The LHCb upgrade

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The LHCb experiment is running at the Large Hadron Collider to study *CP* violation and rare decays in the beauty and charm sectors. The motivation and the strategy of the upgrade envisaged for the long shutdown LS2 (2018) is presented with the expected performance for an integrated luminosity of 50 fb^{-1}.

1 LHCb

Studies of *CP* violation and more generally flavor changing neutral currents were essential in establishing the Standard Model (SM), as the theory describing the *CP* violation observed in the laboratory. Today, they appear as a powerful tool to reveal processes beyond the SM and to understand their nature. In this context, LHCb will play a key role.

The LHCb detector [1], shown in Fig. 1, is a single-arm forward spectrometer covering the forward region of the pp interaction. The detector geometry is driven by the kinematics of the $b\bar{b}$ pair production at the LHC energy where both b and $\bar{b}$ quarks mainly fly in the forward or backward direction.

The interaction point is surrounded by a silicon vertex detector (VELO). It measures precisely the position of primary and secondary vertices as well as impact parameters. The tracking system is composed of a magnet, deflecting particles in the horizontal plane, and two groups of tracking stations: the TT stations before the magnet and the T station after. On both sides of the tracking system, Ring Imaging Cerenkov counters (RICH) are used to identify charged particles. Further downstream, an electromagnetic calorimeter (ECAL) is used for photon detection and electron identification, followed by a hadronic calorimeter (HCAL) and a muon detector (M1- M5). The latter is composed of five stations interleaved with iron shield.

During 2011 both the LHC machine and the LHCb detector performed superbly, allowing LHCb to accumulate 1.1 fb^{-1} of $\sqrt{s} = 7$ TeV pp collisions that is available for physics analysis. The detector was running at an instantaneous luminosity of about 3.5×10^{32} $\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$, constant during the fill duration, and with a number of pp interactions per crossing of ~ 1.4. The values of these running parameters are above the design values by a factor 1.8 and 3.5 respectively.

LHCb is expected to collect 6.5 fb^{-1} in 2018 at different centre of mass energies varying between $\sqrt{s} = 7$ and 13 TeV.

2 Performance in 2018

Among many observables accessible to LHCb, we will only discuss four key measurements selected for their potential to reveal physics beyond the SM:

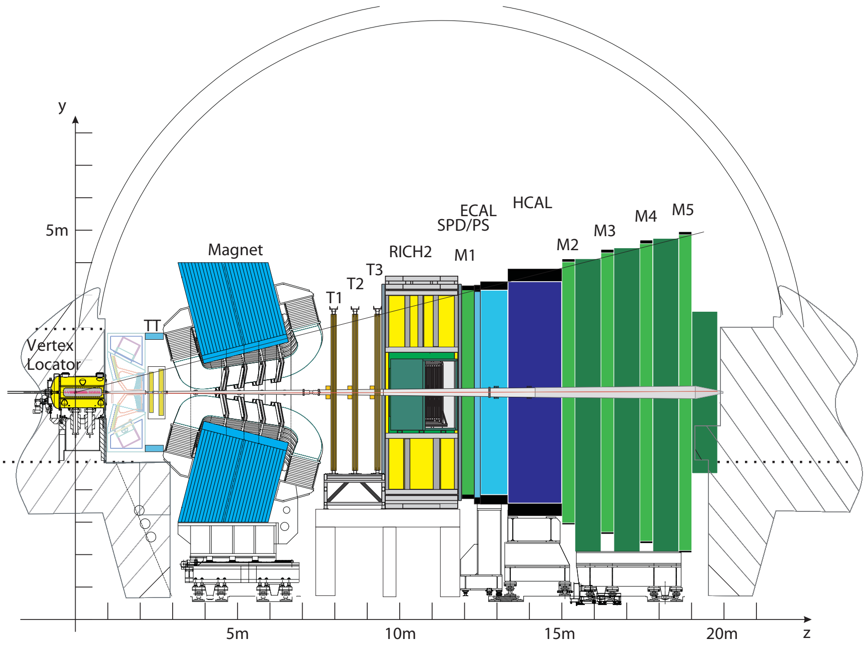

Figure 1: Vertical view of the LHCb detector.

- the branching ratio of the $B_s^0 \to \mu^+\mu^-$ probing new masses and new couplings,
- the weak phase $\phi_s \sim 2 \times \arg|V_{ts}|$ in the $B_s^0 \to J/\psi\,\phi$ decay, which probes new phases,
- the zero-crossing point (s_0) of the forward backward asymmetry $A_{\rm FB}(B^0 \to K^{*0}\mu^+\mu^-)$, which probes the Lorentz structure of the new coupling.
- the weak phase $\gamma \sim \arg|V_{ub}|$ in B^0 and B_s^0 decays to DK mediated by tree amplitudes since it is a reference measurement, not affected by new physics.

Observable	Sensitivity	SM prediction
$\mathrm{Br}(B_s^0 \to \mu^+\mu^-)$	0.5×10^{-9}	$(3.2 \pm 0.2) \times 10^{-9}$ [2]
ϕ_s	0.025 rad	(0.036 ± 0.002) rad [3]
$s_0 A_{\rm FB}(B^0 \to K^{*0}\mu^+\mu^-)$	6% of the SM value	4.36 GeV^2 [4]
γ (tree amplitude)	4 °	$(67.1 \pm 4.3)^\circ$ [3]

Table 1: LHCb Sensitivity in 2018 [5]

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The summary of the expected sensitivity in 2018 is given in Table 2 assuming a detector performance as achieved during 2011 data taking [5].

3 The LHCb detector upgrade

The aim of the LHCb upgrade is to run at $\mathcal{L} = 1 \times 10^{33}$ cm^{-2} s^{-1} with a fully flexible software trigger running at a readout rate of 40 MHz [6]. This increases the annual signal yields by a factor around ten for muonic B decays and twenty or more for heavy-flavour decays to hadronic final states, as compared to those obtained by LHCb in 2011. The upgraded experiment will collect a total sample of 50 fb^{-1}. For reason of flexibility, and to allow for possible evolutions of the trigger, we have decided to design those dectectors that need replacement such that they can substain a lumnosity of $\mathcal{L} = 2 \times 10^{33}$ cm^{-2} s^{-1}.

The challenge of this update is related to the number of pp interactions per crossing. The average number of interactions per crossing is about 2.3 at $\mathcal{L} = 1 \times 10^{33}$ cm^{-2} s^{-1} and reaches more than 4 interactions per crossing at 2×10^{33} cm^{-2} s^{-1}. In the latter case, all crossings have at least one interaction. These extreme conditions put heavy requirements on the tracking as well as on the trigger algorithms.

3.1 New trigger strategy

The current LHCb trigger contains two stages, the Level-0 (L0) and the High Level Trigger (HLT). The L0 reduces the rate from 40 MHz down to 1 MHz. It is based on custom electronics receiving dedicated information from the calorimeters and from the muon detector. It looks for lepton and hadron candidates with a high transverse momentum.

The HLT trigger reduces the rate down to a few kHz. The HLT is a software trigger running on a dedicated CPU farm and receiving the full detector information at 1 MHz. By running tracking and vertexing algorithms it selects leptons and hadrons with a high transverse momentum as well as a high impact parameters. More elaborate algorithms, close to the off-line selections, are then applied to select inclusive or exclusive heavy-quark decays.

The L0 saturates for hadronic channels when the luminosity increases [6]. At high luminosity we cannot rely only on the transverse momentum cut for efficient triggering. A software based trigger, however, allows use of many discriminants including track impact parameters and combinations of different criteria.

The more flexible way to trigger at high luminosity is to readout the whole detector at 40 MHz instead of 1 MHz and to select interesting events in the HLT.

3.2 Upgrading the tracking system

The VELO is a silicon strip detector with r and ϕ geometry. It will be replaced by either a pixel or a strip detector. The pixel version provides a very low occupancy for each channel, reducing the combinatorial for the tracking algorithm. The base line is a modified version of the TimePix readout chip [7] with a pixel size of 55×55 μm^2.

The TT station is a silicon-strip detector. It will be replaced by the same technology with an enlarge acceptance and an improved granularity.

The T stations are composed of an OT with straw tube detectors and an IT with silicon-strip detectors to cover the high occupancy area near the beam pipe. To account for the higher occupancy due to the increase in luminosity, we are investigating two options, a large area silicon-strip IT completed by OT straw tubes, or a Central Tracker made from scintillating fibres read by silicon photomultipliers.

3.3 Upgrading the particles identification

The RICH photon detector is an HPD with the readout frequency limited to 1 MHz. The replacement candidate is a multi-anode photomultiplier which can be readout at 40 MHz. The front-end electronics of the calorimeters will be replaced while the muon systems will almost remain unchanged.

4 Expected performance

The estimated sensitivities are given in Table 4 for an integrated luminosity of 50 fb^{-1}, taking into account all necessary trigger improvements [5].

Observable	Sensitivity	Theory uncertainty
$\text{Br}(B_s^0 \to \mu^+\mu^-)$	0.15×10^{-9}	0.3×10^{-9}
ϕ_s	0.008 rad	~ 0.003
$s_0 A_{\text{FB}}(B^0 \to K^{*0}\mu^+\mu^-)$	2% of the SM value	7%
γ (tree amplitude)	0.9 °	negligible

Table 2: LHCb Sensitivity with an upgraded detector and $\int \mathcal{L} = 50\ \text{fb}^{-1}$ [5].

Many more observables will be accessible with high statistics, like the measurement of ϕ_s in the B_s^0 decay to $\phi\phi$, the measurement of γ in decays mediated by loop amplitudes, or the fraction of longitudinal K^{*0} polarization, F_{L} in $B^0 \to K^{*0}\mu^+\mu^-$.

It must be emphasised that the upgraded experiment will have exciting opportunities to perform studies in the lepton flavour physics, electroweak physics, exotic search and QCD sectors.

5 Conclusions

The performance of the current detector and the purity of the samples already accumulated gives confidence that measurements of very hight sensitivity can be achieved with the upgraded LHCb detector. A challenging upgrade is under preparation, aiming at an integrated luminosity of 50 fb^{-1}. The detector TDRs will be published in 2013.

References

[1] LHCb Collaboration, A. A. Alves *et al.*, JINST 3 (2008) S08005.

[2] A. J. Buras *et al.*, JHEP 1010 (2010) 009.

[3] J. Charles *et al.*, Eur. Phys. J C41 (2005) 1. Updated results and plots available at http://ckmfitter.in2p3.fr.

[4] M. Beneje *et al.*, Eur. Phys. J. C41 (2005) 173.

[5] LHCb Collaboration, I. Bediaga *et al.*, Framework TDR for the LHCb upgrade, CERN-LHCC-2012-007

[6] LHCb Collaboration, R. Aaij *et al.*, Letter of Intend for the LHCb Upgrade, CERN-LHCC-2011-001

[7] Medipix web site (http://medipix.web.cern.ch/MEDIPIX/).