READINESS OF AND PLANS FOR THE INJECTORS FOR 2009

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Abstract

A large diversity of beams have been prepared in the LHC injectors in the past few years, such as single-bunch and multi-bunch beams, with 25 ns and 75 ns bunch spacings. In 2008 the efforts were mainly devoted to the revival of the multi-bunch beam with 50 ns bunch spacing, and the production of the different beams with intermediate intensities per bunch. The purpose of the present paper is twofold: firstly, review the status of the proton beams in all their forms, which could be delivered by the injectors in 2009 on request from the LHC; secondly, summarize the situation with the ions and in particular the SPS commissioning with the early ion beam, which took place at the end of the 2007 run.

INTRODUCTION

Beams for LHC have been prepared in the injector chain for more than ten years [1]. Very often the beam intensities were pushed to their maximum to try and indentify as soon as possible all the possible bottlenecks. With the LHC commissioning foreseen in September 2008, a particular attention was paid to low-intensity beams (with good reproducibility) in 2008 to be ready for the LHC's (first) requests. The results of these studies with protons are presented in the first section, while the SPS commissioning with the early ion beam is reviewed in the second section.

PROTONS: NEWS IN 2008

Rephasing SPS-LHC

The remaining item from 2007 which could prevent us from extracting proton beams in the LHC was the rephasing between SPS and LHC [2]. This is a two-step process, where the first one consists in frequency matching, i.e. lock SPS RF onto LHC RF/2. The second step is phase matching, i.e. align SPS bunches with LHC buckets (see Fig. 1). The rephasing SPS-LHC was fully qualified on 08/08/2008, meaning that from this time onwards it was possible to extract proton beams from the SPS into the LHC.

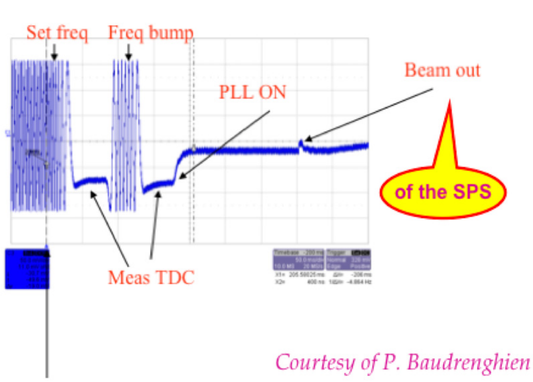

Figure 1: Example of signals measured during the rephasing between SPS and LHC.

New definition of the LHCPROBE beam

Following the first LHC injection tests held on 09-10/08/2008 and the first quench made in the LHC with a LHCPROBE bunch of 5E9 p/b, it was decided to redefine the LHCPROBE bunch to 2E9 p/b. Discussions (and actions) took place to see whether the intensity should be reduced in the PSB, PS or SPS. Finally, it was decided to do it in the PS by longitudinal shaving at the start of the ramp, as doing so it is in fact possible to scan the intensity from ~ 2E9 p/b to ~ 5E9 p/b with only one timing (see Fig. 2).

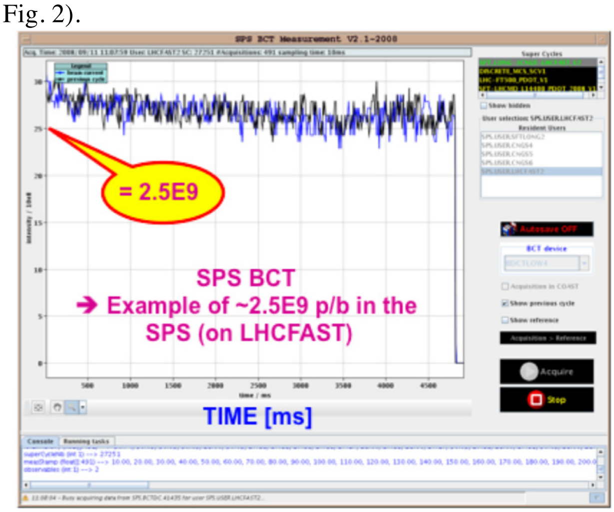

Figure 2: Example of SPS BCT (Beam Current Transformer) with a LHCPROBE bunch of ~ 2.5E9 p/b.

Multi-bunch beams with intermediate intensities

The LHC will not start immediately with multi-bunch beams (spaced by 25 ns or 75 ns) of nominal intensities. Therefore, the beginning of the year 2008 was devoted to the production of the 25 ns and 75 ns beams with intermediate intensities in a clean and reproducible way, i.e. in an operational manner. The following intensities were created in the PSB (and archives were made for LHC25) [3]: 1/10 (see Fig. 3), 1/5, 1/3, 1/2 and 2/3, WITHOUT taking care of the transverse emittances, as it was decided (at the beginning of the year 2008) that the controlled transverse emittance blow-up will be done, if needed, in the SPS. However, the nominal longitudinal parameters should be preserved.

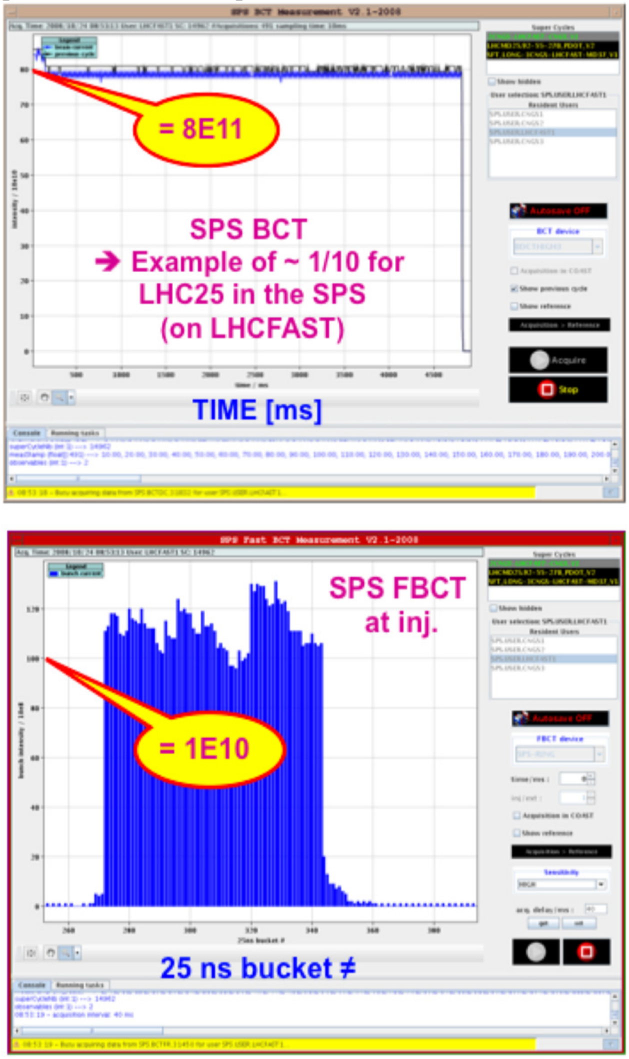

Figure 3: Example of (a) SPS BCT with a LHC25 beam (only 1 batch of 72 bunches on the LHCFAST cycle) of ~ 1/10 of the nominal intensity, and (b) SPS FBCT (FAST BCT) at injection.

Controlled transverse emittance blow-up in SPS

If the transverse emittances of some LHC beams produced in the PS complex are too small a controlled transverse emittance blow-up is now available in the SPS. This mechanism was already studied in 2003 [4] and applied in 2007 during ecloud MDs [5], but no remote control was available (adjustments on the transverse damper were made in BA2). The idea was to try and have it operational by the end of the year 2008. The goals were reached for both single-bunch and multi-bunch beams, as blow-ups from ~ 1 μm to ~ 3-3.5 μm (rms, norm) were obtained with good reproducibility [6]. Note that the final value of 3-3.5 μm was chosen as it is the nominal one but larger blow-ups can be achieved. The case of the previous beam (LHC25, 1/10) on the LHCFAST cycle is shown in Fig. 4.

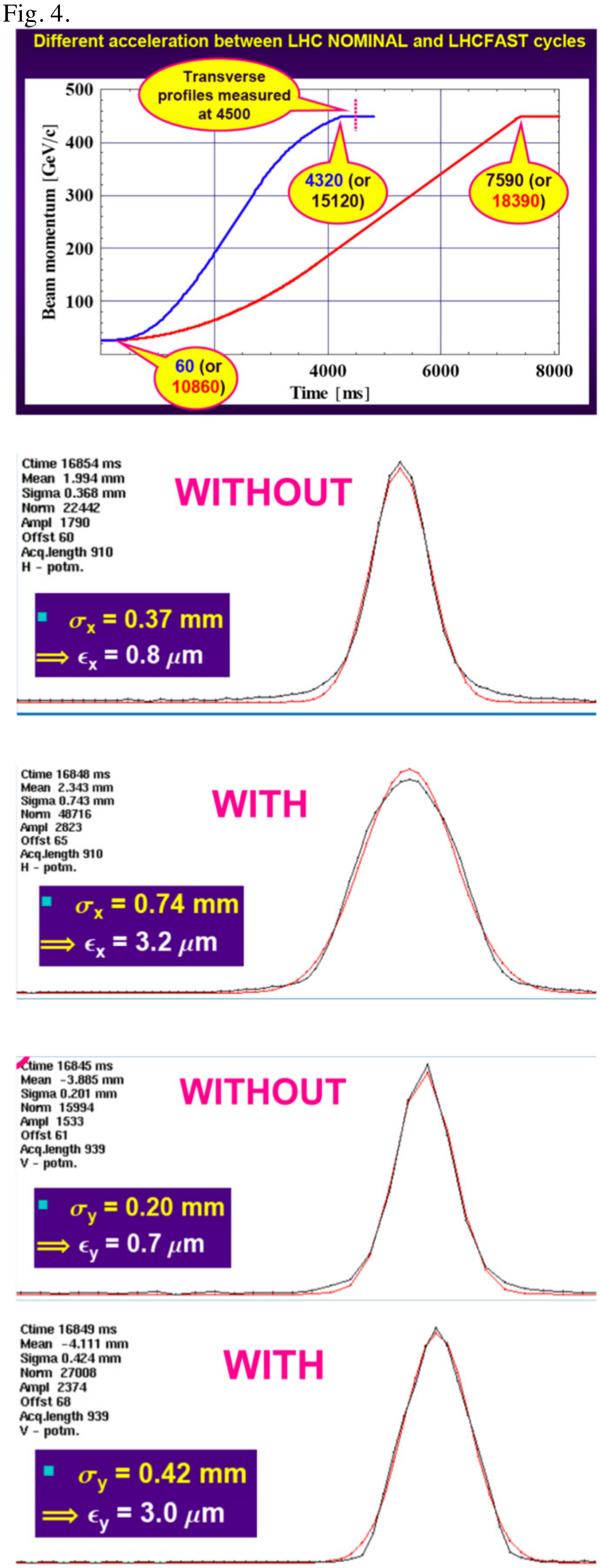

Figure 4: (a) Comparison between the nominal LHC cycle (of 21.6 s) and the LHCFAST cycle (of 8.4 s). The transverse profiles measured with the wire scanner

BWS51995 are shown below in the horizontal/vertical plane (b/d) without and (c/e) with controlled transverse emittance blow-up.

Two requests from the LHCCWG

During the LHCCWG held on 13/02/3008, two requests were made to the LHC injectors: (1) check what happens in the SPS if 2 bunches of different intensities are injected, 1 with high intensity (LHCINDIV in the PS, i.e. ~ 1.15E11 p/b) and 1 with low intensity (LHCPILOT in the PS, i.e. ~ 5E9 p/b); (2) check that we can still produce the 50 ns beam in the PS. The motivation for the revival of the 50 ns option [7] is that it is interesting again to try and satisfy the need of low luminosity in IP2, or in a more general way to modulate the luminosity at the different IPs. Furthermore, with the 50 ns beam (without changing anything) the luminosity is reduced by a factor 2 (as there are 2 times less bunches) and the long range effects are also reduced by a factor 2. If in addition, the transverse emittances are 10-15% smaller then one can almost completely forget about long-range beam-beam effects [8]. The idea was therefore to try and produce the nominal 50 ns beam in the whole injector chain and measure the transverse emittances at 450 GeV/c to see if they are smaller than the nominal values.

The results for the first subject can be seen in Fig. 5, where both bunches were accelerated in the SPS. The bunch lengths (at 4σ) measured just before extraction were 1.2 ns for the LHCINDIV bunch and 0.8 ns for LHCPILOT, whereas the measured transverse emittances were ~ 2.5 μm for both.

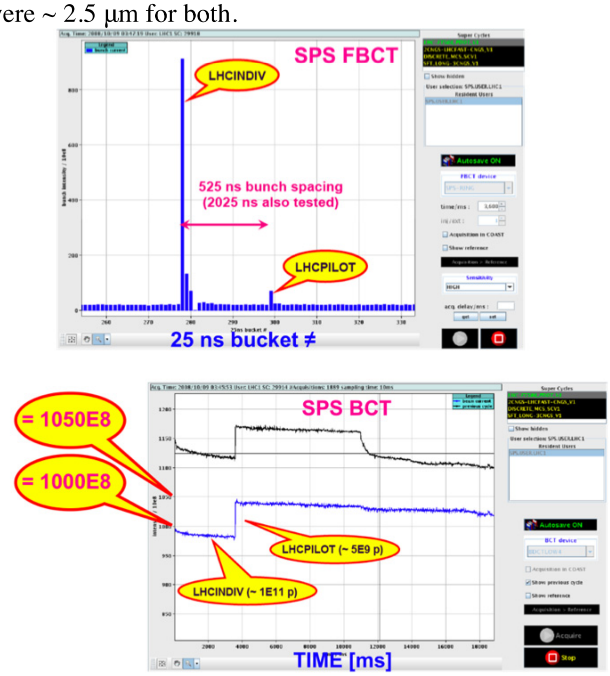

Figure 5: SPS (a) FBCT and (b) BCT with 2 bunches of very different intensities (LHCINDIV and LHCPILOT) at the same time in the SPS on the nominal LHC cycle.

Concerning the second item, no user was available in the PSB for the "new" 50 ns beam, but the nominal LHC50 beam is nothing else than the (LHC25, ½), i.e. the archive of LHC25 with half intensity. However, it should be noticed that the batch spacing for LHC50 in the SPS should be 9 (25 ns) empty buckets (instead of 8 for both LHC25 and LHC75), i.e. 250 ns (instead of 225 ns for LHC25 and LHC75). Figure 6 reveals that ~ 80% of the nominal intensity could be achieved in a clean way. For higher intensities, some issues with SPS interlocks (due to outgassing) on the ZS ion trap and MKDV1 were found, which still need more investigations. It should be noticed that the MKDV1 will be changed in 2009. Finally, for short time the nominal intensities could be reached and the transverse emittances measured, as shown in Fig. 7. As can be seen the transverse emittances (~ 1-1.5 μm) are much smaller than the nominal value of 3.5 μm.

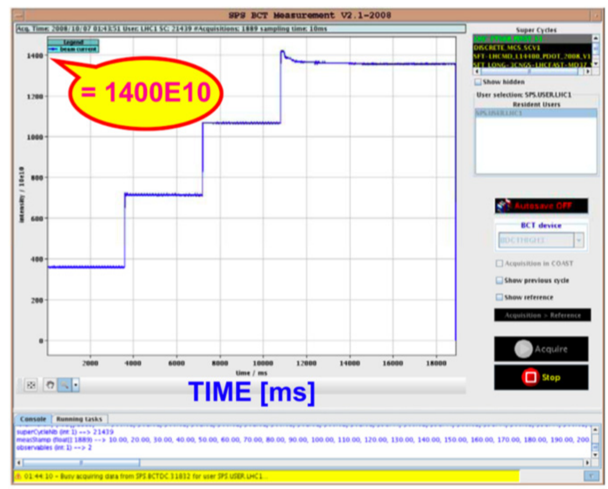

Figure 6: SPS BCT with ~ 80% of the nominal intensity of the LHC50 beam (4 batches of 72 bunches) on the nominal LHC cycle.

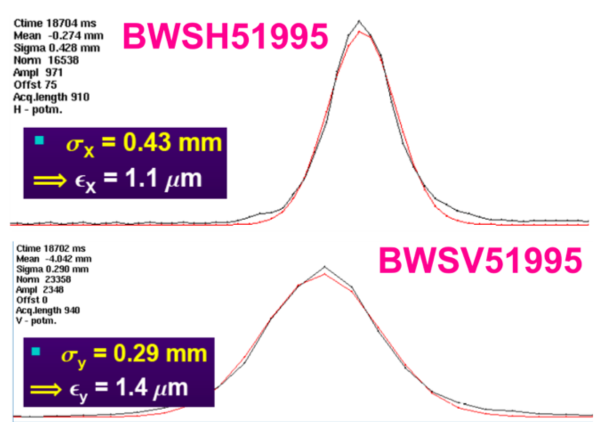

Figure 7: Measured transverse emittances at 450 GeV/c with nominal intensity (~ 1650E10 p) on the LHC50 beam.

Production of LHC75(50) in 1 batch instead of 2 into PS

Another important subject concerns a new idea of producing the LHC75, LHC50 and LHC25 (up to a certain intensity) in 1 batch from the PSB into the PS instead of 2. Very promising results were obtained for LHC75_1b in the PSB and PS (as well as with LHC50_1b in the PSB). No major difficulties were encountered in the PSB, where 3 rings have to be used on harmonic h2 at extraction with some h1 (to match h7 in the PS) as well as a synchro h1. However, there is a trade-off between longitudinal emittance and PSB extraction kicker rise-time (~ 106 ns) [9]. As a consequence, LHC25/50_1b are excluded in the PS without lengthening the injection plateau by ~ 40 ms for longitudinal emittance blow-up before the triple splitting.

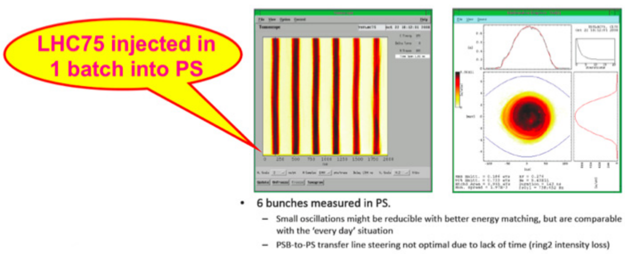

Figure 8: Tomogram revealing the injection of 6 bunches into the PS in 1 batch instead of 2 with the LHC75 beam.

IONS: NEWS IN 2007 AND 2008

SPS commissioning in 2007

The 2007 run was devoted to the commissioning of the early ion beam in the SPS [10]. The main results are that the achieved intensity was 10% smaller than design (which is 295.2E8 charges, corresponding to 4 bunches of 9E7 Pb82+ ions) in transverse emittances 25% smaller than design (which is 1.2 µm, rms norm). Note that the tunes were optimized to (26.13, 26.25). The evolution of the beam intensity can be seen on Fig. 9 in the case of the record intensity and for a magnetic field with an injection plateau of ~ 7 s instead of ~ 40 s in the nominal scheme. The beam was also extracted and seen at the beginning of one of the extraction lines towards LHC (TT60/TI2). However, the beam was not synchronised to the LHC.

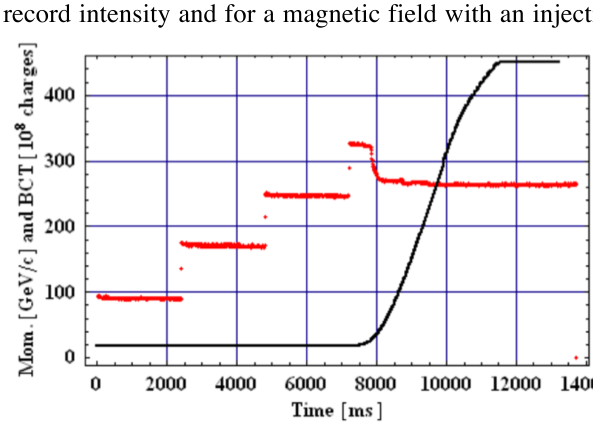

Figure 9: Evolution of the SPS BCT along the magnetic cycle in the case of the record intensity.

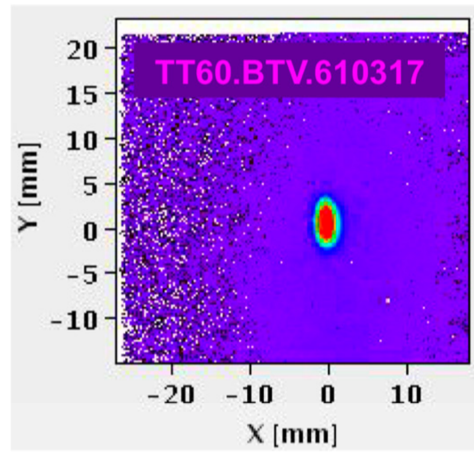

Figure 10: Beam seen at the beginning of one of the extraction lines towards LHC (TT60/TI2) on the screen TT60.BTV.610317.

New 18 GHz source in 2008

The intensity should scale with the square of the frequency [11]. Therefore, going from 14.5 GHz to 18 GHz should increase the ion current by ~ 50%, giving more margins for the nominal LHC beam.

The results obtained in 2008 revealed that the source works with 18 GHz, i.e. it is as stable as with 14.5 GHz. However, no performance increase was observed yet with 18 GHz at the end of the linac, but the performance with 14.5 GHz was the result of several years of tuning.

CONCLUSION AND PLANS FOR 2009

Protons

Several "new" LHC beams/flavours have been produced in 2008 and are ready for the LHC in 2009.

A particular attention was paid to low-intensity beams (with good reproducibility) in 2008 to be ready for the LHC's (first) requests.

As concerns the production of the LHC75 in 1 batch (instead of 2) into the PS, MDs are planned as soon as possible to check all open issues in detail. It should then become the baseline scenario, after approval by the relevant committee.

The production of the LHC25/50 in 1 batch (instead of 2) into the PS will also be studied in detail. However, in this case, the PS injection plateau has to be increased by ~ 40 ms for longitudinal blow-up before the triple splitting. Furthermore, MDs are needed to study the evolution of the transverse emittances vs. intensity.

Ions

As concerns the early beam, several weeks of setting-up and MD time are necessary to make a first LHC ion run possible (by the end of September 2009).

For the nominal beam, only LEIR made some progress in 2007. RF hardware in the PS needs rebuilding, testing and setting up. Alternative filling schemes (to minimize IBS and SC) need to be tested in the SPS. Furthermore, many MDs are foreseen in 2009 to study crystal collimation, as crystals could provide a possible solution for the collimation of ions in the LHC.

Finally, it should be noted that no ions were circulating in rings since November 2007, which means that many recommissionings will be needed (controls, RF, power supplies, etc.).

ACKNOWLEDGEMENTS

I would like to thank all my colleagues from the injectors complex and in particular P. Baudrenghien, C. Carli, S. Hancock, K. Hanke, D. Küchler, D. Manglunki, S. Maury, G. Rumolo and R. Steerenberg for helpful information in the preparation of the present paper.

APPENDIX: ULTIMATE LHC PROTON BEAM IN THE INJECTOR CHAIN

One of the main advantages of LINAC4 for LHC operation should be to possibility to produce the nominal beam in the PS in one batch from the PSB instead of two. However this new linac will not replace LINAC2 before 5 years. If the ultimate beam is needed in the LHC before this date, could we produce the ultimate beam in the PSB and in the whole injector complex?

It was said in the past that the ultimate beam couldn't be produced in the PSB, as deduced from Fig. A1, which shows the measured normalized vertical and horizontal transverse emittances as a function of the bunch population at extraction. The full green and orange vertical lines indicate the nominal and ultimate bunch populations while the dashed green vertical line indicates the required bunch population in order to achieve the nominal bunch population at the SPS extraction taking into account the losses occurring in the PS and in the SPS. These losses amount to approximately 10-15 %. The blue horizontal line represents the design transverse emittance. The measured data for each of the 4 PSB ring is presented together with the average over the 4 rings. Although the nominal design parameters have been fully achieved the ultimate ones are not within reach at present.

However, as mentioned already at the Beam'07 workshop [12,13], what is important for the LHC are the beam parameters at LHC injection. In particular a ultimate bunch should have an intensity of 1.7E11 p/b and transverse emittances (rms, norm) of 3.5 μm. Furthermore, the important parameter is in fact the sum of the transverse emittances (i.e. 7 μm), as the required beam is round and emittance sharing can be done by linear coupling between the transverse planes. Looking at Fig. A1, it is seen a value of 7 μm is obtained for the sum of the transverse emittances (average over the 4 rings) when the PSB bunch intensity is ~250E10 p/b. This intensity corresponds to 2.1E11 p/b in the LHC if there is no beam loss in the downstream accelerators. The ultimate LHC bunch intensity (1.7E11 p/b) could therefore be produced with 20% of beam losses in the downstream accelerators of the PSB. Of course, in this scheme no transverse emittance blow-up is allowed through the injector chain, but one has to remember that for the main sources of emittance blow-up (mis-steering and dispersion mismatch, space-charge induced emittance growth and/or losses on the PS injection flat-bottom and ecloud instability at SPS injection) the larger the transverse emittances the better. Therefore, the best strategy for the transverse emittance control along the accelerators could be in fact to start in the PSB with values close to the required ones at LHC injection. This still has to be investigated in detail, but it should be noticed that the transverse emittances of ring 3 (the worst on Fig. A1) were even smaller in 2008, which should give more margin.

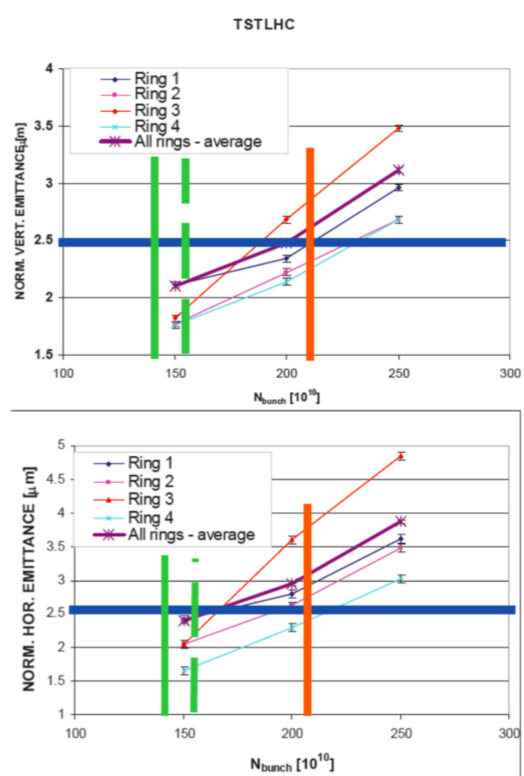

Figure A1: Measured normalized vertical (top) and horizontal (bottom) emittance vs. bunch population for the LHC beam at extraction from the PS Booster. Courtesy of K. Hanke and B. Mikulec [12].

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