

UFOs IN THE LHC

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Abstract

One of the major known limitations for the performance of the Large Hadron Collider are so called UFOs (Unidentified Falling Objects). UFOs were first observed in July 2010 and have since caused numerous protection beam dumps. UFOs are thought to be micrometer sized dust particles which lead to fast beam losses with a duration of about 10 turns when they interact with the beam.

In 2011, the diagnostics for such events was significantly improved which allows estimates of the properties, dynamics and production mechanisms of the dust particles. The state of knowledge and mitigation strategies are presented.

INTRODUCTION AND UFO RELATED BEAM DUMPS

Between July 7th 2010 and end of August 2011, in total 35 LHC fills were terminated by a protection beam dump due to localized fast beam loss events with similar, characteristic beam loss profiles: the temporal loss profile is typically of Gaussian shape with a width of a few LHC turns. Such events were observed in the whole machine and for both beams. Figure 1 shows the temporal loss profile of a typical event.

Out of the 35 events that caused a beam dump, 13 occurred around the injection kicker magnets (MKI), 9 in the long straight sections or in the dispersion suppressor, 7 in the arcs (\geq cell 12) and in 6 cases the beam was dumped by the beam loss monitors (BLM) or beam condition monitors (BCM) of the experiments.

Since autumn 2010, the amount of protection beam dumps, especially in the arcs, is significantly reduced by successive increasing of the BLM thresholds (for the arc BLMs a factor 5 above their initial values [1]).

It is believed that the cause of these beam losses are micrometer sized macroparticles which interact with the proton beam. Thus the acronym UFO for *Unidentified Falling Object* is associated to these events.

DETECTION OF UFO TYPE BEAM LOSSES BELOW DUMP THRESHOLD

In a post-analysis of the BLM data stored in the LHC Logging Data Base (LDB) during 2010, in total 113 additional similar events below the beam dump threshold were found [2].

For 2011, the approach was changed and UFO events below dump threshold are now detected directly online. This

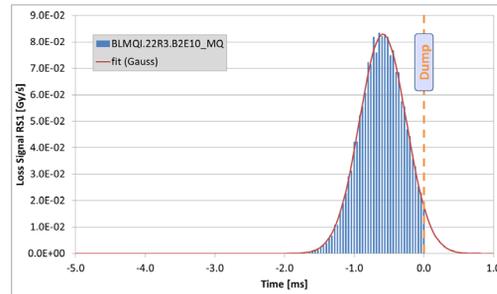


Figure 1: Temporal loss profile of a fast beam loss event on 23.08.2010. The beam loss in running sum (RS) 5 (2.5 ms integration time) exceeded the corresponding threshold and caused the beam dump. The loss occurred on beam 2 in the arc of sector 34. The temporal width of the Gaussian fit is $335 \mu\text{s}$ ($\hat{=}$ approximately 3.8 turns).

includes the advantage of an up to sixty times better time resolution of the online data compared to the data from the LDB. The detection algorithm is based on the requirement that a signal of at least $1 \cdot 10^{-4} \text{ Gy/s}$ in RS4 (640 μs integration time) is detected by at least 2 BLMs within 40 m of each other¹. In addition, the signal for each BLM has to pass a noise filter which requires the loss ratios of RS2 (80 μs integration time) over RS1 (40 μs integration time) to exceed 0.55 and the loss ratios of RS3 (320 μs integration time) over RS2 to exceed 0.45².

With this approach, over 10,000 candidate UFO events were detected between April and end of August 2011.

UFO STATISTICS

Most of the UFO events are much below the BLM dump thresholds. Figure 2 shows the distribution of the ratio of the beam losses over dump threshold for the arc UFO events. The two events right of the dashed blue line are the two arc UFO events which caused a beam dump in 2011. The distribution can be approximated by a $1/x$ dependency. This underlines that changes of the BLM thresholds have a significant influence on the expected number of beam dumps. A similar $1/x$ dependency was measured for the distribution of the dust particle volume in the magnet test halls [3, 4]. Since there is an almost proportional dependency between dust particle volume and resulting beam

¹The noise level is about $2 \cdot 10^{-5} \text{ Gy/s}$ in RS4 for the arc BLMs

²The detection thresholds are set rather wide in order to record all potentially interesting events. This results in an occasional false detection of non-UFO events. Thus, depending on the analysis, additional cuts are used which are benchmarked against a manually verified collection of reference datasets [3]. In the detection algorithm, additional conditions are used for special cases.

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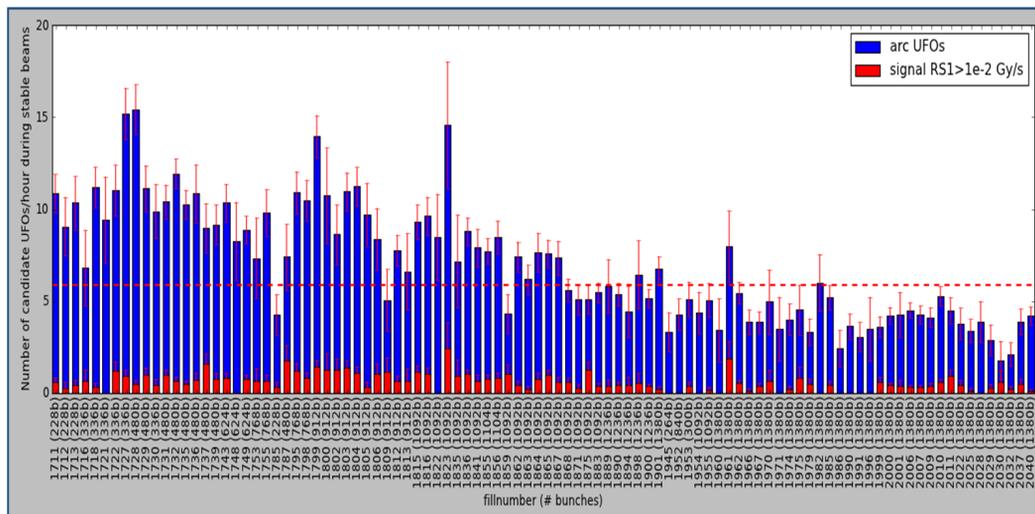


Figure 3: The number of candidate arc UFO events (\geq cell 12) per hour during stable beams for all fills with at least one hour of stable beams between April 2011 and August 2011. 5238 candidate UFO events are taken into account. The average rate is 6.0 UFOevents/hour.

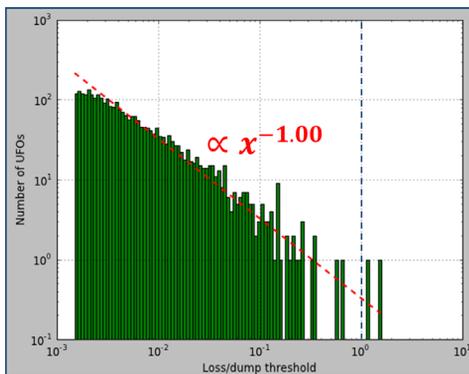


Figure 2: The distribution of beam loss/dump threshold for 2780 candidate UFO events in the arcs (\geq cell 12) with a signal in RS5 of at least $2 \cdot 10^{-4}$ Gy/s.

losses according to the theoretical model [5], the dust particle distribution explains well the observed UFO event distribution.

Figure 3 illustrates the rate of the arc UFOs since April 2011. During this period, the beam intensity was increased from 228 to 1380 bunches. Whereas for a lower number of bunches, a linear intensity dependency was found in 2010 [1], this is not observable above several hundred bunches. Between April and end of August 2011, the UFO rate decreased from 10 to about 5 events per hour. The intrafill UFO rate stays constant during stable beams [3].

The spatial UFO distribution (Fig. 4) underlines that the events occur all around the LHC with exceptionally many events around the MKIs left of Pt. 2 and right of Pt. 8.

Most critical for LHC operation is the expected scaling of the UFO events with energy. Based on observations with the beam wire scanner, it is calculated in [1] that the expected signal of an UFO event at 7 TeV is about 3 times higher than at 3.5 TeV. At the same time, the beam loss thresholds of the arc BLMs are about 5 times lower

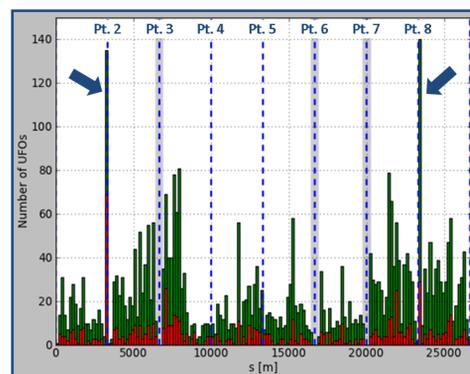


Figure 4: The spatial distribution of 3686 candidate UFO events at 3.5 TeV with a signal in RS5 of at least $2 \cdot 10^{-4}$ Gy/s (green) and with an additional cut that discards events with a signal below $1 \cdot 10^{-2}$ Gy/s in RS1 (red). The vertical blue lines indicate the locations of the interaction regions, the blue arrows show the locations of the injection kicker magnets (MKIs). The gray areas around collimation and dump region are excluded from UFO detection.

at 7 TeV than at 3.5 TeV due to the lower magnet quench limit. Assuming that the UFO rate is energy independent (which is consistent with the observations [1]), out of the arc UFO events which were recorded in 2011, 82 would have caused a protection beam dump at 7 TeV (compared to 2 protection beam dumps by arc UFOs at 3.5 TeV).

No correlation with bunch intensity was observed [3].

UFOS AROUND MKIS

During the first half of 2011, the UFO events around the injection kicker magnets (MKIs) had, with 11 beam dumps, the largest impact on the operation of the LHC. In total, over 1500 UFO type beam loss patterns have been observed around the MKIs so far. Figure 5 illustrates that most of the

UFO events around the MKIs occur within ≈ 30 minutes after the last injection.

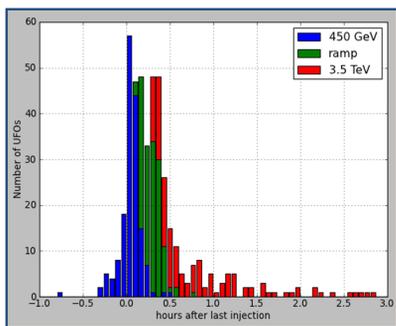


Figure 5: The distribution of the occurrence (w.r.t. the last injection) of 479 MKI UFO events. Only fills which lasted at least 3 hours after the last injection are taken into account.

During a dedicated machine development session, several UFO events were observed directly after pulsing the injection kicker magnets [6]. An analysis of the data from the BLM injection capture buffer, which records the losses with $40 \mu\text{s}$ resolution for about 20 ms around each injection, revealed many additional UFO type beam loss patterns within a few milliseconds after normal injections. Figure 6 shows the distribution of the delay w.r.t. the injection of these UFO events. The shortest observed delay is 3.3 ms. Assuming that a dust particle is released from the MKI aperture in the moment of the kicker pulse and that it is subject to a constant acceleration, this acceleration would have to be $\approx 3500 \text{ m/s}^2$. Hence, the particle dynamics cannot be explained by the gravitational field alone, and requires that the dust particle is accelerated towards the beam by electric and/or magnetic fields as well.

No correlation between MKI UFO events and vacuum activity or MKI temperature has been observed.

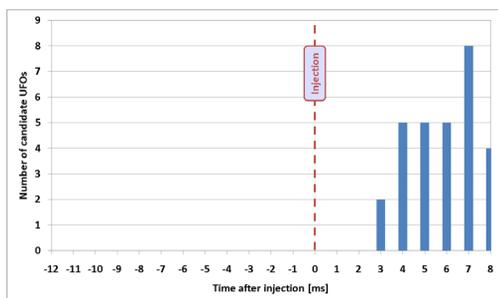


Figure 6: The delay between the pulsing of the MKIs and the occurrence of an UFO event for 28 UFO events which were recorded by the BLM injection capture buffer during normal operation in 2011. The shortest observed delay is 3.3 ms.

CONCLUSION AND OUTLOOK

The UFO events have a significant impact on LHC operation. Whereas similar in loss pattern, at least three types of UFO events should be distinguished:

01 Circular Colliders

A01 Hadron Colliders

- UFO events in the arcs: the impact of these events increases significantly with beam energy. Thus, these events are expected to be very critical for LHC operation at higher energies. The number of related beam dumps has been reduced to 2 events in 2011 so far due to increased BLM thresholds.
- UFO events around the MKIs: these had, with 11 beam dumps so far, the largest implication for LHC operation in 2011. The occurrence of the events seems to be related to the pulsing of the MKIs.
- UFO events in experiments: for the UFO related beam dumps by experiments, the corresponding signal in the LHC ring BLM system is generally very small and in many cases hardly above noise level.

Many additional studies are ongoing to gain a more profound knowledge about the behavior, impact and production mechanism of UFOs: In addition to a constant improvement of the diagnostics for UFO events [3], dedicated experiments and measurements are being carried out in the LHC and in the laboratory [6, 7] and are complemented by FLUKA simulations [8] and theoretical studies [5].

As long as the exact production mechanism is not understood, the main mitigation strategy is to increase successively the BLM thresholds towards the quench limit of the superconducting elements.

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