

STUDIES OF HADRONIC B DECAYS WITH EARLY LHCb DATA*

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The 2010 LHC proton run has provided LHCb with a rich dataset. Several exclusive hadronic B decays are reconstructed with high signal to background ratios. We outline here our strategy for measurements of the angle γ of the Unitarity Triangle of the CKM matrix.

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1. Introduction

Hadronic B decays offer a particularly rich playing field for flavor physics: the two-body decay channels number in the hundreds, and thousands of different three-body decays can be accessed. Each of these decays is sensitive to a unique combination of interfering amplitudes: Cabibbo-favored and Cabibbo-suppressed, tree diagrams and loop diagrams, spectator and exchange/annihilation diagrams, color-suppressed and color-favored diagrams. By studying many different decay modes, we hope to achieve the aim of disentangling signs of new physics from hadronic uncertainties. The focus of this presentation is on measurements and techniques developed at LHCb to make a clean measurement of γ , the weak phase of the $b \rightarrow u$ transition relative to the $b \rightarrow c$ transition.

2. The LHCb detector

The LHCb detector is a forward spectrometer positioned around interaction point 8 of the LHC [1]. The first detector encountered by the collision products is the Vertex Locator (VELO), a movable silicon detector with 21 stations, each giving an R and a ϕ measurement. During injection, ramping,

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and squeezing, the VELO is retracted by 30 mm, and only when the LHC declares stable beams, the VELO is moved in to a distance down to 7 mm from the circulating proton beams. Particle identification is crucial in LHCb, and immediately downstream of the VELO is the first RICH detector, with both aerogel ($n = 1.03$) and C_4F_{10} ($n = 1.0014$) radiators. The RICH1 gives π/K separation in the momentum range 2–60 GeV. Momenta of charged particles are measured with a 4 Tm dipole, in combination with precise trajectory measurements before and after the magnet: upstream are the VELO and the TT, a 4-layer silicon strip detector. Downstream of the magnet, the Outer Tracker (OT), a 12 double-layer drift tube detector with 4 mm diameter straws, complemented by the Inner Tracker (IT) a 12-layer silicon strip detector close to the beam where the high track multiplicity demands a more fine-grained detector. A second RICH system with CF_4 ($n = 1.0005$) as radiator extends the π/K separation up to 100 GeV. The calorimeter, lead and scintillator for the electromagnetic measurement, and iron with scintillator for the hadronic measurement, is essential for identifying photons and electrons, and for first-level triggering on hadronic B decays. Finally, iron absorbers interspersed with proportional chambers give very robust muon identification.

3. Trigger for hadronic decays

While B decays with muons in the final state are relatively easy to trigger on, hadronic B decays require online measurements of displaced tracks to distinguish the B decays from the overwhelming background. Thus, the following trigger strategy has been adopted at LHCb to record hadronic B decays: at Level 0, a cluster in the Calorimeter with transverse energy $E_T \geq 3.6$ GeV is required. This brings the collision rate far enough down that the whole detector can be read out. The readout speed is foreseen to reach 1 MHz, but in 2010 speeds up to ≈ 300 kHz have been achieved. This was partly due to the incomplete readout farm, but also related to the larger event size. Nominal LHCb data taking was foreseen at an average interaction multiplicity of 0.4, but in 2010 LHCb ran with average multiplicities up to 2.6, resulting in larger event sizes from overlapping interactions. The High Level Trigger (HLT) resides as software in a computing farm with 1.6×10^4 CPUs. Event selection is factorized in two parts. First the rate is brought down to 30 kHz by requiring at least one track with transverse momentum $p_T \geq 1.5$ GeV and impact parameter $\text{IP} \geq 125 \mu\text{m}$ [2]. In a second stage (HLT2), 2, 3 and 4-track combinations are evaluated for consistency with the B decay hypothesis [3]. Up to 2 kHz of collisions are written to tape, but this dataset is too large to be directly analyzed by the individual collaborators. Therefore, the events are “stripped” offline to achieve another factor ten of data reduction, about 200 user-written stripping lines are used to separate the data into streams corresponding to different sets of specific B decays.

4. Measurements of γ

Measurements of γ can be categorized as those based on final states that also have sensitivity to loop diagrams (“ γ with loops”, mostly charmless decays) and those that use charmed final states that are to a very good approximation insensitive to loop contributions. The former at the moment provide a more precise measurement of γ , $\sigma_\gamma \approx 8^\circ$ [4], but new physics contributions may give a bias from the true value of γ . The measurements with trees are currently less precise ($\sigma_\gamma \approx 20^\circ$) but these measurements are almost completely insensitive to new physics contributions. At the moment both measurements agree, but the potential for future disagreements is large, given the sizable uncertainties from present data. The focus of the measurements discussed here is on the γ with trees measurements, since that is where the largest gain in precision is to be made. LHCb strategies are described in detail in [5].

4.1. Direct CP violation in $B \rightarrow DK$ decays

Final states with a neutral charm meson and a kaon can occur both through $b \rightarrow c\bar{u}s$ and $b \rightarrow u\bar{c}s$ diagrams. If the D^0 and $\bar{D}^0$ decay to a common final state, the two diagrams interfere and direct CP violation is the result, measurable as the asymmetry $A \equiv \frac{\Gamma(B^- \rightarrow DK^-) - \Gamma(B^+ \rightarrow DK^-)}{\Gamma(B^- \rightarrow DK^-) + \Gamma(B^+ \rightarrow DK^-)}$. At LHCb, we expect to be quickly competitive with the B factories on these measurements, since no flavor tagging is required.

In the GLW technique [6] the common final state is achieved by looking for final states that are CP eigenstates: $D^0, \bar{D}^0 \rightarrow \pi^+\pi^-, K^+K^-$. In LHCb, these final states are well accessible, as is demonstrated in Fig. 1, indicating our $B^+ \rightarrow D_{\text{CP}}\pi^+$ signals from 2010 data taking. The method can be extended by also considering $D^0, \bar{D}^0 \rightarrow K^-\pi^+$ decays [7]. Using an external constraint on the strong phase difference $\delta_{K\pi}$ helps to further improve this measurement. Figure 2 shows the LHCb $B^+ \rightarrow D^0K^+$ signal from 2010 data in the Cabibbo favored $D^0 \rightarrow K^-\pi^+$ decay.

A third group of common final states between D^0 and $\bar{D}^0$ are the $K_S h^+ h^-$ final states [8]. Figure 3 demonstrates that B decays with both $D^0 \rightarrow K_S \pi^+ \pi^-$, and $D^0 \rightarrow K_S K^+ K^-$ are reconstructible with good purity at LHCb.

The same technique can also be applied to $B^0 \rightarrow DK^{*0}$ decays [9]. The difference with the B^+ decays is that now both diagrams are color-suppressed, resulting in smaller branching fractions, but larger CP asymmetries. Figure 4 shows the related decay $B^0 \rightarrow \bar{D}^0 \rho^0$ from 2010 data.

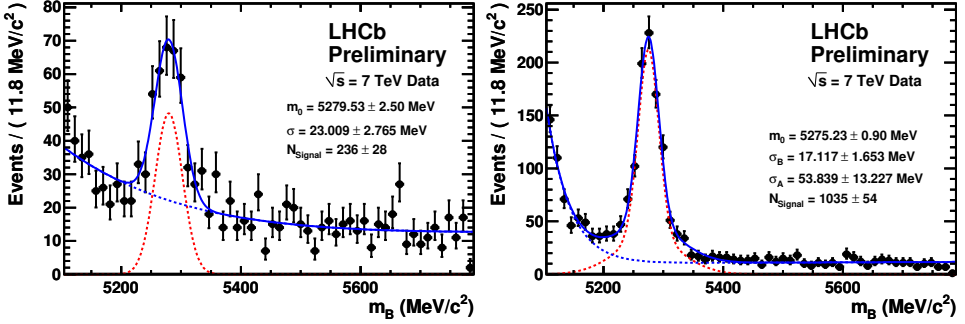


Fig. 1. Reconstructed signals of $B^+ \rightarrow \bar{D}^0 \pi^+$ from LHCb 2010 data taking with $D^0 \rightarrow \pi^+ \pi^-$ (left) and $D^0 \rightarrow K^+ K^-$ (right).

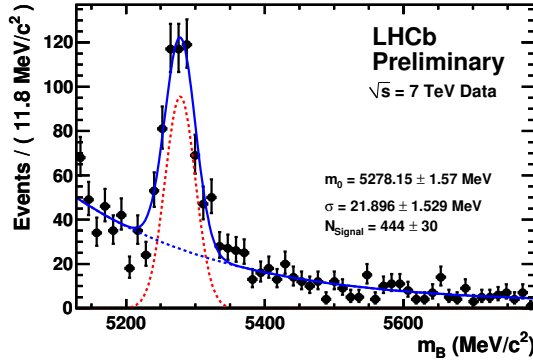


Fig. 2. Reconstructed signals of $B^+ \rightarrow \bar{D}^0 K^+$ from LHCb 2010 data taking with $D^0 \rightarrow K^- \pi^+$.

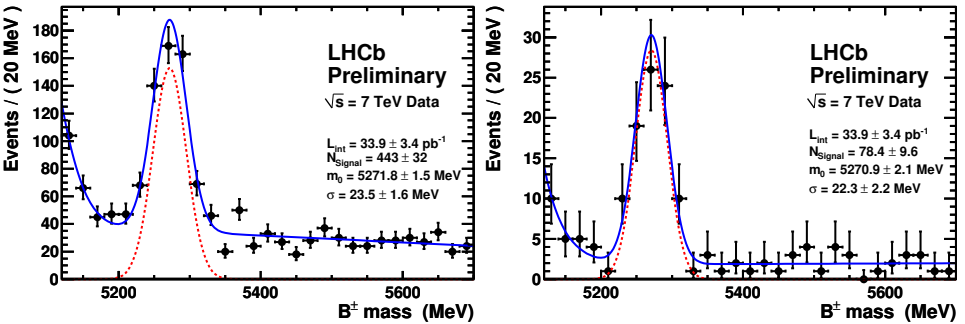


Fig. 3. Reconstructed signals of $B^+ \rightarrow \bar{D}^0 \pi^+$ from LHCb 2010 data taking with $D^0 \rightarrow K_S \pi^+ \pi^-$ (left) and $D^0 \rightarrow K_S K^+ K^-$ (right).

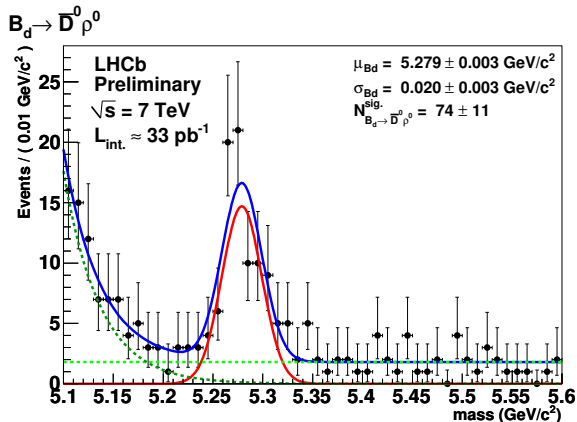


Fig. 4. Reconstructed signals of $B^0 \rightarrow \bar{D}^0 \rho^0$ from LHCb 2010 data taking.

4.2. Time-dependent CP violation in $B_s \rightarrow D_s^+ K^-$ decays

A method unique for hadron colliders is to make use of the large time-dependent CP violation expected in $B_s \rightarrow D_s^- K^+$ decays [10]. This is modulated by the fast B_s oscillation frequency, and flavor tagging is required to measure the CP asymmetry. As a first step, we will reconfirm B_s oscillations with $B_s \rightarrow D_s^- \pi^+$ decays. Figure 5 shows our signal with 2010 data.

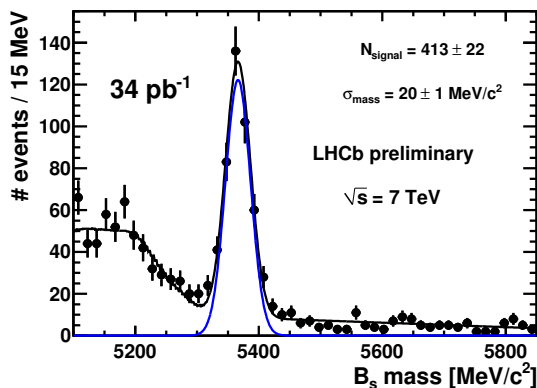


Fig. 5. Reconstructed signals of $B_s \rightarrow D_s^- \pi^+$ with $D_s^+ \rightarrow \phi \pi^+$ from LHCb 2010 data taking.

4.3. Loop-sensitive measurements of γ

Many charmless B decays depend on V_{ub} , and γ can be measured through the time-dependent CP asymmetry due to the interference between mixing

and decay in decays such as $B_d \rightarrow \pi^+\pi^-$. However, loop diagrams have contributions with similar magnitude to the trees, and additional information is needed to disentangle the two. An example of such a technique is given in [11], and makes use of U-spin symmetry: when replacing all d quarks by s quarks, one finds that the decay $B_s \rightarrow K^+K^-$ is sensitive to exactly the same diagrams as $B_d \rightarrow \pi^+\pi^-$, thus allowing to constrain some of the hadronic uncertainties from loop contributions. Figure 6 illustrates how the powerful particle identification helps to disentangle a broad $B \rightarrow h^+h^-$ without particle identification into two narrow peaks: one at the B_d when requiring pions and one at the B_s mass when requiring kaons.

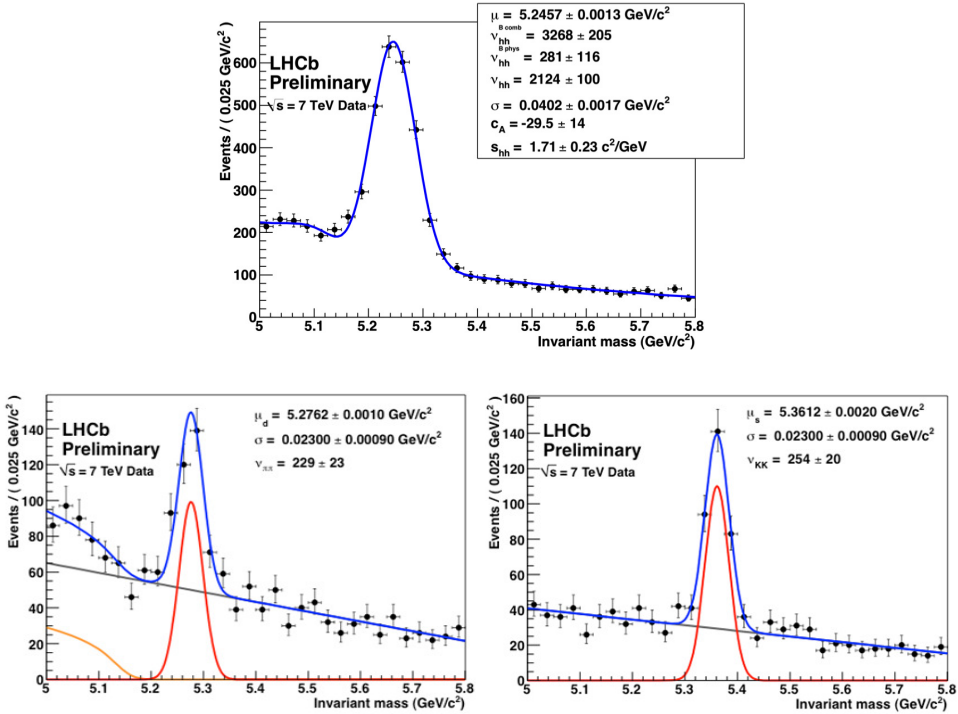


Fig. 6. Reconstructed signals of $B \rightarrow h^+h^-$ without PID (top), $B_d \rightarrow \pi^+\pi^-$ (bottom left), and $B_s \rightarrow K^+K^-$ (bottom right) from LHCb 2010 data taking.

5. Perspectives and conclusions

The 37 pb⁻¹ collected in 2010 has demonstrated the excellent performance of the LHCb detector. The 2011 data should allow for a measurement of γ from trees with a precision better than the current world-average. Moreover, the open trigger and stripping scheme allows studies of many more decays than mentioned here.

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