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 caused numerous protection beam dumps since then. They are presumably micrometer sized dust particles that 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 are highly increased which allows estimations of the properties, dynamics and production mechanisms of the dust particles. The state of knowledge and mitigation strategies are presented.

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INTRODUCTION AND UFO RELATED BEAM DUMPS

Between July 7th 2010 and end of August 2011, in total 35 LHC fills where 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 (≥ 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 [2]).

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 postanalysis 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 [5].

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

Figure 1: Temporal loss profile of a fast beam loss event on 23.08.2010. The beam loss in runningsum 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 μs (≈ 3.8 turns).

This 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 $1 \cdot 10^{-4}$ Gy/s in runningsum 4 (640 μs integration time) is detected by at least 2 BLMs within 40 m. On top, the signal for each BLM has to pass a noise filter which requires the loss ratios of runningsum 2 (80 μs integration time) over runningsum 1 (40 μs integration time) to exceed 0.55 and the loss ratios of runningsum 3 (320 μs integration time) over runningsum 2 to exceed 0.45\(^\dagger\).

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 3 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 \(\frac{1}{x}\) dependency. This underlines that changes of the BLM thresholds have a significant influence on the expected number of beam dumps. A similar \(\frac{1}{x}\) dependency was measured for the distribution of the dust particle volume in the magnet test halls [1, 4]. Since there is an almost proportional de-

\(^{\dagger}\)The 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 [1]. In the detection algorithm, additional conditions are used for special cases.
Figure 2: The number of candidate arc UFOs (≥ cell 12) per hour during stable beams for all fills with at least one hour of stable beams between April and August 2011. 5238 candidate UFOs are taken into account. The average rate is 6.0 UFOs/hour.

The dependence between dust particle volume and resulting beam losses according to the theoretical model [3], the dust particle distribution explains well the observed UFO event distribution.

Figure 3: The distribution of beam loss/dump threshold for 2780 UFO events in the arcs (≥ cell 12) with a signal in runningsum 5 of at least $2 \cdot 10^{-4}$ Gy/s.

Figure 2 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 identified in 2010 [2], this is not observable above several hundred bunches anymore. Between April and end of August 2011, the UFO rate decreased from 10 to about 5 events per hour. During stable beams, the UFO rate stays constant [1].

The spatial UFO distribution (Fig. 4) underlines that the events occur all around the LHC with exceptionally many events around the injection kicker magnets 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 [2] 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 at 7 TeV than at 3.5 TeV due to the lower quench limit at higher energies. Assuming that the UFO rate is energy independent (which is consistent with the observations [2]), 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 [1].

Figure 4: The spatial distribution of 3686 candidate UFO events at 3.5 TeV with a signal in runningsum 5 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 runningsum 1 (red). The gray areas around collimation and dump region are excluded from UFO detection.
UFOS AROUND MKIS

For 2011, the UFO events around the MKIs had with 11 beam dumps the largest impact on the operation of the LHC. In total, over 1500 UFO type beam loss pattern were 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 μs resolution for about 20 ms around each injection, revealed many additional UFO type beam loss pattern within a few milliseconds after normal injections. Figure 6 shows the distribution of the delay to 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 be ≈ 3500 m/s². Hence, the particle dynamics cannot be explained by the gravitational field alone, but it 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 was observed.

Figure 6: The delay to the injection of 28 UFO events which were recorded by the BLM injection capture buffer during normal operation in 2011. The first event occurred 3.3 ms after the injection.

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:

- 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 was reduces to 2 events in 2011 so far due to increased BLM thresholds.

- UFO events around the MKIs: These had with 11 beam dumps the largest implication for LHC operation in 2011. The occurrence of the events seems to be related to the pulsing of the injection kicker magnets.

- 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 additional knowledge about the behavior, impact and production mechanism of UFOs: Next to a constant improvement of the diagnostics for UFO events [1], dedicated experiments and measurements are done in the LHC and in the lab [6, 7] and are complemented by FLUKA simulations and theoretical studies [3].

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

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