SPS AND LHC BATCH SPACING OPTIMISATION

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Abstract

In 2016, part of the luminosity performance improvement for the ion run could be achieved by reducing the PS batch spacing in the SPS. The same optimisation process was then applied to proton beams resulting in the reduction of both SPS and LHC batch spacing in 2017 operation, i.e. to 200 and 800 ns respectively. In this contribution, the operation with and evolution of the new injection settings over 2017 is presented, together with the stability of rise-time of the individual switches for the two kicker systems. The luminosity gain following these changes is also evaluated and the expected luminosity for potential beam filling patterns in 2018 is investigated. Finally, the possibility for further improvements is discussed.

INTRODUCTION

The filling schemes used until 2015 LHC runs comprised minimum batch spacings, at the LHC and SPS, as specified in the LHC design report, i.e. 900 ns and 225 ns, respectively. As already extensively discussed in [1], [2] and [3], the measurement campaign that brought to the batch spacing reduction in the SPS for the Pb-Pb ion run also leaded to the batch spacing reduction for p-p physics run of 2016 and 2017, both in the SPS and LHC.

Batch spacing reduction can be achieved with improved individual kicker synchronisation, i.e. the so-called fine synchronisation [1], and optimisation of kicker-beam delay synchronisation. This is done to limit emittance blow-up and intensity reduction to operationally acceptable levels. Such an optimisation directly translates in the maximum number of bunches that can be stored in the LHC, leading to luminosity increase.

During 2017 LHC physics run, the batch spacings used to fill the LHC were 200 ns and 800 ns for the MKP (SPS injection kicker) and the MKI (LHC injection kicker) respectively. In this proceeding, the performance of such a scheme is presented. The main affected beam parameters are compared with other schemes and luminosity increased discussed. Finally, the proposed settings for the 2018 LHC run are indicated, together with the plan for possible further improvements.

2017 PERFORMANCE IN THE SPS AND LHC

In 2017, the MKP batch spacing was gradually reduced from 250 ns to the final 200 ns, as shown in Fig. 1. The single switches fine synchronisation was only performed at the beginning of the run. The overall kicker delay was instead adjusted at each iteration, following the measurements presented in [1]. The 200 ns batch spacing was also kept when, due to the LHC beam scream warm up, the LHC physics beam type was changed from BCMS to 8b4e.

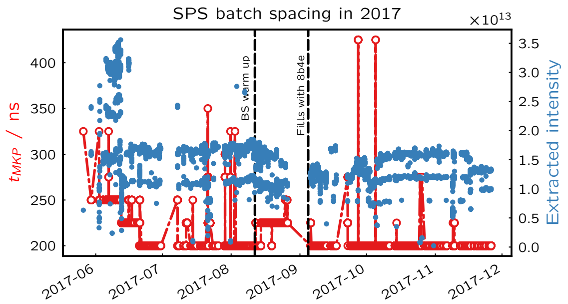

Figure 1: Evolution in time of the batch spacing at the SPS injection for the whole 2017 run.

Also in the LHC, after an initial commissioning and intensity ramp up, the MKI batch spacing was reduced from 900 ns to the operational 800 ns. Such a a batch spacing was kept also for the whole physics run, as well as when it was switched to the 8b4e beam.

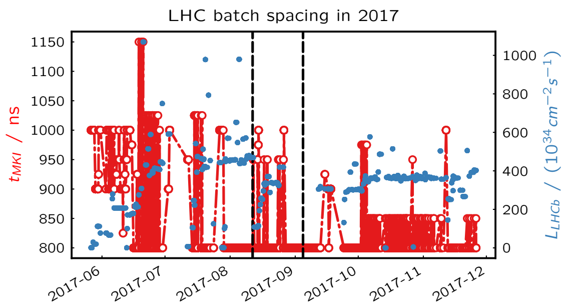

Figure 2: Evolution in time of the batch spacing at the LHC injection for the whole 2017 run.

In both SPS and LHC, no further switch synchronisation was needed to keep such batch spacings, also thanks to the great performances of the transverse feedbacks.

The increase in luminosity that this schemes led to was calculated as about 6% with respect to the 2016 run, for BCMS beam (Fig. 3).

In the following two subsections, the individual performance of the two batch spacing reductions are evaluated. As figures of merit, the intensity fluctuations of the closest bunches to the kicker field and their emittances are taken. In the SPS, the Beam Quality Monitor (BQM) bunch-by-bunch intensity measurements are used. For the emittances, for both LHC and SPS, the LHC Beam Synchrotron Radia-

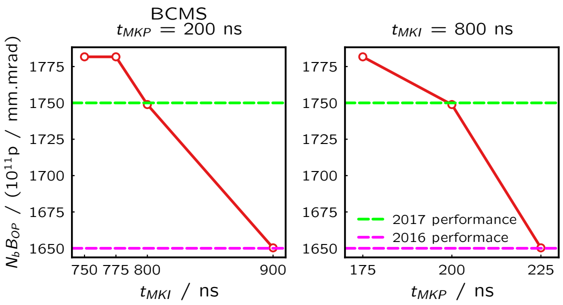

Figure 3: Effect of the MKI batch spacing (left) and MKP batch spacing (right) on the total number of bunches stored in the LHC times the beam brightness (I_b/ϵ_N).

tion Monitor (BSRT) is used to evaluate possible emittance degradation at injection in the LHC. All measurements are normalised by the batch average and the error bars represent the standard deviation of the measurements.

200 ns MKP batch spacing

The overall performance of the 200 ns MKP batch spacing scheme can be evaluated analysing the full 2017 LHC fills, in terms of losses and emittance blow up. As previously mentioned, the bunches taken as witnesses are those at the edges of a new injected batch. The intensity fluctuations of these bunches, as a function of the MKP batch spacing, for the period of the run where the BCMS beam was used, are shown in Fig.4. In Fig. 5, the emittances for the same bunches are shown.
From these two figures, it is evident that the evolution with the MKP batch spacing is fairly constant and within the error bar of the measurements.

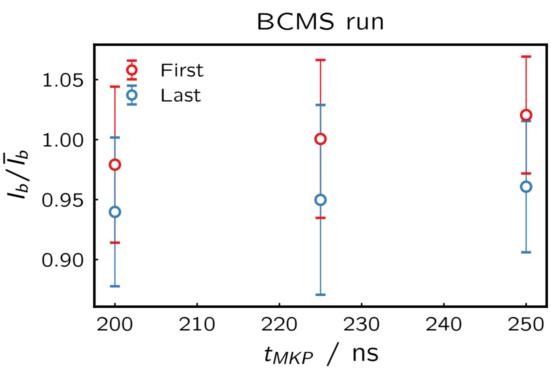

Figure 4: Mean intensity of the first and last bunch (closest to the MKP field rise) of a batch over the BCMS run of 2017 as a function of the MKP batch spacing. The error bar represent the standard deviation.

Very similar behaviour, as expected, is also observed when the operational LHC beam was changed to the 8b4e (Fig. 6 and 7).

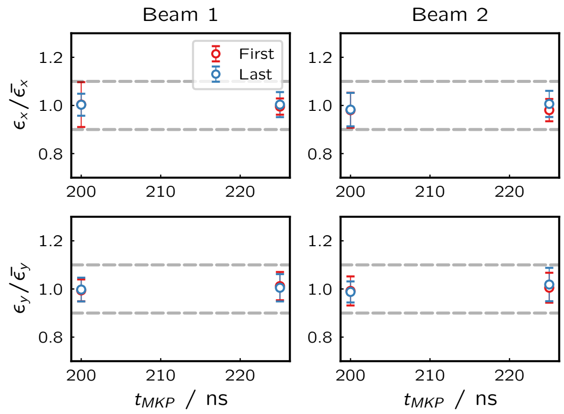

Figure 5: Mean emittance of the first and last bunch (closest to the MKP field rise) of a batch over the BCMS run of 2017 as a function of the MKP batch spacing. The emittances were measured in the LHC using the BSRT. The error bar represent the standard deviation.

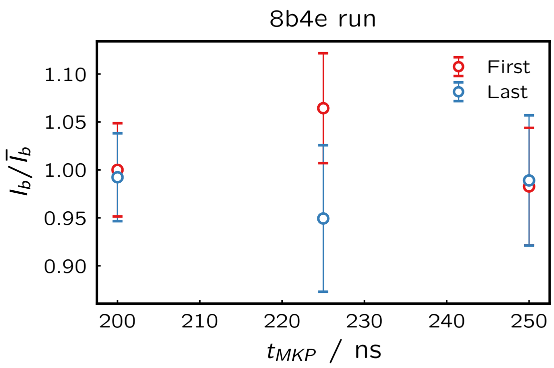

Figure 6: Mean intensity of the first and last bunch (closest to the MKP field rise) of a batch over the 8b4e run of 2017 as a function of the MKP batch spacing. The error bar represent the standard deviation.

The stable operation with 200 ns MKP batch spacing was one of the main concern of the proposed scheme. It was shown in [3] that the reduced batch spacing could lead to losses at the transfer line collimators, as consequence of tail population increase. This was not the case for either the BCMS or the 8b4e beams.

800 ns MKI batch spacing

The first measurements of reduced MKI batch spacing were performed in 2016 and documented in [2]. It was already shown, that the expected emittance increase as consequence of the reduced batch spacing would have been negligible. In Fig. 8 and Fig. 9, the emittances of the closest bunches to the MKI field rise, normalised to the average batch emittance, is plotted for both BCMS and 8b4e runs. Except for isolated events (outliers), the vertical emittances are confined between ±10% the batch average emittance.

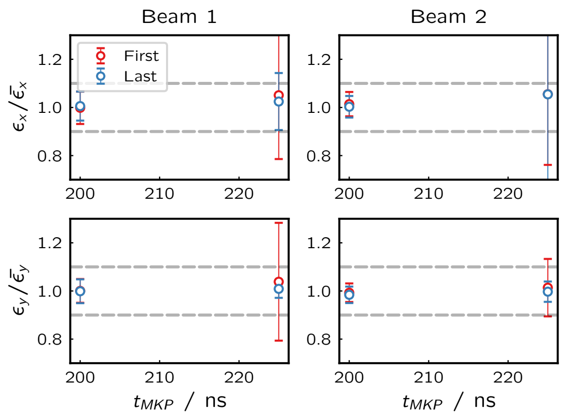

Figure 7: Mean emittance of the first and last bunch (closest to the MKP field rise) of a batch over the 8b4e run of 2017 as a function of the MKP batch spacing. The emittances were measured in the LHC using the BSRT. The error bar represent the standard deviation.

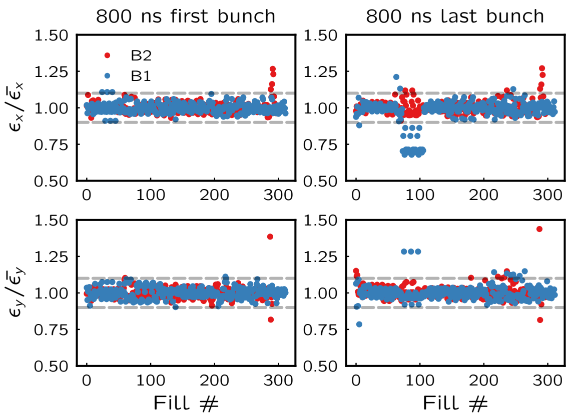

Figure 8: Emittance evolution of the first and last bunch (closest to the MKI field rise) of a batch over the BCMS run of 2017. The emittances were measured using the BSRT.

ROOM FOR (EVEN MORE) IMPROVEMENT

Up to date, the MKP and MKI modules synchronisation is measured using the current in the Terminating Magnet Resistor (TMR). Other current measurements are also available, for both MKP and MKI, using capacitive pick-ups at the beginning and exit of a magnet. During a measurement campaign, it was observed a discrepancy between TMR and pick-up current measurements. In theory, the current measured at the exit of the magnet, using a capacitive pick-up, should give a more accurate measurement of the end of the field rise in the kicker. Understanding the source of discrepancy and using the capacitive pick-ups directly (new will be installed during the 2017/18 YETS to cover more kickers) may lead to a better kicker module synchronisation. The maximum gain should be around 10 ns, according to the kicker experts.

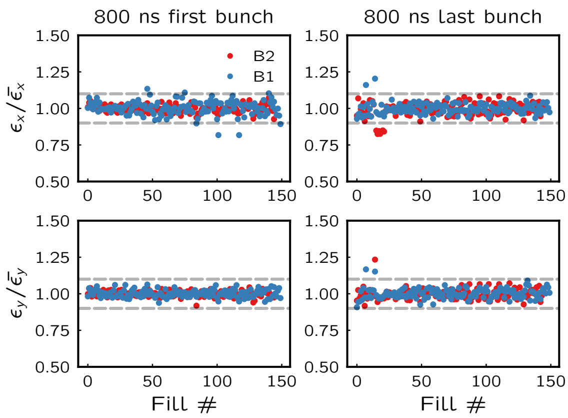

Figure 9: Emittance evolution of the first and last bunch (closest to the MKI field rise) of a batch over the 8b4e run of 2017. The emittances were measured using the BSRT.

In the case the MKI and/or MKP batch spacing could be further reduced, the gain in terms of number of bunches that can be stored in the LHC (for BCMS beam) is shown in Fig. 10. Any reduction of either of the two would lead to a 2% increase in the total number of stored bunches.

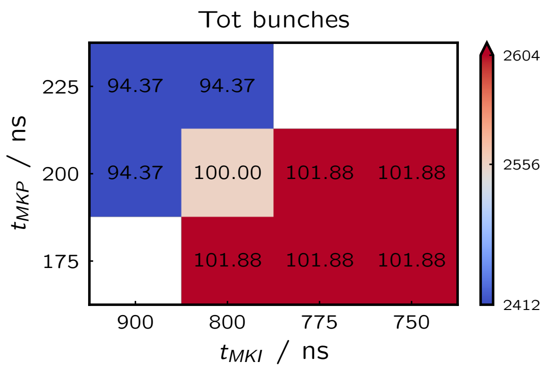

Figure 10: Heat map of the total number of bunches injectable in the LHC as a function of the MKP and MKI batch spacing. In the plot are also expressed the percentage of bunches with respect to 2017 BCMS operation.

The possibility to use a different production scheme, the so-called BCS (Batch Compression Splitting) or simply the pure batch compression scheme [4], has been also evaluated. The brightness of this beam type is higher as consequence of the lower splitting ratio (4 with respect to 6 for BCMS scheme). Due to the limitation imposed by the SPS-to-LHC transfer line collimators (TCDI), the number of batches is limited to 3 for both BCMS and BCS beams (Fig. 11). Following these considerations, the possible gains for the LHC physics are compared in Fig. 12.
For the BCS case, it is clear that only significant reduction of one of the two batch spacings (175 ns or 750 ns for the MKP and MKP respectively) would give a tangible number

of stored bunches increase. This possibility looks out of reach at the moment.

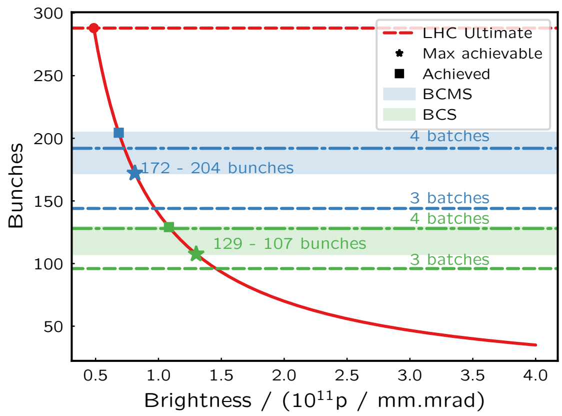

Figure 11: Maximum number of bunches transportable from the SPS to the LHC as a function of the beam brightness (constant attenuation factor in case of interaction of the beam with the TCDIs).

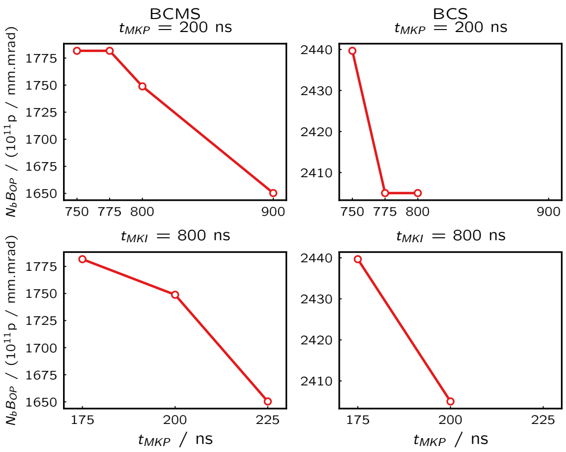

Figure 12: Effect of the MKI and MKP batch spacing on the total number of bunches stored in the LHC times the beam brightness (I_b/ϵ_N) for BCMS (left) and BCS (right) scheme.

CONCLUSIONS

During the whole LHC 2017 run, the batch spacings used were 200 ns and 800 ns for the MKP and MKI, respectively. The operational stability of such a configuration was proved, as the MKP fine synchronisation was only needed once at the beginning of the run.

There was no observation of beam quality degradation (intensity or emittance), thanks to both the LHC and SPS transverse dampers and the optimal settings for the MKI and MKP delays. Comparable performances were observed for BCMS and 8b4e beams.

Possibility for further improvements are under investigation. Beam time will be requested during commissioning to evaluate the synchronisation of individual modules using capacitive pick-ups. Also, MDs will be proposed in both SPS and LHC to investigate the limits of these systems and to perform more detailed beam dynamics studies on the effect of different configurations (e.g. tail population evolution).

It is suggested to keep the batch spacings as for the 2017 run, i.e. 200 ns and 800 ns for the MKP and MKI, respectively.

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[3] B. Goddard, *et al.*, “SPS Injection and Beam Quality for LHC Heavy Ions With 150 ns Kicker Rise Time”, in Proc. 7th Int. Particle Accelerator Conf. (IPAC’16), Busan, Korea, May 2016, paper TUPMR048, pp. 1360–1362, 2016.

[4] A. Lasheen, *et al.*, “Overview of the beams from the injectors”, these proceedings.