# OPERATIONAL EXPERIENCE DURING THE LHC INJECTION TESTS

K. Fuchsberger, R. Alemany-Fernandez, G. Arduini, R. Assmann, R. Bailey, O. Brüning, B. Goddard, V. Kain, M. Lamont, A. MacPherson, M. Meddahi, G. Papotti, M. Pojer, L. Ponce, S. Redaelli, M. Solfaroli Camillocci, W. Venturini Delsolaro, J. Wenninger, CERN, Geneva, Switzerland

*Abstract*

Following the LHC injection tests of 2008, two injection tests took place in October and November 2009 as preparation for the LHC restart on November 20, 2009. During these injection tests beam was injected through the TI 2 transfer line into sector 23 of ring 1 and through TI 8 into the sectors 78, 67 and 56 of ring 2. The beam time was dedicated to injection steering, optics measurements and debugging of all the systems involved. Because many potential problems were sorted out in advance, these tests contributed to the rapid progress after the restart. This paper describes the experiences and issues encountered during these tests as well as related measurement results.

## INTRODUCTION

In 2008 injection tests have proven to be a very useful preparation for the beam commissioning phase of the LHC [1, 2]. Thus in preparation for the recommissioning in 2009 two injection tests were scheduled reasonably close to the actual start of the beam commissioning phase of the whole machine.

The first injection test took place during the weekend of October 25, 2009. It started by injecting ions into the LHC for the first time. On Friday beam was sent through TI 2 down to point 3. On Sunday beam was injected in point 8 and sent to point 7. Beam time was dedicated to injection steering, aperture studies, dispersion and kick-response measurements, injection protection commissioning, a check of the closure of the LHCb spectrometer bump and higher order polarity checks, both in sector 23 and 78.

The second injection test was scheduled for the weekend of November 8, 2009. It also started with beam through TI 2 to point 3 on Friday. On Saturday the beam was taken through TI 8, first to point 6 and later to point 5. Beam time was dedicated to BLM threshold tests, checks of the Alice spectrometer bump, again kick-response and dispersion measurements and towards the end detailed beam dump studies. Some "splash" events - beam on the tertiary collimators close to the experiment - were delivered to CMS.

## PREPARATION

The success of the LHC injection tests, both in 2008 and 2009, is due to the impressive quality of the hardware, due to the hardware commissioning of the powering systems and other systems and clearly also due to the machine checkout and dry runs where equipment was tested with operational parameters, using operational tools and following operational scenarios like injection, inject & dump or circulate and dump. A major factor of the success of the injection tests was also the experience and knowledge of the commissioning team gained during the injection tests and beam commissioning phase in 2008.

## RESULTS: EXAMPLES

The results will not be discussed in detail as most of them are presented in other contributions to these proceedings. References will be indicated where appropriate.

### *First Ion Beam in the LHC*

The first injection test in 2009, on the weekend 24/25 October, 2009, started by successfully taking Lead ions into the LHC for the first time. The ions, injected in point 2, went straight through to point 3 without any correction. The trajectory of this first ion beam injection is shown in Fig. 1.

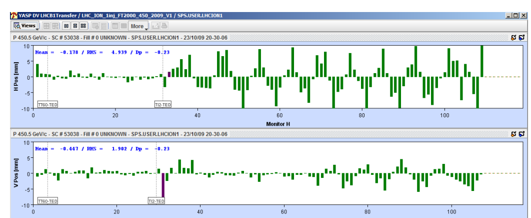



Figure 1: Trajectory of first injected ions into the LHC.

### *Injection Setup*

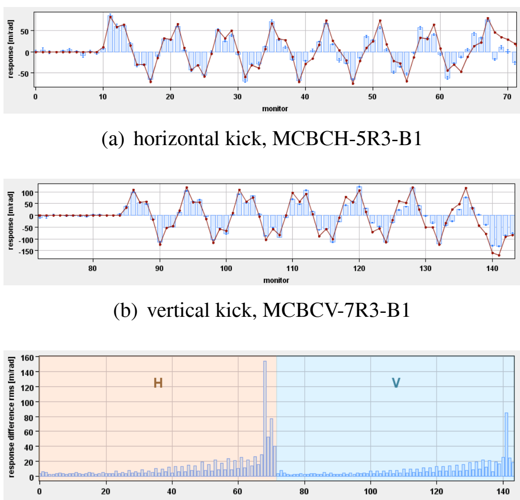
While the trajectory injected in IP2 could be easily corrected with few correctors and responded very well on steering with correctors towards the end of the transfer line, the setup in TI 8 turned out to be a little bit more tricky (no response of some screens, erratic BPM readings, possibly because of losses) and fairly large kicks were needed (up to 22 $\mu$rad). A lot was learned from these exercises and solutions were implemented in future setup procedures. Eventually, the trajectory was nicely corrected.

The injection dump (TDI) was set up by scanning both jaws through beam which worked very well in point 2. Also measurements with a tilted TDI (by 2mrad) were performed as well with ALICE and LHCb. Experiment signals were worse when TDI was tilted, and an asymmetry was found on one side of the scan in P8, pointing to an alignment problem of the TDI in point 8.

By varying the kicker delays and recording the beam positions in the LHC ring, the kicker waveforms of both injection kicker systems were measured. Apart from a small unexpected overshoot of about 2% for both systems [3], both waveforms were found very close to specifications.

### *Kick Response Measurements*

In the new models of the transfer lines the systematic $b_2$ and $b_3$ components were taken into account and the optics of the lines had been rematched with the LHC. As a result of this the measurements in the transfer lines were in almost perfect agreement with the model [4]. The $b_2$ (and other higher order field components) in the LHC dipoles were still uncorrected and therefore a phase error was visible in the kick response measurements. This is shown in Figs. 2. Furthermore a systematic kick response measurement in sector 23 proved the correct functionality and polarities of all the tested correctors. Also some new features of the steering application were tested and bugs could be sorted out.




(a) horizontal kick, MCBCH-5R3-B1

(b) vertical kick, MCBCV-7R3-B1

(c) difference measurement-model

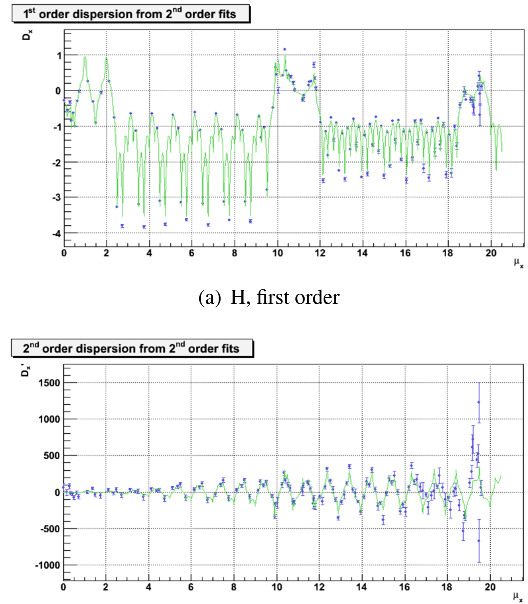
Figure 2: Example of kick response measurements in LHC sector 23. The (growing) phase error due to the uncorrected $b_2$ is well visible.

### *Dispersion Measurements*

From data of transfer line tests in June 2009 it was possible to disentangle some BPM problems (e.g. electronics non-linearities [5]) before the injection tests. Therefore the measured dispersion data, apart from an error which was clearly due to wrong initial conditions, was in very good agreement with the model dispersion right from the beginning. As an example Figs. 3 show the horizontal dispersion (first and second order) of TI 8 plus LHC sector 78 with a model using new initial conditions ($dx = -0.3356$) derived from the data.

### *Magnetic Model*

Comparisons of the beam trajectories before and after the precycle of the magnets on Saturday of the first injection test gave very encouraging results for the reproducibility. The RMS of the difference trajectory before and after cycling was between 0.31 mm (V) and 0.47 mm (H) as shown in Fig. 4. The long term reproducibility (comparisons with trajectories of 2008) was also found to be excellent.




(a) H, first order

(b) H, second order

Figure 3: First and second order horizontal dispersion for TI 8 + LHC sector 78. Blue dots represents measured data, green lines the model.

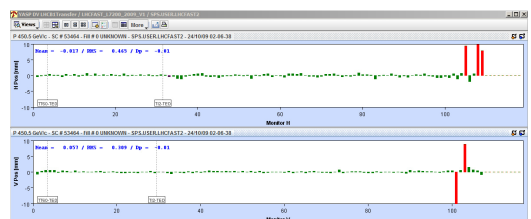


Figure 4: Difference trajectory before and after cycling.

### *Aperture Studies*

The aperture in the available sectors was studied carefully with a strong focus on the injection and dump regions [6]. Around IP2 the aperture promised physical limits of $\pm 8\ \sigma$ at the MSI as expected, while around IP8 a vertical aperture restriction was located between MSI and Q5. Figure 5 shows an example of simulated free oscillations launched to probe the aperture for beam 2 from point 8 to point 6.

### *BLM System*

First experiences were gained in the setup of the BLM thresholds. Four dumps were provoked by driving orbit bumps until the BLM triggered. In all cases post-mortem data has been correctly produced. The amplitude of the bump which triggered the dump was found to be very reproducible [7]. Also calibration checks of the losses at the

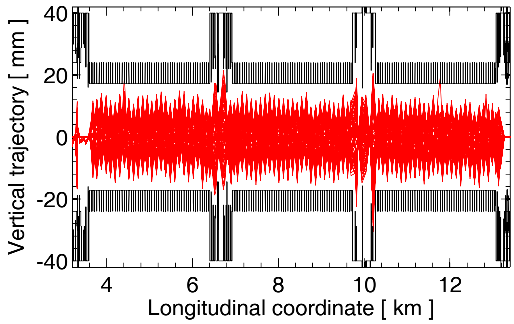



Figure 5: Aperture measurements in sectors 78, 67 and 65.

collimators were done.

### *Injection Quality Check*

The IQC (injection quality check) system was deployed the first time and was working very well. It turned out to be very useful and reliable for diagnosis and interlocking in case of injection problems [8]. For example, every time the beam was sent on TDI this was systematically, correctly, reported as bad injection by the IQC system.

### *Higher Order Polarity Checks*

By launching on or off-momentum difference trajectories via appropriate orbit correctors for varying strength settings of the magnet circuits under study polarities and calibrations of quadrupoles, sextupoles and octupoles in the LHC sectors 23 and 78 were checked [9]. All the quadrupoles, sextupoles and octupole elements were found in perfect agreement with the model but a systematic reversed polarity for all skew quadrupoles and sextupoles was found, which later on was taken into account in the knobs generation application.

### *Spectrometer Bumps*

The spectrometer magnets of the ALICE and LHCb experiments were switched on together with their compensator magnets and the non-closures of these bumps were observed on the beam trajectory. The non-closure of the orbit for ALICE was found to be around 1.1 mm RMS (polarity +) and 1.0 mm RMS (polarity -). For the LHCb spectrometer bump the result was about 1.0 mm for both polarities.

### *Beam Dump System*

By simulating different kicker strengths using orbit correctors to extract the beam into the dump channel the losses on TCDS (collimator which masks the dump septum) and MSD (dump septum) were observed and were found to be as expected. The minimum physical aperture in the dump channel was found to be about 8 $\sigma$ in both H and V. No major problems could be found.

By varying the injected bucket number the full dilution sweep on the dump, generated by the dilution kickers was scanned. The shape was as expected, but a horizontal offset was observed [10]. A superimposed image of all these shots is shown in Fig. 6.

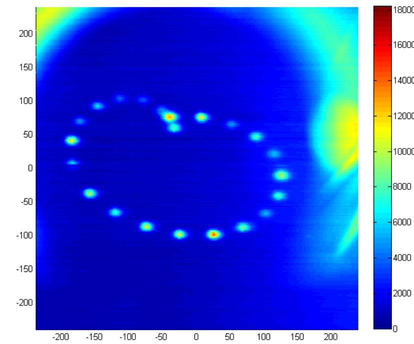


Figure 6: Superimposed image of all the shots on the dump varying the injection bucket number.

## SUMMARY

For the first time after the long shutdown for the LHC repairs all the systems were used again under operational conditions during the two injection tests. Diligent preparation, acceptance tests and dry runs paid off: all systems were found in good shape and small errors and bugs were sorted out easily enough. The injection tests in 2009 proved to be crucial for the smooth restart of the LHC on November 20, 2009.

## REFERENCES


[1] M. Lamont et al., "The LHC Injection Tests", LHC Performance Note 001.

[2] V. Kain, "Injection Tests", Proceedings of the Chamonix 2009 workshop on LHC performance, p. 192, CERN, 2009.

[3] M. Barnes et al., "Beam-Based Measurement of the Waveform of the LHC Injection Kickers", these proceedings.

[4] M. Meddahi et al., "Results of 2009 optics studies of the SPS to LHC transfer lines", these proceedings.

[5] K. Fuchsberger et al., "Kick response measurements during LHC injection tests and early LHC beam commissioning", these proceedings.

[6] B. Goddard et al., "Aperture Measurements of the LHC Injection Regions and Beam Dump Systems", these proceedings.

[7] B. Dehning et al., "LHC Beam Loss Measurements and Quench Level Abort Threshold Accuracy", these proceedings.

[8] B. Goddard et al., "Injection Beam Loss and Beam Quality Checks for the LHC", these proceedings.

[9] F. Zimmermann et al., "Single-pass Beam Measurements for the Verification of the LHC Magnetic Model", these proceedings.

[10] J. Uythoven et al., "Beam Commissioning and Performance Characterization of the LHC Beam Dump Kicker Systems", these proceedings.