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MD#3246 16L2 UFO dynamics investigations

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Summary

Micrometer sized particles (UFOs) entering the beam are a known cause of localized beam losses since the beginning of high intensity beam operations, however the origin of these particles is not fully known. Furthermore, during 2017 a new type of UFO events appeared around the 16L2 interconnection in the LHC, leading to beam instabilities resulting in a major impact on beam availability. In MD#2889 these *16L2 UFOs* were studied with the help of very fast diamond beam loss monitors (dBLM) that were installed at the source of the UFOs, providing important data on the dynamics of the UFOs. However, only one event could be recorded. In order to acquire more data, and of better quality using the significantly improved data acquisition system, this MD was executed.

The MD was done in parallel with MD2484. and the procedure was adjusted for both MDs to profit as much as possible. The UFO part of the MD was split into two parts; one with a small number of blown-up bunches as not to negatively impact the other MD, and lastly one EOF where a large number of bunches were to be blown-up and a 16L2 event was to be provoked, however the beams were dumped at the start of the blow-up. One small event was recorded during the first part of the MD.

Contents

1 Introduction

Micrometer sized particles (UFOs) entering the beam are a known cause of localized beam losses since the beginning of high intensity beam operations, however the origin of these particles is not fully known. Furthermore, during 2017 a new type of UFO events appeared around the 16L2 interconnection in the LHC, leading to beam instabilities resulting in a major impact on beam availability.

While traditional UFOs are distributed throughout the ring, occurring sporadically, it is difficult to study them with a high temporal resolution, since the ICBLMs are limited to a $40\,\mu$s (half-turn) integration. dBLMs have a significantly better temporal resolution at $\sim 1\,$ns, providing bunch-by-bunch resolution in the measured losses. Consequently, 16L2 provided a unique opportunity, where dBLMs could be installed downstream of this interconnect to intercept the locally produced losses. This was utilized in MD#2889, where a total of 256 bunches were blown-up to roughly a factor two larger emittance in each plane. One event was recorded, providing important information for the dynamics studies of UFOs, as well as validating the method of blown-up bunches that had hitherto only been used in a proof-of-principle with the help of wirescanners (MD#2036). The results of MD#2889 are presented in reference [2].

Since then, the ROSY data acquisition system for the dBLMs has been upgraded to a custom FPGA solution, providing significantly better dynamic resolution in the signal readout. Thus, in order to record more than the single data point, and in particular to record data of better quality, this MD was executed.

The MD was done in parallel with MD#2484 and split into two parts; during the first part it was important not to provoke a 16L2 event and also to not disturb the heat measurements of the other MD, putting constraints on the 16L2 study. The second part was done as an EOF, where the idea was to blow-up a lot of bunches and then remove the mitigations implemented to prevent 16L2, thus provoking an event.

2 Measurement setup

The dBLMs installed in 2017 at the position of maximum signal expected from FLUKA simulations [1], were used together with the dBLMs installed downstream of the primary collimators in the betatron collimation region, for all the measurements. Both the new VFC readout system and the old ROSY system were used (as a backup).

During the first part, 876 bunches using injections of 2x48 bunches in the 8b4e pattern were injected. The bunch intensity was 1.7e11 p/bunch. The emittance was then blown-up by a factor two for 18 bunches in each plane separately (capped to a maximum emittance of $4\,\mu\mathrm{m}\cdot\mathrm{rad}$), both beams. The beams were then accelerated to 6.5 TeV and brought into collision for the MD#2484 studies.

In the second part, 1836 bunches of the same parameters were injected and brought into collision, without any blow-up. 30 minutes before the end of the MD, the beams were taken out of collision and a total of 575 bunches were blown-up in each plane separately. The 16L2 solenoid was then switched off, followed by waiting for a potential event until the end of the MD time slot.

3 Results

During the first part of the MD, one event was recorded at 6.5 TeV. However, during the second part of the MD, when 575 bunches were to be blown-up in each plane, the resulting beam losses went to 140% of the dump threshold in the 655 ms running sum at TCSG.A4R7.B2 on the first horizontal excitation in beam 1. The excitation windows were different in the first and the second parts, due to different number of bunches required to be blown-up, however the same excitation settings were used, which was the cause for the dump. The results below consequently refer to the single event recorded during the first part of the MD.

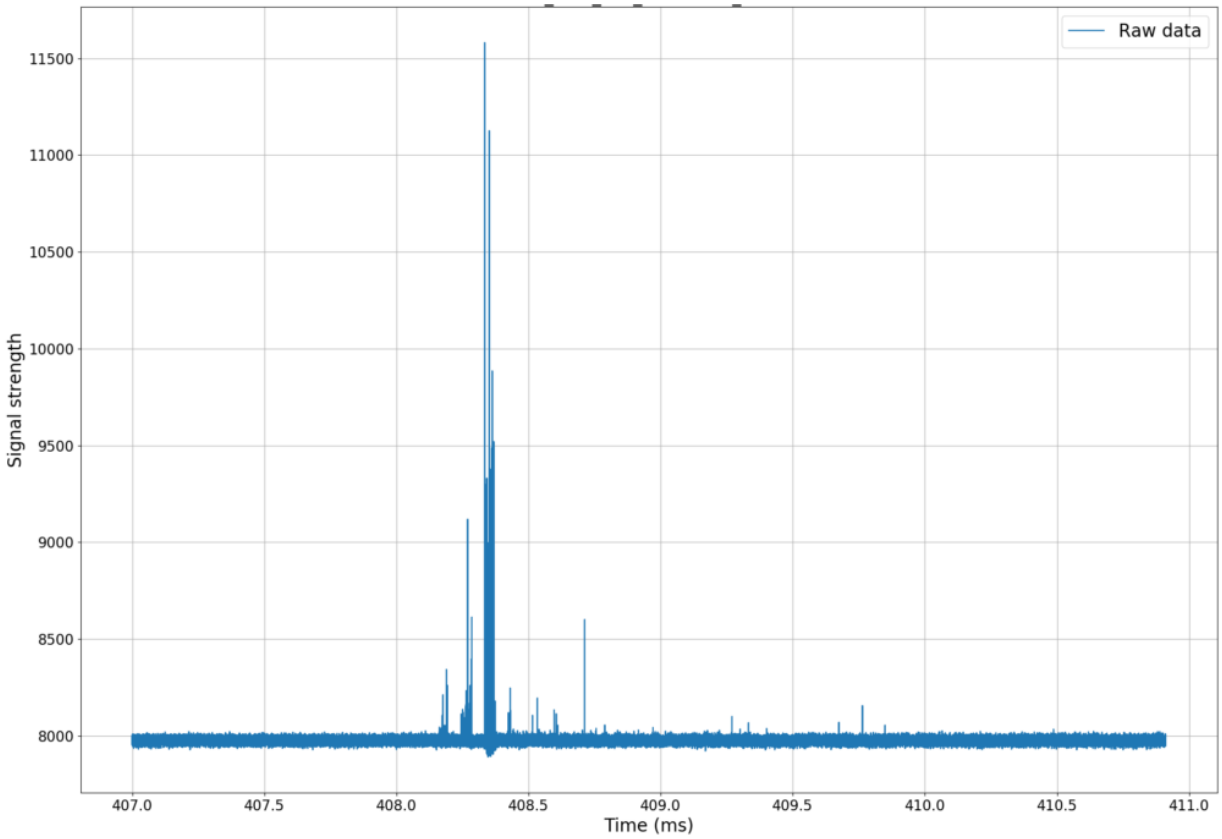

Figure 1: Raw signal of the 16L2 UFO recorded by the local dBLM during the first part of the MD, with 18x2 blown-up bunches.

The raw signal recorded by the local BLMs can be seen in Fig. 1. It was a very fast event, visible over three turns but only reaching a decent bunch-by-bunch signal on one turn. A zoom into the raw signal of the blown-up bunches, as recorded by the TCP dBLM, is shown in Fig. 2. This figure also shows the individual bunch intensities. One can see that the first half of each of the three trains gives a much larger signal than the second half, despite having a lower intensity. These are the horizontally blown-up bunches.

The signal was first corrected for the baseline drop caused by the AC/DC splitter in the readout chain (only the AC part of the signal is recorded). The overlap of the signal from one bunch to the next was then removed, by fitting an exponential decay to the falling

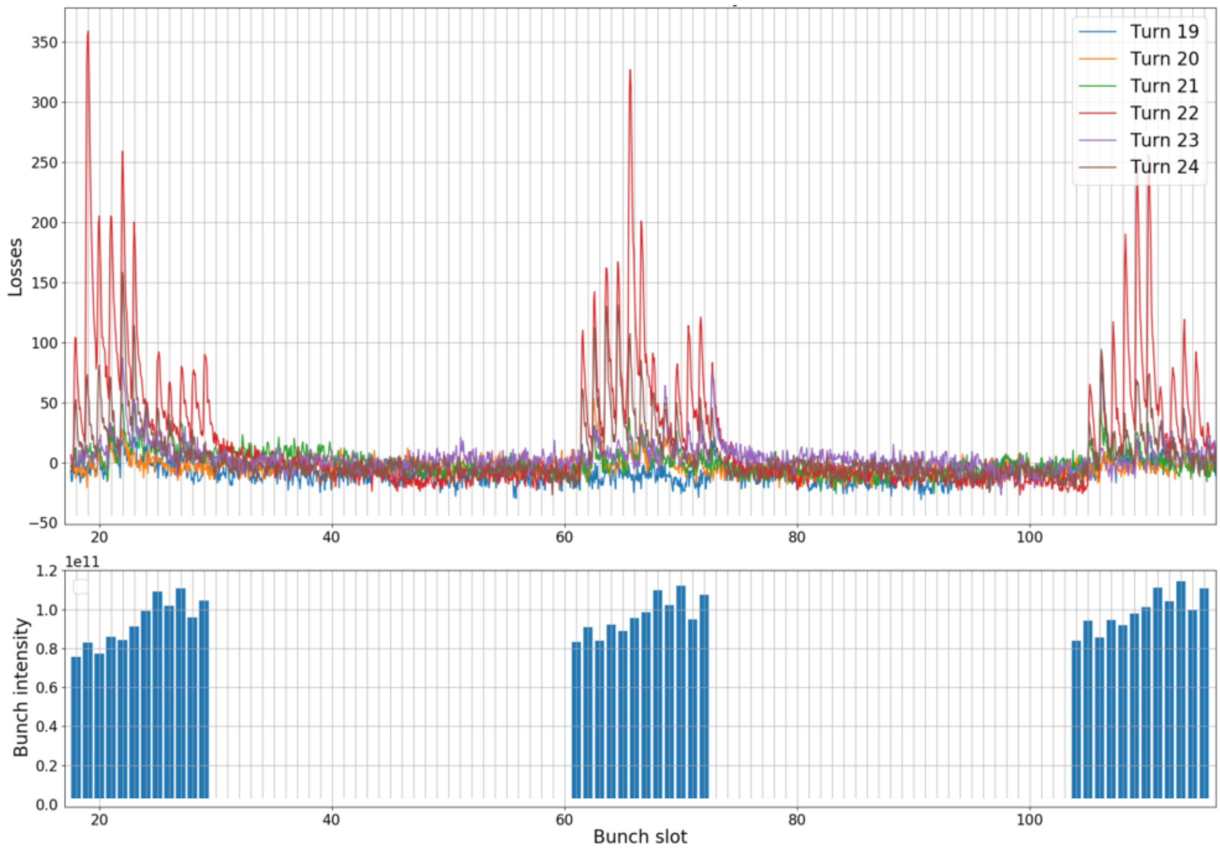

Figure 2: Zoom of the raw signal of the 16L2 UFO recorded by the TCP dBLM during the first part of the MD. The signal from the 18x2 blown-up bunches is shown, including their individual bunch intensities.

edge of each signal. Each bunch was then integrated to provide a value proportional to the amount of charge that was induced into the diamond. While integrating, the rising part was taken as is and integrated numerically, whereas the falling edge, from the data point directly following the peak of the bunch signal, was integrated using the fitted exponential decay. The latter is to include the part of the signal that overlaps with subsequent bunches. The result of this is shown in Fig. 3, where the vertical axis shows the integrated value in arbitrary units, and is proportional to both the induced charge and the amount of produced beam losses.

Below the plot, the corresponding horizontal and vertical emittances of the bunches are shown.

In this plot, one can see that the horizontally blown-up bunches give significantly more signal than the vertically blown-up bunches, implying that the UFO was horizontally offset when interacting with the beam. The location can be estimated, by taking the fraction between the signals of the horizontally and vertically blown-up bunches to the non-blown-up bunches, as done previously [3].

The result of this is shown in Fig. 4. The color density lines ranging from purple to yellow comes from dividing the bunch distribution of a horizontally blown-up bunch to that of the non-blown-up bunches. The distributions are assumed to be Gaussian. One can e.g. see

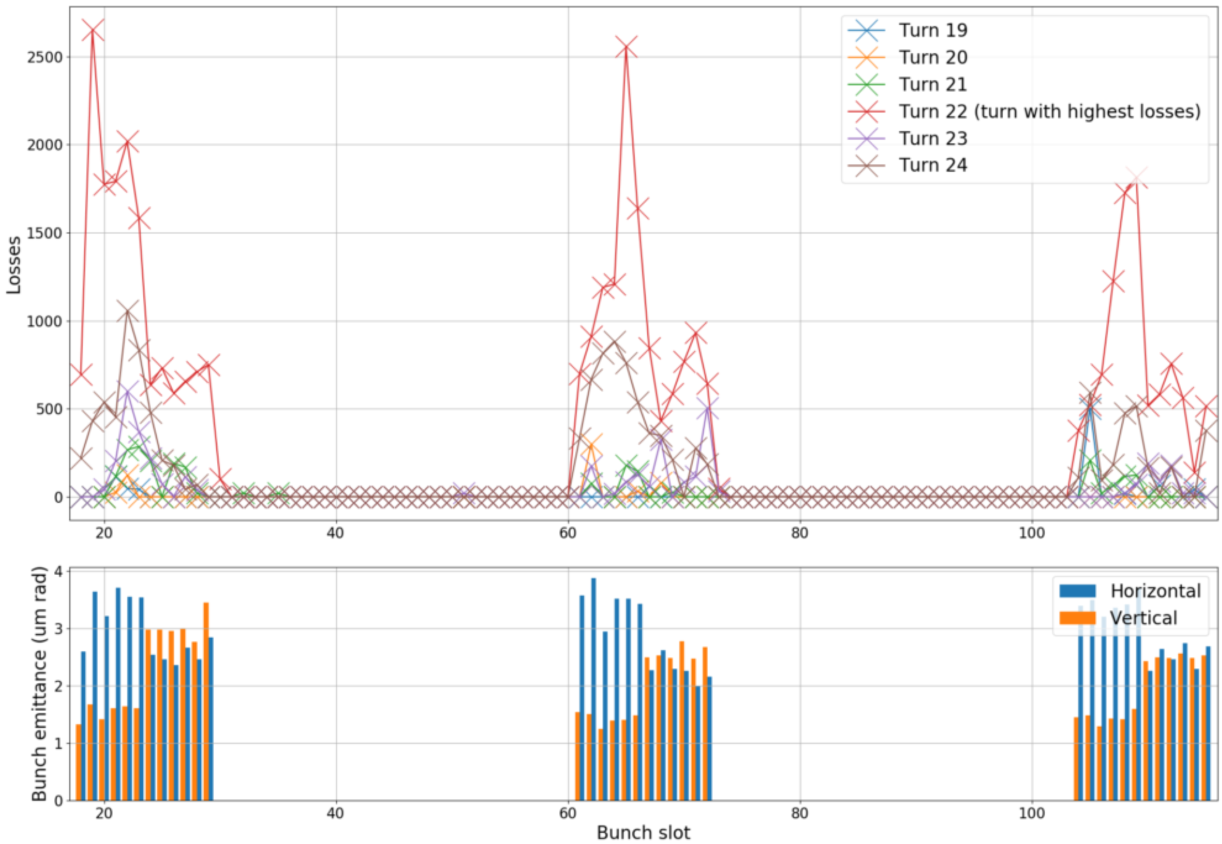

Figure 3: Integrated bunch-by-bunch signal, showing the blown-up bunches and their horizontal and vertical emittances. The integrated signal is in arbitrary units, but is proportional to the amount of losses produced by the beam-UFO interaction.

that the value is large (yellow) at positions offset strongly on the horizontal axis, whereas the values is close to one in the center. In the white region, the non-blown-up bunch distribution has a larger value than the horizontally blown-up one, giving a fraction smaller than one.

The red line is the contour corresponding to the fraction between the measured signals of the horizontally blown-up bunches and the non-blown-up bunches, whereas the cyan line is the same but for the vertically blown-up bunches. Since each line, individually, shows the possible positions where the dust particle could have been in order to produce the observed losses, a location that fulfills the requirements of both lines must be found. This is found in the four intersection points, symmetrically around the center. These four locations are the estimates of the location of the dust particle, that is, at $\pm 3.7\hat{x} \pm 2.0\hat{y}\,\sigma$.

4 Discussion

Given the short duration of the single recorded event, it is difficult to conclude on the UFO dynamics from the measurement alone. Given a longer event, one could repeat the location estimate on consecutive turns to try and see the time evolution of the locations, and thus determine the trajectory. What we can say for sure, given the dominance of the signal

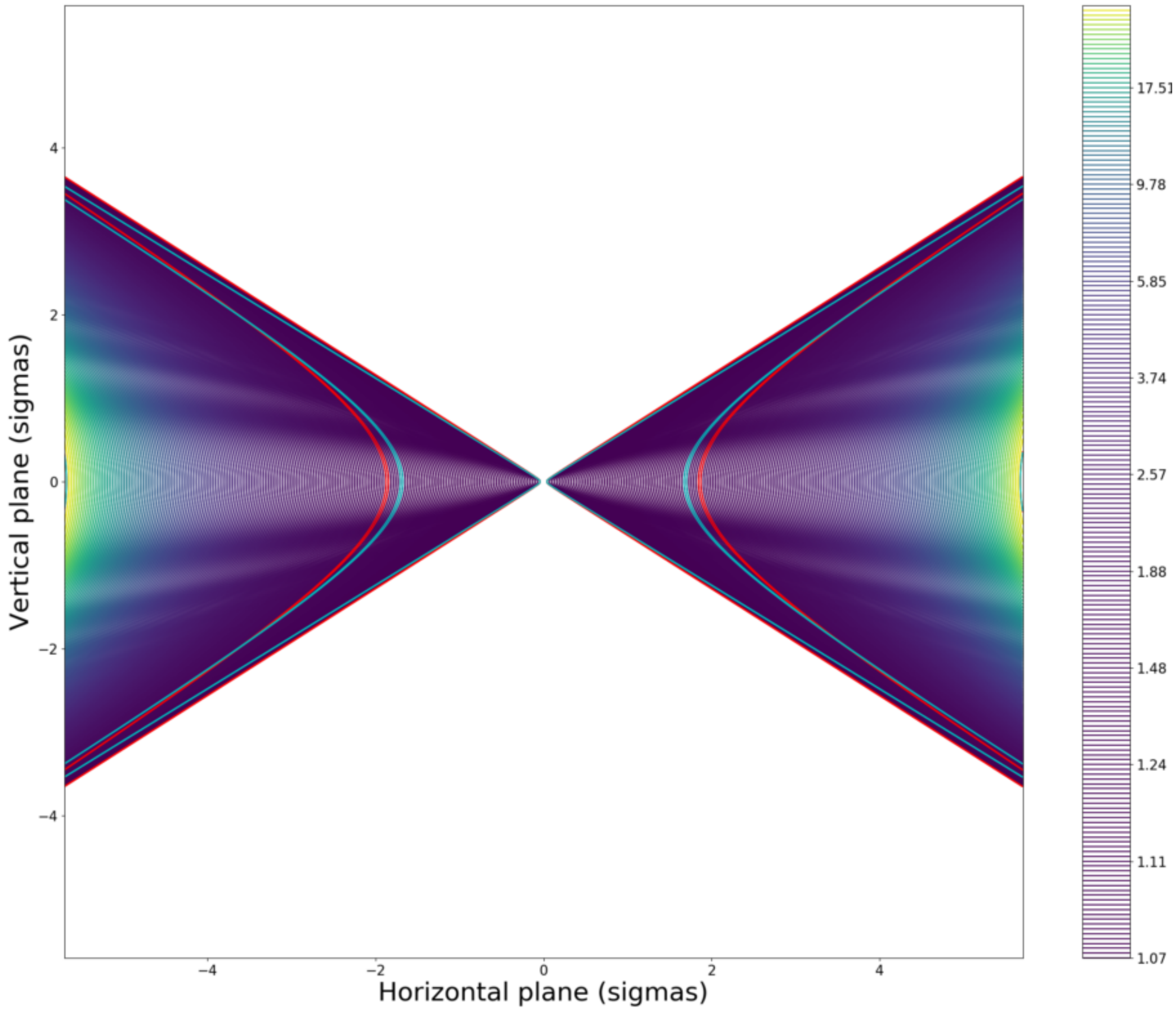

Figure 4: Estimated location of the dust particle on the turn with the highest losses. The red and cyan lines show the contours of the fraction between the different bunch distributions, where it equals that of the fraction between the losses from the horizontally and vertically blown-up bunches to that of the non-blown-up bunches.

from the horizontally blown-up bunches, is that the dust-particle was offset horizontally as compared to the beam center. To study this further, one could approach the problem from the opposite direction: *What kind of trajectories can a dust particle, under some assumptions on its parameters, follow? Are any of these trajectories consistent with what we measured, as in, does it reach the same maximum depth at the same location as we estimated?*.

The latter is part of an ongoing study, where not only the event from this MD, but events with blown-up bunches recorded by dBLMs during the end of Run II, as well as the ICBLM measurements recorded throughout the full run, are taken into account and compared with existing theoretical models. From this, several hypotheses can be tested, such as whether or not the dust particles only fall by gravity, whether or not dust particles can have an initial negative charge, allowed charge to mass ratios, allowed dust particle size ranges and allowed mass ranges. The results of these full studies are being summarized in a PRAB paper.

5 Conclusions

The MD was split into two parts, one with 36 blown-up bunches that were in the machine for one complete fill, and one part with 1150 blown-up bunches as an EOF. The latter part failed due to incorrect ADT settings, leading to a dump of the beams on losses following the first excitation of beam 1 horizontally. The first part however successfully recorded one 16L2-type UFO, with a strong dominance of the signal from the horizontally blown-up bunches. The event was very short, making it difficult concluding on the UFO dynamics from the measurement alone, and a much more in-depth study is being conducted, taking data from other recorded UFO events and comparing with a theoretical model.

References

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[3] Bjorn Lindstrom, Andrea Apollonio, Philippe Bélanger, Martyna Dziadosz, Arkadiusz Gorzawski, Laura Grob, Eva Barbara Holzer, Anton Lechner, Rudiger Schmidt, Matthieu Valette, Daniel Valuch, and Daniel Wollmann. Results of UFO dynamics studies with beam in the LHC. *Journal of Physics: Conference Series*, 1067:022001, sep 2018.