# BLMs AND THRESHOLDS AT 6.5/7 TeV

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## *Abstract*

During Long Shutdown 1 the Beam Loss Monitoring system went through several hardware upgrades and general maintenance. Many elements of the system, starting from the tunnel detectors to the threshold-comparator cards were brought from their locations to the lab and refurbished. Almost 30% of the detectors will be reinstalled in new positions, optimizing system sensitivity to so called UFO losses. In order to tune the thresholds on cold magnets a series of quench tests has been performed during Run 1. An extensive analysis of these tests has been done leading to suggestions of a new sets of beam abort thresholds. The threshold setting strategy has been proposed. New tool to generate and set thresholds is being developed.

## INTRODUCTION

The Beam Loss Monitoring system (BLM) performed very well during LHC Run 1, dumping the beam in cases of losses due to beam instabilities and providing terabytes of diagnostic data. The beam-abort thresholds have been tuned during the 3-year run and allowed a safe and efficient machine operation. Nevertheless, a series of hardware upgrades and refurbishments were performed during LS1. A campaign to recalculate the BLM thresholds has started in view of Run 2. These two main aspects of the preparation of the system for the next run are discussed in this paper.

## HARDWARE CHANGES

**Relocation of detectors -** One of the most important change in the BLM system is the relocation of about 30% of the detectors on the cold magnets. Motivation for this relocation was the observation of losses all along the ring and not only in short straight sections where beam size reaches its maximum. This change is discussed in detail in [1].

**High-voltage issues -** In case of very high and prolonged losses the High Voltage (HV) power distribution network was unable to support the detectors leading to a decrease or disappearance of their output signal. The voltage drop is monitored and interlocked by the Software Interlock System. During Run 1 the HV drops lead to unnecessary beam dumps as well as non-reliable measurement of extensive losses. Two mitigations to the this problem have been applied [2]. The first one is the installation of suppressor diodes and resistors in some of the HV distribution boxes. This allows to limit the voltage drop to 220 V. The second mitigation is an exchange of resistors in BLECF tunnel cards what decreases the voltage at which the card issues the HV beam dump interlock signal from 1370 V to 950 V.

**Maintenance and upgrade of the system -** The following changes to the BLM system hardware have been agreed:

- Installation of temperature-regulated racks.
- Exchange of signal cables to better isolated cables for 240 detectors with the largest noise.
- Refurbishment and re-check of all electronics cards.
- Improvement of the system sanity checks.

At the same time, a series of changes in the firmware is planned as well as the replacement of the front-end computers in the processing crates with newer and faster Linux CPUs. They will allow faster data transfer rates, that will be utilized, for instance, to increase the length of the transmitted post-mortem and UFO buster data to the full 43690 samples. This change is discussed in detail in [3].

**New measurement techniques -** Although the backbone of the BLM system are standard, 50-cm long ionization chambers (IC), other types of detectors are also used.

The maximum current which can be measured by the BLM electronics is limited to 1.27 mA, what limits the maximum radiation level which can be monitored using standard IC to about 23 Gy/s. In some cases, for instance during the injection process, the losses can be much higher, therefore a less sensitive detector was needed. A scaled-down version of the IC is called Little Ionization Chamber (LIC). Those detectors are about 10 times less sensitive then the original ICs and their maximum measurement range extends to about 230 Gy/s. They have been installed in IR6 (dump losses observation), IR2 and IR8 (injection losses) and discussion about installation in IR3 and IR7 is ongoing. In many cases they replace Secondary Emission Monitors (SEM) which have a sensitivity about $7 \cdot 10^4$ smaller then standard detectors and were found not sensitive enough to observe the majority of LHC beam losses.

Diamond detectors were tested during Run 1 for high temporal resolution measurements of beam losses. They were used by the machine systems as well as by the experiments (cf. CMS Beam Condition Monitors). During LS1 a total of 12 diamond detectors will be installed in IR2, 4, 5, 7 and 8 and connected to machine beam observation systems. They will be used to observe the bunch structure of the losses.

BLM IC location outside of the magnet cryostat leads to relatively low sensitivity to the loss pattern. As a consequence in some cases it is difficult to distinguish between

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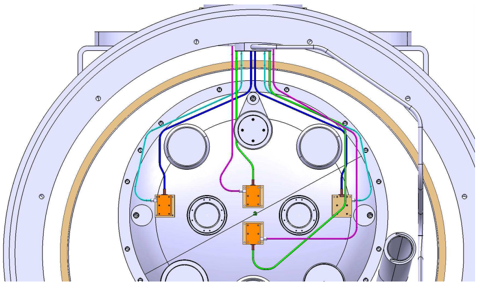

Figure 1: Installation of Cryogenic BLMs on the front face of main dipole cold mass.

normal losses (eg. due to luminosity production) and potentially quench-provoking abnormal losses [4]. In order to restore the ability the BLM system to prevent quenches the radiation sensors should be installed closer to the superconducting coil, improving the correspondence between BLM signal and energy deposition in the coil.

While the final cryogenic BLMs will be installed only during LS2 and LS3, a test installation on the cold masses of two main dipoles (MB) has been performed. Fig.1 presents the location of the four detectors on the MB end cup. The installation is described in [5].

## QUENCH TEST RESULTS

Numerous quench tests have been performed during the Run 1 [6]. The last, most advance series of experiments took place in February 2013. The analysis started afterwards and is being finalized now. The quench tests allow not only to assess limits of the machine performance but also allow to fine-tune quench-preventing BLM thresholds, study particle shower beam loss simulations and validate models of heat transfer inside the superconducting coils.

The main loss types threatening LHC operation after LS1 are expected to be steady state losses in cleaning and luminosity insertions and so called UFO losses everywhere in the cold sections. Both loss types produce different temporal and spatial patterns and both were investigated.

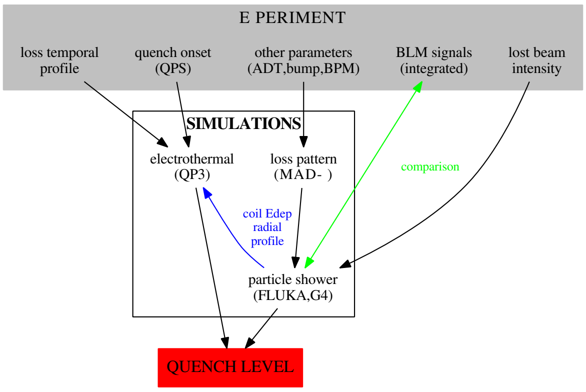

Figure 2: Schematics of quench test analysis procedure.

The complete analysis procedure of the quench test is schematically illustrated in Fig. 2. It consists of the following steps:

- Perform experiment assuring a good confinement of the losses and a good measurement of beam intensity decay and BLM signals; other parameters are measured depending on experiment.
- Based on knowledge of the beam trajectory, aperture and the beam excitation mode, simulate the loss pattern.
- Use the loss pattern together with FLUKA/Geant4 geometry of the sector of the accelerator involved in the test to run particle shower simulations.
- Scale the simulation results: BLM signals and energy deposit in the coil ($E_{dep}$), with number of lost protons measured during the experiment.
- Compare obtained BLM signals with the ones measured during the experiment; a good agreement gives a confidence in accuracy of $E_{dep}$ estimation.
- The energy density in the coil is the first main result of the test.
- The radial profile of the $E_{dep}$ is an input to electro-thermal simulations (usually QP3 code).
- Second input is the temporal behaviour of the beam loss (from measurement).
- Output of the electro-thermal code is the second result of the test.

The above analysis scheme is complex. The two quench level values obtained at the end are not independent as the electro-thermal simulation uses the radial shape of the energy deposition in the coil obtained with particle shower simulation.

The outcome of the quench test experiments is a better understanding of electro-thermal properties of the coils and the loss patterns generated by various beam excitation mechanisms. These studies were reported in numerous Quench Test Analysis Working Group meetings [7], conference papers and ATS notes. A journal publication summarizing the results is prepared and a Workshop on Beam Induced Quenches will take place in September 2014. The most important quench level values obtained are shown in Table 1. In both cases the quench levels are higher then assumed for the initial settings of BLM thresholds. Particularly in the millisecond timescale the difference is factor 5 to 10. In addition, for this timescale, the discrepancy between electro-thermal and particle shower analyses is the largest.

## BLM THRESHOLDS FOR STARTUP

Thresholds settings at the beginning of Run 1 were based on a limited number of simulations which were available at that time and an algorithm from [9]. During the Run 1 the thresholds were tuned, what is documented in numerous ECRs and presentations of the BLM threshold working group [8]. Clearly, this experience is a solid base for defining the new thresholds for LHC startup in 2015.

Table 1: The main results of the quench tests.

| **Loss duration** | **Experiment + FLUKA** | **QP3** | **Run1 value** |
|---|---|---|---|
| 5 ms | $198-400$ $[\mathrm{mJ/cm^3}]$ | $58-80$ $[\mathrm{mJ/cm^3}]$ | $40$ $[\mathrm{mJ/cm^3}]$ |
| 20 s | $41-69$ $[\mathrm{mW/cm^3}]$ | $74-92$ $[\mathrm{mW/cm^3}]$ | $20$ $[\mathrm{mW/cm^3}]$ |

On the other hand, the thresholds were verified up to the beam energy of 4 TeV and the extrapolation to 7 TeV, at which the quench levels are 2-3 times lower, represents a serious challenge. Therefore, an effort to recalculate the BLM thresholds has started.

The values of the BLM thresholds depend on the assumed loss scenario. For instance, a localized loss typically gives lower values of the BLM thresholds than spread loss. Moreover, many of the loss scenarios used to calculate BLM thresholds for Run 1 turned out to be not relevant and others - like the UFO losses - were not initially considered. Therefore, a **review of the loss scenarios** is being performed.

The BLMs are grouped in families which have identical beam-abort master threshold tables, usually because they protect the same elements from the same beam loss scenarios. The number of independent families is more than 150, but many of them have identical thresholds. In order to reduce system complexity the **BLM families will be reviewed** and their number will be reduced.

One of the main tasks is also **reviewing the models** used by the threshold calculation procedure. On the cold magnets the thresholds are calculated following Equation 1:

$$T(t_{loss}, E_b) = f \cdot \frac{S_{BLM}(t_{loss}, E_b)}{E_{dep}(t_{loss}, E_b)} \cdot QL(t_{loss}, E_b) \quad (1)$$

where:

- $S_{BLM}(t_{loss}, E_b)$ is a BLM signal as a function of beam energy, for a given loss scenario, obtained from particle shower simulations and checked with experiments.
- $E_{dep}(t_{loss}, E_b)$ is energy density in the coil; it is obtained from particle shower simulations and it is a function of beam energy but also the loss duration/scenario.
- $QL(t_{loss}, E_b)$ is the quench level, obtained from electro-thermal simulations and from measurement; it is a function of magnet current (which in case of dipoles is proportional to $E_b$) and the loss duration.
- $f$ represents empirical corrections to the threshold values, for instance the discrepancy between electro-thermal simulations and quench test results.

The new particle shower simulations give more accurate parametrizations of $S_{BLM}(t_{loss}, E_b)$ and $E_{dep}(t_{loss}, E_b)$. To prepare the thresholds the extensive simulation program has started.

It must be noted that the tools used during Run 1 did not allow for generation or threshold based on more then one loss scenario for a given BLM family. The tool developed for startup will contain this functionality.

Another action foreseen before the startup is a check of minimum thresholds against loss fluctuations appearing in various moments of the accelerator cycle, as done in [10].

Despite of all the experience collected during the Run 1 and quench tests it is crucial to be ready to introduce empirical corrections to the BLM thresholds during the Run 2.

### *New threshold generation approach*

The current thresholds generation application (called `thrc++`) is a standalone C++ application making use of `root` classes for visualization and interpolation. The program was compiled and all the parameters defining BLM thresholds were stored in card-files in svn directory, providing history of changes.

In the new approach the algorithm to generate thresholds as well as values of parameters characteristic for each BLM family is stored within the LSA database [11]. The security of the data, the algorithm and the whole application is improved not only by Oracle mechanisms but also by the RBAC mechanisms.

## CONCLUSIONS

During LS1 the BLM system went through a hardware maintenance and upgrades which will increase its reliability, availability and diagnostic potential. As one of the main tasks of the system is quench prevention, a series of quench tests have been performed and analyzed. As a result new, more realistic estimations of quench levels have been established and the code which will be used for BLM threshold settings has been validated. The thresholds need to be recalculated as new simulations and measurements are available now. The structure of the BLM families will be reviewed, reducing unnecessary complexity. A new, safer implementation of the threshold calculation algorithm will be used.

## ACKNOWLEDGMENT

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