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LHCb upgrade plans

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The LHCb experiment at the LHC is dedicated to the search of physics beyond the Standard Model in the beauty and charm sector. A major upgrade of the detector will take place during Long Shutdown 2. The upgraded LHCb detector will collect physics data at an instantaneous luminosity of $2 \cdot 10^{33}$ cm^{-2} s^{-1}, a factor five higher than the current instantaneous luminosity. A new full software trigger will significantly increase the signal yield, especially for the hadronic final states. The upgrade of several subdetectors is needed in order to cope with the higher occupancy and radiation doses. This upgrade will allow LHCb to reach unprecedented precision in flavour physics.

Flavor Physics and CP Violation,
6-9 June 2016
Caltech, Pasadena CA, USA

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PoS(FPCP2016)041

1. Introduction

The LHCb [1] is one of the four major experiments at the LHC. Its main goal is the search for physics beyond the Standard Model in CP violation and rare decays in the beauty- and charm-quark sector. At the LHC the $b\bar{b}$ quarks are predominantly produced in the same forward or backward direction. This is the reason why the LHCb detector was designed as a single-arm spectrometer with a forward angular coverage in the pseudo-rapidity range of $2 < \eta < 5$. A sketch of the LHCb detector with its subdetectors is shown in Fig.1. The Vertex Locator (VELO) is a silicon vertex detector that surrounds the interaction region where the proton-proton collisions take place. Together with the VELO, the tracking system is based on a silicon strip detector (TT) and a combination of silicon strip detectors and straw drift chambers (T1-T3), located respectively in front and behind a 4 Tm dipole magnet. The particle identification relies on two Ring Imaging Cherenkov (RICH) detectors, one electromagnetic and one hadronic calorimeter and finally on muon stations (M1-M5). During Run 1, the LHCb detector has collected data corresponding to an integrated luminosity of 3 fb^{-1} at a maximum instantaneous luminosity of $4 \cdot 10^{32}$ cm^{-2} s^{-1}. It has produced a wide range of remarkable results for particle physics. Nevertheless most results on key observables sensitive to physics beyond the Standard Model are statistically limited. A detector upgrade is needed to significantly go further in precision. The upgraded LHCb detector is designed to collect at least 50 fb^{-1} at an instantaneous luminosity of $2 \cdot 10^{33}$ cm^{-2} s^{-1} and with a readout rate of 40 MHz. The sensitivity to various flavour observables is summarised in Table 1 [2].

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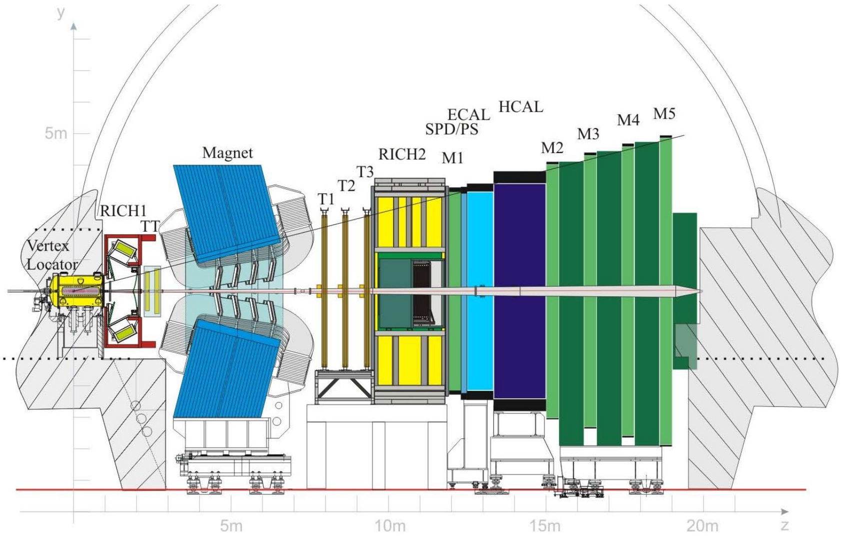

Figure 1: Layout of the LHCb detector.

2. The trigger

The first selection in the current LHCb trigger is provided by a hardware trigger based on informations such as transversal energy and transversal momentum [3]. This hardware trigger has a maximum readout of 1 MHz, which is one of the main limitations of the current detector. As shown in Fig.2, with the current trigger an increase in luminosity corresponds to a saturation in

Table 1: Statistical sensitivities of the LHCb upgrade to key observables. For each observable the sensitivity which will be achieved by LHCb before the upgrade in 2018 is compared to that which will be achieved with 50 fb^{-1} by the upgraded experiment.

Type	Observable	LHCb 2018	**Upgrade** ($50\ \mathrm{fb}^{-1}$)	Theory uncertainty
B_s^0 mixing	$2\beta_s(B_s^0 \to J/\psi\phi)$	0.025	0.008	~0.003
	$2\beta_s(B_s^0 \to J/\psi f_0(980))$	0.045	0.014	~0.01
	a_{sl}^s	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
	$2\beta^{\mathrm{eff}}(B^0 \to \phi K_S^0)$	0.30	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	$S_3(B^0 \to K^{*0}\mu^+\mu^-; 1 < q^2 < 6\ \mathrm{GeV}^2/c^4)$	0.025	0.008	0.02
	$s_0 A_{\mathrm{FB}}(B^0 \to K^{*0}\mu^+\mu^-)$	6 %	2 %	7 %
	$A_{\mathrm{I}}(K\mu^+\mu^-; 1 < q^2 < 6\ \mathrm{GeV}^2/c^4)$	0.08	0.025	~0.02
	$\mathcal{B}(B^+ \to \pi^+\mu^+\mu^-)/\mathcal{B}(B^+ \to K^+\mu^+\mu^-)$	8 %	2.5 %	~10 %
Higgs penguins	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	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	$\gamma(B \to D^{(*)}K^{(*)})$	4°	0.9°	negligible
	$\gamma(B_s^0 \to D_s K)$	11°	2.0°	negligible
	$\beta(B^0 \to J/\psi K_S^0)$	0.6°	0.2°	negligible
Charm *CP* violation	A_Γ	0.40×10^{-3}	0.07×10^{-3}	–
	$\Delta\mathcal{A}_{CP}$	0.65×10^{-3}	0.12×10^{-3}	–

signal yields for hadronic channels. In order to overcome this obstacle anew full software trigger will be used. The upgraded trigger will be able to process the full event information, having access to variables which are more discriminating than the transverse energy, like the impact parameter of tracks originating from a secondary vertex. This requires reading out the whole detector at 40 MHz. As a consequence, the font-end electronics of all the subdetectors must be replaced.

3. The Tracking System

The upgraded VELO [4] will surround the luminous region at LHCb and cover the full angular acceptance of the LHCb detector. It will consist of two retractable halves, each one composed by an array of 26 L-shaped silicon pixel sensors. The two halves are moveable in order to protect the VELO during LHC injection or non-stable beams situations. The detector will be housed in a secondary vacuum, separated by the machine vacuum by an aluminium tank. With respect to the current vertex detector the active region will be moved by 3 mm closer to the beam pipe, at a distance of 5.1 mm from the beam. The VELO will be exposed to an harsh radiation environment: in the innermost region it is expected to have accumulated an integrated flux of up to $8 \cdot 10^{15}\ n_{\mathrm{eq}}/\mathrm{cm}^2$ after 50 fb^{-1}. A cooling system is needed to prevent the silicon from thermal runaway effects due to irradiation and to cope with the ASIC power dissipation. The cooling will be achieved by evaporative CO_2 circulating within microchannels integrated in the L-shaped sensors.

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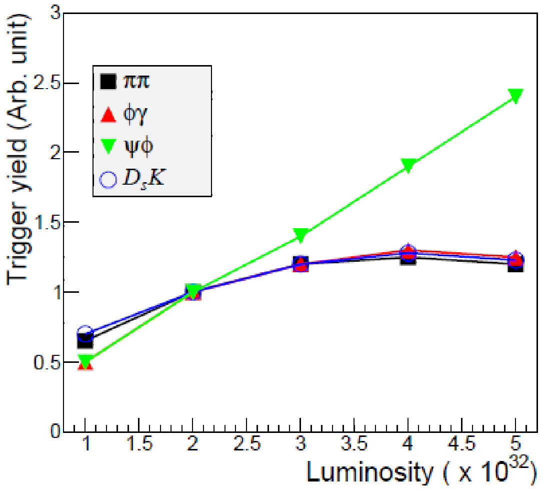

Figure 2: Trigger yield of the current trigger as a function of the luminosity for different decay channels

The Upstream Tracker (UT) is the upgraded version of the TT detector [5]. It will be composed of four planes of silicon strip sensors, as the TT, but with higher segmentation. The two middle planes will be rotated by ±5° in order to perform stereo measurements. The finer granularity is needed in order to reduce the occupancy in the detector at upgrade conditions. Furthermore the UT will be be moved closer to the beam pipe, consequently improving the small-angle acceptance.
The Scintillating Fibre (SciFi) Tracker [5] will substitute the silicon strip detectors and straw drift chambers (T1-T3). It will be composed by three stations located just after the magnet. Each station will consist of 4 detection layers, with the two central layers of each station rotated by a stereo angle of $+5^\circ$ and -5°, respectively. The active element of the SciFi Tracker will be plastic scintillating fibres, with a diameter of 250 μm. The 2.5 m long fibres will be glued together in a six-layer pattern. A mirror will be glued on the fibres extremity close to the beampipe, while on the other end the fibres will be read out by SiPMs. Simulations and several dedicated irradiation campaigns has been performed in order to test the ageing of the fibres due to the harsh irradiation environment (after 50 fb^{-1} the absorbed dose in the fibres is expected to be of 35 kGy in the region close to the beam pipe and of 50 Gy at the SiPMs). As a result, a signal loss of 40% is expected at the end of the SciFi's lifetime.

4. Particle Identification

The overall structure of the two RICH detectors will remain unchanged in the upgrade [6]. Nevertheless the currently used Hybrid Photon Detectors need to be replaced, since the 1 MHz readout electronics is embedded within the tube. It has been chosen to substitute them with Multi-anode Photomultipliers with external readout electronics. Furthermore the optical layout of RICH1 will be modified in order to reduce the hit occupancy. This is achieved by increasing the focal length of the spherical mirrors.
The calorimeters and muon system will only undergo minor changes during the upgrade, since the active elements do not need to be replaced. Since their main purpose in the current detector is in

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the hardware trigger, the Scintillating Pad Detector and the Preshower will be removed, which is expected to ease the calibration of the calorimeter system. The gain of the PMTs in the calorimeters will be reduced by a factor 5 in order to cope with the higher luminosity. In the muon system, because of the high particle flux, only the first of the five muon stations will be removed and an additional shielding will be installed around the beam pipe in front of the second station.

5. Conclusions

The LHCb detector has been collecting data since 2010, producing world-leading results in flavour physics. A major upgrade of the detector will take place during Long Shutdown 2. The upgraded detector will have a full software trigger capable of 40 MHz readout and will collect data with an instantaneous luminosity of $2 \cdot 10^{33}$ cm^{-2}s^{-1}. The increased luminosity and trigger yield will improve the statistical sensitivity on key observables in flavour physics. In addition, other physics in the forward direction at the LHC can be pursued. The LHCb upgrade is now fully approved and in the production phase.

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