ANALYSIS OF FAST LOSSES IN THE LHC WITH THE BLM SYSTEM

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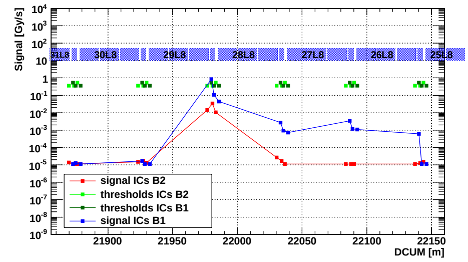
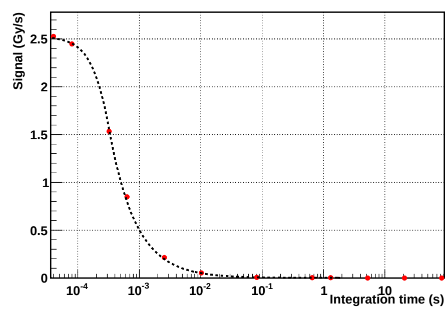
Abstract

About 3600 Ionization Chambers are located around the LHC ring to detect beam losses that could damage the equipment or quench superconducting magnets. The BLMs integrate the losses in 12 different time intervals (from 40 us to 83.8 s) allowing for different abort thresholds depending on the duration of the loss and the beam energy. The signals are also recorded in a database at 1 Hz for offline analysis. During the 2010 run, a limiting factor in the machine availability were sudden losses appearing around the ring on the ms time scale and detected exclusively by the BLM system. It is believed that such losses originate from dust particles falling into the beam, or being attracted by its strong electromagnetic field. This document describes some of the properties of these "Unidentified Falling Objects" (UFOs) putting special emphasis on their dependence on beam parameters (energy, intensity, etc). The subsequent modification of the BLM beam abort thresholds for the 2011 run that were made to avoid unnecessary beam dumps caused by these UFO losses are also discussed.



(a) Longitudinal profile of a UFO-like loss



(b) Time evolution of a UFO-like loss

Figure 1: UFO longitudinal profile and time evolution.

INTRODUCTION

During the evening of the seventh of July of 2010, the BLM system requested a beam dump as a consequence of the observation of beam losses on the millisecond time duration. Since then, 35 beam dumps have been requested due to similar losses happening at different locations around the LHC ring, becoming one of the limiting factors for the performance of the machine. Figure 1 (a) shows the longitudinal profile of the loss produced by a UFO in the LHC arc. In this particular case the loss originated in beam 1 (B1), as the signals recorded in the BLM monitor in that beam (blue points) are higher. The cross talk signal observed by the B2 monitors located at the opposite side of the magnet indicate that the loss was initiated inside the adjacent bending magnet, since the first BLM observing a signal is located on the main dipole. In Figure 1 (b) the time evolution of the signal observed in the most critical BLM is shown. The signal has a Gaussian core with a σ in the millisecond scale and it follows a $\sim 1/t$ for $t > \sigma$. In the text we will refer to σ as loss duration. In this document we summarize the analysis performed on these type of losses as well as the actions taken in order to minimize their impact in the performance of the LHC.

INTENSITY DEPENDENCE

A systematic search for below threshold UFO-like events was carried out in order to accumulate statistics and study their behaviour. The detection conditions were based on two local BLMs (within 40 meters) having a signal above $1 \cdot 10^{-4}$ Gy/s in the $640\ \mu s$ integration window. We will refer to this as detection condition 1. For the results presented in this section a more restrictive condition (detection condition 2) was applied in order to avoid accounting for fake UFOs, estimated to be in the range of 20 % in [1], and to compare with data collected during 2010 [2]. In this case a signal higher that $6 \cdot 10^{-4}$ Gy/s in the $2.4\ ms$ integration window was required in three local BLMs. The rate at which UFO events appeared during stable beams at 3.5 TeV is illustrated in Figure 2. In both cases an increasing rate with intensity is observed. However, while a clear increase in UFO rate with the number of circulating bunches was observed in 2010, this is not the case in 2011. The reason is not clear, but may point to a conditioning or cleaning effort.

Figure 3 shows the loss duration versus intensity of the UFOs observed (in stable beams at 3.5 TeV) during both the 2010 and 2011 (until the beginning of June) runs. The small dots represent the duration for every UFO whereas

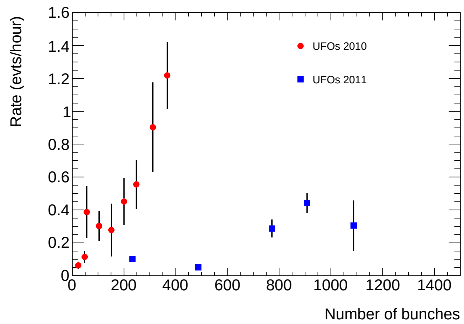


Figure 2: UFO rate versus number of nominal intensity bunches for event observed under detection condition 2.

the large circles and squares show an average. A decreasing tendency with intensity is observed. The difference in the parameters of the linear fits is attributed to a lack of statistics in the first two intensity bins during 2010, where the intensity in the machine was low and not many UFOs were observed. The same study was performed for the observed peak signal, i.e., the signal observed in the BLM in the shortest (40 μs) integration window. As shown in Figure 4, no clear dependence with intensity was observed. These two features qualitatively agree with theoretical models that describe the dynamics of dust particles falling into the beam [3].

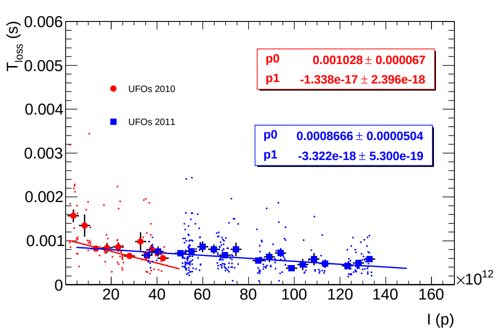


Figure 3: Loss duration versus intensity.

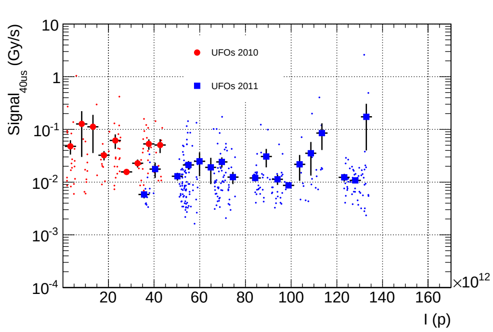


Figure 4: Peak signal (signal in 40 μs) versus intensity.

Finally, a correlation between the loss duration and the peak signal can be seen in Figure 5. The inverse proportionality seems to indicate that the lower the duration of the loss, the larger the size of the dust particle (assumed to be related to the peak signal).

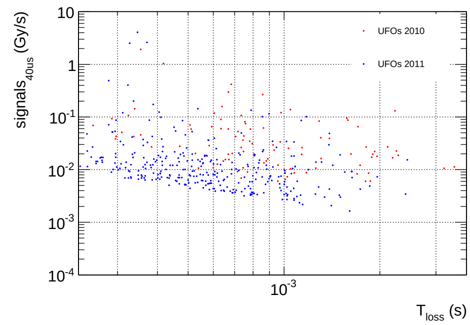


Figure 5: Peak signal versus loss duration.

ENERGY DEPENDENCE

Except for events happening at very specific locations around the ring [1], a lack of UFOs has been observed while running at injection energy. In this section we present a study performed in order to understand this issue. The losses produced by wire scans during the LHC ramp have been used as a benchmark. Figure 6 shows the integrated dose recorded in the BLM detectors while performing scans at different energies. A second degree polynomial reproduces the data for all three detectors. The fitted functions were used to estimate the doses at injection and nominal (7 TeV) energy, see Table 1, relative to the doses at the current running energy of 3.5 TeV.

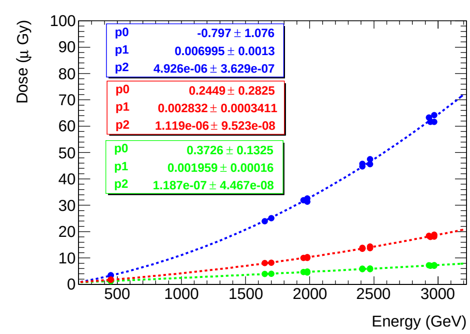


Figure 6: Signals observed in the BLM monitors located downstream the wire scanners during ramp.

Table 1: Dose during wire scans relative to dose at 3.5 TeV in the three BLMs located downstream of the Wire Scanner.

Energy	BLM1	BLM2	BLM3
450 GeV	0.07	0.15	0.04
7 TeV	3.14	2.29	3.44

In the following exercise we take a set of UFOs selected with the detection condition 1 and we scale up the original detection threshold ($6.4 \cdot 10^{-8}$ Gy) to study the selection efficiency. We assume that a reduction in the recorded dose by the BLMs (due to a decrease on the beam energy) is equivalent to an increase in the detection threshold, and the relative doses presented in Table 1 for 450 GeV are used as scaling factors. Figure 7 shows a reduction on the selection efficiency by a factor 0.17, 0.09 and 0.05 respectively. Thus, we estimate that the UFO rate at 450 GeV should be a factor $(0.17 - 0.05)$ lower than the observed at 3.5 TeV.

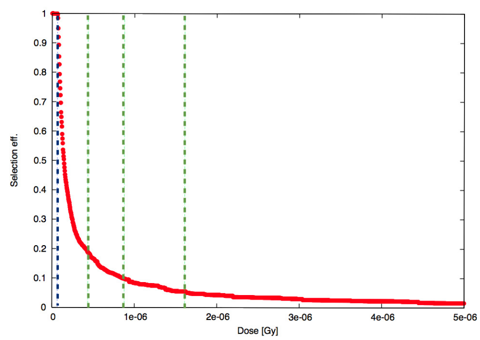


Figure 7: Variation of the selection efficiency with detection threshold.

To compare the UFO rates at injection energy and 3.5 TeV, 64 LHC fills (between the 25th of May and the 31st of August) were analyzed. During 329.1 hours of stable beams 1751 UFOs were observed. The candidates were selected with detection condition 1. Therefore, the rate 5.32 ± 0.13 $evts/hour$ is much larger than the rates discussed in the previous section [1]. With the scaling numbers obtained above the estimation for the UFO rate at 450 GeV is in the range $(0.90 - 0.27)$ $evts/hour$. In the same fills, 15.3 hours of full intensity beam at 450GeV were analyzed and 2 UFOs were found. The calculated UFO rate at injection energy was 0.13 ± 0.09 $evt/hour$. Furthermore, an extra 9 hours of high intensity circulating beam, during the 10th and 11th of april, were analyzed finding 0.44 ± 0.22 $evts/hour$. Hence, the difference in UFO rates at injection energy and 3.5 TeV may be compatible with the dependence of the BLM signals with the beam energy.

ABORT THRESHOLD INCREASE

UFO-like beam losses became a limiting factor since they produced signals in the BLM detectors that exceeded the abort thresholds resulting in a beam dump. Despite this fact, no quench of SC magnet was observed due to losses in the millisecond time scale. Modifications were therefore implemented in the BLM abort thresholds in a modular way. The thresholds were originally increased by a factor 3 independently of the time scale and subsequently by up to a factor 5 since more beam aborts were requested without observation of a magnet quench. Before the 2011 start up, the time dependence of the abort threshold was modified in order to allow for extra losses on the millisecond scale (due to UFO losses) but to be protected for longer losses. Figure 8 compares thresholds with measured data for a BLM detector protecting a main quadrupole due to beam losses created by a UFO (green circles). The UFO induced signal exceeded the 2010 abort thresholds (blue line) in the integration windows between 0.1 and 10 milliseconds. The thresholds were increased in these three integration windows by a factor 5 while they were increased by a factor 3 in the integration windows shorter than 0.1 milliseconds. Note that the abort thresholds for the 2011 run (black line) were decreased in the long integration windows. This was done due to an underestimation of the quench levels found with dedicated beam quench measurements (red circles). The abort threshold were set applying a safety factor of 3.

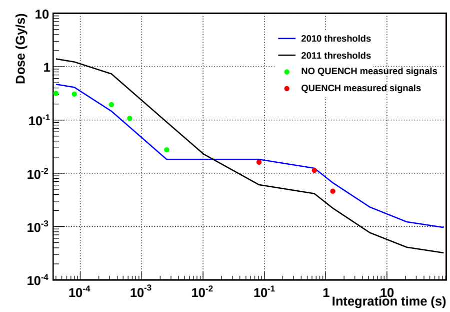


Figure 8: Comparison of abort threshold and measured signals during the 2010 and 2011 runs.

CONCLUSIONS

Unforeseen beam losses in the millisecond scale have been observed in the LHC to become a limiting factor. It is believed that such losses are caused by microscopic dust particles falling into the beam. The dependence of the duration and peak signal of these losses qualitatively agrees with theoretical models of interaction of dust with the LHC beams. A study was carried out to conclude that the energy dependence of the UFO rates is compatible with the energy dependence of the signals observed in the BLM detectors. Finally, due to the absence of magnet quenches caused by these type of losses, the BLM abort thresholds were increased in order to increase the availability of the machine.

REFERENCES

[1] T. Baer et al., "Dust particles in the LHC", IPAC'11, Valencia, September 2011.

[2] E. Holzer et al. , "Losses away from collimators: statistics and extraplolation.", CERN-ATS-2011-017, Evian, December 2010.

[3] F. Zimmermann et al , "Interation of macro-particles with LHC proton beam", CERN-ATS-2010-040, IPAC'10.

[1] The number of detected UFOs by using detection condition 2 was estimated to be a factor ~ 16 lower than the observed with condition 1.