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# The LHCb Upgrade

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Future flavour physics experiments will be required in the second half of the next decade to either elucidate the flavour structure of new particles discovered at the LHC or to probe new physics at the multi-TeV scale. The planned upgrade of the LHCb detector involves at least five years of operating at ten times the current design luminosity, i.e. at about $2\times10^{33}\text{cm}^{-2}\text{s}^{-1}$. The aim is to collect a data sample of $\sim$100 $\text{fb}^{-1}$ as well as to increase the trigger efficiency for hadronic decays by at least factor of two. The present paper descibes briefly the physics motivation for an LHCb upgrade and the required technologies for the detector working at high luminosity.

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## 1. Introduction

LHCb is a dedicated heavy-flavour physics experiment designed to perform precise measurements of CP violation as well as rare decays of $B$ hadrons at the Large Hadron Collider (LHC) [1]. After starting data taking in 2009, LHCb is planned to operate for five years at a luminosity of $2\times10^{32}$cm$^{-2}$s$^{-1}$, accumulating a data sample of $\sim$10 fb$^{-1}$. At 14 TeV, with the 500 $\mu$b $b\bar{b}$ production cross-section, which scales approximately linearly with energy, LHCb will be able to collect much larger $B$ meson data samples as compared to previously available. The LHCb physics programme initially will address such issues as CP violation in $B_s$ decays, measuring the rare decay rates (e.g. $B_s \rightarrow \mu^+\mu^-$), and making a precise measurement of the CP violating angle $\gamma$. However, 10 fb$^{-1}$ will not be enough data to finally settle these issues.

The LHCb upgrade [2] is being designed to be able to run at luminosity $\sim2\times10^{33}$cm$^{-2}$s$^{-1}$, and improve the hadron trigger [3] efficiency by a factor of two as well as to collect an integrated luminosity of about 100 fb$^{-1}$. Consequently, with higher luminosity, the collision rate with at least one interaction will increase to $\sim$30 MHz, and the average number of visible interactions per beam crossing to $\sim$5. This requires new front-end electronics to read out all detectors at 40 MHz. Then, it becomes possible to use all elements of the detector in the trigger, which becomes entirely based on software. The LHCb detector working at high luminosity requires also more radiation hard solutions, especially for the vertex detector.

While it is expected that new particles will be found directly in ATLAS or CMS, the kind of New Physics (NP) represented by these discoveries will likely be very difficult to discern. How these new particles participate in quantum loop processes, therefore will give essential information on their nature. Hence the desire is to study rare and CP violating decays of $b$ and $c$ quarks with excellent precison.

NP can be probed for by studying Flavour Changing Neutral Current (FCNC) in hadronic $b \rightarrow s$ transitions, improving the precision on sin($2\beta^{eff}$) to 0.04 [4]. One approach is to compare the time-dependent CP asymmetry in a hadronic penguin loop decay (e.g. $B_d \rightarrow \phi K_s^0$) with a decay based on a tree diagram (e.g. $B_d \rightarrow J/\psi K_s^0$) when both decays have the same weak phase. This approach can also be applied to $B_s$ mesons which will be exploited by LHCb. The CP violating phase $2\beta_s$ uses $B_s \rightarrow J/\psi\phi$ or $B_s \rightarrow J/\psi f_0$ to see the effect of NP. It is possible to measure significantly larger value with respect to the Standard Model (SM) expectation. With a 10 fb$^{-1}$ data sample the weak phase $2\beta_s$ will be determined with a precision of 0.01, which is still statistically limited [5]. An upgrade of LHCb has the potential to improve the precision of $2\beta_s$ by a factor three [6]. In the $B_s \rightarrow \phi\phi$ system the precision of $\beta_s^{eff}$ is expected to be $\sim$0.05 with a 10 fb$^{-1}$ data sample, while five years of running with upgraded LHCb may improve this precision to $\sim$0.015 [7]. It will be also possible to find NP in $B_d \rightarrow K^*\mu^+\mu^-$, $B_s \rightarrow \phi\mu^+\mu^-$ etc., and to search for evidence of very rare decays like $B_d \rightarrow \mu^+\mu^-$ or $\tau \rightarrow \mu\mu\mu$.

Detail information about expected sensitivities for LHCb upgrade is included in [2].

## 2. LHCb trigger upgrade

The current trigger scheme has three basic levels, Level-0 (L0) that is hardware based on either muons or calorimeter energy; High Level Trigger 1 (HLT1) that is based on software and

HLT2. Since LHCb upgrade is designed to be able to run at luminosity $\sim 2 \times 10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, all detector elements should be read out at the 40 MHz collision rate. This means that L0 trigger has to be removed, and then it will be possible to use all elements of the detector in the trigger, which becomes entirely based on software. The main goal is to increase the hadron trigger efficiency by at least factor of two, keeping the minimum bias rate at the acceptable level [8]. The proposal for trigger upgrade is to use the cuts on track impact parameter and on its transverse momentum at the same time as well as to improve detector granularity to deal with CPU time required for LHCb upgrade.

## 3. LHCb detector upgrade

As has been already mentioned the entire front-end electronics and the DAQ system must be replaced and all event selection is done in software in a large CPU farm.

Vertex Locator (VELO) needs first of all more radiation hard solutions and improved pattern recognition. Pixel system seems to be the best solution for upgraded vertex detector, since, as compared to the strip one, it has better resistance to radiation, noise immunity, better ghost reduction as well as lower occupancy. There are several pixel-based solutions under study, based on square pixel cells with ASIC from TIMEPIX / MEDIPIX. The configurations with smaller station size are also tested to omit possible problem with the cooling system.

In the tracking system with higher luminosity expected for LHCb upgrade the main limitation seems to be the larger occupancy and higher ghost rate as compared to the nominal luminosity. This concerns mostly Outer Tracker (OT), where the gas technique is used. Furthermore, new front-end electronics chip for 40 MHz readout is required for Inner Tracker (IT). There are two main possible options: (i) fiber tracker with different fiber dimensions for inner and outer parts - this option may solve the problem with services (e.g. cables, cooling, material budget etc.) and improve spatial resolution as well as time performance; (ii) the use of new silicon strips. In both cases the idea is to remove the inner section of OT and increase IT in order to reduce occupancy and improve resolution.

In the case of particle identification the idea is to maintain present RICH1 and RICH2 detectors but change photo sensors. This requires new chip readout to decouple it from the sensor (now the front-end electronics is bump-bonded). Another possibility is to replace the aerogel in RICH1 with the so-called TORCH, being a combination of Time Of flight and RiCH. It is designed to be a stand-alone quartz plain at the M1 muon station position. TORCH allows to measure the time and position of Cherenkov $\gamma$'s, but it requires more R&D work on mechanics, ageing and focusing system.

The front-end electronics in the calorimeter system is already at 40 MHz, but some noise reduction as well as improvement in the preamplifier sensitivity is required. Furthermore, the reduction of the photomultiplier gain is needed. The major limitation seems to be the radiation dose in the inner regions, so the more radiation hard technology is required.

The front-end electronics in the muon system is also at 40 MHz. M1 station will be probably removed due to the background and removal of L0 trigger, and then momentum of muon candidates will be determined by tracking stations. To solve the possible problem of the ageing caused by radiation in the inner regions, the replacement of inner section with large area Gas Electron

Multiplier (GEM) or with Multi Wire Proportional Chamber (MWPC) is taken into account. Another important issue is a dead time caused by high rate in the inner regions, but in order to evaluate these effects one have to wait for the first data.

## 4. Conclusions

The upgrade of the LHCb detector, foreseen for 2015/2016, is designed to be operating at 10 times the design luminosity. It is assumed to be a broader scope of NP exploration, with at least twice higher hadron trigger efficiency and all sub-detectors readout at 40 MHz. Since it is expected to collect a data sample of $\sim$100 fb$^{-1}$ after five years of data taking, it will be able to explore more precisely the flavour sector of particle physics. The main limitations for higher luminosity have been identified as well as first trigger and detector simulations have been started.

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