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Intensity dependence of the train instability threshold and high pile-up test with 12b trains (MD3294)

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Summary

As signs of electron cloud driven instabilities at top energy were observed in MDs in 2017 even with short trains (12b), an additional experiment was performed in 2018 to assess the intensity scaling of this instability mechanism using high intensity 12b trains available from the existing injector chain, i.e. without upgrade. An intensity dependence of the instability threshold could be observed at constant brightness, nevertheless the instability detected seem to be of the different type w.r.t. those observed in past experiments.
The high intensity 12b trains were used to provide the highest pile-up with 25ns spacing to the experiment in order to probe regimes close to ones expected in the HL-LHC era. The machine and beam aspects are described in this note.

Contents

1 Introduction

Dedicated studies in 2017 revealed a significant difference in the stability threshold of 25ns bunch trains w.r.t single bunches or trains with a larger bunch spacing [1]. As the coupled bunch instability driven by the impedance is expected to be well suppressed by the transverse feedback, this effect is not expected

and further investigations are needed to asses the nature of this instability.
Two instability types could be distinguished in past experiments: the first seems to affect the bunches towards the head of the trains more significantly than the ones at the tail, with a threshold higher than could be obtained with the octupoles at their maximum strength. This horizontal instability was observed sporadically in MDs with non-colliding 25ns bunch trains and is referred to as the Ghost train instability as its nature is currently unknown. When this instability didn't occur, a variation of the instability threshold ranging from 25% to 100% w.r.t. other beam types was observed. As opposed to the Ghost train instability, bunches at the tail of the trains were mostly affected, suggesting an impact of electron clouds.
Bunch trains of high intensity, yet constant brightness, with a 25ns spacing could be produced in the injector chain. This experiment aims at using this beam to probe the stability of bunch trains with intensities expected for the HL-LHC project.

High pile-up were achieved in IPs 1 and 5 with single bunches in previous years, this new high intensity 12b trains allows to reach a pile-up comparable to the one expected in the HL-LHC with 25ns bunch trains. Even though the trains are shorter, this provides an opportunity to test the detector performance in such a regime. The machine and beam aspects of an experiment aiming at providing the highest pile-up in IPs 1 and 5 using high intensity 12b trains is described in Sec. 5.

2 Setup

Figures 1 and 2 show the properties of the different bunches that could be injected and accelerated to an energy of 6.5 TeV. The variation of the average brightness and bunch lengths for the trains of different intensities remained within 10%, while the average bunch intensity of the first train is $\approx 10^{11}$ protons per bunch, the second $\approx 1.4 \cdot 10^{11}$ and the last $\approx 1.9 \cdot 10^{11}$. We note that the bunches of the two beams do not travel simultaneously in any of the common chambers.
The attenuators of the transverse damper (ADT) were optimised for a bunch intensity of $2 \cdot 10^{11}$, the pickup noise floor is therefore suboptimal for the bunches in the low and medium intensity trains.
At the end of the ramp, the octupole current was reduced in steps in the two beams, while monitoring each bunch oscillation amplitude allowing for a measurement of the instability threshold.

3 Results

The result of the instability threshold measurements is shown in Fig. 3. One observes a clear dependence of the threshold with the bunch intensity, in spite of the similar brightness. The negative correlation between the instability threshold and the bunch intensity rather than the bunch brightness is also visible by comparing Figs 4a and 4b.
In order to quantify this difference, we focus on the bunch which became unstable at the earliest time within each of the trains. The measured stability threshold in term of octupole current is higher than the one expected based on the impedance model and the measured individual bunch intensity, transverse emittances and lengths by 59%, 71% and 83% for the low, medium and high intensity trains of beam 1 respectively. For beam 2 we have 63%, 51% and 71%. These discrepancies are incompatible with the past observations for the Ghost train instability for which the measured threshold was more than a factor four higher than predicted. The bunch pattern is similar to the Ghost train instability (Figs. 5a and 5b), i.e. the bunches initiating the instability are located at the head of the train. Nevertheless, it is likely that this bunch pattern is in fact linked to the reduction of the bunch intensity along the train shown in Fig. 1, which comes from the injection chain. Indeed, Figs 5c to 5f show that in most of the trains, the first bunch to become unstable is the most intense, corresponding also to the brightest. This

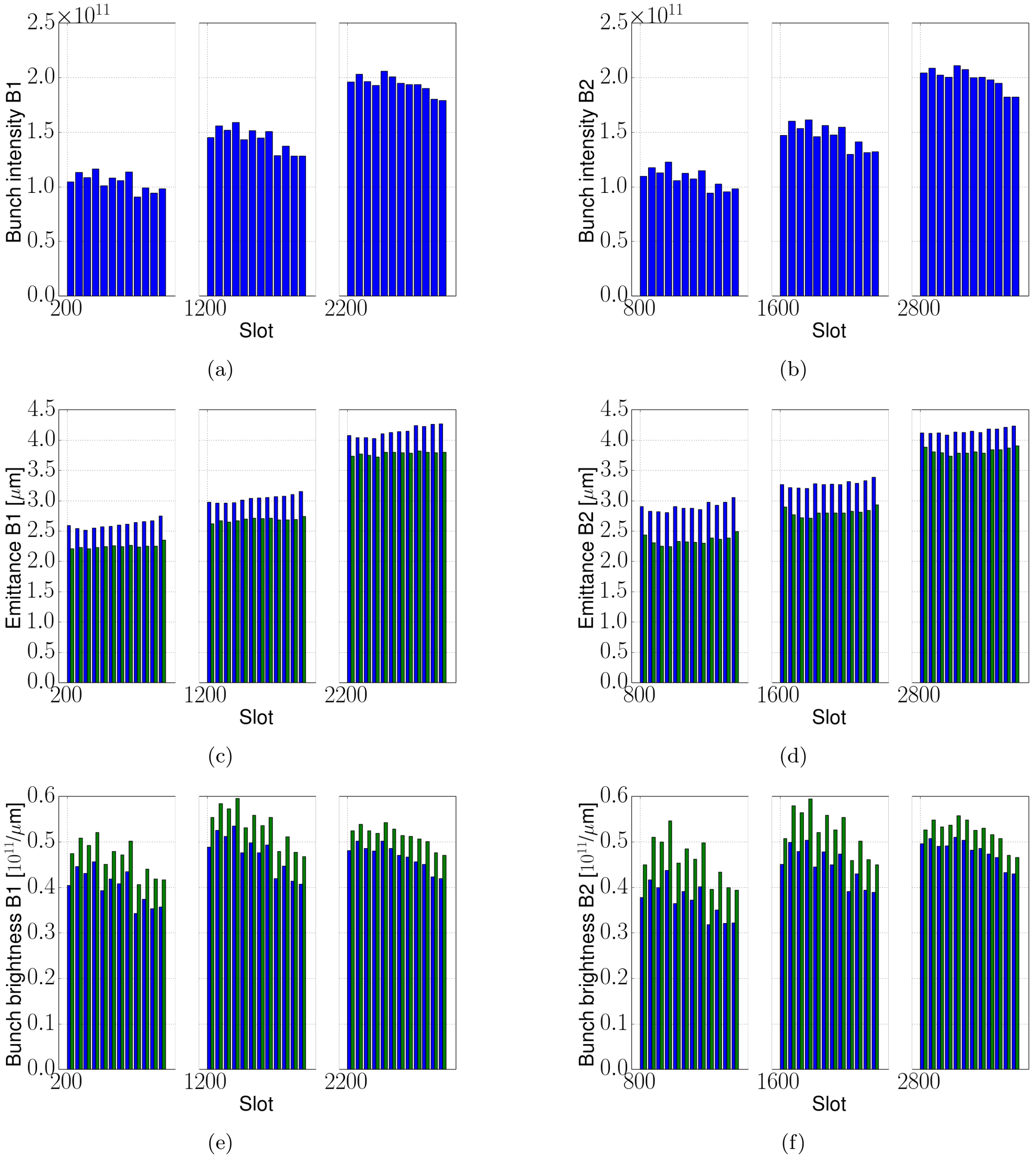


Figure 1: Bunch-by-bunch intensities, emittances and the corresponding brightnesses, measured by the FBCT and BSRT respectively at the start of the octupole current scan. The horizontal and vertical measurements are represented in blue and green respectively.

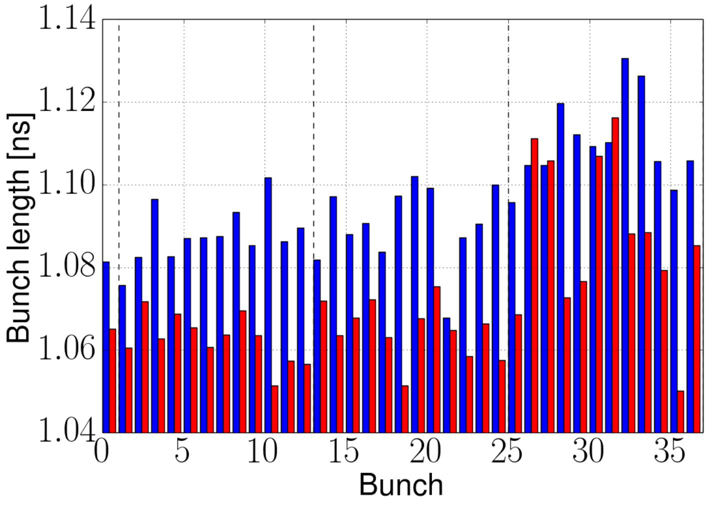
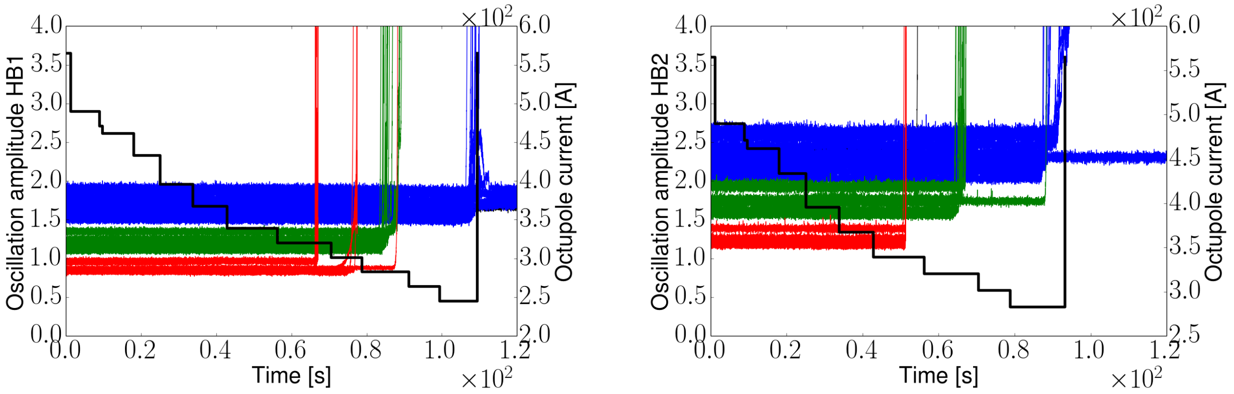


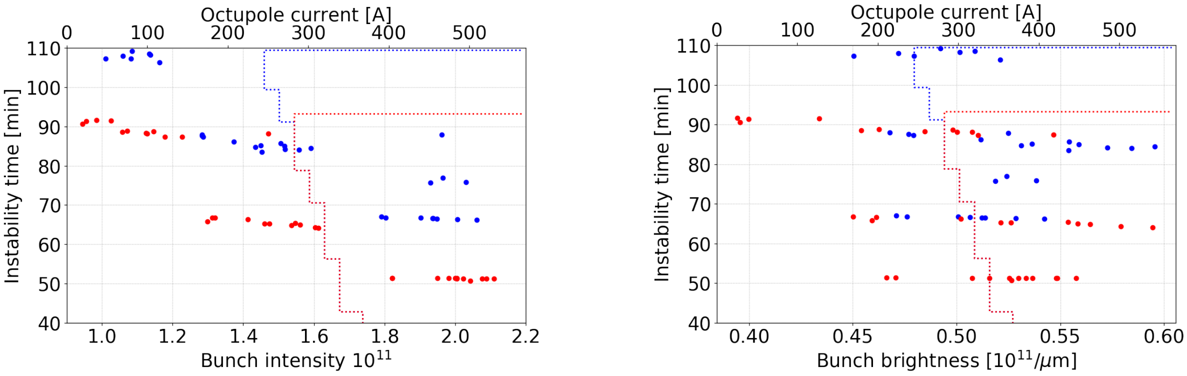
Figure 2: Bunch-by-bunch 4σ-length measured by the BQM for B1 and B2 in blue and red respectively. The separation between the bunches belonging to the low, medium and high intensity trains is marked with black dashed lines.



(a) Beam 1

(b) Beam 2

Figure 3: Bunch-by-bunch oscillation measured by the ADT activity monitor of the bunches of the low, medium and high intensity trains in blue, green and red respectively. The octupole current is represented by a black line.



(a) (b)

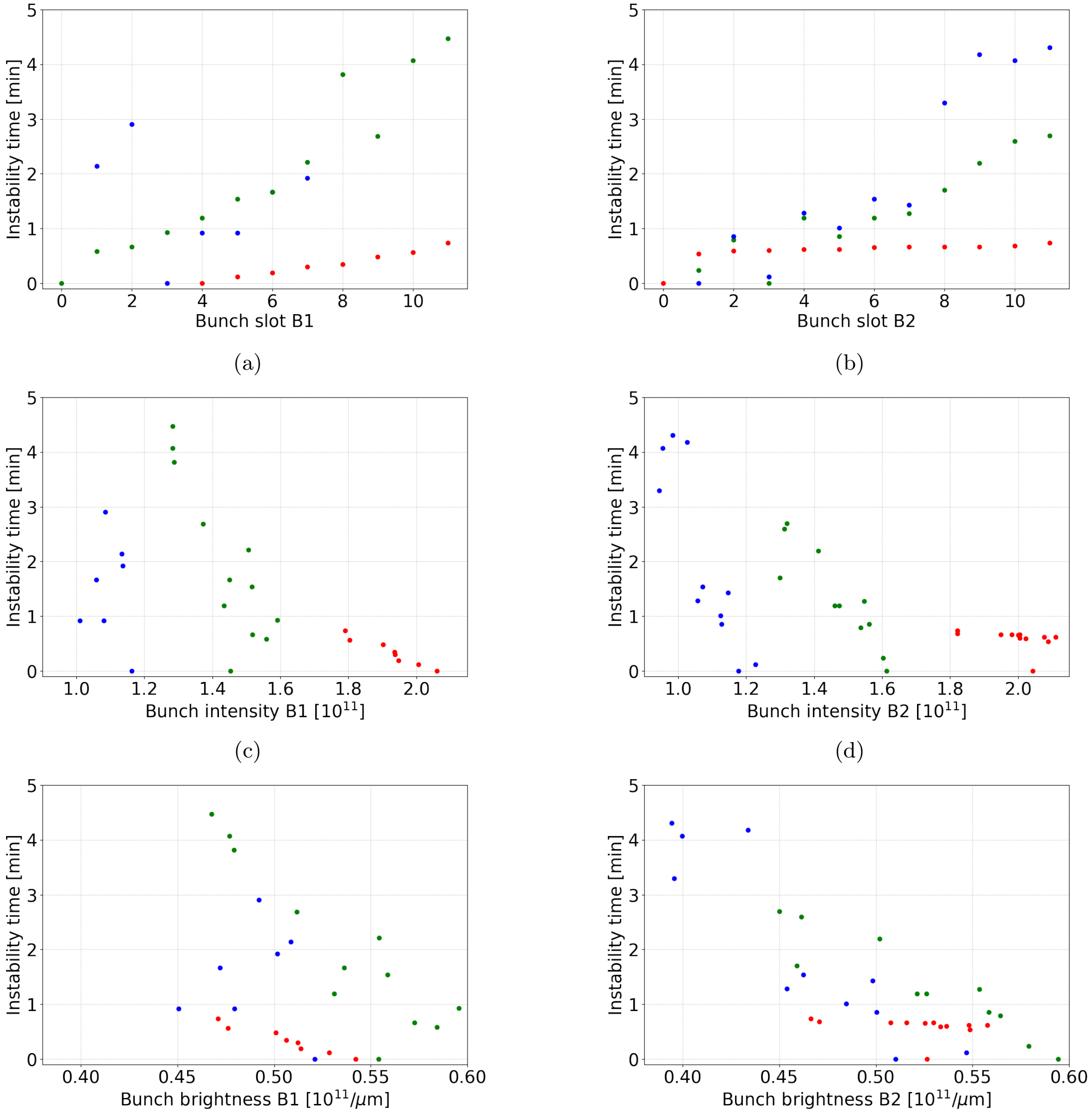
Figure 4: Time at which instabilities were detected based on the ADT activity monitor data as a function of the bunch intensity as well as the bunch brightness for B1 and B2 in blue and red respectively. The octupole currents are marked with dotted lines with the corresponding colours for the two beams.

feature is not observed in the intermediate intensity train of B1 and the high intensity train of B2.

We note that the oscillation amplitude measured by the activity monitor in stable conditions (Fig. 3) is lower for higher intensity bunches, compatibly with the setup of the attenuators, adjusted for high intensities. The increase of the instability threshold for high intensity bunch trains can therefore not be attributed to a detrimental effect of the noise.

4 Conclusion

Neither the Ghost train instability nor the electron cloud instability observed in past experiments in similar conditions could be reproduced, nevertheless a weak intensity dependence of the instability threshold of bunch train could be observed. The cause for this effect is currently not understood.

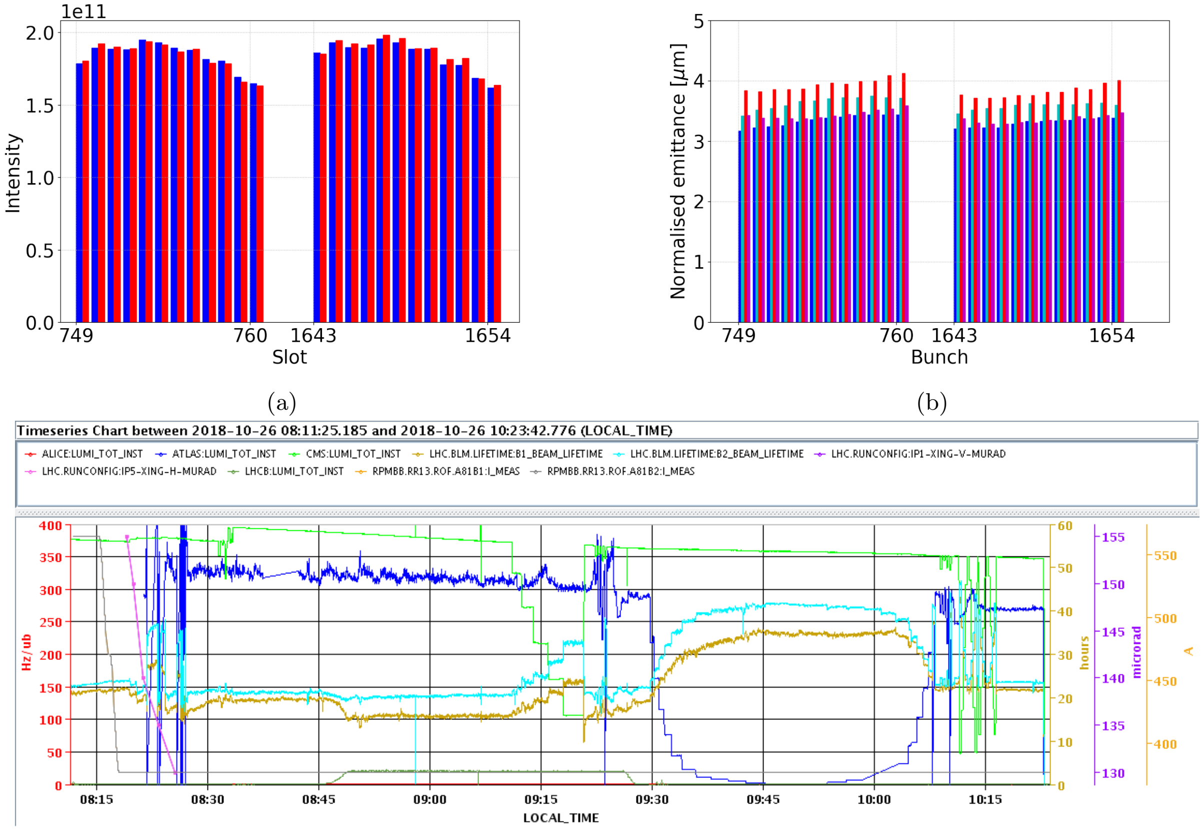


(a) (b)

(c) (d)

(e) (f)

Figure 5: Time at which instabilities were detected w.r.t. to the earliest time at which one of the bunches of a given train became unstable based on the ADT activity monitor data, as a function of the position of the bunch in the train (upper plots), the intensity of the unstable bunch (lower plots). The low, medium and high intensity bunch trains are shown in blue, green and red respectively.



(a)

(b)

(c)

Figure 6: Machine and beam parameters in STABLE BEAM during the high pile-up test.

5 High pile-up test

Two trains of 12b were injected in each beam, providing collisions in all IPs. The octupole current was kept low (13A) during the injection and raised to the operational value of 45A just before the start of the ramp to simplify the incorporation of the settings in the ramp. The standard operational cycle was performed with a higher octupole current at the end of the ramp (565A), until collision the declaration of STABLE BEAM. No major issues with the preservation of the beam quality were encountered, in particular no instabilities were observed.

The measured bunch intensities, emittances and length at the start of STABLE BEAM are shown in Fig. 6, along with the evolution of the main parameters. While the beams are colliding, the luminosity is not published in the first ≈ 10 minutes due to saturation of the luminometers. During this time, the octupole current was reduced from 564 A to 377 A, without a significant impact on the beam lifetime. The crossing angle was reduced using the levelling application as in regular fills down to 130 μrad. Given the good lifetime in this configuration ($\approx 20h$), a reduction of the β^* from 30 to 25 cm using the operational settings would also have been possible, yet was not allowed by the Machine Protection Panel. An attempt was made at 8:28 to improve the beam lifetime by reducing the chromaticity by 5 units, the effect is however not significant. Other variations of lifetime can be linked to orbit movements at the various IPs, in particular the establishment of head-on collision in IP8 (8:48) and the introduction of transverse offsets in IPs 1 and 5, visible through the reduction of the corresponding luminosity signals. Using the averaged measured beam parameters and machine settings shown in Fig. 6, as well as an average bunch length of 8.1 cm measured by the BQM, the expected pile-up is ≈ 110 in IPs 1 and 5. A reduction of β^* to 25 cm would have allowed for a further increase by 15%. The pile-up densities for the HL-LHC range from 131 for the nominal scenario up to 197 for the ultimate [2].

References

[1] L. Carver, et al., 'The Ghost Train Instability (MDs 2066 and 2936)', CERN-ACC-NOTE-2018-0013

[2] E. Métral, et al., 'Update of the HL-LHC operational scenarios for proton operation', CERN-ACC-NOTE-2018-0002