Abstract

The main topic of the thesis is the study of a novel option for the high-luminosity upgrade of the Large Hadron Collider (LHC) comprising a large Piwinski angle, flat beams, and crab waists. Flat beams and crab waists are not only pre-requisites for a crab-waist scheme, but, even by themselves; each of these two elements alone could boost the luminosity of the existing collider as built.

The new optics involves an upgrade of the interaction region of the two high-luminosity experiments, ATLAS and CMS, in order to provide them with a substantially higher luminosity. To this end, a flat-beam optics scenario has been explored for the High Luminosity LHC (HL-LHC), with a much reduced vertical beta function at the interaction point (IP), β_y^*. In addition, a large Piwinski angle is considered. Advantages of a large Piwinski angle include a reduction in the hourglass effect over the length of the collision area, which allows for the significant β_y^* decrease. In addition there is a reduction of the beam-beam effect so that the same beam-beam tune shift is reached only for much brighter beams, with a consequent luminosity increase. Flat beams and large Piwinski angle can boost the luminosity of the existing LHC as built, but they also open up the possibility to implement a crab-waist collisions scheme. The challenge here was to apply the collision concept, which so far has been employed only in the DAΦNE e^+e^- ϕ factory, to a much bigger collider with pp collisions, which do not easily allow for a symmetric optics.

The second important concept implemented in this version of the LHC upgrade is a (partially) local chromatic correction scheme, by installing chromatic sextupoles near the IP. For this purpose, the interaction region had to be redesigned. As the optics for the crab-waist scheme must be symmetric, the polarities of the final quadrupoles must change with respect to the present configuration. This includes the region where the two beams share the same aperture. In this case, a novel magnetic element called “double-half quadrupole” (DHQ) is proposed, which would provide quadrupolar fields of opposite sign at opposite locations from the centre. The element then acts as a horizontally defocusing element for either beam, and helps focusing the vertical beta-function to the small value required at the IP.

Finally, this thesis includes some considerations on applying the same optics and collision concepts to the High Energy LHC (HE-LHC) and to a design of the final-focus system for the LHeC electron line, which is also equally based on a local chromatic correction scheme.

Keywords: LHC, HE-LHC, LHeC, accelerators design, beam optics, beam dynamics, crab waist, final-focus systems, flat beams, large Piwinski angle, local chromatic correction,

luminosity.

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