OBSERVATION OF BEAM INSTABILITIES WITH VERY TIGHT COLLIMATION

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Abstract

We report about the observation of instabilities in the LHC in special runs with high beta* and very tight collimation down to 2 sigma which increases the transverse impedance significantly. The losses appeared primarily on the highest intensity, non-colliding bunches which can be interpreted as evidence for insufficient Landau damping. We describe the beam conditions, observations and possible explanations for the observed effects.

INTRODUCTION

We describe observations in the LHC from 2012, which were recorded in a special physics run in the LHC, using only 3 intense bunches per beam. Two of the three bunches were colliding in the LHC interaction regions IR1 and IR5 for measurements of the low angle proton-proton scattering at $\beta^* = 1000\,\mathrm{m}$ [1]. In this run, the primary collimators were moved much closer than usual, down to $2\,\sigma$ compared to $4.3\,\sigma$ used in regular operation in 2012 [2]. As expected, we observed losses by halo scraping at times when collimators moved in to tighter settings, predominantly on beam 2, which had larger emittances, see Table 1.

Table 1: Normalized emittances, as measured by wire scans on the 24 Oct. 2012 at 21:50 in the LHC, before collimators were closed to the very tight settings.

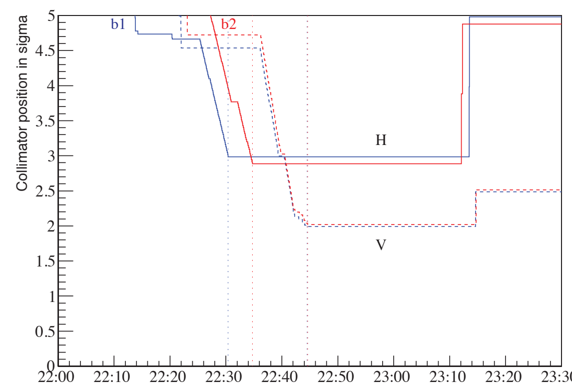
beam	$\epsilon_{V,\mathrm{N}}$ in μm	$\epsilon_{H,\mathrm{N}}$ in μm
1	1.83	1.30
2	3.31	2.24

Here we focus on an additional loss which was seen on the strongest, non-colliding bunch, shortly after that all primary collimators were in their closest position, at $3\,\sigma$ in the horizontal plane and $2\,\sigma$ in the vertical plane.

OBSERVATIONS

Figure 1 shows the closest distance of the horizontal and vertical collimators from the beam axis over 1.5 hours around the time of the first very tight collimation in the $\beta^* = 1000\,\mathrm{m}$ physics run performed on the LHC on the 24 October 2012.

During the first scraping, losses were observed on all bunches present in the ring, as can be seen in Figure 1: the top plot shows the collimator movements (thus the scraping) and the bottom plot the bunch-by-bunch intensity. The



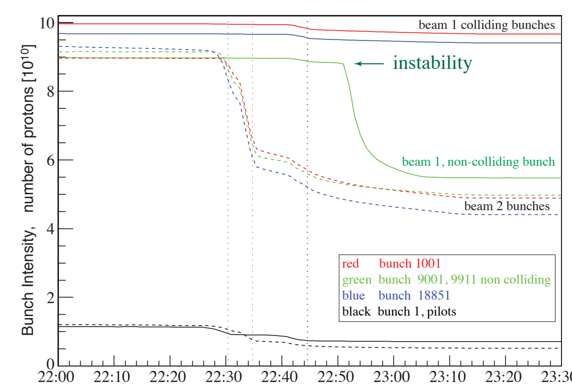


Figure 1: Primary collimators (top, in red for beam 1, blue for beam 2) and bunch intensities (bottom) from 22:00 to 23:30 hours.

tightest collimator settings corresponding to $2\,\sigma$ in the vertical plane were reached at 22:44:31 for beam 1 and 5 s later, at 22:44:36 for beam 2.

The instability discussed here became visible as significant loss in bunch intensity at 22:51, or 7 minutes after the last step in closing the collimators. Within 3 minutes, the intensity decreased from 8.7×10^{10} to 6.7×10^{10} (23% loss) and stabilized after 10 minutes at 5.5×10^{10} protons.

Throughout this run, coherent beam motion was measured and recorded using the based-band tune (BBQ) monitor of the LHC. By analyzing this data, we found that the loss coincides with the on-set of coherent beam motion. This can be seen in Figure 2, where we have plotted the evolution of the FFT spectrum of the BBQ position data

over several minutes before and during the losses. A coherent line appears in the spectrum just before the losses begin, accompanied by another slightly weaker line later on, separated by $\sim 2.4 \times 10^{-3}$ which matches the small amplitude synchrotron tune $Q_s \approx 2.3 \times 10^{-3}$.
The rise time of the instability, calculated by an exponential fit versus time of the maximum amplitude of the FFT spectrum of the BBQ data is around 30 s as can be seen in Figure 3. Finally, in Figure 4 we show the bunch length evolution around the instability time; for the bunch that became unstable, a clear bunch lengthening appears at the time of the instability. Initially all bunches had a very similar bunch length, of 1.25 ns (the value is the "total" or $4\,\sigma$ bunch length). For the unstable bunch, it increased to 1.65 ns. Bunch lengthening connected with transverse instabilities have been already observed previously in the LHC [3].

The chromaticities were not re-measured in this run. From the commissioning for this special run, we expect that they were in the range of $Q' = 1$ to 3 for both beams and planes. The transverse feedback was active in the vertical plane, with a damping time corresponding to 100 turns. The LHC octupoles which provide Landau damping to all bunches were powered at 38% of their maximum value (-209 A for the defocusing and $+209$ A for the focusing octupoles, the maximum being 550 A).

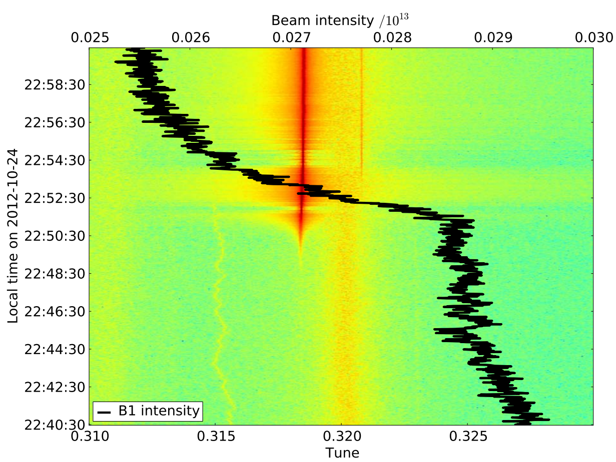


Figure 2: BBQ spectrum versus time for beam 1 in vertical (from an FFT performed on a sliding window) together with beam intensity. The color indicates the amplitude of the spectrum lines.

INTERPRETATION

A tentative explanation for the appearance of the coherent instability is the increased transverse impedance due to tightened collimator settings, combined with insufficient Landau damping.

We used our LHC impedance model [4] to predict the impedance for the tightest collimator settings of this run ($2\,\sigma$ vertical, $3\,\sigma$ horizontal) and compared the prediction

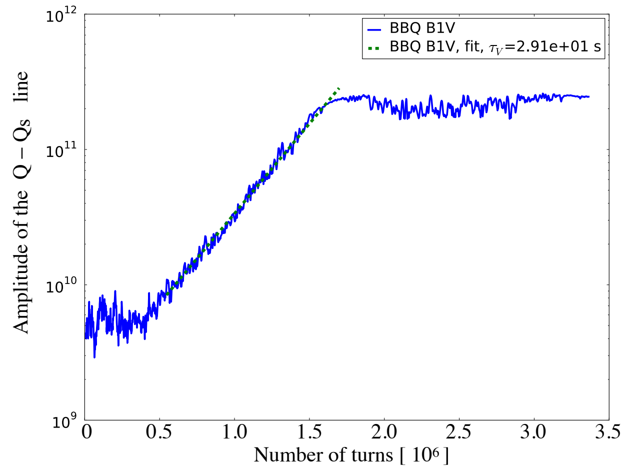


Figure 3: Maximum amplitude of the BBQ spectrum versus time for beam 1 in vertical (from an FFT performed on a sliding window) together with its fit by an exponential.

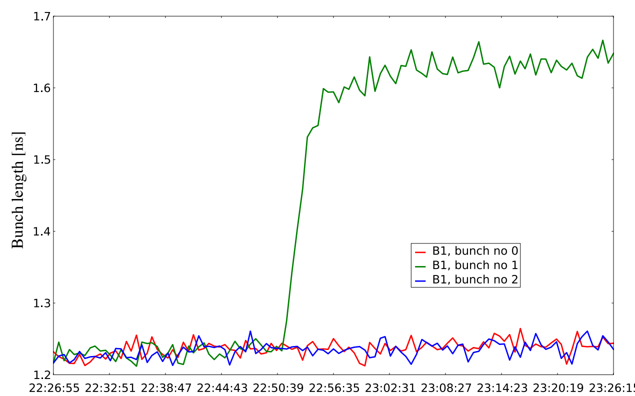


Figure 4: Bunch length evolution for beam 1 over 1 hour around the occurrence of the instability. The color code identifying each bunch is identical to the one used in Figure 1.

with the standard settings. The result is shown in Figure 5. We can see that the tight collimation increases the transverse impedance by up to $\sim 50\%$ in the frequency domain of interest (i.e. between several hundreds of MHz and a few GHz – the bunch length being ~ 1.25 ns).

Tail particles contribute to Landau damping [5]. Scraping off the transverse halo by tight collimation may have contributed to reduce Landau damping.

For the colliding bunches, the tune spread produced in the collisions provides extra Landau damping. In standard runs with many bunches, the beam-beam effects in the LHC are rather complex and require an evaluation of both head-on and long range beam-beam effects [6, 7]. Here the situation is much simpler. We only need to consider the head-on collisions for the two colliding bunches in the interaction points 1 and 5. The bunch spacing and the use of parallel separation and crossing angles in the other interaction regions was such, that the effects from long range encounters

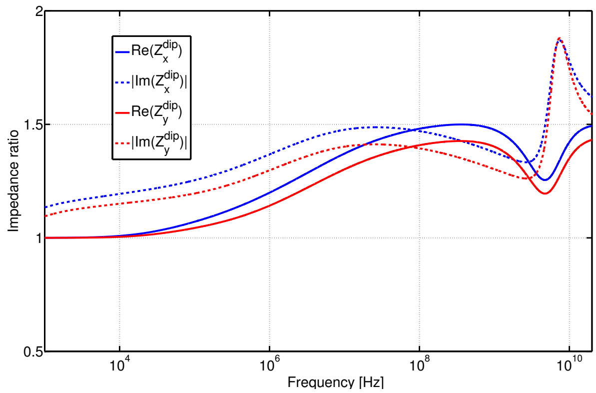


Figure 5: Ratio between the transverse dipolar impedances before and after the scraping.

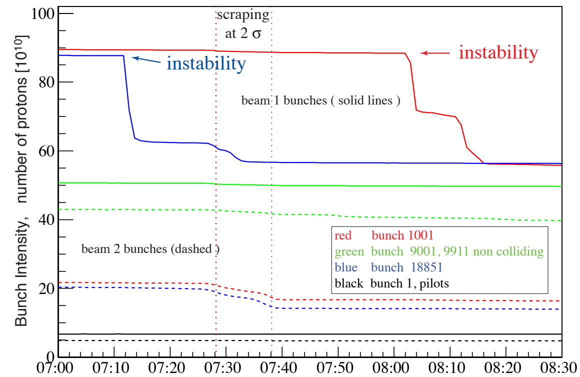


Figure 6: Bunch intensities towards the end of the run, on Oct. 25 from 07:00 to 8:30 hours.

were negligible.

For an estimate of the head-on beam-beam effect, we evaluate the beam-beam tune shift parameters according to

$$\xi_{x,1} = \frac{r_c\, N_2\, \beta^*_{x,1}}{2\pi\gamma_1\, \sigma_{x,2}\, (\sigma_{x,2} + \sigma_{y,2})}\,,$$

$$\xi_{y,1} = \frac{r_c\, N_2\, \beta^*_{y,1}}{2\pi\gamma_1\, \sigma_{y,2}\, (\sigma_{x,2} + \sigma_{y,2})}\,, \qquad (1)$$

and give numerical values in Table 2. The formulas give the tune shift induced by beam 2 on beam 1 (and vice versa by exchange of indices). r_c is the classical proton radius, γ the Lorentz factor, and N the bunch population.

Table 2: Beam-beam tune shift parameters at 22:50

beam 1 , $N = 9 \times 10^{10}$		beam 2, $N = 5 \times 10^{10}$	
ξ_x	ξ_y	ξ_x	ξ_y
0.0020	0.0025	0.0077	0.0065

The beam sizes were calculated using the initial emittances given in Table 1.

A further evidence for the stabilizing effect of the beam-beam interaction was observed at the end of this special run, when also the colliding bunches of beam 1 became unstable as visible in Figure 6. The intensities of beam 2 had reduced to the level of 2×10^{10}, implying $\xi_{x,y,1} < 0.001$ which was insufficient to stabilize these bunches.

SUMMARY AND CONCLUSION

We describe observations of a coherent, transverse instability in the LHC, seen in October 2012 in a special run with few bunches and very tight collimator settings. We also present first estimates and a tentative explanation of these observations, according to which the effects can be accounted for by an enhanced transverse impedance dominated by collimators combined with a reduction of Landau damping due to the removal of the tail particles.

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