Optical links for the LHCb upgrade

CBPF/IF-UFRJ/PUC-Rio/LHCb Collaboration

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1 Identification of groups and members

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2 Project Summary

The LHCb experiment is a detector system specially designed to perform flavour physics measurements at the LHC. Its physics programme will be executed in two phases. The goals of the first phase of the experiment can be achieved with around 5 fb\(^{-1}\) of integrated luminosity and will take several years to accomplish with the current detector. With this data set, it will be possible to significantly extend the precision of many key observables in B and D physics beyond what was possible at the B-factories, and make a unique exploration of the \(B_s\) system. To exploit fully the flavour physics potential of the LHC, the LHCb experiment will require a significant upgrade of its detector systems.

The upgrade will allow the experiment to operate at a higher instantaneous luminosity, and will equip the detector with a fully flexible software trigger. The trigger system is divided into two parts, the Low Level Trigger (LLT) and the High Level Trigger, replacing the current scheme with a L0 hardware trigger. This modification is the most crucial one to improve the signal retention of hadronic final states of B and D decays, while keeping a low background level. The upgraded detector will be able to collect 50 fb\(^{-1}\) of data integrated over around ten years of operation. The new trigger design and the high
precision tracking system will allow for a unique reach for new physics in the forward region, unattainable to detectors such as ATLAS and CMS.

3 Justification

This project consists in the production of a large quantity of optical fibres for the LHCb upgrade. The main goal is to make such production in the Brazilian industry and provide them as an in-kind contribution to the experiment. This contribution would be therefore accounted as part of the common fund that each institution has to provide to participate in the collaboration. This approach has the obvious advantage of investing money directly in the Brazilian industry, instead of contributing with (or to buy) components that can only be manufactured in foreign industries. Moreover this would consist of one more channel between the research groups working in big international collaborations and the Brazilian industry, among the very few examples until now. This channel could be maintained and used for the mutual advantage of both ends. Many of the big experiments work with new technology in order to produce its components. Thus the created channel can also represent the beginning of a collaboration that could bring, in the future, technology transfer to the Brazilian industry.

4 Research Plan

The general readout architecture for the upgrade of the LHCb detector is shown in Fig. 1. The front-end electronics (FE) amplifies and shapes the signals generated in the detectors. These signals are digitised, compressed, formatted and then transmitted through a high-speed optical link. The back-end electronics (BE) sits in the counting room and receives the data from the optical links. After buffering and filtering by the LLT, the data are
formatted for transmission to the data-acquisition system. Data from the Calorimeter and Muon sub-detectors are extracted via an independent transmission system to the trigger processors where the LLT is generated. The transmission of the trigger information is performed through a Timing and Fast Control (TFC) system in the form of bunch-crossing identification numbers for which the LLT gave a positive decision. Configuration and monitoring of the BE and FE electronics are done through an interface to the Experiment Control System (ECS). More details on the architecture and the specifications can be found in [1].

A typical FE module consists of one or more FE chips connected to an optical link, implemented using the technology developed under the “Radiation Hard Optical Link Project”. This project aims to develop a radiation hard bi-directional optical link for use in the LHC upgrade programs. The GigaBit Transceiver (GBT) chip-set and the Versatile Link have been developed as generic building blocks for data transmission between the on-detector and off-detector electronics serving simultaneously applications such as data acquisition, timing, trigger and experiment control. The GBT chip-set is composed of radiation-tolerant components for mounting onto FE modules and compatible with firmware for commercial FPGAs in the BE modules. The GBT is designed to be operated in duplex or simplex mode. The Versatile Link project offers radiation qualified electro-optical components to implement a complete optical transmission system.

Details of the GBT and Versatile link can be found in [2, 3], but the most relevant points for LHCb are summarised in [4], with suggestions for implementation. The components of the chip-set and the versatile link are shown in Figure 2. The trans-impedance amplifier (TIA), PIN diode (PD), laser driver (LD) and laser will be mounted together onto a bi-directional Small-Form-Pluggable (SFP) Package. Another option will be a dual-transmitter SFP where the receiver components are replaced by a second transmitter channel.
Each of these components is described in the following sections.

The back-end electronics are located on or close to the detector, and are therefore exposed to radiation. The counting end electronics are through a radiation qualified electro-optical transmission system. The counting end electronics by a Timing and Fast Control (TFC) system.

The GBT and 2 bits reserved for internal configuration of the LLC. Configuration and monitoring of the TFC and slow control (SC) field is divided into eight ports running at 320 Mbit/s. Serial mode has different configurations, from a parallel or serial bit bus running at 80 Mbit/s. Serial mode will be a dual laser will be mounted together in a bi-axial mounting and the versatile link offers radiation qualified electronics architecture.

The GigaBit Transceiver chip is composed of an impedance amplifier (TIA), PIN diode (PD), laser driver (LD) and a generic building block in a Pluggable (SFP) Package. Another SOIC package for 120 bits is the serialiser/deserialiser chip operating at a serial rate of 4.8 Gbit/s, and the most relevant points for LHCb are summarised here, and the versatile link has been developed as a complete optical transmission system.

The header (H) and forward error correction (FEC) fields are not available to the user.

The data (D) field is fully available to the user for data transmission. These 2 user bits will be transmitted/received by an E- port running at 80 Mbit/s. This E- port can be interfaced to the GBT-SCA (slow control)

This E-port running at 80 Mbit/s. This E-port can be interfaced to the GBT-SCA (slow control)

The data from the optical links are transmitted down a high speed optical link running at 80 Mbit/s. Serial mode has different configurations, from a parallel or serial bit bus running at 80 Mbit/s.

Figure 1: Overview of electronics architecture

Figure 2: Overview of GBT/Versatile link
The data bandwidth from the LHCb detector to the counting room will be many times larger than the TFC and ECS traffic in the opposite direction. Therefore it is likely that the GBTX will be widely used in simplex-transmitter mode. However, duplex transceivers will be required for writing and reading the ECS information and the receiver mode for TFC operations (clock, calibration, resets). An example of a possible implementation is shown in Figure 3(a) for a system with a FE module containing many channels and hence a high data bandwidth. The FE chips drive multiple GBTXs configured in simplex-transmitter mode. These then drive a number of dual-transmitter optical packages connected to fibres that fan into a 12-way fibre ribbon. This arrives at a 12-way receiver on the BE board. The implementation of the links has to be optimised according to the bandwidth and integration requirements of each sub-detector.

The back-end electronics are situated in the counting room and act as an interface between the FE modules, DAQ, TFC and ECS systems. The counting room is a radiation-free
environment and commercial components can be used without the need for radiation qualification. Electronics modules should be implemented in industrial formats to allow the use of standard mechanics, cooling and power supplies.

The baseline solution states that the optical fibres used to equip the GBT link will be of the OM4 multimode type, a commercial item produced in Brazil by at least one company, obeying international standards\textsuperscript{1}. Different connection solutions are being investigated, while the 12-fibre MPO “breakout” or “fanout” cable being the most likely to be used (see Fig. 3(b)).

Given the fact that we have two scientific projects on the upgrade, the development of the vertex detector readout and control system (UFRJ/PUC-Rio) and the development of the control system for generic systems (CBPF), our interest in the data links is more technical and strategical. Members of the groups participating on the proposal will get involved on the planning and installation of the readout optical paths, which is centralised by the LHCb’s “Online group”. They will also be responsible for preparing and following up the purchase orders of the cables. Since the data transmission over optical fibres will be mandatory for all sub-detectors, these people will be in close contact with each subdetector group and will get familiar with the details of all existing readout chains of the experiment. This is therefore a very important role for the collaboration and the upgrade efforts.

The general schedule is given in Table 1.

\textsuperscript{1}Technical specifications are given in the appendix
Table 1: Milestones

<table>
<thead>
<tr>
<th>Date</th>
<th>Milestone</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>Qualification of Brazilian sample cable in the GBT test stand</td>
</tr>
<tr>
<td>2012-2013</td>
<td>GBT and Versatile link prototypes tests</td>
</tr>
<tr>
<td>2013</td>
<td>Construction of support structures during shutdown</td>
</tr>
<tr>
<td>2013-2014</td>
<td>planning of readout electronics paths and definition of connection solution</td>
</tr>
<tr>
<td></td>
<td>BE electronics, GBT and Versatile link production</td>
</tr>
<tr>
<td>2015-2016</td>
<td>ordering of optical cables</td>
</tr>
<tr>
<td>2017</td>
<td>mass production of optical cables</td>
</tr>
<tr>
<td>2018</td>
<td>cabling and detector/electronics installation</td>
</tr>
<tr>
<td>2019</td>
<td>commissioning and start of operation</td>
</tr>
</tbody>
</table>

5  Coordination with and relevance to the larger collaboration

As discussed in the previous section, the acquisition of the optical fibres is mandatory in any of the LHCb upgrade scenarios. Therefore, this project has a strong strategical component inside the LHCb collaboration.

During the extension of the project, at least one researcher of the group will be responsible for the administrative activities, including all the necessary steps for the purchase of the cables. At the same time, the group will be in charge of a key role in the collaboration, being responsible for the communication to the company, installation of the cables and in the planning of the readout optical paths. This person will be in close contact with all LHCb sub-detectors and centralise a significant knowledge about the readout chain of the experiment.
6 Budget

The budget and schedule presented here is based on the “Framework Technical Design Report for the LHCb upgrade” [5], in particular on its last section. Summing over the different subdetectors, about 12,000 fibres will be required. This amounts for a total cost of 560,000 CHF. Optical fibres between patch-panels and connectors are also included as part of the “Common Electronics” project, under the total cost for the Common Fund, and amounts for 500 kCHF.

As explained before, we foresee this contribution as an in-kind contribution to the experiment, that in principle could cover partially our contribution to the detector and also part of the contribution to the common fund.

Table 2: budget

<table>
<thead>
<tr>
<th>Date</th>
<th>Investment</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>2013</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2014</td>
<td></td>
<td></td>
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<tr>
<td>2015</td>
<td>300 CHF</td>
<td>optical cables</td>
</tr>
<tr>
<td>2016</td>
<td>300 CHF</td>
<td>optical cables</td>
</tr>
<tr>
<td>2017</td>
<td>200 CHF</td>
<td>optical cables</td>
</tr>
</tbody>
</table>

References


Appendix - Technical Specifications

TECHNICAL SPECIFICATION
1854 - V 12 (09/05/2012)

OPTICAL PATCH CORD

<table>
<thead>
<tr>
<th>Product Type</th>
<th>Optical Cord</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Family</td>
<td>TeraLAN</td>
</tr>
</tbody>
</table>

**Description**
Optical Patchcord is a single fiber or duplex cable with optical connectors on both sides.

**Applications**
- Installation Environment: Internal
- Operation Environment: Non-aggressive
- Compatibility: All Furukawa Cabling System line.

**Warranty**
- 12 months
- Extended Guarantee: 15 or 25 years (1)

**Advantage**
- Recommended for internal use only, interconnecting optical internal distributors with networking equipments, in optical systems with low loss and high bandwidth, like: high distance systems, backbone networks, video and data transmission and distribution;
- Exceeds performance requirements of EIA/TIA-568-C.3 standard;
- Support for background requirements of IEEE 802.3 (Gigabit and 10 Gigabit Ethernet)(2), ANSI T1 1.2 (Fibre Channel)(3) standard and ITU-T-G-987(11);
- Full assembled and tested on factory;
- High performance for insertion loss and return loss (backreflection);
- Available in diverse kinds of optical connectors;
- Available for singlemode and multimode optical fiber;
- Available in PC and APC polishing;
- Available in several lengths.

**Marking**
- Length: 1,5m; 2,5m; 3,0m; 4,0m; 5,0m; 7,0m; 10m; 15m and 20m (3)

**Nominal Diameter**

<table>
<thead>
<tr>
<th>OPTICAL CORD (4)</th>
<th>SINGLE-FIBER</th>
<th>DUPLEX</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,0 mm</td>
<td>2,0 x 4,5 mm</td>
<td></td>
</tr>
<tr>
<td>3,0 mm</td>
<td>3,0 x 5,9 mm</td>
<td></td>
</tr>
</tbody>
</table>

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### Assembled Optical Cable LC/SC

<table>
<thead>
<tr>
<th><strong>Product Type</strong></th>
<th>Connected Optical Cord</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product Family</strong></td>
<td>TeraLAN</td>
</tr>
<tr>
<td><strong>Description</strong></td>
<td>Optical fiber cable, construction type “tight buffer” (indoor or indoor/outdoor), assembled in factory on both ends with LC or SC connectors, for use in distribution or cabling backbone in high density environments.</td>
</tr>
</tbody>
</table>

**Applications**

| **Installation Environment** | Indoor or Indoor/outdoor⁷¹ |
| **Operation Environment** | Non agressive |
| **Warranty** | 12 months |
| **Extended Guarantee** | 15 or 25 years⁷² |

**Advantage**

- Owned by Family of Products TeraLAN® is suitable for high density optical fiber environments, completely eliminating the need of splices and significantly reducing installation time.

  1. Modularity and flexibility with ease of expansion without quality degradation;
  2. Ensures high performance and reliability in the management of optic cabling;
  3. Fast and easy installation and reconfiguration (plug and play);
  4. Simple handling, no need for special tools;
  5. High Density, maximizing use of space in the routing infrastructure.

- Exceeds the performance requirements of the standard EIA/TIA-568-C.3;
- Supports IEEE 802.3ae second applications (10 Gigabit Ethernet) and ANSI T11.2 fibre Channel;
- Available in 12, 24, 36 or 48 fibers⁷³;
- Construction of cable type “tight buffer” (indoor or indoor/outdoor);
- Assembled in both ends with optical connectors SC or LC (ST / FC / MT-RJ / E2000 on demand);
- UPC polishing type;
- High performance in insertion loss (IL) and return loss (RL);
- 100% assembled and tested on factory.

**Length**

From 10 to 100m²³