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New Physics perspectives with the upgraded LHCb detector

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Summary. — First encouraging deviations from Standard Model have been observed by the LHCb Collaboration in the first phase of data taking. The LHCb upgrade will be crucial to conclude if New Physics exists up to $\sim \mathcal{O}(100\text{ TeV})$, thanks to the collection of a very large data sample of $\sim 50\text{ fb}^{-1}$ and to an innovative flexible software based trigger system. An overview of the main observables accessible to LHCb that could reveal New Physics effects is reported.

1. – New Physics at LHCb

The LHCb detector [1] flavour physics program is suited to carry on indirect searches of New Physics (NP) beyond the Standard Model (SM) through precision measurements of b and c hadrons decays. An overview of the main observables with their expected experimental uncertainties after the LHCb upgrade [2] is shown in fig. 1.

The production of beyond the SM virtual particles is investigated in loop processes of heavy flavour hadrons decays. The Higgs, electroweak and photonic penguins are determined with high precision within the SM and for this reason they are the ideal environment to search for NP. These processes are very rare, of the order of 1 over a billion b decays in the case of Higgs penguins. A very high statistics is therefore necessary to be sensitive to NP contributions that could manifest themselves through an increase of branching ratios or through deviations from predicted angular distributions.

Higgs penguins are mainly studied through the $B_{s,d} \to \mu^+\mu^-$ decays [3]. The statistical error on the branching ratio $\mathcal{B}(B_s \to \mu^+\mu^-)$ is expected to be lower than the theoretical one after the upgrade. The uncertainty on the ratio $\mathcal{B}(B_d \to \mu^+\mu^-)/\mathcal{B}(B_s \to \mu^+\mu^-)$ will improve from the $\sim 100\%$ with the current detector data to $\sim 35\%$ with the upgraded LHCb data.

Electroweak penguins are currently probed studying decays involving $b \to s\mu^+\mu^-$ transitions, like $B_d \to K^*\mu^+\mu^-$. First tensions with the SM have been observed [4], to be investigated from both the theoretical and experimental point of view. With the upgrade a complete angular analysis will be achievable and the statistics will also allow

Type	Observable	Current precision	LHCb 2018	Upgrade (50 fb^{-1})	Theory uncertainty
B_s^0 mixing	$2\beta_s(B_s^0 \to J/\psi\phi)$	0.10	0.025	0.008	~0.003
	$2\beta_s(B_s^0 \to J/\psi\, f_0(980))$	0.17	0.045	0.014	~0.01
	a_{sl}^s	6.4×10^{-3}	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguins	$2\beta_s^{\mathrm{eff}}(B_s^0 \to \phi\phi)$	–	0.17	0.03	0.02
	$2\beta_s^{\mathrm{eff}}(B_s^0 \to K^{*0}\overline{K}^{*0})$	–	0.13	0.02	< 0.02
	$2\beta^{\mathrm{eff}}(B^0 \to \phi K_S^0)$	0.17	0.30	0.05	0.02
Right-handed currents	$2\beta_s^{\mathrm{eff}}(B_s^0 \to \phi\gamma)$	–	0.09	0.02	<0.01
	$\tau^{\mathrm{eff}}(B_s^0 \to \phi\gamma)/\tau_{B_s^0}$	–	5 %	1 %	0.2 %
Electroweak penguins	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	0.08	0.025	0.008	0.02
	$s_0 A_{\mathrm{FB}}(B^0 \to K^{*0}\mu^+\mu^-)$	25 %	6 %	2 %	7 %
	$A_{\mathrm{I}}(K\mu^+\mu^-; 1 < q^2 < 6\,\mathrm{GeV}^2/c^4)$	0.25	0.08	0.025	~0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	25 %	8 %	2.5 %	~10 %
Higgs penguins	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	1.5×10^{-9}	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	–	~100 %	~35 %	~5 %
Unitarity triangle angles	$\gamma(B \to D^{(*)}K^{(*)})$	~10–12°	4°	0.9°	negligible
	$\gamma(B_s^0 \to D_s K)$	–	11°	2.0°	negligible
	$\beta(B^0 \to J/\psi K_S^0)$	0.8°	0.6°	0.2°	negligible
Charm CP violation	A_Γ	2.3×10^{-3}	0.40×10^{-3}	0.07×10^{-3}	–
	$\Delta\mathcal{A}_{CP}$	2.1×10^{-3}	0.65×10^{-3}	0.12×10^{-3}	–

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Fig. 1. – List of observables sensitive to NP effects. Current, before and after the upgrade statistical errors and corresponding theoretical uncertainty are shown (adapted from [5]).

to study processes such as $b \to se^+e^-$ and $b \to dl^+l^-$ $(l = \mu,\ e)$. Electroweak penguins are very interesting because they can also probe the lepton universality through precision measurements of observables like $\mathcal{B}(B^+ \to K^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+e^+e^-)$. Deviations from SM have already been observed [6-10]. The increase of statistics will be crucial to confirm them.

Photonic penguins ($b \to s\gamma$ transitions) are interesting because they are sensitive to models that predict new right-handed currents as extension of the SM. The uncertainties with the upgrade statistics will be comparable to theoretical errors.

The precise measurement of the CKM matrix elements and of B_d and B_s mixing parameters will allow to search for new sources of CP violation. The uncertainty on β_s will be comparable to the theoretical one after the upgrade. The uncertainty on γ and β CKM parameters and on the CP violation parameters in the charm sector will be lower of about one order of magnitude with respect to the current detector.

The huge production rate of heavy flavour hadrons, like quarkonium and B_c states, will make it possible to acquire a better knowledge of non-perturbative QCD and of the hadronization processes. The search for new exotic states will be feasible in many b hadron decay channels.

The potential of the upgraded LHCb extends far beyond quark flavour physics. Important studies are also possible in the lepton sector, including the search for lepton-flavour violating $\tau^\pm$ decays and for low mass Majorana neutrinos. Furthermore, with the new flexible trigger system, LHCb will measure the electroweak mixing angle $\sin^2\theta_W$ through the $Z \to \mu^+\mu^-$ decay channel with the best precision ever achieved. Other topics, like production rate and asymmetry of $W^\pm$ and Z bosons, top quark physics and $H \to b\bar{b}$ decays, will be also included to the program of the upgraded LHCb detector.

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