MD on UFOs at MKIs and MKQs

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Summary

UFOs (“Unidentified Falling Objects”) are expected to be one of the major known performance limitation of the LHC. In this MD, the production mechanism and the dynamics of UFOs at the injection kicker magnets (MKIs) and the tune kicker magnets (MKQs) were studied. This was done by pulsing the MKIs and MKQs on a gap in the partly filled machine.

During the MD, in total 58 UFO-type beam loss patterns were observed directly after pulsing the MKIs. None were observed after pulsing the MKQs, which provides important input for possible mitigation strategies. The temporal and spatial distribution of the UFO events could be determined by using a dedicated BLM Study Buffer, the implications for the UFO dynamics are discussed.

1 Introduction

An important limitation for the performance of the Large Hadron Collider are so called UFOs (“Unidentified Falling Objects”) [1]. UFOs were first observed in July 2010 and caused 35 protection beam dumps in 2010 and 2011. They are presumably micrometer sized dust particles that lead to fast beam losses when they interact with the beam. The duration of the beam losses is of the order of 10 turns. With large-scale increases of the BLM thresholds, their impact on LHC availability could be mitigated in the second half of 2011. For higher beam energy and consequentially lower magnet quench limits, the problem is expected to be considerably worse, though.

Many UFO events occur especially around the injection kicker magnets (MKIs). In a previous UFO MD [2] it was shown that many events occur directly after pulsing the MKIs. The layout of the region around the MKIs is shown in Fig. 1. The schematic layout of a MKI tank is shown in Fig. 2a. Due to the high UFO activity, additional BLMs have been installed in the MKI regions. The exact positioning of these monitors is described in [3, 4, 5].
2 Motivation

The motivation for the MD is to study the following four aspects:

- **Study UFOs at the MKQs:** The tune kickers MKQ are by design similar to the MKI kickers but have a metalized ceramic tube in contrast to a ceramic tube with metal wires in case of the MKIs (cf. Fig. 2b). In normal LHC operation the MKQs are almost never used. By pulsing the MKQs on a gap in the partly filled machine it can be studied if pulsing the MKQs stimulates the occurrence of UFOs.

- **Study temporal distribution of UFOs after MKI pulse:** In the previous MKI UFO MD, some UFO events occurred only a few ms after pulsing the MKIs [2]. The observed delays are too short to be explained only by gravitational acceleration of macro particles from the aperture towards the beam. For this MD, a dedicated BLM Study Buffer covering about 11 s with a time resolution of 2.56 ms was put in place for all BLMs. This provides a significantly improved diagnostics in order to study the temporal distribution of the occurrence of UFOs after pulsing the MKIs on a gap in the partly filled machine.

- **Study influence of electron cloud activity:** It is assumed that electron cloud can have an impact on the UFO activity. The electron cloud influence on the UFO activity can be studied under controlled conditions by turning on/off the electron cloud solenoids around the MKIs in Pt. 8 while pulsing the MKIs on a gap in the partly filled machine. Due to an early protection beam dump, the test with deactivated electron cloud solenoids lasted only for 12 min.
• **Study MKI asymmetry:** An asymmetry between the number of UFOs occurring at the individual MKIs was observed in the past [2, 6]. The asymmetry can be studied directly by pulsing individual MKIs only. This requires severe hardware changes and implicates operating the MKIs in a non-conform mode. The detailed procedure to ensure machine protection is described in [7]. Due to the early protection beam dump, this test could not be done.

### 3 Experimental conditions

The MD was done at 450 GeV in parallel to TDI impedance studies. The *UFO Buster* was used for a first automatic detection of UFO events. In contrast to normal operation, the detection was also active after injections and wire scans. Additionally, the BLM study buffer was triggered after every MKI and MKQ pulse. All the datasets were analyzed manually for UFO-type beam loss patterns. The detailed planning of the MD and the procedures are described in [7].

The MD started on 1\(^{st}\) November 2011 at 01:45 and ended at 09:56. First, the machine protection verification procedure was done with pilot beams for beam 1 and beam 2. After that, the injection of high intensity beams (1236 nominal bunches with 1.4 · 10\(^{11}\) protons/bunch) in both rings started with a delay due to a PS cavity problem at 05:20. The data taking began at 08:05 on beam 2. From 08:43 onwards, all MKIs in Pt. 8 were pulsed together about every 2 min on a gap after the 1236 circulating bunches. The parallel TDI impedance studies were done on beam 1 and finished at 08:55. After that, the UFO studies could continue on both beams in parallel, by pulsing additionally also all the MKIs in Pt. 2. From 09:13 onwards, additionally the MKQs were pulsed (both beams, both planes together), always in between the MKI pulses. At 09:44 the electron cloud solenoids around the MKIs in Pt. 8 were switched off. A protection beam dump occurred at 09:56, about 1 hour before the scheduled end of the MD. Due to a lack of time it was decided to end the MD at this point. The protection beam dump was caused by beam losses at the TDI in Pt. 8 which exceeded the abort threshold. The high beam losses were due to an inactive injection cleaning caused by a server communication problem, resulting in about 4 times higher losses at the TDI from unbunched beam while pulsing the MKIs [8].

An overview of the different tests and the observed beam losses is given in Fig. 3.

### 4 Observations and Results

During the MD, the MKIs in Pt. 2 (beam 1) were pulsed in total 35 times. After these pulses in total 12 clear UFO events (and 1 ambiguous case) were found. The MKIs in Pt. 8 (beam 2) were pulsed in total 41 times. After these pulses in total 28 clear UFO events (and 17 ambiguous events) were found. The MKQs were pulsed in total 34 times. Throughout the MD no UFO type beam loss pattern was observed around the MKQs (cf. also Fig. 3c).

An example of the beam losses after an MKI pulse is shown in Fig. 4. Figure 4a shows the spatial distribution of the losses after the MKI pulse from the BLM concentrator data (maximum of signal integrated for 2.56 ms within one second). The data reveals increased losses at the MKIs. The temporal structure of these losses is resolved by the data from the BLM Study Buffer. Figure 4b shows these losses with a temporal resolution (x-axis) of 2.56 ms. The timing is set-up such that the MKI pulse always coincides with index 500.
Figure 3: Overview of MKI/MKQ pulses, beam losses and vacuum activity (for b) around MKIs in Pt. 2 (a), MKIs in Pt. 8 (b) and MKQs (c).
Normally, after the MKI pulse, there are increased losses for up to a few 10 ms, which are expected to be due to backscattering from the losses of unbunched beam at the TDI. Low amplitude UFOs cannot be detected against this background. Several clear UFO signatures are visible later in the dataset. The background level of the BLMs around the MKIs for the data in the BLM Study Buffer is about $10^{-5}$ Gy/s. Occasional single noise spikes with a typical signal of up to $10^{-4}$ Gy/s can be well distinguished from a UFO signature by requesting a significant signal at several BLMs (preferably connected to different acquisition cards), with a reasonable spatial loss profile.

Figure 4: BLM data after pulse of the MKIs for beam 2 at 09:54:27. The 1 Hz data from the BLM concentrator provides information about the spatial and temporal (running sums) loss profile, but is of limited use after the MKI pulse, because different losses occurring within one second cannot be resolved (a). From the BLM Study Buffer data with 2.56 ms time resolution, most of the different loss patterns can be well resolved (b).

Figure 5 shows the temporal distribution of the observed UFO events after the MKI pulses. The distribution looks similar for Pt. 2 and Pt. 8, with several events within a few 10 ms after the MKI pulse and the tails extending to a few hundred ms. In the first few 10 ms the distribution is biased because of the high background signal after the MKI pulse. The first clear UFO event occurred 10.2 ms after the MKI pulse. Compared to that, under the assumption that a particle is released from the aperture in the moment of the kicker pulse and accelerated only by gravitational force $g$ towards the beam, the expected delay $\Delta t$ would be

$$\Delta t = \sqrt{\frac{2 \cdot s}{g}} = \sqrt{\frac{2 \cdot 19 \text{ mm}}{9.81 \text{ m/s}^2}} = 62.3 \text{ ms.}$$

This confirms the result of [2] that the distribution cannot be explained by acceleration of dust particles by gravitational force alone.

A possible explanation would be initially (negatively) charged dust particles which are accelerated by the electric field of the MKI and the electric beam field towards the beam [9]. Figure 6 shows no clear correlation between temporal distance from the MKI pulse and the signal amplitude of the UFO-events, though.

Another alternative explanation would be macro particles produced by sparking. These UFOs could have an initial velocity component.

$^1$The shortest ever observed delay between MKI pulse and UFO occurrence is 3.3 ms [6].
Figure 5: Temporal distribution of observed UFOs after MKI pulse. The distribution is biased in the first few 10 ms because of the high background. The first clear UFO event occurred 10.2 ms after the MKI pulse.

Figure 6: Peak signal of UFOs in RS05 (2.56 ms integration time) versus the temporal distance from the MKI pulse.
The distribution of the spatial position of the UFOs is shown in Fig. 7. As for the UFOs during normal operation [6], in Pt. 2, most UFO events occur around the MKI.D, whereas the distribution is more equal for the UFOs in Pt. 8.

![Figure 7: Distribution of the most upstream BLM at which the UFO is observable. The BLM dedicated to a MKI is located directly downstream of the corresponding MKI tank.](image)

5 Conclusion and Follow-up

A key result from the MD is that no UFOs were observed after pulsing the MKQs, which suggests that a metalization of the ceramic chamber inhibits the production/release of macro particles. Concerning the MKIs, a metalization as mitigation of the UFO problem implicates many disadvantages, among which are a significantly increased kicker rise time and problems with the beam induced power deposition [10].

The temporal distribution of the UFOs occurring after the MKI pulse is measured with a time resolution of 2.56 ms. The observation of events which cannot be explained by dust particles released in the moment of the kicker pulse and are accelerated towards the beam by gravitational force alone, is confirmed. On the other hand, the temporal distribution of the UFO events extends for several 100 ms after the MKI pulse. A correlation between UFO signal amplitude and the temporal distance from the MKI pulse is not found. For 2012, the time resolution of the BLM Study Buffer will be changed to 80 µs, which will allow to resolve the temporal profile of single UFO events.

After switching off the electron cloud solenoids, the vacuum activity increased by a factor 2.5. Due to the premature protection beam dump, the time under this condition was too short to obtain any conclusive results, though. It is highly recommended to study this crucial aspect in a later MD under controlled conditions.

As a result of the early protection beam dump, also the foreseen test of pulsing the MKIs individually could not be done and should be included in a later MD. A further test for a following MD is a modification of the MKI pulse length. This would influence the acceleration of initially charged particles and also the likelihood and strength of electrical sparks while pulsing the MKIs.

In due course, an extended analysis of the BLM data from the IQC Buffer, which is acquired after every injection during normal operation, will follow (cf. [6]). The IQC Buffer covers about 20.5 ms with a time resolution of 40 µs and can help to better characterize the rising edge of the temporal distribution of the occurrence of UFO events after pulsing the MKIs.
References


