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Initial settings of Beam Loss Monitors thresholds on LHC collimators

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Summary

Beam Loss Monitors are installed in vicinity of every LHC Collimator. The main goal of these monitors is protection of collimators from damage by the beam. Therefore the beam abort thresholds must be estimated and set in the threshold comparator card of the system. In this Note a description of a procedure leading to initial settings of the thresholds is presented. The procedure takes into account beam loss scenario due to failures of specific magnets which lead to a very high loss rate.

1. Introduction

This document describes the procedure to obtain beam-abort thresholds for Beam Loss Monitors (BLM) [1] protecting the LHC collimators. BLMs can issue a beam dump signal in case of signal excess in any of 12 signal integration times between 40 microseconds and 84 seconds. The procedure to obtain thresholds for all integration times is presented.

The input data are:

1. maximum allowed protons lost or loss rate on a given collimator obtained from the collimation team [2] – this number is determined by the collimator damage level or by minimum allowed beam lifetime,
2. simulations and measurements estimating the signal in the BLMs due to a single particle impacting in the collimator (a given one or one of the upstream primary collimators) [3],
3. simulations of the worst case magnet failure scenarios where the loss rate is very high and additional safety margin must be taken into account [4].

The starting point is a set of values of maximum allowed number of protons lost on a collimator. These values for various collimators are presented in Table 1. They contain already the safety factor 10 [5], i.e. they are below the collimator damage level. They do not take into account the cross-talk effect, i.e. the influence of loss on primary collimators on the secondary and tertiary ones [3,6].

The thresholds are defined in three time-interval domains. For losses which last less than 1 second the amount of allowed lost protons ($N_{<1}$) is constant, what means that a loss of *n* protons within a microsecond is expected to affect collimators in the same way as the same loss lasting one second. For longer losses the maximum allowed loss rate is presented ($dN_{1\text{-}10}/dt$ and $dN_{>10}/dt$).

The maximum number of lost protons N(t) in a time period t multiplied by the signal expected from a single proton gives the threshold which is send to the electronics of the BLM system. N(t) is defined in the following way:

- for t<1 s : $N(t<1) = 1\,[s] \cdot dN_{1\text{-}10}/dt = N_{<1}$
- for 1 s < t < 10 s : $N(1<t<10) = t \cdot dN_{1\text{-}10}/dt$

For losses longer then 10 seconds the maximum allowed number of lost protons contains protons lost in the shorter interval and assumes a decrease of the loss rate from $dN_{1\text{-}10}/dt$ to $dN_{>10}/dt$ for the time after 10 s from the beginning of the loss:

- $N(t>10) = 10\,[s] \cdot dN_{1\text{-}10}/dt + (t-10[s]) \cdot dN_{>10}/dt$

Device	**Location**	**Beam Energy**	**t > 10s**	**1s < t < 10s**	**t < 1s**
			$dN_{>10}/dt$ [p/s]	**$dN_{1\text{-}10}/dt$ [p/s]**	**$N_{<1}$ [p]**
TCP	IR3	450 GeV	1.20E+12	6.00E+12	6.00E+12
TCP	IR3	7 TeV	8.00E+10	4.00E+11	4.00E+11
TCP	IR7	450 GeV	1.20E+12	6.00E+12	6.00E+12
TCP	IR7	7 TeV	8.00E+10	4.00E+11	4.00E+11
TCSG	IR3	450 GeV	1.20E+11	6.00E+11	6.00E+11
TCSG	IR3	7 TeV	8.00E+09	4.00E+10	4.00E+10
TCSG	IR7	450 GeV	1.20E+11	6.00E+11	6.00E+11
TCSG	IR7	7 TeV	8.00E+09	4.00E+10	4.00E+10
TCLA	IR3	450 GeV	6.00E+08	3.00E+09	3.00E+09
TCLA	IR3, IR7	7 TeV	4.00E+07	2.00E+08	2.00E+08
TCLA	IR7	450 GeV	6.00E+08	3.00E+09	3.00E+09
TCLA	IR3, IR7	7 TeV	4.00E+07	2.00E+08	2.00E+08
TCTH, TCTVA, TCTVB	IR1, IR2, IR5, IR8	450 GeV	6.00E+08	3.00E+09	3.00E+09
TCTH, TCTVA, TCTVB	IR1, IR2, IR5, IR8	7 TeV	4.00E+07	2.00E+08	2.00E+08
TCL, TCLP	IR1, IR5	450 GeV	6.00E+09	3.00E+10	3.00E+10
TCL, TCLP	IR1, IR5	7 TeV	4.00E+08	2.00E+09	2.00E+09
TCLIA, TCLIB, TCSG	IR2, IR6, IR8	450 GeV	1.20E+11	6.00E+11	6.00E+11
TCLIA, TCLIB, TCSG	IR2, IR6, IR8	7 TeV	8.00E+09	4.00E+10	4.00E+10

Table 1: The maximum allowed loss rates for various collimators [2].

2. Correction for fast failures

Failures of some LHC elements might lead to a very fast loss rate. The BLM system is able to issue a beam dump signal within a single LHC turn (89 µs), but the whole sequence until the beam leaves completely the ring lasts about 4 turns. In case of a very high loss rate during this time the total loss can already exceed the damage level of the collimators. Therefore the BLM thresholds should be lowered to take into account the scenarios with very high loss rate. These scenarios are discussed in [4], where the fast decay of magnetic field due to quench or powering failure has been introduced to MADX [7] optics program.

The correction should be made to the shortest signal integration times: half LHC turn (running sum RS01, 40 µs integration time), one LHC turn (running sum RS02, 80 µs integration time) and 4 LHC turns (running sum RS03, 320 µs integration time). One of the worst case scenarios has been found to be a powering failure of one of the normal-conducting dipoles D1 in the insertion region (in IR1 or IR5). In case of injection beam energy it corresponds to powering the D1 with a voltage applicable for collision beam energy. In case of collision energy it corresponds to a fast current decay.

The Figure 1 shows the amount of lost protons (normalized to total amount of circulating protons before the failure) as seen on the collimators, integrated from the beginning of the failure. Reading this Figure for the TCP.C6L7 collimator (green line) one finds that the critical number of protons (from Table 1): $6 \cdot 10^{12}$ protons (which is 2% of the nominal beam) is reached after 28 turns from the failure. Knowing that the time needed to dump the beam is about 4 LHC turns, the amount of protons read 4 turns in advance should be used as the threshold. This number can be read from the Figure 2: the loss at the 24th turn is about 0.001 of the nominal beam intensity i.e. about $4 \cdot 10^{11}$ protons.

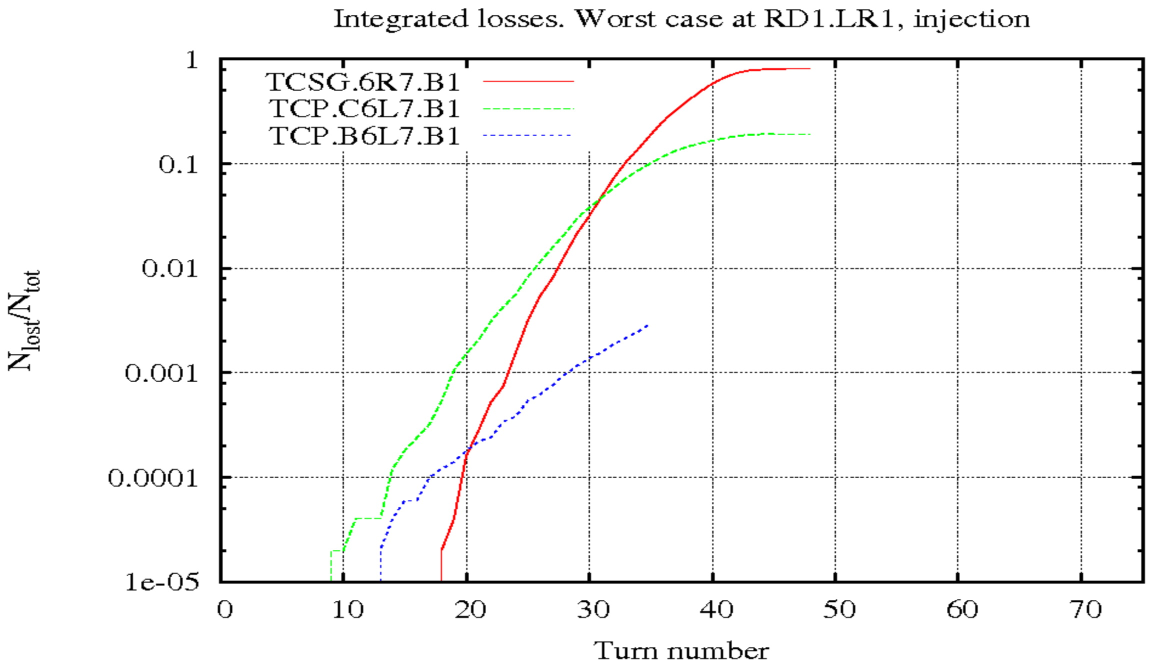

Illustration 1: Number of lost protons integrated from the beginning of the failure normalized to total number of circulating protons before the failure [4].

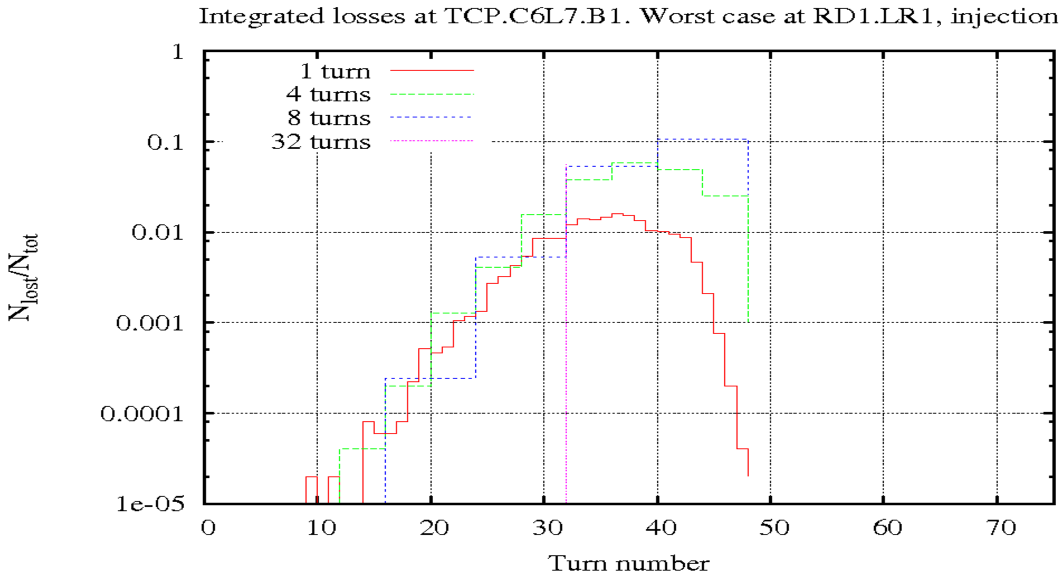

Illustration 2: Number of protons lost per turn (red curve), per 4 turns (green dashed curve), per 8 turns (blue dashed curve) and per 32 turns (magenta dotted curve).

Performing similar calculations for the TCSG collimator at injection beam energy one obtains $3 \cdot 10^{10}$ protons which should trigger the beam abort instead of initial $6 \cdot 10^{11}$ lost protons (cf. Table 1).

In the Figure 3 an example of thresholds expressed in number of protons lost on a collimator is shown. It assumes similar effect at injection and at collision beam energies, although the effect is typically worse at injection energy when it is easier to deflect the beam. The new thresholds allow to loose $3 \cdot 10^{11}$ protons i.e. 3 nominal LHC bunches at injection energy.

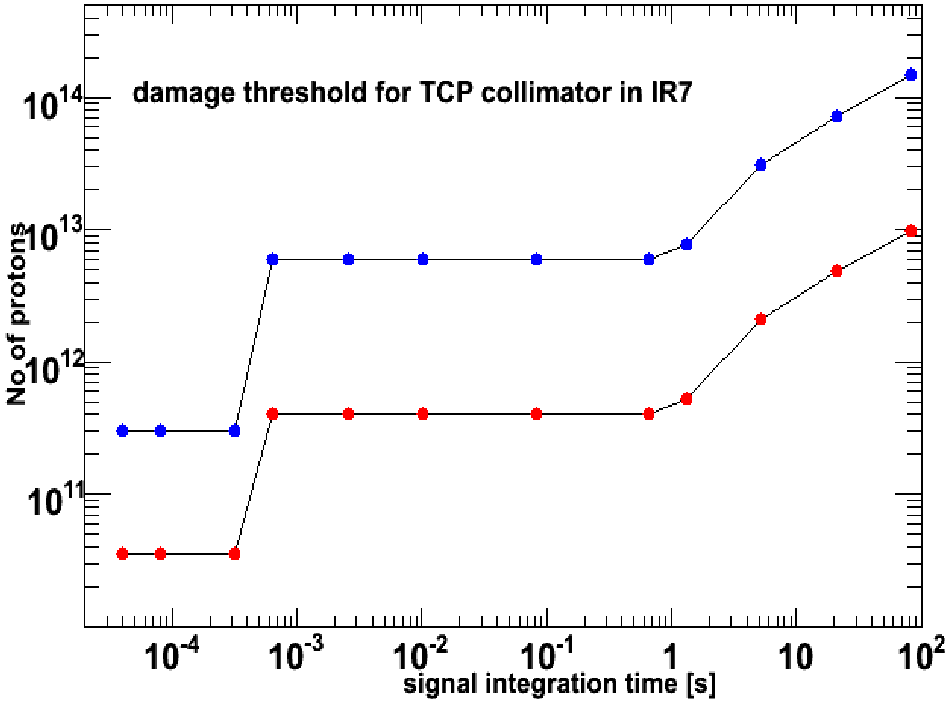

Illustration 3: Time evolution of thresholds for TCP collimator for injection (blue dots) and collision (red dots) beam energy.

3. Signal in the BLM monitors

FLUKA [7] simulations, showing what dose is registered in the Beam Loss Monitor due to a single proton loss on the collimator, are discussed in [3]. On the right plot of Figure 6.9 of [3] a signal after loss on TCP collimator is presented as a function of relative angle between beam and the collimator jaw. For large angles the signal is as low as 10^{-14} Gy/proton while for small angles it reaches about 10^{-12} Gy/proton. These values correspond to an unrealistic case of a pencil beam impacting on a collimator with impact parameter of 2 μm. This example is used here but the final values, depending on the impact parameter map, are produced in various simulations [9]. Therefore the proposed thresholds, expressed in total dose allowed in a given integration time, are shown in Figure 4. For very short losses (40 and 80 μs) an additional correction due to charge collection time [10] is applied.

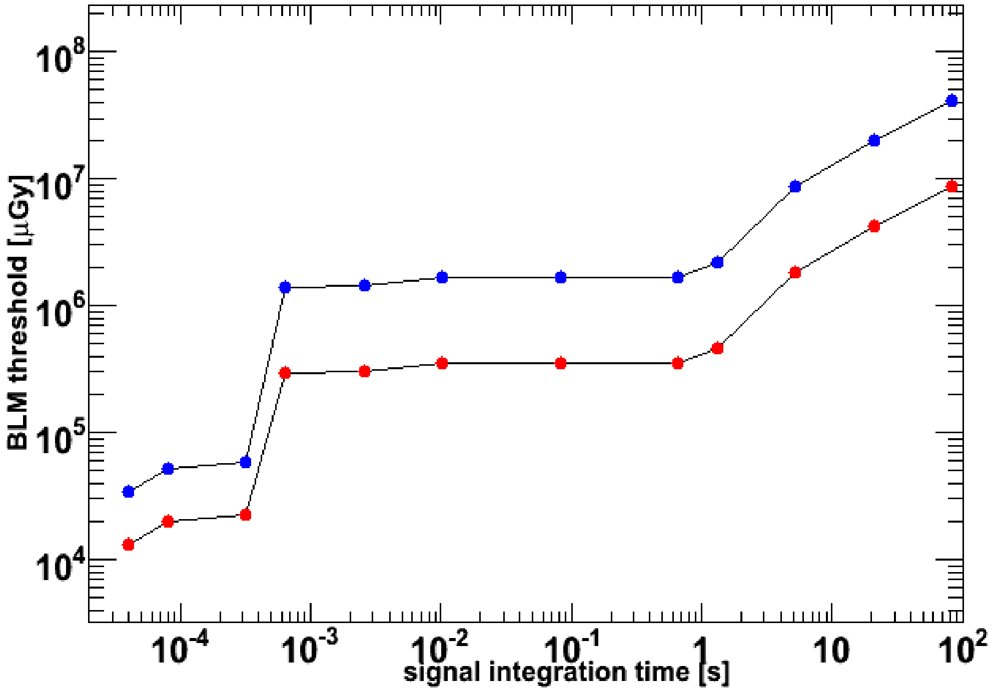

Illustration 4: BLM thresholds on TCP collimator in IR7 expressed in dose, as a function of signal integration time. A dose of 10^{-12} *Gy per impinging proton is used.*

The threshold value for transient losses is 35 mGy (or 87.5 Gy/s for RS01 ie. 40 μs integration time) and at injection energy and 13 mGy (or 32.5 Gy/s for RS01) at collision energy. The quench-protecting thresholds for the MB magnets are 30 times smaller at injection energy and 60 times smaller at collision energy (without taking into account the safety factor) [10].

For steady-state losses the collimator threshold is 0.5 Gy/s at injection and 0.1 Gy/s at collision energy. The corresponding threshold on MB magnet is 1000 times lower.

4. Secondary collimators

In case of the secondary and tertiary collimators (this statement is also valid for some primary which see already protons scattered from upstream collimators) the ratio of energy deposited in the BLM to energy deposited in the collimator jaw can be by a factor 5 smaller than in case of the primary collimators [6]. This is due to higher-order beam halos produced by upstream collimators. Therefore the thresholds in BLMs should be about a factor 5 smaller than the outcome of the procedure presented above.

At the same time the non-primary collimators are less sensitive to the angle between the jaw and the beam, therefore the factor 10, quoted before, can be dropped. Further studies of these effects are necessary to optimize BLM thresholds on collimators.

5. Conclusions and remarks

The method of initial determination of BLM thresholds protecting the LHC collimators is presented. Conservative results concerning the primary collimators (TCPs), which are typically the most exposed ones in case of fast failure scenario, are shown. Input to this method are maximum allowed amounts of protons lost on the collimators, FLUKA simulations of detector signal in the BLMs due to protons lost on the jaws and MADX simulations of fast magnet failures.

A different approach to threshold simulations is presented in chapter 6.5.1 of [3].

6. Acknowledgements

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