NEW PHYSICS SEARCH AT LHCB

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Abstract

Although direct detection of new particles will be the main focus of the LHC, indirect New Physics searches are expected to provide useful complementary information. In particular, precision measurements of rare processes occurring in flavour physics are of utmost importance in constraining the structure of the New physics low energy effective Lagrangian. In this paper, few key LHCb studies, including $B_s - \bar{B}_s$ mixing and rare decays through the quark level $b \to s$ loop transition, are presented to illustrate New Physics effects at low energy.

1 Introduction

Weak decays of hadrons are generically described by a low energy effective hamiltonian expressed as an expansion of local operators O_i [1]:

$$H_{eff} = \sum_i C_i O_i \qquad (1)$$

The Wilson coefficients C_i include the short distance effects and are computed perturbatively at the electroweak scale and then derived at the $\sim m_b$ scale through the renormalization group equations. The matrix elements of the O_i operators represent the long range effects related to hadronization and are derived non-perturbatively, using various techniques (QCD sum rules, Lattice, etc...). Note that the O_i also mix under renormalization, the consequence being that a given C_i coefficient may receive contributions from other C_j coefficients: in this case, we talk about effective coefficients, C_i^{eff} associated to O_i.

In this framework, the intervention of virtual new heavy particles in loop dominated processes will affect the C_i coefficients. We are therefore in search for any observable sensitive to these coefficients and for which the theoretical uncertainties are relatively small.

2 B_s mixing

The $B_s - \bar{B}_s$ meson oscillation is described by the $\Delta B = 2$ box diagrams shown in figure 1.
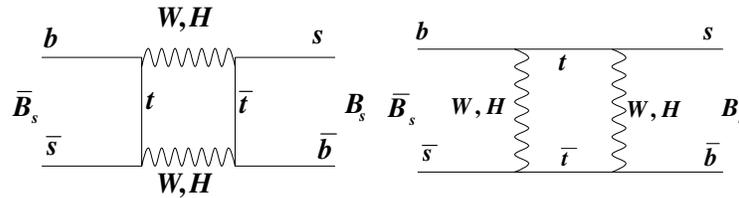

Figure 1: Box diagrams for B_s mixing. In Standard Model, the loop is mediated by a W boson. For illustration, the case where a charged Higgs is involved is depicted.

In the Standard model, the box diagrams carry the weak phase $(V_{tb}V_{ts}^*)^2$. The best way to probe new contributions in the box is to compare B_s and $\bar{B}_s$ decays to common CP final states as a function of the B_s proper time. Similarly to the B_d case, the preferred final states f_{CP} are the ones induced by the $b \to c\bar{c}s$ quark tree transition, leading to the golden mode $B_s \to J/\Psi\phi$ and other modes less favored experimentally such as $B_s \to J/\Psi\eta^{(\prime)}$, $B_s \to \eta_c\phi$

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and $B_s \to D_s^+ D_s^-$. All these modes carry the weak phase $V_{cb}V_{cs}^*$.

The amplitude of the mixing-induced asymmetry, $A_{CP}(t) = \frac{\Gamma(\bar{B}_s(t) \to f_{CP}) - \Gamma(B_s(t) \to f_{CP})}{\Gamma(\bar{B}_s(t) \to f_{CP}) + \Gamma(B_s(t) \to f_{CP})}$ is proportional to $sin(2\beta_s)$, where $2\beta_s = 2arg(-\frac{V_{ts}V_{tb}^*}{V_{cs}V_{cb}^*}) = -0.04$ to a precision of 5% in the Standard Model. This small value implies that the measurement of a sizeable amplitude will point directly to the intervention of New Physics.

Table 1 shows results of sensitivity studies performed for various decay channels with the LHCb simulated events. The numbers have been obtained for a statistics corresponding to one year of data taking at nominal luminosity $L = 2 \times 10^{34} cm^{-2}.s^{-1}$.

Sample	Expected yield/2 fb^{-1}	$\sigma(2\beta_s)$
$B_s \to J/\Psi(\mu^+\mu^-)\eta(\gamma\gamma)$ [3]	8.5k	0.109
$B_s \to J/\Psi(\mu^+\mu^-)\eta(\pi\pi\pi^0)$ [3]	3k	0.142
$B_s \to J/\Psi(\mu^+\mu^-)\eta'(\pi\pi\eta)$ [4]	2.2k	0.154
$B_s \to J/\Psi(\mu^+\mu^-)\eta'(\rho\gamma)$ [5]	4.2k	0.080
$B_s \to \eta_c(4h)\phi(K^+K^-)$ [3]	3k	0.108
$B_s \to D_s^+ D_s^-$ [3]	4k	0.133
All pure CP eigenstates	-	0.046
$B_s \to J/\Psi(\mu^+\mu^-)\phi(K^+K^-)$ [3,6]	130k	0.023
All modes	-	0.021

Table 1: Expected yields and sensitivities on $2\beta_s$. Reconstructed submodes are indicated between brackets. For η_c reconstruction, $4h$ means a combination of four charged kaons or pions.

For a short term scenario with an integrated luminosity of 0.1 fb^{-1} the sensitivity to $2\beta_s$ is still better than 0.1, which means that a deviation of ~ 0.3 would be detected with very early data.

New physics contribution to the mixing is usually parameterized in a model-independent way [2]:

$$\frac{< B_s|H_{eff}^{total}|\bar{B}_s >}{< B_s|H_{eff}^{SM}|\bar{B}_s >} = C_{B_s}e^{2i\phi_{B_s}} \qquad (2)$$

It follows from this parameterization that $sin(2\beta_s)$ becomes $sin(2(\beta_s - \phi_{B_s}))$. Fits for C_{B_s} and ϕ_{B_s} parameters have been performed using available experimental data [7]. The recent Tevatron results on the mixing phase and width difference $\Delta\Gamma_s$ [8], $-1.20 < 2\beta_s < 0.06$ and $0.06 < \Delta\Gamma_s < 0.30$ ps^{-1} at 90% confidence level, triggered a statistical analysis [9] which allowed to constrain the $C_{B_s} - \phi_{B_s}$ parameters space, suggesting a hint for beyond SM contributions. No doubt that the coming improvements in Tevatron results and above all, the first LHCb results, will definitely clarify the picture and help us quantify more accurately the size of any New Physics contribution.

3 Radiative $b \to s\gamma$

$b \to s\gamma$ is one of the benchmark New Physics probe in b physics. It is mediated by the electromagnetic dipole operator, $O_7 = \bar{s}\sigma^{\mu\nu}(m_b R + m_s L)bF_{\mu\nu}$, where $R = 1 + \gamma^5$, $L = 1 - \gamma^5$. The amplitude is therefore driven by the effective Wilson coefficient C_7^{eff}.

Given that $m_s << m_b$, one photon polarization is suppressed by m_s/m_b: the photon is mostly right-handed in $\bar{b}$ decays and left-handed in b decays. However, enhancement of the suppressed polarization could come from New Physics contributions. Furthermore, it can be shown that the mixing-induced asymmetry in $B^0 \to V^0\gamma$ decays has the same suppression factor as the photon polarity.

Several radiative decays studies have been performed in LHCb, among them: $B_d \to K^{*0}(K^+\pi^-)\gamma$,

and $B_s \rightarrow \phi(K^+K^-)\gamma$ [10]. These modes have been jointly analyzed and common selection cuts have been applied, when possible. For the photon, a ECAL cluster not associated to a track is required, along with a transverse energy cut to suppress π^0 background. To reconstruct K^{*0} and ϕ, impact parameters and particle ID cuts are applied to pions and kaons, as well as vertex quality requirements for $K\pi$ and KK. B flight is used to reject prompt background from primary production vertex.

The studies have shown that yields of 68k and 11k signal events are expected with 2 fb^{-1} for $B_d \rightarrow K^{*0}\gamma$ and $B_s \rightarrow \phi\gamma$, respectively. With this statistics, a 1% sensitivity is expected for the CP asymmetry. A dedicated photon polarization study was performed for the $B_s \rightarrow \phi\gamma$ channel [11] and has shown a sensitivity better than 0.2 for the suppressed polarization fraction.

4 Electroweak $b \rightarrow sl^+l^-$

This transition is governed mostly by electroweak and electromagnetic penguin operators, O_7, O_9 and O_{10}. The rate is dominated by $|C_9^{eff}|^2$, $|C_{10}|^2$ and the sign of C_7^{eff}. An interesting observable is the leptons forward-backward asymmetry which is highly sensitive to the relative sign of C_7^{eff} and C_{10}. In the leptons pair rest frame, we consider the angle θ_{ll} of the leptons with respect to the B meson momentum. The asymmetry is then defined as:

$$A_{FB}(\hat{s} = \frac{m_{ll}^2}{m_b^2}) = \frac{\int_0^1 dcos\theta_{ll} \frac{d^2\Gamma(B \rightarrow X_s l^+ l^-)}{dcos\theta_{ll}d\hat{s}} - \int_{-1}^0 dcos\theta_{ll} \frac{d^2\Gamma(B \rightarrow X_s l^+ l^-)}{dcos\theta_{ll}d\hat{s}}}{\int_0^1 dcos\theta_{ll} \frac{d^2\Gamma(B \rightarrow X_s l^+ l^-)}{dcos\theta_{ll}d\hat{s}} + \int_{-1}^0 dcos\theta_{ll} \frac{d^2\Gamma(B \rightarrow X_s l^+ l^-)}{dcos\theta_{ll}d\hat{s}}} \quad (3)$$

The point $\hat{s}_0$ where this quantity cancels to zero has a particular theoretical interest since it is known with a reasonable accuracy [12].
Studies have been performed for the decay $B_d \rightarrow K^{*0}\mu^+\mu^-$ [13]. Particular care has been taken to apply selection cuts that don't bias the dimuon invariant mass distribution. 7.2k signal events are expected for an integrated luminosity of 2 fb^{-1}. Figure 2 shows the resulting expected asymmetry distribution, along with theoretical predictions on the shape (taken from reference [14]). The remarkable feature of the predictions lies in the fact that, beside the
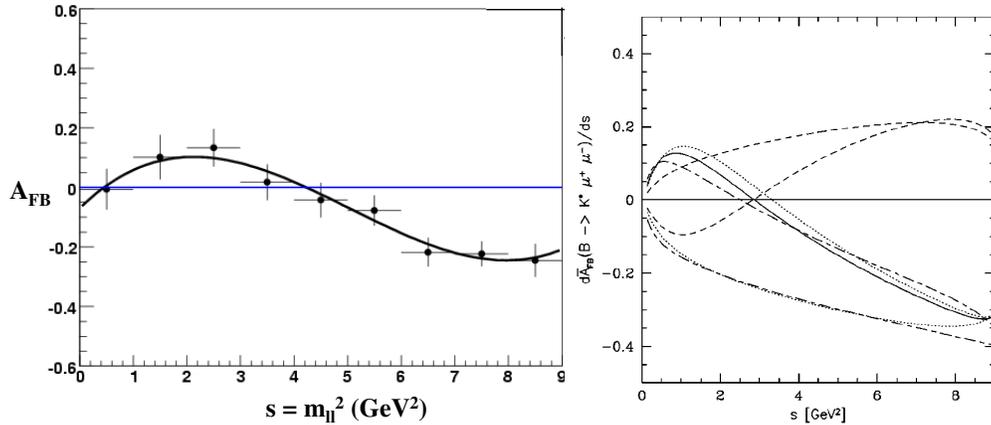

Figure 2: Dimuon forward-backward asymmetry as a function of the squared dimuon invariant mass. The left plot shows the experimental result while the right plot shows theoretical predictions for several working hypotheses. Right plot: the solid line is for the SM-based prediction and the dotted and dashed lines represent results from different SUSY-based scenarios where the signs of C_{10} and C_7^{eff} Wilson coefficients are flipped.

result that the zero point of the asymmetry is known to a precision of ~ 0.6 GeV^2 in the Standard Model, models where $C_7^{eff} > 0$ predict that the asymmetry does not cancel. In the same studies, other variables with minimal theoretical uncertainties, such as the fraction of longitudinal polarization of the K^{*0}, have been considered as interesting probes and are expected to provide further sensitivity to New Physics.

The analysis of $B^+ \to K^+ l^+ l^-$ modes (with $l = e,\ \mu$) has also been considered [15]. It has been shown [16] that the following ratio:

$$R_X = \frac{\int_{s_{min}}^{s_{max}} ds \frac{d\Gamma(B \to X\mu^+\mu^-)}{ds}}{\int_{s_{min}}^{s_{max}} ds \frac{d\Gamma(B \to Xe^+e^-)}{ds}} \tag{4}$$

, can be predicted with a very good precision in the Standard Model. In particular for $X = K$, this ratio is equal to one at the 10^{-4} level. Substantial deviations from this value could occur from scalar $\sim \bar{s}Rb\bar{l}l$ and pseudo-scalar $\sim \bar{s}Rb\bar{l}\gamma^5 l$ operators contributing to the effective hamiltonian. The corresponding Wilson coefficients include the lepton masses and are therefore responsible for a possible difference between electron and muon modes. Experimentally, selections have been optimized to reject backgrounds of type Xl^+l^- with badly reconstructed X and it has been shown that the sensitivity to R_K reaches few percent with an integrated luminosity of 10 fb^{-1}.

5 $B_s \to \mu^+\mu^-$

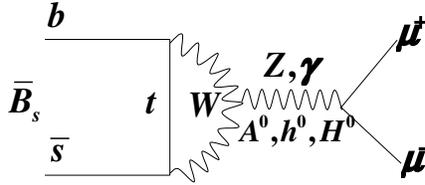This rare mode is mediated by second order annihilation diagrams such as the one shown in figure 3.

Figure 3: Annihilation diagram of the decay $B_s \to \mu^+\mu^-$. In MSSM or Double Higgs Model, Z boson or γ mediation can be replaced by neutral Higgs bosons, as depicted.

It is suppressed by a factor $\sim m_\mu^2/m_B^2$ in the Standard Model, leading to a branching ratio of $\sim 3 \times 10^{-9}$, [17]. A possible enhancement could occur through neutral Higgs mediation in constrained Minimal Super Symmetry or Two Higgs Models with large $tan\beta$ [17]. In that case, phenomenology predicts $\Gamma(B_s \to \mu^+\mu^-) \propto \frac{m_b^2 m_\mu^2 tan^6\beta}{M_{A^0}^4}$.

On the experimental side [18], the decay is easy to reconstruct but is embedded in a huge background coming from leptonic b decays. Sensitivity studies have been performed to test the discovery power as a function of statistics. Figure 4 shows the results. Early observation with 2 fb^{-1} is possible for SM-like rates while discovery can be envisaged with even lower statistics if New Physics enhances the branching ratio.

Conclusion

The key studies reviewed in this paper reflect the New Physics sensitivity timeline for the LHCb experiment. First data (integrated luminosity $<\sim 0.5 fb^{-1}$) will give us first answers on any substantial enhancement of Standard Model suppressed observables, such as the weak mixing phase β_s in the B_s oscillations or the rate of $B_s \to \mu^+\mu^-$. The 2 fb^{-1} milestone will then consolidate the first observations. Final data sample of what one could qualify as a first "phase", $\sim 10 fb^{-1}$, is expected to give us more insight on the flavour structure of New Physics through precise measurements of rates and CP asymmetries and will also allow more significant determination of differential rate asymmetries and polarizations in rare processes.

References

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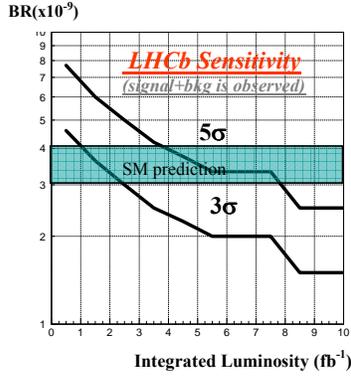
Figure 4: Observation (3σ) and Discovery (5σ) limits for $B_s \rightarrow \mu^+\mu^-$ as a function of integrated luminosity in case where both signal and background are observed.

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