# LHC Design Report - Volume I

## (Chapters)

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## 01 Introduction

*Editorial linkman :* *Myers S.*
*Responsible* *Evans L.*

## 02 Beam Parameters and Definition

*Editorial linkman :* *Brüning O.*
*Responsible* *Brüning O.*

### 2.01 Glossary

Definition of sector and octants
Beam1 and beam2; upstream and down stream
LHC filling pattern and PS and SPS batches
Units and definitions for main beam parameters

## 03 Layout and Performance

*Editorial linkman :* *Brüning O.*
*Responsible* *Brüning O.*

### 3.01 Performance

Nominal luminosity and summary of the nominal LHC beam parameters
Crossing angle
Summary of expected luminosity beam lifetime and turn around time (*this will only be a short summary of the main parameters with reference to the chapters where more detailed information can be found)*

### 3.02 Lattice layout

Geometry: the LHC position in the LEP tunnel and its implication to the design

Modular design approach: arc cells, dispersion suppressor (individual powering of the quadrupoles), matching sections and triplet layout (including D1/D2)

Functional description of the arc correction circuits:
Combined MB, QF and QD powering of beam1 and beam2
Summary of the spool piece and lattice correction circuits

Functional description of all insertions:
Luminosity insertions with beam crossing and low beta -> IR1 and IR5
Combined luminosity and injection insertions -> IR2 and IR8
RF insertion
Beam dump
Beam cleaning (betatron and momentum cleaning)

### 3.03 References

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## 04 Optics and Single Particle Dynamics

*Editorial linkman :* *Brüning O.*
*Responsible* *Brüning O.*

### 4.01 Arc optics

Nominal 90 degrees lattice with tune split in horizontal and vertical plane
(required for coupling correction and dynamic aperture)

### 4.02 Insertion Optics:

The high luminosity insertions: IR1 and IR5
The combined luminosity and injection insertions: IR2 and IR8
The RF insertion
The beam dump insertion
The betatron cleaning insertion
The momentum cleaning insertion

*Each of the above sub-section will address the following key points:*
*-summary of the main optics constraints (constant phase advance over IR, DS aperture etc)*
*-nominal optics and crossing angle for beam1 and beam2*
*-tuneability*
*-mechanical acceptance*

### 4.03 Mechanical acceptance

Definition of the halo shape for a two (three) stage collimation system
*(summary of LHC Project NOTE 111)*
Summary of all contributions and tolerances for the aperture analysis
*(beta-beat, spurious dispersion, injection oscillations, mechanical tol. etc.)*
Difference in the horizontal / vertical and radial apertures (na and nr)

### 4.04 Beam and machine parameter tolerances for operation

Specification of the operational tolerances for orbit, tune, coupling, chromaticity, tune spread and beta beat (-> accessible area in tune diagram)
Specification of the maximum acceptable magnet alignment tolerances (orbit and feed down errors)

### 4.05 Field quality specification

Summary of the main dipole field quality specification and the available corrector strength
Summary of the main quadrupole field quality specification
Summary of the triplet and the D1/D2 field quality specification

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## 4.06 Special optics solutions

Alignment optics for the luminosity insertions
Resonance free lattice and limits for the arc tune split

## 4.07 Dynamic aperture

Justification for a 100000 turn DA of 12 sigma for a machine that has a mechanical aperture of 6 sigma (collimator jaws) (reduction factor of 2 in the DA)
DA for the specified field error tolerances at injection (-> justification for a tune split of 5 units)
DA for the injection optics with long-range beam-beam interactions (-> justification for 10 sigma beam separation)
DA for the squeezed optics with triplet field errors and long-range beam-beam at top energy (-> specification of the maximum acceptable crossing angle)

## 4.08 References

# 05 Collective Effects

*Editorial linkman : Brüning O.*

*Responsible Ruggiero Fr.*

## 5.01 Impedance budget

Overview of components (pumping slots, collimator jaws, RF tanks etc)
Inductance

## 5.02 Single beam instability mechanisms

Short summary of key mechanisms and related threshold currents
(Resistive wall, general multi bunch, microwave, head tail instability etc)

## 5.03 Cures against instabilities

Tune spread: Landau damping octupoles and beam-beam
Transverse feedback system
RF voltage program

## 5.04 Electron cloud

Heat load
Beam stability
Emittance growth

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### 5.05 Emittance growth

Intra beam scattering
Touchek effect
Rest gas scattering
Emittance growth due to feedback in presence of tune spread

### 5.06 Synchrotron radiation

Emittance damping
Heat load
Gas and electron desorbtion

### 5.07 Heat load summary

Summary of total budget
Sort description of heat load coming from particles leaving the IP

### 5.08 Beam-Beam

Tune spread (head-on and long range)
Budget from past experience (SPS and Tevatron)
Pacman bunches
Coherent beam-beam instabilities

### 5.09 References

## 06 The RF Systems (& Longitudinal Beam Feedback)

*Editorial linkman :* *Collier P.*

*Responsible* *Linnecar T.*

### 6.01 Introduction

Recalling main beam parameters and longitudinal beam parameters in the flat bottom, ramping and in coast influencing the RF manipulations necessary and the design of the RF system (and transverse feedback system).

### 6.02 Discussion of particularities: one RF system per ring, choice of SC,

Capture/accelerating systems (staging of latter), 1 Klystron /cavity, why no separate longitudinal FB etc.
Results of simulations and calculations - emittance, impedance, power, losses etc. Main RF system parameters.

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### 6.03 Main 400MHz RF system

specification
cavities and ancillaries
power amplifiers
HT system and protection

### 6.04 Staged 200 MHz capture system -

specification
cavities
power amplifiers
HT system and protection

### 6.05 Beam control

specification
cavity feedbacks and servo controls
main beam control systems
synchronization system
techniques used - implementation

### 6.06 Beam control

specification
cavity feedbacks and servo controls
main beam control systems
synchronization system
techniques used - implementation

### 6.07 Equipment Controls

Equipment level: PLCs, layout, interlocking, protection, etc.
front ends
analogue acquisition
post mortem

### 6.08 Layout in tunnel and cavern

e.g. impact of ACS move into UX45, radiation(Wall),
LLRF siting, Vacuum, Cryo etc. etc plus safety issues

## 07 Main Magnets in the Arcs

*Editorial linkman :* *Lebrun P. Ostojic R.*

*Responsible* *Rossi L.*

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## 7.01 Overview

## 7.02 Cryodipoles

7.2.1. Dipole cold mass
Superconducting cable
Collared coils
Magnetic yoke
He II heat exchanger tube
Helium enclosure
Cold bores
Spool correctors
Protection diodes
Instrumentation
Production QA and steering
7.2.2. Cryostat
Vacuum vessel
Radiation shield and MLI
Support posts
Cryomagnet assembly
7.2.3. Cryodipole performance
Equipment and procedures for cold tests
Power tests
Magnetic measurements

## 7.03 Short Straight Sections

7.3.1 Quadrupole cold mass
Superconducting cable
Collared coils
Magnetic yoke
Helium II heat exchanger tube
Helium enclosure
Cold bores
Corrector magnets
Protection diodes
Instrumentation
Production QA and steering
7.3.2. SSS cryostat
Vacuum vessel
Radiation shield and MLI
Support posts
Vacuum barrier
Technical service module
SSS assembly
7.3.3. SS performance
Equipment and procedures for cold tests
Power tests
Magnetic measurements

## 7.04 Reference Magnet System (RMS)

(I do not like the phrase "multipole factory")

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### 7.05 Interconnections

7.5.1. Electrical
7.5.2. Hydraulic/cryogenic
7.5.3. Vacuum
7.5.4. Thermal insulation
7.5.4. QA for interconnections

## 08 Insertion magnets

*Editorial linkman :* *Lebrun P. Ostojic R.*

*Responsible* *Siegel N.*

### 8.01 Overview

### 8.02 Dispersion suppressors

a. MB in the dispersion suppressors
b. Dispersion suppressor quadrupoles in the experimental, dump and RF insertions insertions
c. Dispersion suppressor quadrupoles in the cleaning insertions IR3/7
d. Cold testing and performance of the magnets

### 8.03 Matching sections

a. Superconducting matching quadrupoles
   i. Standard stand-alone cryo-magnets (magnet and cold mass design, cryostat design, interfaces, performance)
   ii. Special stand-alone cryo-magnets
      a. Q6 in the injection and extraction areas
      b. Q4-D2 cryo-magnet string
      c. Q7 cryo-magnet at end-of-arc
b. Resistive matching quadrupoles in IR3 and IR7

### 8.04 Separation dipoles

a. Superconducting separation dipoles in the experimental and RF insertions: design and performance
b. Resistive separation dipoles in the cleaning insertions

### 8.05 Low-beta triplets

a. Low-beta quadrupoles: design and performance
b. Cryostat design and interconnects
c. Electrical feedboxes DFBX

### 8.06 Orbit and multipole correctors in the Insertions

### 8.07 Compensator dipoles in ALICE and LHCb experiments

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### 8.08 Specific installation requirements

a. Interface of low-beta triplets with experiments
b. Alignment of low-beta triplets (alignment galleries, specific equipment, performance)
c. Radiation protection of the insertion magnets (TAS, TAN)

## 09 Powering and protection

*Editorial linkman :* *Lebrun P. Ostojic R.*

*Responsible* *Mess K.H.*

### 9.01 Overview

### 9.02 Powering circuits

### 9.03 Powering equipment

a. Current leads
b. Electrical feedboxes
c. Busbar systems
d. SC links

### 9.04 Protection equipment

a. Quench detectors
b. Quench heater power supplies
c. Energy extraction systems
d. Controllers, supervision

### 9.05 Operational aspects and reliability

## 10 Power Converter System

*Editorial linkman :* *Proudlock P.*

*Responsible* *Bordry F.*

### 10.01 Introduction and design constraints

Environmental considerations, space restrictions, underground, sectorisation
Performance requirements plus parameter table per circuit type

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## 10.02 Overview of system

Design considerations
Overall system description
Table of power converter types with characteristics

## 10.03 Equipment subsystems

Brief description of each type of voltage source
DCCTs
ADCs
PC Control system

## 10.04 Specific requirements placed on other systems and interfaces to them

AC power requirements
Cooling requirements
Controls, Postmortem and logging
Interlocks and quench protection
EMC

## 10.05 Operational aspects

System reliability
Expected fault frequencies
Radiation tolerance
Maintenance issues

## 10.06 Scheduling, installation and commissioning

Subsystem construction, integration ..
Installation
Hardware commissioning without beam

## 10.07 References

## 10.08 NB :

Assumes sectorisation and basic powering configuration is dealt with in chapter 9, "powering and protection,……….".
Deals with all Power Converters of the Machine, including Experiments, Klystron, undulators, but excludes Power Converters for QPS, which are dealt with in chapter 9.
Does not cover the beam transfer lines.

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## 11 Cryogenics

*Editorial linkman :* *Lebrun P. Ostojic R.*

*Responsible* *Tavian L.*

### 11.01 Overview

### 11.02 Functions, constraints, architecture

### 11.03 Heat loads and temperature levels

Static & dynamic heat loads, dependence on beam parameters, basic thermal design features of cryostat/cryoline.

### 11.04 Operating modes

From the point of view of cryogenics, including transient modes such as cooldown, warmup, quench recovery.

### 11.05 Arc magnet cooling scheme

From principles to standard cell flow-scheme, cryogenic sectorization

### 11.06 Cryogenic distribution

QRL, QUI, local lines

### 11.07 Cryogenic plants

11.7.1. 4.5 K refrigerators
Cycle, compressor station, cold box, purifiers, LN2 subcoolers

11.7.2. 1.8 K refrigeration units
Cycle, warm compressor station, cold compressors, cold box.

### 11.08 Instrumentation

### 11.09 Process control

### 11.10 Cryogen storage and management

11.10.1. Helium
Management, gas storage, gas ring line, "virtual" or liquid storage

11.10.2. Liquid nitrogen
Usage for cooldown, purification
Supply logistics, buffer storage, transfer

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## 12 Vacuum system

*Editorial linkman :* *Lebrun P. Ostojic R.*
*Responsible* *Hilleret N.*

### 12.01 Overview

### 12.02 Beam vacuum system in the arcs

a. Beam screen: design and performance
b. Interconnection elements

### 12.03 Beam vacuum system in the insertions

a. Beam screens (1.9 K magnets, 4.5K magnets)
b. Cold-warm transitions
c. Interconnection elements
d. Warm chambers (magnets, field-free regions)
e. Sectorization

### 12.04 Beam vacuum system in the experiments

### 12.05 Insulation vacuum systems

a. Cryo-magnets in the arc and insertions
b. Cryogenic distribution line

### 12.06 Vacuum controls

### 12.07 Operational aspects

## 13 Beam Diagnostics and Instrumentation

*Editorial linkman :* *Collier P.*
*Responsible* *Schmickler H.*

[For each instrument/monitor discuss the :
a) beam requirements,
b) the hardware implementation,
c) the anticipated performance, calibration issues etc. ]

### 13.01 Beam Position Monitors

Arc monitors, straight section monitors, warm monitors, directional couplers, alignment of monitors and calibration

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## 13.02 Beam Current transformers

Ring systems: DC and bunch-by-bunch monitors
Beam dump extraction channel systems

## 13.03 Beam loss system

Arc monitors
Critical section monitors (BLMS) - installed close to aperture limits, low-beta
Collimator monitors - fast and slow (BLMC)
Optimisation of monitor position for maximum coverage of losses
Calibration and thresholds

## 13.04 Transverse Profile Measurement

Screens in the ring and in the dump extraction lines
Wire scanners,
Synchrotron light monitors (inc Detector, wiggler magnets, power supplies etc)
Ionization profile monitors,
Conversion to emittance and cross-calibration of emittance measurement devices.

## 13.05 Longitudinal Profile Measurement

High sensitivity monitor for monitoring the beam dump gap, debunched beam fraction, ghosts and tails.

## 13.06 Luminosity Monitors

TAN Type

## 13.07 Tune, Chromaticity and Betatron Coupling

Pickups : High sensitivity, resonant, head-tail
Q-kicker Kickers (magnets, pulse generators & transmission lines)

## 13.08 Aperture and non-linear measurements

Pickups?
Aperture Kickers (magnets, pulse generators & transmission lines)

## 13.09 Other Baseline Instruments/Systems

K- modulation system
Dedicated BPM's: Damper, IP timing, radial loop control, dump septum aperture control …
High frequency pickup
Quadrupole pickup (for betatron matching)
Schottky system
Beam synchronous timing

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### 13.10 Non-Baseline, Staged or Proposed Instruments

AC Dipole.
Long-range beam-beam compensator

### 13.11 Beam Feedback Systems

Tune, Chromaticity, Orbit, Coupling, Energy

## 14 Control System

*Editorial linkman :* *Poole J.*

*Responsible* *Frammery B.*

### 14.01 Introduction

What the control system is - machine, industrial systems, slow controls …
What the controls Group is responsible for and what is delivered by other Groups
Interfaces to the rest of CERN, the world- hardware and software

### 14.02 Hardware

General architecture
Details

### 14.03 Software

Architecture
Functionality
Development process

### 14.04 Data Management

General principles
Development process

### 14.05 Security ??

## 15 Machine Interlock System

*Editorial linkman :* *Collier P.*

*Responsible* *Schmidt R.*

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## 15.01 Introduction

The need for the machine protection / machine interlock system
The challenge of operation with very high stored beam and magnet energy
Basic philosophy of machine interlock system power abort, beam abort etc.

## 15.02 Interface with other systems

The glue between the systems for protection is the machine interlock system

- Beam dump system
- Some part of beam instrumentation (beam loss monitors, a small subset of beam position monitors, beam current monitors, abort gap monitors)
- Quench protection system
- To some extent, collimation and cleaning systems
- Protection devices in other systems (for example, in the RF, in the vacuum, …)

For other systems the required protection in case of failure had also an important impact on the system design (for example for the power converters)

## 15.03 System Reaction Times vs. fault Scenarios

Possible fault scenarios and system reaction times …
Counter measures … such as D1 problem

## 15.04 Powering Interlocks

The power abort philosophy
System layout
Powering sectors & sub-sectors
Power interlock controller system
Interfaces to other systems

## 15.05 Beam Interlocks

The beam abort philosophy
System layout (includes beam permit loops)
The beam interlock controller
Interfaces to other systems

## 15.06 Other Protection Devices

Anything not included in the above and not adequately treated in other chapters (from a machine protection point of view). This should include energy tracking, transfer line collimators and other additional elements.

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## 16 Injection System

*Editorial linkman :* *Proudlock P.*

*Responsible* *Mertens V.*

### 16.01 System and parameters

Beam characteristics (pilot and nominal). *Briefly or not al all since covered in general parameters*
Operational assumptions (injection schemes, intensities)
System overview and design considerations
Overall system parameters

### 16.02 Reliability and fault cases

Acceptable (design) fault cases and associated parameters
Expected fault frequencies

### 16.03 Equipment subsystems

TCDI collimators
MSI septa (magnets, powering, controls, surveillance, special vacuum chambers)
MKI kickers (magnets, generators, transmission lines, controls)
TDI diluter
TCDD shielding
TCL collimators
Vacuum (subsystems, sectorisation, bakeout, beamlines)
Beam Instrumentation (BPMs, BLMs, BTVs)
Electronics and controls (accessibility, interventions)
Alignment issues

### 16.04 Interfaces to other systems

SPS machine and Transfer Lines (fill sequencing, injection and extraction inhibits)
PO (MSI powering)
RF (injection synchronisation)
Controls system (settings, alarms, timing, postmortem and logging)
Integration (physical layout and installation sequencing)
Collimators (interdependence of settings with LHC collimation system)
Machine protection (beam permit)

### 16.05 Radiation protection

Activation and dose levels
Monitoring
Test conditions (special precautions, sectorisation)

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### 16.06 Performance and operational aspects

Trajectories
Apertures (circulating and injected beams)
Interlocks
Postmortem and logging (internal, external)
Spares
Procedures for component replacements (kickers, septa, protection devices)
Modes of operation for TDI (limits, assumptions)

### 16.07 Specific requirements placed on other machine systems

Collimators (loading for MKI fault case)
Beam dumping system (direct link to avoid ’deadlock’ case)

### 16.08 Scheduling, installation and commissioning

Subsystem construction
Installation
Hardware commissioning without beam
Reliability tests without beam

### 16.09 References

## 17 Beam Dumping System

*Editorial linkman :* *Proudlock P.*

*Responsible* *Goddard B.*

### 17.01 System and parameters

Beam characteristics (nominal and worst-case). *Briefly or not al all since covered in general parameters.*
Operational assumptions (dump trigger frequency, intensities)
System overview and design considerations
Overall system parameters

### 17.02 Reliability and fault cases

System reliability
Availability considerations
Acceptable (design) fault cases and associated parameters
Unacceptable (beyond design) fault cases
Expected fault frequencies

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## 17.03 Equipment subsystems

MKD kickers (magnets, generators, controls)
MKB kickers (magnets, generators, controls)
MSD septa (magnets, powering, controls, surveillance)
TCDS diluter
TCDQ diluter
TDE dump (core, shielding)
Vacuum (subsystems, TD beamlines, exit window)
Beam Instrumentation (BPMs, BLMs, BTVs)
Electronics and controls
Alignment issues

## 17.04 Interfaces to other systems

Machine Protection (BIC)
PO (MSD powering, Beam Energy meter)
RF (Revolution frequency and abort gap synchronisation)
Controls system (settings, alarms, timing, postmortem and logging)
Safety (fire detection, access)
Integration (physical layout and installation sequencing)
Collimators (interdependence of settings with TCDQ)

## 17.05 Radiation protection

Activation and dose levels
Containment issues (ventilation, N2 flushing, environmental impact)
Monitoring

## 17.06 Performance and operational aspects

Trajectories
Apertures (circulating and extracted beams)
Interlocks
Postmortem and logging (internal, external)
Limitations on LHC operation (staged MKB installation and TDE cooling)
Spares
Procedures for component replacements (kickers, septa, TDE core)

## 17.07 Specific requirements placed on other machine systems

RF (abort gap cleaning)
BDI (beam position interlock, abort gap density monitor)
Collimators (impact following asynchronous dump)
LHC magnets (Q4 current tolerance, D1 trips, MSD short circuit surveillance)
Localised orbit feedback

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### 17.08 Scheduling, installation and commissioning

Subsystem construction
Installation
System tests
Reliability tests without beam

### 17.09 References

## 18 Beam Cleaning and Collimation System

*Editorial linkman :* *Myers S.*

*Responsible* *Assmann R.*

### 18.01 Summary of functions

i) Cleaning of beam halo to avoid quenches
ii) Tuning of experimental backgrounds due to beam halo
iii) Passive protection
iv) Scraping and special studies

### 18.02 Basic definitions and notation

i) Cleaning efficiency
ii) Notation in normalized phase space

### 18.03 Design constraints

i) Proton/ion intensity and allowable loss rate in operation (lifetime)
ii) Cleaning efficiency from quench thresholds
iii) Acceptable extension of halo (aperture, beta*, ...)
iv) Maximum impedance from collimators
v) Proton shock impact from irregular dumps
vi) Vacuum constraints (bake-out, local e-cloud, ...)
vii) Available space in cleaning insertions
viii) Handling and maintenance (radioactivity, limits on personnel exposure, ...)

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## 18.04 The overall LHC collimation system

i) Separate betatron and momentum cleaning
ii) Two-stage cleaning system with additional absorbers
iii) Number of devices and phase advance rules
iv) Beta functions in the cleaning insertions (required gaps)
v) Minimal allowable settings for other absorbers
vi) Extension to a three-stage system for 7 TeV
vii) Predicted cleaning efficiency
viii) Basic operational tolerances
ix) Mechanical tolerances for collimator jaws
x) Required DOF's in collimator movement
xi) Constraints on operational freedom (allowable perturbations, ...)
xii) Abort gap cleaning

## 18.05 Collimator materials

i) Overview on possible materials - Advantages and disadvantages
ii) Energy deposition in materials
iii) Damage and fatigue analysis for proton/ion shock impact
iv) Vacuum considerations (out-gassing, dust, ...)
v) Radiation impact analysis
vi) Choice of best material (robustness, impedance, vacuum, ...)

## 18.06 Mechanical layout

i) Basic scheme for the LHC collimator
ii) Heat maps in the collimator
iii) Estimates of deformations during normal operation
iv) Moving mechanism (reliable and accurate motors, ...)
v) Vacuum pumping, clearing electrodes, solenoids, ...
vi) Reliability and maintenance (activation, required cooling period before access, estimated frequency of access, easy or remote handling, detection and localization of errors, number of spares, ...)

## 18.07 Required instrumentation for collimation set-up and tuning

i) Beam loss monitoring for beam-based optimization of settings (required dynamical range, sampling, ...)
ii) BPM's for local orbit stabilization (sampling, required performance, errors due to shower impacts, ...)
iii) Determination of the local beta function
iv) Instrumentation in the collimator tank (temperature sensor, charge measurement, fail-safe determination of collimator gap, halo measurement with crystals, ...)
v) Background signals from the experiments

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### 18.08 Constraints on commissioning and operation of the LHCg

i) Conditions for initial set-up of the collimation system (tuning with "safe" beams, low activation allowing easier access, ...)
ii) Increase of intensity and decrease of collimator gap (cleaning efficiency, background, damage risk, ...)
iii) Strategy for handling collimator impedance through the LHC cycle (collimator gaps, beta squeeze, octupoles, ...)
iv) Required sequence of collimator adjustments in relation to overall LHC cycle (injection, ramp, squeeze, collision)
v) Daily fine tuning of efficiency and background conditions
vi) Possible operational impact due to collimator maintenance

## 19 Interface with and Requirements from the Experiments

*Editorial linkman :* *Poole J.*

*Responsible* *Potter K.*

### 19.01 Introduction

what experiments are where

### 19.02 Requirements

Highest possible time integrated Luminosity for ATLAS & CMS
Early commissioning preferences such as smallest possible number of interactions per bunch crossing
Heavy Ion (Pb)operation for ALICE, ATLAS & CMS
Medium Luminosity (2 x 10**32 cm-2.s-1) for LHCb with very clean conditions
Low Luminosity proton running for ALICE. (4 sigma separated beams)
Special High beta* runs for TOTEM (36 half intensity, small emittance bunches)
Background conditions

### 19.03 Interface

Data exchange ( Timing signals, Luminosity, bunch currents & background, logging of machine conditions - vacuum etc.) - giving information concerning both directions (to and from the machine)
Beampipes for experiments (40m of beampipe between low-beta quadrupoles), design, interface

## 20 Parameters, commissioning and operation

*Editorial linkman :* *Myers S.*

*Responsible* *Bailey R.*

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TT40 and TI8 tests
Sector test with beam
Hardware commissioning, from separate systems to the full machine
Cold checkout
Constraints and challenges with beam
Special magnetic cycle (to avoid dynamic effects)
Special working point (to de-couple the tunes)
Minimum number of circuits powered (to separate out the challenges)
Inject pilot, commission BPM system
Threading, first turn, close trajectory, circulating beam
RF-capture
Commission mandatory beam instrumentation
Measure and correct the basics; closed orbit, tune, chromaticity, coupling
Optimize collimators and TDI
RF commissioning and intensity increase ( ib and nb )
Measure and correct everything at 450GeV
Feedback systems
Multipole factory
Ramp and squeeze with pre-programmed stops
Measure and correct at high energy, un-squeezed and squeezed
Operation without crossing angle, 43 on 43, some bunches at +75ns for LHCb
Parameters and performance estimate for 43 on 43
Operation with 75ns spacing and relaxed crossing parameters
Parameters and performance estimate for 75ns relaxed crossing
Operation with 75ns spacing and nominal crossing parameters
Parameters and performance estimate for 75ns nominal crossing

## 21 Ions

*Editorial linkman :* *Myers S.*

*Responsible* *Jowett J. Schindl K.H.*

Heavy ion (Pb-Pb) collisions were included in the LHC conceptual design study right from the beginning and are scheduled for one year after the start-up with protons. While the major hardware systems appear compatible with ion operation, a closer look reveals several phenomena specific for heavy ions with potentially serious consequences on some systems.
The most important ones are:
(i) Pb ion losses generated by electro-magnetic interactions during collisions, which in turn may lead to magnet quenching;
(ii) Pb losses, IBS, etc and their impact on the luminosity lifetime;
(iii) desorption of gas molecules by lost Pb ions impinging on the beam screen and potential impact on LHC vacuum conditions;
(iv) collimation of Pb ions - are ions behaving the same way as protons?
(v) limitations due to the performance of beam instrumentation and feedback loops;
(vi) minimization of the ion crossing angle in ALICE. A diagram showing the small working area determined by various limitations reveals the small margin to commission the nominal Pb beam; an "early" scheme, albeit yielding lower luminosity, is proposed which enables running-in and early physics with relaxed parameters and more margin.
A comprehensive parameter list of Pb ions in the LHC for both schemes, including Pb beam characteristics required from the injectors, is presented.