HIGH-BETA OPTICS

H. Burkhardt, CERN, Geneva, Switzerland

Abstract

High-beta optics are essential for the LHC forward physics program which includes the total proton-proton cross-section measurement, and which can be expected to ultimately allow for the most precise absolute luminosity calibration at the LHC. The strategy to commission the intermediate 90 m optics is discussed, as well as a possible running scenario for this year and requirements of the knowledge of beam parameters.

INTRODUCTION

Special high-β optics and dedicated running time are required for the forward physics program of TOTEM and ATLAS-ALFA [1, 2]. The status and prospects of these experiments have been discussed earlier in this workshop [3, 4].

We will concentrate here on the optics and commissioning aspects of this part of the LHC physics program.

The LHC interactions regions have been designed with low-β^* insertions to allow squeezing the beams to small beam sizes ($\sigma = \sqrt{\beta^* \epsilon}$, where ϵ is the beam emittance) at the interaction points (IPs) for maximum luminosity and interaction rates.

High-β^* optics are required to minimize the beam-divergence $\sqrt{\epsilon/\beta^*}$ at the interaction point for measurements at small scattering angles. Challenges of high-β^* optics include

- large tune changes compared to the normal optics implying global optics changes
- additional constraints between the IPs and roman-pots
- aperture limitations at very high-β^*
- need for precision and stability of optics parameters
- operation of some insertion quadrupoles and power converters at their limits

The effect on the tunes of the squeeze and un-squeeze can be understood by general optics considerations. The betatron phase advance is

$$\mu(s) = \int_0^s \frac{1}{\beta(s')}\, \mathrm{d}s' . \qquad (1)$$

We recall that the phase advance μ and tune are directly related by $Q = \mu(C)/\,2\pi$, (where C stands for the circumference).

The β-function in a drift space where s_0 is the position of the interaction point is given by

$$\beta(s) = \beta^* + \frac{(s - s_0)^2}{\beta^*} . \qquad (2)$$

The phase advance and tune contribution from the insertion can be obtained analytically by integration from -ℓ to +ℓ. The result is

$$\mu = 2 \arctan\left(\frac{\ell}{\beta^*}\right) . \qquad (3)$$

This agrees well with the phase advanced obtained from MAD-X for $\ell = 26.15\,\mathrm{m}$, which is the distance between the IP and the centre of the first quadrupoles (Q1). A low-β insertion with $\beta^* \ll \ell$ contributes with a phase advance of π and tune of 0.5. For very high $\beta^* \gg \ell$ instead, the phase advance and tune contribution drops to zero.

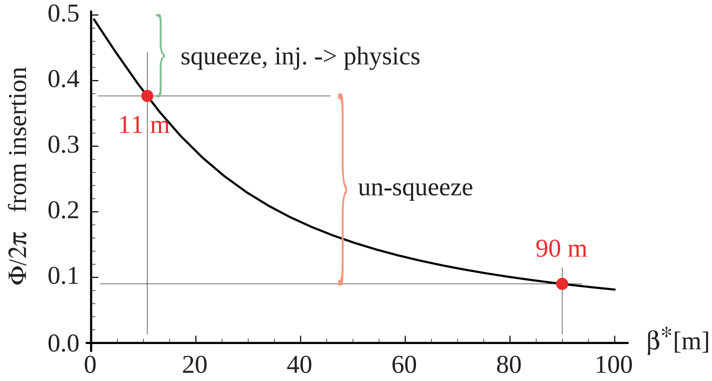

Figure 1: Tune contribution from the insertion $\pm 26\,\mathrm{m}$ from the IP as relevant for the LHC.

This is illustrated in Fig.1. We see that the local tune change from the IR for the squeeze from 11 m to 0.55 m is approximately +0.1 and about -0.3 for the un-squeeze from 11 m to 90 m. The tune changes in the un-squeeze are too large to be fully compensated internally.

The 90 m optics for TOTEM is shown in Fig. 2. It provides a phase advance between the IP and the roman pot at 220 m of π in the horizontal and of $\pi/2$ in the vertical plane.

A similar optics for ATLAS-ALFA is currently being prepared together with S. Cavalier for a phase advance of $\pi/2$ in the vertical plan to the roman pots, which in the case of ATLAS-ALFA are located at 240 m downstream from the IP.

The aperture for the 90 m optics is not critical, see Fig. 3.

STRATEGY

The top priority for LHC operation in 2011 is to maximize the total integrated luminosity.

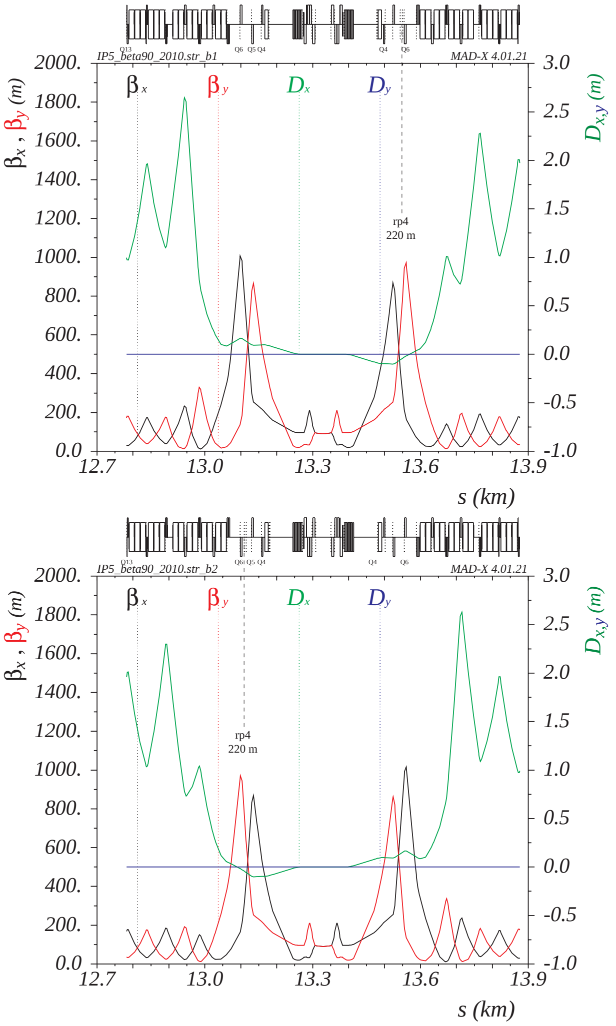

Figure 2: 90 m TOTEM optics, compatible with all known constraints of the nominal LHC. Up for Beam 1 and down for Beam 2.

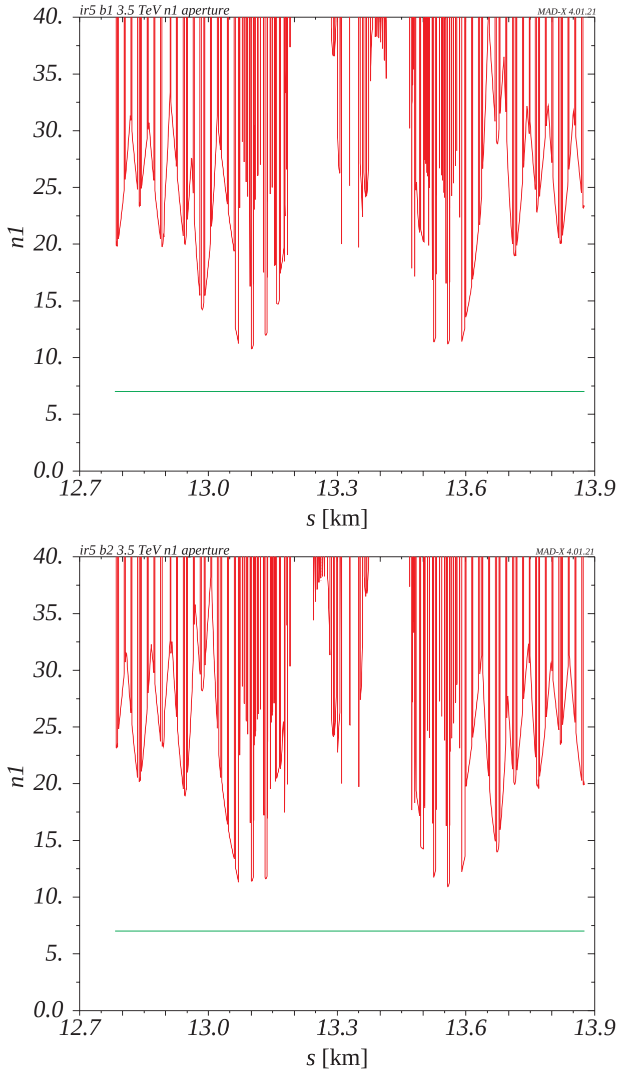

Figure 3: Aperture in terms of n1 at 90 m with vertical separation of ±2 mm at 3.5 TeV, for $\epsilon_N = 3.75\,\mu$m. Up for Beam 1, down for Beam 2.

Here we will argue, that it will be very important to nevertheless spend some shifts in 2011 to commission the 90 m optics for IP1&5 and to allow for some days of physics operation in 2011. In addition to physics arguments, this will provide essential input for the "real" high-β optics, which can only be realized later. Further delaying high-β operation may interfere with LHC upgrade plans and the reduction of the beam-pipe radii at the IPs.

As discussed in [5], the very high-β^* (≫90 m) optics were designed for the full LHC beam energy of 7 TeV and a reduced emittance of $\epsilon_N = 1\,\mu$m.

The $\beta^* = 1535$ m TOTEM optics requires additional cables to be installed [6].

The $\beta^* = 2625$ m ATLAS-ALFA optics was designed for an inverted Q4 polarity (the hardware to allow the switching is installed) and requires dedicated injection at $\beta^* = 200$ m and a dedicated ramp and un-squeeze.

Experience with the 90 m optics will be important to determine which cables should be added for TOTEM, and to develop a realistic and effective strategy to get to very high-β^* in later years : using un-squeeze starting from the standard ramp or by dedicated injection, ramp and squeeze.

STUDIES AND COMMISSIONING PROPOSED FOR 2011

The first step proposed for a machine development shift, is to study the feasibility of an un-squeeze to 90 m with external tune compensation. It is planned to use the standard injection and ramp optics with ($\beta = 11$ m at IP 1 and 5) for this purpose. The crossing angles in IP1&5 have to be off for the un-squeeze and at 90 m. Seventeen intermediate optics files have been prepared to allow for a very smooth un-squeeze from 11 to 90 m. The files have been matched with knobs to allow for a constant ±2 mm parallel separation through the un-squeeze.

The main difference compared to the squeeze to low-β

is the need for a significant external tune compensation of 0.22 in the horizontal and 0.05 in the vertical plane. Details are described in [5].

Three alternatives have been considered for the external tune compensation

- use another IP like IP4 (with consequences on instrumentation and the damper); limited to changes of 0.2 in tune [7]
- use the trim quadrupoles, implies some β-beating (8.5% in x and 4.5% in y)
- use the main arc quadrupoles, implies small β-beating (4.5% in x and 1.5% in y)

To save time, we will try to test and commission the 90 m TOTEM and ATLAS-ALFA optics simultaneously. This doubles the need for external tune compensation. For the large tune compensation required, the most attractive alternative is to ramp up the arc quadrupoles during the unsqueeze for tune compensation. An initial eight hours shift to study this will be requested for the first machine development period in 2011.

PHYSICS OPERATION AND REQUIRED ACCURACY

Depending on the progress in the initial machine study, further machine development studies or commissioning time will be needed to get the 90 m optics ready for physics operation in the second part of 2011.

A good knowledge and stability of the beam parameters is important for physics operation at high β^*. Following discussions with H. Niewiadomski et al. from TOTEM for the required accuracy at 90 m, we should aim for a 1% precision in the knowledge of β-functions and phase advances between the IP and the roman pots and also for a knowledge of the dispersion at the roman pots to the 1% level. Following discussions with R. Tomas, high-β^* should be easier to measure than low-β^* and a precision around 1% may become feasible with dedicated measurements at $\beta^* = 90\,\mathrm{m}$.

It is very likely that several iterations will be required to reach a good precision.

For the physics operation at 90 m in 2011, we are talking about few days or fills : TOTEM requests four fills of each eight hours [3]. The schedule should allow for some days between 90 m physics fills for checks, validation and optimization.

ACKNOWLEDGMENT

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