UFOs IN THE LHC: OBSERVATIONS, STUDIES AND EXTRAPOLATIONS

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Abstract

Unidentified falling objects (UFOs) are potentially a major luminosity limitation for nominal LHC operation. They are presumably micrometer sized dust particles which lead to fast beam losses when they interact with the beam. With large-scale increases and optimizations of the beam loss monitor (BLM) thresholds, their impact on LHC availability was mitigated from mid 2011 onwards. For higher beam energy and lower magnet quench limits, the problem is expected to be considerably worse, though.

In 2011/12, the diagnostics for UFO events were significantly improved: dedicated experiments and measurements in the LHC and in the laboratory were made and complemented by FLUKA simulations and theoretical studies. The state of knowledge, extrapolations for nominal LHC operation and mitigation strategies are presented.

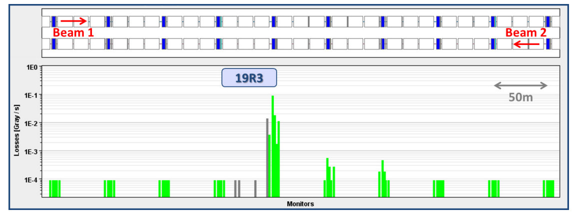
OBSERVATIONS AND CORRELATIONS

Since July 2010, UFOs led to 37 premature protection beam dumps of LHC fills. UFOs are presumably micrometer sized dust particles that lead to beam losses with a duration of about 10 turns when they interact with the beam. Such events were observed in the whole machine and for both beams, for proton as well as for lead ion operation. From mid 2011 onwards, their impact on LHC availability was mitigated by increasing and optimizing the BLM thresholds. An introduction to the topic is given in [1, 2].

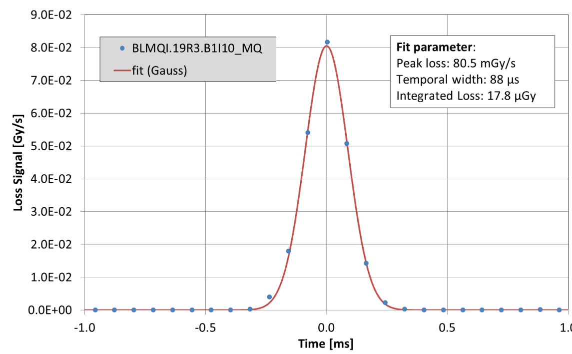
Most of the UFO events lead to beam losses far below the BLM dump thresholds. These events are detected in real time by the *UFO Buster* application [1]. In 2011, more than 16'000 candidate UFO events have been detected. Figure 1 shows the spatial and temporal loss profile of a typical UFO event.

The evolution of the arc UFO rate in 2011/12 is shown in Fig. 2. While the beam intensity was increased from 228 to 1380 bunches, the arc UFO rate decreased in 2011 from about 10 events/hour to about 2 events/hour. In the beginning of 2012, the arc UFO rate was a factor 2-3 higher than at the end of the 2011 proton run[1]. Throughout the flat top of a fill, the arc UFO rate remains constant [2].

The spatial distribution of the UFO events (Fig. 3), underlines that UFOs occur all around the LHC. Many events occur especially around the injection kicker magnets (MKI). Similarly, there is an increased UFO activity in some arc cells (e.g. cell 19R3 beam 1). Extensive



(a) Spatial loss profile.



(b) Temporal loss profile.

Figure 1: Spatial (a) and temporal (b) loss profile of a typical UFO event on 08.04.2012. The event occurred on beam 1 in the arc cell 19R3 at flat top (4 TeV). The beam losses reached about 7% of the BLM dump thresholds. In this cell, additional diagnostics BLMs (grey) are installed.

studies concerning MKI UFOs were made, which include improvements to the diagnostics, dedicated experiments in the LHC and in the laboratory, inspection of an operational MKI tank for macro particles, FLUKA [3, 4] simulations and theoretical studies. As a result, MKI UFOs have been identified as being most likely macro particles of up to 100 μm size which originate from the ceramic beam screen support tube surrounding the beam. The studies concerning MKI UFOs are discussed in detail in [5].

The dependence of the UFO rate on the beam intensity could be observed during the fast intensity ramp up in 2012 without being biased by the conditioning effect (Fig. 4). In agreement with previous studies [6], the rate of detectable UFO events increases proportionally to the beam intensity for small intensities. Above a few hundred bunches, the effect saturates. This is qualitatively consistent with the theoretical model [7].

Furthermore, the number of UFO events is inversely proportional to the associated beam losses [2]. This is well explained by the measured distribution of dust particle sizes and underlines that BLM threshold changes have a significant influence on the expected number of beam dumps.

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[1] The flat top beam energy was changed from 3.5 TeV in 2011 to 4 TeV in 2012.

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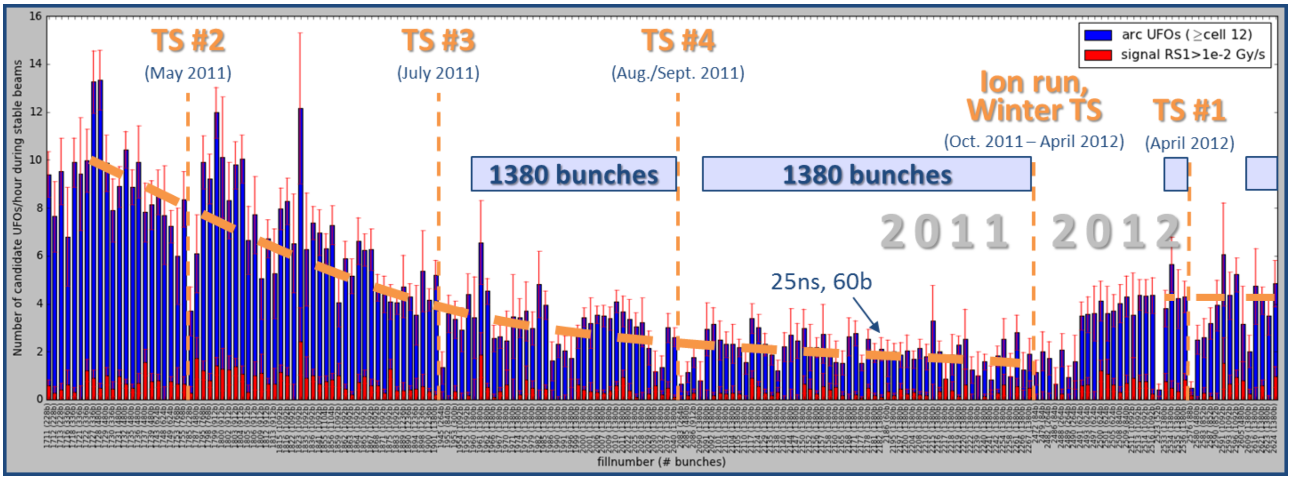

Figure 2: The rate of 5957 arc UFO events (≥ cell 12) during stable beam operation at top energy (stable beams) for all proton fills with at least one hour of stable beams between April 2011 and May 2012. During 2011, the rate decreased from about 10 events per hour to about 2 events per hour. The rate is reduced during the low intensity fills directly after the technical stops (TS).

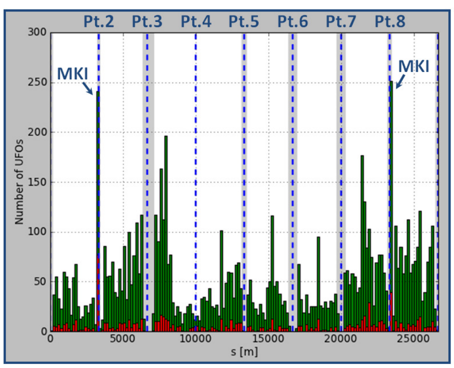

Figure 3: The spatial distribution of 7784 UFO events at 3.5 TeV between April and October 2011. The red bars correspond to events with a peak loss $> 10^{-2}$ Gy/s. The vertical dashed blue lines indicate the locations of the insertion regions. Gray areas are excluded from UFO detection.

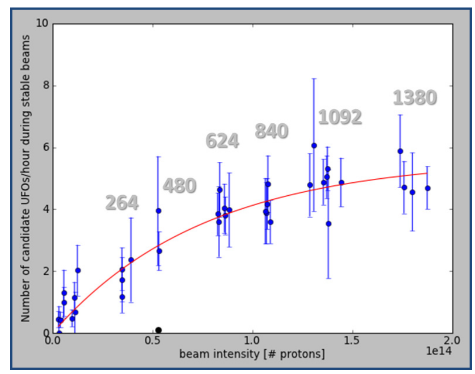

Figure 4: The rate of 500 arc UFO events (≥ cell 12) as a function of the maximum beam intensity of the fills during the fast intensity ramp up in the beginning of 2012. The gray numbers indicate the number of bunches.

ARC UFO STUDIES

To identify potential UFO locations, FLUKA simulations of proton-UFO interactions and induced particle showers were performed [8]. In Fig. 5, typical BLM dose patterns measured in 2011 are compared to simulation results. The simulations reveal that with standard quadrupole BLMs (see Fig. 1a) a precise loss location cannot be identified. To improve the spatial resolution, additional BLMs were installed at the three dipole magnets in cell 19R3 in early 2012. As indicated by the simulations, with these new BLMs, significant discrepancies in spatial loss patterns are expected for different loss locations (see Fig. 5). UFO events observed in cell 19R3 in 2012 indeed exhibit different loss patterns, suggesting that UFOs originate from various positions across the arc cell.

Dedicated simulations of the dynamics and interactions of macro particles falling from the top into the circulating proton beam were made [7]. A general conclusion is that macro particles are charged up positively by the proton beam and are deflected or even repelled by the beam. Many predictions are described in [7], in particular that (in agreement with the observations [6]) the typical loss duration is of the order of 1 ms and that the loss duration becomes shorter for larger beam intensities.

MID-TERM EXTRAPOLATION

As shown in [2], there are indications that the UFO activity could be significantly higher with 25 ns bunch spacing compared to 50 ns bunch spacing as used in 2011/12. Dedicated tests are envisaged for 2012.

The beam loss due to UFOs is expected to increase with beam energy. Based on the FLUKA simulations, the peak energy deposition of an arc UFO is expected to be about four times higher at 7 TeV than at 3.5 TeV[2]. Moreover, due to higher currents, the magnet quench limit is lower for higher beam energy (about a factor 5 for operation at 7 TeV

[2]Peak energy deposition in an arc dipole magent for an UFO event directly upstream of the diple magnet [8]. A scaling of a factor 3 was found from wire scanner measurements at different energies [6] and FLUKA simulations for MKI UFOs [9].

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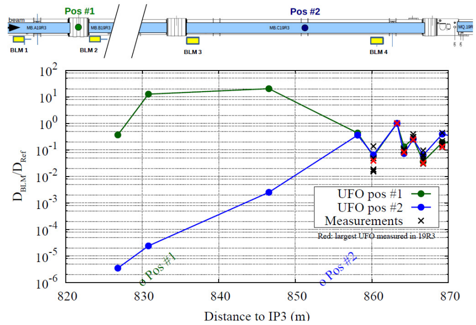

Figure 5: Comparison of measured and simulated BLM dose patterns corresponding to UFO-induced beam losses in the standard arc cell 19R3. Simulations were performed for two potential UFO locations (*Pos #1*, *Pos #2*). The signal at the six standard quadrupole BLMs (860 m - 870 m) and the additional diagnostics BLMs (820 m - 860 m) normalized to the highest signal in the quadrupole BLMs is shown (courtesy of A. Lechner and the FLUKA team [8]).

compared to 3.5 TeV). Figure 6 shows the expected scaling of BLM signal/BLM threshold. Applying the scaling to the BLM signals and thresholds of all 2011 arc UFOs, they would have caused 112 beam dumps, if the LHC would have been operated at 7 TeV instead of 3.5 TeV (Fig. 6). An additional 27 beam dumps would have been caused by MKI UFOs. During the first quarter of 2012, 13 arc UFOs and one MKI UFO would have caused a beam dump when scaling to 7 TeV operation. These numbers have to be compared to two actual dumps by arc UFOs and 11 dumps by MKI UFOs in 2011 and one additional dump by an MKI UFO in 2012 so far[3].

SUMMARY AND OUTLOOK

In 2011/12 extensive UFO studies were made, which include improvements of the diagnostics [1, 10], dedicated experiments in the LHC [10, 11] and in the laboratory [2, 5], FLUKA simulations [8, 9] and theoretical studies [7]. As a result, fundamental correlations were found, the macro particle dynamics are characterized, the response of the BLM system is understood and the source of the UFO events at the MKIs has been identified [5]. This allows for mid-term extrapolations and mitigation strategies.

The energy dependence indicates that UFOs could be a major performance limitation for LHC operation after the long shutdown in 2013/14.

For 2012, the UFO-specific instrumentation will be further improved. Complementary FLUKA and MAD-X simulations are ongoing. Additional experimental studies (including tests with 25 ns bunch spacing) and dedicated magnet quench tests are in preparation.

As long as the production mechanism of the arc UFOs is not understood, the main mitigation strategy is to increase the BLM thresholds towards the magnet quench limit. The arc FLUKA simulations and the additional instrumentation in cell 19R3 show that the current BLM distribution is not optimal for protection against beam losses due to UFOs. With a different BLM distribution, the UFO events could be detected more locally, which could allow a further increase of the BLM thresholds.

[3] The extrapolation assumes (apart from the beam energy) identical running conditions as in 2011. Excluded are potential increases of the BLM thresholds, the conditioning effect (Fig. 2), a possibly increased UFO rate at 25 ns operation and changes in beam intensity and beam size. Concerning the MKI UFOs, only the BLM thresholds at the superconducting elements are assumed to be limiting.

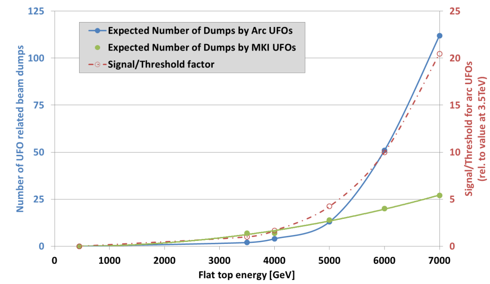

Figure 6: The expected number of beam dumps by arc UFOs and MKI UFOs and the expected scaling of BLM signal/BLM threshold for different energies. All 2011 UFO events since 14th April are considered (based on [8, 6, 9]).

ACKNOWLEDGMENTS

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REFERENCES

[1] T. Baer et al., "UFOs in the LHC", IPAC'11, TUPC137, 09/2011.

[2] T. Baer et al., "UFOs in the LHC after LS1", Chamonix 2012 Workshop, 02/2012.

[3] G. Battistoni et al., "The FLUKA Code: Description and Benchmarking", HSS'06, 03/2007.

[4] A. Ferrari et al., "FLUKA: a Multi-Particle Transport Code", CERN-2005-10, 10/2005.

[5] B. Goddard et al., "Transient Beam Losses in the LHC Injection Kickers from Micron Scale Dust Particles", IPAC'12, TUPPR095, 05/2012.

[6] E. Nebot del Busto et al., "Analysis of Fast Losses in the LHC with the BLM System", IPAC'11, TUPC136, 09/2011.

[7] N. Fuster Martinez et al., "Simulation Studies of Macroparticles Falling into the LHC Proton Beam", IPAC'11, MOPS017, 09/2011.

[8] A. Lechner et al., "FLUKA Simulations of UFO-induced Losses in the LHC Arc", 2nd Quench Test Strategy Working Group Meeting, CERN, 05/2012.

[9] A. Lechner, "FLUKA Simulations of UFO-Induced Losses in IR2", 3rd LHC UFO Study Group Meeting, CERN, 09/2011.

[10] T. Baer et al., "MD on UFOs at MKIs and MKQs", CERN-ATS-Note-2012-018 MD, 08/2011.

[11] T. Baer et al., "MKI UFOs at Injection", CERN-ATS-Note-2011-065 MD, 08/2011.

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