STUDY OF HIGH BETA OPTICS SOLUTION FOR TOTEM

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Abstract

The TOTEM experiment requires special high beta optics solutions. We report on studies of optics for an intermediate $\beta^* = 90\,\mathrm{m}$, as well as a solutions for a very high β^* of 1535 m, which respect all known constraints. These optics are rather different from the normal physics optics and will require global tune changes or adjustments.

INTRODUCTION

The TOTEM experiment shares one of the LHC interaction points (IP5) with the CMS detector. TOTEM has special detectors called roman pots (RP) close to the beam pipe downstream from the interaction point. They will allow to measure the total proton proton cross-section at the LHC in a luminosity-independent way and to study elastic and diffractive scattering [1]. On the machine side, this will require special optics solutions, which are optimized for small beam divergence and correspondingly high β^* at the interaction point as well as special phase advances $(\pi/2, \pi)$ between the interaction point and the roman pot detectors of TOTEM.

Here we report on the more recent intermediate $90\,\mathrm{m}$ optics and on recent efforts to re-match the very high $\beta^* = 1535\,\mathrm{m}$ optics to respect additional constraints.

The strengths of the quadrupoles in the insertions can be individually adjusted. It was always known and taken into account that the strength of each of the quadrupoles will have to remain between the specified minimum and maximum limits. Depending on the quadrupole type, the maximum strength corresponds to 130 - 220 T/m. Restrictions in the cabling introduced later currently require that the currents used to drive any of the quadrupoles Q4 - Q10 in the insertions do not differ by more than a factor of 2 between beam 1 and beam 2 [2]. In the normal approximately anti-symmetric physics optics this is always the case.

90 M OPTICS

For the earlier LHC operation, TOTEM requests an optics at the intermediate β^* of $90\,\mathrm{m}$ [3] with a phase advance of π in x and $\pi/2$ in y between the IP and the RP 220 m further downstream. Fig. 1 shows the 90 m optics solution, as developed and presented to the CERN experiments committee in 2007 [4].

A general feature of the high β^* optics compared to our normal injection and physics optics is a reduction in phase advance around the IP by nearly π which corresponds to 0.5 in tune [5]. Since the roman pot phase advance constraints are only required on the downstream side, we have

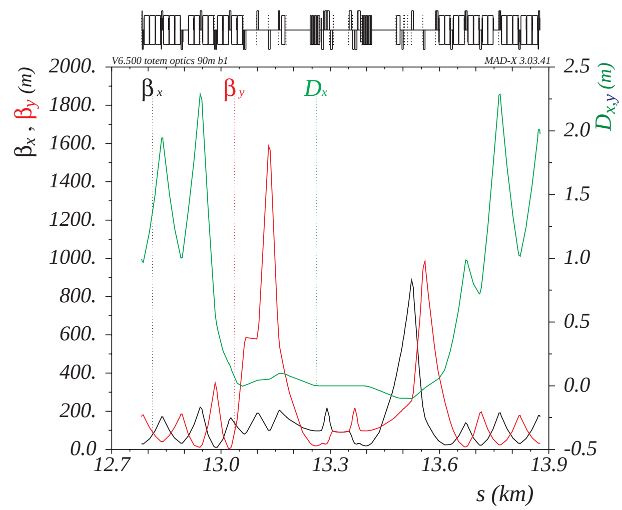

Figure 1: 90 m TOTEM optics designed in 2007. Shown is beam 1.

some flexibility to use the other (upstream) side to compensate the loss in tune. Any remaining tune compensation will have to be done elsewhere in the machine, see [6]. The optics shown in Fig.1 requires an external tune compensation of about 0.1 in the horizontal and 0.03 in the vertical plane.

We succeeded to match transition optics between our usual optics and 90 m using a sequence of small incremental strength changes [4]. This makes us confident that it will be possible to commission a smooth un-squeeze of the IP5 insertion optics starting at $\beta^* = 11\,\mathrm{m}$ as used at injection throughout the ramp to $90\,\mathrm{m}$.

We have recently rematched the 90 m optics to respect the additional limitation on the strength ratio r between beam 1 and beam 2 of $0.5 < \mathrm{r} < 2$. The result is shown in Fig. 2. Beam 2 has the same phase requirements at the roman pots but travels in the opposite direction. Looking from the center of the LHC, we have a roman pot constraint on the right hand side of IP5 for beam 1 and on the left hand side for beam 2. With the extra ratio limit, we loose in flexibility for internal tune compensation. To keep the overall tunes constant, we now require an increase for 0.2 in the horizontal and 0.045 in the vertical plane, still well within the tuning range discussed in [6]. We are confident that it will still be possible to use the normal injection and ramp followed by an un-squeeze to arrive at 90 m. At present, it is hard to judge how difficult this would be operationally and how much commissioning time would be required for the 90 m optics. A lot more will be known after first tests in the LHC to un-squeeze beams. We propose that these tests

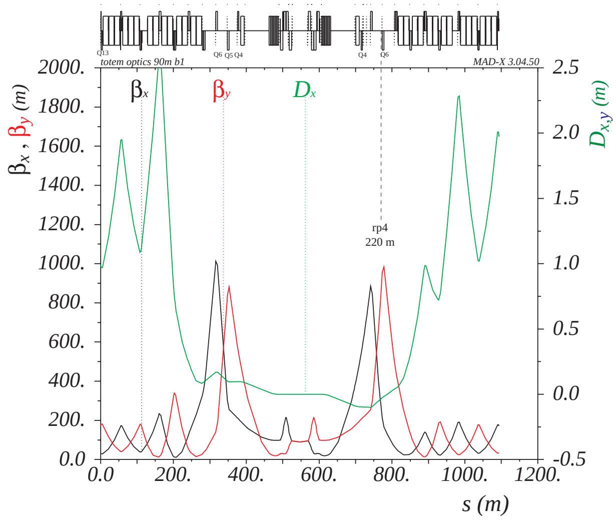

Figure 2: 90 m TOTEM optics compatible with all known constraints. Shown is beam 1.

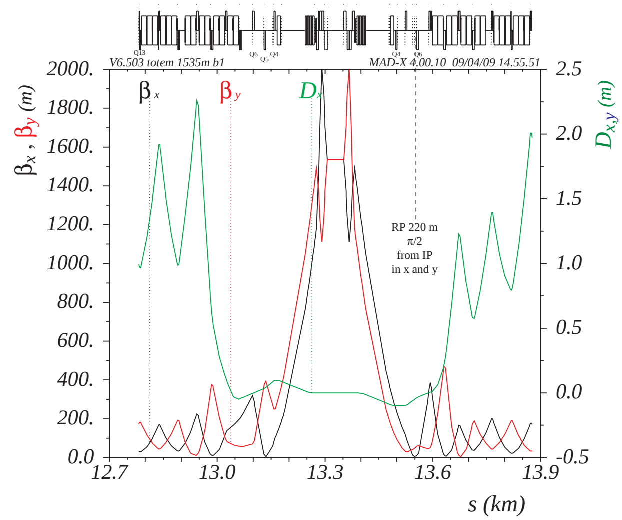

Figure 3: Beam 1 optics of the baseline solution.

will be scheduled soon after the squeeze commissioning.

VERY HIGH BETA OPTICS

The very high-β^* optics for the TOTEM experiment was developed several years ago. Operation with this optics will be used to measure the rate of forward elastic scattering at very low angle. To minimize uncertainties from optics on the measurements, a special parallel to point focusing optics with $\pi/2$ phase advance between the IP and the detector (roman pot) in both planes is required. Our study is based on the high β^* optics solution for TOTEM as documented in 2005 in [7]. We briefly review some main features of this optics and then discuss modifications required by the additional beam 1 / beam 2 ratio constraint.

Baseline Solution

As a baseline we start from the optics presented in [7]. It has a β^* of 1535 m and phase advances of $\mu_x = 0.956 \times \pi/2$ and $\mu_y = \pi/2$ between the IP and the roman pot 220 m downstream of the IP.

The optics parameters of this solution are shown in Figure 3 for beam 1. The roman pot is situated for beam 1 on the right hand side of the IP. The left side is used for partial tune compensation. The baseline solution requires an external tune compensation of ΔQ of ≈ 0.5 in the vertical plane to keep the overall tunes at their standard physics values. The later introduced strength ratio constraint is not compatible with the previously approved $\beta^* = 1535$ m optics. The latter would not be feasible in the LHC as currently installed. The ratio constraint can in principle be removed by adding extra cables [2]. The quadrupoles which are outside the beam 1 / beam 2 strength ratio constraint are listed Table 1.

This baseline solution has the Q4 magnet at the roman pot switched off. This cannot be done dynamically after injection. The minimum strength required with the magnet switched on corresponds to 3% of the maximum strength. This solution therefore requires a special injection and ramp with Q4 already turned off. Even in this case, the constraint from the electrical powering topology imposes that a zero field strength cannot be guaranteed.

Table 1: Beam 1 / Beam 2 Strength Ratios Outside Limits

Magnet	left side of IP5	right side
Q4	0	1/0
Q7	26	1/30
Q8	2.1	1/2.1

Alternative Solution

From the earlier studies, it was already known, that solutions exist in which the polarity of Q4 on both sides of the IP is inverted. This is in fact planned for the ATLAS high-β^* optics [5]. With the inverted Q4 polarity in IP5, it will be possible to respect all known constraints for TOTEM.

Figure 4 shows the optics solution found when the Q4 polarity is inverted. This solution has a β^* of 1535 m and the phase advance from the IP to the roman pot is exactly $\pi/2$ in both planes. The tune contributions from the IP5 insertion are $Q_x = 2.49$ and $Q_y = 2.54$ in this case. This is not too far from the nominal values in standard physics ($Q_x = 2.633, Q_y = 2.649$ in LHC optics verion V6.503) and requires external adjustments of less than 0.15 which are well within the range considered in [6].

The inversion of the Q4 polarity makes this optics incompatible with the normal injection and ramp. A special injection and ramp with inverted Q4 polarity is required.

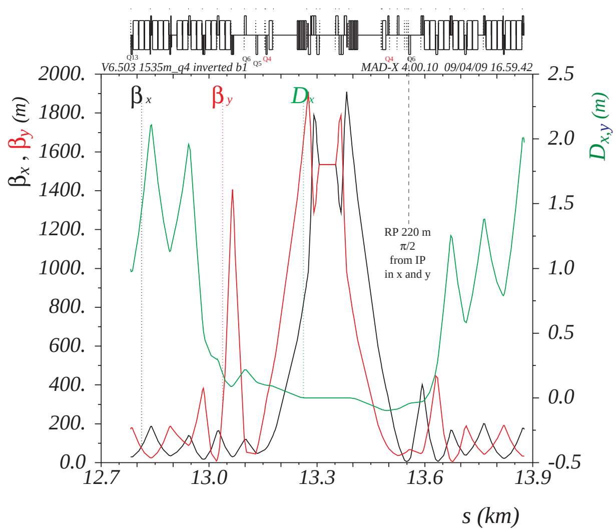

Figure 4: Beam 1 optics solution with inverted Q4 polarity.

Discussion

Inversion of the Q4 polarity by hardware intervention (swapping cables) or remote control if extra switches are installed appears to be a valid alternative.

The installation of extra cables on the Q4-Q10 quadrupoles would allow to remove the constraints on the strength ratios and make the baseline optics feasible as originally planned. Compared to the Q4 polarity switch, this would provide more flexibility. It allows for optics solutions with β^* above 90 m which could potentially be reached by un-squeeze from the normal physics optics without the need for extra injection and ramp.

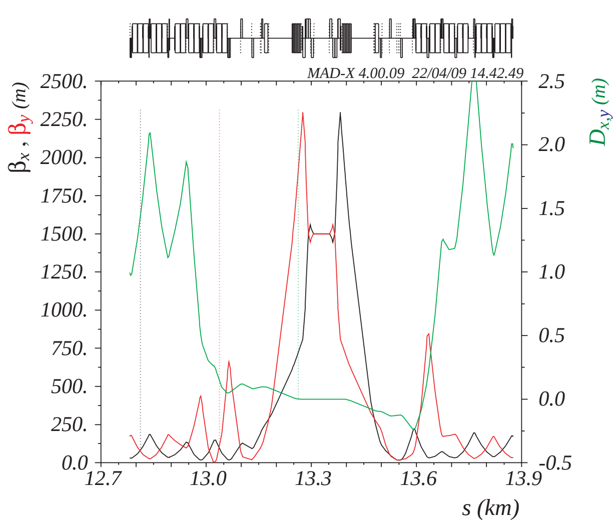

Figure 5: Beam 1 optics solution with Q4 powered and no strength ratio constraint.

Fig. 5 shows an example of an optics which would become accessible with extra cables. For this solution we have left Q4 on. This will imply some loss in aperture but has the major advantage of making this optics potentially reachable by an un-squeeze from the normal injection and ramp. The optics has β^* of 1500 m and $\pi/2$ phase advance to the roman pots in the two planes. The tune compensation is between 0.3 and 0.4 in both planes.

SUMMARY

We present a review of high-β^* optics solutions for TOTEM in the light of all currently known constraints. Solutions for the 90 m optics required for initial TOTEM operation exist for the LHC as presently installed.

We discuss solutions for the very high-β^* TOTEM optics. We present a solution in which the Q4 polarity is inverted which is compatible with all known constraints.

More flexibility would be reached by adding few extra cables to the insertion quadrupoles. In particular, this could potentially allow to reach high-β^* by an un-squeeze based on the standard injection and ramp.

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