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LHCb prospects for the Unitarity Triangle

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Summary. — The LHCb experiment will play soon an important role in the sector of B-Physics by realizing new key measurements looking for New Physics beyond the Standard Model. It will improve the existing measurements provided by the B-factories and the Tevatron, such as the CKM angles, the B_s mixing phase and the branching ratio of the very rare decay $B_s \to \mu^+\mu^-$. In this paper a summary of the LHCb potential for these measurements will be given, together with an estimate of their impact on Unitarity Triangle fits.

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1. – Introduction

The B-factories have ended taking data and almost completed their most important analyses, while the Tevatron is starting to achieve an interesting level of accuracy for some measurements, such as those of the B_s mixing phase [1] and of the $B_s \to \mu^+\mu^-$ branching ratio [2]. By using in particular the CDF and DØ results, the UT$_{\mathrm{fit}}$ Collaboration reported a discrepancy of the value of the B_s mixing phase from the Standard Model (SM) expectation of about 3 standard deviations [3]. LHCb will have soon the possibility to confirm or disprove such an evidence of NP by measuring with high precision the B_s mixing phase. On the other hand, LHCb will also measure with high precision other relevant quantities, such as the angles of the CKM matrix, and in particular the γ angle. In the remainder of this paper the LHCb physics performance on some core measurements will be briefly discussed, together with their impact on Unitarity Triangle (UT) fits.

2. – Current experimental status

The knowledge of the CKM matrix, which describes CP violation in the SM, has improved significantly in recent years. However, several of its parameters remain poorly constrained by direct measurements (*e.g.*, the CKM angle γ). The current experimental knowledge of the relevant quantities used as inputs in UT fits is summarized in table I.

TABLE I. – *Experimental knowledge of some relevant B-physics quantities, used as inputs in UT fits. The 68% probability intervals are quoted.*

	Current experimental knowledge	Reference
α	$(92 \pm 8)^\circ$ SM solution	UT$_{\text{fit}}$ [4]
$\sin 2\beta$	0.668 ± 0.028	UT$_{\text{fit}}$ [4]
γ	$(80 \pm 13)^\circ U(-100 \pm 13)^\circ$	UT$_{\text{fit}}$ [4]
Δm_s	(17.77 ± 0.12) ps^{-1}	CDF [5]
Φ_{B_s}	$(-69 \pm 7)^\circ \cup (-19 \pm 8^\circ)$	UT$_{\text{fit}}$ [4]
$\mathrm{BR}(B_s \to \mu^+ \mu^-)$	$< 4.7 \times 10^{-8}$	CDF, DØ [2]

3. – LHCb prospect on key measurements

Thanks to the large $b\bar{b}$ cross-section at the LHC and to the design of the LHCb detector optimized for B-Physics, LHCb will collect an unprecedented sample of B-hadron decays. For example, with an integrated luminosity of $2\,\text{fb}^{-1}$, corresponding to one nominal year of data taking, LHCb will trigger and reconstruct $220\,\text{k}$ $B_d \to J/\psi K_s$ decays [6], $120\,\text{k}$ $B_s \to J/\psi \phi$ decays [7] and $40\,\text{k}$ $B \to DK$ [8] decays. We can summarize the expected LHCb sensitivities as in the following:

– The sensitivity on $\sin 2\beta$, measured from the mode $B_d \to J/\psi K_s$, is estimated to be $0.02\,\text{rad}$ per $L = 2\,\text{fb}^{-1}$ of integrated luminosity.

– The impact of LHCb on the measurement of the α angle, by means of the time-dependent Dalitz analysis of the $B_d \to (\rho\pi)^0$ decay, is about 10° per $L = 2\,\text{fb}^{-1}$.

– LHCb has explored all the various ways and methods for measuring the angle γ. One possible way is to extract the angle γ from time-independent analyses. It requires the reconstruction of $B \to DK$ decays. The methods used in this analysis are the so-called ADS, GLW and GGSZ. Another possibility is to realize a time-dependent analysis of the decay $B_s \to D_s K$. The combined sensitivity of all methods is about 4° per $L = 2\,\text{fb}^{-1}$, *i.e.* by collecting in a few years of running an integrated luminosity of $L = 10\,\text{fb}^{-1}$, the error could be brought down to about 2°.

– The expected LHCb sensitivity on the B_s mixing phase is $0.034\,\text{rad}$ per $L = 2\,\text{fb}^{-1}$ (the sensitivity is evaluated from the decay $B_s \to J/\psi \phi$ alone). It means that LHCb will confirm or disprove the existing evidence of NP in this sector starting from about $0.2\,\text{fb}^{-1}$ of integrated luminosity (*i.e.* few weeks of data taking), if the central value measured at the Tevatron is confirmed.

– Another important goal of the LHCb experiment is the precise measurement of the branching ratio of the very rare decay $B_s \to \mu^+\mu^-$. This FCNC mode is expected to have a SM branching ratio of $(3.35 \pm 0.32) \times 10^{-9}$, but can be significantly enhanced by the presence of NP. According to the most recent analysis, LHCb will have a sensitivity of 3 standard deviations per $L = 2\,\text{fb}^{-1}$ of integrated luminosity or 5 standard deviations per $6\,\text{fb}^{-1}$, assuming the SM value of the branching ratio.
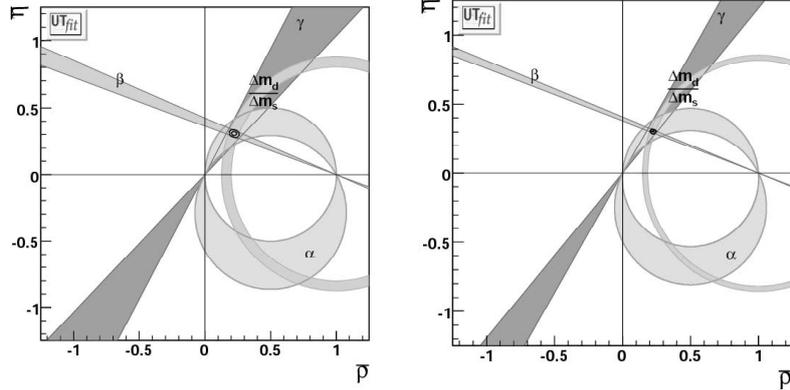
Fig. 1. – Possible scenarios of the Unitarity Triangle using only LHCb measurements of α, β, γ and Δm_s with $L = 2\,\text{fb}^{-1}$ (left) and $L = 10\,\text{fb}^{-1}$ (right) of integrated luminosity.

4. – Unitarity Triangle prospects from LHCb

Figure 1 shows two possible scenarios of the UT, obtained by employing hypothetical future measurements of LHCb corresponding to integrated luminosities of $L = 2\,\text{fb}^{-1}$ and $L = 10\,\text{fb}^{-1}$. UT fits were performed using only the sensitivities of α, β, γ and Δm_s expected at LHCb, but also including a projection of the expected improvements in the lattice QCD calculation of some relevant hadronic parameters. The sensitivities on the measurements used as inputs in the UT fits are reported in table II. The expected relative errors on the CKM parameters $(\bar\rho, \bar\eta)$ are reported in table III.

5. – Conclusions

Thanks to the increased precision in the measurement of the CKM angles, in particular β and γ, LHCb will bring a considerable improvement in the knowledge of the UT. Very early it will be able also to confirm or disprove the evidence of NP claimed at

TABLE II. – *LHCb statistical sensitivities for relevant measurements used as inputs in UT fits.*

UT parameters	$2\,\text{fb}^{-1}$	$10\,\text{fb}^{-1}$
$\sigma(\alpha)$	$10°$	$5°$
$\sigma(\beta)$	$0.6°$	$0.3°$
$\sigma(\gamma)$	$5°$	$2.5°$
$\sigma(\Delta m_s)$	$7\,\text{fs}^{-1}$	$3\,\text{fs}^{-1}$

TABLE III. – *Expected relative errors on $(\bar\rho, \bar\eta)$ at LHCb.*

	$2\,\text{fb}^{-1}$	$10\,\text{fb}^{-1}$
$\sigma(\bar\rho)/\bar\rho$	7.1%	3.6%
$\sigma(\bar\eta)/\bar\eta$	3.9%	1.8%

the Tevatron, by measuring with much higher precision the B_s mixing phase. LHCb will search evidences of NP also through other outstanding measurements, *e.g.*, the branching ratio of the rare $B_s \rightarrow \mu^+\mu^-$ decay.

With such precise measurements, in the unfortunate case that no direct detection of NP particles will emerge from the LHC general purpose detectors Atlas and CMS, LHCb might be the only way in the LHC era to look for NP effects, by exploiting powerful indirect measurements in the flavour sector.

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