The LHCb Upgrade – Status and Plans

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1 Introduction

The primary goal of the LHCb experiment at the LHC is to search for new physics beyond the Standard Model. LHCb has been taking data with high efficiency over the last three years, producing a wide range of exciting physics results. Some of these are summarized in Ref. [1].

With the Letter of Intent (LoI) for the LHCb upgrade [2], submitted in March 2011, the collaboration declared its interest in upgrading the detector to 40 MHz readout with a highly flexible software-based trigger. This will allow the data rate to be increased substantially, as well as the trigger efficiency, leading to significant improvements in annual signal yields compared to those obtained in 2011. The increase corresponds to a factor of around ten for muonic B decays and twenty or more for heavy-flavour decays to hadronic final states. In addition, the experiment will be capable of triggering on other interesting signatures, such as long-lived particles, and thus act as a general purpose detector in the forward region.

The detailed physics case for the upgrade has been endorsed by the LHCC and is presented in Ref. [3]. Moreover, a Framework Technical Design Report (TDR) [4] has been submitted in May 2012 to the LHCC, giving an overview of the schedule, cost and participating institutes. This document has been endorsed by the LHCC in its September 2012 session.

The LHCb sub-systems are currently in a period of R&D for the upgrade. In the present document, the status of the various options concerning the technologies are reviewed and updated. As an annex to this document, a proposal for the "Memorandum of Understanding for the Common Projects of the LHCb Upgrade" is presented, to submit to the LHCb Funding Agencies the scheme of funding agreed by the Collaboration for the activities which are common to the whole experiment. Following the completion of the R&D phase, the remaining choices of baseline technology will be made in time for the sub-system TDRs, scheduled for the second half of 2013. Future subsystem MoUs will be submitted, once the corresponding TDR will have completed their approval process. The overall timescale sees installation of the upgraded experiment in the second long shutdown (LS2) of the LHC in 2018, to be ready for data taking in 2019.

2 Physics Motivation

Studies of flavour physics observables have provided critical input in the construction of the Standard Model (SM). Flavour measurements provided the first indications of the existence and nature of the charm quark, the third generation, and the high mass scale of the top quark. In searching for physics beyond the Standard Model it is also evident that flavour observables will play a central role.

Flavour physics measurements already exert significant weight in limiting the parameter space of new physics beyond the SM. Some of the strongest constraints on supersymmetric Higgs bosons come not from direct searches, but from limits on, and measurements of, the rates of suppressed heavy flavour decays such as $B_s^0 \to \mu^+\mu^-$, $b \to s\gamma$ and $B^- \to \tau^-\overline{\nu}_\tau$ [3]. These observables continue to have great importance in the era of the LHC.

A particular attraction of performing flavour physics at the LHC is the opportunity to make measurements of CP-violating asymmetries with much higher precision than has been possible hitherto. These asymmetries are a priori very sensitive to the contribution from new physics effects. It is therefore surprising that the measurements of CP violation performed with B^0 and $B^\pm$ mesons at BaBar and Belle are broadly consistent with the CKM mechanism of the SM. If new particles exist at the TeV mass scale, as is expected, then this is already an indication that the flavour couplings of the new physics have a very particular structure, so as not to have given rise to effects inconsistent with the SM expectations. More precise measurements are needed to test whether the CKM description remains successful at better than the 10% level. Even more exciting is the extension of this programme to the B_s^0 sector, about which very little was known before the recent LHCb results, and where more visible effects may be apparent.

The LHCb physics programme will be executed in two phases. The aims of the first phase of the experiment can be achieved with about 7 fb^{-1} of data, using the current detector, and will be completed in 2017 according to the present LHC schedule. With this dataset, the precision of many key observables in B and D physics will be extended significantly beyond what was possible at the B factories, and the first detailed exploration of the B_s^0 system will be completed.

To exploit fully the flavour-physics potential of the LHC will then require an upgrade to the detector, which will allow the experiment to operate at higher luminosity and will equip the detector with a highly flexible software trigger. This latter attribute will be invaluable for improving the selection efficiency for hadronic final states in B and D decays. The upgraded detector will be able to collect 50 fb^{-1} of data.

A selection of the physics topics that will be addressed by the LHCb upgrade, and the corresponding sensitivities, are given in Table. 1, which has been taken from Ref. [3]. The measurements considered include CP-violating observables, rare decays and fundamental parameters of the CKM Unitarity Triangle. The current precision, either from LHCb measurements or the averaging groups HFAG, CKMfitter and UTfit is given and compared to the estimated sensitivity with the upgrade. As an intermediate step, the estimated precision that can be achieved prior to the upgrade is also given for each observable. For this, a total integrated luminosity of 1.0 (1.5, 4.0) fb^{-1} at pp centre-of-mass collision energy $\sqrt{s} = 7$ $(8, 13)$ TeV recorded in 2011 (2012[1], 2015–17) is assumed. The extrapolations assume the central values of the current measurements, or the Standard Model where no measurement is available. While the sensitivities

[1] These estimates were made before the extension to the 2012 LHC pp-run was announced; we now expect 2.2 fb^{-1} to be recorded in 2012, but this does not affect the conclusions significantly.

Table 1: Statistical sensitivities of the LHCb upgrade to key observables. For each observable the current sensitivity is compared to that which will be achieved by LHCb before the upgrade, and that which will be achieved with $50\,\mathrm{fb}^{-1}$ by the upgraded experiment. Systematic uncertainties are expected to be non-negligible for the most precisely measured quantities [3].

Type	Observable	Current precision	LHCb 2018	**Upgrade** ($50\,\mathrm{fb}^{-1}$)	Theory uncertainty
B_s^0 mixing	$2\beta_s$ ($B_s^0 \to J/\psi\,\phi$)	0.10	0.025	0.008	~ 0.003
	$2\beta_s$ ($B_s^0 \to J/\psi\, f_0$)	0.17	0.045	0.014	~ 0.01
	$A_{\mathrm{fs}}(B_s^0)$	6.4×10^{-3}	0.6×10^{-3}	0.2×10^{-3}	0.03×10^{-3}
Gluonic penguin	$2\beta_s^{\mathrm{eff}}(B_s^0 \to \phi\phi)$	–	0.17	0.03	0.02
	$2\beta_s^{\mathrm{eff}}(B_s^0 \to K^{*0}\bar{K}^{*0})$	–	0.13	0.02	< 0.02
	$2\beta^{\mathrm{eff}}(B^0 \to \phi K_S^0)$		0.30	0.05	0.02
R-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 %
EW penguin	$S_3(B^0 \to K^{*0}\mu^+\mu^-)$ $(1 < q^2 < 6\mathrm{GeV}^2/c^4)$	0.08	0.025	0.008	0.02
	$s_0(B^0 \to K^{*0}\mu^+\mu^-)$	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 %	$\sim 10\,\%$
Higgs penguin	$\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	1.5×10^{-9}	0.5×10^{-9}	0.15×10^{-9}	0.3×10^{-9}
	$\mathcal{B}(B^0 \to \mu^+\mu^-)/\mathcal{B}(B_s^0 \to \mu^+\mu^-)$	–	$\sim 100\,\%$	$\sim 35\,\%$	$\sim 5\,\%$
Unitarity triangle angles	γ ($B \to D^{(*)}K^{(*)}$)	~ 10–12°	4°	0.9°	negligible
	γ ($B_s^0 \to D_sK$)	–	11°	2.0°	negligible
	β ($B^0 \to J/\psi\, K_S^0$)	0.8°	0.6°	0.2°	negligible
Charm CPV	A_Γ	2.3×10^{-3}	0.40×10^{-3}	0.07×10^{-3}	–
	ΔA_{CP}	2.1×10^{-3}	0.65×10^{-3}	0.12×10^{-3}	–

given include statistical uncertainties only, preliminary studies of systematic effects suggest that these will not affect the conclusions significantly, except in the most precise measurements, such as those of $A_{\mathrm{fs}}(B_s^0)$, A_Γ and ΔA_{CP}. Further details can be found in Ref. [3].

The potential of LHCb extends well beyond quark flavour physics. Important studies are also possible in the lepton sector, including the search for lepton-flavour violating tau decays and for low mass Majorana neutrinos. Furthermore, the forward geometry, precise vertexing and particle identification capabilities of the detector give LHCb unique and exciting possibilities in areas as diverse as electroweak physics, the search for long-lived new particles, and QCD [2]. In all cases great benefit will come both from the increased sample sizes that will be made available with the upgrade, and the flexible software trigger.

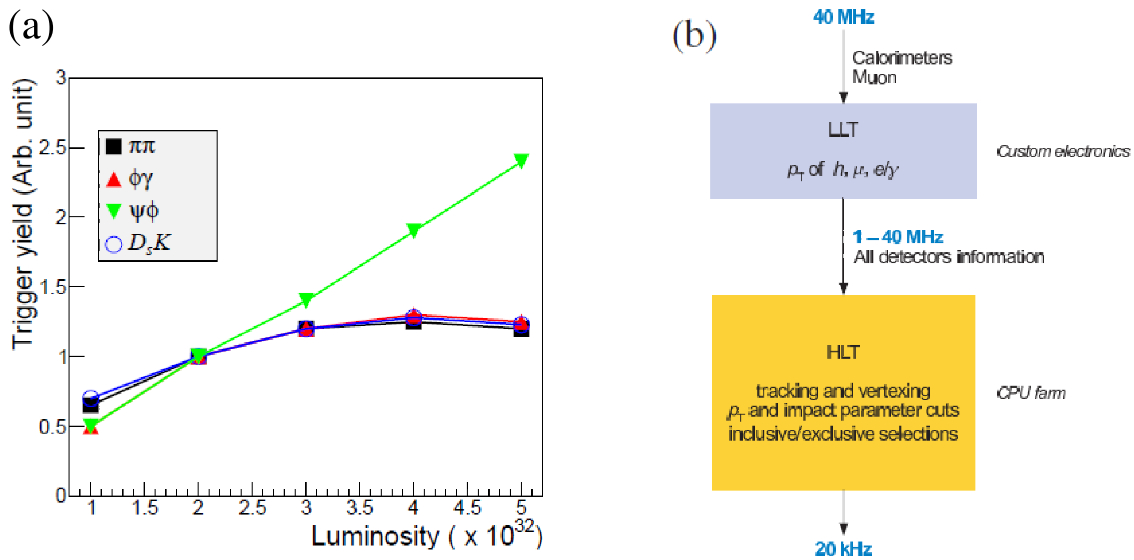


Figure 1: (a) The trigger yield for different decays of B mesons; each point is normalized to the trigger yield expected at a luminosity of 2×10^{32} cm^{-2}s^{-1}. The hadronic yields saturate, while the muon triggers continue to gain with increased luminosity. (b) Overview of the upgraded trigger.

3 Trigger Upgrade

The present first level trigger (L0) is implemented in hardware [5]. Trigger selections are made at the 40 MHz beam crossing rate using either the calorimeters or the Muon system. Criteria are based on the deposit of several GeV of transverse energy, E_{T}, by charged hadrons, muons, electrons or photons. While this provides high efficiencies on dimuon events, it typically removes half of the fully hadronic signal decays. In these hadronic decays the E_{T} threshold required to reduce the rate of triggered events to an acceptable level is already a significant fraction of the B meson mass. Any further increase in the rate requires an increase of this threshold, which then removes a substantial fraction of signal decays. As a consequnece the trigger yield saturates for hadronic channels with increasing luminosity, as shown in Fig. 1 (a). Therefore, assuming that LHCb would be able to run at $L = 10^{33}$ cm^{-2}s^{-1}, the decrease in L0-hadron efficiency would result in an almost constant signal yield for $L > 4 \times 10^{32}$ cm^{-2}s^{-1}. Unless the efficiency can be improved by removing the L0 1 MHz limitation and introducing information that is more discriminating than E_{T} earlier in the trigger, the experiment cannot profit from increasing the luminosity.

The most effective way of achieving such a trigger upgrade is to supply the full event information, including whether tracks originate from the displaced vertex that is characteristic of heavy flavour decays, at each level of the trigger. This requires reading out the whole detector at 40 MHz and then analysing each event in a trigger system implemented in software. A detector upgraded in this way will allow the yield of hadronic B decays to be substantially increased for the same LHC machine run-time. The trigger architecture proposed for the upgrade is shown in Fig. 1 (b), where the L0 trigger has been replaced by a Low-Level Trigger (LLT). The key change from L0 is that the LLT has a tunable output rate between 1 and 40 MHz, allowing the trigger bandwidth to be adapted to the available CPU power in the HLT farm.

4 Detector modifications

Since submission of the Letter of Intent there has been some evolution of requirements to the upgraded detector and of the main technical options, presented in the Framework TDR [4]. In the LoI we considered operating the upgraded detector at a luminosity of 1×10^{33} cm^{-2}s^{-1}. For reasons of flexibility, and to allow for possible evolutions of the trigger, we have decided to design those detectors that need replacement for the 40 MHz upgrade such that they can sustain a luminosity of 2×10^{33} cm^{-2}s^{-1}. For the other detector components, including the RICH system, calorimeters and Muon system, we are evaluating the effect of such a luminosity increase. In the following we describe the main evolution in R&D of the different technologies that are under consideration for the tracking system, for the particle identification detectors, and for data processing.

4.1 Tracking system

4.1.1 Vertex Locator

The VELO detector is particularly demanding as it is very near to the beam and its material budget should be as light as possible to optimize vertexing and tracking performance. Two alternative technology options are being pursued for the VELO, strip and pixel sensors. Work is ongoing to define a more compact detector geometry for both the pixel and strip sensor options in order to improve the impact parameter resolution. Discussions with the LHC experts have started in order to understand the consequences of a reduced machine aperture at the VELO. The detector R&D has been focusing mainly on three key topics in the past months: the Radio-Frequency (RF) shielding box, cooling strategy and Front-End (FE) ASIC developments.

A new method of RF box production has been investigated. The box is produced out of a block with a precision five-axis CNC milling machine. The first round of prototyping has proven to be very successful, with a double demonstrator box with thickness close to target. A definition of the minimum inner radius for the VELO RF box is being worked on and will be finalized before the end of the year.

The cooling challenge is common to the two sensor solutions that are being considered. Several prototype microchannel substrates have been produced and tested with high pressure CO_2 coolant. The next step is to produce a full-silicon substrate of suitable thickness and prove that it can be used for the upgrade.

The pixel solution has been progressing well with a series of test beam and lab measurements on the new radiation hard Medipix3-RX chip, the fully debugged 130 nm precursor to the Timepix3. Prototype sensors including edgeless designs from three vendors have been evaluated and bump bonding tests are progressing. In parallel, prototype strip sensors from one firm have been received and are being tested in the laboratory.

Finally, a specification for a common silicon strip FE-ASIC has been defined. This chip specification takes into account the requirements from the VELO strip option, the Trigger Tracker and the Inner Tracker option. A first design including an ADC and PLL block has been submitted and produced. Simulation and design of the FE part has just been started.

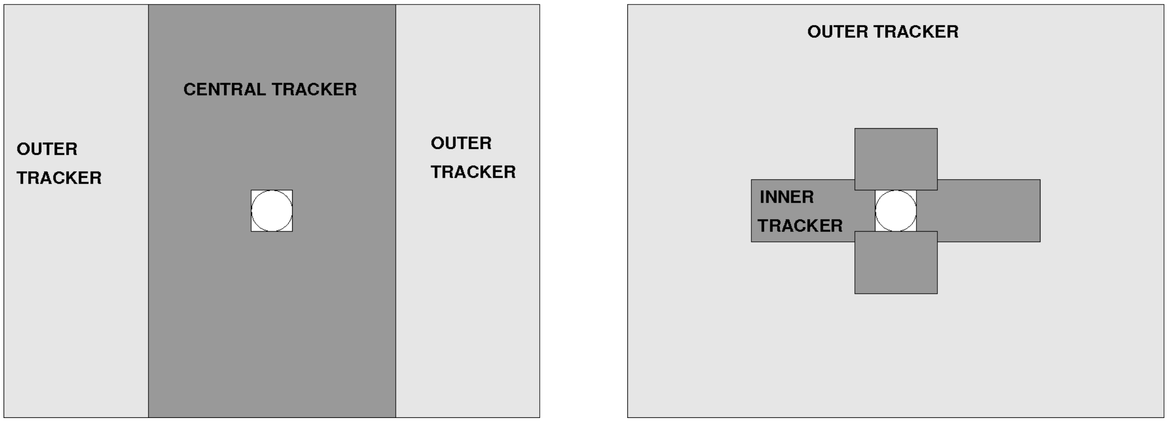


Figure 2: Schematic layouts of the two options being studied for the upgrade of the LHCb tracking stations (not to scale). Left: OT straw tubes (light grey area) with scintillating-fibre CT (dark grey area). Right: OT straw tubes (light grey area) with IT made of microstrip silicon sensors (dark grey area). The central hole is for the beam pipe.

4.1.2 Trigger Tracker

The key elements of the TT R&D are: geometry optimization in the innermost portion of the detector plane, mechanical and thermal studies to design the lowest mass system delivering the desired performance, and implementation of low mass power distribution and data transmission to the detector periphery.

A simulation effort has been undertaken to optimize the geometry and to understand the advantages of an increased acceptance at high pseudorapidity, as well as the impact of different segmentation options in the detector. The final configuration will be decided in consultation with LHC experimental beam pipe experts.

Sensors are currently being designed that would achieve optimum coverage with non standard detector edges. Silicon sensor prototypes with segmentation close to the desired value and with non-standard edges are about to be purchased. In parallel, elements to compose a first readout slice are being acquired and an electronics test stand based on a prototype TELL40 is being developed which will be used to optimize data processing algorithms.

The key aspect of the detector to be optimized is the overall mechanical design in order to achieve efficient cooling and mechanical stability, while minimizing the overall material budget. A test stand has been built to check mechanical and thermal properties of different substrate materials. In the next six months, a mock-up of a section of a sensing plane will be constructed, including substrate, thin film hybrids and mechanical silicon wafers.

4.1.3 Tracker Stations

For the Tracker two technology options are being pursued, one with an enlarged silicon microstrip Inner Tracker (IT) and shortened Outer Tracker (OT) straw tube modules around it, another with a scintillating fibre Central Tracker (CT) covering the high track density area from the beam plane all the way to the upper and lower edges of the acceptance, with the remaining acceptance covered by the existing straw-tube modules. The two options are illustrated in Fig. 2.

The design of the shortened straw tube modules coupled to the silicon option is ready for prototyping. Both options need the straw tubes modules to be equipped with new front-end electronics and significant progress has been made in the design of a new TDC based on a rad-hard FPGA and the corresponding service board. Prototypes have been produced and successfully tested, and a serializer/transmitter board is now designed.

For the silicon option, the main challenges lie in the development of 3-sensor long (30 cm) low-mass modules and a forced gas flow cooling solution. Prototype modules with low-mass flex cables of different lengths have been produced and will be tested in the next 6 months. A mock-up system is being constructed for thermal tests.

For the fibre option much effort has been invested in developing a 2.5 m long module and in the studies of radiation effects on both fibres and silicon photomultipliers (SiPM). A first 2.5 m prototype was semi-automatically fabricated with excellent fibre alignment. Several other modules (22 and 86 cm long) have been exposed to radiation and are being characterized. Studies on irradiated SiPMs have demonstrated that dark currents will have to be suppressed by various means (shielding and cooling). More tests are ongoing to narrow down the range of parameters for the required performance. In the next six months the viability of the fibre option (mainly with respect to radiation resistance) will be assessed.

4.2 Particle identification

4.2.1 RICH system

It is currently planned to reuse the vessels of RICH-1 and RICH-2. Since the front-end electronics is encapsulated within the current photon detectors (HPDs) they will need to be replaced by multi-anode photomultipliers (MaPMTs) with external 40 MHz readout electronics. The photon-detector mounting frames to house the MaPMTs and their local magnetic shielding will be re-designed and replaced. Owing to the higher occupancies in the upgrade environment, the RICH aerogel radiator will be removed.

The baseline MaPMT photon detector is currently under test. The MaPMT readout must conform to the upgraded 40 MHz LHCb electronics architecture. The FE-chip will be an ASIC which provides the shaping and amplification as well as discrimination and digitisation of the MaPMT signals. A prototype FE electronics 4-channel readout chip, now named the CLARO-CMOS, has been fabricated, initially in 0.35 μm-CMOS technology. As a parallel activity, we are evaluating the Maroc-3 readout chip. Simulations will be made to investigate whether the Maroc-3 shaping time is compliant with the expected maximum occupancy and whether spillover/dead-time effects are tolerable. The decision on which final readout chip to use will be taken after test-beam operation and radiation testing, and is a major milestone scheduled for June 2013.

With the absence of the RICH-1 aerogel radiator, in principle the photodetector plane of RICH-1 can be significantly reduced in area from the existing detector, resulting in an overall cost saving. Whilst the default option is to retain the current RICH-1 geometry, studies to verify that occupancies are tolerable in the innermost regions are still on-going. It has already been confirmed through simulation that occupancies in the inner regions are very high (well above 10%) and therefore a modification of the RICH-1 optics is also considered. In this arrangement, replacement of the carbon-fibre mirrors would spread the C_4F_{10} rings over a greater number of

MaPMTs. The current schedule, independent of RICH-1 optical modification, plans the RICH Technical Design Report in November 2013.

In the LoI we proposed that the RICH system would also be augmented by the TORCH, a novel detector based on time-of-flight to identify low momentum particles below ~ 10 GeV/c. The R&D funding for this detector has been the subject of a successful 4-year EU grant award which started in June 2012. Assuming an effectual R&D period, a TDR addendum will be submitted to the LHCC, proposing the TORCH detector to be part of a staged programme for later installation in the LHCb detector.

4.2.2 Calorimeter system

The main challenge of the calorimeter upgrade is to replace the current front-end electronics by a new system able to send data to the DAQ at 40 MHz. Moreover, the new electronics must have a gain five times higher than the present system, in order to compensate for a gain reduction that will be imposed on the photomultipliers so that the mean anode current remains at an acceptable level during high-luminosity running. This requirement has implications for the maximal acceptable noise level for the analogue components. Two analogue implementations based either on the ICECAL ASIC or on discrete components are already at an advanced stage of design. The digital front-end is being developed in parallel and is based on the ACTEL A3PE flash-based FPGA and on the GBT ASIC from CERN. The choice of which analogue solution to adopt will be made by mid-2013, following beam and radiation tests. Then, a new prototype merging both the analogue and the digital parts on a single board will be designed. A final prototype will follow, with the full target number of 32 channels per board.

The Scintillating Pad Detector (SPD) and the Preshower (PRS) of the current detector will most probably be removed for the upgrade. Although the removal of this system is expected to lead to some loss in particle identification performance at low p_{T}, partial compensation will come from an improved energy resolution in the ECAL itself, on account of the reduction in material before the detector. The role that the SPD/PRS system plays in the current L0 trigger is not considered essential for the Low Level Trigger of the upgrade. A final benefit of the removal is that the calorimeter calibration will be more straightforward without the SPD/PRS in place. Simulation studies are ongoing to confirm this decision.

4.2.3 Muon system

In the LHCb upgrade, station M1 of the muon system will be removed and the critical question then concerns the rates in stations M2-M5. The current system was designed in order to stand incident particle rates up to 1 MHz per front-end channel without any loss of efficiency due to space charge effects and without any degradation of the time resolution. The rates expected from simulation at $1 \times 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ and $\sqrt{s} = 14$ TeV are all below this value [2]. It is therefore concluded that at nominal upgrade luminosity the rates in the muon system will be tolerable, and so only minimal modifications will be necessary, in order for the readout to comply with the new DAQ and trigger scheme. These modifications remain essentially unchanged from those described in the LoI.

In the case of operating LHCb at the higher luminosity of $2 \times 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$, new solutions will be required in order to deal with, in particular, the problems that will arise from detector rate limitations and electronics dead-time in the inner regions of the M2 and M3 stations. One possibility would be to go from a combined wire/cathode readout with FE-channels reading out a surface area of about 15 cm^2, to a simple cathode readout with pads of a smaller size, thus minimizing the rate effects. Simulation studies are planned to optimize the required granularity. Investigations of candidate technologies to implement this solution are proceeding in parallel. The possibility to design and develop new faster front-end electronics is also under investigation. This solution, by reducing the dead time, would allow more flexibility in the optimisation of the detector granularity. Finally, the increased rate could be suppressed by installing additional shielding downstream of the hadron calorimeter in front of the M2 inner region. All of these approaches are under consideration.

4.3 Data processing

The task of the data processing concerns the transport of the data from the output of the FE electronics up to their reconstruction. It encompasses data acquisition, trigger and computing.

4.3.1 Data acquisition and trigger

The readout board is one of the key components of the data processing. The so-called TELL40 interfaces the FE electronics with the online network. The board collects event fragments at 40 MHz and merges them into packets of a local area network technology. The packets are sent to the event processing farm via a fast network based on a standard protocol for which 10 Gigabit Ethernet is the favoured option. In this system, timing and fast control (TFC) as well as slow control (ECS) have to be distributed to each readout board as well as to the FE electronics. The main evolution since the LoI is the use of the same generic board to satisfy all the requirements for data transmission, TFC and ECS. We are planning to implement this hardware using the ATCA standard. This follows trends in industry and HEP, and we will benefit from ATCA evaluations planned at CERN as well as developments in other experiments. The first full-size prototype is expected by the end of 2012 with which we aim to validate serial links running at 10 Gigabit/s, investigate the FPGA resources required by the most demanding processing and gain experience of the ATCA standard.

The upgraded LHCb read-out system aims at a trigger-free read-out of the entire detector at the bunch-crossing rate of 40 MHz. In order to adapt the network and event-filter farm capacity to the available resources the existing Level-0 hardware trigger will be upgraded and adapted to become the LLT, which allows a smooth variation of the input rate to the farm between 1 MHz and 40 MHz.

Another key component is the online network for the upgrade. The readout network must be able to connect approximately 4000 10-Gigabit/s input ports with up to 5000 compute nodes. The challenge in the network design is to come up with a cost-effective solution for a large multi-Terabit/s network. We are investigating two network technologies: Ethernet and InfiniBand. The architecture will use either large core-routers with deep buffers or cheap switches with short buffers. The former implementation is more expensive but minimizes the traffic management and the need for buffering in the readout boards. The latter requires more sophisticated traffic management and more buffering in the readout boards. Studies and prototyping are ongoing to arrive at a decision in 2015.

4.3.2 Computing

The computing covers several domains: the workload management system, the framework, the simulation, the reconstruction applications, as well as the daily operation for data reconstruction and stripping. Some of these software and applications will run in a very demanding context in the event filter farm.

Areas of R&D and implementation, for which additional manpower is required, include the following tasks: (i) development of the distributed computing and workload management system for high rate; (ii) use of Cloud services; (iii) parallelisation of LHCb applications within the framework, and efficient use of many core processors; (iv) databases with high throughput; (v) code developments needed for software to run on the event filter farm. An upgrade computing coordinator will be identified in the coming months who will set up and coordinate a team of developers with specialised skills in order to start the R&D as soon as possible. The required manpower is expected to be available and acknowledged by the collaboration, and will be defined in more detail in the Computing TDR.

The hardware resources needed have been estimated at first pass, and this estimate will be refined in the next years. These resources will be requested in due time via the WLCG, in the usual manner.

4.4 Common projects

The common projects of the LHCb upgrade are: the general infrastructure, the common electronics and the online system.

In order to prepare for the LHCb upgrade, various activities in relation ot the general infrastructure are already planned during long shutdown 1 (2013 and 2014). Since the present CPU farm will have to be tripled in size for its final upgrade configuration, the currently used space will not be sufficient and therefore the new farm will be installed at the surface. To send the data to the surface more than 15000 optical fibers will be required between the underground and the surface. The support structures will have to be installed in LS1 and the fibers during any longer winter shutdown between 2014 and 2017. Furthermore, prototypes of the LHC detector upgrade will have to be installed for test purposes. The installation of an improved shielding behind the Muon system in view of the expected background at the upgrade luminosity has been scheduled for LS1 as well.

Data transmission over optical fibres will be mandatory for all sub-systems for the upgrade. The fibres between patch-panels and connectors are part of the common electronics, together with the GBT electronics, versatile links, DC-DC converters and power supplies. In the course of 2013 a financial commitment for the versatile links is required. The GBT electronics will be validated in prototype tests in the coming year, so that the production can be started by early 2014.

An Upgrade Common Fund (UCF) has been established to the level of the combined cost of the Common Projects. First contributions for the general infrastructure and the common electronics are necessary already in 2013 to prepare for the LHCb upgrade. The contributions to the UCF for the online system will be finalized at the time of the approval of the online system TDR and will not require funds before 2016.

5 Requirements to the LHC

Although the intended instantaneous luminosity for the upgrade of LHCb of up to $2 \times 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ is well below the LHC design luminosity, the envisaged instantaneous luminosity has implications for the operation of the LHC.

A bunch spacing of 25 ns is essential for the LHCb upgrade, to limit the pile-up of pp interactions at the increased luminosity. In order to maintain a luminosity of $2 \times 10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ at LHCb throughout a fill two options are considered in discussions with the LHC machine groups: luminosity levelling through beam separation in a plane orthogonal to the crossing plane, as done currently, or levelling through the variation of β^*.

The question whether the triplet quadrupole magnets and other machine elements need to be protected from particles leaving the interaction point (IP) by a Target Absorber for Secondaries (TAS) and Neutrals (TAN), as done at IP1 and IP5, is currently addressed by the LHC machine groups and detailed FLUKA simulations are ongoing. Issues in relation to the expected radiation levels due to the higher luminosity are addressed as well.

Finally, in order to control well the systematic uncertainties in the measurement of CP asymmetries with LHCb, it is of particular importance that equal amounts of data are taken with the two spectrometer polarities, and that the polarity of the LHCb dipole magnet is changed with a frequency similar to current running. For 25 ns bunch spacing, as required for the upgrade, this is only possible if the external crossing angle is in the vertical plane. As a consequence the effective crossing angle for both magnet polarities will have the same absolute value and will be in a tilted plane. The implementation of the external vertical crossing has already been done successfully for the LHC physics run in 2012.

Good progress is being made in addressing these issues in discussion with the machine groups and by the recently formed HL-LHC Coordination group.

6 Preparation of the LHCb upgrade

The plan for the preparation of the LHCb upgrade has been laid out in the Framework TDR [4], and is summarized here. Detailed schedules for the various sub-systems are available in that document.

6.1 Schedule

LHCb expects to accumulate about 7 fb^{-1} in the years up to 2017. It is proposed to install the upgrade in the second long shutdown of the LHC, starting in 2018. The upgraded experiment would then run from the second half of 2019, accumlating at least $\sim 5\ \mathrm{fb}^{-1}$ per year, until the target integrated luminosity of 50 fb^{-1} has been collected. The upgrade is not tied to any luminosity increase of the LHC, as the required luminosity will already be available.

Currently R&D for the various sub-systems is ongoing, with the aim of submitting subsystem TDRs in 2013. The years 2014–16 will be used for the tendering and series production, followed by assembly and quality control in 2017. All systems will be tested and ready for installation in 2018. The open geometry of the LHCb detector allows components of the upgraded detector to be installed as they become available.

Table 2: Estimated cost for the upgrade of the LHCb detector.

	Sub-Detector	Options	Cost (kCHF)
Tracking systems			
	VELO	Pixel Option	5430
		Strip Option	4530
	Trigger Tracker		6215
	T-stations with CT + OT option		
		CT	7860
		OT	2000
	T-stations with IT + OT option		
		IT	5350
		OT	5915
Particle Identification			
	RICH		9435
	Calorimters		1905
	Muon System		1805
Trigger and Readout			1840
Common Projects			
	General Infrastructure		2500
	Common Electronics		2500
	Online System		10670

6.2 Cost

The overall cost of the LHCb upgrade has been evaluated for different choices of sub-system technology. The cost for the various sub-systems and the common projects is summarized in Table 2.

The investment cost for the upgrade of the experiment, including the pixel solution for the VELO and an Inner Tracker, amounts to 53.6 MCHF. The choice for the VELO strip and a Central Tracker would reduce the overall cost only slightly to 51.3 MCHF. Any other combination of technologies will stay in between these values. For the particle identification systems, i.e. the RICH, calorimeters and Muon detectors, we foresee an additional reserve of 3.4 MCHF in order to account for possible modifications of some of the detector elements to comply with a luminosity of 2×10^{33} cm^{-2}s^{-1}. Including this reserve, the total upgrade cost amounts to 57 MCHF, which includes 15% contingency.

In appendix A we present a proposal for the "Memorandum of Understanding for the Common Projects of the LHCb Upgrade", which provides the LHCb Funding Agencies with the scheme for financing the activities common to the whole experiment, as agreed upon by the collaboration.

It should be noted that, unlike ATLAS and CMS, LHCb is proposing a single upgrade phase. Although further improvements might be considered on a longer time-scale than the installation of the 40 MHz readout in 2018, such as improvements in the particle identification capabilities, the cost estimated above will be the dominant part of the full upgrade programme for LHCb.

Table 3: Expressions of interest to the detector construction, subject to funding.

Detector	Sub-system	Countries involved
VELO	modules & infrastructure	BR, CERN, ES, IE, NL, RU, UK, US
	electronics & readout	BR, ES, CERN, CN, NL, PL, UK, US
Tracker	modules & infrastructure	CERN, CH, DE, NL, RU, UK, US
	electronics & readout	BR, CERN, CH, CN, DE, ES, FR, NL, PL, US
RICH	mechanics & infrastructure	CERN, IT, UK
	electronics & readout	CERN, IT, RO, UK
Calo	electronics & readout	ES, FR, RU
Muon	chambers	IT, RU
	electronics & readout	IT
Trigger	electronics & readout	BR, CN, FR, IT

Table 4: List of institutes currently participating in the LHCb upgrade.

Code	Country	Institutes
BR	Brazil	CBPF, UFRJ, PUC-Rio
CERN	CERN	CERN
CN	China	Tsinghua Univ.
CH	Switzerland	EPFL Lausanne, Univ. Zürich
DE	Germany	TU Dortmund, MPIK Heidelberg, Uni Heidelberg, Uni Rostock
ES	Spain	Univ. Barcelona, Univ. Santiago de Compostela
FR	France	CNRS/IN2P3: LAPP, LPC, CPPM, LAL, LPNHE
IE	Ireland	Univ. College Dublin
IT	Italy	INFN: Bari, Bologna, Cagliari, Ferrara, Firenze, Frascati, Genova, Milano, Padova, Pisa, Roma Tor Vergata, Roma La Sapienza
NL	Netherlands	Nikhef, VU Univ. Amsterdam
PK	Pakistan	Lahore Univ.
PL	Poland	Henry Niewodniczanski Inst. Krakow, AGH Univ. Krakow, Soltan Inst. Warsaw
RO	Romania	Horia Hulubei Nat. Inst. Bucharest
RU	Russia	PNPI, ITEP, SINP MSU, INR RAN, SB RAS Novosibirsk Univ., IHEP
UA	Ukraine	NSC KIPT, KINR
UK	Great Britain	Birmingham, Bristol, Cambridge, Warwick, STFC RAL, Edinburgh, Glasgow, Liverpool, Imperial College London, Manchester, Oxford
US	United States	Cincinnati, Maryland, Syracuse

6.3 Expressions of interest

Subject to funding, Table 3 summarizes the expressions of interest of the countries in the LHCb collaboration to the construction of the different detector sub-systems, while Table 4 lists the institutes that are currently participating. The collaboration welcomes applications from any new institutes that are interested. In addition to contributing to the core detector cost, all institutes will participate with manpower and common funds to the common projects.

7 Conclusion

The LHCb experiment is currently taking data successfully at the LHC. After the experiment has run for about five years at its design luminosity, it is proposed to upgrade the experiment to run at higher luminosity. The upgraded detector is planned to be installed in the second long shutdown of the LHC that is foreseen in 2018. Since the LHCb detector is spread out along the beam line, it is possible to work on several detectors at the same time, so that the total time for disassembly of the existing components and installation of the new ones is minimized. Nevertheless, in the first long shutdown in 2013–14 as much of the infrastructure work as possible will be done in order to speed up the eventual installation.

The main focus of the upgrade is to increase the read-out of the experiment to 40 MHz, so that the increase in luminosity can be exploited with an improved trigger. All detector elements are needed to achieve full performance with the 40 MHz readout. A strategy has been developed that will allow individual elements to be installed when received and when installation time is available, so that experience can be gained in running them. This will be achieved by reading out all the detectors at the current 1 MHz readout rate, even if they have 40 MHz capabilities, until the upgrade installation is complete.

The physics case for the LHCb upgrade points to the compelling necessity for the experiment to measure the effects of any new particles seen by any of the LHC detectors. Such new physics will require thorough study for its identification and classification, and the upgraded LHCb would be the ideal experiment to perform this task using flavour physics observables, especially since B_s^0 decays are an important element of that work. The forward geometry, particle-identification capabilities and flexible trigger of the upgraded detector will also give LHCb unique and complementary capabilities in important topics beyond flavour physics.

The LHCb experiment has taken data and demonstrated its abilities even under the challenging circumstances of many interactions per crossing, and is at a machine that will provide the needed luminosity. The LHCb upgrade is a golden opportunity to contribute to the optimal exploitation of the investment that has been made in the LHC, and to broaden the physics programme in the upgrade era.

References

[1] LHCb collaboration, “Status of the LHCb experiment”, CERN-RRB-2012-106, October 2012.

[2] LHCb collaboration, “Letter of Intent for the LHCb Upgrade”, CERN-LHCC-2011-001, March 2011.

[3] LHCb collaboration with representatives of the theory community, "Implications of LHCb measurements and future prospects", LHCb-PUB-2012-006; a summary has been submitted to the ESPG, LHCb-PUB-2012-009.

[4] LHCb collaboration, "Framework TDR for the LHCb Upgrade", CERN-LHCC-2012-007, May 2012.

[5] LHCb collaboration, "The LHCb Detector at the LHC", JINST **3** (2008) S08005.

Addendum No. 01

to the

Memorandum of Understanding
for Collaboration in the Construction of the
LHCb Detector

The Upgrade of the LHCb Detector: Common Project items

Considering that:

- the construction of the LHCb detector is governed by a Memorandum of Understanding, along with its Amendments and Addenda, setting out the responsibilities of the different participating Institutes and Funding Agencies for the construction of the LHCb detector (Construction MoU)[1];

- the Maintenance and Operation of the LHCb detector is governed by a Memorandum of Understanding for Maintenance and Operation (M&O MoU)[2];

- in order to be able to take full advantage of LHC luminosity, the LHCb Collaboration (the Collaboration) has proposed in the document CERN-RRB-2012-119 an upgrade program of the LHCb detector (the LHCb Upgrade), based on readout of the detector at 40 MHz rate, and a flexible software-based trigger system, which also involves modifications or replacements of existing sub-detectors;

- this process has started in 2011 with the Letter of Intent (LoI, CERN-LHCC-2011-001), endorsed by the LHC Committee (CERN/LHCC 2011-004 and CERN/LHCC 2011-008), followed by the Framework Technical Design Report (Framework TDR in the following, CERN-LHCC-2012-007), and it is expected to be completed in 2019, based on installation during the second long shutdown of the LHC, on a similar timescale as the Phase I upgrades of the other LHC experiments;

- based on the aforementioned documents, the Framework TDR for the LHCb Upgrade has been reviewed by the LHCC and recommended for approval to the CERN Research Board (CERN/LHCC 2012-xxx);

- the CERN Research Board has approved the Framework TDR for the LHCb Upgrade on dd.mm.yyyy (see CERN-RB-2012-xxx).

- a TDR will be produced for each of the individual sub-detector upgrades and will constitute the basis of the specific sub-detector addenda to the Construction MoU, to be signed between the Funding Agencies contributing to these upgrades and CERN as the Host Laboratory;

[1] Memorandum of Understanding for Collaboration in the Construction of the LHCb Detector, CERN-LHCb-RRB-D-2000-24 rev.

[2] Memorandum of Understanding for Maintenance and Operation of the LHCb Detector, CERN-RRB-2002-032

- a preliminary evaluation of the cost of the LHCb Upgrade has been documented in the Framework TDR, both for the modifications or replacements of existing sub-detectors, and for the Common Project items, whose costs the Collaboration has agreed to bear as its common expense.

It is agreed as follows

Article 1: Purpose

1.1 The purpose of this Addendum and its annexes is to lay down the rules governing contributions to and execution of the Common Projects of the LHCb Upgrade in conformity with the Construction MoU, its amendments and addenda.

1.2 The signing parties agree to participate to the LHCb Upgrade, consisting of specific contributions to subsystems.

1.3 Financial responsibilities and sharing of the sub-detectors specific investment costs for the LHCb Upgrade will be defined upon approval of respective TDRs and preparation of the corresponding Addenda to the Construction MoU.

1.4 The Annexes are an integral part of this Addendum.

Article 2: Parties

2.1 The Parties to this Addendum shall be all the Institutes members of the Collaboration (the Institutes) and their Funding Agencies, and CERN as the Host Laboratory. The current list of Institutes is given in Annex 1 and the current list of Funding Agencies contributing to LHCb is given in Annex 2.

Article 3: Duration

3.1 This Addendum takes effect from the date of signature and shall remain valid until the LHCb Management declares the end of the LHCb Upgrade project.

3.2 Any Institute that joins the Collaboration subsequent to the signature of this Addendum shall accept the agreements in force and shall be expected to make an appropriate contribution to the Common Project items as shall be specified in a corresponding Addendum to this Addendum. This shall be negotiated by the LHCb Management and endorsed by the RRB.

Article 4: Common Projects

4.1 The Common Projects of the LHCb Upgrade are: the Common Electronics, the General Infrastructure and the Online System. They are listed in Annex 3 together with their estimated costs, while their expenditure profile is given in Annex 4.

4.2 An Upgrade Common Fund (UCF in the following) is established, to the level of the combined cost of the Common Electronics, the General Infrastructure, and for the Online System. This will allow the preparation of the infrastructures of the LHCb Upgrade during the LHC Long Shutdown no. 1 in 2013-14. The contributions to the UCF for the Online System will be finalized at the time of the approval of the Online System TDR and will not require funds before 2016.

4.3 The obligations of the Institutes and their Funding Agencies towards the Common Projects will be shared in accordance with the principle defined in Article 9 of the M&O MoU CERN-RRB-2002-032, stipulating that they are proportional to the number of scientists holding PhD or equivalent qualifications. The actual sharing corresponds to that presented in document 'LHCb Maintenance & Operations in the Year 2013' CERN-RRB-2012-108 and is shown in Annex 5, separately for the items composing the Common Projects of the LHCb Upgrade. Contribution of the Institutes and their Funding Agencies to the UCF, in the ways described in point 4.4 below, is considered an integral part of their commitment to the LHCb Upgrade.

4.4 Contributions to the Common Projects can be made in three ways:

4.4.1 By cash payment to the UCF which has been established for the Common Projects through a dedicated account at CERN. The UCF is managed and operated by the LHCb Resources Manager, taking advice from the LHCb Management together with the CERN Finance and Procurement Department.

4.4.2 By cash payment for a Common Project item or part of an item, in agreement with the LHCb Management and Collaboration Board and endorsed by the Resources Review Board (RRB).

4.4.3 By taking responsibility for a Common Project item or part of an item, in agreement with the LHCb Management and Collaboration Board and endorsed by the RRB. This is commonly referred to as an "in-kind contribution".

4.5 All Common Fund operations are monitored by the RRB.

4.6 The LHCb Management may recommend to the RRB to update the level and the sharing of contribution to the Common Projects, for example due to a major change in the level of participation of an Institute or due to an Institute joining or leaving the Collaboration.

4.7 Procedures for contributions and contracts follow the procedures set out in the Construction MoU.

ANNEXES

Annex 1:	List of Institutes currently participating in LHCb and Contact Persons
Annex 2:	List of Funding Agencies currently contributing to LHCb and Contact Persons
Annex 3:	Common Projects expenditure
Annex 4:	Common Projects expenditure time profile
Annex 5:	Contributions by Funding Agency to the Common Projects for the LHCb Upgrade

The European Organization for Nuclear Research (CERN)

and

....

declare that they agree on the Present Addendum to the Memorandum of Understanding for Collaboration in the Construction of the LHCb Detector

Done in Geneva	Done in ....
....	....
for CERN	for ....
....	....
S. Bertolucci Director of Research and Scientific Computing	....

Annex 1 - List of Institutes currently participating in LHCb and Contact Persons

Countries	Institutes	Team Leaders
Brazil	Rio de Janeiro, CBPF	Ignacio De Bediaga Hickman
	Rio de Janeiro, UFRJ	Leandro De Paula
	Rio de Janeiro, PUC (associate member)	Carla Gobel Burlamaqui de Mello
France	Annecy, LAPP	Marie-Noëlle Minard
	Clermont-Ferrand, LPC	Pascal Perret
	Paris, LPNHE	Eli Ben Haim
	Marseille, CPPM	Renaud Le Gac
	Orsay, LAL	Marie Helene Schune
Germany	Dortmund, Univ.	Bernhard Spaan
	Heidelberg, MPIK	Michael Schmelling
	Heidelberg, Univ.	Ulrich Uwer
	Rostock, Univ. (associate member)	Roland Waldi
Ireland	University College Dublin	Ronan McNulty
Italy	Bari, INFN and Univ.	Antimo Palano
	Bologna, INFN and Univ.	Umberto Marconi
	Cagliari, INFN and Univ.	Biagio Saitta
	Ferrara INFN and Univ.	Stefania Vecchi
	Florence INFN and Univ.	Giovanni Passaleva
	Frascati, Laboratori Nazionali - INFN	Matteo Palutan
	Genoa, INFN and Univ.	Flavio Fontanelli
	Milan Bicocca, INFN and Univ.	Marta Calvi
	Padua, INFN and Univ.	Donatella Lucchesi
	Pisa, INFN, Univ. and SNS	Giovanni Punzi
	Rome La Sapienza, INFN and Univ.	Roberta Santacesaria
	Rome Tor Vergata, INFN and Univ.	Giovanni Carboni
Netherlands	Amsterdam, NIKHEF	Marcel Merk
	Amsterdam, Free Univ.	Gerhard Raven
Pakistan	Lahore, COMSATS (associate member)	Shabana Nisar
Poland	Kracow AGH, Univ. of Science and Tech.	Bodgan Muryn
	Kracow HN Inst. for Nuclear Physics	Grzegorz Polok
	Warsaw, Soltan Inst. for Nuclear Studies	Marek Szczekowski
Republic of China	Beijing, Tsinghua Univ.	Yuanning Gao
Romania	Bucharest-Magurele, IFIN-HH	Raluca Muresan
Russia	Gatchina, PNPI	Evgueni Gushchin
	Moscow, INR	Andrey Goloutvin
	Moscow, ITEP	Alexander Leflat
	Moscow, State Univ.	Alex Bondar
	Novosibirsk, INP and State Univ.	Alexei Vorobyev
	Protvino, IHEP	Vladimir Obraztsov
Spain	Barcelona, Univ.	Eugeni Grauges Pous
	Santiago de Compostela, Univ.	Bernardo Adeva Andany
Switzerland	CERN	Monica Pepe Altarelli
	Lausanne, EPFL	Tatsuya Nakada
	Zürich, Univ.	Ulrich Straumann
Ukraine	Kharkov, Acad. of Sci., KIPT	Yury Ranyuk
	Kiev, Acad. of Sci., INR	Valery Pugatch
United Kingdom	Birmingham, Univ.	Nigel Watson
	Bristol, Univ. and H.H. Wills Physics Lab.	Jonas Rademacker
	Cambridge, Univ.	Valerie Gibson
	Rutherford Appleton Laboratory	Fergus Wilson
	Edinburgh, Univ.	Franz Muheim

	Glasgow, Univ.	Paul Soler
	Liverpool, Univ.	Themis Bowcock
	London, Imperial College	Ulrik Egede
	Manchester, Univ.	Christopher Parkes
	Oxford, Univ.	Neville Harnew
	Warwick, Univ.	Tim Gershon
United States	Maryland, Univ.	Hassan Jawahery
	Syracuse, Univ.	Sheldon Stone
	Cincinnati, Univ. (associate member)	Michael Sokoloff

Annex 2 - List of Funding Agencies currently contributing to LHCb

Countries	Funding Agency	Representative
Brazil	CNPq, FINEP	Arthur Maciel
France	CNRS/IN2P3	Laurent Serin
Germany	BMBF	
	Max-Planck-Institut, Heidelberg	
Ireland	University College, Dublin	
Italy	INFN	Fernando Ferroni
Netherlands	NIKHEF	Frank Linde
Poland	Ministry of Science and Higher Education	
Republic of China	NSFC	
Romania	ANCS/IFA	Florin Buzatu
Russia	Ministry of Education and Science	Evgeniy Masterskih
	NRC "Kurchatov Institute"	Vladimir Shevchenko
Spain	Ministerio de Economia y Competitividad	
Switzerland	SNSF	
Ukraine		
United Kingdom	STFC	
United States	NSF	Saul Gonzales, Randi Ruchti

Annex 3 - Common Projects expenditure

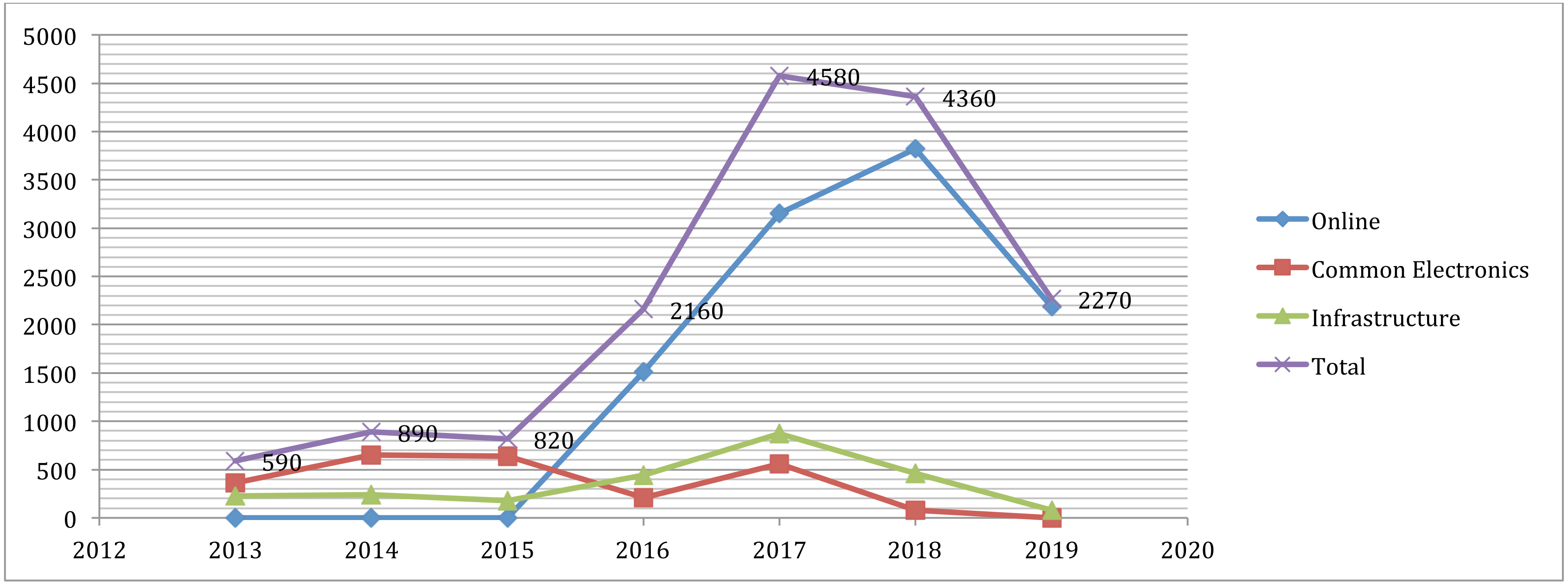
Common Project		kCHF	15670
Common Electronics			2500
	Timing & Fast control	500	
	Optical fibres and connectors	500	
	Common spares	700	
	Power supplies, Racks, Crates	450	
	DC-DC Converter	350	
General Infrastructure			2500
	Civil Engineering and building	450	
	Cooling and ventilation	380	
	General assembly	230	
	Electrical power supply	110	
	Radiation shielding	200	
	Survey	120	
	Cabling long distance	590	
	Safety	300	
	Gas and fluids piping	120	
Online system[3]			10670
	Readout network	4940	
	Controls network	905	
	Controls system	930	
	PC farm	3125	
	Infrastructure	770	

[3] The expenditure for this item will be finalized at the time of the approval of the Online System TDR.

Annex 4. Table 1 - Common Projects expenditure time profile.

Common Projects		2013	2014	2015	2016	2017	2018	2019
	kCHF	kCHF	kCHF	kCHF	kCHF	kCHF	kCHF	kCHF
Total	**15670**	**590**	**890**	**820**	**2160**	**4580**	**4360**	**2270**
Common Electronics	**2500**	360	650	640	210	560	80	
Timing & Fast control	**500**			500				
Optical Fibres & Connectors	**500**	50	50			400		
Common Spares	**700**	210	420	70				
Power Supplies	**60**				10	50		
Crates	**90**				20	50	20	
Racks, Monitoring, Fire Detection	**300**				180	60	60	
DC-DC converter	**350**	100	180	70				
Infrastructure	**2500**	230	240	180	440	870	460	80
Civil Engineering and buildings	**450**		180	180	40	50		
Cooling and Ventilation	**380**				110	160	110	
General assembly	**230**					160	70	
Electrical power supply	**110**				110			
Radiation shielding	**200**					160	40	
Survey	**120**					10	70	40
Gas and fluids piping	**120**					30	80	10
Cabling long distance	**590**	230	60		120	120	60	
Safety	**300**				60	180	30	30
Online[3]	**10670**				1510	3150	3820	2190
Readout network	**4940**				990	1970	1980	
Controls network	**900**				180	360	360	
Controls system	**930**				190	280	460	
PC farm	**3130**					310	630	2190
Infrastructure	**770**				150	230	390	

[3] The expenditure for this item will be finalized at the time of the approval of the Online System TDR.



Annex 4. Figure 1 - Common Projects expenditure time profile (in kCHF).

Annex 5 - Contributions by Funding Agency to the Common Projects of the LHCb Upgrade.

	TOTAL	BRASIL	CHINA	FRANCE	GERMANY BMBF	GERMANY MPG	IRELAND	ITALY	NETHERLANDS	POLAND	ROMANIA	RUSSIA	SPAIN	SWITZERLAND	UK	UKRAINE	USA	CERN	
PhD eq 2013	394	18	6	42	13	5	2	58	17	8	7	30	16	25	73	3	16	55	**394**
	100.0	**4.6**	**1.5**	**10.7**	**3.3**	**1.3**	**0.5**	**14.7**	**4.3**	**2.0**	**1.8**	**7.6**	**4.1**	**6.3**	**18.5**	**0.8**	**4.1**	**14.0**	**%**
Common Electronics	**2500**	114	38	266	82	32	13	368	108	51	44	190	102	159	463	19	102	349	kCHF
Infrastructure	**2500**	114	38	266	82	32	13	368	108	51	44	190	102	159	463	19	102	349	kCHF
Online[3]	**10670**	487	162	1137	352	135	54	1571	460	217	190	812	433	677	1977	81	433	1489	kCHF
	15670	**716**	**239**	**1670**	**517**	**199**	**80**	**2307**	**676**	**318**	**278**	**1193**	**636**	**994**	**2903**	**119**	**636**	**2187**	kCHF

[3] The expenditure for this item will be finalized at the time of the approval of the Online System TDR.