TRACKING AND TOLERANCES STUDY FOR THE ATLAS HIGH-BETA OPTICS

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Abstract

For luminosity and proton-proton total cross section measurement, the standard LHC Physics optics has been modified for the ATLAS experiment in the so-called High Beta optics with β*=2625 m. The high beta optics takes into account the whole LHC ring. Protons are tracked from the interaction point to the detectors. Tolerances on the β* are given and the effect of misalignment errors is checked. We show the impact of the misalignment on the measurement.

INTRODUCTION

For the ATLAS experiment at LHC the absolute luminosity will be measured by the ALFA detectors which consist of Roman Pots (RP) on each part of the interaction point (IP) in the forward direction (see Fig. 1). The RPs are compact detectors designed to operate very close to the beam when it is stable and to be extracted during setting up phases. The absolute luminosity is linked to the elastic rate in the forward direction through the optical theorem. To perform the measurement, the proton-proton elastic scattering interactions occurring at the IP must be tagged.

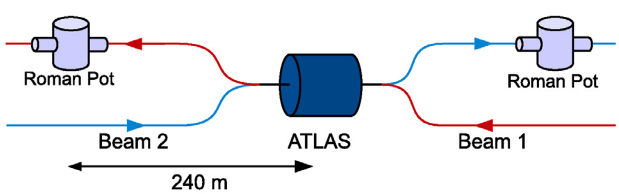

Figure 1: Scheme of the experiment.

The typical diffusion angle at 7 TeV is 3.5 μrad [1]. However we cannot intercept protons with such small angles before the inner focusing triplet. As a consequence, a parallel to point focusing optics is set in the vertical plane providing a 90° phase advance between the IP and the RP. This leads to the fact the transversal position in the RP is related to the scattering angle at the IP. Another requirement to reach such small angles is to minimize the angular dispersion at the IP. This has been done using a special high-beta optics (β*=2625 m) [2]. The detection of these protons will allow to reconstruct the differential elastic cross section spectrum as a function of the scattering angle. The Mandelstam variable t which represents the square of the momentum transfer between the initial and the final state of the proton is linked to the scattering angle which at the low angles relevant for this study can be expressed $t = (p\theta)^2$. This will be the variable used later on. By fitting the reconstructed spectrum as a function of t, we determine the absolute luminosity, the total cross section and other forward physics parameters [1]. One crucial input to achieve the measurement is the overall acceptance, i.e. the proportion of particles entering the active area of the detector compared to the generated ones. This acceptance is computed as a function of t. It cannot be known or deduced from the experiment, it has to be done using the tracking of the protons from the IP to the RPs. The purpose of this study is to evaluate the impact of the quadrupole misalignment on the transport of the elastic protons, thus the determination of the acceptance and finally the effect on the luminosity and the total cross section measurement errors. The ultimate goal of the ALFA experiment is to reach 2-3 % accuracy on the absolute luminosity. This implies that all corrections must have negligible effect with respect to 1 %.

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SIMULATION

Using the Monte-Carlo generator Pythia [3], the elastic scattering protons are generated.

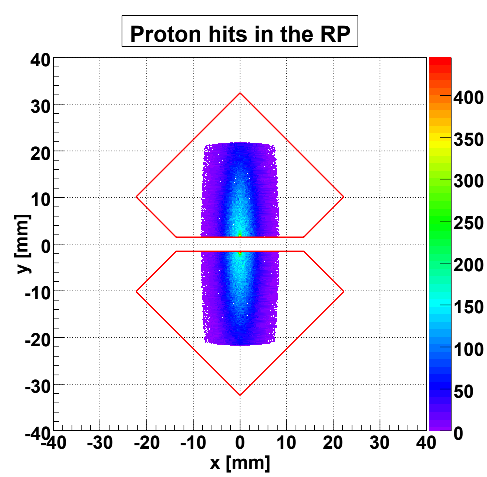

Figure 2: Proton hits distibution in the RPs. The two red diamond shape represents the upper and the lower part of the RPs.

Energy dispersion, vertex smearing and angular divergence can be introduced at this level. Once all events have been generated by the Monte-Carlo, we keep the momentum, the position and the angle of the protons after the interaction and transport it with MAD-X [4] from the IP to the RPs. The knowledge of the position with respect to the beam center together with the geometry of the detectors allow to tag the relevant protons that would be used for the determination of the luminosity as seen in Fig. 2. This figure also shows that most of the protons are scattered with small angles thus passing between the upper and lower part of the detectors. One can see that the upper and lower extremities of the scattering pattern are cut, this is due to the physical aperture of the magnetic elements.

Once the reconstruction is done, we have two distinct information:

- The generated spectrum which contains all protons (real information)

- The reconstructed spectrum which contains only protons that have passed the tracking and hit the sensitive area of the detectors (detected information). This spectrum depends upon the distance d we can bring the detector to the beam center. We usually used 1.5 mm which is equivalent to 12σ.

The ratio of these two distributions defines the acceptance which can be seen on Fig. 3. On this plot we can distinguish two parts: above $\log_{10}(t)$ = - 1.2 where the lowering is mainly due to the losses during the transport, whereas below this value, it can only be attributed to the detector geometry. Thus, to recover the generated spectrum from the reconstructed spectrum we have for each part of the spectrum to weight it using the inverse of the acceptance.

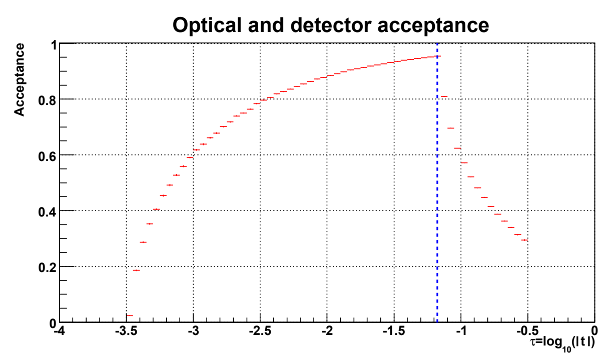

Figure 3: Acceptance as a function ot $log(|t|)$ for d = 1.5 mm.

Any parameter (magnet currents, beam properties...) that is not known perfectly and given as input for the simulation is a source of error on the acceptance determination thus on the luminosity and total cross section determination. The misalignment of the quadrupoles is one of these.

MAGNET MISALIGNMENTS

In this study we focus on the LHC beam line from IP1 where ATLAS is located to the Roman Pots. The main magnetic elements are the inner triplet, the separation dipoles and three quadrupoles called Q4, Q5 and Q6 [5]. The complete simulation needs tracking on both beams. To evaluate the worst misalignment configuration, only one beam is modified for the tracking, the beam 1 which circulates clockwise in the LHC conventions. Only the quadrupoles misalignments will be studied. The accuracy on the quadrupole alignment is expected to be 250 microns [5]. To begin, we misalign Q4, Q5 and Q6 one after the other. Then all combination will be done following the scheme in table 1.

Table 1: Different configurations with corresponding vertical displacements in micron.

	Q4	Q5	Q6	+ + +	+ + -	+ - +	+ - -
Q4	+250	0	0	+250	+250	+250	+250
Q5	0	+250	0	+250	+250	-250	-250
Q6	0	0	+250	+250	-250	+250	-250

We have done the three first cases for horizontal and vertical displacements. However due to the fact that the parallel to point focusing optics is set in the vertical plane, an horizontal displacement has no impact on the detector acceptance and a small one on the reconstruction. On Fig. 4, one can see the impact of the +++ configuration on the closed orbit.

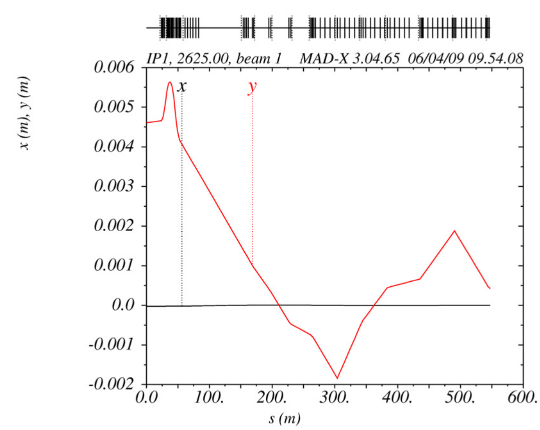

Figure 4: Displacement of the closed orbit for the +++ configuration.

Figure 5 displays the effect of different misalignment configurations on the acceptance. From this we can foreseen how such an effect could be damaging not only for the luminosity measurement but also for the machine settings. In the LHC sequence, such cases has been anticipated introducing a BPM and a corrector in front of all quadrupoles between the ATLAS IP and the RPs. The BPMs measure

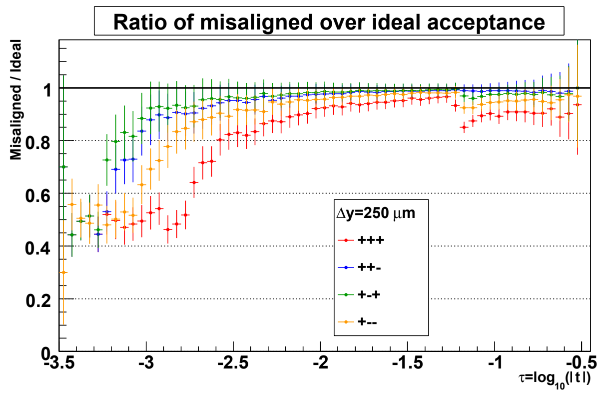

Figure 5: Ratio of the acceptance determined for different configuration of quadrupole misalignement over the ideal one.

the displacement of the beam with respect to the magnetic axis. This information is used to determine the corrections to apply. This procedure is done using the MICADO correction algorithm within MAD-X. For the luminosity measurement it is very important that the correction converges before the protons reach the first RP in order that no effects are visible. The correction is done with all the different configurations of misalignments already mentioned. We assume that the BPM measurement error is negligible. Due to the linear treatment of the optics, any misalignment has a linear impact on the position and the angle of the tracked protons. As a consequence, the impact can be measured in terms of position and angle offset at the RPs. These results have shown that we are able to correct up to a 2 mm vertical offset in the RPs. If for some configurations, the correction allows to retrieve the initial settings, some cases still show a little difference as we can see on Fig. 6 where the + + + configuration and the + - - could not be perfectly corrected before the RPs. Further studies are under way to improve these results.

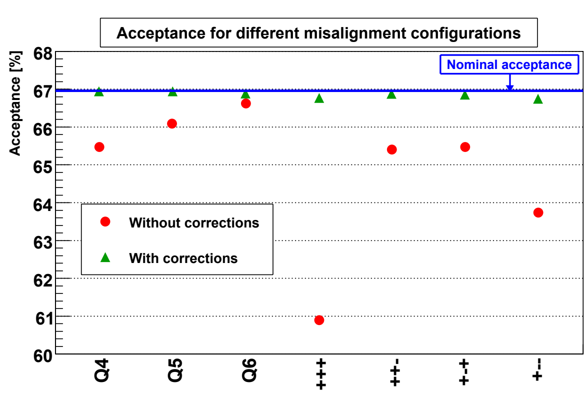

Figure 6: Acceptance variation as a function of the misalignment configurations.

ACCEPTANCE AND LUMINOSITY

A former study [6] has shown that considering errors on β and β* measurements as well as on the phase advance, a total contribution on the systematic uncertainties for the beam properties should be around 0.7 % on the luminosity. However this figure does not take into account the magnet misalignments. To minimize statistical effects, we have generated 10 million events. The luminosity and the total cross section are strongly correlated. Futhermore, the effect of the misalignment can only lower the acceptance as it introduces a skewness in the proton distribution wich is not counter-balanced in the other arm of ALFA. The consequence is that the luminosity is underestimated whereas the total cross section is overestimated. In the worst case (+ + +), we obtain +1.9 % of uncertainty on the luminosity and -0.8 % on the cross section.

CONCLUSION

Considering the worst case of vertical misalignment for one beam, we have shown that assuming a perfect correction introduces a systematical uncertainty of 1.9 %. This large effect comes from the fact none of the alignement information is taken into account in the simulation. This will be needed for the final analysis. The key issue will be to achieve the corresponding correction in the short range going from IP to RP during the operation of the machine. A complete study including the inner triplets should be done. Furthermore all misalignment and rotations should be considered and one should be able to set boundary conditions.

ACKNOWLEDGEMENT

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