CERN
CH-1211 Geneva 23
Switzerland

the **Large Hadron Collider** project

LHC Project Document No.
LHC-BSRL-ES-0001.00 rev 0.1 draft

CERN Div./Group or Supplier/Contractor Document No.
SL/BI

EDMS Document No.
328145

Date: 2001-11-11

Functional Specification

HIGH SENSITIVITY MEASUREMENT OF THE BEAM LONGITUDINAL DISTRIBUTION IN THE LHC RINGS

Abstract

The present specification provides the functional requirements of a monitor that will measure the longitudinal distribution of the LHC beams. It will make use of the synchrotron radiation signal emitted by the beam and will share this signal with another monitor providing transverse beam distributions.

Due to its expected wide dynamic range, of the order of 10^4, this monitor is particularly suited to measure tails within nominal RF buckets and low density beams either bunched in parasitic buckets or debunched.

Data related to the beam core distribution: centre of gravity, edges, length, shape, which can also be measured with other devices like electromagnetic pick-ups, as done for example in LEP [1], will also be measured.

Prepared by :
Claude Fischer
[SL/BI]
claude.fischer@cern.ch

Checked by :
Oliver Brüning [SL/AP]
J-Jacques Gras [SL/BI]
J-Pierre Koutchouk [SL/BI]
Rüdiger Schmidt [AC/TCP]
Jörg Wenninger [SL/OP]

Approval group members:

D. Brandt, A. Burns, E. Chapochnikova, P. Collier, D. Cocq, P. Faugeras, J.B. Jeanneret, R. Jones, R. Jung, P. Lefevre, T. Linnecar, V. Mertens, K. Potter, R. Saban, H. Schmickler, J. Tückmantel, L. Vos, E. Weisse.

History of Changes

Rev. No.	***Date***	***Pages***	***Description of Changes***
1.0	11/11/2001		Initial submission.

Table of Contents

1. SCOPE

The present specification provides the functional requirements of a monitor that will measure the longitudinal distribution of the LHC beam, using the synchrotron light emitted by the beam.

A large dynamic range is required to extract information like tail distribution within nominal RF buckets, parasitic circulating bunches and de-bunched beam population in addition to more basic data related to the beam core distribution: centre of gravity, edges, length, shape.

This monitor shall provide information on the time scale of the synchrotron oscillation or slower. It will not be used on a turn by turn basis as is required for example in feedback systems. This application is better handled with other devices like electromagnetic pick-ups [2], which are faster but with a reduced dynamic range of the order of 10^2. Likewise, fast beam current transformers can also be used to cover some aspects related to safety like the amount of current present in the dump kicker gap.

The monitor will also be used during the ion operation periods. We therefore consider not only the nominal proton beams but as well the ions. The emitted synchrotron radiation power is strongly dependent on the charge and on the particle mass within a beam. For ions, the nominal bunch charge may vary, depending on the species, from the proton pilot bunch charge of 5 10^9 (Pb ions) to nearly the proton nominal bunch charge of 1.1 10^{11} (O ions). Moreover, 608 ion bunches spaced by 125 ns are foreseen to compose a nominal beam.

2. DESCRIPTION OF THE OBSERVABLES

The primary observable, [3], is the number of synchrotron light photons emitted at the source. The same time slice averaged turn after turn provides a signal proportional to the beam population in that time slice.

The average longitudinal beam density distribution around the machine circumference is obtained by shifting the time slice. This is the basic beam observable [3] of this monitor.

3. DESCRIPTION OF THE DIFFERENT USES.

Figure 1 describes the time structure of the nominal LHC beam.

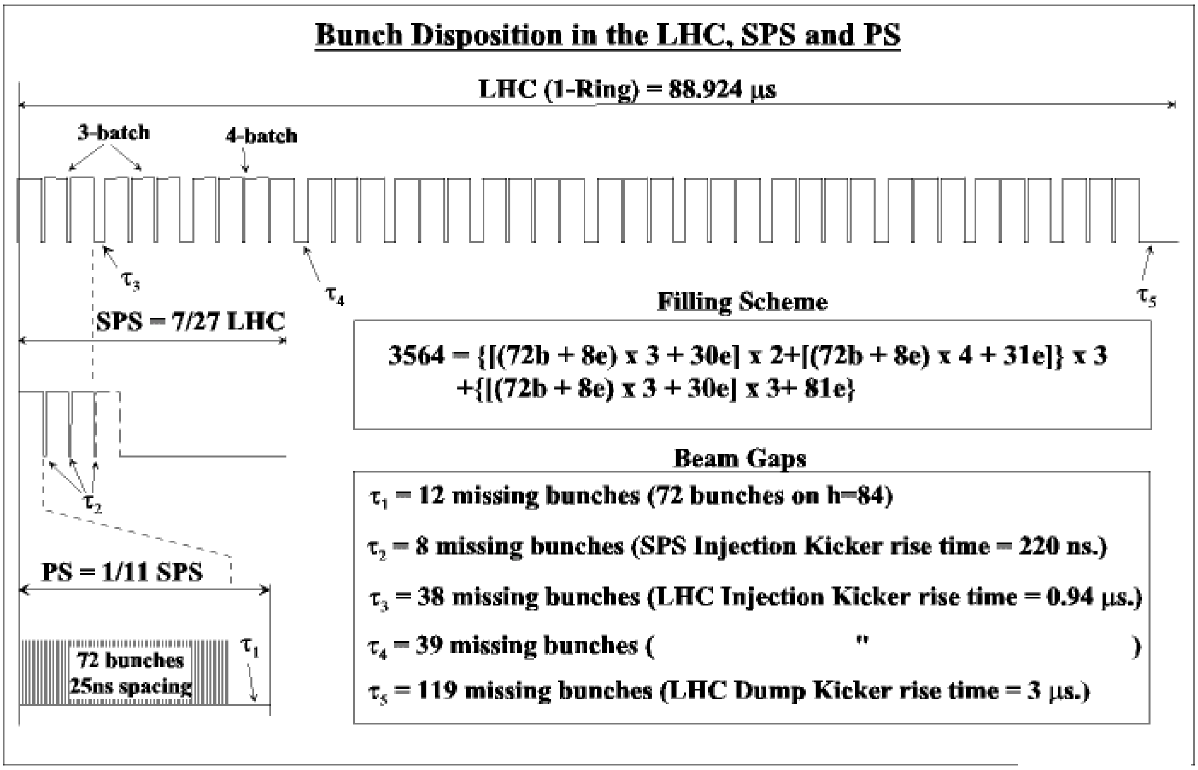

Figure 1: Bunch pattern in the LHC machine.

3.1 MONITORING OF THE RADIATION FLASH AT THE BEGINNING OF THE RAMP

At the beginning of the ramp, the particles not trapped in an RF bucket will be lost against aperture limitations as soon as the bending field is increased. One must stay below a safe level to ensure that the momentum cleaning system can cope with them. The momentum cleaning system can deal safely with a debunched current up to 50% of the nominal beam current [4]. We foresee a warning level a factor of five below this threshold, i.e. 10% of the nominal current, one must detect at any position between two nominal bunches a beam density 200 times smaller than the maximum amplitude of the nominal bunch distribution.

3.2 MONITORING OF THE ABORT GAP

At top energy, it is important to monitor permanently the amount of particles present within the rise time gap (3 µs) of the dump extraction kicker (MKD), as part of them will not receive the proper kick if the dump system is fired. Between injection and top energy, quench thresholds dropped by roughly 100 times [5]. Hence, with respect to the maximum amplitude of a nominal bunch, densities 10^4 times lower must be measured with at least 50% accuracy. This measurement is not time critical and may require seconds.

3.3 DETECTION OF GHOST BUNCHES

Ghost bunches, above a given level, may disturb the BPM system read-out or the physicists data taking. They can disturb the experiments if their population exceeds around 1 per mil of the nominal bunch current [6]. They start to affect the BPM system above 1% of this current in the worst case, when they are located in the middle of the interval between two nominal bunches [7].

3.3 STUDY OF TAILS

Diffusion mechanisms can be analysed through the evolution of tails within the RF bucket. When particles reach the bucket separatrix, they are likely to cross it and to increase the fraction of de-bunched beam current. For these tail studies, it is estimated than the criterion required in section 3.2 is also suitable, i.e. measurements of tail densities 10^{-4} times lower than the nominal bunch distribution maximum with an accuracy better than 50%.

3.4 CHECK OF THE BEAM STRUCTURE AND NOMINAL BUNCH PARAMETERS

The monitoring of the complex beam structure and of the basic bunch parameters, (bunch length and energy spread, density distribution and possible longitudinal oscillations of the core), is foreseen to be performed with electro-magnetic detectors. The synchrotron light monitor should provide as well this information requiring only post-processing of the available data. They can be used directly or for cross-calibration purposes, given the robust nature of photon counting.

4. SUMMARY ON THE REQUIRED BEAM PARAMETERS

From the above-mentioned uses, the data to measure are:

- the fraction of de-bunched beam current. The de-bunched beam current distribution will be distinguished from ghost bunches as these de-bunched particles will populate potential well regions squeezed in between consecutive RF buckets.
- the distribution of tails averaged over the bunches or over a few given bunches.
- the number and the population of ghost bunches.
- the longitudinal distribution of nominal bunches, with associated parameters: bunch length, energy spread.

5. FUNCTIONAL REQUIREMENTS

5.1 TOLERANCES

Table 1 summarises the functional requirements with two modes of operation :

- A high resolution mode, where priority is given to maximising the dynamic range. The integration time can extend to one minute.
- With lower resolution, a longitudinal bunch profile will be acquired within one millisecond, i.e. a time significantly shorter than the synchrotron tune period. The evolution of profiles measured during about 100 ms (a few synchrotron periods), can then be monitored and stored.

For these different tasks, a time resolution of 50 ps is adequate as it provides more than 5 points per rms bunch length at all energies, (σ_l = 0.28 ns at 7 TeV).

Mode	High resolution	Low resolution
Ultimate sensitivity	less than 10^{-4} times the nominal density distribution maximum	~ 10^{-3} times the nominal bunch maximum density
Precision at ultimate sensitivity	better than 50%	1%
Integration time	10 s	1 ms
Transmission rate	1 minute	100 ms
Beam conditions: *	Densities below 1% of the maximum of a nominal bunch	pilot to nominal bunch
Source wavelength range **	300 nm to 2000 nm	300 to 2000 nm
Proposed wavelength range for longitudinal distribution monitor in IR4	1000 nm to 2000 nm	1000 nm to 2000 nm
Time resolution	down to50 ps	down to 50 ps
Tails	X	
Ghost bunches	X	
De-bunched beam	X	
Bunch core		X

*If, depending on the beam type, it is feasible to use a different gain, the necessary dynamic range is reduced accordingly

** The spectral power distribution changes with beam energy

Table 1

5.2 SYNCHRONISATION

Measurements will be initiated by timing events like an injection pre-pulse or a start of ramp signal. It should also be possible to trigger them at any time via the control system.

5.3 DATA FLOW

Sampling every 50 ps over a full turn (89 μs) will provide 2 10^6 data for the most accurate sampling of the longitudinal density along the machine circumference. In many instances, the data flow can be reduced by averaging the data over several sampling intervals: for example the data can be integrated over each bucket or over each group of 10 buckets.

The smallest possible time resolution, (50 ps), can also be used to examine carefully portions of the whole beam, for example intervals between nominal bunches, (25 ns).

5.4 DATA TO BE MADE AVAILABLE TO THE CONTROL ROOM

Data provided either systematically or on request are:

- the current within each RF bucket and hence the fraction between nominal and ghost bunches.
- the dump kicker gap population.
- the fraction of de-bunched beam current.
- the distribution of nominal bunches belonging to given batch(es), including the importance of tails.

Histograms can be used to present clearly these data which in addition could be analysed statistically to identify potential problems.

5.5 POST MORTEM

For post mortem analysis, data will be stored in two different buffers to be frozen by external events (triggers):

- one buffer containing data recorded at 50 ps intervals.
- another buffer with data recorded with lower time resolution.

6. DESIGN CONSTRAINTS

6.1 INSTALLATION

The monitor will use one of the two, or both, synchrotron light sources which are under investigation for transverse profile monitors [8]. One is provided by the radiation originating in the D2 (MBRC) magnets in insertion 5. For the second source, super-conducting undulator magnets will be installed in insertion 4. The IR4 location is more favourable for this application. In version 6.4 of the LHC lay-out, their proposed location is close to and upstream the D3 super conducting separator magnet in either beam direction. The light analysed by the longitudinal monitor will be extracted at the same location as for transverse profile measurements; this is close to quadrupole Q5 in the first case, Figure 2, and about 10 meters downstream the D3 magnet in LSS4, Figure 3. Compatibility between the two longitudinal and transverse profile measurement applications must be looked at.

6.1.1 POSITION IN THE MACHINE.

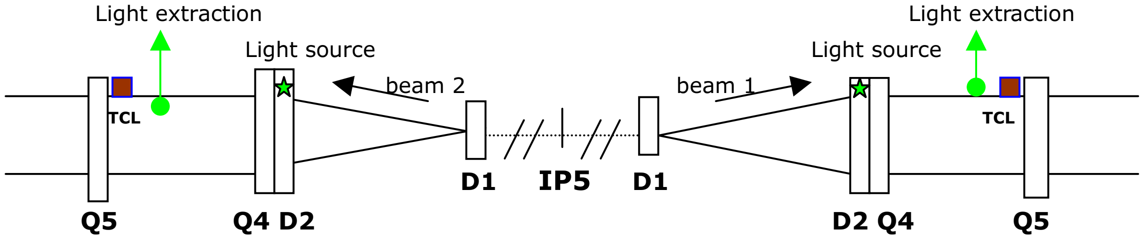

Figure 2: Telescope configuration in IR5.

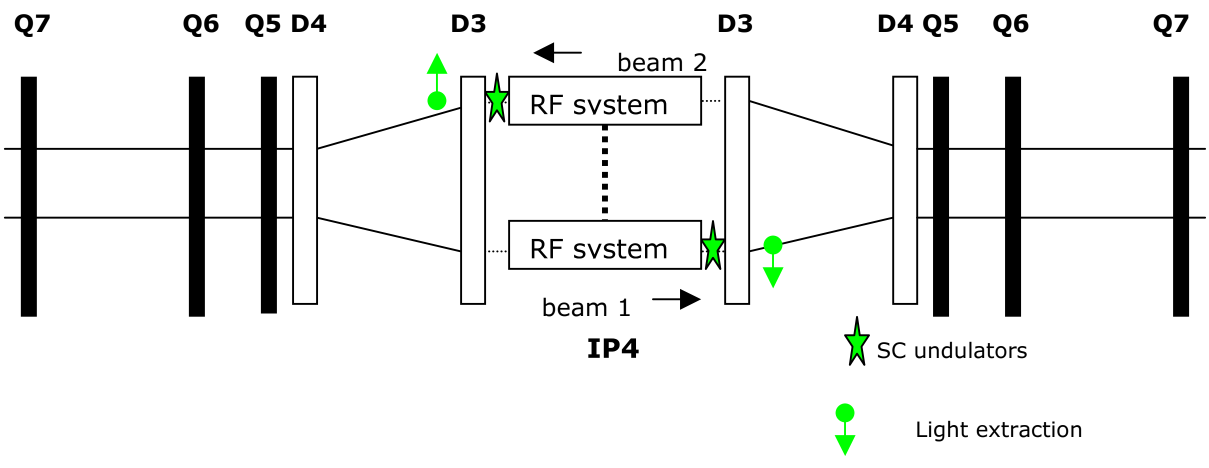

Figure 3: Telescope configuration in IR4.

6.1.2 ALIGNMENT AND IMPEDANCE

The longitudinal distribution monitor will be incorporated into the design of the monitors foreseen for transverse distribution measurements. These two items will then be taken care of by the specifications of these monitors.

6.2 RADIATION HARDNESS

As far as radiation is concerned, the location in LSS5 is the most stringent, IP5 being a high luminosity insertion point. The expected activity in the detector region has been evaluated [9] and [10]. A dose between 10 Gy/year and 100 Gy/year is expected.

6.3 INB CONSTRAINTS

The LHC has been classified as an "Installation Nucleaire de Base" by the French Authorities. CERN is therefore obliged to conform to their relevant regulations, guidelines and procedures. Within this context CERN has to establish traceability & waste management procedures and maintain a radiological and zoning system. In order to meet these requirements, information such as: material content, location history, sub-assemblies, etc…, shall be supplied by the Contractor and will be maintained in a CERN database. CERN has created a set of procedures and conventions as part of the Quality Assurance System for LHC, which will also be used to facilitate these INB requirements. The relevant quality documents are listed below and shall be applied by the Contractor during the production, testing and assembly of components: "The Equipment Naming Convention", "The LHC Part Identification", "The Manufacturing and Test Folder".

7. RELIABILITY, AVAILABILITY AND MAINTAINABILITY

The information provided by the monitor will contribute to clean machine operation; some safety aspects being also involved. Although it is not intended for the time being to use it as an active element of interlock chains, this possibility shall not be completely excluded.

Hence, the longitudinal profile monitor must be designed to offer reliable and continuous operation during the LHC running periods.

8. SAFETY AND REGULATORY REQUIREMENTS

The longitudinal profile monitor must meet the safety guidelines put forward by the CERN Technical Inspection and Safety Commission (TIS). TIS have issued safety documents in compliance with LHC-PM-QA-100 rev1.1, and the guidelines in these documents will be incorporated into the monitor design.

9. REFERENCES

[1] L.Vos, Proceedings of the 6th EPAC, Stockholm, 22-26 June 1998, pp1626-1628, and CERN SL-98-028 AP.

[2] T. Linnecar, SL/HRF, Private Communication.

[3] J.J. Gras, J. P. Koutchouk, Concepts and Glossary for the Specification of the Beam Instrumentation, SL-Note-2001-039.

[4].J.B. Jeanneret, Proceedings of the LHC Workshop Chamonix XI, 15-19 January 2001.

[5] J.B. Jeanneret et Al., LHC Project Note 44, July 1996.

[6] A. Morsch, ALICE collaboration, Private Discussion.

[7] D. Cocq, SL/BI, Private Communication.

[8] L. Cadet Ponce, Contribution to the LHC Emittance Workshop, CERN, 3-4 July 2000.

[9] N. Mokhov, FNAL, Unpublished.

[10] P. Cruikshank et Al., LHC Engineering Specification-LHC-PM-ES-0002.00.rev1.1, p11.