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B physics prospects of CMS with the first LHC data

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B physics will be one of the key physics themes at the Large Hadron Collider (LHC). B hadrons are an ideal tool for advancing our current understanding of the flavour sector of the Standard Model (SM), and searching for effects originating from physics beyond the SM, thanks to the large production rate and the fact that B hadrons are relatively easy to trigger on and identify due to their long lifetime and high mass. The interplay between strong and electroweak effects in the production and decay of B hadrons makes them a unique test ground for both forces.

The integrated luminosity collected by the CMS experiment during the first LHC running period 2009-2010 is expected to be of the order of a few hundred pb $^{-1}$. The first B physics measurements with the CMS experiment include quarkonia production cross section and polarization, cross sections and lifetimes of exclusive B decays, b production cross section, and $b\bar{b}$ correlations. In this paper, some examples of the estimated sensitivities of CMS with the first LHC data, up to an integrated luminosity of about 50 pb^{-1}, are presented.

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1. The CMS detector layout and trigger

A detailed description of the CMS experiment can be found in Ref. [1]. The central feature of the CMS apparatus is a superconducting solenoid, providing a 3.8T homogeneous magnetic field. Within the field volume are the silicon pixel and strip tracker, the crystal electromagnetic calorimeter and the brass-scintillator hadronic calorimeter. Muons are measured in gaseous detectors embedded in the iron return yoke.

The B physics channels discussed here are triggered with dimuon triggers, requiring two muons with $p_T > 3$ GeV/c. The initial rapidity coverage of the muon trigger is $|\eta| < 2.1$, while the design coverage is up to 2.4. Single muon triggers with a p_T threshold starting from 3 GeV/c can be used as well in the beginning.

2. CMS physics prospects with an integrated luminosity from 1 pb^{-1} to 50 pb^{-1}

CMS will be able to reconstruct large samples of quarkonia decaying into muons, and B decays including a J/ψ in the final state, already during the first few months of LHC running. Here a few examples of these measurements are presented. Heavy flavour production at CMS is discussed in another contribution to this conference [2]. All the simulation studies shown here were performed with a full GEANT based detector simulation, and passed through the standard CMS reconstruction program.

One of the first measurements at CMS with a few pb^{-1} of integrated luminosity will be **the measurement of inclusive J/ψ differential production cross section** and determination of the fraction of J/ψ's from $B \to J/\psi X$ [3]. J/ψ decays are very useful as "standard candles" for controlling and checking the tracker and muon system performance. Nevertheless, the measurement will also be provide us with new data on J/ψ production at LHC centre-of-mass energy and at $p_T(J/\psi) > 20$ GeV/c.

The simulation study was performed assuming 14 TeV LHC centre-of-mass energy, and an integrated luminosity of 3 pb^{-1}. Signal and background events were simulated using Pythia [4], including leading-order colour singlet and colour octet mechanisms and setting the polarization to zero for the prompt J/ψ's. The following sources of background were considered: generic $pp \to \mu X$ events, and Drell-Yan events.

For details of the trigger, reconstruction and event selection, see Ref. [3]. Events with two muons, each with $p_T > 3$ GeV/c, were selected. J/ψ candidates were reconstructed by pairing muons with opposite charge and requiring a common vertex. A double Gaussian was used to fit the simulated J/ψ signal, while a linear function was used for the background. The dimuon mass resolution was about 17 MeV/c^2 at $\eta = 0$ and about 40 MeV/c^2 at $|\eta| = 2.4$.

The J/ψ yield was about 70 000 events in the p_T range 5-40 GeV/c, over a very small combinatorial background. The inclusive differential cross-section was measured from a fit to the mass distribution. B- and prompt fractions were measured from an unbinned maximum likelihood fit to the mass and the transverse proper decay length[1] distributions.

[1]Transverse proper decay length l_{xy} was calculated as $l_{xy} = Lxy \cdot m_{J/\psi}/p_T^{J/\psi}$ where L_{xy} is the 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 mass

With 3 pb^{-1}, the inclusive $p_T^{J/\psi}$ differential $J/\psi \to \mu^+\mu^-$ production cross section and the fraction of J/ψ's produced by B-hadron decays can be measured with a precision of about 15% in the $p_T^{J/\psi}$ range between 5 and 40 GeV/c. The precision of the result is limited by systematic uncertainties. The dominating systematic uncertainty stems from the luminosity uncertainty, which was assumed to be 10%.

Exclusive B decays $B \to J/\psi K^{(*)}$ can be used as one of several early checks on the CMS tracker alignment and overall performance. Moreover, well-understood B^+ and B^0 decays will be used later on as control samples for other measurements, such as weak phases, CP violation, rare decays, and B_c decays.

This simulation study was performed by assuming $\sqrt{s} = 10$ TeV and an integrated luminosity of 10 pb^{-1} [5]. The signal and $b\bar{b}$ background were studied by using a samples simulated with Pythia [4]. For the prompt J/ψ background a sample of $pp \to J/\psi X$ events were used. QCD background was investigated by using an inclusive sample of $pp \to \mu X$ events.

For details of the trigger, reconstruction and event selection, see Ref. [5]. J/ψ candidates were reconstructed by vertexing oppositely charged muons with p_T>3 GeV/c. Candidate K^{*0} mesons were reconstructed from pairs of oppositely charged tracks having p_T > 0.5 GeV/c. The $K\pi$ mass assignment resulting in a mass closest to the nominal K^{*0} mass was retained.

B^+ mesons were reconstructed by combining a J/ψ candidate with a track having p_T > 0.8 GeV/c, and B^0 mesons by combining J/ψ candidates with K^{*0} candidates. For each event, the B^+ and/or B^0 candidate with the best vertex probability was chosen, requiring p_T^B>9 GeV/c.

Signal yields and lifetimes were extracted using an unbinned extended maximum-likelihood fit to the invariant mass and proper decay length[2] $c\tau$ of the reconstructed candidates, integrating over p_T^B. Figure 1 shows the fitted distributions of M_B and $c\tau$ for the B^+ and B^0 samples. The fit results were: 1731 ± 46 $B^+ \to J/\psi K^+$ events and 890 ± 39 $B^0 \to J/\psi K^{*0}$ events per 10 pb^{-1} (statistical error only).

The B^+ and B^0 lifetimes were then fixed to their measured values and the signal and background yields were fitted again in each p_T^B bin (seven bins for the B^+, four bins for the B^0). The differential cross sections for the exclusive decays $B^+ \to J/\psi K^+$ and $B^0 \to J/\psi K^{*0}$ can be measured to a statistical precision of less than 10%, while the systematic uncertainty is 13-14% per p_T^B bin. The lifetime ratio $\tau(B^+)/\tau(B^0)$ can be measured with a precision of 1.10 ± 0.05(stat.)$\pm$0.01(syst.), where it was assumed that the misalignment and $c\tau$ resolution uncertainties cancel exactly.

Events of type $b\bar{b} \to (J/\psi X)(\mu X)$ can be used to probe the **azimuthal opening angle** $\Delta\phi$ **between the bottom quarks**. This variable is sensitive to the higher-order QCD contributions to the b quark production.

This simulation study was performed with $\sqrt{s}$=10 TeV, assuming integrated luminosity of 50 pb^{-1} [6]. Dimuon events were selected for the analysis, for details see Ref. [6]. Fractions of flavour creation, gluon splitting and flavour excitation contributing to the $b\bar{b}$ production were measured from a simultaneous fit to the J/ψ mass distribution, transverse flight length of the J/ψ, and the impact parameter of the (third) muon.

[2]The two-dimensional proper decay length $c\tau$ was defined as $c\tau = M_B \cdot L_{xy}/p_T^B$, where M_B and p_T^B are the mass and transverse momentum of the B candidate, and the transverse flight length L_{xy} is the projection of the vector pointing from the primary to the secondary vertex onto the transverse momentum.

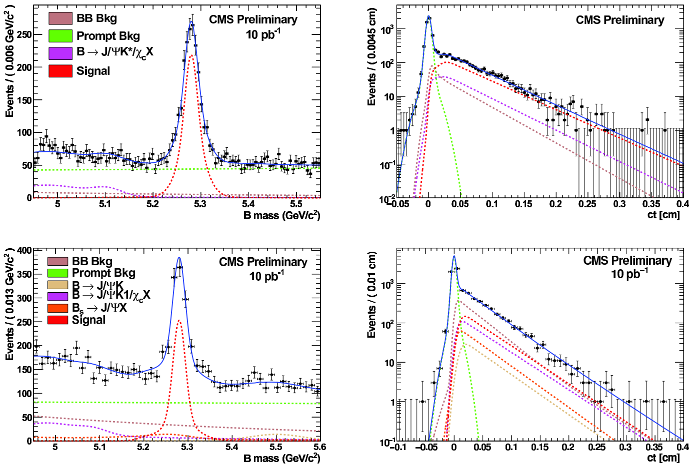

Figure 1: Distributions of M_B and $c\tau$ for the B^+ (top) and B^0 (bottom) fits integrating over all p_T bins, assuming an integrated luminosity of 10 pb^{-1}. Individual contributions from the various components are shown in different colors (see legends in the plots).

With 50 pb^{-1} of collision data, CMS can achieve an accuracy of 15-25% on the differential cross-section per $\Delta\phi$ bin, combining statistical and systematic uncertainty. The total error is dominated by the systematic uncertainty from luminosity. An accuracy at the 10% level is expected for the integrated total cross section.

3. Summary

Already with a very small statistics, ranging from 1 to 50 pb^{-1}, large statistics of quarkonia, inclusive and exclusive B's will be collected in CMS. While these measurements are important tests and cross-checks for the detector performance and input for Monte Carlo event generator tuning, we will also obtain first glimpses to properties of B hadrons at LHC energies.

References

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