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Functional Specification

DATA AND SIGNALS TO BE EXCHANGED BETWEEN THE LHC MACHINE AND EXPERIMENTS

Abstract

An analysis of the functional requirements concerning data and signals to be exchanged between the experiments and the accelerator are presented. Emphasis is placed on observables that can provide a measure of the LHC accelerator operating conditions and on the state of detector systems of the experiments.

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History of Changes

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1. INTRODUCTION

The data exchange between the LHC accelerator and experiments, both at the hardware and software levels, has the aim of communicating information on the state of the machine and experiments as a whole and on their various sub-systems, as well as providing a means to understand the causes of error by acting as a recording and diagnostic tool. It is essential to retain flexibility in the data and signals to be exchanged as experience with the experiment and accelerator operation develops.

The communication link is based on a) the software-based DIM Data Interchange Protocol (DIP) [1] providing a simple and robust publish/subscribe system, which will support an on-change data exchange and b) dedicated hardware links.

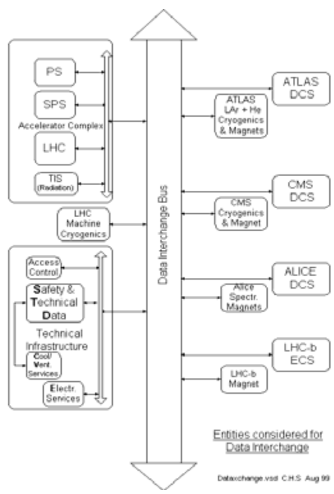

Figure 1: Entities considered for data exchange at the LHC.

Figure 1 shows the conceptual lay-out of the entities considered for data exchange.

LHC data from the accelerator and experiments will have an absolute UTC time stamp, which will be derived from a GPS module located in the CERN Control Centre (CCC). Connections to the experiments will be done via an RS-485 differential twisted pair.

In addition, a concise summary of the LHC accelerator operation status, as has been the case for the PS, SPS and LEP, is required. This should be made available on TV monitors throughout CERN and also accessible via the WWW.

2. EXPERIMENTS TO ACCELERATOR

2.1 QUALITY OF BEAM COLLISIONS

Table 1 provides a minimum set of data to be provided by the experiments to the accelerator. The overall data rate of 966 bytes/sec is considered to be low frequency and thus should not be limited by bandwidth. As experience with the experiment and accelerator operation develops, this may result in the number and choice of quantities exchanged to vary, thus altering the production rate and hence the data exchange rate.

Table 1: Data produced and sent from experiments to the accelerator via the DIP

Measurement	Units	Production Volume (Bytes)	Production Interval (sec)	Data Rate (Bytes/sec)
Total luminosity	$cm^{-2}s^{-1}$	4	1	4
Average rates	Hz	12	1	12
Luminosity per bunch	$cm^{-2}s^{-1}$	14256	60	238
Rates for individual bunches	Hz	42768	60	713
Position and size of luminous region (average over all bunches)	cm	24	600	0.04
Total per experiment				**966**

A collision point in the centre of the experiments is required. For example, fast reconstruction of tracks in ATLAS and CMS will provide a measurement of the longitudinal position of the collision to within ± 2 mm. Such measurements would require that the inner detectors, including the pixel detectors, are powered and operational and would only be possible once stable beams are established. Moreover, ATLAS and CMS plan to monitor the transverse position of the collision point by reconstructing tracks in the inner detectors. A measurement of this position to about 10 μm accuracy could be provided in 10 s. The luminous region will also be measured by reconstructing tracks in the inner detectors of the experiments.

The experiments have demonstrated their ability to assess the quality of the collisions based on measuring observables in their detectors. Several trigger rates will be measured continuously by the experiments. For example, the measurement of cluster rates and muon candidates above threshold can be integrated over all bunches and can also be measured on a bunch-by-bunch basis. Information from the muon detectors can be used to study the muon halo and the neutron background. Moreover, information from the forward rates and the vertex counting per event in the inner detectors will provide a measurement of the relative luminosity. Finally, a measure of the occupancies in the hadron calorimeter sectors may lead to an estimation of the background imbalance.

ATLAS and CMS plan to install detectors to monitor the collision rates at IR1 and IR5. Data from the Cerenkov Integrating Detector (LUCID) [2] at IR1 and the Beam Scintillation Counters (BSCs) [3] at IR5 will be made available on the DIP data exchange. The detectors have a fast response to provide bunch-by-bunch information on the collisions.

The absolute luminosity will be measured by the TOTEM and ATLAS Roman Pot experimental set-ups at IR5 and IR1, respectively.

The transmission of physics event displays from the Experiment Control Rooms (ECRs) to the CCC is expected to prove useful in communicating the state of collisions and the machine-induced background.

2.2 EXPERIMENT BEAM INTERLOCKS

Beam interlock signals will be provided from the experiments [4]. These signals will cover the beam abort requests, injection inhibits, software interlocks, the spectrometer magnet interlock systems, the interlocking of the moveable devices of the experiments and any other special signals from the experiments.

Table 2 provides a minimum set of signals to be provided from the experiments to the accelerator.

Table 2: Signals to be sent from the experiments to the accelerator

Signal	Client	Type
Spectrometer Magnet Interlock	LHC Beam Interlock System (BIS)	Hardware
Beam Abort	LHC Beam Interlock System (BIS)	Hardware
Injection Inhibit	Experiment Injection Interlock System	Software (Hardware remains as upgrade option)
READY-FOR-ADJUST	CERN Control Centre (CCC)	Software
READY-FOR-BEAM-DUMP	CERN Control Centre (CCC)	Software

2.2.1 SPECTROMETER MAGNETS

Interlock signals will be provided for all experiment spectrometer magnets, consisting of solenoid, dipole and toroid magnets, and will be generated whenever the state of any magnet is FAULT. One USER_PERMIT summary signal per experiment concerning only the state of their spectrometer magnet system will be provided to the LHC Beam Interlock System (BIS) [5].

The operation of the ALICE and LHCb spectrometer dipole magnets is coupled strongly to the accelerator operation, as the dipole magnets will distort the beam orbit. This distortion will be offset locally with dedicated compensation magnets. The spectrometer dipole magnets (and corresponding compensation magnets) will be operated by the CCC and will be ramped with the energy of the beam. ALICE and LHCb request to have the ability to control their spectrometer magnets after the beam is dumped. Control will then pass back to the CCC prior to ramping. These spectrometer magnets will also be connected to the LHC BIS.

The spectrometer solenoid magnets are also expected to create orbit distortions, and in some cases may need to be compensated during beam operation. The ATLAS solenoid and toroid magnets as well as the CMS solenoid will be operated by the respective ECRs, at least during the first years of LHC operation. It is expected that the ALICE solenoid magnet will be operated by the CCC. For the solenoids and toroids, the decision to connect the interlock signal to the LHC Injection System will be taken based on tests that will be performed during the beam commissioning period of the LHC.

The status of all spectrometer magnets, including the currents and polarity, will be monitored in the CCC and in the ECRs with data sent via the DIP data exchange from the respective Magnet Control System. Implementation of beam interlocks may also be needed.

The detailed procedures on the operation of all spectrometer magnets shall be agreed imminently.

3. ACCELERATOR TO EXPERIMENTS

3.1 BEAM INSTRUMENTATION

Table 3 provides a minimum set of data to be provided from beam instrumentation of the accelerator to the experiments. As experience with the experiment and accelerator operation develops, this may result in the number and choice of quantities exchanged to vary, thus altering the production rate and hence the data exchange rate.

Table 3: Data to be sent from the beam instrumentation of the LHC accelerator to the experiments via the DIP (p-p and ion-ion modes)

Producer	Measurement	Data type	Production Volume (Bytes)	Production Speed	Production Rate (kB/s)	Expected Accuracy	Remarks
AB-BDI	Total beam intensity	Charges	8	1 sec	0.008	1%	
AB-BDI	Individual bunch intensities	Charges	28 512	1 min	0.475	5%	
AB-BDI	Average 2D beam size	mm	16	1 sec	0.016	15%	For transport to IP will require knowledge of beta function
AB-RF	Average bunch length	ps	8	1 min	$1.3\ 10^{-4}$	10%	
AB-BDI	Luminosity		28 512	10 sec	2.851	1% relative	Relative measurement between bunches
AB-BDI	Average Beam Loss		16	10 sec	0.002		Average from 50 selectable BLMs
AB-BDI	HOR & VER Positions	µm	128	1 sec	0.128	5µm Resolution	From all Q1 BPMS
AB-BDI	HOR & VER Positions	µm	64	1 sec	0.064	5µm Resolution	From 8 TOTEM BPMWT
AB-BDI	HOR & VER Positions	µm	16	1 sec	0.016	5µm Resolution	From 2 ATLAS Roman Pot BPMSA
AB-BDI	Total longitudinal distribution		285.120	1 min	4.752		Will be able to detect ghost proton bunches at the 0.1% level of nominal. Instrumentation will not be available in time for LHC Phase I.

3.2 LHC TIMING SIGNALS & DISTRIBUTION TO THE EXPERIMENTS

The Timing, Trigger and Control (TTC) [6] architecture provides for the distribution of synchronous timing, Level-1 trigger broadcast, and individually-addressed control signals to electronics controllers with the appropriate phase relative to the LHC bunch structure, taking account the different delays due to particle time-of-flight and signal propagation.

The LHC RF group will provide three clocks to the experiments: a stable reference clock at 40.08 MHz delivered from the Faraday Cage at Point 4, which will serve as a reference clock of the LHC accelerator and which can be used by the experiments to clock their electronics, and two clocks which will drive the RF for the two beams. The latter two clocks will vary in order to follow the energy ramp and will be locked to the reference clock at top energy.

The experiments rely on collisions being as close as possible to the nominal IP at the centre of their detectors. The jitter of the reference clock is approximated to be ~10 ps at the origin, while the RF clocks will be less accurate and whose phase could differ from that of the reference clock by up to 300 ps. As the jitter affects the average time of collisions in the experiments with respect to the reference clock and the average collision point itself, the latter jitter implies a significant displacement from the nominal IP, since, for example, the CMS calorimeter digitisation requires a timing signal with <50 ps jitter.

From first injection into the LHC until end of physics, the RF group guarantees a clean, stable and non-interrupted 40.08 MHz signal within the range of the experiment QPLLs. However, during access, after a beam dump, during periods of shutdown or repair, the RF-supplied bunch frequency can be (almost) anything and could even be missing. The experiments, therefore, have implemented a switch at the TTC input to select either the RF-supplied signal or a local reference.

In addition, the machine status and beam information will be available through the LHC Beam Synchronous Timing System (BST) [7]. The BST's primary use will be to synchronise the LHC beam instrumentation but GPS timing signals as well as LHC data will be available to be added to the experiments' event records and detector control systems.

Moreover, the GPS-derived General Machine Timing (GMT) [8, 9] data will be available as a hardware link to all experiments.

3.3 THE LHC BEAM POSITION SYSTEM

A total of 1080 Beam Position Monitors (BPMs) are needed for the LHC rings, including those for TOTEM and the ATLAS Roman Pots. This includes one experiment BPM (BPTX) timing pick-up per incoming beam at Points 1, 2, 5 and 8. The BPTXs will be located about 175 m from the IP and will be used exclusively by the experiments. Button electrodes have been chosen for the pick-up technology.

Two applications of the BPTX timing signals have been identified by the experiments. They may be used to monitor the phase of the clock of the two beams locally at the interaction regions, thus determining whether the TTC system is synchronised with the actual arrival of the bunch. Moreover, the monitors can be used to identify the location of the gaps in the LHC bunch train, which is considered to be particularly useful during the setting up stage of the experiments.

The BPMs for the TOTEM experiment will be interfaced to and controlled by the respective LHC Machine control system and the data will be made available on the DIP data exchange.

3.4 DETERMINATION OF COLLISION RATES

The LHC Collision Rate Monitor [10] - *Luminometer* – will provide a means to monitor the machine operation parameters and conditions. Its anticipated applications include the initial beam finding and beam overlap maximization, equalization of the collision rates amongst the experiments, monitoring of the crossing angle, and the bunch-by-bunch measurement of the collision rate. The *Luminometers* will be installed in a slot inside the TAN absorbers and two technologies – fast ionization chambers and polycrystalline Cadmium Telluride detectors – will be implemented. Data from the *Luminometers* will be made available on the DIP data exchange.

3.5 COLLIMATION SYSTEM

Protecting elements of the LHC machine and experiments against the high intensity beams and the corresponding high loss rate of protons requires a multi-stage collimation system [11]. Data from the LHC collimation system, such as the settings and positions of the various collimators – primary, secondary, tertiary, injection protection, protection luminosity debris and beam scraping – will be made available on the DIP data exchange.

3.6 LHC VACUUM SYSTEM

In the interaction regions around the experiments, the residual gas densities must be minimised in order to reduce the machine-induced background to the experiments. Data on the levels of the residual pressure gauges in the Long Straight Sections around the experiment interaction points will thus be made available on the DIP data exchange.

3.7 LHC MACHINE MODES

During its cycle, the LHC evolves through various stages referred to as MODES – Injection, Filling, Ramp, Adjust, Stable Beams, Unstable Beams, Beam Dump and Recover [4]. The LHC MODE information is transmitted to the experiments through a software exchange mechanism such as the DIP data exchange protocol and over a hardware link via the Safe LHC Parameter (SLP) System [12, 13].

For the particular MODE of Stable Beams, additional information on the beam energy and possibly on the state of the collimators will also be provided.

3.8 SUMMARY OF SIGNALS

Table 4 provides a minimum set of signals to be provided from the accelerator to the experiments.

Table 4: Signals to be sent from the accelerator to the experiments

Signal	Client System	Type
RF Timing	Timing, Trigger, Control (TTC)	Hardware
Beam Synchronous Timing	Experiment Detector Control System / DAQ	Hardware
General Machine Timing	Experiment Detector Control System / DAQ	Hardware
BPTX Timing	Experiment Detector Control System / DAQ	Hardware

4. COMMISSIONING AND TESTS

The data and signal exchange commissioning will be done either during the LHC hardware commissioning or during the accelerator check-out. All software and hardware links must be tested regularly to ensure correct functionality.

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