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► **To cite this version:**

S. Cavalier, Hans Burkhardt, M. Fitterer, G. Müller, S. Redaelli, et al.. 90 m optics commissioning. 2nd International Particle Accelerator Conference (IPAC'11), Sep 2011, San Sebastian, Spain. pp.1795-1797. in2p3-00675300

**HAL Id: in2p3-00675300**

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Submitted on 29 Feb 2012

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# 90 m OPTICS COMMISSIONING

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## Abstract

Special  $\beta^* = 90$  m optics have been developed for the two very high luminosity insertions of the LHC [1] [2], as a first step to allow for very low angle precision measurements of the proton-proton collisions in the LHC. These optics were developed to be compatible with the standard LHC injection and ramp optics. The target value of  $\beta^* = 90$  m is reached by an un-squeeze from the injection  $\beta^* = 11$  m. We report about the implementation of this optics and the first experience gained in commissioning with beam during two machine studies.

## INTRODUCTION

High- $\beta^*$  optics with  $\beta^* > 1000$  m have been requested by the ATLAS-ALFA and TOTEM experiments to allow for very low angle precision measurements of the proton-proton scattering in the LHC using Roman Pot detectors installed in the very forward region around the LHC interaction points IP1 and IP5. We report here about the first experience with the commissioning of the 90 m optics. This is important both for the machine to see how these optics can be efficiently implemented in the LHC as well as for the experiments to allow for first very forward proton-proton scattering data at LHC energies and four-momentum transfers down to  $\sim 10^{-2}$  GeV<sup>2</sup>.

The target value of  $\beta^* = 90$  m is reached by an un-squeeze from the injection  $\beta^* = 11$  m using 17 intermediate steps.

## UN-SQUEEZE

The simultaneous un-squeeze in IP1 and IP5 from the injection  $\beta^* = 11$  m to  $\beta^* = 90$  m results in a significant tune reduction of up to 0.45. It is compensated by an increase of the strength of the main LHC quadrupoles (QD, QF). The validity of this approach was demonstrated in a first test performed in May 2011. As illustrated in Fig. 1 and Fig. 2, it was possible to reach  $\beta^* = 90$  m without any significant beam losses.

To keep matters simple and minimize the risk of damage in case of uncontrolled beam loss, the first study was performed using single bunches of rather low intensity in each of the LHC proton rings, placed such that they would not collide in the interaction regions. This worked very well. The beam intensity was close to  $1.2 \times 10^{10}$  protons for both beams. Feedbacks were used to automatically correct orbits and tunes. Linear interpolation is used for the magnet strength between the steps. The tune distortions introduced by the linear interpolation were calculated. The calculated

corrections reach values up to 0.006 between the steps and can be corrected using the LHC trim quadrupoles. To test the procedure, the calculated corrections were only applied for beam 1.

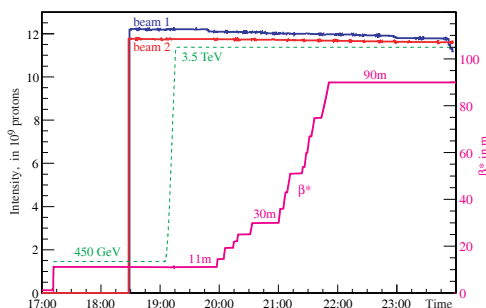


Figure 1: Beam intensities (blue, red), energy (green) and  $\beta^*$  (pink) as a function of time during the first un-squeeze.

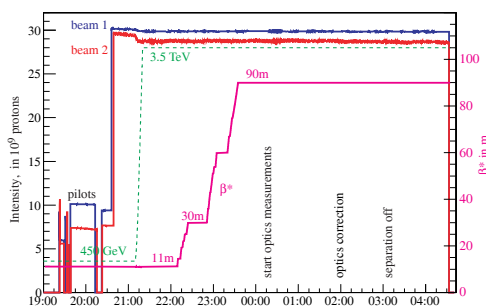


Figure 2: intensities, energy and  $\beta^*$  as a function of time during the second un-squeeze.

The time evolution of the orbit and tune trims during the first un-squeeze study are shown in Fig. 3.

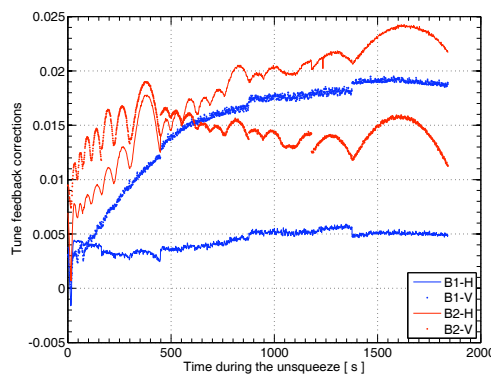


Figure 3: Evolution of orbit and tune trims with time. The tune evolution for beam 1 is rather flat which shows,

that the tune excursion between the un-squeeze steps was well predicted and corrected while these excursions are visible for beam 2 and compensated by tune feedback. The orbit and tune corrections found in the first un-squeeze were incorporated as correction for the second un-squeeze.

In the second study, beams were injected in the same buckets in beam 1 and beam 2 of the LHC to allow for collisions. This requires beam separation at the interaction points to avoid collisions during the injection and un-squeeze. The separation is provided by closed orbit bumps in the interactions regions which keep the beams transversely separated by at least  $\pm 5\sigma$ . The intensity in the second study was increased to  $3 \times 10^{10}$  protons.

## OPTICS MEASUREMENTS

Optics measurements are an important part of the commissioning for two different reasons : the first is to make sure the optics is overall sufficiently well known and corrected and the second to obtain a good knowledge of  $\beta^*$  and the optics parameters between the interaction point and the roman pot detectors of the experiments.

### $\beta$ Beating

This was measured at three steps : 11 m, 30 m and 90 m. The evolution of the  $\beta$ -beating is shown in Fig. 4.

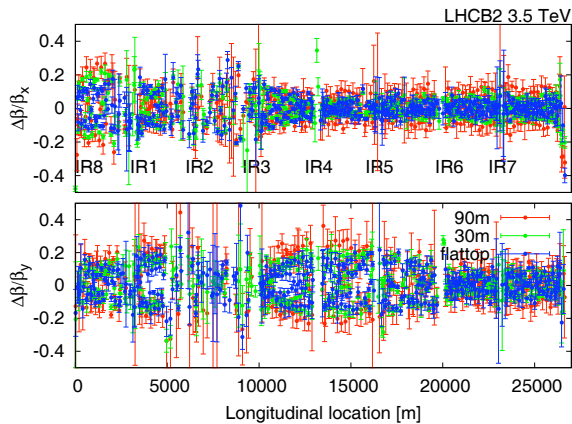


Figure 4: Evolution of the beta-beat during the un-squeeze for beam2

It shows that there is no major anomaly and that the un-squeeze behaves basically as expected. The peak value for  $\beta$  beat is 25% for beam1 in the horizontal plane and 20% in vertical plane. For beam2 the peak value is close to 30%.

### Coupling

The standard LHC tunes which are also used here are  $Q_x = 64.31$  and  $Q_y = 59.32$  which is close to the coupling resonance and requires a good tune and coupling control. The technique used to calculate the local corrections at IP1, IP2, IP5 and IP8 is called segment by segment technique and described in [3]. The local corrections applied on the quadrupoles are summarized in Table 1

Table 1: Summary of Local Corrections

Corrector	Strength(m)	Corrector	Strength(m)
kqsx3.l1	0.0008	kqsx3.l5	0.0006
kqsx3.r1	0.0008	kqsx3.r5	0.0006
kqsx3.l2	-0.0009	kqsx3.l8	-0.0007
kqsx3.r2	-0.0009	kqsx3.r8	-0.0007

Fig. 5 and Fig. 6 shows the coupling measurement at  $\beta^* = 90$  m after correction. Small remaining effects can still be seen at IP6 for beam 1 and at IP1 for beam 2.

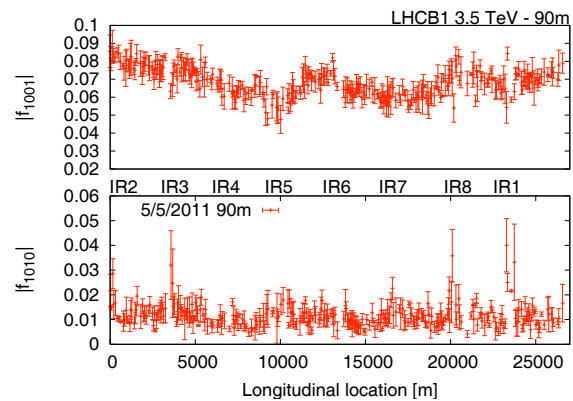


Figure 5: Measured coupling for Beam1 for  $\beta^* = 90$  m

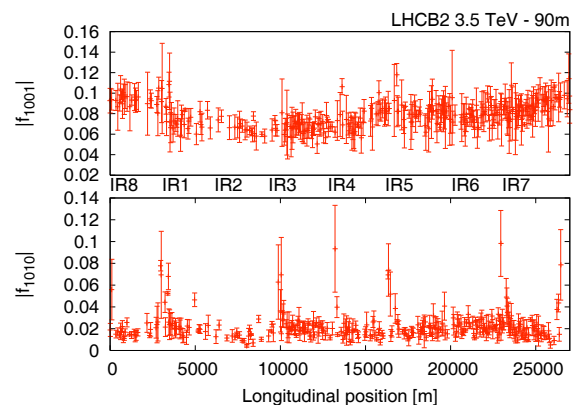


Figure 6: Measured coupling for beam 2 for  $\beta^* = 90$  m

### Dispersion

The technique to measure dispersion is to use a turn-by-turn data acquisition with an energy offset  $\frac{\Delta p}{p}(B_1) = -0.4076$  and  $\frac{\Delta p}{p}(B_2) = -0.394$ . Fig. 7 and Fig. 8 shows the difference between the measured and predicted dispersion for beam1 and beam2.

Then K-modulation [4] was used to calculate the  $\beta^*$  and the waist for both IPs.

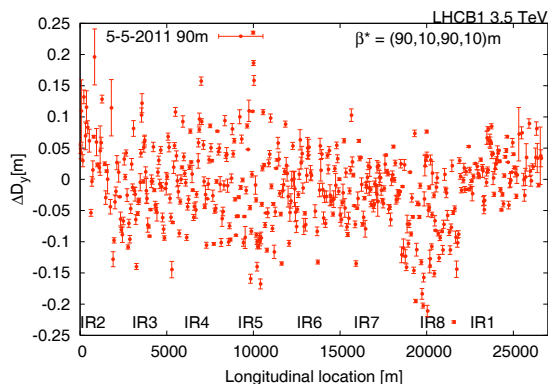


Figure 7: Difference between predicted and measured vertical dispersion function for Beam1.

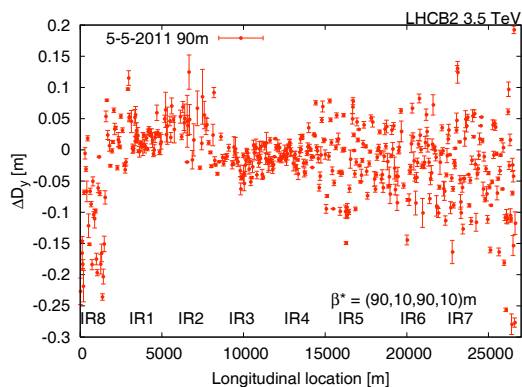


Figure 8: Difference between predicted and measured vertical dispersion function for Beam2.

*Emittance Measurement*

The measured emittances for beam 1 and beam 2 are summarized in Table 2.

Table 2: Measured Normalized Emittances for Beam 1 and Beam 2

	Beam 1	Beam 2
$\epsilon_{N,x}$ ( $\mu\text{m}$ )	2.6	3.0
$\epsilon_{N,y}$ ( $\mu\text{m}$ )	2.0	2.4

**SEPARATION BUMPS**

To separate the two LHC beams, three types of different corrector magnets are used : MCBC, MCBY and MCBX. The shape of these bumps is shown in Fig. 9.

The separation bumps were calculate to provide a constant parallel separation of  $\pm 2\text{mm}$  between beam1 and beam2 at IP1 and IP5. Since the optics changes during the un-squeeze and since IP1 and IP5 generally use separation in opposite planes, this required the separated calculation of separation bumps for every step separately for IP1 and IP5.

01 Circular Colliders

A01 Hadron Colliders

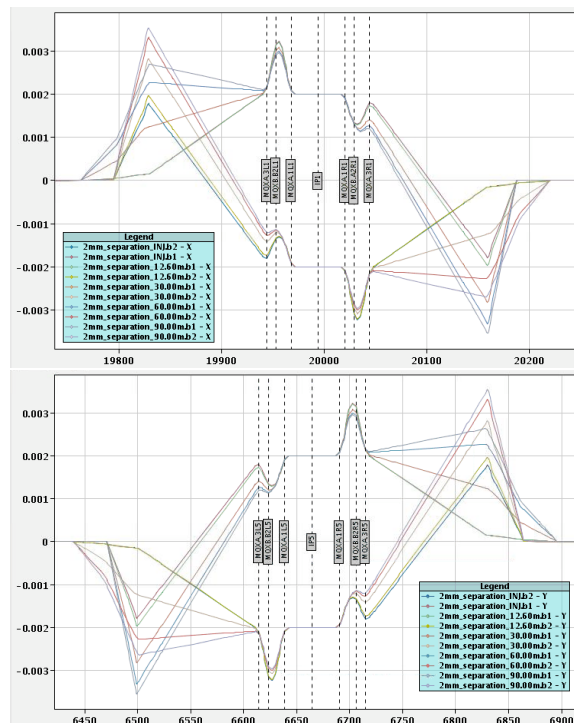


Figure 9: Calculated parallel separation bumps from  $\beta^* = 11\text{ m}$  to  $90\text{ m}$ . The horizontal separation in IP1 is shown in the upper figure and the vertical separation in IP5 in the lower figure.

**ACKNOWLEDGMENT**

Thanks to M. Deile et al. for TOTEM and to P. Fassnacht, K.H. Hiller et al. for ATLAS-ALFA.

**CONCLUSION**

The commissioning of the  $90\text{ m}$   $\beta^*$  optics went very well. Beams were un-squeezed without any significant losses and first collisions could already be provided to the experiments at the end of the second study with beams. The experience gained with the  $90\text{ m}$  commissioning is essential both for the machine to see how these optics can be efficiently implemented in the LHC as well as for the experiments to provide for first very forward proton-proton scattering data at LHC energies.

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