# Status of LHCb

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## 1 Introduction

The LHC machine has a unique potential for the study of CP violation and rare decays in the heavy-flavor sector due to the combination of a large $b\bar{b}$ and $c\bar{c}$ production cross-section and high luminosity. Even at an average luminosity of L = $2\times10^{32}\text{cm}^{-2}\text{s}^{-1}$, well below the machine design value, $10^{12}$ $b\bar{b}$ pairs are produced per year at a center-of-mass energy of $\sqrt{s}$ = 14 TeV, offering interesting perspectives in the search for New Physics with an approach complementary to those of the general purpose experiments. This complementary approach consists in measuring quantum corrections in the decay of already known particles especially in flavor-changing neutral-current (FCNC) transitions, and looking for deviations from the Standard Model (SM) predictions.

## 2 The LHCb experiment

The LHCb experiment has been designed specially for precise measurements of CP violation and rare decays of hadrons containing a $b$ quark [1]. The LHCb detector [2] is a single-arm spectrometer (see Fig. 1 left) covering the forward region ($1.9\leq \eta \leq 4.9$) where the $b\bar{b}$ production is peaked. It incorporates precision vertexing and tracking systems, particle identification over a wide momentum spectrum and relies on relatively soft transverse momentum triggers, efficient for both leptonic $B$ decays (∼90%) and purely hadronic $B$ decays (∼40%).

In the first LHC physics run that started on March 30, 2010 (see Fig. 1 right) the center-of-mass energy was $\sqrt{s}$ = 7 TeV, reducing the expected $b\bar{b}$ and $c\bar{c}$ production rates as compared to to the nominal energy of $\sqrt{s}$ = 14 TeV by about a factor of two, without any major impact on the physics reach. LHCb can work at constant luminosity independently from the other intersections, thus optimizing the number of interactions per bunch crossing for collecting clean events. Whilst the nominal instantaneous luminosity has been reached only at the beginning of 2011, the lower luminosity at the start-up in 2010 allowed for lower trigger thresholds, and hence better efficiencies for hadronic $B$ decays ($\sim$75%). This also gave a good opportunity to collect rapidly very large samples of charm events, with a corresponding trigger efficiency boosted up from $\sim$10% to $\sim$40%.

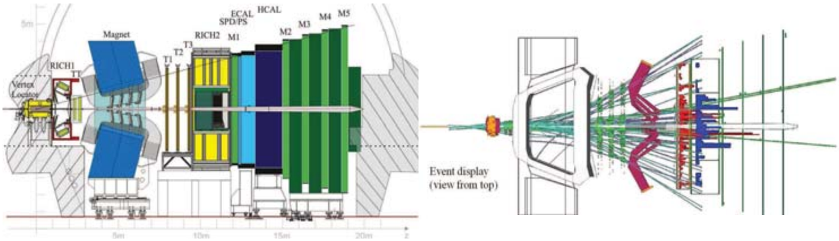

Figure 1: Left: Side view of the LHCb spectrometer, showing the Vertex Locator around the interaction region on the left, the tracking stations before and after the dipole magnet, the ring-imaging Cherenkov detectors (RICH), the calorimeter system, and the muon stations. Right: Event display (top view, in bending plane) of one of the first recorded pp collisions at $\sqrt{s} = 7$ TeV on March 30, 2010.

The results presented here correspond to the machine startup phase with a beam energy of $\sqrt{s} = 7$ TeV and a luminosity that was increasing by two orders of magnitude over the running period. The number of colliding bunches was growing continually up to a maximum of 344, with an average number of visible pp-collisions per crossing varying from 0.5 to 2.7. Approximately 37 nb$^{-1}$ of data have been collected in 2010, partly with a fully inclusive trigger requesting at least one reconstructed track in the detector. With increasing intensity a High-Level Trigger was run in rejection mode to limit the output rate to a few kHz.

## 3 Preliminary results

The first preliminary results demonstrate the excellent performance of the LHCb detector. For example, the quality of the tracking system is well illustrated by the mass resolutions of better or equal 10 MeV/c$^2$ that has been obtained in reconstructing various $B \to J/\psi X$ (with X representing a hadron) decays. With the 2010 data set, this has led already to the world's best $B$ hadron mass measurements [3]. Furthermore, the resolution of the tracking system provides a proper-time resolution of $\sim$ 50 fs and precision measurements of the $B$ hadron lifetimes [4]. Examples of the $B$ mass and proper time distributions are shown in Figure 2.

The production mechanism for onia at hadron colliders is not well understood and measurements from the LHC can provide invaluable new input. The study of such bound $c\bar{c}$ and $b\bar{b}$ states decaying into di-muons is a natural early physics topic for

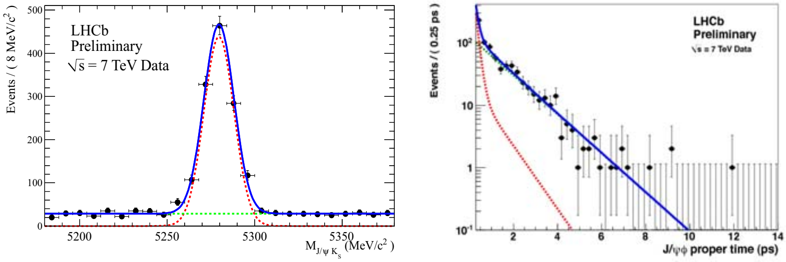

Figure 2: The $B_s^0 \to J/\psi\phi$ mass (left) [3] and proper time (right) [4] distributions. The total fit is represented by a blue solid line, the signal distribution by the red dashed line and the background distribution by the green dashed line. The red-green colour scheme is reversed in the right plot.

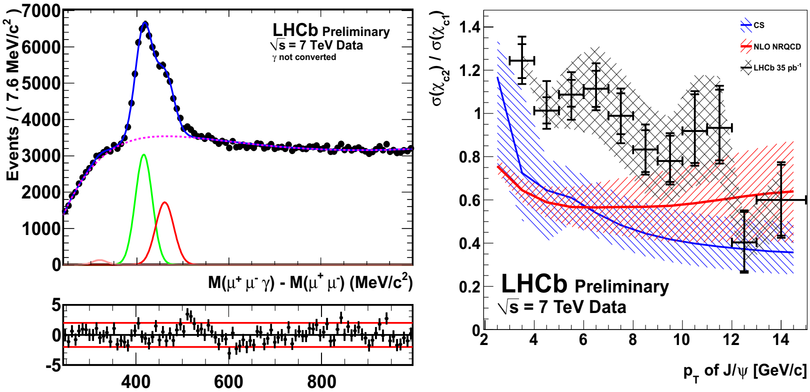

Figure 3: Left: The $\Delta M$ distribution of selected candidates with $p_T^{J/\psi} \in [3;15]$ GeV/c and for which the photon has not converted. The $\chi_{c0}$, $\chi_{c1}$ and $\chi_{c2}$ peaks are shown in orange, green and red from left to right, respectively. The background distribution is shown as a dashed purple curve [7]. Right: The ratio of the prompt production cross sections for the $\chi_{c2}$ to $\chi_{c1}$ charmonium states compared to theoretical predictions [7].

LHCb. Due to its forward acceptance and dedicated trigger, LHCb has the largest $J/\psi$ sample at the LHC, which was used to study $J/\psi$ hadroproduction. LHCb has published results on inclusive $J/\psi$ production [5] and released preliminary results on upsilon production [6]. Results have also been reported on the ratio of the prompt production cross sections for the $\chi_{c2}$ to $\chi_{c1}$ charmonium states [7] as shown in Figure 3.

Already with the little data accumulated in 2010 it has been possible to discover new decay channels. These include the gluonic-penguin dominated decay of $B_s^0 \to K^{*0}\overline{K^{*0}}$ [8] as well as $B_s^0 \to J/\psi f_0(980)$ [9] where the final state is a CP eigenstate. The latter can be used together with $B_s^0 \to J/\psi\phi$ to measure the $B_s^0$ phase, which is responsible for mixing-induced CP violation. Any significant enhancement in this CP violating phase above the small value predicted by the Standard Model would be a clear sign of new physics. Being a time-dependent angular measurement, the $B_s^0 \to J/\psi\phi$ analysis is a very challenging study. Critical to the measurement is the ability to resolve the very fast $B_s^0 - \overline{B_s^0}$ oscillations. This has been demonstrated by LHCb's worlds best measurement of the oscillation parameter $\Delta m_s = 17.63 \pm 0.11(stat.) \pm 0.04(syst.)$ ps$^{-1}$ [10], as shown in Figure 4 left. A preliminary flavour-tagged analysis of the $B_s^0$ mixing phase has been performed with the 2010 data [11]. The sample size is not yet sufficient to extract a significant value of $\phi_s$ but contours may be drawn in the plane of $\phi_s$ against the width difference between the $B_s^0$ mass eigenstates, $\Delta\Gamma_s$, as shown in Figure 4 right. With ~1 fb$^{-1}$ of data expected by the end of 2011, LHCb will be able to produce the world best measurement of $\phi_s$ with a precision of about 0.1 radians.

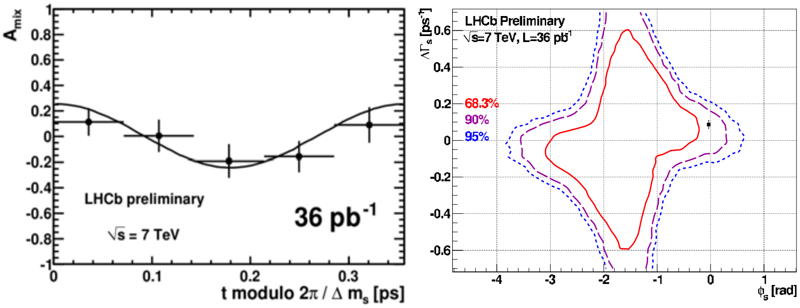

Figure 4: Left: The mixing asymmetry for $B_s^0$ signal candidates as a function of proper time modulo $\frac{2\pi}{\Delta m_s}$ [10]. Right: Contours indicating the allowed region for $\phi_s$ against $\Delta\Gamma_s$ from the preliminary LHCb analysis. Only statistical uncertainties are considered but these are dominant with the present dataset. The point with the small error bar close to $\phi_s = 0$ is the Standard Model prediction [11].

Another quantity sensitive to new physics effects is the decay rate asymmetry $A_{CP}$ in charmless two-body $B$ hadron decays, which is a measure of direct CP violation. By the end of 2011 the LHCb experiment has an excellent potential to dramatically improve the world knowledge of such decays. The first analysis of this asymmetry with 2010 data [12] already illustrates the potential of LHCb in hadronic final states and the power of the particle identification capabilities thanks to the RICH system. The study of the two-body $B$ decays shows evidence for CP violation in the channel $B^0 \to K\pi$ (see Fig. 5). The preliminary values of the direct CP asymmetries $A_{CP}(B^0 \to K^+\pi^-) = -0.074 \pm 0.033(stat.) \pm 0.008(syst.)$ and $A_{CP}(B_s^0 \to \pi^+K^-) = 0.15 \pm 0.19(stat.) \pm 0.02(syst.)$ are consistent with previous measurements.

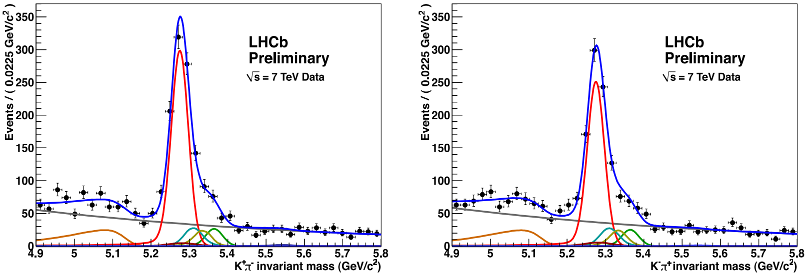

Figure 5: $B^0 \to K\pi$ events selected in the 2010 data (left $K^+\pi^-$ and right $K^-\pi^+$). The fitted signal component is the dominant red curve. The difference in yields between $K^+\pi^-$ and $K^-\pi^+$ is driven by CP violation in the $B^0$ decay. The other curves show the contribution of background components [12].

One of the most promising ways to look for new physics is the search for very rare decays such as $B_s^0 \to \mu^+\mu^-$. The value of its branching fraction is predicted with high precision in the Standard Model, $(0.32 \pm 0.2) \times 10^{-8}$, but large enhancements are possible in many variants of SuperSymmetry and alternative new physics models. LHCb has recently published the results of the search for this decay based on the data collected in 2010 [13]. No signal is yet observed, and an upper limit is placed on the branching fraction of $5.6 \times 10^{-8}$ at the 95% confidence level. With the data foreseen by the end of 2012 it will be possible to improve the sensitivity to around the Standard Model value of the branching fraction, with the potential to reveal new physics beyond the Standard Model or to severely constrain new physics models.

# 4 Conclusion

The large $b\bar{b}$ production cross section at the LHC provides a unique opportunity to study in detail CP violation and rare decays with the LHCb detector. The abundant production of $B$ and in particular of $B_s$ mesons will allow for unprecedented precision measurements to search for deviations from the Standard Model. LHCb has already performed many high-quality measurements with the data collected in 2010, and has the potential to reveal new physics already with a data set of ∼1 $\text{fb}^{-1}$ expected by the end of 2011.

# References

[1] LHCb Technical Design Report, CERN/LHCC 2003-030, (2003).

[2] LHCb Collaboration, A. A. Alves et al., "The LHCb Detector at the LHC," JINST 3 (2008) S08005.

[3] The LHCb Collaboration, "Measurement of b-hadron masses with exclusive $J/\Psi X$ decays in 2010 data", LHCb-CONF-2011-027.

[4] The LHCb Collaboration, "b-hadron lifetime measurements with exclusive $b \to J/\Psi X$ decays reconstructed in the 2010 data", LHCb-CONF-2011-001.

[5] R.Aaij et al. [LHCb Collaboration], "Measurement of $J/\psi$ production in pp collisions at $\sqrt{s} = 7$ TeV", Eur. Phys. J. C 71 (2011) 1645.

[6] The LHCb Collaboration, "Measurement of the $\Upsilon(1S)$ production cross-section at $\sqrt{s} = 7$ TeV in LHCb", LHCb-CONF-2011-016.

[7] The LHCb Collaboration, "A measurement of the cross-section ratio $\frac{\sigma(\chi_{c2})}{\sigma(\chi_{c1})}$ for prompt $\chi_c$ production at $\sqrt{s} = 7$ TeV in LHCb", LHCb-CONF-2011-020.

[8] The LHCb Collaboration, "First observation of the decay $B_s^0 \to K^{*0}\overline{K^{*0}}$", LHCb-CONF-2011-019.

[9] R.Aaij et al. [LHCb Collaboration], "First observation of $B_s^0 \to J/\psi f_0(980)$ decays", Phys. Lett. B 698 (2011) 115.

[10] The LHCb Collaboration, "Measurement of $\Delta m_s$ in the decay $B_s^0 \to D_s^-(K^+K^-\pi^-)3(\pi)$", LHCb-CONF-2011-005.

[11] The LHCb Collaboration, "Tagged time-dependent angular analysis of $B_s^0 \to J/\psi\phi$ decays with the 2010 LHCb data", LHCb-CONF-2011-006.

[12] The LHCb Collaboration, "Measurement of direct CP violation in charmless charged two-body $B$ decays at LHCb", LHCb-CONF-2011-011.

[13] R.Aaij et al. [LHCb Collaboration], "Search for the rare decays $B_s^0 \to \mu^+\mu^-$ and $B^0 \to \mu^+\mu^-$", Phys. Lett. B 699 (2011) 330.