First results and prospects in B physics at CMS

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Abstract. The first results in b physics obtained by the CMS collaboration from the data collected in pp collisions at 7 TeV at the LHC. In particular, results are reported on heavy quarkonium production (J/ψ and Υ), and on inclusive b jet production cross section. Progress on exclusive reconstructions is also mentioned.

1. Introduction
Thanks to the impressive performance of the LHC accelerator in the past months, the CMS experiment collected about 43 pb⁻¹ of data from pp collisions at 7 TeV by the end of 2010. The relatively low luminosity of the first months of data-taking allowed early measurements of high-rate b-related processes such as quarkonium (J/ψ and Υ) and inclusive b-jet production. An important part in these measurements is played by muons; the loose trigger requirements allowed by the low instantaneous luminosity made it possible to extend the kinematic reach of the reconstructed muons to very low transverse momentum especially in the forward region. Muons are used to select quarkonium decays and to discriminate b jets by exploiting the semileptonic decays of the b quark. A very important role is also played by the excellent tracking and vertexing capabilities of the CMS detector, which allow a lifetime-based discrimination of b decays.

The early results presented here are obtained from just a fraction of the 2010 data statistics.

2. The CMS detector
A detailed description of the Compact Muon Solenoid (CMS) experiment can be found elsewhere[1] The central feature of the CMS apparatus is a superconducting solenoid, of 6 m internal diameter. Within the field volume are the silicon tracker, the crystal electromagnetic calorimeter (ECAL) and the brass/scintillator hadron calorimeter (HCAL). Muons are detected in the pseudorapidity window |η| < 2.4, by gaseous detectors made of three technologies: Drift Tubes (DT), Cathode Strip Chambers (CSC), and Resistive Plate Chambers (RPC), embedded in the iron return yoke. The silicon tracker is composed of pixel detectors (three barrel layers and two forward disks in either side of the detector, made of 66 million 100×150 µm² pixels) followed by microstrip detectors (several layers with strips of pitch between 80 and 180 µm). Thanks to the strong magnetic field, 3.8 T, and to the high granularity of the silicon tracker, the transverse momentum, p_T, of the muons matched to reconstructed tracks is measured with a resolution better than 1.5% for p_T smaller than 100 GeV.
2.1 Performance of the tracking detector and muon reconstruction

The performance of the silicon tracker has been tested with the first data collected by the CMS experiment. The left plot in figure 1 shows the measured longitudinal impact parameter resolution as a function of the track pseudorapidity; data and simulation agree very nicely. The same is true for the impact parameter significance (right plot), whose exponential tail on the right side of the peak is due to the long lived heavy quark component.

Muons in CMS are reconstructed from silicon tracker and muon detector information [2]. Reconstruction algorithms use iterative Kalman-filter procedures which, starting from track «seeds», build the candidate track following either an inside-out (from the central region outwards) or an outside-in extrapolation approach. The so-called Tracker muons follow the inside-out approach and consist of tracks reconstructed in the silicon tracker and spatially matched to single track segments found in the muon detectors. The reconstruction of so-called Global muons starts from tracks

Figure 1. Left: measured resolution of the track longitudinal impact parameter as a function of the track pseudorapidity, for real and simulated data. Right: distribution of the three-dimensional track impact parameter significance for real and simulated data.

Figure 2. Reconstruction efficiencies measured with the tag-and-probe method for Global muons and for Tracker (here called «soft») muons, in real and simulated data.

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reconstructed in the muon system and extrapolated from the outside in to match tracks from the silicon tracker. The latter algorithm gives a lower background contamination but also a lower efficiency, especially for low-momentum muons.

The muon reconstruction efficiency is measured in real data using the tag and probe technique. This is a general technique which is also used to measure other similar properties such as trigger and tracking efficiencies, and exploits the decays to muon pairs of narrow resonances such as the J/ψ, which also have the advantage of providing high statistics. Opposite-sign tracks whose invariant mass is consistent with the chosen resonance (J/ψ) are selected, where one of the two tracks (the tag track) is identified as a muon: the other track (the probe) is then used to measure the reconstruction efficiency, or other analogous properties. Figure 2 shows the measured reconstruction efficiency for Global and Tracker muons in simulated events and in minimum bias events from the first 84 nb⁻¹ of CMS data.

3. Quarkonium production

Muon pairs are used to reconstruct J/ψ [3] and Y mesons, exploiting the high production rate and the use of dedicated muon triggers, made possible by the relatively low luminosity, which allowed to lower the p_T threshold and explore low transverse momentum ranges. The interest in measuring the quarkonium differential cross section lies basically in the comparison with various QCD models describing the prompt production in pp collision. In the J/ψ case, the possibility to separate the non-prompt mesons coming from b-hadron decays provides an additional test of theoretical predictions.

![Figure 3](image3.png)

**Figure 3.** Left: mass fit for the selected J/ψ candidates in the rapidity range 1.6 < |y_J/ψ| < 2.4. Right: lifetime fit to the measured pseudo-proper decay length of the J/ψ candidates in the same rapidity range.

![Figure 4](image4.png)

**Figure 4.** Measured differential cross-section as a function of p_T, in the forward rapidity range, for the reconstructed J/ψ mesons coming from b hadrons, compared with different theoretical predictions.
3.1 Prompt and non-prompt J/ψ production
After some quality cuts on the reconstructed tracks and on their compatibility with coming from a common vertex, muon pairs from candidate J/ψ decays are selected by means of a fit to the invariant mass distribution (figure 3, left). The non-prompt fraction is extracted by fitting the distribution of the lifetime-related variable called pseudo-proper decay length (figure 3, right), essentially given by the projection of the decay vertex separation onto the flight direction of the decaying meson. From the first 314 nb⁻¹ of data a total of about 27000 J/ψ candidates have been reconstructed. The differential cross-section for both the prompt and non-prompt production is then measured as a function of the meson’s transverse momentum, in three different rapidity ranges. As shown in figure 4 (for the forward rapidity range), the results appear to be in agreement with the theoretical predictions from the models considered.

3.2 Y production
Similar criteria are applied to select muon pairs from the three bF bound states Y(1s), Y(2s) and Y(3s), where the various contributions are extracted from an invariant mass fit. The value of the measured cross section depends on the assumed polarization of the produced Y meson, which is not known at present (this is also true for the prompt J/ψ), because the polarization determines the muon spectrum, which in turn affects the estimated acceptance. Therefore five different «extreme» polarization scenarios are assumed in the acceptance determination, which give rise to variations in the cross section up to 20%. Polarization measurements for both the Y and the J/ψ are currently being addressed by the collaboration and will hopefully be available in the near future, already from the analysis of the full 2010 statistics.

Figure 5. Left: invariant mass distribution for the selected muon pairs in the Y mass range (using most of the 2010 statistics). Right: Measured cross section for the three Y resonances in the central rapidity region (using the first 3pb⁻¹).

4. Exclusive B decays
J/ψ mesons are also used for exclusive B decay reconstructions such as B → J/ψ K and B_s → J/ψ ℓ⁺ℓ⁻, for which preliminary invariant mass plots are shown in figure 6. The full 2010 statistics should already allow a differential cross-section measurement for the B⁺ → J/ψ K⁺ channel.
5. Inclusive b production

Inclusive b-jet events are selected using two complementary b-tagging approaches characterized by different systematics, each of which exploits the other for consistency checks or for measuring relevant quantities such as signal efficiencies on data.

5.1 Semileptonic decays

This method exploits the high transverse momentum of leptons from b decays with respect to the jet direction, due to the comparatively high mass of B hadrons [4]. Jets containing a muon are selected, and the discriminating variable, called $p_T^{\text{rel}}$, is defined as the transverse component of the muon with respect to the jet axis, whose determination does not include the muon momentum. Events are selected with a single-muon trigger and the requirement of at least one well reconstructed muon; jets are formed using just the tracker information. The observed $p_T^{\text{rel}}$ distribution in data, shown in figure 7, is fitted to a sum of templates for the expected signal and background contributions. Only the charm contribution is taken from the simulation; the shape of the light quark background, due to misidentified hadrons, is taken from the hadron track spectrum and from the misidentification probability measured on data, while the signal template is taken from simulation and validated on data using a b-jet enriched sample obtained with a vertex tagging technique similar to the one described below. The measured cross section is shown in figure 8 as a function of the muon transverse momentum and pseudorapidity. Although the figure only refers to a small fraction of the 2010 statistics, the experimental error is already comparable to the theoretical uncertainty on the next-to-leading order QCD predictions, which appear to underestimate the production cross section, especially in the central region.

5.2 Secondary vertex tagging

In the second approach [5] jets are formed starting from «particle flow» objects [6], reconstructed by a technique designed to optimize the jet energy reconstruction and resolution down to low transverse momenta of the jet. The b-jet fraction is measured using a secondary vertex tagging algorithm, based on the three-dimensional significance of the detected secondary vertex. The purity of the tagging algorithm is determined from data by means of a fit to the measured invariant mass of the secondary vertex. Similarly to what was done in the previous approach, the tagging efficiency is measured on data exploiting the properties of semileptonic decays, i.e. by fitting the $p_T^{\text{rel}}$ distribution in a muon-enriched sample.
Figure 9 shows the measured double-differential cross-section as a function of the jet transverse momentum and rapidity, obtained after deconvoluting for smearing effects due to finite resolution. The experimental errors, dominated by the luminosity and tagging efficiency uncertainties, are again comparable in size to the theoretical error on the expected cross-section as computed at next-to-leading order (MC@NLO). The prediction seems to describe the data distribution fairly well, except for the tail at high transverse momentum and rapidity.

Figure 7. Measured distribution of the muon transverse momentum with respect to the track-jet axis. The signal template distribution is derived from the simulation but has been validated on a b-enriched data sample.

Figure 8. Preliminary cross-section for inclusive b-quark production measured at CMS using semileptonic decays, as a function of the muon transverse momentum (left) and pseudorapidity (right).
6. Prospects for the near future and conclusions
The results presented here only refer to a (sometimes small) fraction of the statistics collected by CMS in the 2010 run. The full data sample is currently being analyzed, and aside from the updates of the above measurements, new results from a number of new interesting analyses are expected.
Among them, the measurement of the quarkonium polarization (Y and J/ψ) will greatly reduce the corresponding uncertainty on the cross-section measurement; a study of the b-jet angular correlations will shed light on the b production mechanisms in pp collisions. Other foreseen measurements include the determination of the integrated B mixing parameter, the reconstruction of exclusive decays such as $B \to J/\psi K$ and $B_s \to J/\psi \phi$, the latter being relevant for CP violation studies.

7. References
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