PROCEEDINGS OF SCIENCE

Early CMS B Physics with the First 1 - 50 pb^{-1}

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B-hadrons provide a tool to improve the current understanding of the flavor sector of the Standard Model. Thanks to their large production cross section and long life time, B-hadrons can be efficiently detected in the early LHC data. We present the Monte Carlo based measurements of the J/ψ and $B \to J/\psi K^*$ production cross sections, accompanied by the analysis of the $b\bar{b}$ angular correlation. These studies assume a 1-50 pb^{-1} sample of proton-proton collisions produced by the LHC at $\sqrt{s} = 10 - 14$-TeV and collected by the CMS experiment.

12th International Conference on B-Physics at Hadron Machines - BEAUTY 2009
September 07 - 11 2009
Heidelberg, Germany

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PoS(BEAUTY 2009)029

1. Introduction

Up until today the heavy flavor production holds unresolved questions. The production mechanism of prompt J/ψ's is not well understood. There are several models for quarkonium production [1, 2, 3] including Color Singlet Model (CSM) and Color Octet Mechanism (COM). The latter model fits the differential-p_T cross section data of the Collider Detector at Fermilab (CDF) experiment [4, 5], however it is in disagreement with the polarization measurement [6]. With the higher p_T reach available at LHC, the production mechanism models will be tested in regions of p_T and pseudorapidity, never probed before.

The b production at the LHC is dominated by pair production through the strong interaction. Previous measurements at the Tevatron Collider of inclusive b production and correlations between b and $\bar{b}$ [7] agree in shape with the next-to-leading order perturbative QCD predictions [8], but not in the normalization. Possible explanations for this discrepancy involve b fragmentation models [9], possible large higher order terms [10] or supersymmetric production mechanisms [11]. New measurements at the LHC will further test QCD and its ability to accurately predict expected background rates for several processes of interest.

Even at a lower LHC energy of $\sqrt{s} = 10$ TeV, the large production cross section of $c\bar{c}$ and $b\bar{b}$ will provide $\mathscr{O}(10000)$ $J/\psi \to \mu\mu$ and $\Upsilon \to \mu\mu$ decays and $\mathscr{O}(100)$ B^+ and B^0 decays per pb^{-1} triggered and fully reconstructed by the Compact Muon Solenoid (CMS) experiment [12]. Consequently the B physics program will play an important role in CMS right from the startup.

2. J/ψ Cross Section Measurement

The measurement of the $J/\psi \to \mu\mu$ differential cross section $d\sigma/dp_T$ will be already possible with the first few pb^{-1} of data collected by the CMS detector, providing competitive results with respect to the Tevatron measurements over the J/ψ transverse momenta in the range from 5 GeV/c up to about 40 GeV/c.

The analysis in [13] assumes 3 pb^{-1} of data collected at a center-of-mass energy of 14 TeV with a dedicated J/ψ trigger at an instantaneous luminosity of 10^{32} cm^{-2}s^{-1}. The trigger requires two muons with $p_T > 3$ GeV/c at Level 1. In the High Level Trigger the muons are confirmed and the reconstruction is further refined by adding the silicon tracker information. Finally, the event is accepted if there are two HLT muons with $p_T > 3$ GeV/c and invariant mass between 2.8 and 3.4 GeV/c^2. Offline, J/ψ candidates are reconstructed by selecting muons reconstructed with a global fit to the silicon tracker and muon system hits. Further requirements are opposite charge, $p_T > 3$ GeV/c and common vertex, which is determined by the point of their closest approach in space.

The dimuon mass spectrum including background and signal is given in Fig. 1. The differential cross section $d\sigma/dp_T$ is obtained by a 1-d fit to the J/ψ invariant mass in several different p_T intervals. The sum of two Gaussian functions is used to parametrize the J/ψ signal and a linear polynomial for the background shape. To determine the fraction f_B of J/ψ's from B-hadron decays, a 2-d unbinned maximum likelihood fit to the J/ψ invariant mass and the pseudo proper time l_{xy} is performed. The pseudo proper time is defined as $l_{xy} = L_{xy} \cdot m(J/\psi)/p_T(J/\psi)$, where L_{xy} is the

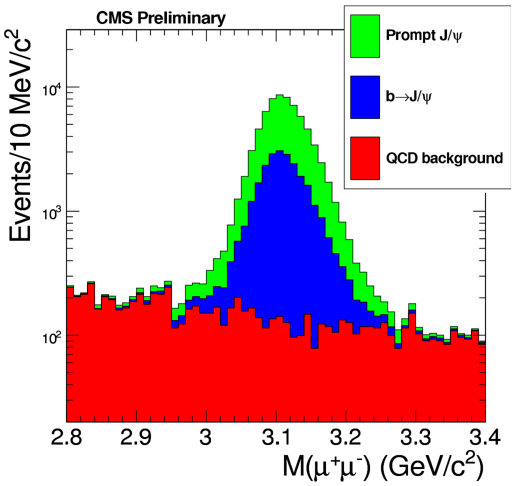


Figure 1: Dimuon invariant mass distribution normalized to 3 pb^{-1}. The green (light grey), blue (black) and red (dark grey) areas are the prompt, non-prompt and QCD background contributions, respectively.

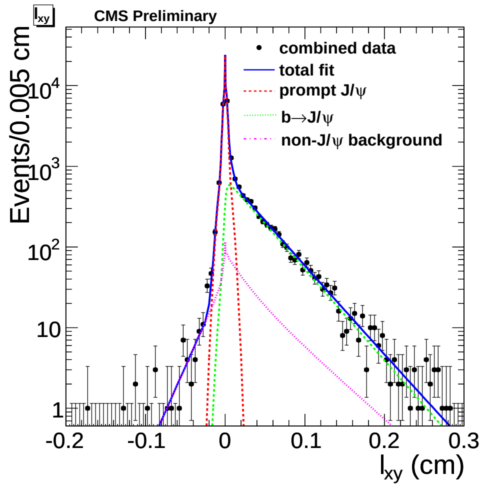
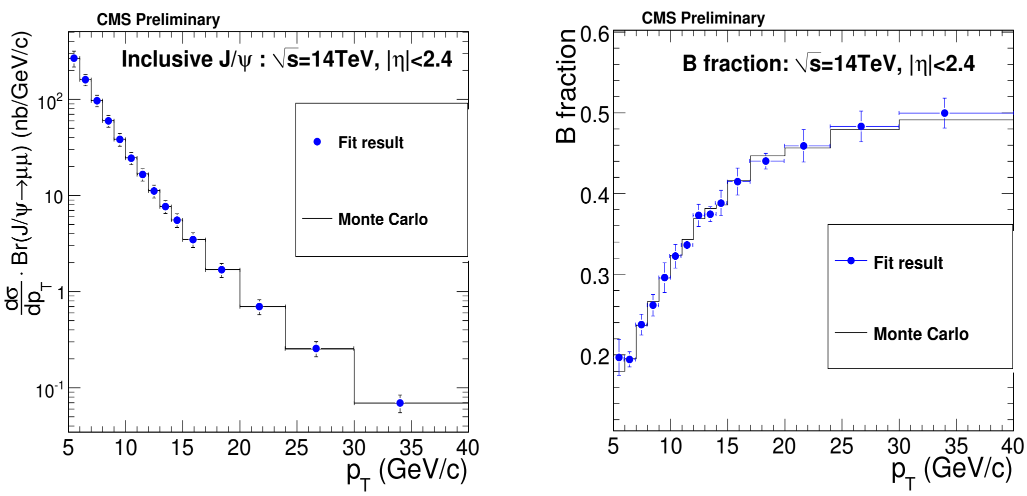


Figure 2: Distribution of l_{xy} and likelihood fit result in the range of $9 < p_T < 10$ GeV/c.



(a) (b)

Figure 3: (a) The inclusive J/ψ differential cross section, $d\sigma/dp_T \cdot Br(J/\psi \to \mu\mu)$ and (b) the fitted fraction of J/ψ's from B-hadron decays, as a function of $p_T^{J/\Psi}$, integrated over the pseudorapidity range $|\eta^{J/\Psi}| < 2.4$, corresponding to an integrated luminosity of 3 pb^1.

distance in the transverse plane between the vertex of the two muons and the primary vertex of the event, and $m(J/\psi)$ is the J/ψ invariant mass, Fig. 2.

With an integrated luminosity of 3 pb^{-1} , the precision of the result is limited by systematic uncertainties, and is around 15%, where the largest systematic uncertainties are on the luminosity measurement (10%), the dependence on the J/ψ polarization (2-7%) and the fit technique (1-6%). Fig. 3(a) displays the inclusive J/ψ differential cross section, with combined systematic and

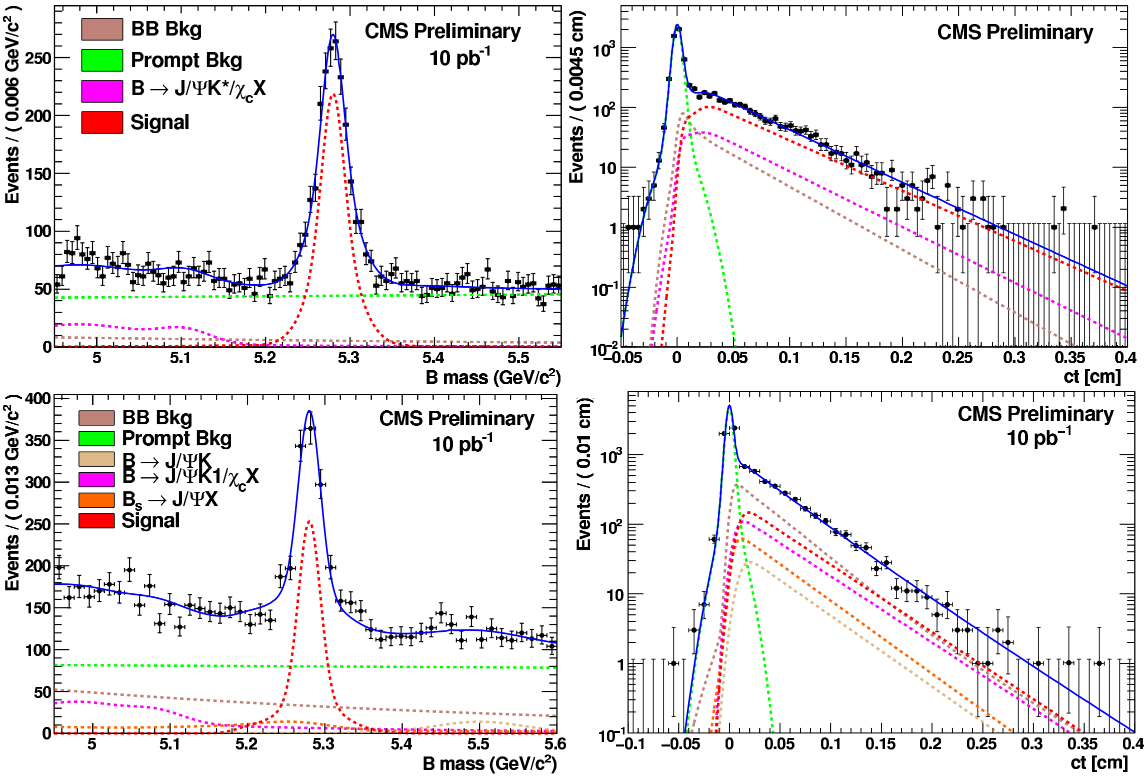


Figure 4: Distributions of m_B and ct for the B^+ (top) and B^0 (bottom) fits integrated over all p_T bins. Individual contributions from the signal and various background components are shown in different colors (see legend in the plots).

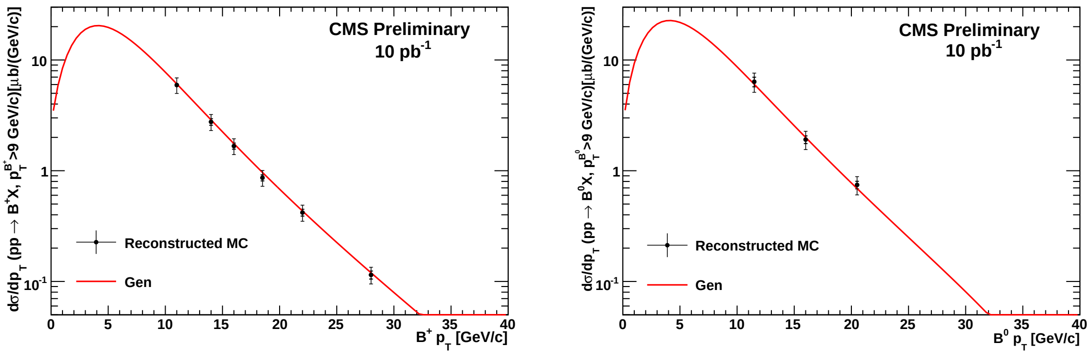
statistical uncertainties. Fig. 3(b) shows the result of the fits to the fraction of J/ψ's from B-hadron decay in each bin of transverse momentum.

3. Exclusive B Decays

The exclusive $B^+ \to J/\psi\ K^+$ and $B^0 \to J/\psi\ K^0$ decays can be measured during the initial luminosity phase of the LHC because of the clear event topology and rather large branching ratio. The CMS Collaboration has studied the feasibility of the measurement with 10 pb^{-1} of data collected with a dimuon trigger with $p_T > 3$ GeV/c threshold at $\sqrt{s} = 10$ TeV [14].

Event selection starts with the reconstruction of J/ψ candidates from oppositely charged muons with quality cuts and common vertex requirement and only candidates having an invariant mass within 150 MeV/c^2 of the nominal value are retained. K^{*0} mesons are reconstructed from oppositely charged silicon tracks with $p_T > 0.5$ GeV/c passing quality cuts. From the two possible mass assignments the one that results in an invariant mass closer to that of K^{*0} is chosen. Finally, all K^{*0} candidates are required to have mass within 120 MeV/c^2 of the world average.

B^+ candidates are reconstructed by pairing the J/ψ candidates with non-overlapping silicon tracks with $p_T > 0.8$ GeV/c^2 and same quality cuts as for the K^{*0} daughters. A kinematic fit to the J/ψ and track combinations is performed, where the dimuon pair is constrained to the nominal



(a) (b)

Figure 5: (a) Measured differential cross section $d\sigma/dp_T^B$ vs. p_T^B for the B^+ (a) and B^0 (b) samples including systematic uncertainties, compared with the generated (true) distributions.

J/ψ mass and the track is assigned with the kaon mass. The B^0 mesons are formed by pairing the J/ψ candidates with K^{*0} candidates and applying the kinematic fit with the J/ψ mass constraint. The selection of the unique B^+ and B^0 candidates per event is based on the best vertex probability and only candidates with mass in the $4.95 < m_B < 5.55$ GeV/c^2 range are used for the analysis. The total efficiency of this selection including acceptance and trigger efficiencies is 11.6% (8.6%) for B^+ (B^0) decays.

A two-dimensional proper decay length ct for the B candidates is calculated in the following way

$$ct = \frac{m_B}{p_T^B} L_{xy}, \quad L_{xy} = \frac{\vec{s} \cdot \vec{p}_T^B}{|\vec{p}_T^B|},$$

where m_B and p_T^B are the mass and the transverse momentum of the B candidate. L_{xy} is the projection of the distance between the primary and B-decay vertex, $\vec{s}$, projected onto the transverse momentum of the candidate.

The major sources of background are:

- $B \to J/\psi\pi$ – the Cabibbo-suppressed analog of the $B^+ \to J/\psi K^+$. It is measured to be 5% of the Cabibbo-allowed mode [15] and it is included in the fit as a fixed fraction of the signal.
- Misreconstructed B decays that peak in the mass window. For the $B^+ \to J/\psi K^+$ selection it is dominated by $B^0 \to J/\psi K^{*0}$ events where the pion is lost and $B \to \chi_c X$ events where the χ_c decays to J/ψ and a random track is added. For the $B^0 \to J/\psi K^{*0}$ selection the main contributions come from $B^+ \to J/\psi K^+$ events with an added track and from $B \to J/\psi K_1$ and $\chi_c X$ decays with lost particles. In addition, there is a non-negligible contribution from misreconstructed B_s decays.
- $b\bar{b}$ events that contain a non-prompt J/ψ that is combined with a random track and give a non-peaking contribution.
- Prompt J/ψ that is non-peaking and isolated at $ct \sim 0$.

The signal yields and lifetimes are extracted from the selected samples using an unbinned extended maximum likelihood fit to the mass m_B and proper decay length ct of the reconstructed B candidates. The PDF shapes for the background can be determined from the mass sidebands. The momentum and mass scales as well as the ct resolution function can be obtained from the large statistics of the inclusive J/ψ sample.

To determine the lifetimes and total yields the fit is performed by integrating the $p_T^B > 9$ GeV/c. Fig. 4 shows the results of the fit for a sample of 10 pb^{-1} integrated luminosity. Having determined the lifetimes, they are fixed when fitting for the signal and background yields in each p_T^B bin, see Fig. 5. The expected precision is about 10% on the differential cross section measurement and about 5% on the B^+/B^0 lifetime ratio. The major sources of uncertainties are luminosity (10%), efficiencies (5%), branching fractions (4%) and misalignment (3%).

4. Measurement of the Azimuthal Correlation in b$\bar{\text{b}}$ Production

The $b\bar{b}$ differential cross section $d\sigma/d\Delta\phi$ is sensitive to the production mechanism and serves as a probe of effective contributions from higher-order QCD processes. The analysis described in [16] assumes 50 pb^{-1} of collision data collected by CMS at $\sqrt{s} = 10$ TeV.

The b quarks are identified with purely muonic signatures. One of the b quarks is required to decay to $J/\psi \to \mu^+\mu^-$ and the second is tagged via the semileptonic decay. Although this final state has low branching fraction, it has the advantage of being sensitive at small opening angles of $b\bar{b}$, where the NLO processes dominate. It is also expected to give low backgrounds and does not rely on advanced b-tagging techniques. The main backgrounds include events with a real non-prompt J/ψ and a misidentified muon or decay in flight, events with a real prompt J/ψ, and events with a fake J/ψ.

The J/ψ candidates are reconstructed by vertexing every pair of muons with opposite electric charge. The unique J/ψ candidate in the event is selected based on the highest vertex probability. The third muon in the event is chosen with the highest p_T requirement satisfying quality cuts on the silicon track, deposited calorimeter energy and muon system penetration depth to increase purity. All three muons in the event must have $p_T > 3$ GeV/c and $|\eta| < 2.4$. The trigger requirement is a double muon trigger with a $p_T > 3$ GeV/c threshold.

The cross section is measured in eight $\Delta\phi$ bins. The signal is obtained from a simultaneous unbinned maximum-likelihood fit to the J/ψ invariant mass, the transverse flight length L_{xy} of the J/ψ, defined as the distance in the x-y plane between the primary vertex and the common vertex of the J/ψ dimuon pair, and the impact parameter d_{xy} of the third muon in the event. Fig. 6 shows the fit results for a sample corresponding to an integrated luminosity of 13 pb^{-1}.

To obtain the true $\Delta\phi$ distribution of the original b quarks, an unfolding procedure [17] that takes into account detector effects such as acceptance, efficiencies and resolution has to be applied. Fig. 7 shows the comparison between the generated and unfolded $\Delta\phi$ distributions. Depending on the particular $\Delta\phi$ bin, for an integrated luminosity of 50 pb^{-1}, an accuracy of 15-25% on the differential cross section can be obtained, combining statistical and systematic uncertainty. The accuracy of the integrated $\sigma(pp \to b\bar{b})$ total cross section measurement is expected to be at the 10% level.

PoS(BEAUTY 2009)029

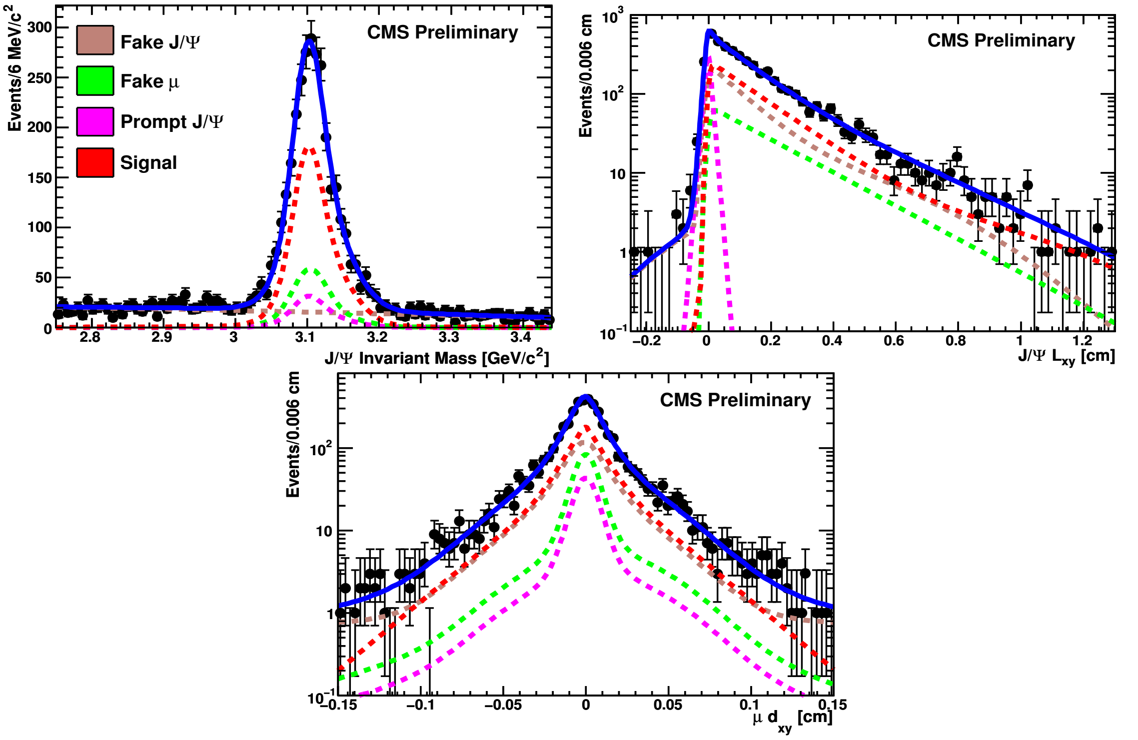


Figure 6: Results of the three-dimensional fit for a Monte Carlo sample of an integrated luminosity of 13 pb^{-1}. The Monte Carlo distributions (points with error bars) are compared to the results of the overall fit (solid line, blue color). The PDFs for the different fit components are shown in different colors.

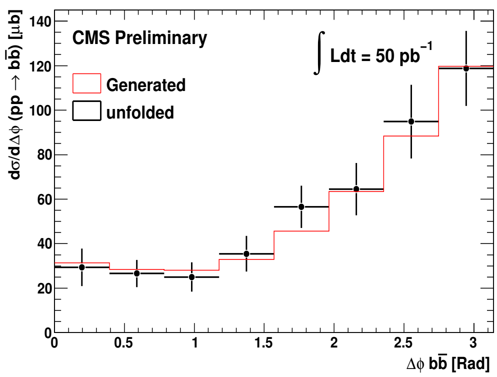


Figure 7: Differential cross section measurement $d\sigma/d\Delta\phi$ after unfolding and including systematic uncertainties.

5. Acknowledgments

The author would like to thank the CMS Collaboration for the contributions and the BEAUTY 2009 conference organizers for the excellent program and warm hospitality.

References

[1] N. Brambilla et al., CERN Yellow Report, CERN-2005-005 (2005).

[2] J. P. Lansberg, Int. J mod. Phys. A**21**, 3857 (2006).

[3] M. Kramer, Prog. Part. Nucl. Phys. **47**, 141 (2001).

[4] D. E. Acosta *et al*. [CDF Collaboration], Phys. Rev. Lett. **79** (1997) 572.

[5] D. E. Acosta *et al*. [CDF Collaboration], Phys. Rev. D **71** (2005) 032001.

[6] D. E. Acosta *et al*. [CDF Collaboration], Phys. Rev. Lett. **99** (2007) 132001.

[7] D. E. Acosta *et al*. [CDF Collaboration], Phys. Rev. D**71**, 092001 (2005), and references therein.

[8] M. Mangano, P. Nason, and G. Ridolfi, Nucl. Phys. B**373**, 295 (1992).

[9] M. Cacciari, and P. Nason, Phys. Rev. Lett. **89**, 122003 (2002).

[10] F. Halzen, W. Y. Keung, and D. M. Scott, Phys. Rev. D**27**, 1631 (1983).

[11] E. L. Berger, *et al*., Phys. Rev. Lett. **86**, 4231 (2001).

[12] The CMS Collaboration, *The CMS experiment at the CERN LHC*, JINST 3, S08004 (2008).

[13] The CMS Collaboration, *Feasibility study of a J/ψ cross section measurement with early CMS data*, CMS PAS BPH-07-002.

[14] The CMS Collaboration, *Measurement of Differential Production Cross Sections and Lifetime Ratio for Exclusive Decays of B^+ and B^0 Mesons in pp Collisions at 10 TeV*, CMS PAS BPH-09-001.

[15] BABAR Collaboration, B. Aubert et al., *Study of $B^{\pm} \to J/\psi\pi^{\pm}$ and $B^{\pm} \to J/\psi K^{\pm}$ decays: Measurement of the ratio of branching fractions and search for direct CP violation*, Phys. Rev. Lett. **92** (2004) 241802, arXiv:hep-ex/0401035.

[16] The CMS Collaboration, *Measurement of the Azimuthal Correlation in bb Production in pp Collisions with the CMS detector*, CMS PAS BPH-08-004.

[17] A. Hocker and V. Kartvelishvili, Nucl. Instrum. Meth. A**372**, 469 (1996).