90 m β* OPTICS FOR ATLAS/ALFA

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Abstract

We describe a high β^* optics developed for the ATLAS detector at the LHC interaction point IP1. Roman Pots have been installed 240 m left and right of IP1 to allow to measure the absolute luminosity and the total elastic cross section for ATLAS with ALFA (Absolute Luminosity for ATLAS). Ultimately, it is planned to perform these measurements at a very high β^* of 2625 m. Here we describe a new, intermediate β^* = 90 m optics, which has been optimized for compatibility with the present LHC running conditions. We describe the main features and the expected performance of this optics for ALFA.

INTRODUCTION

ALFA (Absolute Luminosity For ATLAS) aims to measure absolute luminosity and total cross section for the ATLAS experiment located at IP1. For this purpose, 8 Roman Pots have been placed on both sides of the LHC ring, for beam 1 on one side and for beam 2 on the other side, at 240 m from the interaction point 1 (IP1) of the LHC. These Roman Pots (RPs) use scintillating fibers for particle detection and should allow to detect elastic proton scattering down to very low momentum transfer t of about $-6.5\times10^{-4}\,\mathrm{GeV}^2$.

To reach this low value of t, the ATLAS/ALFA detectors require special very high beta optics. For the design beam energy of the LHC of 7 TeV, an optic with a β^* of 2625 m [1] was designed for this purpose. The measurement can only be achieved with a good precision, if the beam divergence $\sigma' = \sqrt{\epsilon/\beta^*}$ remains small compared to the scattering angle of, in this case, 3.5 μrad. The roman pot detectors will have to operate very close to the beam, at a small number of σ's, were σ stands for the r.m.s. beam size.

Table 1: 2625 m optics parameters for beam 1, at 7 TeV beam energy and for an emittance of $\epsilon_N = 1\,\mu$m. D is the dispersion and σ' the beam divergence.

LHC version V6.503

IP1		RPs	
ϵ_n (μm)	1.0	β_x (m)	95.2-97.9
β_x^* (m)	2625	β_y (m)	123.9-117.1
β_y^* (m)	2625	σ_x (μm)	113-114
α_x^*	0.0	σ_y (μm)	129-125
D_y^* (m)	0.0	σ_x' (μrad)	1.19-1.17
$D_y^{*'}$	0.0	σ_y' (μrad)	1.04-1.07
σ^* (mm)	0.593	$\Delta\mu_x$ (2π)	0.534-0.541
$\sigma^{*'}$ (μrad)	0.226	$\Delta\mu_y$ (2π)	0.247-0.252

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The optics parameters are summarized in Table 1. The 2625 m optics also require a normalized emittance close to 1 μm which is 2 times smaller than currently achieved and an inversion of the polarity of the Q4 magnet which is not compatible with the present LHC operation.

The intermediate $\beta^* = 90$ m optics described here was developed to allow to study how higher β^* values can be reached in the LHC in conditions which are not too far from standard operation and at the same time to allow for first physics measurements in the very forward region.

ATLAS/ALFA 90 M β^* OPTIC DESCRIPTION

The 90 m β^* optics has been described in [2] and [3]. The main parameters useful for ATLAS/ALFA are the following:

Table 2: 90 m Optics Parameters for Beam 1. LHC optics V6.503

LHC version V6.503

IP1		RPs	
ϵ_n (μm)	3.75	β_x (m)	193.5-124.2
β_x^* (m)	90	β_y (m)	857.5-780.4
β_y^* (m)	90	σ_x (μm)	374-353
α_x^*	0.0	σ_y (μm)	926-883
D_y^* (m)	0.0	σ_x' (μrad)	2.67-2.83
$D_y^{*'}$	0.0	σ_y' (μrad)	1.08-1.13
σ^* (mm)	0.3	$\Delta\mu_x$ (2π)	0.515-0.519
$\sigma^{*'}$ (μrad)	3.33	$\Delta\mu_y$ (2π)	0.249-0.250

As can be seen on Table 2, the main parameters used in the 2625 m β^* optics have been kept in the 90 m β^* optic. In particular, the phase advance between the IP and the RPs is equal to 90 $^\circ$ and the dispersion is equal to zero.

The general scheme aims at focussing the particles with the same angle at the same position in the detectors. The y-position in the roman pots is directly related to the scattering angle θ_y^* at the IP by

$$y = \sqrt{\beta_y \beta_y^*}\,\theta_y^*\,, \qquad (1)$$

where β_y is the vertical β-function at the roman pot. Using the relation, the scattering angle at the IP is measured as vertical position at the Roman pot detector.

The 90 m β^* optics described here and shown in Figs. 1 and 2 was designed to be similar to the 90 m optics developed for the TOTEM experiment installed at IP5 to allow for an efficient commissioning and operation of both optics in parallel. As TOTEM Roman Pots are located at 220 m instead of 240 m for ATLAS/ALFA, a rematch to obtain the $\pi/2$ phase advance was required. The initial IP5 quadrupole strengths have been used as start values for the rematch for IP1.

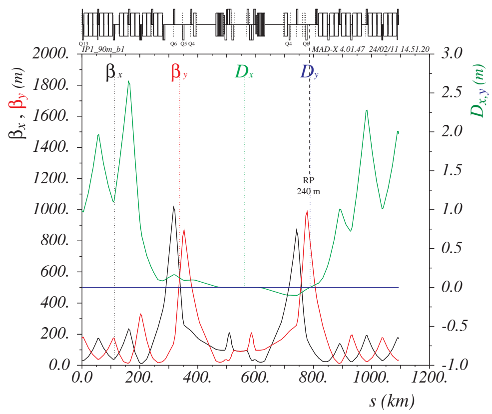

Figure 1: 90 m ATLAS/ALFA optics for beam 1.

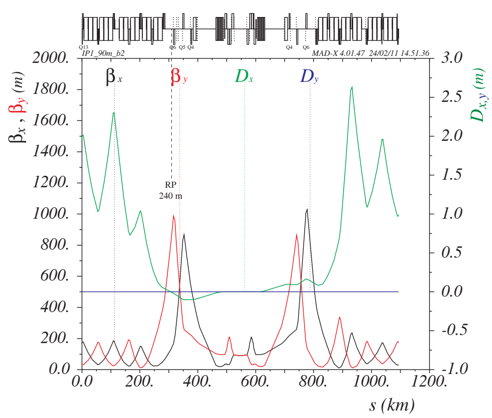

Figure 2: 90 m ATLAS/ALFA optics for beam 2.

This optics is reached by an un-squeeze from $\beta^* = 11$ m. used at injection and throughout the energy ramp, in 17 steps by strength interpolation between 17 intermediate optics files. All the un-squeeze files were generated for IP5 files and the quadrupole strengths are identical until the last intermediate steps at $\beta^* = 75$ m. The quadrupole strengths ratio r beam 1 over beam 2, $0.5 < r < 2$, has been kept in the allowed range. Only the final step at $\beta^* = 90$ m differs between IPs 1 and 5 to fulfill the different requirements for the ATLAS/ALFA and TOTEM experiments (The phase advance reaches its final value of 90 ˚ only for 90 m).

Throughout the un-squeeze, the beams are kept separated using a parallel constant separation at the IPs. In the LHC the standard injection and ramp uses a separation which is horizontal in IP1 and a vertical crossing angle as illustrated in Fig. 3, whereas at IP5 the separation is vertical with a horizontal crossing angle. This requires a completely different set of parallel separation bumps for all intermediate steps from 11 m to 90 m to conserve the horizontal separation in IP1 and the vertical separation in IP5 up to a $\beta^* = 90$ m.

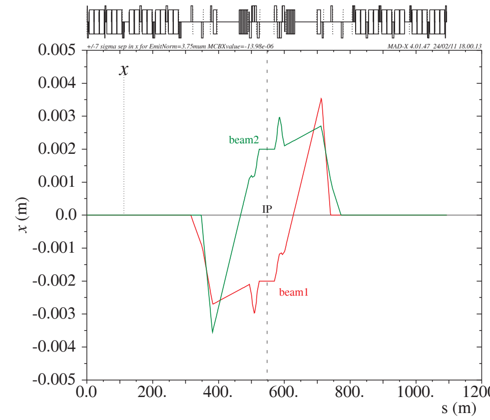

Figure 3: Horizontal separation bump at IP1. The separation is $\pm 2\,\mathrm{mm}$ at the IP which corresponds to $\pm 6.65\sigma$ at 3.5 TeV at $\beta^* = 90\mathrm{m}$ for a normalized emittance of $\epsilon_N = 3.75\,\mu$m.

As can be seen in Fig. 4 and Fig. 5, the calculated aperture at 90 m is not critical and well above the specification. The calculation was done for the standard normalized emittance of 3.75 μm at 3.5 TeV. The specification is that the aperture shown in terms of a figure of merit value ”n1” remains well above the specified value of 7 including separation over the full interaction region.

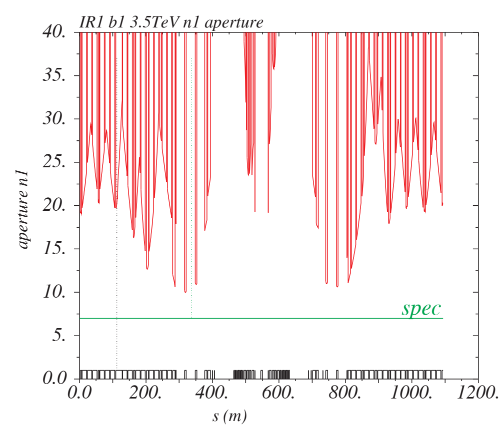

Figure 4: 90 m ATLAS/ALFA optics. Left for beam 1

The un-squeeze from β^* = 11 m to 90 m results in a significant loss in phase advance which has to be compensated in the rest of the LHC to keep the overall tunes constant. The numerical values are given in Table 3. A machine study performed earlier this year in the LHC has demonstrated, that it is possible to provide the external tune compensation by ramping up all main LHC arc quadrupoles (QF, QD) during the un-squeeze, such that the tunes are kept constant and the beam lifetime is not reduced [4].

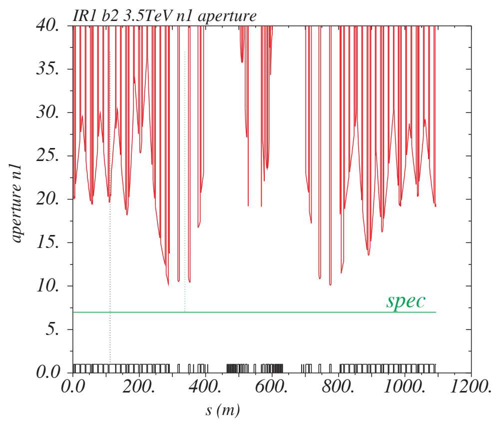

Figure 5: 90 m ATLAS/ALFA optics. Right for beam 2.

Table 3: External Tune Compensation Required for the 90 m Optics in IP1 and IP5

	beam 1		beam 2	
	ΔQ_x	ΔQ_y	ΔQ_x	ΔQ_y
IP1, 90 m	0.2251	0.0569	0.2237	0.0550
IP5, 90 m	0.2219	0.0546	0.2203	0.0528
total	0.4470	0.1115	0.4440	0.1078

ATLAS/ALFA SIMULATIONS WITH THE 90 M β^* OPTIC

The Roman Pots are movable in the vertical position and the closer they can go to the beam axis the better it is. For the measurement, a smaller emittance than $\epsilon_N = 3.75\ \mu$m would also be useful. A smaller emittance allows measurements down to smaller scattering angle and momentum transfer. All the simulations in this study have been made for 3.75 μm but as it has been seen during the commissioning of the optic, the emittance value is close to 2.0 μm. This smaller emittance will be very useful.

An important parameter for the measurement is the acceptance which is the ratio between the elastic protons collected after the tracking at the RPs and the generated elastic protons at the IP. This acceptance can only be known by the simulation. Indeed, when elastic protons are collected at the RPs, the way to know the initial t-spectrum goes through the acceptance value.

The simulation for ATLAS/ALFA is made of three different steps [5]:

- the generation of elastically scattered protons using the Monte Carlo generator PYTHIA [6], defining also vertex smearing, angular divergence and energy dispersion.
- the tracking along the LHC beam line with MadX-PTC [7]
- the collection of the datas at the RPs and acceptance calculation

The acceptance is shown on Fig. 6. The plot shows two different parts : one above $\log_{10}(|t|) = -1.2$ linked to the losses due to the transport and the other one below the same value, linked to the detector geometry. What is relevant looking at the acceptance plot is the values above 50%. We can see that the acceptance is much bigger with a peak of 0.8 for 8σ when the distance of the pots is closer to the beam as this can be seen for three different values corresponding to 8.1 mm, 6.8 mm and 5.4 mm (12σ , 10σ and 8σ).

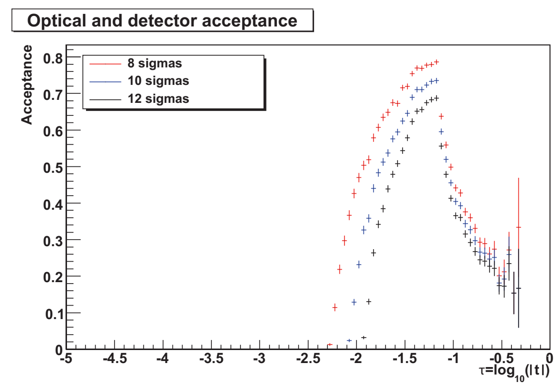

Figure 6: Acceptance as a function of $\log(|t|)$ for different σ values : 8, 10 and 12

This illustrates the great interest to put ATLAS/ALFA detectors close to the beam.

CONCLUSION

The intermediate 90 m β^* optics described here presents a major milestone in the use of very high-β^* optics in the LHC. First studies with beam have already demonstrated that the major external tune compensation required for high β^* optics can be well controlled using the main LHC ring quadrupoles. The 90 m optics will now be used for precision measurements and adjustments of the optical parameters and initial physics studies.

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[6] http://home.thep.lu.se/ torbjorn/Pythia.html

[7] http://wwwslap.cern.ch/mad/