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OVERALL OPTICS SOLUTIONS FOR VERY HIGH BETA IN ATLAS

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Abstract

An insertion optics with a β^* of at least 2600m has been requested by the ATLAS experiment at the LHC. This is very far from the standard LHC physics optics and implies a significant reduction in the phase advance from this insertion corresponding to about half a unit in tune. We describe several alternatives how this could be integrated in overall LHC optics solutions with the possibility to inject, ramp and un-squeeze to the required very high-β^*.

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Abstract

An insertion optics with a β^* of at least 2600 m has been requested by the ATLAS experiment at the LHC. This is very far from the standard LHC physics optics and implies a significant reduction in the phase advance from this insertion corresponding to about half a unit in tune. We describe several alternatives how this could be integrated in overall LHC optics solutions with the possibility to inject, ramp and un-squeeze to the required very high-β^*.

INTRODUCTION

The luminosity can be defined as the ratio of the collision rate $\dot{N}$ and the cross section σ for a given process:

$$\mathcal{L} = \frac{\dot{N}}{\sigma} \tag{1}$$

One of the methods to determine the absolute luminosity is to measure the rate of elastic scattering at very small angles [1]. For a scattering angle extrapolated to zero the optical theorem states that the total cross section is proportional to the imaginary part of the forward elastic scattering amplitude.

The most suitable configuration in terms of optics is the so called parallel-to-point optics. This kind of optics requires a phase advance of $\frac{\pi}{2}$ between the interaction point and the detector (Roman pot) and a very small intrinsic divergence at the interaction point. This leads to several constraints concerning the beam properties that can be summarized as follows:

- $\beta^* > 2600$ m, $\beta_d > 70$ m, $\alpha^* \approx 0$, negligible dispersion.
- $\frac{\pi}{2}$ phase advance between the interaction point and the Roman pot.
- ε_N=1 µmrad.

These requirements were given by the experiment and will be rather challenging to achieve during LHC operation. All the following studies were made assuming that they will be fullfilled.

EFFECT OF THE HIGH-BETA* ON THE TUNE

The LHC nominal overall tunes are $Q_x = 64.31$ and $Q_y = 59.32$ at top energy and $Q_x = 64.28$ and $Q_y = 59.31$ at injection. A high-β^* insertion optics can affect these global tunes in a non negligible way. The β-function in a drift space where s_0 is the position of the interation point is given by:

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

and the phase advance:

$$\mu(s) = \int \frac{1}{\beta(s)}\,\mathrm{d}s. \tag{3}$$

Integrating around the minimum from -ℓ to +ℓ (Q1L to Q1R) with the condition $\beta^* \gg \ell$ we get:

$$\mu(s) = 2 * \arctan\left(\frac{\ell}{\beta^*}\right). \tag{4}$$

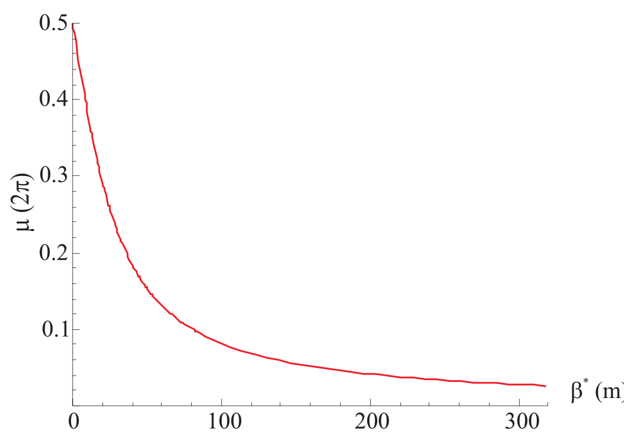

Figure 1: Influence of β^* on the tune.

We can easily see on Fig. 1 that the contribution in tune for a low-β insertion will approximately be 0.5 while for a high-β insertion it is close to 0. Therefore a high-β insertion will be contributing for approximately half an integer less in tune than a low-β insertion. In the case of Atlas the constraint over the phase advance only applies in the vertical plane and it was possible to recover the loss in the horizontal plane with a local matching. The loss in tune due to the Atlas high-β insertion is therefore only in the vertical plane and we get the following contributions from this insertion:

$$\mu_x = 2.633,\ \mu_y = 2.149, \tag{5}$$

which gives for the overall LHC tunes:

$$Q_x = 64.31,\ Q_y = 58.82, \tag{6}$$

* Work supported by CERN

A complementary study on tune compensation [2] for the high-β optics has been done for IR8 and IR2. This study showed that it would be possible to compensate for the half integer lost in the vertical plane with either of these insertions. Using those results we would keep the nominal physics and injection overall tunes while running the LHC with the Atlas high-β optics.

OPTICS FOR PHYSICS

Starting from a good existing baseline solution [3] with $\beta^* = 2625$ m it was possible to produce new optics for both beams keeping the same β^* value and a phase advance of $\frac{\pi}{2}$ in the vertical plane between the interaction point and the Roman pot. In this case the Roman pots are situated 239.6 m away from the interaction point. The optical functions for beam 1 are shown Fig. 2 and the matching results are summarized in Table 1.

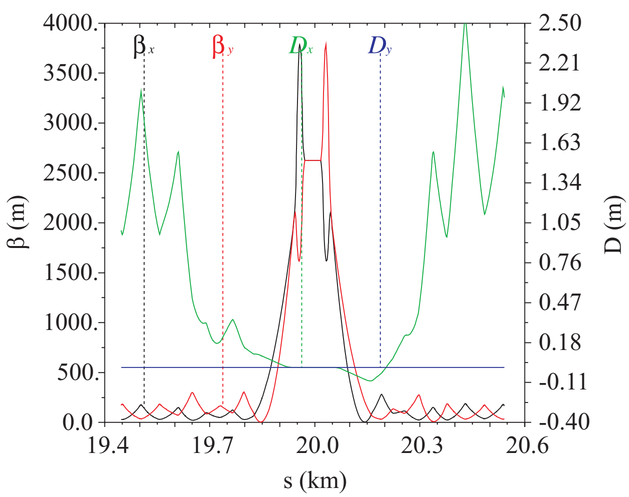

Figure 2: Beam 1 Optical functions for $\beta^* = 2625$ m.

Table 1: Results after matching

	Beam1	Beam2
	At the Interaction Point	
β^*(m)	2625	2625
α^*	0	0
D_x	0	0
D_y	0	0
	At the Roman Pot	
β_x(m)	96.5	92.3
β_y(m)	120.2	123.4
$\Delta\mu_x(2\pi)$	0.538	0.539
$\Delta\mu_y(2\pi)$	0.25	0.25

The constraints given by the power converters are:

- Quadrupole stength within 3% and 100% of the nominal value,
- From Q4 to Q10 the three-lead powering scheme imposes for the excitating current to fullfill the constraint $\frac{1}{2} * I_{\text{Beam2}} < I_{\text{Beam2}} < 2 * I_{\text{Beam2}}$.

In order to stay within all those constraints the polarity of Q4 on the upstream and downstream part of the insertion had to be reversed. Trying to keep Q4 at the standard polarity either forces the other quadrupoles to go over the strength limit [3] or makes it very difficult to respect the three lead connections constraint.

Aperture

The LHC specification in terms of aperture is $n1 = 7\sigma$ [4]. This limit has been set for LHC nominal beam conditions but for the high-β operation we have a small number of bunches (43-156) and a low intensity (10^{10} protons per bunch). These special conditions might give us a little more freedom in terms of aperture. Looking at the $n1$ function over the insertion we can see that the aperture constraints are respected for the required normalized emittance of 1.0 µmrad. The 7σ criteria is respected for a value of the normalized emittance up to 1.13 µmrad.

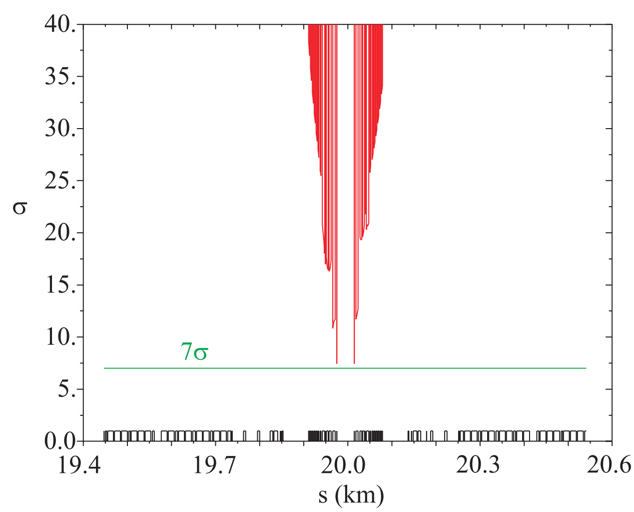

Figure 3: $n1$ function with 1.0 µmrad emittance.

Tune

The constraint on the phase advance in the vertical plane reduces the possibilities for tune adjustements. The maximum tuning ranges in the horizontal and vertical planes are $\Delta\mu_x \approx 0.3$ and $\Delta\mu_y \approx 0.07$.

In order to be able to make some adjustements on other parameters we should be situated close to the center of the tuning diagram. Fig. 4 shows that for this optics it will then be very hard to recover the nominal tune compensations ($\mu_x = 2.663$, $\mu_y = 2.149$) with just a local matching of the insertion and it will probably be necessary to compensate the small $\Delta\mu$ left with another insertion.

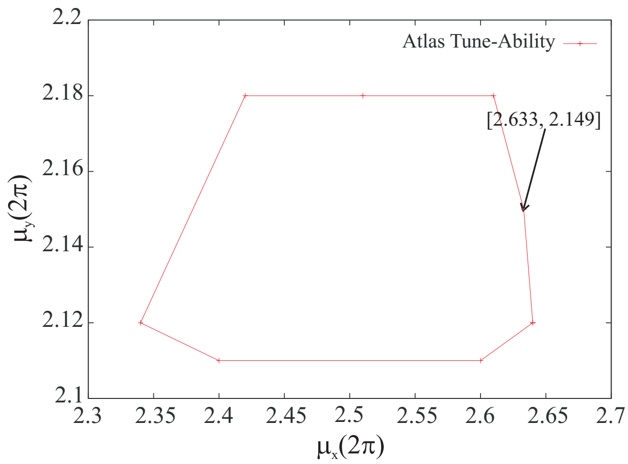

Figure 4: Tuning diagram for the Atlas high-β optics.

OPTICS FOR INJECTION

In order to respect the aperture and hardware constraints while keeping the polarity of Q4 inverted and assuming that we have the emittance of 1.0 µmrad required for the high-β experiments we had to increase β^* compared to the nominal LHC injection optics. A solution matching the nominal LHC tunes over IR1 has been found with $\beta^* = 180$ m.

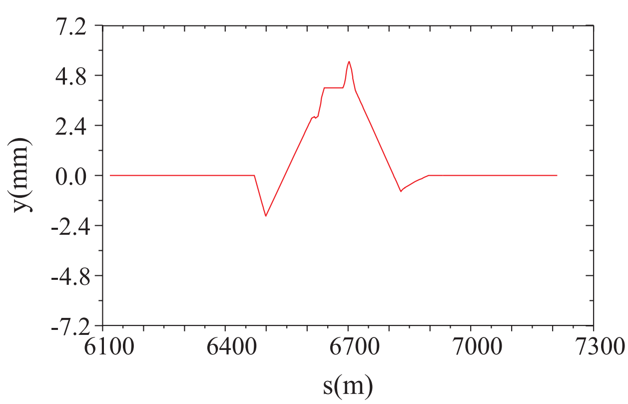

Figure 5: Parallel separation $\beta^* = 180$ m.

Fig. 5 shows the orbit with a parallel separation of 7σ which corresponds to 4.2 mm for an emittance of 1.0 µmrad. On Fig. 6 we can see a peak in Q6L where the minimum $n1$ is situated and equal to 7.14σ. Being so close to the specification leaves no margin concerning the emittance. In order to get this separation of 7σ with $\beta^* = 180$ m the strength in the separation magnets are the ones shown in Table 2.

We are well under the maximum value of the strength in the separation magnets without using the MCBX that are common for both beams. These optics will then be compatible with the strength limit at 7 TeV and would not require to change the optics during the ramp.We recall that all those results rely on an emittance of 1.0 µmrad and are not compatible with an emittance of 3.75 µmrad.

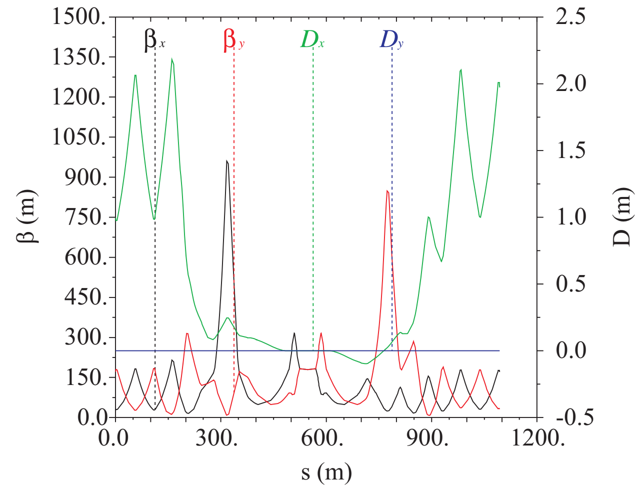

Figure 6: Beam 1 Optical functions at injection for $\beta^* = 180$ m.

Table 2: Strength in the separation magnets at 450 GeV

	k	kmax	%kmax
acbcv5.l5b1	−7.200E-05	1.865E-03	3.8%
acbyvs4.l5b1	1.013E-04	1.799E-03	5.6%
acbyvs4.r5b1	6.837E-05	1.799E-03	3.8%
acbcv6.r5b1	−9.844E-06	1.865E-03	0.5%
acbxv1.l5	0	1.042E-03	
acbxv1.r5	0	1.042E-03	

CONCLUSION

We studied alternative solutions for the Atlas high-β experiment. A change of Q4 polarity at top energy compared to the standard LHC optics case is required. A consistent solution for both injection and top energy with Q4 inverted which satisfies all requirements is described. It requires small emittances at injection. The tunes can be kept at their standard values by tune compensation in other interaction regions.

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