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Engineering Specification

Application Software for the LHC Collimators and Movable Elements

Abstract

The operation of the LHC will rely on the proper functioning of many collimators and beam absorbers for beam cleaning and machine protection. In its final configuration, the LHC "Phase I" collimation system will consist of 42 ring collimators and absorbers per beam (of type TCP, TCSG, TCLA, TCTH, TCTV, TCL, TCLP, TCLI and TDI). In addition 14 transfer line collimators (of type TCDI) will also be used. The overall system includes more than 450 degrees of freedom that have to be coherently controlled. This document presents the engineering specifications for the high-level application software required for the control of the LHC collimators listed above. Other movable elements such as the beam dump diluter block (TCDQ) and the Roman Pots can adopt the same solution to the extent that their control systems comply with the one adopted for the collimators discussed here.

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History of Changes

Rev. No.	*Date*	*Pages*	*Description of Changes*
0.1	2006-03-20		First draft finished
	2006-03-28		First version sent to R. Assmann, M. Lamont and M. Jonker and others.
	2006-04-07		Comments fully implemented. Also add several snapshots of the first draft of the GUI for the single collimator control. These specs have been used for the prototyping of the single collimator control at the SPS tests.
	2006-04-18		Proposed coordinate notation is sent to, and then approved by A. Masi, R. Chamizo and M. Sobczak.
	2006-05-08		Minor changes. Add the detailed table with the estimates of required disk space for data logging.
	2006-05-24		Class-like structure of the collimator in appendix. Table with the requirements for collimator database.
	2006-08-09		Fix bug on the formula for the calculation of the collimator jaw angles.
	2006-12-14		Minor updates on the plots of software architecture (triggered by discussions on the collimator control review of Dec. 18, 2006).
	2007-01-11		Revised version after the prototyping tests at the SPS.
	2007-02-24		First version submitted to EDMS approval system. Include comments from authors. Also add a scheme of the settings parameter space and a tentative list of “machine states” that are relevant for collimator operation.
	2007-03-07		Submission for Engineering check.
0.2	2007-07-02		Implementation of comments from the first round of checks. Add some considerations on machine protection functionality.
	2007-07-04		Submission for approval.
1.0	2007-10-16		Released version

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1. SCOPE

Controlling the LHC collimators and protection devices is one of the main operational challenges for the LHC. The overall system performance depends critically on the precision of single collimator positioning with respect to the beam as well as on the relative retraction of collimators placed at a distance of several kilometres apart (a well defined hierarchy has to be respected, e.g. between primary, secondary and tertiary collimators). Tolerances are as small as 20 μm for the most critical elements (synchronicity tolerance of 20 ms for jaw speed of 1 mm/s).

Safely operating such a complex system demands powerful application software for the collimator control. Amongst the most critical challenges, are the required position accuracy, the required synchronicity of movement, the interface with many other systems, the criticality of collimator position for machine safety and also the requirement of sophisticated functionality for beam-based optimization of the system (manual or automatic). The software must be able to cope with all these demands and also flexible enough to evolve according to the additional requirements from experience. The software should allow easy manipulation of the collimator settings during the LHC commissioning and a reliable and safe standard operation.

This document describes the architecture of the top-level application for the movement control of the collimators of type **TCP**, **TCSG**, **TCLA**, **TCTH**, **TCTV**, **TCL**, **TCLP**, **TCLI**, **TDI** and **TCDI** and defines its functionality and required interfaces. Other movable elements such as the beam dump diluter (TCDQ), the Roman Pots of TOTEM and the movable TCDD can be controlled by the same software to the extent that their control systems provide the same functionality as of the one adopted for the other collimators. Details for these devices will be discussed in separate documents.

After a brief review of the beam dynamics requirements, of the mechanical design of the LHC collimators and of the architecture of the control system, we will discuss the collimation operational scenarios (Sec. 2). The proposed architecture of the collimator application software is presented in Section 3. In Section 4, we describe in detail the functionalities that must be provided by the collimator software, with the required links to existing LHC application software and to the measurement systems. In Section 5 we suggest some advanced functionalities that could also be implemented.

2. INTRODUCTION

2.1 BASIC PRINCIPLES OF LHC COLLIMATION

Beam cleaning and passive machine protection is achieved by placing blocks of material (*jaws*) close to the beam in order to catch large amplitude halo particles or mis-steered beams. These "**collimators**" typically consist of two "jaws" whose positions and tilt angles must be properly adjusted according to the local beam properties (position, size, divergence). The system consists of 98 collimators [1], i.e. settings are required for 392 jaw positions and 82 transverse collimator tank positions.

The operational procedures for the collimator setup with beam have been defined and experimentally assessed with beam tests at the SPS in 2004 and 2006. The collimator control application must provide the required functionalities for single collimator controls as well as the possibility of managing the overall LHC system.

The experience from other machines shows that the operation efficiency can be greatly improved by automatic procedures for the collimator alignment. For the LHC such kind of procedures will be implemented by middle-level control systems (CSS units, see below) and not by high-level software. Control of these automatic procedures will be possible from the control room but details of the implementation are not discussed in this document.

2.2 BEAM DYNAMICS REQUIREMENTS AND CONSTRAINTS

The nominal collimator settings have been specified [1, 2] and will not be reviewed here. It is just noted that not only **the precise single collimator positioning** must be achieved but also **a strict hierarchy of relative collimator retractions** must be respected among elements placed all along the ring. For example, the tertiary collimators in the experimental insertions must always be retracted (in beam sigma units) with respect to the secondary collimators in the betatron cleaning insertion, which are located at longitudinal distances up to 23 km.

The collimation system must work in an integrated way with the LHC **protection systems** (transfer line, injection, dump). Protection devices have similar requirements in terms of single element positioning and relative retraction with respect to other elements along the ring. Most of them are in fact identical or based on the same mechanical design of the cleaning collimators and will be controlled by the same software. Here, we refer to all these elements as “collimators”.

Collimator settings are defined in terms of the local betatron beam size, $\sigma_i = (\beta\varepsilon)^{1/2}$ ($i \equiv x$, y), which can be converted in millimetres for known optics (β) and beam emittance (ε). **Normalized settings** are independent of the local optics and are therefore used to define the retraction of elements that are placed at different machine locations. However, in order to convert nominal normalized settings to millimetres, **the local beam position and beam size must be accurately known** at each collimator. This is a serious operational challenge that will require dedicated beam-based alignment procedures, to be repeated in case of major optics changes.

Without providing details of the operation scenarios and tolerances [2], we summarise here the main requirements and constraints for the collimation control:

- Large number of degrees of freedom (**> 450**) to control simultaneously;
- Precise absolute positioning accuracy with respect to the beam (tolerances are as small as **20 μm** for the most critical elements);
- Precise relative retraction of different elements all along the beam line(s);
- Synchronicity of movement for distant elements below **20 ms** (20 μm at 1 mm/s);
- Detailed knowledge of the local optics (beam position, beta functions) and of various beam parameters (energy, emittance, ...);
- Required optimization of setting-up time (improve the beam availability);
- Required link to various measurement systems to set up the beam-based adjustment procedures (BLM’s, BCT’s, ...)

2.3 RELEVANT ASPECTS OF COLLIMATOR DESIGN

A detailed description of the LHC collimator design goes beyond the scope of this paper and shall be found in dedicated publications [3]. We present instead the different core systems used for the collimator jaw movement and survey, which have direct implications for the design and the implementation of the collimator control software. All the collimators concerned by this document have similar components.

The collimator design adopted for the LHC is shown in Fig. 1. The figure shows the design of the LHC secondary collimator, which is used as a reference for most of the other collimator types. The collimators can be mounted at different azimuthal angles (*horizontal*, *vertical* or *skew*) by rotating the whole structure of Fig. 1 (horizontal collimator shown) without changing the support underneath (not shown in Fig 1). Each collimator has one or two "jaws" of variable lengths and made of different materials - Carbon composites, Tungsten or Copper - depending on the functionality. Jaw position and tilt angle relative to the beam are controlled by means of two stepping motors per jaw, which can be independently moved within a specified range (maximum tilt angle

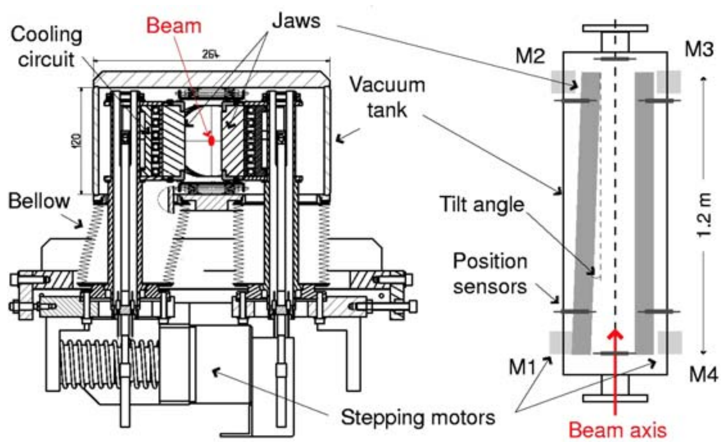

Figure 1: Schematic view of a horizontal LHC collimator. Front view (left) and top view (right) are shown. Each collimator has 4 independent motors, 4 resolvers that count the motors steps and 6 position sensors (LVDT's) for *direct* jaw position and gap measurements.

of ± 2 mrad). A fifth motor controls the transverse tank position and can be used to offer to the beam a clean surface after damage.

The LHC collimator is designed such that the position of the collimator jaws can be referenced outside of the vacuum tank and directly measured with precise position sensors. Six LVDT's (linear variable displacement transducers) will be used to measure jaw positions and gaps upstream and downstream. Four resolvers measure the angular rotation of each motor axis and effectively count the motor's steps. In total, **4 motor settings** and **10 position measurements** must be managed. Various temperature sensors will survey the heating of jaws and cooling water.

2.4 ARCHITECTURE OF THE COLLIMATOR CONTROL SYSTEM

The architecture of the middle- ("tier-1") and low-level ("tier-2") collimator control systems was presented in [4] and will be briefly summarized here. The system architecture consists of three distinct levels (*3-tier control*, see Fig. 2):

1. The lowest level consists of *Motor Driver Control*, *Position Readout and Survey* and *Environmental Surveillance*. Each collimator has these units.
2. A *Collimator Supervisor System* is used at the middle level to control and supervise up to 20 collimators, grouped depending on their location in the ring.
3. A central collimation application software is used to provide a coherent interface to all collimators of LHC ring and injection lines. This application will be used from the control room to control and optimize the overall system. The specification of this software is the subject of this paper.

2.5 OPERATION SCENARIOS

Without going in details through the list of foreseen use-cases for collimator operation [2], we distinguish here between the following operational scenarios for machine protection and collimator systems:

– **Setting up of the system: definition operational settings and their tolerances (beam-based calibration)**. In this phase, collimator experts are requested to setup the overall system and optimize its performance. The setting of each collimator must be optimized based on (1) local optics, (2) beam

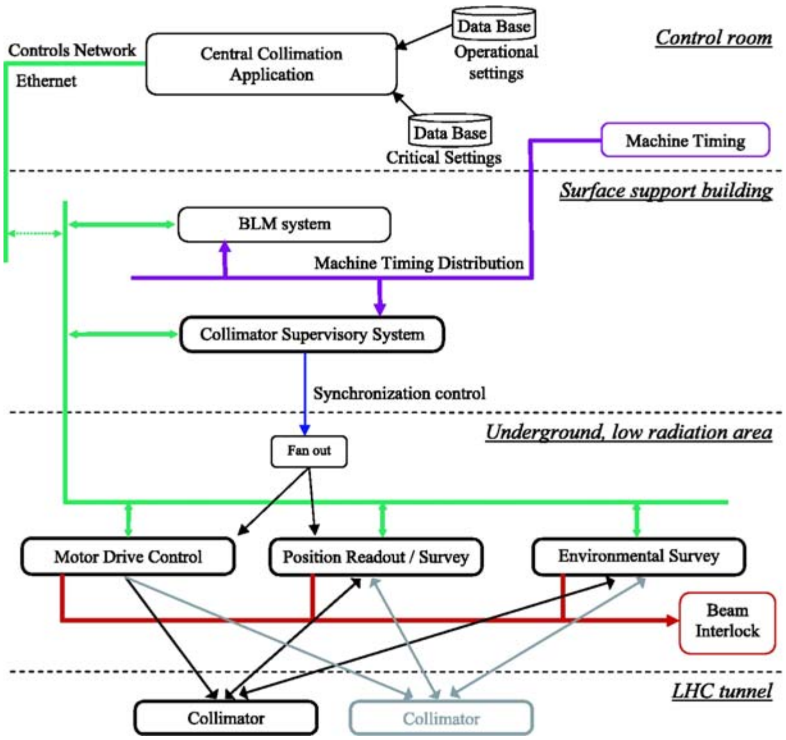

Figure 3: Architecture of the collimation control system.

parameters (energy, emittance, intensity, …), (3) machine modes (injection, ramp, squeeze, …) and (4) crossing and separation schemes. The outcome should be a series of **reference collimator settings** and their tolerances to be adopted during the standard operation, from injection to collision. It is noted that the beam-based reference settings can be achieved via manual or automatic procedures.

– **Standard operation for physics runs, with minor tweaking of system performance**. Once satisfactory settings are defined for all collimators, they have to be adopted during the standard operation of physics runs, possibly with minor modifications and tuning. For each collimator, the settings will be defined by functions of time whose execution will be triggered by predefined timing events. . **Limit functions** will define safe operational margins. **Synchronized trims** of all collimator settings must be done within each machine context (e.g. “move out injection protection devices at the end of the injection”, or “move in tertiary collimators during the squeeze”). **Monitoring** of relevant optics and beam parameters, of jaw positions and of jaw temperature should be carried out continuously for an early detection of abnormal or dangerous situations.

– **Calibration of position readout versus jaw position.** Remote crosschecks of the sensor calibration and re-calibrations of the readout signals must be possible. This is not part of the standard operation with beam. The calibration will be instead implemented under expert applications (low-level implementation).

3. COLLIMATOR SOFTWARE ARCHITECTURE

As discussed in the previous section, the collimator control will require dedicated software for the single collimator control as well as a global application for the management of the overall collimation system. In order to achieve the requirements, we propose here a software architecture that relies on the existing LHC Software

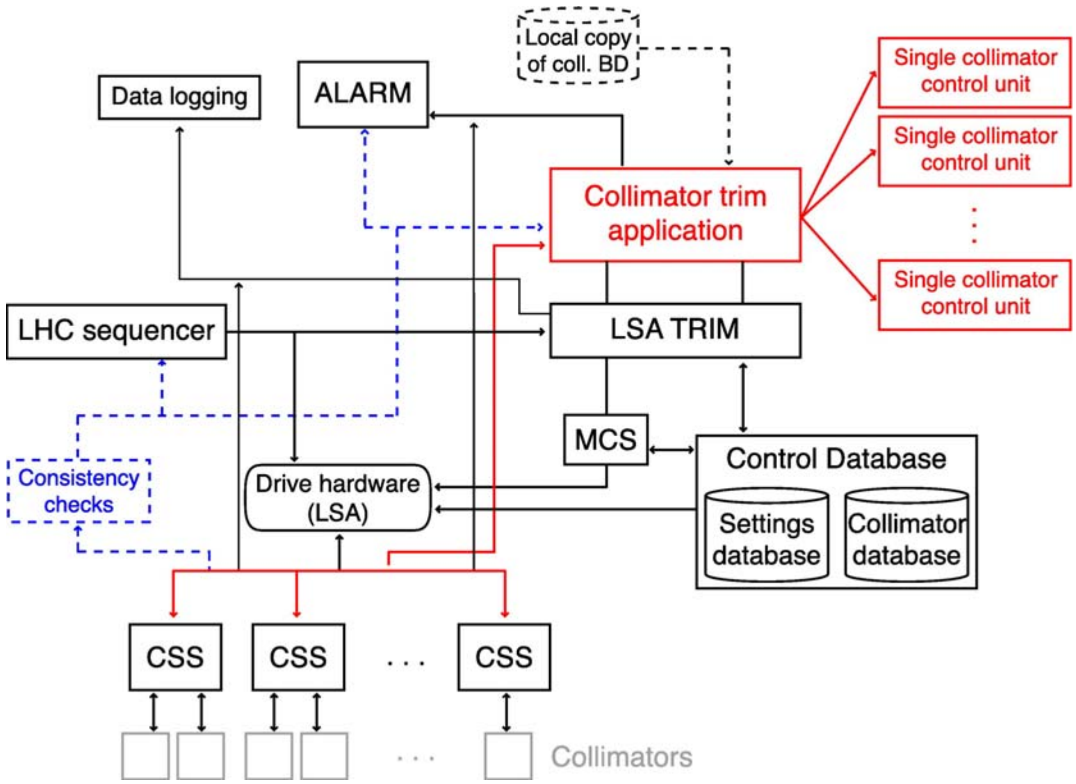

Figure 4: Proposed architecture of the software application for the collimator control.

Applications (LSA) environment. This is the control application software developed for the LHC and also adopted for most of the CERN accelerator complexes. Dedicated packages have been built to provide a common interface between the high-level application software and the accelerator equipment. We intend to exploit as much as possible the available software environment and to limit the newly developed code to the specific collimator requirements that cannot be met by what is available.

The proposed architecture for the collimator control software is shown in Fig. 4. Black boxes represent packages that are (or will be) provided by LSA whereas red boxes show dedicated software that has to be developed for the collimator control. A **master trim application software** must be developed for controlling the overall collimator system. The natural choice to send collimator movement requests to the middle-level, the collimator supervisory systems (CSS's), is to rely on the existing "**TRIM**" and "**Drive Hardware**" packages that will control most of the LHC devices. In addition, the collimator application must also be interfaced (1) to various **LHC databases**; (2) to the **LHC sequencer**; (3) to the **data logging system**; (4) to **the management of critical settings** (MCS) and to the **ALARM system**. Detailed requirements of these interfaces are outlined in the next sections.

The basic interfaces described above will also be used for several other LHC devices that are driven through **functions of time** and can therefore be considered as standard implementation to be adapted to some specific requirements of the collimation system (see details below). In addition, **single collimator control units** will also be needed to individually control each collimator. These units will be the main tools for the manual beam-based alignment of each collimator and must therefore provide the main functionality for the motor control and the sensor readout and also ensure the interfaces to the required measurement systems (BLM, BCT, optics). Direct trim of collimator movements without synchronization to the machine timing must be possible ("discrete" trims). This software can be used to define operational and critical settings for single collimators and to transmit these settings to the trim collimation software (see later).

It is noted that definition of reference settings can also be provided by **user-defined functions** without strictly requiring the beam-based alignment of each collimator. However, during commissioning and in early operation, manual adjustment of each collimator unit has to be envisaged. The full required functionality (set of motor movements, interfaces with dedicated measurement systems, etc.) must therefore be accessible to the operator. The master trim application should be flexible enough in the definition of reference functions (e.g., copy-and-paste between various elements, rescaling with local beam size, etc. – see next section).

It is noted that, according to the general LHC control philosophy, the collimator motor settings should not be controlled by direct links from the high level software to the collimator supervisory systems (CSS's) but rather through the TRIM LIBS functionalities within the LSA environment. The sensor readout can, on the other hand, be achieved by direct link to the CSS units.

Having seen the criticality of the collimator control for the machine safety, an application could be setup to perform **consistency checks** of the collimator position readouts and of the settings generated for the various collimators. This checks should be done in addition to the checks performed at lower levels (e.g. rejection of settings beyond mechanical constrains).

4. REQUIRED FUNCTIONALITY AND INTERFACES

Here, we outline the basic core functionalities that have to be provided by the master collimator software and by the single collimator control software, with particular emphasis on what is specific for the collimation system.

4.1 MAIN TRIM APPLICATION SOFTWARE

4.1.1 SCOPE

The main collimator control software must provide **trim functionality** for the overall collimation system within the LHC machine contexts and a global view of the system status. It should also provide the possibility of accessing each single collimator control unit (see next section). A general **system settings window** should be available and coherently show the relevant information and status of all collimators. Figure 5 shows the required **parameter space** of collimator settings. It should also be possible to select sub-groups of collimators, sorted by accelerator area (e.g. IR3, IR7, IP1) of by scope (e.g. tertiary collimators, injection protection).

LSA offers the required links to drive hardware functionalities, tools for function generation and editing, knowledge of machine context and beam processes (links with the timing), traceability and setting history, interfaces to other standard LSA packages. It seems therefore reasonable to adopt as much as possible what is available. The collimator control will require (1) definition of settings in units of beam sigmas; (2) generation/editing of functions for warning levels and interlock levels; (3) simultaneous editing of several functions; (4) simultaneous trims of collimator families (sub-groups of the whole system such as primary, secondary, tertiary collimators, etc.). Dedicated application will have to be prepared if not available within LSA.

4.1.2 SETTINGS IN UNITS OF BEAM SIGMA

A basic requirement is to define collimator settings in **beam sigma units** with respect to the position of the local closed orbit at each collimator. This is required, for example, to respect the hierarchy of settings (primary collimators at 6 σ and secondary collimators at 7 σ) but also to re-generate settings in case of changes of optics and/or beam emittance. In addition, the setting definition in sigma units also has clear advantages in the control of collimators with the same functionality: for example, operationally it will be more convenient to issue a command like "change the aperture of all IR7 secondary collimators by 0.2 σ" instead of changing 11 gaps by 40 to 80 μm depending on the location (7 TeV case).

The conversion to beam sigma units requires the knowledge of optics functions (Twiss parameters) and beam position at each collimator, together with mechanical parameters of the collimator (angle, length), beam parameters (energy, emittance). The parameter space is shown in Fig. 5. The control software should allow trimming at all the hierarchy levels. It is noted that **beam-based parameters** will be used and not the nominal machine parameters. Notably, the beam-based values of beam size and divergence will be used to calculate the collimator position and angle. However, the explicit dependence on optics Twiss functions (β_{coll}, α_{coll}) and beam emittance ($\varepsilon_{beam} \sim E^{0.5}_{beam}$) should be kept in the parameter hierarchy in order to enable setting scaling for different optics and energies. The coordinate system used for the four motor positions is discussed in detail in Appendix AI.

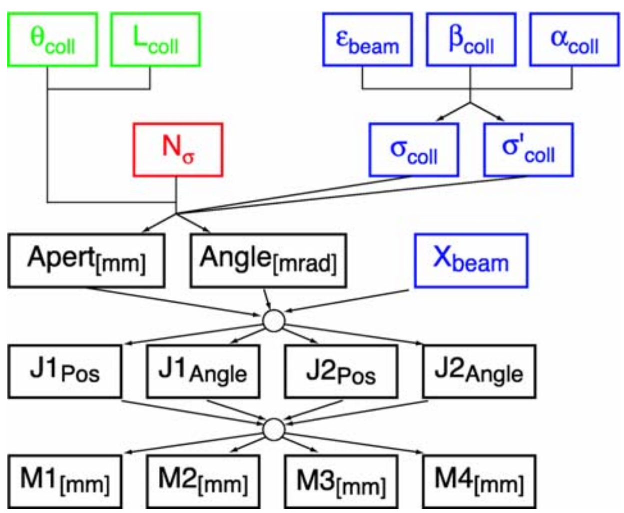

Figure 5: Parameter space for the collimator settings. N_σ is the normalized collimator aperture. Beam-based parameters (blue) and mechanical parameters (green) are needed to calculate the aperture and jaw angles. Only jaw corner positions are sent to the lower-levels.

4.1.3 TIME-FUNCTIONS AND SYNCHRONIZED TRIMS WITHIN MACHINE MODES

It must be possible to efficiently define **time-functions** for the collimator settings within each machine context and to trigger them **synchronously** for different collimators, possibly grouped according to different criteria (see next section). The setting functions will be loaded into the low-level controls and then triggered by predefined timing events, synchronously distributed by the CSS units.

Dedicated **function generation** and **function editor** tools must be available to provide various functionalities, such as **loading pre-defined functions**, **copying functions** defined for one collimator and **pasting** them to another collimator, assigning functions to a collimator group. **Saving functions** as reference and **loading** existing reference functions must also be possible.

The function-based setting generation and trim is a standard operational requirement for many LHC devices and is provided by LSA. The existing LSA-TRIM packages should be adopted for the collimator control and extended to meet the following requirements: (1) **simultaneous editing and trimming of multiple functions** and (2) selective choice of different **collimator families** (see next section). Notably, (1) will be used to edit settings, warning levels and dump levels for each collimator within a machine context, as shown in the illustrative example of Fig. 6. These functions shall be treated in the same way by the top level (same parameter space of Fig. 5 applies to all functions types). Note that typically the interlock thresholds and the warning levels are not symmetric around the settings (e.g. relative setting of the secondary collimators with respect to the primary collimators) and hence 5 distinct functions must be generated for each device.

Relevant **machine contexts** that might require different collimator settings are: (1) Setup/magnetic tests without beam (all collimator out); (2) Pre-injection ("parking") settings; (3) injection; (4) flat-bottom (circulating beam at injection energy); (5) energy ramping; (6) flat-top (circulating beam at 7 TeV with injection optics); (7) squeezed optics; (8) beam in collision (no separation). Within each machine context, the collimator settings will depend on the beam intensity, on the beam energy and on the beta* at the various IP's.

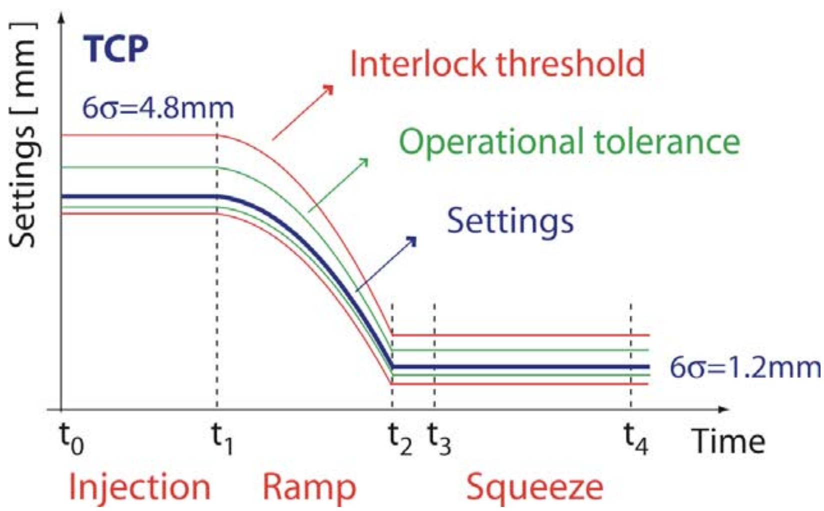

Figure 6: Qualitative example of settings, tolerances and critical interlock levels for a primary collimator in various machine contexts.

4.1.4 COLLIMATOR GROUPING

Simultaneous collimator driving within a machine context is mandatory and must therefore be ensured for one or more **groups (or *families*) of collimators** (by accelerator areas or by functionality). The main relevant collimator families are primary (TCP), secondary (TCS) and tertiary (TCT) collimators, active beam absorbers (TCLA), physics debris absorbers (TCLP), injection protection devices (TCLI, TDI), TCSG in the dump regions, beam scrapers (TCSH) and transfer line collimators (TCDI). Each of these families can be further broken down into sub-families according to the line or to the beam (e.g. secondary collimators of IR7 and/or IR3, acting on beam 1 and/or beam 2) and also according to the azimuthal orientation (horizontal, vertical or skew type). Settings generation and trim must be possible within each family or sub-family through appropriate **enable/disable** tools. **Commissioning scenarios** when sub-sets of the total system will be need shall also be handled in a similar way.

An **example** that illustrates the required functionality for function generation, collimator grouping and synchronous motion triggering, is the following: bringing the tertiary collimators of IR1 and IR5 in their operational settings during the betatron squeeze. This operation requires an efficient setup of the following functionalities:

- Group the collimators concerned (four per beam: TCTH and TCTV at IR1 and IR5);
- Depending on the beta* values, the betatron cleaning collimators and the dump protection devices might also required to be grouped and simultaneously moved;
- Define for each collimator the required time-dependent movements. Note that (1) normalized gap values are the same for all collimators but a rescaling to the local beta functions is required; (2) the gap shifts required to follow the orbit during the crossing bumps are different for horizontal and vertical collimators; (3) the two IP's are not symmetric because the crossing schemes are different;
- Synchronously with magnet powering, the sequencer must trigger the movements of the concerned elements according to the defined function(s).

Prerequisites: operational squeeze procedure well defined; crossing and separation bumps well defined; local optics at the collimators known; well defined procedure agreed for the number of steps of collimator movements.

4.1.5 STOP-ALL / ALL-OUT / CANCEL-LAST FUNCTIONS

In addition, the top level collimator software must provide the functionality of **aborting the undergoing collimator movements** (possibly for selected families) and of **moving the collimators to the previous settings or to a predefined "parking" position**. This functionality must be available for the overall system or for collimator families. For example, if during the setup of tertiary collimators abnormal beam losses are seen, one must be able to stop the undergoing movements of the selected elements to cross check or revise the target values before a beam dump is triggered or a quench is induced. Experience from other accelerators suggests this kind of functionality would be very profitable to avoid downtime from collimator-induced quenches during setup.

4.1.6 SETTING OF ADDITIONAL OPERATIONAL PARAMETERS

The top-level application must be able to control the various parameters of the collimator controls that are not considered as operational settings (non-frequent changes only, scalar values and not functions). The **jaw speed** and the **transverse tank positions** are two key examples of these "configurable settings" and they can be handled by LSA. Note that the speed is a parameter of the jaw and has to be the same for the two motors that move the jaw edges.

4.1.7 TRIGGER ITERATIVE MOVEMENTS TO REACH A REFERENCE POSITION

If for some reason (e.g., step losses) a target position is not reached after a movement command, one should be able to re-trigger a movement to compensate for the difference with respect to the desired position. This functionality is in principle simple (measure the difference and generate for all concerned collimators the "missing" steps) and could be introduced in the master collimator software.

4.1.8 INTERFACES TO THE LHC SEQUENCER

When the reference settings are defined for each collimator within all machine contexts, it must be possible to drive the global system through the **LHC sequencer**, which will automatically drive most of the LHC operational devices through the various machine states. As for other equipment, the sequences must be able to load collimator settings functions and to trigger them. The required protocols for the communication between collimation system and sequencer must be defined. Notably, (1) the **system states** (e.g. "Moving", "Request done", "Functions armed", ...) and (2) the warning/error messages (e.g. "Jaw temperature too high", "Inconsistent measurements of jaw positions", ...) must be defined.

4.1.9 INTERFACE TO MANAGEMENT OF CRITICAL SETTINGS (MCS)

Dedicated software is being built to ensure the integrity of settings and parameters of LHC devices critical for the machine safety. This is referred to as the MCS (Management of Critical Settings) [5]. The detailed implementation of this system is being implemented and is not discussed here. The collimator system will heavily depend on the MCS functionalities because most of the system parameters are critical.

It is noted here that the **management of critical settings must be decoupled from the application software for the collimator control**. The definition of operational settings, operational tolerances and limit functions for dump thresholds will be under the responsibility of the collimator and machine protection experts, who will provide the settings to be loaded into the hardware. Hence, the **safe management of critical settings and their distribution to the concerned parts (database, lower level) is not under the responsibility of the collimator application software and will be taken care of by the MCS within LSA**.

The collimator application must provide the functionality to define for each device the **limit functions** for interlock thresholds, as discussed in Section 4.1.3, which will then be handled by MCS. The parameter space of Fig. 5 applies to interlock levels as well as to operational settings: function generation in beam sigma unit will be used also for critical functions. It remains to be decided whether the digital signature required by MCS to ensure data integrity [5] will be done also at top level of the parameter hierarchy (N_σ) or only at the level of single motor settings that are sent to the hardware (M1, M2, M3 and M4 in Fig. 5). It is noted that **the discrete beam based parameters** are also critical for safety and must then be managed within MCS.

4.1.10 SAFETY ASPECTS OF THE COLLIMATOR APPLICATION

The collimation system has a critical role for the machine passive protection in case of major beam failures that could cause significant downtime (massive quench of superconducting magnets or even permanent damage of sensitive components). A well-defined setting hierarchy must be respected among the various collimator types to ensure the required performance [1]. If the optimum condition is not maintained, the cleaning performance of the system and/or the machine passive protection are compromised. The occurrence of dangerous situations is often difficult to detect form beam measurements because in most cases wrong settings only become apparent after failures, when it is too late.

Therefore, once good settings and safe interlock thresholds are defined for all the collimators, the cleaning and machine protection functionality of the system will **rely on an accurate survey of the collimator jaw positions**. This will be achieved with high-accuracy LVDT position sensors, as mentioned in see Section 2.3. The collimator low-level supervisory systems (Fig. 3) have direct links to the LHC beam interlock system. A beam dump will be triggered if the measured jaw positions or the collimator gaps are beyond predefined tolerance windows, which will be defined for each machine mode as functions of time (as illustrated in Fig. 6). Depending on the collimator type, interlock thresholds will be assigned to the position of each motor axis and/or to the collimator gap. In addition, the temperature of collimator components and the status of critical elements (motors, interlocked sensors, ...) are surveyed and can also trigger beam dumps.

The machine safety will therefore not be based on the reliability of the top level collimator control software. This software will be used to allow authenticated expert operators to define the threshold interlock levels and to ensure that consistent settings are defined for the overall collimation system. The critical parameters needed for the generation of settings (like the beam based parameters, see Section 4.1.2: blue boxes in Fig. 5) and the threshold functions will be safely stored into the setting database and will be managed through the Management of Critical Settings. Obviously this implementation does not protect the machine against errors of operators who might define wrong interlock thresholds.

In order to further increase the reliability of the system, one could add to the top level redundant software, independent from the main collimator application, to perform **sanity checks** of the settings for the overall system. In addition, consistency checks could be performed to assess the integrity and the consistency of the jaw position measurements (e.g. to check if the direct gap measurement is consistent with the difference of the two jaw positions). We also mention that the option to redundantly generate settings as a function of the beam energy and of the minimum beta* is under investigation. This would be a low-level implementation to independently verify the correct execution of the time functions at the CSS level during critical machine modes like the energy ramp and the betatron squeeze [6].

4.2 APPLICATION FOR SINGLE COLLIMATOR CONTROL

4.2.1 GENERAL SCOPE

For each collimator, the single control units provide the basic functionalities to trigger **motor movements**, to readout positions and survey sensors and the interfaces to the various LHC measurement systems required for the **beam-based collimator set up**. This will need a simultaneous **on-line display** of the BLM signal and of the jaw positions, as discussed in [7]. At some later stage of the LHC commissioning it is foreseen to replace manual collimator alignment with automatic algorithms for the beam-based optimization of the overall system. However, performing automatic procedures will not be available in early commissioning and in any case the control of single collimators will certainly be required. It is therefore necessary to set up dedicated software for the **single collimator control**, which provides a convenient environment for the determination of the relevant beam-based parameters.

In order to better illustrate the functionalities discussed in this section, Appendix AIII present the collimator application that was successfully tested during the collimator tests with beam at the SPS (2006).

4.2.2 MOTOR POSITION CONTROL

The application for the single motor control must ensure the full control of the 4 stepping motors that control jaw positions and tilt angles. The operator must request the **desired movements in millimetres** or, alternatively, in **units of beam sigma**. **Absolute settings** with respect to the nominal beam position (collimator centre) must be used at the top-level. The conversion to the corresponding motor step count should be carried out at the lower levels. In order to provide a large operational flexibility, we propose to have the following options to move the collimator jaws:

– Definition of **absolute jaw positions and angles**. This is the typical request that is needed once the reference settings are defined - “go to reference”.

- **Increment/decrement steps** (position and/or angle). Experience shows that, during setting up, it would be extremely useful to define a given step of jaw position and angle and just trigger +/- variations of the specified amount. One could also specify number of time and waiting time for repeating incremental several consecutive times.
- **Direct control of corner edges**. Direct control of number of motor steps for the four motors independently should be possible.
- **Save/load reference settings** for different machine contexts.

Similarly to what has been discussed for the master trim application, also at the single collimator control unit the "**Stop movement**", "**Revert previous settings**" and "**Move all out**" functionalities should be provided.

If already defined in the operational database, **tolerances** and **critical settings** should be displayed and possibly warnings and/or **software inhibits** should be setup to prevent collimator movements beyond tolerances. These settings "sanity" checks at software level should also take into account **mechanical constraints** such as switch positions, maximum jaw tilt angle, superimposition of jaws, etc (this feature is for operator convenience only: hardware protection against wrong settings is implemented independently in the low-level system).

4.2.3 READOUT OF POSITION AND ENVIRONMENTAL SENSORS

The application must provide a clear on-line display of the relevant measurements provided by the Position Readout/Survey and Environmental Surveillance units (see Fig. 3). There is an intrinsic redundancy in the measurements see Section 2.3) and the displaying should not be complicated by un-necessary information. The basic readout panel should provide the readings of all relevant position measurements and also the jaw temperatures at a frequency of at least 1 Hz. It should be possible to choose the sensors to display, for example through appropriated check boxes, and also to perform basic operations such as calculate the gaps and the jaw tilt angles from the positions of the jaw corners.

The **lower level** must provide to the high-level the readout values in **physical units** in the same coordinate frame used for the settings (see coordinate definitions in the appendix). **Conversion** between various coordinate systems (e.g. 2 jaw corner positions ↔ jaw positions/angles) and to beam sigma units should be done at the top-level (the latter requires knowledge of optics and beam parameters not available at lower levels).

4.2.4 EMPIRICAL DEFINITION OF BEAM-BASED COLLIMATOR PARAMETERS

The collimator control software must enable authenticated authorized operators to **define for each collimator the beam-based parameters** needed to generate the settings in millimetres from the normalized beam sigma units (see settings parameter space of Fig. 5). These parameters must be stored as **critical settings** in appropriate database and require the MCS functionality. The empirical definition of these parameters, notably of beam position and size at the collimator, relies on dedicated procedures [7, 9] that, amongst other, require an on-line display of beam loss signals at each collimator and of beam current measurements (see Section 4.2.5).

4.2.5 REQUIRED ON-LINE DISPLAYS

4.2.5.1 BEAM LOSS MONITORS

The alignment procedures foreseen for most LHC collimators rely on the on-line measurements of dedicated beam loss monitor systems installed in the vicinity of each collimator [4]. It is foreseen to have two different beam loss monitor (BLM) types at each collimator in order to cover a wider dynamics range. The application software must ensure the following functionalities.

- **On-line display** of the BLM signals at frequencies of the order of **a few Hz**, as required by the manual adjustment procedure. Signals from both BLM types should be given.
- Possibility of **choosing the BLM(s)** to be displayed. This option is necessary in case of failure of some monitors or if experience suggests that other BLM locations are more sensitive than the ones originally foreseen.
- If basic data logging is not provided elsewhere, the collimator software should do this. See dedicated section.
- Perform basic operation on BLM signals (sum, difference, ratio, average, ...) and plot them.
- Envisage faster acquisitions for dedicated studies.

Graphical tools have to be developed for an on-line display of **synchronized** jaw positions and BLM data. The efficient beam-based alignment will rely on this (see [4], where the procedure is illustrated starting from data analysed *off-line*).

4.2.5.2 GRAPHICAL DISPLAY OF COLLIMATOR SURVEY MEASUREMENTS

Convenient graphical tools to display on demand **requested settings**, measurements of **jaw positions** (from various position sensors, in various coordinate systems), single motor positions **and jaw temperatures** should also be provided. Tools to calculate sum and difference of measured positions should also be provided to infer, for example, the average jaw position and the collimator gap from the measurements of single jaw corners. The information on the **statistics of lost steps** for each motor should also be available on demand.

The status of the **10 collimator switches** (switches of full-in and full-out positions of 4 jaw corners, 2 anti-collision switches) and the status **2 tank switches** should also be graphically displayed.

4.2.5.3 BEAM PARAMETERS AND OPTICS MEASUREMENTS

For diagnostics purposes or for possible future implementations, it should be possible to access at frequencies of about 1 Hz the following measurements:

- **Beam energy**
- **Beam emittance** (get upon request latest measurement results)
- **Orbit**. Possibly, one could get estimate of beam position at the collimator from close-by BPM's (interpolation required).
- **Beta function, optics information**. One should get the last measured value or the projected value from other reference locations or from the optics model.

4.2.5.4 ADDITIONAL REQUIRED MEASUREMENTS

Beam current measurements must also be accessible. This information (1) will be regularly used to setup the injection line collimators [8] and (2) can be used to measure the local beam size in case of destructive full beam scraping [3] (low-intensity beams). Therefore, the software could provide the option to display also the BCT measurements alternatively (or in parallel) to the BLM displaying if this is not available from other applications. Existing tools for the beam current acquisitions could also be used.

The display of an appropriate **detector background signal** will be required for the empirical tuning the collimators position, in particular of the tertiary collimators that are located at either side of the quadrupole triplets. This should also be available.

4.2.6 ADDITIONAL FEATURES

The experience during the SPS test for the single collimator control proved the usefulness of the following features, which should also be envisaged for the LHC: (1) local history of discrete trim; (2) graphical display collimator layout, coordinate system and notation of position and angle signs; (3) possibility of displaying the database information for the collimator that is being controlled, including beam based parameters and optics and nominal optics; (4) calibration tool for the sensor readout. The item (4) will not be needed at the LHC if this functionality will be available as a lower level expert application.

4.2.7 SIMULTANEOUS CONTROL OF SEVERAL COLLIMATORS

It must be possible to operate several collimator control panels in parallel. This will be required to set different elements relative to each other, for example by generating a “flat surface” of the beam halo at one collimator and align other collimators (possibly at far locations in the ring) to this reference. We also proposed procedure to measure the beta functions at different collimators [9]. In addition, simultaneous beam-based optimizations for the two beams must be possible.

4.3 DATABASE REQUIREMENTS FOR THE COLLIMATION SYSTEM

An **operational collimator database** is required to provide relevant information on the collimators and to store the reference collimator settings. We can distinguish between the following different kinds of required information, as listed below (see also Table 1). See also Appendix II for the class-like diagram of the collimator device.

– **Operational collimator information**, such as (1) ring location, (2) configuration for the connections to the CSS units, (3) jaw azimuthal angle, (4) sensor calibration curves, (5) name (or ID) of the BLM(s) assigned to each collimator, (6) nominal optics functions… These parameters are quasi static and are normally not changed during operation. However, in some cases it must be possible to access or change the standard setting (e.g., if a dedicated BLM is broken, then one must be able to change the default link to it).

– **Settings parameters**: (1) Jaw positions, (2) jaw tilt angles, (3) jaw speed, (4) transverse tank position. Jaw positions and angle could be equivalently expressed in physical (mm, mrad) and normalized (σ, σ') units.

– **Low-level calibration constants**, maintained by the hardware owners.

– **Nominal optics functions at the collimator.**

– **Beam based calibration data,** such as (1) local values of beam position and (2) beta functions (beam size) at the collimator location, (3) relative offset between beam and collimator centre, (4) (possibly) reference BLM readings … This includes various kinds of parameters that will be inferred from beam-based collimator setup and kept as a reference for various purposes. For example, one will need to store the beam positions at each collimator to be reloaded at the next fill. Another example is that the knowledge of the beam sizes at each secondary collimator (TCS) allows rescaling the settings to all TCS’s after a suitable configuration is found for one TCS.

  It is clear that this database requires **regular updates** in case of optics changes. The beam-based “optimized” parameters do not necessarily agree with the nominal optics functions and must be stored separately. An **on-line optics model** could certainly help if it could provide reliable optics function all along the LHC (e.g. propagation of a the beta-beating to collimators of a line)

– **General information for offline use**, such as (1) jaw flatness, (2) results of auto-retraction measurements, (3) various results from hardware commissioning,

(4) positions of mechanical stops and switches, (5) **statistics of lost steps**... These parameters are not regularly used during operation but must be accessible upon request, e.g. in case of failures of some components (after a major sensor failure we may want to go on the switches to cross-check the position readouts).

Parameter	Type	Source
Name, angle, material, length, **beam**, **family**, **line** (IP num.,transfer line)	static	Hardware owner
Longitudinal ring position, nominal optics ($\beta_{x,y}$, $\alpha_{x,y}$, $D_{x,y}$, ...)	static	Layout DB → MAD
Mechanical plays, switch/stop positions, sensor calibrations, BLM-ID	static	HW owner (metr.)
Jaw positions, jaw angles, jaw speed, tank position [BOTH mm ↔ σ]	**parameter**	**OP settings**
Beam-based parameters ($\sigma_{x,y} \leftrightarrow \beta_{x,y}$, centre, reference BLM threshold)	Beam-based	Beam commissioning
Reference settings + tolerance + critical settings (vs. machine context)	Beam-based	Beam commissioning
Statistics of faulty motor/sensors		HW owner

Table 1: Database information required for the collimation system.

The above list of parameters conceptually belongs to different types of databases ("configuration", "settings", "optics", "static" information). The existing databases that will be used at the LHC will be able to cope with our requirement and there should be no need to build-up a dedicated collimation database. The exact splitting of information among the various databases will be worked out in detail.

The setting up and maintenance of the "static" collimator database will **be under the responsibility of the hardware owners** (collimation, injection, dump projects).

It is also noted that **links** from the collimation application to the relevant databases must be efficiently available. For example, the conversion between settings in millimetres or in unit sigma requires information on the (1) machine mode or context (beam energy, optics, ...), (2) static collimation information (azimuthal tilt angle), (3) beam-based parameters (local beam size and position).

4.4 DATA LOGGING

Data logging and post-mortem are foreseen for all the relevant information. Notably, **for each collimator and protection devices** the parameters listed in Tab. 2 must be saved (and backed up) at acquisition frequencies ≥**1 Hz**. For each measurement set, the corresponding synchronized time stamps must also be provided. It is noted that the possibility of faster data acquisitions should be available for special runs (e.g., faster acquisitions of LVDT and BLM readouts to study rise and decay times of beam loss spikes). We assume that the **history of collimator settings and parameter changes** is also saved. This must include also calibrations of position sensors and changes of jaw speed. Statistics of motor faults should also be saved.

In addition to the standard logging, for on-line data analysis it will be useful **to save locally** (at the tier-2 and/or tier-3 levels) the interesting parameters in a dedicate storage space. We propose to save the parameters listed in Table 2. Assuming a total of approximately 100 collimators (rings and transfer lines), the required storage disk space is approximately 22 kb/s (acquisition at 1 Hz), e.g. about **2 GB per day**. In addition, for machine development studies, **dedicated faster acquisitions** should also be possible for specific beam parameters of interest, such as local and distributed beam losses from the BLM system, beam current, beam orbit etc. Mechanical collimator movements are slow compared to the beam timescale and hence acquisitions as fast as 0.5 Hz should be sufficient.

Parameter	Number	Format
Motor steps	4	Double
Resolver readout	4	Double
LVDT's readout	6	Double
Jaw/water temperature	5	Double
Motor/LVDT/Resolver status	14	Integer
Switch status	10	Integer
Beam loss monitor (BLM)	2	Double
Beam orbit	2	Double

Table 2: Logging requirements for collimators and protection devices.

4.5 ERROR/WARNING HANDLING (INTERFACE TO ALARM)

A detailed list of use scenarios and error states has been worked out in [2] and will not be discussed here. The high-level software must be able to recognize the system states and display to the operators the error and warning messages received from the low level in case of problems. Additionally, loss of synchronicity of movements should also be reported. Each collimator should have a STATE flag that provides a green or red light (or equivalent appropriate colour coding, possibly with intermediate "yellow" warnings) depending on the status of each component. The status flags should appear in the master trim collimator application and also be transmitted to the LHC sequencer to inform the operator about the collimator state (standard operation).

Errors and warnings should also be sent to **LHC sequencer** and **ALARM system**. Links to the **software interlock system** also need to be defined. Even though redundant checks can be envisaged at the top level, reliable software interlocking of critical parameters will not rely of the interactive collimator control application but will be based on lower level implementations.

4.6 ADDITIONAL SOFTWARE FOR INDEPENDENT CONSISTENCY CHECKS

It has been already mentioned that jaw position and gap measurements will rely on a redundant set of sensors mounted on each collimator. Motor settings, resolver measurements, jaw position measurements and gap measurements must consistently agree within specified tolerances, otherwise a warning/error messages should be issued. We propose to have dedicated software to perform cross-checks of the performed measurements, including the required interfaces as discussed above.

5. ADVANCED FUNCTIONALITY

5.1 SCOPE

We outline here a proposed list of ideas for advanced functionalities that could be implemented in the application software for the collimator control. This goes beyond the basic requirements needed to operate the system but could nevertheless provide valuable outcomes, in particular if available during the system commissioning. The following proposals have been worked out based on the experience from the previous collimator tests with beam. The experience with the LHC will suggest additional functionalities.

5.2 BEAM CURRENT VS. JAW POSITION TO MEASURE LOCAL BEAM SIZE

We have already emphasised the importance of knowing the local beam position and size at each collimator. A measurement of these two important parameters with circulating beam can be achieved by fully scraping the beam with one collimator jaw. If the beam profile is Gaussian, a fit of the BCT measurement versus jaw position allows calculating local beam position and size, and hence the local beta function. This destructive method is precise but only useful if the optics is well reproducible from fill to fill and for different beam intensities (measurement only possible at low intensities). This method was successfully tested at the SPS in 2004 and in 2006 with a prototype of an LHC secondary collimator. An example is shown in Fig. 7.

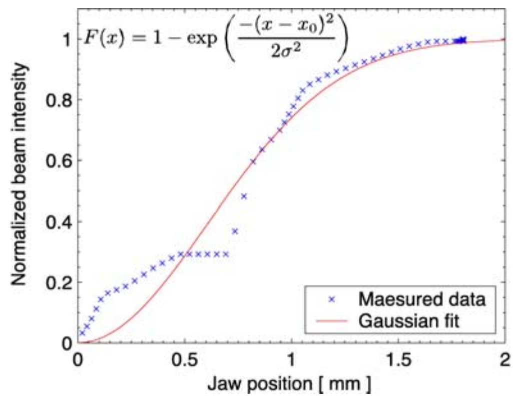

Figure 7: Measured beam intensity versus collimator jaw position during beam scraping (blue) and corresponding Gaussian fit. Measurements carried during the 2004 SPS beam tests [7].

In order to carry out the proposed measurement, it is required to have (1) simultaneous measurements of BCT (acquisition frequency of at least 100 Hz) and jaw positions: (2) dedicated fitting functionality with Gaussian functions; (3) dedicated plotting tools for a prompt feed back from the control room; (4) basic functionality to save/load data and plot.

5.3 DISPLAY AND ANALYSIS OF MICROPHONE MEASUREMENTS

Acoustic and vibration measurements have been proposed as a way to detect beam impacts on the collimator jaws in case of accident [10]. For this purpose, a few microphones will be installed close to critical collimators to record the acoustic noise level in the collimator vicinity. Dedicated software should be set up to readout the microphone measurements. Measurements will not be carried out on a regular basis but in two cases: (1) upon request, in case of specific tests and (2) in case of failure. The case (2) requires continuous data acquisition and a buffer with threshold trigger. This must be setup at the low-level controls. Instead, the case (1) required the possibility of achieving for a few seconds data at very high acquisition frequencies, up to 50 kHz. Details of this implementation are yet to be finalized.

5.4 GRAPHICAL TOOLS FOR ON-LINE DATA ANALYSIS

If data logging of jaw positions and the BLM signal is available at the top-level (retrieved from the logging system itself or from dedicated acquisition), graphical tools could be provided for the study of correlation between jaw positions and BLM spikes, as it is used for the beam-based alignment.

5.5 LOCK COLLIMATOR GAP CENTRE TO BPM MEASUREMENT

A **slow feedback** could be set up at the top-level to move the collimator jaw centre such as to follow the beam orbit. This could be useful to track slow orbit changes during long beam stores. This functionality will require accessing on demand the BPM measurements and possibly some interpolation tools to infer the beam orbit at the collimator(s) from the measurements of several BPM's (beam position measurements are not integrated into the collimator design and one should therefore use BPM's close-by). However, the principle feasibility of this method has to be demonstrated because, if the orbit feedback is operational, it will keep the orbit to the same BPM readings. Slow drifts, e.g. induced by transverse variations of the quadrupole position with respect to the collimator centre, will not be measured by the BPM's.

6. REFERENCES

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7. APPENDIX I: NOTATION FOR POSITION AND ANGLE SETTINGS

We define here the coordinate system and the sign notation for positions and tilt angles of the collimator jaws with respect to the circulating beam. This notation must consistently be used to transmit the movement requests from the collimator software to the low-level electronics via the middle-level collimator control system. The metrology measurements carried out at the company and the sensor calibration performed at CERN must be converted to the appropriate beam coordinate system.

Figure A1 shows the standard Cartesian coordinate systems used for the LHC beam 1 (blue) and beam 2 (red). These are right-handed coordinate systems commonly used to describe the dynamics of particle beams. The horizontal axis points outwards for beam 1 and inwards for beam 2. The collimator azimuthal angles as they appear in the LHC mechanical layout database (see [1] for the complete list of devices) are defined according to this notation (positive azimuthal angles are measured clockwise in the *x*-*y* plane).

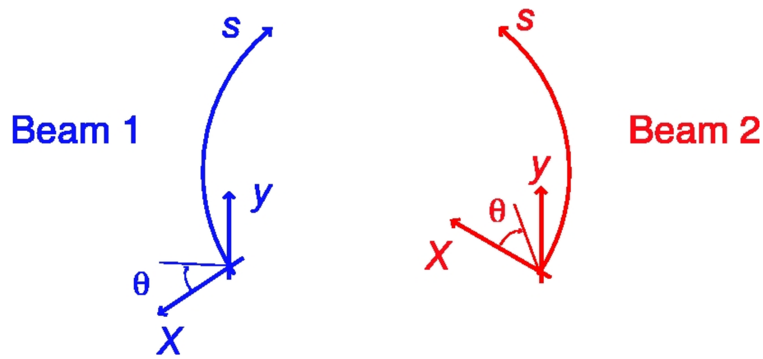

Figure AI.1: Coordinate systems for the LHC beam 1 and beam 2 used for the definition of the collimator azimuthal angle (see also Fig. AI.2).

It is noted that the notation of Fig. AI.1 does **not comply to the standard coordinate system used for the LHC beam orbit**, which uses instead for both beams a common *x* axis pointing outwards (beam 2 has an opposite x axis with respect to Fig. AI.1). For an efficient beam operation **the collimator control must be based on the beam orbit notation**. The appropriate conversions will be taken care of by the various collimator control level in order to make sure that (1) the settings sent by the top-level are correctly converted into the motor step number and (2) the readout positions from the low-level comply to the beam notation.

Figure AI.2 shows the naming used for the collimator jaws. The “upstream”, “downstream”, “left” and “right” labels are referred to the direction of the incoming beam. Correspondingly, the “jaw corners” are labelled “L-U”, “L-D”, “R-U” and “R-D”. Same labels must be used for the corresponding motors, resolvers and LVDT’s mounted on each collimator. In Figure A3, the notation of the jaw longitudinal tilt angles is defined. Both for the left and for the right jaws, positive tilt angles correspond to upstream jaw side close to the beam axis than the downstream side.

It is noted that the metrology measurements are carried out before assigning the collimator position in the ring. Measurements are referred to the measurement bench at the company and use different coordinate systems and labels than the beam systems adopted here. Therefore, as soon as a collimator is assigned to a given machine location, the metrology measurements and the sensor calibration should be changed to match the beam frame.

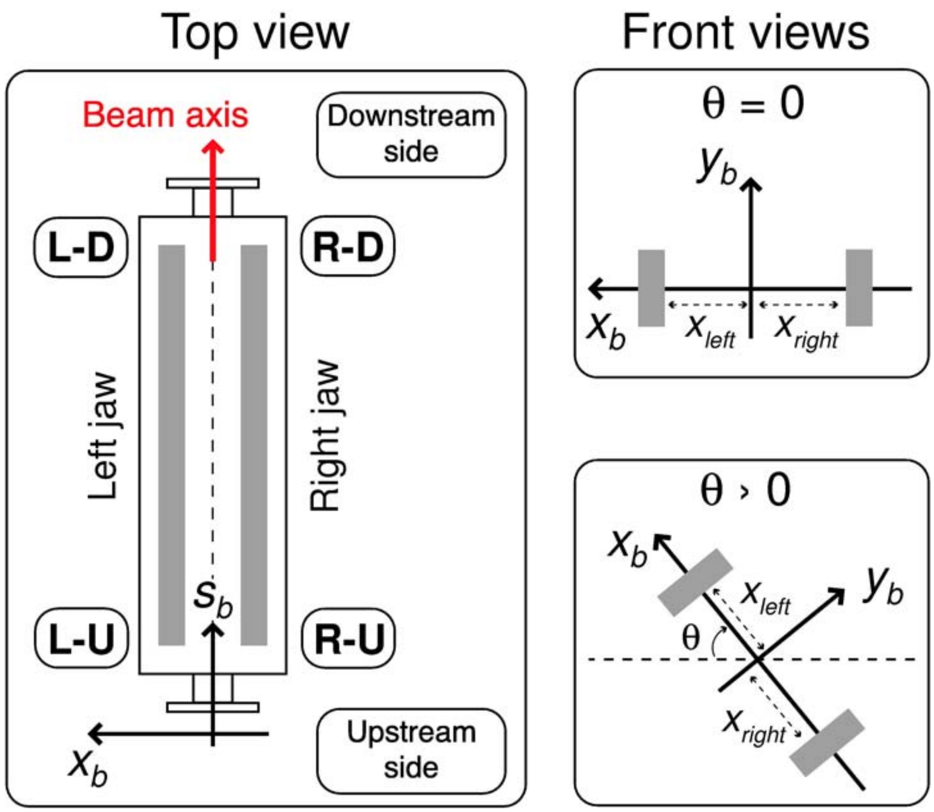

Figure AI.2: Naming conventions for the collimator jaw sides, where motors and position sensors are installed. Top (left) and front (right) views are shown.

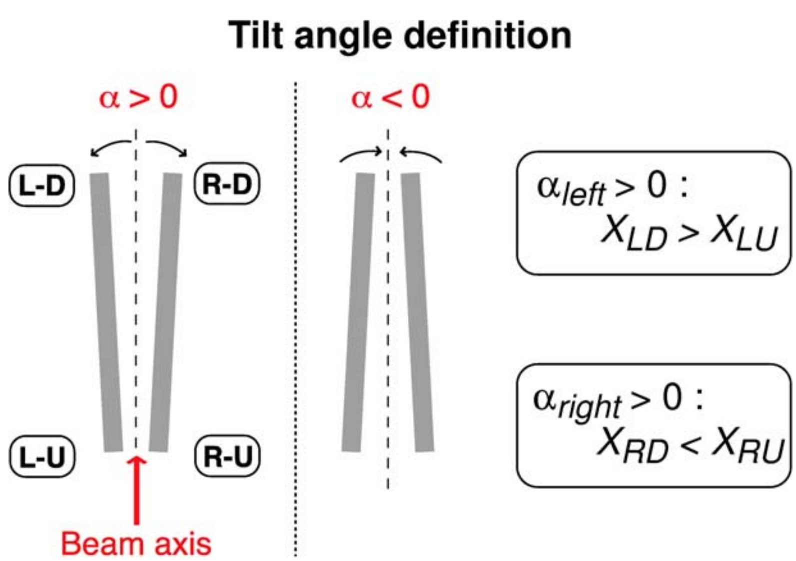

Figure AI.3: Sign notation for the definition of tilt angles of the collimator jaws. A positive tilt angle corresponds to a jaw with upstream side closer to the beam axis than the downstream side.

We outline here the relevant formulae for calculating average jaw positions (x_{left}, x_{right}) and tilt angles (α_{left}, α_{right}) with respect to the beam axis. By construction, these definitions do not depend on the collimator azimuthal angle, θ, because the jaw movements are always 1-dimensional in the frame of the vacuum tank (see right part of Fig. A2). We also remind that the positions of the various jaw sides are mechanically constrained within the following boundaries,

$$-5\ \text{mm} \le x_{LU}, x_{LD} \le +30\ \text{mm},$$

$$-30\ \text{mm} \le x_{RU}, x_{RD} \le +5\ \text{mm},$$

where the given positions ± 30 mm and ± 5 mm correspond to the nominal positions of the jaw switches for the standard TCS/TCP collimator design is considered (special design collimator might differ slightly). The (signed) variables x_{LU}, x_{LD}, x_{RU} and x_{RD} are defined according to the notation of Fig. A2.

The **average positions** of left (x_{left}) and right (x_{right}) jaws are respectively defined as

$$x_{left} = \frac{x_{LU} + x_{LD}}{2},$$

$$x_{right} = \frac{x_{RU} + x_{RD}}{2}.$$

The **average tilt angles** are defined by

$$\tan\alpha_{left} = \frac{x_{LD} - x_{LU}}{L_{jaw}},$$

$$\tan\alpha_{right} = -\frac{x_{RD} - x_{RU}}{L_{jaw}},$$

where L_{jaw} is the length of the jaw (more specifically, the distance between the upstream and downstream motor locations: L_{jaw}=1.0m). The **upstream and down-stream gap values** are calculated as

$$\text{gap}_{Up} = x_{LU} - x_{RU},$$

$$\text{gap}_{Down} = x_{LD} - x_{RD}.$$

We propose that the **flatness of the jaw surface** should be defined as **positive** if the jaw surface is locally closer to the beam axis then the nominal flat surface.

For **skew collimators**, the “left” jaw is defined as the one on the left side of an observer that looks at the collimator from the incoming beam direction (i.e., the jaw that is sitting a positive x values in the coordinate systems of Fig. AI.1). For **vertical collimators**, the “left” jaw is defined as the one located on top of the collimator (y>0 according to the coordinate systems of Fig. AI.1).

We note here that, in order to change the jaw tilt angle without modifying the average jaw distance from the beam axis, one can either move one or two sides of the jaw. We suggested that **changes of the jaw tilt angle** should be made by **moving both upstream and downstream motors** and not by moving one motor only. For example, a tilt angle variation of Δ=100μrad should be obtained with simultaneous steps of ±50μm of both jaw corners rather than with a single step of 100μm with one corner only. This procedure has the advantage that the average jaw distance from the beam centre is not affected by changes of the tilt angle.

8. APPENDIX II: CLASS-LIKE STRUCTURE OF THE "COLLIMATOR"

A diagram of the LHC collimator components is shown in the Fig. AII.1. This does not reflect the details of the actual control implementation but is only given as an illustrative scheme of the collimator components relevant for the collimator controls.

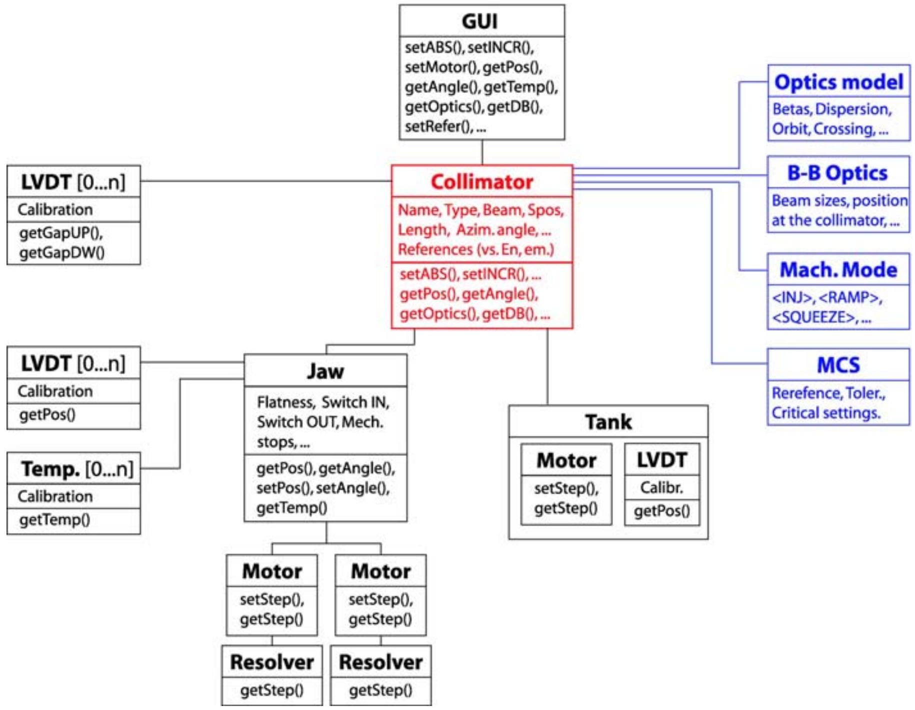

Figure AII.1: Illustrative diagram of the main LHC collimator components.

9. APPENDIX III: SNAPSHOTS OF GRAPHICAL USER INTERFACES

Figure AIII.1 shows the graphical user interface (GUI) of the **single collimator control application** that was successfully tested during the 2006 SPS beam tests. This first version featured most of the functionalities of Section 4.2 except the function-based trims in beam sigma units. The following features were provided:

- Trim of settings in various coordinate frames as shown in Fig. AIII.2, left part (single motors / average jaw positions; absolute positions and incremental values; repeat option). See detail of Section 4.2.2.
- Readout of all relevant survey sensors and possibility of converting the reading in different coordinate systems (Fig. AIII.2, right part), as discussed in Section 4.2.3. This also included the status of 10 jaw switched (Section 4.2.5.2).
- Synchronized graphical display of requested settings, measured positions and BLM signals (Fig. AIII.1, left part). Four BLM's were mounted close to the collimator prototype and could all be displayed.
- Dedicated separate display panels for jaw temperature, single motor positions, transient BLM data.
- Plot selection panel to efficiently show the BLM signals and the position readouts to display (Fig. AIII.3).

– Data saving tools for the local storage of all the relevant parameters as of Section 4.2.

– History of trim settings.

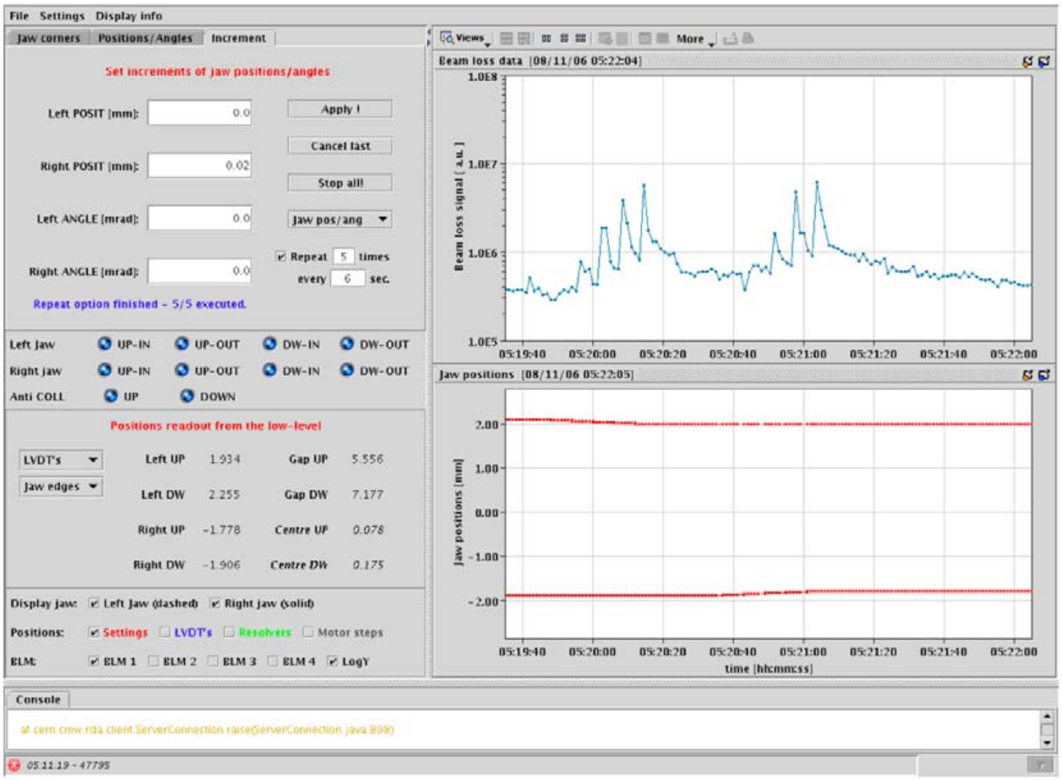

Figure AIII.1: Graphical user interface of the single collimator control application tested during the collimator control experiment with beam at the SPS in 2006.

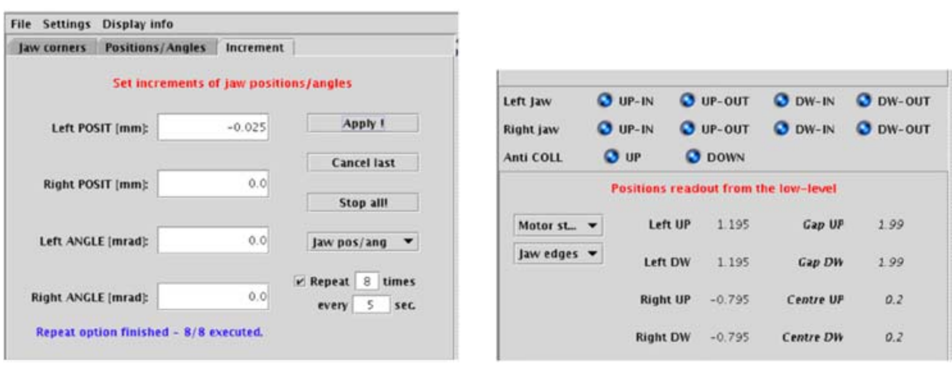

Figure AIII.2: Setting panel (left) and switch/sensor readout panel (right).

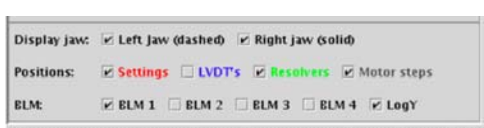

Figure AIII.3: Plot selection panel.