EXPECTED PHYSICS PERFORMANCE OF THE LHCb EXPERIMENT

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LHCb is a dedicated B-physics experiment at the LHC. It is currently under construction, to be ready for first collisions in 2007. We give an overview of the expected physics performance: sensitivity in typical channels for study of B_s^0 mixing, CP violation and rare B decays.

1. Introduction

The LHCb experiment, its tracking and particle identification systems have been introduced elsewhere in this conference^{1,2}. Here we will illustrate the LHCb physics performance with some key measurements. More detailed results can be found in³.

CP violation is described in the Standard Model by a complex phase in the CKM matrix^{4,5}. The B meson sector is a place where theoretical predictions can be precisely compared with experimental results. LHCb will measure precisely fundamental parameters of the Standard Model like the phases $\arg V_{td} = -\beta$, $\arg V_{ub} = -\gamma$ and $\arg V_{ts} = -\phi_s/2 + \pi$. We will measure the B_s^0 oscillation frequency and explore many rare decays involving radiative, electroweak and gluonic penguin amplitudes. There is also a B_c^+ and b-baryon physics program and our trigger is designed to face unexpected decays. With all these measurements, we will over constrain the unitarity triangles in order to search for inconsistencies and to exhibit new physics. Indeed new physics scenarios propose new particles and new couplings which can modify the amplitudes of penguin and box diagrams.

Physics potential of LHCb is estimated using Monte Carlo simulation. Proton-proton collisions are generated using PYTHIA 6.2 including hard QCD processes, single and double diffraction. Multiple parton interactions are tuned to reproduce the track multiplicities observed at SPS and Teva-

tron energies. The particles are propagated through the detector using Geant simulation. Each sub-detector response, resolution, efficiency, noise and cross-talk is taken into account using test beam data. Then the offline reconstruction is done using a full pattern recognition program, including track finding and RICH reconstruction. More than 40M $b\bar{b}$ events have been generated to perform detailed background studies.

The B_s^0 proper time resolution¹ is around 43 fs. The flavour of the signal B meson is tagged using fragmentation kaon or pion as well as the opposite b-hadron decay products: kaon, leptons and vertex charge. All information is combined using a neural network. Typical effective tagging efficiencies vary between 4-5% for B^0 and 7-9% for B_s^0 .

2. B_s^0 mixing, phase and $\Delta\Gamma_s$

The B_s^0 oscillation frequency, Δm_s will be measured using $B_s^0 \rightarrow D_s^- \pi^+$ decays. The statistical uncertainty will be 0.01 ps^{-1} , with 2 fb^{-1} ^a if Δm_s is equal to 20 ps^{-1} . We can observe B_s^0 oscillation with a significance of at least 5σ up to 68 ps^{-1} . Hence Δm_s range will be explored well beyond the Standard Model prediction.

The B_s^0 mixing phase, ϕ_s , will be measured using the CP asymmetry in $B_s^0 \rightarrow J/\psi \phi$ events. This channel is the B_s^0 counterpart of the golden mode $B^0 \rightarrow J/\psi K_S^0$. The J/ψ is reconstructed in $\mu^+ \mu^-$ or $e^+ e^-$ and the ϕ in $K^+ K^-$. An angular analysis of the decays products is necessary to separate the CP-even from the CP-odd contributions. The ϕ_s phase can also be extracted from pure CP eigenstates like $B_s^0 \rightarrow J/\psi \eta$ or $B_s^0 \rightarrow \eta_c \phi$. These channels have a much lower statistics, but do not require an angular analysis. Combining all these modes, we expected a statistical uncertainty at the level of 0.013 radians with 10 fb^{-1} . The Standard Model predicts ϕ_s around -0.036 , but values order of magnitude higher can be expected in the presence of new physics.

3. The α phase

The Snyder and Quinn prescription⁶ to measure α has been studied in LHCb. The decays of B^0 meson to $\pi^+ \pi^- \pi^0$ is exploited, assuming that the intermediate $\rho\pi$ state is dominant. Compared to two-body decays approach, discrete ambiguities are theoretically removed and an independent measurement of tree and penguin parameters is possible. The

^aIn nominal condition, we expected 2 fb^{-1} per year.

$B^0 \rightarrow \pi^+ \pi^- \pi^0$ selection is based on a multivariate analysis. Both π^0 giving merged and resolved clusters in the electromagnetic calorimeter are exploited. We expect 14,000 events per year after trigger, reconstruction and offline selection. The background-over-signal ratio from inclusive $b\bar{b}$ events has been estimated to be less than 1. The full Monte Carlo parameters are used to build toy Monte Carlo experiments, in order to assess the sensitivity to α . Eleven-parameter likelihood fits are performed in time-dependent Dalitz space, on hundreds of toy Monte Carlo experiments. Assuming a flat and resonant background, we conclude that a statistical uncertainty of 10 degrees on α can be reached with 2 fb^{-1} .

4. The γ phase

The γ phase can be measured with at least six methods and only two are discussed here. The first one uses $B_s^0 \rightarrow D_s^\mp K^\pm$ events. Inteferece between two tree diagrams and B_s^0 mixing in $B_s^0 \rightarrow D_s^\mp K^\pm$ allows an extraction of $\gamma + \phi_s$ from two time-dependent decay rate asymmetries. The mistag fraction can be extracted from the $B_s^0 \rightarrow D_s^- \pi^+$ sample and ϕ_s is measured with $B_s^0 \rightarrow J/\psi \phi$, as explained previously. Sensitivity have been estimated using fast Monte Carlo programs. The uncertainty on γ is 14 degrees after one year of data taking. This assumes $\Delta m_s = 20 \text{ ps}^{-1}$, $\Delta \Gamma_s / \Gamma_s = 0.1$, γ between 55 and 105 degrees and the strong phases difference between the 2 tree diagrams to be below 20 degrees. This method has no theoretical uncertainties and is insensitive to new physics in the B_s^0 mixing.

The ADS method⁷ exploits the interference between the favoured and doubly Cabibbo-suppressed decay modes of neutral D mesons to states such as $K\pi$ in charged B decays to DK. For these decays, the reversed suppression of the D decays relative to the B decays results in similar amplitude and big interference effects. No tagging nor proper time measurement is necessary, hence it is just a counting experiment. The interference depends on five parameters: γ , r_B , the ratio between the colour-allowed and colour-suppressed B decays, δ_B , the strong phase difference between the two diagrams, $r_D^{K\pi}$, the ratio in magnitude of the two D decay processes and $\delta_D^{K\pi}$, the strong phase difference between the two D diagrams.

Four possible B decays have to be reconstructed: $B^- \rightarrow (K^- \pi^+)_{\text{D}} K^-$, $B^- \rightarrow (K^+ \pi^-)_{\text{D}} K^-$, $B^+ \rightarrow (K^+ \pi^-)_{\text{D}} K^+$, $B^+ \rightarrow (K^- \pi^+)_{\text{D}} K^+$. The first and the third decays are favoured. The second and the last are suppressed, but have interference term appearing at leading order, so that they are particularly sensitive to $\delta_D^{K\pi}$ and γ . Even though they are suppressed,

the expected statistics in 1 year is 50 times higher than what is currently available at the B factories. Measuring the relative rates of these 4 processes give three observables which depend on four unknowns: r_B , γ , δ_B and $\delta_D^{K\pi}$. In order to constrain the problem, it is necessary to look for the D decay into another final state such as $D \rightarrow K\pi\pi\pi$.

Toy Monte Carlo experiments have been performed to estimate the sensitivity to γ . The level of background has been estimated to be around 0.5 for the two-body D decays, but is not yet known for the four-body D decays. Nevertheless, an arbitrarily B/S has been introduced in the toy Monte Carlo and the result does not depend a lot on this B/S . The expected statistical uncertainty on γ is around 5 degrees with 2 fb^{-1} .

5. Rare decays

The forward-backward asymmetry in the $\mu^+\mu^-$ rest frame for $B^0 \rightarrow \mu^+\mu^-K^{*0}$ decays is interesting because it allows to distinguish various extensions of the Standard Model⁸. The branching ratio of this decay is around 10^{-6} . We expect to select 4,400 $B^0 \rightarrow \mu^+\mu^-K^{*0}$ events per year, with a B/S ratio smaller than 2.6. With 10 fb^{-1} , we expect to locate the zero of the forward backward asymmetry to $\pm 0.53 \text{ GeV}$, which will allow to determine the ratio of the effective Wilson coefficients C_7^{eff} and C_9^{eff} with a 13% error.

6. Conclusion

LHCb will collect unprecedented statistics of B decays. $B_s^0\bar{B}_s^0$ oscillation will be measured with a 5σ significance up to 68 ps^{-1} . Many measurements of rare decays and CP asymmetries will be performed. The statistical uncertainty on α , γ and ϕ_s after one year of data taking is expected to be 10, 5 and 2 degrees, respectively. CP phases will be determined via channels with different sensitivity to new physics, so that detailed tests of the CKM description of the quark sector will be possible. A summary of the performance is given in Table 1.

LHCb offers an excellent opportunity to spot new physics signal beyond Standard Model and to pin down its nature.

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Table 1. Expected statistical performance of the LHCb experiment for key measurements with 2 fb^{-1} (1 year of data taking). Untagged signal yields and background-over-signal ratios estimated from inclusive $b\bar{b}$ events are given.

	Decay channel	Annual yield	B/S	Stat. uncertainty
γ	$B_s^0 \rightarrow D_s^+ K^\pm$	5.4k	< 1	$\sigma(\gamma) \simeq 14^\circ$
	$B^0 \rightarrow \pi^+ \pi^-$	26k	< 0.7	
	$B_s^0 \rightarrow K^+ K^-$	37k	0.3	$\sigma(\gamma) \simeq 6^\circ$
	$B^0 \rightarrow D^0 (K^- \pi^+) K^{*0}$	0.5k	< 0.3	
	$B^0 \rightarrow \bar{D}^0 (K^+ \pi^-) K^{*0}$	2.5k	< 2	$\sigma(\gamma) \simeq 8^\circ$
	$B^0 \rightarrow D_{CP}^0 (K^+ K^-) K^{*0}$	0.6k	0.3	
	$B^+ \rightarrow D^0 (K^- \pi^+) K^-$	60k	0.5	
	$B^+ \rightarrow D^0 (K^+ \pi^-) K^-$	2k	0.5	$\sigma(\gamma) \simeq 5^\circ$
α	$B^0 \rightarrow \pi^+ \pi^- \pi^0$	14k	0.8	$\sigma(\alpha) \simeq 10^\circ$
ϕ_s	$B_s^0 \rightarrow J/\psi \phi$	125k	0.3	$\sigma(\phi_s) \simeq 2^\circ$
	$B_s^0 \rightarrow J/\psi \eta$	12k	2-3	
	$B_s^0 \rightarrow \eta_c \phi$	3k	0.7	
Δm_s	$B_s^0 \rightarrow D_s^- \pi^+$	80k	0.3	Δm_s up to 68 ps^{-1}
β	$B^0 \rightarrow J/\psi K_S^0$	216k	0.8	$\sin(2\beta) \simeq 0.022$
rare decays	$B^0 \rightarrow \mu^+ \mu^- K^{*0}$	4.4k	< 2.6	NP search
	$B_s^0 \rightarrow \mu^+ \mu^-$	17	< 5.7	NP search
	$B^0 \rightarrow K^{*0} \gamma$	35k	< 0.7	$\sigma(A_{CP}^{\text{dir}}) \simeq 0.01$

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