Active halo control through narrow-band excitation with the ADT

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Summary

During this MD (MD312), the capabilities of an active halo control for beam tail depletion in the LHC were tested. The studied method relies on using the Transverse Damper (ADT) to perform a narrow-band excitation.
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1 Introduction

The possibility to implement mechanisms to control actively the beam halo population at the LHC is considered as an important possible upgrade for the collimation system in view of the operation at high intensity. During Run 1, several LHC beam dumps occurred during squeeze due to orbit jumps causing scraping of beam tails at the collimators. Such bumps would be mitigated if a depletion of the beam tail is carried out and therefore no beam would be scraped off. In addition, and looking towards the future LHC upgrade (HL-LHC) if tails are depleted, fast crab-cavity failures pose lower risk to send beam onto sensitive elements.

In order to increase the diffusion speed of the halo while leaving the core unaffected three different methods have been proposed: electrons lenses \[1\] \[2\], tune modulation \[3\] and ADT narrow-band excitation. In the present MD we focus on the latter method. By means of the transverse damper (ADT) we can create a narrow-band excitation at a given frequency. Relying on the amplitude detuning by which particles with different amplitudes have different tunes, we can excite just particles at a certain amplitude kicking them to larger amplitudes until they are intercepted by the primary collimator. It is expected that if this excitation is made in a controlled manner and the dominating source of tune spread comes from the amplitude detuning, the tails will be depleted while the core of the beam remains unperturbed.

We present here the results of the MD proposed to investigate the effectiveness of this method in the LHC at injection energy (450 GeV). This was the first time that this novel method was tested and several uncertainties needed to be clarified during the development of the MD. The final goal of the MD was to first get a proper understanding of the principle of the active halo control using ADT and to demonstrate that one can deplete the tails of the tested bunches without affecting beam core and emittance.

The MD covered over 14 hours with a very good availability of the LHC and injectors. This MD was carried out in parallel to MD333 on crystal collimation, which was constrained by the installed hardware to use only beam 1. Therefore, the active halo control could be tested only on beam 2, and the needed beam excitations could be performed only when they did not perturb the parallel MD. Almost all the time was devoted to the ADT excitation at different frequencies, ranges and planes. During the excitations with ADT frequency scans and fixed frequencies, several beam parameters were constantly monitored using BSRT, BCT, BWS. The BLMs delivered losses produced by the halo scraping. In addition, during this MD the measurement of the detuning with amplitude was performed using the AC dipole following the same procedure of the measurement taken during Run 1 in 2012 \[4\]. In the next sections the experimental setup and main results obtained during the MD are described and summarized.
2 Preparation

2.1 ADT Configuration Setup

An online application for ADT frequency control was prepared for the MD. This application allows to have a turn-by-turn control of the ADT frequency and amplitude. It was tested during the first fills of the MD to verify that it worked as required.

Using theoretical models we could predict the range of frequencies interesting for tail depletion. Therefore the tune spread was derived by MADX simulations at 450 GeV whereas the octupoles were set 10 A. The resulting tune footprint is shown in Fig. 1.

In the horizontal plane $Q_x$ the fractional tune spreads from 0.2715 to 0.291 and in the vertical plane $Q_y$ from 0.3015 to 0.3215 for a $6\sigma$ amplitude. The tune step was set to $\Delta Q = 10^{-4}$ per time step $\Delta t$ of 1 or 2 seconds. The ADT amplitude could be set between 0 and 1. For the amplitude scaling see Sec. 5.2.

![Figure 1: Tune footprint from MADX model at injection energy](image)

2.2 Beam Wire Scanner preparation

Before the day of the MD several beam wire scanner measurements were performed trying to find suitable settings to measure beam tails. The idea of the method is to increase the transmission of secondary emitted light and exhaust the full gain range of the photomultiplier. This rise of sensitivity brings the electronics into saturation for the part of the beam core of the measured beam profile but lifts the signal for the beam tail part above the noise level. In order to have more than a qualitative measurement of the beam tail a limited number of scaling values for the relation to the actual beam core were derived.
3 Experimental procedure

The MD was carried out in parallel with the MD devoted to crystal collimation. Therefore just one beam (B2) was used to perform the measurements. Due to the novelty of the depletion method and the absence of detailed and conclusive simulations the parameter space which had to be explored was vast. Approaching a suitable set of parameters one had to iterate over several settings and evaluate the measurable quantities of beam loss online. The machine availability during the MD was throughout very good. Thus the overview of the MD in Fig. 2 shows no major downtime.

![Figure 2: Summary plot of preparation, tests and measurements during the day of the MD.](attachment:image.png)

The machine was initially filled with a few pilots in order to align the Primary Collimators (TCPs) and set them to the nominal value of 5.7σ. Once the TCPs were aligned both horizontally and vertically two pilot bunches and one nominal bunch were injected and the ADT setup was carried out. After that, several injections of a nominal bunches were used to perform collimator scraping tests.

Evaluating the impact of the ADT excitation the first frequency sweeps were done with one or two nominals. The actual tail depletion measurements were performed with three freshly injected nominal bunches (later with pilots) for each excitation run. This followed a certain bunch scheme (three bunch scheme) shown in Fig. 3 and Fig. 4. Before the narrow-band excitation, one of the bunches was blown up transversally using a white-noise excitation of the ADT (as done for standard collimation loss maps). This bunch shall be denoted as blown up bunch or fat tail bunch #1500. This should enhance the observable signals of the wire scanners and BLMs.
Figure 3: Filling scheme screenshot with three bunches illustrating the spacing between the reference bunch #0 and the excited bunches #1500 & #1700. In pink the ADT excitation window for the preparatory blow up is shown. During the actual ADT excitation for halo depletion it covered both latter bunches.

Figure 4: Wire scanner profiles describing the definition of the three bunch scheme. In blue the profiles show the state before the preparatory blow up of bunch #1500 to enlarge its tails. In green the profiles are shown after this procedure.
Then the ADT was used in narrow-band excitation mode with either a dynamically changing frequency (frequency sweep/scan) or a fixed frequency in order to attempt depleting the beam tails. By studying the losses as a function of the excitation frequency during the sweeps, we can determine the most interesting fixed frequencies for exciting only the halo later on. This excitation was applied to the fat tail bunch #1500 and to the witness bunch #1700. The witness bunch should show that its core is not affected when the ADT excitation depletes particles from the beam halo. The expectation was that a sweep of frequencies from large amplitudes to smaller amplitudes should decrease the intensity of the blown up bunch much earlier than of the witness bunch #1700. The reference bunch #0 outside the ADT excitation window was present to demonstrate that the active halo control acts only on the selected bunches and to provide a reference emittance blow up measurement without excitation.

4 Experimental results

The measurements of the ADT excitation with the described bunch scheme covered frequency sweeps and fixed frequencies on nominals for the horizontal plane. Different excitation runs were carried out with certain ADT amplitudes $A$ and steps $\Delta t$ staying at a frequency increment. Further similar frequency sweeps were done with pilots either for the horizontal and the vertical plane. The full set of the excitations are summarized in the tables 1, 2 and 3 which can be found in the Appendix A.

4.1 Measurements with ADT frequency sweeps on nominal bunches

In the beginning, for the ADT setup, only one nominal bunch was injected and blown up vertically before starting transverse excitation tests. The ADT amplitude was set to $A = 0.3$ and we approached the tune footprint from right going from $Q_x = 0.31$ downwards (Run n2). This showed that the amplitude setting was very high since the bunch intensity dramatically dropped about 30% as the excitation began. Another sweep (Run n3) with an amplitude of $A = 0.1$ starting with a $Q_x$ of 0.295 going downwards depleted parts of the bunch slowly after a value of $Q_x = 0.29$ and then affecting the majority with 80% of bunch particles around $Q_x = 0.285$. This led to go even further down in amplitude. Adjusting the amplitude to $A = 0.03$ (Run n4) and repeating the frequency settings the measurement of the individual bunch intensity illustrated how the bunch core was approached by at first slowly and then a more significant decrease in intensity, see Fig. 5. The actual decrease in intensity was a lot less with a few percent than during the excitation with an amplitude of 0.1.
After identifying an amplitude where the bunch is not rapidly destroyed we went on with applying the three bunch scheme. In order to have a bit more depletion we doubled the time step staying at a frequency increment of $\Delta t = 2$ s and repeated all other settings. With the beam wire scanners the initial bunch profiles were measured, whereas the fat tail bunch had $2.3\sigma$ of the witness bunch, see Fig. 6. The effect of a narrow-band ADT excitation applying a frequency sweep to the bunches in the three bunch scheme is shown in Fig. 7.

![Figure 5: Individual bunch intensity and BLM loss of nominal bunches during Run n4.](image)

![Figure 6: Beam wire scanner profiles of the three bunches before the ADT excitation of Run n5.](image)
expected a heavier impact on the intensities than in the run before. Beam wire scans after the ADT excitation reveal that the performed frequency sweep affected the beam cores of both bunches #1500 and #1700, see Fig. 8 and 9.

Figure 7: Individual bunch intensities with BLM losses and individual emittances of nominal bunches during Run n5.

Figure 8: Beam wire scanner profiles of the fat tail bunch #1500 before and after the ADT excitation of Run n5.

Figure 9: Beam wire scanner profiles of the witness bunch #1700 before and after the ADT excitation of Run n5.

The next step was to switch the direction of the frequency sweep starting at tune values corresponding to particles within the beam tails and heading outwards, see Fig. 10. All the other ADT settings were kept the same as before. As can be seen in Fig. 10, there is an instant decrease of the intensities for both bunches, which then flattens out. For the witness bunch a definite flat line was not achieved. This can be explained having a look at the wire scan before the ADT excitation in Fig. 11. The initial bunch profiles of #1500 and #1700
had literally no differences concerning the flanks. Due to the previous ADT excitation the witness bunch was already blown up too much.

This measurement clarified that the excitation was very close to the core because of the steady loss for the witness bunch #1700 from the beginning. Comparing the wire scan and the individual bunch intensities for both excited bunches the different slopes represent the profile shapes. For the emittances one can say that there is no significant increase and the values are within the failure margin since the emittance of the reference bunch #0 shows the same behaviour.

Figure 10: Individual bunch intensities with BLM losses and individual emittances of nominal bunches during Run n6.

Figure 11: Beam wire scanner profiles of the three bunches before the ADT excitation of Run n6.
For the frequency sweeps on nominal bunches a final measurement was carried out by sweeping inwards in terms of tune covering a range beyond the nominal tune of $Q_x \approx 0.278$. By having a look at the BLM losses this resembles a tune spread measurement. After swiping over the core the signals flatten out. The plot with the individual emittances shows that after a first emittance increase of both excited bunches while approaching the tune of the core particles the quality of the bunches is instantly destroyed which was foreseen.

![Figure 12](image1.png)

**Figure 12:** Individual bunch intensities with BLM losses and individual emittances of nominal bunches during *Run n7*.

### 4.2 Results of particle excitation with fixed ADT frequencies on nominal bunches

From the frequency sweeps we have seen that with a low amplitude of $A = 0.03$ and a horizontal ADT excitation frequency expressed in terms of fractional tune above $Q_x \approx 0.291$ to 0.292 the depletion of particles aside the core seemed to be possible. In the following measurements the idea was to perform horizontal ADT excitations with fixed frequencies in the interesting fractional tune region for longer time. A first measurement showed a promising

![Figure 13](image2.png)

**Figure 13:** Individual bunch intensities with BLM losses and individual emittances of nominal bunches during *Run fn2* with fixed ADT frequency.
result being able to clean particles without affecting the witness bunch i.e. the core, see Fig. 13. The excitation was carried out with a fractional tune frequency of $Q_x = 0.295$ and an amplitude of 0.03 for 120 s.

From the individual bunch intensities of Fig. 13 one can conclude that only particles of the fat tail bunch #1500 were removed. The witness bunch #1700 was not touched. The wire scans in Fig. 14 demonstrate a significant difference of the profile shapes concerning populated tails for the initial distributions. Unfortunately the decrease of only 2% in intensity for the fat tail bunch is within the noise of the beam wire scanners. Therefore this can not be observed in the wire scans before and after the excitation, see Fig. 15. Retrospectively the fractional tune of $Q_x$ with 0.295 relates to $5.5 \sigma$ consulting the results of the detuning with amplitude measurements, see Section 4.5. The emittances of all bunches stayed quite stable. Comparing the results of the excited bunches to the reference bunch one cannot see an increase. The values seemed to stay within the margin of the natural fluctuation of the measurement, which can be seen by studying also the reference bunch #0. The particle loss turned out to be stronger earlier and then stabilizes to a constant stream. For future investigations it would be interesting to repeat an excitation with exactly the same settings in order to show whether this result is reproducible. Further, exciting over a longer period could show if the decrease of the bunch intensity stops after depleting all particles at that tune and how this result is connected to the repopulation of the excited tune space.

In a second measurement the ADT amplitude was increased from 0.03 to 0.15. Unfortunately the effect was not only having a stronger loss on the fat tail bunch since the witness bunch was affected as well, see Fig. 16. This shows also its emittance blow up. Several additional performed excitation runs with fixed frequencies further away from the core and amplitudes of 0.05 always affected the witness bunch, see appendix A Fig. 30 ff.
Figure 16: Individual bunch intensities with BLM losses and individual emittances of nominal bunches during Run fn3 with fixed ADT frequency.

4.3 Measurements with ADT frequency sweeps on pilot bunches

During the last four hours of the MD a set of ADT excitation sweeps on pilots in either the horizontal and the vertical plane were performed. The idea was to eliminate other possible sources of tune spread which could introduce core losses even when staying at excitation frequencies far from the tune. The measurements were undertaken while the feedback damper was switched off and the chromaticity was set to zero.

The settings of the first case were an amplitude of $A = 0.05$, a time step of $\Delta t = 2$ s and starting at $Q_x = 0.295$ sweeping inwards. These settings resemble the ones of Run n4 and n7. The result of this measurement revealed that without the damper feedback, which typically does not see the pilot bunches, the bunch losses are by far larger than with nominal bunches. Additionally the intensity of the fat tail bunch decreases instantly, see Fig. 17.

Figure 17: Individual bunch intensities with BLM losses and individual emittances of pilot bunches during Run p2.

For the next scans the preparatory blow up of bunch #1500 was omitted since the primary collimator was horizontally moved to tighter settings. In Run p3 the TCP.H was at 2.69σ. The ADT excitation started at $Q_x = 0.295$ sweeping inwards. The result can be seen in Fig. 18. First of all the individual bunch intensities of the excited bunches #1500 and #1700
show the same behaviour as expected since there was no blow up in advance. Comparing the intensity decrease result to the excitation with a wider TCP setting in Fig. 17 one can observe that the values differ around 37% at $Q_x = 0.288$ and the intensity decrease starts instantly. This fractional tune value of the ADT excitation corresponds to approximately $4\sigma$. At this amplitude we assume there are no particles. The excitation must have affected particles of the core which are now significantly depleted by the collimators. With another collimator setting of $3.67\sigma$ this sweep was repeated in Run p4, see Fig. 19. The measurements resulted in around 20% less decreased bunch intensity at $Q_x = 0.288$. This means that a large fraction of particles from the inside of the bunch are excited, but not shifted too far in terms of amplitude.
4.4 Scraping with collimators

As in previous MD’s several beam scrapings with collimators were performed to reconstruct and investigate the beam halo [5] [6]. Two nominal bunches were separately scraped vertically whereas one of them was blown up vertically with the ADT in advance. Preliminary results illustrating the jaw position, bunch intensity and losses on the BLM’s are shown in Fig. 20 & 21. Further a complete scraping in the horizontal plane was measured, see Fig. 22. The

![Scraping with TCP-V](image1)

Figure 20: Scraping of nominal bunch with left upstream collimator jaw in the vertical plane.

![Scraping with TCP-V](image2)

Figure 21: Scraping of a blown up nominal bunch with left upstream collimator jaw in the vertical plane.

![Scraping with TCP-H](image3)

Figure 22: Scraping of nominal bunch with left upstream collimator jaw in the horizontal plane.

analysis in comparison with wire scanner measurements is ongoing.
4.5 Detuning with amplitude

Due to the presence of multipolar fields, the tune of each individual particle depends upon its amplitude. The tail depletion relies on the precise knowledge of the tune/amplitude correspondence. For that reason, it is very important to have a precise measurement of the detuning with amplitude. The detuning $\Delta Q$ depends quadratically on the particle amplitude which we induced with an AC dipole kick. Hence we model it as a parabola,
\[
\Delta Q_x = \Delta Q_0 + b \cdot A^2,
\]
where $A$ as beam oscillation amplitude in beam size units. In that case the nominal normalized emittance is chosen to be $\epsilon_{\text{norm}} = 3.75 \, \mu\text{m}$. The parameter $\Delta Q_0$ corresponds to the tune shift for a perfectly centered particle.

During Run I & II, several measurements of the amplitude detuning were carried out at different energies [4] [7] [8]. We measured it again during the present MD. The octupole current was set to 10 A in order to have the same tune spread as during the ADT narrow-band excitations. A measurement with more statistics than before was performed and the result is shown in Fig. 23. In the same plot the parabola fit is given. The coefficients corresponding to Eq. 1 are the following.
\[
\begin{align*}
\Delta Q_0 &= 1.7 \cdot 10^{-3} \pm 0.2 \cdot 10^{-3} \quad (2) \\
b &= 0.52 \cdot 10^{-3} \pm 0.13 \cdot 10^{-3} \quad (3)
\end{align*}
\]
A significant deviation from the result predicted by the model is observed and it is under investigation. These results will be used to select appropriate values of the ADT frequency in simulation models and the preparation of upcoming MD’s in order to get rid of particles at the corresponding amplitude.

![Figure 23: Detuning with amplitude measurement including a parabola fit and the results expected using the model.](image)
5 Further measurements and investigations

5.1 Case repetition experiments during MD block III

After the first attempt using ADT excitation for active halo control a second parasitic time slot of 3 hours was provided in MD block III. A plan was prepared taking in account previous results and the measurement of detuning with amplitude for targeting certain $\sigma$ values. The main objective was trying to repeat the promising result of Run fn2 with fixed ADT frequency in which only the fat tail bunch experienced an intensity decrease whereas the witness bunch stayed untouched, see Fig. 13. The idea for this case was to excite for a larger time period to investigate whether only beam tail particles of the fat tail bunch will be depleted constantly.

Due to the missed fact, that the ADT injection cleaning was switched on this and the majority of measurements were taken out with a wrongly adjusted ADT excitation window targeting only the latest injected bunch. The result can be seen in Fig. 24. The fat tail bunch #1500 was not excited. The only measurement with the correct ADT window acting on fat tail bunch and witness bunch is illustrated in Fig. 25. This measurement was meant to be a check of the general reproducibility. Therefore a ADT frequency sweep from high to low values over the nominal tune was repeated resembling a tune spread measurement. Following the frequency sweep the shape of the intensity curve for the fat tail bunch #1500 is qualitatively similar to the measurement during the first MD. This is not the case for the percental intensity decrease. During the repeated measurement the reference bunch #170 (#0 in the first MD) was one of nominal intensity. The two other bunches were pilots. Hence these were not handled by the feedback system. Additionally the witness bunch #1700 merely had a fifth of the fat tail bunch intensity and a poor quality, which explains the noise and the early drop of the signal. Deriving the individual bunch intensities from the BSRT measurements for the two bunches was not possible. Since pilot and nominal bunches were present in the machine the BSRT was blind for the pilot signals. Reworking

\footnote{6th of November 2015.}
the results of the attempt being able to reproduce and understand the mechanisms of the method brought a gain of insights for future measurements.

Figure 25: Individual bunch intensities with BLM losses during Run n4 (left) and the repeated measurement in MD block III (right).

5.2 ADT kick amplitude scaling

For a better understanding and planning of the halo excitation with the ADT the investigations are accompanied by simulations. To provide the modeling with the corresponding kick strength of the ADT deflector plates we evaluated the relation between amplitude $A$ in the software and ADT voltage $U_{\text{ADT}}$.

The first relevant setting for the transverse damper plates is the loop gain which is expressed in dB and sets the limit for the applicable voltage. For the ADT excitation the loop-$C$ is in operation. During the MD on the 30th of August its gain was $g_{l,c} = -10.7$ dB. This leads to a maximum voltage for the deflector plates of $U_{\text{ADT}} = 600$ V. The maximum loop gain would result in $\hat{U}_{\text{ADT}} = 7.5$ kV. In addition to the loop gain there are filter coefficients which sum up to a certain value $f_c$. The finally applied voltage $U_a$ is given in Eq. 4.

$$U_a = Af_cU_{\text{ADT}}(g_{l,c})$$

As derived in [9], the maximum kick $k_m$ induced by the set of 4 ADT’s with $U_a = 10.5$ kV would be $2.7 \mu\text{rad}$ (or $0.5\sigma$) at injection energy (450 GeV). Scaled to 7.5 kV which provides the current hardware this gives $k_m \approx 1.93 \mu\text{rad}$. The resulting kick $k$ taking in account amplitude, loop gain and filters can be written as

$$k = k_m \frac{Af_cU_{\text{ADT}}(g_{l,c})}{U_{\text{ADT}}} = k_m \frac{U_a}{\hat{U}_{\text{ADT}}}.$$  (5)

The filter settings during the active halo MD were set to flat response ($f_c = 70772/9300$). Exemplary, with a widely applied amplitude of 0.03 this results in a kick of $\approx 35$ nrad which corresponds to $6.53 \cdot 10^{-3} \sigma_p$.

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213th of November 2015
6 Conclusion

This document summarizes the measurements of the very first attempt to excite and deplete particles of certain amplitudes tune space with the transverse damper (ADT) for an active halo control at the LHC. The MD was carried out at injection energy 450 GeV on the 30th of August 2015.

The ADT narrow-band excitation was applied to nominal bunches in the horizontal plane and in a second part to pilot bunches for both planes. In order to show that the method does not affect the beam core the excitation was performed simultaneously on two bunches, one with populated tails and one regular bunch ("witness bunch"). Further a reference bunch circulated in the machine outside the excitation window. Individual bunch intensity measurements during ADT frequency sweeps on nominal bunches approaching the beam core in tune space led to a kick amplitude of $A = 0.03$. This corresponds to 35 nrad or $6.53 \cdot 10^{-3} \sigma_p$ for the current ADT voltage settings with 7.5 kV. Higher amplitudes resulted in dramatic losses even for excitations far from the core. Adding bunch profile shapes taken by beam wire scanners before the excitation it was shown that the individual bunch intensities decrease accordingly of the targeted tune space. Particle depletion in the fat tail bunch was observed until an ADT frequency of $Q_{\text{ADT},x} = 0.291$ without affecting the witness bunch, which corresponds to $\approx 4.6 \sigma$. The reference bunch was kept stable during all measurements. Since only one ADT sweep starting from beam core towards the tails was carried out with unfavourable initial bunch conditions this gave no evidence for the feasibility of the method, although also for this case the bunch shapes were qualitatively confirmed.

Investigations modeling the method with simulations indicate that sweeping outwards in frequency might be successful to constantly push particles towards the collimators. This will be tested in a future MD. For ADT excitations staying at a fixed frequency it was confirmed that a low kick amplitude of 35 nrad seems reasonable. One measurement turned out to be a promising case of settings. For a frequency of $Q_{\text{ADT},x} = 0.295$ (i.e. $\approx 5.4 \sigma$) only the bunch with populated tails displayed a decrease in intensity. A particle depletion of 2% was achieved for an excitation of 120 s. Concerning the emittances all bunches stayed stable. Since the resolution of the wire scanners is not sensitive enough these ADT settings will be repeated in upcoming measurements for larger timescales. Several ADT excitations were repeated with pilot bunches while the feedback damper system was switched off and the chromaticity was set to zero to eliminate other possible sources of tune spread. This resulted in large particle loss and instabilities compared to similar settings during the runs with nominals. Performing narrow-band excitations with pilots turned out not to be suitable. Since the feedback damper does not act on pilots even when it is switched on one would have the same situation. During the MD additionally the measurement of detuning with amplitude in the horizontal plane with octupoles at 10 A was accomplished. This will be beneficial as a reference for further ADT excitation studies. Already another short MD was realized on the 6th of November. Its objective was to check the reproducibility of certain excitation runs of the previous MD and further several methodical narrowband-excitation sweeps. Accidentally these measurements were done while the injection cleaning was on which changed the ADT settings and resulted in non applicable data.

Summing up, the first attempt using the ADT for active halo control gave interesting and promising results. With the exploited parameter space, the gained experience operating
the RF and awareness of possible sources of errors it is feasible to follow up this method of
tail depletion in future MD’s.

7 Acknowledgements

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MADX we thank X. Buffat, T. Pieloni and D. Banfi of the beam beam effects team for the
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A Appendix

A.1 Tables of ADT excitation runs settings

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<th>Run</th>
<th>plane amplitude</th>
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<th>step $\Delta Q_x$</th>
<th>step $\Delta t / s$</th>
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<td>$10^{-4}$</td>
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<td></td>
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<td>comments</td>
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<td></td>
</tr>
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<td></td>
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Table 1: List of ADT excitation sweeps on nominal bunches

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<th>tune $Q_x$</th>
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<td>120</td>
</tr>
<tr>
<td>fn4</td>
<td>H 0.5</td>
<td>0.3</td>
<td>30</td>
</tr>
<tr>
<td>fn5</td>
<td>H 0.5</td>
<td>0.298</td>
<td>30</td>
</tr>
<tr>
<td>fn6</td>
<td>H 0.5</td>
<td>0.296</td>
<td>30</td>
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Table 2: List of ADT excitation runs with fixed frequencies on nominal bunches
Run plane amplitude $A$ sweep in $Q_x$ or $Q_y$ step $\Delta Q$ step $\Delta t$ / s comments

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<tbody>
<tr>
<td>p2</td>
<td>H 0.05 0.28 ← 0.2949 10^{-4} 2</td>
<td>damper off and octupoles at 10A</td>
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<tr>
<td>p3</td>
<td>H 0.05 0.28 ← 0.2949 10^{-4} 2</td>
<td>same scan as the last one, but with TCP.H at 2.69σ, no preparatory ADT blowup on bunch 1500</td>
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All following sweeps were carried out without a preparatory ADT blowup of bunch #1500.

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<tr>
<td>p4</td>
<td>H 0.05 0.2821 ← 0.2949 10^{-4} 2</td>
<td>TCP.H at 3.67σ (i.e. 1σ more opened than last scan), damper off</td>
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<tr>
<td>p5</td>
<td>H 0.05 0.2817 ← 0.2949 10^{-4} 2</td>
<td>TCP.H 2.67σ, damper off, octupoles with flipped sign</td>
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<tr>
<td>p6</td>
<td>H 0.05 0.2651 → 0.2793 10^{-4} 2</td>
<td>only b#1500 &amp; b#1700. TCP.H at 2.67σ, damper off, octupoles with flipped current sign, abort gap cleaner off</td>
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<tr>
<td>p7</td>
<td>V 0.079 0.2651 → 0.2694 10^{-4} 2</td>
<td>this was only a test for the ADT, no beam in the machine</td>
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<tr>
<td>p8</td>
<td>V 0.079 0.3244 ← 0.3269 10^{-4} 2</td>
<td>only b#1500 &amp; b#1700. TCP.V at 3.17σ, flipped octupole currents, damper off, chroma set again to 0 (EiC). losses went on even if the ADT excitation was off, due to the abort gap cleaner.</td>
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<tr>
<td>p9</td>
<td>V 0.079 0.3139 ← 0.3269 10^{-4} 2</td>
<td>only b#1500 &amp; b#1700. TCP.V at 3.17σ, octupoles with flipped current sign, damper off.</td>
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<tr>
<td>p10</td>
<td>V 0.079 0.2971 → 0.307 10^{-4} 2</td>
<td>TCP.V at 3.17σ, octupoles with flipped current, damper off</td>
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<tr>
<td>p11</td>
<td>V 0.079 0.3111 ← 0.3349 10^{-4} 2</td>
<td>TCP.V at 3.17σ, octupoles with flipped current, damper off</td>
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Table 3: List of ADT excitation sweeps on pilot bunches
A.2 Complete set of ADT excitation runs

ADT frequency sweeps on nominal bunches

Figure 26: Individual bunch intensities with BLM losses and individual emittances of nominal bunches during Run n1.

Figure 27: Individual bunch intensities with BLM losses and individual emittances of nominal bunches during Run n2.
Figure 28: Individual bunch intensities with BLM losses and individual of nominal bunches emittances during Run n3.

Figure 29: Individual bunch intensity and emittances of nominal bunches during Run n4.
ADT excitation runs with fixed frequencies

Figure 30: Individual bunch intensities with BLM losses and individual emittances of nominal bunches during Run fn4 with fixed ADT frequency.

Figure 31: Individual bunch intensities with BLM losses and individual emittances of nominal bunches during Run fn5 with fixed ADT frequency.
Figure 32: Individual bunch intensities with BLM losses and individual emittances of nominal bunches during Run fn6 with fixed ADT frequency.

ADT frequency sweeps on pilot bunches

Figure 33: Individual bunch intensities with BLM losses and individual emittances of pilot bunches during Run p5.
Figure 34: Individual bunch intensities with BLM losses and individual emittances of pilot bunches during Run p6.

Figure 35: Individual bunch intensities with BLM losses and individual emittances of pilot bunches during Run p8.

Figure 36: Individual bunch intensities with BLM losses and individual emittances of pilot bunches during Run p9.
Figure 37: Individual bunch intensities with BLM losses and individual emittances of pilot bunches during Run p10.

Figure 38: Individual bunch intensities with BLM losses and individual emittances of pilot bunches during Run p11.