on the excellent muon identification of the CMS detector. Furthermore, the CMS High Level Trigger (HLT) uses the information of the silicon tracker to select events with two muons forming a vertex (displaced or not with respect to the beam line), in several p_{T} and mass ranges.

Using the dimuon trigger, CMS produces several competitive results on B hadron properties, reconstructing decays such as $B_s^0 \to J/\psi\,\phi$, $B_s^0 \to J/\psi\,\pi^+\pi^-$ and $B_c^+ \to J/\psi\,n\pi^\pm$ (J/ψ trigger), or $B_s^0 \to \mu^+\mu^-$ (dedicated trigger path) and $B^0 \to K^{*0}\mu^+\mu^-$ (low mass double muon trigger). Fig. 1 illustrates the performance of the BPH trigger menu used for Run I and Run II [1], respectively. The Run II menu incorporates a dimuon+track trigger with a lower dimuon mass threshold for rare decay searches.

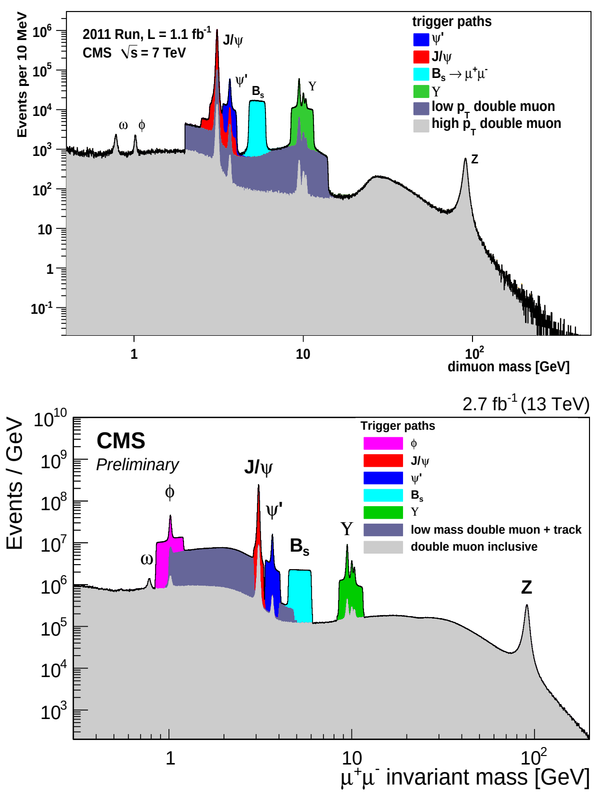

Figure 1: Dimuon mass distribution collected with various dimuon triggers, during the Run I (top) and Run II (bottom) data taking periods.

This paper summarizes several B hadron property analyses by CMS and plans for Run II. Charge conjugation is implied in what follows.

2. CP violation in $B^0_s \to J/\psi\,\phi$ decays

The CP-violating (CPV) weak phase ϕ_s, originating from the interference between direct B^0_s decays into $J/\psi\phi$ and decays through $B^0_s - \bar{B}^0_s$ mixing to the same final state, is determined within the Standard Model (SM) to be $\phi_s \simeq -2\beta_s = -0.0363 \pm 0.0016$ rad [2]. Any significant deviation from this value would be an indication of new physics in the loop diagrams describing B^0_s mixing.

CMS measured ϕ_s and the decay width difference $\Delta\Gamma_s$ between the light and heavy B^0_s mass eigenstates using 19.7 fb^{-1} of pp collisions collected at $\sqrt{s} = 8$ TeV [3].[1] A time-dependent and flavor-tagged angular analysis of the $J/\psi(\mu^+\mu^-)\phi(K^+K^-)$ final state is used to disentangle the CP-odd and CP-even components. A likelihood fit to 49,200 reconstructed B^0_s signal candidates results in values of $\phi_s = -0.075 \pm 0.097$ (stat) ± 0.031 (syst) rad and $\Delta\Gamma_s = 0.095 \pm 0.013$ (stat) $\pm$ 0.007 (syst) ps^{-1}. These are presented in Fig. 2 in a $\Delta\Gamma_s - \phi_s$ plane together with confidence level (CL) likelihood contours.

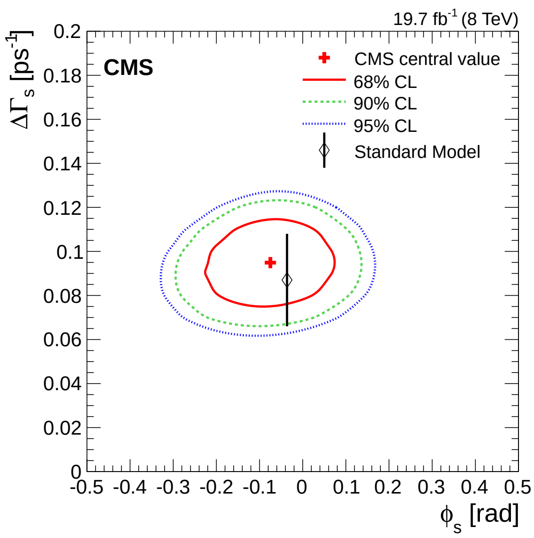

Figure 2: Measured values of $\Delta\Gamma_s$ and ϕ_s, and 68%, 90%, and 95% CL contours.

The dominant sources of systematic uncertainties are related to the 3D angular efficiency function and fit model bias. Therefore, significant efforts have been made recently to measure ϕ_s also in a well defined CP eigenstate, such as in $B^0_s \to J/\psi\pi^+\pi^-$ decays, where the analysis is simplified because no angular modeling is needed.

3. Branching ratio of the decay $B^0_s \to J/\psi\,\pi^+\pi^-$ in the $f_0(980)$ region

A first step at CMS to study the decay $B^0_s \to J/\psi\pi^+\pi^-$ was to measure its branching ratio in a region of the $\pi^+\pi^-$ invariant mass consistent with the $f_0(980)$ meson (hereafter denoted as f_0). Using an integrated luminosity of 5.3 fb^{-1} collected at $\sqrt{s} = 7$ TeV, CMS measured [4]

$$R = \frac{\mathscr{B}(B^0_s \to J/\psi\pi^+\pi^-)}{\mathscr{B}(B^0_s \to J/\psi\phi)\mathscr{B}(\phi \to K^+K^-)} = \frac{N^{\pi\pi}_{\text{obs}}}{N^{KK}_{\text{obs}}}\frac{\varepsilon^{KK}}{\varepsilon^{\pi\pi}}\,, \tag{3.1}$$

[1] See also the contribution by T. Jarvinen, *Mixing and CPV at CMS*, in these conference proceedings.

where $N_{\text{obs}}^{\pi\pi}$ (N_{obs}^{KK}) and $\varepsilon^{\pi\pi}$ (ε^{KK}) are the signal yield and detection efficiency corresponding to $B_s^0 \to J/\psi\pi^+\pi^-$ ($B_s^0 \to J/\psi K^+K^-$) decays. Here $|M_{\pi^+\pi^-} - 974\text{ MeV}| < 50$ MeV, where 974 MeV and 50 MeV are the measured mass and width, respectively, of the f_0 signal in data. This mass region is pure enough to measure the CP-odd B_s^0 lifetime and the CPV ϕ_s phase in future analyses.

The fits to the $J/\psi K^+K^-$ and $J/\psi\pi^+\pi^-$ mass distributions, shown in Fig. 3, give $N_{\text{obs}}^{KK} = 8377 \pm 107$ and $N_{\text{obs}}^{\pi\pi} = 873 \pm 49$, respectively. Detection efficiencies are obtained by Monte-Carlo (MC) simulation. MC simulated samples are validated by comparing relevant variables with background subtracted data, which are found to be in agreement.

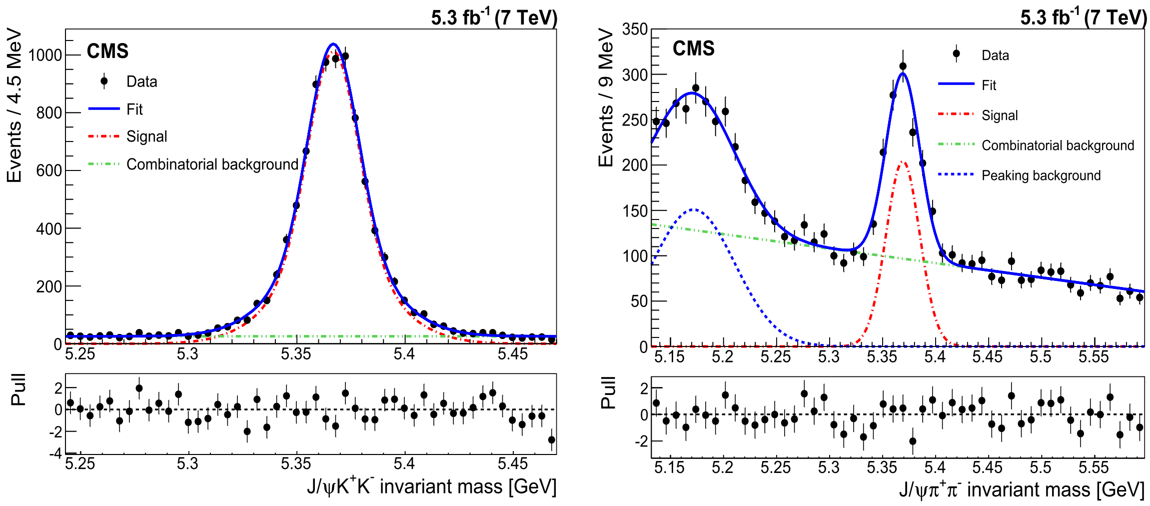

Figure 3: Invariant mass distributions of $B_s^0 \to J/\psi(\mu^+\mu^-)\phi(K^+K^-)$ (left) and $B_s^0 \to J/\psi(\mu^+\mu^-)f_0(\pi^+\pi^-)$ (right) candidates.

Several sources of systematics uncertainties are investigated. These include variants of the fit models (2.1%) in data, and alternative decay models (6.2%) and f_0 lineshapes (5.8%) in MC. Effects on the results due to resonant and non-resonant contaminations (6.4%) as well as interferences (5.6%) are estimated, respectively, by increasing the $M_{\pi^+\pi^-}$ region up to 100 MeV around the fitted f_0 mass, and by comparing the nominal f_0 model and the fitted models by LHCb [5] for different f_0 fraction scenarios in the relevant $M_{\pi^+\pi^-}$ region. Additional systematic uncertainties are included due to the finite MC simulation sample (7.1%) and the uncertainty on the true f_0 width (8.6%). The last is estimated by varying the f_0 width by ± 10 MeV in the MC simulation.

The result is $R = 0.140 \pm 0.008\text{ (stat)} \pm 0.023\text{ (syst)}$, consistent with the theoretical prediction of about 0.2 [6] and with previous measurements in different ranges of $M_{\pi^+\pi^-}$ [7, 8, 9].

4. Cross section times branching ratio of B_c^+ decaying to a J/ψ and pions

The B_c^+ meson is a unique laboratory to study heavy-quark dynamics. The two heavy quarks, b and c, compete in the decay of the B_c^+ meson, explaining the shorter lifetime of the B_c^+ with respect to other B mesons. Since the $b \to c$ transition has a high probability to produce a J/ψ, it is not strange that many production and decay studies have been made in the $B_c^+ \to J/\psi\ell^+\nu$ or $B_c^+ \to J/\psi n\pi^\pm$ channels, using large samples of $J/\psi \to \mu^+\mu^-$ decays.

Using an integrated luminosity of 5.1 fb^{-1} collected at $\sqrt{s} = 7$ TeV, CMS measured [10]

$$R_{c/u} = \frac{\sigma(B_c^+)\mathscr{B}(B_c^+ \to J/\psi\pi^+)}{\sigma(B^+)\mathscr{B}(B^+ \to J/\psi K^+)} = \frac{Y_{B_c^+ \to J/\psi\pi^+}}{Y_{B^+ \to J/\psi K^+}}, \tag{4.1}$$

$$R_{B_c} = \frac{\mathscr{B}(B_c^+ \to J/\psi\pi^+\pi^+\pi^-)}{\mathscr{B}(B_c^+ \to J/\psi\pi^+)} = \frac{Y_{B_c^+ \to J/\psi\pi^+\pi^+\pi^-}}{Y_{B_c^+ \to J/\psi\pi^+}} \tag{4.2}$$

where Y_X are the efficiency corrected yields for channel X in the kinematic region $p_T(B_c^+) > 15$ GeV and $|y(B_c^+)| < 1.6$. The $B_c^+ \to J/\psi\pi^+$ ($B_c^+ \to J/\psi\pi^+\pi^+\pi^-$) signal has a yield of 176 ± 19 (92 ± 27), fitted with a Gaussian function on top of a polynomial background as shown in Fig. 4.

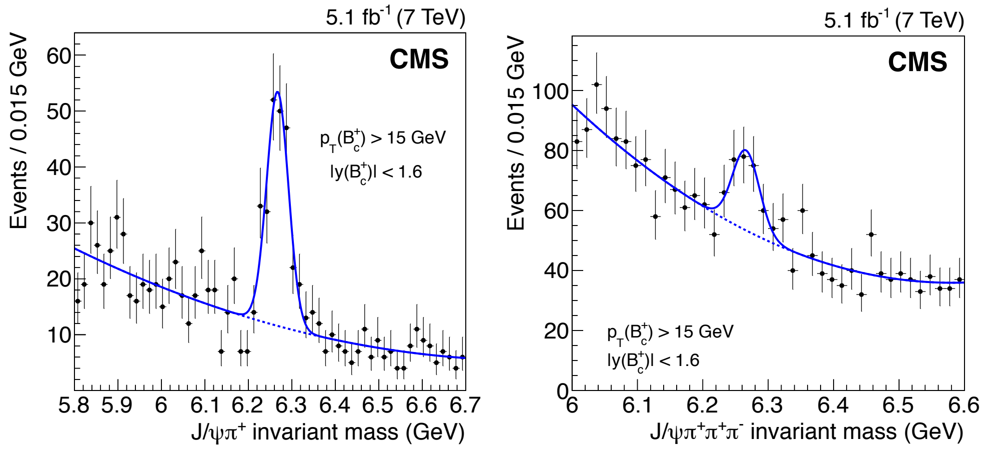

Figure 4: The $B_c^+ \to J/\psi\pi^+$ (left) and $B_c^+ \to J/\psi\pi^+\pi^+\pi^-$ (right) invariant mass distributions with fits superimposed.

Non-negligible sources of systematic uncertainties common to $R_{c/u}$ and R_{B_c} are due to the finite MC sample size (2.1% and 4.1%), fit model variants (5.3% and 9.4%), and efficiency binning (3.1% and 1.9%). Other than that, the efficiencies used to evaluate $R_{c/u}$ are strongly affected (10.4%) by the uncertainty in the B_c^+ lifetime, which motivated an ongoing measurement of the B_c^+ lifetime at CMS. Also, the addition of two pion tracks in the evaluation of the numerator of R_{B_c} leads to a subdominant systematic uncertainty (7.8%) due to the uncertainty on the tracking efficiency.

The final result of $R_{c/u} = [0.48 \pm 0.05\ (\text{stat}) \pm 0.03\ (\text{syst}) \pm 0.05\ (\tau_{B_c})]$ % is about 30% lower than the measured value by LHCb [11] in a complementary kinematic region, $p_T > 4$ GeV and $2.5 < \eta < 4.5$. This behavior is expected because of the softer p_T distribution of the B_c^+ with respect to that of the B^+, implying a lower value of the ratio at higher p_T. Finally, the measurement of $R_{B_c} = 2.55 \pm 0.80\ (\text{stat}) \pm 0.33\ (\text{syst})\ ^{+0.04}_{-0.01}\ (\tau_{B_c})$ represents a confirmation of the $B_c^+ \to J/\psi\pi^+\pi^+\pi^-$ decay, first observed by LHCb [12] that measured $R_{B_c} = 2.41 \pm 0.30\ (\text{stat}) \pm 0.33\ (\text{syst})$. These results are consistent with theoretical predictions of R_{B_c} ranging between 1.5 and 2.3 [13, 14].

5. Angular analysis of the decay $B^0 \to K^{*0}\mu^+\mu^-$

Flavor-changing neutral current decays, forbidden at tree level in the SM, can be sensitive to possible non-SM particles appearing in higher-order loop diagrams. These effects can be probed via the measurement of decay properties such as branching ratios, and quantities directly related to the Wilson coefficients in the operator product expansion (OPE) of the decay amplitude of a B hadron. A significant achievement of CMS during Run I was the measurement of $\mathscr{B}(B_s^0 \to \mu^+\mu^-) = 3.0^{+1.0}_{-0.9} \times 10^{-9}$ [15], which was later combined with LHCb data [16] to establish conclusively the existence of the $B_s^0 \to \mu^+\mu^-$ decay, well in agreement with the SM prediction. This measurement provides strong constrains on theories beyond SM.

While the $B_s^0 \to \mu^+\mu^-$ decay provides information of scalar/pseudoscalar interactions in the OPE, the $B^0 \to K^{*0}\mu^+\mu^-$ is complementary, allowing to probe vector/axial-vector interactions. Recently, CMS reported the measurement of the branching fraction and other properties of the $B^0 \to K^{*0}\mu^+\mu^-$ decay [17], such as the forward-backward asymmetry of the muons, A_{FB}, and the longitudinal polarization fraction of the K^{*0}, F_L. This analysis uses an integrated luminosity of 20.5 fb^{-1} collected at $\sqrt{s} = 8$ TeV and fits the angular distribution of the final state particles of the $B^0 \to K^{*0}\mu^+\mu^-$ decay to obtain A_{FB} and F_L.[2] Results of the fit to 1430 signal events in bins of $q^2 \equiv m^2_{\mu^+\mu^-}$ from 1 to 19 GeV^2, combined with a previous CMS measurement that used independent data [18], are shown in Fig. 5 together with results from other experiments. CMS results are among the most precise to date and are consistent with SM predictions and previous measurements. A more detailed analysis is being performed at CMS to measure the observable known as P_5', in which significant anomalies have been found recently [19].

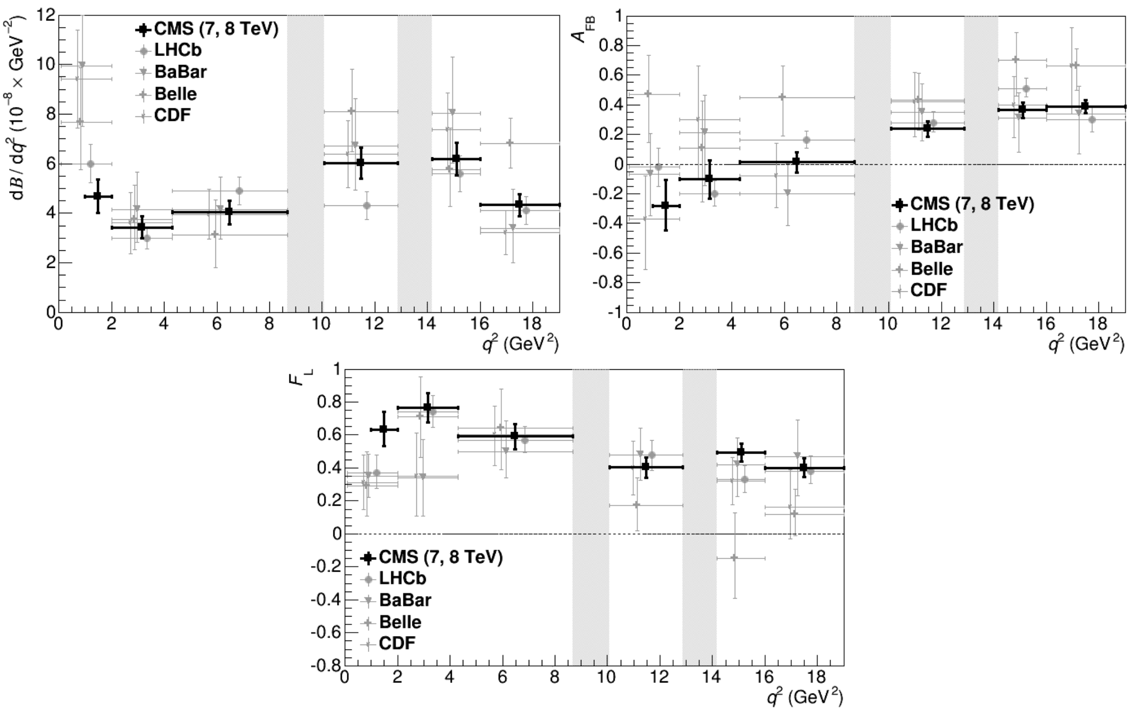

Figure 5: CMS measured values of $d\mathscr{B}/dq^2$ (top-left), A_{FB} (top-right), and F_L (bottom) vs. q^2 for $B^0 \to K^{*0}\mu^+\mu^-$ decays, compared with results from other experiments.

[2]See also the contribution by A. Bolleti, $B^0 \to K^{*0}\mu^+\mu^-$ *and rare decays at CMS*, in these conference proceedings.

6. Summary and prospects

The measurement of B hadrons properties will remain an important part of the CMS physics program in the following years. The search for anomalous CPV using decays to $J/\psi K^+K^-$ and $J/\psi\pi^+\pi^-$ as well as the B_c^+ program will benefit greatly from the Run II data. The observation of the $B^0 \to \mu^+\mu^-$ decay is one of the main long term goals at CMS. Similarly, $b \to s\mu^+\mu^-$ analyses ($B^0 \to K^{*0}\mu^+\mu^-$, $\Lambda_b \to \Lambda\mu^+\mu^-$, ...) are becoming a fundamental part of the CMS BPH program and special trigger paths are being designed for their detailed study. Still, there are several measurements using Run I data that will be realeased soon, such as B hadron lifetimes, polarizations, etc.

Acknowledgments

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References

[1] CMS Collaboration, CMS-DP-2015-055.

[2] J. Charles *et al.*, Phys. Rev. D **84** (2011) 033005.

[3] CMS Collaboration, Phys. Lett. B **757** (2016) 97-120.

[4] CMS Collaboration, Phys. Lett. B **756** (2016) 84-112.

[5] LHCb Collaboration, Phys. Rev. D **86** (2012) 052006.

[6] S. Stone and L. Zhang, Phys. Rev. D **79** (2009) 074024.

[7] LHCb Collaboration, Phys. Rev. D **86** (2012) 052006.

[8] CDF Collaboration, Phys. Rev. D **84** (2011) 052012.

[9] D0 Collaboration, Phys. Rev. D **85** (2012) 011103.

[10] CMS Collaboration, JHEP **01** (2015) 063.

[11] LHCb collaboration, Phys. Rev. Lett. **109** (2012) 232001.

[12] LHCb collaboration, Phys. Rev. Lett. **108** (2012) 251802.

[13] A. Rakitin and S. Koshkarev, Phys. Rev. D **81** (2010) 014005.

[14] A.K. Likhoded and A.V. Luchinsky, Phys. Rev. D **81** (2010) 014015.

[15] CMS Collaboration, Phys. Rev. Lett. **111** (2013) 101804.

[16] CMS and LHCb Collaborations, Nature **522** (2015) 68-72.

[17] CMS Collaboration, Phys. Lett. B **753** (2016) 424-448.

[18] CMS Collaboration, Phys. Lett. B **727** (2013) 77.

[19] S. Descotes-Genon, L. Hofer, J. Matias and J. Virto, JHEP **06** (2016) 092.

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